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Discrimination between inrush and fault current of a transformer using FPGA

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Abstract: Discrimination between an internal fault and a magnetizing inrush current has long been recognized as a challenging power transformer problem. This paper presents a new method of detection of inrush and fault current considering current waveform and its magnitude and time samples as ADC emulated data. An algorithm is used to compare the data of magnitude and time of both inrush and fault current with the help of FPGA. Decision can be made based on the output of FPGA whether to provide trip circuit for fault current and allow the inrush current to pass through as it exist for a duration lesser than the fault. Several investigations have been carried out on a single phase transformer and simulated for different fault and switching conditions. The results prove that the proposed technique is able to offer fast responses in detection of inrush and fault current.

Index Terms: Inrush Current, fault current, FPGA, Differential Relay.

I. INTRODUCTION

Large power transformers protection is a very challenging problem in power system relaying. These transformers are a class of very expensive and vital components of electric power systems. Inrush could be mistaken for a short circuit current and the transformer is erroneously taken out of service by the relay. Since there is a high demand imposed on power transformer protective relays, which includes the requirements of dependability associated with mal-operation, security associated with no false tripping, and operating speed associated with short fault clearing time [1].

This research will analyze the problem of discrimination of inrush and fault current. For power transformers, the magnitude of the first peak of inrush is initially several times the rated load current but slowly decreases by the effect of oscillation damping due to winding and magnetizing resistances of the transformer.

Research are done considering the magnitude of the second harmonic in an internal fault current and magnetizing inrush current using wavelet transform method ,can be close to or greater than that present in the magnetizing inrush current [1]. The second harmonic components in the magnetizing inrush currents tend to be relatively small in modern large power transformers because of the improvements in the power transformer core material. The commonly employed conventional differential protection technique based on the second harmonic restraint will have difficulty in distinguishing between an internal fault and an inrush current thereby threatening transformer stability [1].

Early methods were based on desensitizing or delaying the relay to overcome the transients [2]. These methods are unsatisfactory nevertheless, since the transformers were exposed to long unprotected times. Improved security and dependability then was appreciated when the second harmonic content with respect to the fundamental one as introduced as an identification criterion, known as harmonic restraint differential protection [3]. However, some researchers reported the existence of a significant amount of the second harmonic in winding faults [4] [5]. In addition, the new generations of power transformers use low-loss amorphous material in their core, which can produce inrush currents with lower harmonics contents and higher magnitudes [5]. In such cases, some authors have modified the ratio of second harmonic to fundamental restraining criterion by using other ratios defined at a higher frequency [6]. While other researchers proposed hidden Markov's model (HMM) [7], fuzzy-logic-based techniques [4,8], wave shaped recognition technique [1,9], and also artificial neural networks (ANN) [4] based learning pattern approach to get better classification accuracy, low computational burden, and fast response of the relay.

II. MAGNETIZING CURRENT IN TRANSFORMER

The current equation that is used to calculate the peak value of first cycle of inrush current in Amps

$$I\,pk = \frac{\sqrt{2}\mathrm{U}\ \ (2B\mathrm{N} + B\mathrm{R} - B\mathrm{S})}{\sqrt{\omega L^2 + R^2}\ \ \mathrm{BN}}$$

Where:
U = Applied voltage [Volts]
L = Air-core inductance of the transformer [Henry]
R = DC resistance of the transformer windings [Ohms]
B_R = Remnant flux density of the core [Tesla]
B_S = Saturation flux density of the core material [Tesla]
B_N = Normal rated flux density of the core [Tesla]

When the transformer is energized initially there is no induced emf, the condition is similar to switching of an inductive circuit. The resistance being low, large inrush of magnetizing current takes place. The magnitude of current inrush can be several times that of load current. The magnitude of inrush current depends on circuit conditions and voltage at the instant of switching.

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The maximum peak values equal to 8 to 10 times the rated current can occur.

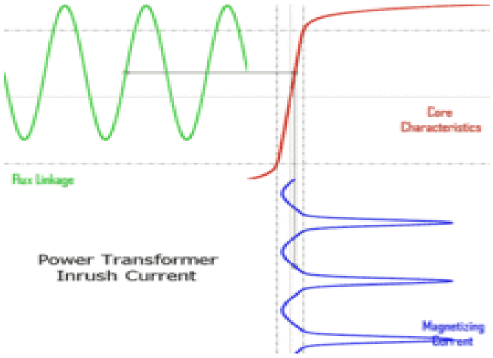


Fig 1. Inrush current waveform

Maximum inrush current can occur if transformer is energized when the voltage wave is passing through zero. At this instant, the current flux should be maximum in highly inductive circuit and in next half wave the flux should change its direction to attain the maximum value. If there is residual flux in transformer, the flux may be in the same or opposite direction. Accordingly the magnetizing current will be less or more, it will saturate the core and increase the magnetizing component further.

