Comparative Advantages Using Solar and Wind Energy in Hybrid Systems at the Same Site

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Abstract: - Main objectives of the paper were to examine the complementary nature of solar and wind energy in primary and in "useful" form. Analyses are performed on real, measured solar and wind potential data at the same site. Solar irradiation and wind power density have been assessed as primary forms. In order to examine effects of their complementarity in real applications, i.e. in power systems, a hybrid system, consisting of a photovoltaic power plant (PVPP) and a wind power plant (WPP), was modelled and simulated. Those effects were verified through output power variations of these facilities individually, compared to output power variations of two different hybrid system configurations. Analyses were also made with respect to hourly load demand profile of the consumption centre located in proximity of the potential hybrid power plant.

Key-Words: -Complementary nature, demand, hybrid system, power output variability,solar energy, wind energy.

1 Introduction

Environmental concerns, exhaustible nature of fossil fuels and the ever increasing need for energy, coupled with steady progress in renewable energy technologies, are opening new opportunities for utilization of renewable energy sources (RES) across the world. Still under-exploited wind and solar potential draw attention over recent years as free, widely available, local, clean energy sources, offering sustainable energy alternatives with zero environmental pollution. Also, they can complement each other to some extent in certain configurations of hybrid energy systems and in that way increase availability and reliability of electricity supply to customers, compared to a system based on a single resource. Due to this feature, hybrid energy systems have caught worldwide research attention [1] - [6].

In order to show the complementary nature of wind and solar energy, in this paper, analyses of solar insolation [W/m^2] and wind power density (WPD) [W/m^2] were made. Consideration of the sum of these two primary values mainly emphasizes their complementarity on monthly and seasonal level.

For the purpose of further research, an own model for converting the primary energy resource, i.e. solar and wind energyinto output power and thus generated electricity in specific hybrid energy systemshas been developed. Calculations and analyses are based on real, measured data in a full year cycle, overtaken from an actual wind and solar data acquisition and monitoring system in Bosnia and Herzegovina (BIH). Unfiltered data has been used in order to avoid subjectivity. The model took into account currently available technologies, all restrictions in conversion of wind and solar energy into electricity in wind power plants (WPP) and photovoltaic power plants (PVPP), as well as the available area at the location of interest. The model has been developed for two hybrid system configurations; namely, the first one consisting of PVPP with installed capacity of 2 MW and a wind turbine (WT) with the same installed capacity and the second consisting of the same 2 MW in PVPP and a WPP of 10 MW installed capacity [7]. The 2 MW PVPP can be installed at the same location as the WPP or dispersed on roofs of houses in the observed consumption center.

Main objectives of the study were to examine the complementary nature of the two RES in primary and "useful" forms. Hourly output power variations from each of the generating facility have been elaborated, as well as the output power variations for two selected hybrid system configurations, in order to assess effects of joint utilization of wind and solar potential. Analyses were extended by short consideration of real load data from a consumption centre near the proposed hybrid system location. A rough evaluation of effects of implementing a hybrid system has been provided in this paper.

2 Problem Formulation

Given the expected trend of development and growth of RES in power systems around the world [8] - [10], an important contribution from appropriate hybrid system configurations, especially in the future, is anticipated. These systems will also play an important role in the electrification of consumption centers remote from power networks [5], [9]. In this paper such locations are emphasized, where attention is devoted to PVPP and WPP. Although these sources are considered as complementary, the extent of this nature has been investigated and discussed in certain hybrid system configurations, based on simulations performed with real, measured data. Further on, such systems are characterized by significant output power variability, primarily wind power; low conversion efficiency of primary into useful energy, i.e. electricity, in particular for solar energy; special requirements for optimal utilization of these resources (available space, surface slope and orientation); high investment costs of available technologies; relatively short lifetime compared to conventional power facilities, etc.

Since it is difficult to match variations of consumption with the volatile generation of facilities based on intermittent RES, this issue has been given a special evaluation further in this work.

