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Internal fault fast identification criterion based on superimposed component comparison for power transformer

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ABSTRACT

Due to the interference of false differential current caused by the saturation of the iron core, the differential protection for the power transformer may suffer mal-operation and long response time. According to the investigation for the characteristic of transformer core, there should be a time interval between the sudden change of phase voltage and the emergence of differential current. And it can be utilized to distinguish between the external and the internal faults. A new time-interval based criterion for transformer differential protections is proposed, aiming at identifying transformer fault type by virtue of highly accurate time interval. Furthermore, a novel filter algorithm is proposed to determine the time interval for its excellent singularity detecting and effective noise-repressing ability as well as high-speed response. The EMTDC-based simulation, which covers various fault situations, is analyzed, of which the results confirm that the criterion can effectively prevent the differential protection from mal-operations and meanwhile guarantee the high-speed response to the internal fault.

Introduction

The differential protection is a widely-applied main protection of power transformers [1]. Due to the influence of the saturation of the iron core of the transformers, the sensitivity and reliability of the relay are not always harmonized in terms of identifying between the inrushes and fault currents [2,3].

Up to now, many solutions are proposed, for example, multi-piecewise based percentage differential protection, 2nd harmonic restraint [4], and so on. These methods have been successfully applied on sites. However, there are also some disadvantages to be overcome. To make full use of the ferromagnetic materials, the point of saturation is designed at a relatively low value, which leads to the challenges to such criteria as the 2nd harmonic based methods, the waveform symmetry based methods and et al. As a matter of fact, the average correct operation ratio of the differential protection of the transformers of 220 kV and above is only 76% approximately in recent years [5].

The faults of the transformer can be classified as the external fault and the internal fault. The former ones include the phase-phase faults and the earth faults, etc. Such kind of faults will induce high short-circuit current, leaving a damaging impact on the transformers. With respect to the internal faults, they include the inter-turn faults and turn-to-ground fault and also lead to the overheating of the transformer, which is a threat to the transformer winding and the core if not cleared in time. However, to against mal-operations resulting from such false differential current as the magnetizing inrushes, the sensitivity of the protection is conventionally not high enough.

Besides, the differential protection will be blocked by the restraint element when the false current results from the transformer energization or the voltage recovery. In this case, if the cross-country fault occurs during this period, some existing criteria are incapable of identifying the developing fault and lead to the long-time fail-to-trip of the protection. It is perhaps a small-probability event as it may seem, similar events were reported several times previously [6]. Therefore, a well-designed protection, despites its conventional advantages, should be capable against developing faults caused by false fault current and can trip within a short time delay.

In addition, to identify the magnetizing inrush current, most conventional criteria based on the high order harmonic or waveform characteristic need one-cycle post-fault current sampling data, which limits the operation speed. A scope of research in this aspect is left for enhancement as well, as the benefit of the reliable and high-speed main protection of the transformer is self-evident if we can increase the speed of fault identification.

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Aiming at solving the problems above, the characteristic of the time interval between the superimposed component of phase voltage and the superimposed component of differential current is investigated in this paper, and a new time-interval based protection criterion for differential protections is proposed. It is confirmed by numerous EMTDC/PSCAD based simulations that the proposed criterion is effective and practical.

The fundamental of the time difference based method

At present, the time difference based methods have been widely applied to detecting the saturation of the current transformer (CT) [7–9], convincing that the CTs on the two sides of the transformer will not saturate immediately even exposed to severe faults [10]. The change of the phase current and the real fault differential current will be detected at the same time in the case of the internal fault even if the CT will saturate ultimately, as long as the CTs on the two sides of the transformer can transfer as normal during the beginning period of the fault occurrence. In this case, there will be no time difference theoretically.

By virtue of the characteristic above, a Mathematical Morphology based method to detect the time difference between the emergence of the fault and the emergence of the differential current is put forward in [9], which can effectively prevent the mal-operation of the differential relay protection resulting from the high through current. In [10], the time difference of the sudden change of the line current at one side and the time when the differential current occurs is utilized to decide whether there is sympathetic inrush current. Furthermore, it can be detected whether there is an external or internal fault in the existence of the sympathetic inrush current. The two time difference based methods above both take the line-line current at the *Y* side and the differential current of the CTs on two sides of the transformer as the reference. However, when the transformer is energized under no-load conditions, such a time difference will not exist in that the differential current is actually the line current at the switching side. Therefore, above criteria based on the time difference are not valid in this scenario [11].

