Islanding Detection and Protection Strategies for Electric Vehicle Charging Station

Xiaoyang Zhang

Southampton Ocean Engineering Joint Institute, Harbin Engineering University, Harbin, 150000, China
xz5e21@soton.ac.uk

Abstract. This article systematically reviews the research progress on the formation mechanism, risk influencing factors, and protection strategies of the islanding effect in electric vehicle charging stations. The article first analyzes the potential hazards that may be caused by the isolated operation of electric vehicle charging stations, such as voltage and frequency fluctuations, equipment damage, and personal safety risks. The article then elaborated on the limitations of the existing detection methods, such as the limited accuracy of passive detection methods and the negative impact of active detection methods on the quality of the power grid. Then, starting from the development process of traditional detection methods to intelligent detection, the article discusses the current research status and future trends of protection strategies. The article also analyzed the main challenges currently faced by the technology, such as its insufficient adaptability in the complex grid environment, as well as the contradiction between cost and scalability. Finally, the article focuses on the integration of intelligent detection technology and multi-source collaborative protection strategies, and looks forward to the future research direction of islanding protection for charging stations. This article provides a theoretical reference for the construction of safe and reliable charging infrastructure for electric vehicles.

Keywords: Electric vehicle, V2G, Islanding effect.

1 Introduction

In the context of global efforts to combat climate change and promote sustainable development, electric vehicles have emerged as the core carrier of the energy revolution in the transportation sector due to their advantages, such as zero emissions and high energy efficiency. The International Energy Agency (IEA) predicts that by 2030, the global number of electric vehicles will exceed 300 million, and the demand for supporting charging infrastructure will grow exponentially. However, the grid connection operation of a large-scale charging station poses new challenges to the power system. Among them, the islanding detection and protection technology faces technical difficulties such as interference from multiple devices in parallel connection, and it is difficult to balance detection accuracy and response speed.

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At present, scholars both at home and abroad have conducted preliminary research in the field of islanding detection and protection for charging stations. U.B. Irshad et al. adjusted the reference value of the inverter's reactive power dynamically. When they detected that the PCC voltage deviated from the nominal value, they actively created a reactive power mismatch, causing the system frequency to rapidly deviate from the rated value, thereby triggering the protection action. Compared with the traditional detection methods, it has a faster speed and higher reliability [1]. T. Prasad et al. achieved seamless switching between grid mode and island mode through adaptive filtering algorithms and Dual Higher Order Generalized Integrator Quasi Type-2 (DHOGI-QT2） phase-locked loop technology. The technology ensured that the charging station could continue to supply power and produce hydrogen even in the event of grid failures [2]. From this, it is evident that the combined use of passive and active detection methods, as well as intelligent detection based on artificial intelligence and communication technologies, has become a new trend. In the field of protection, a technical system based on intelligent algorithm applications and multi-energy collaborative protection has been established. However, there are still deficiencies in terms of detection speed and applicability. Developing efficient and precise island detection and protection technologies has become the core issue for the safe operation of charging stations.

In this context, this paper focuses on exploring the formation principle of the islanding effect of electric vehicle charging stations, as well as the research progress in detection and protection strategies. The study conducted a systematic analysis of the potential impacts of the islanding effect on the operation of power grid equipment and the threat to personnel safety. It also summarized the current technical difficulties, such as the limited quality and detection accuracy of the power grid, as well as the future development trends. This article aims to provide a systematic reference for improving the detection and protection technology system and methodology for islanding charging stations of electric vehicles, and to promote the innovative development of intelligent detection and collaborative protection.

2 Islanding Effect and Its Hazards

The formation mechanism of the islanding effect is shown in Figure 1. The distributed power generation system is connected to the power transmission grid. The system supplies power to the distribution network loads through equipment such as transformers and circuit breakers. When the main power grid experiences a failure that causes the connection between the transmission grid and the distribution grid to be cut off, and the power generation system fails to detect the disconnection in time, it will continue to supply power to the isolated distribution grid, thereby forming an isolated island.

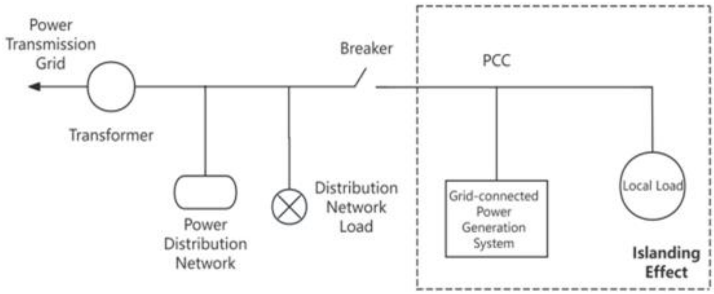

Fig. 1. Islanding Effect Diagram.

