Modelling of Power Transformer for Differential Protection Using ATP-EMTP

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Article History Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 20 April 2021

Abstract: The calculation of electromagnetic transients of a three phase transformer model under differential protection scheme is presented in this paper. Due to certain disadvantages such as expensiveness and prolonged calculation with time consuming it is difficult to perform analysis of a power transformer in real time. The simulation method of transformer modelling is more attractive and less expensive as different conditions can be simulated such as over excitation and internal / external fault conditions. For modelling the transformer energization, faults and excitation conditions the software tool used in this paper is ATP-EMTP. Using the above model, any internal faults inside the transformer and disturbances which leads to mal-operation of the system can be simulated. The model is obtained utilizing the existing elements in ATP-EMTP. This facilitates easy inclusion of the model in more complex power system studies, and allowing the investigation of transformer relations with elements from neighboring systems.

Keywords: Transformer, EMTP, fault, over-excitation.

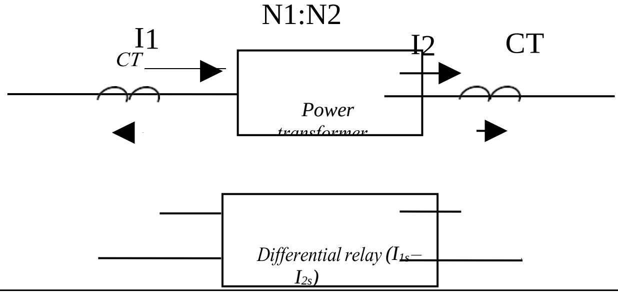
1. Introduction

One of the significant and costlier apparatus in electric power systems is the large power transformers. When a fault is experienced by a power transformer, it is essential to bring the transformer out of service. This should be done immediately to reduce the damage of the apparatus as the repairing cost of the same may become very high. Also, the sudden outage of the transformer affects the cost of the electric utilities which is unimaginable. Hence, such a case in power transformers is undesirable which leads to the discontinuity in power delivery. The frequency and duration of such unwanted outages is to be minimized as it's of great importance. The relaying task could not be made easy by the operating conditions of the transformer. The challenging area to be taken care of in the power system protection of transformer is relaying.The significance of protective devices in power system is identification of faults. To make certain that the safety and reliability of the system is better, a suitable protection scheme is to be selected. In general, the power transformers are protected by any one of the following relays such as over current relays, pressure relays and differential relays based on the purpose. The differential current which is the current due to the difference in the primary and secondary current is identified using the current transformers. This differential current is required for differential protection of power transformer which is for detecting internal faults in transformer windings. If there is any external short circuit conditions or during normal operation, the differential relay should not function as the differential current is very small. Sometimes, the magnetizing inrush current is identified as fault by the differential protection which has to be avoided. The discrimination of such magnetizing current, external faults with that of the internal faults has to be done properly to avoid the false operation of the differential relay. This paper presents how the simulation of over excitation, energization, Internal and External faults are created and cleared.

2. Importance Of Power Transformer Protection

A proper protective scheme is required for the power transformers. If proper protective action is not being taken against the system disturbances, the fault will spread both in terms of time and areas that leads to expensive blackout or serious damage to the equipment. The main consequence of the fault is fire, which is the most serious one. The next series consequence of the fault is short circuit which leads to break down of power supply, damage to equipment due to mechanical force, electric arc and overheating and disturbance of stability. To overcome these disturbances, effective protection system is needed which ensure the reliability, selectivity, sensitivity and fault discrimination.The differential protection:

Due to the importance of electrical power system concerning abnormal situations, several protection methods for every type of system apparatus was developed. Differential protection is one of the protection methods used by the power transformers.

