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Countermeasures on preventing backup protection mal-operation during load flow transferring

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ABSTRACT

Removal of transmission lines in power systems may result in load flow transferring and unreasonable operations of backup protections, which may develop into cascading tripping accidents and even blackouts. Traditional backup protection based on local measurement information has disadvantages in preventing from cascading trip because it cannot distinguish the over load reason between due to faults and due to load flow transferring. On the premise that the load flow transferring can be identified based on wide-area coordination system, concise adaptive adjustment methods for the operation characteristics of zone III distance protection and overcurrent protections are proposed to avoid the mal-operation caused by load flow transferring. Meanwhile, their backup protection functionality can be reserve to a great extent. The simulation test results illustrate the validity of the proposed method.

Introduction

The blackout of power systems is usually a result of cascading failures on the condition of heavy loads. Removal of fault lines possibly causes the load flow to transfer among the same or different transmission sections, which may cause other transmission lines to be overloaded, and lead to cascading trip incidents. It will result in further deterioration of the system operation [1–5]. However, the existing line backup protection, such as distance protection, is regarded to act "correctly" according to its setting and configuration requirement when cascading trip occurs. Actually, the existing backup protection only depends on the local measurement information to achieve the purpose of removal of faulty components, regardless of the impact of their actions on the overall system. Therefore, it cannot distinguish the overload caused between by actual faults and by amount of load flow transferring scenarios [6], and it is difficult to prevent cascading trip incidents caused by line overload successively (see Fig. 1).

Comprehensive identification based on wide area information can improve the performance of the existing protection system and prevent from cascade tripping [7–10]. To address the issue of load flow transferring caused by branch removal, the concept of flow transferring relativity factor is put forward in literature [11], which is used to estimate the load flow distribution after load flow transferring occurring. However, it does not fully discuss how the protection responses after detecting the lines affected by load flow transferring. In fact, zone III distance relay of a line acting as the remote backup of adjacent lines has the advantages that other protections cannot provide, especially when the out of service of the protection is due to the problem of the public loop, such as loss of common DC power supply of the substation and so on. In this case, the function of the protection must be fulfilled by the remote backup protection of the adjacent substation. Therefore, zone III distance protection should not be canceled even though it may encounter inappropriate actions during load flow transferring. Instead, reasonable countermeasures should be designed to improve its operation reliability in this case. Previously, the researches in this field were focused on preventing from the over-reach due to external faults and improving the ability to withstand the fault resistance. Studies on the countermeasures to deal with the impact of load flow transferring are seldom. A novel adaptive algorithm for identifying high-resistance earthed fault based on real-time impedance locus estimation is put forward in [12]. Theoretical analysis and digital simulation tests show that this new protection scheme with enhanced resistive tolerance can overcome steady-state over-reach. In [13], the authors propose a novel adaptive distance relay approach that is able to adjust the operating

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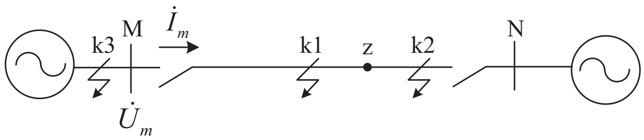

Fig. 1. Schematic diagram of distance protection range.

thresholds according to the real-time CVT transient error estimation. This approach hardly affects the operating performance for normal lines and allows the relay to rapidly trip the short line with close-in faults. In this case, the performance of distance relay is greatly improved. Literature [14] proposes to avoid load encroachments by combining a Mho element with load blinder, by which way it shrinks the area of the impedance characteristic that may result in unwanted operation under maximum dynamic load conditions. However, all above literatures do not make adequate discussions on how to judge whether the "invaded" region of the protection operating characteristic is due to real faults or load flow transferring, and the modification on the operating characteristics of the existing protections is complex as well.

To address the problem of the incorrect operation of the zone III distance protection and the overcurrent protection caused by load flow transferring, concise adaptive adjustment methods for the operation characteristics of backup protections are proposed on the premise of the identification of load flow transferring. The schemes of adaptive backup protection are designed and a series of simulation tests are carried out to verify the proposed schemes.

Adaptive adjustment of operation characteristics of backup protections

Analysis of load flow transferring

When a tie line in the system is removed because of a fault, the load flow will be transferred to the other transmission lines which still work normally in the system. It may lead the normal lines to being overloaded and result in cascading trip incidents.