2.1 Case study description

All calculations and analyses are based on real measured values. Data used for output power, i.e. electricity generation simulations are overtaken from an active 30 m high measurement station Medvedjak, in BIH. 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 [11] and MEASNET recommendations [12]. This location has been selected after previously performed evaluations and analyses of measured data from ten different locations spread throughout BIH. The choice of an appropriate location for this type of analysis and modelling was 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, October 2011th to September 2012th, which resulted in 52,560 observations per measured value. Since the measured wind speed values relate to 30 m and 10 m height, an extrapolation to a height of 78 m has been done (this height has been selected as the height of the chosen WT type, later on used for modeling of output power simulation of the WPP). For these purposes following logarithmic function has been used:

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

where z and z0 represent 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(z0) denotes the known 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 in 5.7 m/s when extrapolated to 78 m, and the corresponding energy based on WPD at 78 m height resulting in 2,273 kWh/m2. The average annual insolation measured on this location, is 1,742 kWh/m2.

Analyses were extended by considering real load data from a consumption center near the location of the potential hybrid system, with recorded maximum hourly load of 3.5 MW. It is approx. 70 km away from a big consumption center, linked through a 110 kV transmission line.

2.2 Hybrid system configurations

10 minute wind and solar potential measurement data from the station Medvedjak, recalculated on hourly time intervals, were used for modeling and simulating of hourly output power values, and frequency of their variations. Two cases were considered:

- Case I: total installed capacity of 4 MW: 2 MW in a PVPP and 2 MW in a WT
- Case II: total installed capacity of 12 MW: 2 MW in a PVPP and 10 MW in a WPP.

Selection of these sizes is not typical for hybrid systems. This choice was driven by exploring possibilities for electricity supply to a group of consumers located near the potential hybrid facility and achieving effects like distributive losses decrease, security and reliability of supply increase, as well as exploitation of otherwise unused area [13].

The simulation is done with respect to currently available technologies, space availability and other prevailing conditions at the considered location. For the PVPP near shadings, indices air mass factor (IAM), PV conversion factor, PV loss due to irradiance level and temperature, array soiling loss, module quality and 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 [14], [15]. Simulations of output power/energy yield from the WPP were done for the WT type Vestas V 80.2.0. This WT type has been chosen because of its widespread presence in the world market.

3 Problem Analyses and Simulation Results

3.1 Complementarity analyses of solar and wind energy

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. Since the intent was to consider the presence of two different types of solar energy (the luminous and thermal component) at the same site, WPD was used in order to express wind potential in the same unit as solar irradiation, i.e. [W/m^2]. WPD calculations are based on wind speed data from the measurement station Medvedjak, extrapolated to 78 m height and air density, all at a surface of 1 m^2. Graphics for two characteristic months are presented, i.e. December 2011th (see Fig. 1) and July 2012th (see Fig. 2).

