Complementary Use of Solar Energy in Hybrid Systems Consisting of a Photovoltaic Power Plant and a Wind Power Plant

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Abstract: - Still under-exploited wind and solar potential draw attention over recent years as free, widely available, local, clean energy sources. However, efficiency level of used solar technologies, relatively high investment costs for both facilities, their intermittent nature andvariabilityof power output in corresponding power plants are restricting available potential exploitation.
In order to show the complementary nature of wind and solar energy, in this paper, analyzes of solar insolation and wind power density were made. The proposed simulations and analyzes are based on real, measured solar and wind potential data for a specific location Medvedjak in Bosnia and Herzegovina. Consideration of the sum of these two "raw" values mainly emphasizes their complementarity on monthly and seasonal level.
An own model for estimation of power output, from a hybrid system, consisting of a photovoltaic power plant (PVPP) and a wind power plant (WPP) was made. Two cases were considered; the first where both generating facilities have equal installed capacities and the second where the installed capacity of the WPP is five times larger than the one for the PVPP. Analyzing the results of performed simulations it can be concluded that the complementarity of these two energy sources, after their conversion from available, raw forms into a usable form, in this case electrical power, is more prominent in hybrid system applications with equal amounts of installed capacity.

Key-Words: -Hybrid system, solar energy, wind energy, intermittence, complementary nature, power output variability, technologies efficiency

1 Introduction

The ever increasing energy consumption, soaring costs and exhaustible nature of fossil fuels, intensified environmental pollution and global warming have created increased interest in renewable energy sources (RES) utilization across the world. In most of the countries, available hydro potential is close to full exploitation. As a consequence, under-exploited wind and solar potential draw attention over recent years as free, widely available, local, clean energy source. However, wind and solar technologies are broadly characterized as expensive and relatively inefficient, restricting available potential exploitation, especially when it comes to solar energy. Besides that,intermittent nature and variability of these sources, primarily wind, represent some of major issues, which further raise costs of RES utilization and their integration into power systems across the world.

In order to show the complementary nature of wind and solar energy, in this paper, analyzes of solar insolation [W/m2] and wind power density (WPD) [W/m2] were made. Analyzes are based on real, measured, one year data[1] for a specific location Medvedjak in Bosnia and Herzegovina (B&H). Consideration of the sum of these two "raw" values mainly emphasizes their complementarity on monthly and seasonal level. This characteristic is one of the main reasons for their increasingly popular combination in hybrid systems [1], [2],[3].

Furthermore, an own model for estimation of power output, i.e. generated electricityfrom a hybrid system, consisting of a PV power plant (PVPP) with installed capacity of 2 MW and a wind turbine (WT)with the same installed capacity amount was made. The model took into account currently available technologiesand all restrictions in conversion of wind and solar energy into electricity. Additionally,a modelof a hybrid system consisting of the same 2 MW PVPP and a wind power plant (WPP) of 10MW installed capacity was made, with

[1] Unfiltered data has been used in order to avoid subjectivity.

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the aim of presenting a more common ratio of installed capacities in WPP and PVPP in realistic applications.

Analyzing the results of performed simulations, it can be concluded that the complementarity of these two energy sources, after their conversion from available raw forms into a usable form, in this case electrical power, is more prominent inhybrid system applications with equal amounts of installed capacity.

Additionally, the paper briefly considers the current development of existing technologies for solar and wind energy conversions and gives a vision for their future applications.

2 Problem Formulation

Constant consumption growth and non-renewable energy sources issues, have, among other things, led tointensified integration of RES. The focus is set on solar and wind sources. Special attention is given to the electrification of consumption centres remote from power networks [4], [5]. This paper emphasizes such locations with significant solar and wind potential, suitable for implementation of specific hybrid systems. However, these systems are characterized by significant output power variability, primarily wind power;low conversion efficiency of raw potential into useful energy, i.e. electricity, in particular for solar energy; special requirements for optimal utilization of these resources (available space, surface slope andorientation); high investment costs of available technologies; relatively short lifetime compared to conventional power facilities, etc.

