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Mitigation of Transformer Magnetic Inrush Current

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Abstract-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. Transformer inrush current is high magnitude and harmonic rich current. These current produces undesirable operations of the protective equipments in the power system. Due to these inrush current some undesirable operations may happen such as protective relays disoperation, loss of life of transformer potential damage, mechanical stress on the transformer and affects on the winding and bushing of transformer and reduce power quality. There are many sensitive electrical loads such as computer and medical equipments connected to the power system may disrupt. So the reduction and way to control transient current is important. There are different method used to minimize inrush current such as controlled switching ,virtual airgap techniques ,and prefluxing method. In this paper explains above written method of minimization of inrush current in the transformer .

Key words: - controlled switching, inrush current, prefluxing method

I. INTRODUCTION

Three-phase transformers are key components in power system 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 overvoltage resulting from the inrush current causes serious damage to power apparatus. It is very important to solve the effect of inrush current. The uncontrolled energization of transformer produces high inrush currents, which can reduce the transformer'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

$1-\emptyset$ hysteresis- characteristics of the core, the resistance in the primary circuit, and many others which has been described in. There are three negative side-effects of inrush currents: 1) The protective devices for overloads and internal faults may falsely operate and disconnect the transformer. There are examples of the available techniques for relays to distinguish between faults and inrush currents used to reduce the number of undesirable trips 2) The windings are exposed to mechanical stresses that can damage the transformer and 3) Power-quality problems may arise: high resonant harmonic over voltages and voltage sags. 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. This paper proposes a new technique to mitigate inrush current of three phase power transformer called prefluxing. In this method, some 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 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. 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.

III. CAUSE OF INRUSH CURRENT PHENOMENON

There are two main cause of inrush current in the transformer

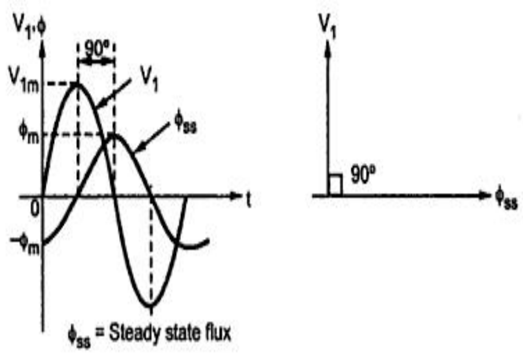


Fig.1

When the primary voltage V1 is switched on to the transformer, the core flux and the exciting current undergo a transient before achieving the steady state. They pass through a transient period. The effect of transient is severe when voltage wave pass through origin. In the inductive circuit flux can start with zero value. But the steady state value of flux at start is-$\emptyset_m$, as shown in the Fig. 1, at t = 0. Thus during transients a transient flux called off-set flux, $\emptyset_t = \emptyset_m$ originates such that at t = 0, $\emptyset_t + \emptyset_{ss}$is zero at the instant of switching. This transient flux $\emptyset_t$ then decays according to circuit constants i.e. ratio L/R. This ratio is generally very small for transformers. Practically initial core flux can not be zero due to the residual flux $\emptyset_r'$ present, due to retentively property Switching instant of transformer energization angle.

Switching instant of transformer energization angle- In the steady state operation, both V1 and Φ are sinusoidal and Φ lags V1 by 90°as shown in the Fig1 of core. The transient resultant flux goes through$\emptyset_r = \emptyset_r' + 2\emptyset_m$ and there is heavy inrush current in practice. The effect of transient is even severe in practice Such high transient current gradually decreases and finally acquires a steady state. It can last for several seconds. The transient flux $\emptyset_t$ and exciting current both are unidirectional during transients. In steady state, exciting current becomes sinusoidal. The Fig. 3 shows the oscillogram of the inrush current. Thus during transients, the total flux goes through a maximum value of $2\emptyset_m$. Such effect is called doubling effect. This is shown in the Fig.2 Due to the doubling effect; core flux achieves a value of $2\emptyset_m$ due to which transformer draws a large exciting current. This is due to the fact that core goes into deep saturation region of magnetization. Such a large exiting current can be as large as 100 times the normal exiting current. To withstand electromagnetic forces developed due to large current, the windings of transformer must be strongly braced. This large current drawn during transient is called inrush phenomenon.