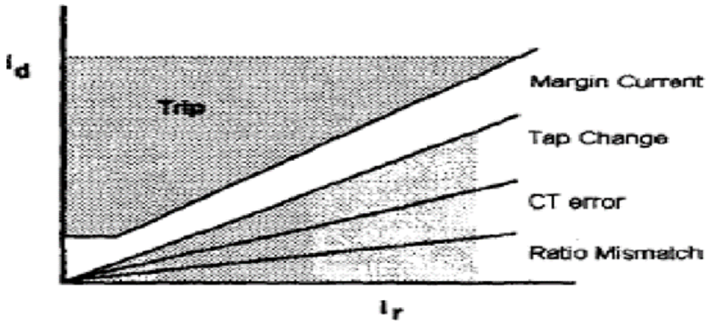


Current transformers (CTs) are used for current data acquisition and they are coupled at the primary and secondary sides of the power transformer. The current obtained from the CT will follow the transformation ratio and thus both the current from CT and transformer will be similar. The secondary of the CTs are coupled to an over current relay. Its function is to turn off the system in the case of differential current is greater than a certain limit.

Adjust the CTs in such a way that both the currents I1s and I2s will be same for both the normal in addition to external fault conditions.

Consider the internal fault case, the difference between these currents becomessignificant,andtheovercurrent relay operates in this condition. . Due to various factors, such as ambiguity or CTs, differential current due to the variation in the power transformer tappings , and little differential current as a result of adjustment of ratios, a restraint differential current is fixed. This restraint current set up an upper limit for the differential current in the relay without disconnecting the system.

The percentage differential relay characteristics is



Percentage differential relay characteristics

Magnetizing Inrush:

Any unexpected change of the magnetizing voltage causes magnetizing inrush current in power transformers. There are several factors such as transformer size, system impedance, core magnetic property , core remanance, switching in time and the method of switching in which influences the shape, magnitude and duration of the inrush current.

Transformer Over-Excitation:

The parameters which the magnetic flux inside the transformer core depends upon are the applied voltage which is directly proportional and the frequency which is inversely proportional to the above. The transformer core may get saturated if there is any over voltage and/or under frequency conditions. These anomalous operating conditions may occur in any part of the power system and the transformer is subjected to over excitation. This is a typical case of a.c. saturation of the core which develops odd harmonics in the exciting current. The third harmonics is the most suitable for detecting over excitation conditions, but either the delta connection of the CTs or the delta connection compensation of the differential relay filters out the harmonic, even though, the fifth harmonic is dependable quantity for detection over excitation conditions. This results in transformer heating and increases exciting current, noise and vibration. For better and safe performance severely over excited transformer should be disconnected.

3. Proposed Model

The ATP-EMTP computer tool presents software for simulating the normal operating condition and fault condition of transformer. Conditions such as Normal operating condition, Magnetizing inrush current, Over excitation and Phase to ground fault , Phase to phase fault, Three phase fault in both primary and secondary.

BCTRAN MODEL:

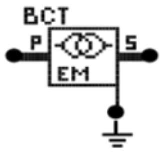


Figure.1. BCTRAN model represented in ATP

Supporting routine BCTRAN can be used to derive a linear [A] – [R] or [R] – [ωL] representation for single or 3 phase (both core and shell type); 2-winding, 3- winding, or multiple-winding transformer; using test data of both the exciting test and the short-circuit test at the rated frequency. Excitation losses can be considered by this proposed model, although these losses can be neglected for both single-phase transformers and three-phase low reluctance transformers. The short circuit losses can, and always should, be taken into account.

Nonlinear behavior cannot be included in the BCTRAN model proper. Such behavior (saturation or hysterisis) can be taken into account, however, connected to the proper transformer terminals (i.e., those winding which are closest to the core) in the electrical network, during the steady state or transient run.

The characteristics of the nonlinear inductance added with BCTRAN model to include hysterisis effect are shown in the fig.2.

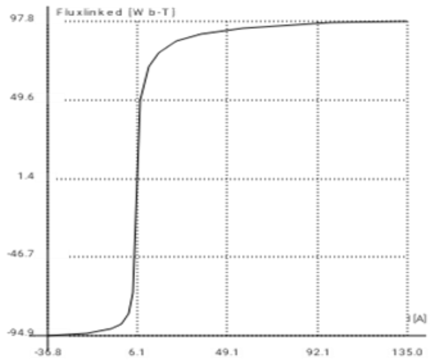


Figure.2. Characteristics of nonlinear inductance included.

