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The concept of algorithm for optimal selection of power and the number of generators in hybrid solar–wind power plant

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The paper presents the power–split algorithm of hybrid power plant. The article focuses particularly on the optimal, in order to ensure the best opportunities for regulation, in a hybrid system. The document presents the concept of the algorithm selection quantity of generators and division of power individual generators. The proposed algorithm takes into account the use of energy storage as part of the buffer, reducing fluctuations generated power. The results of calculations and comparison for a couple of accepted variants for the sample location are presented in the article.

KEYWORDS: optimization of the hybrid power plant, energy storage, minimizing the fluctuations of power, photovoltaics, wind power plant

1. Introduction

A power station is an object producing the electric energy on industrial scale and therefore using usually organic or nuclear fuel. It is also capable of adjusting the already produced parameters (power, voltage and frequency) [9].

Nowadays there is a perceptible trend to use the renewable resources like the wind or the sunlight. Apart from ecological advantages, the use of such types of resources is supported by orders and incentive from the European [1] and national legislation [11, 12]. For both of these resources there are difficulties in the power, voltage and frequency regulation. The combined object can be built, it means a combination of aero generator and solar panels, contributes to improve working conditions and decreasing the power fluctuations, which result from the stochastic nature of wind and the change of density of power–radiation during the day. On this basis it is possible to build a combined object, which means combining the aero generators and the solar panels. An example of a structure of wind–solar hybrid power station is illustrated in the Figure 1.1.

Planning to build a hybrid power plant should take into account the weather conditions that prevail in a given area. In the Figure 1.2 and 1.3 the weather parameters are shown.

It is most preferred when the photovoltaic panels and turbines operate in locations with high radiation power density and good wind conditions. In designing hybrid power plant it is necessary to obtain accurate measurement data such as wind speed and intensity of radiation. The source of data is usually measurement (often very accurate) made by professional companies or public (less accurate) measurement data of the Ministry of Development [13].

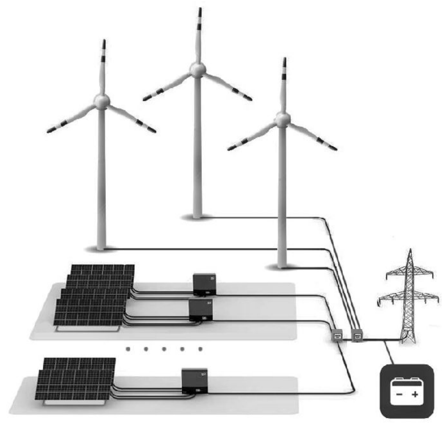


Fig. 1.1. Hybrid power plant structure

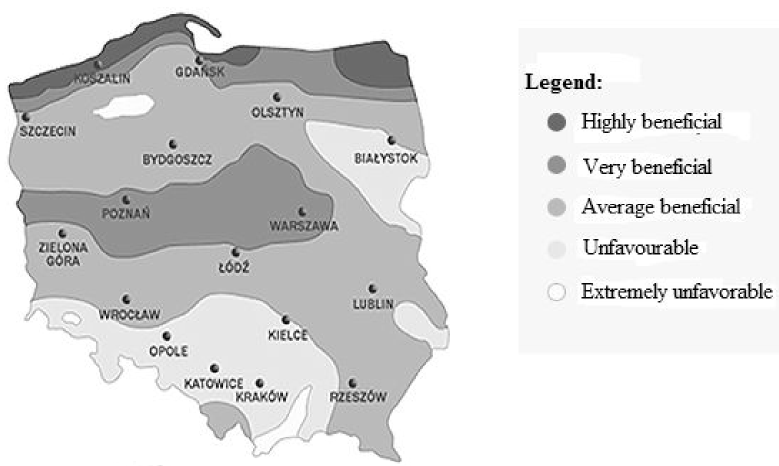


Fig. 1.2. The wind conditions in Poland [14]

The power variation is an inherent problem during the exploitation of energy resources. In case of using the renewable energy resources in hybrid power stations, a system eliminating these variations has to be taken into consideration. Such an object is for example every energy storage, that provides a possibility to store the energy excess or to keep the energy flow to electricity network even during bad weather conditions. The buffer should not lose the capacity to send the power during the exploitation time.

