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HYBRID SYSTEMS BASED ON THE SOLAR AND WIND POTENTIAL IN THE BANJA LUKA REGION

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Abstract. Production of energy from the system with distributed energy resources takes place close to consumers, and, due to the absence of transmission losses and high thermal efficiency, their overall efficiency is higher than in centralized systems. This paper considers dual hybrid systems for the electricity production, based on wind and solar potential in the Banja Luka region. Each location has its own specifics, related to the availability of certain types of energy (wind and solar radiation), and the input data on their intensity and the distribution in the selected area is a key factor in the implementation of the optimization process. Wind and solar radiation, as sources of energy, have a stochastic character. The stochasticity manifests itself at all levels: daily, monthly, seasonally and yearly level. Solar energy is, assuming favourable weather conditions, available only from sunrise to sunset, depending on seasonal changes in the Earth's orbit around the Sun. Wind energy is available to a greater extent, but its intensity is relatively low in the Banja Luka region. For the utilization of wind energy in remote rural areas, it is important to know its spatial circulation, which is affected by local conditions (temperature air and ground, as well as the existence of natural obstacles on the considered macro and micro - location). The optimization process as well as performed economic and financial analysis, with the initial assumptions, confirmed the feasibility of the construction of hybrid systems based on wind and solar energy.

Keywords: Data Analysis, hybrid systems, solar potential, wind potential, Banja Luka region

AMS Subject Classification: 62-07 Data analysis.

1. Introduction and methodology

Increased needs for cheap and "clean" energy points to the need to introduce modern technologies of combustion of fossil fuels (State of the Art), renewable energy, and the introduction of savings in production and consumption, including implementation of energy efficiency. One of the ways of including renewable energy sources is the construction of small systems for power generation that satisfy energy needs of small consumers. In this context, one can consider small communities located far away from the transmission and distribution network, as well as entities which have their own system for the production of energy from renewable sources, and which have the option of connecting to the distribution network with two-way flow of energy. In areas where the electric grid is unavailable, autonomous hybrid systems are often viable alternatives, including systems based on the use of solar and wind energy. The complementary availability of these two sources helps solving the issue of restrictions on their individual availability. The intensity of solar radiation is always greater during the summer months, while in the winter, wind energy can significantly contribute to the stability of electricity supply from the system (the intensity of the winds are often stronger in winter compared to summer). In the context of reducing harmful effects on the environment and climate change and the possibility of depletion of fossil fuels reserves, renewable energy is being promoted as an important factor in energy supply. In the same time, because of their pronounced stochastic nature or unequal distribution, they do not represent a source that guarantees security of supply. To improve the security of supply, renewable sources are often combined with other technologies, among others, the technologies for combined heat and power generation (Combined Heating and Power - CHP Systems) or (Combined Cooling, Heating and Power Systems – CCHP Systems), when heat from a cogeneration process is used for cooling by using cooling devices. Complex systems, in which energy is produced from a number of different sources of energy, are in the professional and scientific literature known as systems with distributed energy resources (Distributed Energy Resources Systems - DER Systems or Multi Energy Systems - MES), and often as hybrid systems (e.g. Hybrid Photovoltaic - Trigeneration Systems, Hybrid Photovoltaic - Cogeneration Systems, etc.). Production of energy from the system with distributed energy resources takes place close to consumers, and, due to the absence of transmission losses and high thermal efficiency, their overall efficiency is higher than in centralized systems. This paper considers dual hybrid systems for the electricity production, based on wind and solar potential in the Banja Luka region. For the purpose of the optimization, an algorithm for evaluating small power generating systems, either autonomous or grid-connected, with abetment for renewable energy sources usage, has been developed. Performed optimization, realized on the basis of an iterative model, and utilising the specially defined algorithm, has provided a good starting point for establishing guidelines for the development of similar projects, along with the order of magnitude of the required investment. Each location has its own specificities regarding the availability of certain types of energy (wind and solar), so the data concerning their intensities and presence on chosen locations represent the key factor and a starting point for the optimization. The developed model for predictive analysis of availability of wind and solar energy, together with the iterative method for optimization, are of general character. They are applicable for any region with available basic meteorological data. The results of the optimization provide a basis for determining the optimal combinations of hybrid systems with the lowest price of generated energy.

