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A Sensitive Method for Identifying winding turn to turn faults in Power Transformer

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Abstract: This paper presents the development of a new approach for diagnosing the occurrence of turn to turn short-circuits in the windings of three-phase power transformers. The main problems of the current differential relay are short circuits of one or more turns of a transformer winding. Hence a new approach using' power differential' is developed to discriminate turn to turn faults by the sum of active power flowing into transformers from each terminal. The proposed scheme is tested using EMTP/ATP as well as an internal fault simulation program and gave reliable and accurate results.

Key words: Transformer, Protection, turn to turn faults, Power Differential Relay, EMTP, TACS

INTRODUCTION

Transformers are a critical and expensive component of the power system. Due to the long lead time for repair of and replacement of transformers, a major goal of transformer protection is limiting the damage to a faulted transformer. A high voltage transformer connected to an overhead transmission system will be subjected to steep fronted impulse voltages, arising from lightning strikes, faults and switching operations. A line surge, which may be of several times the rated system voltage, will concentrate on the end turns of the winding because of the high equivalent frequency of the surge front. Part-winding resonance, involving voltages up to 20 times rated voltage may occur. The interturn insulation of the end turns is reinforced, but cannot be increased in proportion to the insulation to earth, which is relatively great. Partial winding flashover is therefore more likely. The subsequent progress of the fault, if not detected in the earliest stage, may well destroy the evidence of the true cause. Differential relays are commonly used for the transformer protection. They detect differential current or the sum of current flowing into the transformer. To avoid the needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking the relay operation. This method was invented more than 60 years ago (Kennedy, 1938).

Theoretically, differential protection provides the best overall protection for a power transformer. In principle, this protection scheme makes use of current difference flowing through the different terminals of transformer so as to distinguish between internal and external faults. Discrimination between internal and external faults is easily achieved using a current differential relay, but problems, which might result in malfunction, can occur during magnetic inrush. Recently, enhanced communication systems have become available to apply the differential ralay algorithms for power transmission line protection. However, transmission of the electrical signal data initiates some malfunction problems that can be partially overcome by the power differential relay introduced in (Darwish, 2005; Taalab, 2007). In addition an increase in demand for electricity, power transmission systems are steadily becoming larger both in capacity and voltage levels and transmission lines, which are normally composed of multi-conductors, are becoming longer. A direct consequence of the latter is an increase in line capacitance to ground and a widespread usage of underground cable sections also contributes to an increase in the line capacitance. This inevitably results in an increase in the level of lower harmonics(in particular the second harmonic) present in the transformer windings due to a fault, arising as a result of the interaction of the line inductance with capacitance; in certain cases its magnitude can be close to or greater than that present in the magnetizing inrush current. The problem is accentuated by the employment of special iron-cored materials in modern large transformers; their magnetizing characteristics have shown that the increased residual flux can lead to transformer saturation on energizing and a reduction in the second harmonic component present in the inrush current, consequently. Conventional protection techniques will thus have difficulty in distinguishing between an internal fault and an inrush transient. Alternatively, improved protection techniques have thus to be found.

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A short circuit of a few turns of the winding will give rise to a heavy fault current in the short-circuited loop, but the terminal currents will be very small, because of the high ratio of transformation between the whole winding the short-circuited turns. Fig.1 shows the corresponding data for a typical transformer of 3.25% impedance with the short-circuited turns symmetrically located in the centre of the winding (GEC book). Consequently, Conventional current differential relay will thus have difficulty in distinguishing turn to turn faults. Alternative, improved protection techniques have thus to be found.

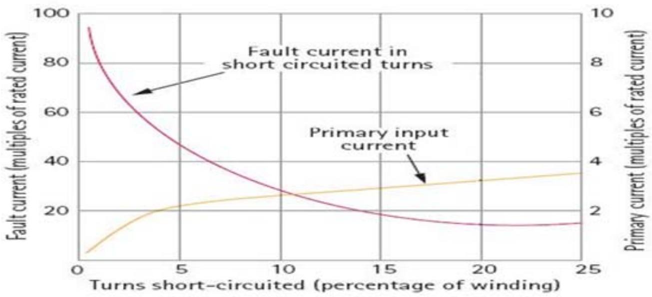

Fig. 1: Turn to turn fault current/number of turns short-circuited.