Factors influencing the magnitude and duration of magnetizing current inrush are:

1. Size of transformer: as size of transformer increases, the inrush current also increases.
2. Type of magnetic material in the core: if the core is made up of material having good permeability then the inrush current automatically decreases.
3. Residual flux of transformer before switching in: presence of residual flux also increases the magnetizing current.
4. Instant of switching: if the transformer is switched on at the instant when the voltage wave is passing through zero value, then the magnetizing inrush current at that inrush will be maximum.

The inrush current of a transformer can be as high as 5-10 times the rated transformer current. This current appears only on one side of the transformer and is not reflected on the other side of the transformer. This causes an imbalance of the currents appearing at the transformer differential relay. This imbalance will be seen as a differential current and will cause the differential relay to trip. Since an inrush condition is not a fault condition, the operation of a differential relay during an inrush condition must be prevented.

III. TYPES OF FAULTS

Faults can be classified as through faults and internal faults. A through fault is located outside the protection zone of the transformer. The unit protection of the transformer should not operate for through faults. The transformer must be disconnected when such faults occur only when the faults are not cleared by other relays in pre-specified time. Internal faults can be phase-to-phase and phase-to ground faults. These internal faults can be classified into two groups.

Group I: Electrical faults that cause immediate damage but are generally detectable by unbalance of current or voltage. Amongst them are the following:

• Phase-to-earth fault
• Phase-to-phase fault
• Short circuit between turns of high-voltage or low-voltage windings
• Faults to earth on a tertiary winding or short circuit between turns of a tertiary winding

Group II: These include incipient faults, which are initially minor but cause substantial damage if they are not detected and taken care of. These faults cannot be detected by monitoring currents or voltages at the terminals of the transformer. Incipient faults include the following:

• A poor electrical connection between conductors
• A core fault which causes arcing in oil
• Coolant failure, which causes rise of temperature
• Bad load sharing between transformers in parallel, which can cause overheating due to circulating currents

For a group I fault, the transformer should be isolated as quickly as possible after the occurrence of the fault. The group II faults, though not serious in the incipient stage, may cause major faults in the course of time. Incipient faults should be cleared soon after they are detected.

IV. EXPERIMENTAL SETUP

Fig 2. shows the exciting current recorded during a real test of a 1.5 KVA, 230/230 V, single-phase laboratory transformer.

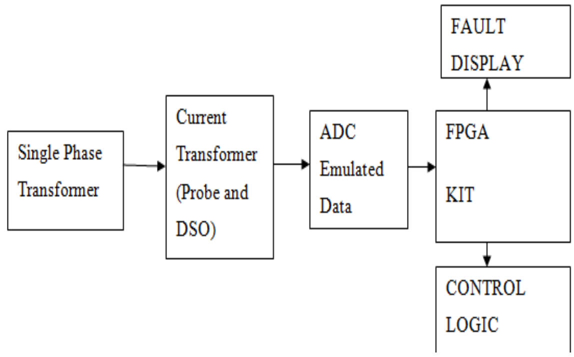
The current corresponds to an overvoltage condition of 150 percent at nominal frequency. For comparison purposes, the peak value of the transformer nominal current is 6.5 A, and the peak value of the exciting current is 65A

Here, the FPFA based algorithm is designed and trained with experimental data in laboratory using single phase transformer.

Transformer type	KVA rating	Primary side voltage	Secondary side voltage	Rated current
Single phase Two winding	1.5 KVA	230v	230v	6.5A

Table 1

BLOCK DIAGRAM



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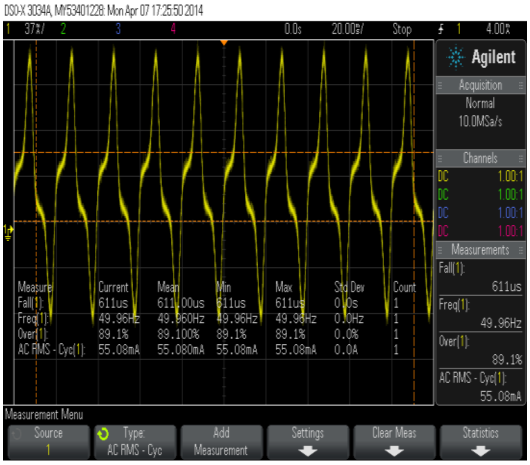

