Analysis and Mitigation of Shunt Capacitor Bank Switching Transients on 132 kV Grid Station, Qasimabad Hyderabad

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ABSTRACT

In this paper analysis and mitigation methods of capacitor bank switching transients on 132KV Grid station, Qasimabad Hyderabad are simulated through the MATLAB software (Matrix Laboratory). Analysis of transients with and without capacitor bank is made. Mathematical measurements of quantities such as transient voltages and inrush currents for each case are discussed. Reasons for these transients, their impact on utility and customer systems and their mitigation are provided.

Key Words: Capacitor Banks, Switching Transients, Capacitor Inrush Current, Pre-Insertion Resistor, Current Limiting Reactor, Surge Arrestor, MATLAB.

1. INTRODUCTION

In power system, transients have bad impact on its reliability and may cause damage to or malfunctioning of major equipments. The source of these transients may be switching operations, lightning strikes or failure of equipment. When shunt capacitor bank is to be switched on live network, high frequency and high magnitude transients may occur. Usually capacitor banks are installed at feeder circuit to improve power factor and voltage profile. Normally, these capacitor banks are not connected all the time but switched on and off many times during the day because the load on power system changing with time according to certain load curves. These switching actions will be accompanied by transient currents, when a capacitor bank is closed on energized circuit [1].

Actually switching of capacitors produces more severe transients as compared to energisation of load or cable [2]. When an uncharged capacitor is switched on to network, the system voltage will reduce, as it starts taking energy from network instead of supplying. Hence severe transients will take place when uncharged capacitor is being switched on to network at peak voltage. The system voltage will shoot up by the magnitude equal to the difference between the system voltage and the voltage of capacitor bank when a charged capacitor is switched on [3-4]. Theoretically, it has been observed that these transients would lead to peak amplitude of 2 pu (per unit) but due to inherent damping present in circuit, these transients are limited below this value. The initial peak of transients usually during sub-transient period is the most dangerous one [5]. However effects of these transients are not damaging enough to cause failure of line equipments, but can act as catalyst to affect the most sensitive equipments of the system and may produce un-necessary tripping of equipments [6].

In this paper we are presenting Simulink analysis and mitigation of capacitor switching transients on the

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distribution feeder connected to 40 MVA transformer at 132 kV grid station Qasimabad Hyderabad. Capacitor banks are placed before feeder circuit and initially energized at peak voltage of the circuit at grid station and transients in current and voltage near the bank are analyzed. Now in order to remove these transients different mitigation techniques are to be adopted and there results have been included too in this paper and finally comparison is made on techniques that which is most efficient one.

2. BASIC CONCEPT CONCERNING ENERGIZATION OF CAPACITORS

Fig. 1 represents distribution network which provides conceptual introduction about the capacitor switching transients. R_1 and L_1 represent the resistance and inductance of source. As shown in Fig. 1 capacitors C_1 and C_2 are fed by circuit breaker CB_4. S_1 and S_2 represent switches used to take in and out the capacitors C_1 and C_2. Inductance of feeder between C_1 and C_2 is represented by L_B. Total impedance of feeder and distribution transformer is represented by the combination of R_2 and L_2. Circuit breaker CB_3 is used here to interrupt the ground fault at some distance on the feeder.

When switches S_1 and S_2 close at any instant to energize capacitors, voltage at feeder to which CB_4 is connected collapses to the voltage on the capacitors and produce oscillations. When these oscillations are damped out, feeder voltage would return to its normal value again. But if the capacitors are energized at peak value of voltage,

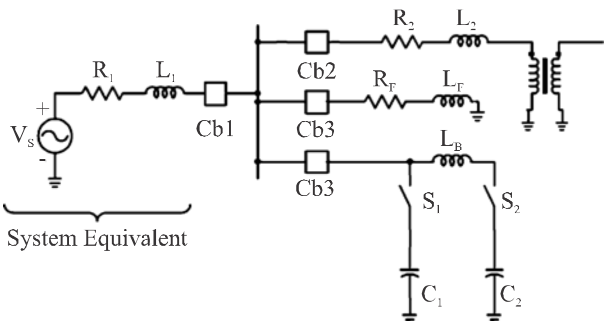

FIG. 1. NETWORK USED TO ILLUSTRATE CAPACITOR SWITCHING TRANSIENTS

which is typically about 1.5-1.8 pu of phase to ground voltage, large transients with frequency in range of 300-800 Hz are produced initially. The frequency of these transients is determined by source inductance L_1 and capacitance of capacitors connected [2].

