Reduction of transient inrush current in transformer using 'Point on Wave Switching 'method

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***Abstract*: This paper introduces a methodology to investigate Point on wave switching to reduce magnetizing inrush in Transformer. When transformer is switched into a service, transformer will get energized and transformer primary draws high current. This mentioned current is 'transient inrush current' and it may raise two to ten times the nominal rated current of transformer during operation. The method of using point on wave switching consists in energizing transformer at proper instant on voltage waveform judiciously chosen to prevent generation of high magnitude inrush current. Though transient inrush current lasts within few cycles, it has some adverse effects like problems in intended operations of protective devices, production of mechanical stress to the transformer core, power system quality issues and disruption in operation of sensitive electrical loads such as computers and medical equipment connected to the system. Hence Control and mitigation of transient inrush currents has become one of the concerns to power industry. One of the methods to reduce inrush current i.e. Point On Wave Switching method is investigated in this paper; an investigation is simulation based and design of an electronic switching controller to mitigate the transient inrush current of a power transformer. For switching power to the transformer, firing angle of Triac which acts as a switch is controlled using microcontroller. MATLAB/SIMULINK R2013a based simulation as well as experimental results are discussed to support the developed concept i.e. Point on wave switching method. Finally, the proposed concept is validated.**

***Keywords*: Transformer inrush currents; Point on wave switching; Thyristors.**

I. Introduction

Transformers are used in most of the electronic devices around us. Transient inrush current in transformer is often gets less importance compared to other effects or faults. Though the magnitude of transient inrush current may be in some cases less as compared to short circuit current, the frequency and duration of transient inrush current is generally more frequent hence it will have more adverse effect compared to other faults. Transient inrush current may flow when transformer is energized. The amount of inrush current depends on in the voltage cycle and residual flux in the transformer. [**2**] In recent years; mitigating the magnitude of transient inrush current, numbers of protection systems for transformers, based on the differential relaying, complex circuit or microcomputers has been proposed.. In this paper design of simulink model for implementation of Point on wave switching and design of an electronic switching controller to reduce transient inrush current of transformer is discussed. An electronic device 'Triac' will be utilized to switch power to the transformer. Switching will be controlled by controlling firing angle of Triac with the help of microcontroller. Logic behind Point on wave switching method is that minimizing the flux will minimize the inrush current. Closing at peak voltage by point on wave will minimize the transient flux generated by the transformer, this will results into reduction of transient inrush current to a lower value from its initial value **[1].** The relevant information was sourced from varieties of resources. Majority of the references are from the relevant research, conference and journals of Institutes of electrical and electronics engineering. Significant parts of citation were derived from professional printed books. A number of figures and photos are sourced from reputed internet sources such as manufactures, professional body, research institutes and universities.

II.Calculation

[Paper 2] In the methodology using point-on-wave switching, energizing the transformer at an instant on the voltage wave, judiciously chosen to prevent the generation of high magnitude peak fluxes in core. Ever since the early quantitative investigations of the single-phase transformer inrush current dynamics, it has been ascertained that in the absence of residual core magnetization, the most favourable switching moment is at the voltage supply crest instant, given that at this moment the prospective magnetic flux level is zero, thus minimizing the subsequent transient flux excursion and thus the peak value of the ensuing transient inrush current. The steady state magnetizing current of a transformer is, typically, 1-2 percent of the rated operating current but capable of becoming as high as 10-20 times that when switched, across the line. Generally the flux in the transformer is zero (no remanent flux) and hence switching to voltage when it reach to max value then corresponding flux in ideal condition should be near zero. This will be like ideal normal condition.

$$e=E*\sin wt$$

$$V=V_{max}\cdot\cos(wt+\alpha) \quad \text{.......... (1)}$$

Where
v = Applied voltage at primary
Vmax = Maximum voltage
t=time

The moment ac voltage is applied to winding, emf is produced in it and it is opposite direction to supply voltage

$$e \cong -V$$

$$e \cong -V_{max}\cdot\cos(wt+\alpha)$$

Also

$$e=-N1\cdot\frac{d\phi}{dt} \quad \text{........... (2)}$$

Now comparing equations (1) and (2),

$$-N1\cdot\frac{d\phi}{dt} = -\,Vmax\cdot\cos(wt+\alpha)$$

$$\frac{d\phi}{dt} = \frac{Vmax}{N1}\cdot\cos(wt+\alpha)$$

Integrating above equation, we get

$$\phi=\frac{Vmax}{N1}*\int\cos(wt+\alpha)\,dt$$

$$\phi=\frac{Vmax}{N1}*\sin(wt+\alpha)+C$$

$\phi=\phi max\cdot\sin(wt+\alpha)+C$.................... (3)

Where,

$\phi max=\frac{Vmax}{N1}$ and

C=asymmetrical component of flux

The core contains some residual magnetic flux in it; denoted by ϕresidual.

