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Real Time Analysis Mitigation of Inrush Current Generated by Power Transformer to Improve Power Quality on the System

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Abstract: **This inrush current is generated typically in unloaded power transformers and at times can attain the value of around 10 times the full load value. In this method it is proposed to use a voltage source PWM converter which is to be connected in series to the transformer that will produce a dynamic resistor in series with transformer and reduce inrush current. This method will be validated using MATLAB Simulations. It is expected that the proposed method removes inrush current substantially .It is expected that this strategy will be easier to implement because it has simple control method and requires no information of the transformer parameters, power on angle circuit breaker and measurement of residual flux and so on.**

***Keywords*— WM, MATLAB, dynamic resistor, circuit breaker.**

I. INTRODUCTION

When a power source is applied to the transformer the iron core may be saturated as a result of the phase of the power source voltage even when there is no load the inrush current tends to reach a value approximately ten times greater than the rated current. Such high value of inrush current has been a major cause of concern when energizing unloaded transformers in a power system. If this energization is left uncontrolled it will lead to high value of inrush current resulting in reduction of transformer's residual life due to the high mechanical stresses involved, and can also lead to the unexpected operation of protective relays and power quality reduction. This value of inrush 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 others [2]. The basic methodology for reducing magnetizing inrush currents includes removal of residual flux, adjustment of the phase angle of source voltage, insertion of resistance, PWM inverter and others. Apart from the passive solutions mentioned above, this work intends to present a series voltage-source PWM converter for minimizing the undesired inrush current during startup mode. This strategy with control reference signal for generate switching signals operated at a resistance of $K[\Omega]$ with respect to the transformer primary current, and the inrush current accompanying the input of the transformer is suppressed.

II. LITERATURE REVIEW

Transformer inrush currents have always been a concern in a power industry. Inrush currents generated by unloaded power transformer often reduce power quality on the system. Over the last decades, methods have been proposed to remove transformer inrush currents [1]. Inrush currents generated by unloaded power characteristics of circuit breaker also have a strong influence transformer often reduce power quality on the system. To determine the correct instant of mechanical closing time. Improve this situation; this paper proposes an active inrush meanwhile, various statistical deviations in the characteristics current compensator that is capable of reducing the inrush [2]. This paper presents a new, simple and low cost method to reduce inrush currents caused by transformer energization. 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 energization inrush currents [3]. In the power system voltage sag become the important issue for industries. According to the survey 92% of the interruptions at industrial installations are voltage sag related [4]. This paper presents a novel method for the minimization of three-phase transformer inrush current in the case of sustained switching-on operations [5]. Sympathetic inrush current phenomenon occurs when a transformer is switched on in a power system network containing other transformers which are already energized. In this paper, the phenomenon of sympathetic inrush current is investigated using nonlinear transient field-circuit coupled finite element formulation [6]. Digital techniques for modeling the inrush current associated with the energization of single-phase transformers are described. [7]. It was found that a neutral resistor together with `simultaneous' switching didn't have any effect on either the magnitudes or the time constant of inrush currents [8]. With more and more renewable and other distributed energy resources (DERs) being adopted, the utility requires these DERs systems have low voltage ride-through (LVRT) capability, which means the DERs [9]. A methodology for the reduction of the residual flux in network transformers is proposed in this paper. The purpose is the mitigation of large inrush currents taken by numerous transformers when a long feeder is energized. Time-domain simulations are used to prove that a small-power device can substantially reduce the residual flux of all transformers simultaneously [10].

III. MOTIVATION

When a power source is applied to the transformer the iron core may be saturated as a result of the phase of the power source voltage even when there is no load the inrush current tends to reach a value approximately ten times greater than the rated current. Such high value of inrush current has been a major cause of concern when energizing unloaded transformers in a power system. Any effort in the direction of reducing the inrush current will improve the power quality of the system.

IV. PROBLEM DEFINITION

Transformer inrush currents have always been a concern in a power industry. When a power source is applied to the transformer the iron core may be saturated as a result of the phase of the power source voltage even when there is no load the inrush current tends to reach a value approximately ten times greater than the rated current. Such high value of inrush current has been a major cause of concern when energizing unloaded transformers in a power system. If this energization is left uncontrolled it will lead to high value of inrush current resulting in reduction of transformer's residual life due to the high mechanical stresses involved, and can also lead to the unexpected operation of protective relays and power quality reduction. Over the last decades, methods have been proposed to remove transformer inrush currents.

