HYBRID WIND-DIESEL SYSTEM FOR ELECTRICITY SUPPLY OF ISOLATED CONSUMERS IN SOUTH-BANAT REGION (SERBIA)

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SUMMARY: In this paper, based on a realistic example of two-member household which was identified in this region, technical and economical aspects for the development of a hybrid wind-diesel system for electricity supply is analysed. Key questions addressed in this paper are: estimation of daily and seasonal load profile for isolated consumer, estimation of available renewable potential at isolated consumer micro-location, optimal design of electricity source based on renewable technologies, optimal design of energy storage system, demand side management aspects.

1. INTRODUCTION

The investigation of the wind energy potential in Serbia clearly emphasized the region of Vojvodina as the most promising region [1]. Basic characteristics of this region regarding the utilization of wind energy resources are:

- Good potential of wind energy,
- Accessible terrain and low costs of constructing wind power plants,
- Low level of atmospheric storms,
- A good potential of other renewable sources of energy (biomass, solar, and geothermal energies) allowing design of hybrid systems,
- In the area there are relatively many isolated consumers which could be supplied with electricity by the small isolated wind-aggregates or hybrid isolated systems.

Target region of special interest for this paper is Deliblatska Peščara. Deliblatska Peščara is characterized with good wind potential. In that area many various isolated consumers exist. Technical advantages of supplying these consumers with electricity from small wind turbines were tested on an example of a two person household, which is located in the wider region of targeted area of Deliblatska Peščara.

2. WIND POTENTIAL OF TARGET REGION DELIBLATSKA PEŠČARA

Based on wind measurements conducted in targeted region using 40 m anemometer mast and meteorological data from regional measurement stations, and by using WAsP software, a high resolution (200×200)m map of wind potential for a wider area of Deliblatska Peščara was created, Fig.1. [1].

The geographical coordinates of isolated consumers which were identified in targeted area were obtained using GPS receiver, and were used to identify wind potential for every consumer and for measuring their distance from existing power grid. Based on available meteorological wind speed measurements for every location, wind potential was determined using WAsP software.

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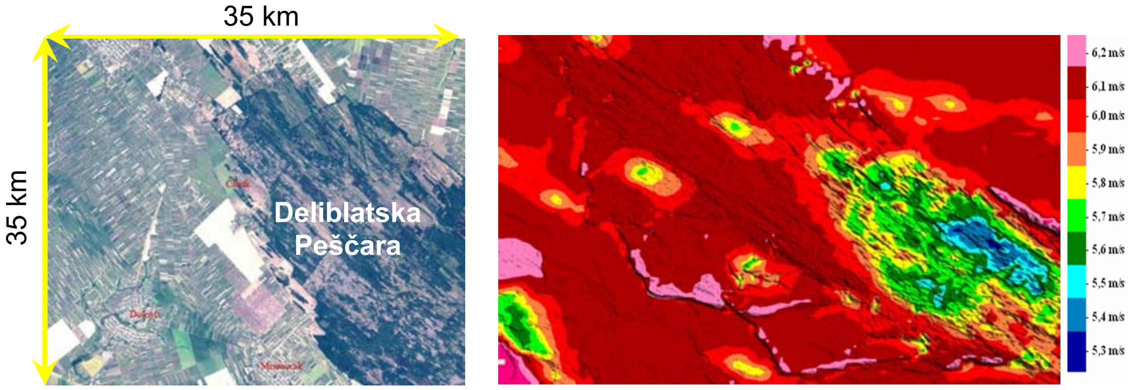

Fig. 1: Climatologic corrected wind potential map at 50 m height of target region

Fig. 2 shows photos of some isolated consumers located within the targeted area of Deliblatska Peščara.

Fig. 2: Several isolated consumers located within targeted area of Deliblatska Peščara

Considering the economical and social benefits, the isolated household has been chosen (two persons household – salash, Fig. 3) for detailed analysis. Basic activity of the household members is small scale agricultural production. Electricity is currently used for light and powering of the radio. The electricity is generated by diesel units and accumulator batteries. The energy for heating and food preparing is gained by burning biomass (wood and agricultural waste). Water is supplied from the well, which is located in the back yard.

Providing the electricity supply for this household would drastically improve living conditions there. This household is situated distant from the existing power grid, approximately 2 km away. Although it is relatively short distance, the costs of interconnection to power grid are relatively high.

