The Application of Lightning Detection on Power Grid Dispatching

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1. INTRODUCTION

Lightning is one of the main causes of electric power system fault. It is well known that the entire power system consisting electrically of power plants, substations, transmission lines, distribution feeders and power consumers. Generally, the Power Grid or Electric Power Network referred to that part of the electric power system except the power plants and consumers. All components of the power system form an organic whole and maintenance the dynamic balance in operation. The system frequency, voltage, tie-line flows, line currents and equipment loading must be controlled and kept with limits determined to be safe. Lightning, especially Cloud-to-Ground (CG) lightning could damage power transmission lines, distribution lines, substations and power plants. Furthermore, such hazard may lead to loss of system stability and uncontrolled separation of power network even threatens the whole electric power grid.

For the power grid lightning protection, an ACTIVE concept had been introduced this paper, which is different from the traditional passive lightning protection ways. It's mode base on a reliable lightning detection network and emphasizes the measures before the potential accidents but not after them. In this paper, we also discuss such Lightning Detection application mode in power grid dispatching and operation field, and describe a system named ALPS used to reduce the potential damage to Electric Power System.

2. LIGHTNING EFFECT ON POWER GRID STABILITY

It is generally accepted by the industry that CG lightning is one of the significant causes of electric power system fault. It could damage many important components of the system.

After researched for many years, peoples find many available measures to protect the power system from lightning hazards, but all these ways are limited and each of them have many immanent defects. This had been discussed in lots of other papers and references.

As a primary part of Power Grid, transmission and distribution lines are mostly exposed, covering long distance and large areas. This character of them greatly increase their probability of being struck. Correspondingly, lightning is one of the main causes of transmission line trips, or outages in practice. Overhead grounded wires, lightning arresters or reduce the grounding resistance are ordinarily measure used to prevent lines from stroke. And furthermore, we can not deny the probability of an Ultra-high Voltage transmission line being struck and lead to trip or outage, although it was consider that the higher voltage level transmission lines have fewer influence of lightning strikes because their higher insulation performance. However, if it really happened, the Power Grid would suffer the great impact obviously.

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 transmission line in wave form. This lightning incoming wave would do damage to electrical equipments and facilities in substation. For example, if the SPD (Surge Protection Device) on the incoming lines did not sensitive or reliable enough, the whole station would be at risk of lost the inside precision devices, control systems or information network, even lost all of it’s power. As a indivisible part of the power grid, a substation be out of operation would lead to unpredictable consequence.

Similarly, the lightning hazards to power plants could cause the proper voltage profile of the power grid, load shedding, abnormal oscillation, frequency collapse or power network separation.

Not only harm the individual components of system, indeed the main damaging effect of lightning is they destroy the dynamic balance of power system, harm to the stability of power grid indirectly and cause the serious effect subsequent.
Moreover, each of these types of power interruption and failure has devastating effects on the information infrastructure. Such imbalances can lead to the partial or whole breakdown of the electric power grid, as the complexity of the grid is mutually dependent on automation systems, computers and networks. And it even could finally results in large areas outage.

In respect of the most normal condition, the power system has a relatively mature protection mechanism namely the protective relaying system. It tends to separate those defective elements from the system automatically and selectively. But in some cases, it would expand the fault area unexpectedly; because of the power system is a complex and interconnected dynamic balance system.

Thus, from the point of view of power grid lightning protection, we should regard all parts of the electric power system as an integrated system. And we are preferable to emphasize the dispatch and operation measures before the potential accidents rather than after them really happened.

3. COMBINE POWER GRID DISPATCHING WITH LIGHTNING DETECTION

Almost every country of the world has different industry structure and operation mechanism of electric power industry. In the United States, Independent System Operators (ISOs) or Regional Transmission Organizations (RTOs) coordinate, control and monitor the operation of the electrical power system. And the National Grid Company (NGC) of UK operates and developed the HV power transmission network in England and Wales. Nordic countries interconnection their national power grids and established the Nordic pool. Accordingly, there are various grid operate, control and dispatch mode.

Ordinarily each electric power grid has a Dispatch Center or Control Center. They are the hub of grid operation. The centers control and maintain the electricity flow, match the supply with demand and centralized dispatch the power resource. It operates based on system requirements and according to special rules.

As above (Section 2), the partial or whole of power grid could loss of stability during thunderstorm. Interruptions to large areas remain a possibility, although such occurrences may be very infrequent. For electric utilities the ability to prevent or minimize lightning damage on power system is of great importance. Many power utilities used lightning data in ordinarily practice, but in this paper, we are more interest in the whole Grid’s security under thunderstorm.

3.1 Framework of ALPS

The ACTIVE concept is presented here and means more attention paid to the whole grid’s safety. We consider that it’s important to combine lightning information system with power grid dispatch system. Integrate real-time lightning data into power grid dispatching strategies; carry out more measures before faults occurred could reinforce the stability of grid and its resistance ability of lightning.

