eNergetics 2015

1st Virtual International Conference on Science, Technology and Management in Energy

Proceedings

Editors: Janjić, A., Stajić, Z.

Publishers: Research and Development Center
"ALFATEC", Niš, Serbia;
Mathematical Institute SASA, Belgrade, Serbia

Serbia, Niš, 02-03 July, 2015

eNergetics 2015

1st Virtual International Conference on Science, Technology and Management in Energy

Proceedings

Editors: Janjić, A., Stajić, Z.

Publishers: Research and Development Center "ALFATEC", Niš, Serbia;
Mathematical Institute SASA, Belgrade, Serbia

Serbia, Niš, 02-03 July, 2015

Proceedings of 1st **Virtual International Conference on Science, Technology and Management in Energy**

Serbia, Niš, 02-03 July, 2015

Editors: Prof. Dr. Aleksandar Janjić and Prof. Dr. Zoran Stajić

Technical Editor: Dr. Lazar Z. Velimirović

Published by: Research and Development Center “ALFATEC”, Niš, Serbia, and Mathematical Institute SASA, Belgrade, Serbia

Printed by: Research and Development Center “ALFATEC”, Niš, Serbia, and Mathematical Institute SASA, Belgrade, Serbia

Number of copies printed: 100

Printing of this edition has been financially supported by Serbian Ministry of Education, Science and Technological Development

ISBN 978-86-80593-54-8

CIP - Каталогизација у публикацији

Народна библиотека Србије, Београд

620.9(082)

VIRTUAL International Conference on Science Technology and Management in Energy (1 ; Niš ; 2015)
Energetics 2015 = Proceedings / 1st Virtual International Conference on Science Technology and Management in Energy, Niš, 02-03 July 2015 ; editors Janjić [Aleksandar], Stajić [Zoran]. - Niš : Research and Development Centar "Alfatec", 2015 (Niš : Research and Development Centar "Alfatec"). -
99 str. : ilustr. ; 26 cm

Tiraž 100. - Abstracts. - Bibliografija uz svaki rad. - Registar.

ISBN 978-86-80593-54-8

a) Енергетика - Зборници
COBISS.SR-ID 218611724

1st Virtual International Conference on Science, Technology and Management in Energy

organized by

- **Research and Development Center "ALFATEC"**
- **Mathematical Institute of the Serbian Academy of Sciences and Arts**
- **Faculty of Electronic Engineering Niš**
- **Complex System Research Centre**
- **Academy of Sciences and Arts of Republic of Srpska**

supporter:

- **Serbian Ministry of Education, Science and Technological Development**

Program Committee

Chair:

Prof. Dr. Aleksandar Janjić, Faculty of Electronic Engineering, Niš, Serbia

Members:

Prof. Dr. Zoran Stajić, Faculty of Electronic Engineering, Niš, Serbia

Prof. Dr. Miomir Stanković, Faculty of Occupational Safety, Niš, Serbia

Prof. Dr. Zoran Ognjanović, Mathematical Institute of the Serbian Academy of Sciences and Arts, Belgrade, Serbia

Prof. Dr. Bojan Srđević, Faculty of Agriculture, Novi Sad, Serbia

Prof. Dr. Radomir Stanković, Faculty of Electronic Engineering, Niš, Serbia

Prof. Dr. Suzana Savić, Faculty of Occupational Safety, Niš, Serbia

Prof. Dr. Milan Gocić, Faculty of Civil Engineering and Architecture, Niš, Serbia

Prof. Dr. Mileta Janjić, Faculty of Mechanical Engineering, Podgorica, Montenegro

Prof. Dr. Zdravko Milovanović, Faculty of Mechanical Engineering, Banja Luka, Bosnia and Herzegovina

Prof. Dr. Marko Serafimov, Faculty of Mechanical Engineering, Skopje, Macedonia

Prof. Dr. Miloš Jelić, Research and Development Center “ALFATEC”, Niš, Serbia

Prof. Dr. Velimir Stefanović, Faculty of Mechanical Engineering, Niš, Serbia

Prof. Dr. Jovica Milanović, School of Electrical and Electronic Engineering, Manchester, UK

Organizing Committee

Chair:

Prof. Dr. Miomir Stanković, Faculty of Occupational Safety, Niš, Serbia

Members:

Prof. Dr. Zoran Stajić, Faculty of Electronic Engineering, Niš, Serbia
Dr. Lazar Velimirović, Mathematical Institute of the Serbian Academy of Sciences and Arts, Belgrade, Serbia
Ljubiša Stajić, Research and Development Center “ALFATEC”, Niš, Serbia
Biserka Mijucić, Research and Development Center “ALFATEC”, Niš, Serbia
Tanja Petrović, Research and Development Center “ALFATEC”, Niš, Serbia

Table of Contents

Thursday, July 2th, 2015

Hybrid Ensemble Model for Short-Term Load Forecasting

Miloš Božić, R&D Center ALFATEC, Niš, Serbia, milos1bozic@gmail.com

Zoran Stajić, R&D Center ALFATEC, Niš, Serbia, zoran.stajic@elfak.ni.ac.rs

Nikola Milosavljević, Electrical Utility "Centar", Kragujevac, Serbia, nmilosavljevic84@gmail.com

Abstract—**Electric load is a random non-stationary process influenced by a number of factors which makes it difficult to model. To achieve better forecasting accuracy, a wide variety of models have been proposed. This paper presents a hybrid ensemble model for short-term load forecasting based on three base estimators: double seasonal ARIMA model, artificial neural network and least square support vector machines. The effectiveness of the presented model is shown on real electrical load data of the City of Niš. The obtained results confirm the validity advantage of the proposed approach.**

Keywords: ***load forecasting, ensemble metod, machine learning***

I. INTRODUCTION

With the deregulation of the energy market and with the promotion of the smart grid concept, load forecasting has gained even more significance. The load forecasts for different time horizons are important for different planning and operations within a utility company. Therefore, in terms of the planning horizon's duration, load forecasting is classified into three categories: short-term, medium-term and long-term. Short-term load forecasting (STLF) deals with load forecasting from one hour up to one week ahead. Medium-term load forecasting covers the time period from a few days up to a few weeks and long-term load forecasting covers a period from one to a couple of years.

For the improvement of network reliability and the reduction of occurrences of equipment failures and blackouts, correct and timely decisions are needed. Generation capacity scheduling, generator maintenance scheduling, scheduling of fuel and coal purchases, coordination of hydro-thermal systems, system security analysis, energy transaction planning, load flow analysis and so on are tasks which rely on accurate STLF [1]. On the other hand, electric load is a random non-stationary process which is influenced by a number of factors, including: economic factors, time, day, season, weather and random effects, all of which leads to load forecasting being a challenging subject of inquiry.

During the past few decades, a wide variety of models have been proposed for the improvement of STLF accuracy. Conventional methods include: linear regression methods [2], exponential smoothing [3] and Box–Jenkins ARIMA approaches [4] are linear models which cannot properly represent the complex nonlinear relationships between load and its various influential factors. Artificial intelligence-based techniques are employed because of the good approximation capability for non-linear functions. These methods include: Kalman filters [5], fuzzy logic [6, 7], knowledge-based expert system models [8], artificial neural networks (ANNs) models [9, 10] and support vector machines (SVMs) [11, 12]. No single model has performed well in STLF and hybrid approaches are being proposed to take advantage of the unique strength of each method. An adaptive two-stage hybrid network with a self-organized

ISBN: 978-86-80593-54-8

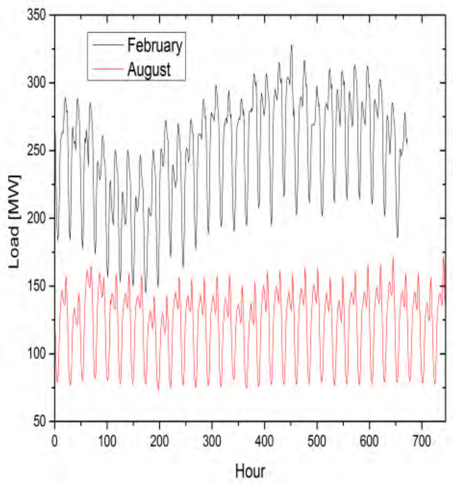


Figure 1. Electrical loads curves for February and August

map and support vector machines is presented in [13]. A hybrid method composed of a wavelet transform, neural network and evolutionary algorithm is proposed in [14]. A combined model based on the seasonal ARIMA forecasting model, the seasonal exponential smoothing model and weighted support vector machines is presented in [15] with the aim of effectively accounting for the seasonality and nonlinearity shown in the electric load. Another seasonal model which combines the seasonal recurrent support vector regression with a chaotic artificial bee colony algorithm is proposed in [16] to determine suitable values of three parameters of support vector regression.

In order to improve forecasting accuracy, in this paper emphasis is placed on building hybrid ensemble short-term forecasting model based on three base estimators: double seasonal ARIMA model, artificial neural networks and least square support vector machines.

The rest of the paper is organized as follows: Section 2 presents the basics of base estimators used in the ensemble. Then Section 3 shows electrical load data features. Section 4 includes a variety of experiments to verify the proposed approach. Finally Section 5 outlines the conclusions.

II. Electric Load Features

The electric load is a random non-stationary process influenced by a number of factors which makes it difficult to model. Choosing appropriate input features to build the model is an important task in load forecasting. There is no general approach to conduct this problem, but load curve analyses and statistical analyses can be helpful for choosing key features to build a good load forecasting model.

The real-life STLF test case is considered in this paper to evaluate the performance of the proposed forecast approach. This STLF test case is related to the electric load consumption of the City of Niš. Fig. 1 shows the 2009 power load curves for February and August.

In Fig. 2, the daily load curve during the week is presented, for one week in February and one week in August. It is obvious that the daily load on work days is greater than the load on weekends. The reasons for this are people’s behavior during the week, and this

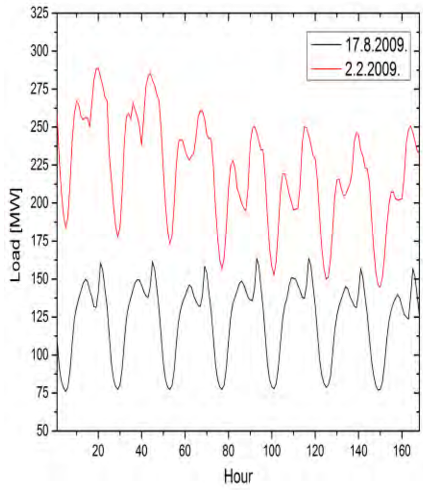


Figure 2. Hourly load during the week

pattern is periodically repeated each week. All this imposes using the day of the week for the features in the model.

ISBN: 978-86-80593-54-8

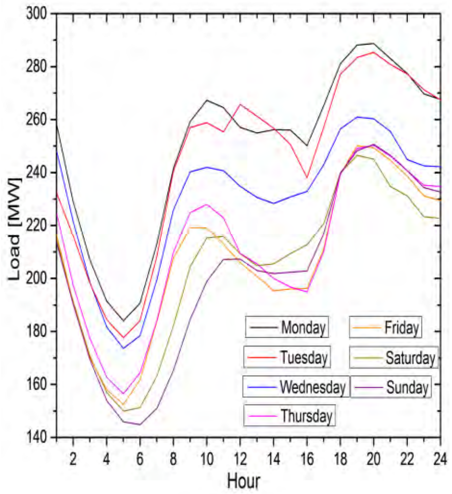


Figure 3. Hourly load during the day

Fig. 3 shows hourly load during the day for each day in one week. This curve is influenced and shaped by people's daily life. The load changes from hour to hour during the day, indirectly following consumer behavior. This brings one more important variable to the feature set, and that is the hour of the day. Also, it can be noticed that the curves have a similar shape but different magnitude from day to day in the week. This also confirms the validity of using the day of the week for the model feature with the aim of mapping this property.

However, from Fig. 1 and 2 it can be observed that the daily load curve is different for two given months. This difference is reflected not only in load magnitude but also in the shape of load curves.

III. Forecasting Methods

A. Double seasonal ARIMA model

The multiplicative double seasonal ARIMA model [17] can be written as

$$\begin{aligned}&\phi_p(L)\phi_{P_1}\left(L^{S_1}\right)\Omega_{P_2}\left(L^{S_2}\right)\nabla^d\nabla_{S_1}^{D_1}\nabla_{S_2}^{D_2}\left(y_t-c\right)\\&=\theta_q(L)\Theta_{Q_1}\left(L^{S_1}\right)\Psi_{Q_2}\left(L^{S_2}\right)\varepsilon_t\end{aligned}, \quad (1)$$

where y_t is demand in period t, c is a constant term, s_1 and s_2 are the number of periods in the different seasonal cycles, L is the lag operator, ∇ is the difference operator, ∇ and ∇_{S_2} are seasonal difference operators, d, D_1 and D_2 are the orders of differencing, ε_t is a white noise error term, and $\phi_p, \Phi_{P_1}, \Omega_{P_2}, \theta_q, \Theta_{Q_1}$, and Ψ_{Q_2} are polynomial functions of orders p, P_1, P_2, q, Q_1 , and Q_2 , respectively. This model can be expresses as $ARIMA(p,d,q)\times(P_1,D_1,Q_1)_{S_1}\times(P_2,D_2,Q_2)_{S_2}$.

To apply model to our data, we set $S_1=24$ to model the within-day seasonal cycle of 24 hours, and $S_2=168$ to model the within-week cycle of 168 hours. Box-Jenkins methodology is used to identify the most suitable ARIMA model based on the 20 week estimation sample. The autocorrelation and partial autocorrelation function were used to select the order of the model, which was then estimated by maximum likelihood. The following model is obtained: $ARIMA(3,0,3)\times(3,0,3)_{24}\times(3,0,3)_{168}$.

B. Artificial neural networks

In this paper, single hidden layer feedforward network is used, with a set of k inputs which are connected to each of m units in single hidden layer, which, in turn, are connected to an output. The resultant model can be written as

$$f(x_t,v,w)=g_2\left(\sum_{j=0}^{m}v_j g_1\left(\sum_{i=0}^{k}w_{ji}x_{it}\right)\right), \quad (2)$$

where $g_1(\cdot)$ and $g_2(\cdot)$ are activation functions, which is chosen to be sigmoidal and w_{ji} and v_j are the weights. Weights are estimated using the following minimization:

$$\min_{v,w}\left(\begin{aligned}&\left(\frac{1}{n}\sum_{t=1}^{n}\left(y_t-f(x_t,v,w)\right)^2\right)\\&+\left(\lambda_1\sum_{j=0}^{m}\sum_{i=0}^{k}w_{ji}^2+\lambda_2\sum_{j=0}^{m}v_i^2\right)\end{aligned}\right), \quad (3)$$

ISBN: 978-86-80593-54-8

where n is the number of in-sample observations, and λ_1 and λ_2 are regularization parameters which penalize the complexity of the network and thus avoid overfitting. The number of inputs $k = 26$ and the number of units in hidden layer is $k = 24$.

C. Least-square support vector machines

Least squares support vector machines (LS-SVMs), as a reformulation of base support vector machines (SVMs), are commonly used for function estimation and for solving non-linear regression problems [18]. The main property of these methods is that they obtain a solution from a set of linear equations instead of solving quadric programming problem, as in SVMs. Therefore, LS-SVMs have a significantly shorter computing time and they are easier to optimize, but with a lack of sparseness in the solution. The regression model in primal weight space is expressed in:

$$y(x) = \omega^T \phi(x) + b \,, \tag{4}$$

where ω represents the weight vector, b represents a bias term and $\phi(x)$ is a function, which maps the input space into a higher-dimensional feature space.

LS-SVM formulates the optimization problem in primal space defined by:

$$\min_{\omega,b,e} J_p(\omega, e) = \frac{1}{2}\omega^T \omega + \frac{1}{2}\gamma \sum_{k=1}^{N} e_k^2 \,, \tag{5}$$

subject to equality constrains expressed as:

$$y_k = \omega^T \phi(x_k) + b + e_k \,,\ k = 1,...,N \,, \tag{6}$$

while e_k represents error variables, γ is a regularization parameter which gives the relative weight to errors and should be optimized by the user.

Solving this optimization problem in dual space leads to obtaining α_k and b in the solution represented as:

$$y(x) = \sum_{k=1}^{N} \alpha_k K(x, x_k) + b \,. \tag{7}$$

The dot product $K(x, x_k) = \phi(x)^T \phi(x_k)$ represents a kernel function while α_k are Lagrange multipliers. When using a radial basis function (RBF) defined by:

$$k(x, x_k) = e^{-\frac{\|x - x_k\|^2}{\sigma^2}} \,, \tag{8}$$

the optimal parameter combination (γ, σ) should be established, where γ denotes the regularization parameter and σ is a kernel parameter. For this purpose, a grid search algorithm in combination with *k*-fold cross validation was a commonly used method [19].

D. Average ensemble method

The goal of ensemble methods is to combine the predictions of several base estimators built with a given learning algorithm in order to improve generalizability/robustness over a single estimator [20]. There are two base families of ensemble methods: averaging methods and boosting methods. In averaging methods, the driving principle is to build several estimators independently and then to average their predictions. On average, the combined estimator is usually better than any of the single base estimator because its variance is reduced. In boosting methods, base estimators are built sequentially and one tries to reduce the bias of the combined estimator. The motivation is to combine several weak models to produce a powerful ensemble.

In this paper, hybrid average ensemble method is built using few base estimators formed with different learning algorithms. Because different learning algorithms are used for built base estimators this is a hybrid ensemble method.

IV. RESULTS

For the evaluation of the proposed STLF approach, the forecasting of hourly loads in

ISBN: 978-86-80593-54-8

2009 was done for each day. The prediction quality is evaluated using the mean absolute percentage error (MAPE), symmetric mean absolute percentage error (sMEPE) and root mean square error (RMSE) as follows, respectively:

$$MAPE[\%] = 100\frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_i - \hat{P}_i}{P_i}\right|, \quad (9)$$

$$sMAPE[\%] = 200\frac{1}{n}\sum_{i=1}^{n}\frac{\left|P_i - \hat{P}_i\right|}{P_i + \hat{P}_i}, \quad (10)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(P_i - \hat{P}_i\right)^2}. \quad (11)$$

Four models are built which are denoted with:

- DSARIMA – double seasonal ARIMA model
- ANN – artificial neural network model
- LSSVM – least-square support vector machines model
- EN – average ensemble model.

Table 1. annual average mape, smape and rmse

MODEL	Errors		
	MAPE [%]	***sMAPE [%]***	***RMSE [MW]***
DSARIMA	4.12	4.14	9.08
ANN	4.13	4.13	9.06
LSSVM	4.51	4.42	10.18
EN	3.64	3.62	8.23

In Table 1, annual average values for MAPE, sMAPE and RMSE error for each model are shown. Obtained results show that the best result is gather using average ensemble method. Almost similar results are get by the DSARIMA and ANN models and the worst results are shown by LSSVM model.

In Fig. 4, real and forecasted hourly load curve for each formed model for one week is presented. It can be noticed that the models curves stand to real load curve in the same rank as in Table I.

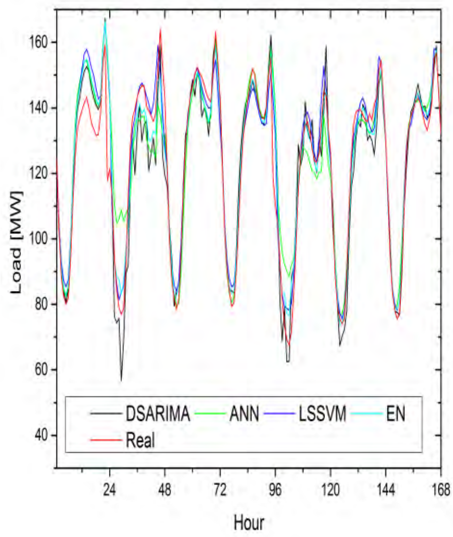


Figure 4. Real and forecasted hourly load during the week

V. Conclusion

In this paper, hybrid ensemble model based on three base estimators is presented. For base estimator are used: double seasonal ARIMA model, artificial neural networks and least-square support vector machines model. Obtained results unequivocally shown that the ensemble model get the best results, besides that this is a simple average ensemble model. This leads to the conclusion that if a few models are built, the most chances for the best results has ensemble model with base estimators of these few models.

Acknowledgment

This work was supported by the Ministry of Science and Technological Development, Republic of Serbia (Project number: III-44006).

ISBN: 978-86-80593-54-8

References

[1] S. A. Soliman, A. M. Alkandari, Electrical load forecasting: modeling and model construction; Butterworth-Heinemann: Burlington, MA, 2010.

[2] A. D. Papalexopoulos, T. C Hesterberg, "A regression-based approach to short-term system load forecasting", Power Systems, IEEE Transactions on, vol. 5, 1990, pp. 1535-1547.

[3] W. R Christiaanse, "Short-Term Load Forecasting Using General Exponential Smoothing", Power Apparatus and Systems, IEEE Transactions on 1971, PAS-90, pp. 900-911.

[4] P. Vähäkyla, E. Hakonen, P. Léman, "Short-term forecasting of grid load using Box-Jenkins techniques", International Journal of Electrical Power & Energy Systems, vol. 2, 1980, pp. 29-34.

[5] G. D. Irisarri, S. E. Widergren, P. D. Yehsakul, "On-Line Load Forecasting for Energy Control Center Application", Power Engineering Review, IEEE 1982, PER-2, pp. 23-23.

[6] H. Mori, H. Kobayashi, "Optimal fuzzy inference for short-term load forecasting", Power Systems, IEEE Transactions on, vol. 11, 1996, pp. 390-396.

[7] D. K. Ranaweera, N. F. Hubele, G. G. Karady, "Fuzzy logic for short term load forecasting", International Journal of Electrical Power & Energy Systems, vol. 18, 1996, pp. 215-222.

[8] S. Rahman, R. Bhatnagar, "An expert system based algorithm for short term load forecast", Power Systems, IEEE Transactions on, vol. 3, 1988, pp. 392-399.

[9] T. S. Dillon, S. Sestito, S. Leung, "Short term load forecasting using an adaptive neural network", International Journal of Electrical Power & Energy Systems, vol. 13, 1991, pp. 186-192.

[10] H. S. Hippert, C. E. Pedreira, R. C. Souza, "Neural networks for short-term load forecasting: a review and evaluation", Power Systems, IEEE Transactions on, vol. 16, 2001, pp. 44-55.

[11] C. Bo-Juen, C. Ming-Wei, L. Chih-Jen, "Load forecasting using support vector Machines: a study on EUNITE competition 2001", Power Systems, IEEE Transactions on, vol. 19, 2004, pp. 1821-1830.

[12] W. C. Hong, "Electric load forecasting by support vector model", Applied Mathematical Modelling, vol. 33, 2009, pp. 2444-2454.

[13] S. Fan, L. Chen, "Short-term load forecasting based on an adaptive hybrid method", Power Systems, IEEE Transactions on, vol. 21, 2006, pp. 392-401.

[14] N. Amjady, F. Keynia, "Short-term load forecasting of power systems by combination of wavelet transform and neuro-evolutionary algorithm", Energy, vol. 34, 2009, pp. 46-57.

[15] J. Wang, S. Zhu, W. Zhang, H. Lu, "Combined modeling for electric load forecasting with adaptive particle swarm optimization", Energy, vol. 35, 2010, pp. 1671-1678.

[16] W. C. Hong, "Electric load forecasting by seasonal recurrent SVR (support vector regression) with chaotic artificial bee colony algorithm", Energy, vol. 36, 2011, pp. 5568-5578.

[17] G. E. Box, G. M. Jenkins, G. C. Reinsel, Time series analysis: Forecasting and control (3rd ed.). Englewood Cliffs, New Jersey: Prentice Hall, 1994.

[18] J. A. K. Suykens, T. Van Gestel, J. De Brabanter, B. De Moor, J. Vandewalle, Least Squares Support Vector Machines, World Scientific, Singapore, 2002.

[19] S. Arlot, A. Celisse, "A survey of cross-validation procedures for model selection", Statistic Surveys, vol. 4, pp. 40-79.

[20] D. Opitz, R. Maclin, "Popular ensemble methods: An empirical study", Journal of Artificial Intelligence Research, vol. 11, 1999, pp. 169–198.

ISBN: 978-86-80593-54-8

Solar Energy Potential in Serbia and Possible Effects of Solar Plants on the Environment

Dragan Antić, R&D Center "Alfatec" Ltd., Niš, Serbia,
dragan.antic@alfatec.rs

Snežana Antolović, R&D Center "Alfatec" Ltd., Niš, Serbia,
snezana.antolovic@alfatec.rs

Ana Stanković, R&D Center "Alfatec" Ltd., Niš, Serbia,
ana.stankovic@alfatec.rs

Abstract—**Solar energy technologies offer apparent ecological advantages compared to conventional energy sources, which contributes to sustainable development. Excluding the continuing depletion of natural resources, their main advantage becomes apparent through the reduction of carbon-dioxide emissions and the general absence of atmospheric emissions or waste products during the exploitation phase. This paper presents a small 30 kW solar plant, installed on the roof surface of the Domit enterprise in Leskovac, as well as its impact on the environment.**

Keywords: ***solar energy systems, life cycle assessment, environmental impact assessment***

I. Introduction

The world is nearing a major energy crisis, and analyses show that, by the middle of this century, many countries will be facing a giant problem of not being able to produce the necessary amount of energy for sustainable development, i.e. existence.

The global warming phenomenon and carbon-dioxide emissions into the atmosphere are the main factors in climate change and environmental degradation. In response to the harmful effects of the aforementioned occurrences and thanks to the increase of environmental preservation and advancement awareness, alternative or renewable energy sources (RES) have become a point of interest for many countries in recent years. They represent a model of energy security and one of the ways to provide energy for the future, as well as putting a stop to further negative influences on the environment.

Solar energy is, directly or indirectly, the source of life and almost all energy on Earth. Fossil fuels represent solar energy accumulated in plant matter from a past geological period. Biomass turns solar energy into fuel, which can then be used for heating, production of electric energy or vehicle propulsion. Through the Earth's rotation and the heating of the soil by solar radiation, wind is formed, the energy of which has long since been known. Electric energy produced by hydro plants also comes from solar energy: heating large surfaces of water causes evaporation, and subsequently, in the form of precipitation, water returns and forms a water mass, which turns the turbines in hydro plants.

Solar radiation energy reaching the Earth's surface, i.e. potentially usable solar radiation, amounts to 190 million terawatt hours a year. That energy is about 170 times larger than the energy of the world's entire coal reserves, and when compared to the energy needs of humanity, which amount to 130 thousand terawatt hours a year, it

ISBN: 978-86-80593-54-8

becomes clear that the solar radiation energy received in just 6 hours is enough to satisfy all the needs throughout the world for an entire year. Considering the presented facts, solar energy is more than enough to satisfy the world's energy demands, but, even with this knowledge, solar energy is still deemed an alternative energy source.

II. Solar Energy Potential in Serbia

Solar energy potential makes up 15 % of the exploitable RES potential in Serbia. Solar energy potential in Serbia is 40 % above the European average, and solar radiation intensity is among the largest in Europe. The average daily amount of global radiation energy on a horizontal surface during the winter period ranges from 1.1 kWh/m^2 in the north to 1.7 kWh/m^2 in the south, and between 5.4 kWh/m^2 in the north to 6.9 kWh/m^2 in the south during the summer period. For comparison, the average value of global radiation across the territory of Germany amounts to 1000 kWh/m^2, while that value is at 1400 kWh/m^2 in Serbia. The optimal regions in Serbia see a large number of sunny hours, and the yearly ratio between actual and potential solar radiation is nearly 50 % [1].

Unfortunately, that potential has not been exploited enough. One of the reasons for this situation is the lack of investments in this sector. The Government of the Republic of Serbia has accepted the decision of the Ministerial Council of the Energy Community to promote renewable energy by transposition of the 2009/28/EC Renewable Energy Directive, which sets the goal of increasing usage of renewable energy in total energy consumption to 27 % by 2020, from 21.2 % in the referential year of 2009, *Official Gazette of the Republic of Serbia, reg. No. 53/2013* [2].

Table 1 shows average daily sums of global radiation energy on a horizontal surface for some places in Serbia.

All of this data clearly indicates that Serbia has access to solar radiation energy resources well above the European average with an extremely favorable seasonal distribution. Its efficient and long-term exploitation is necessary to be planned out as soon as possible, among other reasons, for coordinating with European measures and plans related to renewable energy sources.

III. Possible Effects of Solar Plants on the Environment

A large possibility of exploiting solar insolation via solar plants, on the other hand, can have potentially negative implications on the environment. Through a life cycle analysis of the product (LCA analysis), these influences can be presented over a period needed to build and install the system, its exploitation, up to the final phase of removal, i.e. dismantling. All of these phases are accompanied by influences such as:

- **noise;**

  As with all other types of construction activity, during the process of construction or dismantling of solar panels/ collectors, noise is an unavoidable factor. As a consequence of construction machinery and tools, and because of material and equipment transport via freight trucks, produced noise has an adverse and harmful impact on employees, local population, the animal world and the environment. However, during the process of work, the noise can be deemed insignificant, and this is especially evident when compared with any conventional method in the energy production process, such as wind or gas turbines.

  In cities, using solar panels in modern architecture and achieving a very attractive mirror effect on the facades or roofs of office buildings, at the same time contributes to reducing noise levels within the building. In the same way, solar panels can be applied as solid sound insulation on highways or near hospitals.

- **visual influence;**

  In the process of construction, the use of freight trucks, equipment and construction machinery, which "cruise"

ISBN: 978-86-80593-54-8

through the area, negatively affects the visual experience of the landowner, local populace, and road users. The dust caused by this further adds to the

Table 1. Average daily sums of global radiation energy on a horizontal surface, in kWh/m^2 for some places in Serbia, [1]

AVERAGE DAILY SUMS OF GLOBAL RADIATION ENERGY ON A HORIZONTAL SURFACE, IN kWh/m^2, FOR SOME PLACES IN SERBIA									
place	month								
	I	II	III	IV	V	VI	VII	VIII	IX
Beograd	1,40	2,20	3,35	4,85	6,00	6,45	6,75	6,00	4,65
Vršac	1,00	2,00	3,35	4,40	6,00	6,40	6,55	6,85	4,60
Palić	1,30	2,10	3,45	5,00	6,15	6,25	6,35	5,85	4,30
Novi Sad	1,45	2,35	3,20	4,65	5,80	6,20	6,35	5,75	4,40
Niš	1,75	2,60	3,45	5,00	6,10	6,35	6,70	6,15	5,35
Kuršumlija	2,15	3,00	3,60	5,05	5,85	6,05	6,55	6,10	5,30
Peć	1,85	2,95	3,70	4,85	5,95	6,15	6,75	6,15	4,90
Priština	1,85	2,90	3,70	5,25	6,30	6,60	6,95	6,30	5,10
Vranje	1,70	2,70	3,65	5,15	6,15	6,40	6,50	6,35	5,25
Loznica	1,50	2,30	3,05	4,35	5,30	5,75	6,15	5,60	4,30
Kragujevac	1,50	2,40	3,35	4,80	5,85	6,10	6,45	5,90	4,85
Negotin	1,35	2,05	3,25	4,85	6,05	6,60	6,95	6,25	4,75
Zlatibor	1,50	2,30	3,10	4,35	5,10	5,65	5,90	5,35	4,30

AVERAGE DAILY SUMS OF GLOBAL RADIATION ENERGY ON A HORIZONTAL SURFACE,IN kWh/m2, FOR SOME PLACES IN SERBIA					
place	month			total annual radiation [kWh/m^2]	average annual radiation [kWh/m^2]
	X	XI	XII		
Beograd	3,05	1,60	1,15	1.446,80	3,96
Vršac	3,00	1,55	1,00	1.424,75	3,90
Palić	2,85	1,40	1,15	1.407,40	3,80
Novi Sad	2,90	1,45	1,20	1.392,64	3,82
Niš	3,45	1,85	1,50	1.531,40	4,20
Kuršumlija	3,50	2,00	1,75	1.550,50	4,25
Peć	3,65	2,25	1,60	1.546,25	4,24
Priština	3,35	1,90	1,60	1.578,25	4,32
Vranje	3,45	1,85	1,50	1.543,40	4,23
Loznica	2,80	1,45	1,20	1.333,50	3,65
Kragujevac	3,30	1,70	1,30	1.447,85	3,97
Negotin	2,90	1,45	1,20	1.453,35	3,98
Zlatibor	2,75	1,60	1,30	1.316,40	3,61

ISBN: 978-86-80593-54-8

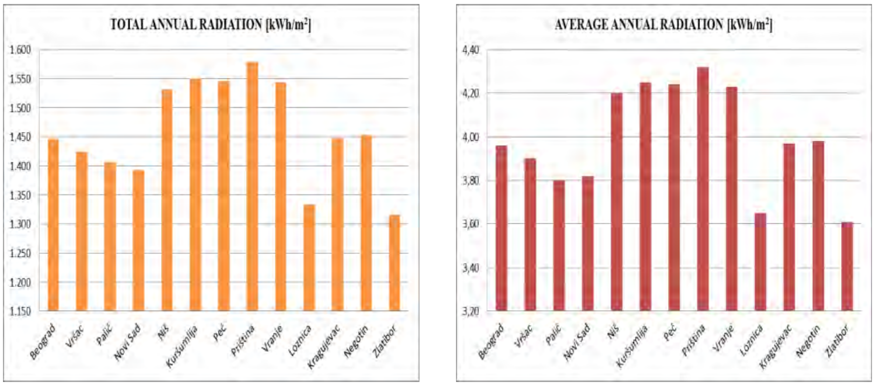


Diagram 1. Total and average annual values of global radiation energy on a horizontal surface, in kWh/m^2, for some places in Serbia

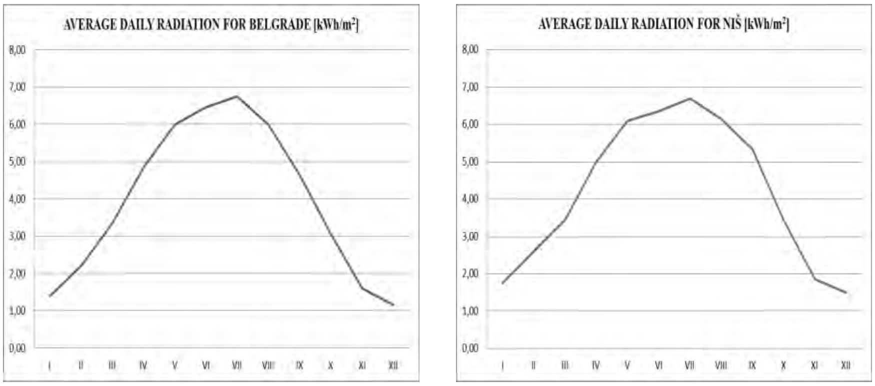


Diagram 2. Average annual values of global radiation energy on a horizontal surface, in kWh/m^2, for Belgrade and Nis

negative effect. By using techniques to settle the dirt in camps or on the road, it is possible to remove dust and unwanted evaporations.

The term "integration" was, until recently, used in architecture as a synonym for "invisibility", and was especially applicable to solar panels. The primary reason for this was mitigating the fact that these solar panels were different from other construction elements. Luckily, this trend has changed, given that architects have found solutions for using solar panels to improve the aesthetics of a building [3].

On the other hand, users of solar technology could be proud of that fact, and advertise themselves as "green energy" consumers. Today, solar panels are used as attractive architectural elements, in a way that they complete and add to the visual appearance of a building. The aesthetic contribution of solar panels is evidently a matter of taste and personal choice, but they are certainly designed to follow the

ISBN: 978-86-80593-54-8

construction of the roof and to produce an effective sheen. Modern solar technology systems allow the production of panels/ collectors which are integrated easily and in an aesthetically pleasing way, especially in newly-built buildings. Within the next few years, architectural plans and solutions for new buildings in urban environments should begin to use facade photovoltaic (PV) devices, and a similar practice would be applied with old building renovation. Hence, facade PV modules should become a necessary part of construction material, as are, for example, windows or doors.

Particularly responsible for the visually unpleasant experience, besides system collectors, are the central receiver towers. Their placement is influenced by atmospheric conditions, but it is of major importance that they are placed in locations of lower population density and in areas which do not represent national or natural assets of special importance. Light emissions during the night can also diminish the visual experience of local populace, fauna and road users, but this negative effect can be diminished through light emission reduction and secure lighting.

- **greenhouse gas emissions;**

Inciting RES power production represents part of a larger battle for stopping climate change. These changes were primarily caused by greenhouse gas emissions. This is why the EU, next to the targeted RES power production, has also established ambitious goals of reducing greenhouse gas emissions for every member country. Inciting RES power production relies on a whole set of programs, starting with feed-in tariffs, and including subsidized investments and tradable green certificates.