Fig. 3: Selected isolated consumer, location N: $44^0 56.712'$; E: $20^0 44.060'$

3. OPTIMAL DESIGN OF WIND ENERGY CONVERSION SYSTEM

Optimal design of isolated electricity supply system represents complex optimisation problem because it has to include many different factors which are very often difficult to quantify. Key questions in optimal design of isolated electricity supply systems are:

- Estimation of available renewable potential at isolated consumer micro-location
- Estimation of daily and seasonal load profile for isolated consumer
- Optimal design of electricity source based on renewable technologies
- Optimal design of energy storage system
- Demand side management aspects
- Economic, environmental, regulatory and social aspects of renewables for isolated consumers

3.1 Estimation of available renewable potential at isolated consumer micro-location

Micro-location of the selected consumer is characterised with good wind potential with average yearly wind speed of 6 m/s at 50 m above ground level (Fig.1). In order to get realistic insight in the conditions for electricity production at selected site, detailed wind potential analysis were conducted. Fig.4 shows wind rose, estimated wind potential at micro-location and Weibull statistics parameters (A and k). Wind energy characteristics at the selected location are calculated using the WAsP software. The inputs for the calculation were the wind measurements taken for the time period of one year using the 40 m anemometer mast which was located 5 km from the selected consumer.

-	Total
Mean wind speed	5.83 m/s
Mean power density	224 W/m²

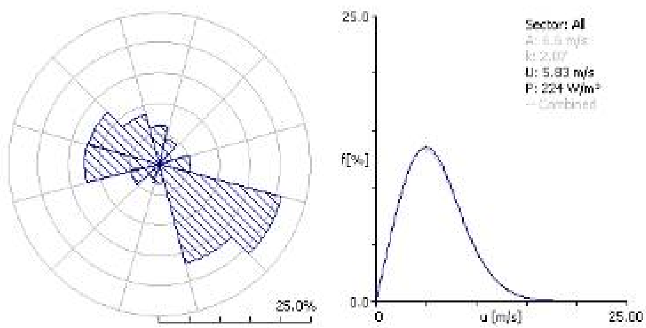

Fig. 4: Estimated wind potential (40 m a.g.l.) at micro-location of the selected isolated consumer

3.2 Estimation of daily and seasonal load profile for selected isolated consumer

In order to establish adequate daily electricity demand profile for selected isolated consumer, electricity consumption measurement of a similar household which is connected to grid were conducted. Both households were inhabited by two persons. From the conversation with members of both households it was concluded that their electricity needs are very similar to ones of the analyzed household which is connected to power grid.

Based on two-year electricity measurements for selected reference consumer, typical monthly electricity demand was established. Basic idea for optimal design of wind energy conversion system at the selected sites is identifying the most critical period which is characterized by large consumption and low wind resource. Based on wind speed measurements using 40 m anemometer mast, average wind power density for each month was established. Fig. 5 shows comparative analysis of average monthly specific wind power and estimated monthly electricity demand at consumer side.