When the transformer is energized under no-load condition or when the transformer terminal voltage recovers, as the core of the transformer will not saturate immediately, the false differential current caused by the magnetizing inrush current will lag behind the applied voltage for 3–5 ms. This phenomenon is the fundamental of the time difference based method.

When the normal transformer is switched on under no-load condition, the differential current is the magnetizing current caused by the core saturation, and the emergence of the magnetizing current lags behind the terminal voltage. The time interval between the voltage occurrence and the changing of the differential current can be detected. In this case, the differential current is also the magnetizing current at the switching side. If this time interval is longer than a specific threshold, the differential current is identified as the magnetizing inrush and the differential protection will be blocked. In the case of internal faults, whenever it occurs during normal operations or transformer energization, the time interval between the change of the applied voltage and the emergence of the differential current is quite short, which should be zero theoretically. In this case, the differential current can be recognized as the fault current. Especially, when the transformer is switched on accompanied by a light inter-turn fault, the fault current will be mixed with the magnetizing inrush current, and the conventional methods based on the 2nd harmonic restraint may fail-to-trip for a period of time as a result. However, the time interval corresponding to the fault current still satisfies the characteristic of simultaneity. According to the on-site experiences and various simulation test result analysis, the threshold value of this time interval can be set as 3 ms.

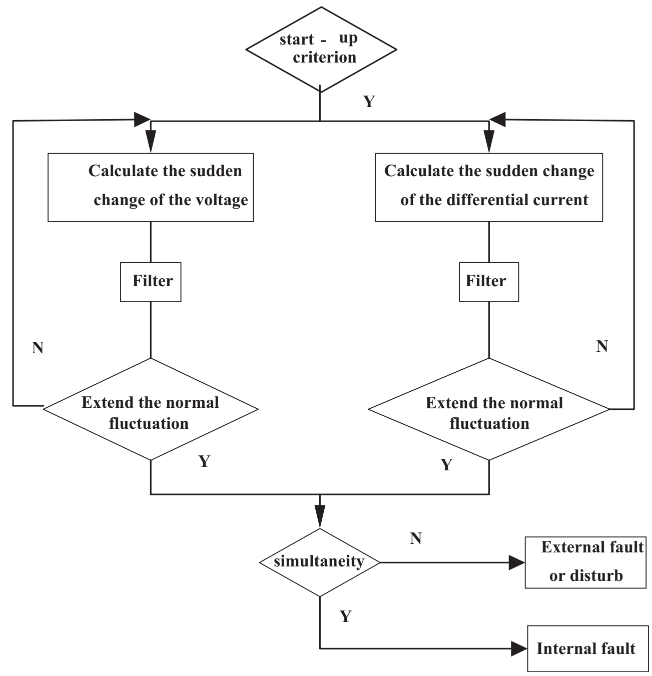

Fig. 1. Criterion flow diagram.

Therefore, a new criterion utilizing the time interval between the sudden change of the phase voltage and the sudden change of the differential current is proposed in this paper, as shown in Fig. 1. As indicated in the flow diagram, the superimposed components of the phase voltage and the differential current are obtained in real time with a so-called "one-cycle subtracting algorithm". The change of the current sampling with respect to the sampling one-cycle before is calculated and recorded. Once above components exceed the specified threshold, the corresponding moment will be detected and recorded, according to which the time interval is calculated. If this time interval exceeds 3 ms, the differential current will be regarded to be induced by the abnormal situation like magnetizing inrush instead of internal faults, and the protection is therefore blocked. Otherwise the protection should trip to isolate an internal fault.

Preset filter

The signals sampled from the secondary side of the real potential transformer (PT) and the CT in the power systems usually contain some electromagnetic interference noises. The superimposed component used in this criterion is the transient component induced by the change of the power frequency component. In some scenarios, the magnitude of the superimposed component may be weak to some extent, which results in the low signal-to-noise ratio. It is difficult to extract the real electrical information if not adopting reliable countermeasures. Therefore, we need to remove the noise component by virtue of some appropriate filters [12]. In this case, the sensitivity and reliability can be improved.

The superimposed signal series gained by the method of one-cycle subtraction often contains some high-frequency interference like burrs [13]. Usually, the useful electrical quantity is the power-frequency component used by the power system protection, while the noise is usually the higher harmonics of the power frequency. As for this criterion, the main interference is the burr with high magnitude, which may result in the wrong