This paper emphasizes the variability problem of the two considered sources, based on real, measured solar insolation and wind potential data at a selected location, as shown in Fig.1. Also, the problem of insufficient technology efficiency for benefiting from complementarity of these two RES is analysed.

Data used for the performed analysis and modelling are overtaken from an active 30 m high measurement station Medvedjak, in B&H.The station is equipped with two first class anemometers, a wind vane, an air pressure, humidity and temperature sensor, as well as a pyranometer, all in accordance with IEC 61400-12 [6] and MEASNET recommendations [7].

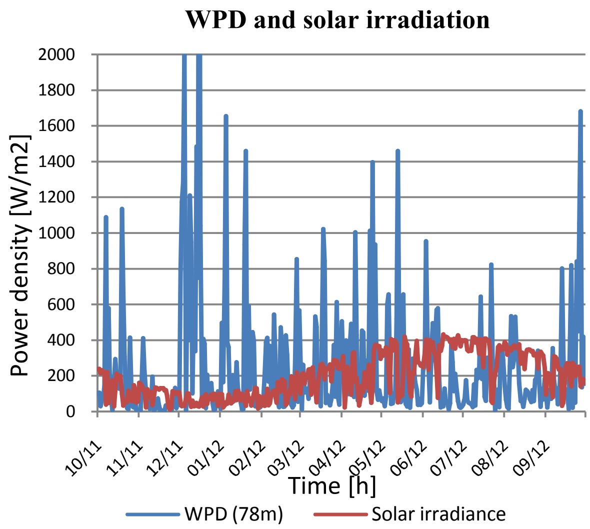

Fig.1.WPD and solar irradiation based on daily values - one year data

This location has been selected after a previously performed evaluation and analysis of measured data from ten different locations spread throughout B&H. The choice of an appropriate location for this type of analysis and modellingwas based on following criteria:

- available wind potential
- available solar potential
- available space
- consumption centre vicinity
- power network distance.

Analyses are performed for a one year period of time, i.e. October 2011[th] to September 2012[th], which entailed making 52,560 observations per measured value. Since the measured wind speed values relates to 30 m and 10 m height, an extrapolation to a height of 78 m has been done[2]. For these purposes following logarithmic function was used:

$$v(z) = \frac{\ln\left(\frac{z}{\alpha}\right)}{\ln\left(\frac{z_0}{\alpha}\right)} v_0 \qquad (1)$$

where z and z_0 present heights above the ground at 78 m and 30 m, respectively; v(z) presents the calculated 10 minute average wind speed at 78 m height, $v(z_0)$ denotes the measured 10 minute average wind speed at 30 m height and α is the roughness length determined using the software tool WindPRO.

The average annual wind speed at 30 m height is 5.2 m/s, amounting 5.7 m/s when extrapolated to 78 m, and the corresponding energy based on WPD at

[2] This height was selected as the height of the chosen wind turbine type, which was later on used for modelling of output power simulation of the WPP

78 m height resulting in 2,273 kWh/m^2. The average annual insolation measured on this location, is 1,742 kWh/m^2.

3 Problem Analysis and Solution Vision

3.1 Wind and solar complementarity

With the aim of analyzing solar and wind energy complementarity, hourly values of solar irradiation and WPD were examined, processed and graphically presented in this paper. The intent was to consider the presence of two different types of solar energy (the luminous and thermal component) at the same site, and in respect to this, WPD was used in order to express wind potential in the same unit as solar irradiation, i.e. [W/m^2]. WPD is calculated based on wind speeddata from the measurement station Medvedjak,extrapolated to 78 m height andair density, allat a surface of 1 m^2.