Fig. 1.3. The density of solar radiation for Poland [6]

2. General selection criteria of components in hybrid power plant

Choosing the devices that will be part of larger and more complex systems it is necessary to pay attention to a number of aspects relating to the component and system. Among the first can be distinguished such as: nominal power of the device, efficiency, availability on the market failure, durability and warranty conditions of the manufacturer and the cost of the component. Considerable importance to the technology of each part. The individual properties of each element that should be taken into account when choosing solutions, but depend on the type of device and the type of their tasks. In the case of hybrid power plant basic components are photovoltaic panels, wind turbines, and energy storage.

During the selection of photovoltaic panels to hybrid power plant sun exposure occurring at the location of the project should be analyzed. These conditions determine the choice of technology of modules – in Polish conditions, a better solution is to use polycrystalline panels that absorb inferior energy in scattered radiation. In addition, pay attention to the existing security panels against partial shading (eg. By the LED by–pass) and the level of protection modules against the influence of atmospheric factors [2].

The choice of a model of a wind turbine to hybrid power plant depends on wind conditions. In this case, it is necessary to appoint a histogram of wind speed which takes into account the most common values. For an insufficient number of data it is possible to determine the probability of a given wind speed, eg. Using the Weibull distribution, using reliable, average wind speed in a given period. Information on the most frequent wind speeds allows choosing turbine power characteristics of guarantees for start–up wind speed lower than most. On this basis, it is possible to estimate the probable yields from power turbine [8].

The energy storage in hybrid system plays a very important role, because it prevents fluctuations of output power which is brought into the system. The energy storage is installed in power plant to buffer excess energy in times of high wind or solar radiation and giving this energy to the network when the weather conditions does not allow the production of the required amount of energy [7]. During the selection of the energy storage the primary criteria is capacity of storage and the time of charging and discharging. In addition, the energy storage system should be equipped with system which will be gathering the information about the control and regulation of the charging process. When the energy storage include battery modules the manufacturer should also the number of discharges and re–charges. Due to the wide range of energy storage which can be used in power plant system the nomograms can be used to determine the type of this device. The sample of nomogram is shown in Figure 2.1.

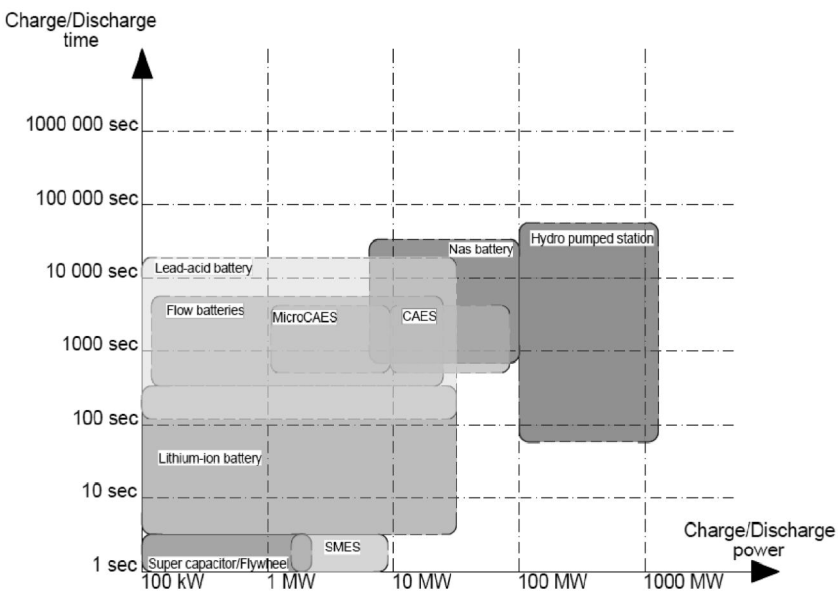


Fig. 2.1. An overview of chosen storage technologies depending on time of unload/load and the power; NAs – soda–sulfurous battery CAES – compressed Air Energy Storage, SMES – superconductive energy storage [9]

3. The concept of power split algorithm of a hybrid power station

3.1. Preparation of the data

Developed algorithm for optimization will use climate data on the structure similar to records obtained research station of the Ministry of Development. They are available in the form of files called *Statistical year climate* [15]. Measurements of wind speed and solar radiation intensity (for different geographical configuration and angle) are given every hour throughout the year, giving the final number of samples equal to 8760.

