IMPLEMENTATION OF DIFFERENTIAL PROTECTION OF THREE PHASE TRANSFORMER USING MATLAB SIMULINK

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ABSTRACT: Power Transformers are vital components for electrical energy transfer in a power system. In power system protection high sensitivity and fast operation of transformer protection is required while maintaining security from mal tripping. In this paper a simulation model for differential protection of three phase transformer is presented for determining its behavior during various operating conditions. Many mal-operation cases of transformer differential protection are caused by inrush and over fluxing problems. The proposed simulation model is tested on 2.5 MVA, 11 kV/400 V, delta-wye three phase transformer. The result shows that simulink model presented for differential protection of three phase transformer work properly and this will allow rapid modeling and testing of new algorithms in view to improve protection of transformer.

KEYWORDS: Transformer differential protection, trip signal, fault current, magnetising inrush current, internal faults, overfluxing condition, MATLAB SIMULINK.

INTRODUCTION

The power transformer is one of the most essential components in the electrical power network and its protection is also equally important [1].The almost universal protection scheme for within the transformer uses differential relay. The aim of this paper is to simulate differential relay for fault conditions (both internal and external faults), abnormal conditions like magnetizing inrush and over fluxing etc. and to analyze relay performance for all above said conditions. Such study is important to explore new protection algorithms. In this paper the physical model of a two winding 2.5 MVA, 11 kV/400 V, delta-wye three phase transformer is simulated on MATLAB simulink environment. An example presented in this paper demonstrates the capabilities and underline the advantages of MATLAB simulink environment to study differential current patterns for various operating conditions which can be subsequently used for designing suitable digital relay.

CASE STUDY

Figure 1.Illustrates the studied electrical power system.

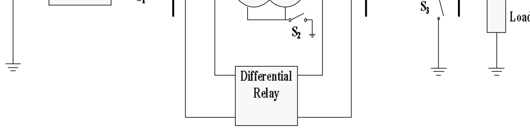


Figure 1. Power System Model

The power system shown in fig1.has been simulated in MATLAB using simpower toolbox of SIMULINK. It consists of,

1. Three phase supply from Grid: The Voltage and frequency of the bus is set equal to 11kV (line to line) and 50 Hz respectively.
2. Two winding Transformer: 2.5 MVA, 3 phase, 11/0.4kV, delta-wye grounded two winding transformer. The block parameters of transformer are selected such that per unit regulation is 0.0675.Appendix 1 gives the parameters of Two winding Transformer.
3. Current Transformer (CT): Many of the earlier researchers have used only gain block to simulate current transformer [2], [3], [4]. In this paper saturating transformer of simulink is used to simulate current transformer. The delta–wye connection of two winding transformer introduces certain phase shift between the currents on H.V. and L.V. side .To nullify phase shift, current transformers on the delta side is connected in wye and current transformers on wye side is connected in delta. The ratios of current transformers on two sides are selected so that during normal condition (load condition) operating current is near to zero.
4. Transmission line: The L.V side of transformer is connected to load through π model of transmission line.
5. Variable Load: Full load at a power factor 0.8 lag is selected.
6. SwitchS_1: It is used to simulate the energisation operation of transformer. In this case transformer is connected without load. It consists of a three phase breaker where all three phases are closed simultaneously.
7. Switch S_2: It is used to simulate various internal faults at the terminal in Two winding transformer.
8. Switch S_3: It is used to simulate various external faults in Two winding transformer. Switch S_2 and S_3 consists of a three phase fault block where various faults (short circuit) between phase and ground, between phase and phase can be simulated along with varying fault resistance and ground resistance
9. Differential relay: Percentage bias differential relay has been simulated with harmonic restrain and through fault stability.