2. The overview of research to date

Hybrid power systems consist of two or more power sources, control system, and equipment for the storage of excess energy. The use of wind and solar energy to generate electricity for households has several advantages, one of which should be noted in particular is their economic appeal as an energy source (free) and also availability, sustainability and clear ecological advantage (do not pollute the environment, reduce greenhouse gas emissions - GHG). Wind and solar radiation, as sources of energy, have a stochastic character. The stochasticity manifests itself at all levels: daily, monthly, seasonally and yearly level. Solar energy is, assuming favourable weather conditions, available only from sunrise to sunset, depending on seasonal changes in the Earth's orbit around the Sun. Wind energy is available to a greater extent, but its intensity is relatively low in the Banja Luka region. For the utilization of wind energy in remote rural areas, it is important to know its spatial circulation, which is affected by local conditions (temperature air and ground, as well as the existence of natural obstacles on the considered macro and micro - location). For an isolated autonomous hybrid system to produce energy sustainably, from technical and technological aspects, apart from devices that convert wind and solar energy into electricity, required are devices for short-term accumulation of electrical energy and for the transformation of electricity from DC to AC. Storage batteries for hybrid systems are designed in a way that enables optimum utilization of the produced energy of each of the components of the hybrid system. Also, the energy produced should meet the needs of consumers. The currency of this optimization has been confirmed through a number of published articles. A review of researches on the current status and the participation of the different energy resources and the benefits of decentralized systems based on renewable energy, is given in the works of *Bazmi, A.A. & Zahedi, G., 2011.* It was pointed out that modern power systems have to meet a number of important objectives, including environmental, economic and social goals of sustainable development. In this context, technologies based on renewable resources have great potential for the development of the energy sector. Also, the authors state about three hundred relevant papers on this topic, including research studies on potential and effects of renewable energy, process modelling, optimization and simulation. The numerous analyses of the potential of solar and wind energy, which are already mentioned in the introduction, differ in what locations were selected for study, as well as in the model of optimization (different starting criteria). Methodologies for evaluation of systems with distributed energy resources can have a qualitative nature, but in most cases, quantitative metrics is critical for performing analyses and formulation of the optimization problem (*Mancarella, P., 2014*). In this context, several software tools were mentioned, such as RETScreen, EnergyPLAN, DER-CAM and others. While researching the possibilities of application of hybrid systems with renewable energy sources, *Zhou et al. (Zhou, W., Lou, C., Li Y, Lu, L. & Yang, H., 2010)*, as a possible optimization criteria of hybrid systems, stated the criterion of analysis of energy availability and a number of economic criteria. In the context of the optimal design of components of hybrid systems with renewable energy sources, it was pointed to the possible application of software solutions such as HOMER, HYBRID2, HOGA and HYBRIDS, as well as to the possibility of applying various optimization techniques, among which, for identifying global minimums, are most effective techniques of artificial intelligence. *Lu et al. (Lu, H., Yu, Z., Alanne, K., Zhang, L. Fan, L., Xu, X. &*

Martinac, I., 2014) base the optimization of hybrid systems on two criteria - the maximum exergetic efficiency (EE) and the minimum life cycle cost (LCC). The criterion of minimum life cycle cost is one of the economic optimization criteria, while the concept of maximum exergy efficiency is based on the fact that exergy represents both qualitative and quantitative measure of energy. Exergy is a measure of maximum possible work that can be extracted from a system by bringing it to equilibrium with the reference environment. This method of optimization was applied on a case study, where an optimization was conducted of a system for energy supply for a business complex in China. Depending on to the thermodynamic cycle applied within the plant, different ratios between produced electricity and heat can be obtained, and, in the context of supplying a certain type of consumer, the criteria of selecting the optimal thermodynamic cycle can be the subject of optimization. Thus, *Nema P. et al.* provided within reference [8] overview of the design, operation and management of autonomous hybrid solar-wind energy systems by 2009, with proposed directions for further development of autonomous (island mode operation) as well as grid-connected systems (exchange of electricity with the relevant distribution companies). Similar systems that have been built, as well as results of analyses published in prestigious journals, have shown that such a system should have at least one-day's worth of energy stored in its rechargeable batteries, Figure 1. Designs that incorporate greater autonomy (over three days) based on batteries are questionable from an economic point of view. Knowledge about the spatial position of the object, its energy needs on a daily basis, as well as the types of consumers in the object, and the ways and timing of its use, require that, in addition to the typical approach in the design, additional information relevant to a specific location be taken into account. This can prolong the project and increase the initial investment, but it can result in an optimal and quality system and more satisfying user. *Arribas, L. et al.* propose a new approach in terms of measuring and collecting data necessary for the analysis of hybrid solar-wind energy systems, [9]. During the project CICLOPS, for micro hybrid system with photovoltaic power of 5 kW and wind power of 7.5 kW (installed on site Corna, Spain), standard IEC 61724 was used for systems that contain a wind component. Results of one-year long monitoring of the system provided estimates for the initial characteristics of certain parts of the system.