The power based differential protection (PDP) discussed here is designed for three phase transformers. The algorithm calculates and works with the products of current and voltage and calculates the active power. turn to turn fault during an inrush current is a very common fault. Therefore it should be recognized fast.

Previous work on transformer protection includes transformer inductance during saturation (Inagaki, 1988). Flux calculated from the integral of voltage, and the differential current (Akimoto, 1978; Phadke, 1983). New methods have been adopted which include ANN (Perez, 1994), and fuzzy logic (Wiszniewski, 1995). Also, some techniques have been adopted to identify the magnetizing inrush and internal faults. In (Sidhu, 1992), a modal analysis in conjunction with a microprocessor-based system was used as a tool for this purpose.

This paper develops a power differential-based method focusing on the consumed energy that shows the heat from arc discharge during the insulation fault in proportion to the damage in transformers. At first, the basic theory and algorithm are explained, afterward simulation results for turn to turn fault condition in transformer is presented by using EMTP software. At last, by simulating the power differential relay the operation of this relay is shown in turn to turn fault condition at power transformer.

II. Theory Of Power Differential Method:

In the normal operation state of higher voltage power transformer, the sum of power flowing into the transformer is very little. The reason lies in copper loss and core loss, which are less than 1% of the transformer rating capacity. Considering the instantaneous power, it flows in and out according to the magnetic energy stored in the transformer windings. However, the average power or active power is almost negligible. After energizing, large amount of magnetizing current flows while the iron is saturated. The current depends on the remnant flux in the iron core as well as the energizing phase in voltage. Instantaneous power is also large, but the average power is still small though iron and copper losses as well as eddy current loss may be increased a little bit. On the other hand, when a transformer has an insulation failure, large power is consumed by arcing discharge. This power or heat makes gas inside the transformer oil. If the protection relay cannot operate at an appropriate speed, the liquid medium pressure in tank is increased and oil is poured out or the tank is exploded. In this process, the average of instantaneous power is large. Therefore, if a threshold of average power flowing into the transformer is set, faults can be detected and then cleared. A good way can be tracking the power calculated from the average power minus copper loss when large fault current flows through transformers while a substation bus or line has faced a fault. The power can be easily calculated from the current and voltage at each terminal of the transformer using today’s microprocessor-based digital relays.

Although the method is effective for every multi-winding oil impregnated transformers, in order to simplify the explanation, a two-winding transformer is presented in this study.

$$W(t) = \frac{1}{T}\int_{t-T}^{T} \left(V_1 I_1 - V_2 I_2 - (R_1 + R_{G1})I_1^2 - (R_2 + R_{G2})I_2^2\right)dt \quad (1)$$

where V_1, I_1, V_2, I_2 are instantaneous voltage and current at the primary and secondary winding terminals. R_1, R_{G1}, R_2, R_{G2} are winding and neutral resistances at the primary and secondary winding terminals. *W(t)* presents the average power flowing into transformer during one period T, which is 20ms in a 50Hz system. When large inrush current starts to flow, *W(t)* is increased to serve magnetic energy stored in the windings. However, *W(t)* should be almost equal to the core loss plus stray losses from the second period after energizing.

On the other hand, when a transformer has an internal fault, large amount of power is consumed proportional to the fault degree or arc discharge distance. *W(t)*is increased according to the fault current multiplied by the arc voltage. By tracking *W(t)*, which is directly related to damage inside the transformer, internal faults can be discriminated even if the fault current includes the large second harmonic.

