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Power differential relay for three phase transformer

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Abstract : To avoid the needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. However, the second harmonic component in fault current is increased in long lines and underground cable because increased together with the capacitance in power system.
This paper describes a method to discriminate internal fault from inrush current by the sum of active power flowing into the transformer from each terminal. The average power is almost negligible for energizing, but an internal fault consumes large power.

Key-Word: transformer, protection, fault, active power relays, EMTP,TACS

1. INTRODUCTION

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 [1-2].
Due to 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. Alternative, improved protection techniques have thus to be found

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. A winding fault during an inrush current is a very common fault. therefore it should be recognized fast. such faults can be analyzed much faster and more sensible with the new power based differential protection(PDP) relay than with a conventional current differential protection(CDP) relay.

As for 500KV or less transformer, ideas focusing on the inductance during iron saturation [3]. or on the flux calculated from the differential current and integral of voltage have been proposed [4]. These years new methods using artificial neural networks and fuzzy logic are also proposed [5]. However , no method seems to be practical level yet.

This paper propose a new 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 inrush current and 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 fault condition at power transformer.

2 Theory of power differential method

2.1 Physical phenomena and theory

In the normal operation state of higher voltage power transformer, the sum of power flowing into the transformer is very little, because the copper loss and core loss are less than 1% of the transformer capacity. When we consider instantaneous power, it flows in and out according to the magnetic energy stored in windings. However, the average power or active power is almost negligible. Just after the energizing, large magnetizing current flows during the iron saturation. 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 loss 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 from the insulation oil. If the protection relay cannot operate at the enough speed, the pressure in tank is increased and the oil is discharged or the tank is exploded. In this process, the average of instantaneous power is large.Therefore, if we set a threshold of average power flowing into the transformer, faults can be detected. It is better way to watch the power calculated from the average power minus copper loss when large fault current flows through transformers when a substation bus or line has a fault. The power can be easily calculated from the current and voltage at each terminal of transformer using today's microprocessor based digital relay [6].

2.2 Discrimination algorithm

Though the method is effective for every multi-winding transformer, in order to simplify the explanation, two-winding transformer is adopted here.

$$W(t)=\frac{1}{T}\int_{t-T}^{T}(V_1I_1-V_2I_2-(R_1+R_{G1})I_1^2-(R_2+R_{G2})I_2^2)dt \qquad (1)$$

where V_1, I_1, V_2, I_2 are instantaneous voltage and current at the primary and secondary winding terminal. R_1, R_{G1}, R_2, R_{G2} are d.c resistance and neutral resistance at the primary and secondary winding terminal. $W(t)$ means the average power flowing into transformer during one period T(20ms in 50Hz system).when large inrush current starts to flow, $W(t)$ is increased to serve magnetic energy stored in windings. However, $W(t)$ should be almost equal to core loss plus stray losses from the second period after the 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 arc voltage. By watching $W(t)$, which is directly related to damage received by 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.

$$p(t)=V_1I_1-V_2I_2-(R_1+R_{G1})I_1^{2}-(R_2+R_{G2})I_2^{2} \qquad (2)$$

is stored in the memory, and calculates the next.

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

If $W(t)$ exceeds a threshold, the relay judges there is an internal fault. The threshold be set to avoid the needless operation by the inrush current, and to coordinate the strength of transformer tank and the required clear time.

This method is easily applied also to three-winding transformer, and is not affected by the

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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. The differential power protection algorithm is shown in fig.1