ALTERNATIVE TRANSIENT PROGRAM (ATP)

ATP is a universal digital simulation program system for analyzing electromagnetic and electromechanical transient studies. Any complex networks can be simulated with this digital program. Also. the indiscriminate structure's control can be simulated using ATP. Besides the above features, ATP has extensive modeling capabilities. Supporting Routine: Data modeling of transformer and its calculation.(XFORMER, BCTRAN).

SIMULATION RESULTS

Based on the BCTRAN modified model of the power transformer with the effect of hysteresis and the simulation of the current signals using ATP may be performed. The transformer data and simulation results are presented.

Transformer data:

Three phase two winding 50 Hz, shell type power transformer 35 MVA, 132/11.05 KV, with Delta / star connection on HV and LV sides respectively, having following data:

SC test : Voltage 100%, Current 0.1316%, Losses 18.244 kW.

OC test : Impedance 26.291%, Power 35 MVA, losses 192.53 kW.

NORMAL OPERATING CONDITION:

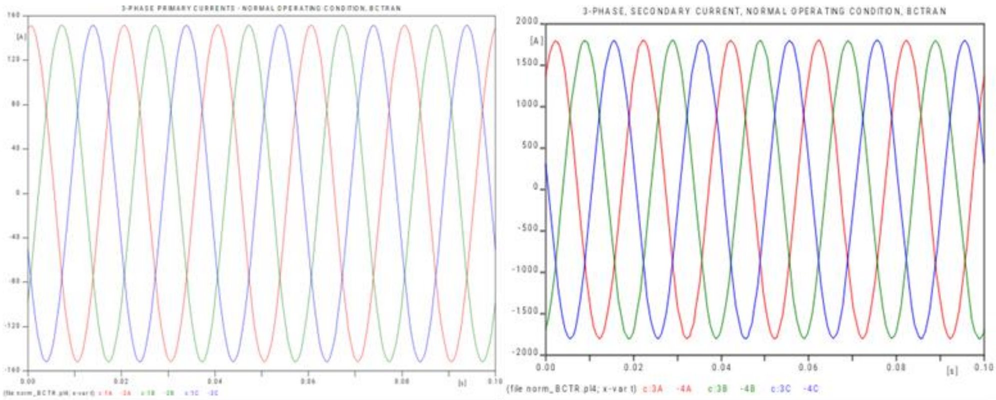


Figure.3. ATP model and three phase primary and secondary simulated current wave form for normal operating condition.

TRANSFORMER OVER EXCITATION:

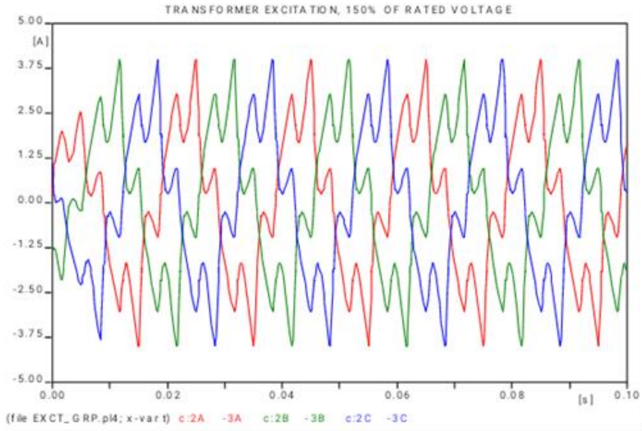


Figure.4. ATP model for Transformer over excitation and primary current wave form.

