Generation and Control of Transient Overvoltages in Power System Networks

Dr. T. Murali Mohan[1], T. Ramya Durga[2]

[1]Dr. T. Murali Mohan, Associative Professor, Electrical and Electronics Engineering & Jntuk University of College, Kakinada& India
[2]T.Ramya Durga, M.Tech Student, Electrical and Electronics Engineering & Jntuk University of College, Kakinada & India

---***---

Abstract – *This paper presents the increase of power factor and reduces the power quality problems such as the generation of transient overvoltages and harmonics on the power distribution system side. Among these problems, the effects of generating transients and controlling the transients using the various mitigating techniques are used to control the transients in a specific distribution feeder line and also calculate the mathematical computations of quantities such as peak transient overvoltages, high-frequency inrush currents occur in each case. Mitigating values in each case is compared to other cases using MATLAB/Simulink Software.*

***Key Words*: Capacitor bank switching (CBS), current limiting reactor, Harmonic analysis, Inrush current, Power quality, Pre-insertion resistor, Surge arresters, Transient Overvoltages.**

1. INTRODUCTION

The main cause for the generation of transient overvoltages is due to capacitor bank switching, which is identified in the 19th century. In those days a power quality problem is the main issue and it is increasing on day by day basis. The generation of power was insufficient, so the production of electric power mostly depending on the thermal and few watts of electric power generating in the hydroelectric power. At that time the population was increasing and the usage of electronic equipment for the household also increasing. In U.S & U.S.A the usage of electronic equipment is more and the generation is less.

The Power quality problems are raises due to high voltages, low voltages (fluctuations) and these types of fluctuations must be reduced and the power factor must be improved. This can be done using a capacitor switching bank which also reduces the reactive power. Capacitor banks will hold reactive power whenever reactive power needs release.

Capacitor switching is one of the most important sources of generating transient overvoltages and inrush currents in electrical power systems. But because of switching operations, the electronic equipment will damage. In order to overcome this problem, a fixed capacitor is used. In 1954 large capacitor banks are used and in 1974 small size capacitor banks are used which reduces cost. Capacitor banks control the ON & OFF positions of the switch. If energization of capacitor banks is done, a switch will get closed automatically and peak transient overvoltages will occur in the range of 2to 3p.u which produces transient overvoltages, inrush currents and if de-energization is done, a switch will get open and minor transients will occur below 2p.u.

In this paper, these transients can be controlled using some mitigation techniques and FFT analysis of harmonic distortion of peak voltage is calculated.

2. GENERATING TRANSIENT OVERVOLTAGES

2.1 Basic Concept of Energizing Capacitor Bank Switching Transients

Fig.1 represents a single line circuit diagram of energizing capacitor bank switching transient. This circuit will be connected to the distribution side feeder line and used in the utility consumer side. The network provides a visionary introduction about the Energization CBS transients. Rs and Ls represent the resistance and inductance of source with a frequency of 60 Hz and also fixed capacitor banks are used. In this circuit, the load is connected after the VCB switch.

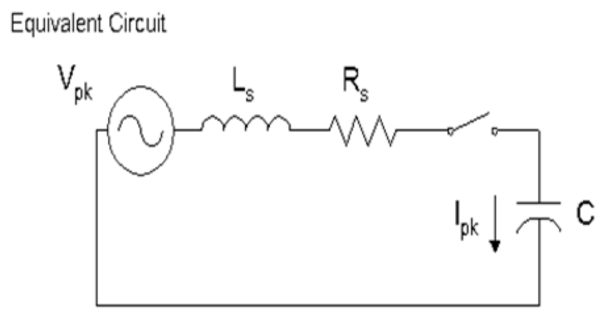

Fig -1: Single line diagram of energizing capacitor bank switching transient

Where:

f = frequency in Hz.

L =source inductance, H.

C = capacitance of the capacitor bank, F.

V_{pk} = peak voltage.

I_{pk} = peak inrush current.

