MITIGATION OF MAGNETIC INRUSH CURRENT IN A SINGLE PHASE TRANSFORMER USING VOLTAGE SOURCE CONVERTER

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ABSTRACT
In a power system, transformers are critical components for electrical energy transfer. The transformer is a static device that uses mutual induction between the windings to transfer electrical energy from one circuit to another without using any direct electrical connections. It transfers power from one circuit to another at varying voltage levels without affecting the frequency. The transformer will draw a large amount of current when it is switched on which is known as transient inrush current. A transient current up to 10 to 50 times greater than the rated transformer current can flow for several cycles when a transformer is first energized. Any rapid changes in the magnetizing voltage cause a magnetizing inrush current in the transformer. The magnitude of this current is determined by several factors, including the supply voltage switching instant, residual flux, the transformer core's hysteresis characteristics, the primary circuit impedance, and so on.
The system is disrupted by the magnetizing inrush current, which destroys the transformer windings. Inrush current must be lowered to improve this scenario. This project will look at inrush current limiters, which are used to reduce inrush current when a transformer is switched on. Inrush current limiters such as voltage source PWM converter are employed in this application. The simulation is run in MATLAB, and the results are tabulated.
Keywords: Transformer inrush current, Core saturation, Residual flux, PWM converter.

1. INTRODUCTION
A power transformer is a type of electrical power system component that is extremely expensive and essential. If a power transformer develops a malfunction, it must be removed from operation as soon as feasible to limit the damage. Transients are one of the most common anomalies in transformer circuits. A transient is a brief surge in voltage or current lasting less than 10 microseconds. The transformer runs inefficiently as a result of transients, and the temperature of the transformer windings rises above the tolerable limit, causing damage to the transformer [1,2]. Transients must be suppressed in order to solve the problems they cause.
The usage of power electronic converters to reduce transformer inrush current is explored in this work.

2. ANALYSIS OF MAGNETIZING INRUSH CURRENT
There are two sorts of transients in power transformers. Transients that occur both internally and externally in a transformer. Switching procedures cause external transients [3]
There are three forms of internal transients.
Magnetizing inrush current
Internal fault
Over excitation

Magnetizing inrush current

Any abrupt shift in the magnetizing voltage causes a magnetizing inrush current in the transformer. The inrush current waveform is rich in harmonics and has a substantial and long-lasting DC component [5]. It can reach huge peak levels (up to 30 times the rated value) at first, then slowly decays for a few tenths of a second before fully decaying after several seconds. Figure 1 depicts a typical inrush current waveform. It clearly shows DC offset and even harmonics of varying magnitudes, generally with high second harmonic values.

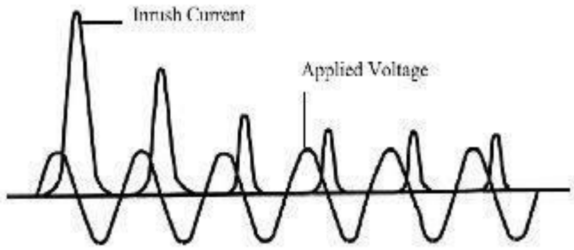

Figure 1. Magnetizing inrush current of transformer

Several factors influence the shape, amplitude, and duration of the inrush current [4,6].

1. Size of the transformer.
2. Source impedance.
3. Magnetic property of the core material.
4. Remanence in the core
5. Switching instant of the transformer.
6. Way a transformer is switched on.

As previously stated, the magnetic inrush current is determined by the transformer's switching instants. Inrush current would appear if the transformer was turned on at the Zero crossing instant. The inrush current will not arise in the transformer if the transformer was turned on at the positive or negative peak. Since the transformer's instantaneous switching is beyond our control. We can turn on the transformer at any time utilising a series-connected voltage source PWM converter without causing the inrush current to flow.

3. INRUSH CURRENT REDUCTION TECHNIQUES

Years of research have gone into determining the optimal approach for controlling transformer inrush current. The majority of inrush current reduction strategies are centered on removing asymmetry in the core flux during switch-on [7,8]. It has been discovered that the ideal time to turn on the transformer is when the voltage wave reaches its highest value, resulting in the least amount of inrush current. When a transformer is turned on at the voltage wave's zero crossing instant, the maximum inrush current is measured [9]. Setting a single-phase transformer's residual flux to a known polarity after the transformer has been de-energized, referred to as "prefluxing," and controlling the instant of transformer energization depending on flux polarity is a novel inrush current reduction approach [10]. The inrush current is likewise reduced by pre-insertion of resistance, but ohmic losses are increased. Other options, such as altering the core material or adding an auxiliary winding to operate as a virtual air gap, raise the cost.