To realize this method by digital relay that has sampling per period, the following algorithm can be adopted:

$$p(t) = V_1 I_1 - V_2 I_2 - (R_1 + R_{G1}) I_1^2 - (R_2 + R_{G2}) I_2^2 \quad (2)$$

P(t) is stored in the memory, and *W(t)* is calculated as below:

$$W(t) = \frac{1}{T} \sum_{n=0}^{N\_!} \{p(t - \frac{n}{N} T)\} \quad (3)$$

If *W(t)* exceeds a threshold, the relay judges there is an internal fault.

This method is easily applied also to three-winding transformer, and is not affected by the state of on-load tap changer. This is another merit of the proposed method when the traditional ratio differential relay has to decrease its sensitivity to avoid the error by tap changer. Therefore we can simulate this method by computer.

In an electrical system, energizing a transformer might cause high inrush currents. Although magnitude of the energization current is only 1–2% of the transformer rated current under steady state operating conditions, it may become as high as several tens times the rated current when transformers are energized. Due to slow attenuation of this transient current, its effect may persist for several seconds before the steady state is reached. These transients may cause unnecessary tripping of relays, so it affects the reliability of the system. The classical second harmonic restraint compares the magnitude of the second harmonic with the magnitude of the fundamental frequency component. The logical implementation for power differential protection is shown in Fig. 2.

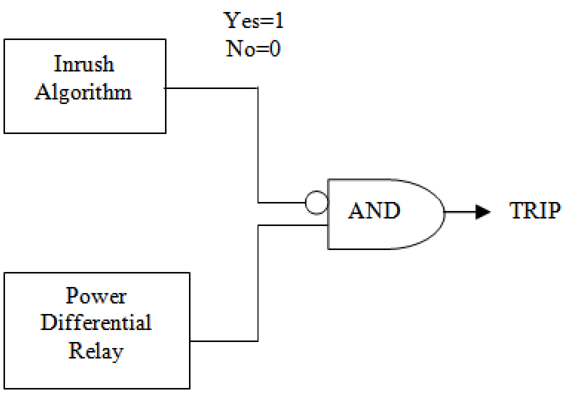

Fig. 2: Inrush trip suppression logic.

III. Simulation Results Of Transformer Turn To Turn Fault:

In order to investigate the applicability of the proposed method, a three-phase 230/63 kV power system including a 100 km transmission line and 230/63 KV(160 MVA) power transformer, as shown in Fig. 3 has been used. Simulation studies were performed using EMTP software (Bastard, 1994; Kezunovic, 2000; EMTP, Manual, 1992). The turn to turn fault was applied in the power transformer to verify the modeling technique proposed in this paper.Fig.4 shows a simulated waveform of turn to turn faults current at primary winding and Fig.5 shows calculated *W(t)* of the same case as fig.3 (The faults have been occurred at 100ms).

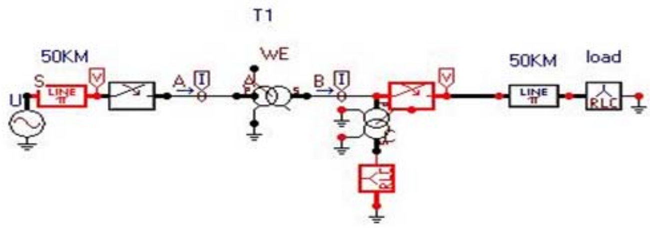

Fig. 3: The considered power network.

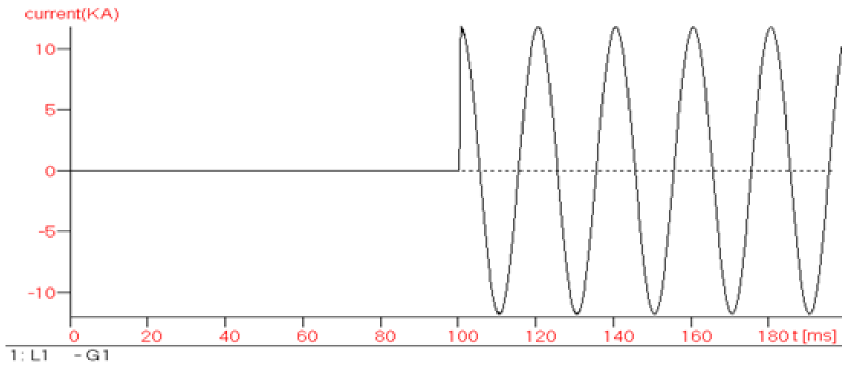

Fig. 4: Simulated waveform of the fault current (turn to turn fault) in the case of the primary winding short circuit.

