Hourly Weather Parameters Analysis for Prediction of Electricity Generation by Photovoltaic Power Station on the Day Ahead

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Abstract:

The paper presents an analysis of the mechanisms of functioning of the new model of the wholesale electricity market new model. According to this, the work of stations based on the use of renewable energy sources (RES), in particular photovoltaic power stations (PPS), should take place on the basis of the announced hourly generating schedule by the owner of the station one day in advance. In order to ensure the accuracy of the predicted schedule, a study was carried out on the determination of meteorological parameters that most affected the generation of electricity at photovoltaic power plants. Results of cluster and regression analysis were conducted on the basis of meteorological data, measured at the station located in the Vinnitsia region.

Keywords:

Photovoltaic Power Stations, Hourly Weather Parameters, Prediction, Solar Radiation, Panel Temperature, Humidity

1. Introduction

Due to the fact that alternative and renewable energy sources are being developed in electric grids, the latter take signs of local electric systems (LES) [1]. This means that for them there are problems that are typical for electric power systems (EPS) with large thermal, nuclear and hydroelectric power stations. These include the assurance of reliability of electric power supply to consumers, maintenance of voltage levels within permissible limits, optimization of power flows in order to reduce losses, as well as maintenance of balance reliability in LES with combined electric supply from local and centralized sources of energy [2-4]. Determining the priority of solving problems arising in LES, note the balance reliability as the reliability of LES when its

calculation model is determined by the balance of consumption and generation of electric energy, with the external supply being taken into account. The successful solution of other problems depends on the methods and means used to ensure the balance reliability. Technical and economic indices of LES depend on the balance of its active and reactive power [5]. The instability of RSE generation, in particular, by SPP and WEP, greatly influences the process of power balancing in LES. The instability of SPP and WEP generation is compensated by the power supplied to LES from EPS. As a result, the conditions of LES mode balancing influence the EPS modes. The optimization of LES and EPS's joint operation is considered in a number of research works [6-9]. The given paper is considers the method of balance reliability assessment, which is based on the assessment of renewable source generation instability in the problem of covering the load graph of a local electric system. As the instability of WEP and SPP's generation is of different nature, and, correspondingly, the character of its impact on electric energy balance in LES is also different, then they must be considered separately. The objective of the given paper is the development of an assessment method of SPP impact on the formation of electric energy balance in LES.

It is known [10] that RSE can be used in LES applying various criteria of optimality. Correspondingly, their participation in maintaining the balance of active and reactive power in LES is different. For instance, when optimizing a daily mode of RSE for the purpose of providing maximum operating revenues of their electric energy and minimizing electric power supply intended for consumers to LES from the electric energy market, EPS maintains the balance reliability. In this case, the task is to assess the instability of SEP and WEP generation and determine the EPS power reserve necessary to provide the balance reliability of LES. The role of SPP and WEP in maintaining the balance reliability is passive.

Another case is when to provide the LES stability or under limited possibilities of a centralized power supply system, it is necessary to influence the generation of energy sources in LES. In this case, a prior substantiated graph of their generation is set for RSE. There arises a task of RSE modes optimization in order to minimize the deviations from the set centralized schedule of their total generation $PRSE\ (t)$ at the set limitations of primary energy resources and RSE characteristics [11]:

$$\int_{t_0}^{t_k} \frac{1}{2}\left(P_{\text{RSE}}(t) - \sum_{i=1}^{n} P_i(t) \right)^2 dt \to \min \qquad (1)$$

where $P_i\ (t)$ – current values of RSE power in the time interval t_0, t_k, n – the number of RSE involved in the RSE control.

The forecast information regarding weather parameters that is provided by the corresponding subsystem of an automatic control system (ACS) and enables the states of the controlled RSE to be rather adequately reproduced should be taken into account. In the new economic conditions, photovoltaic power stations (PPS) of direct transformation of energy are more and more widely used. Their use, in addition to making a profit from electricity sales [14], allows, under certain conditions, to unload the electricity grids and improve the quality of electricity [12-16].

However, the growth of their share in the energy balance of Ukraine, as well as the increase of individual installed capacities, leads to the need to take into account and compensate for the instability of such energy sources. The latter is due to the significant dependence of their modes of operation on the environmental impact. The

instability of the PPS operation modes [17] can negatively affect the balance reliability of the grid, as well as the stability of its operation. In order to ensure the functioning of the energy market of Ukraine, taking into account the positive trend towards the development of the PPS, it is expected to change the conditions of their functioning by introducing the practice of previous applications for generation to coordinate their joint work with traditional energy sources.