Actually capacitors are connected in the form of three phase large banks and breaker closes all three phases of a capacitor bank simultaneously, so voltage at one of the phase is always at peak [6-7].

3. REDUCTION OF CAPACITOR SWITCHINGTRANSIENTS

Many topologies and techniques are available to mitigate transients such as; use of pre-insertion resistors, inrush limiting reactors and surge arrester connected across the capacitor bank. Each technique results in a different manner to reduce the switching transients.

3.1 Current Limiting Reactors

Here reactor of suitable rating is used in series with the capacitor bank. Due to use of this reactor the surge impedance of the circuit increases and hence the peak of inrush current is reduced. Since the inductor opposes the change in current so current cannot change instantly, therefore elevated frequency components of transient are restricted and the effect of these inrush transients current is condensed [2,7].

3.2 Pre-Insertion Resistors

In this method, switched resistors are used in series with capacitor banks. Here the switch will introduce resistors initially into network and then make contact with capacitor bank. Due to the use of these resistors, overall losses in the circuit are increased which facilitate to decrease the peak value of transients in the voltage and current. The time at which pre-insertion resistors are introduced into circuit is about one fourth of supply frequency i.e. 50 Hz. This helps to decrease the initial peak which is most damaging one of transients [7].

3.3 Surge Arrester

Gap type surge arresters with a series non-linear resistor can be used along with capacitor bank to reduce higher magnitude transient stresses. Gap in the arresters is set in such a way that it remain non conducting at terminal voltage but when transients energizes the gap, the capacitor will discharge completely and energy is dissipated through arrestor. However if gap less metal oxide arresters are used then capacitor will not discharge below terminal voltage [8-12].

4. NETWORK REPRESENTATION

4.1 Network Data

The network of 132 kV grid station Qasimabad, Hyderabad shown in Fig. 2 includes two 132 kV sources, four different MVA transformers, 25 feeders and four capacitor banks. Here the analysis is made on one 132 kV source having a three phase short circuit MVA level of 24.4 MVA which is connected to 132/11.5 kV, 40MVA transformer. A load of 15 MVA at power factor of 0.87 lagging is simulated. The typical values of circuit capacitance, resistance and inductance are included in our MATLAB/Simulink model. For improving power factor from 0.87-0.93, capacitor banks of 1.211 MVAR have be installed at the grid station and switching transients in the voltage and current were analyzed then.

5. SIMULINK REPRESENTATION OF SYSTEM

132 kV grid station Qasimabad, Hyderabad, is feed from two 132 kV sources, one is from TPS (Thermal Power Station), Jamshoro and other from Halla. Fig. 3 represents the Simulink model of 132 kV grid station Qasimabad Hyderabad from 132 kV TPS, Jamshoro source to Cumulative load of 14 feeders. With the help of sim power system laboratory of MATLAB, the load is simulated as lump sum three phase load of 14 feeders and transmission network is simulated through pi-section with a transformer of 40 MVA to step down voltage to 11 kV. Three phase breaker which is externally controlled is connected to capacitor bank on one side and to feeder circuit on other side is also simulated.