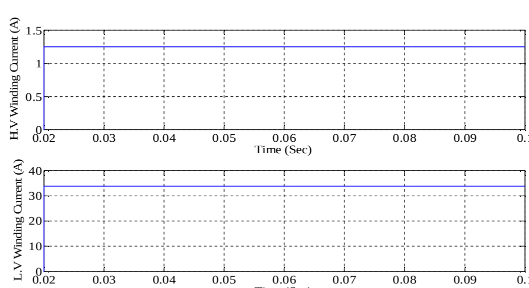
Validation of Simulink Model

For load of P=20kW and Q= 15kVAR (inductive),

$$I_{HV} = \frac{25000}{\sqrt{3}*11000} = 1.312\ A \quad (1)$$

$$I_{LV} = \frac{25000}{\sqrt{3}*400} = 36.08\ A \quad (2)$$

Figure 2. Shows the currents on HV and LV windings. (RMS values)



Figue 2. R.M.S. Values of H.V. and L.V. winding currents

The waveforms obtained by the simulink model are in line with actual calculations.

Performance of Current Transformer

Figure 3.Shows the instantaneous currents on primary winding sides of current transformers on HV and LV sides. The two currents are nearly same in magnitude and phase shift so that operating current during normal condition is very small.

Through fault stability

To provide through fault stability, percentage bias differential relay is used where the relay automatically adopts its pick up value Figure 5.shows biased differential relay characteristics.

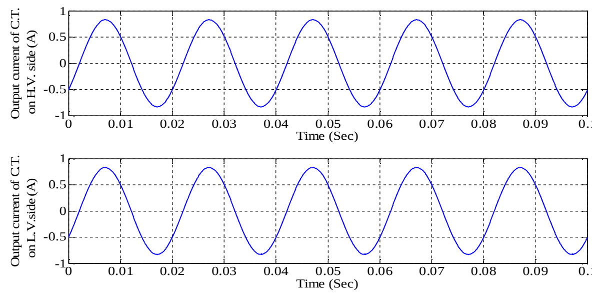


Figure 3. Instantaneous Values of currents on primary winding sides of CTs on H.V. and L.V. windings

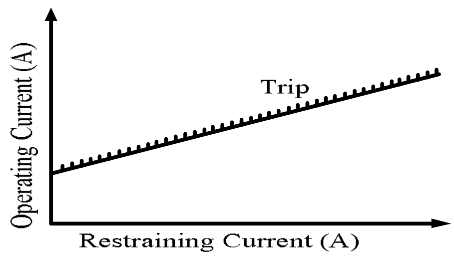


Figure 5. Biased differential relay characteristics

The relay operates if

$$\text{Operating Current} > I_{MIN} + \text{bias}\left(\frac{I_{d1}+I_{d2}}{2}\right) \qquad (3)$$

In this case minimum pick up is set equal to 0.025 Amp and bias is set equal to 30%. The differential relay issues trip signal if operating current exceeds the restraining current at least in any one phase keeping harmonic restrain into considerations.

Harmonic Restrain

The popular designs of high speed percentage bias differential relays are of the harmonic restrain type. The harmonic restrain feature, which in fact has a biasing effect is beneficial in ensuring stability during transformer charging conditions or during over fluxing conditions. During energisation condition the current drawn into the transformer, apart from being quite large has no counterpart on the secondary winding side. Consequently there is a spill current in the differential circuit which can cause the differential relay to operate, since there is no through current bias available to mitigate the effects under these working conditions. But these currents have a predominantly high second and fifth harmonic content in case of magnetizing inrush and over fluxing conditions respectively. This fact is therefore used in contemporary relay designs to provide stability to relays. Thus in these conditions restrain comes into picture and relay does not operate

FLOWCHART OF IMPLEMENTED DIFFERENTIAL RELAY SCHEME

Figure 6. Illustrates the flowchart of implemented differential relay scheme for two winding transformer. In this algorithm the output currents of CTs undergo over two analyses, amplitude comparison of operating and restraining current and harmonic analysis and its comparison with set limits. For amplitude comparison if the operating current is more than restraining current then logic 1 takes place which indicates a detection of an inrush or over fluxing or an internal fault. Otherwise logic 0 takes place which indicates healthy condition for transformer and relay issues no trip signal.

For harmonic restrain if the second or fifth harmonic components of differential current is above the set limit then logic1 takes place which indicates inrush condition in case of second harmonic restrain and over fluxing condition in case of fifth harmonic restrain and relay issues no trip signal.Otherwise logic 0 takes place which indicates an internal fault and relay issues trip signal.