- **ecosystems, flora and fauna;**

The precision and care in the process of planning, designing, building and exploiting, can contribute to minimizing the influence on the vegetation, soil and habitat. Furthermore, shadows cast by panels can have a positive effect on the microclimate and vegetation. Linear elements of accompanying plant infrastructure elements can interfere with natural animal paths. Provided that the solar technology projects do not affect ecologically sensitive areas, or regions of remarkable natural beauty, it is unlikely that any of the aforementioned changes can be deemed relevant. Large solar plants can affect birds and flying insects which come within the area of effect of reflectors or the central energy collector.

- **effect on the soil;**

A solar plant with 350 MW of installed power takes up 25 km^2 of space, a 50 MW plant takes up 2 km^2, and if one wanted to cover the whole world's power production by solar plants, with a modest solar radiation level of 1000 kWh/year, one would require 150 km^2 of space [4]. A major part of this absorption surface could be placed on the walls and roofs of buildings, meaning extra surface on the ground would not be required.

Occupying additional new surfaces and damaging or wasting the surface layer of soil are consequences of a permanent character, while soil contamination and effects on underground waters can be mitigated by producing an action plan for hazardous matter and waste, and a strict application of prescribed measures.

Most of the more serious and professional solar plants today are built on dry desert ground characterized by infertile soil and poor flora.

- **effects on water resources;**

Building solar plants can damage coasts and shorelines, implying a change in hydrological characteristics, including erosion, dust emission, direct removal of vegetation and soil, as well as material depositing into swamplands. At the same time, the potential negative effects can be seen through worsening the quality of

ISBN: 978-86-80593-54-8

water and sediments, endangering wetland vegetation, and losing animal habitats in coastal areas.

On the other hand, a central tower system which uses a conventional steam drive for power production requires water for cooling, which is not considered an adequate technical solution in arid environments. In addition, as a result of letting heated water into present streams, or in case of chemical disposal accidents, the water resource ecosystem can be negatively affected. This can be prevented or mitigated by producing a plan for water protection and strictly adhering to the measures prescribed in the plan for the construction phase and the operational method, and carrying out safety procedures and applying good practices.

- **impact on indigenous vegetation and protected natural areas;**
  Construction of certain solar plant system elements, and the accompanying activities in the worker camp during the construction phase, can cause unwanted side-effects and loss of indigenous vegetation, as well as temporary or permanent changes on natural goods or protected areas.

  Clearing the field, tracing infrastructure lines, setting up plant elements, as well as soil and water contamination, can lead to endangering and the extinction of indigenous vegetation or protected natural species.

- **occupational health and safety;**
  Generally speaking, during production, use and disposal of solar system elements, slight health hazards are present, however, they can be overcome by good work policy, which implies using protective gloves, glasses, equipment, clothes and footwear. The present risks of work at high places during system installation, open flame and flammable material hazards, releasing and potentially breathing in toxic matter, the existence of a DC charge when connecting PV panels to the system, can be reduced to an acceptable level, through applying regulations and procedures, as well as using examples of a conscientious work practice.

- **impact on archeological sites or sensitive ecosystems;**
  It is recommendable to avoid ecologically or archeologically sensitive areas when choosing the installation location for solar technologies on the ground surface. During the construction of solar plant system elements, unfavorable effects on unregistered archeological sites are possible. In such cases, destruction, damage, unearthing or relocation of cultural heritage items can occur. Measures taken in order to avoid this imply rerouting the solar system infrastructure element.

  Regions of exquisite natural beauty, protected cultural sites and natural resources, national parks, cannot represent favorable areas for exploiting solar energy. On the other hand, isolated desert areas with a large number of sunny days throughout the year represent the most convenient coordinates for solar plant construction.

- **socio-economic effects.**
  Renewable energy sources, like solar technologies, play a vital role in the decrease in carbon-dioxide emissions, and represent an important aspect of climate and energy politics. With this, using solar technologies is reflected highly positively on the populace and the economy, especially from the aspect of regional/ national energy safety, security in power supply, as well as supporting the electrification of rural areas.

  Construction, putting operational activities into effect, and solar plant maintenance improve many socio-economic aspects: employment (opening new and keeping existing jobs), increasing local and regional economic

ISBN: 978-86-80593-54-8

activity, creating additional income, total social involvement through fulfilling climate policy goals, and reducing poverty.

These potential problems can sometimes be a strong obstacle for certain consumers, however, through environmental impact assessment and recommended safety measures, in the form of innovations, technical and technological solutions, as well as good work practices, they can be overcome.

Therefore, from the environmental aspect, solar energy transformation has positive implications, such as:

- always available free fuel;
- reduction of greenhouse gas emissions (CO_2, NO_X) and prevention of toxic gas emissions (SO_2, dust particles);
- reclamation of degraded soil;
- decreasing power distribution system workload;
- improving quality of water resources;
- no waste in operations.

Solar plant shortcomings include:

- energy is only produced during the day;
- the effectiveness of solar plants is reduced in case of shadows falling on the panels;
- the effectiveness of solar plants is reduced with dirty panels (areas with a high concentration of dust, grime and similar industrial areas);
- the effectiveness of solar plants is reduced in rainy or cloudy conditions;
- the effectiveness of solar plants is reduced during winter, when the solar radiation intensity is almost five times smaller than during the summer;
- large surfaces are sometimes required.

IV. THE EFFECT OF THE 30 KW SOLAR PLANT OF DOMIT IN LESKOVAC ON THE ENVIRONMENT

Producing electric energy on unused roof surfaces can become an additional source of income which decreases large power bills.

Pertaining to this, a small, 30 kW solar plant has been set up on the roof of the existing office building of the Domit enterprise in Leskovac, figure 1. The PV plant was designed exclusively as a network-connected system. The composition of the solar plant consists of 115, 260 W PV panels connected into strings, 2 three-phase 15 kW inverters, protective and connected equipment located in special DC and AC lockers, and a measurement group which registers received electric energy. All produced electric energy is transmitted into a low-voltage public distribution network, through a special connecting locker and counter. Through the inverter, the generated DC and input current is transformed into AC and output current, during which it is automatically synchronized with a public LV network.

Solar panels are mounted on appropriate stationary metal frames, i.e. the structure that was previously assembled and secured on the roof of the Domit enterprise. The narrower sides of the panels are oriented towards the south (azimuth) and at an incline of 33 °. In order to maximally exploit the sun’s insolation, the orientation and incline of the panels are extremely important.

Figure 1. Solar plant installed on the roof of the Domit enterprise in Leskovac

ISBN: 978-86-80593-54-8

During the assembly of the previously prepared supporting structure for PV panels, and during the installation of the panels themselves, the work was done on the roof of the Domit enterprise building in Leskovac, which does not belong to the high-rise class. Certainly, from the aspect of occupational health and safety, all employees involved in the installation should keep to safety measures and procedures for working in high places. This implies exclusively employing well-trained, physically and mentally healthy people, who use adequate means of personal protection and the necessary safety girdle in this type of work. At the same time, atmospheric conditions under which installation, repair, cleaning or dismantling is not permitted imply bad weather accompanied by atmospheric discharge, strong wind or extreme temperatures.

As an unavoidable factor of all construction work, noise was present in an amount not harmful to workers involved in the installation, the local populace or the animal world. During the process of exploitation, the factor of noise was deemed irrelevant.

Given that the solar panels closely follow the roof structure, it can be said that an improvement has been made from a visual standpoint. Viewed from the air, the roof surface of the building now possesses an attractive look with and an effective sheen, which cannot influence air traffic in a significant way or harm birds in flight. As a filler roofing material, the solar panel field contributes to a higher quality heat and sound insulation for the subroof building structure.

In accordance with the fact that the solar plant is located on the roof of the building, all factors pertaining to claiming new land surfaces, influencing archeological sites or sensitive ecosystems, as well as impacting water resources, become irrelevant for further consideration.

Conclusion

Constructing a solar plant with accompanying installations and infrastructure, the exploitation and dismantling phases, can cause certain minimal drawbacks for the environment and the population. These effects should be identified in the planning and designing phase so that problems related to choosing the optimal location can be avoided in the early stages, and a contribution can be made to minimizing unwanted effects on the environment and the populace through adequate safety measures.

In the designing phase, detailed geotechnical research on the desired location is of extreme importance, as well as choosing technical solutions which will especially focus on visual aesthetics (the landscape), flora and fauna, water resources, the soil, and the cultural heritage of the area.

Solar plants, today, represent a safe and long-term oriented form of investment. By setting them up and exploiting them, people can produce “green energy”, and thus meet the demands regarding the quality of the living environment, improve natural and artificial values, and, eventually, make a contribution to sustainable development.

References

[1] LJ. Stamenić, “Korišćenje solarne fotonaponske energije u Srbiji”, Jefferson Institute, 2009.

[2] Vlada RS, Ministarstvo energetike, razvoja i zaštite životne sredine, “Nacionalni akcioni plan za korišćenje obnovljivih izvora energije Republike Srbije”, “Službeni glasnik RS”, br. 53/2013, Beograd, 2013.

[3] T. Tsoutsos, N. Frantzeskaki, V. Gekas, “Environmental impacts from the solar energy technologies”, Energy Policy, vol. 33, no. 3, pp. 289-296, 2005.

[4] J. Baruhović, “Solarne elektrane sa heliostatima i sa fotonaponskim ćelijama”, Magazin za nauku, istraživanja i otkrića, http://www.planeta.rs/52/08%20energija.htm

[5] European Photovoltaic Industry Association (EPIA), “Global Market Outlook for Photovoltaics 2014-2018”, 2014, http://www.epia.org/news/publications/

[6] “Studija energetskog potencijala Srbije za korišćenje sunčevog zračenja i energije vetra”, NPPE, Evidencioni br. EE704-1052A,

ISBN: 978-86-80593-54-8

Ministarstvo nauke i zaštite životne sredine, Beograd, 2004.

[7] Grupa autora, Liber Perpetum, "Knjiga o potencijalima obnovljivih izvora energije u Srbiji i Crnoj Gori", OSCE Mission to Serbia and Montenegro, 2004.

[8] S.B. Đurić, I. Biočanin, S. Bektašević, "Perspektive razvoja i primena alternativnih izvora energije", 1st International Conference Ecological Safety in post-modern environment, Banja Luka, RS, BiH, 2009.

[9] G.M. Masters, "Renewable and Efficient Electric Power Systems", John Wiley & Sons, Inc., Hoboken, 2004

ISBN: 978-86-80593-54-8

The Effect of Optical Errors on the Absorbed Flux of a Paraboloidal Solar Dish Mounted Spiral Heat Absorber

Saša Pavlović, Faculty of Mechanical Engineering, Nis, Serbia,
saledoca@gmail.com

Velimir Stefanović, Faculty of Mechanical Engineering, Nis, Serbia,
veljas@masfak.ni.ac.rs

Zoran Stamenković, Faculty of Mechanical Engineering, Nis, Serbia,
zoki2101984@gmail.com

Abstract—**A dish-mounted spiral heat absorber is investigated for the use in a hot water system, steam generation, cogeneration, polygeneration system, etc. These systems are suitable for cooling and industrial processes. High-quality solar energy can be utilized as energy source for many processes with the temperatures above 100°C.**

The efficient conversion of solar radiation into heat at these temperature levels requires the use of solar thermal collectors (STC) of concentrating type. The absorbed solar heat flux on the solar receiver is determined with SolTrace. The diameter of the proposed parabolic solar dish is 3.8 m and the focal length is 2.26 m. The outer diameter of the cylindrical cavity receiver is 400 mm. The reflectivity of the solar dish segmented mirror is 90% and the absorptivity of the solar thermal absorber is 90%. A pillbox sunshape is assumed in the SolTrace analysis. The parameter for the pillbox, being a flat distribution, is chosen as 4.65 mrad.

SolTrace includes the effect of the shade of the receiver on the concentrator. The effect of the optical error on the absorbed solar heat flux at the spiral heat absorber is investigated.

Keywords: ***ray racing analysis, optical modeling, optical errors, soalr receiver, solar parabolic concentrating collector***

I. Introduction and Literature Survey

The utilization of modern parabolic dish concentrators for conversion of solar radiation into heat energy requires the development and implementation of compact and energy efficient heat absorbers. A solar paraboloidal dish concentrator and solar thermal receiver is investigated for the use in hot water systems, steam generation, cogeneration, polygeneration systems. In solar thermal applications a parabolic dish can be used to reflect the sun's rays onto a receiver.

The parabolic dish can be constructed from 12 segments but in many cases the 12th segment is removed to accommodate a receiver structure. In this paper the effect of focal distance and optical error are investigated to find the best distribution of heat flux on a dish-mounted spiral receiver for the use in a polygeneration system. The absorbed solar heat flux on the solar receiver is determined with SolTrace.

The diameter of the proposed parabolic solar dish is 3.8 m and the diameter of the spiral solar receiver is 400 mm. The reflectivity of the solar dish is 90% and the absorptivity of the solar receiver is 90%. A pillbox sunshape is assumed in the SolTrace analysis. The parameter for the pillbox, being a flat distribution, is chosen as 4.65

ISBN: 978-86-80593-54-8

mrad. SolTrace includes the effect of the shade of the heat absorbers on the concentrator. The effect of the optical error and focal length on the absorbed solar heat flux at the spiral receiver (heat absorber) is investigated. The focal length is adjusted between 2.26 and 2.3 m and the optical error between 5 and 50 mrad.

In addition, the list of possible alternative applications of this technology is growing, due to the problems of oil dependency and global warming. They can be designed as various devices including solar cooker [1], solar hydrogen production [2,3] and Dish Stirling system of harvest electricity [4,5]. Usually reflecting petals are made from glass and their thickness is from 0.7 to 1.0 mm. Traditionally, the optical analysis of radiation concentrators has been carried out by means of computer ray-trace programs. Recently, an interesting analytical solution for the optical performance of parabolic dish reflectors with flat receivers was presented by O'Neill and Hudson [6]. Their method for calculating the optical performance is fast and accurate but assumes that the radiation source is a uniform disk. Imhamed M. Saleh Ali et al. [7] have presented study that aims to develop a 3-D static solar concentrator that can be used as low cost and low energy substitute. Their goal were to design solar concentrator for production of portable hot water in rural India. Their used ray tracing software for evaluation of the optical performance of a static 3-D Elliptical Hyperboloid Concentrator (EHC).

Optimization of the concentrator profile and geometry is carried out to improve the overall performance of system. *Kaushika and Reddy* [8] used satellite dish of 2.405 m in diameter with aluminium frame as a reflector to reduce the weight of the structure and cost of the solar system. In their solar system the average temperature of water vapor was 300^0C, when the absorber was placed at the focal point. Cost of their system was US$ 950. *El Ouederni et al.* [9] was testing parabolic concentrator of 2.2 m in diameter with reflecting coefficient 0.85. Average temperature in their system was 380^0C.*Y. Rafeeu and M.Z.Z.AbKadir* [10] have presented simple exercise in designing, building and testing small laboratory scale parabolic concentrators. They made two dishes from acrylonitrile butadiene styrene and one from stainless steel.

Three experimental models with various geometrical sizes and diameters were used to analyze the effect of geometry on a solar irradiation. *Zhiqiang Liu et al.* [11] presented a procedure to design a facet concentrator for a laboratory-scale research on medium – temperature thermal processes. The facet concentrator approximates a parabolic surface with a number of flat square facets supported by a parabolic frame and having two edges perpendicular to the concentrator axis.

The decision to make solar parabolic concentrator with 11 petals is based on large number of design concepts that are realized in the world. This concept already proved useful in solar techniques, especially in production of heat and electrical energy as well as in trigeneration and polygeneration systems.

Only with employment of parabolic concentrating systems it is possible to obtain high temperatures in range from 200°C to 800°C and high optical and thermal efficiency of concentrating solar collectors.

II. Geometrical Model of Solar Parabolic Dish Concentrator and Receiver

The design of the solar parabolic thermal concentrator, and operation are presented. Optical design is based on parabolic dish with 11 curvilinear trapezoidal petals. Solar dish concentrators are generally concentrators that concentrate solar energy

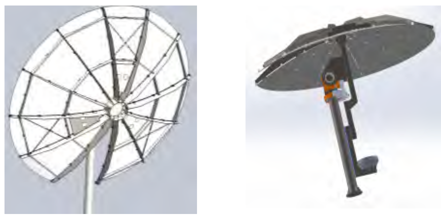


Figure 1. CAD model of solar parabolic concentrator in safe position and rear view of solar concentrator system

ISBN: 978-86-80593-54-8

in a small area known as focal point. Dimensions of reflecting surfaces in solar dish concentrator are determined by desired power at maximum levels of insolation and efficiency of collector conversion. The ray tracing technique is implemented in a software tool that allows the modelling of the propagation of light in objects of different media.

This modelling requires the creation of solid models, either by the same software or by any computer aided design (CAD) software. Once in the optical modelling software, portions of the rays of the light source propagate in the flow of light, in accordance with the properties assigned to the relevant objects, which may be absorption, reflection, transmission, fluorescence, and diffusion.

The sources and components of the light rays, adhering to various performance criteria involving the system parameters, result in simulation of the spatial and angular distribution, uniformity, intensity, and spectral characteristics of the system. Mathematical representation of parabolic concentrator is paraboloid that can be represented as a surface obtained by rotating parabola around axis. Mathematical equations for the parabolic dish solar concentrator in Cartesian and cylindrical coordinate systems is defined as:

$$x^2 + y^2 = 4fz, \quad z = r^2/4f \qquad (1)$$

where are x and y are coordinates in aperture plane and z is distance from vertex measured along the line parallel with the paraboloid axis of symetry; f is focal length of paraboloid.

The relationship between the focal length and the diameter of parabolic dish is know as the relative aperture and it defines shape of the paraboloid and position of focal point. The shape of paraboloid can be also defined by rim angle ψ_{rim}. Usually paraboloids that are used in solar collectors have rim angles from 10 degrees up to 90 degrees. The relationship between the relative aperture and the rim angle is given by:

$$f/D = \frac{1}{4\tan\left(\psi_{rim}/2\right)} \qquad (2)$$

The paraboloid with small rim angles have the focal point and receiver at large distance from the surface of concentrator. The paraboloid with rim angle smaller than 50^0 ($\psi_{rim} = 45{,}6$) is used for cavity receivers while paraboloids with large rim angles are most appropriate for the external volumetric receivers (central receiver solar systems). $f/D = 0.59$

The geometric concentration ratio can be defined as the area of the collector aperture A_{app} divided by the surface area of the receiver $A_{rec}$and can be calculated by eq.3.

$$CR_g = \left(\sin^2\theta_a\right)^{-1} = A_c A_r^{-1} = A_{app}/A_{rec} \qquad (3)$$

The designed solar parabolic concentrator has geometric concentration ratio $CR_g = 100$.

Selected model of solar dish concentrator with 11 petals requires very precise definition of parameters during geometrical modelling of system. Results obtained by optical analysis of solar concentration system are very much dependent on the selected method of the CAD model generation.

III. METHODOLOGY

The rim angle of the solar dish is calculated from Eq. (4). The rim angle is determined from the focal length as shown in Table 1. to be 45.24^0.

$$A_s = 4\pi f^2 \frac{sin^2\phi_{rim}}{\left(1 + cos\,\phi_{rim}\right)^2} \qquad (4)$$

Table 1. Rim angle of parabolic dish concentrator

Focal length	Rim angle
2.26 m	45.6^0
2.28 m	45.24^0
2.3 m	44.89^0

ISBN: 978-86-80593-54-8

The optical error is determined as follows:

$$\omega_{optical} = \left(4\omega_{slope}^2 + \omega_{specularity}^2\right)^{1/2} \qquad (5)$$

Optical errors of 5, 20, 35 and 50 mrad are considered respectively and a tracking error of 0^0isassumed. It is assumed that the slope error and specularity error are equal for each optical error considered. A DNI of 1000 W/m^2 is assumed. Soltrace was used to do the analysis as shown in Fig. 2.

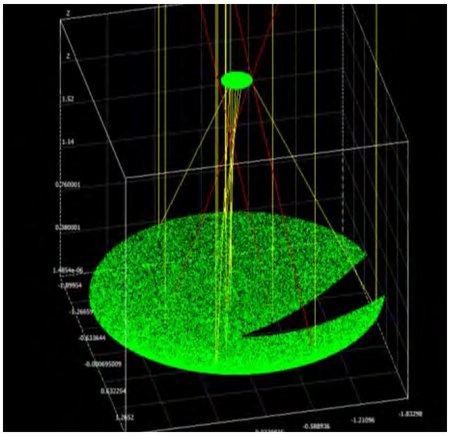


Figure 2. SolTrace analysis showing 10 random rays

III. RESULTS

Figure 3 – 6 shows the heat flux on the solar spiral absorber with focal length of 2.26 m. Figure 7 – 10 shows the heat flux on the solar receiver with focal length of 2.28 m. Figure 11 – 14 shows the heat flux on the solar receiver with focal length of 2.3 m. The total absorbed heat rate on the absorber is shown in Table 2.

Table 2. Total absorbed heat rate on solar spiral absorber

	5 mrad	**20 mrad**	**35 mrad**	**50 mrad**
2.26 m	8413	8390	7525	5711
2.28 m	8414	8405	7568	5738
2.3 m	8412	8403	7568	5735

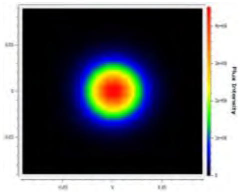


Figure 3. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.26 m and optical error of 5 mrad

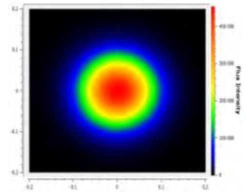


Figure 4. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.26 m and optical error of 20 mrad

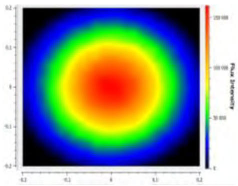


Figure 5. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.26 m and optical error of 35 mrad.

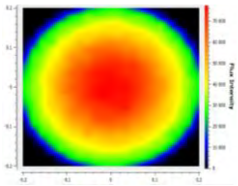


Figure 6. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.26 m and optical error of 50 mrad

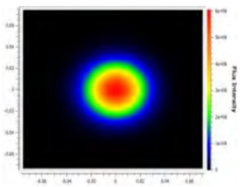


Figure 7. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.28 m and optical error of 5 mrad.

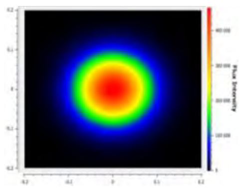


Figure 8. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.28 m and optical error of 20 mrad.

ISBN: 978-86-80593-54-8

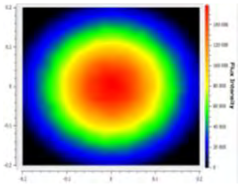


Figure 9. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.28 m and optical error of 35 mrad.

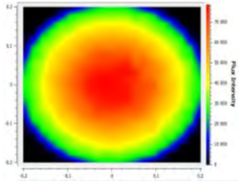


Figure 10. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.28 m and optical error of 50 mrad.

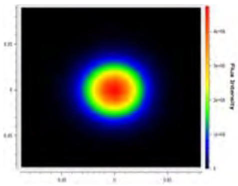


Figure 11. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.3 m and optical error of 5 mrad.

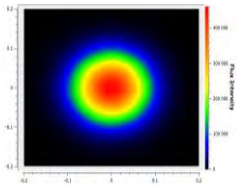


Figure 12. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.3 m and optical error of 20 mrad.

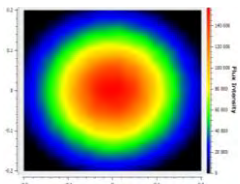


Figure 13. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.3 m and optical error of 35 mrad.

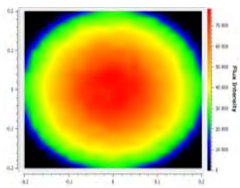


Figure 14. Absorbed solar heat flux (W/m^2) on the spiral solar receiver with focal length of 2.3 m and optical error of 50 mrad.

IV. CONCLUSIONS

The absorbed solar heat flux for a spiral solar thermal absorber was given and the effect of focal length and optical error was investigated. It was shown that the maximum absorbed solar heat flux can range from almost 80000 to 5000000 W/m^2 for optical errors of between 5 and 50 mrad and focal length of between 2.26 m and 2.3 m. The next investigation will be effect of the tracking error on the absorbed solar heat flux at the spiral receiver and optimization of distance for set up of spiral heat absorber/receiver and their effect on the distribution of radiant heat flux at the outer absorber surface wall.

ACKNOWLEDGMENT

This paper is done within the research framework of research projects: III42006 – Research and development of energy and environmentally highly effective polygeneration systems based on renewable energy resources. Project is financed by Ministry of Education, Science and Technological Development of Republic of Serbia.

REFERENCES

[1] A.A. Badran, et al., “Portable solar cooker and water heater”, Energy Conversion and Management 51 (8), 2010, pp. 1605–1609.

[2] A. S. Joshi, I. Dincer, B. V. Reddy, “Solar hydrogen production: a comparative performance assessment”, International Journal of Hydrogen Energy vol. 36 no. 17, 2011, pp. 11246–11257.

[3] P. Furler, J. R. Scheffe, A. Steinfeld, “Syngas production by simultaneous splitting of H_2O and CO_2 via ceria redox reactions in a high-temperature solar reactor”, Energy & Environmental Science, vol. 5, no. 3, 2012, pp. 6098–6103.

[4] T. Mancini, et al., “Dish–Stirling systems: an over view of development and status“, Journal of Solar Energy Engineering-Transactions of the ASME, vol. 125, no. 2, 2003, pp. 135–151.

[5] D. Mills, “Advances in solar thermal electricity technology”, Solar Energy, vol. 76, no. 1–3, 2004, pp. 19–31.

[6] M. J. O'Neill, S. L. Hudson, “Optical Analysis of Paraboloidal Solar Concentrators." Proceedings 1978 Annual Meeting, U.S. Section of Int. Solar Energy Society, vol. 2. no. 1, 1978, p. 855.

[7] I. M. Saleh Ali, T. S. O’Donovan, K. S. Reddy, T. K. Mallick, “An optical analysis of a static 3-D

ISBN: 978-86-80593-54-8

solar concentrator", Solar Energy, vol. 88, 2013, pp. 57-70.

[8] N. D. Kaushika, K. S. Reddy, "Performance of low cost solar paraboloidal dish steam generating," Energy Conversion & Management, vol. 41, 2000, pp. 713-726.

[9] A. R. El. Ouederni, M. Ben Salah, F. Askri, F. Aloui, "Experimental study of a parabolic solar concentrator, Revue des Renouvelables, vol. 12, 2009, pp. 395-404.

[10] M. Z. Rafeeu, A. A Kadir, "Thermal performance of parabolic concentrators under Malysian environment", A case study, Renewable and Sustainable Energy Reviews, vol. 16, 2012, pp. 3826-3835.

[11] Z. Liu, J. Lapp, W. Lipinski, "Optical design of a flat solar concentrator, Solar Energy 86, 2012, pp. 1962-1966.

ISBN: 978-86-80593-54-8

EU Legislation in the Field of Protection of the Environment and Climate Change for Electrical Energy Sector

Slađana Mirjanić, Faculty of Science and Mathematics, Banja Luka, Republika Srpska, B&H, sladjanamirjanic@yahoo.com

Abstract – **The European Union legislation in the field of protection of the environment and climate change for the energy sector is analyzed in the paper. In the first part of the paper the European Union legislation is presented, while the second part deals with the harmonization of the Republic of Srpska and Bosnia and Herzegovina legislation with the EU directives as well as the proposal of further activates, especially the obligations relating to the signed international treaty on energy community.**

Keywords: ***energy sector, climate change, EU legislation***

I. INTRODUCTION

Joining the European Union (EU) is a strategic goal of the Republic of Srpska and BiH. The process of approaching sets new challenges before the candidate countries when it comes to protection of the environment. EU demands detailed organization of all issues in this field, with numerous legal, administrative, institutional and financial changes. At the same time, significant changes in organizing human resources in the field of protection of the environment, in accordance with the EU *acquis communautaire* are required. Previous experience shows that approaching the policy and the standards of protection of the environment is extremely demanding and complex for candidate countries due to pronounced differences in present standards, in legislative and administrative system, as well as in the state of affairs in the environment itself. [1].

An overview of selected EU legislation in the field of environment protection, relevant for the energy sector, is set out below:

- NEC Directive 2001/81/EZ on national upper limits for emissions for certain pollutants;
- IPPC Directive 96/61/EZ on integrated prevention and control of pollution of the environment;
- LCP Directive 2001/80/EZ on limitations of emissions of certain pollutants into the air from large combustion plants.
- SEA Directive 2001/42/EZ on the Assessment of the Effects of Certain Plans and Programmes on the Environment;
- EIA Directive 85/337/EEZ on the assessment of the effects of certain public and private projects on the environment, as amended by Directive 97/11/EC;
- Directive 2003/35/EZ on participation of public in drawing up of certain plans and programs relating to the environment and amending with regard to public participation and access to the judiciary;
- Seveso II Directive 96/82/EC on the control of major-accident hazards involving dangerous substances;
- Directive 91/689/EEC on hazardous waste and Directive 94/31/EZ amending the Directive on hazardous waste;
- Directive 2000/60/EZ establishing a framework for Community action in the field of water policy.
- Decision 280/2004/EZ concerning the mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol.

ISBN: 978-86-80593-54-8

- EU-ETS Directive 2003/87/EZ on establishing a scheme for greenhouse gas emission allowance trading within the EU;
- Directive 2004/101/EZ on linking the scheme for greenhouse gas emission allowance trading with more flexible Kyoto protocols;
- Directive 91/689/EEC on hazardous waste and Directive 94/31/EZ amending the Directive on hazardous waste;
- Directive 2000/60/EC establishing a framework for the European Community's action in the field of water policy;
- Decision 280/2004/EC on the mechanism for monitoring the greenhouse gases in the Community and for the implementation of the Kyoto Protocol;
- EU-ETS Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community;
- Directive 2004/101/EC on connecting the system of emission trading with more flexible mechanisms of Kyoto protocol.

II. Analysis of the Directives

NEC Directive – Directive 2001/81/EZ of the European Parliament and the Council of 23 October 2001, is a part of the strategy of the European Union to abate acidification, eutrophication and ground-level ozone and is compatible with the previously signed Protocol on the Control of Acidification, Eutrophication and Ground-Level Ozone.

It establishes the national peak values of the emission of the pollutants causing acidification, eutrophication and formation of the ground-level ozone. The Directive also establishes and sets forth the national annual emission quotas for sulfur dioxide ($S0_2$), Nitrogen oxides (NOx), volatile organic compounds – VOC) and ammonia (NH 3) which should be fulfilled no later than by the end of 2010. Member countries are required to prepare the programs for phasing out of its annual emissions. Member countries are also required to prepare annual reports and update the national inventories and projections of emissions for $S0_2$, NO_x, VOC and NH3. These inventories and projects must be submitted to the European Commission and the European Agency for Protection of the Environment, in the form of reports, every year, by 31 December at the latest [2].

IPPC Directive – The goal of the Directive 96/61/EC of 24 September 1996 on integrated prevention and control of pollution is to achieve an integrated approach in prevention and control of pollution that comes from a large spectrum of industrial and agricultural activities. In Appendix I of the Directive, a number of industrial plants to which the provisions of this Directive refer are stated, which include energy sector, production and metal processing, mining, chemical industry, waste management, cattle breeding and the other. An integrated approach implies taking account of a certain industry as a whole (air, water, soil) and its overall impact on the environment. The Directive sets forth a procedure to conduct the analysis, set the protection measures and select the best available techniques, which are appropriate and in accordance with the economic possibilities of the user, as a condition for issuing a permit for operation of an industrial or agricultural installation [3].

In order to ensure the implementation of an integrated prevention of pollution of the environment, the Directive lays down the requirements to be contained in the operation permit, as follows:

- Emission limit values for polluting substances;
- Any soil, water and air protection measures required;
- Waste management measures;
- Measures to be taken in exceptional circumstances;
- Measures for minimisation of long-distance or transboundary pollution;
- Emission monitoring measures, and
- Other appropriate measures.

LCP Directive – the goal of the Directive 2001/80/EC of the European Parliament and

ISBN: 978-86-80593-54-8

the Council of 23 October 2001 on limiting the emissions of certain pollutants into the air from large combustion plants (LCP) includes phasing out of the annual emission of $S0_2$, NOx and suspended particles from the existing large combustion plants, thus reducing acidification, the presence of ozone precursors and of suspended particles in the air, as well as to set the limit values for $S0_2$, NOx and suspended particles in case of construction of new plants. The Directive is applied to the plants with furnaces with installed heat power equal or higher than 50 MW, regardless of the fuel they use (solid, liquid or gaseous). The application of the Directive is based on the system of permits. Besides the limit values of emissions, the operation permits for plants should also contain the procedures of suspending the operation of a plant in case of malfunction of the equipment for reduction of emissions, conditions for gas release, including the stack height too.

The Directive further mandates constant measuring of the emissions from large combustion plants, the method of measuring the emissions, regular reporting to competent bodies on the results of measuring emissions by pollutants as well as reporting to the European Commission by the member countries. Since all the plants to which the LCP directive refers also fall in the category of the plants for which an integrated license is issued under the IPPC directive, this Directive too is included in the Proposal of the Directive on Industrial Pollution (COM (2007) 843 final) which replaces eight existing EU directives including the LCP and IPPC Directive. The LCP Directive in this form (2001/80/EC) shall cease to be valid on 01 January 2016, because most its relevant provisions will be contained in a new directive on industrial pollution. [4].

SEA Directive – Directive 2001/42/EC of the European Parliament and the Council of 27 June 2001 on the assessment of certain plans and programmes on the environment (*Strategic Environmental Assessment - SEA)* [5]. The aim of the SEA Directive is to ensure that the consequences of the impacts on the environment by certain plans and programmes be recognized and assessed during the preparation of plans and programmes and taken into account before adoption.

The Directive defines the plans and programs for which the assessment of the impact on the environment is obligatorily performed, and lays down the method of determining a need for the assessment in cases of applying the plans and programs at the local level, as well as for minor adjustment of the same. Among others, this also includes the plans and programmes relating to the electrical power sector.

Furthermore, the Directive provides a framework for conducting the process of strategic procedure which must be determined in detail at the national level; it determines the minimum character of information that must be presented in the report on conducted assessment; it refers to intrastate exchange of information and cooperation in case of possible cross-boundary harmful impacts as well as a minimum level of inclusion of relevant state institutions in the process.

After the adoption of the plan or the program, the public must be informed about the decision and the manner in which the decision was taken. In case of possible cross-boundary impacts, both the member country and its public must be informed and have a possibility to make their objections in order to integrate them in the national decision-making process [6].

EIA Directive – Directive 85/337/EEC of the Council of 27 June 1985 on the impact of certain public and private projects on the environment, as amended by the Directive of the Council 97/11/EC of 3 March 1997 and the Directive 2003/35/EC of the European Parliament and Council of 26 May 2003, which lays down participation of the public in drawing up of certain plans and programs relating to the environment (EIA Directive; *Environmental Impact Assessment).* EIA directive mandates the member countries to define a binding procedure of the assessment of environmental impact before issuing, for their implementation, for such projects the implementation of which may lead to unfavorable// environmental impacts.

ISBN: 978-86-80593-54-8

Annex I of the Directive defines the types of projects for which the environmental impact assessment is obligatory, while Annex II defines the types of the projects for which the environmental impact assessment may be sought, which is then determined in accordance with the criteria set in Annex III of the Directive. Given the character of the project within the energy sector, *the environmental impact assessment is obligatory for almost all projects in this sector.*

The other requirements of the Directive relate to the character and scope of information to be contained in the report on the conducted assessment, the right of the public to participate in the process and access to information about regarding the activities in the process as well as the final decisions made [7].

Seveso II Directive – Directive 96/82/EC of the Council of 9 December 1996 on the control of major accidents involving hazardous matters (Seveso II Directive). There are two basic goals of Seveso II Directive, i.e. prevention of large accidents on industrial plants and decreasing their consequences. Seveso II Directive deals with the types and quantities of hazardous matters being produced, processed, stored and/or transported in different plants, and, depending on that, lays down the obligations for the owners of such plants and relevant authorities bodies. Hazardous matters are divided into 10 categories, more precisely: very toxic, toxic, oxidants, explosives, flammable, highly flammable matters, matters hazardous for the environment (i.e. very toxic matters for aquifiers) and other hazardous matters that are not included in the previous nine categories (e.g. matters that in contact with water release toxic gases). As for the quantities of hazardous matters, Seveso II Directive makes a difference between two limit values, lower and upper. The lower and upper limit values for hazardous matters stated in Seveso II Directive have been determined on the basis of their physical-chemical characteristics, their toxicity, method of production, processing, storing and transport and the number and type of registered accidents in which these matters were involved. By drawing up the Seveso Directive in the European Union member countries, a legal basis was created which enabled a consistent and efficient improvement of the safety of industrial plants, prevention against major accidents and the degree of protection of the employed, population and the environment [8].

Directive on Hazardous Waste – the Directive 91/689/EEC of 27 December 1991 on hazardous waste and the Directive of the Council 94/31/EC of 27 June 1994, which amends it, lays down the rules on the management of hazardous waste. These directives amend the Directive 2006/12/EC which set a framework for waste management.