The implementation of such a mechanism necessitates the development of an efficient system for short-term hourly forecasting of electricity generated by PPS and their operating modes.

2. Analysis of Recent Research and Publications

In order to fulfill obligations under the Treaty of Establishing the Energy Community, the Ukrainian state authorities together with the Energy Community Secretariat (ECS) began the process of transposition of the Third Energy Package, according to which a new law "On the Electricity Market of Ukraine" was adopted. In accordance with the provisions of the law [18], for producers who produce electrical energy at wind energy and solar energy installations for which there is a "green tariff", the fee for the imbalance is set as follows: until December 31, 2019 - 0%, from January 1, 2020 - 10%, from January 1, 2021 - 20%, from January 1, 2022 - 40%, from January 1, 2023 - 60%, from January 1, 2024 - 80%, from 1 January 2025 - 100%.

Thus, the producer of electrical energy from the RES is charged / accounted for the cost of balances at the price of imbalance multiplied by the volume of imbalance, which is calculated as the difference between its own forecast for the day in advance and the actual measured volumes. In order to increase the accuracy of such a forecast, it is necessary to determine which meteorological parameters most influence the generation of electricity at power stations based on RES, in particular PPS.

The purpose of the article is to analyze the influence of weather parameters for hourly forecasting of power generation by photovoltaic power stations one day ahead.

3. Basic Research Materials

The conducted analysis of the results of field experiments allows us to determine the list of meteorological parameters and the accuracy of their estimation in the task of forecasting the generation of electric energy by a specific PPS for the day ahead.

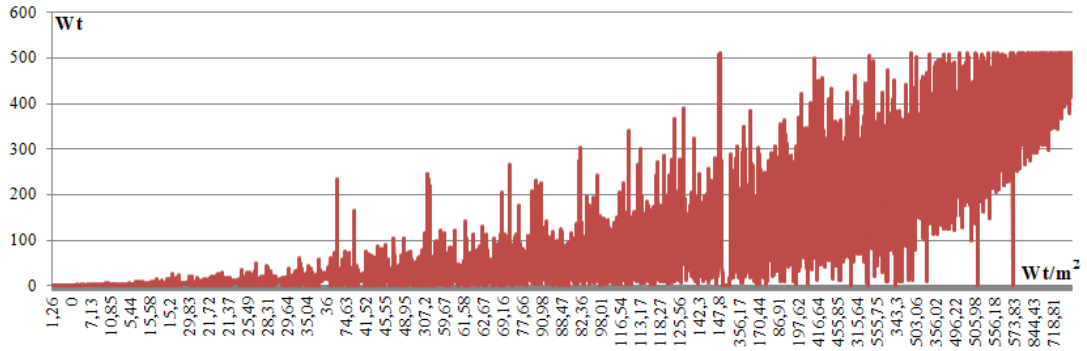

Figure 1. *Dependence of active power from solar radiation on the panel surface (during the year).*

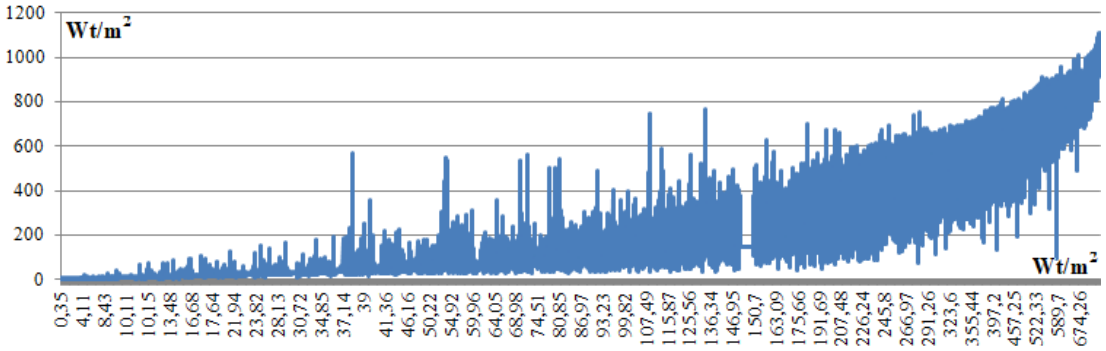

Figure 2. *Dependence of solar radiation on the surface of the earth from solar radiation on the surface of the panel (during the year).*