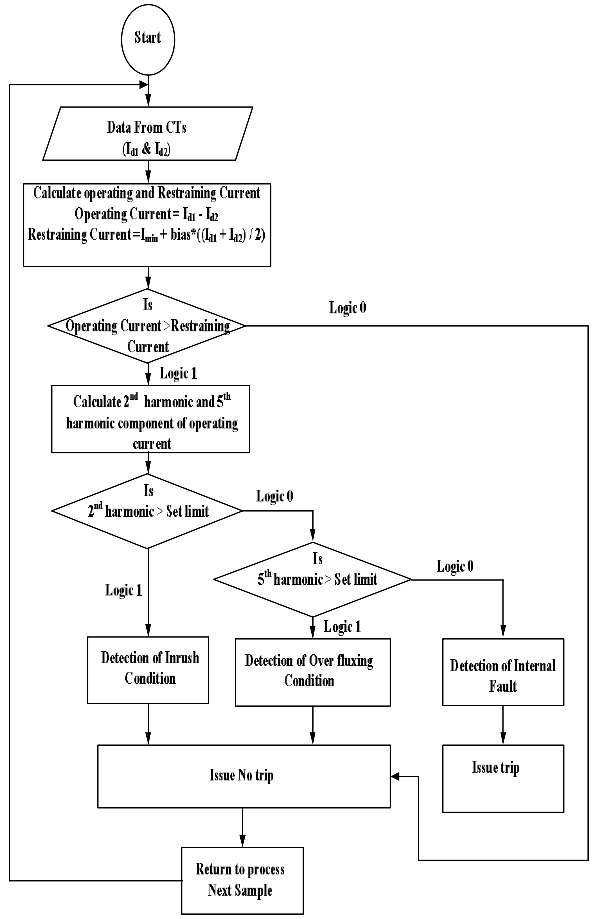


Figure 6. Flowchart of Implemented Differential Relay Scheme

RESULTS AND DISCUSSION

The following cases are presented in this paper,

1. Normal condition
2. Internal faults
3. External faults
4. Magnetizing inrush condition
5. Clearance of an External fault
6. Over fluxing condition

Normal Condition

When the transformer is operating normally, the differential currents in all the phases are well below peak up value and relay does not issue any trip signal. Figure 7.Shows operating and restraining currents in any one phase (phase A) and relay output.

Since the operating currents in all three phases are well below the restraining currents the relay does not issue any trip signal. It is the correct operation of relay. In Figure time axis starts from 0.02 sec. because RMS block used in simulation require one cycle for calculation and then it gives rms value of instantaneous current over a running window of one cycle.

Internal Faults

Various internal faults like line-to-ground, line-to-line, double line to ground, Triple line, Triple lineto ground are simulated. Figure 8. shows operating and restraining currents in any one phase (phase A) and relay output when phase A is shorted to ground.

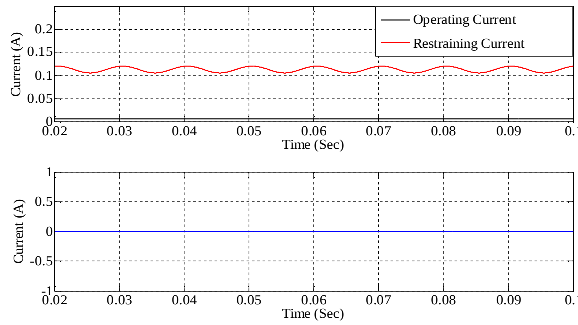


Figure 7. Operating and restraining currents in phase A and Relay logic for load condition

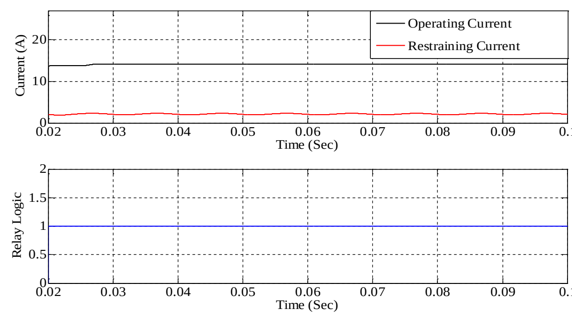


Figure 8. Operating and restraining currents in phase A and Relay logic for internal fault condition

Since the operating current is well above the restraining current and the amount of harmonic components in operating current is below the set limit, the relay does not issue any trip signal. It is the correct operation of relay. Similarly the cases of other internal faults are simulated and the performance of differential relay is ensured in all the cases.