MAGNETIZING INRUSH CURRENT:

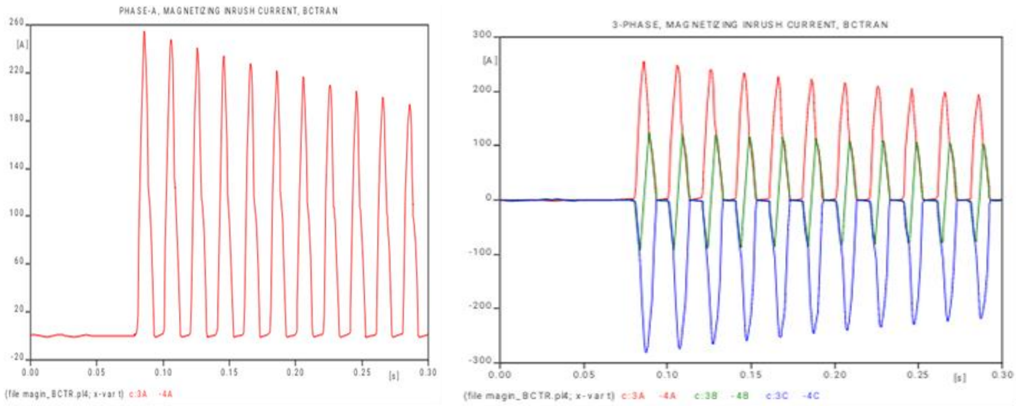


Figure.5. Primary phase A and three phase simulated current waveforms of transient inrush of magnetizing current.

PHASE TO GROUND FAULT IN PRIMARY:

The above condition is created by simulating a single phase - ground fault at phase A in primary side of the transformer. The fault is created at 0.045 second and cleared at 0.1 second

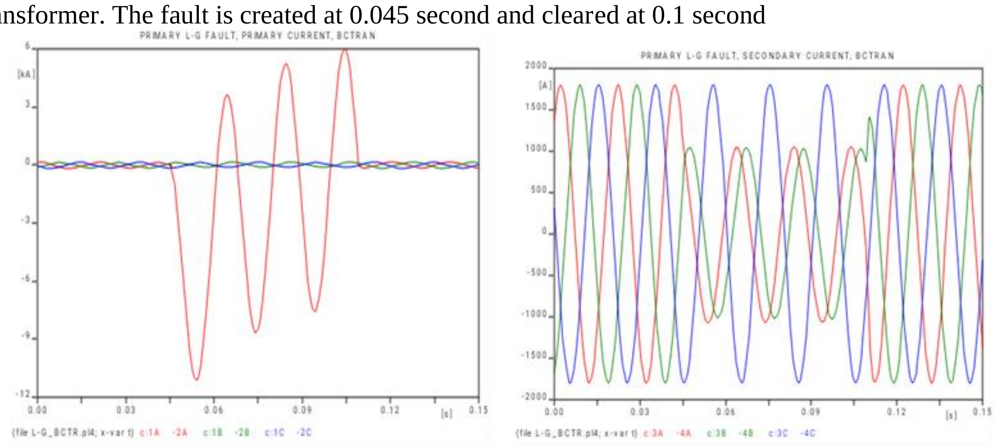


Figure.6. ATP model and current wave forms for phase - ground fault in primary.

PHASE - GROUND FAULT IN SECONDARY:

The above condition is created by simulating a single phase - ground fault at phase A in transformer's secondary side. The fault is created at 0.045 second and cleared at 0.1 second

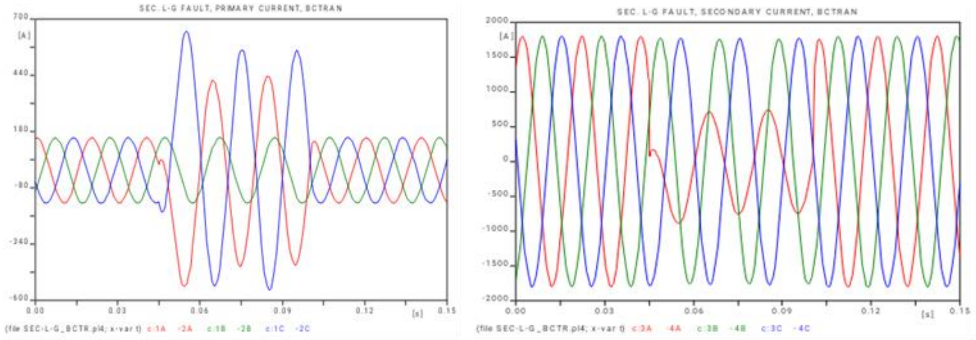


Figure.7. ATP model and three phase primary and secondary simulated current wave forms for phase to ground fault in secondary

