Mitigate Inrush Current of transformer with Prefluxing Technique

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Abstract:- **Energization transient can produce mechanical stress in the transformer causes protection system mal-function. At the time of transformer energization, a high current will be drawn by the transformer. This current is called transient inrush current and it may rise to ten times the nominal full load current of transformer during operation. This current often affects the power system quality and may disrupt the operation of sensitive electrical loads such as computer and medical equipment connected to the system. Reduction and the way to control energization transient currents have become important concerns to the power industry. Conventionally, controlled switching or point on wave switching was the method being used to counter the problem, but this method requires the knowledge of residual fluxes of transformer before energization, which was quite tedious to get. Hence, this paper proposes a technique to mitigate inrush current in three phase transformers which involves injecting some amount of DC flux in the primary of transformer, the process known as prefluxing. After setting the initial fluxes of the transformer it is energized by conventional controlled switching.**

***Index Terms*— Controlled switching, Inrush current, MATLAB, Prefluxing, transformer, transient, point on wave switch**

I. INTRODUCTION

Three-phase transformers are key components in power sys-tem network. Security and stability of transformers are both important and necessary to system operation. The large transient current of transformer due to flux saturation in the core, which is called inrush current, often causes the malfunction of the protective relaying system. This transient current affects costing time and money as the engineers have to examine closely the transformer and the protective system, to check for faults. The large transient current also causes serious electromagnetic stress impact and shortens the life of transformer. The over-voltage resulting from the inrush current causes serious damage to power apparatus. It is very important to solve the effect of inrush current[1].The uncontrolled energization of transformer produces high inrush currents, which can reduce the trans-former's life due to the high mechanical stresses involved, and can also lead to the unexpected operation of protective relays and power quality reduction. This current depends upon various operating conditions, such as the magnitude of the voltage, the switching-on angle, the residual flux, the [I-φ] hysteresis-characteristics of the core, the resistance in the primary circuit, and many others which has been described in [8]. There are three negative side-effects of inrush currents:

In recent years, various protective systems for transformers, based on the differential relaying system, were developed. Various techniques based on complex circuits or microcomputers and proposed to distinguish inrush current from fault current. However, the transformer still must bear with large electro-magnetic stress impact caused by the inrush current. Transformer is the most sensitive component in response of power system harmonics. As non-sinusoidal harmonics have been generated from many sources, harmonic flow through many transformers and causes the compound effect the power system. The main factors affecting the magnetizing inrush current are point- on- wave voltage at the instant of energization magnitude and polarity of remnant flux. In addition total resistance of the primary winding, power source inductance, air-core inductance between the energizing, the core geometry of transformer core and the maxi-mum flux carrying capability of the core material is also affected inrush current[3][4]. This paper proposes a new technique to mitigate inrush current of three phase power transformer called prefluxing. In this method, amount of DC flux is injected in primary of transformer before energization.

II. NATURE OF INRUSH TRANSIENT

Caused by switching transient, out of phase synchronization of a generator, external faults and fault 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 sys-tem components that develops into over-voltages and resonant phenomena. The study of the energization of a transformer in-stalled in an industrial facility carried out in highlights problems due to harmonics, over-voltages and resonances. In [5] 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. 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 [3].

III. MODELING OF INRUSH CURRENT IN TRANSFORMER

In [5] had done the modeling of transformer for his doctorate thesis. Firstly, he had done the magnetic modeling of core and then transformed it into electric modeling by using Maxwell's equations. A MATLAB model has been prepared for simulation study. Three-phase power transformer having a rating of 250 MVA, 25 kV/400 kV, 50 Hz, connected to a supply source as shown in Fig. 1. A three phase 25 KV source connected with the transformer [6]. Current and flux measurement devices are connected. The results are shown in Section V.