Statistical data on wind speeds are given for up to 10 m n. P. G., To obtain information for a different level of high, use the relation [10]:

$$v_2(h_2) = v_1(h_1)\left(\frac{h_2}{h_1}\right)^{\alpha} \tag{1}$$

where: $v_2\ (h_2)$ – searched value of the wind speed at a predetermined height, $v_1\ (h_1)$ – known value of the wind speed at a given height, $h_1,\ h_2$ – analyzed height, α – parameter, constant value – 0.14.

Data from the statistics of the Ministry of Development were obtained by measuring wind speeds at a height of 10 m. The height of the turbine is 100 m and for such values the conversion of speed was made.

In this case, the analysis of solar radiation, the geographical angle should be assumed. For this purpose it is necessary to compute, annual amount of radiation achieved in each configuration, and select one in which the total value of the radiation intensity is the highest.

3.2. The process of operation of the algorithm

In the proposed algorithm, it is assumed that the design process will be conducted in the following stages:

1. selection of kind / type of wind turbines and photovoltaic panels for the assumed conditions of wind and solar based on statistics – Fig. 3.1;
2. estimate the expected yields for the individual components of the system – Fig. 3.2;
3. determine the division of power according to the adopt criteria.

The main objective of the algorithm is the division of the power of individual sources, to minimize power fluctuations, and consequently, the required storage capacity of energy.

For analysis, the special program was written. The program allows to summarize the results for various configurations of hybrid power plant. The algorithm suggests the appropriate amount of wind turbines and solar panels, depending on the required power level. The program also allows to manually change the quantity of generators.

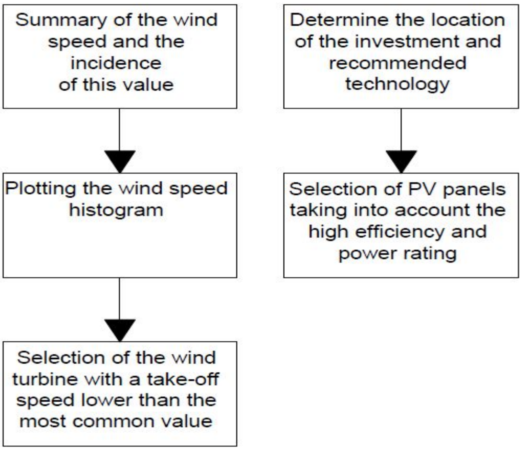


Fig. 3.1. The selection process for the turbine and photovoltaic panels to hybrid power plant

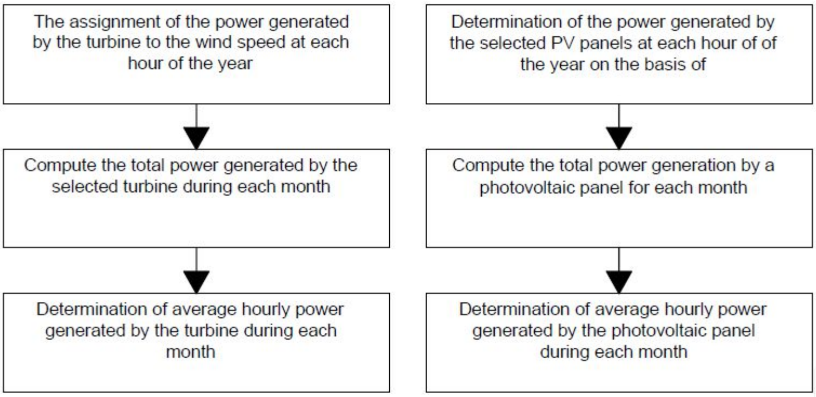


Fig. 3.2. The process of estimating the expected benefits for the individual system components

