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FORECASTING DAY-AHEAD OF POWER GENERATION FROM PHOTOVOLTAIC STATIONS AND USE WEATHER APPS

Abstract: *This article presents the results of research on the influence of meteorological parameters on the amount of electricity generated by photovoltaic plants. The dependences of the amount of energy generated by the photovoltaic station on the time of generation and the length of daylight, the average daily temperature and the number of clear hours during the day are given. We proposed to use cloud level coefficients to reflect changes in solar insolation. Based on the obtained data, a new mathematical model of the daily forecast of electricity generation of photovoltaic stations is created. Weather forecast applications are recommended to determine the input parameters of the forecast model.*

Keywords: *photovoltaic station, forecasting, apps weather forecast, energy efficiency, level of cloudiness, duration of daylight.*

Introduction

Solar energy increases it`s impact on countries' energy systems by creating total installed power capacity of photovoltaic stations (PVS), but beside reducing the emissions of coal-fired power plants [1] and increasing the share of "green generation" in energy balance, the problems appear with balancing of energy regimes. Changes in the expected level of outturn of electricity generated into the electricity grid from renewable energy sources (RES) due to weather disasters and anomalies have already led to several accidents, power outages of some parts of consumers. It is important for power system managers to have accurate forecast data on changes in the amount of generation by photovoltaic and wind power plants, so that in case of their discrepancy, they can be quickly replaced by shunting power capacity. The problem can be partially resolved by building of new storage systems (hydro storage stations, Tesla Powerpack, Demand Side Management), introduction of fines for imbalances in electricity generation by renewable energy sources, as well as new rules of electricity in Ukraine. These innovations stimulate the study of changes in the generation of electricity of photovoltaic stations from the array of meteorological parameters, as well as to apply predictive generation models for a specific region with high accuracy. A set of input data for the mathematical model can be obtained from PVS monitoring systems, weather applications that forecast the weather and offer a large base of archival data of meteorological parameters. Synthesis of input data, mathematical forecasting model and program or environment (Matlab Simulink, LabView, Phyton) will allow to get the value of PVS generation with acceptable accuracy.

Literature review

Methods of forecasting of power generation by photovoltaic stations are presented in the publications [3-5], and their choice depends on the time range and the possibility of using statistics, ARIMA models, numerical weather prediction (NWP). These models are quite complex, expensive and are rarely used in local photovoltaic power plants. This study search new relationship between the output characteristics of the system and input factors.

The goal of this paper is to develop and testing a model for forecasting the electricity production and increase the reliability.

A photovoltaic stations that generates power electricity to the grid is a complex and dynamic system, and its parameters depend on solar radiation, temperature, and grid voltage:

$$P_{PV} = N \cdot FF \cdot U_{PV} I_{PV} \quad (1)$$

$$I_{PV} = \frac{I_\beta}{I_K}\left(I_K + k_i (T_0 - 25)\right) \quad (2)$$

$$U_{PV} = U_X - k_U T_{PV} \quad (3)$$

$$T_{PV} = T_i + E_\beta \frac{(T_0 - 20)}{800} \quad (4)$$

where:

N – number of photovoltaic modules;

FF – coefficient (full factor);

I_β – photopanel current at standard parameters;

E_β – solar insolation, W/m²;

I_K – short circuit current;

k_i – current-temperature coefficient, A/°C;

T_0 – temperature on the sensor of the photomodule at ambient temperature 20°C, solar insolation 800 W/m² and wind speed 1 m/s;

U_X – no-load voltage;

k_U – voltage-temperature coefficient, V/°C;

T_{PV} – the actual temperature on the sensor of the photomodule, °C;

T_i – ambient temperature, °C.

Full factor is the determined base on the results obtained in the previus iteration:

$$FF = \frac{U_{MPP} I_{MPP}}{U_X I_K} \quad (5)$$

where:

U_{MPP} – voltage when searching for maximum power (MPPT – Maximum power point tracker);

I_{MPP} – current at MPPT.

The use of inverters with additional functions will help to make autonomous decisions to improve network stability, maintain power quality and provide ancillary services to reduce imbalances in the system. When the grid frequency or mains voltage does not meet the permissible values according to the standard, the inverters unplug the PVS from the mains, but by changing the level of real output power of the system (by limiting active power or regulating reactive power) you can change the level of generation, that is, to reduce its value in case of excess in the power system or in case of fines for imbalances. This can be done with reactive power compensation functions or dynamic reactive power control [2].