The Directive on Hazardous Waste obliges the member countries to set up a system of hazardous waste management, and to ensure that hazardous waste is identified and registered. In management, one must prevent mixing of different types of hazardous waste as well as of hazardous waste and non-hazardous waste, and take appropriate measures for protection of health and the environment. Furthermore, the Directive requires that only such companies, to which a permit (license) for this type of operations was issued, may engage in collection of hazardous waste. Moreover, the carriers, producers and the companies managing the waste must keep the activities register and submit it to competent services. The Regulation establishing the European Pollutant Release and Transfer Register harmonizes the regulations on regular reporting to the European Commission on pollutants, including the waste [9].

Framework Directive on Waters – Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy (Framework Water Directive), relates to the management of inland surface waters, groundwater, transitional waters and coastal waters in order to prevent and reduce pollution, promote sustainable use, protect the water environment, improve the state of

ISBN: 978-86-80593-54-8

aquatic eco-systems and reduce the effects of floods and droughts [10].

A number of directives and other legal regulations have been built on following the Framework Water Directive, to regulate certain segments of water management. A key idea behind the Waters Directive is to establish the system of water management at the level of river basins, rather than at the level of individual countries, that is to say, even across the administrative and international borders. The goal of management is sustainable use of waters and achieving a good ecological status of all waters within 15 years from coming into force of the Directive.

In order to fulfill the goals established by the Directive, the member countries are obliged to identify all river basins in their territories, perform an analysis of water characteristics and evaluate the impacts of human activities on waters, as well as draw up the economic analysis of water use and register the areas requiring special protection. Based on performed analyses during a nine-year period from coming into force of the Directive, the members are obliged to adopt the management plan and the program of measures for individual river basin.

The measures proposed by the river basin management plan are supposed to:

- Prevent deterioration, improve and restore the surface waters, achieve good chemical and ecological status of such waters and reduce pollution from waste waters discharges as well as the hazardous matters emission;
- Protect, improve and restore to original state ground waters, prevent pollution and deterioration of ground waters and ensure the quantitative balance between groundwater abstraction and replenishment;
- Preserve the protected areas [11].

Decision on Monitoring Greenhouse Gas Emissions – Decision no. 280/2004/E2 of the European Parliament and the Council of 11 February 2004, for monitoring all anthropogenic greenhouse gas emissions which gases are not controlled by the Montreal Protocol, monitoring progress in this field in order to fulfill the obligations related to climate change, application of UNFCCC Convention and the Kyoto Protocol and ensuring that the information reported by the EU to UNFCCC Secretariat is complete, accurate, consistent, transparent and comparable. EU member countries are required to draw up and implement the national programs of reduction or limiting the anthropogenic emissions of greenhouse gases.

Member countries were obliged to, by 31 December 2005, establish the national system for inventory-making of the greenhouse gas emissions. Apart from that, every year the EU member countries were required to prepare a report on greenhouse gas emissions by 15 January, to enable the European Commission to prepare and submit to the UNFCCC Secretariat a joint report for EU, by 15 April. Moreover, based on this Decision, the EU and member countries are obliged to establish the registers designed for issuing, archiving, transfer, annulment and withdrawal of emission permits [12].

EU-ETS Directive and Linking Directive – Directive 2003/87/EC (EU-ETS directive) of the European Parliament and the Council of 13 October 2003, establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (IPPC Directive).

The Directive establishes a scheme for greenhouse gas emission allowance trading within EU. The aim of the scheme is to reduce the greenhouse gas emissions in a more economical manner. By using the emission trading scheme (cap and trade program), the governments limit the maximum quantity of carbon that individual industries may emit. The companies emitting less carbon than the limit may sell their remaining emission allowances in the carbon market, while the companies exceeding the set limit of the emission may buy the carbon credits in the same market. In essence, the buyer of the credit is punished for the pollution caused by it, while the seller is rewarded for reduction of the emission. The

ISBN: 978-86-80593-54-8

more the companies that must buy the credits, the higher the price of the credit, which, finally means that it is more economical to reduce the emission of harmful substances. Each country is required to develop the National Allocation Plan for all plants, i.e. activities stated in the directive and establish the Register of Emission Permits. With the application of the Directive, the member countries will provide free trade of emission allowances within EU [13].

The Directive 2004/101/EC (Linking Directive) of the European Parliament and the Council of 27 October 2004 amending the Directive 2003/87/EC on establishing the system of greenhouse gas emission allowance trading within the Community, in respect of Kyoto Protocol's project mechanisms – its aim is to link the flexible mechanisms of the Kyoto Protocol – Joint Implementation (JI) and the Clean Development Mechanism (CDM) with the system of trading of greenhouse gas emission allowances within EU. The essence of the Directive is to recognize the equivalence of JI and CDM certificates with the emission allowances within the EU emission allowance trading scheme [14, 15].

As part of the preparation for the post-Kyoto period, at the end of 2008 the European Union adopted the so-called Climate and Energy Package for 2013-2020, which obliges the member countries to reduce, by 2020, the greenhouse gas emission by 20%, increase the energy efficiency by 20% and increase the share of electrical energy produced from renewable energy sources in total energy consumption by 20%. In order to be able to implement the set goals, as early as in the next year, i.e. 2009, EU adopted the Climate and Energy Legislative Package which consists of six new legally binding directives that came into force in 2013. The Package consists of the following:

- Revising the EU ETS Directive on trading the greenhouse gas emission allowances to include the new industries, aluminum, oil refineries and production of ammonia, commercial aviation, which came into force on 01 January 2013.
- The decision on the so-called *distribution of burden* in the sectors that are not included in the emission allowance trading, such as road and maritime transport, building construction, services, agriculture and minor industrial installations that must reduce the emissions by about 10% at the national level; the decision came into force in 2010.
- The legislative framework for collection and storage of Carbon dioxide in geological formations by which the future power plants are required to store $C0_2$ under ground instead of emitting it into the air; it came into force in 2011.
- The new Directive on renewable energy sources setting minimum national goals that have to be met by the member countries through increase of production of renewable energy and promoting energy efficiency which came into force in 2011.
- Regulation on $C0_2$ emission from cars that sets an average goal of 120 gr $C0_2$/km for the whole car industry by 2012 in comparison with the current level of 160 gr/km., and a long-term goal which is 95 gr $C0_2$/km by 2020.; it came into force in 2012.
- The new Directive on Quality of Fuel which sets the conditions for reduction of emission of GHGs which arise from the life cycle of transport fuels, by 10%, by 2020, which came into force at the end of 2010 [13].

III. HARMONIZATION OF DOMESTIC LEGISLATION

In this part we will provide an overview of harmonization of domestic legislation with the aforementioned EU directives. Besides Bosnia and Herzegovina Constitution and the Republic of Srpska Constitution, from which the responsibilities of RS institutions for energy arise, the Power Act makes the basic legal source of RS energy law, as a key legal regulation for the field of electrical power, and the laws regulating certain energy sectors (Electrical Energy Act, Gas Act, Oil and Oil Products Act), the laws that lay down the conduct and regulation of transmission activity at the level of Bosnia and Herzegovina (The Law

ISBN: 978-86-80593-54-8

on Transmission, Regulator and Electrical Energy System Operator in BiH, the Law on Founding a Company for Transmission of Electrical Energy in BiH, the Law on Founding an Independent System Operator in BiH), the laws regulating the concession regime for exploration and use of natural resources and construction of energy objects (Concessions Act and Public Private Partnership Act), as well as by-laws elaborating on the issues of billing and licensing the energy activity, relations with buyers, opening of the energy market and the activity of the Republic of Srpska Regulatory Commission in performing monitoring relations in the electricity, gas and oil market. Legal regulations governing the field of energy, also define the legal status and competencies and responsibilities of the institutions in charge of the development and planning, functioning, regulating and monitoring the Republic of Srpska energy sector [16, 17].

There is no adequate regulation or another by-law in the Republic of Srpska legislation which would appropriately cover the *NEC Directive* – Directive 2001/81/EC; however, there is a legal basis for adoption of such regulation in the Air Protection Act.

Furthermore, an integrated approach to the protection of the environment has been laid down in the Republic of Srpska in its Environment Protection Act ("RS Official Gazette", nos. 28/07; 41/08; 29/10; 71/12). Ten by-laws have been passed on the basis of this law, so that the procedure and the conditions for issuing an integrated license are fully harmonized with the IPPC Directive. As of the day of coming into force of the Environment Protection Act, no new plant can start operating without an integrated license. So far there have been no requests to issue integrated licenses for new plants, as no such plants have been constructed since the day of application of this law.

The procedure of strategic assessment of the impact on the environment in the Republic of Srpska was introduced after coming into force of the Environment Protection Act which is fully harmonized with SEA Directive 2001/42/EC.

The process of assessment of the impact on the environment was introduced in the Republic of Srpska by coming into force of the Environment Protection Act, i.e. by passing eight by-laws on the basis of this Act, by which the requirements of EIA Directive have been fully transferred in national legislation.

The requirements of the Hazardous Waste Directive have been fully transposed in the Republic of Srpska through the Waste Management Act ("RS Official Gazette", nos. 53/02 and 65/08) and seven by-laws promulgated on the basis of that law.

The Republic of Srpska Waters Act which was promulgated in 2006 ("RS Official Gazette", no. 50/06) contains the elements of the Framework Waters Directive. Full harmonization of legislation with the Framework Water Directive was fulfilled by passing of twelve by-laws [18].

In the Republic of Srpska legislation, with the Air Protection Act ("Off. Gazette", no. 124/11) and nine by-laws, the above Decision was transposed in national legislation.

There are no appropriate regulations in the Republic of Srpska legislation covering the field of greenhouse gas emission trading in the EU (Directive 2004/101/EC). By joining the European Union, the power plants in the Republic of Srpska and BiH which meet the criteria defined by EU-ETS Directive (2003/87/EC) on trading the emission rights, will be included in the existing system of trading the rights to the emission of CO_2. This will create an additional obligation/opportunity for which preparations should start already now. Pre-conditions for joining the EU-ETS system include, among others, ratification of the Kyoto Protocol, existence of the System for Inventory Making of Greenhouse Gases, making of the National Allocation Plan (NAP), establishing the Greenhouse Gas Register and passing of the appropriate legal regulations.

The Republic of Srpska is, through BiH, in the process of joining the EU-ETS system; it has drawn up the First and the Second

ISBN: 978-86-80593-54-8

National Reports according to the UN Framework Convention on Climate Change and is working on establishing a system for inventory-taking of the greenhouse gases. Moreover, BiH is supposed to prepare NAP which should define the emission quotas for all subjects covered by EU-ETS Directive. This plan will also define the emission quotas for thermal power plants in the RS and FBiH.

By signing the international treaty on energy community on 25 October 2005, the countries of the region committed to the adoption and application of EU legal regulations in the field of power sector, environment protection, renewable energy sources and market competitiveness. By coming into force of the Treaty, the customs duties and quantity limits are eliminated and the legal and institutional framework is created for free transfer and trading with energy sources. This will help attract the investors, improve the safety of investments and energy supply with higher environment protection and will also encourage efficient energy consumption and development of renewable energy sources.

IV. CONCLUSION

To the end of more complete harmonization of the Republic of Srpska and BiH legislation in the field of power sector with the European Union legislation, and in order to meet the commitments undertaken from the agreements, the power law, electrical energy law, law on renewable energy sources, Gas Act and Oil and Oil Products Act have been promulgated – as they contain the provisions relating to the security of electricity and gas supply, cogeneration as well as the provision relating to the obligation of securing the reserves of oil products.

In the process of joining EU, as part of harmonization of regulations with EU *acquis communautaire,* these directives and decisions should be implemented in the RS and BiH legislative system before joining the EU. Unlike the directives that are negotiable in terms of the beginning of application of certain limits determined by them, the decision and regulations are fully applied.

The international treaties signed by Bosnia and Herzegovina and that were made, ratified and published in accordance with constitutional acts and that are in force, are also a part of BH, i.e. RS legal system, governing the field of power sector. Along with the Treaty on Energy Charter with the Protocol on Energy Efficiency and Appropriate Problems of Environment Protection (PEEREA) signed by Bosnia and Herzegovina in 1995 and ratified in 2000, and which presumes the introduction of the model of long-term energy cooperation in Europe, while taking account of protection of the environment, CEFTA Agreement signed in 2006 obliging the parties to establish the area of free trade in accordance with the relevant rules and procedures of WTO and the Agreement on Stabilization and Association signed in 2008 by which the status of a potential candidate for the membership in the European Union is confirmed in BiH as well as cooperation in the energy sector, direct towards the priorities of EU legal legacy in the power field [17, 19]. The Treaty on Establishing the Energy Community is of special importance in terms of creation of legal and institutional framework of the Republic of Srpska energy sector, based on the principles of efficient regulation and improvement of competition, safe supply of energy and ensuring the environment protection.

REFERENCES

[1] S. Mirjanic, European Union legislation in the field of environmental protection for the energy sector, Proc. Int. Sci. Conf. UNITECH, vol. 3, 2011, pp. 464-470.

[2] Directive 2001/81/EC on national emission ceilings for certain pollutants.

[3] Directive 96/61/EC on integrated protection and control of pollution of the environment.

[4] Directive 2001/80/EC on the limitations of emission of certain pollutants into the air from large combustion plants.

[5] Directive 2001/42/EC on the assessment of the impact of certain plans and programs on the environment, Directive 85/ 337/EEC on the assessment of the impact of certain public and

ISBN: 978-86-80593-54-8

private projects on the environment, as amended by Directive 97/11/EC.

[6] Directive 85/337/EEC of the Council of 27 June 1985 on the assessment of the impact of certain public and private projects on the environment, as amended by the Directive of the Council 97/11/EC of 3 March 1997 and the Directive 2003/35/EC of the European Parliament and the Council of 26 May 2003 which sets forth participation of the public in drawing up certain plans relating to the environment.

[7] D. Lugic, Ecological Upbringing and Education in Elementary and Secondary Schools in the Republic of Srpska, I international congress of ecologists, Banja Luka, 2012.

[8] Seveso II Directive 96/82/EC on the control of major-accident hazards involving dangerous substances.

[9] Directive 91/689/EEC on hazardous waste and Directive 94/31/EC amending the Directive on Hazardous Waste.

[10] S. Mirjanic, The implementation of European legislation in the field of water protection, Proc. Int. Sci. Conf. UNITECH, vol. 3, 2012, 325–327.

[11] Directive 2000/60/EC establishing a framework for the activity of the European Community in the field of water policy.

[12] Decision 280/2004/EC on the mechanism for monitoring the greenhouse gases in the Community and for implementing the Protocol from Kyoto.

[13] Directive 2003/87/EZ (EU-ETS Directive) of the European Parliament and the Council of 13 October 2003, establishing a scheme for greenhouse gas emission allowance trading within the Community and amending the Directive of the Council 96/61/EC (IPPC Directive).

[14] Directive 2004/101/EC on linking the system of trading the emissions with flexible Kyoto protocol mechanisms.

[15] S. Mirjanic, The influence of the Kyoto protocol and the system of tradingCO_2 emissions on the development of the Republic of Srpska electric power sector, Proc. Int. Sci. Conf. UNITECH I vol. 1, 2014, pp. 361-366.

[16] Strategy of the Development of the Republic of Srpska Energy Sector by 2030, Banja Luka, 2012.

[17] S. Mirjanić, Legal Aspects of Protection of the Environment, Banja Luka University, PMF Banja Luka, 2013.

[18] S. Mirjanic, Protection of ground waters in the Republic of Srpska and B&H, The 2nd Global Virtual Conference, Section Ecology, 2014, pp. 449–453.

[19] S. Mirjanic, M. Gasic, Influence of Education on Improvement of the Quality of Working and Living Environment, Banja Luka University, PMF Banja Luka, 2014.

ISBN: 978-86-80593-54-8

PROMETHEE method for the multi-criteria decision models in determination of maintenance policy

Bojan Kojičić, Reseerach and Development Center “Alfatec”, Niš, Serbia,
bojankojicic@alfatec.rs

Aleksandar Janjić, The Faculty of Electronic Engineering, Niš, Serbia,
Aleksandar.Janjic@elfak.ni.ac.rs

Abstract—**Maintenance is becoming a critical functional area in most types of organizations and systems including the power generation, transmission and distribution. This increasing role of maintenance is reflected in its high cost, which is estimated to be around 30% of the total running cost of modern manufacturing and construction businesses. As such, planning for maintenance is becoming an essential part of planning for the whole organization.**

Preventative maintenance has become a very useful instrument to gain a competitive edge. However, in maintenance decisions, there are some contradictory criteria or points of view that are vital and must to be looked at simultaneously. In this context, the multi-criteria decision analysis (MCDA) approach is very important, allowing not only for the trade-off of multiple factors, but also taking in account the preference structure of the decision-maker with respect to these contradictory criteria.

This paper presents a multi-criterion decision-aided maintenance model in the choice of times for preventative maintenance of capacitors for reactive power compensation in distribution systems, with three criteria that have more influence on decision making: reliability, maintenance cost, and maintenance downtime. The model preserves some important concepts from the classic models of component replacement and improves an existing multi-criteria model, by taking criterion downtime into consideration, making a more appropriate treatment possible than the previous model for situations in cases where repair time cannot be ignored.

Keywords: ***Maintenance, Multi crtieria, Distribution networks, Weibull Distribution***

I. Introduction

The current competitive environment in power systems is demanding more and more efficient and accurate tools to support decisions for asset management and maintenance resource scheduling. The effectiveness of expanding maintenance resources can vary dramatically depending on the type, target and timing of the maintenance activities.

Distribution networks are one of the most maintenance-intensive parts of power systems. As maintenance budgets are a substantial share of costs in distribution networks, this area has been an active research topic in recent years.

The purpose of maintenance activity is to extend equipment life time and/or reduce the probability of its failure. Utilities follow different strategies to maintain different kinds of equipment. Maintenance strategies can be broadly classified into corrective and preventive maintenance. Corrective maintenance also known as “run to failure” involves no maintenance of equipment until it fails. However, preventive maintenance is performed on equipment before a failure occurs. The state-of-the-art in preventive maintenance offers at least three basic approaches: 1) time-based maintenance; 2) condition-based maintenance; and 3) reliability-centered maintenance [1].

This paper is focused on time-based maintenance so it is important to mention that maintenance schedule of distribution system is timely action plan with purpose to extend

ISBN: 978-86-80593-54-8

life cycle of the system, in order to reduce overall operation costs. Maintenance is closely related to reliability. If maintenance actions are performed rarely, it can cause a large number of faults and outages, while done too often, costs will be greatly increased. Therefore, it is necessary to make an appropriate balance between maintenance costs and outage duration costs [2].

The proposed methodology in this paper determines an optimal plan of actions for multi-year maintenance schedule. Idea is to make the best compromise between these three criteria: reliability, maintenance cost and maintenance downtime, and to establish replacement intervals. The mathematical model, proposed in [3] is based on Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), integrating the Bayesian approach with regard to the preference of the decision maker to the problem.

II. Mathematical Requirements

This part explains the mathematical requirements. In order to plan a maintenance program in this research, a failure distribution is needed which has a wear-out characteristic, namely the failure rate should increase with age. The Weibull model is a most prevalent distribution that satisfies this perquisite. It can be shown to be of the form:

$$f(t) = \frac{a}{b} \cdot \left(\frac{t}{a}\right)^{b-1}, \; b, a > 0, t > 0 \tag{1}$$

A. The Criterions involved in decision making

This paper proposes a multi-criterion decision-aided model with three criteria which deals with the problem of the replacement times of low voltage capacitors for reactive power compensation in distribution substations. It determines the best timing and frequency for replacing components by taking into account three criteria, which are the total cost of maintenance per unit of time, the reliability, and the total maintenance downtime per unit of time. Thus, after choosing the policy followed by this research, it is important to describe these three criteria in maintenance decision making.

Reliability, R(t), is the probability that a component or system will perform its design function for a specified mission time, given the operating conditions. [3]

Reliability is represented by

$$R(t) = e^{-\left(\frac{t}{a}\right)^{b}} \tag{2}$$

where:

- b is the shape parameter of the Weibull distribution;
- a is the scale parameter of the Weibull distribution.

Substation downtime is obviously related to the time when a component is not functioning because it has failed. In many cases, this criterion is significant, particularly where the continuity of a production process is vital, for example in systems of mass production and energy supply where repair times takes long enough to be considered seriously. Similar to the criterion of cost, downtime has an explicit optimum, which illustrates a paradox because by trying to reduce downtime, many small stops in operation must be made.

The downtime is represented by:

$$D(t) = \frac{T_{sp} R(t) + T_{sf}\left[1 - R(t)\right]}{\int_0^t x f(x)\,dx + \left(t + T_{sp}\right) R(t) + T_{sf}\left[1 - R(t)\right]} \tag{3}$$

When measuring time between preventative maintenance actions, the usual criterion in decision making is the expected cost per unit of time, also called the rate of expected cost, represented by C_m. In the present model, it is one of the criteria that can be seen in the decision of time alternatives (tp). In practice, the criterion describes the expected cost at the end of a long period of time where a replacement policy has already been applied. Actually there are two costs which must be considered: that of replacement before a failure; and the cost of replacement after a failure has occurred. These are represented by C_b and C_a, respectively. [4]

ISBN: 978-86-80593-54-8

The cost per unit of time:

$$C_m(t) = \frac{C_b R(t) + C_a\left[1 - R(t)\right]}{\int_0^t x f(x)dx + \left(t + T_{sp}\right)R(t) + T_{sf}\left[1 - R(t)\right]} \quad (4)$$

C_a – is the cost of a replacement due to a failure;
C_b – is the cost of a preventive replacement;
T_{sp} – is the time it takes to make a preventive replacement;
T_{sf} – is the time it takes to make a replacement of repair due to a failure;
t – is the time between replacement;
R – is the reliability for the time t; and
$f(x)$ – is the probability density function for time to failure. [4]

B. PROMETHEE II method

After estimating the Weibull parameters, evaluation of the cost, reliability, and maintenance downtime criteria can be obtained using the model, and then a multi-criterion decision with PROMETHEE methods can be made. [3]

The PROMETHEE methods are some of most popular in the world of outranking methods. The problem of the selection or ranking of alternatives submitted to a multi-criteria evaluation is not an easy problem. The many criteria are conflicting in decisions.

Compromise solutions have to be considered. The PROMETHEE Methods are known as some of the most efficient and also some of the easiest to use in the multicriteria decision aid field. They begin with a decision matrix of evaluations of alternatives with respect to an appropriate set of criteria (see Table 1):

Table 1. Matrix of evaluations of parameters

	f_1	f_2	f_k
a_1	$f_1(a_1)$	$f_2(a_1)$	$f_k(a_1)$
a_2	$f_1(a_2)$	$f_2(a_2)$	$f_k(a_2)$
:			
a_k	$f_1(a_k)$	$f_2(a_k)$	$f_k(a_k)$
:			
a_n	$f_1(a_n)$	$f_2(a_n)$	$f_k(a_n)$

Where A is the countable set of n potential actions and $f_j(.)$, $j = 1, 2,..., k$, is the set of evaluation criteria. In this paper the criteria are cost, reliability and downtime. The set of alternatives A is the set of feasible times for component replacement.

The preference structure of the PROMETHEE methods is based on pairwise comparisons. In this case the deviation between the evaluations of two alternatives of a particular criterion is considered. For each criterion a specific preference function Pj () must be defined. This function is used to compute the intensity of preference associated with the deviation or difference dj() between the evaluations in criterion fj() for a pair of alternatives. The greater the deviation, the greater the preference. Thus, the frame of preference is based on these differences and not on the absolute values of the evaluation of alternatives for each criteria.

$$d_j(a,b) = f_j(a) - f_j(b) \quad (5)$$

$$P_j(a,b) = P_j\left[d_j(a,b)\right] \quad (6)$$

The index $P_j(a,b)$ is a measure of preference of a on b taking into account all criteria. This measure supports the hypothesis that a is preferable to b through the following relation:

$$p(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \quad (7)$$

Similarly, $P_j(b,a)$ indicates how much b is preferred to a. In most of the cases there are some criteria in favor of b and others in favor of a. Thus, both $P_j(b,a)$ and $P_j(a,b)$ are usually positive.

As soon as $P_j(b,a)$ and $P_j(a,b)$ are computed for each pair of alternatives of A, a set of complete valued outranking measures can be derived, named outranking flows.

PROMETHEE methods calculate positive and negative outranking flows for each alternative. The positive outranking flow expresses by how much an alternative outranks the others; and the negative outranking flow expresses by how much it is outranked by the others. [4]

ISBN: 978-86-80593-54-8

$$f^{+}(a)=\frac{1}{n-1}\sum_{x\epsilon A}p(a,x) \tag{8}$$

Where f^{+} is the positive outranking flow

$$f^{-}(a)=\frac{1}{n-1}\sum_{x\epsilon A}p(x,a) \tag{9}$$

where f^{-} is the negative outranking flow.

Based on the net outranking flow, corresponding to the difference between both positive and negative outranking flows, the PROMETHEE II provides a complete ranking, where a is preferable to b if $f^{+}(a) > f^{-}(a)$ and they are indifferent if $f^{+}(a) = f^{-}(a)$. [4]

$$f(a)=f^{+}(a)+f^{-}(a)$$

where f is the net outranking flow.

III. RESULTS OF THE PROPOSED MODEL

Proposed model has been presented in Matlab, and all the calculations have been done in this software package.

Let us consider the failure behavior for a particular component used in power distribution systems. Items under consideration are capacitors for power factor correction in power substations. Failure of this piece of equipment, besides representing loss of the item, results in downtime for the power factor correction as the required power factor or power quality defined by standards cannot be met. Owing to the characteristics of this particular component, a replacement policy based on age was deemed appropriate. So the age when the equipment ought to be replaced becomes the only decision variable. To apply this policy, the failure times and cost of replacement (Cb) and repair (Ca) have to be estimated. To choose the age at which the replacement should be made, the three criteria discussed above, reliability, cost per unit of time, and downtime must be taken into consideration.

Table II presents the input needed in the model. This input constitutes the parameters of failure times of the component, as well as the costs Ca and Cb. Following the steps of the decision model, once the component has been identified, the alternatives of the problem which correspond to the time values which are best for the replacement must be drawn up.

Table 2. Input parameters

Weibull	a	3.6
	b	17500
Cost	C_b	400
	C_a	3000
Time	T_{sp}	0.1 h
	T_{sf}	2.5 h

Table 3 displays the groups of action Ti in units of working years.

Table 3. Possible replacement alternatives

Alternatives	Time in years
T1	1
T2	2
T3	3
T4	4
T5	5
T6	6
T7	7
T8	8
T9	9
T10	1

The identification of the alternatives can be made through a matrix of evaluation criteria, which assigns a value to each alternative using the expressions for criteria calculation. These values can be seen in Table 4. Using the criteria evaluation matrix, the aggregation process proceeds, where the alternatives can be considered in the light of all the criteria and according to the preferences of the decision-maker.

Following the steps set out by the PROMETHEE method, once the evaluation of alternatives has been carried out, through an interactive process between the decision‐maker and the decision-analyst, the preference function (P_j(.)) can be determined. This is the one that models most closely the behavior of the decision-maker

ISBN: 978-86-80593-54-8

Table 4. Evaluation matrix of the decision problem

Alt	$T_p(y)$	$R(t_p)$	$C_m(t_p)$	*D*
T1	1	0.9999	0.4000	0.1000
T2	2	0.9995	0.2005	0.0504
T3	3	0.9982	0.1348	0.0347
T4	4	0.9950	0.1033	0.0279
T5	5	0.9890	0.0858	0.0253
T6	6	0.9790	0.0761	0.0251
T7	7	0.9637	0.0711	0.0269
T8	8	0.9420	0.0697	0.0302
T9	9	0.9127	0.0710	0.0354
T10	10	0.8751	0.0745	0.0411

given the differences ($d_j(.)$) among the evaluations of each criterion (($f_j(.)$). Table 5 illustrates the preference functions and their respective parameters [4].

Table 5. Preference functions and characteristics of cirteria

Characteristics	R	Cm	D
Max/Min	Max	Min	Min
Weight	0.24	0.5074	0.2526
Preference functions	Tip 5	Tip 1	Tip 2
Indifference threshold	0.001	-	0.005
Preference threshold	0.01		

Table 6. Evaluation matrix of the decision problem

Alt	Tp(y)	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$
T1	1	0	5.649	-0.627
T2	2	0.507	5.121	-0.512
T3	3	0.562	4.548	-0.442
T4	4	1.056	4.138	-0.342
T5	5	2.382	3.737	-0.150
T6	6	3.737	2.989	0.083
T7	7	4.991	1.734	0.361
T8	8	6.246	0.48	0.640
T9	9	5.979	0.747	0.581
T10	10	5.204	1.522	0.4091

Having done this, obtaining the preferential intensities between each pair of actions in the light of each separate criterion, a degree of outranking, $P_j(b,a)$, can be established, representing the degree of preference for a over b, for all the criteria. Following the sequences of steps of the PROMETHEE method, the next thing to do is to calculate the positive outranking flow and negative outranking flow for each alternative, allowing for the establishment of the outranking relationships, as can be seen in Table 6. When this done, then the PROMETHEE II method is applied, using the net outranking flow, that is the difference between the positive and negative flows for each alternative, to establish a complete pre-order of the evaluated alternatives, which constitutes the decreasing order of the net outranking flows. The result of this application of the multi-criteria decision aiding model is a complete pre-order of the alternatives, as can be seen in Figure 1.

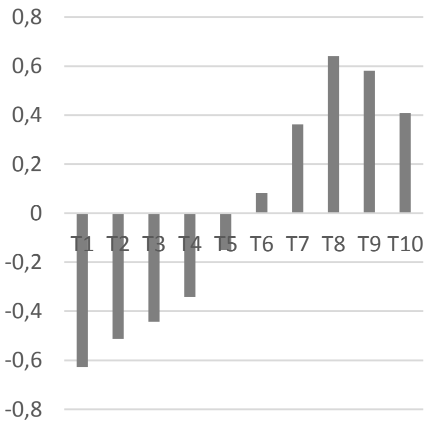


Figure 1. Net outranking flow

In Figure 2, the best alternative can be seen, that is, the one that is in the first place in the complete pre-order, alternative T8, corresponding to component replacement after every 8 years [4] [3].

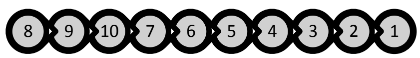


Figure 2. Complete pre order of replacemnt times

ISBN: 978-86-80593-54-8

IV. CONCLUSION

This paper proposes a multi-criterion decision-making model for preventive maintenance planning which determines the best compromise time for replacement of a certain item based on more than one criterion.

One of the most important goals that this approach could give in the future is to give a broader view of the maintenance managers by considering more than one criterion in making an appropriate decision for replacement of an item in preventive maintenance problems (PM). Taking these three criteria into consideration, this paper does not imply that they are the most important criteria that need to be considered for replacement of an item in PM planning. It implies that in order to make a complete and timely PM planning which considers many aspects of the problem, decision makers have to study the problem completely and consider the factors which affect a PM planning for replacement of item because ignoring the influential factors in different situations can lead to disastrous results. Therefore, it is not true to say that there are some factors which are important for all the systems. Moreover, changing the weights shows that for different preferences of decision makers and different conditions of the systems, different weights are needed. Therefore, the structure of the model can be applied to different systems and situations.

REFERENCES

[1] A. Abiri-Jahromi, M. Fotuhi-Firuzabadi, "An Efficient Mixed-Integer Linear Formulation for Long-Term Overhead Lines Maintenance Scheduling in Power Distribution Systems", IEEE Transactions on Power Delivery, vol. 24, no 4, 2009, pp. 2043-2053.

[2] A. Janjić, D. Popović, "Selective maintenance schedule of distribution networks based on risk management approach", IEEE Transactions on Power Systems, vol. 22, no. 2, 2007, pp. 597-604.

[3] E. Faghihinia, N. Mollaverdi, "Building a maintenance policy through a multi-criterion decision-making model", Journal of Industrial Engineerging International, 2012, pp. 1-15.

[4] C. Cavalcante, A Costa, "Multicriteria model of preventive maintenance", Brazilian Journal of Operations & Production Management, vol. 3, no 1, 2006, pp. 71-86.

[5] M. M. Hudej, "Multi-Variable Methods of Managemant in Mining", Doctoral disertation, Belgrade, 2013.

[6] J. P. Brans, P. H. Vincke, "A Preference Ranking Organisation Method", Management Science, vol. 31, no. 6, 1985, pp. 647-656.

[7] J. J. Wang, Y. Y. Jing, C. F. Zhang, J. H. Zhao, "Review on multi-criteria decision analysis aid in sustainable energy decision-making", Renewable and Sustainable Energy Reviews vol. 13, 2009, pp. 2263–2278.

ISBN: 978-86-80593-54-8

On-Line LS-SVM Model for Short-Term Load Forecasting

Miloš Božić, R&D Center ALFATEC, Niš, Serbia, milos1bozic@gmail.com

Marko Milošević, R&D Center ALFATEC, Niš, Serbia, marko.milosevic@alfatec.rs

Aleksandar Gošić, R&D Center ALFATEC, Niš, Serbia, aleksandar.gosic@alfatec.rs

Abstract—**Forecasting model based on an online update scheme is proposed for the short-term load forecasting, using least square support vector machines, is proposed in this paper. The model is based on historical hourly load in combination with calendar features. The presented model was tested on real-life load data and the results show that the proposed approach can lead to significant improvements in the accuracy of load forecasts, by catching the evolving nature of the load pattern and dynamically updating the training set with new instances.**

Keywords: ***load forecasting, on-line model, short-term***

I. Introduction

Nowadays, with the deregulation of electricity market, accurate electric load forecasting has an even more important role in the planning, operation and control of electric power systems. Usually, the short-term load forecast (STLF) is related to the hourly prediction of electricity load demand for a time period from one hour to a few days in advance. Many operating decisions rely on accurate STLF, such as generation capacity scheduling, scheduling of fuel and coal purchases, system security analysis, energy transaction planning, etc. It also plays a significant role in the coordination of hydro-thermal systems, generator maintenance scheduling, load flow analysis, etc. Therefore, improving STLF accuracy is crucial for increasing the efficiency of energy systems and reducing operational costs.

However, STLF is a complex problem because of load nonlinear relationships with other factors such as weather conditions, social activities, seasonal factors, past usage patterns and calendar features. Each of these factors has a significant impact on future load.

In recent decades, many STLF methods have been developed. These methods can generally be classified in one of three categories: conventional methods, artificial intelligence techniques and hybrid methods. The most frequently used conventional techniques are linear regression methods [1], exponential smoothing [2], the Box-Jenkins ARIMA approach [3] and the Kalman filter [4]. Artificial intelligence based techniques include neural network models [5], expert system models [6], fuzzy inference [7], support vector machines [8], least squares support vector machines [9] and relevance vector machines [10]. Hybrid models have been presented for STLF in [11-15].

LS-SVMs, proposed in [16], as reformulations of standard SVMs, instead of solving the quadric programming (QP) problem, which is complex to compute, obtain a solution from a set of linear equations. Therefore, LS-SVMs have a significantly shorter computing time and they are easier to optimize.

In this paper a forecasting model based on the on-line update of a training set with new instances is proposed for the hourly load demand of the next day, using LS-SVMs. Most machine learning based models,

ISBN: 978-86-80593-54-8

employed for the STLF, use a fixed size training set, i.e. forecasts for several days or even weeks are being made by a training model with the same training set. But in many forecasting problems, such as STLF, where new data is constantly arriving, a dynamic update of the model is crucial for improving and preserving its performance. Accordingly, after the hourly forecasting of the load for the next day has been completed, the initial training set is updated by adding hourly data from the previous day, which is in that moment known. Then, for next day prediction, the model is retrained with an extended training set. As the experimental results show, in this way improvements to the accuracy of forecasting results can be achieved.

The rest of this paper is organized as follows: Section 2 presents the used method. Section 3 describes the proposed forecasting model. Section 4 gives the experimental results. Finally, Section 5 provides conclusions.

II. METHOD

Consider a known training set $\{\mathbf{x}_k, y_k\}$, $k=1,...,N$ with input vectors $\mathbf{x}_k \in R^n$ and output scalars $y_k \in R$. The following regression model is built by using the non-linear mapping function $\varphi(\cdot): R^n \to R^{n_h}$ which maps the input space into a high-dimensional feature space and constructs a linear regression in it, expressed in:

$$y(\mathbf{x}) = \boldsymbol{\omega}^T \varphi(\mathbf{x}) + b\,, \tag{1}$$

where $\boldsymbol{\omega}$ represents the weight vector and b is a bias term. The optimization problem is formulated in primal space:

$$\min_{\boldsymbol{\omega},b,\mathbf{e}} J_p(\boldsymbol{\omega},\mathbf{e}) = \frac{1}{2}\boldsymbol{\omega}^T\boldsymbol{\omega} + \frac{1}{2}\gamma\sum_{k=1}^{N} e_k^2\,, \tag{2}$$

subject to linear equality constrains expressed by:

$$y_k = \boldsymbol{\omega}^T \varphi(\mathbf{x}_k) + b + e_k, k = 1,...,N\,, \tag{3}$$

where e_k represents error variables and γ is a regularization parameter which must be determined by the user.

