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Application of Real Time Lightning Detection for Smart Gird Distribution Systems of Power Grid Load Centers

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***Abstract*—This paper presented the research and application of real time lightning detection data for the Smart Girds distribution systems in power grid load centers. A Smart Gird dynamic protection mode based on real time lightning tracking is also introduced. The dynamic mode provides alternative solutions to minimize the impacts of lightning-caused disturbances and improve the global lightning performance of the Smart Grids distribution systems.**

***Keywords*—Smart Gird; Real time lightning detection; distribution system; power grid load center**

I. Introduction

The increasing development of Smart Grids leads to more complex network structure and dynamic behaviors. Smart Grids are still facing threats of local or Grid-scale blackouts in extreme situations, which could be further deteriorated by lightning disturbances.

It's estimated about 30 percent of all power outages in the United States are lightning-related. It's about average 50 percent in Nordel. In China, the lightning-caused power outages are more than 50 percent from 2005 to 2015. In those electric power grid load centers, such as a city or an area with numerous manufactures, a lightning-caused fault would impact a large number of customers in a small geographic area.

A Smart Grid does not mean the whole system would be reliable enough.

The potential lightning disturbances of power grids could be approximately predicted through a real time lightning detection network. Based on real time lightning tracking and warning, the dynamic protective actions could be automatically carried out in advance to improve the global lightning performance of a Smart Grid. These protection solutions name

Dynamic Lightning Protection (DLP) have been discussed in [Tong et al., 2012].

The topic of this paper is around the Smart Gird Distribution Systems of the Power Grid Load Centers.

II. Lightning-caused outage Problems of Smart Gird Distribution Systems

A. Limitations of conventional solutions

Distribution networks are more sensitive and susceptible to lightning disturbances and damages. Hence, they suffer more outages than transmission networks. To improve the lightning performance of distribution lines, various measures including underground cable solution, surge arresters, line insulation, shield wire, ground resistances, critical impulse flashover voltage (CFO) should be comprehensively considered. While, economical rationality of these solutions should always be evaluated.

Most distribution systems include considerable number of lines. Careful design, installation and maintenance can minimize the deleterious effects of lightning, but cannot eliminate them.

B. New challenges of Smart Grid

On the other hand, 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 Microgrids, the Smart Grid distribution systems are more decentralized and interactive. The integration of DGs and Microgrids changes the radial topology of distribution systems, causes the bidirectional power flows, increases fault current levels.

Furthermore, most DG energy sources are interfaced through power electronic converters. The interfaces of converters increase the flexibility of control but reduce the inertia. Lack of inertia and different operation modes pose difficulties in maintaining a power balance between generation and consumption.

During lightning storms, the nonpersistent fault caused by lightning could be cleared by instantaneous circuit breakers and relay reclosing operation (0.5～1.5 seconds). Improper relay reclosure on the permanent fault, will impact the distribution system again.

The increasing development of Smart Grids has not decrease the power supply interruptions caused by lightning. In China, the lightning-caused power outages are more than 70% in some power grid load centers.

In the operating stage, a Smart Grid distribution system is still apt to cause local outage, if it purely depends on the conventional lightning protection mode.

As the current conventional solutions are inadequate and cannot be achieved economically, the dynamic protection mode based on real time lightning detection became a complementary solution.

III. Dynamic Protection Based on Real Time Lightning Detection

Smart Grid distribution systems are able to adjust various operation modes, switch control strategies, and coordinate with multiple Microgrids. These actions can be employed by a dynamic protection system to minimize the lightning disturbance and ensure the continuous power supply.