Z_0 =Surge impedance.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$I_{peak} = \frac{Vpeak}{Zo}$$

$$Z_0 = \sqrt{\frac{L}{C}}$$

The generated transient overvoltages are computed by using distorted harmonics waveforms generated by the consumer's nonlinear loads and gets amplified. In this harmonic distortion is reduced using the FFT analysis and also the calculation is done at the different loads near the transients and at different capacitor bank sizes. These values are compared to obtain values from simulations of each case study and the high magnitude of peak transient overvoltage and high frequency of inrush currents are observed. When Is >>1 and ωls<< l/ωc, the current is leading the supply voltage by 90°and energizing transients 2.5 P.U to 3.0 P.U are at the peak. In this case, less is more so a reduction of loss is done using many topologies and techniques available by controlling the transients such as a pre-insertion resistor, current limiting reactor and surge arresters. These techniques are used to mitigating the generating transient overvoltages.

2.2 System Circuit Representation

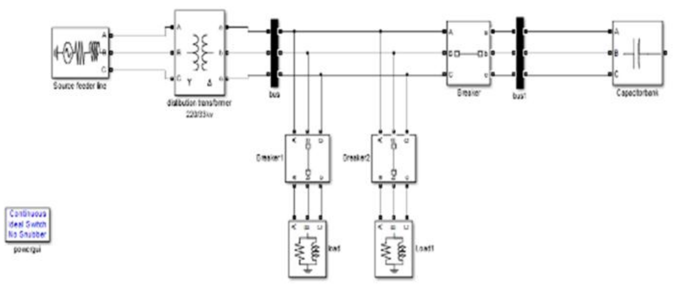

Fig.2: Simulink Model of Generating and control of transient overvoltages in distribution

Table -1: Circuit parameters

Parameters	values
Three-phase source	220 kV
Three Phase transformer	220/33 kV
Power factor	0.9 p.f
load	64 MVA
Capacitor bank	14.7 MVAR

These values are used to simulate the circuit using

MATLAB/Simulink software and the values used in the model are resistance, reactance, and capacitance. These values are important which are used in the three-phase fixed Capacitor bank, connected in series with the feeder line with a frequency of 60 Hz. The capacitor bank produces a high magnitude of transient overvoltages and inrush currents.

3. CONTROLLING OF TRANSIENT OVERVOLTAGES

Generating transient overvoltages is reduced using many techniques but only three mitigation techniques are considered.

3.1 pre-insertion resistor

There are various techniques for controlling the generating transient overvoltages and currents in the distribution feeder line. The pre-insertion resistor is known as an old classical method. In this circuit, the pre-insertion resistor switched before the CBS and connected in series to the feeder line with frequency 50 Hz. The pre-insertion resistor controls the high magnitude of transient overvoltage and high frequency of inrush currents.

3.2 Current limiting reactor

The second controlling technique used is the Current limiting reactor also called a series reactor. High inductive reactance is produced in this reactor. It is correlated with its resistance. The current limiting reactor reduces the short circuit currents in the power system networks and increases the magnitude of surge impedance and reduces the peak inrush currents and transient overvoltages.

3.3 Surge arresters

Surge arresters are considered as third controlling technique. Surge arresters are used for the primary protection and designed with high resistance for normal systems and low resistance for transient overvoltages. MOV type arresters are used to reduce the transient overvoltages and they are of two types: gap type and gapless surge arresters

4. SIMULATION AND RESULT ANALYSIS

4.1 Base Case-1

The base case circuit diagram is shown in Fig.2. When the capacitor bank starts, energizing voltage is pulled to zero or voltage is overshoot or rebound complete and the switch will get closed. At that time the high magnitude peak transient overvoltages (2.5P.u) and high-frequency peak inrush current (2.7 KA) will produce but at phase A high transients and high inrush currents occurs and closing of switch happens at 6.5ms.