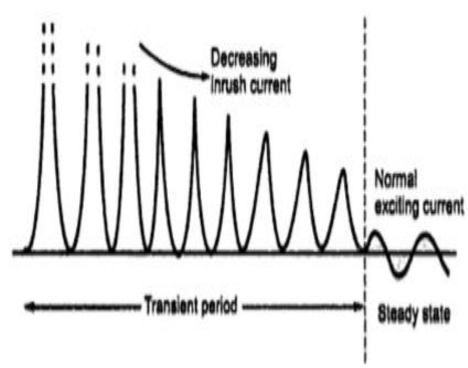


Fig.2 oscillogram of inrush current

Residual flux in the transformer core-Whenever a power or distribution transformer is isolated from the power system, it is very probable that residual magnetism remains in the core due to the phase shift. However, residual magnetism also occurs when performing winding resistance tests. Residual magnetism leads to high inrush currents, which put a great and unnecessary load on the transformer. When a transformer is re-energized, an inrush current occurs that can greatly exceed the nominal current. If the transformer core still contains residual

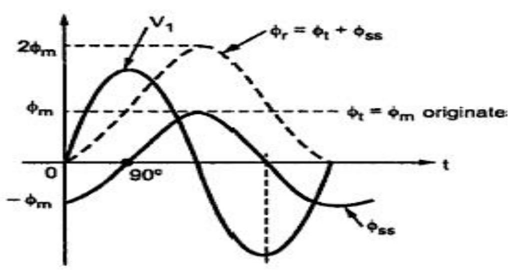
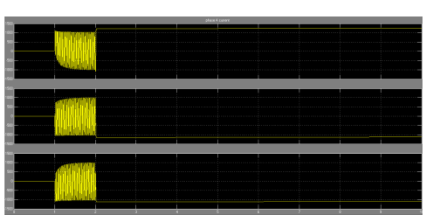


Fig.3

magnetism, the first peak current can even reach the level of the short-circuit current. These high currents can cause undesirable effects, such as mechanical deformation of the windings, incorrect triggering of protection equipment, increased stress for the installation, and voltage dips in the grid. Only the ohmic components, such as the winding resistance, are capable of attenuating the high inrush currents to a stable level within just a few cycles. The highest inrush current occurs when the voltage is applied near the zero crossing and the polarity of the voltage is applied in the same direction as the residual

Fig.4 shows the MATLAB model for simulation study. Fig.5 & Fig.6 respectively show the inrush current wave and flux wave in all the three phase.



magnetism in the core or the corresponding limb.A. large, unsymmetrical magnetizing current is required to support this level of flux in the transformer core, because the transformer core operates in saturation at this level of flux.