External Faults

Various external faults like line-to-ground, line-to-line, double line to ground, Triple line, Triple line to groundare simulated. Figure 9. shows operating and restraining currents in any one phase (phase A) and relay output when phase A and phase B is shorted.

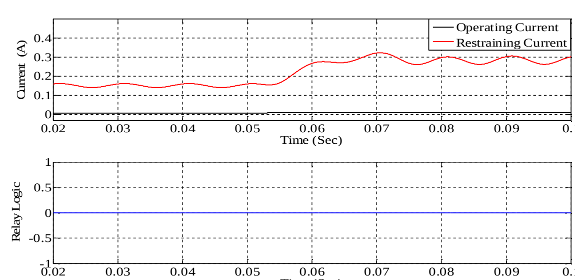


Figure 9. Operating and restraining currents in phase A and Relay logic for external fault condition

The operating currents in all the phases are well below restraining values and relay does not issue any trip signal. It is the correct operation of relay. Similarly the cases of other external faults are simulated and the performance of differential relay is ensured in all the cases.Thus the differential relay provides through fault stability for all external faults by properly adjusting the bias of percentage differential relay.

Magnetizing Inrush Current

Magnetizing currents appear during transformer energization due to its core magnetization and saturation. This inrush current which appears as an internal fault to the differentially connected relays may read instantaneous peaks of 8 to 30 times those for full load. Inrush current is highly asymmetric. It results from saturation of core of transformer caused by excessive growth of magnetic flux in one direction only. Figure 10.shows the waveform of a magnetizing inrush current for phase A with transformer energized at instant zero on the input voltage wave.

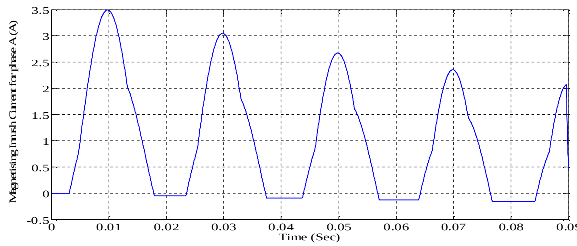


Figure 10. Waveform of Magnetizing Inrush current in phase A

Figure 11.shows operating and restraining currents in any one phase (phase A) and relay output

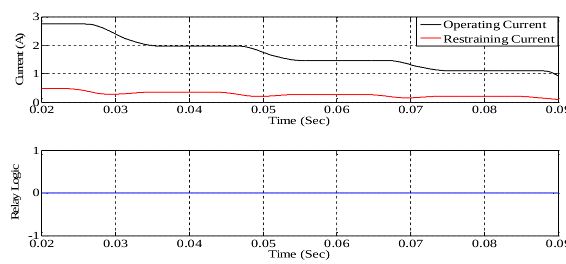


Figure 11. Operating and restraining currents in phase A and Relay logic for energization condition

The operating current exceeds the restraining current but still the relay does not issue any trip signal be-cause these currents have a predominantly high second harmonic content and this fact is therefore used in contemporary relay designs to provide stability to relays. Thus a restrain based on second harmonic content of the inrush current comes into picture and relay does not operate. It is the correct operation of realy. However ,some power transformers, especially new designs with core material improved for lower losses but also older units under some conditions, produce low levels of second harmonic(less than traditional 15 to 20 percent) in their magnetizing currents during energisation.[6]The low second harmonic is caused by deep saturation or Ultra saturation of the transformer core.Moreover,somemaloperations of transformer differential protection during external fault clearance are reported by the East China and North china grid companies.[7]

Figure 12. below shows the FFT analysis of inrush current for phase A when transformer is energized at instant zero on the input voltage wave with saturation characteristics modified to account for low core losses wherein it is clear that the second harmonic contents of inrush currents are below the set value of 12 %.

