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STEP VOLTAGE WITH MICROCONTROLLER TO REDUCE TRANSFORMER IN RUSH CURRENT

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ABSTRACT: When a transformer is energized by the supply voltage, a high current called transient inrush current which it may raise to ten times of the transformer full load current could be drawn by the primary winding. This paper discusses a microcontroller circuit with the intention of controlling and limiting the inrush current for a transformer by the method of ramping up the supply voltage feeding to the transformer primary. Simulations and the experimental results show a significant reduction of inrush current when the ramping up voltage is applied to the three-phase transformer load. Inrush current could be almost eliminated if choosing a correct switching step rate.

KEYWORDS: Transformer inrush current, Zero-crossing on sine wave, Triac/SCR, Microcontroller

INTRODUCTION

Inrush current is a serious problem that plagues almost every electrical equipment and electrical machineries, especially those which are inductive in nature such as transformers, switching power supplies and synchronous/induction motors. In transformer study, a phenomenon which engineers always encounter, amount of produced inrush current can be very large, many times larger than the transformer full-load current rating. Inrush current can produce mechanical stress to the transformer, damaging to transformer windings, it often affect the power system quality, may disrupt the operation of sensitive electrical loads due to voltage dips, and also maloperation cases of transformer protection relays sometimes happen. Therefore, it is a very serious that has to be tackled by electrical engineers all over the world [1,2].

There are a few methods that are used to protect transformer against inrush current. Most of these methods do not exactly eliminate inrush current but they reduce the current to a level which is safe for the equipment. A well-known method is a passive method which is done by using Negative Temperature Coefficient thermistors. Controlled switching, and sequential phase energization also are the other methods to eliminate the inrush current caused by the transformer primary windings [1,2]. The simplified equation often used to calculate the peak value of the first cycle of inrush current in Amps is as follows:

$$I_{inrush} = \frac{\sqrt{2}V}{\sqrt{(\omega \cdot L)^2 + R^2}} \left[\frac{2B_N + B_R - B_S}{B_N} \right] \quad (1)$$

Where: V = Applied voltage in volts, L = Air core inductance of the transformer windings in ohms, B_R =

Remnant flux density of the transformer core in Tesla, B_S = Saturation flux density of the core material in Tesla, B_N = Normal rated flux density of the transformer core in Tesla [3]. As the equation shows applied voltage V is an effective part of the formula and its magnitude will change the amount of inrush current remarkably.

Voltage ramping up method to increase the transformer primary voltage gradually is suggested in this paper. The gradually increase of supply voltage is injected to the transformer primary in few cycles, until the full amount of the transformer rated voltage is connected. By the help of power electronic components and amicrocontroller the method works in such that a percentage of the supply voltage is firstly injected to the primary of transformer, then, the amount of the injected voltage is gradually increased to the full voltage value after maximum of 20 cycles or 1000 mili- seconds time period counted in 50 Hz supply. The microcontroller is assisted by a zero-crossing detecting circuit to synchronise switching times, and sending pulses to the power electronic elements the triacs/SCRs, capable of switching on/off the main supply voltage to the transformer load. Initial switching tests, and simulations by software NI Multisim have been successfully done to help the experiment research. The suggested method is generally more expensive and is complicated due to usage of active components.

This work implements an 8052based microcontroller to trigger three power electronics elements Triacs/SCRsas switches to turn on a three-phase transformer. High voltage section of the three-phase power supply is isolated from the low voltage microcontroller circuitry by optocouplers, and a zero-

crossing detector works in tandem with the microcontroller to synchronise the switching of the Triacs/SCRs so that the timing and triggering of the voltage ramping is coordinated [4].

