Designation of Short-term Power Forecasting System for PV Power System and Its Cluster Integrated with Distribution Power Network

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Abstract: This paper analysis under the conditions of power penetration of PV power system integrated with distribution power network is 0\%, 5\%, 10\%, 15\%, 20\%, 24.46\%, 30\%, 35\%, 40\%, 50\%, 60\% and 75\% respectively, the effects for common bus-bar load forecasting accuracy. Then, designation for the configuration, NWP solving, real-time data collection and PV power system and its cluster power forecasting of short-term PV power forecasting system. In addition, validation for the accuracy of PV power system cluster short-term power forecasting results, and the results indicate that the proposed system is able to explore and technical adaption for the business demand for operator of power grid dispatch department and PV power system.

1 Introduction

Distribution network for PV power generation is one of the key ways to apply solar energy generation, and the full power access to the network is the main way to access the 10kV bus-bar, directly providing power to the local load, resulting in transformation of the power distribution network from passive grid into active grid. Also, due to the inherent power instability, output period and power fluctuations of PV power generation, the time-varying load and current of the distribution network are caused. Power forecasting of the photovoltaic power generation system is an important means for the distribution network to control the impact of photovoltaic power generation on the load and power flow\textsuperscript{[1-3]}.

The early power prediction method for PV generation is mainly based on simple statistical models, due to the large fluctuation of solar irradiance, the prediction error of this model is large and the prediction result is unstable. The estimation methods of PV generation based on AI are mainly Auto-Regressive Moving Average Model, Kalman Filtering Algorithm or the method combining Time Series Method and Kalman Filtering Algorithm together\textsuperscript{[4-7]}.

Time scale of these improved method is short (mainly power estimation of 0-5h), because the changes are mainly determined by the continuity of the atmospheric conditions. Therefore, a certain
 prediction results can be obtained without numerical weather prediction data; and for power prediction with a time scale over 5h, irrespective of that numerical weather prediction cannot reflect the nature of atmospheric motion, and numerical weather prediction is difficult to achieve certain prediction effects [8-10]. With development of technology and demand of power prediction for PV generation, current prediction method has turned to the highly mechanistic numerical prediction methods.

At present, there are few systems that have overall plan and power prediction design for the distribution network of PV generation system. This paper firstly analyzes the influence of the distribution network for PV generation system with a power penetration rate respectively of 0%, 5%, 10%, 15%, 20%, 24.46%, 30%, 35%, 40%, 50%, 60% and 75% on the conventional short-term prediction accuracy of the bus-bar, carried out the integrated design for distribution network for the PV generation system and structure of the cluster power prediction system, numerical weather prediction (NWP), real-time data acquisition, PV power and its cluster prediction, and tested it with real cases. Results show that the design scheme has strong technical applicability and can meet the actual business needs of the power grid dispatching department and PV power generation system.

2 Demand of power prediction of the PV generation system connected to the distribution network

Short-term bus-bar load prediction is an important part of power system load prediction, which is of great significance for optimal unit combination, economic dispatch and electricity market trading. However, when there are a large number of dispersed PV generation systems connected to the power distribution network, causing changes to the conventional load demand. Therefore, the key is to analyze the its influence on the bus-bar load prediction. Since short-term load prediction has the characteristics of periodic and stochastic processes, conventional load prediction generally applies a time series analysis method based on the same type of day-ratio smoothing method.

In this paper, the medium-short-term bus-bar load prediction method is the day-ratio smoothing method, the prediction idea of which is: the per-unit load curve of the date of prediction is to be obtained by the smoothing point by point of the per-unit curve of relevant load, and the base value is to be predicted based on the multiple proportion relationship of the former week. The prediction is divided into 3 steps:

(1) Per-unit curve prediction

Take the relevant load of the day n, and the per-unit curve value of time t on the day to be predicted is the single exponent smoothed value of the per-unit value at the same time on different days in a relevant load set, shown as in equation (1).

\[ \hat{L}_t = aL_{n} + a(1-a)L_{n+1} + a(1-a)^2L_{n+2} + \cdots + a(1-a)^{t-1}L_n \]  

The thus formed daily per-unit curve \( \hat{E} = [\hat{L}_1, \hat{L}_2, \cdots, \hat{L}_r] \), where \( \alpha \) is the smoothing coefficient of standard curve prediction, and it is ranged in the interval \((0,1)\).

(2) Base value prediction

Calculate the smoothed value of the base value of different types of days within the first period,
and analogize other periods, shown as in equation (2) and (3).

\[ A_{n,0} = a P_{t_0} + a(l-a)P_{t_1} + \ldots + a(l-a)^{k-1}P_{t_n} \]  
\[ \hat{P}_0 = \frac{A_{n,0}}{A_{2,0}} \cdot P_{1,0} \]  

Through the means of linear multiple proportion, the base value of the day to be expected is obtained.

(3) Actual value of the prediction curve

According to the standard curve obtained above and the base value of the day to be predicted, the prediction curve is shown as in equation (4).

\[ \hat{D} = \left[ \hat{P}_1, \hat{P}_2, \ldots, \hat{P}_7 \right] \]  

According to the standard curve obtained above and the base value of the day to be predicted, the prediction curve is shown as in equation 4.