Fig 2 Inrush Current of a single phase transformer

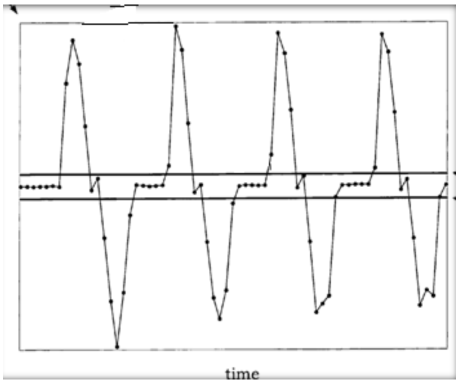

Fig 3 Samples of Inrush Current waveform

Agilent 1146A AC/DC Oscilloscope Current Probe

Fig 4 Test Setup to measure inrush current

Fig 5 Test setup to measure fault current when secondary shorted

The 1146A AC/DC Current Oscilloscope Probe expands oscilloscope applications in industrial, automotive or power environments, and is ideal for analysis and measurement of distorted current waveforms and harmonics.

The probe permits accurate display and measurement of currents from 100 mA to 100A rms, DC to 100 kHz without breaking into the circuit. The probe uses Hall effect technology to measure AC and DC signals. The probe connects directly to an oscilloscope through a 2 meter coaxial cable with an insulated BNC.

V. RESULTS

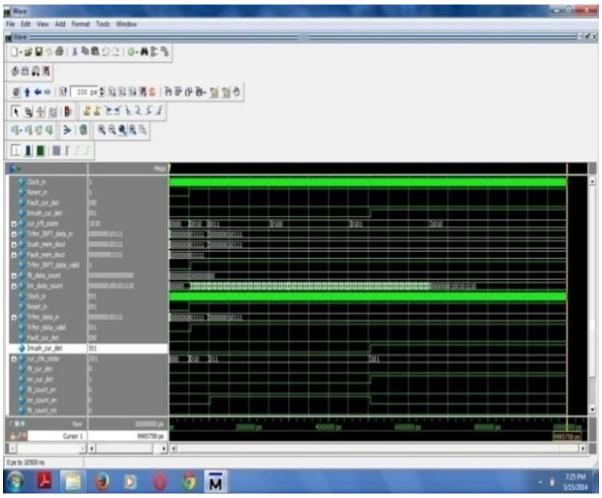

Fig 6 Inrush current detection

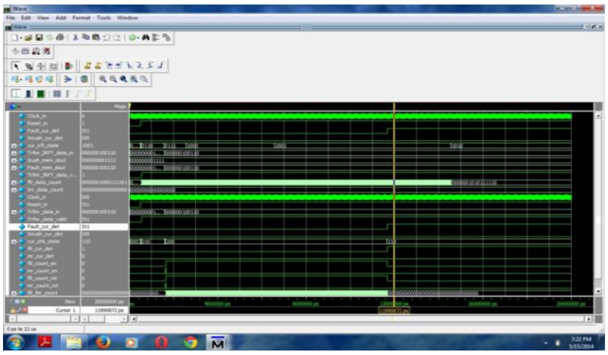

Fig 7 Fault current detection

Waveform Analysis :

The result of discrimination of inrush or fault current is obtained using Altera's ModelSim simulator and the logic with Verilog HDL code. Inrush or fault current display can be obtained using LED display on the FPGA board once the program is downloaded on hardware.

VI.CONCLUSION

In this project we are conducting test on 1.5KVA, 230Vsingle phase transformer for measurement of inrush current and fault current. The waveforms are captured using Agilent current probe 1146A and Agilent make DSO (Digital Storage Oscilloscope) for which the waveform data is emulated for simulation. Logic is written using Verilog code for discrimination of two currents comparing the magnitude peak samples and time and same is implemented using Altera FPGA. In real time system FPGA acts as controller and can be used for relay operation in protection of transformer.

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The present work describes simulation of the captured current waveform of inrush and fault current based on the verilog code and the same is downloaded to the Altera FPGA Kit. Based on the values of current magnitude and time the display of respective currents are shown. The same can be implemented to the real time system having data acquisition with the additional hardware of ADC and a trip circuit for protection. The waveforms can also be obtained using PSCAD/EMTDC software.

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