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Temperature safety analysis and backup protection scheme improvement for overhead transmission line in power oscillation condition

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ABSTRACT

The oscillating block module is usually adopted to avoid false action of distance protection of overhead transmission lines during power oscillation. However, this scheme ignores the safe operation of conductor temperature during oscillating block. This paper focuses on the conductor overheating problem and safety protection issue during power oscillation. Firstly, through analysis the differences in conductor temperature calculations under oscillating current, short-circuit current and normal load, a numerical iterative method of conductor temperature rise (CTR) calculation under power oscillating current is proposed using the transient thermal balance equation. Then, the safe operation scheme of transmission line is proposed by setting temperature alarm and temperature off-limit trip out. An improved backup protection based on the combination of temperature and impedance is proposed to avoid false action of distance protection, also provide overheating protection for transmission line during power oscillation. Finally, a two-source power system and the modified 29-bus system are adopted to verify the CTR calculation and the improved backup protection. Results indicate that the proposed scheme can provide effective evidence of safe operation and relay setting for transmission lines through excavating the tolerance ability of overcurrent and oscillating current.

1. Introduction

Oscillation occurs when the power systems or power plants in parallel operation run out of sync. Oscillation, which is a severe system accident, not only seriously degrades the stability of power system and the safety of units, but also restricts the power transfer capacity of power grid. The further spread of oscillation can easily cause power system cascading trip and can even trigger large-scale blackout, thereby leading to huge losses on the national economy and severe negative impacts to the public.

Occurrences of power oscillation are common in various countries and regions. Power system splitting has been directly caused by the accident-induced oscillation in USA WSCC system in 1996 [1]. In 2008, the Colombian power system experienced large low-frequency oscillations that lasted for about 90 min [2]. Large sustained power oscillation in the northeastern area of the Iranian interconnected system occurred on January 21, 2008 [3]. The power oscillation induced by false action of relay protection at a substation in Brazil disconnected the northeast power grid, which led to power blackout in seven states [4]. The false action of distance relay zone 3 of transmission line in a power system in India on July 30 and 31, 2012 caused power flow transferring and power oscillation, which resulted in cascading trip of other transmission lines and accelerating expansion of blackout [5,6]. The power systems of China have also suffered from power oscillations. The false action of relay protection in the 500 kV Song-Zheng line in Henan on July 1, 2006 resulted in power oscillation, which spread to north China power grid due to the migration of the oscillation center and the failure of the out-of-step splitting device; this event brought serious economic loss [7]. The WAMS (Wide Area Measurement System) had monitored 2360 power oscillations in central China power grid from July 2007 to March 2009, especially at the transmission section of Chuanyu-Henan. Several oscillations had occurred in central China power grid during the frozen disaster in early 2008, which were the widest-reaching ones in central China power grid, and affected the power grids of Hunan, Hubei as well as Henan [8]. In short, oscillation is a common occurrence in large-scale interconnected power systems, and it has become an

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important factor that threatens the security and stability of power systems.

The expansion in interconnection power system size and the increase in system complexity have introduced new characteristics of power oscillation. Many scholars and engineers have conducted extensive and in-depth research on induced mechanism [9,10], dynamic characteristics [10,11], influences and control measures [12,13] of power oscillation. Power oscillation not only seriously affects the stable operation of power grid but also causes damage to power equipment due to sustained oscillating current [14]. However, existing research mainly focuses on the impact of oscillation on generation units [15,16] and relay protections [17–19], especially on the false action of distance protection.

Relay protection devices in different countries and regions have differences in dealing with oscillations. For instance, the distance protections in India, North America, and Western Europe power grids usually do not have the ability of oscillating block [6], which may easily cause the false action of relay protection and accelerate the collapse of power grid. Some countries and regions adopt the scheme of "large circle over small circle" to handle the false action of relay protection during power oscillation [20]. This scheme utilizes the action time difference of distance relays with large and small circle characters to identify oscillation and then takes oscillating block measures. However, this oscillating block strategy is unsuitable for long-distance and heavy-load transmission lines because the action time difference of distance relays with large and small circle characters may be less than the set threshold. The relay protection devices in China have good performance of oscillating block [21] and have the ability of short-time block open function when faults occur at the same time. This scheme is suitable for large-capacity and long-distance power transmission lines in China, but it lacks safety consideration when power oscillation continues during protection blocking, which may count against the safety operation of transmission lines. Thus, attention should be paid to the safety performance of conductors subjected to large power oscillation during protection blocking.