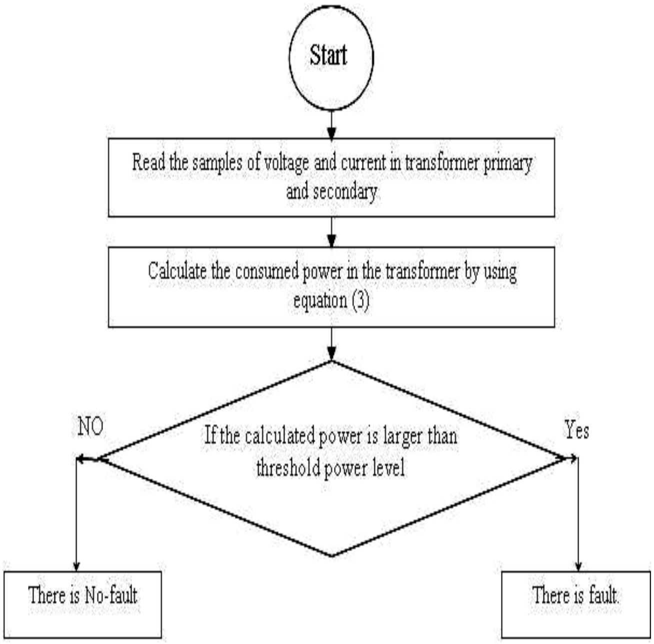

Fig.1 Differential power protection algorithm

3 . Simulation results for the largest inrush current

Transformer manufacturers simulated various kinds of inrush current using EMTP with their design data. The sensitivity and speed of this method depend on how much the $W(t)$ is increased by the inrush current. Table 1 and 2 show the specifications of transformer. The considered circuit is as shown fig.2.

Table1. Transformer general specifications

Type	Three phase,3 leg core, 2 winding
Rated voltage	230kv/63kv
Rated capacity	160MVA
Connection	YNd11(neutral grounding) Primary: Direct Secondary: Direct

Table2. Transformer no load specifications

No Load Measurement		
$\frac{V}{V_{rat}}\%$	Voltage KV (rms)	Io (A)
110%	69.3	1.3141
100%	63	0.7366
90%	56.7	0.6630
80%	50.4	0.5910
70%	44.1	0.5138

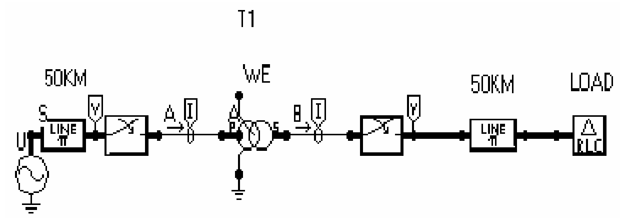

Fig.2 The considered power network

Fig.3 shows inrush current. Because the secondary terminal was open, the primary winding current only showed. In this case, the peak of primary current (phase B) reaches 4.4 times of the rated current peak. Inrush current is highly unbalanced in the three phase and also contain a lot of harmonics (Fig.4). The principle of the conventional inrush stabilization known since 1920 is to filter the 2^{nd} harmonic of the current. If the ratio 2^{nd} harmonic to 1^{st} is above 20% the CDP detects an inrush current. The algorithms of the PDP are based on power calculation only. These increase the maximum peak of the apparent power. Particularly the distortion active power rapidly increases. Fig.5 shows calculated $W(t)$ of the same case as fig.3.monitoring the maximum of $W(t)$ and its declining, the aim of an inrush stabilization can reached very effectively.