Depending on the location of PVS, not only the magnitude of insolation changes, but also the typical daily irradiance patterns and cloud cover of daytime (clear sky, instantaneous cloud change, foggy day with limited generation input, high variability due to rapid cloud cover changes), and photoelectric power generation changes need to balance with the power system [3].

Ukraine has joined the requirements of many countries to collect PVS electricity generation forecasts with a power capacity of more than 1 MW for resolving of the variability and uncertainty of photovoltaic power generation. Methods and statistical models, as well as time intervals are described in [3, 4]. Compensation for imbalances in electricity generation in February 2021 will be about 1%, and in the summer months will increase the amount of generation and the range of changes in this percentage. The influence of photomodule temperature, shading, degradation, inverter power, system age are presented in [4, 5], so the determination of the coefficients of influence on the generation for specific photovoltaic systems require detailed study.

Problem formulation

Most weather forecast applications do not show the amount of solar insolation required to calculate power, and the cloud level is difficult to apply without additional mathematical apparatus. In addition, most PVS do not have SCADA and online solar insolation monitoring systems. Finding an available set of input parameters and selecting weights for output power is important for predicting the amount of PVS electricity generated.

Using a new mathematical model of the dependence of the amount of electricity on the level of cloudiness and forecast power, we obtain a forecast of generation for a local source

Results and Discussions

The results of this study based on statistical data on the amount of electricity production from photovoltaic plants «Poberezhia» and «Tlumach» (Ivano-Frankivsk region in Ukraine) for the period between April 2020 and April 2021. All calculations are made for a power of 1 kW. Meteorological data from the Meteoblue server, Solcast and the WetterRadar information website were also used [6, 7, 9], which allows the Excel interface to extract data for the project and use it in the LabVIEW virtual devices [8].

FIGURE 1. *Example of information about cloudiness and temperature in the forecast application [7]*

The amount of electricity produced by PVS on any day of the year W_{G_i} depends on the length of daylight and the amount of solar electricity that enters the photomodule. The generation curve can be described using the harmonic function (1), as well as using the normal distribution function (2) using equation (1)-(2).

The amount of electricity generated by the PPS on any day of the year is determined by formula:

$$W_{G_i} = W_{G0} \sin(\delta + \varphi) \pm k_1 a \pm k_2 b \qquad (6)$$

where:

W_{G0} – maximum value of the amount of electricity generated by the PPS per day according to statistics, kWh;

δ – coefficient of generation time, which characterizes the dependence of the increase in the duration of daylight on the amount of generated electricity of PPS;

φ – the value that takes into account the beginning of the reference (the day of increasing of the duration of daylight);

k_1 – coefficient that characterizes the level of cloudiness (relative number of sunny hours) of a given day and depends on meteorological data;

k_2 – coefficient that characterizes the temperature of a given day and depends on meteorological data;

a, b – variables;

$$W_{G_i} = W(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \pm k_1 a \pm k_2 b, \quad -\infty < x < +\infty \qquad (7)$$

Define variables for a given graph, where: μ = 179 – mathematical expectation at value W_M = 3.6 kW; mean $\sigma = \frac{1}{\sqrt{2\pi} W_{G_{MAX}}}$ = 0.1108; k_1, k_2 – weights, which take into account deviations from the nominal parameters when changing solar insolation (cloudiness *a*) and temperature *b*.

Let's make a graph of the dependence of the amount of generated electricity PVS from the day of the year using the normal distribution function. The December Solstice can happen on December 20, 21, 22 (beginning of the curve, point X = 178.8). Every day the value “x” increases by 0.0011.