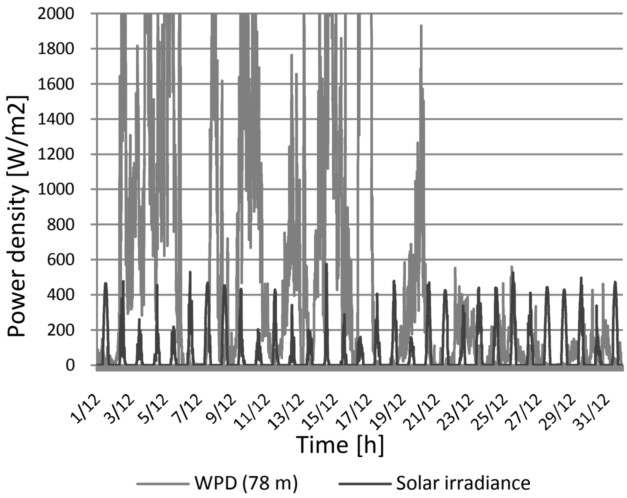

Fig. 1 WPD and solar irradiation during December - hourly values

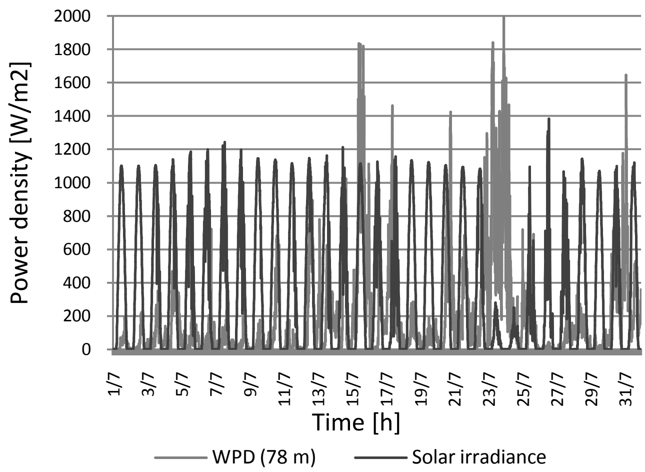

Fig. 2 WPD and solar irradiation during July - hourly values

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 and hourly 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 [16]. During the summer period, solar irradiation is dominant in relation to WPD, days are 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. From the figures, it is also 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 phenomenon should be more investigated.

3.2 Output power simulation results

3.2.1 Simulation results for Case I

In Fig. 3 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. 4.

Despite the fact that the selection of such configuration of a hybrid system is not usual, comparative analysis of data shown in Fig. 3 and Fig. 4 indicate limitations in conversion of total available solar and wind energy potential in real systems, based on currently available technologies.

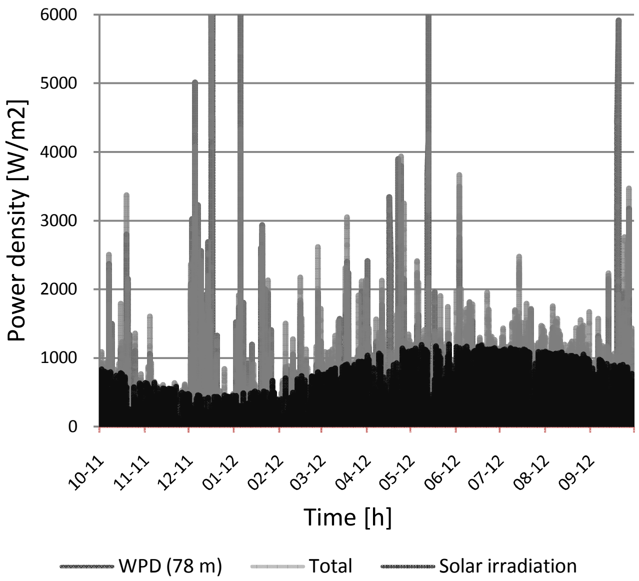

Fig. 3 One year data of WPD and solar irradiation - hourly values

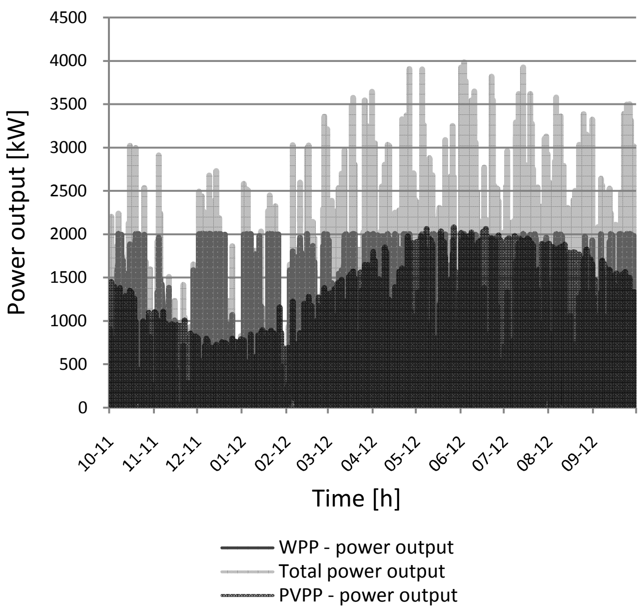

Fig. 4 One year data of output power from the hybrid system for Case I - hourly values

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 [17], investment requirements for the installation of a PV generating unit of 2 MW installed capacity would amount approx. €6.08 mil. (3.04 €/WDC). A WT of 2 MW installed capacity would require approx. €2.5 mil. (1.25 €/W) [18].

