Fault Diagnosis and Detection Based on Efficiency Loss Test of Photovoltaic Power Station

Xiangying Xie¹, Fanteng Meng¹, Xin Luo¹, Shixia Cai¹, Xiaoguang Ma¹, Zhixiong Na¹, Dayan Ma¹, Yu Shan¹, Leyi Ge¹, Yunchao Liu²

¹ State Grid Electronic Commerce Co., Ltd. Beijing 100032, China
² Beijing China Power Information Technology Co., Ltd. Beijing 100192, China
*Corresponding author’s e-mail: mengfanteng@126.com

Abstract. The existing operation and maintenance system of photovoltaic power station can analyze partial equipment problems, but due to the data storage, processing and transmission capacity can hardly meet the requirements of a large number of operation data acquisitions and processing of photovoltaic power station, the operation status of photovoltaic power station cannot be comprehensively evaluated. This paper proposes to analyze the overall efficiency and key link efficiency of the photovoltaic system through long-term monitoring, extract the efficiency model parameters of the key components and important links of the photovoltaic power station, and establish the performance evaluation implementation process. At the same time, based on different actual detection conditions, photovoltaic fault diagnosis is carried out by time domain reflectometry, prediction theory comparison and sensor optimization.

1. Introduction

The 19th National Congress of the Communist Party of China (CPC) put forward the overall strategic plan of promoting energy production and the revolution of consumption, building a clean, low-carbon, safe and efficient energy system, and building a beautiful China. The Central Economic Work Conference has emphasized on many occasions to promote ecological progress and accelerate the adjustment of energy structure. The development of new energy industry in China is in an important period of strategic opportunity, and relevant industries actively implement the energy strategy of "Four Revolutions and One Cooperation", conscientiously implement various national requirements, and promote the higher quality and more sustainable development of new energy industry.

In recent years, the construction scale of photovoltaic power generation projects and the number of power stations increase year by year. As shown in Figure 1, more and more distributed photovoltaic projects are faced with operation and maintenance problems. The existing photovoltaic power station operational system can analyze partial equipment problems, but due to the data storage, processing and transmission capacity can hardly meet the requirements of a large number of operation data acquisitions and processing of photovoltaic power station, the operation status of photovoltaic power station cannot be comprehensively evaluated. At the same time, it is difficult to correctly identify and deal with fault information during operation failure, and it is impossible to optimize and improve the power generation efficiency of photovoltaic power station.
2. Operation performance analysis and evaluation of photovoltaic power station.

The analysis and evaluation of the power generation capacity of photovoltaic power station refers to the realizing the evaluation ability of the medium and long-term power generation performance of photovoltaic power station via the analysis of the overall and key link efficiency of photovoltaic system through long-term monitoring during the actual operation of photovoltaic system, the determination of the sampling object of the key components of the power station, the extraction of the efficiency model parameters of the key components and key links of the photovoltaic system, and the input of the extracted parameters into the power generation performance evaluation tool, and also considering the impact of the reliability on the power generation capacity of photovoltaic power station.

Without considering the failure rate of photovoltaic power station, the operation performance evaluation and implementation process of photovoltaic power station is shown in Figure 2. Based on the analysis of the operation performance of the photovoltaic system, the key links of the existing problems of the photovoltaic system are tested on the spot. Through the field test of photovoltaic modules and arrays, the model parameters such as module efficiency, inconsistency, module attenuation, and photovoltaic array attenuation are obtained. By testing the efficiency of photovoltaic inverter, the model parameters of photovoltaic inverter are obtained. Through the efficiency loss test of photovoltaic power station, the model parameters of efficiency loss are obtained. The medium and long term power generation performance of the power station is evaluated by using the evaluation tool.

By extracting relevant data, the operating performance indices of photovoltaic power stations in different time scales (day, week, month, year, etc.) are analyzed. When studying the operating performance index, we use three typical indices of theoretical generating hours (YR), full operating hours (YF) and system efficiency (PR) to measure the operating performance of photovoltaic power station, and the impact of the results on the evaluation index based on different time scales.
Looking at the monthly distribution of the PR value of a photovoltaic power station in the west of China, it shows the situation of "high at both ends and low in the middle". In the summer when the monthly average radiation is large, the PR value of the photovoltaic power station is small, which reflects that the PR value of the photovoltaic power station is not determined by the radiation amount of the array slope, but caused by the negative temperature effect of the crystalline silicon material. The high temperature causes the reduction of the generation efficiency of the photovoltaic array and the PR value.