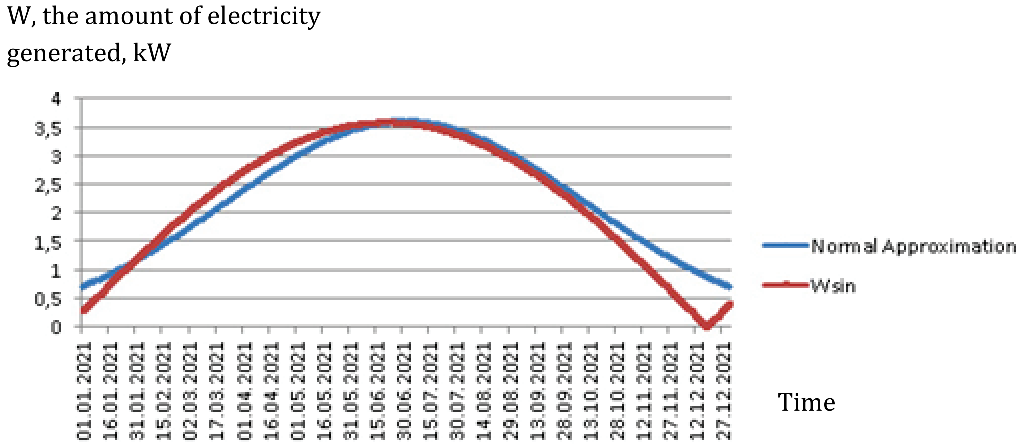

FIGURE 2. *Dependences of the amount of electricity generated by the harmonic function and the function of normal distribution from the day of the year*

Figure 3 shows an example of a change in the power of the solar system in 1 kW during one day. Due to the increase in the length of the daylight and the amount of solar insolation, the total amount of electricity produced by the PVS increases as a result. When the clouds shade the solar panels, the power of the system drops sharply, respectively, after the cloud cover disappears, the power increases again.

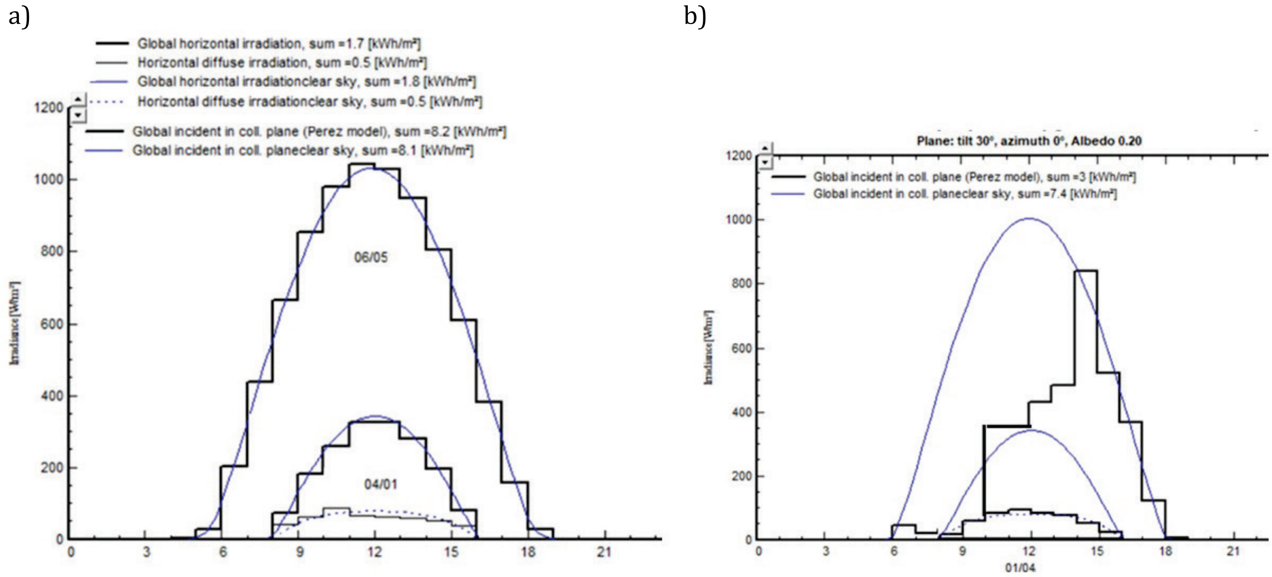

FIGURE 3. *Graph of the dependence of the amount of electricity generated by PPS in January and May for sunny day (a) and partly cloudy day (b)*

Figure 4 shows the correspondence of the constructed graph of dependence of the produced electricity of FES during the day (kWh) for April 2021 with the graph constructed according to the forecast data according to the forecast "day ahead" and according to the available values of meteorological data.