Analyzes were performed for a one year periodof time, whereas in this section, graphics for two characteristic months are presented, i.e. December 2011th (see Fig.2) and July 2012th (see Fig.3). It is possible to conclude that, at the considered location, characteristic days,which reflect a typical situation, could not be specially singled out. Variations of WPD are significantly expressed, especially in the 10 minute andhourly time interval,compared to the solar irradiation values, which can be relatively constant in the same time period. However, in some periods, solar irradiation can be highly variable within time frames of seconds to minutes, changing quickly with passing clouds [8]. During the summer period, solar irradiation is dominant in relation to WPD, daysare longer and the total insolation is up to 6 times higher compared to values in the winter, which in the end would result in higher electricity generation from a PVPP.During winter months, the situation is opposite; wind speeds are higher than on calm summer days and the sunlight period is shorter. All specified characteristics are shown in Fig.2 and Fig.3. From these figures, it is possible to conclude that in moments of sun irradiation decrease, especially in summer, higher values of WPD (also wind speed) occur and vice versa. This characteristic is linked to the fact that wind is a direct consequence of solar radiation and occurs because of uneven warming of the Earth's surface. Also, at days with a common irradiation curve, without significant fluctuations, movements of air masses are not stressed out, respectively, values of WPD (also wind speed) are low. However, these statements are based on one year observations for this specific site and the phenomenonshould be more investigated.

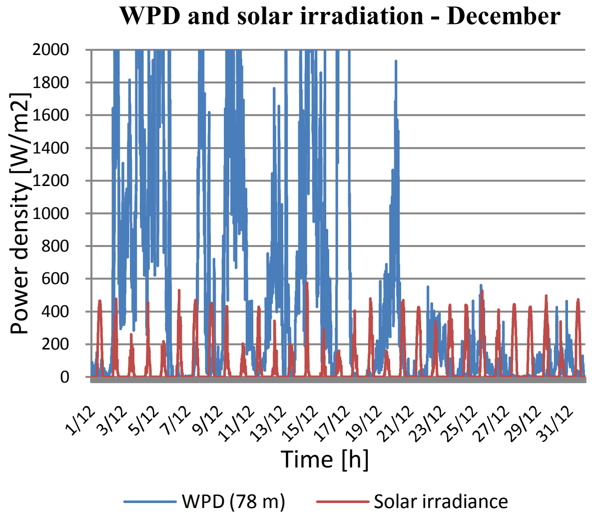

Fig.2.WPD and solar irradiation during December 2011 - hourly values

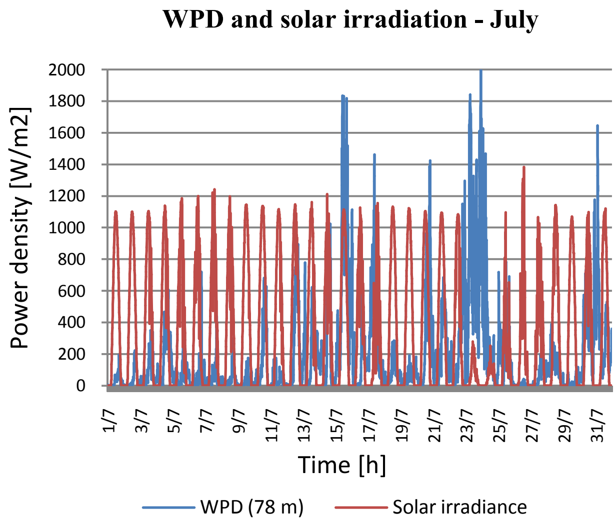

Fig.3.WPD and solar irradiation during July - hourly values

3.2 Hybrid system power output analyzes

10 minute wind and solar potential measurement data from the station Medvedjak, recalculated on hourly time intervals, were used for modeling and simulation of hourly power output values of a hybrid system. Two cases were considered:

Case I: total installed capacity of 4 MW:
2 MW in a PVPP and 2MW in a WT

Case II:total installed capacity of 12 MW:
2 MW in a PVPP and 10 MW in a WPP.

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Selection of these sizes is not usual for hybrid systems. This choice was driven by exploring possibilities for electricitysupply to a group of consumers located near the potential hybrid facility, in order to achieve known positive effects on distributive losses decrease, security and reliability of supply increase, as well as exploitation otherwise unused area.