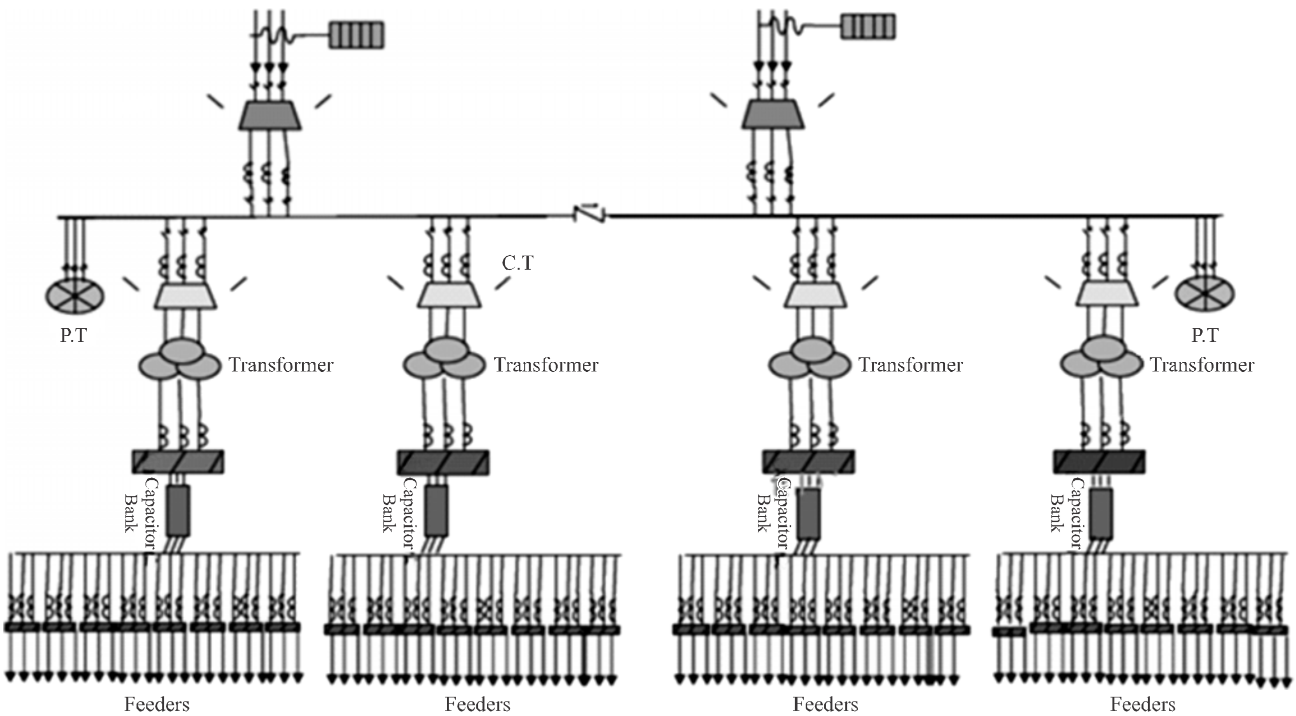

FIG. 2. GRAPHICAL REPRESENTATION OF 132 KV GRID STATION QASIMABAD, HYDERABAD

6. SIMULATIONS

6.1 Initial Scenario

The Simulink diagram is shown in Fig. 4. The capacitor bank was introduced into network at 0.06 sec and taken out at 0.08 sec. the phase A peaks at 0.06 on the feeder. The transients in voltage and current on Phase-A are analyzed as result of capacitor bank being switched. Fig. 5 depicts three phase voltage at the load side before and after the capacitor bank was switched in.