One of the biggest advantages of using a combination of solar and wind energy via installation of autonomous hybrid systems, as compared to their individual use, is greater availability of such systems, which is especially important in the absence of one of the sources (sources are stochastic in nature) or in case of a failure of one of the system components. Necessary financial investment in autonomous hybrid systems at the start, is a major outlay for future users However, these investments should be seen in the context of the reasons for their installation, which, for autonomous systems, are mainly related to the lack of a distribution network or remoteness of the site. The fact that the price of electricity produced by these systems, for an extended period of time, remains practically insensitive to changes in the market (until the moment when the replacement of some of its components is required), also gives them a significant advantage. As described in reference [10], *Celik A.N.* provides different results of the systems' technical and economic analysis by varying designs, and simultaneously taking in account the degree of independence and the cost of the system operation. In doing so, the analysis for the worst month of the year is taken as a reference. The result of the analysis justifies increase of the number of energy sources, instead of increase of the capacity of existing systems. An analysis of the viability of hybrid solar-wind systems for rural places was given by *Dihrab S.S. et al*. in reference [11], with emphasis on the selection of micro-location with the best potential for generating solar and wind energy. *Bakić V. V. et al*. analyse integrated typical hybrid photovoltaic (PV)-wind energy system using the method of dynamic simulation for a typical meteorological year for the city of Belgrade, Serbia, [12]. Using commercially available software package TRANSYS 16, an assessment of generated energy from PV-wind household systems was conducted, as well as an estimate of the reduced CO_2 emission by using such systems. As a subject of further research, the authors suggest consideration of a combined system with hydrogen H_2 storage, which would be used for generating electricity in unfavourable weather conditions. Such an analysis would include the daily fluctuations during each month in the year. The research related to the study of the performance of cogeneration plants (*Kanoglu, M. & Dincer, I., 2009*) showed that the exergy analysis is a useful tool in assessing the performance of cogeneration systems and it allows the rational use of different cogeneration systems in relation to their efficiency, [13]. Through the research conducted in the Ransberg region in Belgium (*Swolfs, S. & Haeseldonckx, D., 2012*), a techno-economic optimization model of autonomous hybrid systems was presented, based on the application of a system for combined heat and power generation, consisting of photovoltaic panels and wind turbines, [14]. Based on meteorological data, economic parameters and the known needs for heat and electricity, by using MATLAB and GAMS software packages, the process was modelled, and after a series of iterative procedures, the optimal configuration was identified (using linear programming of the objective function). In doing so, they minimized the total life cycle cost. A similar example of optimization is presented for the area of Athens, Greece, (*Mehleri, E.D., Sarimveis, H. & Markatos, N.C., 2013*), which analyses a grid-connected hybrid system based on the use of a plant for combined heat and power generation and photovoltaic panels, [15]. For this optimisation, the objective function was based on determining the minimum total cost of the energy system. Analysed are three scenarios for the supply of residential sector with heat and electricity (conventional method of supply, supply via a CHP system with a capacity to satisfy demand for heating and a concept of energy supply via PV-CHP systems). According to the results of the performed optimization, the best effects, in terms of economics, are associated with the PV-CHP system. This system also showed superior performance in terms of reducing CO_2 emissions. Among a number of other researches, we would like to point out to a comparative analysis of the systems based on PV-cogeneration and PV-trigeneration, both analysed under the conditions of the same geographical area (*Nosrat, A.H., Swan, L.G. & Peace, J.M., 2013*), [16]. The study applied photovoltaic-trigeneration optimization model (PVTOM), based on genetic algorithm (GA). The results of the simulation and optimization has shown that photovoltaic- trigeneration system, in its optimal configuration, has better performance in terms of energy efficiency, compared to the photovoltaic-cogeneration system, as well as better performance in terms of reducing CO_2 emission. The research related to the optimization of the energy supply system for a hospital in Japan (*Kayo, G. & Ooka, R., 2009*), with application of the Multi-Objective Genetic Algorithm (MOGA) technique, pointed to the possibility of optimizing the structure of the devices used for the building's energy supply (heating, cooling, hot water and electricity), [17]. Taking in account the performance of each of the devices, their prices and actual energy needs, an optimal structure was selected based on the criteria of minimum energy consumption and energy costs. Adopting the concept of combined heat and electricity production within a hybrid system, opens up more alternative options in terms what technology and which thermodynamic cycle within the plant can be applied. Several types of such plants are described within the following references, listed in the appendix: *Petrovic, P., Milovanovic, Z., Milanović, D., Knezevic. D., Kotur, M., Tica, G. and Papuga, S. (2009), Loncar, D., Krajačić, G. and Vujanovic, M., (2009), Ebrahimi, M. & Kashavarz, A. (2015)*, [18÷23]. As a part of the proposed topic, particular attention will be placed on analysis of plants with a nominal capacity of up to 100 kWe. Therefore, the focus of interest is on Stirling machines and plants that utilise Organic Rankin cycle powered by biomass.

The analysis of papers relevant to this research pointed to a wide range of possibilities for the research in the field of optimization of the systems with distributed energy resources, and to the possibilities of applying various optimisation techniques. Modelling of these systems, in addition to application of theoretical knowledge and its mathematical interpretation, implies the need to analyse behaviour of the environment in which the system is located. It is evident that a large number of research papers is related to a specific geographical area, so it is important to perform similar studies for the Republic of Srpska. As a part of the proposed topic, the interaction between buildings and the surrounding will be analysed. This subject, relating to the Banja Luka region, has been investigated, within the doctoral theses listed in the references (*Đuričković V., 1984 and Tica G., 2009*), [19, 20]. Researches related to the potential of solar and wind energy in this area were also conducted to some extent. Among others, it is worth mentioning research [5] (*Dumonjić-Milovanovic S. and Gvero, P. 2013*), which included predictions of solar radiation and wind phenomena in the Banja Luka region and which analysed possibilities for integration of these two resources in a hybrid system for electricity generation. The developed prediction model has enabled the application of genetic algorithm to perform a search through a complex state space to find the global minimum, based on the criterion of minimum energy price.