In order to solve the optimization problem defined with (2) and (3), it is necessary to construct a dual problem using the Lagrange function. The solution to this problem is presented as:

$$\begin{bmatrix} 0 & \mathbf{1}_v^T \\ \mathbf{1}_v & \boldsymbol{\Omega} + \mathbf{I}\gamma^{-1} \end{bmatrix} \begin{bmatrix} b \\ \boldsymbol{\alpha} \end{bmatrix} = \begin{bmatrix} 0 \\ \mathbf{y} \end{bmatrix}. \tag{4}$$

In (4), $\mathbf{y}=[y_1,...,y_N]^T$, $\mathbf{1}_v=[1,...,1]^T$ and $\boldsymbol{\alpha}=[\alpha_1,...,\alpha_N]^T$ represents column vectors of dimensions N x 1, where α_k, $k=1,...,N$ are Lagrange multipliers, $\mathbf{I}$ is the identity matrix and

$\boldsymbol{\Omega}_{kl} = \varphi(\mathbf{x}_k)^T \varphi(\mathbf{x}_l) = K(\mathbf{x}_k, \mathbf{x}_l), k,l = 1,...,N$

denotes the kernel matrix, both of them of dimensions N x N. Linear system defined in (4) is of the order $(N+1)$ x $(N+1)$. It is important to notice that in (4) vector $\mathbf{y}$ is formed form the training set outputs y_k, $k=1,...,N$.

The resulting LS-SVM model for function estimation in dual form is represented in (5), where α_k and b are solutions of linear system defined by (4):

$$y_k = \boldsymbol{\omega}^T \varphi(\mathbf{x}_k) + b + e_k, k = 1,...,N\,. \tag{5}$$

The dot product $K(\mathbf{x},\mathbf{x}_k) = \varphi(\mathbf{x})^T \varphi(\mathbf{x}_k)$ represents a kernel function. Kernel functions enable the computation of the dot product in a high-dimensional feature space by using data inputs from the original space, without explicitly computing $\varphi(\mathbf{x})$. A commonly used kernel function in non-linear regression problems, one that is employed in this study, is a radial basis function represented as:

$$K(\mathbf{x},\mathbf{x}_k) = e^{-\frac{\|\mathbf{x}-\mathbf{x}_k\|^2}{\sigma^2}}\,, \tag{6}$$

where σ represents a kernel parameter which should be determined by the user. When choosing an RBF kernel function with LS-SVM, the optimal parameter combination (γ,

ISBN: 978-86-80593-54-8

σ) should be established. It can be noticed that only two additional parameters (γ, σ) need to be optimized, instead of three (γ, σ, ε) as in SVM, but at the cost of lack of sparseness of solution, which follows from (5).

Parameter selection is the most important part in the formation of the LS-SVM model, because it significantly affects performance. Accordingly, a grid search algorithm in combination with a k-fold cross-validation is employed in this paper.

III. Model Formation

Different factors that have an influence on electric load were analyzed, and accordingly appropriate features were chosen for the model. The past load time horizon used in this paper is m=24, i.e. the model used the last 24 hour loads from the prediction moment. Input vectors consist in total of $m+s$ features, where m is the past load time-series features P_k, k=1,..,24 and s = 2 non-time series features: the hour of the day H_k, $H_k \in \{1,2,...,24\}$ and the day of the week D_k, $D_k \in \{1,2,...,7\}$ where 1 corresponds to Monday, 2 to Tuesday and so on.

In order to have an optimal training of the model, the data set has to be normalized before training. This prevents the dominance of any features in the output value and provides faster convergence and better accuracy of the learning process. Accordingly, all features and their output values are normalized within the range [0, 1].

The model training procedure and the hourly forecasting of the load for one day in advance is presented in Algorithm 1, where $\{\mathbf{X},\mathbf{Y}\} = \{\mathbf{x}_k, y_k\}, k = 1,...,N$ denotes the initial training set with input vectors $\mathbf{x}_k \in R^{m+s}$ and outputs $y_k \in R$.

Algorithm 1. LS-SVM model training and forecasting

for *j = 1 … number of days*
  $\mathbf{x}_t$= $\mathbf{X}_t(j)$
  (γ,σ)=tunesvm($\mathbf{X}$, $\mathbf{Y}$*, grid-search, cross-validation)*
  model = trainsvm($\mathbf{X}$, $\mathbf{Y}$*, γ , σ)*
  for *i = 1 … 24*
    P(i) = forecast(model, $\mathbf{x}_t$*)*
    Update $\mathbf{x}_t$*:*
    $\mathbf{x}_t(1) = h_{i+1}$
    $\mathbf{x}_t$ *= shift_ left_time-series(*$\mathbf{x}_t$*, 1)*
    $\mathbf{x}_t(m+s)=P(i)$
  endfor
  Results(j)=P
  Update($\mathbf{X}$, $\mathbf{Y}$*)*
endfor
Output : *Results*

The first step in the algorithm is the selection of a new instance $\mathbf{x}_t$ from the test set $\mathbf{X}_t$. After that, the optimal (γ, σ) pair is determined on ($\mathbf{X}$, $\mathbf{Y}$) using a grid search with k-fold cross validations, as mentioned in section *2.* The training set is randomly subdivided into k disjoint subsets of approximately equal size and the local LS-SVM model is built k times with the current pair (γ, σ). Each time, one of the k subsets is used as the test set and the other k - 1 subsets are put together to form a training set. After k iterations, the average model error is calculated for the current pair (γ, σ). The entire process is repeated with an update of the parameters (γ, σ) until the given stopping criterion (e.g. mean squared error) is reached. The parameters (γ, σ) are updated exponentially in the given range using predefined equidistant steps, according to the grid-search procedure. After obtaining the optimal (γ, σ) combination, an LS-SVM forecasting model is formed according to (5) and (6).

The model is then employed for the prediction of load demand for one step ahead, i.e. for the next hour, and the result is placed in vector P. After that, it is necessary to update the $\mathbf{x}_t$ vector for the next prediction step. The update is needed because the true values of the load for the past 24 hours are available only for the first prediction step.

After that, for the next predictions, the predicted values from the previous steps are used instead of the true ones, which are unknown at the moment. Accordingly, hour feature hi+1 is updated (day feature remains

ISBN: 978-86-80593-54-8

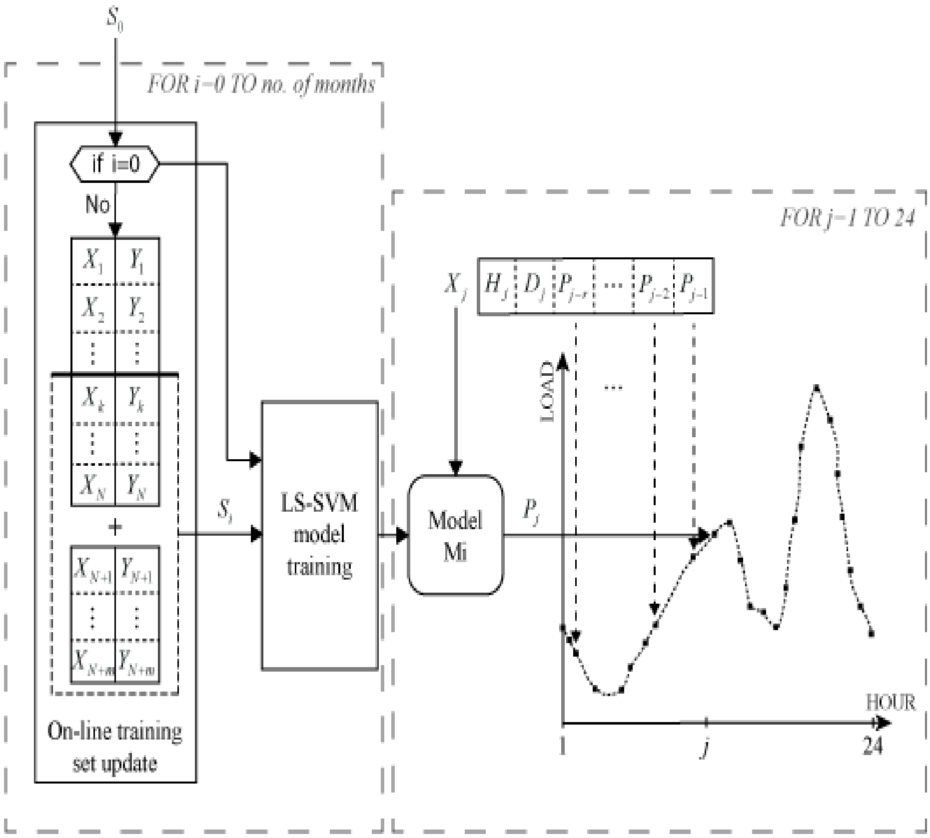


Figure 1. On-line update model forecasting sheme

the same for current day), load time-series is shifted left for one place in order to remove load from the earliest hour and the prediction from the previous step is placed in the last position of time-series instead of the true load from the last hour. The whole process is repeated 24 times and at the end, hourly predictions for the following day will be obtained.

Initial training set is update after some period of time with new training vectors and model is retrained. In this way, model is refreshed with new information. In this paper, for update time period is chosen period of one month, which mean that on each time period of one month new training vectors which match to that month, are added to training set and old training vectors (furthermost training vectors) are thrown from training set and the model is retrained. This process repeats after each chose time period.

IV. EXPERIMENTAL RESULTS

For methodology evaluation, the forecasting of hourly loads of the City of Niš in 2009 was done for each day. Two models are generated, the first with the initial training set configuration and the second with an on-line training set update scheme. These models are denoted with:

- LSSVM - a model trained with an initial training set that contains 2136 vectors,
- OL-LSSVM - a model with on-line training set update scheme.

To be clear, for the prediction of the first day in the test set (1. January) the OL-LSSVM model is trained with a training set that contains 2136 vectors, same as model LSSVM. For the prediction of the first

ISBN: 978-86-80593-54-8

February, 24*31 vectors from the previous month (which are known at the moment) are added and the model is then retrained with about the same number of vectors, because the furthermost training vectors are thrown from training set.

The prediction quality is evaluated using mean absolute percentage error (MAPE), symmetric mean absolute percentage error (sMEPE) and root mean square error (RMSE) as follows, respectively:

$$MAPE[\%] = 100\frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_i - \hat{P}_i}{P_i}\right|, \quad (7)$$

$$sMAPE[\%] = 200\frac{1}{n}\sum_{i=1}^{n}\frac{\left|P_i - \hat{P}_i\right|}{P_i + \hat{P}_i}, \quad (8)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(P_i - \hat{P}_i\right)^2}. \quad (9)$$

Table 1. Annual average mape, smape and rmse

MODEL	Errors		
	MAPE [%]	***sMAPE [%]***	***RMSE [MW]***
LSSVM	4.51	4.42	10.18
OL-LSSVM	3.87	3.86	8.84

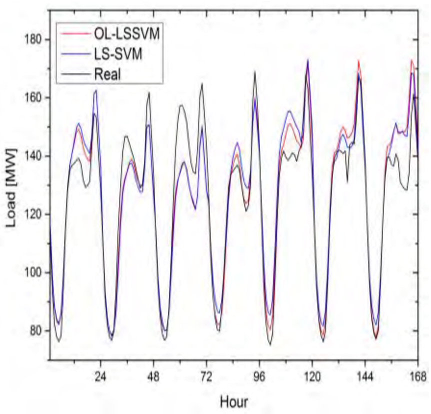


Figure 2. Real and forecasted hourly load during the week

In Table 1, annual average values for MAPE, sMAPE and RMSE error for each model are shown. Obtained results show that the best result is gather with on-line learning model scheme.

In Fig. 2, real and forecasted hourly load curve for each formed model for one week is presented. It can be noticed that the models curves stand to real load curve in the same rank as in Table I.

V. CONCLUSION

One method for improving short-term load forecasting is presented in this paper. The proposed approach is based on the online update of the initial training set by adding new instances into it as soon as they become available and then retraining the model. By this approach the evolving nature of the load pattern is followed and the model performance is preserved and improved, as the experimental results confirm, although the model trained only with an initial training set showed quite a good performance.

Different features that affect load demand are analyzed, and the appropriate ones were chosen for the structure of training vectors. Model evaluation was done hourly for period of one year, which represents the large test segment, taking into account that the predictions are made by hours. The LS-SVMs were chosen for the non-linear model because of their good generalization performance and ability to avoid local minima.

Further work could consider the development of an algorithm for the determination of which vectors should be added into the initial training set, and possibly which need to be discarded.

ACKNOWLEDGMENT

This work was supported by the Ministry of Science and Technological Development, Republic of Serbia (Project number: III - 44006).

REFERENCES

[1] A. D. Papalexopoulos, T. C. Hesterberg, "A regression-based approach to short-term load forecasting", IEEE Transactions on Power System, vol. 5, 1990, pp. 1535–1550.

ISBN: 978-86-80593-54-8

[2] W. R. Christiaanse," Short term load forecasting using general exponential smoothing", IEEE Transactions on Power Apparatus and Systems, vol. 90, 1971, pp. 900–911.

[3] S. J. Huang, K. R. Shih, "Short-term load forecasting via ARMA model identification including non Gaussian process considerations", IEEE Transactions on Power System, vol. 18, 2003, pp. 673–679.

[4] G. D. Irisarri, S. E. Widergren, P. D. Yehsakul, "On-line load forecasting for energy control center application", IEEE Transactions on Power Apparatus and Systems, vol. 101, 1982, pp. 71–78.

[5] H. S. Hippert, C. E. Pedreira, R. Castro, "Neural networks for short term load forecasting: A review and evaluation", IEEE Transactions on Power System, vol. 16, 2001, pp. 44–55.

[6] S. Rahman, R. Bhatnagar, "An expert system based algorithm for short term load forecast", IEEE Transactions on Power System, vol. 3, 1998, pp. 392–399.

[7] H. Mori, H. Kobayashi, "Optimal fuzzy inference for short-term load forecasting", IEEE Transactions on Power System, vol. 11, 1996, pp. 390–396.

[8] B. Chen, M. Chang, C. Lin, "Load forecasting using support vector machines: A study on EUNITE competition 2001", IEEE Transactions on Power System, vol. 19, 2004, pp. 1821–1830.

[9] M. Božić, M. Stojanović, Z. Stajić, "Short - term electric load forecasting using Least squares support vector machines", Facta Universitatis Automatic Control and Robotics, vol. 9, 2010, pp. 141-150.

[10] L. Wang, Z. Liu, "RVM with wavelet kernel combined with PSO for short-term load forecasting in electric power systems", Przegląd Elektrotechniczny, vol. 88, 2012, pp. 146-149.

[11] N. Amjady, "Short-term bus load forecasting of power systems by a new hybrid method", IEEE Transactions on Power System, vol. 22, 2007, pp. 333–341.

[12] C. M. Huang, C. J. Huang, M. L. Wang, "A particle swarm optimization to identifying the ARMAX model for short-term load forecasting", IEEE Transactions on Power System, vol. 20, 2005, pp. 1126–1133.

[13] A. Asrari, D. S. Javan, M. H. Javidi, M. Monfared, "Application of Gray-Fuzzy-Markov Chain Method for Day-Ahead Electric Load Forecasting", Przegląd Elektrotechniczny, vol. 88, 2012, pp. 228-237.

[14] G. Dudek, "Neuro-fuzzy approach to the next day load curve forecasting", Przegląd Elektrotechniczny, vol. 87, 2011, pp. 61-64.

[15] G. Dudek, "Artificial Immune Clustering Algorithm to Forecasting Seasonal Time Series", Computational Collective Intelligence. Technologies and Applications, vol. 6922, 2011, Springer, pp 468 – 477.

[16] K. Suykens, T. Gestel, J. Brabanter, B. Moor, J. Vandewalle, Least Squares Support Vector Machines, World Scientific, Singapore, 2002.

ISBN: 978-86-80593-54-8

Analysis of Household Coal Consumption in Serbia Based on Grey System Theory and K-means Clustering (Base for Distribution Network Optimization)

Zoran Gligorić, Faculty of Mining and Geology, Belgrade, Serbia,
zoran.gligoric@rgf.bg.ac.rs

Svetlana Štrbac-Savić, The School of Electrical and Computer Engineering,
Belgrade, Serbia, svetlanas@viser.edu.rs

Miloš Gligorić, Faculty of Mining and Geology, Belgrade, Serbia,
milos.gligoric@rgf.rs

Čedomir Beljić, Faculty of Mining and Geology, Belgrade, Serbia,
cedomir.beljic@rgf.bg.ac.rs

Abstract—**This paper represents the model developed in the purpose of forecasting the household coal consumption in Serbia. Forecasting model is based on The Grey system theory while K-means clustering algorithm is used to group districts into larger areas and create base for coal distribution network optimization. Entering the data related to existing coal storage facilities we can make functional analysis of storage operation over time.**

Keywords: ***household coal consumption analysis, Grey system theory, time series, clustering***

I. INTRODUCTION

Coal is still an important source of energy using for heating households in Serbia. Households in Serbia obtain coal by purchasing from coal merchants.

Serbia is divided into districts (see Figure 1) and each district has a different rate of coal consumption influenced by many parameters, such as population size, presence of other sources of energy used for heating, price of coal and other energy sources, vicinity of storage facilities, etc. Monitoring of coal consumption data per district can help us to create overall picture about consumption distribution over territory of Serbia. Applying The Grey system theory we can see how distribution will be changed over defined future time

Figure 1 – District map of Serbia

ISBN: 978-86-80593-54-8

horizon. Applying K-means clustering we can see how morphology of the clusters was changed over observed time and how it will be changed over defined future time horizon with respect to forecasted values of coal consumption per district. Developed model enable us to create production plans of operating coal mines and optimize the distribution network. The model can be also used in the context of electricity consumption analysis.

II. MODEL OF ANALYSIS

Consider household coal consumption (HCC) in Serbia over time as follows:

$$HCC = X_j^{(0)}(k) = \begin{bmatrix} X_j^{(0)}/k & k_1 & k_2 & \dots & k_n \\ X_1^{(0)} & x_{1,1}^{(0)} & x_{1,2}^{(0)} & \dots & x_{1,n}^{(0)} \\ X_2^{(0)} & x_{2,1}^{(0)} & x_{2,2}^{(0)} & \dots & x_{2,n}^{(0)} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_m^{(0)} & x_{m,1}^{(0)} & x_{m,2}^{(0)} & \dots & x_{m,n}^{(0)} \end{bmatrix}, \quad (1)$$

where $X_1, X_2, \dots, X_j$ are districts, $k_1, k_2, \dots, k_n$ are periods within overall time of observation and $x_{j,k}^{(0)}$ is the consumption per j-th district with respect to period k.

Information related to the HCC can be treated as time series data. It is assumed that all data values to be used in any analysis are positive, and the sampling frequency of the time series is fixed (yearly time resolution).

In this paper we apply the Grey system theory [1] to analyze HCC data. In grey system theory, Multi-variable grey model (MGM(h, m)) denotes a grey model, where h is the order of the differential equation and m is the number of variables. According to our problem, the MGM(1,1) is employed [2, 3,4].

- Definition 1:

Let $X^{(0)}(k) = \left[x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(k)\right], k = 1,2,\dots,n$ be an original, nonnegative data sequence taken in consecutive order at equal time intervals, then the Accumulating Generation Operator (AGO) is defined as $x^{(1)}(k) = \sum_{k=1}^{n} x^{(0)}(k)$.

- Definition 2:

Let $X^{(1)}(k) = \left[x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(k)\right], k = 1,2,\dots,n$ be the accumulated data sequence which is used to set up differential equation, then $Z^{(1)}(k) = \left[z^{(1)}(1), z^{(1)}(2), \dots, z^{(1)}(k)\right], k = 1,2,\dots,n$ is the sequence of the generated mean value of consecutive neighbors, where $z^{(1)}(k) = \frac{1}{2}(x^{(1)}(k) + x^{(1)}(k-1)), k = 2,3,..,n$.

According to Definition 1 and 2, the forecast model of HCC is defined as follows:

$$\frac{dx^{(1)}}{dk} + ax^{(1)} = b, \quad (2)$$

where a and b are coefficients. Factors of the matrix $\hat{a} = [a,b]^T$ are obtained by using the least square method as follows:

$$\hat{a} = \left(B^T B\right)^{-1} B^T A, \quad (3)$$

where

$$A = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \end{bmatrix}. \quad (4)$$

The sequence time response formula of HCC is:

$$\hat{x}^{(1)}(k+1) = \left\{x^{(0)}(1) - \frac{b}{a}\right\} e^{-ak} + \frac{b}{a}. \quad (5)$$

The fitting forecast value of $x_k^{(0)}$ can be obtained by the inverse AGO as follows:

ISBN: 978-86-80593-54-8

$$\begin{cases} \hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) \\ k = 2,3,\ldots,n, \hat{x}^{(0)}(1) = x^{(0)}(1) \end{cases}. \tag{6}$$

For $k > n$ we can make forecasts of household coal consumption (FHCC) as follows:

$$FHCC = \hat{X}_j^{(0)}(n+h) = \left[\hat{x}_{j,n+h}^{(0)}\right] =$$

$$\begin{bmatrix} \hat{X}_j^{(0)} / n+h & n+1 & n+2 & \ldots & n+h \\ \hat{X}_1^{(0)} & \hat{x}_{1,n+1}^{(0)} & \hat{x}_{1,n+2}^{(0)} & \ldots & \hat{x}_{1,n+h}^{(0)} \\ \hat{X}_2^{(0)} & \hat{x}_{2,n+1}^{(0)} & \hat{x}_{2,n+2}^{(0)} & \ldots & \hat{x}_{2,n+h}^{(0)} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \hat{X}_m^{(0)} & \hat{x}_{m,n+1}^{(0)} & \hat{x}_{m,n+2}^{(0)} & \ldots & \hat{x}_{m,n+h}^{(0)} \end{bmatrix}. \tag{7}$$

Using information obtained from equation (7) we can create the production plan of operating coal mines.

Given a data set $X_j = \left[X_j^{(0)}(k), \hat{X}_j^{(0)}(n+h)\right]$ we can use them to create larger areas composed of districts having the similar coal consumption. Such areas are called clusters. From data set $X_j^{(0)}(k) = \left[x_{j,k}^{(0)}\right]$ we can see how morphology of the clusters was changed over observed time, while from $\hat{X}_j^{(0)}(n+h) = \left[\hat{x}_{j,n+h}^{(0)}\right]$ we can forecast the morphology of the clusters over the future time horizon.

Cluster analysis is very useful way to group districts. The K-means problem is to partition data into K groups such that the sum of squared Euclidean distances to each group mean is minimized. The term "K-means" was first used by James MacQueen in 1967 [5].

If x are the objects and c are the cluster centers, K-means attempts to minimize the following objective function:

$$F = \sum_{g=1}^{K}\sum_{i=1}^{N}\left\|x_i - c_g\right\|^2. \tag{10}$$

Table 1 outlines the *K*-means clustering algorithm [6].

Table 1. outlines the K-means clustering algorithm [6].

1. Decide on a value for *K*. 2. Initialize the *K* cluster centers (randomly, if necessary). 3. Decide the class memberships of the *N* objects by assigning them to the nearest cluster center. 4. Re-estimate the *K* cluster centers, by assuming the memberships found above are correct. 5. If none of the *N* objects changed membership in the last iteration, exit. Otherwise go to 3.

Cluster analysis of coal consumption over observed and forecasted data is modeled by minimization of two following objective functions:

$$F = \sum_{g=1}^{K}\sum_{i=1}^{N}\left\|x_i - c_g\right\|^2$$
$$F^{(0)}(k) = \sum_{g=1}^{K}\sum_{j=1}^{m}\left\|x_{j,k}^{(0)} - c_g\right\|^2, \tag{9}$$

$$F^{(0)}(n+h) = \sum_{g=1}^{K}\sum_{j=1}^{m}\left\|\hat{x}_{j,n+h}^{(0)} - c_g\right\|^2. \tag{10}$$

Morphology of the clusters ($M^{(0)}(k)$) over observed time can be represented as follows:

$$M^{(0)}(k) = \begin{bmatrix} M_{1,1}^{(0)} & \ldots & M_{k,1}^{(0)} \\ \vdots & \vdots & \vdots \\ M_{1,K}^{(0)} & \ldots & M_{k,K}^{(0)} \end{bmatrix}. \tag{11}$$

Morphology of the clusters ($\widehat{M}^{(0)}(n+h)$) over forecasted time horizon can be represented as follows:

$$\hat{M}^{(0)}(n+h) = \begin{bmatrix} \hat{M}_{n+1,1}^{(0)} & \ldots & \hat{M}_{n+h,1}^{(0)} \\ \vdots & \vdots & \vdots \\ \hat{M}_{n+1,K}^{(0)} & \ldots & \hat{M}_{n+h,K}^{(0)} \end{bmatrix}. \tag{12}$$

Vector space defined by equation (12) serves as a base for distribution network

ISBN: 978-86-80593-54-8

optimization. By including characteristics of operating coal storages (locations, storage space, etc.) we can get the answer whether they can satisfy future requirements or not.

III. CONCLUSION

Having ability to forecast household coal consumption per districts is recognized as crucial issue in the overall energy policy. Model is very useful for mine production and distribution planers. Model is not closed and can be extended by additional components. Further activities are related to combination of multi-parameters grey modeling and interval-valued polygonal clustering based on weighted multi-attributes Mahalanobis distance function. By this approach we can create spatio temporal model.

ACKNOWLEDGMENT

This paper is part of research conducted on scientific project TR 33003, that is funded by Ministry of Education, Science and Technological Development, Republic of Serbia.

REFERENCES

[1] J. L. Deng, "Introduction to Grey System ", The Journal of Grey System, Vol.1, pp.1-24, 1989.

[2] H. Hui, F. Li, Y. Shi, “An optimal multi-variable gray model for logistics demand forecast”, International Journal of Innovative Computing, Information and Control, vol. 9, no. 7, 2013, pp. 2907-2918

[3] K. Tang, F. Wang, J. Liu, P. Jia, J. Liu, “Water vapor permeabilty of leathers by gray system theory”, Rev. Adv. Mater. Sci., vol. 33, 2013, pp. 373-382.

[4] Y. H. Lin, P. C. Lee, T. P. Chang, “Adaptive and high-precision grey forecasting model”, Expert Systems with Applications, vol. 36, no.6, 2009, pp. 9658-9662

[5] J. B. MacQueen, “Some Methods for classification and Analysis of Multivariate Observations”, Proceedings of 5th Berkeley Symposium on Mathematical Statistics and Probability, University of California Press. 1967, pp. 281–297.

[6] E. Keogh, J. Lin, W. Truppel, “Clustering of time series subsequences in meaningless implications for previous and future research”, Proceedings of the 3rd IEEE International Conference on Data Mining, 2003, pp.115 – 122.

ISBN: 978-86-80593-54-8

Android Voice Control in Energy Efficient Objects with the Use of Raspberry Pi Platform

Danijela Stajić, Secondary School of Electrical Engineering "Nikola Tesla", Niš, Serbia, danijelastajic@yahoo.com

Jovan Krstić, Secondary School of Electrical Engineering "Nikola Tesla", Niš, Serbia, jovan-97@hotmail.com

Aleksandar Gošić, Research and Development Centre "Alfatec", Niš, Serbia, aleksandar.gosic@alfatec.rs

Abstract—**The automated system which is realised in practice and portrayed in this paper represents the implementation of advanced information technologies in the field of remote process control. The central part of the system, which includes the controller and sensors, is set inside the controlled object and a virtual remote access from any location is done by the use of mobile devices which support Android operating system. Control can be performed in two ways, manually or by giving voice commands. The application of this system contributes to the increase of safety and saving of energy in the controlled objects, and it can also be used by people with disabilities or mobility impairment.**

Key words: ***control, saving energy, Raspberry Pi, Android***

I. Introduction

The advancement of information and communications technologies also implies their wider application to systems which are constructed and applied in order to reduce energy consumption, which is a primary goal in modern societies. The automated system which is developed in this paper is based on the use of Android-operating mobile devices for the communication between users and a web server which is located in the controlled object with the aim of controlling specific parameters, setting and tracking their reference values, as well as controlling the operation of certain devices. The central part of the system is a Raspberry Pi computer which performs the function of the controller. It embeds a web server which is directly accessed by a user, this makes the system significantly less robust in comparison to the designs which use standard computers.

This system can be applied in almost all objects, including those at inaccessible locations, and it significantly contributes to the saving of energy and the increase of safety. The process of controlling can also be performed by people with disabilities or mobility impairment, and the commands are given either manually or by voice by using any mobile device which can be used for downloading and installing an Android application. The process of controlling includes: control of lights, turning home appliances on and off, control of temperature and humidity, detecting smoke, and the process of monitoring with the aim of detecting movable objects.

II. Description of Functionality

The basic part of the device is set inside the controlled object (a home/building), and it consists of a Raspberry Pi computer, devices whose functionality we want to monitor, and sensors and relays which are connected to the controller. The computer embeds a web server which the user directly accesses with an initial password, by using a mobile phone or a tablet computer [1]. The part of the system which is located within the object requires a permanent connection to a global computer network – the Internet, which most certainly does not represent a

ISBN: 978-86-80593-54-8

problem in a contemporary way of living. The Internet connection can be established through Wi-Fi or 3G/4G networks.

A specialised Android application, which is easily used for the tracking and setting of specified parameters of the features which are controlled, has been designed for the needs of users. If an unwanted situation occurs within the object, a warning message is generated and then e-mailed to the user. The hardware architecture of the system is shown by a block diagram in Fig 1.

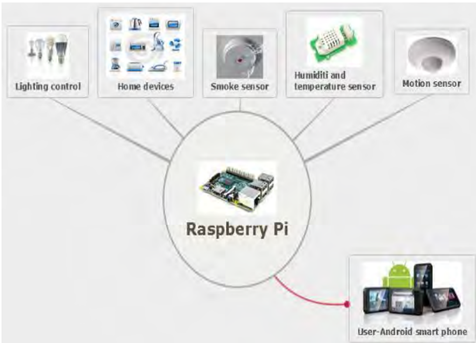


Figure 1. Functional block diagram showing the connection between the parts of the system

During the designing of the system, besides connecting and adjusting hardware units, it is also necessary to provide software support both for the computer and for mobile devices.

III. Hardware Realisation of the System

The hardware basis of the system consists of a Raspberry Pi single-board computer, together with the drivers (relays) for turning on devices, light dimmers, sirens, door and window sensors, a smoke sensor, sensors for temperature and humidity - SHT 75. Raspberry Pi performs all necessary functions in the same way as a desktop computer, however, low-voltage peripherals make it more suitable for the modification of the necessary hardware. A 40-pin GPIO connector enables connection for a 26-pin GPIO, UART, I2C, SPI, and power pins for 3.3V and 5V. A proposed design includes the following functions: lighting control with the possibility of switching on/off or adjusting the intensity of light, control of the heating system and air-conditioning, control of humidity and temperature in the rooms, and the possibility of surveillance of an object through the detection of the presence of movable objects.

The device in its testing phase, in which the connection of sensors and relays for tracking specific parameters is performed, is shown in the following Fig 2.

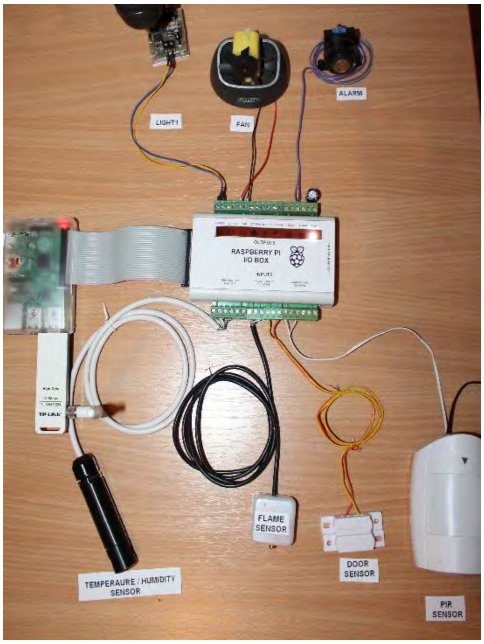


Figure 2. The device in testing phase

A. Raspberry Pi computer

Raspberry Pi is a fully functional computer which is characterised by small dimensions (size of a credit card), low price and a wide range of uses (Fig 3). The primary idea of the manufacturer was to use this computer for educational purposes in schools; however, due to its excellent performances, it has become widely applied. The basis of the Pi computer consists of:

- Broadcom BCM2835 system on a chip (SoC) with integrated CPU, GPU, and RAM memory.
- The 11th generation ARM processor, operating at 700MHz, which runs the Pi computer, while the capacity

ISBN: 978-86-80593-54-8

of RAM memory depends on the model.

- A VideoCore IV graphics processing unit (GPU), which can play videos in Full HD resolution, and it supports composite RCA and HDMI video outputs.
- A standard audio output and an SD card slot.
- A micro USB port for powering the Pi computer.
- An operating system which is used in this computer is a certain modified distribution of Linux, and the possibility of using the Windows 10 operating system has been announced.

Figure 3. Raspberry Pi single-board computer

a. PIR sensor

A passive infrared sensor (PIR sensor) is an electronic sensor that measures infrared (IR) light radiating from objects in its field of view. They are most often used in PIR-based motion detectors.

B. SHT75 sensor

SHT7x, including SHT71 and SHT75, are a Sensirion's family of relative humidity and temperature sensors with pins. The sensors integrate sensor elements plus signal processing in compact format and provide a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. The applied CMOSens® technology guarantees excellent reliability and long term stability. Both sensors are seamlessly coupled to a 14-bit analogue to digital converter and a serial interface circuit. This results in superior signal quality, a fast response time and insensitivity to external disturbances (EMC).

C. Magnet sensor

This type of sensor is used for the protection of doors and windows. Essentially, these are passive devices which operate according to the principles of electromagnetic field. They consist of two parts; one is installed on movable parts of doors or windows, and the other part is installed on an immovable part. A sensor is activated when these two parts get separated. They are resistant to all forms of RF interferences, and they are connected to the central part through wires or wirelessly.

b. Grove – Flame sensor

Flame Sensor can be used to detect fire source or other light sources of the wavelength in the range of 760nm - 1100 nm. It is based on the YG1006 sensor which is a high speed and high sensitive NPN silicon phototransistor. Due to its black epoxy, the sensor is sensitive to infrared radiation.

IV. SOFTWARE REALISATION OF THE SYSTEM

One part of the software which provides the functionality of the proposed system and is intended for mobile devices has been developed on the Android platform which is supported by most modern smartphones, and it has been created in B4A programming language. The application has been developed with options, and commands are written in Serbian, which can be substituted with any other desired language. Besides classic, manual controlling by means of a keyboard, the user can also give a desired command through, which turns on Google speech recognition option.

Necessary conditions under which the remote connection through a network to the controlled object is established are an IP address and the initial password. The application appearance during the stage of connecting to the system is shown in Fig 4.

ISBN: 978-86-80593-54-8

Figure 4. The application appearance after the established connection to the control system

The process of setting reference values of parameters and their change in a chosen moment, and turning on or turning off of devices can be performed directly from the user application, as it is shown in Figures. The functions of turning on and turning off are provided for the selected devices (on-off regulation), while the reading of current values and the setting of reference values can be performed for the parameters which are regulated.

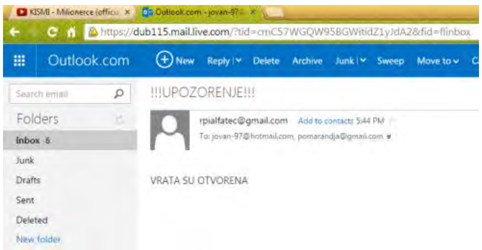


Figure 5. The appearance of the web page with a generated warning message regarding the entry into the building

A web server is the basis of the automation of the controlled object. It consists of the software for Raspberry Pi and the applicable software for controlling, which is written in the Python programming language.

If any of the sensors are activated, the controller generates a interrupt, starts the alarm and notifies the user by email about the situation which has occurred. The appearance of the web page with a generated warning message for an example of detecting an open door is shown in Fig 5.

V. Description of Functionality of the Device

The Raspberry Pi computer starts to operate by initiating and establishing the Internet connection, after which the authorisation process is performed, that is, the password validity is tested (Fig 6).

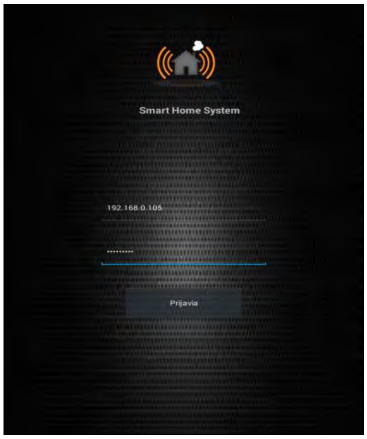


Figure 6. The Android application appearance in the stage of connecting to the system of control

If inaccurate parameters are used for access, the communication between the application and the user will not be permitted. Otherwise, the received data pack is decoded and the given command is executed. If any of the sensors are activated due to the presence of movements, smoke, etc., a microcontroller generates a interrupt, starts the alarm inside the building and notifies the user by email about the situation which has occurred. The alarm can be turned off through the application, which means that it is not necessary to go to the controlled object.