The islanding effect can be classified into planned islanding and unplanned islanding [3-4].The planned islanding is a prearranged operation strategy that utilizes local distributed power sources and energy storage systems for power generation, and remains within a controllable operational state. The unplanned islanding is a passive islanding operation caused by an unexpected failure of the main power grid. It poses a higher risk. If not detected and controlled in time, it may lead to equipment damage or personal safety accidents. Table 1 presents the main differences between the two in terms of formation causes, controllability, and detection methods, indicating the unpredictability and danger of unplanned islanding.

Table 1. Comparison between planned islanding and unplanned islanding..

	Intentional Islanding	Unintentional Islanding
Forming Reason	Pre-planning	By unexpected situations
Controllability	Controllable	Uncontrollable
Safeguard Procedures	Equipped with active control measures	Depend on anti-islanding protection
Communication Requirements	Depend on advanced communication systems	No communication dependence
Detection method	No detection required	Need rapid detection

3 Islanding Detection Method and Limitations

Islanding detection technology is mainly divided into remote communication detection methods on the power grid side and local voltage detection methods on the inverter side [5]. Remote communication detection monitors the status of the distribution network in real time and sends signals to distributed power sources to determine whether an islanding situation has occurred [6-8]. This method can avoid Non-Detection Zone （NDZ）, but communication equipment needs to be deployed, which incurs a relatively high cost. The local voltage detection is divided into active detection and passive detection. By monitoring parameters such as voltage and frequency, it can determine whether the power grid has been disconnected [9]. The typical methods mainly include the following several kinds: Over Voltage (OV) /Under Voltage (UV）Protection, disconnecting the grid connection when the voltage exceeds or falls below the set threshold； Over Frequency (OF）/Under Frequency (UF）Protection, disconnecting automatically when the grid frequency deviates from the rated range by a certain amplitude, to prevent abnormal frequency conditions; Active Frequency Drift (AFD), by actively disturbing the frequency to trigger the protection mechanism. This type of method is fast in response and low in cost, but it has a Non-Detection Zone. Some other specific detection methods are shown in Figure 2.

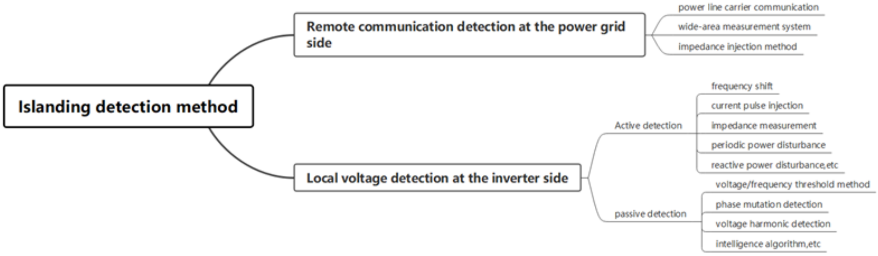

Fig. 2. Main Detection Methods.

In the field of islanding detection, Rui Zhang, in the Space Vector Pulse Width Modulation (SVPWM) modulation, used a digital control system to apply periodic disturbances to the output current frequency of the three-phase inverter of the Vehicle to Grid (V2G) charging station, causing the current frequency to be slightly higher than the grid's frequency[10]. The accumulation of disturbances causes the frequency to rapidly deviate from the threshold after the network is disconnected, triggering protection and subsequently leading to rapid detection. Regarding how to eliminate the Non-Detection Zone, it is proposed that when the voltage phase variation value is abnormal, the current disturbance cycle data should be cleared, and the count should be reset, thereby avoiding interference from the impedance angle.

Mingzhu Sun then classified the three islanding detection methods based on the size of the V2G charging stations [11]. Firstly, a mid-frequency disturbance signal is superimposed onto the inverter modulation wave. Detection is achieved by utilizing the change in impedance amplitude before and after the islanding event. This method is applicable to small charging and discharging stations with a single pile or a few piles. Secondly, for large-scale power stations with multiple generators connected in parallel, the impedance phase angle discontinuity is adopted as the criterion to avoid the failure caused by power matching. Finally, to meet the centralized detection requirements of heterogeneous super-large power stations, an active method based on harmonic voltage pre-detection was adopted, which significantly reduced the disturbance time and decreased equipment losses. These three methods cover the islanding detection requirements, ranging from single piles to super-large charging stations.

