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TRANSFORMER INRUSH CURRENT DETECTOR

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Abstract: Transformer inrush current detection is one of the major concerns in power system. When an unloaded transformer is energized with the normal voltage supply there exist an inrush current which has a peak value several times greater than the normal rated current. This is practically unobservable and sometimes operate the protective devices considering it as fault current instead of inrush current. The conventional method of inrush current detection recognizes the second harmonic[6] component of differential current. The proposed novel method uses Hall Effect ACS 712 current sensors to measure the current and an algorithm to differentiate the inrush current from normal current using ARDUINO microcontroller is used. A 1.5 KVA single-phase transformer was used in the laboratory to collect the data from the experiments.
Index Terms: Inrush Current, fault current, ACS712, Arduino.

I Introduction:

Transformer is one of the most essential part of the power system. Transformer functions as a node to connect two different voltage levels. Therefore, the continuity of the transformer operation is of vital importance in maintaining the reliability of power system. Any unscheduled maintenance, especially replacement of faulty transformer is very expensive and time consuming. In order to detect faults, high speed, highly sensitive and reliable protective relays are required. [1].

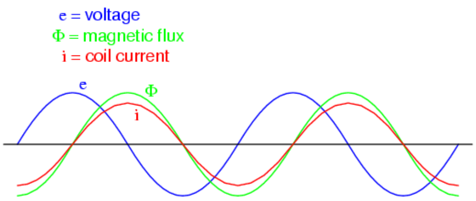
Any transformer protective scheme has to take into account the effect of magnetizing inrush currents. This is because the magnetizing inrush current, which occurs during the energisation of the transformer, sometimes results in ten times full load currents and therefore can cause mal operation of the relays. Accurately discriminating magnetizing inrush currents from internal faults has long been recognized as a very challenging problem to transformer protection engineers.

A differential protection system[7] for power transformers using ACS712 as current sensors can support an inrush current detection. Effective detection of power transformer inrush conditions can enable unwanted switching of a protection relay during inrush. The design involves measurements of the currents from the sensors and programming with Arduino board.

Certain phenomena can cause a substantial differential current to flow, when there is no fault, and these differential currents are generally sufficient to cause a percentage differential relay to trip. However, in these situations, the differential protection should not disconnect the system because it is not a transformer internal fault. Such phenomena can be due to inrush currents.

Inrush Current:

When a transformer is initially energized, there is a substantial amount of current through the primary winding called inrush currents. The rate of change of instantaneous flux in a transformer core is proportional to instantaneous voltage drop across the primary winding. The voltage of the transformer is a derivative of the flux, and the flux is the integral of the voltage. In a normal operation, the voltage and the flux are phase-shifted by 90 as shown in Figure 1.1



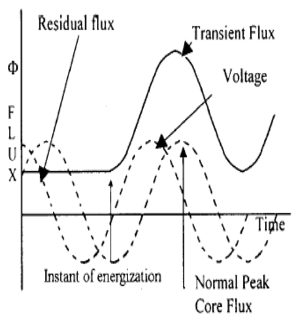


Figure 1.1 Voltage, Magnetic Flux and Current Waveforms Figure 1.2 Transformer energisation with residual flux.

The magnitude of the inrush current strongly depends on the exact time that electrical connection to the source is made. If the transformer happens to have some residual flux in its core at the moment of energisation, the inrush could even be more severe as shown in Figure 1.2

II Magnetizing current in transformer

The current equation that is used to calculate the peak value of first cycle of inrush current[8] in Amps

$$I\,pk = \frac{\sqrt{2}U\ \ (2BN + BR - BS)}{\sqrt{\omega L^2 + R^2}\ \ BN}$$

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]

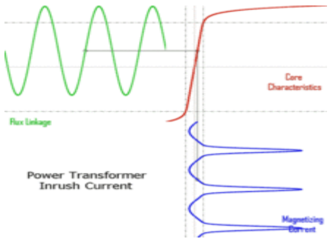


Fig 1.3. Inrush current waveform

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

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.
In the normal condition, rated current flows through the transformer. In this condition normalized differential current[5] is almost zero (only no load component of current). When a transient current occurs, the core of transformer gets saturated. This phenomenon is known as magnetizing inrush, or in other words, inrush can be described by a condition of large differential current occurring when either the transformer is just switched on no-load or the system recovers from an external fault.