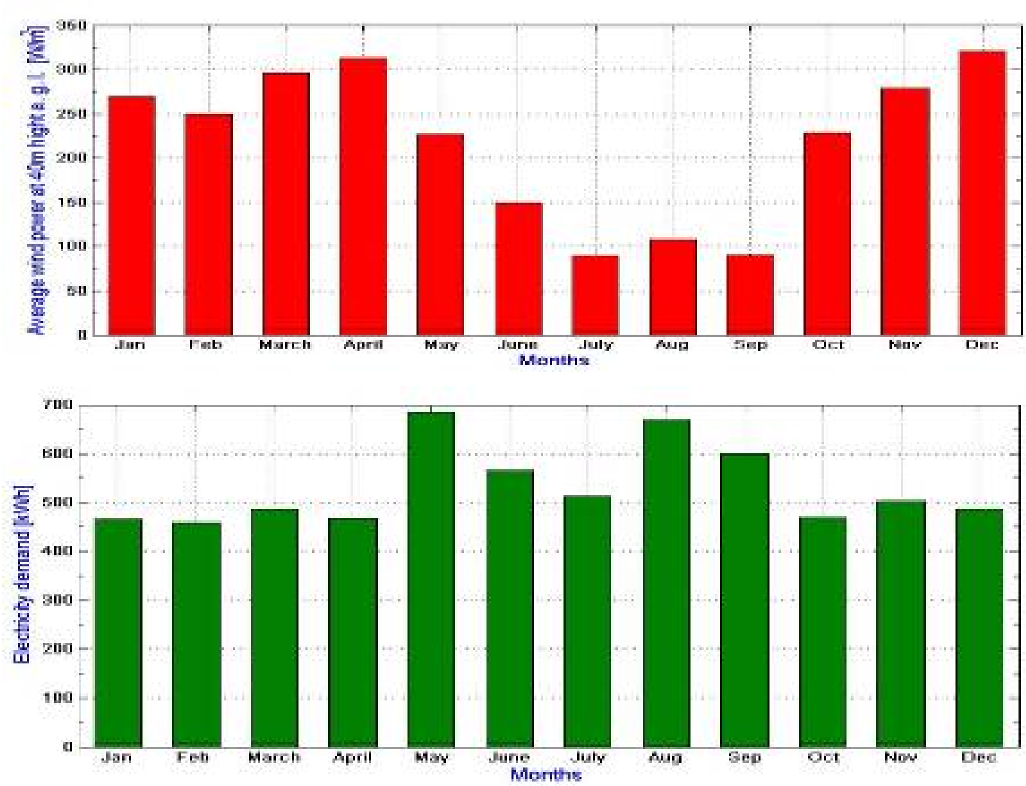

Fig.5: Average monthly wind power density vs. typical monthly electricity demand for the isolated test household

Annual wind variations at analyzed location do not correspond to electricity demand. Critical months are July, August and September when the demand is relatively high and on the opposite side the wind potential is low. In order to create typical daily demand diagram, site measurements were conducted during characteristic period, Fig 6.

Based on the average power consumption measurements of the referent consumer taken every 15 minutes, typical daily demand profile for similar household connected to the power grid was created. Daily demand diagram corresponds to the conditions of grid connected household. Conducting activities which could result in energy consumption rationalisation, electricity consumption management and by using the energy efficient appliances daily demand diagram could be adjusted to the wind conditions.

similar household connected to the grid *load profile measurement* *isolated household*

Fig. 6: Measurements of realistic electricity needs for referent household similar to the isolated household

3.3 Optimal nominal wind turbine power assessment

During the course of the measurement with the sample rate of 10 minutes, measured energy consumption of the referent consumer was W_c=186,6 kWh. Basic assumption was that wind turbine nominal power should be selected in order to fulfil energy production (W_{wg}), which is equal to energy consumption in analysed critical period:

$$W_{wg} = W_c \,. \qquad (1)$$

Using the selected wind turbine characteristic, typical daily diagram of specific wind turbine production for the analysed period was formed. Specific energy output of the wind turbine in the analysed period is given as:

$$W'_{wg} = \int_{t=0}^{10days} P'_{wg}(v)dt = 11{,}48 \text{ kWh/m}^2 \,. \qquad (2)$$

Using the condition defined in relation (1), it is concluded that the active surace of the wind turbine should be $A = \frac{W_c}{W'_{wg}} = \frac{186{,}6}{11{,}48} \approx 16\,\text{m}^2$. The optimal nominal power of the wind turbine is then given with:

$$P_{wgn} = 0{,}5 C_p \rho A v_n^3 = 4 \text{ kW}. \qquad (3)$$

Based on the typical characteristic of the small wind turbine and the 10 minute wind speed measurements at the 20 m height in a time period of one year, the expected amount of generated electricity is calculated for every month. For a comparable analysis, registered consumption of electricity for a specific consumer is given in Table 1.

Table 1. Comparable preview of expected electrical energy production and consumption for the analysed wind energy conversion system

Months	**Wind conversion system electricity generation W_{wg} [kWh]**	**Electricity consumption W_{ec}[kWh]**	**W_{wg} - W_{ec} [kWh]**
January	650	470	180
February	691	460	231
March	992	490	502
April	916	470	446
May	770	690	80
June	680	560	120
July	325	515	-190
August	440	660	-220
September	365	600	-235
October	865	470	395
November	810	505	305
December	746	490	256
Total	**8210**	**6380**	**1830**

Wind powered electricity generation shown in Table 1 referrers to gross energy production, so available net energy is about 10-15% lower due to the losses in the system and the eventual wind turbine outage. Based on a time period of one year, overall efficiency of the specific wind turbine is:

$$\tau = \frac{W_{wg\ yearly}}{8756 \cdot P_{wgn}} = \frac{8210}{8756 \cdot 4} = 23{,}44\% \,. \tag{4}$$

Based on comparative data analysis shown in Table 1, the conclusion is that during the summer months (July, August and September), wind powered electricity generation is insufficient to respond to the consumers demand for electricity. In this period, engagement of diesel unit is necessary, or addition of a PV system as a complementary electricity source knowing that insolation is maximal at this time of year.