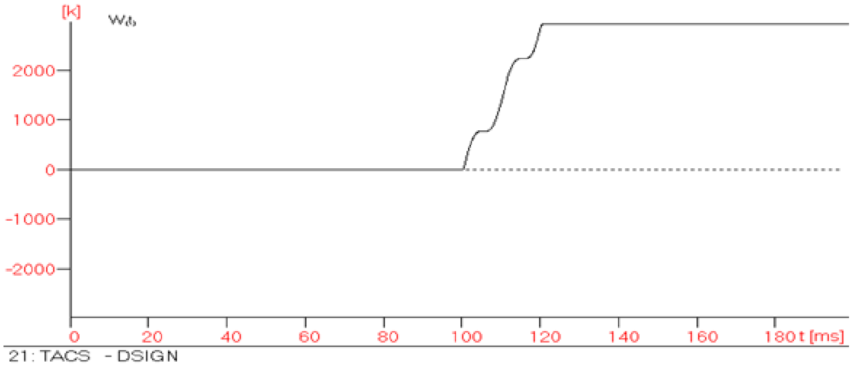

Fig. 5: Simulated waveform of W(t) of the same case as Fig. 4.

IV. Smulation Of Power Differential Relay:

The performance of the power differential relay scheme with the proposed setting is intensively evaluated via TACS (Transient Analysis of Control Systems) in EMTP. The output of this program is a control signal, which controls the opening/closing of the transformer circuit breaker. Circuit breaker is simulated using TACS control switch, which is known as code13. With this type of switch, if the control voltage is positive the switch remains closed, otherwise the switch will be open (Bui, 1992; Lefebvre, 1994; Lasseter, 1994; Wall, 1997). Typically, power differential relay algorithm is applied to a 230/63 KV(160 MVA) power transformer. The considered circuit is as shown in Fig. 2. Fig. 5 shows the power differential method was able to discriminate turn to turn fault case in this model from inrush.

V. Conclusion:

A short circuit of a few turns of the winding will give rise to a heavy fault current in the short-circuited loop, but the terminal currents will be very small. Consequently, Conventional current differential relay will thus have difficulty in distinguishing turn to turn faults. In this paper, setting of the power differential relay scheme for power transformer protection has been presented.. Power based differential protection for three phase transformers have advantages to the conventional current differential protection in sensitivity of turn to

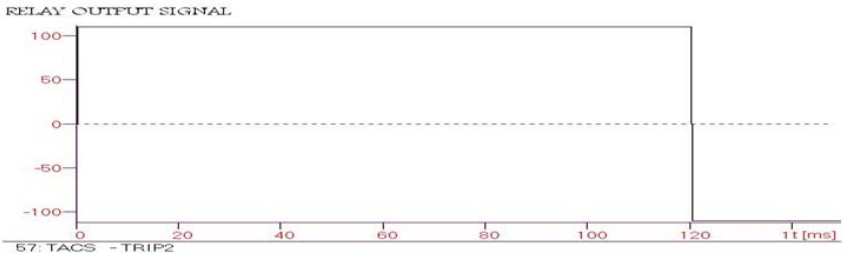

Fig. 5: Power differential relay's output signal of the same case as Fig. 4.

turn faults detection. It can discriminate an turn to turn fault from inrush current. in addition, By combining the current and voltage information, more sensitive detection can be expected. As power is a criterion which neither depends on the frequency nor on the current waveform.

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