The asymmetrical component of flux C is given by,

$C=\phi residual+\phi max\cdot\sin\alpha$

Now putting this value in equation (3),

$\phi=\phi max\cdot\sin(wt+\alpha)+\phi residual+\phi max\cdot\sin\alpha$...... (4)

Now consider the switching instant when $\theta=0$ and $\alpha = (-\pi\backslash2)$ in this case equation is

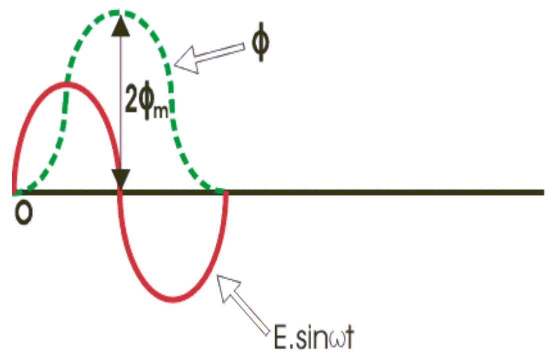


Fig.1 Switching instant when θ=0 and α = (-π\2)

$\phi=\phi max\cdot\sin[wt+(-\pi\backslash2)]+\phi residual+\phi max\cdot\sin(-\pi\backslash2)$

$\phi=-\phi max\cdot\cos(wt)+\phi residual+\phi max$

$\phi=2\,\phi max+\phi residual$...................... (5)

Therefore the flux density is almost double. This is often referred as double fluxing or doubling effect i.e.2 ϕmax. To generate flux more than normal current tends to increase exponentially result into high current.

Now consider the switching instant when $\alpha=0$ or $\pi\backslash2$

Where α = phase angle of flux and $\theta=(\alpha+\pi\backslash2)$ = phase angle of voltage i.e. the voltage is at its peak value. The flux is residual flux in the core at this instant. The operation of transformer is normal at this instant.

$\phi=\phi max\cdot\sin(wt+0)+\phi residual+\phi max\cdot\sin0\quad \phi=\phi max\cdot\sin wt+\phi residual$

$\phi=\phi m+\phi residual$..................... (5)

III. Simulation model and results

Study of inrush current in transformer and investigation of point on wave switching method for reduction of magnitude using R2013a MATLAB simulation is our main aim. Simulation methodology consists point on wave switching to mitigate transient inrush current by means of gang operated circuit breakers. The simulation is based on simultaneous closing times of circuit breakers. Closing of circuit breaker at proper instant will result into reduction in magnitude of transient inrush current in transformer. On the basis of analysis and verification of the results obtained from simulation, effectiveness of proposed scheme has been decided.

In first part of simulation as shown in fig. 2 a simulation model without using any mitigation technique has been designed. Three phase power transformer having a rating of 450 input supply source as shown in figure 2. A three phase 500 kV source connected with the transformer. Three phase transformer used for simulation has grounded Y/D transformer connection of winding. The core magnetization resistance of three phase transformer is 154 ohm and core magnetization inductance is 8.4 mH.

Model 1: Simulink model without using any mitigation technique

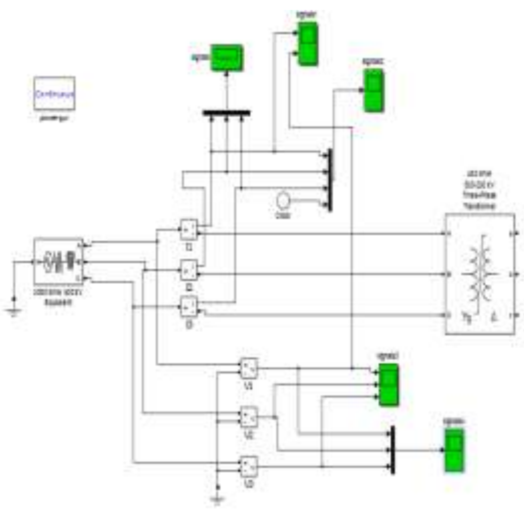


Fig.2 Matlab simulink model without use of any mitigation technique for transient inrush current.

Simulation Result for Model 1: Without use of any mitigation Technique.

Transient inrush current at this condition was very high (up to 1800 Amps) as it is shown in Fig. 3. below.

