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Reduction of Harmonics and Inrush Current of Power transformer using Prefluxing Technique

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***Abstract*— At the time of transformer energisation, a high current will be drawn by the transformer. The mentioned current is called transient inrush current and it may rise to ten times the nominal full load current of transformer during operation. Energisation transients can produce mechanical stress to the transformer, cause protection system malfunction and it often affects the power system quality and may disrupt the operation of sensitive electrical loads such as computers and medical equipment connected to the system. Reduction and the way to control of energisation transient currents have become important concerns to the power industry for engineers. A technique has been proposed to mitigate inrush current in three phase transformer, by a process called pre- fluxing. After setting the initial fluxes of transformer it is energized by conventional controlled switching. In this paper, a system of power transformer of specified rating is simulated in MATLAB/simulink and results were obtained.**

***Index Terms*— Transformer, Harmonics, Inrush Current, Prefluxing, MATLAB/Simulink**

I. INTRODUCTION

Inrush Current is a form of over-current that occurs during energisation of a transformer and is a large transient current which is caused by part cycle saturation of the magnetic core of the transformer. For power transformers, the magnitude of the first peak of inrush current is initially several times the rated load current but slowly decreases by the effect of oscillation damping due to winding and magnetizing resistances of the transformer as well as the impedance of the system it is connected to until it finally reaches the normal exciting current value. This process typically takes several minutes. As a result, inrush current could be mistaken for a short circuit current and the transformer is erroneously taken out of service by the over - current or the differential relays [1]. The transformer design and station installation parameters affect the magnitude of the inrush current significantly. Therefore, it is important to have an accurate calculated value of the magnitude and other parameters of inrush current in order to design the relaying to properly differentiate between inrush and short circuit incidents. Also, a proper calculation of the minimum % ratio of 2nd harmonic content of inrush current is an especially important parameter for this differentiation [2].

This paper contains basic principle, fundamental theory and mitigation of inrush current in transformer. The effects of inrush current are described in brief The MATLAB Simulink is used for the simulation.

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II. NATURE OF INRUSH CURRENT

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 two to three times the rated value of peak flux. There is no direct evidence that the energization of a transformer can cause an immediate failure due to high inrush currents. However, insulation failures in power transformers which are frequently energized under no load condition support the suspicion that inrush currents have a hazardous effect. A more typical problem caused by the energization of transformers is due to harmonics interaction with other system components that develops into over-voltages and resonant phenomena. The study of the energization of a transformer installed in an industrial facility carried out in highlights problems due to harmonics, over-voltages and resonances. In the authors show how the harmonic distortions caused by the switching of lightly loaded or unloaded transformers may be amplified during a power system restoration process, creating high harmonic over-voltages [3] [4]. In the energization of large size transformers in EHV substations with long transmission lines is discovered to cause significant temporary disturbances when harmonic resonances are reached. In particular, when there are transformers already connected to the bus, the disturbances caused by the energization of one more transformer have greater duration and intensity. In it is discussed how transformer inrush current can excite resonance frequencies in inter-connected offshore power systems [5] [6].

Factor Affecting Inrush Current

- Starting phase angle of voltage
- Residual flux in core
- Core material
- Supply/Source impedance
- Loading on secondary winding
- Size of transformer [7] [8]

Reduction of inrush current using Prefluxing

The innovation behind the prefluxing inrush current reduction strategy lies in the prefluxing device itself. The prefluxing device capacitor is charged to a user-specified voltage and then discharged into the transformer when closing the device switch. It is necessary for the prefluxing device to set the residual flux of a transformer as high as possible to minimize the inrush current, but also to do so efficiently. The prefluxing reduction strategy is a two part process. First, the transformer's residual flux is set as close as possible to its maximum achievable residual flux when the transformer is de-energized. The second part of the process controls the CB to energize the transformer at either an angle of 210 for positive residual flux, or 330 for negative residual flux. These angles are chosen as part of an inrush current reduction strategy for three-phase transformers that enable the use of a three-pole CB.

