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## ANALYSIS OF FACTORS FOR FORECASTING ELECTRIC POWER GENERATION BY SOLAR POWER PLANTS

*The new model of the wholesale electricity market in Ukraine causes appearance the market for the day ahead. In this market, the generating company undertakes to supply a certain amount of electricity. So, it is necessary to carry on the most accurate forecast of possible electricity generation by solar power plant (SPP). Generation value depends on certain factors. A brief summary of different influence of parameters on the PV cell performance has been provided. The article analyzes and identifies the factors that should be included in the forecast mathematical model of electricity generation by a solar power plant for a certain short-term period. According to analyzed data from SPP located in the Kyiv region, such parameters are the intensity of solar radiation, temperature and humidity, wind speed, and atmospheric pressure. The degree of influence of these factors on the initial function of electric energy generation were estimated by analyzing the scatter plot diagrams of relationship between parameters and correlation coefficients. Thus, the analysis of the influence of factors on the magnitude of electricity generation allowed to determine the priority of including each of the parameters in the mathematical model of the SPP power forecast. It was established that the influence of certain climate parameters for target function is different in each season. Therefore, in the mathematical model for forecasting electric power generation, it is necessary to take into account seasonality. In addition, the dynamic value change of factors also affects the current magnitude of electricity generation. Moreover, at different times of the year and with different combination of the corresponding values of climatic parameters, this effect may have different magnitudes. Therefore, the data obtained from the last periods before the forecasting should have a greater impact on obtaining the predicted value than the data from previous periods.*

**Keywords:** forecasting, electricity generation, solar power plant, correlation matrix, intensity of solar radiation.

**Introduction.** The wholesale electricity market (WEM) must move to a new operational model according to the regulation's rules adopted by now in Ukraine. This market has been implemented in many foreign countries and is called the model of bilateral agreements and balancing market [1]. One of its distinctive features is organization the general structure of the WEM market for the day ahead with the balancing part. This market allows supplier to purchase additional amount of electricity or sale excessively ordered amount at auction. It causes the appearance of new organizational management issues. Resolving of these tasks requires the development of fundamentally new means of automation the management processes and mathematical modeling that should base on modern mathematical methods. One of such tasks is operational daily planning of electricity supplies inside of the wholesale market. It is impossible without accuracy forecast of generated electricity. The generation of electricity by a solar power plant (SPP) depends on climatic conditions that change over time. To overcome this issue, it is important to use new intelligent methods that take into account value of all parameters which affect the accuracy of the forecast [2].

**Purpose and objectives.** The aim of the work is to determine the patterns for forecasting the amount of electricity generated by solar power plants on the short-term period depending on climatic parameters. These patterns will allow to build forecasting mathematical models. Determination the list of climatic factors, the degree and nature of their impact on the output capacity of the SPP is needed to build dependencies and farther conclusions.

**Material and research results.** One of the most important factors determining the change of the amount of electricity generation in the short term is climate change. The main such climate factor is the intensity of solar radiation,  $W/m^2$ . The voltage produced by the solar cell depends on the incident light flux, namely: the voltage increases with increasing illumination to a certain scale. The next factor that should be highlighted is the ambient temperature. It directly affects heating of the panels. Most panels are designed to operate in temperature mode from  $-40\text{ }^{\circ}\text{C}$  to  $+80\text{ }^{\circ}\text{C}$ . More lower ambient temperature indicates a more higher level of conversion [3]. For example, a 270-watt panel in hot summer with  $+35\text{ }^{\circ}\text{C}$  temperature generate 257 W of electricity, and in winter at  $-20\text{ }^{\circ}\text{C}$  - 298 W [4]. This is due to the fact that with increasing temperature, the flow of electrons inside the element increases. Process of increasing electrons' flow causes an increase current and decrease voltage. The

voltage decreases faster than the current increases. Therefore, the total power ( $P = UI$ ) decreases and the efficiency of the panel is reducing. Manufacturers indicate the value of the temperature coefficient of the panel for the numerical characteristic of the decreasing the electrical energy generation caused by increasing temperature of the solar panel. The temperature coefficient is a parameter that indicates how much the efficiency of the solar panel decreases with increasing air temperature by each degree. The value of this factor is obtained experimentally by the manufacturer and indicated in the specifications. In summer the temperature of panel can rise to 60-70 ° C. On average, rising temperature by 20 °C cause the loss of power generation to about 10% [5].