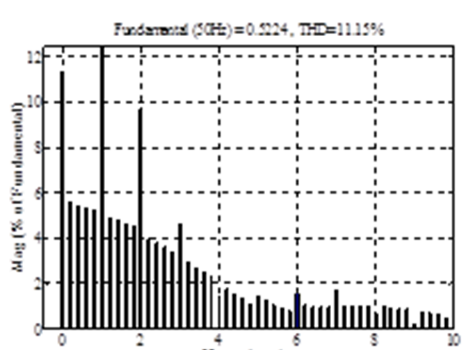


Figure 12. FFT Analysis of inrush current

Figure 13. Shows operating and restraining currents in any one phase (phase A) and relay output

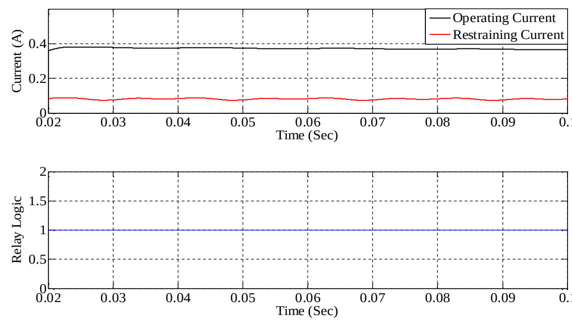


Figure 13. Operating and restraining currents in phase A and Relay logic for energization condition for low second harmonic contents

The operating current exceeds the restraining current and since the second harmonic components in operating current is below the set limit the relay issues trip signal. It is the mal operation of relay.Magnetising inrush current is not a fault, but an abnormal condition which arise only at the energisation and decays gradually.

Therefore, researchers are using technique like wave shape recognition, Digital Signal Processing based techniques for accurate and rapid discrimination between abnormal and fault conditions [9], [14].For the past few years, inrush current became an interesting topic and many researchers have focused their studies in this matter.

It is possible to analyze the various factors which affect the first peak of the inrush current like saturation characteristics of the core, instant on input voltage wave where transformer is energized, residual magnetic flux etc. in the simulation presented in this paper.

Over fluxing condition

A transformer operating under normal design conditions develops a maximum flux density in the core which is proportional to the applied voltage and inversely proportional to the frequency. If either or both of these quantities are varied from the design values, the flux density will suffer a proportionate variation either below or above the design value. Modern core material has relatively sharp saturation characteristics and partly on account of its low inherent losses and partly from economy consideration, the working flux densities could be too close to the saturation value for comfort. Thus with slight excursions in voltage(upward) or frequency(downward) the core is driven into saturation resulting in a higher excitation current which could be sufficient to cause realymaloperation.The ratio V/f is an index of over fluxing. This increased excitation current however is not quite sinusoidal but is made up of higher harmonics especially fifth harmonics. Figure 14.shows operating and restraining currents in any one phase (phase A) and relay output when supplyvoltage is increased by 25% and frequency is reduced by 5 %.

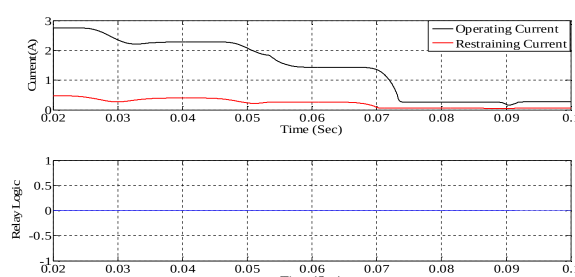


Figure 14. Operating and restraining currents in phase A and Relay logic

The operating current exceeds the restraining current but still the relay does not issue any trip signal because of fifth harmonic restrain criterion.

CONCLUSION

In this paper an attempt has been made through the use of MATLAB SIMULINK to carry out comprehensive study for the analysis of differential protection of three phase treansformer.The simulation model is tested for various operating conditions and it gave satisfactory results in all conditions. Moreover, as future scope this work may be extended to develop the novel techniques for avoiding mal operation of differential relay reported in this paper using the data of operating currentsfor three phases.

APPENDIX I

Transformer parameters

Three phase, 25 KVA, 11 KV / 400 V, Delta-star
Primary winding: R = 0.01509 p.u., x = 0.0203 p.u.
Secondary winding: R = 9.7605726 x 10-3 p.u., x= 0.0203 p.u.

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