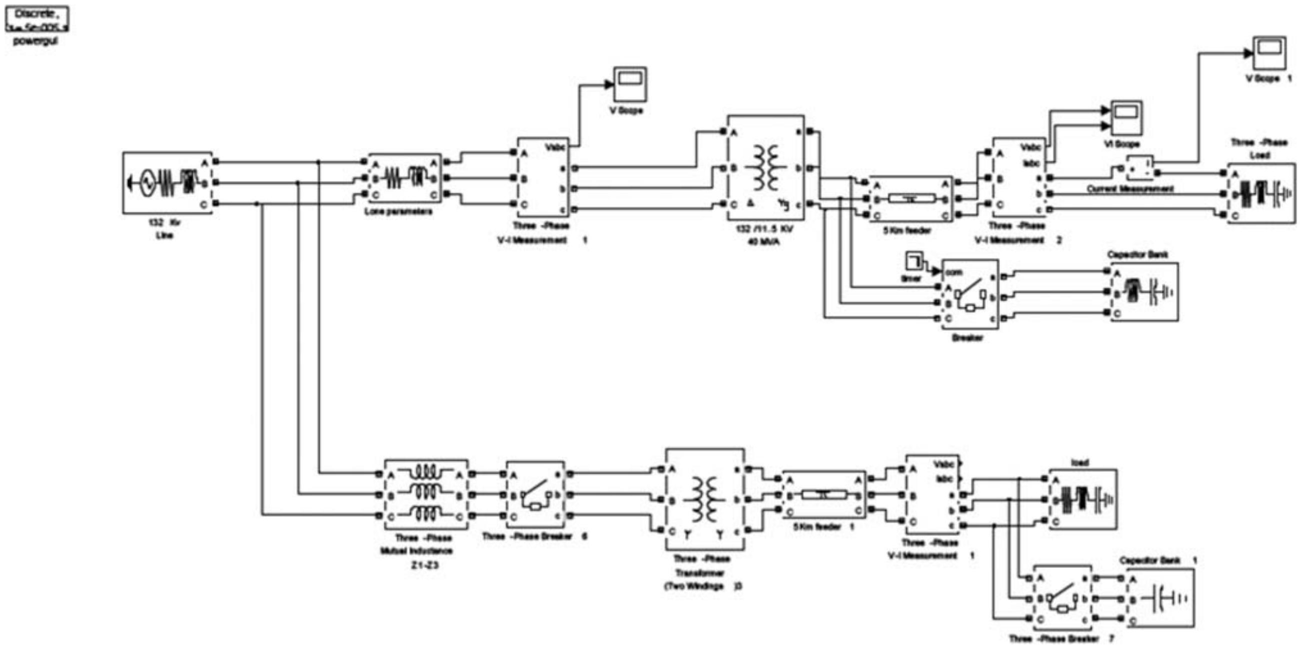

FIG. 3. SIMULATION OF 132 KV GRID STATION QASIMABAD, HYDERABAD

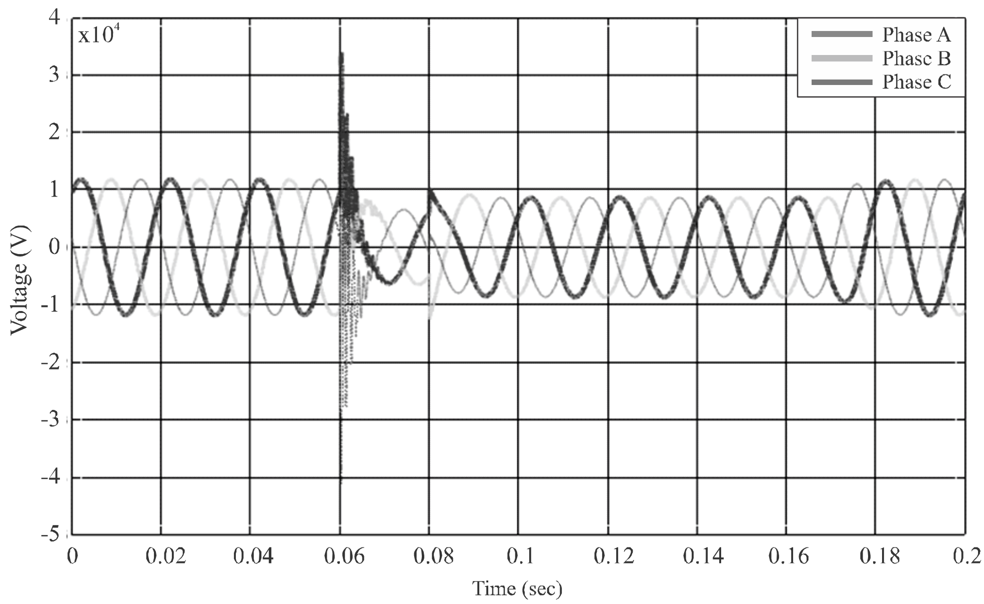

FIG. 4. VOLTAGE NEAR THE CAPACITOR BANK WHEN ENERGIZED AT PEAK VOLTAGE OF PHASE-A

When the capacitor bank is injected into system at the peak voltage of Phase-A then it produces inrush current with magnitude $I_{max\,=}$ 1468 A. This inrush current has transient nature and a frequency of magnitude as determined by the system inductances and capacitor banks' capacitances.

Our objective in this paper is to mitigate the transients in voltages and currents to the normal base value. So the use of current limiting reactors, pre-insertion resistors and surge arrestors is precautionary.

6.2 Simulations Using the Current Limiting Reactors

Referring above simulation results:

$V_{max} = 15\text{kV}, V_{normal} = 11\text{kV}$
$V_{shoot} = (15\text{-}11)\text{ kV}$
$I_{max} = 1468\text{ A}, I_{normal} = 763\text{ A}$
$I_{shoot} = (1468\text{-}763)$
$P.F_{load} = 0.87$
$P.F_{corrected} = 0.93$
$P.F_{difference} = (0.93\text{-}0.87)$

$$Z_{total} = \frac{V_{max}}{I_{max}} = 10.31\text{ ohms} \quad (1)$$

$$P_{reactor} = V_{shoot} * I_{shoot} P.F_{uncorrected} = 169.2\text{ Kvar} \quad (2)$$

The reactor of 169.2Kvar is used with the controlled capacitor bank in order to reduce the inrush current to 763 A which is the normal value of current flowing.

When the capacitor is switched in at the peak value of Phase-A voltage then system voltage suddenly shoots to twice of base value. Behavior of capacitor bank switching transients after being introduced into system along with limiting reactor can be shown by Figs. 6-7.