The influence of air humidity on the efficiency of solar panels was studied in [6-8]. Experiments conducted in [8] showed that humidity significantly affects the performance of the solar panel. The generation of electricity from solar panels can be reduced to 15-30% depending on the humidity level, as high humidity can form a layer of water on their surface. In this case, the probability for appearing clouds, fogs and scattering radiation also increases. In [6] it was shown that an increase in humidity by 5% causes a decrease in efficiency by 7.5%, by 10% - 15.8%, and by 25% - 30%.

The next parameter that affects the amount of electricity generation is the wind speed. By increasing the wind speed, more heat can be removed from the surface of the photocells. Also, higher air velocity reduces the relative humidity of the atmosphere. It leads to improved efficiency. Conversely, the wind raises dust and disperses it in the environment, which can lead to shading and poor performance of photovoltaic cells [9].

The summary of the results is shown in Table 1.

Table 1 – A brief summary of different influential parameters on the PV cell performance

	Dust	Humidity	Air Velocity	Efficiency
Dust	More dust settlement	Insignificant effect	Insignificant effect	Drops
Humidity	Causes more dust coagulation	-	Insignificant effect	Mostly drops
Air Velocity	More dust deposition Less dust deposition	Decreases	-	Surges occasionally  Improves

It is also worth noting the possibility of influencing the wind direction. Depending on the angle at which the wind blows to the panels, the effect of wind speed on the efficiency of the panels may increase or decrease. The direction of the wind can also affect the shading of the panels by the deposition of dust or snow. The snow will settle better on the surface if the wind blows directly on the panel. The influence of wind direction on the placement of modules needs to be further investigated.

It is a known that before bad weather (precipitation) the atmospheric pressure drops, and before clear (dry) weather – the pressure increases [10]. Short-term precipitation has small effect on efficiency. However, significant rainfall is usually character in cloudy weather. Radiation and, accordingly, generation in this situation are reduced. Atmospheric pressure by itself is not a factor that directly affects the level of electricity generation. But it has an indirect effect on the main factors. In general, depending on the increase or decrease of atmospheric pressure, the influence of temperature, wind and humidity on energy production can increase or decrease.

Consider the degree of influence of factors on the value of electricity generation on the example of SPP in the village Dyerka, Kyiv region. The data consist of more than 26 thousand samples collected from July 1, 2020 to December 31, 2020. They are characterizing the operating conditions of solar panels (9 MW).

The data set consists of two types of data:

1) Weather data. The first part of the data consists of measured weather parameters such as temperature, solar radiation, humidity, atmospheric pressure, wind direction and speed.

2) Data from electricity counter. The second part – accounting of the amount of electricity sold to the external general network, including PV power, which is forecasting.

The data set consists of the actual value of electricity generation for 10-minute intervals (the electricity counter transmits the generation value to the monitoring point with a discreteness of 10 minutes) and the measured climatic parameters for this period.

We used a correlation matrix to estimate the actual value of the influence of each parameter on the objective function and separately on each of the input factors of the model. It is a structured approach for ranking the importance of predictors or input variables (input variables that have the greatest impact) on output function. The correlation coefficient for the sample is determined from the expression [11]:

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

where  $\bar{x}$ ,  $\bar{y}$  – the average values for the sample  $x$  and  $y$ ,  $s_x$  and  $s_y$  – unbiased (adjusted) estimate of the standard deviation for  $x$  and  $y$ .

A positive value of the coefficient indicates direct influence of each factors. In case the value of a certain parameter increases, the value of the second placed at the intersection of the matrix also increases and vice versa. For this purpose, a thermal map of the correlation matrix (Fig. 1) was constructed. It basis on the data from the half-year operation of the solar panel with 10-minute discreteness.

