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Detection of Inrush Current in Transformers Based on Instantaneous Reactive Power

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Abstract—When a transformer is energized on no load there is a transient inrush current which causes mal-operation of protective relays. The challenge is to distinguish the inrush current from load and fault currents. In this paper, a new technique, based on instantaneous reactive power theory is proposed for the detection of inrush current in single-phase transformers. During inrush current as the lower order harmonics are significant, the average value of instantaneous reactive power becomes negative, and hence this feature is utilized in this paper to distinguish inrush currents from other currents. Investigations are carried out for different faults and switching conditions on a single-phase transformer using PSCAD software. The simulation results show that the proposed method is able to effectively identify inrush currents from other currents.

Keywords— Inrush current, transformer faults, instantaneous reactive power.

I. INTRODUCTION

Transformer is an expensive equipment and repeated switching on transformers no load/ light load condition is an integral part of any practical power system. Whenever the transformer excitation voltage changed due to energization, fault clearing process or voltage swell high transient magnetizing current - the inrush current- is produced. Such currents are decaying generally results for several cycles, which contain significant low order harmonics and dc component. This causes current transformer saturation, mal-operation of differential protection relays, and can affect both the reliability and stability of the whole power system [1], [2]. In the case of a traction line, when energized after the removal of fault then all the transformers mounted on the locos of the stranded trains, draw inrush current simultaneously tripping the healthier lines [3] So it is necessary to detect inrush current from fault current to avoid the false tripping of transformers and lines. The common technique to detect inrush current is based on the content of second order harmonics in the current waveform [4]. However this requires a longer time and in modern transformers the level of second harmonic is significantly reduced [5]. Moreover, the detection is based on a threshold value below which the inrush currents are not detected. An algorithm based on wavelet analysis of current has been reported in [6], [7] and [8]. However as these methods utilize only the current signals, which cannot be forecasted, the detection of inrush current by these techniques is not always correct. This paper proposes a new decision making technique based on the polarity of average value of the instantaneous reactive power during inrush, load and fault currents. The proposed method is more reliable as it considers both the voltage and the current signals. By this method any value of inrush current can be detected as it does not depend on threshold value.

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II. PRINCIPLE OF DETECTION

During the period of inrush current, transformers behave as a non-linear load generating harmonics for a transient period and p-q theory can be applied for calculating the instantaneous power components, real power (p) and imaginary power (q).

The p-q theory defines a set of instantaneous powers in time domain and is valid during steady state or transient, with or without harmonics. The instantaneous power in three phase frame of reference is transformed into $\alpha\beta0$ reference through Clarke Transformation, consisting of a real matrix that transforms three-phase voltages and currents into the $\alpha\beta0$-stationary reference frame [9].Then the instantaneous real power (p) and the imaginary power

(q) are given by

$$P = v\alpha\, i\alpha + v\beta i\beta$$

$$q = v\alpha\, i\beta - v\beta i\alpha$$

The instantaneous real power (p) is the power that is being transferred from source to the load and the instantaneous imaginary power (q) represents the energy exchange between the phases without transferring energy. However this concept cannot be applied to single-phase circuits as such because the instantaneous imaginary power (q) which is an essential parameter of p-q theory cannot be calculated in single-phase circuits.

So by orthogonal transformation the ordinary single-phase system is transformed into an equivalent two axes orthogonal one [10]. If the voltage is sinusoidal and the load current is non-linear, then the instantaneous real power (p) and imaginary power (q) are given by [11]

$$p = \bar{p} + \tilde{p}$$
$$q = \bar{q} + \tilde{q}$$

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where $\bar{p}$ and ($\tilde{p}$) represents the average and oscillating components of real power (p), $\bar{q}$ and $\tilde{q}$ represent the average and oscillating components of imaginary power (q)

Detection logic

The instantaneous imaginary power (q) differs from the conventional reactive power Q, because in the first case all harmonics in voltage and current are considered. The average value of instantaneous reactive power is given by

$$\bar{q} = \sum_m 3V_+ I_+ \sin\Phi - \sum_n 3V_- I_- \sin\Phi$$

where m=1,4,7 etc and n=2,5,8 etc . V+ and I+ represents the components of positive sequence voltage and currents, V- and I- represents the components of negative sequence voltage and currents respectively. During inrush current as the low order harmonics are rich, negative sequence voltages and currents becomes large, the value of $\bar{q}$ becomes negative and this characteristic of power $\bar{q}$ is taken for the detection of inrush currents. The flow chart of the detection scheme is shown in Fig.1. The