Through the PV power penetration rate algorithm and short-term load prediction method of daily-ratio smoothing, under condition that the simulated penetration rates of the PV connected to the distribution network are respectively 0%, 5%, 10%, 15%, 20%, 24.46%, 30%, 35%, 40%, 50%, 60%, 70% and 75%, the raw data used are active power and bus-bar load data of the above-mentioned PV power plant and 220kV bus-bar between 01/30 to 02/28. The short-term bus-bar load prediction results calculated based on the root mean square error are shown as in Fig. 1.

Fig.1 The daily average accuracy of short-term bus-bar load prediction

It can be found from Fig.1 that for most of the prediction days, the high the PV power penetration rate is, the more the prediction accuracy reduces. Especially for normal days, when the load prediction accuracy is over 90%, this trend becomes more apparent.
Fig. 2 The monthly root mean square under different PV power penetration rates

It can be found from Fig. 2 that, without PV connection, the bus-bar load prediction accuracy is 94.53%, and when the power penetration rate increases to 22.4%, which is the actual penetration rate of Longhe 220kV bus-bar, and the short-term load prediction accuracy is 93.19%, reduced by 1.34%. When the power penetration rate further increases to 75%, the load prediction accuracy reduces to 91.05%. In general, with the increasing of the PV power penetration rate, there is continuous decline in the short-term load prediction accuracy.

3 Structural design of PV short-term power prediction system

The PV generation system and cluster function prediction system of the distributed distribution network consists of 6 parts, including prediction database, numerical weather prediction processing module, real-time data acquisition module, data pre-processing module, independent and cluster power prediction module, short-term prediction post-evaluation module shown as in Fig. 3.
1) Prediction database

The prediction database is a massive data storage module of the system, including historical data and real-time data of the PV power generation system, and interoperations of all other functional modules of the system are all carried out through this database. The prediction database is designed available to store 15 years of historical data, and able to meet requirements of the system on data real-time and reliability, what’s more, it also has good openness and security. The data content stored in the system database mainly includes numerical weather prediction data, meteorological data measured at the weather station, PV power generation system operation data, time period reorganization data, power prediction data and system basic account.

2) Numerical weather prediction processing module

The module is used to download and analyze the numerical prediction data, and the download sub-module needs to communicate with the Internet external network, which is deployed on the downloading server in the self-built safe zone, responsible for the timed automatic loading the numerical weather prediction data released by weather department or other commercial organizations, and the data is re-loaded to the prediction system to ensure the security. And the analysis module deployed in the safe II zone stores the numerical weather prediction data analysis in the prediction system database through screening, formatting, and other processes. The processing module supports manual re-recording and multi-data source downloading functions, and can adapt to the communication and networking characteristics of different PV power generation systems.

3) Real-time data acquisition module

The system automatically realizes the collection of basic data such as active power of PV generation system, total irradiance on horizontal surface of the weather station, irradiance of inclined surface, scattering irradiance, temperature and weather, etc. And according to resolution of the acquired data, the data is converted into the average data for 15 minutes for analysis of generation and prediction of power. In case of problems of exporting data, the data can be supplemented based on the manual intervention.

4) Data pretreatment module

Prior to the data being stored in the database, the system can perform integrity and rationality check, and realize automatic batch correction of data with strong adaptability and flexibility to complete the identification and reconstruction of abnormal data.

Data integrity check of the system includes:

(1) The quantity of data should be equal to the quantity of data expected to be recorded;
(2) Time sequence of the data should be in line with the expected start and end time, and the data should be continuous in the middle part.

Data rationality check of the system includes:

(1) Over-limit check for the power, numerical weather prediction and weather station data, and boundary thresholds can be dynamically set;
(2) Check the change rate of the irradiance and power;
(3) Check the mean value and standard deviation of the power.

5) Independent and cluster power prediction module

The power prediction module is the core module of the entire PV power generation short-term prediction system, and it can perform scientific calculation of the future power generation capacity of the PV power station through physical and statistical methods; and then store the calculation results in
the prediction database. Prediction limit of the PV generation system and cluster short-term system of the distributed distribution network is 0-72 h, mainly in the form of numerical weather prediction, which can be mainly applied in the economic dispatch, formulation of current plan, power market trading. The short-term prediction module extracts numerical weather prediction data from the prediction database, to obtain numerical weather prediction values of meteorological elements such as total irradiance, temperature, and wind speed on the horizontal plane, then corrects the weather prediction results according to the meteorological data obtained by the real-time data acquisition module; finally, the corrected results is entered into the BP neural network model. The conversion between PV and electric energy is completed after taking consideration of the power plant overhaul plan and operation status of inverters, to realize the short-term power prediction of the PV generation system, and the short-term prediction model flow chart is shown as in Fig.4.