Due to the aforementioned limitations, this study discusses some simple and effective approaches for reducing transformer inrush current.

1. Use of series-connected voltage-source PWM converter

The transformer is connected to the source in this method, and the inrush current is suppressed by a series-connected PWM-converter. The series compensator injects a compensatory current into the series transformer's secondary winding. The series compensator's compensating current is polarised in the opposite direction as the power transformer's inrush current. As a result, the inrush current is effectively suppressed [12,13].

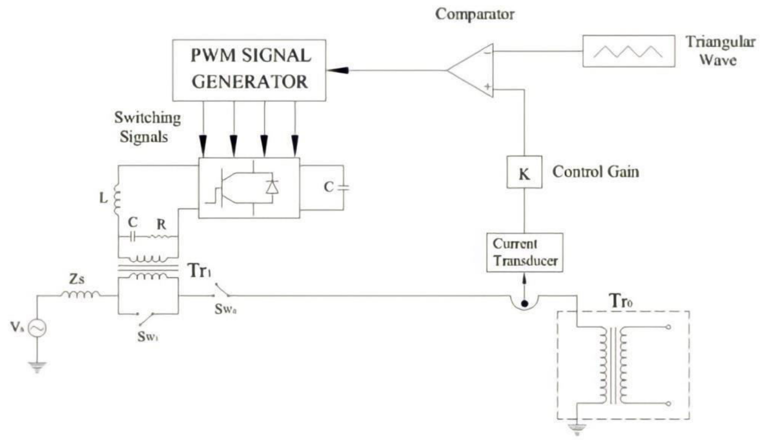

Figure 2. Voltage source PWM converter type inrush current suppresser used in single-phase circuit.

Tr0 is the main transformer in the proposed circuit depicted in Fig. 2 that causes the inrush current phenomenon. Through a matching transformer Tr1, a small-rated voltage-source PWM converter is linked in series between the main transformer Tr0 and the source Vs. When the sine-triangle intercept approach is utilized, the PWM converter serves as a resistor. On the ac side of the PWM converter, a small-rated LC filter is attached to reduce the switching ripple created by the switching action.

The same technique that is utilized in single-phase circuits may also be employed in three-phasecircuits. The simulation circuit of Magnetic Inrush current without Voltage source converter is shown in Fig. 3.

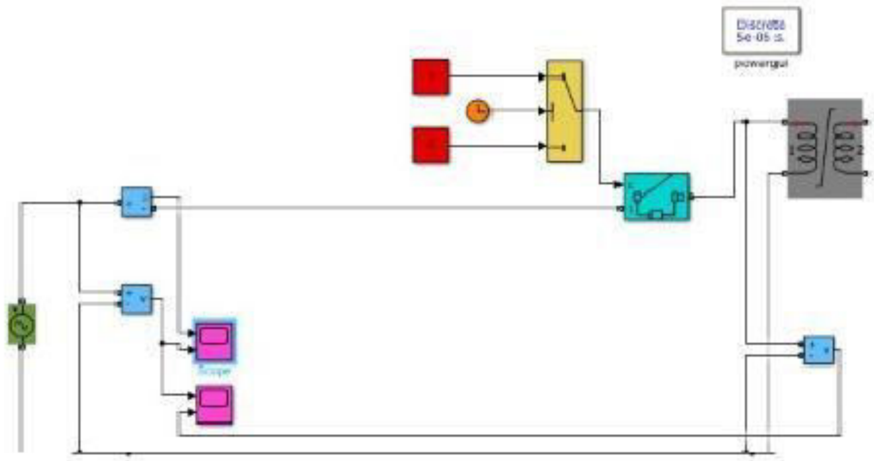

Figure 3. Magnetic Inrush Current without Voltage source converter

The simulation circuit of single phase voltage source PWM converter suppresser is shown below in Fig. 4**.**