IV. MODELING OF INRUSH CURRENT IN TRANSFORMER

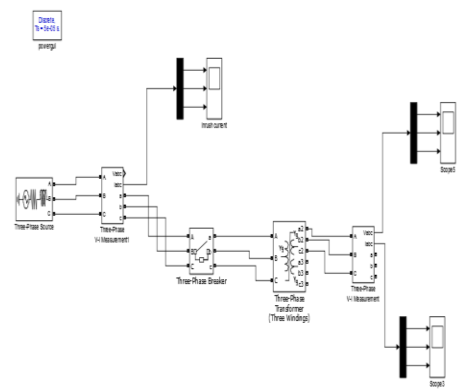


Fig.4 MATLAB model for simulation study

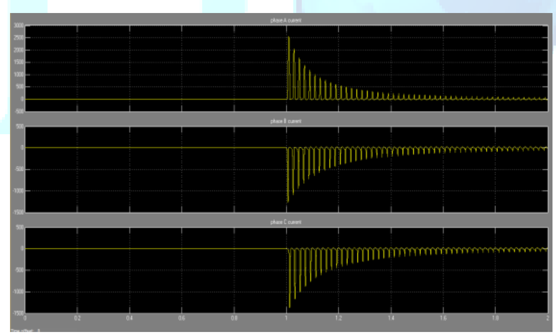


Fig.5 inrush current wave

Fig.6 flux wave in all the three phase

V. TECHNIQUES FOR REDUCTION OF TRANSFORMER MAGNETIZING INRUSH CURRENT

By Controlled Switching- Controlled switching of single phase transformers: In case of Controlled closing of capacitors, optimal energization point is at the instant when the source voltage is equal to the trapped charge voltage on the capacitor. For the case of controlled closing of transformers, the "trapped charge" has a parallel in the residual flux. So the basic principle to eliminate the core flux asymmetry, the "induced" flux (integral of applied voltage) at the instant of energization must equal the residual flux. There is of course no induced flux before energization, but the source voltage has the prospect to create an induced flux. If the source voltage is considered as a virtual flux source, then an optimal instant to energize transformer is when the prospective flux is equal to the residual flux. It provides the basic strategy for controlled closing on single phase transformers. In case of controlled switching in multiphase transformer with no residual flux, only transformers with single-phase cores and only grounded windings may be considered as three single phase transformers, but most transformers on power systems have interaction between the phases. In these other transformers, after one phase has been energised, the flux in the other cores or core legs is not a static residual flux, but a transient flux, in the following called "dynamic" core flux. Residual Flux: The residual core flux can assume values up to 85% of peak normal flux, although more typical magnitudes are in the range of 20 to 70%. In most three phase transformers, it is possible to use residual flux measurements and controlled closing to In these other transformers, after one phase has been energised, the flux in the other cores or core legs is not a static residual flux, but a transient flux, in the following called "dynamic" core flux. Residual Flux: The residual core flux can assume values up to 85% of peak normal flux, although more typical magnitudes are in the range of 20 to 70%. In most three phase transformers, it is possible to use residual flux measurements and controlled closing to eliminate transformer inrush transients. There are three closing strategy for controlled switching.

A. Rapid Closing Strategy - This strategy 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 (no studies were run to compare transient performance of different transformer designs to determine error from assuming a standard model)

B. Delayed Closing Strategy- This strategy 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.

C. Simultaneous Closing Strategy- This strategy 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 that the residual flux magnitudes in two phases are high and follow the most traditional residual flux pattern.

Virtual Air Gap Technique-

This technique is based on the use of virtual air gap which equivalent thickness varies in function of controllable parameters adapted to the configuration of magnetic circuit and the associated control system. This study aims to modify the reluctance of a magnetic circuit using auxiliary windings called AGW (Air Gap Windings). The AGW current is either set to a specific value using an external source, or a current sensor, in the main magnetization winding of the magnetic circuit. Physically, the effects observed on the experimental system are very similar to those of devices with a real built-in-air-gap. The originality of the method is in the control of the air gap thickness by the AGW current. Using an AGW always requires a magnetic circuit which is magnetized through a main winding (primary of a transformer).

Sequential Phase Energisation Technique:- This is a simple and low cost method to reduce inrush currents caused by transformer energisation. The method uses a grounding resistor connected at a transformer neutral point. By energizing each phase of the transformer in sequence, the neutral resistor behaves as a series inserted resistor and thereby significantly reduces the energisation inrush current. This method is much less expensive, however, since there is only one resistor involved and the resistor carries only a small neutral current in steady-state. Simultaneous closing of all three-phase breakers did not produce sufficient reduction on the inrush currents. However, if one closes each phase of the breaker in sequence with some delays between them, the neutral resistance could behave as a series resistor and improve the results. This simple improvement has proven to be very effective. In fact, the idea of sequential energisation of three-phase equipment can lead to a new class of techniques to reduce switching transients

PREFLUXING TECHNIQUE- As controlled switching had been the most popular technique to mitigate inrush current, the most important aspect in the method 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. 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 dischargd into the transformer when closing The device switch, establishing the desired flux polarity. It is necessary for the prefluxing device to set the residual flux of a transformer as high as possible to minimize the inrush cur- rent, but also to do so efficiently

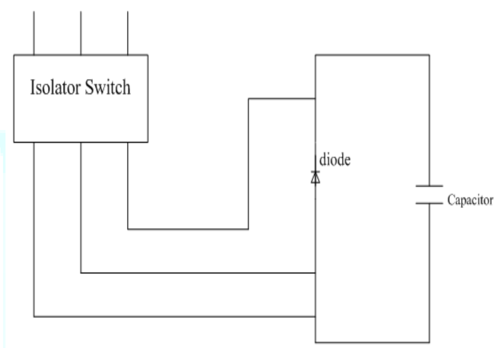


Fig.7. Prefluxing Device

IV. CONCLUSION

The phenomenon of core flux reduction can greatly simplify closing strategies, allowing the delayed strategy to be very effective. The delayed strategy can also provide a reduction of inrush transients when switching transformers with more than three core legs and no delta connected winding. However, complete elimination of inrush currents is not possible with theses configurations. In Sequential phase energization technique, there is an optimal neutral resistor value for the proposed scheme. This value is a compromised value between the need to suppress the inrush currents when the first two phases are energized and need to suppress the current when the third phase is energized. It is not essential to use an exact optimal value. Resistances around the optimal value are almost equally effective. With the proposed resistance value(s), the neutral resistor based scheme can lead to 80% to 90% reduction on inrush current[3]. A small neutral resistor size of less than 10 times the transformer series saturation reactance can achieve 80 to 90% reduction in inrush current among three phases

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