The simulation is done with respect to currently available technologies, space availability and other prevailing conditions at the considered location. For the PVPPnear shadings, indices air mass factor (IAM), PV conversion factor, PV loss due to irradiance level, PV loss due to temperature, array soiling loss, module quality loss, module array mismatch loss, ohm wiring loss and inverter losses were considered.The considered type of solar cells is polycrystalline, where special attention has been paid to the optimal distance and configuration of the PV panels. Simulations of output power/energy yield from the WPP were done for the WT type Vestas V 80.2.0. This WT type was chosen because of its widespread presence in the world market.

3.2.1. Simulation Results for Case I

In Fig.4 one year data of WPD and solar irradiation for Medvedjak site, based on hourly values are presented. Simulation results of output power from the hybrid system for Case I are shown in Fig.5, Significant variations of output power in a relatively short time interval, i.e. on hourly basis, especially from WPP draw attention [9].

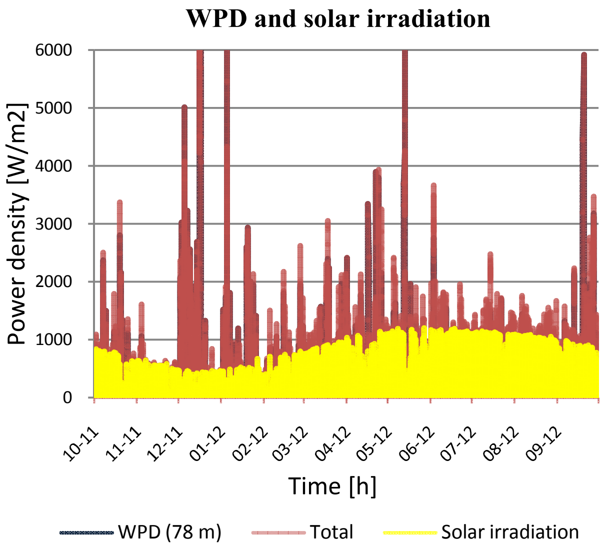

Fig.4. One year data of WPD and solar irradiation - hourly values

Despite the fact that the selection of such configuration of a hybrid system is not usual, comparative analysis of data shown in Fig.4 and Fig.5 indicate limitations in conversion of total available solar and wind energy potential in real systems, based on currently available technologies.

Considering the modeled hybrid system consisting of a PVPP and a WT with even amounts of installed capacity, positive effects of complementarity of output power from these two facilities can be seen. However, implementation of such a system requires large amounts of available space for the considered PVPP. Specifically, such a PVPP potentially good positioned and oriented covers an area of 3.5 ha. Also, according to [10], investment requirements for the installation of a PV generating unit of 2 MW installed capacity would amount cca 6.08 mil. € (3.04 €/W_{DC}). A WT of 2 MW installed capacity would require cca 2.5 mil. € (1.25 €/W) [11].

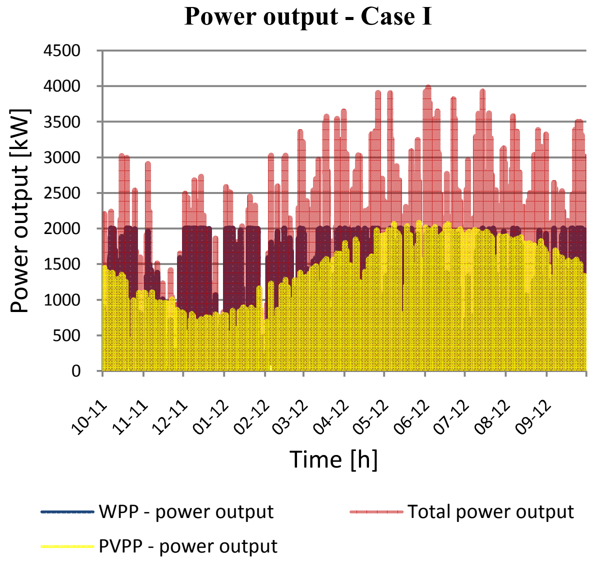

Fig.5. One year data of output power from the hybrid system for Case I - hourly values

From the abovementioned, it can be concluded that available technologies for converting wind energy into electrical power/electricity achieved a much higher level of development, compared to PV technologies, which also resulted in higher viability.