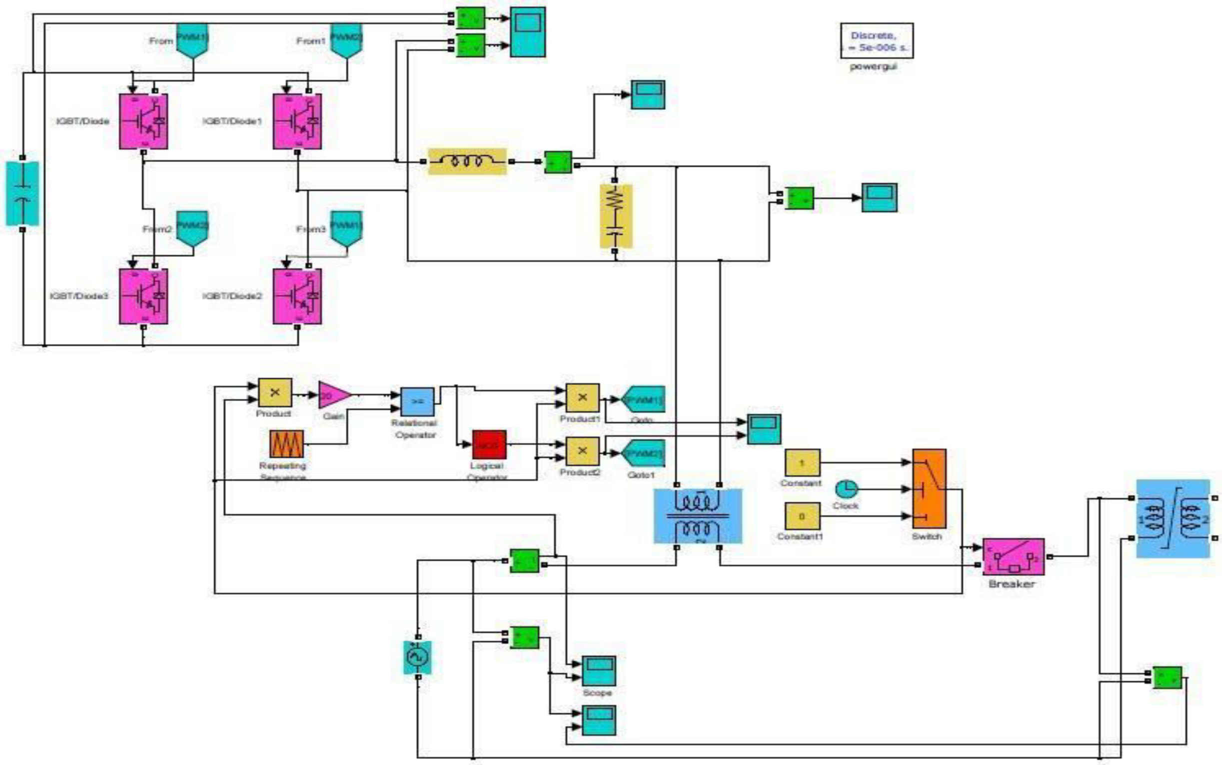

Figure 4: Circuit of single phase voltage source PWM converter suppresser

4. SIMULATION RESULTS

MATLAB SIMULINK is used to conduct simulation studies for the approaches outlined above. Figure 5 shows the simulation result of inrush current in a single phase transformer at zero crossing instant.

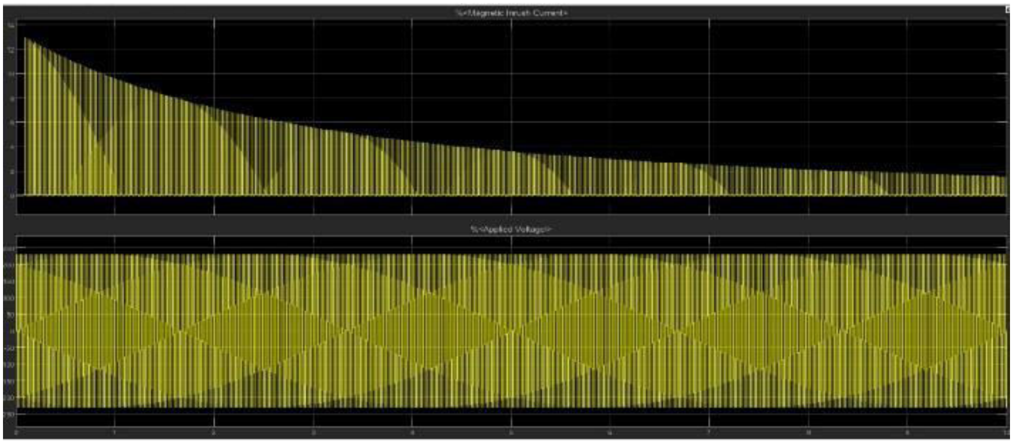

Figure 5. Waveform of inrush current observed at zero crossing

The simulation result of inrush current in single phase transformer when the switch is closed at Positive peak is shown in Fig. 6.