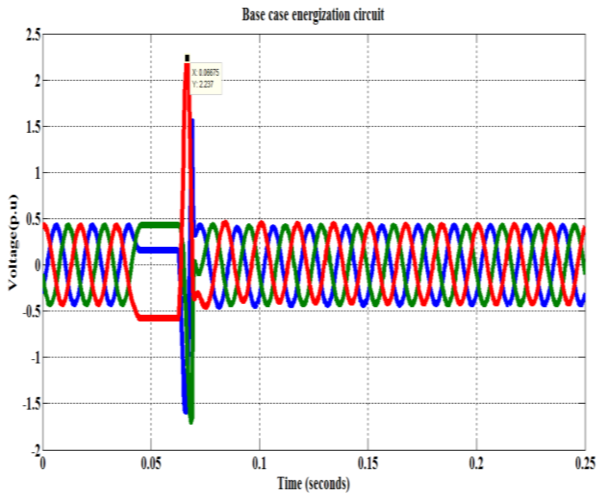

Fig.3 (a): Transient observed near the Energization of Capacitor Bank at peak Voltage

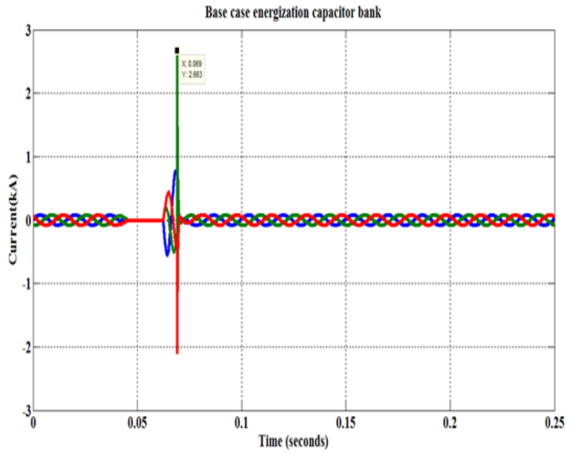

Fig 3(b): Transient observed near the Energization of Capacitor Bank at peak inrush Current.

Table 2: Transient Observed Energization of capacitor bank at the phase a voltage and current

Phase A	The maximum peak observed near the Capacitor bank when switching at t=peak
Voltage	2.5P.u
Current	2.7 KA

Fig.3 (a) and Fig. 3(b) shows the 3 phase Energization of capacitor switching transient disturbance.

4.2 Capacitor bank Energization and FFT Analysis of Fundamental Harmonic distortion calculation.

Fig.2 shows harmonic content present in the voltage near the capacitor bank. Fig.3(c) shows the histogram representation of the harmonic content present in the voltage waveform concerning the magnitude (%of fundamental harmonics).

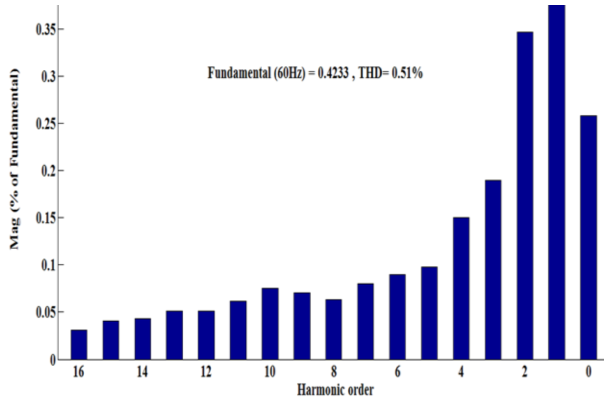

Figure 3(c): Harmonic Content Present in the Voltage Waveform

Phase A peak voltage is calculated using FFT analysis to produce the fundamental harmonics during the energization of the capacitor bank as shown in fig.3(c).

Fig.2 shows harmonic content present in the voltage near the capacitor bank. Fig. 3(d) shows the scatter diagram representation of the harmonic content present in the current waveform concerning the magnitude (% of fundamental harmonics).