With respect to numerous positive aspects of the solar energy as an electricity source, which, compared to wind energy, are reflected in better and more accurate possibilities of forecasting, up to a few days in advance; and a much lower level of variations in 10 minute and hourly time intervals, additional efforts in technology research are expected in order to obtain PV cells with higher efficiency as well as price drop.

Accordingly, there are already some researches indicating PV cells efficiency up to 44% in laboratory conditions [10]. Such technologies would decrease space requirements, when it comes to the implementation of PVPP with significant amounts of installed capacity, which would, further on, contribute to their appliances in hybrid systems in combination with WPP, resulting in additional emphasis on positive effects of such systems.
At this moment, commercial use of high-efficient PV technologies, revealed in laboratory conditions, would require significant price reduction.

3.2.2. Simulation results for Case II

In Case II the installed capacity in WPP is increased five times, resulting in 10 MW, while the installed capacity ofthe PVPP remained the same. Simulation results, which provide insight into annual output power of the considered hybrid system based on hourly values, are presented in Fig.6. The installed capacity ratio of the considered hybrid system is more common in real conditions, but currently installed hybrid systems have much lower installed capacities (few hundred Watts).

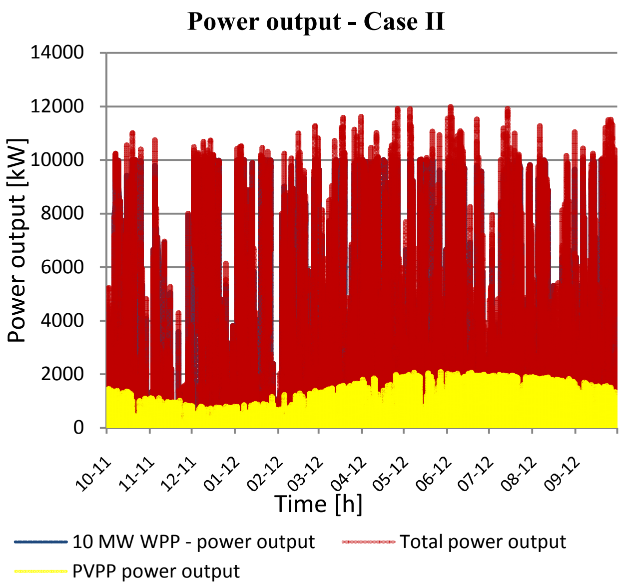

Fig.6. One year data of output power from the hybrid system for Case II - hourly values

Comparing results shown in Fig.5 and Fig.6, a reduction in the complementarity effect of these two generating units can be noticed. Analyzing simulation results, shown in Fig.4,Fig.5 andFig.6, it can be concluded that, due to currently available technologies for converting raw sources into electrical power/ electricity, a variation decrease is evident, especially in cases of extremely high values.

4 Conclusion

Wind and solar energy are two RES that can and must be used more strongly and this can only be accomplished by making the involved technology accessible to all. The research and development of new efficient and cheaper technology is essential to make the production of clean energy affordable.
Despite the complementarity nature of the considered two RES, a hybrid system composed of a WPP and a PVPP cannot independently provide full power for distinct groups of consumers. For such purposes energy storage or the presence of a power network is essential.

Given that the two consider sources by nature arise from solar energy (luminous and thermal component), their usage in hybrid systems is very important at local level, particularly in areas distant from major consumption centers (mountain resorts, tourist centers). Solutions of energy storage would have a dual role; they would solve the problem of output power (energy) variability from WPP in short time intervals (e.g. on hourly basis) and enable electricity supply during times when the generation is significantly lower than the consumption.

Optimal sizing options withappropriate operation strategies were not considered for the generating facilities in this paper. This would be a further step.

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