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Estimation of Residual Flux for the Regulated Transformer Switching

Manoj Kumar Swain[1], Sibananda mishra[2]
1(Department of Electrical Engineering ,Gandhi Engineering College, India)
2(Department of Electrical Engineering ,Gandhi Institute For Technology, India)

Abstract: *My paper basically explores the practical considerations of core flux transients and the applications of circuit breakers to control transformer inrush transients. The magnetizing inrush current which occurs at the time of energization of a transformer is due to temporary overfluxing in the transformer core. Transformer inrush currents are high magnitude, harmonic-rich currents generated when transformer cores are driven into saturation during energization. These currents have undesirable effects, including potential damage or loss-of-life to the transformer, protective relay misoperation, and reduced power quality on the system. Controlled transformer switching can potentially eliminate these transients if residual core and core flux transients are taken into account in the closing algorithm. Its magnitude mainly depends on switching parameters such as the resistance of the primary winding, the point-on-voltage wave (switching angle), and the remanent flux density of the transformer at the instant of energization. This report describes the development of a system for measuring the inrush current. The system is also capable of presetting various combinations of switching parameters for the energization of a transformer.*

Key Word::*Power transformers, over fluxing, energization*

I.Introduction

Power transformers are vital components in electrical networks and are the most expensive equipment in substations. Power transformers are used in a variety of configurations and for various purposes and they may be switched on an occasional (yearly) or frequent (daily) basis. Energizing the power transformers often results in flowing high inrush currents, which finally reduce magnetizing current a little. Many researches and studies have been conducted on reducing the inrush current, controlled switching method is one of the most common ones. The controlled switching method is for reducing the magnetizing inrush current of transformers that make a significant reduction in inrush current, using serial switching of different phases and considering the residual flux existing in them. Controlled switching canbe a cost effective solution to these problems. Controlled transformer switching can potentially eliminate these transients if residual core and core flux transients are taken into account in the closing algorithm.

Motivation

Controlled switching of transformers without inrush currents is hardly possible in the field. This originates from the non-idealities of the circuit breaker (closing time scatter) and of the device for the residual flux determination (measurement uncertainty).This is a live problem which is faced in the industries at the moment. ABB is carrying out this project as a part of their research to reduce the problems that are mentioned earlier.

Problems

Transformer de-energisation results in a permanent magnetisation of the core due to hysteresis of the magnetic material. This value of core flux is known as the residual flux .Transformerenergisation at a non-optimal point on the voltage cycle can create large core flux asymmetries and operation above saturation levels of the core of the transformer. The main cause of this phenomenon is the presence of a residual magnetic flux in the transformer core. This, in turn, may result in high magnitude currents that are rich in harmonic content and have a high direct current component. These currents can cause electrical and mechanical stresses in the transformer and, depending on the prevailing power system conditions, may also cause severe temporary overvoltages (TOV's). In the most severe cases, TOV's may exceed the energy absorption capabilities of surge arresters and expose the equipment in the substation to overvoltages exceeding their withstand levels. Severe TOV's and high inrush currents may also lead to false operation of protective relays and fuses resulting in a general degradation in power quality. Controlled energisation can, in many cases, provide an effective means of mitigating these problems.

II. Literature Review

Magnetizing Inrush Phenomenon

The saturation of the magnetic core of a transformer is the main cause of an inrush current transient. The saturation of the core is due to an abrupt change in the system voltage which may be caused by switching transients, out-of-phase synchronization of a generator, external faults and faults restoration. The energization of a transformer yield to the most severe case of inrush current and the flux in the core can reach a maximum theoretical value of 2 to 3 times the rated peak flux.A transformer inrush event is actually magnetizing inrush current. The windings in a transformer are linked magnetically by the flux in the transformer core. The exciting voltage drives the flux in the core. An increase in the exciting voltage therefore increases the flux. To maintain this additional flux, which may be in the saturation range of the core steel of the transformer, the transformer draws more current which can be in excess of the full load rating the transformer windings. This additional current is the inrush current necessary to supply the magnetizing branch of the transformer.The nature and magnitude of the inrush current will be decided by the direction and magnitude of the residual magnetization flux in the core and switching instant. The inrush currents generated during the energisation of power transformer can reach very high values and may cause many problems in power system. Some problems that can be caused by inrush currents:

- Damage to the transformer
- False operation of transformer protections
- Adverse effects on power quality
- Direct current problems

When a transformer is first energized, a transient magnetizing or exciting current may flow. The inrush current, which appears as an internal fault to the differentially connected relays, may reach instantaneous peaks of 8 to 30 times those for full load.