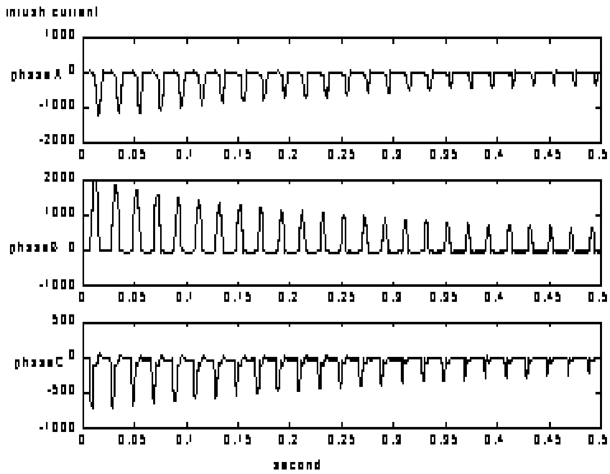

Fig.3 Waveforms of the maximum inrush current

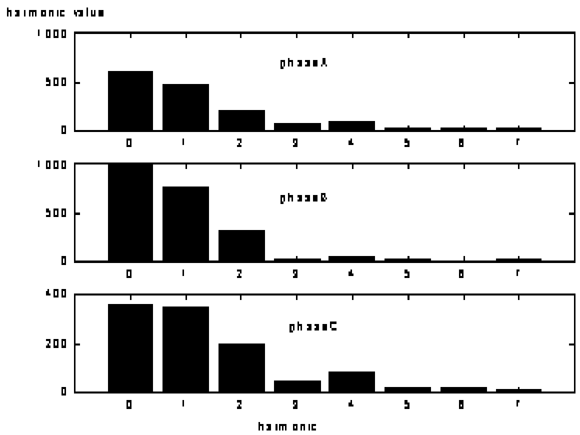

Fig.4 Inrush current harmonic components amplitude

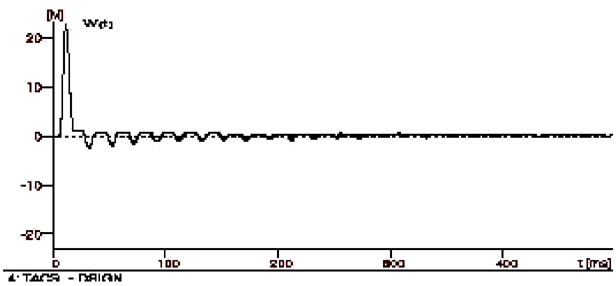

Fig.5 Waveform of the W(t) of the same case as Fig.3

4 . Simulation results of transformer fault

Transformer manufacturers simulated various kinds of faults using EMTP with their design data [7-9]. The considered circuit is as shown fig.2. Fig.6 shows a simulated waveform of fault current (three phase to ground) in the case of 50% short circuit at primary winding and Fig.7 shows harmonic components amplitude of the same case as fig.6 in 160MVA transformer. It includes nearly 30% second harmonic and conventional current differential protection relay are locked.

Fig.8 shows calculated $W(t)$ of the same case as fig.6 in 160MVA transformer (The faults have been occurred at 100ms).

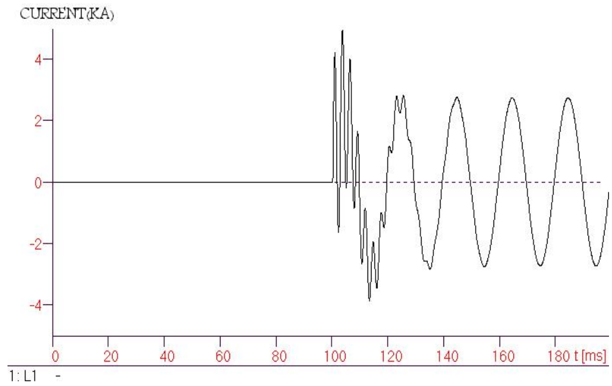

Fig.6 Simulation waveform of the fault current (three phase to ground) in the case of primary winding 50% short circuit