An example of connecting the user to the control system, in which the initial temperature is set to a chosen value (twenty degrees Celsius) and Device 1 is turned on through the application, is shown in the

ISBN: 978-86-80593-54-8

following Figs. In this case we have used a manual mode, i.e. we have given commands manually, but the same procedure of giving commands is possible in the voice mode in which the “Voice” option is selected.

Figure 7. The process of setting the initial value of temperature and turning on one device through the application

It is also possible to track and set several values at the same time, which sets off a signal on the Raspberry Pi computer after the settings have been modified through the application. The option which certainly contributes to the most significant saving of energy is the selection of the reference range of temperature values inside an object when it is not used and when it is going to be used by people. Device 1 and Device 2 can be chosen according to the user’s needs; from the perspective of energy efficiency, it is best to choose large power consumers. Surely, the possibility of controlling the lights is also very appealing, in the sense that the intensity of lights can be set to the desired value, as well as turning the lights on and off [3].

Each situation which triggers an alarm also generates a message on a web page which is then automatically forwarded to the user by email. The alarm situation refers to an entry into the controlled object, smoke detection, or detection of movable objects in rooms.

The appearance of the web page when the PIR sensor for movements signals that there is the presence of movable objects and the controller initiates an alarm situation is shown in Fig 8.

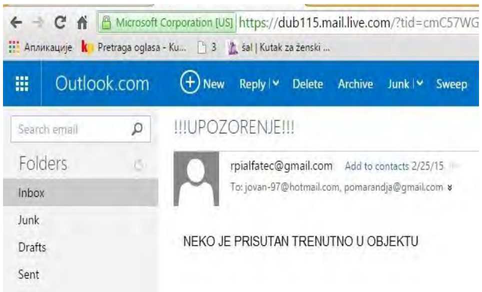


Figure 8. The appearance of the web page with a generated message referring to an entry into the object

VI. Results and Discussion

The central part of the system is a Raspberry Pi computer whose performances fully enable the realisation of the proposed system, and whose role is twofold (the creation of a web page and the role of a controller). Also, due to the low-voltage peripherals, a hardware upgrade is simple and the dimensions of the device are very small.

The Android application has been developed specifically for this purpose; in our case it is in the Serbian language, and the main advantage is simple use and dual mode of operating which is adapted for people with disabilities. The idea is that the device should be primarily used with the aim of increasing

ISBN: 978-86-80593-54-8

energy efficiency of today's "smart" buildings. The second aspect is the surveillance of an object, when it is physically empty, from any geographical location.

The only precondition is a permanent Internet connection and the owning of a unique IP address, which is not considered an obstacle in the contemporary society.

VII. Conclusion

The system of the control of "smart" objects in our case has been fully developed and tested in order to demonstrate its practical realisation and efficiency. Most certainly, it can be upgraded and further developed by some of many functions which can be added as new hardware, such as, for example, the addition of video cameras in rooms or installing wireless connections.

It is also possible to upgrade the software part of the system – the translation of the Android application to a more widely used language, and the extension for other operating systems which are used for mobile devices (first of all, a Windows phone). The web page can also be redesigned according to the needs of a user.

The system has been realised to cover all the necessary functions in the standard objects of today, but its price does not go above the standard price of these devices which are currently on the market. During the realisation, the intention was to make the system less robust and to enable its real-time operation when it comes to residential objects, and also office buildings.

References

[1] S. Prasad, P. Mahalakshmi, A. J. Clement Sunder, R. Swathi, "Smart Surveillance Monitoring System Using Raspberry PI and PIR Sensor", International Journal on Applications of Information and Communication Engineering, vol. 1, no. 1, 2015, pp. 58-62

[2] N. Živković, M. Milojević, N. Nikolić, B. Majkić, S. Stošović, "System control of working hours and access to the lab realized on Rospberry Py platform", IEEESTEC – 7th Students Project Conference, Faculti of Electronic Engineering Niš, 2014.

[3] J. Krstić, D. Stajić, "Web lighting control a smart home", IEEESTEC – 7th Students Project Conference, Faculty of Electronic Engineering Niš, 2014.

[4] J. Krstić, D. Stajić, "Web Home Controller", 2nd Olimpics in technical creativity of young people in Southestern Europe , Zrenjanin, 2014.

[5] Z. Jovanović, M. Jovanović, A. Gošić, M. Milošević, D. Stajić, B. Mijucić, "The remote barrier control via GPS / GPRS networks", The technical solution, Research and Development Centre Alfatec, Niš.

ISBN: 978-86-80593-54-8

Friday, July 3th, 2015

Renewable Energy Sources Construction Small Hydro Power Plant "Zlaca" Banovići

Enver Agić, Chairman of the Supervisory Board JP “Elektroprivreda BiH“ d.d. Sarajevo, Sarajevo, B&H, agabiem@bih.net.ba

Mirza Atić, Gealan Tuzla, Tuzla, B&H, eming@bih.net.ba

Bahrudin Šarić, University of Tuzla, Faculty of Mechanical Engineering, Tuzla, B&H, bahrudin.saric@untz.ba

Abstract— **For the purpose of development of the tourist potential of the site "Zlaća" Banovići made the work "Renewables energy sources-building small hydroelectric power plant Zlaća - Banovićir".**

From short of the analysis concludes that for the construction of SHP "Zlaća" with the power generator of 55.00 kW necessary to provide funds in the amount of approximately € 170,000. The return of this investment is in a period of approximately 7.5 years, which is renewable energy quite acceptable period and cost-effective investment. The investment amount of approximately € 3,000.00 / kW of installed power generators. Indirect benefits that may be achieved by building a mini hydro power plants with a dam is to increase the number of tourists, which is the main business hotel "Zlaća", as well as the accumulation of water, straightening the flow of water river "Expenditure" during the year, etc.

One in a series of necessary background for design MHE "Zlaća" represent the hydrologic, or water and their timing at the proposed location of the SHP. The problem is that this MHE located at ungauged site, which stipulates that the so-called. Hydrological design of such a facility should be based on information spatially transformed with other hydrological trained localities. The amount of water that can be energetic "recycle" depends on the hydrological characteristics, defined the wrong flow duration and size of building (installed capacity MHE), and average annual production of electricity is determined by the flow duration curve, drop, efficiency coefficient and installed capacity.

Duration curve does not give a timetable flow, which gives hydrograph, it except the information needed to estimate the hydropower potential, provides baseline information about the need for the construction of reservoirs on the considered site. Therefore, the duration curve useful and indispensable tool in a preliminary study on the hydroelectric potential of the considered watercourses. For this purpose, are made estimates based on past experience, which should be supplemented in period planning, design and construction of MHE.

Keywords: ***Renewable energy, small hydro power plant, tourism, accumulation, small dams***

I. INTRODUCTION

To warm hotel "Zlaća" used the central heating system with electric boiler, capacity of 138 kW heater. The building is in the canyon of the river, with a predominantly mountainous climate. The area is in Bosnia at the turn of the massif of Mount Majevica, Tuzla Basin and south of the mountain of Konjuh and upper flow Drinjača, with a moderate continental climate, warm summers, the July temperature about 20 ° C and moderately cold winters with January temperature approximately -1 to -2 ° C. The average annual pace of air is 10.2 ° C. Most of the rainfall in June, and in winter in November and December. Basin thus is the mean annual precipitation approximately 1,000 ÷ 1,200 mm or l / m2sa annual precipitation 900-1100 mm. Mean annual precipitation is 956.5 mm psr = / year, which

ISBN: 978-86-80593-54-8

is a continental climate with an increased influence of the height factor and close to the mountain Konjuh. Max annual rainfall is 1254 mm (1964.g) and min 689 mm (1967.g). The distribution of rainfall during the year is characteristic of the continental climatic zone with maximum summer (June-August) and the minim in winter (January-March). The highest average precipitation in June (115.9 mm/month) and the lowest in January (51.0mm/ month). Oscillations of rainfall per month are given, during the summer max (June-July, the differences are between 194-198 mm minim and maximum recorded rainfall). Recorded minimum order fluctuations of rainfall in winter (January-March, amount to 91-112 mm) [1]. River Oskova occurs on the mountain Konjuh merging rivers Large Lace and Krabanje and runs next to the hotel "Zlaća", still in the village Oskova to Prevent Zivinive River, which is the right tributary. There are data for HP Tuzla for the period 1949-1971. with appropriate interpolation and correction at altitude, can be for this level of analysis would change the basic parameters and precipitation for a given river basin Upper Oskova on location "Zlaća". Considered basin is high altitudes of the reference rain gauge stations, and is performed by adjusting the altitude, empirical forms the D. Srebrenović [2]

$$\Phi_S = H \pm 0.75 \cdot \Delta A, \quad (1)$$

where:

Φ_S - corrected value of rainfall for the basin

H - measured value of rainfall and HP Tuzla

ΔA - difference in altitude HP

Mean monthly precipitation corrected by the same procedure and are given in Table No. 2 .

Elevation elements basin are :

1. Mean angle basin 600 m.n.m.
2. Maximum dimension of the basin in 1326 m.n.m.
3. Angle operation 381 m.n.m

Distribution of monthly rainfall is given in the diagram in Figure 1.

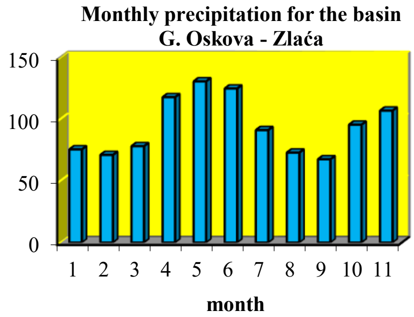


Figure 1. Distribution of monthly rainfall

A. The flows

No measured data on water flow of the water stream, and is determined by the previous average annual and monthly runoff basin by empirical patterns Keller and Srebrenović, based on data on mean rainfall and physical characteristics of the basin. Based on the runoff calculated the average flows in the relevant profile.

1) *Average annual and monthly runoff basin:*

After Keller's modified form of continental characteristics of the catchment basin river Sava (D. Srebrenović), mean annual runoff as a function of rainfall is in the range [3]:

$$Q = 0.90 \cdot H - 480 \quad to \quad Q = 0.90 \cdot H - 590, \quad (2)$$

to respectively, for approximate calculations can be adopted with a 95 % confidence phrase:

$$Q = 0.90 \cdot 1124 - 480 = 531.6 mm. \quad (3)$$

Monthly runoff is defined empirical relationship

$$Q_{mj} = a \cdot (H_i + 10)^b \log(H_{i-1} + 10), \quad (4)$$

where:

ISBN: 978-86-80593-54-8

Q_{mj} - monthly runoff (mm)

H_i - mean monthly precipitation for the reference month

$H_i - 1$ - -secondary monthly precipitation for the previous month

b - parameters obtained equalization least squares

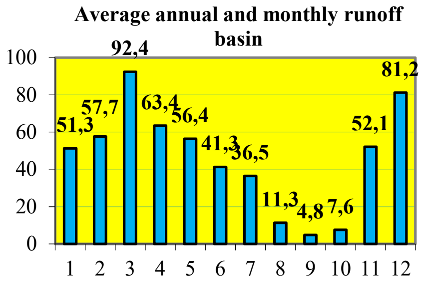


Figure 2. Diagram of flow by months

2) *Average annual and monthly flow at a given profile*

Flow directly as a function of the characteristics and size of the catchment area and runoff, and true relationship:

$$Q_{sr-god} = \frac{F \cdot Q}{31,55 \cdot 10^3} \left[\frac{m^3}{s} \right] , \qquad (5)$$

where:

Q_{sr-god} - average yearly flow on profile (m^3/s)

F - catchment area (km^2)

Q - average yearly flow in basin (mm)

In the same way the monthly flow rates are calculated $Q_{sr\text{-}mj}$. The place of barrier and grip is defined by the hotel „Zlaća“. The reference profile of the basin consists flows "Mala and Velika Zlaća", "Studešnica" and "Krabanja" and the total catchment area is F = 45.5 km2. The basin encompasses the northern slopes of the mountain "Konjuh". The surfaces of the local area are geological substrate of ultrabasic rocks, which are poorly watertight.

B. Rating of maximum incentives

It is a small basin, of high concentration, suitable "rational basis" for the calculation of the maximum flow on the reference profile.

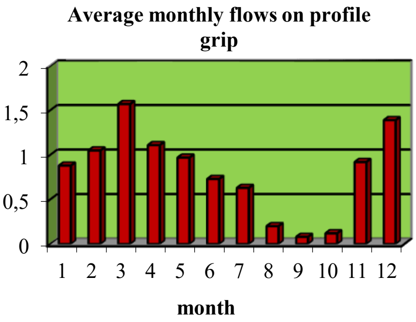


Figure 3. Average monthly flows on profile grip

1) *Physical - geographic parameters of basin*

- size of basin – $F = 45{,}7$ km^2
- the scope of catchment – O=31,3km
- Distance of the center of gravity – U=3.2 km
- concentration coefficients – $k = 2F/OU = 0.91$
- average height of catchment – $A_S = 760$ m.n.m.
- altitude flow profile – $A = 381$ m.n.m.
- height difference – $\Delta A = 379$m
- Average fall of catchment area $S = 2x\, \Delta A/L = 108.3$ m/km
- coordinates of the center of gravity of catchment $\phi = 44^0 20'$ $\lambda = 16^0 15'$

$\Delta\Phi = \Phi - 55 + 0.75\lambda = 1.48$

- annual rainfall of the catchment $H = 1.124$m

2) *Time of concentration (T_1) and propagation (T_2)*

ISBN: 978-86-80593-54-8

The adopted factor of surface runoff is $\beta = 2.5$, and for $H = 1.124$m, $S = 108$ m/km and return periods $P = 10$, 100 and 1000 years, according to a corresponding nomogram [3]

- for $P = 10$ - $T_1 = 3.4$ h
- for $P = 100$ - $T_1 = 2.9$ h
- for $P = 1000$ - $T_1 = 2.4$ h

For F= 45,7km2 and S= 108,3 m/km, the propagation time is towards corresponding nomogram: $T_2 = 2.0$h

Total time of adding run-offs is:

- for $P = 10$ - T_p=5.4h - ω=1+T_1/T_2 = 1.59
- for $P = 100$ - T_p=4.9h - ω=1+T_1/T_2= 1.59
- for $P = 1000$ - T_p=4.4h - ω=1+T_1/T_2 = 1.83

3) *The coefficient of maximum run-off (α)*

From the monogram (Srebrenović 1986), we got the relation and the maximum run-off is about 5% higher and the values are given in Table 1.

Table 1. Coefficients of maximum runoff

P	α_{mj}	α_{max}
10	0.63	0.66
100	0.76	0.80
1000	0.82	0.86

4) *Maximum flow*

From the previously determined values of certain parameters, the maximum flow is calculated as [3]:

$$Q_{\max} = 0.48\frac{\alpha}{(\beta\omega)^{0.75}} F^{0.96}\Psi S^{0.33}, \quad (6)$$

where:

$\psi = f(H,P)$ - average yearly flow on profile (m^3/s)

$\psi_{10} =$ 4.4 - catchment area (km^2)

$\psi_{100} = 8.5$ - average yearly flow in basin (mm)

$\psi_{1000} = 13.2$ - average yearly flow in basin (mm)

folowed by:

$Q_{\max-10}$ = 91.1 m^3/s, $Q_{\max-100}$ = 203,8 m^3/s, $Q_{\max-1000}$ = 320,6 m^3/s,

II. Short Technical Description of Construction Part

The proposal is to build dam on the river "Oskova" near hotel "Zlaća", in order to build accumulation and the necessary height difference for the corresponding energy potential. Due the fall of the river "Oskova" choice is derivation flow-MHE. The height difference between the powerhouse and dam is approx. 10 m1 and the distance is 200m1. Water from the dam to the required machinery is transported by pipeline of width DN = 800 mm. The proposal is to build a dam as gravitational, considering the conditions of the micro location.

The material where to build the dam is solid and impermeable rocks, there is no need for performing grout curtain, or drainage below the dam. In front of the dam install protective coating to prevent land erosion. In preparing the ground remove the broken and crumbling rock, and the foundations set up on a compact and solid rock. The dimensions of the dam is determined in this case, on the basis of the conditions of stability and position of the dam. Lenght of dam is approximately 21 m1, the basis approximately 9 m1, and the height of the dam is approximately 5.50 m1. Dressing takes place on the length of 6 m1. Below the dam waterfall with (dispator) for appeasement of „flood“ water. In the body of the dam install the pipe for bottom outlet, just in case water release from dam. The body of dam is constructed from solid waterproof concrete-MB300, and at the same time all the necessary accessories should be harmonized with technical regulations for this type of work.

ISBN: 978-86-80593-54-8

III. Hydro Power Potential

The hydropower potential of this system is defined by flows and net head that were previously elaborated. As a safe net decrease of 8 m it is adopted in the conceptual phase, because it is evident significantly higher gross head. Only the energy line losses are taken into consideration, power of central is:

$$P = 9.81 \cdot \eta \cdot Q \cdot H_n \quad [\mathrm{kW}] \tag{7}$$

$$\eta = \eta_t \cdot \eta_g = 0.85 \cdot 0.95 = 0.8075$$
$$\eta_t = 0.85 \qquad \eta_g = 0.95 \tag{8}$$

The power of MHE depending on the average monthly flow is given in the table, thereby months with a minimum flow rate are excluded, when it has not included the work of aggregates (7, 8, and 9 months).

Table 2. Flow by month

Month	1	2	3	4	5
Flow Q (m3/s)	0.88	1.05	1.57	1.11	0.97
P (kW)	55.8	66.5	99.5	70.3	61.5
Month	6	10	11	12	6
Flow Q (m3/s)	0.73	0.63	0.9	1.39	0.73
P (kW)	46.3	40	58	88.1	46.3

1) *Concept solutions MHE*

Taking into consideration hydropower potential, the flow rate and the net falls, foresees the installation of hydroelectric power unit which consists: horizontal Francis turbine, nominal power $P_t = 60$ kW, rotor diameter of DN = 400 mm, speed n = 750 r / min, asynchronous generator $P_g = 55$ kW, 380 V, 50 Hz, impulse turbine controller, and control cabinets. Operating modes and ways of handling the equipment MHE are defined as follows: start of aggregates from peaceful state in both modes (parallel and independently) is a handheld, in parallel operation is possible the automatic control of water level or opening the turbine, with or without repair power work independently on your own network with automatic frequency control (turbine governor) and generator voltage (voltage regulator).

2) *The turbine*

It is proposed that the pipeline DN = 800 mm under pressure enters laterally into the interior of the engine room. In front of the turbine is radial butterfly valve, which has a hydraulic drive and perform sealing with rubber. Between closure and the turbine is removable tube, for easy unassembly of closure in case of overhaul. Select the Francis turbine, horizontal structure, with its own shaft. Spiral body of turbine pour out of cast iron and turbine cover in the suction side. On the other side of the housing install an elastic coupling for connecting the turbine and generator. On the base plate is a proposal to incorporate the following elements and assemblies: radial butterfly valve, removable tube, turbine, housing bearings with shaft and elastic coupling, servo motor, oil-hydraulic actuator of the primary control, on-board smoke. 900x1400 mm.

Net decrease – H_n = 8m

Turbine flow max. – $Q_{tmax} = 1.57 \mathrm{m}^3/\mathrm{s}$

Turbine flow min. – $Q_{tmin} = 0.63\ \mathrm{m}^3/\mathrm{s}$

Rotational speed – n = 750 o/min

Speed over speed – n_{max} = 1400 o/min

Nominal power – P_{naz} = 60 kW

3) *The generator*

The proposal is the choice of reluctance asynchronous generator, by characteristics his price is lower in comparison with synchronous same power and fewer parts, can withstand 200% more speed without damage, simpler equipment for automatic regulation, connection is on building TS 10 / 0.4 kV, 400 kVA, with the capacitor battery and voltage regulation allows independent work (island operation), without capacitor battery and voltage regulation is possible by parallel operation with the network, with capacitor battery which performs power correction in parallel operation. Reluctance asynchronous generator by the technical performance is identical tocage asynchronous motor. Stator of generator,

ISBN: 978-86-80593-54-8

besides the three-phase windings, owns a coil for the regulation, on which is attached an electronic controller, which with appropriate change reluctance, maintains the output voltage of the generator in a narrow defined borders.

Technical data:

- nominal rated powers - 55kVA

- voltage - 400V, 50Hz

- cosφ - 0,8

- rotation speed - 750o/min

- shape - B3/B5

- mechanical protection - IP44

- capacitor - 10 kVAr, 40kVAr

- initiative performed with the capacitor battery and voltage regulation in the area of ± 0.5% for the purposes of self-employment

- voltage regulator – exists

4) *Location of connection to the ED network*

Connection to the existing network which is used to provide power to the existing consumers, with underground cable PP41, 1kV, 4x50mm2, to pass the same object from the engine to the BTS 10/0.4 kV, 400 kV.

5) *The planned annual production of electricity*

Considering the available hydropower potential work of MHE is planned nine months a year (out of operation 7, 8 and 9 months), predicted annual energy production is approximately $E = 330.000$ kWh, and would be used for personal needs of the hotel "Zlaća".

6) *Estimated costs*

Predicted basic equipment:

• FRANCIS or Ossberger turbine with its own horizontal axis, rotor diameter $DN = 400$ mm, $n = 750$ r/min, $P_t = 60$ kW, other equipment - 45.000.00 €

• Asynchronous Reluctance Generator $P_n = 55$ kW, 380 V, 50 Hz, and associated equipment - 20.000,00 €

• CONTROL CCABINETS:

(Turbine EH controller, In-egulator, controller-Q energy - 20.000.00 €

Switchgear, Protection and Measurement Equipment, Source aux. voltage UPS)

• Project documentation and legal obligations - 20.000.00 €

Preliminary work with the development of the dam with concrete MB300, $l = 300$ m 70.000,00 €

• Coating the slope with concrete MB150, $l = 50$ m - 5.000.00 €

• Construction works and pipe metal, pipes DN800mm, l = 200m - 40.000.00 €

Total: 170.000.00 €

7) *Economic data on justifiability of construction of MHE*

The project of building MHE will reduce the peak load of the hotel "Zlaća", and it will reduce the consumption of electricity, the power supply is from our own sources and reliability of the hotel "Zlaća" is increased. Construction costs of MHE are approximately € 170,000.00, and it is possible to provide a favorable loan (repayment 10-12 y). By increasing the reliability of power supply and creating accumulation, it is expected more tourists and revenue growth of hotel "Zlaća", and the estimated profit is approximately € 20,000 for 10 years. The following table presents the economic effects of SHP - that could be achieved by building MHE Zlaća for hotel "Zlaća", based on data from FERK (www.ferk.ba).

IV. CONCLUSION

Indirect profit is achieved by building MHE with the dam, which is the increase of the number of tourists to the hotel "Zlaća" and the special benefits are from the accumulation of water, leveling flow during the year and so on. For a period of 50 years down the river "Oskov" passed

ISBN: 978-86-80593-54-8

approximately € 1 million unused electricity. From the brief analysis it is concluded that for construction of MHE "Zlaća" *P* = 55.00 kW funds of approximately 170.000,00 € are necessary, which must be repaid after commissioning MHE for 7.4 years, with "Referential" price 0 , 1056 pf/kWh, realistic and least favorable for such an investment, it is the independent manufacturer of electricity and least favorable price, without "incentives", which can be taken as a "net

Table 3. Total revenue of MHE „Zlaća“ in one year of work

Tariff elements					**Months**		**Total price**
The calculation	KM/kW	HIGHER		15,59	9	140,31 KM	
power 55 kW		LOWER		12	9	108,00 KM	**6.000,00€**
					Days		
Activ energy pf/kWh		The reference electricity price		**10,56**	271	6.600 h	**19.360 €**
			Maintena. costs MHE“Zlaća“/ god				-1.000,00 €
			Clean. costs of dam MHE Zlaća/g.				-1.000,00 €
			Total revenue/yearly approx.				23.000,00 €

profit" and the gain is also "reducing the amount of CO_2 because of the so-called green energy". The technical advantage of MHE "Zlaća" is a direct connection to the 10 kV side 10 (20)/0.4 kV "Zlaća", which powers Hotel "Zlaća", and allows consumption of acceptable "green" hydropower, and in case of system breakdown and difficulty of the EPS , can supply the facility with 40% of installed capacity for heating the building. The new work "Possible work MHE" Zlaća "P = 55kW PV power plant" Zlaća "P = 125kW on the roof of the Hotel" Zlaća "and existing ED network" will consider these three sources, at the next conference, with the results obtained by using the software "HOMER".

REFERENCES

[1] Studije bilansa vode za snabdijevanje tehniĉkom vodom TE Banovići, RIT, Tuzla, 2010, p 23.

[2] R. Žugaj, Velike vode malih slivova, Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet Zagreb, 2010.

[3] D. Srebrenović, Primjenjena hidrologija, Tehnička knjiga, Zagreb, 1986, pp. 509.

[4] D. Srebrenović, Primjena matematskostatističkih metoda u hidrologiji, Sveučilište u Zagrebu, Zagreb, 1970.

ISBN: 978-86-80593-54-8

Thermo-Visual Diagnostics for Increasing Energy Efficiency in Bakery Production Lines

Dragan Antić, R&D Center “Alfatec” Ltd., Niš, Serbia,
dragan.antic@alfatec.rs

Ivan Krstić, Faculty of Occupational Safety, University of Niš, Niš, Serbia,
ivan.krstic@znrfak.ni.ac.rs

Bojan Bijelić, Faculty of Occupational Safety, University of Niš, Niš, Serbia,
bojan.bijelic@znrfak.ni.ac.rs

Abstract—**Decreasing energy consumption by nurturing energy efficient business, based on rational energy use and especially on minimizing energy losses, results in economic benefits, and is of key importance for the functional stability of production systems and environmental protection. This paper presents the application of thermo-visual diagnostics in energy safety risk analysis for the technical process of a bakery production line. To increase energy efficiency through reducing system energy losses, thermo-technical installations were subjected to thermo-visual camera scanning. The color spectrum of the thermal recordings achieved after software processing gives accurate data pertaining to the temperatures of the energy-technology system. This way, “critical spots” in the bread production process can be established, and places of heat breaches can be precisely defined, i.e. positions in which energy diffusion occurs. In accordance with this, as well as by applying a cost-benefit analysis, it is possible to come up with an evaluation for the validity of implementing an investment project for the redesign of the bakery production line system.**

Keywords: ***termovision, energy efficiency, technological process of bread production***

I. INTRODUCTION

The International Energy Agency, IEA has defined energy efficiency increase as a reduction in used energy per unit of production/ service, without affecting the quality of said product/ service.

Energy efficiency should be seen as a group of organized activities which are carried out within the limits of a defined energy system, with the goal of reducing the consumption of input energy by decreasing losses, harmful gasses emissions, and energy costs while keeping the services rendered unchanged or creating new values within the defined technological system. From this definition, the complexity of the problem is apparent, coming from the need to connect people, procedures and technologies, so that consistent and permanent energy efficiency improvements can be achieved [3].

Energy efficiency should also be seen as a means for achieving an overall resource usage efficiency, because improving it will accomplish the goals of economic development and mitigate climate changes.

Viewed from a global point of view, the benefit of an all-around energy efficiency increase directly influences the ecological situation and is seen through decreased harmful matter emission, primarily greenhouse gases, and climate change. Rational energy consumption programs ease possible energy crises, and at the same time increase energy security, leading to their enormous potential being so great that the energy efficiency increase is often called the “fifth energy source” [4].

One of the main problems which the energy sectors of developing countries face

ISBN: 978-86-80593-54-8

today, is a low level of energy efficiency. Missing a systematic approach, insufficient knowledge of modern trends in this area, as well as an inefficient interchange of available data are just some of the more serious issues in increasing energy efficiency, next to outdated equipment and consequences left behind by conditions of non-market operations.

Specific energy consumption in Serbia today is at a relatively meager level in most sectors [5]. The need for energy efficiency is unavoidably imposed when considering facts such as the permanent shortage of own energy resources, the necessary reaching of market prices for energy sources and energy, the importance of a healthy environment, renewing and strengthening the transitional economy.

The approach in considering energy efficiency problems is specific and contains a research and a pragmatic aspect. The basic difference between the two aspects is seen in the fact that the research approach takes all direct and indirect factors into consideration and analyzes the problem over a longer period, while the pragmatic approach of the direct user in energy consumption implies direct influence and an absence of tendencies towards long-term consideration. With large consumers, the main obstacle in improving energy efficiency is the lack of relevant information and recent knowledge about advanced technologies, practical experiences in the field of energy efficiency, as well as a lack of conscience about the environmental impact. In the production sector, it is often the case that personnel management is uninformed of the energy efficiency problem, and that enterprises view their business as separated from the global problem, thus do not give priority to rational energy use. The work will analyze infrared thermography diagnostics on a bread production line, with the goal of increasing energy efficiency of the enterprise's production process.

II. THE ENERGY SYSTEM OF A BAKERY PRODUCTION LINE

In the bakery production line, as a large energy consumer, the ability to recognize a general state of the energy system and the importance of energy efficiency is of crucial importance for securing the production process and a place on the market.

The technological bread production process is made up of a larger number of processes and operations, the most important being the kneading of the dough, cutting, shaping, fermenting and baking it. Given the specificity of the technological process, a large amount of energy is used in order to get the finished product. Figure 1 presents the energy system scheme of the technological bread production process, which shows two gas boilers producing dry saturated steam at 1.5 bars of pressure, condensate storage (where used steam is returned in the form of condensate), fermentation chambers and tunnel furnaces for bread baking.

Thermo-visual scanning of the energy system momentarily registers heat emission, i.e. infrared radiation, which gets a true representation of energy losses. This identifies the so-called “bad spots”, based on which heat loss assessments can be established.

Through a detailed analysis of the decline of annual failures with the number of annual thermo-visual checkups, remarkable results are achieved. It was established that one thermo-visual scanning per year reduces malfunctions by nearly 15 %. Checkups every six months bring that number up to 55 % on a annual level, while a quarterly control eliminates 70 % of malfunctions [6]. Increased failure occurrences, especially in the process industry, cause substantial costs, while on the other hand, periodic thermo-visual checkups can achieve important savings. With a regular and proper application of maintenance, thermovision will maximally protect devices and their soundness, detect possible failure finesses, and always enable repairs in a time best suited to the user.

In this sense, the goal of the paper is thermo-visual diagnostics of energy losses of the technological bread production system, with the aim of optimizing energy flows.

ISBN: 978-86-80593-54-8

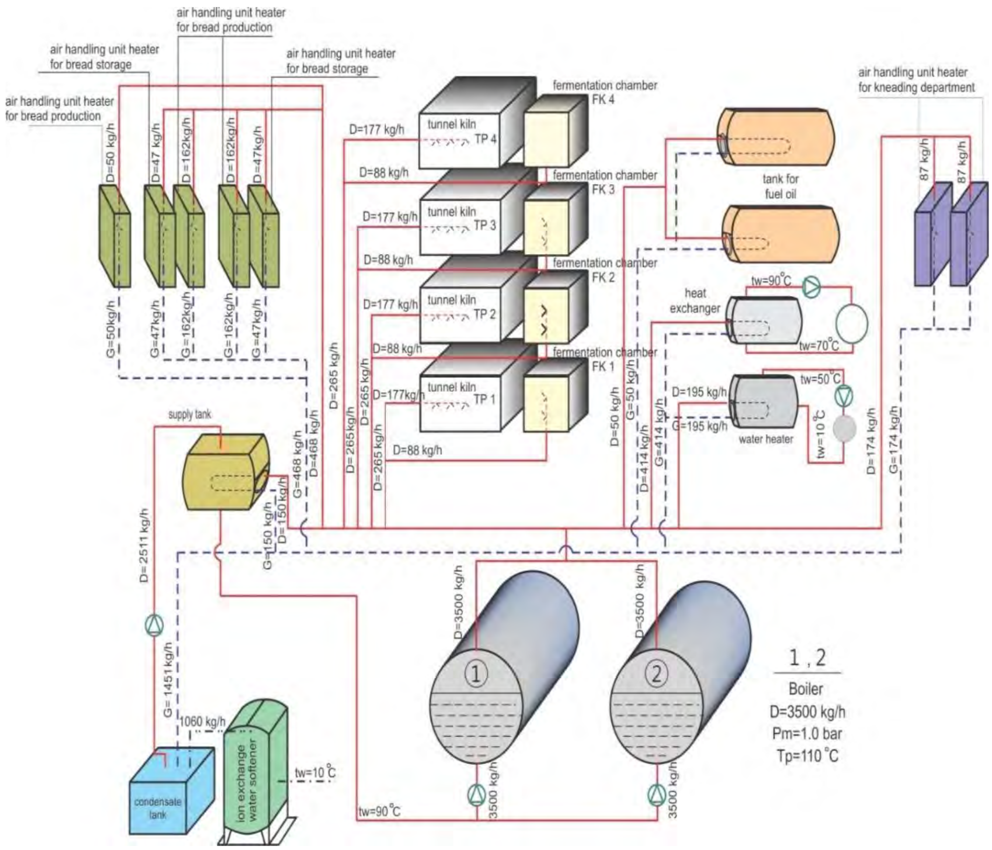


Figure 1. Energy system scheme for the technological bread production process [7]

III. Methods of Work

For non-destructive diagnostics of energy losses in the technological bread production process, a non-contact instrumental measurement method of thermovision or "infrared thermography" was used, which allows measuring infrared (heat) ray emission of every object with a temperature above absolute zero. As opposed to other infrared methods, thermovision offers the possibility of scanning heat ray emissions from machines and equipment from the technological process in a short time interval. As a temperature measurement method, it does not require stopping the technological production process to allow the user to discover various potential failures. Losses caused by potential pausing of work are also avoided through this.

The functioning principle of infrared thermography consists of detecting infrared (heat) radiation with the help of cameras for thermo-visual recording (thermovision cameras or thermocameras), designed to detect the part of the infrared specter invisible to the human eye. Infrared light resides in the part of the electromagnetic spectrum where the wavelength exceeds the length of visible light, while having a smaller frequency, on the other hand. Translating infrared radiation into a visible picture results in a thermograph. Surfaces emitting various amounts of infrared radiation are

ISBN: 978-86-80593-54-8

visible on the thermograph. An area of larger radiation is displayed with a brighter color, and areas with the same color have the same level of radiation.

The production system of the bakery was scanned using the EasIR™-9 infrared camera [8]. The thermo-visual recording was subsequently processed by the EasIR™ software package, and lastly, a protocol for the scanned object was issued with defect indications and a recommendation for intervention. The software features a user-friendly interface and is compatible with Microsoft's OS.

IV. Results and Discussion

The energy system of the bakery production line was scanned with a thermovision camera in order to diagnose heat losses. Thermo-visual diagnostics were implemented for the boilers of the production line, i.e. the "source" itself, where steam was produced, which was necessary for the technological bread and pastry production process, as well as for the production line itself, where fermentation chambers and tunnel furnaces were installed.

The resulting color spectrum gives precise data about the temperatures of the line's walls, as well as of the accompanying installations. Basically, shades of blue represent the thermo-visual representation of the cold parts of the production line, installations and plumbing, while shades of red and yellow, reaching an almost white color, represent hot positions and objects.

Thermo-visual inspection was first done in the part where the complete boiler installation was situated (the boiler room), and the results, ranging from 37.1 °C to 114.6 °C, indicate a solid temperature protection, Figure 2.

On the steam boilers themselves, the temperature was of moderate intensity, measuring at 37.1 °C, while in the uninsulated parts of the boiler, i.e. the combustion product removal chamber, the temperature amounted to 85.1 °C. The accompanying uninsulated pipeline installations, meaning the valve block, the temperature went up to 114.6 °C.

On the pipeline within the room, the place of leakage was located on the arcs, where the temperature went up to 93.7 °C, while for the part of the pipeline outside the boiler room the temperature values of heat leakage turned out to be smaller, at 40.3 °C on the joints, Figure 3.