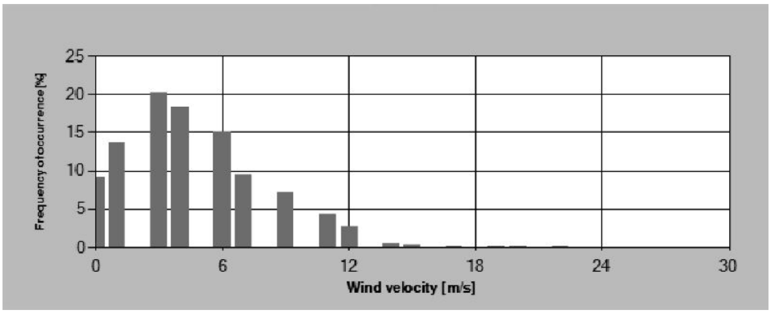
4. Variants of hybrid power–plant

To illustrate the operation of the proposed algorithm and the C# application, will be performed simulation analysis of the theoretical object – hybrid power plant. The location of analyzed structure is city of Poznań. The prepared variants of power plant are the following:

- automatic solution, proposed by program,
- power plant with 72% participation of wind turbines and 28% of PV panels,
- power plant with 48% participation of wind turbines and 52% of PV panels.

Based on measurements of wind speed, velocity for height of 100 m has been calculated. This data allowed to draw the wind histogram of city of Poznań. Similarly the irradiation histogram has been drawn.

a)



b)

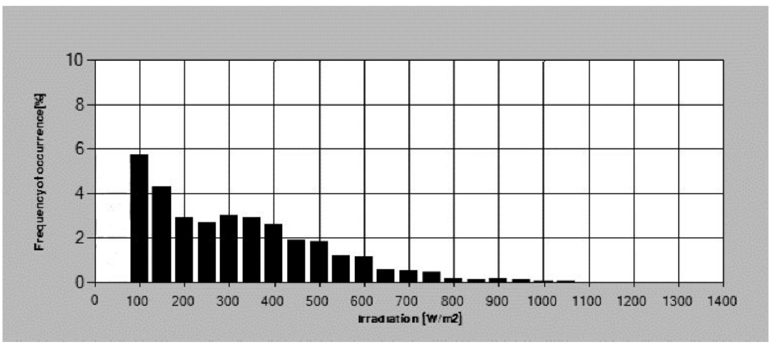


Fig. 4.1. The wind velocity: a) and irradiation, b) histogram of city of Poznań

Selected to the hybrid power plant turbine is Enercon E–44. Rated power of this generator is 900 kW. Other relevant data:

- Velocity Cut In: 3 m/s,
- Velocity Pn: 17 m/s,
- Velocity Cut Out: 25 m/s.

Next step was selection of photovoltaic panel. The chosen one is polycristalline module AC–300P/156, from Axitec company. The rated power of this source of Energy is 300 kW. Figure 4.2 presents power characteristic of chosen turbine and selected PV panel.

The next step was to calculate the total power generated by each energy source in every hour of the year, within a month and an average hourly energy production in a given month. Figures 4.3 – 4.5 present this informations.

The assumed constant level of power transfer to the network by hybrid power plant is 1 MW. To select the shares of individual energy sources C# application was used. The main criterion was very precise average monthly production, which was determinated earlier. The two other variants have been prepared with expemlary shares. The Table 4.1 and Figure 4.6 presents the results of first variant, Table 4.2 and Figure 4.7 – results of second and the third variant's results are in Table 4.3 and Figure 4.8.

a) b)