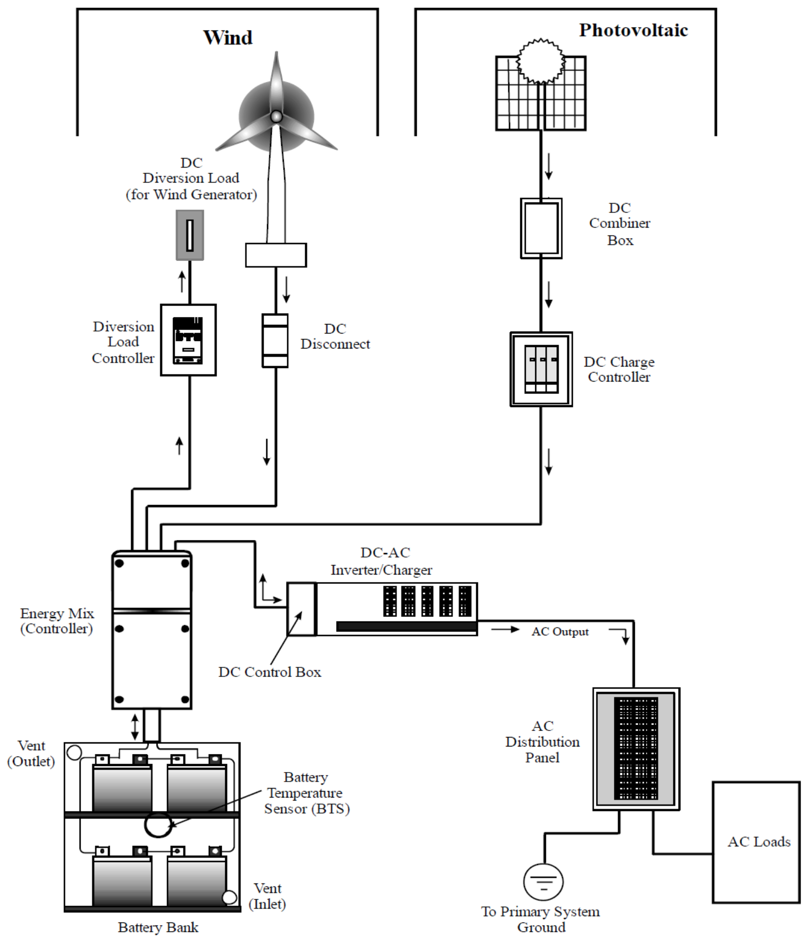


Figure 1. Schematic diagram of hybrid (renewable) solar-wind power source, [9]

The research in the field of renewable energy utilisation in the Republic of Srpska should certainly be continued, and the proposed topic can be seen as an effort in such direction. Bearing in mind the widespread presence of solar radiation, and the potential for use of biomass across the Republic of Srpska, it was decided to focus this study on these two energy resources, enabling the development of the model that is applicable to the whole region. Utilisation of solar energy potential, coupled with plants for combined heat and electricity production powered by biomass, is an area that has not been sufficiently explored in this region. The complexity of the topic will be revealed as it is being researched, but the aim is to present research results in a form which is easily understandable and which can be utilised in the implementation phase (the optimal configuration parameters can be expressed as a function of the type of construction, geographical location as well as the characteristics of the consumption electricity and hot water, etc.).

3. The analysis of the statistical data on wind and solar energy for the Banja Luka region

The Banja Luka region is located at 44.77 ^{o} N and 17.18 ^{o} E. Based on 365-day yearly cycles, key parameters of the Sun radiation geometry were calculated for each moth in a way that each month is represented by an average (typical) day, [3]. Table 1 shows average monthly values of the Sun declination, the sunrise / sunset angle, the azimuth of the sunrise/sunset, the Sun height angle and the zenith angle at the time of the solar noon. These figures are given without corrections related to the refraction of light due to passing through the atmosphere. Since these individual values represent all days of the month, they can not be used as precise figures, but rather as good estimates for the purposes of assessing the potential of solar radiation.

Table 1. Typical parameters of the geometry of the solar radiation in the Banja Luka region*

Month	Day No	Declination of the Sun	Sunrise / sunset angle	Azimuth of the Sun at sunrise / sunset	The maximum elevation angle of the Sun	Zenith angle
January	17	-20.9	∓ 67.72	∓ 59.8	24.3	65.7
February	47	-13.0	∓ 76.81	∓ 71.6	32.3	57.7
March	75	-2.4	∓ 87.60	∓ 86.6	42.8	47.2
April	105	9.4	∓ 99.47	∓ 103.3	54.6	35.4
May	135	18.8	∓ 109.73	∓ 117.0	64.0	26.0
June	162	23.1	∓ 115.01	∓ 123.5	68.3	21.7
July	198	21.2	∓ 112.61	∓ 120.6	66.4	23.6
August	228	13.5	∓ 103.73	∓ 109.1	58.7	31.3
September	258	2.2	∓ 92.20	∓ 93.1	47.4	42.6
October	288	-9.6	∓ 80.34	∓ 76.4	35.6	54.4
November	318	-18.9	∓ 70.13	∓ 62.8	26.3	63.7
December	344	-23.0	∓ 65.03	∓ 56.5	22.2	67.8
*Based on a 365-day cycle						

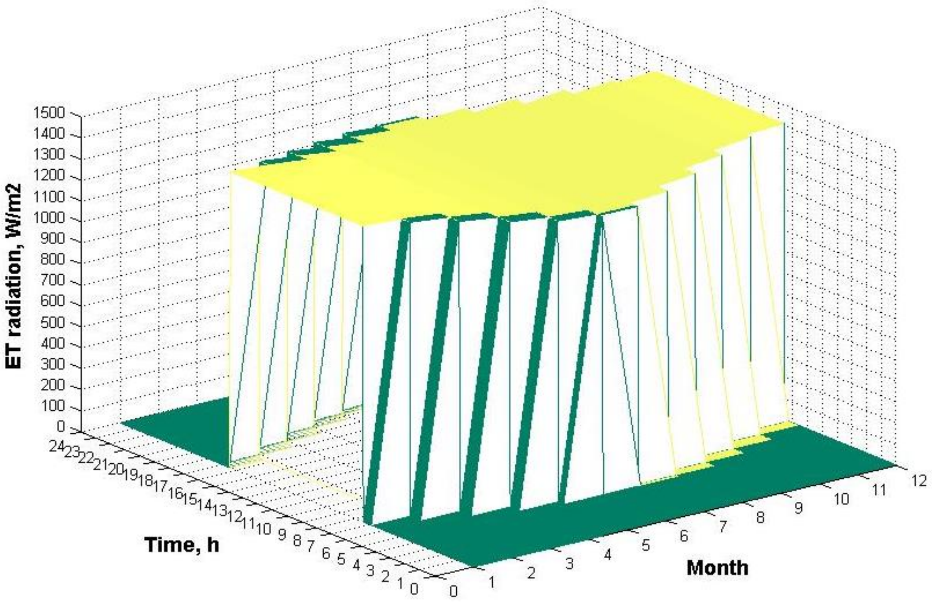
3.1. The analysis of the potential of solar radiation for the Banja Luka region

