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APPLICATION OF LIGHTNING DETECTION IN INTELLIGENT ELECTRIC POWER DISTRIBUTION NETWORK

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1. INTRODUCTION

As a part of Smart Grid, the Intelligent Electric Power Distribution Network which prevails recently integrated automation systems concept of control, interaction, adjusting and aiding decision. It purposed to improve reliability and efficiency, optimize operation and resource distribution, enhance the utilization of new energy, furthermore, build a smart Power Distribution Network. However, electric power network like every else complex system that includes varied components and covers large area can never be absolutely reliable.

The continuous digitization of each part of the power network nowadays lead a mass of sensitive, complex microelectronic equipments applied. The more system depends on computers, electronic devices and communication, accordingly, the more frequent threat of lightning will become. Furthermore, the more serious destructive consequence would be than ever before. Occasional interruption in limited areas because of lightning stroke will continue. Outage to large region caused by lightning directly or indirectly remains a possibility, although such occurrences may be infrequent.

On the other side, Lightning was sure to be one of the major causes of system fault all through the development of electric power network. The conventional lightning protection mode depending on fixed lightning rods, overhead grounded wires, arresters and SPDs couldn't fit for the demand of Intelligent Power Distribution Network. Therefore, it is necessary to explore an available and optional way of lightning protection for the new smart Distribution Network.

2. LIGHTNING HAZARDS TO INTELLIGENT DISTRIBUTION NETWORK

Lightning, especially CG lightning could damage many important components of the Intelligent distribution network such as distribution lines, substations and so on.

2.1 Lightning hazards to Substations

When lightning strikes a phase conductor of transmission line, the current of the lightning stroke will encounter the surge impedance of the conductor so that overvoltage will be built up and propagate to the substation along the line conductors in wave form. In some cases, the lightning incoming wave or direct stoke would damage the electrical facilities, electronic equipments and communication devices in the substation. If the arresters or SPDs on the incoming lines did not sensitive or reliable enough, the whole substation would be at risk of lost the inside microelectronic devices, control systems or information network, even lost all of its power. As an important part of the distribution network and power grid, the substation quit of operation would lead to serious and unpredictable consequence.

Similarly, the lightning hazards to important power plants could cause the load shedding, abnormal oscillation, frequency collapse or power network separation.

2.2 Lightning hazards to Distribution Lines and Systems

The principal mechanism of lightning flashover on HV, EHV and UHV transmission lines are the shielding failure and the backstroke events due to direct stokes. For the lower voltage distribution lines, the induced voltage accompany strokes close to the line predominantly contribute lightning overvoltage. Studies reveal that in distribution network more than 80 per cent of lightning overvoltages are induced overvoltage.

Lightning damages to the power distribution system are a serious problem to many utility-systems and account for the majority of consumer outages causing the highest expense in breakdown of distribution equipment. Inadequate lightning protection results in faults on distribution system that may cause through-fault failures of substation transformers. Pole-mounted distribution transformer failures caused by lightning have also been a longstanding problem on most of the systems.

In respect of the most normal condition, the advanced protective relaying system of Intelligent distribution network separate those defective elements or faulty sections from the system automatically and selectively when a fault occurs. But in some cases, it would expand the fault area unexpectedly and break the dynamic balance of the system. Studies reveal that more than 60 per cent of faults are caused by lightning during storm days include directly or indirectly.

Not only harm the individual components of distribution network, the main damaging effects of lightning are they destroy the dynamic balance of whole smart grid and intelligent distribution network, harm to the stability indirectly and cause the serious effect subsequent.

3. COMBINE LIGHTNING DETECTION WITH LIGHTNING PROTECTION OF INTELLIGENT DISTRIBUTION NETWORK

Lightning could damage distribution lines, substations, plants, communication systems and so on. Furthermore, it may lead to loss of system stability even threatens the whole intelligent distribution network.

Based on Intelligent Control Technology and combined with lightning detection, the Active Lightning Protection (ALP) was researched. It means carrying out preventive measures in advance according to the real time lightning tracing information. It combined protection with lightning detection, and is different from the passive lightning protection mode. The ACTIVE mode more emphasizes the dynamic measures before potential hazards. Accordingly, the ALP could be applied to intelligent distribution network operation.

3.1 Framework of Active Lightning Protection System of Distribution Network

The ACTIVE concept is presented and that means more attention paid to the whole network's safety. It's important to combine lightning information system with dispatch system of distribution network. Integrate real-time lightning data into dispatching and carry out preventive measures before faults occurred could reinforce the stability of network and its resistance ability of lightning.

The system framework of ALPS is shown in figure 1. Figure 2 shows the data process procedure of the ALPS Decision Module.

3.2 Stability analyze

Base on the theory of system stability analyze, we could set the initialization:

$$E(t+N\tau)=r(t+N\tau)-x(t+N\tau).$$

According the initial condition from the theory above: $V(t+N\tau)=\frac{1}{2}E^2(t+N\tau)$

Combined with the formula $\Delta E(t+N\tau)=\frac{\partial E(t+N\tau)}{\partial u(t)}\Delta u(t)=-\frac{\partial x(t+N\tau)}{\partial u(t)}\Delta u(t)=-\frac{\partial x_m(t+N\tau)}{\partial u(t)}$ we could get formula $\Delta V(t+N\tau)=-\frac{1}{\eta}(E(t+N\tau)\frac{\partial x_m(t+N\tau)}{\partial u(t)})^2\bullet(1+\frac{1}{2\eta}\frac{\partial x_m(t+N\tau)}{\partial u(t)})^2)$

From above two formula, we could deduce: when $\eta>0$ □ $\Delta V(t+N\tau)\le 0$ □ the value of system stability could suffice the operation requirement.