A. Lightning Warning

A basic lightning warning method of power grids have been introduced by Tong et al. [2012]. Its main procedures are: (1) Break the entire lightning detection area (a geographic map including the power grid) down to a series of small grid cells, and create a matrix. (2) Define the Area of Concern (AOC) for main grid and define the Area of Warning (AOW), for surrounding area. (3) Create matrixes of AOCand AOW. (4) Set the threshold and alarm levels. (5) Record the lightning detection data in each cell and input into matrixes. (6) Through the calculation and comparison of AOC, AOW matrixes and a preset threshold, conclude an alarm level. (7) According to the alarm level of different AOC matrixes, activate the relevant dynamic actions in each level. More details are in [Tong et al., 2012].

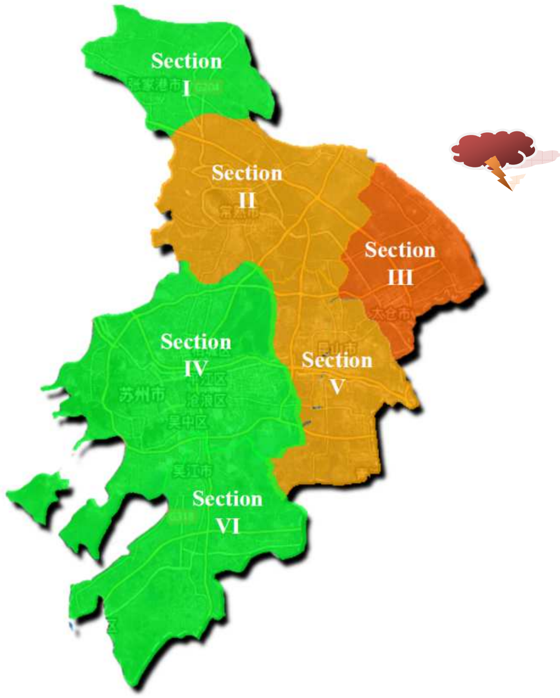


Fig. 1. Multisection lightning warning method

In Fig. 1, the orange level alarm of Section III has been triggered.

As the distrubion systems usually concentrate in small geographical areas, a lightning strom will trigger lightning warning of all the system in most cases.

B. Dynamic Actions

Before a lightning-caused outage occurs in the connected main grid, a dynamic protection system detects and responds to actual, emerging and potential lightning caused incidents. It focuses on prevention and minimizing the system and consumer impacts. Thus, the dynamic protection issues are concentrated on (1) how to effectively deal with the external faults actively, (2) how to properly coordinate the generator/storage units operation before switched to the islanded mode, and (3) how to improve the transient stability when switching the two operation modes (grid-connected and islanded), especially with the Microgrids and various types of DGs and passive local loads.

Ideally, for a group of Micrograds, DGs and local loads in a Smart Grid distribution system, if they have no energy exchange with the connected main grid, the distribution system will suffer from minimal impacts when external faults cause their disconnection. Similarly, under instantaneous connection/islanding, the less electricity input from the main grid, the less side-effect would the whole system have. These side-effects or impacts include unbalance between generation and load, severe voltage or frequency conditions affected by power mismatch, or losing transient stability.