The problem of Inrush current and its effect on the power quality of the system is to be mitigated.

V. DIFFERENTMETHODS

There are many possible mitigation methods which are discussed below are different circuits which are effective in certain operating conditions.

A. NTC Power Thermistor

One of the most common methods used to suppress inrush current is to connect NTC (Negative Temperature Coefficient) power thermistors in series to the line. The resistance of a thermistor varies inversely with temperature and offers variable resistance. One of the main problems with this method is that the thermistor requires a cool down-time to increase its resistance before it can take the next impulse of inrush current. If the system were turned OFF and ON repeatedly in a short amount of time, the thermistors would not have sufficient time to recover in order to limit the current again [1]. Fig. 1 shows effectiveness of NTC to reduce heavy inrush current.

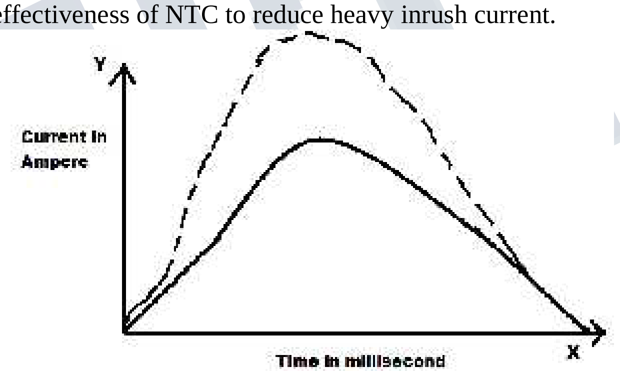

Fig.1. Effect of NTC on inrush current

B. Current limiting impedance

Current limiting impedance can also be used to limit inrush current of transformer. In fig. 2 current limiting impedance is shown that would be bypassed by a short circuit after some time has passed in order to limit the current at the start, but still conserve power in steady state. This impedance could be a resistor, an inductance, or a series combination of both. The drawback of current limiting impedance is power losses that result from steady state current flowing through them. However, these impedances are commonly bypassed by shortcircuiting them to suppress such losses [2].

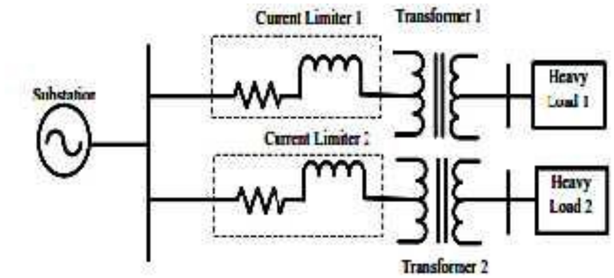

Fig.2. Current limiting impedance on power transformer

The response time of current limiter is decided by its time constant. There has to be optimized value for such circuits which cannot be generalized. When heavy inrush current start flowing through operating transformer, limiter damps its magnitude. It has coupled in such a way which demagnetizes to avoid saturation current.

C. Synchronous Closing

Each winding of the transformer should be switched at the maximum of the voltage so that inrush current can be reduced to avoid saturation. Also by triggering the system at a phase angle that is different from the supply voltage source inrush current can be minimized. The concept behind this technique is to trigger the circuit at the specific phase at which the transient response of the circuit would be minimized. In order to trigger the system at a specific phase-angle compared to the voltage source, a delay can be implemented in the switching mechanism that depends on the phase-angle which depends upon the impedance of the system. Such delays are usually achieved by a separate clock, synchronized with the voltage source [3]. If we choose to switch transformers at voltage zero-crossing instant, the calculated inrush currents will be approximately 10% higher. It is observed that the total inrush currents for four, eight, and sixteen transformers are 23%, 26%, and 27% larger than for a single transformer, respectively.

D. Tap changer utilization

To reduce the inrush current, a higher impedance of the winding is required so, connecting the transformer using the maximum number of turns (lowest tap) in the windings to increase the impedance and reducing the inrush current and their effects. This possibility was accepted due to their reduced cost and easy application. Thyristor tap changers may be configured to provide continuous or discrete level control. Continuous control is based on delay angle control, Delay angle control generates harmonics. To achieve little or no harmonic generation, tap changer must provide discrete level control [4].

