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Dynamic Lightning Protection of Smart Grid distribution system

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ABSTRACT

With the integration of renewable resources, distributed generation (DG) and Microgrids, the Smart Grid distribution systems are more decentralized and interactive. As a System-level protection mode, the Dynamic Lightning Protection (DLP) focuses on the preventive actions for improving lightning performance of the whole system. In this paper, the DLP for Smart Grid distribution system is discussed. Taking advantage of the flexibility and interactivity of Smart Grid, the mode aims to maintain the system dynamic balance and minimize the lightning disturbance during the lightning storms. A dynamic hierarchical multilevel control model is also proposed in the paper, which could coordinate with a Dynamic Lightning Protection System (DLPS) to switch the control strategies, control the power exchange and improve the system reliability.

1. Introduction

In order to address the global challenges of climate change, energy crisis and environmental sustainability, renewable energy resources are being widely integrated into the electric utilities. At the same time, the power grids are facing the challenges of increasing complexity of structure, growing demand of electricity and desires of improving reliability. The Smart Grid and its related technologies which span the entire grid, from generation through transmission and distribution to consumers, are believed to be the best solution [1].

The traditional distribution networks were designed to distribute power from centralized supply sources (e.g., substations, feed lines) to fixed users and predictable loads. With the integrated renewable energy, distributed generation (DG), storage and Microgrid, the Smart Grid distribution systems are more decentralized and interactive.

To ensure the continuous power supply is the primary function of each distribution system. Considering the importance of lightning protection, a Smart Grid and its distribution system could develop more enhanced lightning protection measures.

On account of the interactivity and flexibility, Smart Grid distribution systems are able to optimize operation modes, switch control strategies, and coordinate with multiple Microgrids. These actions can be employed by a System-level protection system to minimize the lightning disturbances and improve the system reliability.

2. Overview of Dynamic Lightning Protection

The lightning performance of a power grid or a Smart Grid means its ability of resisting the lightning damages and lightning disturbances, which results in the stability and robustness of an operating electric power system. The lightning performance of a power grid is based on the performance of each grid unit, however, is not simply determined by the performance of each unit [2].

Dynamic Lightning Protection (DLP) is a kind of flexible global protection mode for improving the lightning performance of a power grid or a Smart Grid. As a System-level lightning protection mode, the DLP focuses on protecting the whole electric grid instead of individual components.

Unlike those system faults caused by random factors, the potential lightning disturbances could be approximately predicted through a real time lightning tracking or detection network. The Dynamic Lightning Protection System (DLPS) is an automatic lightning protection control system for power grids or Smart Grids. Based on real time lightning detection, a DLPS calculates and automatically carries out the dynamic preventive actions. These

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Table 1
Comparison of conventional and dynamic protection mode.

	Conventional mode	Dynamic mode
Means	Protects the whole system through ensuring the normal operating of every unit.	Protects the whole system through ensuring the real time balance of a power grid.
Principle	Leads the damaging energy to the ground safely, improves insulation level.	Leads the power load to the safe parts of a power grid, dynamically alters the grid topology and critical nodes.
Target	An individual device or component, e.g., power line, transformer, electronic equipment or substation.	A whole power grid or a Smart Grid.
Measure	Fixed measures, e.g., overhead ground wires, insulation coordination, arresters, lightning rods.	Flexible measures.
Emphasis	Design stage.	Operating stage.
Purpose	To ensure the normal operating of a power grid or a Smart Grid.	

dynamic actions include: (1) Optimizing Operation Mode to change the power flow routes, and to avoid the power flows passing through the routes which are threatened by lightning, (2) Adjusting Power Flow to reduce the power flows on the routes threatened by lightning, while increasing the power flows on the safe routes, (3) Controlling generation units to control the power flow sources, to increase the outputs in safe sections, and dynamically alter the critical support nodes, and (4) Switching the Microgrids to shift the distributed power self-adaption nodes and to maintain the local balance. The coordination and combination of above actions would minimize the impact of lightning disturbances and improve the lightning performance during the lightning storms.

A comparison of conventional and dynamic protection mode is listed as follows (Table 1). More details of Dynamic Lightning Protection are given by Tong et al. [2].