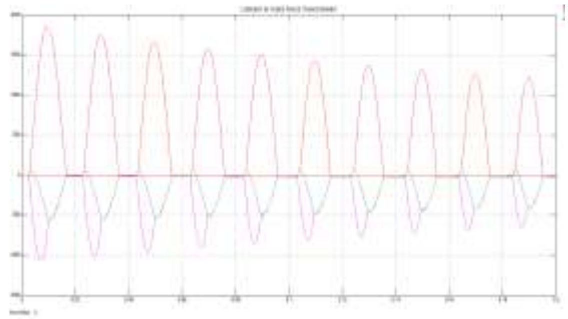


Fig 3 Simulation Result for Model 1: Without use of any mitigation Technique.

Model 2: To simulate reduction of current inrush, supply voltage for phase A was initially connected at **zero degree** waveform for this simulation. For 50 Hz supply we can write;
Tme duration for 50 cycles = 1,000 msec.
Time duration for one cycle = 20 msec.
Time duration for cycle passing from 0° to 90° = 5 msec.
For circuit breakers closing time in sequence of ABC,
Firstly assume that we supply phase A at zero degree waveform as mentioned.
Phase A will have its maximum voltage at 90° in 5 msec time.
Next, phase B is connected 120° apart from phase A, therefore: 120° + 90° = 210° and the time duration for the cycle passing from 0° to 210° =11.666 msec.
Next for phase C: 240°+90° = 330° and time duration is 18.333 msec for cycle to pass from 0° to 330°.
Following closing times of 5 msec, 11.666 msec, and 18.333 msec for circuit breakers of phase ABC.

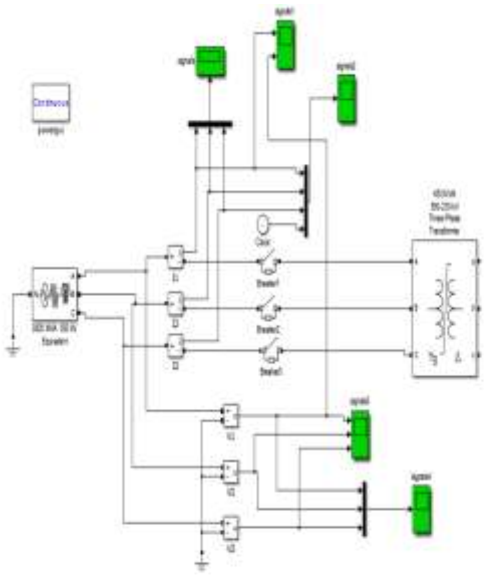


Fig.4 Matlab simulink model using point on wave switching mitigation technique for transient inrush current.

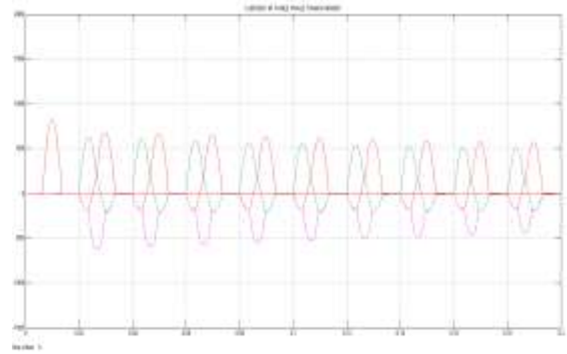


Fig 5 Simulation Result for Model 2: using point on wave switching Technique

IV. Circuit Description

In this paper a new design of switching controller using TRIAC for implementation of point on wave switching for mitigation of transient inrush current has been discussed. A power electronic element called Triac is utilized to energize the transformer primary winding to the main supply in a very short period of time. To obtain the desired result i.e. reduction of transient inrush current, it is essential to switch the supply at proper instant such that magnitude of transient inrush current will get reduced. The microcontroller is utilized for this purpose means it controls the firing angle of TRIAC so that TRIAC will switch the supply at proper instant. To isolate power circuit from microcontroller an optocoupler is used. The triggered pulses will reach Triac through an optocoupler. For the circuit, the firing angle of triacs and voltage injection can be set before switching transformer into service Microcontroller requires DC supply hence Bridge rectifier circuit is used to convert AC supply into DC supply. Since DC supply contains some harmonics or impurities that are not desired hence filter circuit is used. A voltage regulator is used to regulate the DC voltage from 230 V AC to 12V/5V DC. Crystal oscillator is used to generate operating frequency (generally it is 20 MHz)
Basic block diagram of experimental setup is as shown in fig. 5 below