Prefluxing device consists of a capacitor, a diode, a fuse, and a switch. A charging circuit (not shown) establishes the initial voltage across the capacitor. The device is used when the transformer is isolated from the power system and connects across one of the transformer windings [9]. When the maintenance work is completed on the transformer, personnel can charge the device. Once the prefluxing device is charged, the charging circuit is disconnected from the device, and the device is connected to the transformer through the isolators, the switch is closed, and the transformer is fluxed to the appropriate polarity depending on how the device is connected. Prior to energisation, the prefluxing device is safely removed from the circuit and then an intelligent electronic device, such as a protective relay, receiving a voltage signal from a bus PT issues a close command to the connecting CB to energize the transformer at the appropriate angle given the flux polarity. The prefluxing inrush current reduction method overcomes many of the shortcomings inherent in the other inrush current reduction methods discussed previously. Unlike the pre-insertion resistors, the prefluxing device only operates during the isolation period and then is removed from the power system prior to energisation. The controlled closing with flux measurements strategy acquires the residual flux information from the transformer for consistent performance, but requires additional, permanent measurement equipment be mounted on the transformer terminals. The prefluxing device does not require knowledge of the initial transformer flux since the prefluxing device will set the transformer flux to the desired polarity. Hence, supplementary measurement equipment is not needed. In addition, the prefluxing of the transformer is performed after any measurements are made on the transformer during maintenance procedures to ensure the residual flux is at the known polarity prior to the controlled energisation [10].

III. SIMULATION MODEL AND RESULTS

➢ Without using any mitigation technique

A MATLAB model has prepared for simulation study. Here three phase power transformer having a rating of 250 MVA, 11 kV/400 kV, 50 Hz, connected to a supply source as shown in fig. .

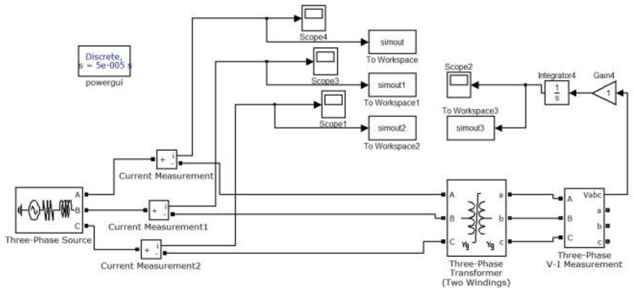

Figure 1: Simulink model of uncompensated System

A three phase 11 kV source connected with the transformer which is shown in figure 1. The results of uncompensated system are shown as under.

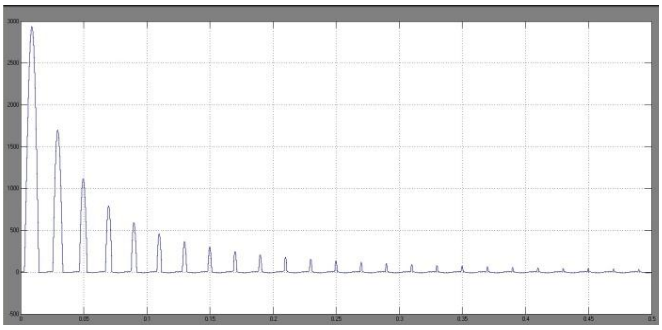

Figure 2: Inrush Current in phase A

Figure 2 shows the inrush current in phase A which is equal to 2900 kA. Figure 3 shows the inrush current in phase B. this current is equal to 2400 kA.

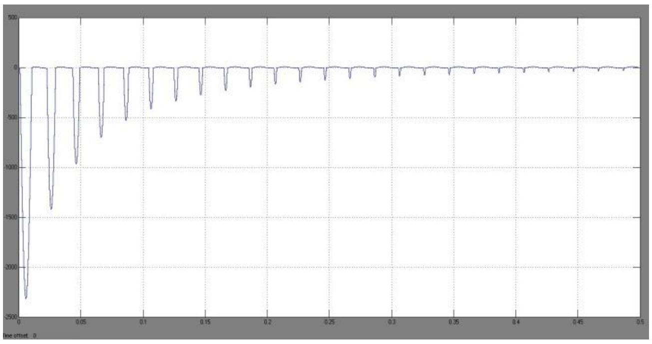

Figure 3: Inrush Current in phase B

Figure 4 shows the inrush current in phase C which is equal to 850 kA and figure 5 shows the flux in all three phases which is saturated.