3.4 Optimal design of energy storage system

Basic disadvantage of the wind as a primary energy source is its stochastic behaviour, so the inevitably consequence is imbalance between available energy production and customers demand. Existence of accumulator batteries could minimize this imbalance, and in the cases of greater variations for a longer time periods, existence of the diesel units or fuel cells are necessary. Fig.7 shows the typical daily wind power profile vs. typical daily electricity demand profile for the isolated test household. It is concluded that the typical daily wind power profile follows the electricity demand profile for the isolated test household, which is very important for minimization and optimization of an energy storage system capacity.

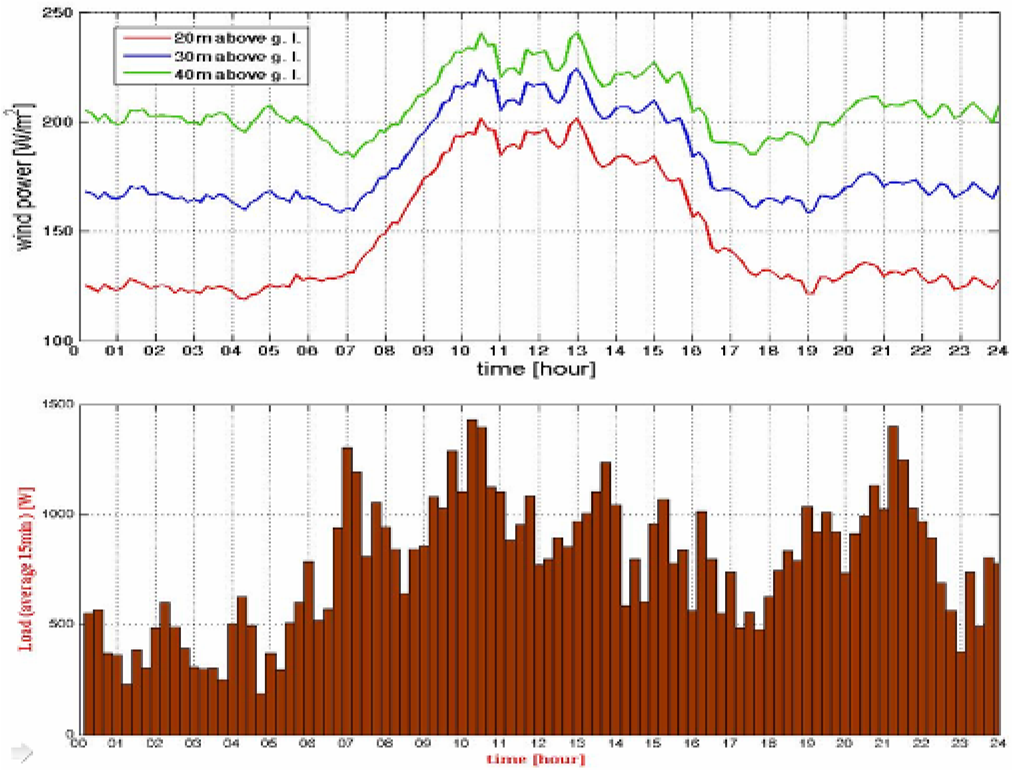

Fig.7: Typical daily wind power profile vs. typical daily electricity demand profile for the isolated test household

Fig.8 shows the difference between real power output and measured power consumption for the isolated test household in analysed measurement period.