Load flow transferring of power systems usually occurs due to the change of network topology structure. As indicated in [11], for a arbitrary network, the current of branch k can be calculated according to (1) after the removal of branch i :

$$\dot{I}_{kC} = \dot{I}_k + \tau_{ki}\dot{I}_i \tag{1}$$

$\dot{I}_k$ and $\dot{I}_i$ are the currents of branch k and branch i respectively before branch i is removed. $\tau_{ki}\dot{I}_i$ is the current components of branch i being transferred to branch k. $\dot{I}_{kC}$ is the calculated current of branch k after branch i is removed.

Based on the calculated current of branch k obtained by (1) and its actual measured value, a load flow transferring incident can be identified with the following criterion:

$$|\dot{I}_{KM} - \dot{I}_{KC}| < \varepsilon\dot{I}_{KC} \tag{2}$$

where $\dot{I}_{kM}$ is the actual measured current of branch k after the removal of branch i. ε is a reliable coefficient taking transient process of the power grid and all kinds of errors into account. The action of the protection is determined to be due to load flow transferring if inequality (2) is tenable. Otherwise, the protection is regarded to operate due to a real fault. With reference to the setting criterion of the current differential protection, ε can be taken as from 0.1 to 0.3. In the following analysis, we set ε to a high value, i.e., 0.3 for the purpose of avoiding load flow transferring not to be detected.

Accordingly, a wide-area coordination system for backup protections based on the above principle is designed in [11]. Its function is to judge if a load flow transferring incident really occurs, and to convey the results to the backup protections of such lines that are overloaded due to load flow transferring by means of appropriate channels. Then, the backup protections will adjust their operation characteristics according to the measurements to avoid protection malfunction due to by this scenario and simultaneously reserve their abilities to protect the adjacent line at the same time. The criteria of adjustments are stated as below.

Adaptively adjusting operation characteristics of backup protection

As long as load flow transferring leads the transmission lines to be overload, the process to identify load flow transferring will be enabled. When the calculation result of the line current meets the identification criterion of load flow transferring, the wide-area backup protection coordination system will issue the command that the characteristics of zone III distance protections and the overcurrent protections of the involved lines should be adjusted to avoid the wrong removal of the lines. The adjustment criteria of the operation characteristics of two kinds of backup protections are given below.

Scenario 1: Adaptively adjusting operation characteristics of distance protection

$\dot{U}_{op}$ is defined as [15]:

$$\dot{U}_{op} = \dot{U}_m - \dot{I}_m Z_{set} \tag{3}$$

where $\dot{U}_m$ is the measured voltage, $\dot{I}_m$ is the measured current and the setting impedance Z_{set} is the impedance from bus M to the setting point z.

When external fault occurs in $k2$:

$$\begin{cases} \dot{U}_m = \dot{I}_m Z_{k2} \\ \dot{U}_{op} = \dot{I}_m (Z_{k2} - Z_{set}) \end{cases} \tag{4}$$

When external fault occurs in $k3$:

$$\begin{cases} \dot{U}_m = -\dot{I}_m Z_{k3} \\ \dot{U}_{op} = -\dot{I}_m (Z_{k3} + Z_{set}) \end{cases} \tag{5}$$

When internal fault occurs in $k1$:

$$\begin{cases} \dot{U}_m = -\dot{I}_m Z_{k1} \\ \dot{U}_{op} = \dot{I}_m (Z_{k1} - Z_{set}) = -\dot{I}_m (Z_{set} - Z_{k1}) \end{cases} \tag{6}$$

According to (4)–(6), the phase difference between $\dot{U}_m$ and $\dot{U}_{op}$ is 0° under external fault conditions while it is 180° under internal fault conditions.

In real applications, the distance protection should trip when the phase difference between $\dot{U}_m$ and $\dot{U}_{op}$ is around 180° (±α) because of the measuring error, transition resistance and other influence factors. Suppose that $\alpha = 90^\circ$ and zone III distance protection adopts the directional circle characteristic whose operation characteristic equation is given by:

$$270^\circ > Arg\frac{\dot{U}_m}{\dot{U}_{op}} = Arg\frac{\dot{U}_m}{\dot{U}_m - \dot{I}_m Z_{set}} > 90^\circ \tag{7}$$

Then, (8) can be obtained by simplifying (7):

$$270^\circ > Arg\frac{Z_m}{Z_m - Z_{set}} > 90^\circ \tag{8}$$

where Z_m is the measured impedance of the distance protection.

If the current of branch k increases to $\dot{I}_{kM}$ because of load flow transferring, the measured impedance of the distance protection Z_M will be within the operating area of the zone III distance protection. In order to avoid the mal-operation due to the above case, zone III distance protection should decrease the operating angle and the operation characteristics will be shrunk as a lens-shaped