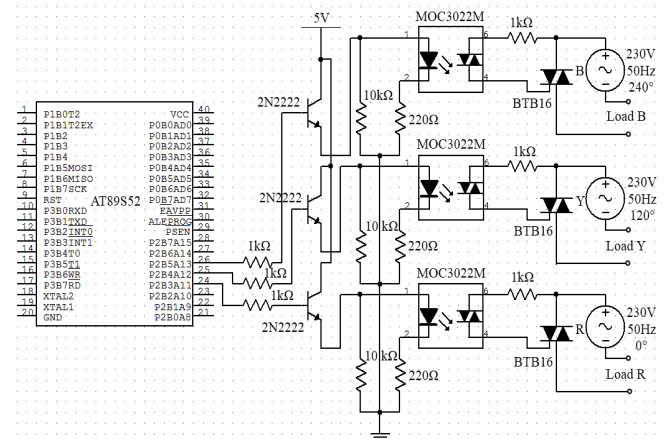


Figure 1: Microcontroller, optocouplers and triacs circuit

The microcontrollers entirely programmed in assembly with the MCS51 Assembly Language. Figure 1 shows the circuit of the microcontroller and the basic components required for the work provided by NI Multisim 11.0 software.

INITIAL TESTING AND TRIGGERING

The zero-crossing detector circuit sends pulses for the positive and negative zero-crossings to the microcontroller. The microcontroller then reads these pulses and it will wait for the last negative zero-crossing and trigger the triacs on the next zero-crossing. For the triggering of the three-phase supply voltage in this research work, a stage triggering method is employed.

The method is to start triggering triacs from the zero-crossings happen at the angle of 90° on the waveform of the supply voltage or when the first cycle of the waveform reaches its peak value. For this triggering method, step rates voltage of 5%, 10%, 20%, and 50% are applied.

Table 1 refers information on triggering on the voltage sine wave, and figure 2 shows the results of NI Multisim 11.0 simulation on starting angle of 90° for single phase switching.

Table 1: Summary of triggering Triggering at 90° of voltage wave

Step-rate (%)	5	10	20	50
No. of cycles to full voltage	20	10	5	2

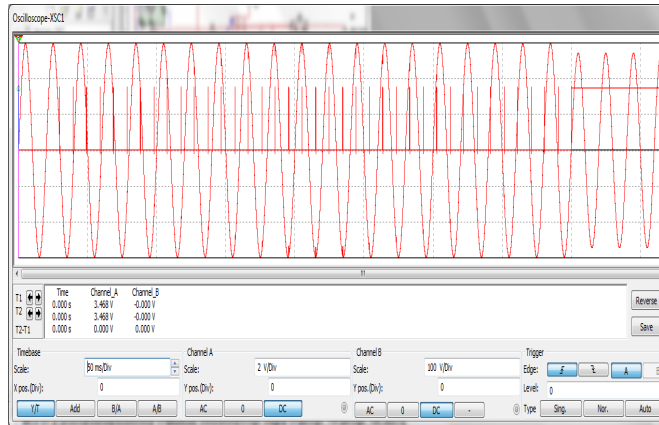


Figure 2: Starting angle of 90° for single phase switching

For the 50 Hz supply voltage, one full cycle of the ac waveform takes 20ms to be completed. Initially, the first phase of three-phase (Aphase) is triggered by a certain time delay according the step-rate chosen. A 50% step-rate has a time delay of 10ms after the zero-crossing is detected. This 10ms time delay is generated in the assembly programming by using loops, which is a conventional but an effective way of generating a time delay.

For the second phase (Bphase), an interrupt timer is being set to count an interval of 6.667 ms after each triggering of the first phase, as the second phase lags the first phase by 120° and it translates into 6.667ms of real time to reach its peak point.

For the third phase (Cphase), the similar method is used to trigger the supply voltage but this time a different interrupt timer is being utilised.

The output voltages for all the step rates were observed to the switching pulses from the microcontroller to insure accurate switching control of stepping ramping voltage for the three-phase transformer before actual experiments of the inrush currents effects.

INRUSH CURRENT TESTS ON TRANSFORMERS

Inrush current tests were conducted with three single-phase 1 kVA transformers which were connected in star in the primary. The inrush current effect tests firstly were conducted with direct-on-line connection to the supply voltage. This should serve as the initial value to compare with the resulting inrush currents with the use the stepping ramping voltage control afterwards.

A lot of trials were done in order to get the highest possible inrush current resulted from the energization of the transformers at 0° of the supply voltage sine wave, and existence of the maximum value of initial core fluxes which is counted as the worst case of producing inrush current in the transformer [5].

