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A Unique Correlation Function based Technique to Identify Fault and Inrush in Transformer

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ABSTRACT: *This paper proposes a unique transformer protection scheme based on correlation coefficient which can effectively differentiate between internal and external faults. It can also identify the inrush phenomena and presence of fault while energizing transformer. Current entering and leaving the transformer have a strong relationship during normal and external fault condition. However during disturbance this relationship is affected, highlighting the change in coefficient value. The change in correlation coefficient value is proposed as a measure to detect the fault and inrush phenomena under various power system conditions. The proposed scheme also found effective to classify different types of short circuit faults. Results from simulation and real time data obtained from the field, supports the feasibility of the concept.*

Keywords – *Transformer protection, Transformer inrush, Correlation coefficient, Fault detection, Fault classification*

I. INTRODUCTION

Transformers are important links within a power network and hence any failure can cause long interruption in the power supply. Although probability of faults in transformer are less as compared with transmission lines. They are subjected to heavy loading for most of their operating duration, thus chances of transformer failures cannot be ignored. Internal winding faults are very common which is developed due to insulation failure. Fault detection and isolation in transformer is vital from both operation and economic point of view. Detection of short circuit faults is crucial, as they are complicated by the factors such as external fault, presence of remanance flux, CT saturation and inrush phenomena [1]. Primary protection using differential protection scheme is well established which can fairly classify the fault between internal and external. However an additional function utilizing information of harmonic content is required to differentiate between inrush and faulty condition [2, 3]. Operation of harmonic current restrain relay is found affected by saturated current transformers, residual flux and point on wave which calls for advanced characterization schemes. Methods employing pattern recognition are utilized to some extent to resolve the issues. ANN based detection technique can be applied to determine inrush current as well as reconstructing distorted secondary CT currents due to saturation [4]. Other pattern recognition techniques such as using decision tree and wavelet transform is also recommended for transformer protection [5]. Recent development in Frequency Response Analysis (FRA) has also been successfully used as diagnostic technique to detect fault in transformers [6].

Correlation coefficient is the part of basic statistic functions, which is considered as an important indication to judge system linearity [7]. Fault identification in transformer is also evaluated using waveform correlation [8]. A unique blocking scheme based on the correlation coefficient between the first half cycle and latter half cycle to distinguish between fault and inrush is also introduced [9]. Another method based on correlation analysis is proposed, which tries to extract the information from current waveform in its non-saturation zone. The properties of wave shape during fault and inrush is used as a base for discrimination. Method seems quite complicated, requires proper selection of data window and it can only detect small turn to turn fault [10].

Existing correlation function based methods faces difficulty in identifying the presence of fault while energizing the transformers. In such conditions existing discrimination function loses its certainty; hence there exist a scope for development of new algorithm to overcome such shortfalls. This paper introduces a new method for transformer protection based on correlation coefficient which can differentiate between internal and external faults. It can also identify the inrush phenomena and presence of fault while energizing the transformer. Case studies are presented in the subsequent sections to establish the feasibility of the proposed scheme.

II. PROPOSED SCHEME

The proposed scheme uses a simple algorithm based on correlation coefficient which can efficiently determine the presence of faults within a transformer. Implementation of the proposed scheme is divided into three major blocks i.e. Disturbance identifier, Fault and inrush detector and Fault classifier.

2.1 Disturbance Identifier

Any anomaly in the power system is to be detected at the earliest to take appropriate precautionary actions. The proposed scheme uses primary and secondary current of a two winding transformer for its operation same as differential protection scheme. The basic difference is that the proposed scheme uses instantaneous values and computes correlation function; while differential protection scheme uses instantaneous values and computes r.m.s values for its operation.

$$f_n = \left| \frac{\sum_{m=1}^{s}\left(i_{pm\,(n)} - \overline{i_{p\,(n)}}\right)\left(i_{sm\,(n)} - \overline{i_{s(n)}}\right)}{\sqrt{\sum_{m=1}^{s}\left(i_{pm\,(n)} - \overline{i_{p\,(n)}}\right)^2 \sum_{m=1}^{s}\left(i_{sm\,(n)} - \overline{i_{s(n)}}\right)^2}} \right| \qquad (1)$$

where,

f_n: Correlation function for each phase, n=1, 2 and 3

$i_{pm\,(n)}$ and $i_{sm\,(n)}$: Phase wise instantaneous values of primary and secondary current