3. Lightning and reliability challenges of Smart Grid distribution systems

With the worldwide development of Smart Grids, more renewable resources will be integrated. Commonly, larger scale renewable generations (e.g., large/offshore wind farms and photovoltaic power plants) are connected to the Smart Grid transmission systems. The distributed renewable generations are integrated to Smart Grid distribution systems dispersedly.

The larger, interconnected and interactive Smart Grids have more complex network structure and more complicated dynamic behaviors. It brings lots of potential threats to the whole power grid and makes the system closer to the crisis margin. Because of (1) Volatility of renewable resources generation, (2) Inter-area oscillations, and (3) Cumulative effects and Cascade effects, the Smart Grids are still accessible to blackouts, which could be aggravated by lightning disturbances in extreme situations. The lightning protection will always be one of the most important topics.

Generally, due to the inherently lower insulation levels, distribution networks are more sensitive and susceptible to lightning disturbances and damages than transmission networks [3,4]. Careful design, installation and maintenance can minimize the deleterious effects of lightning, but cannot eliminate them [5].

As most distribution systems of the power grid/Smart Grid consist of a great number of interrelated devices, lines and components, a tiny fault in an element may lead to the failure of the whole system. Even if the lightning performance of each individual unit is high enough, it is still questionable whether the risks of outage are completely eliminated.

In terms of lightning protection, a Smart Grid does not mean that a grid would be reliable enough. The Smart Grids and its distribution system need more effective lightning protection measures on grid-scale. Application of a System-level protection method can be an alternative solution, such as Dynamic Lightning Protection (DLP). When it is configured for a Smart Grid distribution system, the dynamic action (1) Adjusting Operation Mode and action (2) Controlling Microgrids, are employed.

4. Lightning detection and warning of Smart Grid distribution systems

Lightning warning, which means providing advance notice of the threats, includes two key aspects: SPACE and TIME. The wide area network-based radio frequency (RF) sensors, which detect/process the RF signals emitted by flashes, could provide the real time distance from an existing lightning storm (SPACE). The electric field mills (EFMs), which measure the ground electric field, could estimate the lead time/probabilities of the potential lightning flashes (TIME).

A DLPS of a whole Smart Grid or its transmission system generally implements the power grid lightning warning through a LF/VLF (low frequency/very low frequency) range wide area lightning detection network. Meanwhile, the warning system combines fixed-point method and storm-following method. As a distribution system is commonly located in a relatively small geographic area, the short range single-point RF sensors and the EFMs are also effective, when the detection networks are not available or in some low-cost solutions.

For a Smart Grid distribution system, the main procedures of lightning warning are listed as following: (1) Break the entire lightning detection area (a geographic map including the distribution network) down into a series of small grid cells, and create a matrix according to the location of the cells. (2) Define the area of concern (AOC), where the main distribution network is located in. Define the area of warning (AOW), where are surrounding the AOC. (3) Create a matrix which consists of the cells in AOC (or sometimes create a series of matrixes corresponding to different parts of an AOC), and create a matrix which consists of the cells in AOW (or sometimes create a series of matrixes corresponding to different parts of an AOW). (4) Set threshold for each AOC matrix, set threshold for each AOW matrix, and set three (or more) alarm levels. (5) Record the lightning detection data (typically the cloud-to-ground (CG) stokes number) in each cell in a certain period of time, and input the value into the above matrixes. (6) Through the calculation and comparison of lightning detection data in AOC matrixes, AOW matrixes and a certain combination of preset thresholds, a DLPS will conclude an alarm level for each AOC matrix. (7) According the alarm level of different AOC matrixes (which corresponds to different parts of an AOC), the DLPS will active the relevant dynamic actions in each level. (8) Set a dwell time (typically 30–60 min) for each AOC matrix. The end of warning or the following dynamic actions will be determined by the comparison of detection data in the matrixes and the thresholds. The combination of Cloud flashes data and a reasonable AOW size are recommended for the lightning warning of a Smart Grid distribution system.

5. Operation modes adjusting of Dynamic Lightning Protection

Before a lightning-caused outage occurs in the distribution system or the interconnected main grid, a DLPS detects and responds to actual, emerging and potential lightning caused incidents. It focuses