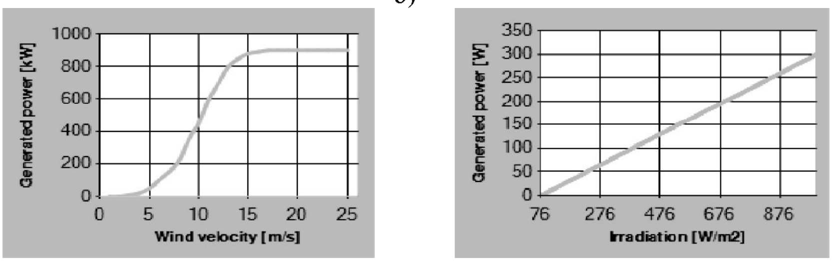


Fig. 4.2. The power characteristics of wind turbine Enercon E–44:
a) and photovoltaic panel AXITEC AC–300P/156, b) [3, 4]

a) b)

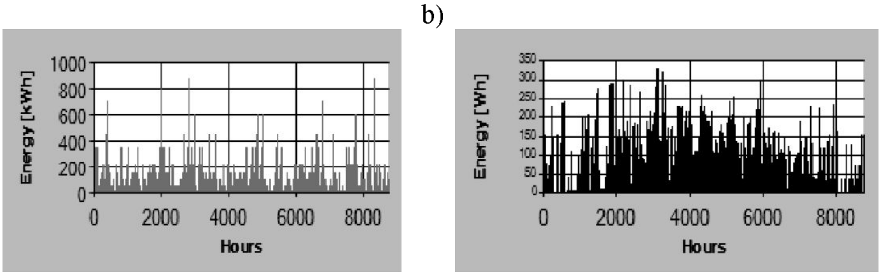


Fig. 4.3. Energy generated by one turbine: a) and by one panel, b) – hours in the year

a) b)

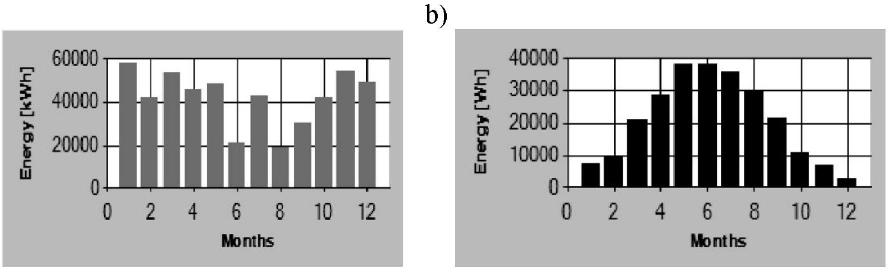


Fig. 4.4. Energy generated by one turbine: a) and by one panel, b) – monthly amounts

a) b)

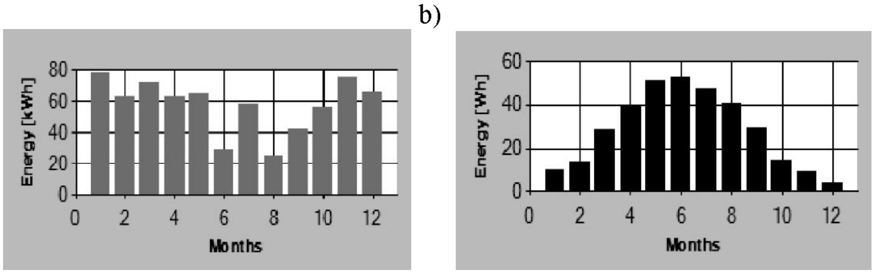


Fig. 4.5. Energy generated by one turbine (a) and by one panel per hour by month (b)

Table 4.1. Results of variant 1 (automatic solution): 17 turbines, 1 000 panels

Month	Avg. hourly yield of wind part	Avg. hourly yield of solar part	The total generated power	Overcapacities of power	Deficiencies of power
	kWh	kWh	kWh	kWh	kWh
January	1322.53	9.99	1332.52	332.52	0.00
February	1065.28	13.79	1079.07	79.07	0.00
March	1222.45	28.32	1250.77	250.77	0.00
April	1075.96	39.24	1115.20	115.20	0.00
May	1105.23	51.08	1156.31	156.31	0.00
June	498.19	52.54	550.73	0.00	449.27
July	979.56	47.57	1027.13	27.13	0.00
August	431.85	40.26	472.11	0.00	527.89
September	716.60	29.53	746.13	0.00	253.87
October	962.19	14.60	976.79	0.00	23.21
November	1268.15	9.40	1277.55	277.55	0.00
December	1121.68	3.92	1125.60	125.60	0.00
Total year	11769.67	340.23	12109.91	1364.15	1254.24