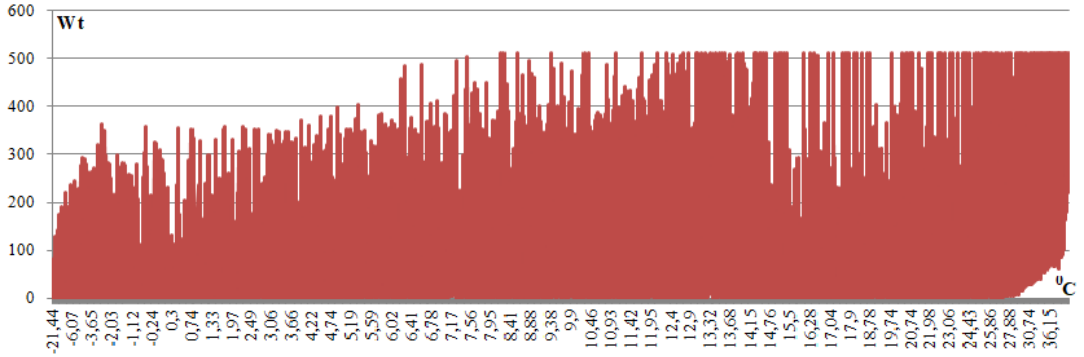

Figure 3. *Dependence of active power on panel temperature (during the year).*

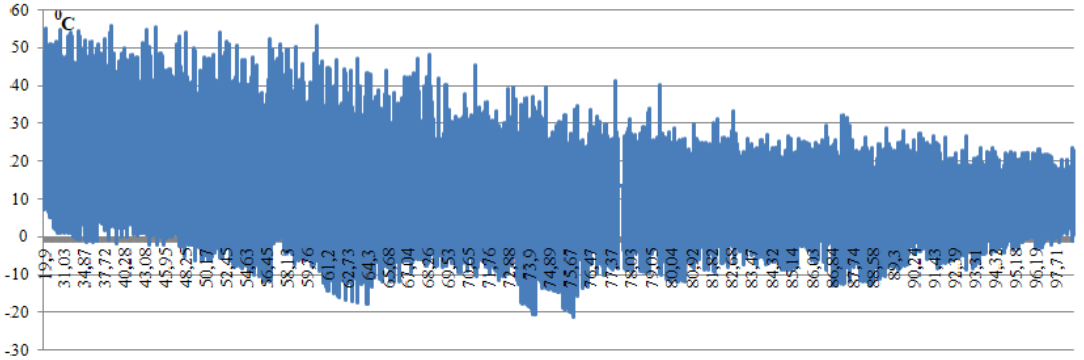

Figure 4. *Dependence temperature of the panel on humidity, r.u (during the year).*

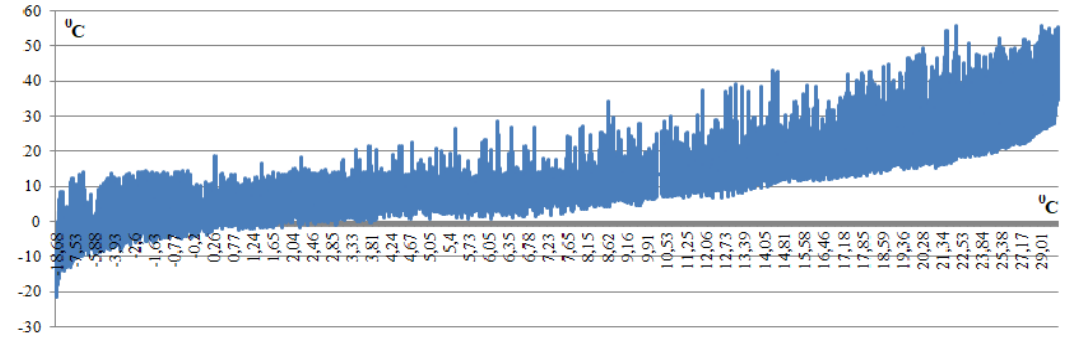

Figure 5. *Panel temperature dependence on ambient temperature (during the year).*