There are various factors affecting the magnitude and duration of the inrush current:

1. The value of the residual flux in the transformer core;
2. The nonlinear magnetizing characteristics of the transformer core;
3. The phase of the supplying source voltage at the instant of energizing transformer;
4. The impedance and short circuit power of the supplying source;
5. The size of the transformer bank;
6. The size of the power system;
7. The type of iron used in transformer core and its saturation density;
8. How the bank is energized.

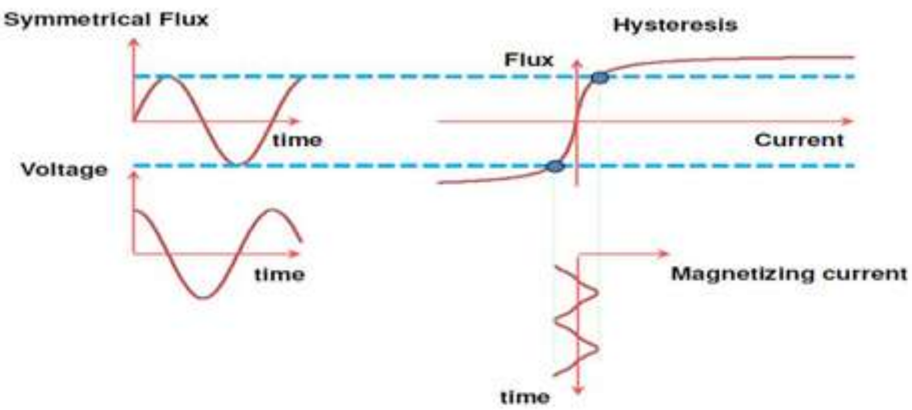


Figure 1 Magnetic flux in steady state

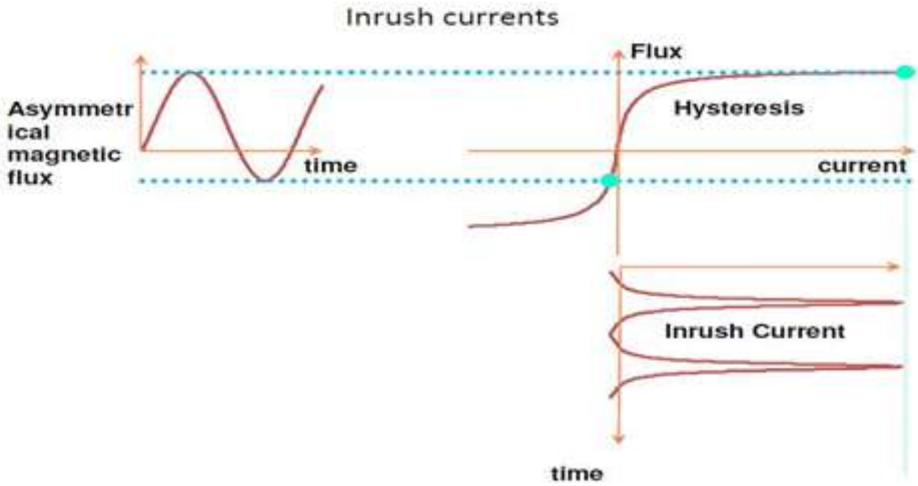


Figure 2 Transient flux

Remenant Flux

In the magnetic hysteresis loops showing the magnetic characteristics of a material, the remanence is the value of the flux density remaining when the external field returns from the high value of saturation magnetization to 0. The remanence is also called the residual magnetization.