![Short-term power prediction model flow chart](image)

**Fig. 4 Process flow chart of the short-term power prediction module**

6) Short-term prediction post-evaluation module

The system can perform error statistics on the short-term power prediction results of distributed PV power generation systems and clusters respectively. The indicators include root mean square error, average absolute error, maximum prediction error and qualification rate. The error statistics can be evaluated and analyzed on multiple time scales. And the correlation of meteorological-power error can be analyzed, to evaluate the trend of error change.

### 4 Development of the prediction system platform

#### 4.1 Overall design scheme of the system

The system consists of two parts, server and client. Functions of the server are mainly to centrally store data and accept user requests, all the calculation, prediction, analysis and information management functions in the system are completed on the server; the client is the tool to access the system, and the user can realize various functions provided by the system through operation on the client, such as the inquiry of the power of the new energy sites, data management, etc.
The system applies a three-layer structure, detailed as follows:

1. Data layer. There are mainly two sources of the data required by the system; one is to collect data through the internal network of the system, the other is to collect data from the external network, through establishing an acquisition system, acquisition programming, and by means of a certain pretreatment procedure for the collected raw data to obtain the data required by the model layer.

2. Model layer. The model layer obtains the processed data, and through predictive algorithm training modeling and daily result prediction, stores the results in the database, for display by the software display layer.

3. Application layer: the application layer is developed with the most advanced B/S application mode and the J2EE structure, to display the prediction results and effects of the system comprehensively in various forms of graphs and tables.

4.2 Network structure

The master dispatching station is equipped with two servers, which are deployed in safe II zone. A set of new energy power prediction system and a set of database are deployed respectively on the two prediction servers, the system is in operation with the double-host mode. PV generation system operation data of distributed distribution network of 10kv and above incorporated in power network is collected through the EMS system.
Fig. 6 System network structure

The numerical weather prediction is placed on the external network of the main station through the download server, and is responsible for periodically downloading the numerical weather prediction data by FTP from the server of the meteorological department (institution) via the Internet. The acquisition equipment is deployed at the selected typical distributed PV station to collect the real-time PV output data and upload it to the downloading server via the public network; and the numerical weather prediction and data of the distributed PV on the downloading server is transferred to the prediction server at safe II zone through the reverse isolation device.

The marketing power data is transferred to the prediction server at safe II zone through the reverse isolation device.

4.3 Hardware device function

The functions are divided into internal network and external network according to the requirements of "Safety Protection Regulations for Secondary Power System". The internal network mainly includes communication server, database server and prediction workstation. The external network is equipped with a downloading workstation for downloading numerical weather prediction. The configuration functions of each hardware device are shown in Table 1.

Table 1. Hardware device functions of the system

| Name of the hardware device                          | Function                                                      |
|------------------------------------------------------|---------------------------------------------------------------|
| Application server                                  | Running WEB services and data acquisition operations.         |
| Database server                                     | Running the prediction database.                              |
| Reverse isolation device                            | Information security isolation between the external network and safe II zone. |
| Data acquisition server                             | Collect numerical weather data and real-time data of the distributed distribution network |
| PV generation data acquisition subsystem             | Deployed on the inverter of the PV generation system and weather station, it collects and uploads the real-time power and status information exported by the inverter and weather station monitoring data. |
5 Application of the PV short-term power prediction system

According to the above-mentioned design scheme, the short-term power prediction system of the PV generation system and its cluster of the distributed distribution network in a city in Hebei province. Since the system was put into operation in March, 2017, the operation has been stable and reliable, and the system has gathered historical data of two PV generation systems with respectively an installed capacity of 40MW and 5MW connected to the distribution network.

According to the cluster prediction results of the power prediction system, the prediction data under typical weather background is selected, and the time when the PV generation system output is 0, with the time resolution of 15 min, the two types of data, short-term power prediction and actual power, are compared and analyzed, with the prediction results shown as in Figure 7.

![Fig. 7 Comparison of measured and predicted power](image)

| Type of prediction | Correlation coefficient | Root mean square error | Qualification rate | Percentage of the installed capacity with an error < 20% |
|--------------------|-------------------------|------------------------|-------------------|--------------------------------------------------|
| Short-term prediction | 97.4                   | 8.58                   | 98.18             | 96.16                                            |

Table 2 shows the overall statistical analysis data of the prediction results from May 1, 2017 to May 20, 2017. It can be seen from Table 1 that the correlation coefficient between the short-term prediction results and the measured data is 97.4, indicating that the prediction trends are consistent; for short-term power, probabilities of the root mean square error, qualification rate and error of the prediction results less than 20% are 8.58%, 98.18% and 96.16%, respectively, and the prediction system can meet the requirements of engineering applications.

6 Conclusions

This paper firstly analyzes the influence of the distribution network for PV generation system with a power penetration rate respectively of 0%, 5%, 10%, 15%, 20%, 24.46%, 30%, 35%, 40%, 50%, 60% and 75% on the conventional short-term prediction accuracy of the bus-bar, carried out the integrated design for distribution network for the PV generation system and structure of the cluster power prediction system, numerical weather prediction (NWP), real-time data acquisition, PV power
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