$\overline{i_{p\,(n)}}$ and $\overline{i_{s(n)}}$: Phase wise mean values of primary and secondary current over a cycle

The correlation coefficient value is calculated independently for each phase as per equation (1). To obtain each phase coefficient; corresponding primary and secondary current are correlated. Thus total three correlation coefficient values (f_n) are calculated at each instant for a three phase system. To determine any abnormality in the system initial value 'f_i' is considered as the average of initial three values assuming pre disturbance data available in the record. If the absolute value of coefficient 'f_n' changes by 25% of its original value, then it indicates that disturbance exists in system. Threshold value is selected based on the number of simulations performed. To avoid misoperation three consecutive values are checked to confirm the disturbance.

2.2 Fault and Inrush Detector

Once the presence of disturbance is detected in the system, the next logical step is to distinguish the event into faulty or normal state. In case of transformer protection, some of the important tasks are discriminating internal and external fault, identifying inrush phenomenon and determining fault during inrush. Correlation function value obtained is investigated to arrive at the desired results. The continuous function computed as per equation (1) is termed as 'f_n'. The correlation function assigned as 'f_o' is the value of coefficient 'f_n' one cycle ahead of fault detection. The value computed after one and half cycle of fault detection is coined as 'f_d'. Check is made on the obtained value of 'f_d' for three consecutive samples. If the value satisfies the predefined condition $f_d > 0.9^* f_o$ then the fault is confirmed in that phase; otherwise it is defined as inrush phenomenon. If both the condition occurs simultaneously for different phases in an event, then the situation is fault during inrush. Here the threshold set is around 90% of the original value, which is arrived by performing various simulation cases.

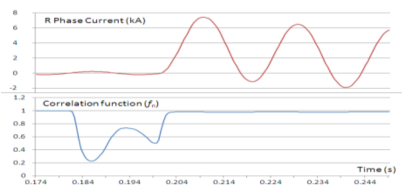

Fig. 1: Fault current and correlation function.

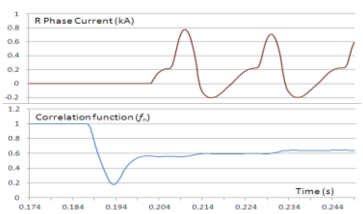

Fig. 2: Inrush current and correlation function

During internal fault though a sudden rise in current is observed, fault current wave still remains sinusoid which allows a better correlation after certain settling time (usually one cycle) as shown in Fig. 1. It is clear that correlation function computed returns back around its original value in the presence of fault. This characteristic is unique for fault currents unlike inrush current which has high frequency component embedded in the waveform. Under inrush condition, magnetizing inrush current often reaches eight to ten times of load current which are comparable with fault currents. However magnetizing current flows in transformer primary winding only and has unique non sinusoidal wave shape. This phenomenon affects the correlation value which increases slowly and has large settling time as shown in Fig. 2. As noted the correlation function computed does not return back near to its original value after the disturbance, however it settles to a much lower value and increases slowly. Transformer energized with short circuit fault will show the combined characteristics of fault and inrush condition in different phases.

2.3 Fault classifier

Identifying the faulty phases can be of great help to the substation personnel. Aiming at this proposed fault classifier logic can identify the faulty phase effectively, once it is confirmed that the event includes fault or fault with inrush. Logic is simple and does not require any additional computations. The phases in which correlation function satisfies the condition of fault i.e. correlation value returns back near to original value are classified as faulty phases. Case studies provided in the subsequent section will clarify the logic followed with appropriate examples.

III. CASE STUDIES

The validity and reliability of the proposed scheme is evaluated using digital simulation in EMTP module of MiPower^{TM} software. A typical four bus system with detailed model of 400/220 kV transformer considering magnetizing branch of 250 MVA capacity is considered as shown in Fig 3. Instantaneous values of primary and secondary current are collected from transformer for various power system conditions.

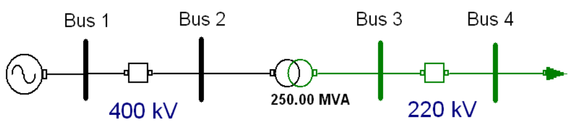

Fig. 3: Single line diagram of 4 bus system

3.1 Internal fault

Identifying internal fault is the most important aspect of transformer unit protection. Various types of internal fault are simulated to determine the performance of the proposed scheme. Case study for single phase fault is reported here in detail.