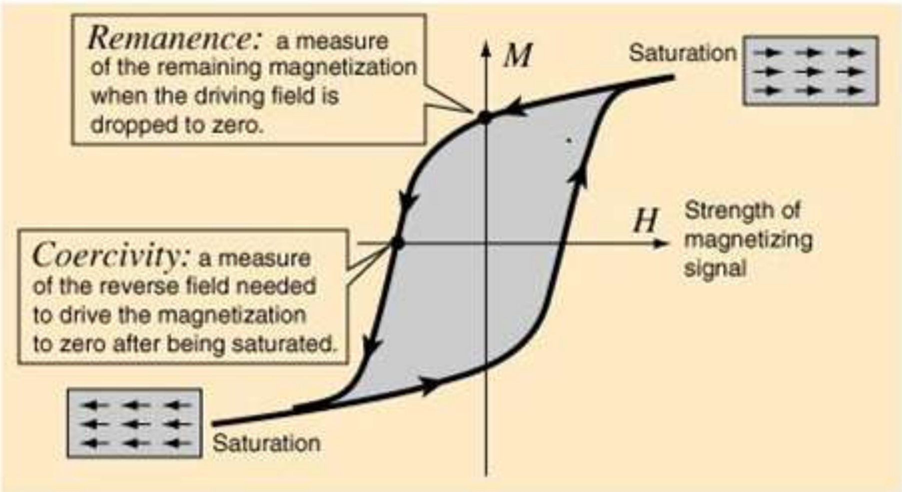


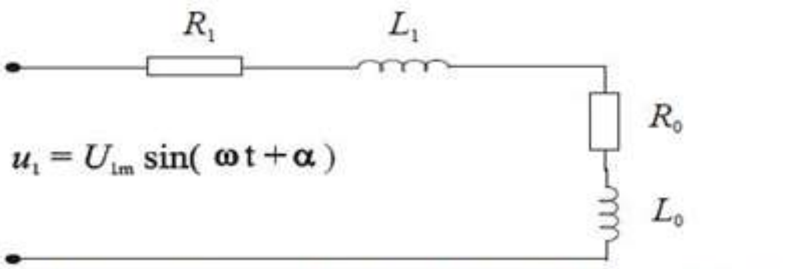
Figure 3 (Google Images)B-H Curve

When a transformer is de-energized, some level of flux remains in the transformer core.
This level of remanent flux is the flux in the core when the exciting voltage is removed.

In an event when the circuit breaker is closed between a transformer and a power source, a transient current (which could be as high as ten times the transformer rated cur- rent) flows for a short period before reaching a steady state. This transient current, known as magnetizing in- rush current of a transformer, is caused by the transformer's saturated core. The excitation characteristic of the transformer core is expressed by a nonlinear relationship between the flux and magnetizing current. In the steady state, transformers are designed to operate below the knee point of their saturation curve. However, when transformers are energized, flux can rise to a high value in the saturation region such that the magnetizing current increases drastically.

Circuit Diagram

The transient electromagnetic state of a transformer connected to the power supply depends on factors such as the instant of switching-on the supply voltage, the residual core flux and the ratio between the core magnetizing inductance L0 and the core loss resistance R0.



Equivalent circuit for an unloaded transformer

Figure 4 Equivalent Circuit for an unloaded transformer (Reference: Damascus Univ. Journal

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The final form of the resultant transient is

$$\Phi = -\Phi_m \cos(\omega t + \alpha) + (\Phi_m \cos\alpha \pm \Phi_r)e^{-(R/L)t}$$

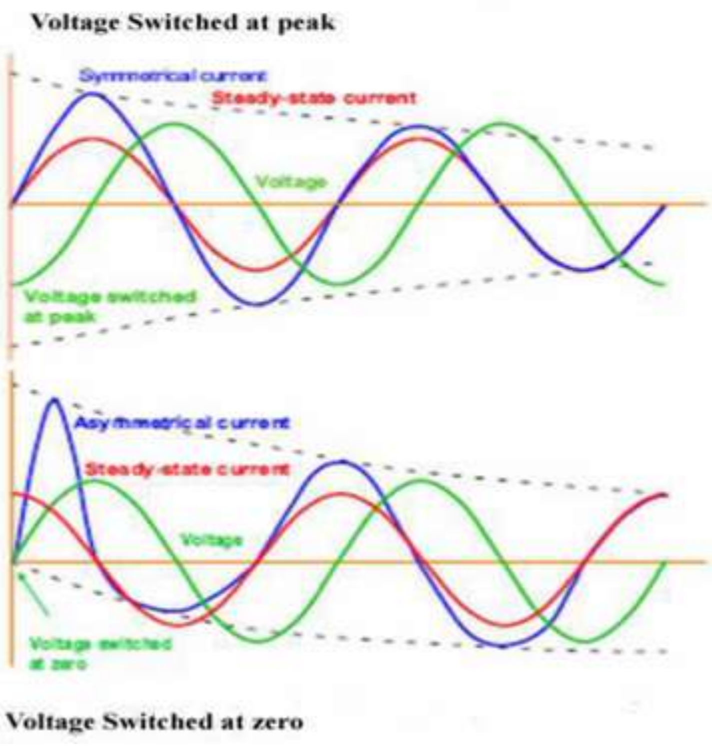

Figure 5 Switching Instants

III. Simulation

Model

The model shown below is the one we carried out our simulation on. It is a 3 single phase 100 MVA each, 230/33kV, 50Hz system that we have considered here. Three breakers are provided for each phase. We can insert the closing and opening times for each breaker inside the breaker logic box. The Transformer is shown unloaded on the secondary side.