3. Fault diagnosis and prediction system of photovoltaic power station

There are numerous components in the photovoltaic power station, including: solar photovoltaic modules, solar photovoltaic stents, DC combiner box, DC lightning protection distribution cabinet, grid connected inverter, AC distribution cabinet, step-up transformer, current transformer, voltage transformer, circuit breaker, isolation switch, metering device, lightning protection and grounding device.
When it is determined that the photovoltaic power station is abnormal, it is necessary to check whether the components have faults in turn. In the existing research, fault tree is used to diagnose the grid connected photovoltaic power generation system. Through analysis, 21 basic events that cause system faults are listed, and the key importance is defined to rank these 21 basic events according to the importance degree. The fault diagnosis is carried out on the basis of the constructed fault tree and the order of key importance is as follow: main wiring of photovoltaic array, main board, memory expansion board of battery group, maximum power point tracking control system, charging circuit, I/O board, grid connected inverter, relay protection, switching board, circuit breaker, transformer, battery charger, external equipment failure of Pt/CT, UPS, DC power supply, power module, AC power supply, transmitter.

3.1. Fault diagnosis of time-domain reflection method
The basic principle of time-domain reflection method is that the waveform on a mismatched transmission line will reflect, and the waveform at any point on the transmission line is the superposition of the original waveform and the reflected waveform. When using TDR, we observe the waveform at the input of the transmission line.

The time domain reflection method uses the signal generated by the function generator to compare with the signal reflected back due to the impedance mismatch to determine the fault of the string. The delay of the reflected signal represents the location of the fault point. The greater the delay is, the longer the distance between the fault point and the TDR equipment is. The delay time can be calculated. According to the propagation speed of the signal, the distance between the fault point and the TDR equipment can be calculated, so as to find out the location of the fault component. The change of the reflected waveform represents the fault type of the component, that is, according to the waveform, the open circuit fault, short circuit fault and component aging fault can be determined respectively.

TDR can be used to diagnose the open circuit fault and attenuation fault correctly. A TDR fault diagnosis can be made at the positive pole, and then another measurement can be made at the negative pole. If the two specified fault points are the same, it means that the string has a single fault; otherwise multiple faults occur in the string. If more than one fault occurs, the first detected fault component can be replaced with a normal component, and then the TDR method can be used to detect the second fault component, and so on. All the fault components can be found.

3.2. Fault diagnosis based on prediction theory
According to the light intensity, temperature and photovoltaic system model, the short-term prediction of photovoltaic output is carried out, and the actual photovoltaic output is compared with the predicted value to determine whether there is a fault. First, according to the radiation intensity obtained from the satellite, the radiation intensity obtained from the ground measurement and the relevant technical parameters of the equipment used in the photovoltaic system, the expected output power of the photovoltaic system is calculated. At the same time, the output power of the actual photovoltaic system is recorded at a given time interval and uploaded to the central server every day. After obtaining the actual power and the calculated expected power, the fault detection program is run on the central server. The program judges the fault by comparing the difference between the actual power and the expected power, and compares the possible fault mode with the pre-defined fault mode to get the actual fault.

3.3. Fault diagnosis based on optimal sensor configuration
The core idea of the fault diagnosis method of photovoltaic array based on optimal sensor configuration is that the photovoltaic array is equivalent to a matrix. The weight node matrix is established, and each battery board is equivalent to a node. The connection between adjacent battery boards in each string is equivalent to the weight edge, and the potential of the connection between
adjacent battery boards to the array negative pole is equivalent to the value of the corresponding weight edge. The node matrix corresponding to photovoltaic array is shown in formula (1).

$$U_{array} = \begin{bmatrix} U_{pv11} & \ldots & U_{pv1p} \\ \vdots & \ddots & \vdots \\ U_{pv1} & \ldots & U_{pvsp} \end{bmatrix} \quad (1)$$

The weight matrix corresponding to photovoltaic array is shown in formula (2).

$$A_{array} = \begin{bmatrix} A_{11} & \ldots & A_{1(p-1)} \\ \vdots & \ddots & \vdots \\ A_{s1} & \ldots & A_{s(p-1)} \end{bmatrix} \quad (2)$$

Then, the output characteristics of the photovoltaic array under different fault conditions are simulated. The change rule of the output characteristics is summarized, and the fault diagnosis strategy based on the combination of branch current detection and battery voltage detection is proposed.