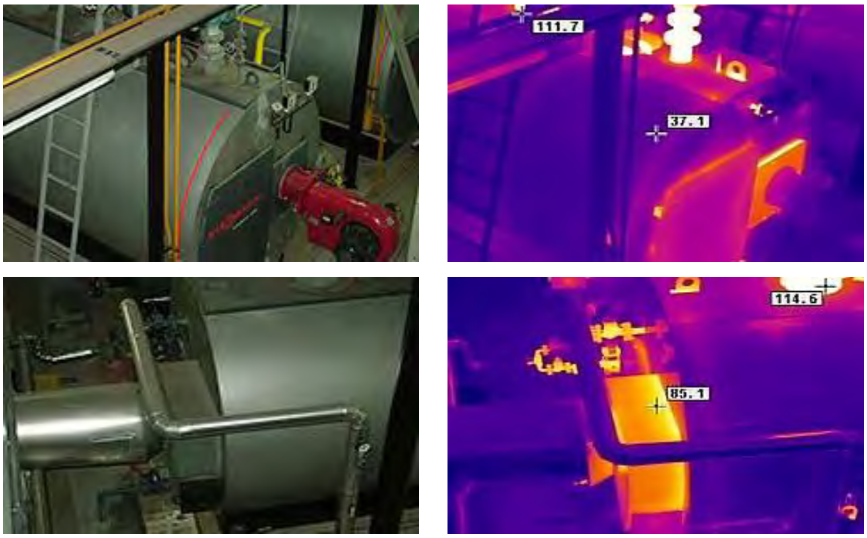


Figure 2. Places of heat leakage on the steam boiler of the production line

ISBN: 978-86-80593-54-8

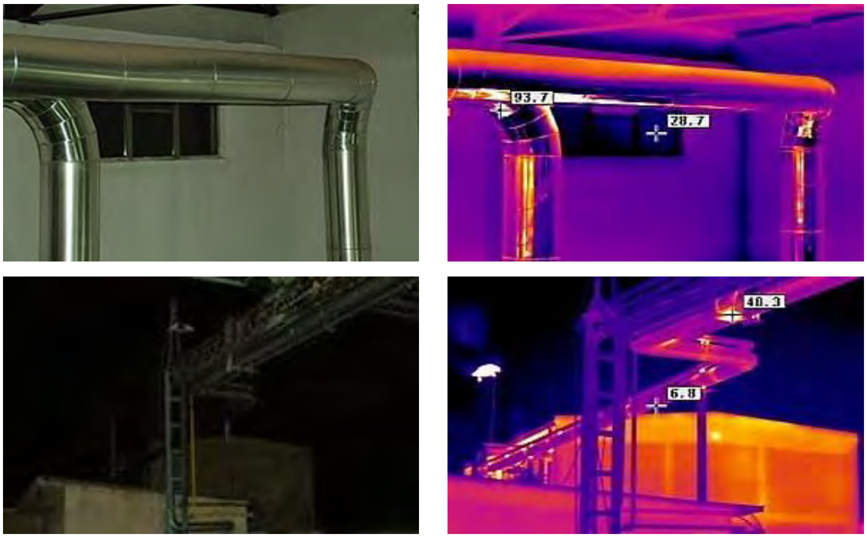


Figure 3. Places of heat leakage on the pipeline of the production line

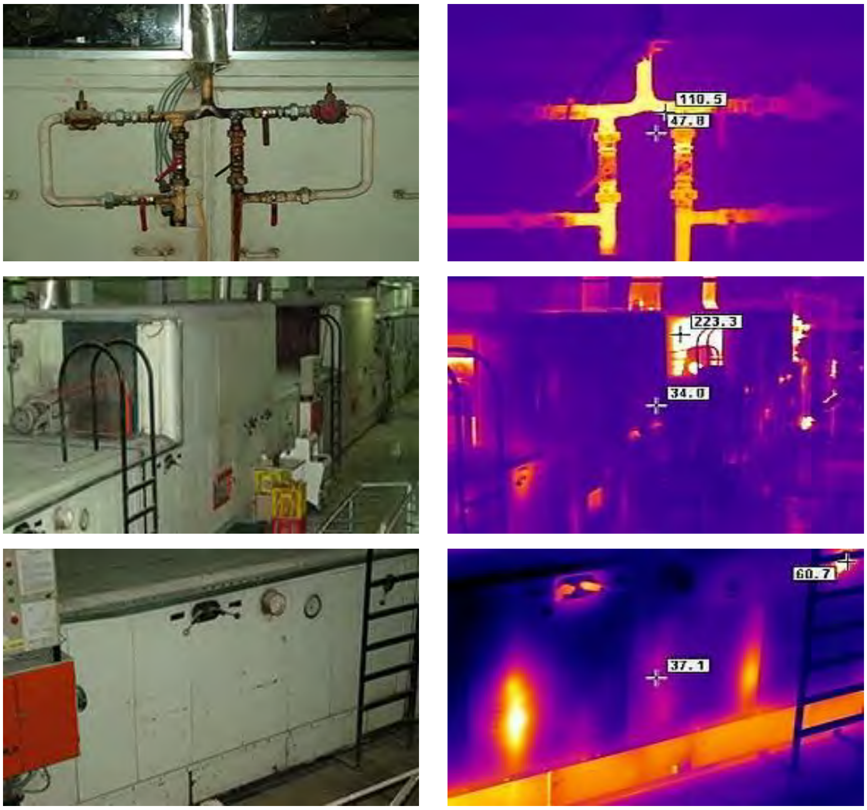


Figure 4. Places of heat leakage on the tunnel kiln of the production line

ISBN: 978-86-80593-54-8

In the part of the production line where the tunnel furnaces are installed, Figure 4, the thermo vision camera registered the most critical parts throughout the production line, with maximal heat losses of 110.5 °C on the uninsulated parts of the bread tunnel furnace and accompanying installations, as well as on the position of the ventilation system's electromotor, 223.3 °C. On the walls of the tunnel furnace, temperatures ranged from 37.1 °C to 60.7 °C in the places of heat leakage.

It can be stated that the heat insulation on the thermo-technical installation of the bakery's production line installations were done relatively well. At the same time, if the management of the enterprise would be interested in increasing the energy efficiency of the production line through investments, it would be possible, via cost-benefit analysis, to determine the economic validity of possible interventions, which would reduce transmission losses in characteristic places, to which the thermo-visual recordings point.

V. CONCLUSION

As a method of preventive maintenance, the infrared thermo-visual principle can be applied for surveillance and diagnostics of energy equipment, production line and system status. Infrared thermography is a valuable and comprehensive tool which achieves remarkable results in the control process. Significant heat losses can occur during work as a consequence of inadequately defined parameters upon system construction, due to malfunctions or equipment and production line damage, can be overcome by timely detecting critical spots in the technological system.

Via the method of infrared thermography, places of heat loss in the energy system of the bread production line, which existed due to poor quality or damage to insulation and the equipment, were documented and presented.

The achieved color spectrum, after software processing, offers precise data about system temperatures of the bakery production line.

This way, the application of thermo vision defines the constructive imperfections, as well as important parameters for a possible system redesign, with the goal of increasing production line energy efficiency, and using energy rationally and sustainably.

REFERENCES

[1] IEA, "World Energy Outlook 2004", International Energy Agency, Pariz, 2004.

[2] U.S. Energy Information Administration (EIA), "International Energy Outlook 2013", Washington, 2013.

[3] D. Gvozdenac, U.B. Gvozdenac, Z. Morvaj, "Energetska efikasnost (industrija i zgradarstvo)", Fakultet tehničkih nauka u Novom Sadu, Novi Sad, 2012

[4] G. Vučković, "Istraživanje energetske efikasnosti složenog termoprocesnog postrojenja primenom metode eksergoekonomije", Doktorska disertacija, Mašinski fakultet u Nišu, Univerzitet u Nišu, Niš, 2013.

[5] S. Filipović, M. Miljković, "Politika unapređenja energetske efikasnosti u industrijskom sektoru", UDK 338.45.01:620.92, 2011.

[6] V. Blagojević, M. Stojiljković, P. Janković, "Mogućnosti korišćenja infracrvene termografije u industrijskim sistemima", 13. Simpozijum termičara Srbije - SimTerm 2007, Sokobanja, 2007

[7] P. Rašković, "Optimizacija energetskih sistema sintezom mreže razmenjivača toplote", Doktorska disertacija, Mašinski fakultet u Nišu, Univerzitet u Nišu, Niš, 2002.

[8] Infrared Camera - EasIR™-9 http://www.hvds.co.nz/files/docs/e9%20brochure%20lo%20re.pdf

[9] D. Antić, "Modeli energetske bezbednosti u malim i srednjim preduzećima", Magistarska teza, Fakultet zaštite na radu u Nišu, Univerzitet u Nišu, Niš, 2014.

ISBN: 978-86-80593-54-8

Microgrids in Power Industry of Serbia: possibilities and challenges

Dragan Stevanović, EPS, Zaječar, Serbia, dragan985@gmail.com

Aleksandar Janjić, University of Niš, Faculty of Electronic Engineering, Aleksandar.Janjic@elfak.ni.ac.rs

Abstract— **Microgrid represents an integrated power system with locally dispersed loads, energy sources and energy storage capacities. The operation of a microgrid is possible in both island conditions (off grid) and connected to the local grid (on grid). In this paper, the overview of basic technical characteristics of a microgrid has been presented. As an illustration of this concept, the determination of technical parameters necessary for the operation of 10 kV feeder "West villages" as a microgrid, in 35/10 kV TS "Sokobanja" has been given.**

Keywords: ***microgrid, relay protection, renewable energy,***

I. Introduction

Microgrids, which are localized grids that can disconnect from the traditional grid to operate autonomously and help mitigate grid disturbances to strengthen grid resilience, can play an important role in transforming the nation's electric grid. Electric Power Industry of Serbia has great potentials concerning the usage of microgrids, especially in rural areas. This paper analyzes possibilities of 10 kV feeder working as microgrid. Considered 10 kV feeder powers 6 villages with 643 houses in total, and 2338 residents, and it consists of 14 LV substations 10/0.4kV.

The distributed energy sources are micro and mini hydroelectric plants, PV panels and wind generators. Geographical area supplied by this feeder has a great hydro potential, with one river and four creeks. The situation with the insolation in this region is also favorable, with 1861 sunny hours in Sokobanja.

In the following sections, calculation of required capacities for the feeder supply has been given, together with the determination of relay protection settings and the time scheduling of distributed resources.

II. Calculation of Required Capacities for the Feeder Supply

A. Required capacities

The single pole diagram of the feeder analyzed in this paper is given on Figure 1.

Considering date from measurements on 10kV feeder, and demographic data from the same territory, approximated daily load diagram is presented in Figure 2.

B. Hydro power

On 10kV feeder analyzed in this paper, five hydro power plants will be connected in total. Hydro power plant labeled H1 on Figure 1, will be designed with rated power of 500kW, and rest of power plants (H2, H3, H4 and H5), will be less power rated (three of 100kW and one of 50kW). Table I shows water quantity and available power for each hydro power plant.

Calculation of expected hydro power:

$$P = 9.81 \cdot Q \cdot H \cdot \eta \quad [kW], \tag{1}$$

Q – water quantity (m^3/s)
H – height (m)
η – efficiencies (%)

Hydro power plant „Moravica" (H_1) will be working constantly P_{H1}=490.5 KW, and other hydro power plants will be used to cover power peaks during the day $PH_{2;5}$=377.685 KW, and they will work constantly during the night. .

ISBN: 978-86-80593-54-8

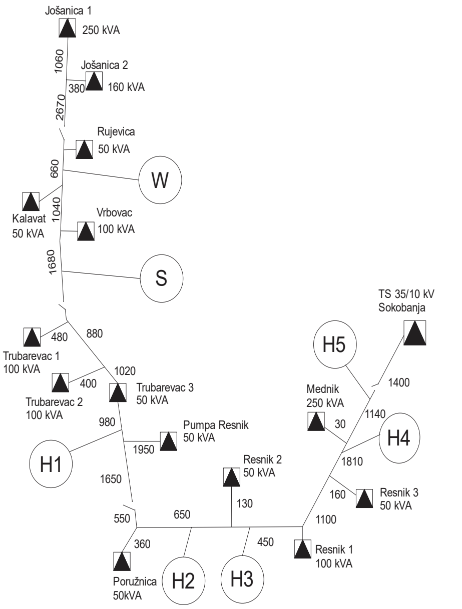


Figure 1. Scheme of 10kV feeder „West villages“ with connected renewable energy sources

Table 1. Obtained values of hydro generators

Label	Water quant (m^3/s)	Height (m)	Efficienc. (%)	Power (kW)
H5	0,5	50	50	122,6
H4	0,3	50	50	73,6
H3	0,5	50	50	122,6
H2	0,3	40	50	58,9
H1	10	10	50	490,5
Total				868,2

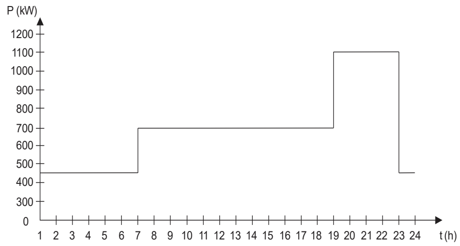


Figure 2. Approximated daily load diagram

C. Wind generators

Only 3% of sun energy that reach earth is transformed into wind movement, and obtained power is not negligible. One of benefits is energy availability. That has made wind generators profitable investment. [1]

Advice of Ministry of Mining and Energy is that location is profitable for investment if lowest wind speed per year is between 4.9 – 5.8 m/s [1].

1) *Calculation of wind generator capacities* [2]*:*

Blade length: $l = 3m$

Wind speed: $\vartheta = 15 \, m/s$

Air density: $\rho = 1.23 kg/m^3$

Power coefficient: $C_p = 0.4$

Swept area is equation of a circle:

$$A = r^2\pi = 3\pi = 9.42 m^2 \ . \qquad (2)$$

Power converted form the wind into rotational energy:

$$P_1 = \frac{1}{2}\rho A \vartheta^3 C_p = 7.8kW \ . \qquad (3)$$

2) *Number of needed wind generators for obtaining power of 200 kW is:*

$$N_{wg} = \frac{P_{uk}}{P_1} = \frac{200}{7,8} = 25 \ . \qquad (4)$$

To overcome problem with uneven weather condition, it is advisable to use battery systems. [3]

D. PV panels

Earth gets more energy from Sun in one hour, than human population spends for whole year. Quantity of solar energy that reaches the Earth is twice bigger of all renewable energy sources on Earth. [1]

Number of sunny days on observed location is favorable from Sun energy exploitation point of view. In table II,

ISBN: 978-86-80593-54-8

duration of solar radiation for each month is given.

Table 2. Duration of solar radiation per month in territory of town Sokobanja [4]

Month	Jan	Feb	Mar	Apr	Total
Hours (h)	59	74	121	161	
Month	May	Jun	Jul	Aug	1861
Hours (h)	201	224	267	262	
Month	Sep	Oct	Nov	Dec	1861
Hours (h)	208	158	78	48	

1) *Calculation of expected solar panel energy per year*

$$W = P \cdot t \cdot 0.75 = 279150\ kWh/year\ , \qquad (5)$$

W – energy from PV panels per year [kWh/year]

P – power of PV panels [kW]

t – number of hours of sunny days per year [h]

$\eta = 0.75$ – average losses of the system

2) *Calculation of area needed for PV panel installment*

For solar panel system of 200 kW needed area for their installment is:

$$A = 10\frac{P(kW)}{0,8} = \frac{2000}{0,8} = 2500\,m^2 . \qquad (6)$$

III. Load Flow Calculation in Off-grid and On-grid Operation Mode

Load flow is given for two cases. The first one, when 10 kV feeder is powered from TS 35/10 kV „Sokobanja", and the second one, when 10 kV feeder operates autonomously. Both cases are given in Figure 3, and Figure 4.

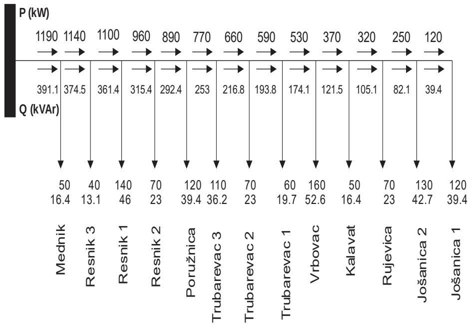


Figure 3. Load flow in on-grid operation mode

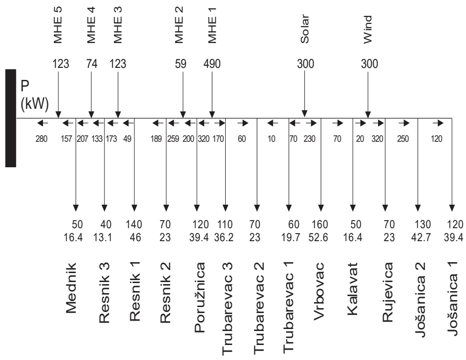


Figure 4. Load flow in off-grid operation mode

Figure 4 represents case when all renewable sources are working with full capacities. In that case renewable sources produce 280kW power more than required.

But, because of weather changing, load flow in off-grid mode is changeable too. In other situations power direction will be different, and battery system may necessary to use.

IV. Relay Protection Settings in the Microgrid

Most of the existing distribution systems are radial where power flows from substation to the customers in a unidirectional manner. The coordination of protective devices based on current is relatively easy in such systems. Usually overcurrent relays are employed for such distribution system protection for their simplicity and low cost. However, the protection of the distribution network

ISBN: 978-86-80593-54-8

becomes more complicated and challenging once a microgrid or several DGs are connected. With such connections, the pure radial nature of utility supply is lost. The power flow then becomes bi-directional. Under such situations, the existing protection devices may not respond in the fashion for which they were initially designed. [5]

The current differential protection is chosen for the microgrid since it is not sensitive to bi-directional power flow, changing fault current level and the number of DG connections. It also provides the required protection for both grid connected and islanded modes of operation. Moreover, the protection is not affected by a weak indeed where it can detect internal faults even without having any DG connected. The current differential protection is effective since it is sensitive, selective and fast. [6]

All the DGs in the microgrid should be protected from abnormal conditions. Therefore, each DG is employed with several protection elements; under voltage, reverse power flow, over voltage and synchronism check. The relay associated with these protection elements issue a trip command to DG circuit breaker once any abnormal condition is detected. [6]

Figure 5 is showing defined zone for relay protection of 10kV feeder "West villages". Feeder is divided into four sections, which in case of failure can be isolated from the rest of the microgrid.

V. Time Scheduling of the System Concerning the Daily Load Profile of the Microgrid

Values from Table III shows that during daily load, available power capacities are enough to satisfied power demand, no mater of weather condition. On the other hand, during night peak load, power from renewable sources is not enough. The worst case scenario is Case II-4 (no wind, and 70% water flow), where difference between needed power in system and produced power is 493 kW.

For that reason, battery installation is needed. For example, in this case it can be system of 8 batteries of 500 kW (Symmetra PX 500 kW, each battery can give 500 kW for 20 min. [7])

In order to ensure control, monitoring, generation and load forecasting in microgrid „Multilin U90 Plus Generation Optimizer" can be used. U90Plus continuously tracks load and generation in order to create load and generation profile for next 24 hours. If the actual measured load usage differs from what the U90Plus, it will continually adjust its forecast to make the best predictions for load requirements. [8]

Table 3. Overview of available and required power, in case of various weather conditions

Day / Night	Weather conditions	Working generators	Available power (kW)
Case I-1	Sunny and windy	H1, S and W	850,5
Case I-2	Cloudy, no wind	H1, H2, H3, H4, H5	868,2
Case I-3	Cloudy and windy	H1, H2, W	729,4
Case I-4	Sunny, no wind, 70% water flow	S, H1, H2, H3, H4, H5	787,74
Case II-1	Windy	H1, H2, H3, H4, H5, W	968,2
Case II-2	Windy, 70% water flow	H1, H2, H3, H4, H5, W	787,74
Case II-3	No wind, full water capacity	H1, H2, H3, H4, H5	868,2
Case II-4	No wind, 70% water flow	H1, H2, H3, H4 i H5	607,74

ISBN: 978-86-80593-54-8

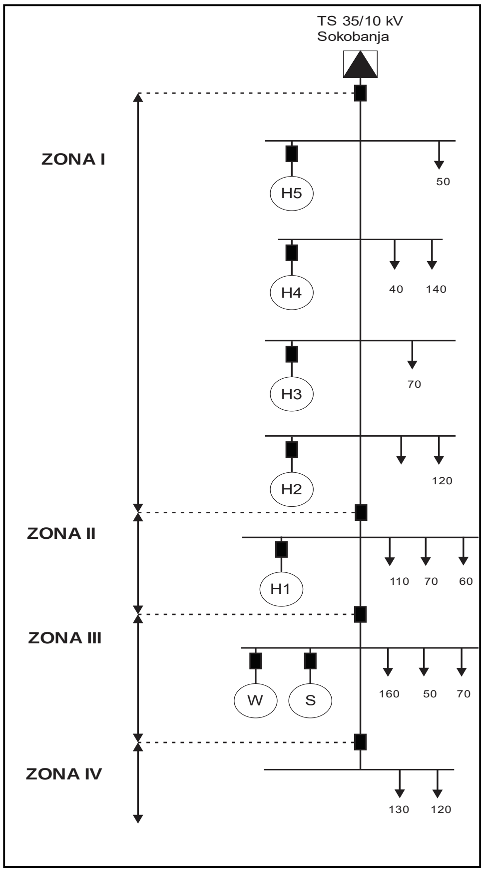


Figure 5. Overview of zones for specific protection relay work

VI. Conclusion

This paper analyses possibilities of supply 10kV feeder as microgrid, and shows existence of sufficient capacities for supplying 10kV feeder. In analysis only renewable energy sources were considered, such as hydro power plants, solar panels and wind generators. In order to ensure full safety of supply, battery systems installation is considered, which would be used during night load peak.

Acknowledgment

The research presented in this paper has been partially supported by Serbian Ministry of education and science (project III 42006).

References

[1] http://www.solarnipaneli.org

[2] Wind Turbine Power Calculations – The Royal Academy of Engineering

[3] http://bigpawer.en.made-in-hina.com/product/ySwEmHUvCPVL/China-Vanadium-Redox-Flow-Battery-From-1-500kw-Used-for-Lab-Research-UPS-Supply-Standby-Power-Battery-Electricity-Peak-Adjustment.html

[4] http://www.opstinasokobanja.com/

[5] CSIRO Intelligent Grid Research Cluster- Project 7 - M4: Microgrid Operation and Control Executive Summary - Manjula Dewedasa, Arindam Ghosh, Gerard Ledwich

[6] Protection of Microgrids Using Differential Relays - Manjula Dewadasa, Arindam Ghosh, Gerard Ledwich

[7] Schneider Electric Symmetra™ PX 250/500 kW 400/480 V, Technical Specifications, 11/2014

[8] GE Digital Energy – Grid IQ Microgrid control system – Optimization solution for permanently islanded or grid-connected microgrid

ISBN: 978-86-80593-54-8

The Impact of the Thermal Impulse to the Electric Arc's Appearance at the Example of Motor's Start

Nenad Floranović, Research and Development Center "ALFATEC", Niš, Serbia,
nenad.floranovic@alfatec.rs

Milica Rašić, The Faculty of Electronic Engineering, Niš, Serbia,
milicarasa@gmail.com

Zoran Stajić, The Faculty of Electronic Engineering, Niš, Serbia,
zoran.stajic@elfak.ni.ac.rs

Abstract—**This paper presents the formation of the electric arc and explains all consequences that follow its appearance in electrical installations. Most frequent electrical arc causes and its impact to the value of thermal impulse are also presented. At the example of one model of induction motor's starting the value of thermal impulse was analyzed. The difference in thermal impulse's value during motor's starting in normal operation and in short circuit is given as a result of investigation. Diagrams of significant electrical parameters during those different motor's starting regimes are presented, as well. Based on all analyses it is presented how high impact thermal impulse can have to the electric arc's appearance in electrical installations.**

Keywords: ***electric arc, arc flash, short cuircuit, motor's starting, thermal impulse***

I. Introduction

In general, the electric arc represents the gas conductor of the electricity and it can be described as the permanent electric discharge of electrodes. The electrical arc represents the flow of the current through the incompletely ionized plasma that is result of ionization of gasses and vapours. Those gasses and vapours are generated by the heating of some parts around electrode's tips (two different conductors at two different electrical potentials) up to really high temperatures. Hard material of electrodes tips changes its form. First, it is converted to the liquid and gas and, finally, it gains the form of incompletely ionized plasma. The arc is characterized by the big current density, small cathode voltage drop and really high temperature in the ionized area [1, 2]. The value range of that temperature is 2000 – 6000 °C.

According to its position in electrical installations, the electrical arc can be serial (regular) or parallel. Serial or regular arc could take place in any point of the electrical circuit from switchboards to all electrical appliances. Opposed to serial arc, parallel arc can appear between the phase and neutral conductor or between the phase conductor and ground. It should be noticed that, with respect to the danger of fire cause, there is a significant difference between serial and parallel arc. In the case of serial arc, in the electrical circuit with the serial arc current drops appear, so it can be expected that overcurrent protection will not react and turn off the electricity. This type of failure can takes a long time, the probability of fire is really high. According to the fact that the serial arc is practically invisible by all static protective components, it represents one of the most frequent causes of fires caused by failures in electrical installations.

ISBN: 978-86-80593-54-8

II. The Most Frequent Arc Causes

The most frequent causes of electric arc are: carbonization of insulation, air ionization caused externally and short circuits.

A. Carbonization of Insulation

In alternating electric circuits it is not difficult to induce and maintain electric arc if there is carbonized conductive path. There are a few different situations in which are possible to create that path in insulation material. The simplest situation is when the insulation material is exposed to the high electrical voltage that causes its breakthrough. Another situation involves the effect of moisture and impurities on the surface of the insulation causing the "leaking" of the electric current across the surface of the conductor's insulation, which can eventually leads to the forming of carbonized conductive path. The probability of this situation is significantly higher, if the electrical installation is older or if it doesn't have appropriate maintenance.

According to its resistance to the carbonization, there are a lot of different types of insulation materials, but in electrical installation at low voltage mostly used are conductors with PVC insulation. Unfortunately, PVC is one of the worst polymers in terms of resistance to the carbonization. When it is exposed to temperatures of 200 – 300 °C, the carbonization process occurs and the part of insulation that has been carbonized obtains semiconductor characteristics, thereby enabling the appearance of current leaking and electric arc. When this type of insulation is once damaged by overheating, its dielectric strength significantly decreases, which can cause electrical insulation breakthrough at rated voltages and standard rooms temperatures. Generally, the appearance of carbonization process at PVC insulation is really often and this is one of the most frequent causes of electric arc.

B. Air Ionization Caused Externally

Natural dielectric breakthrough strength of the air is 3 $\frac{MV}{m}$, but electrical breakthrough can also occur at significantly lower values of electric field, if the air is ionized. The air could be ionized by the flame or by the previously established arc. Experiments have shown that in flames dielectric breakthrough strength of air falls to the value of $0.11\frac{MV}{m}$. For example, if the fault in the form of electric arc appears in the distribution line, the large amount of ionized gasses is going to be created. These gasses can cross a long distance for a short period. If the ionized gas, at its path of spreading, encounters another electric circuit it can cause another new failure and the appearance of electric arc at another location.

C. Short Circuits

Short circuit is a sudden failure caused by a sudden resistance decreasing and current increasing electrical circuit. There are two types of short circuits: direct short circuit when the contact between two metals is generated over the full cross section i.e. metal short circuit and arc flashing where there is not the contact between two metals, but the current flows through the electric arc i.e. arc short circuit.

At the direct short circuit, heating is not localized to the point of failure [3]. Instead of that, the heating is distributed along the entire electrical circuit. The circuit breaker usually breaks electrical supply circuit before any fire caused by the temperature's increasing. In general, it is really rare situation that the fire can be caused by the direct short circuit in well-designed electrical installations. Arc short circuit is a result of the contact of two non-insulated conductors. In their contact the large current that causes melting of materials and ionization of gasses in the area around the contact is established. Magnetic forces tend to separate conductors, but until they are not completely separated, the current flowing through the conductive bridge of liquid metal and ionized gasses (the electric arc). However, the established conductive bridge is interrupted by magnetic forces by spraying of metal's blazing droplets. By the end of the arc short circuit, damaged surface of conductors with large diameters can be

ISBN: 978-86-80593-54-8

noticed, while small section conductors can be completely destroyed at the point of electric arc appearance. Generally speaking, arc short circuit can be really dangerous in terms of the fire causing.

III. PRACTICAL EXAMPLE OF THE ELECTRIC ARC IMPACT

The great impact of the arc flash to the electrical equipment in this paper is presented at the practical example of starting of induction motor which rotor was fixed [4]. This regime is equivalent to the regime of motor's starting in short circuit. As it was explained in the previous chapter, short circuit is one of the most frequent causes of electric arc appearance. The induction motor used for this investigation has following parameters: $P_n = 15kW; f_n = 50Hz;\ n_n = 1440\ \frac{1}{min};\ \ R_s == 0.776\ \Omega; R_r' = 0.776\ \Omega; X_{\gamma_s} = 1.9\ \Omega; X_{\gamma_r}' = 1.9\ \Omega; X_m = 51.2\ \Omega; M = \frac{X_m}{100*\pi} = 0.163\ \Omega; L_s = \frac{X_m + X_{\gamma_S}}{100*\pi} = 0.169\ \Omega;\ \ L_r' == \frac{X_m + X_{\gamma_r}'}{100*\pi} = 0.169\ \Omega; P = 2;\ J = 3 * 0.073 = 0.219\ kgm^2$. The moment of inertia's value is tripled here, because it was important to take into the account the impact of couplings and flywheel. Using the Mat LAB/Simulink software the model for this induction motor was created and its starting using star-delta motor starter was simulated. Two different situations were simulated: motor's starting in normal regime and in the short circuit. All significant electrical and mechanical parameters were analysed. Obtained results are shown in the next chapter.

IV. RESULTS AND DISCUSION

In Fig.1. – Fig. 6. diagrams obtained by Mat LAB simulation for motor's starting in normal operation are presented. It was predicted that the stator's winding connected as star switches to the winding connected as delta one second after motor's starting. Diagram of rotor's speed changes is shown in Fig.1. From this diagram it can be noticed that the rotor during the motor's starting was gradually increasing its speed until it achieved steady state at the value of its rated speed: $n_n = 1440\ \frac{1}{min}$.

In Fig. 2. diagram of motor's electromagnetic torque's changes is presented. The interesting moment for this electric parameter is the moment of stator's winding switching from star to delta connection. The torque's peak is clearly visible in this point and this is the most dangerous moment for the machine's mechanical equipment. Thereafter, motor continued to operate with its rated torque's value $T_n = 100\ Nm$.

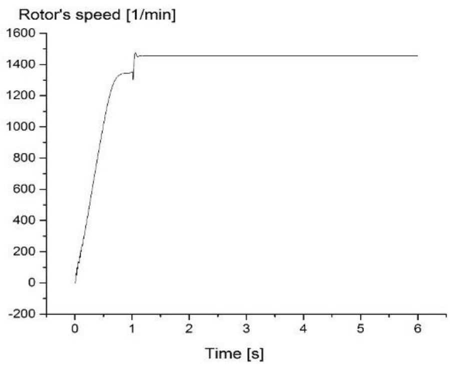


Fig. 1. Diagram of rotor's speed changes during the normal motor's starting

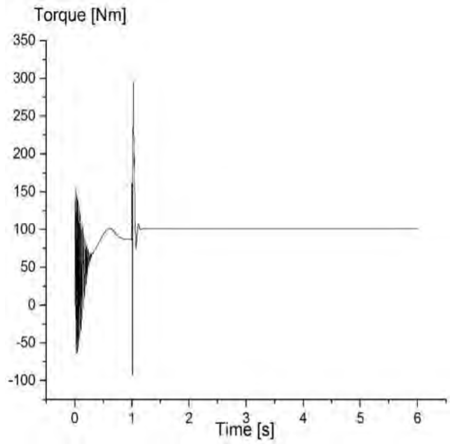


Fig. 2. Diagram of electromagnetic torque changes during the normal motor's starting

In Fig. 3. diagram of machine stator's phase current is presented. From this diagram it can be noticed that the peak value of stator's phase current in its positive part

ISBN: 978-86-80593-54-8

reached the value of more than 100 A. This is the moment when the electric power was supplied to the machine which stator's winding was connected as star. After one second, machine's stator changed its connection to delta and another current peak is also visible. However, this peak is quite lower and its value in positive part is about 70 A.

This current can be compared with the current in supplying cable conductors at motor's start presented at diagram of electric current in supplying cable changes in Fig. 4.

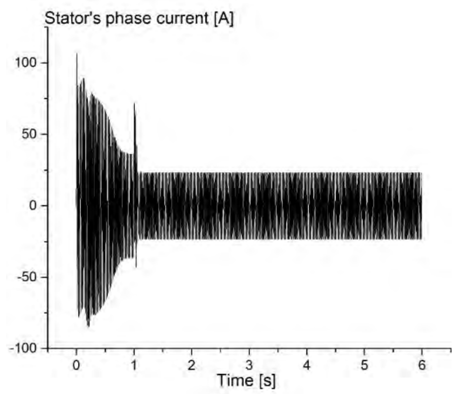


Fig. 3. Diagram of stator's phase current changes during the normal motor's starting

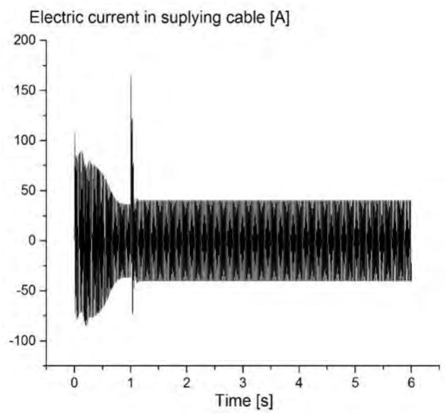


Fig. 4. Diagram of electric current in supplying cable changes during the normal motor's starting

The electric current in supplying cable conductors has similar waveform as the stator's phase current but the difference can be noticed if the value of the current is considered after motor's stator switching from star to delta connection. The current peak value one second after motor's starting in diagram presented at Fig. 4. amounts 160 A what is in comparison with the stator's phase current peak quite higher value.

Naturally, at steady state achieved after machine's starting the current in supplying cable conductors is $\sqrt{3}$ higher than the stator's phase current.

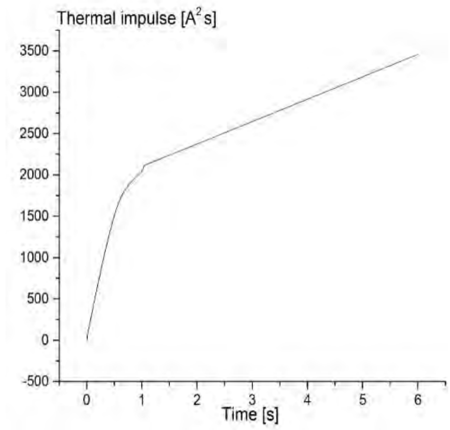


Fig. 5. Diagram of stator's phase current thermal impulse changes during the normal motor's starting

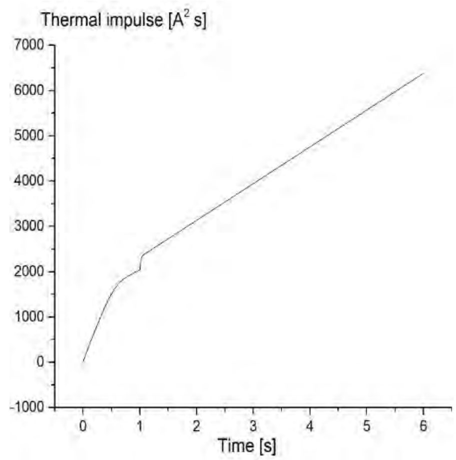


Fig. 6. Diagram of thermal impulse changes in supplying cable's conductors during the normal motor's starting

ISBN: 978-86-80593-54-8

Waveforms and values of those currents are interesting for this analysis regarding to the thermal impulses which diagrams are shown in Fig. 5. and 6.

Thermal impulse presented in Fig. 5. was caused in machine's stator by stator phase current and thermal impulse presented in Fig. 6. was caused in supplying cable conductors by the current flowing through them. In general, thermal impulse represents the integral of squared current in a certain time interval

$$K_t = \int i^2(t)\,dt \tag{1}$$

It is obvious that the higher current produces higher thermal impulse (proportional with its squared value) and therefore thermal impulse is more dangerous in supplying cable conductors than in the motor's stator windings. In order to make easier comparison of thermal impulse's values at motor's start in normal operation, thermal impulse's values were calculated at the end of each second during the simulation process for both currents: stator's phase current and current in supplying cable. Those values are presented in Table I. It is interesting that after interval of 6 seconds thermal impulse in supplying cable has almost doubled value in comparison with the thermal impulse caused by stator's phase current in machine's stator winding.

Table 1. Comparasion of the thermal impulse that developes during motor's start in normal operation

Time [s]	Thermal impulse that develops in motor's stator winding [A^2s]	Thermal impulse that develops in supplying cable conductors[A^2s]
1	2043	2043
2	2375	3133
3	2646	3945
4	2917	4757
5	3188	5569
6	3458	6381

Thermal impulse's values calculated in normal operation are not dangerous for stator's winding and they can't cause its failure.