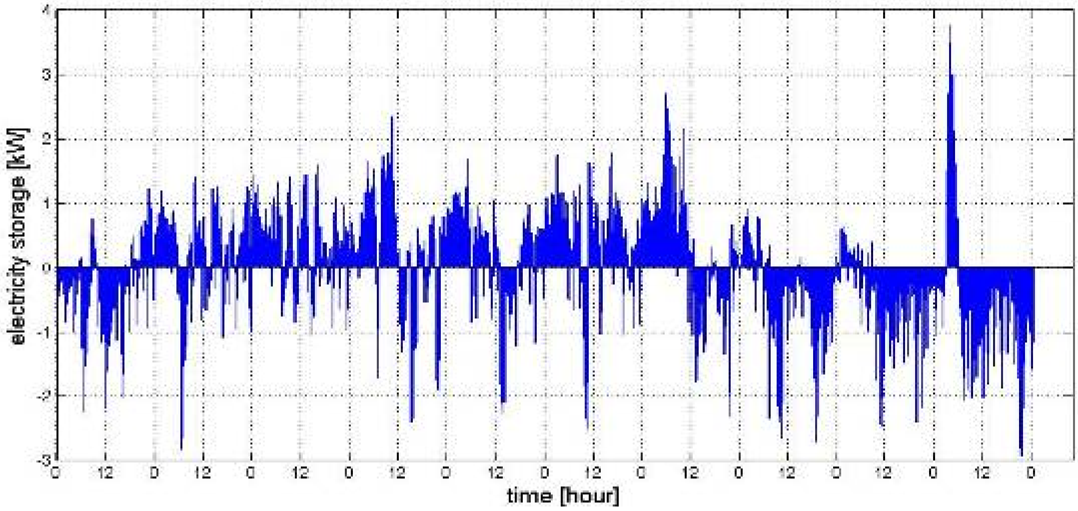

Fig. 8: Accumulator battery charging (discharging) power.

For optimal power usage (consumption), maximal allowed accumulator battery charging power (P_{accmax}) should be:

$$P_{acc\max} \geq P_{wgn} \tag{5}$$

If the relation in (6) if satisfied, then the maximal efficiency of the wind turbine is established when there is no need for electricity. These are periods when the accumulator battery is almost empty.

In order to determine the capacity of the battery, cumulative energy generation and consumption is analysed, and capacity of the battery which could cover the imbalance between electricity production and consumption in analysed measurement period of 10 days is determined.

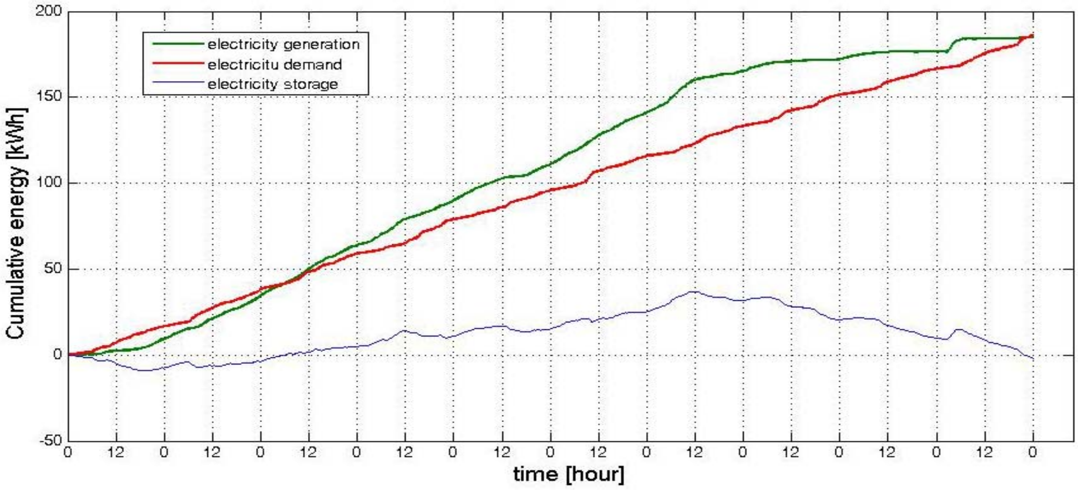

Fig.9: Cumulative energy generation, consumption and storage.

Based on diagram shown in Fig.9, it is concluded that the capacity of the battery should be 42 kWh. Regarding the demand for the large capacity it is necessary to analyse the possibility of battery reduction through consumption management.

3.5 Demand side management aspects

When the consumer is connected to power grid, it has a certain comfort concerning switching the electrical appliances on and off. In conditions of isolated operation, the electrical consumption needs to be adjusted to wind and electricity production conditions. Therefore, it is necessary to define all various consumers and to determine their priority for consumption management. Table 2 shows an overview of all appliances (consumers) in analysed referent household.