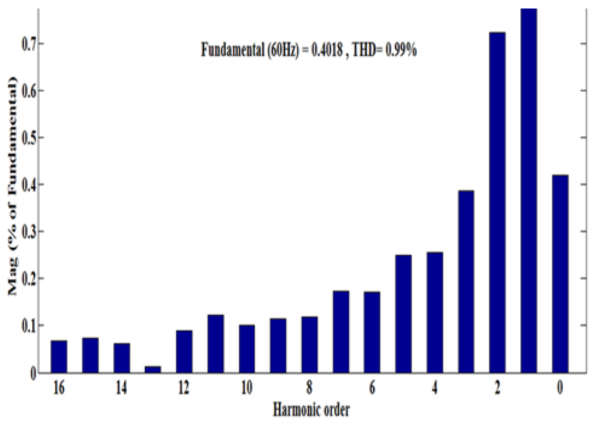

Figure 3(d): Harmonic Content Present in the Current Waveform

Phase A peak inrush currents are calculated using FFT analysis to produce the fundamental harmonics during the energization of the capacitor bank as shown in fig.3 (d).

These Harmonics are calculated at different time intervals because FFT analysis calculations are done based on the frequency-time domains.

4.3 Simulations using the pre-insertion resistors Case-2

To Control the transient overvoltages and inrush currents many techniques are used but the preinsertion method is an old and classical method so the first mitigating technique chosen is a pre-insertion resistor. The pre-insertion resistor is connected in series with a capacitor bank and before the pre-insertion resistor a switch is connected known as "2step switching" and the switch gets closed at 0.25s and resistor value used is 7.35ohms. These values are used to reduce the high-frequency inrush currents (1.78 P.U) and high magnitude of transient overvoltages (1.35 P.U).

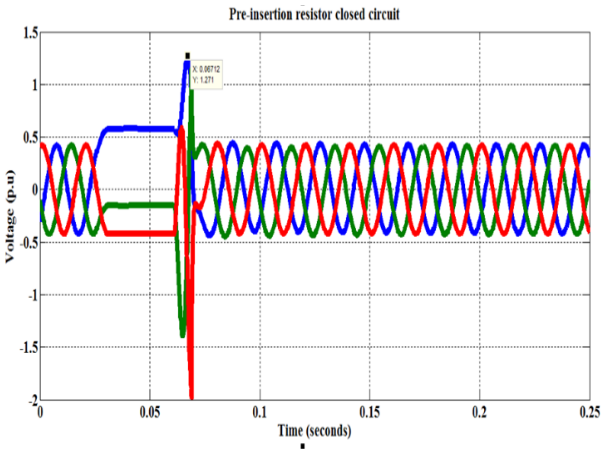

Fig 4 (a): Energization of capacitor bank in the peak voltage nearby VCB using pre insert resistors

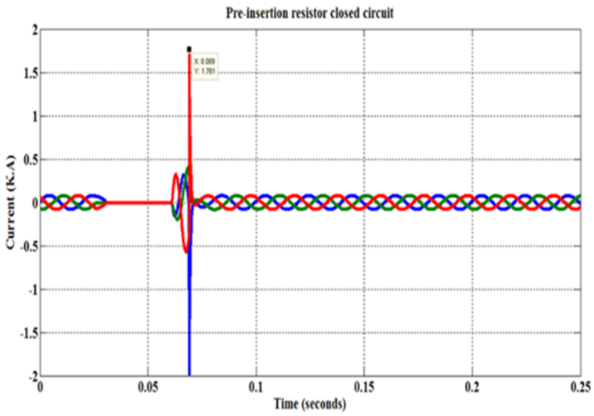

Fig 4 (b): Energization of capacitor bank in the peak inrush current nearby VCB using pre-insertion resistors.

Table 3: Transient Observed Energization of capacitor bank at the phase A voltage and current in pre-insertion resistor switched into the capacitor bank

Phase A	The maximum peak observed near the Capacitor bank when the switch at t=peak
Voltage	1.35 P.U
Current	1.78 KA

Fig.4 (a) and Fig. 4(b) show the Pre-insertion resistance of controlling the high magnitude transient overvoltages (1.35 P.u). The pre-insertion resistor reduces the transient overvoltages more than a current limiting reactor and high-frequency inrush currents (1.78 KA) will get reduced by the current limiting reactor more compared to the pre-insertion resistor.