The highest inrush current for the primary wye connected three-phase transformer 3×1 kVA rating was obtained to be 86A as shown in Figure 3, and the steady state current of this transformer was found to be around 2A as it is shown in figure 4.

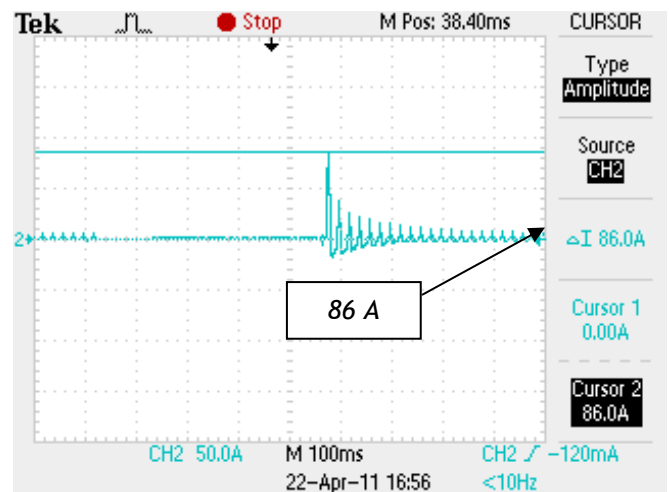


Figure 3: Highest recorded of inrush current for 3×1 kVA transformers

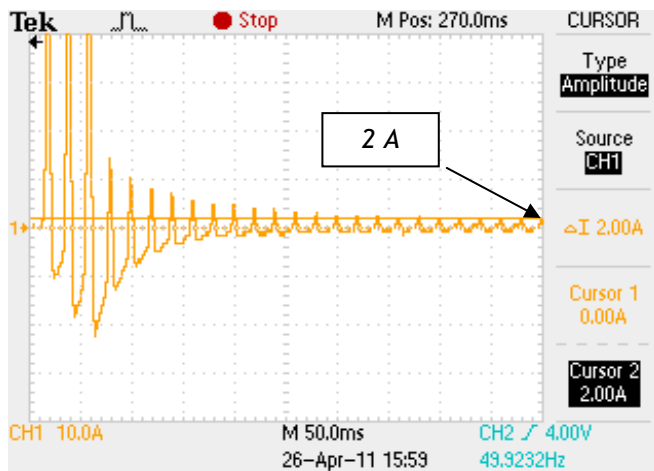


Figure 4: The value of steady state current for 3×1 kVA transformers

In the next step of the work, using the microcontroller ramping voltage circuit in order to reduce the magnitude of inrush current, after series of tests were done, the followings are the results captured by the digital oscilloscope. For the step starting angle of 90° on voltage sine wave and 5% step rate of ramping up voltage shown in figure 5, inrush current was found to be peaking at 70.4A highest. No significant inrush current suppression was observed from the inrush current previous value of 86A.