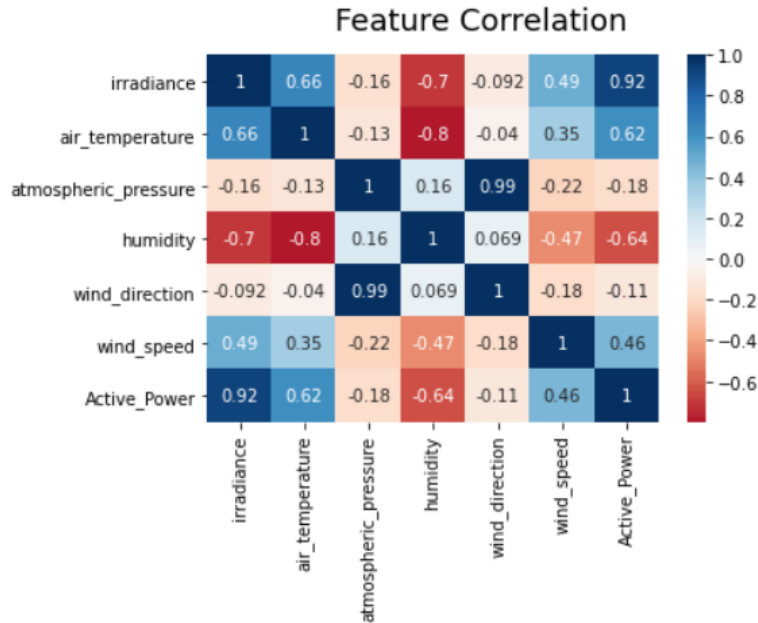


Figure 1 - Correlation matrix

Three parameters have positive correlations with the output – active power generation. Such parameters are solar radiation (92%), air temperature (62%) and wind speed (46%). And relatively humidity has negative correlation. It should be noted that the wind direction is correlated with atmospheric pressure of 99%. This means that the values change of one parameter almost completely depending on the value of another. In other words, these factors in the model will be duplicated. And this will increase the complexity of the model, may increase the error of the model and increase the possibility of retraining. Therefore, the "wind speed" parameter is excluded from the model.

A scatter plot diagram of electric power generation values with solar radiation parameters is shown on Fig. 2, with ambient temperature on Fig. 3, with wind speed on Fig. 4 for the studied period at 10-minute intervals.

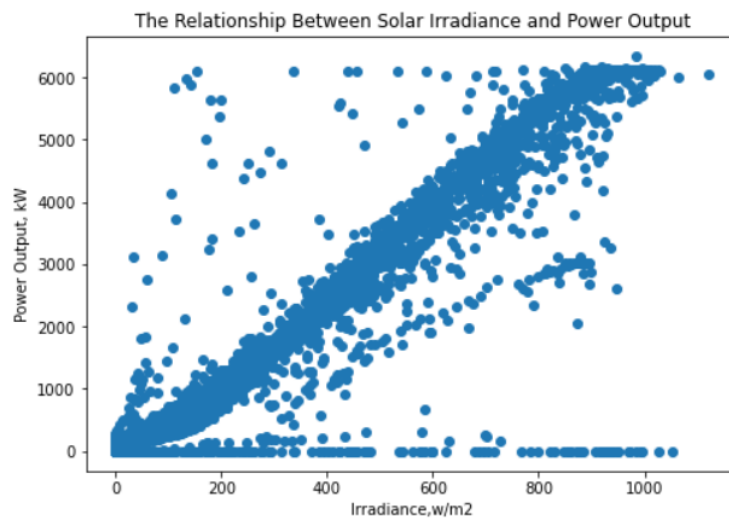


Figure 2 - Dependence of the output electric power generation of the SPP on solar radiation