Similar condition occurs when transformer is energized in parallel with another transformer that is already in service which is known as "*sympathetic inrush*" condition.

Residual flux

Considering a single-phase transformer and neglecting leakage and other magnetic air fluxes as well as the coil resistance, the magnetic core flux Φcore is related to the coil voltage U*coil* by Equation (1).

$$Ucoil(t) = Ncoil\ \frac{d\,\Phi core\ (t)}{dt} \quad \text{-------(1)}$$

When de-energising the transformer out of no-load steady-state, the current will be interrupted at time topen and the residual flux Φ_{Res} is calculated using Equation (1):

$$\Phi_{Res} = \frac{1}{Ncoil} \int^{t_{open}} Ucoil(t)dt \ -\ \ (2) \quad \text{With}$$

$$Ucoil\ (t) = Uo\ \sin(\omega o\ t)\ \ (3)$$

and assuming steady-state, Equation (2) becomes $\Phi_{Res} = -\Phi o \cos(\omega o \text{ topen})$ ---(4)

Because the magnetising current of transformers is often smaller than the chopping current of the circuit breaker, the current will be interrupted prior to its natural zero crossing and the opening time topen of Equation (4) can take any value. As a consequence of this, the residual flux can reach any higher value leading to magnetizing inrush current.

Methods for inrush current detection.

Neural Network consists of three layers namely input layer, hidden (Processing) layer(s), output layer. Input data fed to network through input layer, after that processing takes place. Output value comes out at output layer which compared with target value to find out error. Back propagation algorithm is used to minimize this error or reducing tolerance range. Neural Network has beauty to give accurate value depends on input value after well training of network.

ANN Modeling

The modeling of inrush current of transformer is accomplished by ANN network [1] as shown in figure 2.1. This ANN Network is trained by providing practical data of time and flux linkage value with different time. These data have been obtained by conducting experiments, since these data have their own ranges. Therefore the data has been normalized at same scale for training the network. Trained network represents modeling of inrush current. After training, output of network gives normalized values which will convert back to their original values to ensure practical behavior of inrush current[4].

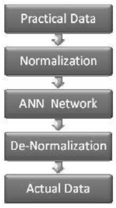


Figure 2.1 Process flow of ANN modeling

Wavelet energy spectrum entropy:

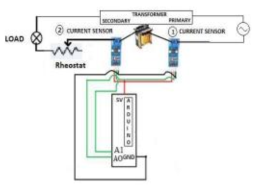
In this method signal is decomposed through wavelet transform, and extracts the high frequency part of energy in each scale of wavelet transform[3] from inrush current signal and the short circuit current signal, and calculates the wavelet energy entropy value, which will be as the input feature vector of modified BP neural network. And this feature vector is used as training characteristic value for training in BP neural network.

Limitations of the system are high magnetizing inrush current in transformer necessitate over-sizing of fuses or breakers. Expensive and complicated as compared to the proposed system.

III Proposed Method

In the proposed system there are two solid-state current sensors i.e. one at the primary side and other at the secondary side of the transformer. The transformer gets 230V as primary voltage from the supply. For this supply, current sensors give the analog current reading to the analog inputs of the Arduino A0 and A1. The current sensors take 5V power supply from the Arduino.The opted sensor has applied current flowing through the copper path and it generates a magnetic field based on Hall IC converts into proportional voltage and it also be used for Output voltage proportional to AC or DC currents.

The sensors take the current reading and it is displayed on a screen connected with the *Arduino*. The sensors were used and the accuracy was tested for providing power supply through USB and found that 0.005A is tolerant.



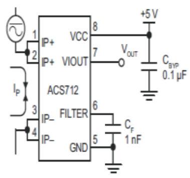


Fig 3.1 connection diagram   Fig 3.2 ACS 712   Fig 3.3 Internal diagram of ACS712

The sensors used are of 20A range as the rated current of transformer is 6.52A. The sensor is connected to the analog inputs A0 & A1 of Arduino board. Both the sensors connected across primary and secondary take 5V supply from the transformer. The ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems.