4 Research Status of Islanding Protection Methods

At present, the main methods of islanding protection include the following several kinds. Installing passive anti-islanding protection devices to monitor key parameters such as voltage and frequency in real time. Employing active disturbance rejection control techniques, such as the frequency offset method and impedance measurement method, etc. Connecting the vehicle Battery Management System(BMS) and the charging station through communication, such as sharing status via Power Line Communication (PLC), and jointly executing power-off or power adjustment.

In the field of islanding protection, M. Sun proposed injecting medium-frequency, small-amplitude single-frequency harmonic disturbance signals into the modulation wave of the inverter [12]. Subsequently, the harmonic voltage and current at the Point of Common Coupling(PCC) were extracted using the Fast Fourier Transform(FFT), and the harmonic impedance was calculated. The results show that the impedance of the harmonic wave varies significantly before and after the islanding event, and the detection sensitivity is high. Moreover, this method is effective for various types of frequency disturbances, and it overcomes the defect of temporary fluctuations in PCC impedance caused by the newly added charging station.

K. Patro implements protection through a collaborative mechanism of "passive monitoring - active verification - rapid isolation" [13]. The system first employs an improved Phase-Locked Loop (PLL) structure to continuously monitor key parameters such as Rate Of Change Of (ROCOF) Frequency and voltage total harmonic distortion. When the passive layer detects an anomaly, intelligent injection of time-varying reactive power disturbances is carried out, and the matching degree between the measured and the model-estimated ROCOF is verified through the Pearson current transformer correlation coefficient. Finally, a split-breaking strategy combining soft turn-off of the Insulated Gate Bipolar Transistor (IGBT) and mechanical disconnection was adopted. The experimental results show that the action time is controlled within 80-120 ms, and the THD impact is less than 0.8%. Compared with traditional methods, the malfunction rate and disturbance amplitude have been significantly reduced.

5 The Development Trend of Islanding Detection and Protection Methods

Currently, electric vehicles are encountering various technical challenges in Islanded Micro-Grids (IMG), which hinder their large-scale application and the improvement of system stability. Firstly, issues related to dynamic response and stability are prominent. The rapid fluctuations in the charging and discharging power of electric vehicles can easily cause voltage and frequency deviations. Moreover, the traditional methods have a delayed response and lack the ability for adaptive regulation, which may lead to oscillations in the charging and discharging power and pose a threat to the stable operation of the system. Furthermore, it has poor adaptability to complex conditions. This problem becomes particularly evident in abnormal scenarios such as distributed power supply failures [14]. Traditional control strategies are difficult to dynamically adjust to maintain system stability. Finally, the lack of infrastructure and over-reliance on communication pose significant challenges to the islanding detection and protection of the electric vehicle charging stations. The current charging management technology heavily relies on communication networks to coordinate charging and discharging behaviors. However, the distribution system often lacks a reliable communication infrastructure, resulting in high upgrade costs and poor real-time performance.

Based on the above analysis, it can be concluded that in the future, both islanding detection and protection technologies will continue to develop rapidly in the direction of intelligence and multi-source collaboration. The adaptive threshold optimization algorithm and multi-band collaborative perturbation will deepen the intelligent hybrid detection technology, enabling real-time and dynamic optimization adjustment of charging and discharging power. Establish a real-time digital model for charging piles and the power grid, simulate the islanded state under different conditions, and optimize the detection algorithm. This technology can provide a more reliable testing and verification environment for the islanding operation of electric vehicles, significantly reducing the risks of actual deployment. Meanwhile, 5G communication and blockchain technology will support multi-source information fusion protection, enabling the transmission and collaborative decision-making of protection instructions, and addressing the collaborative detection challenges in distributed energy scenarios [15].

6 Conclusion

This article systematically reviews the classification and research status of islanding detection and protection strategies for electric vehicle charging stations, and discusses the current technical bottlenecks and possible future development trends. It provides a theoretical basis for the safe design of charging stations and is of great significance for promoting the deep integration of electric vehicles and smart grids. It is worth noting that the introduction of artificial intelligence technology has enabled the islanding detection and protection system to adapt to complex power grid environments, significantly enhancing its reliability and response speed. In the future, with the development of technologies such as digital twins and multi-energy collaborative protection, islanding detection and protection will evolve towards intelligence and high precision, enabling the next generation of charging station to achieve more intelligent and efficient operation management.

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