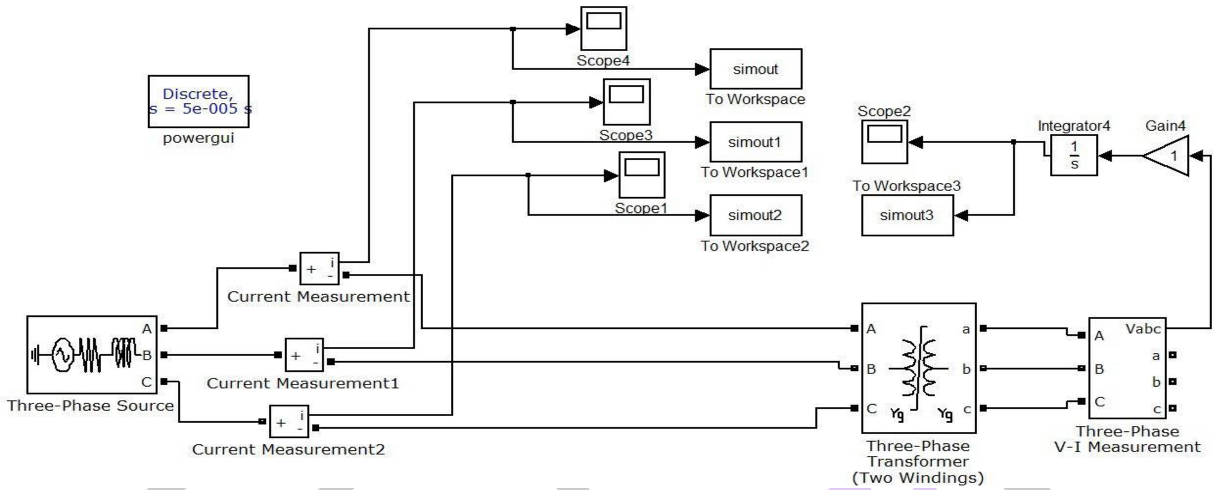

Fig. 1. MATLAB simulink model of inrush current in transformer

The three-phase transformer which is used for simulation has star winding in primary and secondary both. The core magnetization resistance of three phase transformer is 450 ohm and core magnetization inductance is 1.4325 H. The core is used with specified initial fluxes and saturated core. Some amount of flux provided in each phases to get the value of inrush current. When the transformer is energized, the flux of all three-phase will in-crease and reach till the maximum value of flux. After that minimum value, the flux will become saturated and draw more cur-rent from source, which may be 5 to 10 times greater than rated current. The main reason of saturation of flux is residual flux. Residual flux is nothing but it is some amount of flux which re-main in the transformer core at the time of de- energization of transformer. Residual flux is depends on the rating of transformer and de-energization instant. It will have different values for different ratings of transformer [6].

IV. PREFLUXING TECHNIQUE

As controlled switching had been the most popular technique to mitigate inrush current, the most important aspect in the meth-od is knowledge of residual flux of a transformer. Many techniques had been suggested to obtain residual flux on the basis of the instant of transformer was previously turned off, but it is slightly tedious process. To make a user free from knowledge of residual flux the paper proposes a new technique to set the initial fluxes of transformer as per the desired values. This is called as prefluxing [7].

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 isolator 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 process controls the circuit breakers (CBs) to energize the transformer. There are three controlled strategies for switching control of circuit breakers, first is rapid closing, second is delayed closing and third is simultaneous closing.

In rapid closing, closes one phase first and the remaining two phases within a quarter cycle. It requires knowledge of the residual flux in all three-phases, independent pole breaker control, and a model of the transformers transient performance. In delay closing, closes one phase first and the remaining two phases after 2-3 cycles. It requires knowledge of the residual flux in one phase only, independent pole breaker control, but does not require any transformer parametric data. In simultaneous closing, this closes all three phases together at an optimum point for the residual flux pattern. It does not require independent pole breaker control, but requires knowledge of the residual flux in all three phases and the the residual flux magnitudes in two phases are high and follow the most traditional residual flux pattern.[3][4].These closings are chosen as part of an inrush current reduction strategy for the three phase transformer that enables the use of the three pole CBs. The prefluxing device shown in Fig.2 consists of a capacitor, a diode 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 sys-tem and connects across one of the transformer winding (the primary winding).

Ideally, the high voltage winding issued because of the reduced magnetizing current on this winding. Since the prefluxing device is applied only when the transformer is isolated and can operate at very low voltage, relatively inexpensive isolator switches can be used to connect the device to the transformer. The prefluxing device is sized to operate around the transformer's magnetizing current level, so the capacitor, diode and switch can be sized for a fraction of the transformer rated current [7].

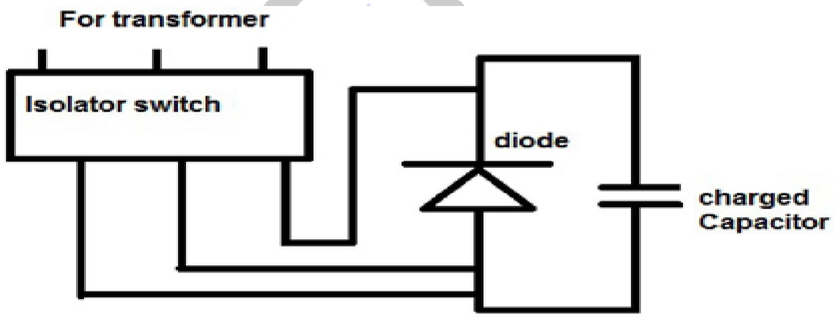

Fig. 2. Prefluxing device

V. MITIGATION OF INRUSH CURRENT IN TRANSFOMER USING PREFLUXING

The inrush current can be mitigating using prefluxing device as shown in Fig.2. As section III describes that mitigation of inrush current is two steps process