Based on this information, and during the use of known relations from the theory of solar radiation, are calculated values of direct terrestrial and extra-terrestrial radiation level for all the angles of inclination of the receiver in the project area. Figure 2 presents only some of the results of direct terrestrial and extra-terrestrial radiation (radiation to normal and horizontal surface). Based on the data obtained through computation, the available key meteorological parameters and the monthly average global radiation on a horizontal surface, a regression model was established, [5÷7]. The regression model includes the following parameters [5]:

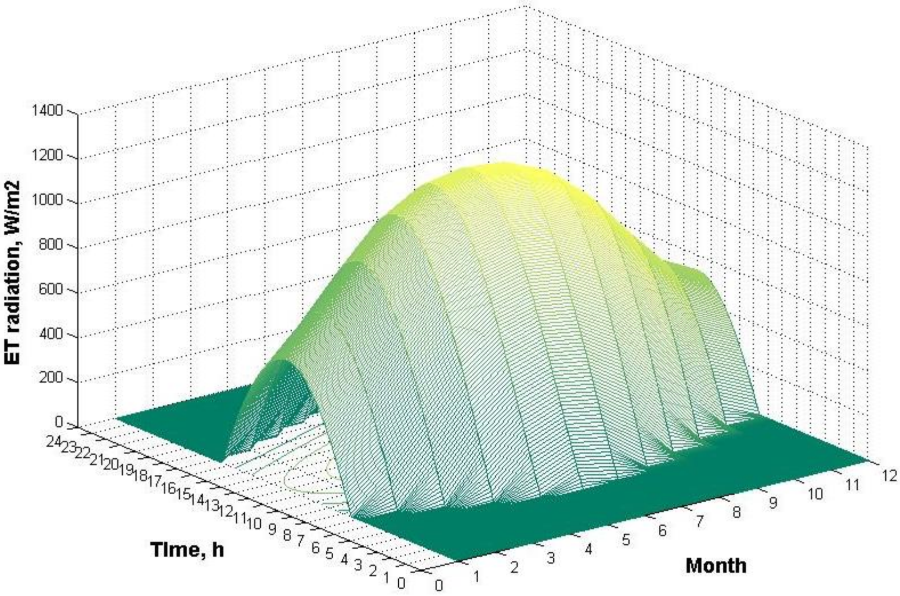
- the relationship between the average global radiation horizontal surfaces and extra-terrestrial radiation $\left(\overline{H}_{GH} / H_{0H}\right)$ (average monthly clearness index of the atmosphere $\left(\overline{K}_T\right)$);
- the ratio of the average sunshine hours to the maximal possible sunshine hours $\left(S_m / S_0\right)$;
- the ratio of the number of days with snow cover to the total number of days in a month $\left(N_{sm} / N\right)$;
- the maximum average temperature $\left(t_{\max}\right)$;
- average relative humidity (RH).

The regression relation is given by the following expression:

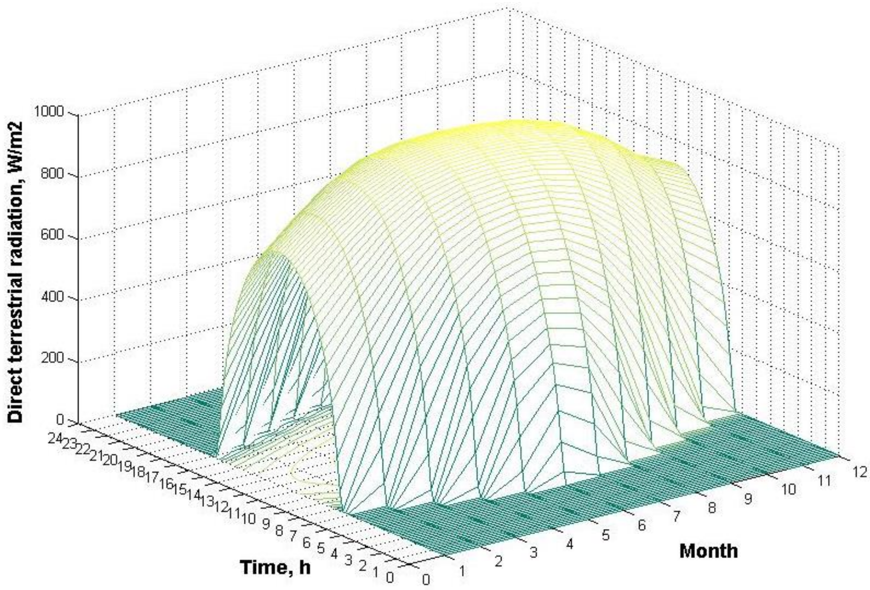
$$\overline{K}_T = 0{,}3790 + 0{,}7320 \cdot \frac{S_m}{S_0} + 0{,}0392 \cdot \frac{N_{sm}}{N} - 0{,}0038 \cdot t_{\max} - 0{,}2385 \cdot RH \; . \qquad (1)$$