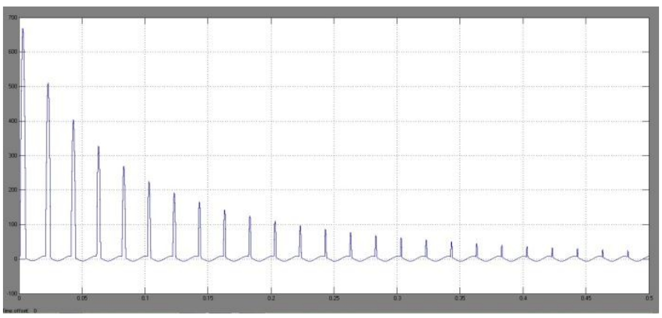

Figure 4: Inrush Current in phase C

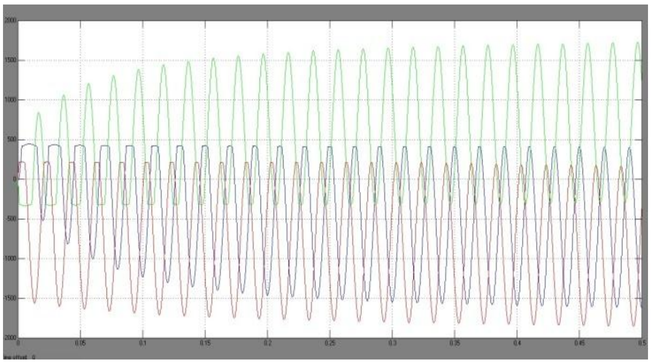

Figure 5: Flux in all three phases

Harmonics

Harmonics of uncompensated system is shown in figure 6,7 and 8. Figure 5 show harmonic in phase A, Total harmonics distortion is 37.37 %.The DC component in this phase is 68 % and second harmonic is 100 %.

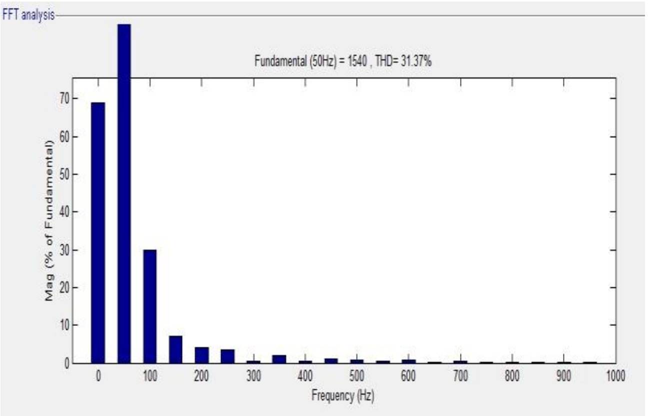

Figure 6: Harmonics in phase A

Figure 7 show harmonic in phase B, Total harmonics distortion is 46.46 %. The DC component in this phase is 62 % which is large compare to phase A DC component but second harmonic is 105 % which less than phase A second harmonic

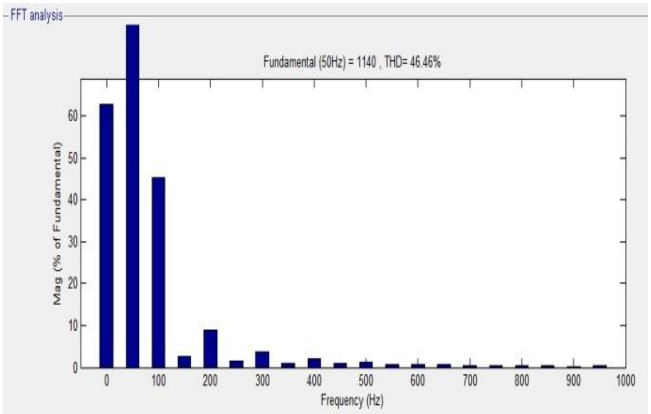

Figure 7: Harmonics in phase B

Figure 8 show harmonic in phase C, Total harmonics distortions 110.86 %.The DC component in this phase is 55 % which is large compare to phase A but less compare to phase B. Second harmonic is 102 % which is highest among all three phases.

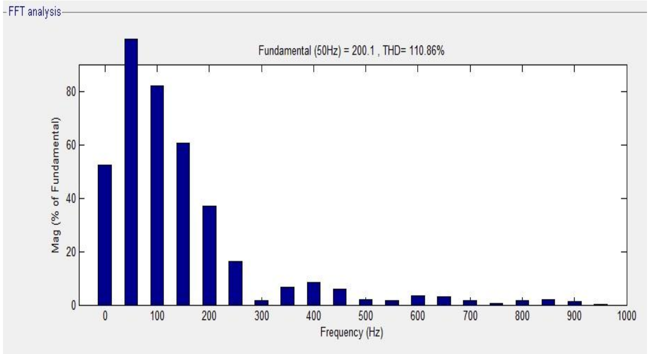

Figure 8: Harmonics in phase C

With using prefluxing technique

Figure 9 shown the simulation model which is same as describe as above but in this model, a new technique has been introduce to mitigate high inrush current. This technique mitigate the inrush current till 90% and provide a smooth wavefrom. The results are shown as below.