A. Step I- Prefluxing Device

The prefluxing device which shown in Fig. 2 is connect in the primary winding of transformer. The device should connect to transformer only when transformer is isolated. It will feed some amount of DC flux before energization of transformer. When the transformer is energized, at the same instant, the prefluxing device will be separated by circuit breakers or isolated switches [7]. This prefluxing device sets a known residual flux in the primary of transformer. Then by point- on- wave switching, the transformer will be energizing at according to the residual flux. The capacitor will be charged according to the maximum value on the transformer. It should be almost equal to the maximum value of flux. Fig. 5 shown the prefluxing device which is connected to primary of power transformer. This device injects DC flux till the phases of trans-former energized. The simulation has been designed and developed in MATLAB and filters are also used to limit the harmonics.

VII. SIMULATION RESULT

A. Inrush Current Without Using Prefluxing

The results of model which shows in Section III . The inrush cur-rent in each phases shown which is 7 times greater than rated cur-rent. Figs. 5, 6 and 7 shows the inrush current in phase A, B and C and Fig. 8 show the flux in primary.

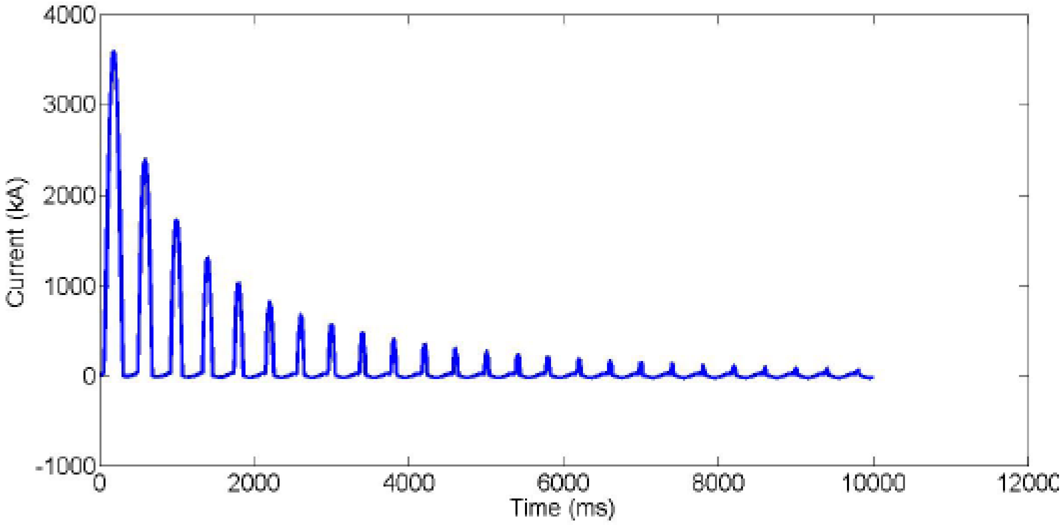

Fig. 3. Magnitude of inrush current

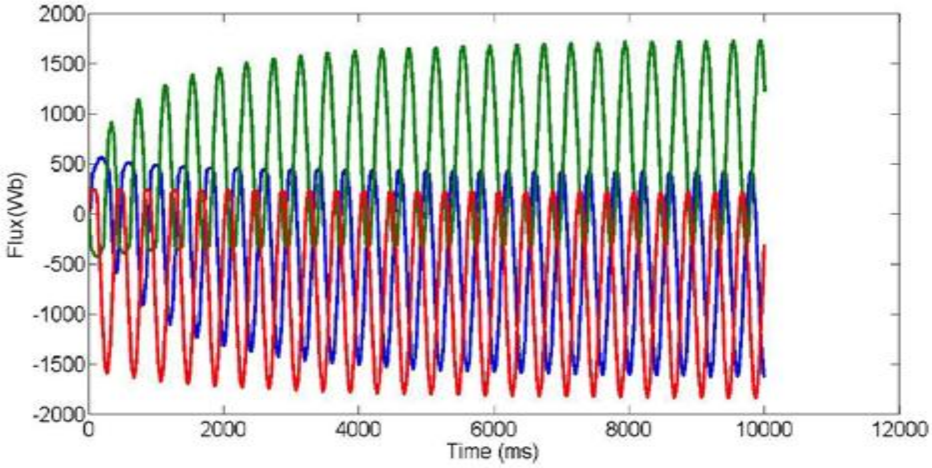

Fig. 4. Fluxes in all three phases.

VIII. CONCLUSION

This paper presents 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 energized the transformer at a specified system voltage angle based on the flux polarity. This strategy has advantage over some of the presently suggested reduction strategies, including removing the need for residual flux measurement during transformer de-energization. The prefluxing device that sets the flux of the trans-former is simple in form and 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 trans-former.

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