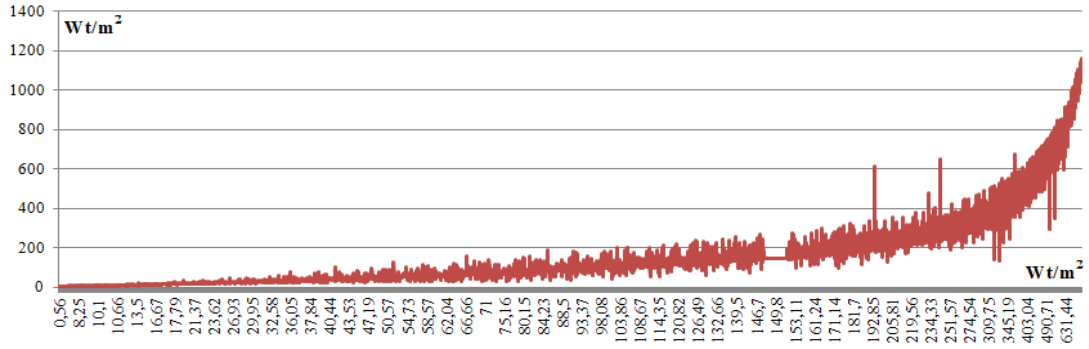

Figure 6. *Dependence of solar radiation on the surface of the panel from solar radiation on the surface of the earth (during March-April-May).*

Figures 1-6 show the dependence between different parameters. There is a clear trend depending on the generated active power and solar radiation (Fig. 1). This allows us to conclude that this parameter is decisive in the task of forecasting the generated power. The presence of a certain area of possible values in the vicinity of the trend indicates the influence of other parameters on the one hand and a certain probability of false monitoring system Analysis of other dependencies can be defined with a list of additional parameters, which, when considering the problem of prediction, will allow for the results of acceptable accuracy. Figure 6 shows the dependence of the generated active power from solar radiation on the panel surface after partial filtration of the source data on the falsehood of the operation of the monitoring system. Evidently, the feasibility of such filtering.

In order to confirm the visual conclusions about the importance of the parameters in the work, mathematical analysis of data was carried out using means of the package STATISTICA 10.

The conducted cluster analysis allowed to break down the results of measurements into groups. Each group has similar laws for their changes. The lengths of the connecting lines between the groups characterize the influence of the groups one by one.

According to the analysis, it can be concluded that solar radiation is the determining parameter for evaluating the generated active power, and the panel temperature is less influential. Since it is not immediately possible to predict solar radiation on the surface of the panel and its temperature, then it is necessary to determine the additional parameters on which the estimated meteorological parameters can be estimated. On this issue, cluster analysis allows you to get an answer. According to influential groups, solar radiation on the surface of the panel can be determined by radiation on the surface of the earth; temperature of the panel at ambient temperature, wind speed and humidity.

In parallel with the cluster analysis, a regression analysis was performed. Regression analysis reveals the quantitative dependence of the sign-factor (dependent variable) on one or more feature-factors (independent variable). The regression coefficients are summarized in Table 1. The bulk of the findings confirmed the results presented above. In addition, it confirmed a rather complicated relationship between additional meteorological parameters.

In accordance with the regression coefficients (table 1), the influence of the parameters can be arranged in the following sequence:

- radiation on the surface of the earth;
- ambient temperature;
- humidity;
- wind speed;

Since the accuracy of the forecasting of the power generation of PES directly depends on the accuracy of the weather forecast, there is a logical question of the analysis of the main meteorological services in relation to obtaining such data.

Table 1. *Results of regression analysis.*

	Active power	**Radiation 0**	**Radiation 25**	**Temperature**	**Panel Temperature**	**Wind Speed**	**Humidity**
Active power	1,00	0,94	0,97	0,28	0,73	0,14	-0,46
Radiation 0	0,94	1,00	0,95	0,34	0,75	0,15	-0,49
Radiation 25	0,97	0,95	1,00	0,24	0,71	0,12	-0,45
Temperature	0,28	0,34	0,24	1,00	0,80	0,07	-0,28
Panel Temperature	0,73	0,75	0,71	0,80	1,00	0,047	-0,42
Wind Speed	0,15	0,15	0,12	0,07	0,04	1,00	-0,18
Humidity	-0,46	-0,49	-0,45	-0,28	-0,42	-0,17	1,00

Radiation 0 - Radiation on the surface of the panel, Radiation 25 - Radiation on the surface of the earth.