By Increasing value of current limiting reactor the magnitude of inrush current is limited to desired value, approximately to half of the base value.

It is confirmed from above simulation results that by increasing the surge impedance of system, the magnitude of transients has reduced. Actually frequency of current transients has been reduced to 0.587 KHz. This recovery of base current and voltage quantities near the capacitor

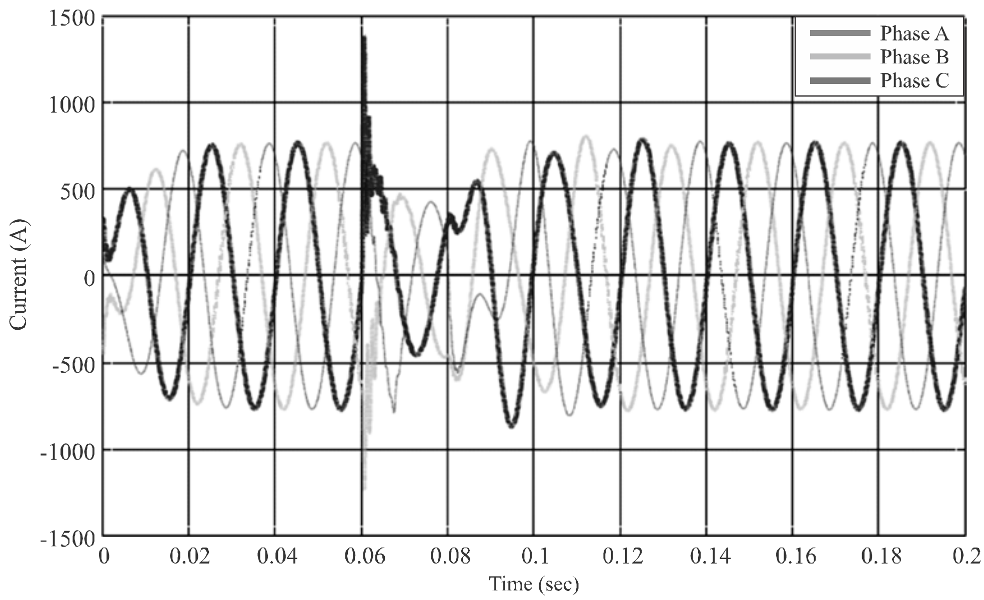

FIG. 5. CURRENT AT CAPACITOR BANKS WHEN ENERGIZED AT THE PEAK VOLTAGE OF PHASE-A

bank can be observed from Figs.6-7. Fig. 6 shows how Phase-A voltage shoots to 142% of base value and then reduces to steady value after damping of transient frequency.

6.3 Simulations using the Pre-Insertion Resistors

Resistors would be connected in series with capacitor bank to damp out the transients mainly in current [12]. Use of this method requires an additional circuit breaker which closes at 0.068 sec of the supply frequency. This breaker would take the resistor out of system after 0.08 sec of supply frequency, to avoid un-necessary power loss. Fig. 8 represents that voltage transients due to capacitor switching have been reduced approximately to base value while some transients are again observed when breaker opens at 0.08 sec, which are mitigated because reactor was also out along with capacitor bank.