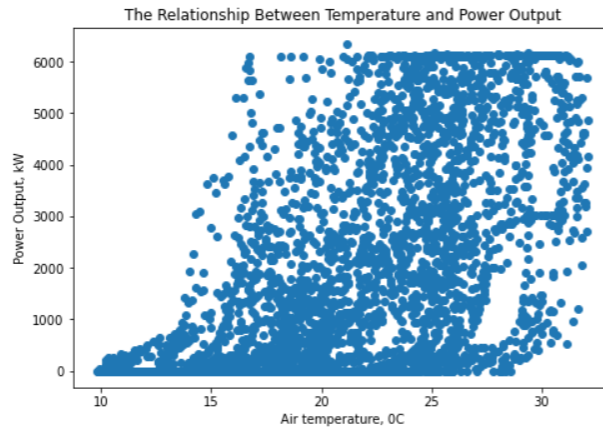


Figure 3 - Dependence of the output electric power generation of the SPP on the ambient temperature

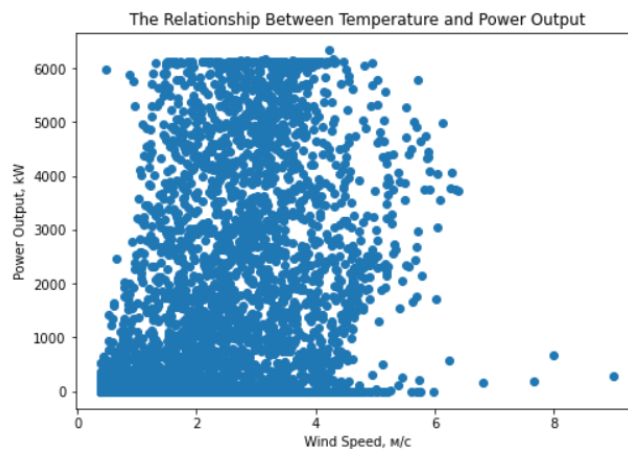


Figure 4 - Dependence of the output electric power generation of the SPP on wind speed

Figure 2 shows a linear relationship between the parameters of solar radiation and output power generation with a certain amount of data emissions. Instead, there is no clear dependence of electricity generation data with wind speed and ambient temperature. This once again indicates that the main parameter that affects the amount of electricity generation of SPP - is the intensity of solar radiation. To determine the influence of other factors, it is necessary to analyze the tendency of change electricity generation at the constant values of solar radiation. Also, it should be analyzing the physical meaning of correlations and determine the sequence of including parameters into the model.

To do this, take a fragment of the input data (Table 2) for the forecasting of energy generation at the same value of solar radiation in the investigative period.

Table 2 - Fragment of data on climatic parameters and the amount of generation active electricity by the same level of solar radiation

Timest amp (day)	Timestamp (hours and minutes)	Solar radiation, W/m <sup>2</sup>	Air temperature, °C	Atmospher ic pressure, mBar	Humidi ty, %	Wind directio n, °	Wind speed, m/s	Active Power, kW
02.07	8:10:00	440,6	24,4	499,85	64,4	66,5	2,0	3984,4
20.07	8:20:00	440,6	21,0	500,13	66,1	104,2	1,1	4262,7
13.10	13:30:00	440,6	18,5	501,62	74,4	311,5	4,8	7102,5
18.10	13:20:00	440,6	7,7	500,44	64,2	141,3	5,3	7490,4

On the table 2 the biggest energy generation by the same solar radiation (W / m<sup>2</sup>) was in the autumn month. The air temperature in July 2<sup>nd</sup> was higher than July 20<sup>th</sup> (above 25 °C), and since it is a summer month, the surface temperature of the panel was higher. This reduces the generation of active power. However, the humidity