Analysis of sources of forecasting of meteorological parameters Despite the huge selection of online weather sites, only some of them use their own forecasts. For example, the weather on Sinoptic.ua site can not be specified in Yandex, since both services use data from the Finnish Meteorological Service Foreca. Also, it is unlikely that significant differences in the forecast will be found in the British BBC and Russian rp5. Both services are based on data from the British MetOffice Meteorological Bureau.

American services such as Weather Underground, AccuWeather, Weather Channel build their forecasts based on the American numerical forecasting model GFS (Global Forecast System). Today in the world there are three major global numerical models of weather forecasting, or hydrodynamic models of the atmosphere. That is, data from all the meteorological stations of the world, satellites, are analyzed, collected and processed in three ways on the basis of nonlinear equations.

Foreca, one of the world's leading suppliers of weather content, uses the ECMWF (European Medium-Range Weather Forecasts) model. This model is the latest, fast growing and specializes in long-term forecasts.

The UkMet model is used by the MetOffice Meteorological Service, the British Government Office. This model specializes in short-term forecasting. As for the American model of GFS, it has the largest coverage (almost the entire globe). The GFS model operates the National Oceanic and Atmospheric Administration (NOAA),

the National Center for Atmospheric and Oceanographic Research in the United States. Currently, GFS source files are open-source free access to US servers.

The use of this model for the latitude of Ukraine is not appropriate, since it does not take into account snow cover. Many meteorological resources combine the data of the major global models and use various additional "wind corrections" from the leading world meteorological organizations. Other resources, such as Gismeteo, develop their own unique models. There are alternative models. For example, the Ukrainian Meteoprog builds its forecast on the basis of a promising model of WRF - a derivative of the GFS model.

All this is an automatic numerical weather forecast. And all Internet resources about the weather traditionally do not like the Weather Center. Still bug: "lying" prognostic models, and folk anger collapses on innocent weather forecasters. Forecast of weather forecasters will always be different from the data of the automatic numerical model. After all, it is in the Hydrometeorological Center to make up the forecast person, that is automatically calculated data pass visual control. Weather forecasters collect together the actual weather data, forecast maps, information from local weather stations and almost with a ruler in the hand make a forecast for a specific region.

Therefore it is assumed that the forecast from the Weather Center for the next 3 days is 15-20% more accurate than the forecast from the numerical models of forecasting. Well, the qualitative forecast for 5 days, according to experts, to make available means has not yet been able to anyone, because the state of the atmosphere is changing too quickly. However, almost all services are making long-term forecasts, with forecasts for at least 10 days at all. However, the probability of their reliability - no more than 20-30%.

3.1 http://www.gismeteo.ua

The site has more than 15,000 cities in Ukraine and about 50,000 cities in the world, using their own unique weather forecasting model based on GFS and UkMET data.

Gismeteo was founded in 1998 by the company "May Maker", which since the 1990s has been developing its own systems for weather information processing for weather forecasters. The main product of the company is the geoinformation system "Meteo", where the site name came from.

3.2 http://sinoptik.ua

The site provides weather information in Ukraine in all 29,815 settlements and for 104,000 cities in the world. The forecasts for Sinoptic are taken by Foreca, and information about the actual weather - in the Ukrainian hydrometeorological center, which allows the resource to confidently hold on the top lines of the ranking of bigmir.net.

3.3 http://www.meteoprog.ua

The forecast for 15,000 cities in the world and 1209 settlements of Ukraine is based on the Meteoprog own high-performance computing cluster based on the WRF (Weather Research and Forecasting) numerical model. This is a subsidiary modification of GFS, developed by the same NOAA, the National Center for Atmospheric and Oceanographic Research in the United States.Meteoprog is a form of displaying weather information: in the form of maps, meteograms, tables and other various interesting infographics and funny pictures. Here you can see and read news

not only about the weather, but also about the events in the world, visit the tourist section, download lovely widgets.

3.4 http://pogoda.yandex.ua

Data for 12146 cities in 228 countries for Yandex is provided by the Finnish Foreca service, which produces a weather forecast for the model ECMWF. In addition to Yandex, Foreca's customers include Google, Microsoft, AOL, Finnish and Swedish airlines, and many other organizations.