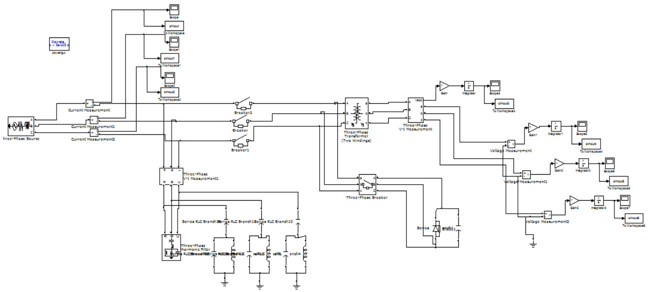

Figure 9: Simulink model of uncompensated System

Mitigate current

Figure 10, shown the inrush current in phase A in power transformer with using prefluxing. The magnitude of current is 38 kA. Compare with figure 2, the inrush current is mitigating from 2900 kA to 38 kA.

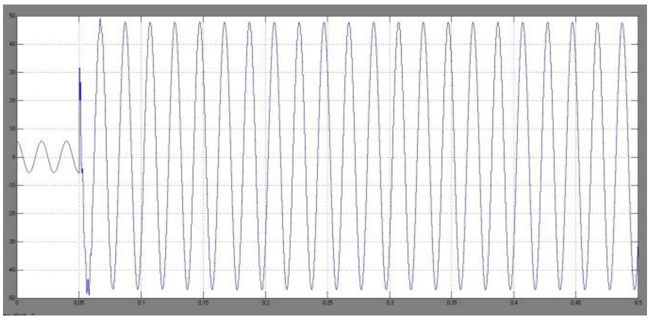

Figure 10: Mitigated current in phase A

Figure 11 , shown the inrush current in phase B in power transformer with using prefluxing. The magnitude of current is 35 kA. Compare with figure 3, the inrush current is mitigating from 2400 kA to 35 kA.

Figure 12 show the inrush current in phase C in power transformer with using prefluxing. The magnitude of current is 35 kA. Compare with figure 4, the inrush current is mitigating from 650 kA to 35 kA.

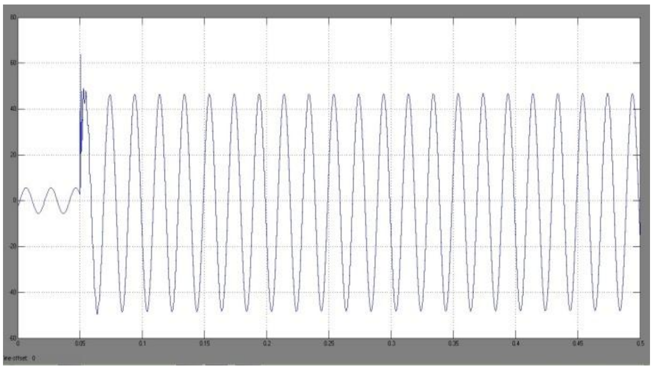

Figure11: Mitigated current in phase B

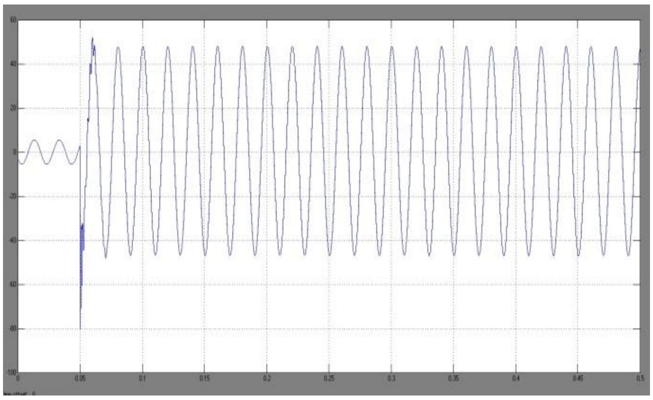

Figure 12: Mitigated current in phase C

Figure 13 shows the flux which is generated by prefluxing device and system voltage source. This flux is more symmetrical then uncompensated system

