

Turn-to-Turn Fault Detection Scheme for Transformers using Digital Relay

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Abstract— Digital microprocessor based protective relays that makes use of negative sequence current magnitude as well as phase difference between the primary and secondary side of the transformer are used for protection purpose. By making use of the information obtained from this data it becomes possible to detect turn-to-turn fault in transformers. However, this method involves the use of current based data for fault detection which becomes insensitive when no current flows through any one of the windings of the transformer. Such situation occurs during transformer energization during which current flows only in primary winding and no current-flow is observed in the secondary winding. Thus, the current based algorithm has some limitations and hence this paper presents development of voltage based algorithm so as to cope up with conditions of no-current flow. In voltage based algorithm, magnitude and phase angle information of voltages on both the sides of the transformer is used to detect the turn-to-turn fault during the condition of no-current flow and it is used in conjunction with the negative sequence current based algorithm which improves the reliability of the relay operating system.

Key words: Negative Sequence Current, Negative Sequence Voltage, Digital Relays

I. INTRODUCTION

SYMMETRICAL components are used to analyze faults in three phase systems. Positive phase sequence system can be defined as the system in which the phase or line currents or voltages attain a maximum cyclic value in the same order that is been observed in normal supply. In other words, a balance system corresponding to normal conditions contains only positive phase sequence. Negative phase sequence is defined as the system in which the values of currents or voltages reaches maximum in reverse order. Such condition is observed only during abnormal or faulty conditions. Hence, negative phase sequence components are used for fault analysis in power systems.

Whenever a fault occurs in transformer it creates unbalanced conditions which gives rise to negative sequence components. A negative phase sequence relay is provided for transformers to protect it against faulty conditions that arises due to turn-to-turn faults. Such type of digital relays are programmed to respond only to negative sequence components.

Microprocessor based digital relays are widely used which provides fast, accurate and reliable operation. They can be easily programmed to achieve desired results to operate and ensure protection of the system during faulty conditions. Also, compactness of digital relays and ability to perform several other functions such as measurement and monitoring makes them more popular. Digital relays are also very sensitive in fault detection and further operation.

In fault analysis of a system, generally currents are measured in symmetrical components. However, sometimes it is necessary to measure voltages as well because all the faults occurring in the system are not current-based faults. Some of them are voltage-based and hence it becomes necessary to measure and know the voltage magnitude along with the phase difference to measure turn-to-turn fault in transformers. Hence, it becomes necessary to program the digital relays to measure voltages along with the currents to detect and diagnose the faulty conditions occurring in the system.

Prior to digital relays, electro-mechanical relays were used for fault detection in power systems. Thereafter, static relays came into use. Such types of relays are bulky in size and also their operating time is greater that is they operate slowly as compared to digital relays. Hence, digital relays are a solution to replace the conventional electro-magnetic relays as they provide better operation thus increasing safety conditions of the power system components such as transformers, motors, generators, busbars and the substation and transmission and distribution lines.

In this paper digital relays are programmed to compute the negative-sequence current on both primary and secondary sides of the transformer along with the phase difference between these two negative-sequence currents. By using data obtained from phase and magnitude measurement, negative-sequence current can be used to detect minor turn-to-turn faults in the transformer. Turn-to-turn faults are also observed even if no current is flowing on one side of the transformer, for example during energization. When no current flows through the secondary windings of the transformer, negative-sequence digital relay based on currents measurements algorithms fails to operate. Hence, it becomes necessary to design a relay prototype, that can measure both negative-sequence current as well as negative-sequence voltage, which retains the sensitivity of relay during conditions of energization.

During energization, the transformer's secondary breaker is open. Inrush current flows on the primary side of the transformer while no current flows on the secondary side of the transformer. Therefore, the phase information of the negative-sequence current on the secondary side of the transformer is not useful during energization.

II. NEGATIVE SEQUENCE BASED SCHEME

A negative-sequence current-based algorithm (NSCA) for sensing turn-to-turn faults is proposed in [3]. First, the negative-sequence current is calculated for both the primary side and secondary side of the transformer. Two negative-sequence current phasors are obtained from the above analysis. Let and denote the negative-sequence current

phasors calculated for the primary and secondary side of the transformer. The next step of this algorithm is to check the magnitudes of and to ensure that they are both above a minimum threshold as shown in (1) and (2). This is important not only to prevent false tripping due to minor imbalances but also to ensure that the phase angle of the negative-sequence currents are reliable.