Safety criteria are required to determine whether the transmission line is in a safe operation condition. Temperature, sag, and stress are important indexes to evaluate the safe operation of transmission line, and they are mutually influenced by each other [22,23]. Different safety indexes of transmission line are directly or indirectly related with conductor temperature; thus, they are generally considered using maximum allowable temperature in a unified way in practical engineering [22]. The amplitude of oscillating current passing through the transmission line during power oscillation is multiple folds than that of the normal load current and is even equal to or greater than that of the fault current. However, research on the conductor temperature rise (CTR) response to the oscillating current is lacking. The CTR will be off limited when oscillation continues. This condition further causes the sag to exceed the limit, accelerates the thermal annealing of conductor, reduces the tensile strength, shortens the life of transmission line, and even leads to conductor fuse by the heating effect of oscillating current. Therefore, checking the conductor temperature online, issuing temperature off-limit alarm, and opening the blocked relay protection in time are necessary tasks during power oscillation.

Long-distance transmission lines often span a long area. There exist difference and diversity of meteorological conditions around transmission lines, which brings difficulty in applying conductor temperature to the decision of power dispatching or action criteria of relay protection. Dynamic Thermal Rating (DTR) is a possible problem-solving technique that evaluates the maximum current carrying capacity and operation temperature of transmission line on the basis of the real-time ambient weather condition and can provide objective operation information of conductors for power grid operators [24,25].

The representative calculation methods of maximum current carrying capacity and conductor temperature for transmission line are IEEE standard model [26], CIGRE standard model [27], and method proposed by Morgan [28]. These methods are similar but different in expression. They are essentially based on the thermal balance of conductors and can be utilized to calculate the operation temperature of transmission line. There is also a little tentative study on application of DTR to relay protection. For example, Yip et al. [29] calculated the maximum current carrying capacity of transmission line from wind farm. When the monitored current exceeds the calculated current carrying capacity, the excess wind power will be cut off to reduce the sending power of transmission line. Cong et al. [30] integrated DTR to the event-driven trip scheme to improve the adaptability to emergency overload of relay protection.

Considering the above-mentioned issues and the possibility of applying the idea of DTR to relay protection, this study analyzes the operation characteristics of distance relay during power oscillation. Then, the transient thermal balance equation is adopted to calculate the operation temperature of transmission line online, judge the conductor safety condition subject to oscillating current in real time, and provide countermeasures such as temperature safety alarm or temperature off-limit trip correspondingly. An improved backup protection scheme for transmission line is proposed by combining conductor temperature and impedance criteria. Finally, a two-source power system and the modified 29 bus system (Hydro Quebec) are adopted to verify the CTR calculation and the improved backup protection. The calculation results under several typical oscillation modes show that the conductor temperature will exceed the maximum allowable temperature in a very short time during oscillating block. The proposed improved backup protection scheme can monitor the safety condition of conductor in real time and realize reliable oscillating block before temperature off-limit. If conductor temperature exceeds the short-time maximum allowable temperature, then the protection will trip off the overheated transmission line promptly to protect the conductor from any damage.

2. Action behavior of distance relay during oscillation

Distance relay is a kind of protection device that reflects the distance or impedance between fault location and the relay installation and take actions depending on the measured impedance. The device has been widely applied to HV/EHV transmission lines [31]. In practice, distance protection usually adopts multiple zones of distance 1, 2 and 3 that are coordinated with each other. For instance, zones 1 and 2 are used as the primary protection to act instantly for isolating a fault, and zone 3 is used as the secondary protection to reflect the abnormal operation conditions and as the backup protection under certain conditions due to the failure of the primary protection.

2.1. Performance of distance relay during oscillation

The amplitude of current and voltage at relay installation periodically changes on a large scale during power oscillation. Consequently, the measured impedance of distance relay, which is represented as the ratio of voltage and current, also periodically changes. If the measured impedance falls into the action zone of distance relay during power oscillation, then it will act falsely.

The simplified two-source power system is shown in Fig. 1 to illustrate the change in electrical variables during power oscillation. If oscillation occurs at three-phase operation, then it can be analyzed in single phase because the three phases of power system are symmetrical.

The parameters of transmission line and power system and the reference directions of current and electromotive force are illustrated in

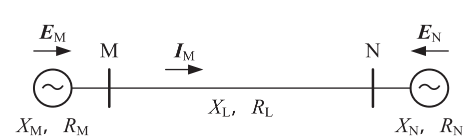

Fig. 1. Single line diagram of simplified two-source power system.

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