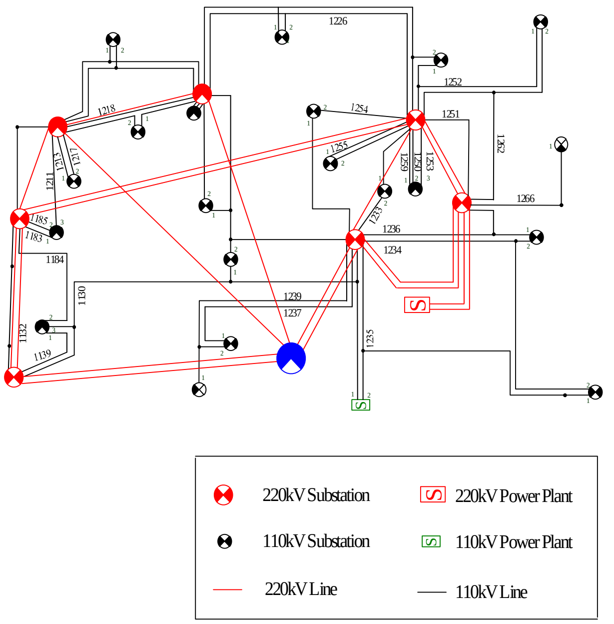


Fig. 2. Connection diagram of the relevant upper level main grid

Fig. 2 shows the connection diagram of the relevant uplevel main grid of a distribution system. We could find that each part of a power grid is correlative in operating. The whole system maintances a balance state in operating. When lightning caused one or more part(s) of the network, the relevant upper or lower level grid would be influnced. Thus, the protection of individual line or device is inadequate and the evaluation of risk of whole system is necessary.

When lightning caused faults (temporary or permanent) occur in the main grid, a dynamic global control and switching can benefit the dynamic balance.

Thus, the principle of Dynamic Lightning Protection is to maintain the balance between DGs and loads, and to control the power exchange in the distribution system.

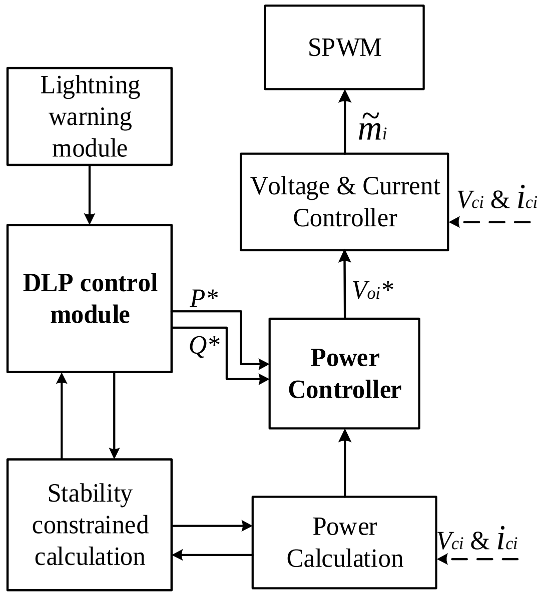


Fig. 3. Framwork of a simplified multi-loop feedback controller

Fig. 3 shows the framwork of a simplified multi-loop feedback controller. The multi-loop feedback could be obtained to control the micro sources that are controlled by the P-f & Q-V droop.

The outer loop is P-f & Q-V droop controller. The inner voltage and current controller insure the output voltage of the inverter equal to the outer controller, while reducing the effect of the disturbances.

Difference PQ controllers for the interface are designed to control the output power of the sources equal to the reference power, which would be adjusted according to the lightning threat level.

The voltage equation of filtering inductance is (value of filter resistance ignored):

$$\Delta C_s(t) L_f \frac{dI_{inv}}{dt} = T(l)(\frac{1}{2} m \sin(\omega t - \phi - i\frac{2\pi}{3}) V_{dc} - V_0) \quad (1)$$

where $\Delta C_s(t)$ is the transfer function of stability constrained calculation, I_{inv} means output current vector:

$$I_{inv} = [i_{inva}\ i_{invb}\ i_{invc}]^T ;$$

and V_0 means output voltage vector:

$$V_0 = [V_{0a}\ V_{0b}\ V_{0c}]^T .$$

And, current equation of filtering capacitance is:

$$C_f \frac{dV_0}{dt} = I_{invc} - I_f \tag{2}$$

where I_f means current vector:

$$I_f = [i_{fa} \ i_{fb} \ i_{fc}]^T$$

According to the equation (1) and (2), we can design a basic lightning threat constrained Voltage & Current loop controller. More details are in [Tong et al., 2014].

IV. Application Sample

A. Background

The main power grid of Suzhou, China consists of ten 500kV substations (22,000 MVA total capacity), 39 500kV lines (1,042 km total length), 83 220kV substations (35,000 MVA total capacity) and 260 220kV lines (3,100 km total length).