Table 2. Appliances (consumer) characteristics in analysed household

Consumer	Number and power per unit [W]	Total power [W]	Priority
Light	5x40	200	1
Refrigerator	1x300	300	1
Freezer	2x400	800	1
Boiler	2x1000	2000	2
Water pump	1x1100	1100	1
Washing machine	1x2000	2000	2
TV	1x60	60	1
Iron	1x1000	1000	2
Bakery	1x1500	1500	2
Stove	2x1000	2000	2
Circular	1x1100	1100	2
Total installed power		**11660**	

Based on information gathered in conversation with household members and by analysing the current harmonic distortion, typical periods of individual unit usage during the day were determined.

06:30-07:30 – household members are waking up, turning on water pump and stove;
08:00-11:00 – every other day bakery is turned on for a time period of 3 hours (average);
11:30-13:30 – preparing of the lunch, stove, water pump, in this period every other day washing machine is working;
15:30-16:30 – bakery, every other day;
19:00-22:00 – TV, light, iron;
22:00-23:00 – water pump, light;

Around 23:00 h (11 PM) most of the electricity appliances are switched off, other than intermittent (refrigerator, freezer and boiler which are powered without interruption). The electric wood saw is operational only when the need for wood appears (it is used for food preparing for domestic animals).

The purpose of energy consumption management is that in the low wind period conditions (energy production deficit) switching on the consumers with priority 2 could be avoided. Switching on these appliances is related to good wind conditions, so it is only a delay of their usage. Regarding the energy consumption management, the water heater is the most suitable one. The energy consumption management of this consumer can significantly reduce capacity of the accumulator battery storage system.