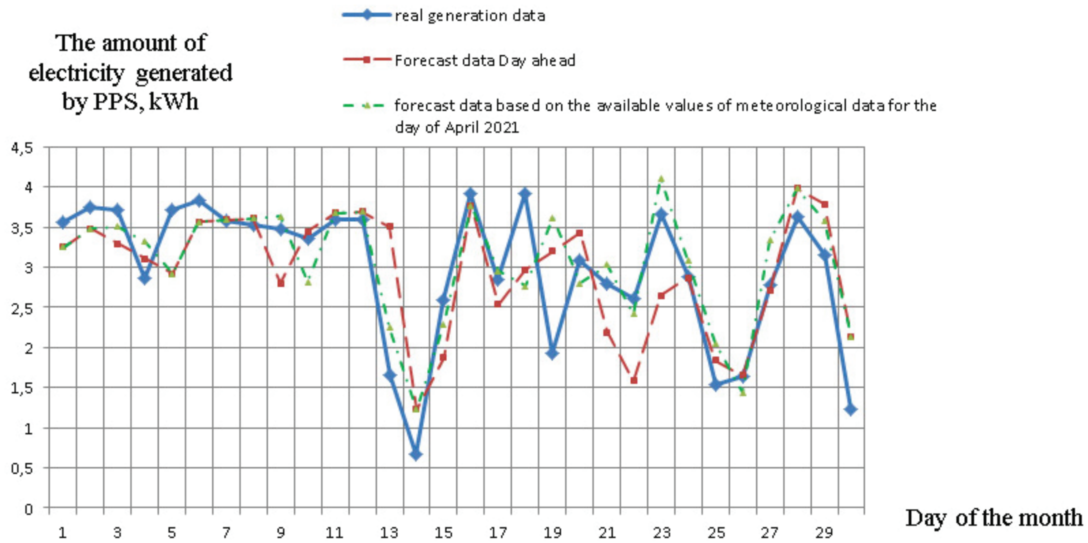

FIGURE 4. *Graphs of PPS electricity generation and projected generation values during the day of April 2021*

For the daily forecast use weights of cloudiness and deviation of temperature from nominal for half-hour or hour time intervals:

$$W_I = \sum_{T_1}^{T_2} \left(P_{IFOR} \sin(\delta + \varphi) \pm k_1 a_i \pm k_2 b_i \right) t \tag{8}$$

where:

T_1, T_2 – local times for sunrises, sunsets;

P_{IFOR} – forecasteted maximum power of the PVS for the i-th day of the year, kW.

These power values are possible for a clear day, and in cloudy weather the power will decrease, and it is found by applying the weights k_1, k_2.

The length of daylight varies during the year depending on the location of the FES, the zenith angle of the Sun at sunrise/sunset, latitude, angle of solar inclination and affects the start and stop of energy generation, and therefore the total amount of electricity generated during the day.

We compare the prediction of the trimetric (harmonic) function and the function of the normal distribution function. For January 2021, the forecast model on the normal distribution curve gives better accuracy.

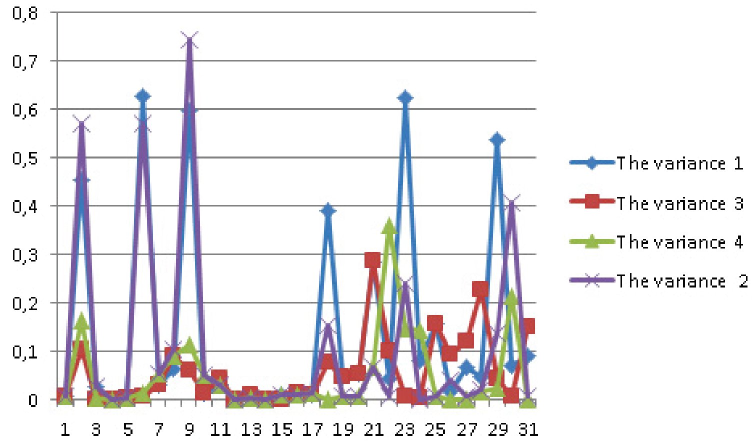

***FIGURE 5.** Illustration of the daily change in the variances of the electricity generation forecast*

The variance in the forecast parameters "day ahead" (σ_1, σ_3) and "real data" (σ_2, σ_4) are actually equal, but more accurately shows the dependences of the harmonic function for February.

$$\sum \sigma_1 = 4.52 < \sum \sigma_2 = 4.6$$

We use LabVIEW virtual instrument technologies and graphical programming environments to obtain input parameters (Fig. 6).