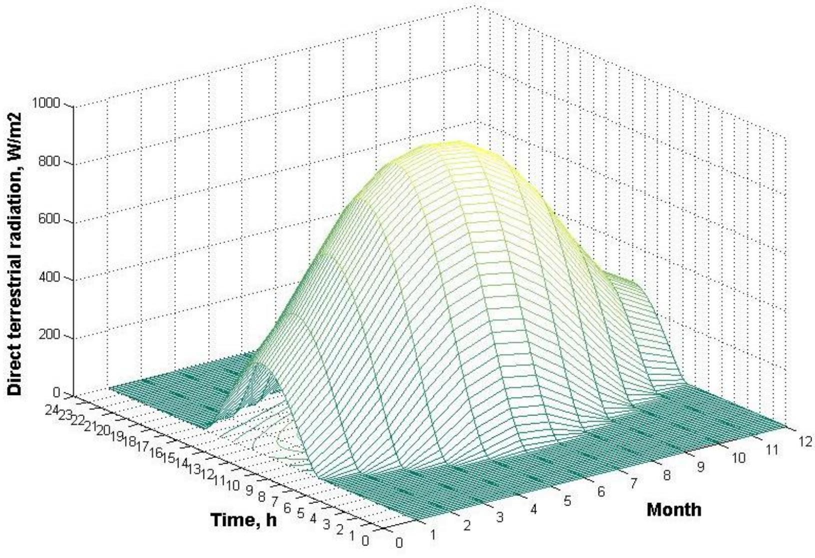
a) extraterrestrial radiation on a normal surface



b) extraterrestrial radiation on a horizontal surface



c) direct terrestrial radiation on a normal surface



d) direct terrestrial radiation on a horizontal surface

Figure 2. Model of extra-terrestrial and direct terrestrial radiation in clear sky conditions, W/m^2

After this are carried out the conversion of global radiation from the real conditions to terms of clear sky, incorporating hundreds of percentage share of sunshine. Thus obtained values are adopted for maximum daily index clearness of the atmosphere, and are given in Table 2.

Table 2. The value of the average monthly clearness index of the atmosphere, average global radiation on horizontal surface and maximum daily index clearness of the atmosphere, [5]

Month	**Average monthly clearness index of the atmosphere** $\left(\overline{K}_T\right)$	**Average global radiation on horizontal surface** $\left(\overline{H}_{GH}\right)$**, kJ/m^2 day**	**Maximum daily index clearness of the atmosphere** $\left(K_T\right)$
January	0.33	4003	*0.92*
February	0.37	6601	0.91
March	*0.43*	10856	0.9
April	*0.44*	14681	0.89
May	0.48	18650	0.87
June	0.49	20453	0.86
July	0.53	21525	0.85
August	0.52	18604	0.85
September	0.49	13793	0.85
October	0.42	8361	0.86
November	0.32	4360	0.87
December	0.29	3097	0.92

Based on the data of direct terrestrial radiation obtained through computation, and during the use of isotropic diffuse model are estimated the total radiation on the all sloped surfaces in clear sky conditions, and then the randomized scenario of possible hourly changes of the radiation intensity for all sloped surfaces. Figure 3 present the radiation on horizontal surface according to one of possible scenarios.

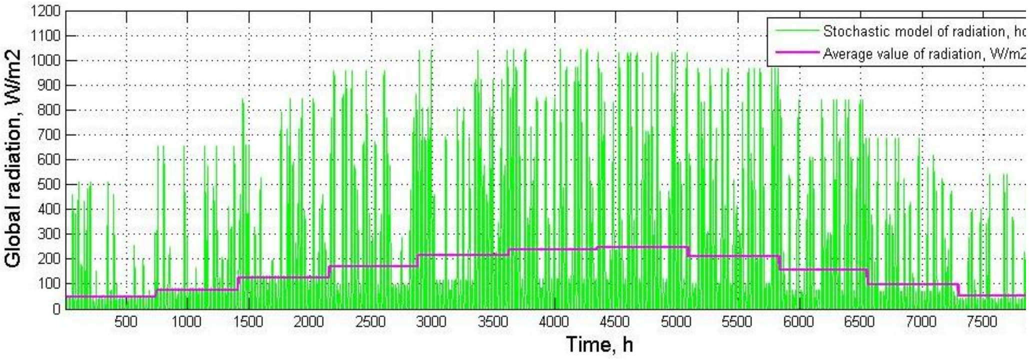


Figure 2. Randomized scenario of possible radiation intensity alteration during the year with mean monthly values for region of Banja Luka, horizontal surface, [1]

3.2. The analysis of the potential of wind for the Banja Luka region

Based on the presented wind data for the Banja Luka region, it can be concluded that wind, despite relatively good presence does not have a significant energy potential, primarily due to the low average speed. The process of energy generation implies the existence of the minimum initial speed, at which the generation begins, and this is a limiting factor in utilizing the entire wind resource in this area. The wind potential is of stochastic nature, which can be partially described by using Weibull's distribution. In order to utilize the existing wind potential at an optimal level, it is necessary that the selected wind turbines have a lower initial speed. Based on the statistical data on the average wind speeds and representation of silence for the area of Banja Luka, was established the Weibull distribution, and model of utilizing wind potential where the adopted initial speed was 2 m/s. Average wind speed and characteristic parameters of Weibul distribution for Banja Luka region are given in Table 3, [5].