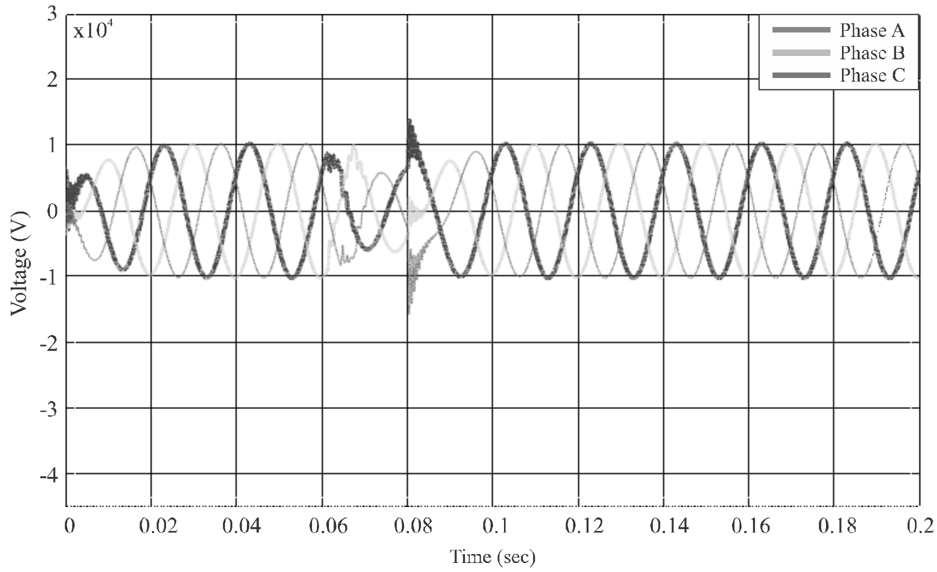

FIG. 6. VOLTAGE AT THE BANK WHEN CAPACITOR BANK ENERGIZED ALONG WITH THE CURRENT LIMITING REACTOR

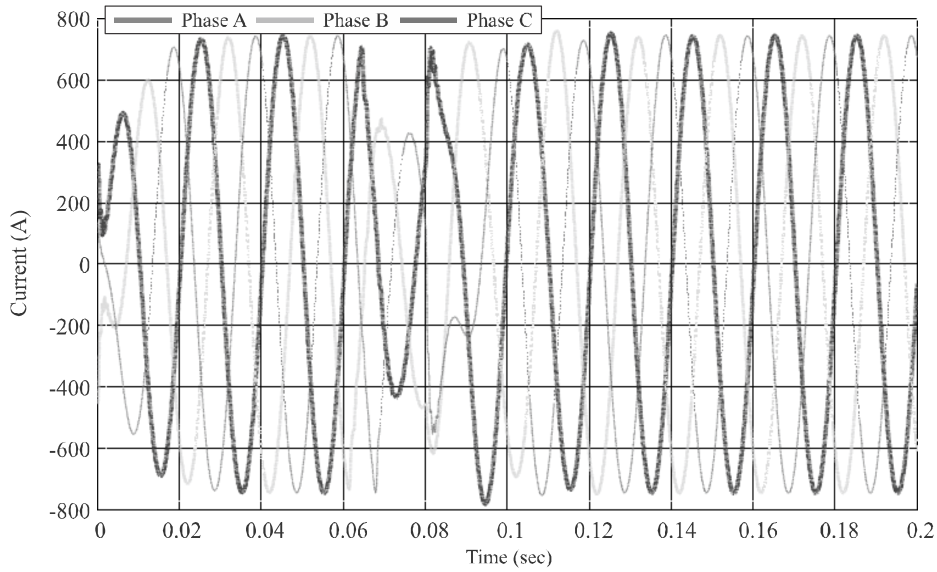

FIG. 7. INRUSH CURRENT NEARBY VCB USING CURRENT LIMITING REACTOR

By knowing the value of capacitance of capacitor bank and current to be reduced, the value of resistor to be connected can be found by Equation (3).

$$R = \frac{1}{2}\frac{\sqrt{Vs}}{\sqrt{IwC}} = 0.75 ohms \tag{3}$$

This perphase resistance mitigates the maximum current and voltage transients nearly at base value.

Fig. 9 illustrates that magnitude of inrush current has reduced to 0.78kA; it is worthwhile to point out that damping of transients is faster with resistors than with the limiting reactors.