Through the fault diagnosis table listed by calculating the characteristic value of voltage sensor in different fault conditions of photovoltaic array in advance, and the fault components can be found by comparing the actual measured voltage and current value with the fault diagnosis table. In the case of single branch single board fault, multi branch single board fault, single string multi battery board fault and multi branch multi battery board fault, the method can accurately locate the fault point. However, in large photovoltaic system, the method can only be used by reducing the resolution and simplifying the diagnosis system due to the large number of voltage sensors and complex wiring.

The main principle of the new fault diagnosis method of photovoltaic array based on current sensor is to locate the fault point step by step by establishing multi-layer current sensor. However, this method is mainly used in the complete cross connection mode, while most photovoltaic power plants mainly use the simple series parallel mode at present. First, the current value of each string of photovoltaic array is compared with the predefined standard value to get the fault string, and then the value of each voltage sensor in the fault string is compared to finally realize the location of the fault point. This method can not only locate the fault point quickly and accurately, but also use fewer sensors. It is practical in large photovoltaic array.

4. Conclusion
1. Efficiency or efficiency-related indicators are difficult to reflect the real performance of photovoltaic power generation system and the single rate loss source of efficiency. Considering that different types of indicator combinations are used in system efficiency analysis, the implementation process of photovoltaic power plant operation performance evaluation is established.

2. All equipment of photovoltaic power generation system can be diagnosed by extension theory, and the fault can be diagnosed and correctly located when a standard fault set is formed.

3. The fault diagnosis of time domain reflection method, fault diagnosis based on prediction theory, fault diagnosis based on optimal sensor configuration, have their advantages and disadvantages and adaptive scenes, which needs to be selected according to the actual situation.

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References

[1] Optimal sizing of PV and battery-based energy storage in an offgrid nanogrid supplying batteries to a battery swapping station[J]. Mingfei BAN, Jilai YU, Mohammad SHAHIDEHPOUR, Danyang GUO. Journal of Modern Power Systems and Clean Energy. 2019(02)

[2] Research on optimal configuration strategy of energy storage capacity in grid-connected microgrid [J]. Jianlin Li, Yushi Xue, Liting Tian, Xiaodong Yuan. Protection and Control of Modern Power Systems. 2017 (1)

[3] Energy Management Systems in Microgrid Operations[J]. Wencong Su, Jianhui Wang. The Electricity Journal. 2012 (8)

[4] GRAVALOS I, MAKRIS P, CHRISTODOULOPOULOS K.et al.Efficient network planning for Internet of Things with QoS constraints. IEEE Internet of Things Journal. 2018.

[5] Mi Zhou, Xin-Bao Liu, Jian-Bo Yang, Yu-Wang Chen, Jian Wu. Evidential reasoning approach with multiple kinds of attributes and entropy-based weight assignment [J].Knowledge-Based Systems. 2018.

[6] Incorporating aging failures in power system reliability evaluation. LI W. Power Engineering Society General Meeting. 2002

[7] Ioannis Chamodrakas, Drakoulis Martakos. A utility-based fuzzy TOPSIS method for energy efficient network selection in heterogeneous wireless networks[J]. Applied Soft Computing Journal. 2012(7).

[8] Anton Beloglazov, Jemal Abawajy, Rajkumar Buyya. Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing[J]. Future Generation Computer Systems. 2011(5).

[9] Adaptive power oscillation damping controller of superconducting magnetic energy storage device [J]. Wei Yao, L. Jiang, Jiakun Fang, Jinyu Wen, Shijie Cheng, Q.H. Wu. International Journal of Electrical Power and Energy. 2016