4.4 Simulations using the current limiting reactors Case-3

The current limiting reactor is connected in series with a capacitor bank. This reactor can effectively reduce the peak value of inrush current (1.5 KA) but can't change instantly and also reduce transient overvoltages.

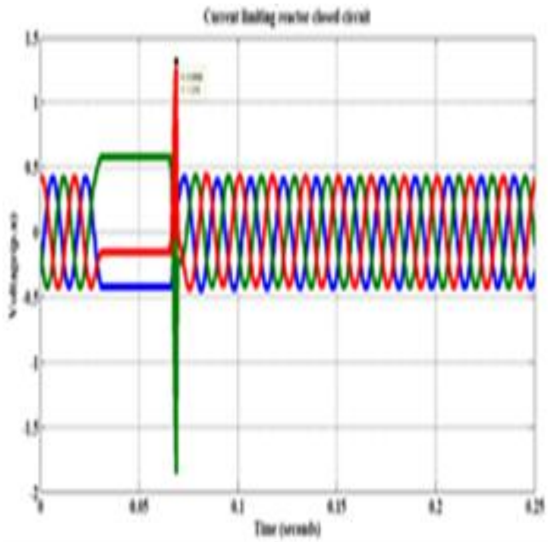

Fig.5 (a): Voltages at the when capacitor bank energizing it along with the current limiting.

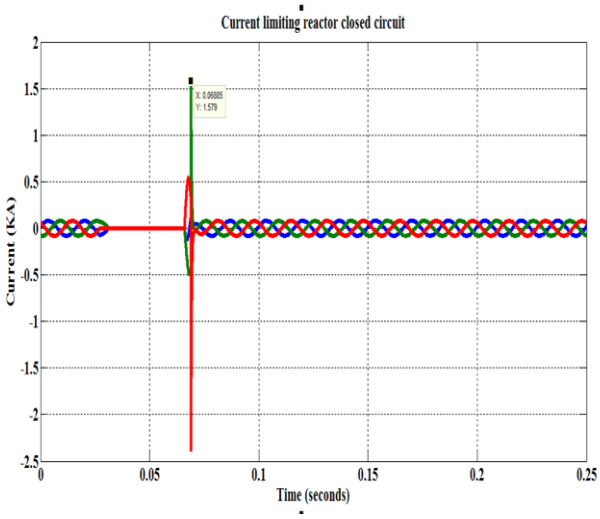

Fig.5 (b): Inrush current at the when capacitor bank energizing it along with the current limiting

$$Z_{total.new} = \frac{Vpeak}{ipeak,new} = 15 \text{ ohm}$$

$$L_{total}, new = (C_{eq})\,(Z_o\, total, new)^2 = 8.537\text{mH}$$

$$L_{reactors} = L_{total} - L_{Cap}\text{ bank}$$

$L_{reactors}$ = 8.537 mH - 5.6mH = 2.937 mH

Table 4: Transient Observed Energization of capacitor bank at the phase A voltage and current in current limiting reactor switched long the capacitor bank

Phase A	The maximum peak observed near the Capacitor bank when the switch at t=peak
Voltage	1.45 P.U
Current	1.5 KA

Fig.5 (a) and Fig. 5(b) show the Current limiting reactor of controlling the high magnitude transient overvoltages (1.45 P.u). The pre-insertion resistor reduces the transient overvoltages more than a current limiting reactor and high-frequency inrush currents (1.78 KA) will get reduced by the current limiting reactor more compared to the pre-insertion resistor.

4.5 Simulations using the surge arrester Case-4

Surge arresters are considered in controlling the transient overvoltages and inrush currents providing primary protection. The MOV gapless type arresters do not discharge the capacitor bank switching and these are connected across the capacitor bank phase to phase and phase to neutral.