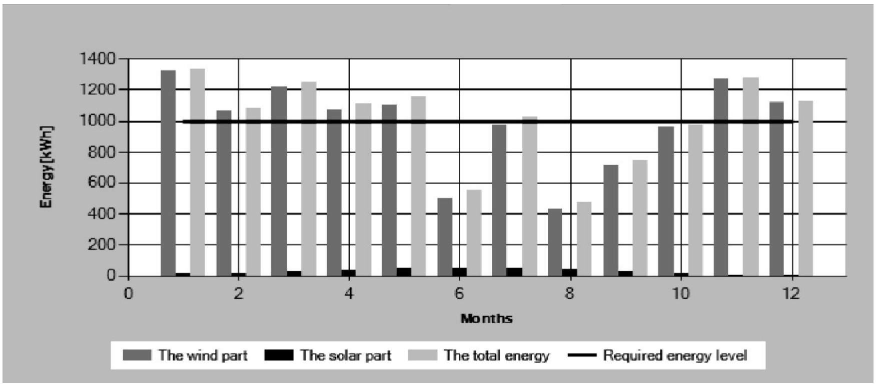


Fig. 4.6. Energy generation by variant no. 1

Table 4.2. Results of variant 2: 11 turbines, 13 000 panels

Month	Avg. hourly yield of wind part	Avg. hourly yield of solar part	The total generated power	Overcapacities of power	Deficiencies of power
	kWh	kWh	kWh	kWh	kWh
January	855.75	129.82	985.57	0.00	14.43
February	689.30	179.21	868.51	0.00	131.49
March	790.99	368.11	1159.10	159.10	0.00
April	696.21	510.15	1206.36	206.36	0.00
May	715.15	664.10	1379.25	379.25	0.00

Table 4.2 cont. Results of variant 2: 11 turbines, 13 000 panels

June	322.36	682.99	1005.35	5.35	0.00
July	633.83	618.47	1252.30	252.30	0.00
August	279.44	523.37	802.81	0.00	197.19
September	463.68	383.89	847.57	0.00	152.43
October	622.59	189.81	812.40	0.00	187.60
November	820.57	122.20	942.77	0.00	57.23
December	725.79	50.93	776.72	0.00	223.28
Total year	7615.67	4423.04	12038.71	1002.36	963.65