The max power load peak of Suzhou is more than 21,000 MW in 2015 which is No. 2 in China (No.1 is Shanghai and No.3 is Beijing).

The main grid concentrates on a region no more than 9,000 km^2. One lightning storm might cover a series of key transmission lines or several distribution Systems at the same time. The city is a typical power grid load center.

The development of Smart Grids in the past sevral years has not decrease the power supply interruptions caused by lightning yet. The lightning-caused power outages are more than 70% in recent years.

The situation of high rate lightning faults is researched and analysed. The main reasons are as following:

1) Lack of historical lightning data

The historical lightning data is insufficient and inaccurate. Important data such as ground flash density, CG strokes amplitude, polarity and proportion were uncertain in the design stage. There is not a lightning detection network with high detection efficiency and accuracy.

2) Rapid expanding of Power Grid

The power networks of Suzhou area was developed and constructed in a high speed. The period is too short to accumulate sufficient operation experiences, including lightning protection. The 76% substations and the 80% length of power lines were built in recnet ten years. The rapidly expanding networks have been facing serious lightning disturbances.

3) Lack of Local power sources

The local power sources are insufficient to support the great power demand especially under those load peak periods. These periods are usally in the summer which lightning acrtivity is more frequent. The extenal power sources faced the risks of transmisson system lightning-caused faults, which could affect the local distribution systems indirectly.

4) Large number of components and concentrated distribution

Due to the big cardinal number of power grid lines and devices, the absolute quantity of failures is considerable. While concentrating in a limited area, they are apt to influnce each other. The increasing renewable energy generation and Distributed Generation (DG) made the network structure and operating state more complicated.

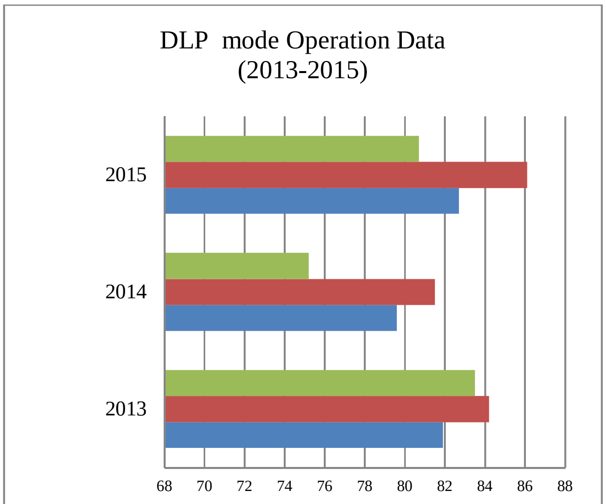
Thus, the Dynamic lightning protection of Smart Grid which based on real time lightning detection became an optional solution.

B. Operation Data

The first Smart Grid distribution system exemplary project of Suzhou has been accomplished in 2015. A complete Smart Grid advance district is planned to be established by 2020. While the Dynamic lightning protection of Smart Grid has been researched and tested from 2011, and the relevant practice project began in 2013.

The dynamic lightning protection system of Suzhou Smart Grid distribution system consisits of three parts: the real time lightning data collection module, the central processing module, and the intelligent control module.

At the present stage, it's a simplified version of a DLPS (Dynamic Lightning Protection System) of a whole Power Grid (including transmission system and distribution system). The system is applied in the Power Grid Dispatch Center.



	2013	2014	2015
RS Rate(%)	83.5	75.2	80.7
AC Rate(%)	84.2	81.5	86.1
AT Rate(%)	81.9	79.6	82.7

Fig. 4. DLP mode Operation Data (2013-2015)

In Fig. 4, RS rate means the successful reclose rate of the relevant power line trips. AT rate means the available action trigger rate of the system and AC rate means the automatic control rate which is relative to manual control rate.