$$|I_{2P}| > 1\% \text{ Primary Base Current} \quad (1)$$

$$|I_{2S}| > 1\% \text{ Secondary Base Current} \quad (2)$$

Phases of and are compared if the magnitudes satisfy the above equations. If (3) is also satisfied, a trip is warranted. The current transformers (CT) are arranged such that negative-sequence current caused by external faults result in phase differences of 180° . Ideally, an internal fault would result in a 0° phase difference. CT saturation is the main cause of excursions from the ideal phase difference [3], making it necessary to allow for a range of angles from 0° to 60° . This may be visualized by setting the relay operating angle (ROA) equal to 60° in Fig. 1

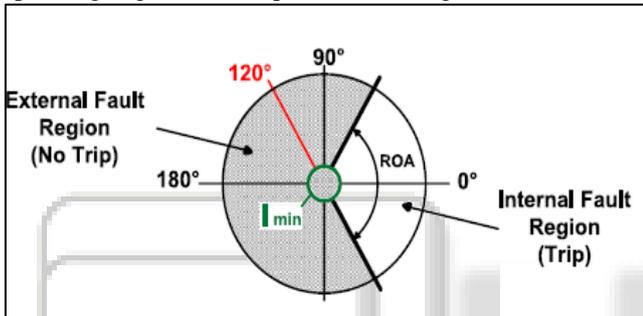


Fig. 1: Negative Sequence Current Fault Detection

III. METHODS TO DETECT TURN-TO-TURN FAULT IN TRANSFORMER

A. Algorithm for Negative-Sequence Current

The above negative sequence current algorithm is used by the negative sequence digital relay for detection of faulty conditions. Whenever, the values of currents in the primary and secondary windings are found to be greater than the normal values, it senses the fault and gives trip command to the circuit breaker to open thus maintaining safety conditions. The above negative sequence current algorithm is used by the negative sequence digital relay for detection of faulty conditions. Whenever, the values of currents in the primary and secondary windings are found to be greater than the normal values, it senses the fault and gives trip command to the circuit breaker to open thus maintaining safety conditions by disconnecting the faulty section from the normal region of operation.

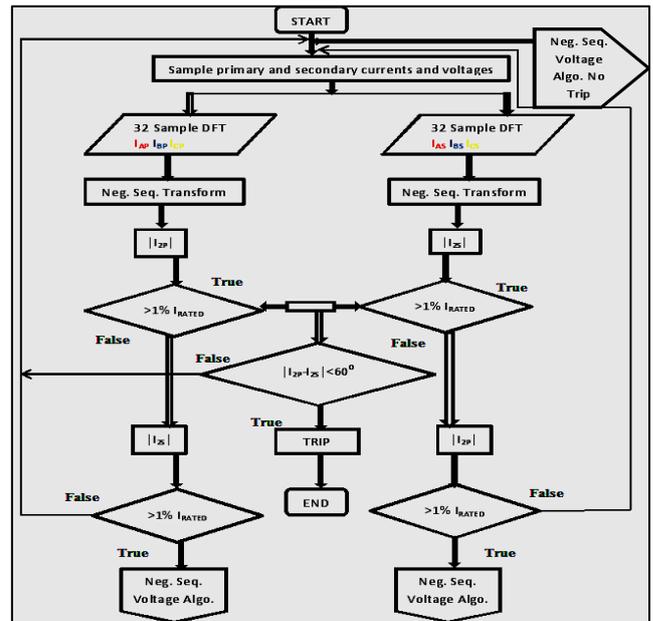


Fig. 2: Negative Sequence Current Algorithm

B. Algorithm for Negative-Sequence Voltage

However, it is found that the negative sequence current algorithm becomes insensitive in case of conditions of transformer energization because no current is present in the secondary winding of the transformer. At such a case if the circuit breaker does not receive trip command, then it remain in the closed position and the fault may penetrate even in the healthy region thereby damaging the entire system.

Therefore, to overcome this problem an attempt is made to design a negative sequence voltage algorithm which retains the sensitivity of the relay during energization to detect turn-to-turn fault in the transformer