We name such system Active Lightning Protection System (ALPS), design it to aid Power Grid dispatching, combine real-time lightning data and the important grid steady state and transient state data, analysis and process them, gives optimal dispatching control decision, which could finally give the optimal dispatch strategy calculate by the ALPS according to the Foundation Dispatch Rule Library, to improve the system stability.

The system framework of ALPS is is shown in figure 1.
3.2 Basic application mode

Figure 2 shown a basic geographical connection diagram of power grid, the (1)-(5) assume the lightning storms move trace in five different cases.
In CASE (1), the lightning storms move from the south to north, and tend to across the Line A-E-F. Because of the importance of this line for the grid, the ALPS would try to reduce the load in this line, and move those load to Line A-D-F and Line A-B-C-F.

The grid would suffer minimal impact, if the line A-E-F failed with minimal load base on it. Oppositely, if the Line A-E-F fail when it full with important load, it could lead to instability of the whole grid more than this line it self. In practice, we need to ananly the lightning information combine with other important grid state data, and give dispatching strategy.

Similarly, in CASE (2), the lightning storm come from north to south, the ALPS system would gives optimal dispatch scheme to move the important load on Line B-C-F to the relatively secure Lines, namely the Line A-D-F and Line A-E-F.

These dispatching measures that carried out in advance would improve the grid stability. Furthermore, the system would guide repair crew, increase plant availability and rapidly locate and analyse faults.

4. BASIC MATHEMATICAL MODEL AND FUNCTIONAL DESIGN

4.1 Overall

The primary principle of the decision system is first collect the kind of data, such as real-time lightning data, SCADA (Supervisory Control and Data Acquisition) system, GIS (Geographics Information System), Extremely Short-team Load Forecast informations and some important steady and transient state data of the grid, and use intelligent control method to analysis and process them. And according to the setting constraint conditions and factors, gives the pretreatment dispatching control decision, aid to estimate the stability of the outcomes valu, than adjust the value with the constraint condition, through iterative calculate optimal dispatching control decision, which could finally give the optimal dispatch strategy calculate by the ALPS combined with the Foundation Dispatch Rule Library.

Figure 3-1 shows the data process strategy calculate by the ALPS combined with the Foundation Dispatch Rule Library.

And the Figure 3-2 shows the lightning data process course in a typical single thread dispatch decision case.
4.2 Dispatch Intelligent Decision Module

The core of the ALPS Intelligent Control Center is the Dispatch Intelligent Decision Module. We design it based on intelligent control technology. For a single control unit, the basic data load and analysis mode is shown in Figure 4.

In Figure 4,  
- $X_i(t)$: Data/Information cell multi-input;  
- $Z(t)$: Reliability inspection of decision;  
- $W_i(t)$: Back coupling coefficient according $X_i(t)$;  
- $K$: Scale coefficient of multidimensional cell;  
- $S(t)$: Primary decision output function.

The figure 5 describes the primary process and calculation and output procedure with two array cells system. In practice, it may be parallel processed as multidimensional array cell, in the most case, the process would be more complex because of the outside limit parameter or factor.
4.3 Fundamental Algorithm of Single Cell initial process

As figure 5, the single cell basic would have a available data load and analyse process, and the formula (5-1) to (5-2) is a simplified deduce procedure.

\[ W_i(t) = W_i(t-1) + dZ(t)U(t)X_i(t) \quad (5-1) \]

\[ Z(t) = r(t) - y(t) \]

\[ X_i(t) = r(t) \]

\[ X_2(t) = r(t) - y(t) \]

\[ X_3(t) = \Delta X_2(t) = X_2(t) - X_2(t-1) \]

\[ U(t) = \frac{k \sum W_i(t)X_i(t)}{\sum W_i(t)} \quad (5-2) \]

As above, \( r(t) \) is the given value of after system load and initialize, \( y(t) \) is the decision system feedback value.

From that, we could get 1st output (5-3), the decision system standard value:

\[ S_T = \frac{K_T(T_0 \times W_{11} + E_T \times W_{12} + CE_T \times W_{13} + E_p \times W_{14})}{W_{11} + W_{12} + W_{13} + W_{14}} = K_T(C_{11}T_0 + C_{12}E_T + C_{13}CE_T + C_{14}E_p) \quad (5-3) \]

And 2nd output (5-4), the decision system optimal value:

\[ S_p = \frac{K_p(P_0 \times W_{21} + E_p \times W_{22} + CE_p \times W_{23} + E_T \times W_{24})}{W_{21} + W_{22} + W_{23} + W_{24}} = K_p(C_{21}P_0 + C_{22}E_p + C_{23}CE_p + C_{24}E_T) \quad (5-4) \]

4.4 Optimal Dispatching Control Decision

4.4.1 Feedback compensation of the output preconditioning

set on the time \( t \), according the preconditioning function, the Control Decision system’s simulate pre-output value is \( x_m(t + N\tau) \), define the moment \( t \), the difference between system optimal output \( x(t) \) and the preconditioning output value \( x_m(t) \) is:

\[ e(t) = x(t) - x_m(t) \quad (5-5) \]

and at the point \( t \), the preconditioning value could be adjust from \( x_m(t + N\tau) \) to \( x_m(t + (N+1)\tau) = x_m(t + N\tau) + he(t) \), and \( h>0 \), means the weight coefficient of the deviation.