on July 2<sup>nd</sup> was higher and the wind speed was lower. According to the correlation analysis, these indicators should indicate that the generation of active power should be higher. Therefore, when the air temperature is more than 20 °C with the same solar radiation. So, surface of panel is heated for more than 25 °C, the efficiency of the panels decreases. Other factors in this case have less influence on the amount of active power generation. Therefore, the air temperature, in addition to having the greatest direct relationship to solar radiation (in general, the amount of solar radiation is greater at higher air temperatures), has the biggest impact on the generation of active electricity at constant light level. And it is negative compare with positive correlation on the whole investigated period (fig. 1). According to table 1, in the autumn month the generation is almost on 30% higher. In this period air temperature is decrease and wind speed increase. It indicates the need to include in the model also the wind speed parameter. On October 18, the electricity generation is bigger than on October 13<sup>th</sup>. In October, the air temperature had less effect than in summer on reducing the efficiency of the solar panel, and the wind speed was increased slightly. In this case, it is necessary to take into account the value of humidity that on October 13<sup>th</sup> compared to October 18<sup>th</sup> is 10% higher. Atmospheric pressure also increased. Therefore, at the last stage of the feature selection is necessary to include into the model the humidity parameters and then atmospheric pressure. And for the model of forecasting the intensity of solar radiation, it is necessary to take into account the change of climatic factors depending on the seasonality.

#### **Discussion of results and conclusions:**

It was established that the level intensity of solar radiation has the greatest influence on the generation of electric energy. Moreover, at different times of the year and in combination with the corresponding values of other climatic parameters, this effect may have different influence on output function. This indicates that to model for forecasting electricity generation in addition to the value of irradiance should include ambient temperature, wind speed, humidity, and in certain periods, atmospheric pressure. It was found that the value of electricity generation is based on the dynamics of data over time. That is why, high temperatures for several days (over 20 °C) cause the solar panels to heat up to high temperatures and, accordingly, reduce their efficiency. Therefore, in a ten-minute interval, the magnitude of lasing under such conditions will be lower than at short-term (several hours) the same temperature. Therefore, to build a mathematical model for the forecast of electricity generation for the day (hour) ahead, the degree of importance of the data taken immediately before the forecast will be higher than the data for previous periods. In addition, the forecast model should take into account the seasonality of the data, when changes in climatic parameters may affect the efficiency of solar panels in different ways.

Thus, the analysis of the influence of factors on the magnitude of electricity generation allowed to determine the priority of including each of the parameters in the mathematical model of SPP power forecast. In further research it is necessary to develop a model that separately calculated the generation forecasts for each period of the year and the dynamics of change of factors. Such a model can be built using a model of long-term short-term memory based on recurrent neural networks [12]. It can be used both for computer modeling of SPP operation and calculation of its technical and economic indicators, and for further analysis of SES operation as a part of combined energy systems with various energy sources, including RES.

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## АНАЛІЗ ФАКТОРІВ ДЛЯ ПРОГНОЗУВАННЯ ГЕНЕРАЦІЇ ЕЛЕКТРИЧНОЇ ЕНЕРГІЇ СОНЯЧНИМИ ЕЛЕКТРОСТАНЦІЯМИ

Нова модель оптового ринку електроенергії передбачає функціонування ринку на добу вперед. На цьому ринку генеруюча компанія бере на себе зобов'язання по постачанню певної кількості електроенергії. Тому для сонячної електростанції (СЕС) необхідно здійснювати якомога точний прогноз можливого виробітку електроенергії, що залежить від певних факторів. В статті було проаналізовано та виділено фактори, що повинні бути включені в прогнозну математичну модель визначення потужності сонячної електростанції на певний короткостроковий період на основі даних СЕС розміщеної в Київській області., а саме інтенсивність освітлення, температура та вологість навколишнього середовища, швидкість вітру та атмосферний тиск. Здійснено аналіз ступеня впливу цих факторів на вихідну функцію генерації електричної енергії. Встановлено, що вплив певних кліматичних параметрів в залежності від пори року є різним, а тому в математичній моделі прогнозу необхідно враховувати сезонність. Окрім цього, динаміка зміни значень факторів також впливає на поточну величину генерації електричної енергії. Тому дані отримані за останні періоди часу перед прогнозом повинні мати більший вплив на генерацію прогнозовної величини аніж дані попередніх періодів.

**Ключові слова:** прогнозування, генерація електричної енергії, сонячна електростанція, кореляційна матриця, інтенсивність освітлення

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