PHASE - PHASE FAULT IN PRIMARY:

The above condition is created by simulating a phase - phase fault in power transformer's primary. The fault is created at 0.045 second and cleared at 0.1 second

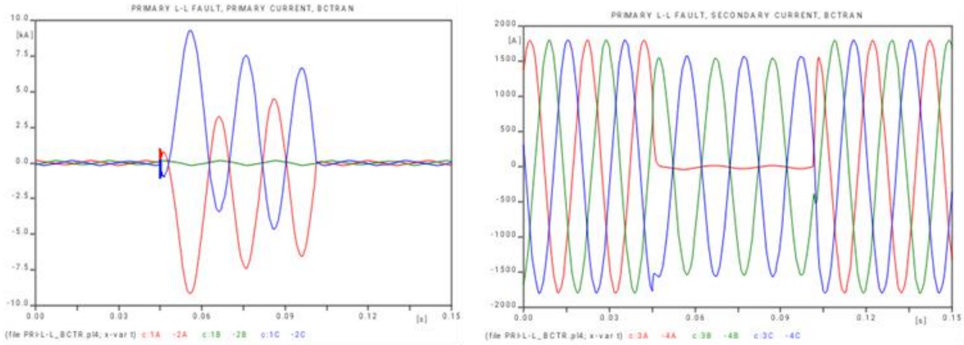


Figure.8. ATP model simulated current wave forms for phase to phase fault in primary.

PHASE TO PHASE FAULT IN SECONDARY:

This condition has been simulated by creating a phase to phase fault in secondary side of the power transformer. The fault is created at 0.045 second and cleared at 0.1 second

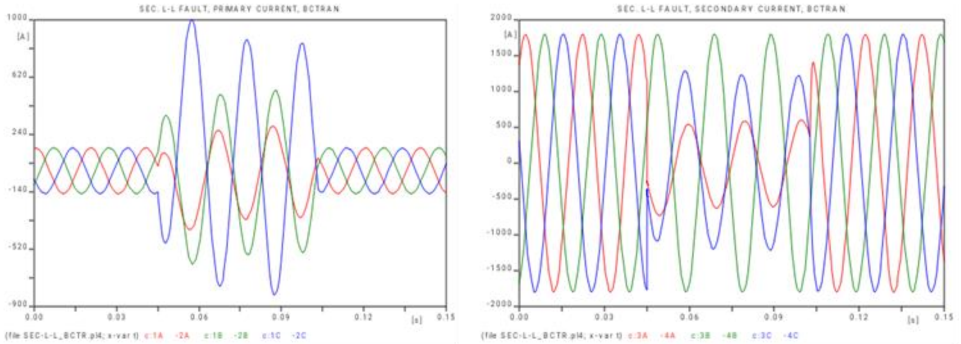


Figure.9. ATP model and three phase primary and secondary simulated current wave forms for phase to phase fault in secondary.

THREE PHASE FAULT IN PRIMARY:

A three phase fault is to be simulated in the transformer's primary side. The fault is created at 0.045 second and cleared at 0.1 second