Here we have calculated flux by using an integrator block. This is used because as we know, flux is integration of phase voltage E_{al}, E_{bl} and E_{cl}. The flux hence calculated, that is, fluxa, fluxb and fluxc is the source (prospective) flux of the model. Residual Flux (denoted by resi_fluxa, resi_fluxb and resifluxc) is calculated directly from the transformer block. The three breakers used are shown by BRKa, BRKb and BRKc.

It is initially considered as closed, then it is opened and then closed again. Thus, two operations are performed by the breaker
Vishesh Shah

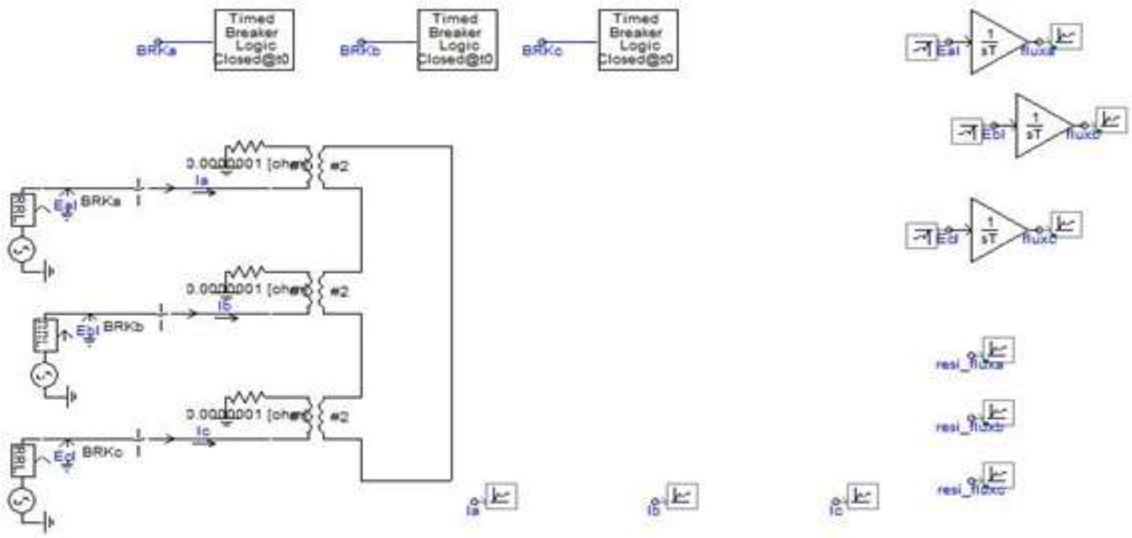

Figure 6 Simulation Model in PSCAD

Transformer Configuration:

This shows Transformer configuration of a single phase 2 Winding Transformer. Such 3 transformers are connected in Star- Delta. We have considered 100 MVA and base operation frequency of 50Hz. The leakage reactance is of 0.1 pu. The No load losses are 0.05 pu and copper losses are 0.05 pu.

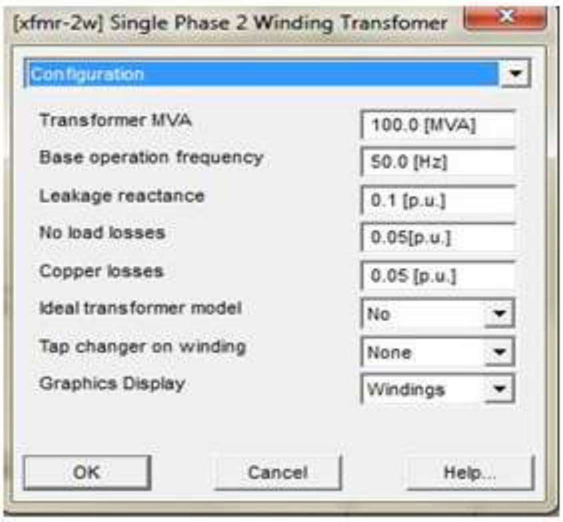

Figure 7 Configuration of Transformer

Saturation Characteristics: The parameters that we have considered for saturation characteristics of our transformer which is saturation enabled are:
Air core reactance= 0.2 pu
Inrush decay time constant= 0.1s
Knee voltage= 0.85 pu

IV.Simulation Results

Ideal Case

Here we can see that before the first switching operation the prospective flux exactly matches the residual flux. After this there is a certain decaying component, which shows the residual flux in the transformer as seen in the figure. Now after switching (that is, when the breaker is closed) the prospective flux matches the residual flux because here switching is done at the instant when the residual flux is equal to the prospective flux of respective phases.