E. Active Series Compensators

An active inrush current compensator is capable of reducing the inrush current effectively during startup. The proposed compensator is based on an inverter-based series compensator which is comprised of a single-phase inverter and series transformer. Voltage sags are very frequent events with energization of transformer or starting of large motors although their duration is very short. Hence, during voltage stabilizer mode, the existing series compensator is controlled by a voltage stabilizer controller and superimposes a compensating voltage on the inverter output whenever the load voltage deviate from the nominal value. This strategy is easier to implement because it requires no information of the transformer parameters [6]. Each power transformer should have dedicated series compensator. Active series compensator has to be critically designed to avoid losses in the form of heat. The magnetic coupling is again in anti-phase if the amount of current passing through compensator is exceeding set value. Switching in the compensator is fast to have proper demagnetizing effect during transients.

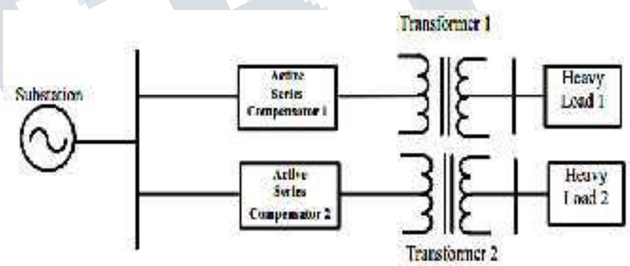

Fig.3. Mitigation by active series compensator

Fig. 3 shows two active series compensators which are connected in series with respective transformers. They have independent switch mode controller circuits with energy storage elements. Depending on inrush current, active series compensator acts to limit current of transformer.

F. Controlling BH curve of transformer

Magnetizing and demagnetizing pattern can be controlled to limit large inrush current. It is achieved by resonating transformer with LC circuit. It is more optimized for medium loading condition [7].

G. Dynamic Voltage Restorer

Dynamic voltage restorer (DVR) has very fast dynamic response. It is featured for current limiting. Thus impact of overvoltage is less. Along with compensation, the harmonics are minimized to improve power quality. Voltage restoration helps in minimizing the fault impact as well as increase stability [7-8].

H. Ultra fast capacitor

An ultra-fast capacitor (UF capacitor) charging and discharging reduces transients. Ultra capacitor is source of energy. It acts as a dynamic voltage source. Two control switches are connected in parallel and this combination is connected in series. One switch controls charging while another is present in discharging. Controller signals are controlling switches. The closed loop operation can be achieved based in the value of overvoltage [9].

I. Inrush current limiting reactors

This method employs reactors in series with the capacitor bank. The reactor increases the magnitude of the surge impedance, effectively reducing the peak value of the inrush current. Also, since the current through the reactor cannot change instantly, the higher frequency components of the transient are limited and the severity of the current inrush transient is reduced. Sometimes reactors are built intentionally with higher resistances to increase damping of the transient [10].

J. Energized by a less capable source

If energized by a less capable source, such as a generator set, the current inrush would be somewhat less than when energized by a utility line, but still very large because of the large short circuit current capability of a synchronous generator. In either case, the severe power transient induced by switching on transformers can be very disruptive to the electrical system, particularly when it is being powered up. If the utility line is live, switching on transformers would not induce a significant inrush current if the transformers were to be energized in a stagger mode allowing sufficient time for the inrush current on each transfer to decay sufficiently (typically 2 to 3 seconds) before switching on the next transformer [11]. However, typically due to cost constraints, in most cases the connection between the transformer and the utility line would be made using a fuse protected switch which would not allow for staggering transformer switch-on, and therefore, all transformers would be energized simultaneously. Energizing multiple transformers at once would then induce a much stronger inrush current onto the utility line, but with a reasonable stiff power source it would be well within the utility source capabilities.

VI. OBJECTIVES

The basic objective of the intended work is to mitigate the problem of Inrush current and its effect on the power quality of the system it is proposed to introduce an active inrush current compensator that is capable of reducing the inrush current effectively during start up mode.

The method will be implemented using a voltage source PWM converter which is connected in series to the transformer that produce a dynamic resistor in series with transformer and remove inrush current.