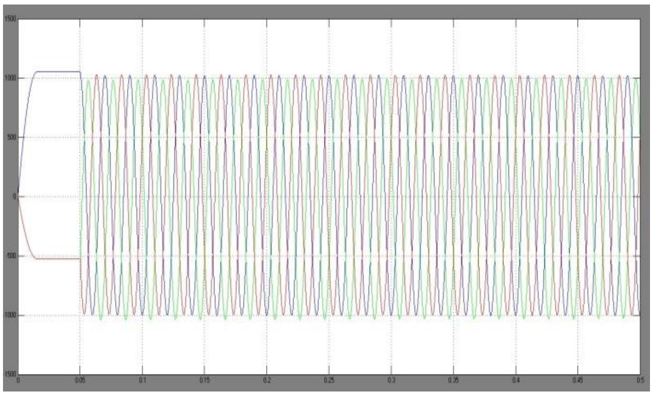

Figure 13: Flux in all three phases

IV. Harmonics

Figure 14 shown harmonic in phase A. Total harmonics distortion is 0.02 %.The DC component in this phase is 0.12 % and second harmonic is 0.25% While THD in uncompensated system is 31.37.

Figure 15 shown harmonic in phase B. Total harmonics distortion is 0.02 %. The DC component in this phase is 0.12 % which is large compare to phase A DC component but second harmonic is 0.30 % which less than the THD which achieved in uncompensated system. The THD in uncompensated system is 46.46%

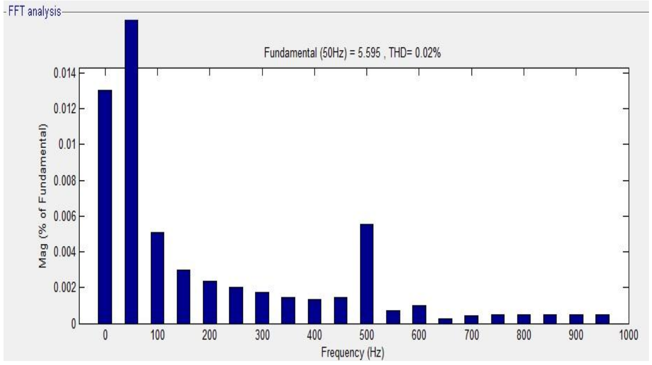

Figure 14: Reduced Harmonic in phase A

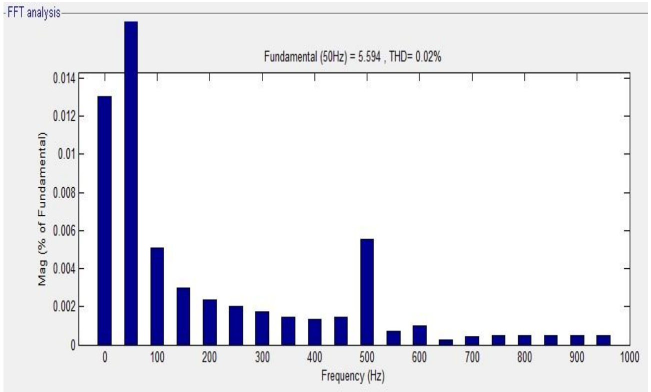

Figure 15: Reduced Harmonic in phase B

Figure 16 shown harmonic in phase C. Total harmonics distortion is 0.04 %. The DC component in this phase is 0.025 % which is large compare to phase A DC component but second harmonic is 0.050 % which less than the THD which achieved in uncompensated system. The THD in uncompensated system is 110.86 %

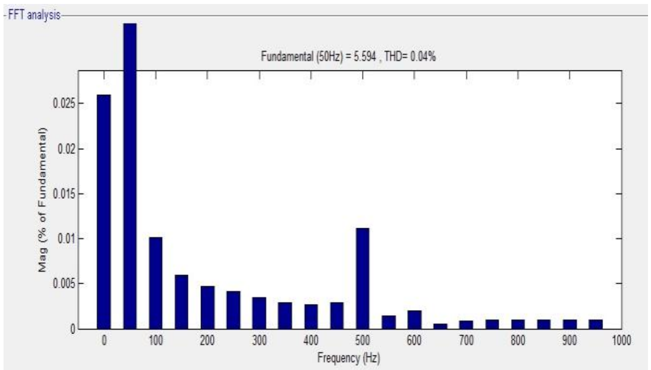

Figure 15: Reduced Harmonic in phase C

V. Conclusion

This paper presented an inrush current reduction strategy which sets the residual flux of a three-phase transformer to a large magnitude and specific polarity in a method known as prefluxing and then energizes the transformer at a specified system voltage angle based on the flux polarity. This strategy has advantages over some of the presently suggested reduction strategies, including removing the need for residual flux measurements during transformer de-energisation. The prefluxing device that sets the flux of the transformer is simple in form and flexible to apply to any range of transformer sizes. In addition, the device can operate at low-voltage levels, such as the substation ac or dc supply, regardless of the voltage rating of the transformer.

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