On the other hand, motor's start in short circuit could be very dangerous for machine's windings and supplying cable due to thermal impulse that can be developed in them. In Fig. 7. - Fig. 11. diagrams of significant parameters obtain by MatLAB simulation of machine's starting in short circuit are presented. As in the simulation of machine's start in normal operation, in this case is also predicted that the stator's winding connected as star switches to the winding connected as delta one second after motor's starting. Due to the fact that the short circuit mode was simulated by the motor which rotor was fixed, there was no sense to simulate rotor's speed changes. All other diagrams are analogous to diagrams presented in Fig. 2. – Fig. 6.

In Fig. 7. diagram of motor's electromagnetic torque changes during motor's start in short circuit was presented. In comparison with the diagram shown in Fig. 2. it can be noticed that in the moment of motor stator's switching from star to delta connection electromagnetic torque's peak is much higher in the short circuit mode. It achieved the value of almost $T = 350\ Nm$, and therefore after achieving of steady state the torque stabilized at $140\ Nm$ (in normal operation this peak value was $300\ Nm$,and the torque in steady state was about $100\ Nm$).This situation can be really dangerous for induction machine, because it can produce machine's mechanical damages. In addition, the time period used here for machine's achieving of steady state was much longer than in the case when the motor has normal start.

The analogous situation is with currents. In Fig. 8. diagram of stator's phase current changes at motor's starting in short circuit is presented.

ISBN: 978-86-80593-54-8

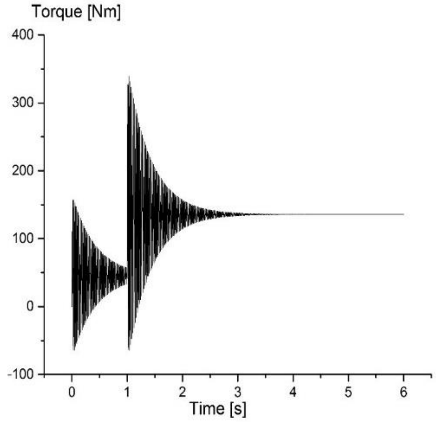


Fig. 7. Diagram of electromagnetic torque changes during the motor's starting in short circuit

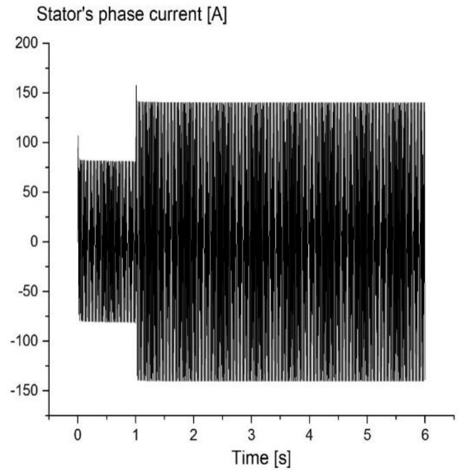


Fig. 8. Diagram of stator's phase current changes during the motor's starting in short circuit

In the moment of motor's stator switching from star to delta connection its phase current reached the peak value of more than 150 A and in the steady state this current has effective value of 99 A. As a comparison, from Fig.3. it can be noticed that those values are 75 A and 17.5 A, respectively.

In Fig. 9. diagram of changes of electric current flowing through the supplying cable conductors during the motor's starting in short circuit is presented. Here is also the most interesting moment of stator's switching from star to delta connection when the peak value of the supplying cable current amounts 280 A. The value of this current in steady state is about 171 A. In comparison with the current in supplying cable during motor's start in normal operation where those values are 160 A and 30 A, respectively, it can be concluded that the peak current value is 1.6 times higher and the current value in steady state is 5.7 times higher at the regime of short circuit than at normal operation.

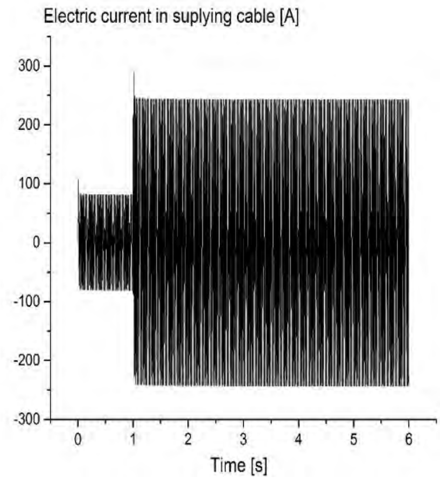


Fig. 9. Diagram of electric current in supplying cable changes during the motor's starting in short circuit

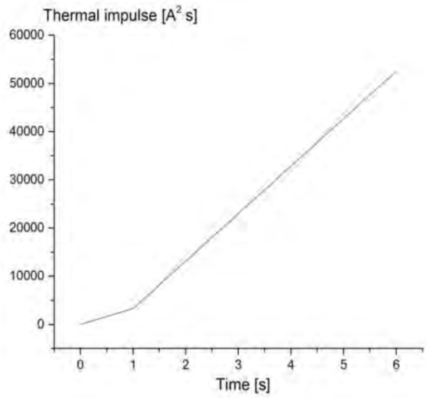


Fig. 10. Diagram of stator's phase current thermal impulse changes during the motor's starting in short circuit

ISBN: 978-86-80593-54-8

Higher values of currents during the machine's start at the mode of short circuit caused higher values of thermal impulses presented by diagrams at Fig. 10. and Fig. 11. From Fig. 10. of diagram of stator's phase current thermal impulse changes it can be noticed that the value of thermal impulse in motor stator's winding after six seconds of simulation achieved the value of 52558 $[A^2\ s]$. Analogously, thermal impulse value in supplying cable after six seconds achieved 151170 $[A^2\ s]$, shown in Fig. 11. For easier comparison thermal impulse's values calculated at the end of each second of motor's start simulation at short circuit mode are presented in Table II.

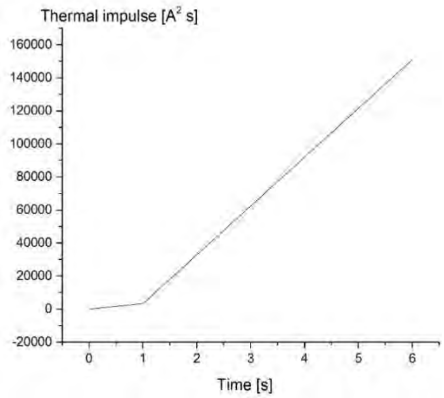


Fig. 11. Diagram of thermal impulse changes in supplying cable's conductors during the motor's starting in short circuit

Table 2. Comparasion of the thermal impulse that developes during motor's start in short circuit mode

Time [s]	Thermal impulse that develops in motor's stator winding $[A^2 s]$	Thermal impulse that develops in supplying cable conductors$[A^2 s]$
1	3307	3307
2	13150	32943
3	23002	62500
4	32854	92056
5	42706	121610
6	52558	151170

As opposed to the Table I, thermal impulse's values presented in Table II could be very dangerous for motor's stator winding, but also for supplying cable. If the value of thermal impulse at the end of second in the mode of normal operation from Table I is compared with its analogue value form Table II (short circuit mode), it can be noticed that thermal impulse after two seconds in stator's winding is 5.5 times higher and in supplying cable is more than 10 times higher. At the end of third second those values from Table II are 8.7 and 15.8 times higher, respectively. Finally, if thermal impulse is compared at the end of sixth second after motor's start, it can be noticed that in motor's stator winding in short circuit regime developed thermal impulse is 15.2 times higher than in the normal operation and in the supplying cable this ratio is 23.7.

After described comparison it is clear that it is really dangerous that motor starts in the mode of short circuit. Higher values of currents expose all conductors and contacts to additional thermal heating and create conditions for electric arc occurrence. On the other hand, with so high currents in short circuit mode, electrodynamics forces that have impact to all elements with current are also higher, and the possibility of arcing occurrence and air ionization at some parts additionally increases. Especially dangerous situation can happen if the initial appearance of electric arc is following with its flashover. This is really often situation in electric switchboards with bad conductor's isolation and it leads to additional electric arc spreading to all surrounding equipment. Based upon this analysis it can be concluded that motor's start in short circuit regime is extremely dangerous and can cause increasing of thermal impulse and therefore electric arc appearance.

V. Conclusion

According to results presented in this paper, higher currents generated in the regime of short circuit have great impact to the value of generated thermal impulse. Extremely high thermal impulse can cause electric arc's emergence and this leads to its spreading to all surrounding parts of electrical installation. At the example of motor's start in the short circuit mode thermal impulse's dependence of currents was explained. Diagrams of all significant

ISBN: 978-86-80593-54-8

parameters were presented and it was confirmed that short circuit represents one of the main causes of electric arc's appearance.

Future investigation in this area can consider other causes of electric arc's appearance, their impact to its value and following disadvantages that arc can cause by its emergence.

ACKNOWLEDGMENT

The paper is a part of the research done within the project III 44006, supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia within the framework of technological development.

REFERENCES

[1] J. C. Das, Arc Flash Analysis and Mitigation, IEEE Press, A John Wiley & Sons, inc, publication, New Jersey, 2012.

[2] Vytenis Babrauskas, "Research on electrical fires: the state of the art", Fire safety science prodeeding of the ningth international symposium, 2008, pp. 3-18,

[3] J. Selwin Rajadurai, Thermodinamics and thermal engineering, New Age International, New Delhi, 2003.

[4] Z. Stajić, Đ. Vukić, M. Radić, Asinhrone mašine, Elektronski fakultet, Niš, 2012. (in Serbian)

ISBN: 978-86-80593-54-8

Multi-criteria Location Selection for Mini Hydroelectric Power Plants

Milan Cvetković, Faculty of Natural Sciences and Mathematics, Niš, Srbija, cvele87@hotmail.com

Slavica Cvetković, Fakultet tehničkih nauka, Kosovska Mitrovica, Srbija, slavica.cvetkovic@pr.ac.rs

Abstract—**This work presents the factors that exist in the process of choosing a location of a mini hydroelectric power plant and its effect on business. One of the most important criteria is to reduce the cost of building and to ensure that the hydroelectric potential is used for several purposes. The selection of the mini hydroelectric power plant location was carried out using multi-criteria analysis.**

Keywords: ***location, criteria, selection strategy, PROMETHEE***

I. Introduction

The development of renewable energy sources is essential for global security. Since only a third of the world's economically exploitable hydroelectric potential was used so far, the emission of greenhouse gases and other heavy pollutants can be reduced through intensive use of hydropower and the reduction of energy acquired through thermal power plants.

At present, hydropower is the only reliable and economically acceptable source of renewable energy, which can cover a substantial portion of the need for electricity. Water reservoirs allow highly efficient energy production exactly at the time it is needed.

Hydroelectric power plants also enable the development of mankind's other vital needs, such as food production, water supply, flood protection and the improvement of navigation conditions, to name a few. [1]

The International Hydropower Association (IHA), a highly influential non-governmental organization whose task is to encourage and promote the development of hydropower as a renewable energy source within the development strategies of countries, presented its views of hydropower development which also ensure the achievement all the environmental protection and social objectives.

II. Factors for Selecting the Location for Building a Mini Hydroelectric Plant

In order to build and use any structure in the Republic of Serbia, including a small hydroelectric power plant, it is necessary to meet the following conditions: 1) obtaining an energy permit; 2) obtaining a location permit; 3) obtaining a construction permit; 4) constructing the structure and providing professional supervision during the construction period, and 5) technical inspection of the structure and obtaining a use permit.

The process of selecting a location for building a mini hydroelectric power plant requires an architectural analysis of a wider area that was determined to possess hydropower potential (Qsr and H).

• The following data is needed in order to select the location and devise a technical solution for a mini hydroelectric plant:

– Topographical data

– Geodetic data

– Geological data

– Geo mechanical data

ISBN: 978-86-80593-54-8

– Meteorological data

– Hydrologic data

– Economic and water management data

• *Topographical* data are contained in topographic maps which need to include: water intake structures, a supply and drainage channel, a sedimentation tank, a pressurized pipeline, a surge tank, the accumulation area (the backwater), an access road, etc.

• *Geodetic* data include geodetic surveys that produce data on:

• the situation of the water intake structure

• the situation of the powerhouse

• the situation of the drainage channel route

• the longitudinal cross-section of the water supply from the water intake structures to the sedimentation tank

• geodetic coordinates of the fixed points of all the hydroelectric plant structures

• The *geological* data show:

– Tectonics and seismicity

– Hydrography and climate

– Erosion

– Hydrological conditions

– Characteristics of the terrain from the perspective of engineering geology

– The geological conditions of constructing a hydro technical structure

• The *geo mechanical* data include:

– The geo mechanical map and the typical profiles of the examined area

– The geo mechanical profiles of exploration wells and excavations

– Examining a soil sample in a laboratory (water content, the specific gravity and bulk density of soil, soil compaction, organic matter content ...)

– The parameters needed for the calculations (soil porosity, soil compaction, the friction coefficient between concrete and soil ...)

• *Meteorological* conditions

– They represent the climate in a certain time period and within an observed basin

– Precipitation (maximum 24-hour precipitation, monthly, yearly and strong precipitation, the number of snow days, etc.)

– Air temperature (mean, monthly and yearly, maximum and minimum)

– Humidity

– Maximum yearly wind speeds

• The *hydrological* conditions are especially significant for constructing mini hydroelectric power plants and they relate to:

– The physical parameters of the drainage basin (the surface and shape of the basin, the flow drop, the centroid of the basin, the length of the river flow, etc.)

– The flow curve

– The hydrograph of mean daily flow – the runoff

– The curve for the duration of mean daily flow

– Mean monthly flow

The economic and water management data encompass and calculate the direct damage caused by building mini hydroelectric power plant structures and focus on the benefits of future water users and their needs.

All these conditions complicate the choice of small watercourses eligible for the construction of mini hydroelectric power plants, which take up 3% of the total renewable energy source potential in Serbia.

However, this task is simplified with the help of certain software.

• It facilitates the identification of suitable locations, the projection of energy needs, the choice of equipment, future spending plans, cost estimates and feasibility studies. This, of course, entails a reduction in

ISBN: 978-86-80593-54-8

the project cost and saving a significant amount of time.

• All these software products aim to estimate the amount of usable energy from a specific hydro schema

• This entails two methods: Flow Duration Curve (FDC) and Simulated Stream Flow (SSF)

• The first method encompasses acquiring the characteristics of the intake: its surface, the amount of precipitation, evaporation and the type of soil

• This is used to estimate a mean flow, and an appropriate FDC curve is selected (out of a spectrum of 30 characteristic curves which were acquired statistically)

• Based on the obtained curve, the program recommends one or more turbines and gives the estimate of annual power production

• The second method uses an existing database of registered flows or uses a simulation flow which creates this database based on this methodological data

• Daily or hourly electricity production can be calculated in this way [2].

III. The Selection of the Mini Hydroelectric Power Plant Location Via Multi-criteria Analysis

This paper examines the selection of a mini hydroelectric power plant location by using multi-criteria analysis. The decision must be made by taking into account several different and often contradictory criteria. Frequently there are a large number of locations that satisfy the set criteria, and the question is how to select the best location out of a set of locations that are approximately of equal quality, while at the same time taking into account the defined criteria. The problem is additionally complicated by the fact that neither are all of the criteria of equal importance, nor are they accorded the same weight values. The issues also include the frequent situation when the criteria values are not given in a quantitative, but a qualitative manner. Apart from that, the opinions of all committee members do not bear the same weight and significance. A series of methods was developed in order to solve these and similar problems, and they belong to the group of multi-criteria analysis and ranking – Multi-Attribute Decision Making (MADM).

The MADM method makes it possible to select the most acceptable variation out of a set of offered possibilities based on the defined criteria. The MADM models feature criteria specified as attributes. There are a finite number of preset variations to choose from, while there are no explicitly defined limitations since they are included in the attributes.

The MADM model is suitable to poorly structured problems and has the following general postulates:

$(\max)\{f_1(x), f_2(x), ..., f_n(x), n \geq 2\}$ with limitations:

$x \in A = [a_1, a_2, ..., a_m]$ where:

n is the number of criteria (attributes), $j = 1, 2, ..., n,$

m are the variations (actions) $i = 1, 2, ..., m,$

f_j are the criteria (attributes), $j = 1, 2, ..., n,$

a_i are the variations (actions) to consider, $i = 1, 2, ..., m,$ and A is the collection of all variations.

Apart from that, the f_{ij} values of every considered f_j criterion are known, and they were acquired with each of the possible variations $a_i : f_{ij} = f_j(a_i), (i, j)$.

The MADM model is traditionally represented via a matrix, which is called a decision matrix. There are several methods that were developed for solving MADM problems (especially multi-criteria ranking), among which the most prominent are: ELECTRE, VIKOR, AHP, PROMETHEE, etc.

This paper used the PROMETHEE-GAIA method.

ISBN: 978-86-80593-54-8

We will define the initial MADM matrix where there are seven main attributes (criteria), which are:

The name and the place of the mini hydroelectric plant

The name of the river or the watercourse

1. M_j – Altitude of the water intake structure

Table 1. Starting data for the given decision problem in the evaluation table

Alt	Criteria						
	M_j m^3/s	D_{ij}	M_k	D_{ik} x1 0^6	Y_i	a	ß
A	0.43	152	500	2.2	5	0.2	0.9
B	0.68	83	420	1.8	4	0.4	0.2
C	0.98	82	600	2.6	3	1	0.9
D	0.29	108	320	1.4	5	0.9	0.2
E	0.28	132	280	1.2	3	0.9	1

2.*Dij* – The net drop for the functioning of the mini hydroelectric power plant

3.*Mk* – The power in kW

4.*Dik* – Yearly production in kWh

5.*Yi* – The lengths and cross sections of supply pipes

6.a – The state of the road network

7.ß – The possibility of connecting to the distribution network

As an example, we will consider 5 locations in the area of the Municipality of Pirot, which is characterized by significant hydroelectric potential, having in mind that the majority of the municipality's theory is on the elevated Balkan Mountains, which have abundant annual rainfall and are rich in water.

The river Visočica features 18 locations where mini hydroelectric power plants can be built. We will consider only 5 of the locations with similar characteristics in order to select the most appropriate one according to its characteristics.

We have five location choice alternatives with seven criteria present, which are given in Table 1. The final two criteria are qualitative criteria. A five-degree sale was used to quantify a qualitative value of the criteria, and the meanings are the following: 1 – very poor; 2 – poor; 3 – satisfactory; 4 – good; 5 – very good. Some of the criteria need to be minimized, while others need to be maximized.

The calculation was performed using Decision Lab, which created a graphic presentation of the results.

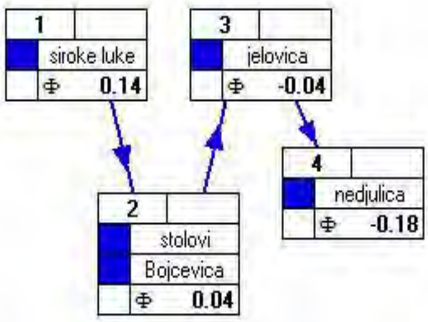


Figure 1. PROMETHEE II ranking

The PROMETHEE II method enables the decision maker to completely rank the alternatives as shown in Figure 1.

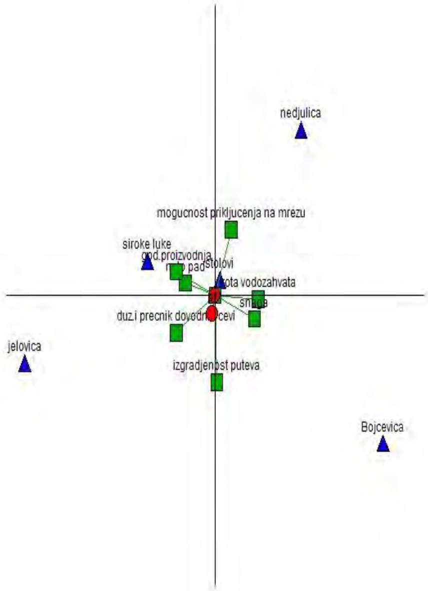


Figure 2. The GAIA plane for the given decision problem

ISBN: 978-86-80593-54-8

Based on the position of the alternatives and the criteria, it is visible that all of the criteria listed are very conflicting (different axis directions).

Figure 2 shows a GAIA plane for the analyzed decision problem.

The directions shows that the best solution is the alternative named "Široke luke" on the river Visočica, on the watercourse of the Jelovica River, with an installed flow of 0.290 m^3/sec, a net drop of 146 m, 2 generators, a P type turbine with the installed power of 320 kW, and the average yearly production of 1,380,000 kWh.

IV. Conclusion

The idea of this paper was to give the theoretical and methodological basis for determining the location of mini hydroelectric power plants. Having in mind that the theme of location was covered multiple times and in many different ways, certain approaches were explained here.

A special part of the analysis is dedicated to the PROMETHEE-GAIA method which is one of the most commonly used methods in multi-criteria decision making. The paper presented some theoretical basis while the application itself was illustrated on the example of selecting/ranking a location for a mini hydroelectric power plant on the river Visočica. The use of these methods is additionally facilitated by using the software Decision Lab, which is a very simple and quick way of reaching a final result. The program also has the possibility of analyzing the sensitivity of the results acquired, which is conducted by using the initial criteria weight. It should be emphasized that the success of the application of the PROMETHEE method largely depends on the following factors:

- the possibility and experience of the decision maker to express his/her own preferences among the alternatives for each explored criteria as an interval scale;

- the decision maker must be in the condition to express the importance of each explored criteria on an interval scale, and the decision maker is certain that he/she wants to consider all relevant criteria in the decision-making process and is aware that the acquired solution will be the best compromise between all of the analyzed criteria.

References

[1] M. Milojević, N. Marković, S. Radojević, Č. Mitrović: “Ekskvizicija vodotoka u predprojektu mini hidroelektrane”, IIPP pp. 59-66

[2] M. Đurić, Ž. Đurišić, A. Čukarić, V. Ilić, Beopres, Elektrane Beograd, 2010.

[3] S. Cvetković, N. Barac, G. Milovanović: “Poslovna logistika”, Niš, 2004. str. 219

[4] S. Lovreta, D. Radunović. G. Petković: Trgovina, teorija i praksa, Svremena administracija, Beograd, 1998.

[5] J. C. John, E. J. Bardi, C. J. Langley: The Management of Business Logistics, West Publishing Company, St. Paul, 5th edition, 1992, p. 426.

[6] A. Gosh, S. L. McLafferty: Locaton Strategies for Retail and Service Firms, Lexington Books, 1987.

[7] K. D. Vandell, C. C. Carter: Store Location in Shopping Centers: Theory & Estimates, Presented at the Asian Real Estate Society Meetings, Beijing China, 2000.

[8] M. J. Eppli, J. D. Shiling: How Critical Is a Good Location to a Regional Shopping Center? The Journal Of Real Estate Research, vol. 12, no. 3, 1996.

[9] R. W. Schmenner: Making Business Location Decisions, Englewood Cliffs, NJ, Prentice-Hall, 1982.

[10] H. Koch: Policy Mechanisms to Influence Location Choices, Linz, Austria, 23-24 September 1998.

[11] S. Cvetković, M. Cvetković: „Izbor lokacije trgovinskih centara“, Četvrti simpozijum sa međunarodnim učešćem, TRANSPORT I LOGISTIKA, TIL, Niš, 2011, pp. 83-86.

ISBN: 978-86-80593-54-8

Analysis of One Parameter Global Solar Radiation Models for Serbia

Mladen Milanović, Faculty of Civil Engineering and Architecture, Niš, Serbia, mmsmladen@gmail.com

Milan Gocić, Faculty of Civil Engineering and Architecture, Niš, Serbia, mgocic@yahoo.com

Slaviša Trajković, Faculty of Civil Engineering and Architecture, Niš, Serbia, slavisa@gaf.ni.ac.rs

Abstract - **The solar radiation represent one of the important aspects of climate change. Through the evapotranspiration, the solar radiation has direct application in defining plants' need for water, and therefore has a huge influence in planning the water resources. In this paper, ten one parameter global solar radiation models are compared and analyzed for the territory of Serbia during the period 1980-2010. All models show that the stations such as Negotin and Vranje had the greatest values of solar radiation, especially in June, July and August. Mean bias error (MBE), root mean square error (RMSE) and Nash-Sutcliffe equation (NSE) were used for comparison of solar radiation models.**

Keywords: ***solar radiation models, climate change, Serbia.***

I. INTRODUCTION

Solar radiation is more pronounced under the influence of climate change. It has been especially expressed in recent years. Solar radiation represents one of important parameters for modelling the crop growth. There are processes in plants where radiation is converting to chemical energy necessary for crop growth [1,2]. According to [3], solar radiation is important in calculating the values of reference evapotranspiration (ET_0) and consequently in designing the irrigation systems.

Analysis of 89 existing monthly average daily global solar radiation (MADGS*R*) models and 19 existing daily global solar radiation (DGSR) models are investigated in [4]. It is shown that linear and polynomial MADGSR models were able to estimate the solar radiation accurately. In addition, multiparameter DGSR models and polynomial models were more accurate than other types of observed models. In [5], a new model for calculation of global solar radiation is developed and compared with the measured data and the existing models such as Angstrőm-Prescott, Bahel, Newland and Abdalla models. The presented model showed the best matching with observed data. In Serbia, the solar radiation and its influence on ET_0 were analyzed in [3].

This paper presents the analysis of ten monthly average daily one parameter global solar radiation models and their comparison on the territory of Serbia for the period from 1980 to 2010.

II. MATERIALS AND METHODS

A. *Data collection and study area*

Climate in Serbia is temperate continental, with the average air temperature of 10.9 ºC, and with the average annual precipitation of 896 mm. Sunshine hours ranged between 1500 to 2200 hours annually. Months with the maximum average sunlight are May, June, July, August and September.

The study area in this paper is Serbia, which territory is observed through the five meteorological stations. The geographical

ISBN: 978-86-80593-54-8

characteristics of the observed stations are given in table 1. Data required for estimation of solar radiation (sunshine duration) was taken from the meteorological yearbooks issued by the Republic Hydrometeorological Service of Serbia (RHMSS). Study period for all observed stations is from 1980 to 2010.

Table 1. Geographical characteristics for observed meteorological stations

Station name	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
Nis	21°54'	43°20'	204
Palic	19°46'	46°06'	102
Negotin	22°33'	44°14'	42
Zlatibor	19°43'	43°44'	1028
Vranje	21°55'	42°33'	432

B. Models for global solar radiation estimation

In this study, ten monthly average daily one parameter models are used for estimation of solar radiation, which are divided into four groups i.e. linear, polynomial, logarithmic and exponential models.

One parameter linear models

Angstrőm-Prescott model [6,7]

$$\frac{H}{H_0} = 0.25 + 0.5\frac{S}{S_0} \quad (1)$$

Bahel et al. model 1 [8]

$$\frac{H}{H_0} = 0.175 + 0.552\left(\frac{S}{S_0}\right). \quad (2)$$

Almorox and Hontoria model 1 [9]

$$\frac{H}{H_0} = 0.2170 + 0.5453\left(\frac{S}{S_0}\right). \quad (3)$$

Jin et al. model 1 [10]

$$\frac{H}{H_0} = 0.1332 + 0.6471\left(\frac{S}{S_0}\right). \quad (4)$$

Srivastava et al. model [11]

$$\frac{H}{H_0} = 0.2006 + 0.5313\left(\frac{S}{S_0}\right). \quad (5)$$

Page model [12]

$$\frac{H}{H_0} = 0.23 + 0.48\left(\frac{S}{S_0}\right). \quad (6)$$

One parameter polynomial models

Rietveld model [13]

$$\frac{H}{H_0} = 0.1 + 1.02\left(\frac{S}{S_0}\right) - 0.44\left(\frac{S}{S_0}\right)^2. \quad (7)$$

Bahel et al. model 2 [14]

$$\frac{H}{H_0} = 0.16 + 0.87\left(\frac{S}{S_0}\right) - 0.61\left(\frac{S}{S_0}\right)^2 + 0.34\left(\frac{S}{S_0}\right)^3. \quad (8)$$

One parameter logarithmic models

Toğrul et al. model 2 [15]

$$\frac{H}{H_0} = -0.0344\,ln\left(\frac{S}{S_0}\right) + 0.1982 + \left(-0.0201\,ln\left(\frac{S}{S_0}\right) + 0.4562\right)\left(\frac{S}{S_0}\right). \quad (9)$$

One parameter exponential model

Almorox and Hontoria model 5 [9]

$$\frac{H}{H_0} = -0.0271 + 0.3096e^{\left(\frac{S}{S_0}\right)} \quad (10)$$

where: H is monthly average daily global solar radiation (MJ $m^{-2}day^{-1}$), H_0 is monthly average daily extraterrestrial radiation (MJ $m^{-2}day^{-1}$), S is actual sunshine duration (h)

ISBN: 978-86-80593-54-8

and S_0 is maximum possible sunshine duration (h).

H_0 can be estimated as [6,7]:

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \quad (11)$$

where G_{sc} is solar constant (0.082 MJ $m^{-2}min^{-1}$), d_r is inverse relative distance Earth-Sun, ω_s is sunset hour angle, φ is latitude (rad) and δ is solar declination. These elements can be calculated using the following equations:

$$d_r = 1 + 0.033\cos\left(\frac{2\pi J}{365}\right), \quad (12)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right). \quad (13)$$

where J is the day of year.

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right] \quad (14)$$

S_0 can be estimated as

$$S_0 = \frac{24}{\pi}\omega_s. \quad (15)$$

C. Methods for comparison of global solar radiation models

Three statistical test methods are used to statistically evaluate the performance of the solar radiation models. These methods are mean bias error (*MBE*), root mean square error (*RMSE*) and Nash-Sutcliffe equation (*NSE*):

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(c_i - m_i) \quad (16)$$

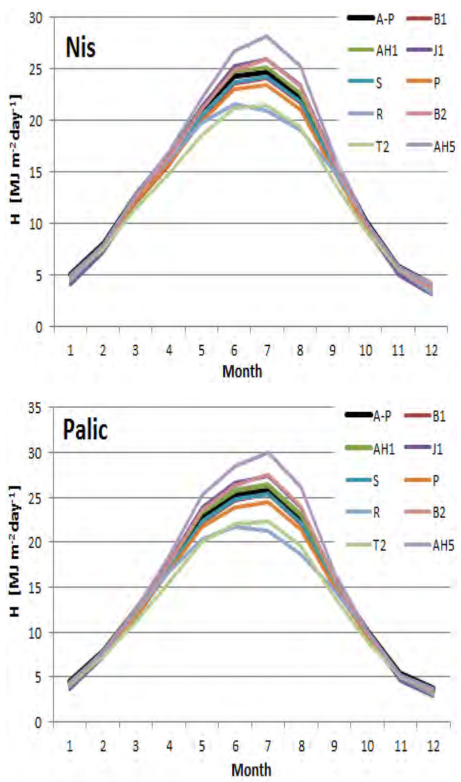
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - m_i)^2} \quad (17)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(m_i - c_i)^2}{\sum_{i=1}^{n}(m_i - m_a)^2} \quad (18)$$

where c_i is the ith calculated value, m_i is the ith measured value and m_a is the average of measured value.

III. Results And Discussion

Analysis of solar radiation is conducted as average value for each month during the period 1980-2010, on the territory of five meteorological stations in Serbia. Fig. 1 shows the values of global solar radiation for Nis, Palic, Negotin, Zlatibor and Vranje stations using the one parameter models: Angstrőm-Prescott model (A-P), Bahel et al. model 1 (B1), Almorox and Hontoria model 1 (AH1), Jin et al. model 1 (J1), Srivastava et al. model (S), Page model (P), Rietveld model (R), Bahel et al. model 2 (B2), Toğrul et al. model 2 (T2) and Almorox and Hontoria model 5 (AH5).



ISBN: 978-86-80593-54-8

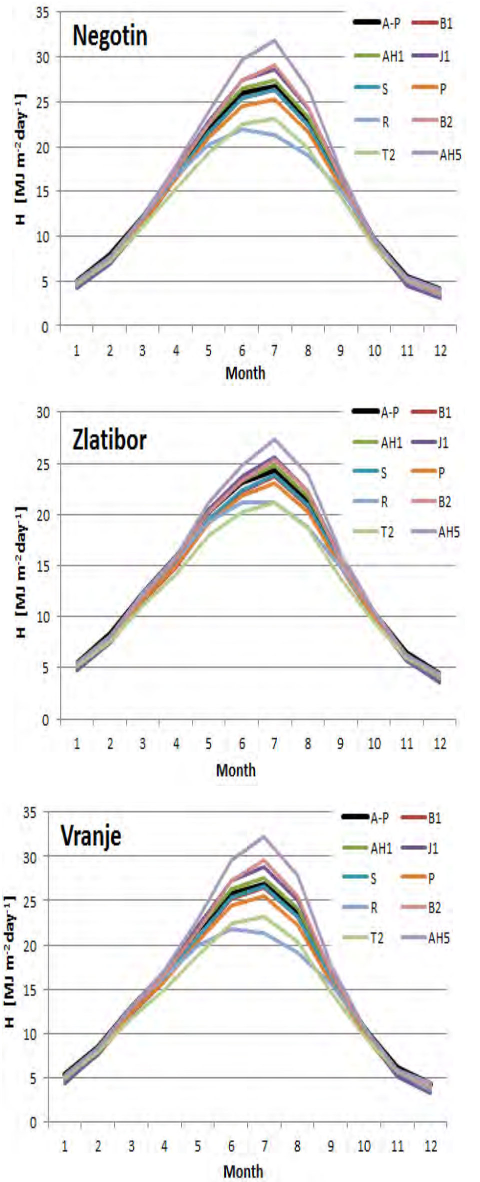


Figure 1. Solar radiation for Nis, Palic, Negotin, Zlatibor and Vranje stations

T2 and R models have the lowest values of solar radiation for all observed stations. AH5 has the greatest values of solar radiation in comparison to other methods for all observed stations. All observed models for all stations show that Zlatibor station had the lowest value of solar radiation, especially in April, May, June, July, August and September.

Vranje and Negotin have the greatest values of solar radiation.

A-P model represents the most reliable way for calculating the solar radiation [3]. For this reason A-P model is compared with other models as reference model, in order to find the model which is the most closely to it, which can be used as an alternative method. Table 2 shows the values of *MBE*, *RMSE* and *NSE* for observed stations.

MBE shows that AH1 model has the best matching with Angstrőm-Prescott model at three meteorological stations, B2 and J1 models have the best matching with AH1 model at Nis and Vranje stations. According to *RMSE*, AH1 model has the best matching with Angstrőm-Prescott model on all observed stations. The *RMSE* and *NSE* show that AH1 model has the best matching with Angstrőm-Prescott model for all stations, with almost perfect matching (0.999-0.998).

IV. Conclusion

Analysis of global solar radiation is conducted using ten one parameter models for five meteorological stations in Serbia over the period 1980-2010. The selected models are compared with Angstrőm-Prescott model using *MBE*, *RMSE* and *NSE*. Analysis shows that the maximum global solar radiation has the graetest values during June, July and August, while the minimum values are in December. The maximum values varies from 20.906 MJ $m^{-2}day^{-1}$ (Almorox and Hontoria model 5) at Zlatibor to 32.303 MJ $m^{-2}day^{-1}$ (Rietveld model) at Vranje station.

The following models Almorox and Hontoria model 1, Srivastava et al. model, Bahel et al. model 2, Bahel et al. model 1 and Jin et al. model 1 show the greatest coincidence with Angstrőm-Prescott model at all observed stations.

Further studies will be directed to analysis of trends in solar radiation and influence of different models of solar radiation on calculation of reference evapotranspiration.

ISBN: 978-86-80593-54-8

Table 2. Comparison of global solar radiation models with Angstrőm-Prescott model for observed stations

Station name	Statistical indicator	Bahel et al. model 1	Almorox Hontoria model 1	Jin et al. model 1	Srivastava et al. model
Nis	MBE	-0.782	0.843	-0.074	-0.566
	RMSE	0.792	0.281	0.843	0.571
	NSE	0.988	0.998	0.987	0.994
Palic	MBE	-0.663	0.117	0.171	-0.491
	RMSE	0.673	0.323	0.923	0.495
	NSE	0.993	0.998	0.986	0.996
Negotin	MBE	-0.712	0.095	0.096	-0.523
	RMSE	0.731	0.345	1.018	0.530
	NSE	0.992	0.998	0.984	0.996
Zlatibor	MBE	-0.793	0.030	-0.118	-0.572
	RMSE	0.804	0.234	0.706	0.580
	NSE	0.986	0.999	0.989	0.993
Vranje	MBE	-0.738	0.091	0.078	-0.541
	RMSE	0.761	0.347	1.029	0.550
	NSE	0.990	0.998	0.983	0.995
Station name	**Page model**	**Rietveld model**	**Bahel et al. model 2**	**Torgul et al. model 2**	**Almorox Hontoria model 5**
Nis	-0.795	-1.207	0.058	-1.570	0.878
	0.874	1.710	0.571	1.939	1.561
	0.986	0.945	0.994	0.930	0.954
Palic	-0.794	-1.497	0.283	-1.681	1.228
	0.886	2.155	0.792	2.077	2.016
	0.987	0.926	0.990	0.931	0.935
Negotin	-0.807	-1.598	0.312	-1.663	1.278
	0.898	2.359	0.976	2.090	2.222
	0.987	0.913	0.985	0.932	0.923
Zlatibor	-0.784	-0.932	-0.005	-1.550	0.661
	0.856	1.373	0.435	1.852	1.257
	0.984	0.959	0.996	0.926	0.966
Vranje	-0.825	-1.601	0.341	-1.670	1.286
	0.909	2.447	1.073	2.103	2.315
	0.986	0.902	0.981	0.927	0.912

ACKNOWLEDGEMENT

The research presented in the paper is funded by the Ministry of Education, Science and Technological Development, Republic of Serbia (Grant No. TR 37003).

