Development and design of photovoltaic power prediction system

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Abstract. In order to reduce the impact of power grid safety caused by volatility and randomness of the energy produced in photovoltaic power plants, this paper puts forward a construction scheme on photovoltaic power generation prediction system, introducing the technical requirements, system configuration and function of each module, and discussing the main technical features of the platform software development. The scheme has been applied in many PV power plants in the northwest of China. It shows that the system can produce reasonable prediction results, providing a right guidance for dispatching and efficient running for PV power plant.

1. Introduction

Photovoltaic (PV) power generation plays an important role in meeting the energy demands, improving energy structure, reducing environmental pollution, protecting the environment and promoting economic and social development, etc. [1]. But it fluctuates randomly when the weather change, especially in the Large-scale grid, so it has a great influence on the grid security and stability. Therefore the effective prediction of PV power will help grid scheduling department to arrange coordination of conventional power and PV power, improving security and stability of power system operation, thereby take full advantage of solar energy resources to obtain great economic and social benefit [2].

A PV power generation prediction model based on past data regarding the inverter’s running state, radiation intensity, wind speed and direction, etc has been built. PV power prediction system can calculate future PV plant output power, which considers the radiation intensity, power and numerical weather prediction (NWP) data as the model input [3]. This paper describes the overall design and application in practical cases of PV prediction system. The results show that this design has been extensive used and meets the practical needs for grid scheduling department and PV power plants.

2. Technical requirements for PV power prediction system

Based on the role of PV power prediction system in electric power production scheduling, it needs to deploy in II security zone of PV power plants (control zone), which benefit to communication with other monitoring and electric power dispatching system. PV power prediction system should abide “the power secondary system safety protection regulations”[4], which issued by the national electricity regulatory commission, request the safety protection of PV power prediction system should insist on the principle of safety partition, special network, horizontal segregation and vertical certification to protect the safety of electric power monitoring system and power dispatching data network.

PV power prediction system needs to meet the following specifications:
(1) Every day before the specified time which is scheduled for the next generation by Dispatch Department, predict PV plant output power over the next three days, time resolution is 15 minutes, to make generation schedule and arranging generator maintenance.

(2) Predict the next 4 hours PV output power, time resolution is 15 minutes and provides the basis for Automatic Generation Control (AGC) real-time scheduling.

(3) Statistical analysis of PV power plant power, meteorological resource distribution and prediction error, which is showed by a graphical report.

(4) A good interface can be used in the other monitoring system, which access to the data of power, working condition and weather station. In addition, it can upload prediction data and meteorological data through the network of II security zone, to the dispatch department.

3. The design of PV power prediction system structure
Photovoltaic power prediction system includes a prediction database, NWP module, real-time data collection, power prediction, data upload module and man-machine interface, As shown in Figure 1

![Figure 1. Architecture of photovoltaic generation power prediction system.](image)

(1) Prediction database: The database includes historical data and real-time data, which is the core of the PV power plant prediction system, various functional modules are all required the database to do the data interaction. Therefore, the design of the database not only takes into account storage and management of long historical data, but also considers the system requirement for data reliability and real-time. The main content, stored in the database, includes: NWP data, meteorological data of weather station, PV power plant operation data, integrate data of time, power prediction data and system based data.

(2) NWP Module: It is divided into two parts, download and parsing. Because the module of download needs to communicate with the outside network, it is usually deployed in the security zone VI and automatically download data of NWP which released by the meteorological department. While the module of parsing, which is deployed in safety zone II, deposit data of NWP to the system database by screening and formatting processes.

(3) Real-time data collection: It is divided into two parts, meteorological data acquisition and real-time power acquisition. The meteorological data acquisition is used to collecting meteorological data from weather station which is related to power prediction, such as wind speed, wind direction, temperature, humidity, pressure, radiation and so on. After preliminary screening, these data will be stored in the database. Real-time power acquisition is used to collect operating data of inverter from the Supervisory Control And Data Acquisition(SCADA) system, including power and working state, these data are used as calculation of power prediction model or comparison between measured
data and predicted data, which are stored in the real-time data sheet of database. In addition, this module can adapt to the diversity of communication protocol in different SCADA system.

(4) Power Prediction: This module is the core of PV prediction system, which scientifically computes generating capacity of PV plants by physical and statistical methods. It is divided into two parts, short-term prediction and very short-term prediction.

On the one hand, in order to achieve 72h short-term prediction of PV power plant, the module of short-term prediction needs to predict correct result of NWP extracting from the database, based on the Real-time Meteorological Data. Then the corrected prediction results of NWP will be involved in the calculation of energy conversion to predict the future power [5].

On the other hand, the module of very short-term prediction is 4h predicting time which is based on the mathematical methods such as linear regression, neural networks and so on, usually including the indirect method and the direct method.

Indirect method is appropriate for the PV plant which has the complete real-time meteorological data. First, this method used historical meteorological data to set the statistical model parameters rate. Then real-time meteorological data entered into a statistical model to calculate the future 0-4 hour weather forecast data. Finally, through the energy conversion model to achieve very short-term power prediction.