4.4.2 Optimal Control Decision

Define the initialization output value is \( r(t) \), to get the current control decision value, need the

\[ J = \left[ r + (t + N\tau) - x(t + N\tau) \right]^2 + \eta \left[ u(t) - u(t - N\tau) \right]^2 \quad (5-6) \]

\( \eta \) means weighting coefficient the control decision value increment, it could limit the instable saltation of the difference. When the less of value of \( \eta \), the conference coefficient of system is higher, but it would lapse when over the limit. General the bigger of \( \eta \) value, the system is more instable.

To get the optimal decision value and the convergence coefficient, we must let the performance function and outcome value of formula (5-7) tend to minimize.

define the \( \frac{\partial J}{\partial u} = 0 \), and then
\[ u(t) = u(t - N \tau) + \frac{1}{\eta} \left[ r(t + N \tau) - x(t + N \tau) \right] \frac{\partial x(t + N \tau)}{\partial u(t)} \quad (5-7) \]

When calculate optimal output and value of \( u(t) \) from the formula (5-7), because \( x_m(t + N \tau) \) includes item of \( u(t) \), so we have the initial valu of \( u(t) = u(t - N \tau) \), at the same time

\[ \frac{\partial x(t + N \tau)}{\partial u(t)} = \frac{\partial x_m(t + N \tau)}{\partial u(t)} \approx \frac{\Delta x_m(t + N \tau)}{\Delta u(t - N \tau)} = \frac{x_m(t + N \tau) - x_m(t)}{u(t - N \tau) - u(t - 2N \tau)} \quad (5-8) \]

from formula (5-7) and formula (5-8), could educe the optimal output.

4.4.3 Analyse of system stability

Base on the YAGMA-HGW analyse theory of system stability, We could set:

\[ E(t + N \tau) = r(t + N \tau) - x(t + N \tau) \quad (5-9) \]

And according the initial condition from the above theory:

\[ V(t + N \tau) = \frac{1}{2} E^2(t + N \tau) \]

And to insure the output of system is stabile enough acrd the operation requiremen.

there must be \( \Delta V(t + N \tau) \leq 0 \), for

\[ \Delta V(t + N \tau) = V(t + N \tau) - V(t) = \Delta E(t + N \tau)(E(t + N \tau) - \frac{1}{2} \Delta E(t + N \tau)) \quad (5-10) \]

from that, \( \Delta E(t + N \tau) = E(t + N \tau) - E(t) \), and because

\[ \Delta E(t + N \tau) = \frac{\partial E(t + N \tau)}{\partial u(t)} \Delta u(t) = - \frac{\partial x(t + N \tau)}{\partial u(t)} \Delta u(t) = - \frac{\partial x_m(t + N \tau)}{\partial u(t)} \quad (5-11) \]

combine with formula (5-9) and (5-11), replace into the (5-10) would get:

\[ \Delta V(t + N \tau) = - \left( \frac{1}{\eta} (E(t + N \tau) \frac{\partial x_m(t + N \tau)}{\partial u(t)})^2 \cdot (1 + \frac{1}{2\eta} (\frac{\partial x_m(t + N \tau)}{\partial u(t)})^2) \right) \quad (5-12) \]

from (5-11) and (5-12), we could say:

when \( \eta > 0 \), \( \Delta V(t + N \tau) \leq 0 \),

and the stability of system could suffice the operation requirement.

5. CONCLUSIONS

Lightning is one of the main causes of electric power system fault. Not only damage the single part, the lightning also destroy the dynamic balance of the electric power system, lead to loss of system stability and uncontrolled separation of power network even threatens the whole electric power grid which would cause large area outages.

For the Whole power grid lightning protection, the ACTIVE concept had been introduced this paper. It’s mode base on a reliable lightning detection network and emphasizes the measures before the potential accidents but not after them. It is different from the traditional passive lightning protection ways, and attention on the grid security. In this paper, we designed and described such ALPS system and it’s application mode in power grid dispatching to reduce the potential damage to Grid.

The paper is not to deny the present lightning protection mode in electric power system, but just try to discuss and find a way that aim at the whole power grid lightning protection. We emphasize the grid dispatch and operation measures before the potential accidents really happened. Designed the ALPS combine with lightning detection, intelligent control technologies, multi-thread state analysis, optimal grid dispatching, and try to research an available lightning protection mode to improve and enhance the power grid stability.
6. REFERENCES