REFERENCES

[1] D.L. Liu, B.J Scott, "Estimation of solar radiation in Australia from rainfall and temperature observations", Agr. and F. Meteo., vol. 106, 2001, pp. 41-59.

[2] M. Trnka, Z. Žalud, J. Eitzinger, M. Dubrovský, "Global solar radiation in Central European lowlands estimated by various empirical formulae", Agr. and F. Meteo., vol. 131, 2005, pp. 54-76.

[3] S. Trajković, "Metode proračuna potreba za vodom u navodnjavanju", Građevinsko-arhitektonski fakultet, Univerziteta u Nišu, 2009.

[4] W. Yao, Z. Li, Y. Wang, F. Jiang, L. Hu, "Evaluation of global solar radiation models for Shanghai, China", E. Conv. and Manage., vol. 84, 2014, pp.597-612.

[5] K.Ouali, R. Alkama, "A new Model of global solar radiation based on meteorological data in Bejaia City (Algeria)", The Int. Conf. on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES14, E. Procedia, vol. 50, 2014, pp. 670-676.

[6] A. Angstrom, "Solar and terrestrial radiation", Quart. J. Roy. Meteor. Soc., vol. 50, 1924, pp.121–126.

ISBN: 978-86-80593-54-8

[7] J.A. Prescott, “Evaporation from a water surface in relation to solar radiation”, Trans. Roy. Soc. Austr., vol. 64, 1940, pp.114–125.

[8] V. Bahel, R. Srinivasan, H. Bakhsh, “Solar radiation for Dhahran, Saudi Arabia”, Energy, vol. 11, 1986, pp. 985–989.

[9] J. Almorox, C. Hontoria, “Global solar radiation estimation using sunshine duration in Spain”, E. Conv. Manage, vol. 45, 2004, pp. 1529-1535.

[10] Z. Jin, W. Yezheng, Y Gang, “General formula for estimation of monthly average daily global solar radiation in China”, E. Conv. Manage, vol. 46, 2005, pp. 257-268.

[11] S.K. Srivastava, O.P. Singh, G.N. Pandey, “Estimation of global solar radiation in Uttar Pradesh (India) and comparison of some existing correlations”, S. Energy, vol. 51, 1993, pp. 27-29.

[12] J.K. Page, “The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sunshine records for latitudes 40N–40S”, Proceedings of UN conf. on new sources of energy, vol. 4. pp. 2003, 378–390.

[13] M.R. Rietveld, “A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine”, Agr. Meteorol., vol. 19, 1978, pp. 243–252.

[14] V. Bahel, H. Bakhsh, R. Srinivasan, “A correlation for estimation of global solar radiation”, Energy, vol. 12, 1987, pp. 131-135.

[15] Í.T. Toğrul, H. Toğrul, D. Evin, “Estimation of monthly global solar radiation from sunshine duration measurement in Elaziğ,” R. Energy, vol. 19, 2000, pp. 587-595.

ISBN: 978-86-80593-54-8

Influence of Different Types of Dust on PV Modules Energy Efficiency

Ivana Radonjić, Faculty of Sciences and Mathematics, Niš, Serbia, r_ivana_fizika@yahoo.com

Tomislav Pavlović, Faculty of Sciences and Mathematics, Niš, Serbia, pavlovic@pmf.ni.ac.rs

Dragana Milosavljević, Faculty of Sciences and Mathematics, Niš, Serbia, dragana82nis@yahoo.com

Dragoljub Mirjanić, Academy of Science and Arts, Banja Luka, Republic of Srpska, mirjanicd@gmail.com

Lana Pantić, Faculty of Sciences and Mathematics, Niš, Serbia, lana@pan.rs

Danica Piršl, University of Niš, Faculty of sport, Niš, Republic of Serbia, danicapirsl@gmail.com

Abstract-**Dust layers on the photovoltaic (PV) modules surface can significantly diminish quantity of solar energy which PV modules absorb. A word dust denotes an umbrella term for any particulate matter whose diameter is less than 500 µm. Dust composition is characteristic for certain locations and is different in different areas worldwide. This paper gives literature review on the worldwide research on the topic of the influence of dust types on the PV modules energy efficiency. Most of the research studies cited in the available literature are investigating artificial dust and just a few of them natural dust. Most influence on PV modules energy efficiency is exerted by limestone, ash, red soil (clay), calcium carbonate, silicon and sand. It can be concluded that all types of dust exert negative influence on PV modules characteristics (currency, voltage, power, efficiency). In the end a recommendation is given for an adequate cleaning and maintenance of PV modules depending on the climate and environmental conditions.**

Keywords: ***PV modules, energy efficiency, dust***

I. Introduction

The performances of PV modules are influenced by various factors such as the material from which the module is made, its angle of inclination (tilt angle), the intensity of solar radiation, soiling area of the module, its temperature, etc. Soiling is a term used to describe the accumulation of dirt (dust) on the solar modules, which reduces the amount of solar radiation that reaches the solar cells. Soiling of solar modules is often a problem in areas where there is no rain for the whole month [1].

The word dust is a general term for any particle of matter with a diameter less than 500 µm. The composition of the dust is characteristic for any particular location and varies in different areas of the world. Important characteristics of dust are the size and distribution of its particles, density, shape, chemical composition, etc. The important environmental conditions that can affect the performance and behavior of dust are air humidity, wind speed (change in

ISBN: 978-86-80593-54-8

direction, speed), etc. [2].

II. Literature Review

There is an ample worldwide research on the topic of the influence of dust on the PV modules energy efficiency. In these studies, there were used different types of dust such as carbon, cement, limestone, ash, red soil, calcium carbonate, silica, sand, sandy soil,

Table 1. An overview of some studies investigating the impact of dust on PV modules energy efficiency [3]

Authors	Year	Location	Type	Composition/name/chemistry
El-Shobokshy and Hussein [4]	1993	Saudi Arabia/indoor	Artificial	Fine dust (fine particles-size fractions less than 2.5 μm) and coarser dust (size fractions 2.5-15 μm)
El-Shobokshy and Hussein [5]	1993	Saudi Arabia/indoor	Artificial	The experimental dust was prepared from limestone rocks containing the minerals calcite and silica
H. Haeberlin [6]	1998	Switzerland	Natural	Biological plants (moss, lichen), Iron oxide, an organic components (Mg, Al, Si, P, S, K, Ca, Fe, Cu)
Asl-Soleimani [7]	2001	Iran/outdoor	Natural	Air pollution
Huey Pang [8]	2006	China/outdoor	Natural	General air pollution, refer to resource carbon-fuel based electricity-generation, factory and vehicle emissions
Kaldellis and A. Kokala [9]	2010	Greece/outdoor	Natural	Urban air pollution (densely populated)
Cabanillas and Manguía [10]	2011	Mexico	Natural	Natural dust in atmosphere
Shaharin A. Sulaiman [11]	2011	Malaysia/indoor	Artificial	Mud and talcum
Kaldellis and Kapsali [12]	2011	Greece/indoor	Artificial	Ash less 10 μm, Limestone less 60 micron, Red soil less 150 micron
Hai Jian [13]	2011	China/outdoor	Artificial	Test dust (ISO 12103-1 A2, Powder Technology Inc.) SiO_2 (68-76.9%), Al2O3 (10-15%), Fe_2O_3 (2-5%), Na_2O (2-4%), CaO (2-5%), MgO (1-2%), TiO_2 (0.5-1%), K_2O (2-5%)
Pavan et al. [14]	2011	Italy/outdoor	Natural	Sand soil
Kaldellis [15]	2011	Greece/indoor	Artificial	Red soil, limestone and carbonaceous fly-ash particles
Kaldellis and Fragos [16]	2011	Greece/indoor	Artificial	Ash
Md. Mizanur Rahman [17]	2012	Bangladesh/outdoor	Natural	Natural dust
Sanusi [18]	2012	Nigeria/outdoor	Natural	Harmattan dust (December, January and February)
E. Suresh Kumar [19]	2013	India/indoor	Artificial	Used clay and refer to natural dust chemical composition of natural dust which are basically SiO_2 and Al_2O_2
Abd Salam Al-Ammri [20]	2013	Iraq/outdoor	Natural	SiO_2, $CaCO_2$, Gibson ($CaSO_4{\cdot}2H_2O$), Dolomite ($CaMg(CO_3)_2$), Anorthite ($CaAl_2Si_2O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Ti, Cr, Mn, Fe and Cu
Hussein A. Kazem [21], [22]	2013	Oman/indoor	Artificial	Red soil, fly-ash, sand, calcium carbonate and silica

ISBN: 978-86-80593-54-8

clay, mud, talc, fine and coarser air borne dust, etc. Most of the research referred to in the literature focuses on the artificial dust, and just a few of them on the natural dust [3].

Table 1 gives an overview of some studies investigating the impact of dust on PV modules energy efficiency.

From the cited papers it can be concluded that the most influence on PV modules energy efficiency is exerted by limestone, ash, red soil (clay), calcium carbonate, silicon and sand [3].

El-Shobokshy and Hussein [5] were among the first to examine the effects of dust on the energy efficiency of PV systems. They conducted research in a controlled laboratory environment, in which the experimental parameters could be maintained, measured and repeated. The purpose of their study was to investigate the physical properties of dust particles accumulated on the surfaces of PV systems, and then to study the impact of dust on the PV modules performance degradation. They used three types of the 'laboratory-defined' dust which are often present in the atmosphere, such as limestone, cement and carbon. Limestone, which they used in their research, was divided into three groups according to the mean value of the diameter of its particles, those of 80 µm, 60 µm and 50 µm, respectively. They used cement due to its presence in building materials and in the air in the most populated areas. Cement also poses a problem in areas where it is produced. In this research, the cement particles with mean diameters of 10 µm were used. Carbon was used in the research because it is one of the main pollutants and is a product in most of the combustion processes. Mean particle diameter of carbon in this experiment was 5 µm. The laboratory experiment was carried out using 1000 W tungsten halogen lamps which gave the intensity of radiation of about 195 W/m^2 on the surface of the monocrystalline silicon modules [2].

Fig. 1 shows some of the results El-Shobokshy and Hussein obtained - short circuit current and output power for different sizes of dust particles (limestone, cement and carbon), depending on the density of the accumulated dust on the PV module surface [2].

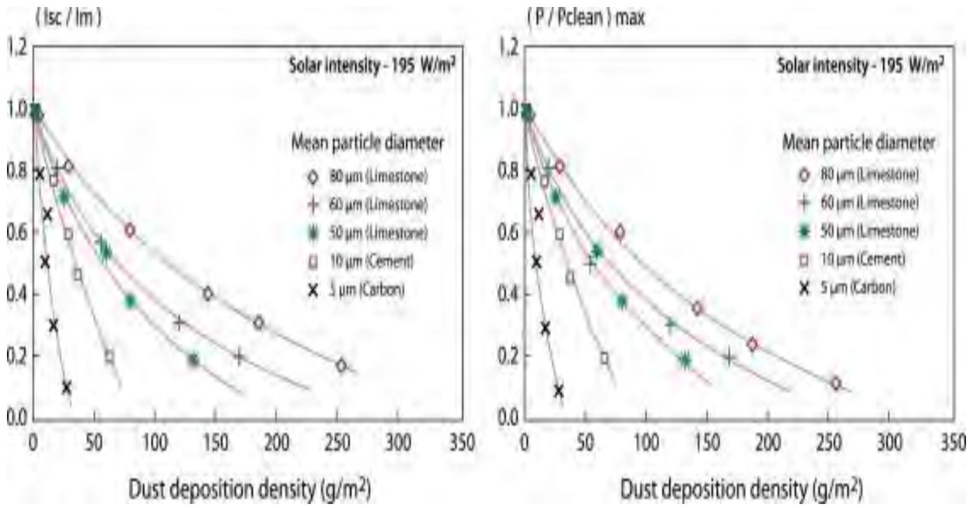


Figure 1. Short circuit current and output power for different sizes of dust particles (limestone, cement and carbon), depending on the density of the accumulated dust on the PV module surface [2]

ISBN: 978-86-80593-54-8

It can be concluded that a degradation of the PV module performance depends not only on the accumulation of dust, but also on the type of dust and a distribution of its particles size. Accumulating finer dust (dust particles of smaller size) on the surface of the PV module has a much greater negative impact on its performance than the accumulation of coarser dust (dust particles of larger size). Finer dust particles are distributed homogeneously (more uniformly) than the coarse dust particles so that the space between particles, through which light can pass in the finer dust is smaller than in the coarser ones. It was also noted that the type of dust affects the performance of PV modules. For example, carbon particles absorb solar radiation more easily than other types of dust (limestone, cement) [2].

III. PV Module Cleaning and Maintaining

To enable PV modules to always have better performance, it is necessary to clean them occasionally so as to remove the dust that deposits on their surfaces. There are general recommendations on the appropriate cleaning and maintenance of PV modules depending on the climatic and environmental conditions in which they are located.

In areas with a wet climate (average temperature of 20-34ºC, annual precipitation higher than 250 cm) it is recommended to operate a weekly cleaning of PV modules during dry spells which may be altered based on the intensity of dust accumulation. High annual precipitation could reduce dust accumulation (by periodic washing).

In areas with wet-dry tropical climate (temperature range 20-30ºC, annual precipitation higher than 150 cm) it is recommended to operate a weekly cleaning for moderate accumulation of dust and a daily basis cleaning in case of intense dust deposits.

In areas with a dry climate (temperature range 20-49ºC, annual precipitation of 15 cm) cleaning depends on the intensity of the accumulation of dust and a minimum of weekly cleaning is recommended. If there are dust storms it is necessary to immediately afterwards clean the PV modules. It is also recommended to use anti dust coatings.

In areas with a semi-arid climate (temperature range -4ºC-40ºC, annual precipitation less than 10 cm in dry regions to 50 cm in moist steppes) in areas with an arid climate with little rainfall and a high tilt angle, a moderate cleaning cycle (weekly) could be adequate. With lower tilt angle (to maximize solar gain) a more frequent cleaning cycle (depending on the dust intensity) might be beneficial.

In areas with a Mediterranean climate (temperature range 10-40ºC, annual precipitation 42 cm), it is recommended to perform the cleaning once during one or two weeks, depending on the pace of dust accumulation on the surfaces of PV modules, and in regions where the dust precipitates faster (proximity to industries) it would be good to clean the modules once a day.

In areas with the pastures (grassland) climate (temperature range -4ºC-22ºC, annual precipitation 81 cm) a less intense (weekly or biweekly) cleaning cycle might be adequate, and in the areas prone to higher dust (due to human activity) a weekly cleaning might be required.

In areas with taiga climate (temperature range -22ºC-16ºC, average annual precipitation 31 cm) a weekly cleaning is recommended, and snow deposits formed on the surfaces of PV modules, must be removed immediately.

In areas with tundra climate (temperature range -22ºC-6ºC, average annual precipitation 20 cm) a weekly cleaning is recommended, that adjusts depending on whether fine or coarse dust deposits are formed. If on the surfaces of PV modules layers of snow are formed they need to be removed immediately [23].

IV. Conclusion

Soiling is a term used to describe the accumulation of dirt (dust) on solar modules. The PV modules performance is influenced by various factors including the soiling of the modules area. Based on these findings it can

ISBN: 978-86-80593-54-8

be concluded that all types of dust adversely affect the performance of PV modules, but the greatest impact on their energy efficiency exerts limestone, ash, red soil (clay), calcium carbonate, silica and sand. Accumulating finer dust on the surface of PV modules has a much greater negative impact on their performance than the accumulation of the coarser dust. To enable PV modules to have always better performance it is necessary to provide for their occasional cleaning, and its pace depends on the climate conditions in which the modules are located. In areas with a wet, wet-dry, dry, semi-arid climate and in the areas with taiga and tundra climate it is recommended to provide for a weekly cleaning of PV modules. In areas with a Mediterranean climate, the cleaning can be performed once during one or two weeks, depending on the pace of the dust accumulation on the surfaces of PV modules. In case of intense dust deposits a daily cleaning of PV modules is recommended. In areas with pastures (grassland) climate a less intense (weekly or biweekly) cleaning cycle might be adequate, and in areas prone to higher dust (due to human activities) a weekly cleaning might be required. If there are dust storms or on the surfaces of PV modules layers of snow are formed it is necessary immediately thereafter to carry out their cleaning.

ACKNOWLEDGEMENT

This paper was done with the financial support of the project TR 33009 approved by the Ministry of Education and Science of the Republic of Serbia and the project 19/6-020/961-102-1/11 approved by the Ministry of Science and Technology of the Republic of Srpska.

REFERENCES

[1] J. Cano, "Photovoltaic Modules: Effect of Tilt Angle on Soiling", A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in Technology, Arizona State University, August 2011.

[2] T. Sarver, A. Al-Qaraghuli, L. L. Kazmerski, "A comprehensive review of the impact of the dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches", Renewable and Sustainable Energy Reviews, vol. 22, 2013, pp. 698-733.

[3] Z. A. Darwish, H. A. Kazem, K. Sopian, M. A. Al-Goul, H. Alawadhi, "Effect of dust pollutant type on photovoltaic performance", Renewable and Sustainable Energy Reviews, vol. 41, 2015, pp. 735-744.

[4] M. S. El-Shobokshy, F. M. Hussein, "Degradation of photovoltaic cell performance due to dust deposition on to its surface", Renewable Energy, vol. 3, 1993, pp. 585–590.

[5] M. S. El-Shobokshy, F. M. Hussein, "Effect of dust with different physical properties on the performance of photovoltaic cells", Solar Energy, vol. 51, 1993, pp. 505–511.

[6] H. Haeberlin, J. Graf, "Gradual reduction of PV generator yield due to pollution", In: Proceedings of the 2nd world conference on photovoltaic solar energy conversion, Vienna, Austria, vol. 1200, 1998, pp. 1400.

[7] E. Asl-Soleimani, S. Farhangi, M. Zabihi, "The effect of tilt angle, air pollution on performance of photovoltaic systems in Tehran", Renewable Energy vol. 24, 2001, pp. 459–468.

[8] H. Pang, J. Close, K-h. Lam, "Study on effect of urban pollution to performance of commercial copper indium diselenide modules", In: Conference record of the 2006 IEEE, 4th world conference on photovoltaic energy conversion, 2006, pp. 2195–2198.

[9] J. Kaldellis, A. Kokala, "Quantifying the decrease of the photovoltaic panels' energy yield due to phenomena of natural air pollution disposal", Energy, vol. 35, 2010, pp. 4862–4869.

[10] R. Cabanillas, H. Munguía, "Dust accumulation effect on efficiency of Si photovoltaic modules", Journal of Renewable and Sustainable Energy, vol. 3, 2011, 043114.

[11] S. A. Sulaiman, H. H. Hussain, N. S. H. N. Leh, M. S. I. Razali, "Effects of dust on the performance of PV panels", World Academy of Science, Engineering and Technology, vol. 5, 2011, pp. 588–593.

[12] J. Kaldellis, M. Kapsali, "Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements", Energy, vol. 36, 2011, pp. 5154–5161.

[13] H. Jiang, L. Lu, K. Sun, "Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules", Atmospheric Environment, vol. 45, 2011, pp. 4299–4304.

[14] A. Massi Pavan, A. Mellit, D. De Pieri, "The effect of soiling on energy production for large-scale photovoltaic plants", Solar Energy, vol. 85, 2011, pp. 1128–1136.

[15] J. Kaldellis, P. Fragos, M. Kapsali, "Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations", Renewable Energy, vol. 36, 2011, pp. 2717–2724.

[16] J. Kaldellis, P. Fragos, "Ash deposition impact on the energy performance of photovoltaic generators", Journal of Cleaner Production, vol.

ISBN: 978-86-80593-54-8

19, 2011, pp. 311–317.

[17] M. Rahman, A. Islam, A. Zadidul Karim, A. H. Ronee, "Effects of natural dust on the performance of PV panels in Bangladesh", International Journal of Modern Education and Computer Science, vol. 4, 2012, pp. 26–32.

[18] Y. Sanusi, "The performance of amorphous silicon PV system under Harmattan dust conditions in a tropical area", Pacific Journal of Science and Technology, vol. 13, 2012.

[19] E. S. Kumar, B. Sarkar, D. Behera, "Soiling and dust impact on the efficiency and the maximum power point in the photovoltaic modules", International Journal of Engineering Sciences and Research Technology, 2013.

[20] A. Al-Ammri, A. Ghazi, F. Mustafa, "Dust effects on the performance of PV street light in Baghdad city", Proceedings of the international renewable and sustainable energy conference (IRSEC) 2013, pp. 18–22.

[21] H. A. Kazem, S. Al-Bahri, Al-Badi Saud, Al-Mahkladi Haifa, H. A. Al-Waeli Ali, "Effect of dust on photovoltaic performance", In: Proceedings of the international conference on frontiers of mechanical engineering, materials and energy, 2012. pp. 1–4.

[22] T. Khatib et al., "Effect of dust deposition on the performance of multi-crystalline photovoltaic modules based on experimental measurements", International Journal of Renewable Energy Research, vol. 3, 2013, pp. 850–853.

[23] M. Mani, R. Pillai, "Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations", Renewable and Sustainable Energy Reviews, vol. 14, 2010, pp. 3124-3131.

ISBN: 978-86-80593-54-8

The Advantages of the Linear Prognosis than Peak Load Limiter in Manufacturing Plant*

Zoran Jovanović, Faculty of Electronic Engineering, Niš, Serbia, zoran.jovanovic@elfak.ni.ac.rs

Marko Milošević, R&D Center ALFATEC, Niš, Serbia, marko.milosevic@alfatec.rs

Danijela Stajić, Secondary School of Electrical Engineering "Nikola Tesla", Niš, Serbia, danijelastajic@yahoo.com

Abstract — **Peak power optimization of the electric energy consumption with linear prediction advantages over the peak load limiter is presented in this paper. We can conclude that in case of peak load limiter usage, energy consumption is extremely reduced, which results in lower productivity and in cases where the limit was exceeded limiter cut power to the greater part of the facility and that is inadmissible in most technological processes. In case of linear prediction usage, continuous calculation of peak power is performed and in accordance with defined peak load, facility work is corrected by power off and power on particular machines, in accordance with the priorities assigned to them.**

Keywords: ***peak power, peak load, limiter, linear prediction***

I. Introduction

Optimal electric energy consumption management is an extremely complex task. However, beside complex theoretical considerations, practical implementation also represents a serious challenge in terms of very complex conditions that occur in different facilities [1]. The first and basic requirement in the implementation of such systems is to do not change existing technological process. Second requirement, that is difficult to fulfill, is that this system can be applied to different types of electrical power consumers and has the possibility of universal application in tasks of power consumption optimal control. Due to the nature of the problem, it is difficult to design and implement a system that could be applied universally in different facilities. In order to create optimal solution for this problem [2], first of all, it is important to answer several questions to get desired information about the facility in which system will be implemented.

This questionnaire contains the following items:

1. What is the total energy consumption (kWh or MWh) of facility in which the system for optimal power consumption is planned to be implemented?

2. What is the peak power, read from maxi graph in the facility plant during the month and throughout the year?

3. Provide bills for the energy consumption in the previous (at least one year) period.

4. In order to achieve optimal energy consumption management, consumers (machines) in the facility need to be divided into groups with different priorities.

5. The most appropriate is to have the following groups:

A - The group of consumers (machines) that can be turned off without notification

*The program committee decided to include this paper in the Proceedings even its reviews arrived after obtaining the ISBN.

ISBN: 978-86-80593-54-8

(for example, heat consumers for heating systems with high thermal inertia).

B - Consumer group that can be turned off after the notification.

C - Consumer group that can be turned off with time delay (extruders, presses, systems for casting).

D - Consumer group with electrical load that can be reduced.

E - Consumer group that can be turned off with previous announcement, only in special conditions.

F - Consumer group that can never be turned off.

If the user can't propose a list of consumers (machines) in the facility and specify which priority group (A-F) belong the individual consumer, professional help can be requested from persons who design and implement systems for optimal energy efficiency [3]. Also, it is very important that consumer that need to be managed is consider in the context of whole factory and do not stand out as an independent unit [4].

To achieve the lowest possible power load during the operation, different devices are used, from the simplest limiter to the sophisticated devices with a strong software support. One of the simplest ways to achieve this is to use the maximum controller. Using the appropriate switching contacts, these controllers can be adjusted so that in critical measurement intervals, or when there is a risk of exceeding adjusted maximum, signaling devices are being activating. Upon receiving the sign still has plenty of time to take measures, such as the turning of some of the consumers (machines).

In some cases, stepping switch can be installed to automatically turn off and turn on certain consumers.

In the selection of these devices, requirements of the facility should be considered and even more it should be considered the consumer turn off order. Power relay belongs to a simple device group used for this purpose. A disadvantage of this relay is that he reacts on any value off delivered power that is above of the adjusted value, so it can often too early fire an alarm signal or turn off consumer. It is found that even without the technical relays, peak power can be reduced in the facility, where it depends on the discipline of the workers and staff. In a well-organized company, one of the measures is using of programed turning on, where larger consumers go into operation while less power load, or with a certain "time delay". Measuring group in the facility where there is a maxigraph must have a pulse output, so only that way the control device can be synchronized with maxigraph and on the basis of the data gathered from maxigraph, can execute appropriate control algorithm [5].

II. PEAK LOAD MANAGEMENT PROBLEM

The first systems that have been used in solving the problem of optimal power management, have been working using the limiter principle. This type of device is used to limit used fifteen-minute energy in the facility, while depending on the technological process power limit is set up by an authorized person. The set demand (electric load) is compared to the value of the facility demand and if facility demand fifteen-minute energy is smaller than the demand set value, limiter would not react otherwise it would turn off some of the machines in facility [6]. The disadvantage of this device is that when the facility is using fifteen-minute energy that is close to a set value, and this is most often case, large number of stops and starts is possible. This operation mode leads to stroke due to switching, which reduces the life of equipment and machines in operation.

Another big problem is that, this way, the facility is limited in terms of production, since limiter in some cases may turn off the vital parts of the facility and thereby jeopardize the production plan execution. As we can see, using limiters in dynamic facilities has resulted in more harm than good.

In some static facilities where there are not rapid changes in the production process, it can make sense to use the limiter to reduce engaged fifteen-minute energy, but the

ISBN: 978-86-80593-54-8

number of these facilities is relatively small. It was obvious that a new solution is needed in order to increase cost-effectiveness [7].

After the limiters, in terms of new solution for this problem, development of more flexible regulator of fifteen-minute energy has started. The first step was taken when forming of machines groups with particular priority has started. Only with this change, limiters improved their efficiency in production and economic performance has been increased.

However, this solution did not satisfy the growing appetites in terms of productivity and development of a new generation of systems for optimizing the power consumption has started, which are based on the power consumption forecast and regulation of fifteen-minute energy, in order to avoid negative characteristics from previous generations of regulators.

The next step was a linear prediction of electric energy consumption [8]. Using mathematical expressions can be described part of the algorithm for systems with linear prediction for optimal power management:

$$E(t) = \frac{E(T) - E(t_k)}{T - t_k} t + E(t_k), \qquad (1)$$

where:

$E(t_k)$ is facility energy at the time t_k,

$E(t)$ - Facility energy current value and

$E(T)$ - Facility required fifteen-minute energy.

This way calculated, energy current value must be less than in each interval of calculation, for algorithm to provide a facility operation within the given parameters. Compared to its predecessors this solution was a big step forward [9, 10].

III. EXAMPLE

Using SCADA program an analysis of the facility in which the management of peak load in the first case is realized using limiters and in the second case, using linear prediction.

The facility consists of 10 machines divided into 4 priority groups. Three machines with the highest priority with power 20.5, 10, 5.3 kW and they can be shut down only when it receives confirmation after the notification. In next, lower priority group there are two machines power 2.9, 3.6 kW and they are turned off with specific time delays.

Machines in next group can be turned off with notification, without operator confirmation and there are three of them with the power of 4.8, 3.2 and 2.5 kW.

And at the end there are two machines that can be switched off without notification, with power of 2 and 1.6 kW.

If we look at the power consumption chart with limiter, as a device for peak load control (Figure 1), it can be noticed that this algorithm has a significant error in terms of achieving the set fifteen-minute energy, more precisely, the current consumption is at most fifteen-minute intervals below the set value.

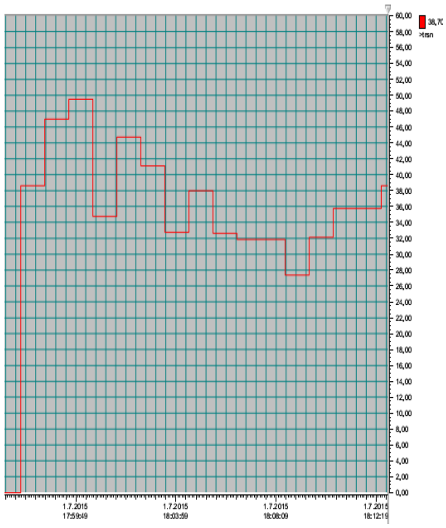


Figure 1. Diagram of current power cosumption in facility with limiters

Diagrams of electrical energy consumption are recorded using the option „Data Log Viewer“. Figure 2 shows that the fifteen-minute energy set value is 10 kWh. At the end of the interval achieved energy consumption is 8.55 kWh, which represents

ISBN: 978-86-80593-54-8

a 14.5% error. This error in energy represents 1.45 kWh per 15 minutes interval.

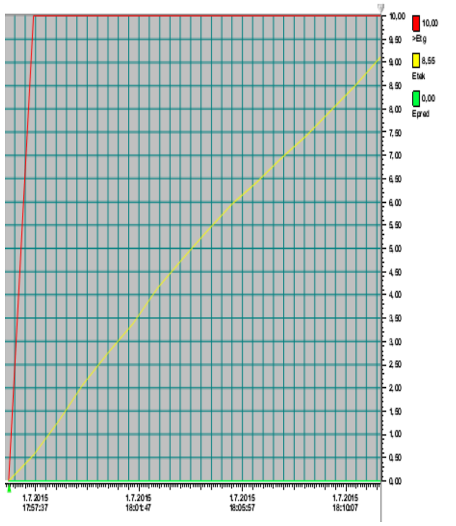


Figure 2. Electrical energy consumption chart at facility with the limiters

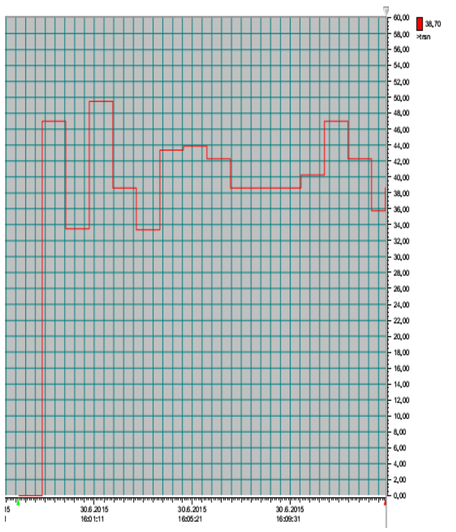


Figure 3. Diagram of current power cosumption in facility with linear prediction

The following classical algorithm is using linear prediction which is far more advanced than previously shown, with more accuracy which can be seen on the basis of the results shown on diagrams (Figures 3 and 4).

A similar analysis can be done in this case. Figure 4 shows that the set value for the fifteen-minute energy is 10 kWh.

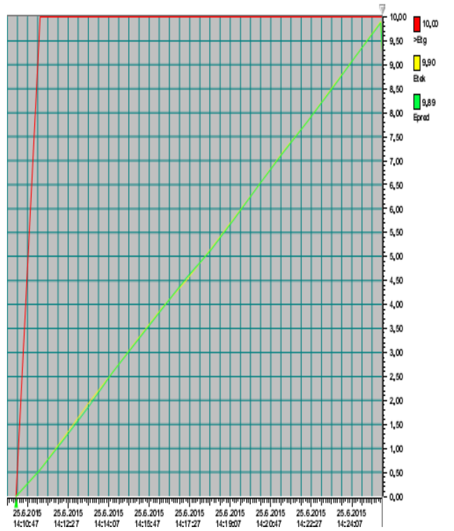


Figure 4. Diagram of energy consumption in facility using linear prediction for optimal electrical energy consumption

At the end of the interval energy consumption is 9.9 kWh, which represents a 1% error. This means that the error was 0.1 kWh per 15 minutes interval.

IV. CONCLUSION

In this paper, the advantage of systems with linear prediction in manufacturing facilities, compared to systems with limiters is shown on practical example. By approximately same working conditions at the facility, linear predictor based on the information from maxi graph controls the work of individual machines in accordance with assigned priorities and strengths and tries to reach the set fifteen-minute value of peak power, and limiter has no control function, it only limits the consumption by turning off some of machines to prevent exceeding the set value for fifteen-minute energy. The system with linear predictor, during the execution of the control algorithm, beside turning off also manage the turning on of some machines in facility, as a limiter is unable to do so. A more detailed analysis shown that the losses, due to lower

ISBN: 978-86-80593-54-8

productivity, are largest at the facilities with limiters. Systems with linear prediction have far higher productivity.

REFERENCES

[1] M. Jevtić, Z. D. Jovanović, "Mikroprocesorski sistem za optimizaciju utroška električne energije", Zbornik radova JUREMA 36 Zagreb Tuheljske Toplice, 2. svezak, pp. 1.123-1.125, 1991.

[2] Jovanović, Z.D., Danković, B.M., "Simulacija sistema za optimizaciju utroška električne energije", Zbornik radova JUREMA 36 Zagreb - Tuheljske Toplice, 2.svezak, p.p. 1.84-1.87, 1991.

[3] Jovanović, Z.D., "Optimalno upravljanje potrošnjom električne energije", magistarska teza, Elektronski fakultet u Nišu, 1992.

[4] Zoran Jovanović, Dragan Antić, Staniša Perić, Saša Nikolić, "Multistage fuzzy optimization of the peak power", Facta Universitatis, Series: Automatic Control and Robotics Vol. 8, No 1, 2009, pp. 99 – 110.

[5] Danković, B.M., Jovanović, D.Z. and Antić, D., "Peak Power Optimization Based On Nonlinear Prediction And Fuzzy Logic", Facta Universitatis, Series Elec. Energ., Vol. 18, No. 3, December 2005, pp. 431-437.

[6] Jovanović, Z.D., Optimizacija potrošnje električne energije primenom prediktivnog upravljanja i fazi logike", doktorska disertacija, Elektronski fakultet u Nišu, 2006.

[7] Fouad Al-Mansour, Boris Sučić, Matevž Pušnik, a linear programming approach for production planning optimisation and peak load management in industrial companies, 7th International Conference on Sustainable Energy & Environmental Protection (seep2014), At DUBAI - UAE, Volume: ISBN-978-903978-49-8.

[8] Fishbone L.G., Abilock H. MARKAL, a linear-programming model for energy system analysis: Technical description of the BNL version. Int. Journal of Energy Research 1981, vol. 5, no. 4, p. 353-375.

[9] Valdma M, Keel M, Liik O, Tammoja H. Method for Minimax Optimization of Power System Operation. Proc. of IEEE Bologna PowerTech 2003, 23-26 June 2003, Bologna, Italy. Paper 252: p. 1-6.

[10] O. Liik∗ , M. Valdma, M. Keel, H. Tammoja, Optimization of electricity production capacity under uncertainty, Tallinn University of Technology, 5 Ehitajate tee, Tallinn 19086, Estonia

ISBN: 978-86-80593-54-8

AUTHOR INDEX

R&DC Alfatec was founded in November 2005, with the purpose of enabling placement of innovative products and services developed by a group of researchers, who have worked as a part of the Section of Electric Machinery, at the Department of Energetics of the Faculty of Electronics in Nis.

R&DC Alfatec, upon being founded, worked in the field of measurement and control systems, where it has developed a substantial number of innovative products for the needs of various users.

In February 2008, R&DC Alfatec became registered as a research and development centre by the Ministry of Science and Technological Development of the Republic of Serbia.

R&DC Alfatec is currently the leader in:

- the number of realised innovative products and services which are successfully administered on the market of Serbia;
- the diversity of realised projects;
- the projecting and realisation of complex measurement and information systems, as well as measurement and control systems;
- savings of electric energy achieved by various users;
- innovative investment models for electric energy consumption reduction in small and medium-sized enterprises;
- software for decision support in emergency situations;
- design of electrical installations according to international standards.