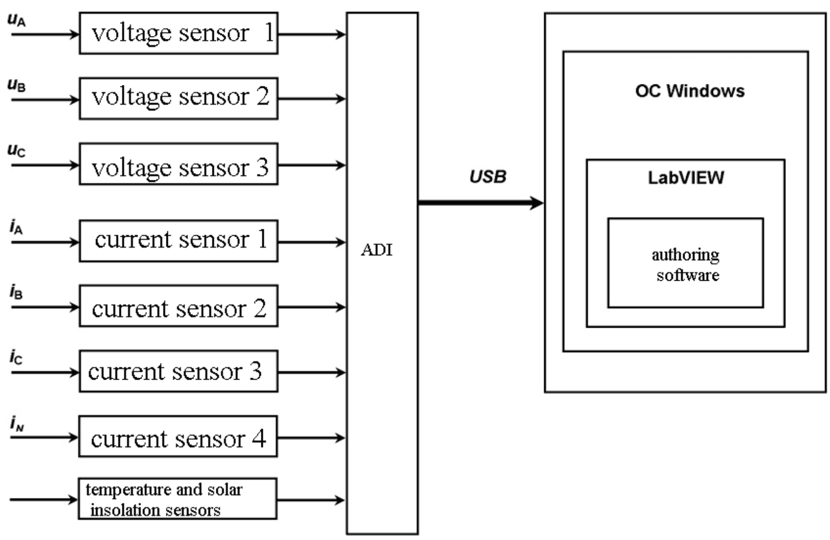

***FIGURE 6.** Block diagram of the monitoring system*

The monitoring and forecasting system has three voltage sensors CV3-1000 and four current type current sensors with analog output ATA 2502. The NI USB-6210 supports 16 analog inputs with 16-bit resolution [8].

The software uses subroutines of standard digital signal processing algorithms (fast Fourier transform, rms determination, etc.), visualization of information and writing to a file on the computer hard disk in binary format tdms.

The combination of the forecasting system with the monitoring system makes it possible to obtain updated parameters in real time and adjust hourly forecasts. This will reduce technological losses at photovoltaic plants and increase the owner's profit.

Conclusions

This article analyzes the possibility of using weather forecast applications to determine the amount of electricity generated by photovoltaic plants. These forecasting tools based on historical measurements will help to more easily calculate the projected amount of electricity generated, which will increase the efficiency of their use compared to complex and expensive forecasting applications.

The accuracy of this forecasting method depends on the term and amount of data and increases with the refinement of data in less than a day.

The forecasting accuracy for the winter months increases due to small changes in values with low generation. Accuracy in the summer months is highly dependent on the weather and requires consideration of "clear sky time coefficients".

References

[1] Kryzhanivskyi Ye., Koshlak H., *Obtaining porous thermal insulating materials based on ash from thermal power plants*. Journal of New Technologies in Environmental Science, 2020, Vol. 4, No. 1, pp. 3-12.

[2] *Advanced Inverter Functions to Support High Levels of Distributed Solar. Policy and Regulatory Considerations* (Brochure). Imprint. Washington, United States. Dept. of Energy. Office of Solar Electric Technology; Oak Ridge, Tenn.: distributed by the Office of Scientific and Technical Information, U.S. Dept. of Energy. 2014, pp. 1-8. Retrieved from: https://www.nrel.gov/docs/fy15osti/62612.pdf.

[3] Reindl T., Walsh W., Yanqin Z., Bieri M., *Energy meteorology for accurate forecasting of PV power output on different time horizons*, Energy Procedia, 2017. No. 130, pp. 130-138, https://doi.org/10.1016/j.egypro.2017.09.415.

[4] Batsala Ya.V., Hlad I.V., Yaremak I.I., Kiianiuk O.I., *Mathematical model for forecasting the process of electric power generation by photoelectric stations*. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 2021, No. 1, pp. 111-116. https://doi.org/10.33271/nvngu/2021-1/111.

[5] Riahi J., Vergura S., Mezghan D., Mami A., *Intelligent Control of the Microclimate of an Agricultural Greenhouse Powered by a Supporting PV System*. Applied Sciences. 2020. No. 10(4):1350. https://doi.org/10.3390/app10041350.

[6] WetterRadar & Warnungen. Wetter Online Meteorologische Dienstleistungen GmbH. Retriewed from: https://www.weatherandradar.com/apps/.

[7] Meteoblue delivers local weather information (n.d.). Retrieved from https://www.meteoblue.com/.

[8] Fedoriv M.Y., *Increasing reliability and energy efficiency of electric driven boring units*. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2017, 2, pp. 93-98.

[9] Sunny Portal. PV System Data. Retriewed from: https://www.sunnyportal.com/Templates/PublicPage.aspx?page=0fa455f6-64b8-4475-b66e-b01cb5a0836d

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