VII. DESCRIPTON OFWORK

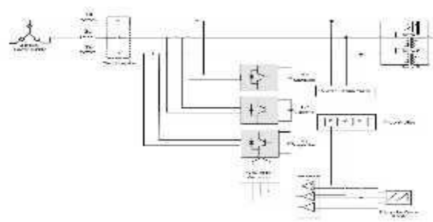

Fig. 5. Description of Proposed Work

Figure 5 above shows a diagram of the main circuit for the device to suppress inrush current in the single-phase circuit proposed in this paper. The voltage-source PWM converter is connected in series to a power source. The filters used to limit switching ripple are connected to the output side of the voltage source PWM converter. The output voltage of the PWM converter is determined by reference signal that produce by source current multiple in *K [Ω] and then comparing it with the triangular* wave[9],[10],[11],[12]. The switching signals apply to IGBT Bridge to produce voltage in phase with current. This IGBT Bridge inserts in series with transformer and reduces inrush current because of limitation initial voltage transformer and prevent from core saturation.

$$v_{out} = k.\, I_{source} \qquad (1)$$

The control gain *K* must be determined so that a voltage that does not exceed the saturation flux value is not applied to the transformer. If we assume that power is introduced in a state in which the transformer is not saturated, then the composite impedance *Z* for a single-phase circuit in the transformer and for an inrush current suppressing PWM converter using *K* [Ω] as its resistance is given by

$$Z = K + j\omega(L_s + L_r) + \frac{1}{g_0 + jb_0} \qquad (2)$$

That jωLs is power supply side impedance g0 and b0 are shunt core loss and shunt magnetizing reactance. As a result, the theoretical value for the transformer primary current Isource is given by

$$I_{source} = \frac{v_{source}}{Z} = \frac{380}{Z} \qquad (3)$$

It is expected that the proposed scheme is validated through MATLAB simulations.

VIII. SIMULATION RESULT

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As considering methods discussed in the above section are considered based on capacity of transformer. Among all types of mitigation, is done to observe parallel performance of transformers. Paralleling of transformers during switching operation is shown in fig. 6. It shows variation in transformer voltages, currents and fluxes. The transients present are high which leads to saturation in magnetic core. Figure 2 shows Fourier analysis of current. It shows large amount of DC and second harmonic component. Large amount of zero and second harmonic of component creates imbalance in fluxes. This has impact on not only core but also insulation strength of both windings.

This shows less variation in transformer voltages, currents and fluxes.

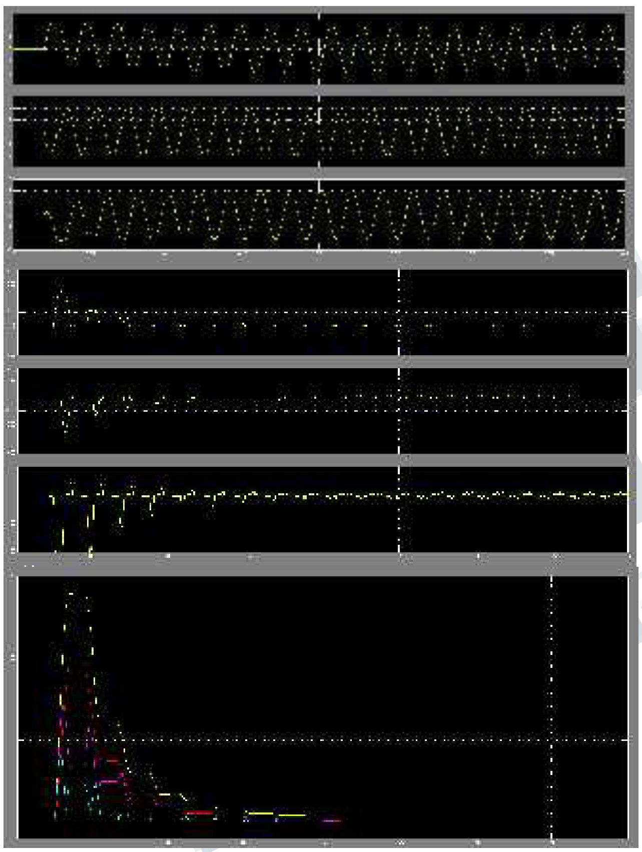

Fig. 6. Transient Periods of final simulation results Case 1, Case 2 and Case 3

IX. RESULT

In this work paper, an effective method for suppression inrush current in single and three phase transformers has been obtained. Specifically, a voltage-source PWM converter in series to the power source without a matching transformer so that the inrush current is suppressed when the transformer is energized. This voltage-source PWM converter acts as a resistance of K [Ω] with respect to the primary current of the transformer, which results in suppression of inrush currents during energization. As a result, the inrush current that accompanies power flow to the transformer can be suppressed. This method will not require any information of the transformer, amount of residual flux, phase angle.

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