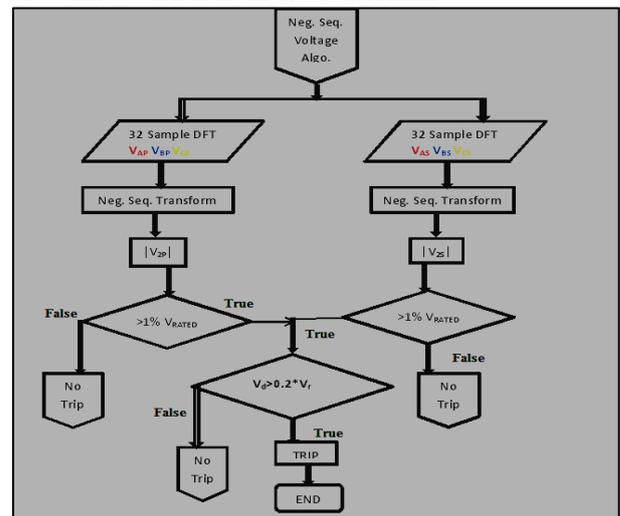


Fig. 3: Negative Sequence Voltage Algorithm

IV. BLOCK DIAGRAM OF PROPOSED SYSTEM

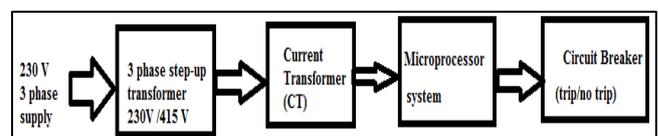


Fig. 4: Block Diagram of Proposed system

Figure 4 shows the block diagram of the hardware system in which three phase 230V supply is used for the system. The system consists of three phase 1KVA 230V/415V step-up transformer. The transformer is energized by the three phase power supply and a fault is created by short circuiting the turns i.e. inter-turn fault is generated. The current transformer will act as a measurement tool for measuring the magnitude of current which in turn will give signal to the microprocessor. The microprocessor will act as a relay system fed with the algorithm used in this project work. Hence, the microprocessor will give the command to the circuit breaker to generate 'trip' signal thereby ensuring the safety of the system. This is the entire design and development of relay prototype for turn-to-turn fault protection of transformer.

V. DESIGN AND DEVELOPMENT OF RELAY SYSTEM

A. List of Components

Sr. No.	Particulars	Quantity
1	Transformer 1KVA	1
2	Current Transformer	1
3	Arduino Processor	1
4	Display	1
5	Circuit Breaker	1
6	Three phase supply	1

B. Hardware Design using three phase transformer

Step up transformer requirement-

- Number of Phases- 3 Phase
- VA rating- 1 KVA
- Primary Voltage- 230V
- Primary Current- 4.5A
- Secondary Voltage- 415V
- Secondary Current- 2.5A
- Terminals to short circuit the number of turns as given

Turn-to-Turn short

Low Voltage side of

- 1) 2% turns of total number of turns
- 2) 3% turns of total number of turns
- 3) 5% turns of total number of turns
- 4) 10% turns of total number of turns
- 5) 20% turns of total number of turns

High Voltage side of

- 1) 2% turns of total number of turns
- 2) 3% turns of total number of turns
- 3) 5% turns of total number of turns
- 4) 10% turns of total number of turns
- 5) 20% turns of total number of turns

VI. RESULTS AND DISCUSSION

In this paper, a Simulink model is presented for detection of turn-to-turn fault using the above mentioned both the algorithms. In this model, two transformers- one healthy and another faulty of rating 1KVA, 230V/415V is taken along with the three phase voltage source in series with RL branch and the series RLC load.

An unhealthy or faulty transformer of the same rating is taken for simulation. Both the algorithms viz. negative sequence current and negative sequence voltage

algorithm are applied involving the calculation of negative sequence currents and voltages followed by the procedure described in the above mentioned algorithm.

A discrete Fourier transform is calculated for primary and secondary winding along with the magnitude and phase angle. Same procedure is repeated for negative sequence current algorithm and after that the condition is verified that whether the signal received is of turn-to-turn fault so as to give trip command to the circuit breaker in order to ensure the protection of the system.

Three phase circuit breakers are used in the simulation. Discrete three phase sequence analyzers are used to calculate discrete Fourier transform of the obtained values of currents and voltages on primary as well as secondary side.

A turn-to-turn fault is created on the primary side of the power transformer model in the simulation and working of both the algorithms is observed. Various waveforms are observed regarding inrush current, change in magnitude of three phase voltages and currents on both the sides of the transformer before and after the occurrence of turn-to-turn fault which is discussed in this section.

This technique allows the smooth functioning of the relay thus improving the performance and helps in getting better protection scheme of the system.

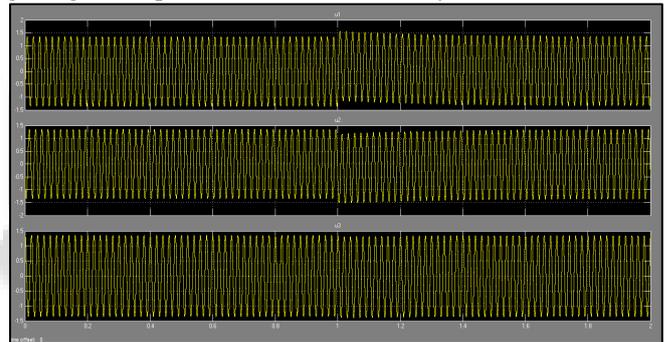


Fig. 4: Inrush Current in three phases on the primary side of transformer

Figure 4 shows inrush current in all the three phases of the primary side of the transformer. X axes denotes time (in sec) and Y axes denotes current magnitude (in amps). It is observed that till 1 sec there is no fault but at the instant of 1 sec fault begins then the magnitude of inrush current rises as shown in figure 4