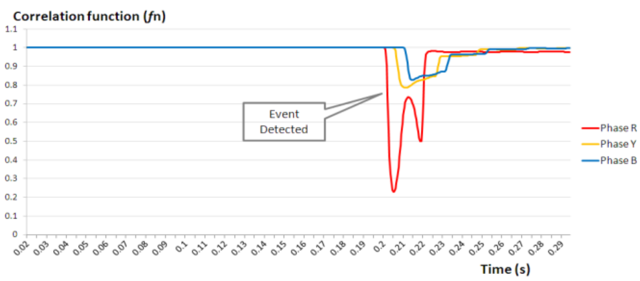

Fig. 4: Correlation function during internal fault

An internal R phase to ground fault is created at 50% of the transformer winding with fault impedance of 1.6 ohm. Fault is created at 0.2 s and cleared at 0.3 s. As seen from Fig. 4, the initial value 'f_i' obtained from averaging first three values is approximately equal to 1. As observed, only R phase correlation function diverts from its initial value at 0.202 s and crosses the set threshold depicting presence of event. To confirm whether event is a fault or normal condition value of function 'f_o' is computed which is 0.999 at 0.182 s and the value of

'f_d' is 0.975 at 0.232 s. As per the fault logic value of function '$f_d > 0.9* f_o$' is satisfied, confirming the presence of internal fault classified as R phase fault.

3.2 Transformer Energization

In order to avoid relay misoperation during transformer energization, an additional harmonic restrained logic is embedded in the conventional relays. The proposed scheme utilizes the same correlation function and does not require any additional information to arrive at the decision of transformer energization.

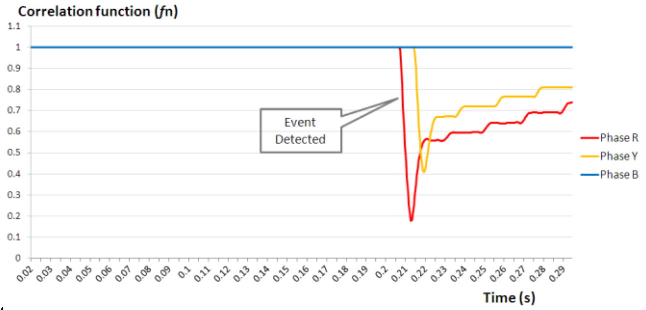

Fig. 5: Correlation function during transformer energization

As seen from the Fig. 5, two of the phase correlation function deviates from its original value indicating the presence of an event. As per the fault logic value of function '$f_d > 0.9* f_o$' is not satisfied for both the phases, which implies that though event is detected it is not a fault. This indicates that the disturbance is due to inrush phenomena. Hence the proposed scheme is simple to implement and found effective in order to differentiate between inrush and fault condition in the transformer without proposing any additional function.

3.3 External fault

An external R phase to ground fault is simulated at the transformer bus after CT connections at 0.2 s.

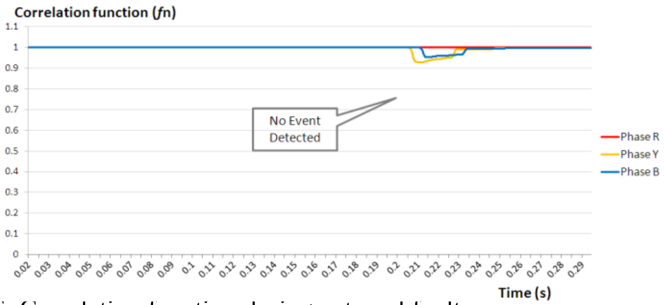

Fig. 6: Correlation function during external fault

As observed from the Fig. 6, that there is slight deviation in the computed correlation function near to 0.2 s. However the change is not sufficient enough to cross the set threshold at any point of time. Thus there will be no disturbance identified by the proposed scheme and can be considered as external fault to the transformer.

IV. CONCLUSION

A new scheme based on correlation function to identify transformer fault is presented. Proposed scheme can sense the disturbance, identify the presence of internal fault and does not respond to any external fault. It can distinguish effectively between a faulty and inrush condition. The scheme also works well in a situation where transformer is energized in the presence of internal fault. Detection of fault is fast and provides the information about the faulted phases as well. The logic is simple and works well for practical system.

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