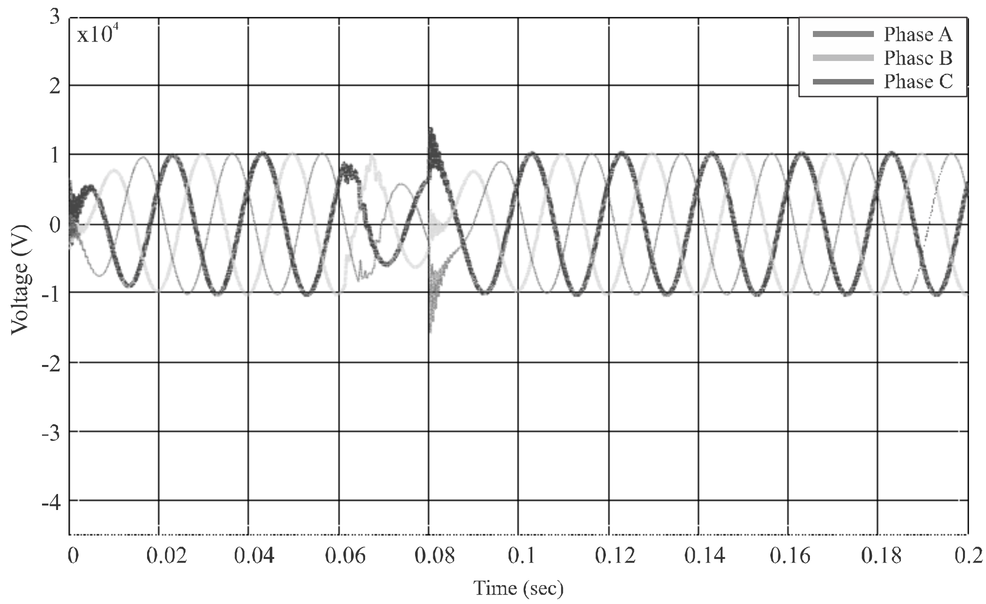

FIG. 8. VOLTAGE NEAR CAPACITOR BANK USING PRE-INSERTION RESISTOR

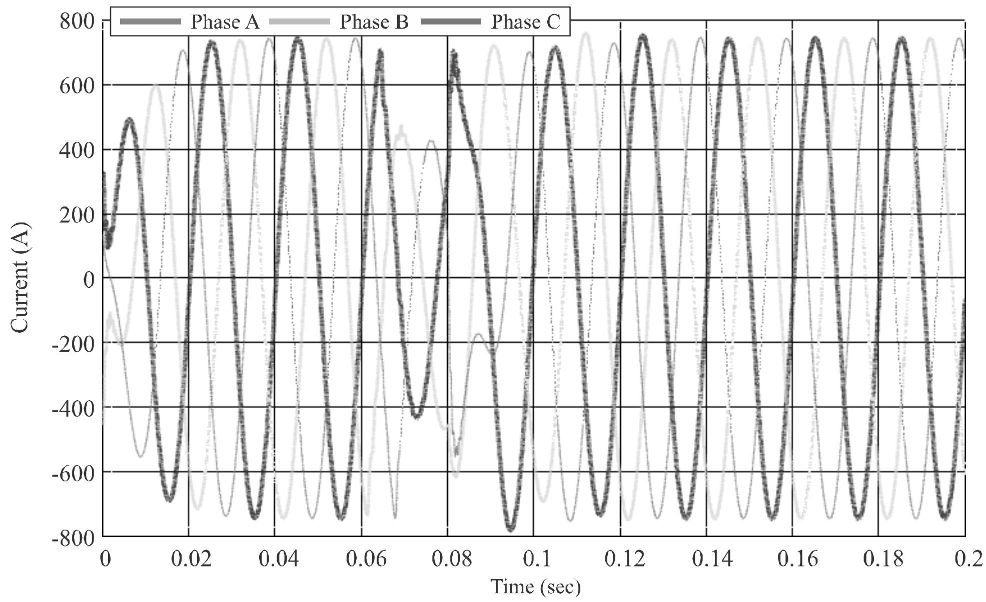

FIG. 9. CURRENT NEAR CAPACITOR BANK USING PRE-INSERTION RESISTOR

Since, it can be viewed from the above Simulink results that high frequency current transients were very closer to one obtained during initial scenario. It is due to the fact that circuit parameters L's and C's remained same. The voltage shoots up to the magnitude of 131% of base value and then returned back to original value after the damping of high frequency transients. The magnitude of transients obtained in this method is less than that, obtained by using current limiting reactors.

6.4 Simulations using the Surge Arrester

Here gap less surge arresters are connected across the capacitor bank either in phase to phase or phase to neutral configuration. With their different position across the capacitor bank, the best choice is the phase to ground connection [7]. We have used this connection for simulation with results shown in Figs. 10-11. The inrush transient current across the switched capacitor bank is limited to 0.783 kA.

7. CONCLUSION

In this paper characteristics of transients which originated from utility capacitor bank switching, were studied. The information obtained from the simulations and results depicts that transients are produced in the current and voltage when capacitor banks are taken into the network along with feeder circuit. These transients' peaks up to 1.5-1.8 pu of base value. Moreover, these high frequency transients were found to be causing malfunctioning of the sensitive devices used in network. Therefore, three different techniques for the mitigation of these transients have been analyzed. Among these techniques the most promising one is pre insertion resistor method, which reduces the transients to such a value that they cause no serious threat to current sensitive switch gears. Other techniques i.e. surge arrester and current limiting reactor methods were also found to be useful in the mitigation of current as well as voltage transients, but at lesser rate. Still their effects were noticeable and lasted for few milliseconds. When our