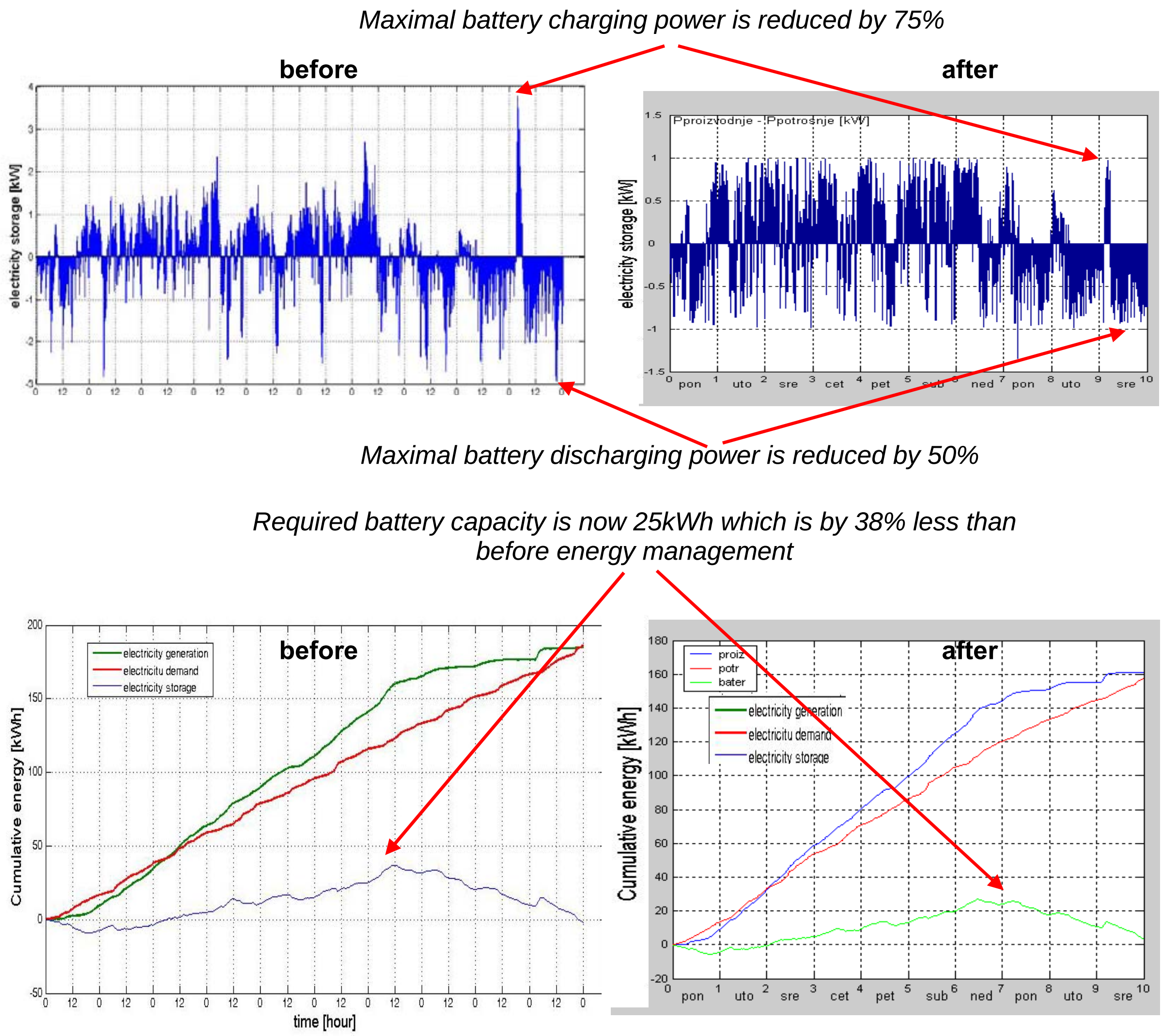

Fig. 10: Effects of water heater energy consumption management on electricity storage system.

In the analysed time period, certain time intervals were identified which could be suitable when the water heater could be switched on. The power of water heater is P_{accb}=2000W, and it is realised with two separate heaters, each with power of P_h=1000W. The only prerequisite is that electrical energy in that period remains unchanged, in other words the cumulative time when it is switched on is equal before and after energy consumption management. Fig.10 shows effects of water heater energy consumption management on electricity storage system.

After energy consumption management using water heater, the imbalance between generation and consumption of electricity is significantly balanced and maximal battery charging power and battery discharging power is app. 1000 W. Main effect of energy consumption management beside the reduction of the power for battery charging and discharging is the reduction of the battery capacity from 42 kWh to 25 kWh. Further decrease in battery capacity could be achieved with further energy management with appliances from the category 2 (switching the washing machine and wood saw could be coordinated with wind conditions), increasing the energy efficiency, resulting rational energy consumption. Based on this assumption, the accumulator battery with the capacity of 12 kWh is selected. Basic role of accumulator battery is to amortize short unbalances between electricity production and consumption. In cases of discharging, the batteries could supply the appliances from the priority category 1. For electricity supply in the conditions of the longer time periods (few days) with low wind speed it is necessary that the system has electricity source which could be engaged if the need for that arise (it should be always in stand-by regime). Realisation of the energy storage system is possible as a combination of the accumulator battery and diesel unit (or fuel cell).

Based on the conducted analysis shown in Table 1, the wind turbine should produce 5535 kWh net electricity annually, approximately 99% of electrical energy needs of this consumer. In order to ensure the remaining 645 kWh/year in the critical period (summer months), a diesel unit must be engaged. In order to fully substitute wind turbine with diesel unit in periods with no or low wind or if the wind energy conversion is not operational, nominal power of the diesel unit should be the same as the nominal power of the selected wind turbine, P_{dgn}= 4kW.

4. CONCLUSIONS

In the target region of Deliblatska Peščara many types of potential consumers, located far from the existing power grid were identified. Wind energy potential was calculated for every identified object based on measurements conducted in this region. Measurements and calculations show that the target region has good technically usable wind potential with average annual wind power density from 250 to 300 W/m^2, at 50 m height. Considering good wind potential, construction of isolated electric systems based on wind turbines is economically and ecologically justified solution for electricity supply of isolated consumers in this region.

As target consumer, the two-person agricultural household was selected. Annual and daily electricity demands of target consumer were estimated by measuring daily load profiles of a similar - referent consumer. Based on realistic electricity needs of isolated household and wind speed measurements (during the most critical 10-day period), the optimal wind turbine power, and the accumulator battery capacity were determined. Examining collected data of monthly electric energy demand and expected production of chosen wind turbine, the conclusion is that during summer months additional electricity generated from diesel units is needed. Wind turbine would still cover 90% of total annual electricity needs.

Acknowledgement

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