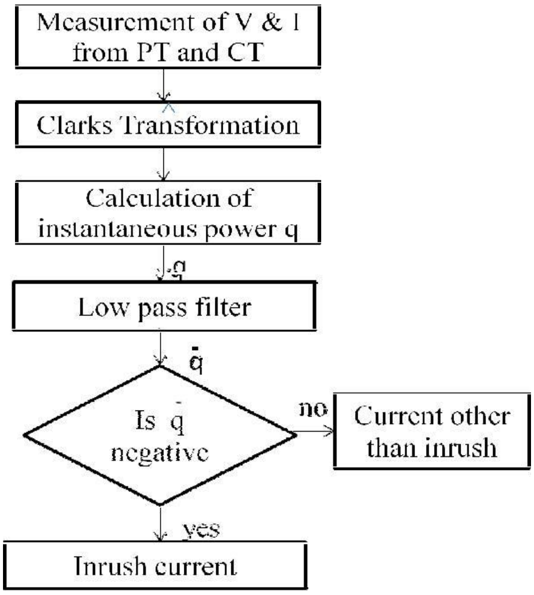

Fig.1. Flow chart for the detection of inrush current

voltage and current signals are monitored through potential transformer and current transformer . The value of imaginary power q is computed, filtered to eliminate the oscillating component $\tilde{q}$ to get the average reactive power $\bar{q}$. When $\bar{q}$ goes negative, a negative going edge detector out a high digital value indicating the presence of inrush current. A timer provides the sufficient pulse duration to activate the detection circuit.

III. SIMULATION RESULTS

The effectiveness of the proposed technique is established through the PSCAD simulation of various faults, voltage swell, load and transient conditions on a single-phase 1kVA 230V/230V transformer, the parameters of which was obtained through experiments is given in the following Table. Magnetic core residual flux is represented by a dc current source in parallel with the low voltage winding; the current is chosen to establish the required level of residual flux linkage [12]. Polarity of the residual flux is changed by reversing the dc source. Different cases of inrush current are simulated by varying those major parameters that influence the characteristics of inrush current. These parameters are switching angle, magnitude and polarity of residual flux. The ability of the logic developed is tested to detect inrush current from faults both on primary and secondary side, energization against fault, fault during normal operation and inter-turn fault. Various cases considered and the simulation results are discussed in this section.

Transformer parameters

Parameters	Value
Area of total winding	38 cm^2
Length of flux path	37.5 cm
No load current	1.08A
Leakage reactance	2.06 Ohm
No load losses	120 W
Air core reactance	2.06 Ohm
Magnetizing current	0.94A
Primary resistance	1.08 Ohm

Case i: Detection of inrush current from load and fault current

Fig.2 shows the various plots obtained when the transformer is energized at 0.1s, rated load current (4A) by switching an R-L load at 0.4s and a line to ground fault at 0.5s followed by the fault clearance at 0.55s.The first plot shows the inrush current followed by load and fault current; second plot the average reactive power q and the last plot the detection signal. The plots indicate that during inrush current average value of reactive power $\bar{q}$ is negative for inrush current only. This negative occurrence of reactive power is detected indicating the presence of inrush current.

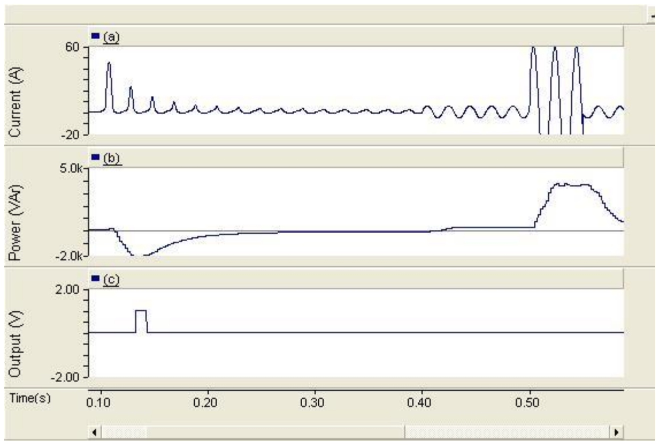

Fig.2 Effect of transformer energization, loading and fault

Inrush current followed by load and fault current.
Reactive power $\bar{q}$ c) Detection signal

Case ii: Detection of inrush current due to voltage swells

A prolonged and excessive voltage swell can cause the transformers to enter into magnetic flux saturation causing high electromagnetic stress. Often voltage sag and swell may occur consecutively.

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This change in voltage can lead to inrush current similar to the energization of transformer. Detection of inrush current due to voltage swell is also tested. For this the transformer is energized and then connected to the rated load and again switched to a capacitive load at 0.5s creating a voltage swell of 430V peak at. 0.55s. Fig. 3 shows corresponding variation of the transformer

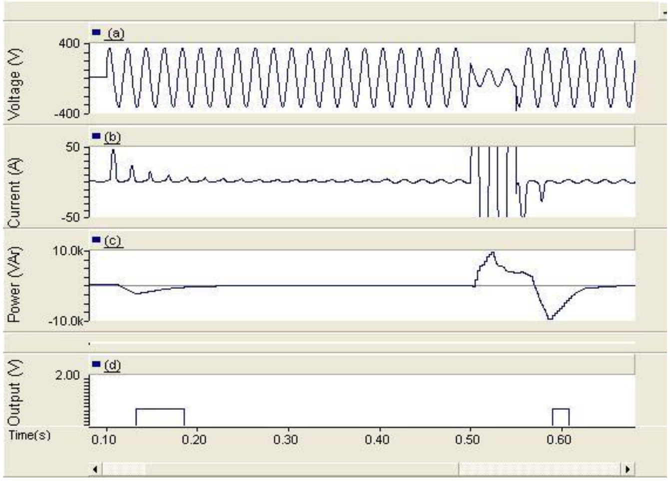

Fig.3 Effect of voltage swells

a) Transformer energization voltage
b) Inrush current followed by load current, capacitive current and inrush current
c) Average reactive power $\bar{q}$ d) Detection signal

voltage, primary current, average reactive power q and the inrush current detection signal respectively. At 0.55s due to the voltage swell, there is an inrush current of peak value 50A and this is detected at 0.57s. It can be observed that the instantaneous reactive power $\bar{q}$ goes to negative only at the occurrence of inrush currents.