As for Yandex, users get a clear and user-friendly interface: a 10-day forecast in plain text. Here you can find the average temperature throughout the entire planet at the moment

3.5 http://www.meteo.gov.ua/

The site of the Ukrainian Hydrometeorological Center is a government synoptic source, which provides official data for Ukrainian mass media. The forecast at the Hydrometeorological Center is based on the monitoring of 10,000 ground meteorological stations, of which 189 are in Ukraine, 1000 aerospace stations on land and on ships, 100 drifting stations, 600 buoys, as well as data from space satellites.An ordinary user will find a forecast for all cities of Ukraine for 5 days, as well as a forecast for the largest cities in Europe.

3.6 Worldweatheronline.com

WorldWeatheronline's American Meteorological Service Network covers more than 2 million locations around the world. To calculate weather forecasts, here are their own global model: the ECMWF ensemble, the US NOAA GFS2, the data from the World Meteorological Organization, data from NASA satellites, data from the Japanese model JMA - Japan Meteorological Agency.

3.7 http://www.intellicast.com

A professional American meteorite for the most knowledgeable users with its own projection based on the GFS model with coverage around the globe. The resource is owned by Weather Services International (WSI), a part of the Weather Channel group. WSI claim that they own the world's largest commercial meteorological database that cooperates with the governments of the United States, Canada, Japan and the United Kingdom. These forecasts are used by most of the world's airlines; the resource delivers weather content to 60,000 media and companies in the energy sector.

3.8 http://www.bbc.co.uk/weather/

The weather service of the Air Force from one of the world's leading news agencies appeared online in 1997 and provides weather information for the license of the British MetOficce Meteorological Service, which uses the Ukmet prognostic model. The Meteorological Bureau of the United Kingdom is the oldest weather service in the world: it was founded in 1854, and in 1861 it introduced the first official weather forecast for English newspapers. The forecast is now for 5000 cities in the world. What's most interesting, the very short-term forecasts from the Air Force are the most accurate for Kyiv on reviews on the Internet.

3.9 www.weather.com

The American Weather Channel The Weather Channel (TWC) service, which has now become a huge corporation. The channel began its broadcast in 1982, and the site

opened in 1995. Interestingly, the founder of the channel John Colman is a leading critic of the theory of global warming.

Estimation of the sources of forecasting was carried out in order to determine the sources that can provide the necessary meteorological parameters (solar radiation, temperature, wind speed, humidity) with discretion about 1 hour, the results of this comparison are given in Table 2.

Table 2. *Comparison of different sources of forecast meteorological parameters.*

Source name	**Availability of hourly forecast**	**Solar radiation forecast**	**Parameters that the resource provides**
www.gismeteo.ua	No	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity
www.sinoptik.ua	No	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Probability of precipitation
www.meteoprog.ua	Yes	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm)
pogoda.yandex.ua	No	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity
www.meteo.gov.ua	No	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm)
Worldweatheronline .com	Yes	No	1.Temperature; 2. Atm. Pressure; 3. Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness
www.intellicast.com	Yes	No	1.Temperature; 2. Atm. Pressure; 3. Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness
www.bbc.co.uk/weather/	No	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness
www.weather.com	Yes	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness
www.accuweather.com	Yes	No	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness
www.meteoblue.com	Yes	Yes	1.Temperature; 2. Atm. Pressure; 3.Strength and direction of wind; 4. Humidity; 5. Precipitation (mm); 6.Cloudness 7. Hourly solar radiation

4. Conclusions

The paper analyzes the principles of functioning of the new law on the wholesale electricity market. The conditions for its implementation include the generation of stations based on renewable energy sources for the pre-scheduled day. For failure to comply with the stated schedule, the law provides for the imposition of fines that by 2025 will correspond to the full amount of the imbalance between declared and generated power, with the exception of 5% provided by the regulator, to reduce losses of the station owners from inaccuracies in the forecast and taking into account the error of the measuring devices. Taking into account the dependence of the generation of RES, in particular PES, on meteorological parameters, the ones that have the greatest influence on the hourly production of electricity by them were determined.

For accurate results, data from various meteorological services were analyzed and compared with meteorological measurements, which were installed directly at the station.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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