TABLE I. SYSTEM RESTORE AND AVERAGE INTERRUPTION TIME

	Remote trip event without DLP	Remote trip event with DLP	Terminal trip event without DLP	Terminal trip event with DLP
SR time	31 min	19 min	18 min	12 min
AI time	N/A	N/A	29 min	11 min

Table I shows the data of SR and AI time in 27 relevant lightning-caused permanent fault trip events. In the table, SR time is average System restore time which means the duration of a system restore to the initial steady state; AI time is Average interruption time which means the duration of a terminal node outage.

C. *Limitaion and Disadvantange*

There still some limitaions and disadvantanges in the application of such a dynamic protection system at present.

1) Unavailable for individual devices

The dynamic mode is designed for the protection of a whole Smart Grid. It is unavailable or has no effects to an individual device. The conventional protection measures of every device are still essential.

2) Lack of accurate lightning data

At presnet, there is still not a lightning detection network with high detection efficiency and accuracy to provide reliable real time lightning data in Suzhou. Thus the performance of the protection system would be limited.

A complementary solution is to employ a local area lighting sensor for the lightning detection of a distribution system. It will be a low cost optional solution in a small protection area.

3) Risk and cost of the extra control actions

The extra control actions would bring more risks to an operating power grid. The necessity must be calculated and evaluated before every action to be implemented.

Compared with the normal daily operations, the dynamic controls are a small proportion, and both of them are automatic. Nevertheless, the risk brought by dynamic protection must be controlled low enough compared with the risk of potential lightning disturbance. Now, an AI Expert System is under developing.

4) Smart Grid construction proceeding

In general, Smart Grids are still under construction. Many dynamic control methods, which could improve the system performance, are still unavailable. At present, there are no enough Distributed Generation sources, storages or Microgrids to support the dynamic protection solution in most traditional distribution system.

V. CONCLUSION

In this paper, the research and application of real time lightning detection data for the Smart Girds distribution systems of power load centers are presented. The preventive dynamic actions of a Smart Gird distribution system are discussed. The paper also introduced a Smart Gird protection system based on real time lightning detection in Suzhou, China.

The application of real time lightning detection data in Smart Girds of Power Grid Load Centers, as discussed in the paper, provides alternative solutions to minimize the impacts of lightning-caused disturbances and improve the global lightning performance of the Smart Grids distribution systems in power grid load centers.

REFERENCES

U.S. Department of Energy, Litos Strategic Communication (2008), “The Smart Grid: An Introduction,” pp.4-5.

Tong C., Gao Y., Tong M.G., Luo J.P., Zhang L.Y. (2012), “Dynamic Lightning Protection of Smart Grid transmission system,” 31st International Conference on Lightning Protection, Vienna, Austria.

Nucci C.A., Rachidi F., Ianoz M., Mazzetti C (1993). ‘Lightning-induced voltages on overhead power lines,’ IEEE Transactions on EMC, 35:75–86, 1993.

Piantini A. (2007), “Lightning transients on LV networks caused by indirect strokes,” Journal of Lightning Research, 1:111–31.

Uman, M.A. (2008), The Art and Science of Lightning Protection, Cambridge: Cambridge University Press, Cambridge.

Lasseter R H. (2002), Microgrids, IEEE Power Engineering Society Winter Meeting. New York, USA, IEEE, 305-308.

Driesen J., Vermeyen P., and Belmans R. (2007). Protection issues in microgrids with multiple distributed generation units[C]. Fourth Power Conversion Conference, Japan, 646-653.

Lasseter R H. and Piagi P. (2004), MicroGrid: a conceptual solution [C]. Power Electronics Specialists Conference, IEEE 35th Annual, Germany, 6: 4285-4290.

Morozumi S. (2006), Overview of MicroGrid research and development activities in Japan [C]. International Symposium on MicroGrids, Montreal, 2006.

Funabashi T., Fujita G., Koyanagi K. and et al. (2006), Field tests of a MicroGrid control system [C]. Proceedings of the 41st International Universities Power Engineering Conference, UK, 1:232-236.