Case iii: Detection of inrush current due to fault clearing

Inrush current is also generated during the fault clearing process. For this the transformer is energized against a line to ground fault, then connected to the rated load and again subjected to the same fault. Fig. 4 shows corresponding variation of the transformer fault current, instantaneous reactive power and the inrush current detection signal respectively.

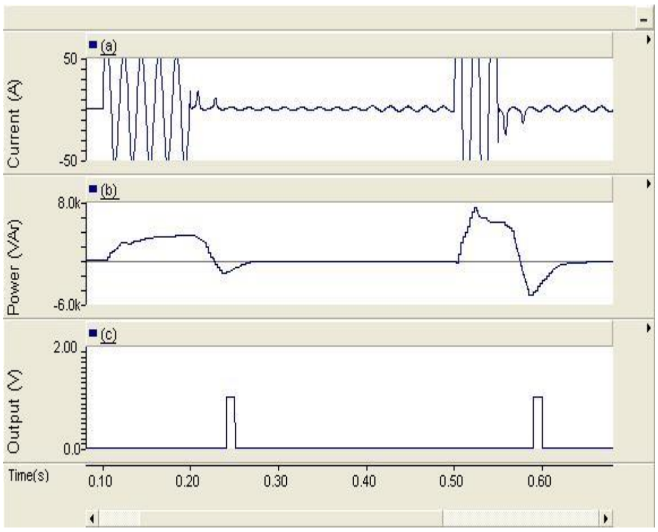

Fig.4 Effect of transformer energization during fault

a) Fault current followed by inrush current, load current and fault current
b) Average reactive power $\bar{q}$
c) Detection signal

From this figure, the presence of fault current can be seen from 0.1s, initiation of the fault up to 0.2s, the instant of clearance. At 0.2s due to the change in voltage magnitude, there is an inrush current of peak value 40A and this is detected at 0.22s. At 0.4s transformer is subjected to the rated load current and at 0.5s a line to ground fault is again applied and cleared at 0.55s. At 0.55s there is negative inrush current peak of 12A which is detected at 0.57s. In this case also the instantaneous average reactive power $\bar{q}$ becomes negative only at the occurrence of inrush current.

Case iv Transients and capacitive load

Impulsive transients are sudden high peak events that raise the voltage and/ or current levels either in positive direction or in negative direction. Fig.4 shows the effect of application of a positive and negative current transient to the transformer by switching on a capacitive load at 0.5s for a period of 0.05s. The first plot in the figure shows the inrush current followed by transients by switching a capacitor during no load and load on the transformer. Second plot shows the instantaneous average reactive power $\bar{q}$ which is always positive except during inrush current. Last plot shows the detection signal during inrush current.

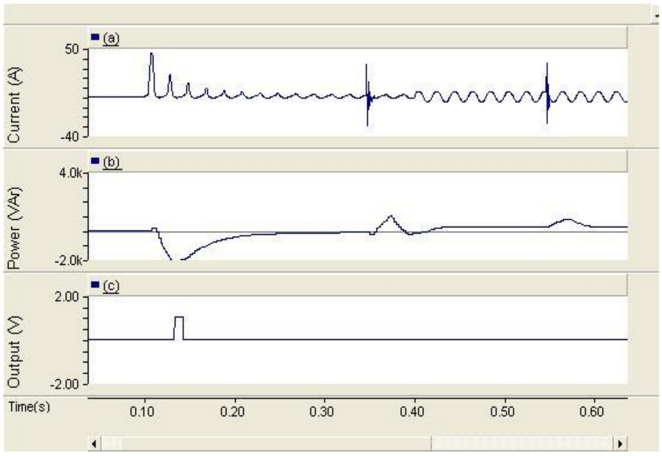

Fig.4 Effect of transients and capacitive load

a) Inrush current followed by transient and capacitive current
b) Average reactive power $\bar{q}$ c) Detection signal

IV. CONCLUSION

In this paper, a novel technique for the detection of inrush currents from faults and load currents in single-phase transformer has been presented. The method proposed is based on instantaneous reactive power (p-q) theory. During inrush current the instantaneous reactive power q becomes negative and hence this feature is utilized to detect. The proposed technique, which takes into account both the current and the voltage signals, is superior to the state-of-the-art technique for the detection of transformer inrush current as it does not rely upon any threshold values of the harmonic current signals.

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Further the proposed technique is simple, and has the capability of detection of inrush current of any magnitude from the load and fault currents.

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