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 [17]. 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

Simulation results, which provide insight into annual output power of the considered hybrid system based on hourly values, are presented in Fig. 5.

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).

Comparing results shown in Fig. 4 and Fig. 5, a reduction in the complementarity effect of these two generating units can be noticed. Analyzing simulation results, shown in Fig. 3, Fig. 4 and Fig. 5, it can be concluded that, due to currently available technologies for converting primary sources into electrical power/electricity, a variation decrease is evident, especially in cases of extremely high values.

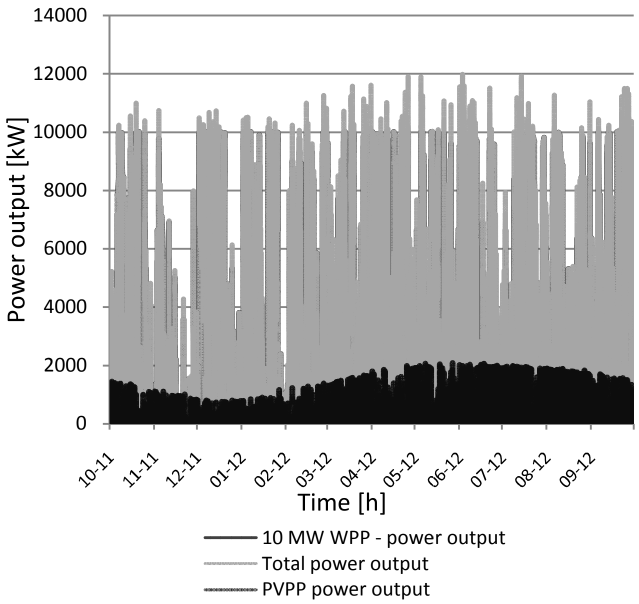

Fig. 5 One year data of output power from the hybrid system for Case II - hourly values

4 Problem Discussion and Solution

4.1 Output power variations analyses

4.1.1 Simulation results for Case I

Simulation results of hourly output power variations for each of the generating facilities under this hybrid system configuration are presented in Fig. 6. Significant variations of output power in a relatively short time interval, i.e. on hourly basis, especially from WPP, draw attention [19], [20].

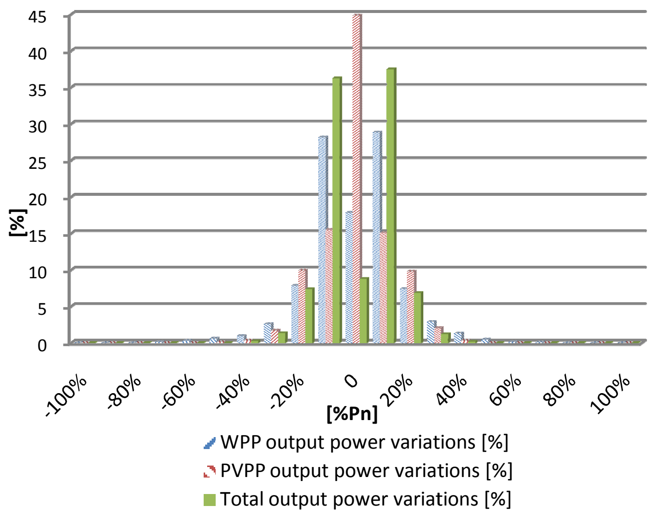

Fig. 6 Frequency of output power variations based on hourly values for Case I - one year data

Analyzing gained results, it can be concluded that hourly variations in output power of the assumed WPP appear in the range from -90% of the nominal installed capacity (Pn) up to 80% of Pn. Only in 17.9% of time there are no variations between two adjacent values. In the case of the PVPP, the range of hourly variations in the output power is narrower, i.e. ±60% of Pn. In 44.9% of time there are no variations between two adjacent values, in this case. In 90.2% of time, hourly output power variations are in the range of ±20% Pn for the WPP and 95.2% for the assumed PVPP.