Table 3. Average wind speed and characteristic parameters of Weibul's distribution for Banja Luka region

Month	***Aver. wind speed,*** v_m	***Shape factor , k***	***Scale factor, c***
January	1.46	*1.77*	*1.65*
February	1.66	1.67	1.86
March	*1.80*	1.55	2.00
April	*1.99*	1.38	2.17
May	1.67	1.58	1.86
June	1.53	1.84	1.72
July	1.44	1.67	1.62

August	1.29	1.50	1.43
September	1.20	1.50	1.33
October	1.40	1.55	1.56
November	1.70	1.45	1.87
December	1.42	1.66	1.59

Wind potential in the area of Banja Luka, according to the Weibull distribution are given on the Figure 4, and the utilizing wind potential on the Figure 5.

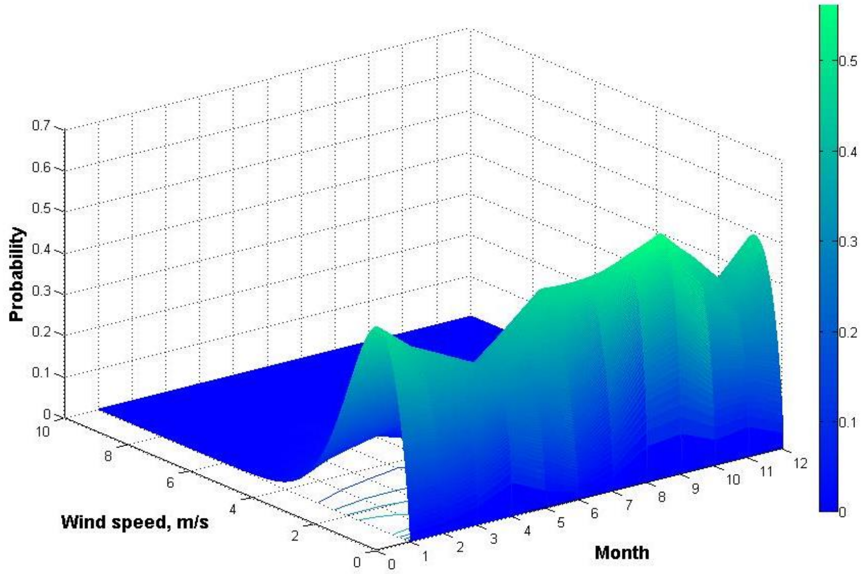


Figure 4. Wind potential in the area of Banja Luka, according to the Weibull distribution

Depending on the altitude, topography, vegetation, level of urbanization, as well as other factors, the true wind speed in the wider area deviate from the values obtained from weather stations. Weibull's distribution describes how likely certain wind speeds ranges will occur, but it does not say anything about their distribution over time domain, so that is unknown for the optimization process. In order to resolve this problem, a randomized model of hourly wind speed values was made, in accordance with the Weibull's distribution. In this case, the scale parameter was allowed to deviate for 0.2 and the shape parameter for 0.1 from the average values.

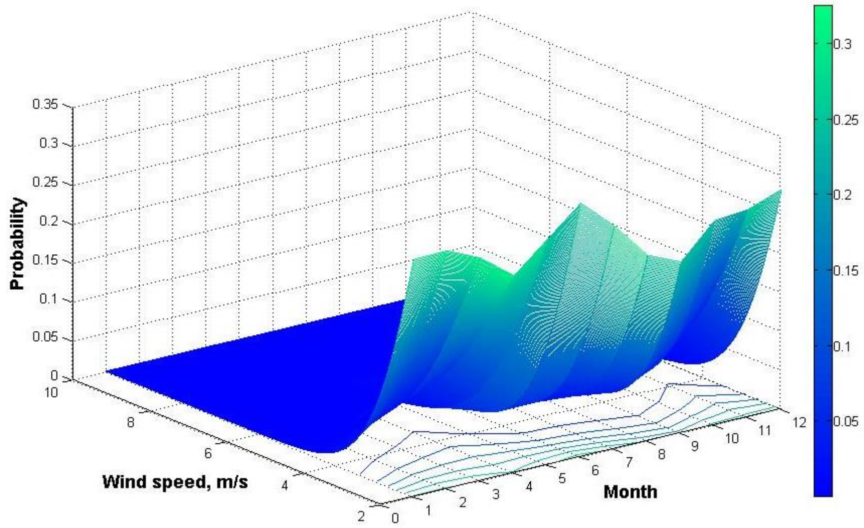


Figure 5. Utilizing wind potential in the area of Banja Luka, according to the Weibull distribution (initial wind speed 2 m/s)

By running a simulation, one can obtain a series of combinations that specify wind speed distribution over time domain during the year. One of these results is shown in Figure 6.