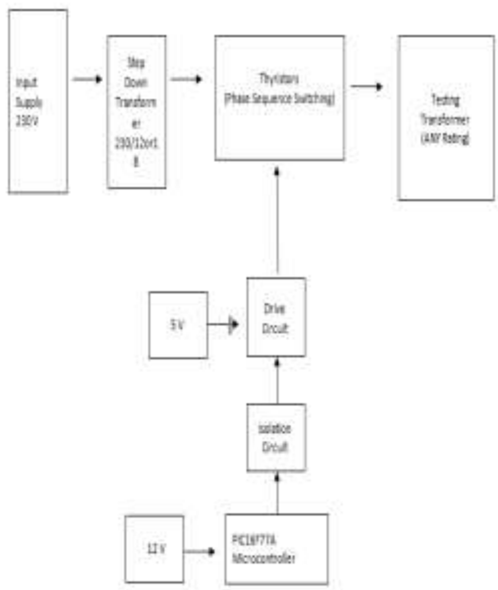


Fig.6: Basic block diagram of experimental setup

The schematic diagram of switching controller using TRIAC for reduction of transient inrush current is shown in fig.7 below

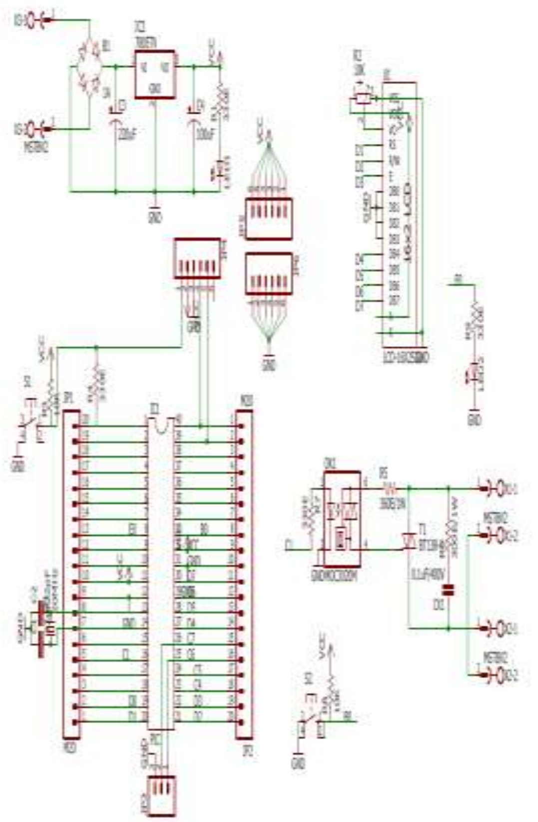
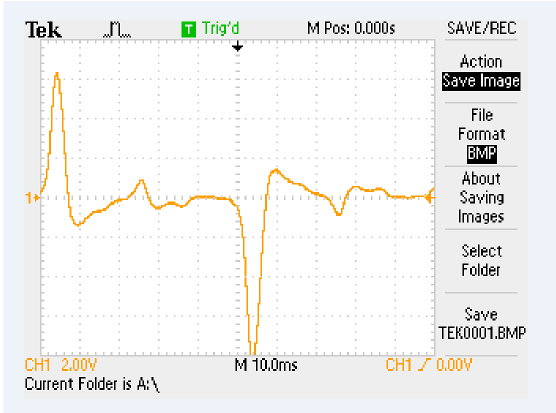


Fig 7 Schematic Diagram

V. Experimental Results

A three phase transformer has been used for simulation and a single phase transformer has been used for the experimentation. An electronic controller using TRIAC is connected to transformer's primary to apply the voltage at proper instant such that magnitude of transient inrush current is reduced. In simulation, from fig.3 it has been observed that transient inrush current raises up to 1800 Amp. When the Point on wave switching method is introduced with the help of selection of proper closing time of circuit breakers, supply is switched at proper instant, as a result magnitude of transient current reduces from 1800 Amp to 800 Amp, this can be observed from fig. 5. Reduction in magnitude of transient inrush current is remarkable.

On single phase transformer, point on wave switching method is implemented using an electronic switching controller; supply is switched through TRIAC at proper instant. Fig.8 has been obtained from number of pictures captured by DSO.



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. **Fig.8: Experimental result using DSO**

V. Conclusion

Inrush current in three phase transformer and single phase transformer can be reduced by switching the supply at proper instant will reduce the magnitude of transient inrush current. Analyzing the results obtained from simulation and testing of an electronic controller, effectiveness of Point on wave (POW) technique has been proved.

Reference

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