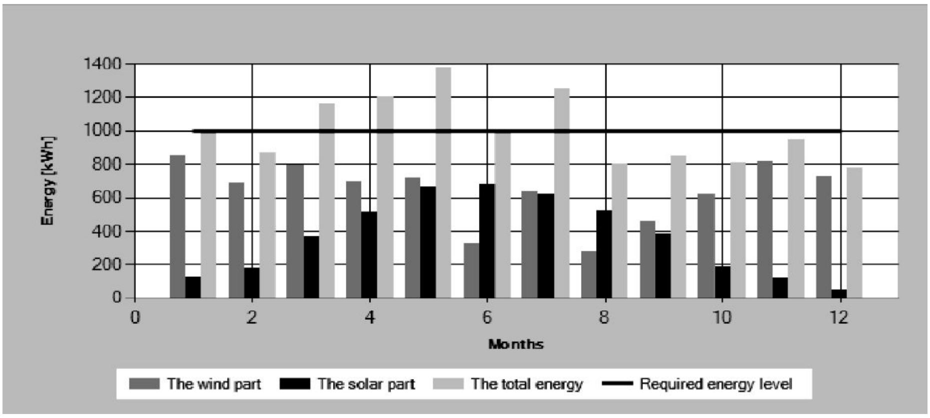


Fig. 4.7. Energy generation by variant no. 2

Table 4.3. Results of variant 3: 7 turbines, 23 000 panels

Month	Avg. hourly yield of wind part	Avg. hourly yield of solar part	The total generated power	Overcapacities of power	Deficiencies of power
	kWh	kWh	kWh	kWh	kWh
January	544.57	229.68	774.25	0.00	225.75
February	438.65	317.07	755.72	0.00	244.28
March	503.36	651.27	1154.63	154.63	0.00
April	443.04	902.56	1345.60	345.60	0.00
May	455.09	1174.95	1630.04	630.04	0.00
June	205.14	1208.37	1413.51	413.51	0.00
July	403.35	1094.21	1497.56	497.56	0.00
August	177.82	925.96	1103.78	103.78	0.00
September	295.07	679.19	974.26	0.00	25.74
October	396.20	335.81	732.01	0.00	267.99
November	522.18	216.19	738.37	0.00	261.63
December	461.87	90.10	551.97	0.00	448.03
Total year	4846.33	7825.37	12671.70	2145.12	1473.42

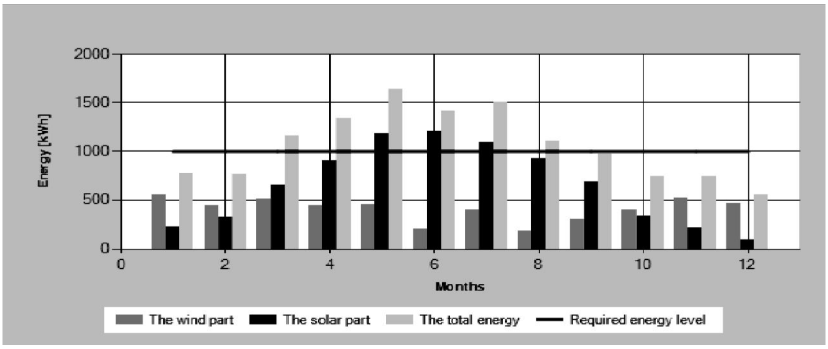


Fig. 4.8. Energy generation by variant no. 3

After all simulation the selection of the best solution was possible. The comparsion of al the variants is prepared in Table 4.4.

Table 4.4. The comparison of variants

	Variant no. 1 (automatic)	Variant no. 2	Variant no. 3
Number of turbines	17	11	7
Number of PV panels	1000	13000	23000
Avg. generation level per month [kWh]	1009.16	1003.23	1055.98
Difference between overpacity and deficiencies per year [kWh]	109.91	38.71	671.70
Difference between overpacity and deficiencies per month [kWh]	9.16	3.23	55.98
Suggested level of power capacity of power storage [MW]	2	2	3

Analyzing accepted cases, the program works with high accuracy as the Table 4.4 shown. Differences between surpluses and shortages constitute about 10% of the assumed power throughout the year. For the purpose of engineering the value is acceptable. Changing the number of turbines or PV panels is causing improvement or deterioration in operating hybrid system. Depending upon the ratio to the number of wind turbines and photovoltaic panels, differences excess and deficiency take larger or smaller values.

For the purposes of the designed hybrid power plant there was determined features that energy storage must fullfill:

- Long life, while maintaining constant performance during use;
- The possibility of communication and monitoring;
- High power rating that meets the requirements as a buffer;
- High efficiency of the system;
- Simple procedure of connecting to grid.

3. Summary

The paper presents the results of analysis based on the concept of the hybrid power plant. In the case of power plants using wind energy and solar radiation to produce electricity significant problem is the instability of these two sources. Both the speed of the wind as the intensity of radiation are stochastic. Designing a hybrid power plant can partially control this process.

The concept of program allows to estimate the yields of energy on the basis of meteorological data. Presented variations show differences that occur at different relative amounts of existing generators. The graphs present the results of calculations performed by the algorithm. The program proposes the size of storage capacity, while the choice of the type of energy storage (SMES, hydro power pump, Li–ion battery, etc.) should be carried out after a more detailed analysis of the electric network, and the parameters of the electric network should be taken into consideration.

In conclusion, it should be noted that the developed algorithm satisfies the assumptions, as shown by example presented.

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