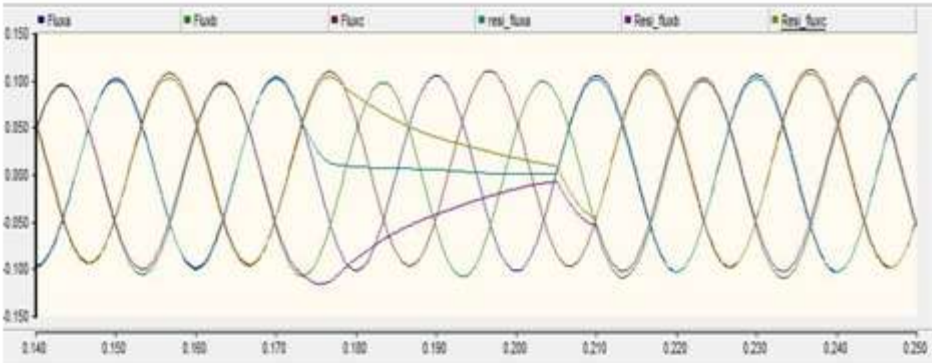

Figure 9 Prospective Flux and Residual Flux (Ideal Case)

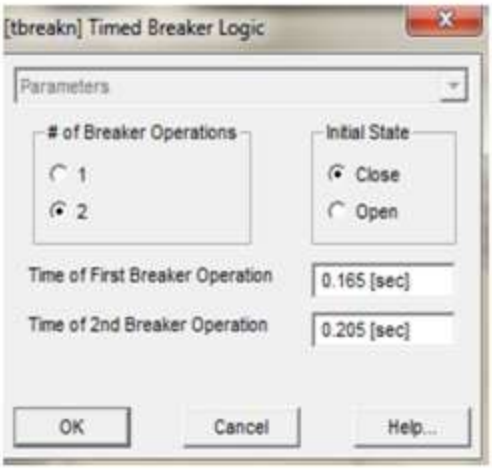

Figure 10 Breaker 1 Logic (Ideal Case)

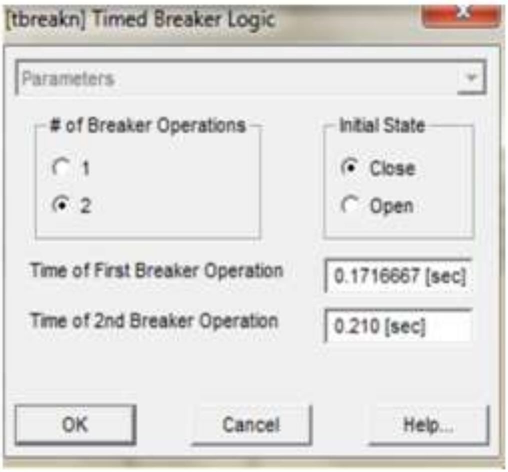

Figure 11 Breaker 2 Logic (Ideal Case)

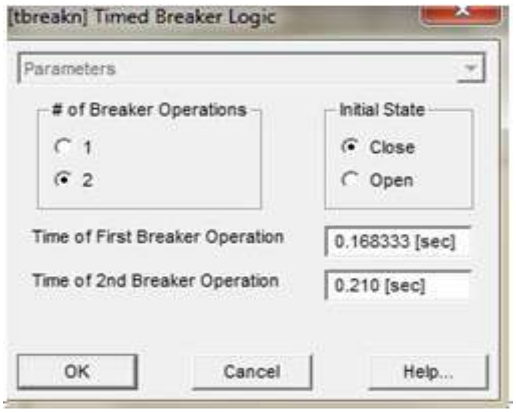

Figure12 Breaker 3 Logic (Ideal Case)

Case 1

Here we can see that before the first switching operation the prospective flux exactly matches the residual flux. After this there is a certain decaying component, which shows the residual flux in the transformer as seen in the figure. Now after switching (that is, when the breaker is closed) the prospective flux and the residual flux does not match. This is because the switching instant that we have chosen is different than the ideal case. Here switching is not done when the prospective flux and residual flux is the same. Thus, as seen from the graph there after the second switching operation the residual and prospective flux does not match. This gives rise to high magnetizing inrush current which is dangerous for the equipment.