This kind of variations, may pose significant problems in managing and operating of a power system, especially in cases of high penetration of such generating facilities. Thus, because of technical limitations, primarily the development of the transmission/distribution system, operating capabilities and power system service insurance as regulation of active power and frequency and reactive power and voltage, power systems are not able to accept unlimited amounts of installed power from PVPP and especially not from WPP.

4.1.2 Simulation results for Case II

Simulation results, which provide insight into annual hourly output power variations of the considered hybrid system in Case II, are presented in Fig. 7.

Analyzing gained results, it can be concluded that hourly variations in output power of the assumed WPP appear in the same range as in Case I, since the frequency of output power variations depend on the considered wind potential data.

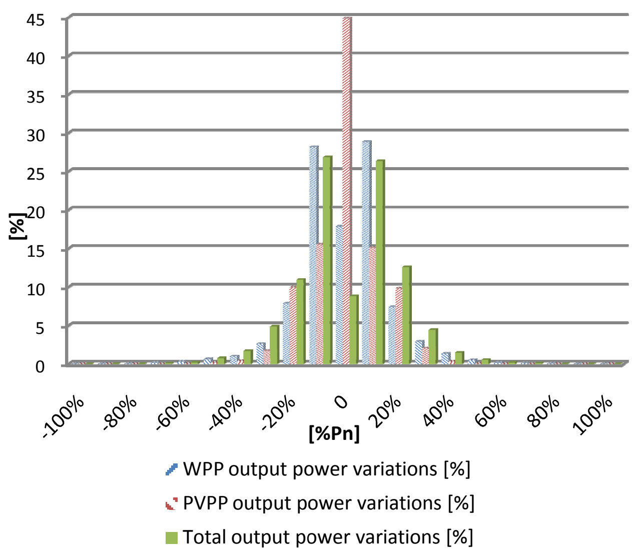

Fig. 7 Frequency of output power variations based on hourly values for Case II - one year data

Although the configuration considered in Case I is not common, this system is reviewed in order to investigate the complementarity nature of the two energy sources in a hybrid system with equal installed capacities, and to examine output power variations reduction of the system as a whole, compared to variations of individual generating facilities. From Fig. 6, significant reduction in the range of hourly output power variations can be observed. They appear in the range of ±50% of Pn, whereby in 96.8% of the time, variations are in the range of ±20% Pn. Only in 8.8% of the time there are no variations between two adjacent values. Reduction of output power variations positively affects the operation and management of the power system, given that for the tertiary (as well as secondary) regulation lower amounts of reserves are necessary. This statement gets on value especially in power systems with high penetration of these renewable, intermittent sources.

Simulation results, representing frequency of output power variations based on hourly values of the hybrid system, compared to variations of individual generating facilities are presented in Fig. 7. A reduction in the range of hourly output power variations considering the hybrid system as a whole, instead of each generating unit individually, is evident. Comparing results shown in Fig. 7 with the ones in Fig 6, a reduction in the complementarity effect of these two generating units can be noticed. This feature is a consequence of unequal power, dominant installed capacity of WPP which are characterized by slice more variability than PVPP, as well as differences in the efficiency of the two applied technologies and availability of the considered resources at the same site. In this case, output power variations of the entire hybrid system range from -90% to 70% of Pn. For Case II in 85.6% of the time, variations are in the range of ±20% Pn. Only in 8.8% of the time there are no variations between two adjacent values.