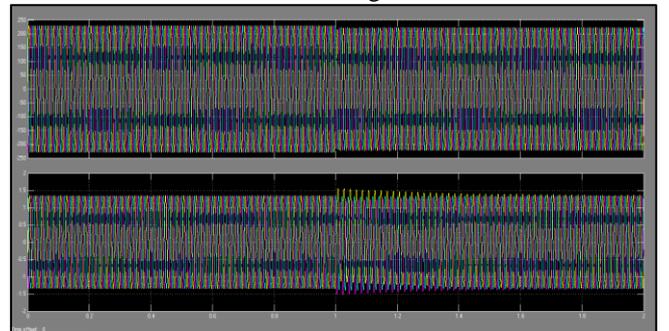


Fig. 5: Voltage and Current on primary side of Transformer

Figure 5 shows voltage and current on primary side of transformer. The upper part denotes voltage while the lower graph denotes current. Voltage and current magnitudes of all three phases is shown in the figure 5.

X axes denotes time (in sec) and Y axes denotes voltage (in volts) and current (in amps) magnitude respectively. It is been observed that till 1 sec there is no fault but at the instant of 1 sec fault begins then the magnitude of inrush current rises as shown in figure 5. As the number of turns decreases, current level increases in case of turn-to-turn fault. Also a change in magnitude of voltage is observed before and after the occurrence of turn-to-turn fault.

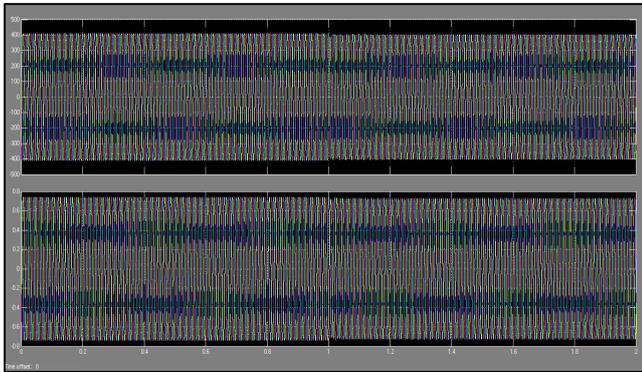


Fig. 6: Voltage and Current on secondary side of Transformer

Figure 6 shows voltage and current on secondary side of transformer after the occurrence of the fault. The upper part denotes voltage while the lower graph denotes current. Voltage and current magnitudes of all three phases is been shown in the figure 6. X axes denotes time (in sec) and Y axes denotes voltage (in volts) and current (in amps) magnitude respectively.

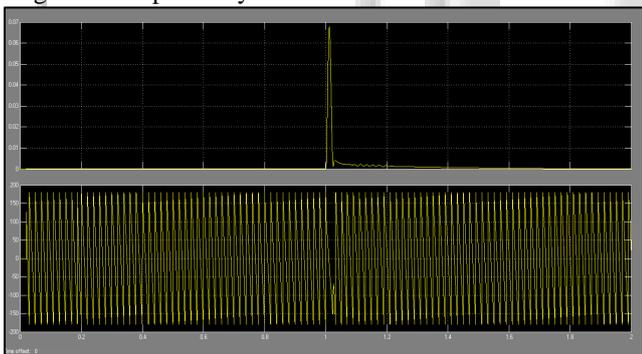


Fig. 7: Magnitude and phase angle of negative sequence current

Figure 7 shows magnitude and phase angle of negative sequence current. The upper part denotes magnitude of voltage while the lower graph denotes phase angle. X axes denotes time (in sec) and Y axes denotes magnitude of current (in amps) and phase angle (in degree) magnitude respectively. The change in magnitude of the current before, during and after the occurrence of the fault is to be noted. It becomes unstable or rises suddenly at the time of occurrence of the fault viz. at the instant of 1 sec and later becomes stable as shown in figure 7.

VII. CONCLUSION

In this paper, the negative-sequence-based algorithm was consistently shown to be more sensitive and faster than the current differential algorithm. This observation is supported by the experimental data. Turn-to-turn faults involving 3% of the transformer's windings were detected consistently by

the proposed algorithm. The current differential algorithm with second harmonic restraint was able to detect turn-to-turn faults involving 10% of the transformer's windings under ideal conditions. The sensitivity of the differential current scheme was found to vary with CT saturation, fault resistance, and transformer overexcitation.

A negative sequence voltage algorithm is been designed in conjunction with the negative sequence current algorithm which had enabled to overcome the insensitive nature of current algorithm observed during condition of energization during which no current is observed in the secondary winding of the transformer. This development of negative sequence voltage algorithm has increased the reliability of the protection system.

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