In this case, as compared to the Ideal case, we changed the switching instant of Breaker 2 (BRKb) and Breaker 3 (BRKc) of phase “b” and phase “c” by 2 milliseconds. Breaking instant for phase a remains the same. Thus as seen from the graph, the residual flux and prospective flux matches for phase “a” but not for phase “b” and phase “c”.

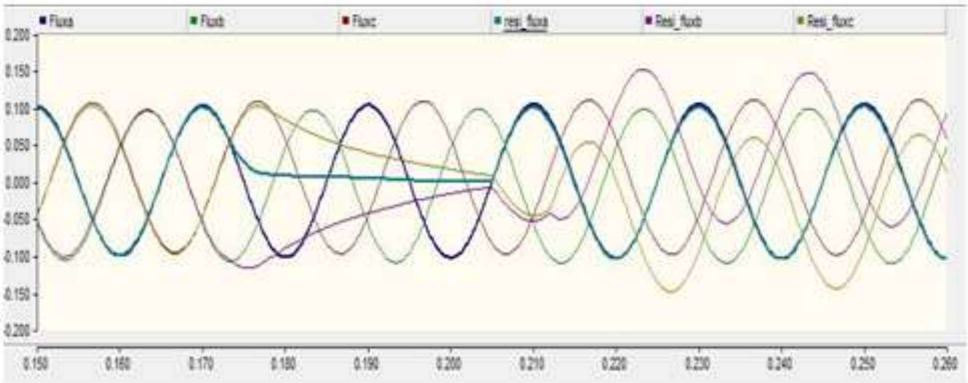

Figure 13 Prospective Flux and Residual Flux (Case 1)

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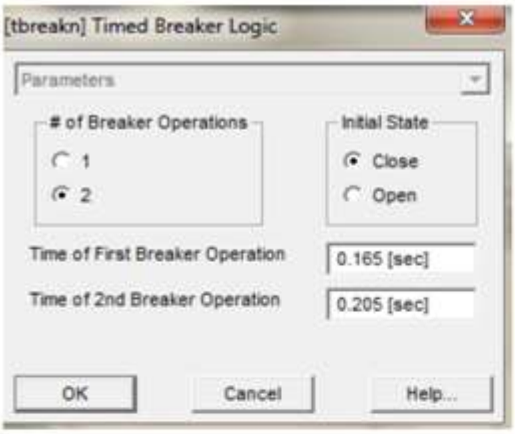


Figure 14 Breaker 1 Logic (Case 1) **Figure 15** Breaker 2 Logic (Case 2)

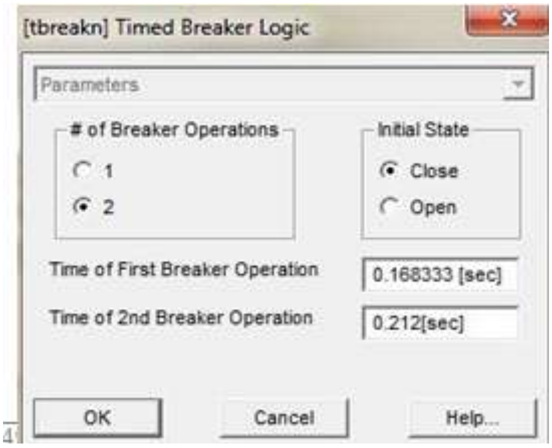


Figure 16 Breaker 3 Logic (Case 1)

Case 2

Here we can see that before the first switching operation the prospective flux exactly matches the residual flux. After this there is a certain decaying component, which shows the residual flux in the transformer as seen in the figure. Now after switching (that is, when the breaker is closed) the prospective flux and the residual flux does not match. This is because the switching instant that we have chosen is different than the ideal case. Here switching is not done when the prospective flux and residual flux is the same. Thus, as seen from the graph there after the second switching operation the residual and prospective flux does not match. This gives rise to high magnetizing inrush current which is dangerous for the equipment.

this case, as compared to the Ideal case, we changed the switching instant of Breaker 1 (BRKa), Breaker 2 (BRKb) and Breaker 3 (BRKc) of phase “a”, phase “b” and phase “c” by 1,2 and 4 milliseconds respectively.