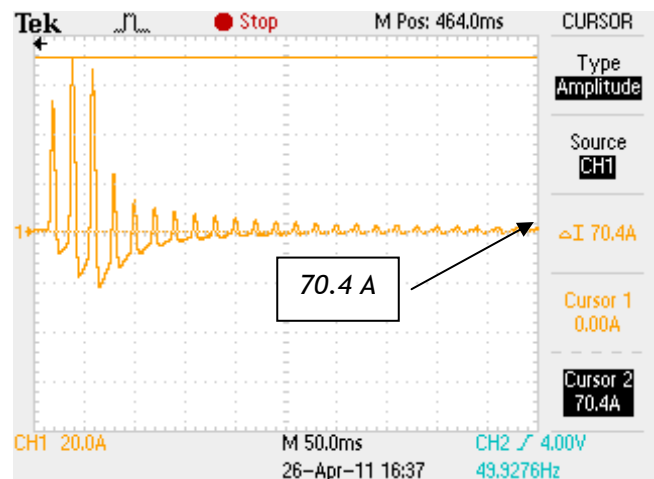


Figure 5: Inrush current for 90° and 5% switching

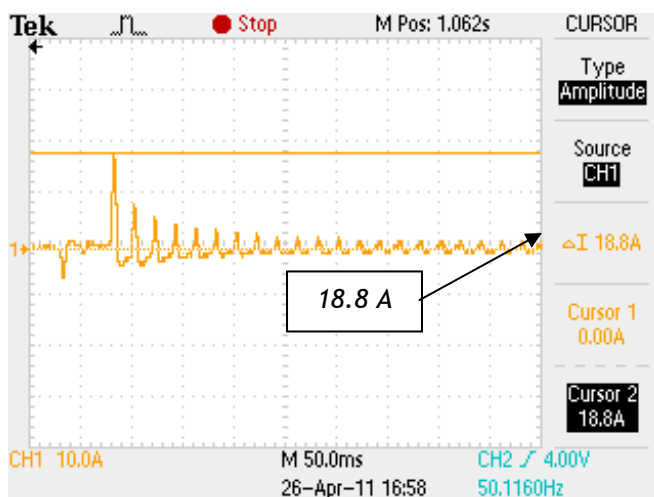


Figure 6: Inrush current for 90° and 20% switching

For the step starting angle of 90° on voltage sine wave and 20% step rate of ramping up voltage, inrush current was found to be dropped to 18.8A highest. A significant suppression of inrush current was observed from the inrush current previous value of 86A to lower value of 18.8A shown in figure 6.

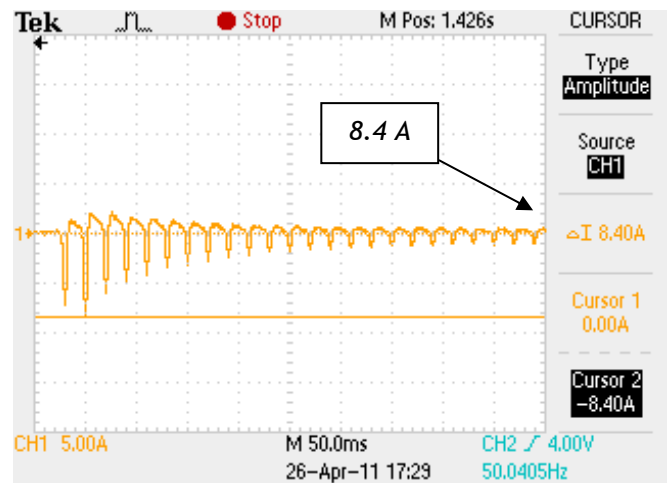


Figure 7: Inrush current for 180° and 50% switching

Lastly, as shown in figure 7 for the step starting angle of 90° on voltage sine wave and 50% step rate of ramping up voltage, the amount of inrush current also has been dropped to 8.4 A.

FINDINGS AND DISCUSSION

At a glance, it seemed that the controlled triggering through voltage ramping up technique is able to reduce the inrush current of a three-phase transformer load up to certain extent. However, the reduction in the inrush current was not so significant until at least 20% step rate in 90° angle on voltage sine wave. The control value of inrush current obtained was peaking at 86A after many trials were done. Basing with the 86A inrush current, a direct comparison was made with the results which were written in Table 2.

Table 2: Reduction in inrush current with controlled triggering on supply voltage (initial record of maximum inrush current was 86 A)

Energization at 90° of voltage sine wave				
Step rate (%)	5	10	20	50
Peak inrush current (A)	70.4	67.2	18.8	8.4

CONCLUSIONS

The method of switching control on three-phase supply voltage is achievable by use of a microcontroller, and some standard electronics components such as Triac/SCR, optocoupler and zero-crossing detector IC.

For transformers loads, the switching with control on the three-phase supply voltage to ramping up can limit inrush current when the step rate is kept relatively high, that is a rate equal or larger than 20%. Though the circuit has not been tested on an AC motor, another type of inductive load, it is believed that switching three-phase ramping voltage can effectively start a ac motor as a soft starter. This is due to the fact that voltage is gradually increased until very low starting current for the motor is observed. The circuit is deemed successful for the

fact that the control switching of a three-phase supply voltage is possible with the help of a microcontroller, and it can effectively limit transformer inrush current when there is no failure in triggering and microcontroller pulses.

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