The test setup of 1.5 KVA transformer with sensors and Arduino is shown below

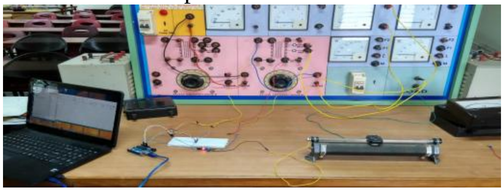


Figure 3.5 Experimental set up

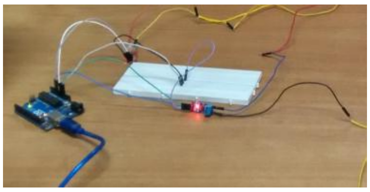
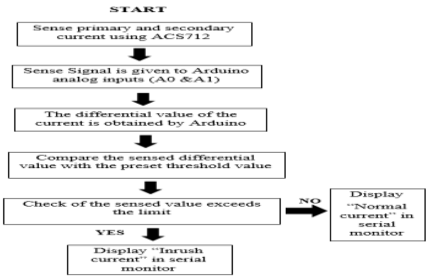


Figure 3.6 Sensors with Arduino.



Process Flow Chart

During the operation of the transformer if the first ten values of the measured current exceeds the threshold values more than 5 times then it is taken as "Inrush Current", otherwise it shows as "Normal Current". The values of currents differ with different operating conditions and switching times.

IV Results:

The normal operation is carried out and the obtained difference value of current of two sensors are plotted. The graph obtained is shown below and the first ten values are taken as threshold.

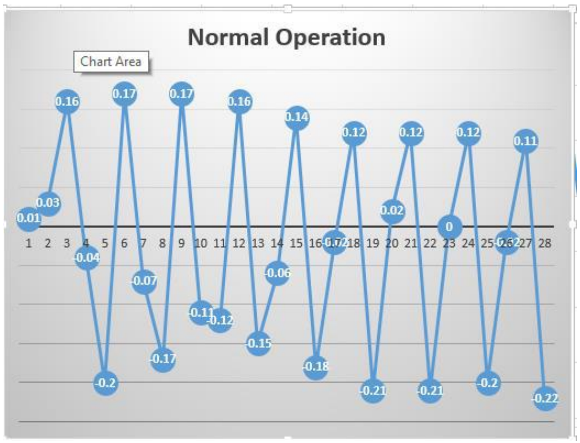


Figure 4.1 Waveform of Normal current

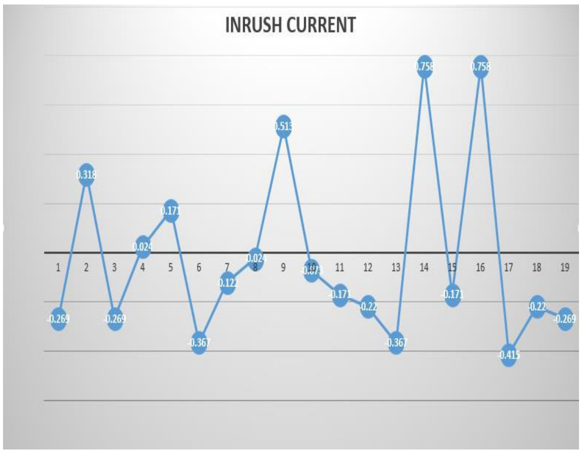
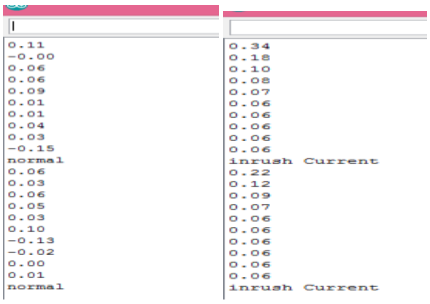


Figure 4.2 Waveform of Inrush Current



V. Conclusions

Proposed method is inexpensive as the sensors and Arduino are cheaper. The problem of saturation of CT(current Transformers) in measurement is eliminated. Analysis of data can be done easily with existing system monitor. Hall Effect based ACS712 current sensors, and Arduino do not consume much power, while in operation. This is one of the major advantages of the model developed. The Arduino based program is more accurate and detection of the inrush current is easy without much theoretical complications and practical challenges.

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