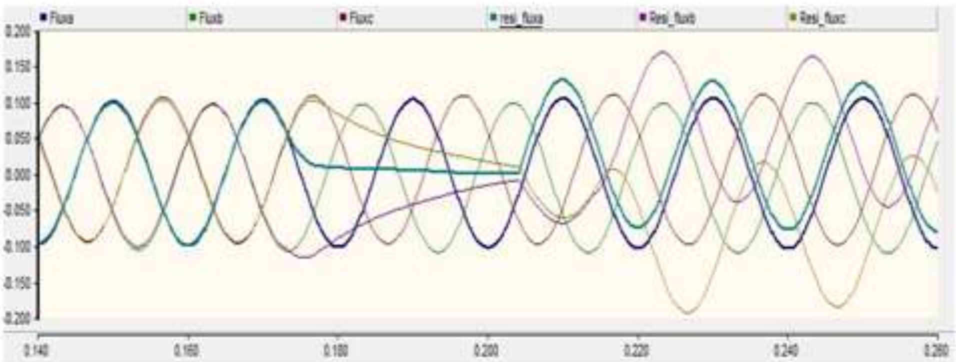
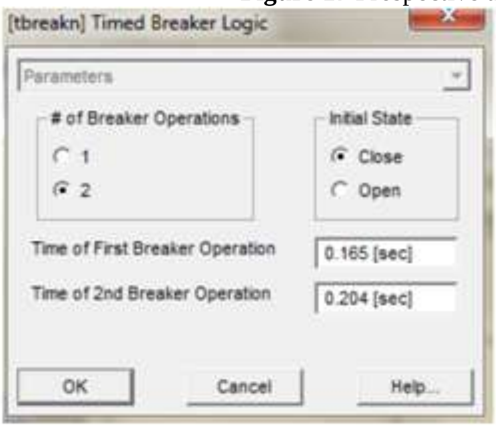


Figure 17 Prospective and Residual Flux (Case 2)



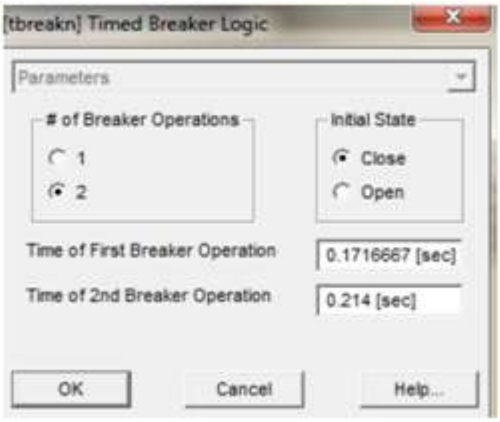


Figure 18 Breaker 1 Logic (Case 2)

Figure 19 Breaker 2 Logic (Case 2)

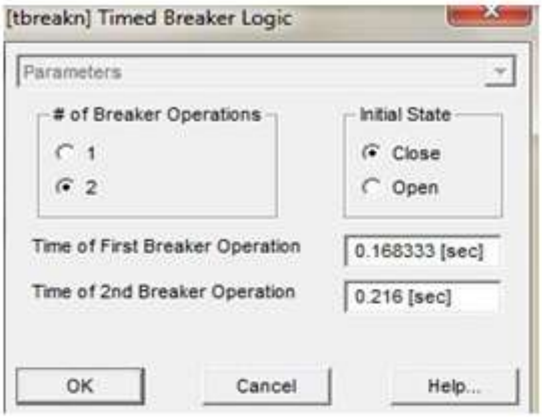


Figure 20 Breaker 3 Logic (Case 2)

Case 3

Here we can see that before the first switching operation the prospective flux exactly matches the residual flux. After this there is a certain decaying component, which shows the residual flux in the transformer as seen in the figure. Now after switching (that is, when the breaker is closed) the prospective flux and the residual flux does not match. This is because the switching instant that we have chosen is different than the ideal case. Here switching is not done when the prospective flux and residual flux is the same. Thus, as seen from the graph Estimation of Residual Flux for the Controlled Switching of Transformer there after the second switching operation the residual and prospective flux does not match.

This gives rise to high magnetizing inrush current which is dangerous for the equipment. In this case, as compared to the Ideal case, we changed the switching instant of Breaker 1 (BRKa), Breaker 2 (BRKb) and Breaker 3 (BRKc) of phase “a”, phase “b” and phase “c” by 1,2 and 2 milliseconds respectivelyEstimation of Residual Flux for the Controlled Switching of Transformer there after the second switching operation the residual and prospective flux does not match.