While some of the PV power plants are put into operation in a short time, they are not having the condition to get the real-time meteorological data. So the direct prediction method can be used to realize the very short-term prediction, which considers the real-time power data as an input factor in statistical model, instead of using the energy conversion model mentioned above.

(5) Data upload module: PV plant need to report data to the direct dispatch department by the method of E language which are included short-term power prediction, capacity and meteorological data. Accordingly, the PV power prediction system is necessary to develop a data upload function module, which transfer data to the dispatch department via the dispatch data network in the security zone II, by the protocol of IEC102 communication or FTP.

(6) Human-machine interface: It is a user interacting with the system platform based on b/s structure, which not only provide a variety interface of monitor, query and analysis but also have comprehensive analysis and comparison of historical data by graphics and list. Thanks to configurable designs, graphics and reports can hybrid displays. Interface shows the meteorological data, real time power data and the prediction results to the user in the form of process lines, data tables and histograms. To begin with, it can meet the basic requirements for the system. then it has powerful scalability and flexibility.

4. Software platform of prediction system developing

PV power prediction system is a multi-module collaboration platform which distributed computing environment, and used the Java programming language as the main development tool, which is an object-oriented programming language [6]. According to different data interface, data collection procedures are developed by programming language such as C or VC++. Man-machine interface can be developed as a browser based B/S architecture. The features of this structure are that almost all the work can be concentrated on the server side including system development and maintenance. When the system needs to upgrade, users can access to the prediction system by the browser simply. The data interaction between browser and server is the technology of asynchronous JavaScript and XML (Asynchronous JavaScript and XML, AJAX). With this technology, the browser can use objects of Extensible Markup Language (Extensible Markup Language, XML) to communicate with the server directly, rather than reload the page to exchange data with the web server. In this condition, the web pages just need a small amount of information request from the server, not the entire page request, which made the machine interface program smaller, faster and more user-friendly[7].

The prediction system is developed with the MVC pattern, and according to the function, it is divided into three parts:
1. Presentation Layer: Using HTML pages, Web page UI Frame ExtJs is 3.0 frameworks, which ensure a unify and beautiful user interface with powerful interface interoperability, while reducing the number of interactions between the client and server.

2. Control layer: Using stable struts framework to accept convey user requests from the presentation layer, analysis and processing, call the model layer of each module to realize each specific application scenarios.

3. Model layer: This part is the realization of the business logic and data persistence, using Web Service technology to register a component to manipulate the database read and writes; maintain the data of connection pool. Business logic layer be specific to queries the database and access operation.

5. Applications of PV power prediction system

According to the above design method, a PV power plant prediction system was established in February 2014 at the Wuzhong Ningxia Hui Autonomous Region which in the northwest of China. Since the system been put into operation, it is operate stable and reliable, as shown in figure 2 is the prediction system of network structure. In accordance with the requirements of “the power secondary system safety protection regulations”, it is divided into internal and external network, internal network mainly contained the communication server, application server, database server, prediction workstation, and the external network is configured with a downloading workstation to download numerical weather prediction. The configuration of the hardware is shown in table 1.

Figure 2. Network configuration of photovoltaic power prediction system.

Figure 3 is the Comparison chart of real-time power data and power prediction of a PV power plant in July 18th, 2014 14:00 pm, which is removed the value of zero in the evening. The blue is the real-time power curve, and the red curve for very short-term prediction, green is short-term prediction curve. real-time power curve shows the power data of PV plant which get from data acquisition module, it end at 14:00 pm. Very short-term prediction system predict the power of the next 4 hours, so prediction value extends back for 4 hours relative to the real-time power. While the short-term prediction is released the day before July 18, so it covers the whole day. The figure shows that, according to changes in radiation and other meteorological factors, the proposed design of the power prediction system can accurately predict the track of the PV power plant output trends, and obtain ideal prediction results.
Table 1. Hardware description.

| Name                     | Introductions                                                                                                                                 |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Application Server       | For real-time data processing, general data processing and computing power to predict the different types of data depending on the application requirements for automatic processing, data conversion, integration and storage. |
| Communication Server     | Access photovoltaic power plant operating data and real-time data from weather stations, upload prediction data, provide web services publishing. |
| Database Server          | Power prediction data collection, storage and management operations and maintenance worker, to realize the human-computer interaction.          |
| Prediction Workstation   | Publish real-time monitoring and prediction information for operation and maintenance worker, to realize the human-computer interaction.          |
| Internet Server          | Download NWP data through FTP or dedicated channel established by issuing authority, transfer data by the communication protocol.              |
| Network Security Equipment| According to the power secondary system safety protection regulations to protect the network security of PV power plant.                      |

Figure 3. Comparison between predicted and measured.

6. Conclusions
Development and application of power prediction system not only can make full use of solar energy resources, but also improves the economic and social benefit of PV power plant. This paper proposed the development and design scheme of a power prediction system, and according to this scheme, several power prediction systems of PV plant have been established in the northwest of China. The result shows that, the scheme of design and development meets the functional specifications and safety regulations. The prediction result is effective, it can be fully satisfied the needs with engineering applications. Therefore, in order to make the design have a broader application, it needs to set up a total-sky image device to put the analysis of cloud conditions into photovoltaic prediction system, which will be focused in the future.
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