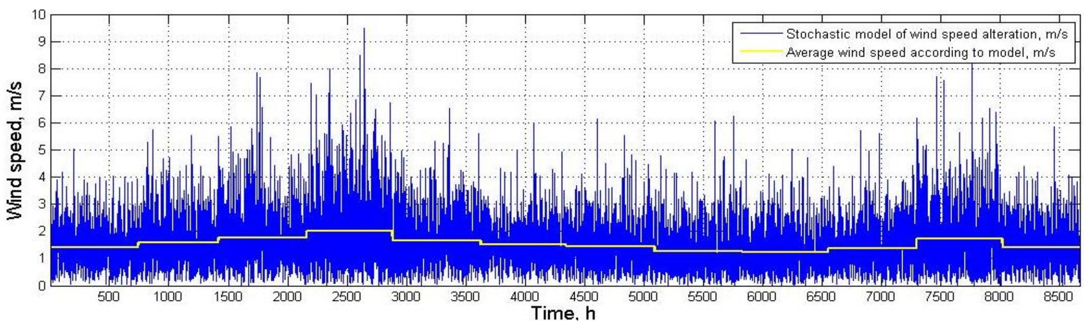


Figure 6. Randomized scenario of possible wind speed alteration during the year with monthly mean values of the wind speed, Banja Luka, [1, 5÷7]

4. Result analysis and discussion

The use of renewable energy has many advantages related to promoting sustainable development and environmental protection. In addition to these advantages of using renewable energy sources, which are not of commercial nature, a significant aspect of such projects is profitability, particularly from the standpoint of potential investors. A very common way of meeting the energy needs via renewable energy sources is the use of wind and solar energy, because they are local energy sources available almost everywhere. The level of electricity production, based on wind and solar energy coupled in a hybrid system, directly depends on the intensity of solar radiation, air temperature, wind speed, and other natural phenomena related to the local environment. Due to the stochastic nature and unpredictable availability of these two resources, and the relatively high cost of the system components, it is necessary to carefully determine the configuration that ensures / maximizes profitability of investment in such systems. During the selection of the key elements of the hybrid system, the decisions are made about its structure, the number of components and their size. Today, we have available a number of technologies with various features. Autonomous hybrid systems, with commercially available technologies for the utilization of renewable energy sources, can provide energy independence to consumers, and represent an alternative to conventional energy sources. Defining the concept, its evaluation and optimization of its parameters, with calculation of its cost-effectiveness and potential profitability, in comparison to the cost of a conventional connection to the distribution network, or to an autonomous power supply using other conventional sources of energy (diesel generator), are very important for application in remote areas that are outside of the existing distribution networks. Besides, the availability of the distribution network does not restrict the application of hybrid systems; due to the two-way flow of energy, they can relieve seasonal overload of the grid and reduce electricity losses. The financial feasibility of investment in grid-connected hybrid systems is provided by encouraging investments through the purchase of the energy sent out to the grid at guaranteed prices, significantly higher than the cost of energy from the grid. Technical and economic criteria for the installation of both types of hybrid system depend on the available wind and solar resources, as well as on the energy needs of the considered consumers. Worldwide, there are several programs developed to design and optimize hybrid systems (HOMER, HYBRIDS, HOGA etc.) that can provide a more detailed analysis, but they are mainly intended for the design and optimization where the consumers profile is already known. In this paper, through the presented optimization charts, the main indicators are expressed in relative ratios (relative active surface area of photovoltaic panels and wind turbines), which can be used as a general recommendation when making decisions to invest in such systems. In order to perform the optimization, a computation model was developed for the evaluation of small energy systems, either operating autonomously (island regime), or being connected to the distribution network and taking advantage of the incentives for the use of renewable energy resources.

4. Conclusion

The performed optimization was based on an iterative model in accordance with a specifically defined algorithm, produced a relatively good starting point, which can be used to determine the guidelines for the development of similar projects and the estimation of the order of magnitude of the required investments. Each location has its own specifics, related to the availability of certain types of energy (wind and solar radiation), and the input data on their intensity and the distribution in the selected area is a key factor in the implementation of the optimization process. The optimization process as well as performed economic and financial analysis, with the initial assumptions, confirmed the feasibility of the construction of hybrid systems based on wind and solar energy. The construction of these systems in rural communities, that are outside of the distribution network, has additional benefits as it supports sustainability of these communities and improves the quality of life of its members through the use of environmentally friendly, widely accessible and readily available source of energy. Using renewable energy does not automatically exclude ineffective and inefficient use of energy, therefore, in parallel with the construction of hybrid systems, particular attention should be paid to the implementation of projects aimed at changing consumers' behavior related to how they use and plan electricity consumption. Considered in this paper is a dual hybrid system for energy production based on wind and solar energy. Potential augmentation of the hybrid system with new components, representing new sources of energy, such as small hydro, fuel cells, etc., would have a positive effect on the overall availability of the system in its autonomous regime of operation, but it would significantly increase the initial investment and the costs associated with their operation and maintenance. What effect would increase of the number of components of the hybrid system have on the overall availability and price of energy, could be the subject of further research. In addition, it is not adequately researched and understood how well would hybrid systems integrate with systems for the production of thermal energy (e.g. heat pumps), as well as with Stirling-cycle engines, which would include the supply of consumers with electricity and heat. A small number of previous studies are aimed at finding the optimal ways of accommodation of small wind turbines and photovoltaic panels in urban areas. Urban areas can significantly affect the air flow, and the way how buildings are distributed in space, as well as their heights, plays important role. The recommendations that followed from these studies indicate that the ideal urban areas for installation of small wind turbines are along straight roads, parallel to the predominant direction of wind and along series of houses aligned with this direction. Photovoltaic panels are sensitive to partial shading, which can cause a disproportionate and progressive reduction of power output compared to the shaded area, and, in this respect, one can analyze the impact of the physical environment on the shading of photovoltaic panels. Due to these facts, the spatial aspects of positioning the components of the hybrid system is also recognized as a hot topic for further research

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