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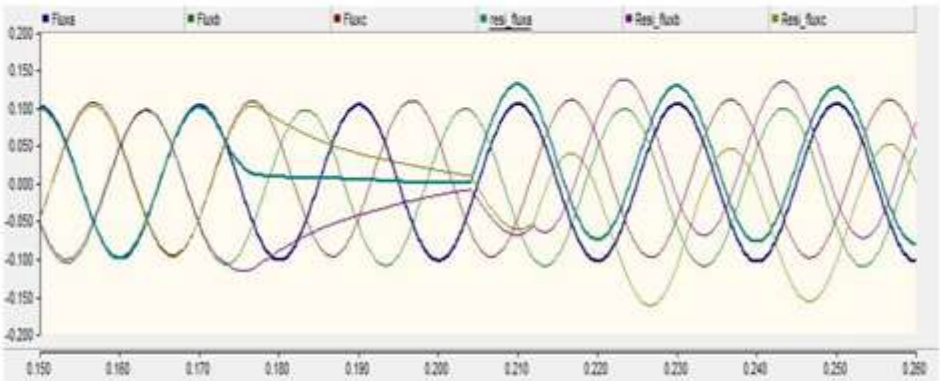

Figure 21 Prospective and Residual Flux (Case 3)

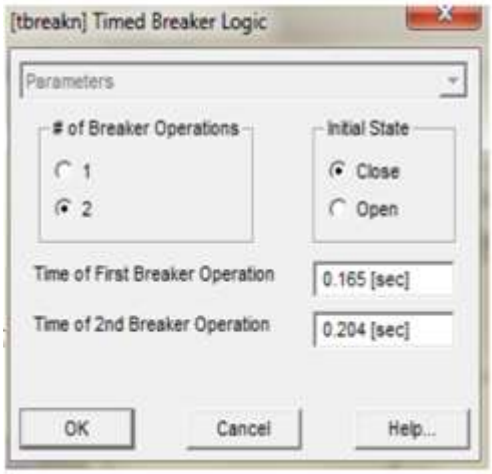

Figure 22 Breaker 1 Logic (Case 3)..

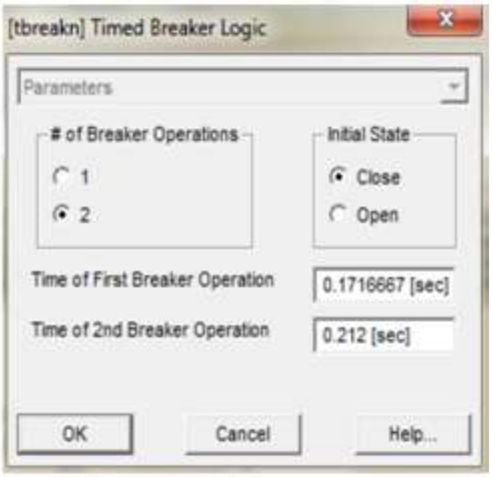

Figure 23 Breaker 2 Logic (Case 3)

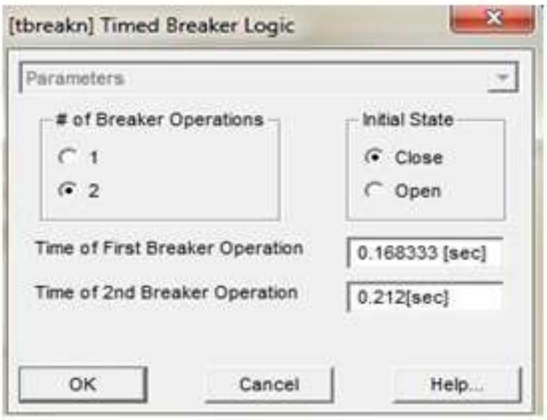

Figure 24 Breaker 3 Logic (Case 3)

V.Solution

Here we can see that if we do the switching at the instant when prospective flux/source flux matches residual flux, the magnitude of magnetizing inrush current will become minimum.

VI. Conclusions

PSCAD based model was used to determine the characteristics of magnetizing inrush currents and residual flux in a three phase unloaded transformer at predetermined switching conditions. This model for an unloaded saturated transformer and predicts the in-rush current when the transformer is connected to the power supply. The model uses non linear core parameters, which vary according to the magnetic state and properties of the non-linear core. The results of this research show the risks of connecting an unloaded power transformer to the power system. It is recommended that this phenomenon is taken into account when protection devices on the transformer are adjusted, to avoid mal-operations and consequent tripping of the transformer circuit breaker. A comparison between simulated results, show a good agreement and prove the validity of the model for detailed study of in-rush current phenomenon.

VII. Future Scope

We have developed this model in PSCAD free version 4.2 which does not allow us to consider all the parameters that we need to consider for the proper switching of the transformer which will ultimately help in switching the transformer more accurately and in reducing the magnetizing current in transformer at the time of switching.Our future goal is to develop a more advanced module which allows us to consider all the parameters in order to obtain more accurate results.

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