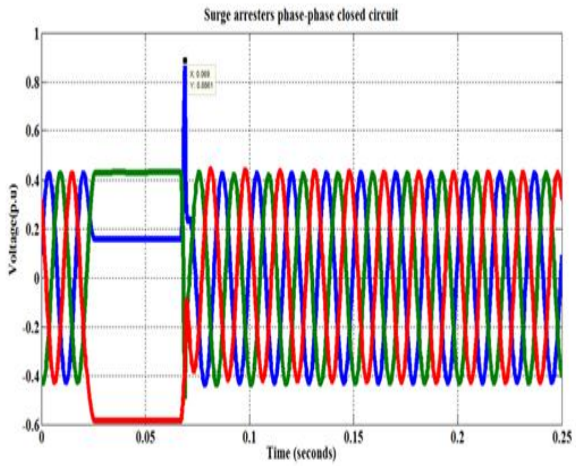

Fig 6(a): Voltages at the controlled Energization of capacitor bank used in the surge arrester.

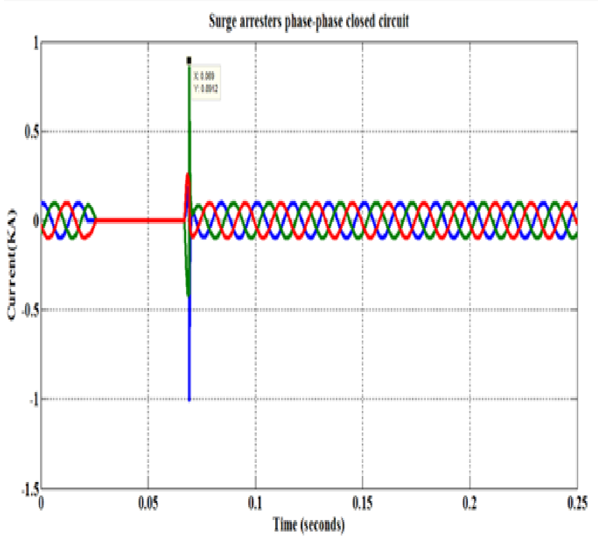

Fig 6(b): Current at the controlled Energization of capacitor bank using the surge arrester.

Table 5: Transient Observed Energization of capacitor bank at the phase A voltage and current in surge arresters connected Phase-Phase in the capacitor bank

Phase A	The maximum peak observed near the Capacitor bank when the switch at t=peak
Voltage	0.8 P.U
Current	1.1KA

The surge, arresters reduces the high magnitude of transient overvoltages shown in fig .6(a) with transient overvoltage value (0.8 P.U) and in fig.6 (b) high frequency of inrush currents (1.1 KA) connected in phase to phase.