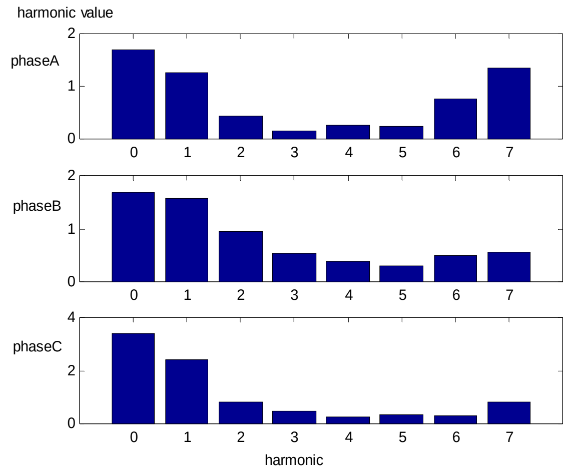

Fig.7 fault current harmonic components amplitude

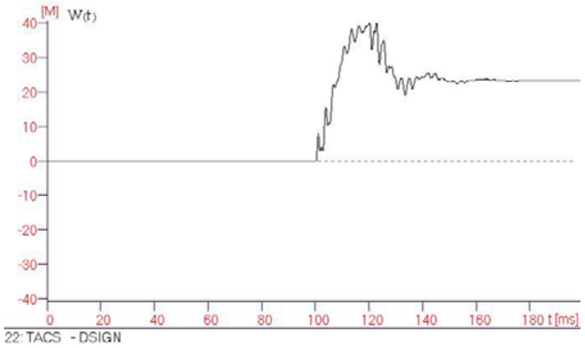

Fig.8 Waveform of the W(t) of the same case as Fig.6

5 . Simulation of power differential relay by using EMTP

For power differential relay simulation we can use control system with TACS (Transient Analysis of Control Systems) in EMTP. The output of this program is a control signal, which control the opening/closing of the transformer circuit breaker. For simulating the circuit breaker we must use TACS control switch, which is known by code13. In this type of switch if the control voltage is positive the switch remained closed. And otherwise the switch will be opened [10-12]. Typically power differential relay algorithm implementation for transformer with YNd11 vector group is simulated. The considered circuit is as shown in Fig.2. Afterward relay operation for fault condition considered in section IV is presented. For demonstrating the relay operation we can use relay output signal, which this signal is positive in normal and energizing condition and also is zero for fault condition. Fig.9 shows the power differential method was able to discriminate every fault case in this model from inrush. Such faults can be analyzed much faster (less than 20ms) and more sensible with the new power differential relay than with a conventional current differential protection relay. It is to stress at this point that the power differential relay does not perform any FFT on the current to stabilize against high inrush currents.

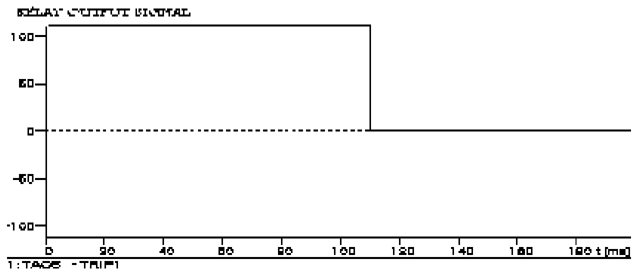

Fig.9 Power relay output signal of the fault current (three phase to ground) in the case of primary winding 50% short circuit

Power differential relay block diagram is shown in Fig.10

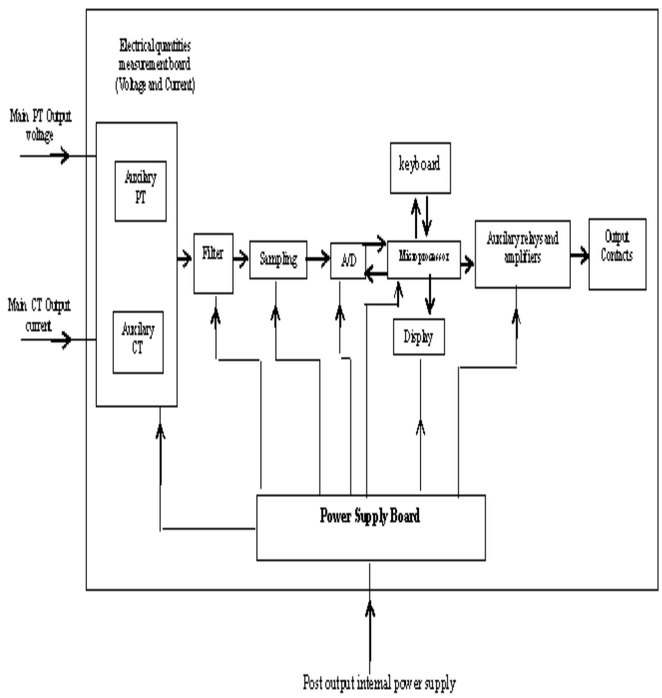

Fig 10. Power relay internal daigram

6 . CONCLUSION

Power based differential protection for three phase transformers have advantages to the conventional current differential protection both in speed and in sensitivity of fault detection. It can discriminate an internal fault from inrush

independent of the harmonics in differential current, and is effective for the forecasted increase of capacitance in power system where second harmonic in faults current is large.
An additional FFT of the current need not to be performed. By combining the current and voltage information, more sensitive detection can be expected. As power is a criterium which neither depends on the frequency nor on the current waveform. The power differential protection can be used for phase shifter transformer and FACTS devices, Where existing protection relay have no possible mode of operation.

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