3.3 ALP of Intelligent Distribution Network

As the power grid which covers several states is macro level of power network, the distribution network which services for a region or area is smaller relativity.

Studies indicate that lightning is responsible for more than 70% of all faults on distribution systems during storm days. Roughly 75-80 per cent of these lightning faults are of a transient nature and lines can be reenergized on reclosing the breaker. And those faults couldn't restore by recloser could cause outage for a period of time.

ALP accord real time lightning detection data adjust the operation mode of intelligent distribution system to improve the power supply reliability and network safety.

The ALP system applied in intelligent distribution network tends to switch feeder line or additional power source that supply to important Loads or density center. It optimal the flow and avoid the path through the thunderstorm center in rule.

3.4 Auto-adjust coefficients

Auto-adjust coefficient on key point for a flow series is often useful for identifying variations. The Auto-adjust coefficient of a flow series could defined as $R_{xx}(\tau)=\frac{\sum_{t=\tau+1}^{T}x_t x_{t-\tau}}{T-1-\tau}$, in a multi-control process, the average coefficient of the flow series in dynamic state should be define as $\rho(\tau)=\frac{R_{xx}(\tau)}{R_{xx}(0)}$. Obviously, the ALP auto control foundation rule library should combine with the auto-adjust coefficients to real time operation data source on a certain unit process.

3.5 Real time load forecasting

It's necessary to forecasting the load in distribution system active lightning protection although it is beyond the scope of this paper. Real time load forecasting for short duration varying from a few minutes to 2-24 hours has been in prevalent by power utilities for normal system operation.

The following formula gives an ALP system statistical mode of distribution in lightning weather conditions:

$$P_r(a < x < b) = \int_a^b \frac{\exp(-\frac{1}{2}(x-\mu)^2 / \sigma^2)}{\sigma\sqrt{2\pi}} dx$$

Active Lightning Protection should change operation state accord the important level and identity of the load when lightning is approaching.

Table 1 shows the operation data of a Local-Area ALPS in a traditional distribution network. The system integrated with a lightning detection sub system and service from 2003. And it was found that the accuracy of the lightning tracking information is one of the most important factor limit the ALPS performance.

6. CONCLUSIONS

The conventional passive lightning protection methods couldn't completely fit for the demand of Intelligent Power Distribution Network. It's necessary to apply the lightning detection and ALP technologies to the new smart distribution network at present.

The ACTIVE mode of lightning protection which discussed in this paper combines lightning detection and emphasizes the real time dynamic measures before potential hazards. It provided an optional way that could improve the passive ones and would become a new available lightning protection approach for the Intelligent Distribution Network. Lightning detection technologies would be applied in this field widely

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8. FIGURES AND TABLES

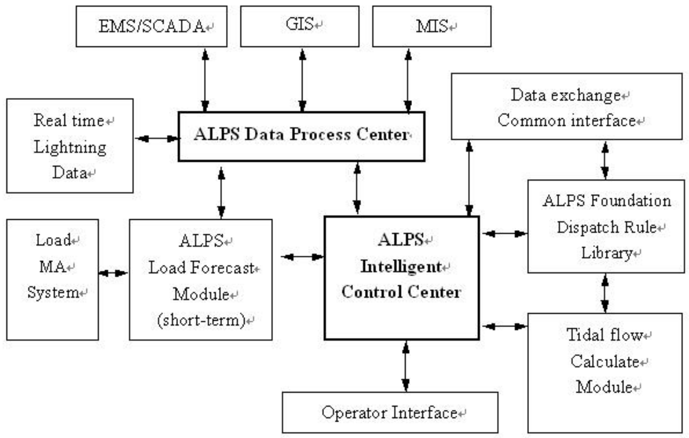

Figure 1. Framework of ALPS

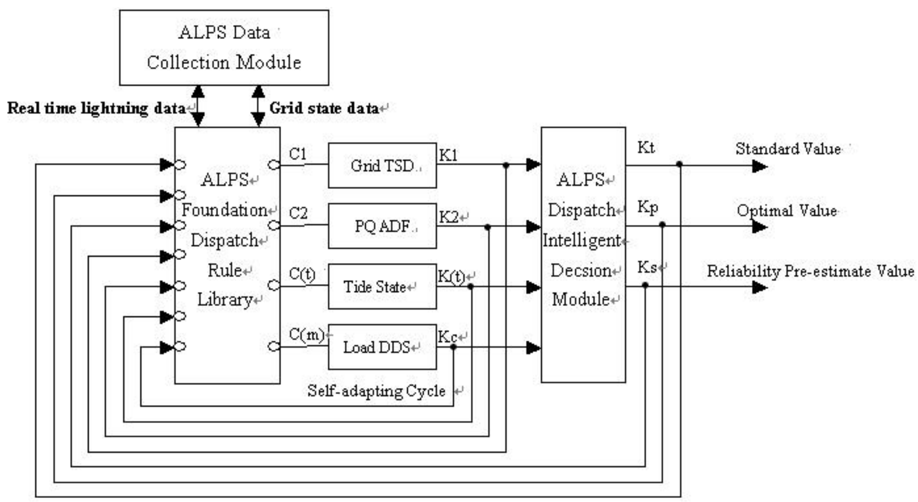

Figure 2. Data process procedure of the ALPS Decision Module

Table 1. Local-Area ALPS operation data of a traditional distribution network

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Trip caused by lightning	1417	1325	1383	1257	1405	1123	1358
Auto recloser failed number	313	308	297	263	321	213	289
ALPS avoid key load outage	215	203	176	218	223	183	213