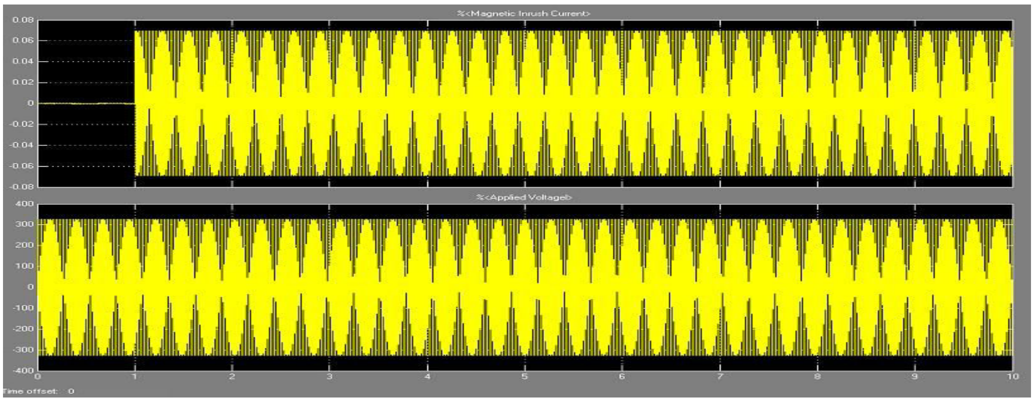

Figure 6. Waveform of inrush current observed at Positive peak

The simulation result of inrush current in single phase transformer when the switch is closed at Negative peak is shown in Fig.7.

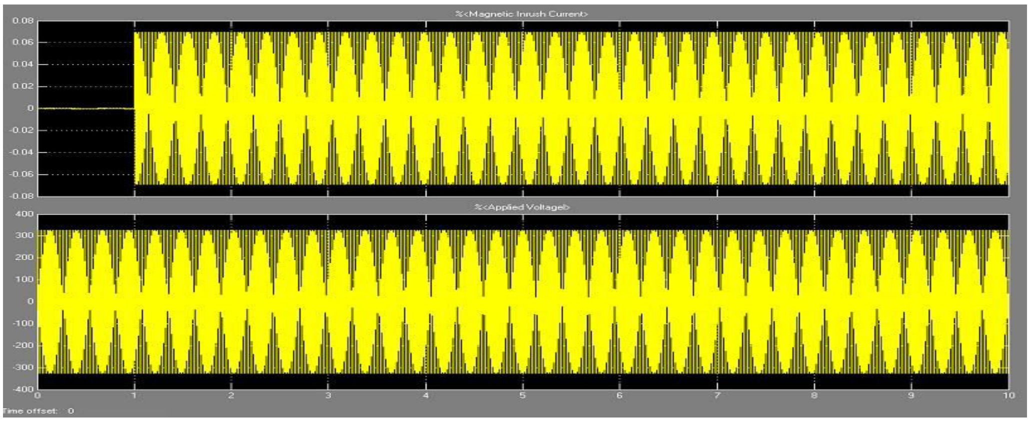

Figure 7. Waveform of inrush current observed at Negative peak

The simulation output of the single phase voltage source PWM converter suppresser is shown below in Fig. 8.

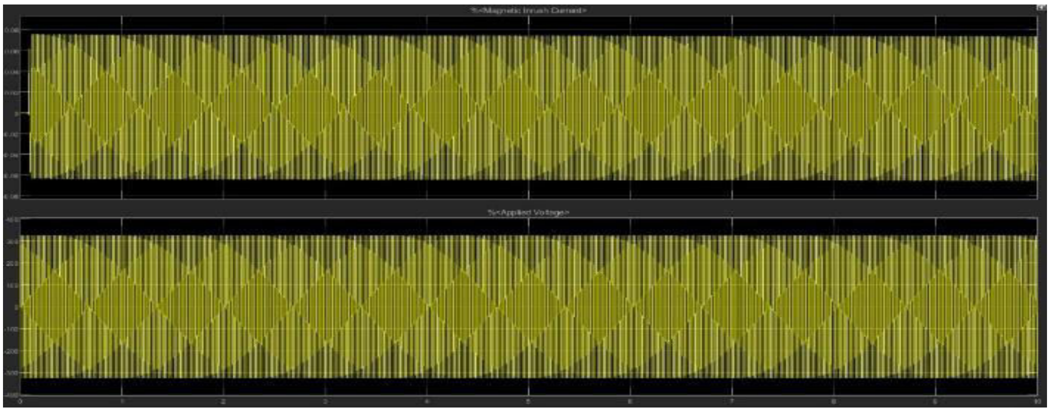

Figure 8. Current waveform using Voltage source PWM converter

CONCLUSION

This work investigates and proves techniques for decreasing transformer inrush current using power electronic converters. These methods have several advantages, including a simple power circuit, reliable operation, no information is required for residual flux, switching instant, and other variables. In addition, these current limiters are less expensive. From the results obtained main conclusion can be summarized from table shown below.

Effect of VSC on Mitigation of Inrush current

Switching Position	Magnitude of Current	
	Without VSC	With VSC
Zero Crossing	48.5 A	1.19 A
Positive Peak	1.19 A	1.19 A
Negative Peak	1.19 A	1.19 A

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