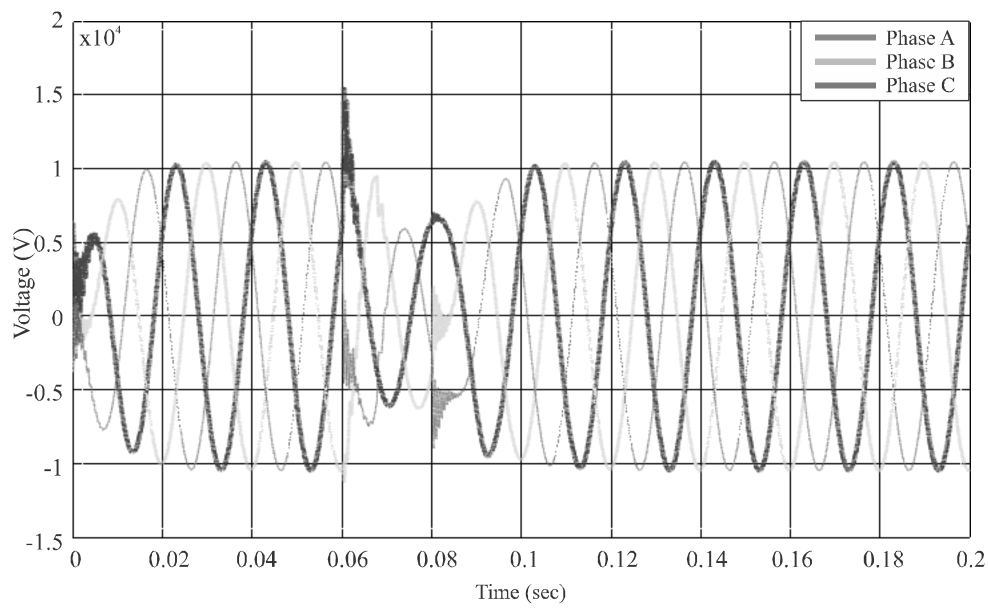

FIG. 10. VOLTAGE NEAR THE CAPACITOR BANK USING SURGE ARRESTOR

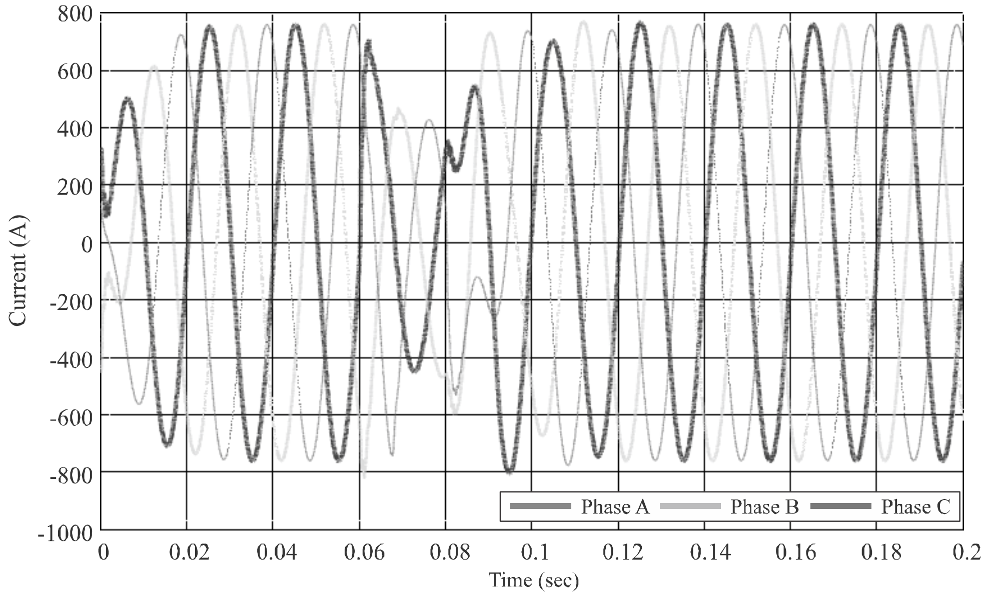

FIG. 11. CURRENT NEAR CAPACITOR BANK USING SURGE ARRESTOR

sole purpose is to mitigate capacitor switching transients, the best option for medium voltage switch gears would be pre-insertion resistor method. It has been observed practically current limiting reactor technique is expensive than other techniques. The most simple and less expensive technique for high voltage switch gears would be the surge arrestor technique.

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