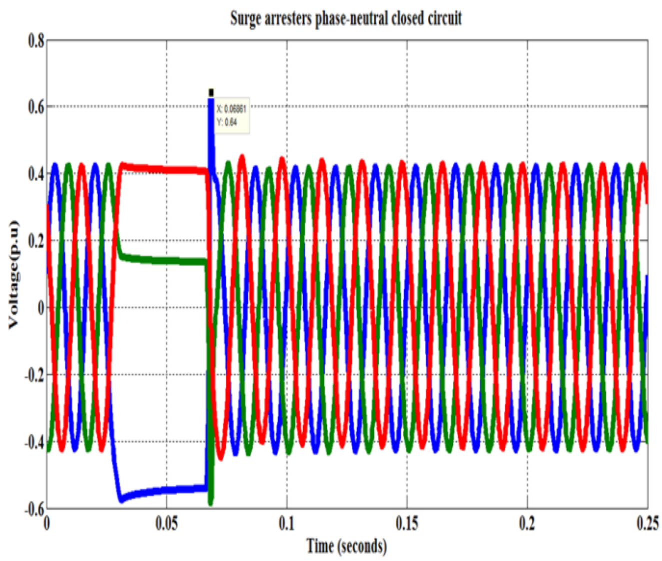

Fig 6(c): Voltages at the controlled capacitor bank using the surge arresters

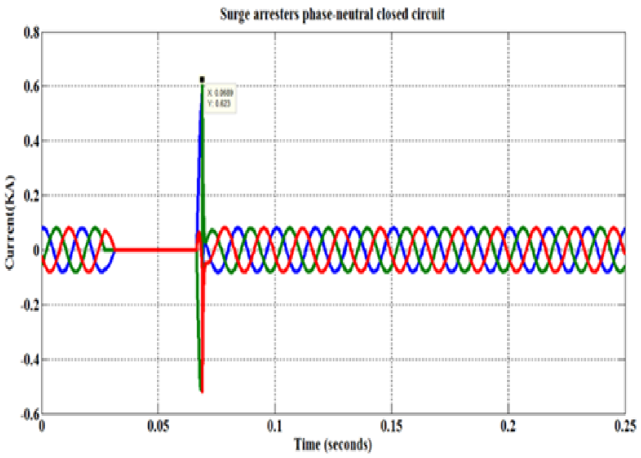

Fig 6(d): Current at the controlled capacitor bank using the surge arrester.

Table 6: Transient Observed Energization of capacitor bank at the phase A voltage and current in surge arresters connected Phase-Neutral in the capacitor bank

Phase A	The maximum peak observed near the Capacitor bank when the switch at t=peak
Voltage	0.64 P.U
Current	0.794KA

In this case surge arresters are connected to the phase to neutral reduces the transient overvoltages shown in fig.6(c) with transient overvoltage value (0.64 P.U) and in fig.6 (d) inrush current values (0.794 KA) and these values are less than the phase-phase values.

These controlling techniques are used to mitigating the generating transient overvoltages and inrush currents and improve the power factor and to reduce the power losses.

5. CONCLUSION

In this paper, the main purpose is to identify the effects and causes of transient overvoltages and methods for solving the transients and the energization of CBS is the most important to initiate the transients. The generation of peak transient overvoltages and inrush currents are produced in this case, the switch will get closed at the peak value of TOV 2.5p.u and inrush current 2.7 KA. In order to reduce these peak values, some controlling techniques are used, which are a pre-insertion resistor, Current limiting reactor, and surge arresters. In this pre-insertion resistor controls the high magnitude overvoltages and high-frequency currents. But if transients produce in second's, the pre-insertion resistor doesn't respond instantly and damage of equipment happens, this can be overcome by Current limiting reactors which effectively reduces the inrush currents but the cost is high, but it takes few seconds. The surge arresters provide the protection of the primary side and it responds in a fraction of seconds and it is most efficient and the cost is very low. So surge arresters are used in controlling the generation of transient overvoltages.

REFERENCES

[1] L. Van Der Sluis, Transients in Power Systems John Wiley &Sons, 200l. ISBNs: 0-471-48639-6;

[2] 2. Grebe, T.E., "Application of Distribution System Capacitor Banks and Their Impact on Power Quality". IEEE Transactions on Industry Applications, 1996.32(3): P. 714-719.

[3] 3. Sahib Abdoolwadood Ali, "Capacitor Banks Switching Transient In Power System" Canada ISSN 1923-8460, 2011.

[4] 4.Cipcigan L., Chandra M., and Rusu A., A transient study for shunt capacitor applications, JUKO CIRED Conference, 5-8 October 2004, Herceg Novi, Serbia, and Montenegro.

[5] 5.Coury D., Jose dos Santos C., Oleskovicz M., and Tavares M., 2„Transient analysis concerning capacitor bank switching in a distribution System", ELSEVIER Electric Power Systems Research, 2002, Vol.6513-21, pp.13-21.

[6] 6. Girgis A., Fallon C., Rubino J., and Catoe R., "Harmonics and Transient Overvoltages due to Capacitor Switching", IEEE Trans. on Industry Application, Vol. 29, Nov./Dec.1993, pp.1184-1188