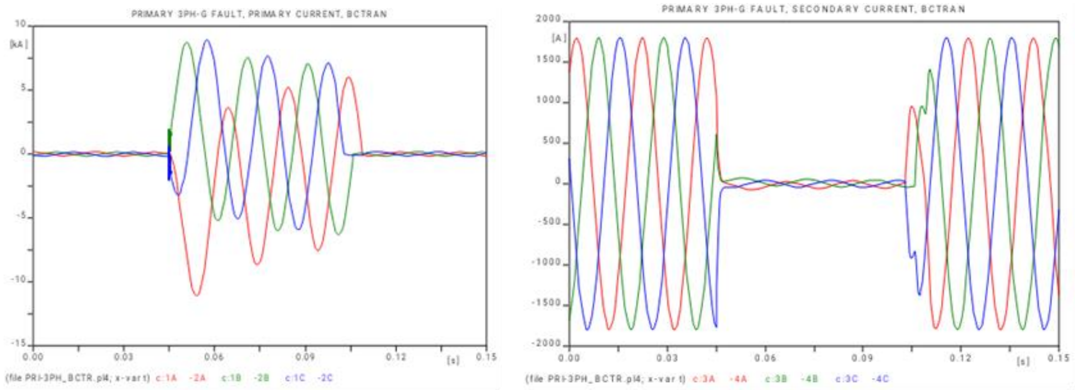


Figure.10. ATP model current wave forms for three phase fault in primary.

THREE PHASE FAULT IN SECONDARY:

A three phase fault is to be simulated in the transformers secondary. The fault is created at 0.045 second and cleared at 0.1 second.

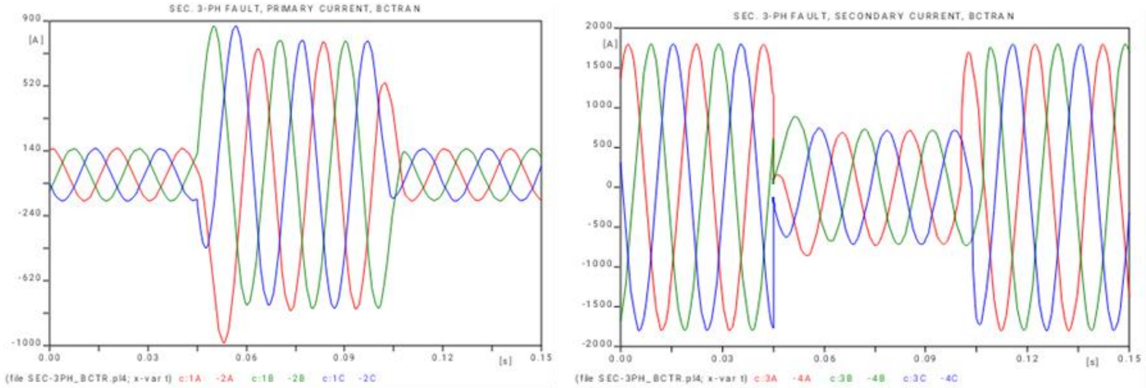


Figure.11. ATP model and current wave forms for three phase fault in secondary.

4. Result Analysis

In case of transformer energization, the presences of high frequency components apart from the fundamental frequency are observed from fig.5. The magnetizing inrush current observed is very high. Since there is no secondary current the differential relay fails to operate if not correctly settled. Fundamental frequency and second harmonics of the A-phase inrush signal is shown in fig.5. Both magnitude decreases as magnetizing current diminishes. Harmonics present in the excitation current while over exciting the transformer up to 150% of rated voltage is also observed from fig.4.

In case of internal faults, the primary current rises considerably all together as there is an distort between the secondary current waves. As the fault is applied at the delta side of the transformer, the current signal in the phase varies form one case to the other due to the vicinity of the internal fault to the most affected phase.

The proposed BCTRAN model offers a better simulated result for different operating and fault conditions of power transformers. The results are similar to the actual transformer operating and fault cases.

For all these studied cases, differences between the transformer primary and secondary currents are observed. The differential currents signals obtained can be used for transient analysis of actual power transformer. It is observed that the harmonics components of current waves differed for the studied cases. This information must be used in the differential protection project, as a way to avoid undesirable protection tripping.

5. Conclusion

A three phase power transformer model for differential protection was presented. The model provides the simulation of internal faults in the transformer, as well as the simulation of other disturbances which leads to undesirable protection system operation. The model is represented through the existing elements in the ATP-EMTP, easing its inclusion in studies of more complex power systems, allowing the interaction between the transformers with neighboring components of the system.

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