4.1 Satisfying local power consumption

For further analyses, small consumption centre in proximity of the location of the potential hybrid system was taken into account, for the same considered time period. The annual peak load of the consumption centre amounts 3.5MW, while the average load is 2.25 MW. The hourly values of output power from hybrid facility in both cases were compared to hourly load values. Fig. 8 indicates the percentile difference between electricity generation and consumption in one year period, based on hourly data. It can be seen that for the hybrid system in Case I for 29.9% of the time the electricity generation can satisfy only 10% of the hourly consumption. Also, in 0.1% of the time, hourly generation exceeds the consumption by 60%.

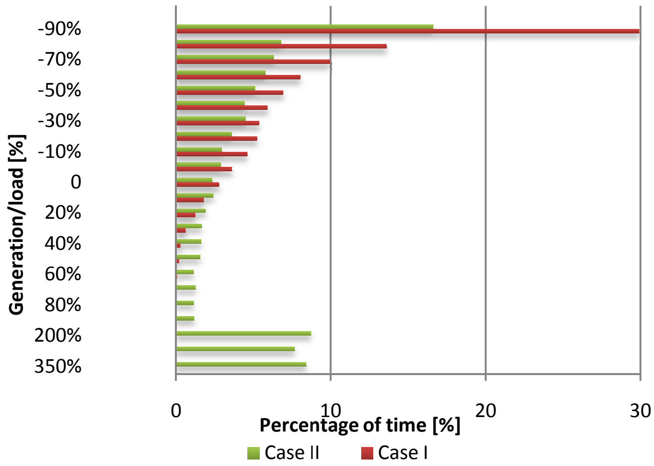

Fig. 8 Hybrid system electricity generation relative to consumption - one year data

From Fig. 8 it can be seen that, for the hybrid system in Case II, for 16.6% of the time the electricity generation can satisfy only 10% of the hourly consumption. Also, there are periods of time when the hourly generation exceeds the consumption by 350%. This happens even in 8.4% of the time. In cases with this amount of energy excess, when the off-grid system is considered, it would be necessary to have some kind of storage.

An appropriately designed energy storage system could improve the situation considering satisfying local power consumption for off-grid consumption centres. However, the investment costs for such hybrid system configuration and energy storage implementations are still very high and commercial appliance of systems of these sizes is far from the viable [21]. Additional analyses have shown that, in case of energy excess storage, a hybrid system consisting of a 2 MW PVPP and an 8 MW WPP could meet local consumer needs. In this case the capacity of energy storage would be lower.

5 Conclusion

Wind and solar energy are two RES that can and must be used more strongly. This can 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. The implementation of WPP and PVPP are predicted for a very high increase and that in a very near future. Their usage in hybrid systems is very important at local level, particularly in areas far away from major consumption centers (mountain resorts, tourist centers). But besides that, these RES are characterized by high output power variability.

In this paper, hourly variations are considered and a positive effect on reducing the range of output power variation in the case of a hybrid system, in comparison with variations when considering generating facilities individually, has been observed. This effect plays an important role when it comes to auxiliary service provision and power balancing in power systems. This approach and the performed analyses point out the complementary nature of solar and wind energy, as two intermittent RES used for electricity generation. Due to equal amounts of installed capacities, the hybrid system configuration considered in Case I has a more positive effect on reducing the output power variation range, compared to the ones gained in Case II. The monthly difference between electricity generation and consumption is somewhat more favorable during summer months, especially in the period April 2012 - September 2012. This feature is attributed to favorable operating conditions for the PVPP and higher values of solar irradiation.

Independent electricity generation of any of the two hybrid systems considered would not meet local consumer needs. In respect to this, an alternative supply is necessary, either through the grid or by providing storage of a useful form of energy that could be converted into electricity, when needed. Energy storage would especially make sense in Case II, given that the absolute annual difference between electricity generation and consumption is positive. However, although total annual electricity generation is 25% higher than the consumption, in 50% of the time the load could not be met. Furthermore, storing of electricity excess, amounting 350% of load in some periods, would require large overall dimensions, which, as with currently available technologies is not profitable.

Optimal sizing options with appropriate operation strategies were not considered for the generating facilities in this paper. This would be a further step. Research in energy storage systems (not only in batteries), especially for remote area electrification, are materials for further investigations.

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