CAPACITOR SWITCHING TRANSIENT: A REVIEW

Amar Jambukar[1], M. F. A. R. Satarkar[2]

[1]M.Tech Student, Dept. of Electrical Engineering,

Dr. B.A.Techological Univercity, Lonare (India)

[2]Asst. Professor, Dept. of Electrical Engineering,

Dr. B.A.Techological Univercity, Lonare (India)

ABSTRACT

Power system components are expose to transient oscillation of voltage and current produced by energizing and de-energizing devices. These transient may be short lived, but they have high peak values and frequency much greater than power system fundamental frequency. The factors that influence their intensities is shown. Characteristics of the transient resulting from the switching utility capacitor bank is analysed in the paper with simulation.

Keywords: Capacitor Switching, Inrush Current, Natural Frequency, Transient, Harmonics.

I.INTRODUCTION

The application of capacitor banks has long back accepted as a necessary step in the efficient design of power systems for power factor improvement, losses reduction, voltage control, or released capacity [5]. Capacitor switching is just one of the many switching event that can cause transient in system. However due to their regularity and impact on power system equipment, they often receive special consideration. Transient overvoltage and overcurrent related to capacitor switching are classified by peak magnitude, frequency and duration. These parameters are useful for evaluating potential impact of these transient on power system equipment [2].Switching large capacitors on the three-phase system is source of several problems. The voltage disturbance associated with current transient that occur at the instant of switching are the most severe problem. If this transient are not limited then amplitude of these transient can easily exceed than normal current and their duration can last up to several milliseconds [3]. These transient can cause voltage dips and tripping of power electronic based devices. Also due to their extreme amplitude, these transient can cause premature wear of mechanical contact and shorten capacitor life.

II. BASIC CONCEPTS CONCERNING ENERGIZATION OF CAPACITORS

Switching of the capacitor bank is a delicate operation due to the nature of such particular network component. In the basic characteristic of capacitor is that the voltage cannot change instantaneously; in other words, closing on a capacitor bank is almost like closing on a short circuit initially. Therefore, when capacitor is connected to power network voltage will pull down to nearly zero for certain time interval. A high current peak, namely an inrush current, will occur while the capacitor is charging. At the same movement the capacitor voltage will start to recover from its initial state and overshoot the system voltage. The capacitor voltage then oscillate around the network voltage for few cycles. As in the case of switching where a second capacitor bank is connected in parallel to one already connected bank (back to back switching), the charged bank dumps a high frequency current peak into the uncharged capacitor bank. The inrush current resulting from back to back closing is much higher in magnitude and frequency compared to single bank closing.

The primary frequency of the oscillation is generally in the range 300- 1000 Hz, although higher frequency component result from the initial step change. Damping from system resistance and loading determines how long the disturbance lasts, typically between 0.25 and 0.5 cycles. The transient magnitude for normal energizing are generally in the range of 1.1 to 1.5 per unit. The higher transients are associated with larger capacitors and weaker system.

There are several different type capacitor bank transient such as normal switching, back to back switching, magnification transients and restrike transients. Back to back energizing occurs when there is a capacitor already energized close to the capacitor switched. The transient frequency in the current is relatively high due to the inrush current from the energized bank to the one being energized, i.e. more than 1000 Hz. The higher frequency oscillation dies out quickly and then there is a lower frequency oscillations determined by the combination of parallel capacitor with the system source inductance. Magnification of capacitor switching transient occurs when a resonance with smaller low voltage capacitor bank.th overvoltage transients in the customer facility can exceed 2.0 per unit and disrupt equipment operation. The frequency of the magnification transients is typically less than that of a normal energizing. De-energizing a capacitor bank should not produce any noticeable transients. However, an unsuccessful de-energization can produce significant transients due to restrike during a failed capacitor opening. When initial contact opening is not successful, an arc forms between the contact and re-energizes bank. This type of energizing is not desire and is consider an abnormal switching. The transient characteristics in restrike energizing are essentially identical with normal energizing, expect that that the step change at the energizing instant is much higher and severe for restrike energization. When capacitor bank opens, there are trapped charges in the bank and when restrike occur the system voltage might be opposite polarity causing the step change to go pass zero.

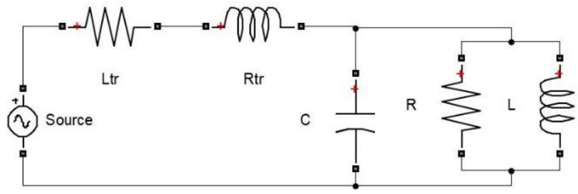
III. A PARAMETERIC STUDY

3.1 Inrush current

Inrush current (input surge current or switch–on surge) refers to the maximum, instantaneous current drawn by an electrical device when first turned on. The inrush current into the newly connected bank is determine by the size of the bank and inductance between two banks. The larger the banks, and the smaller the inductance between banks, the higher will be inrush current. The frequency of the inrush current is determine by the ratio of capacitor bank reactance and the impedance between the banks. The smaller the impedance, the higher will be the frequency.as per the standards(IEC 62305-1-2012,IEC 600060-1-2010, and IEC 62475-1-2010),the inrush

 ISBN : 978-93-87793-02-6

current characterized by following parameters; peak magnitude(kA), maximum time rate of change(kA/s),time



of first peak, frequency, time integral of absolute value of inrush current , Energy(kJ).

3.2 Harmonics

Apart from power, electronics devices there are other sources of harmonic distortion such as arching devices and equipment with saturable ferromagnetic core. Application of capacitor bank can create series or parallel resonance problem, which magnifies the problem of distortion. Due to harmonics there is increase in the RMS value of current it causes excessive heating in system components. IEEE standard 519-1992 recommends limits for the both utility and customers.

IV.CAPACITOR ENERGIZATION

Mathematical relation for nature of inrush current and voltage as follows.

Fig.1 Parameters of capacitor being switched in

Total inductance for the circuit = $L_s + L_{tr} = L$

The total resistance for the circuit = $R + R_{tr} = R$

Capacitance = C

Main frequency = $F_1 = \omega_1 / 2\pi$

Specific frequency = $F_2 = \omega_2 / 2\pi$

V_1= voltage at the fundamental frequency across the capacitor (peak value)

I_1= fundamental frequency load current (peak value)

Φ = phase angle differernace V_1 and I_1

i_1= value of I_1 at instant t

V_e = supply voltage at specific frequency across the capacitor (peak value)

I_e= supply current at specific frequency across the capacitor (peak value)

γ = phase angle difference between V_e and I_e

i_e = value of I_e at instant t

$i_1 + i_e$ = total current at any instant t

$$= I_1 \cos(\omega_1 t + \Phi) + I_e \cos(\omega_2 t + \gamma)\, e^{\frac{-t}{2T}} \qquad (1)$$

$V_1 + V_e$= total voltage across the capacitor at instant t

$$= I_1\, \omega \sin(\omega 1 t + \Phi) + Ie \sqrt{\frac{L}{C}}\, e^{\frac{-t}{2T}} \operatorname{Sin}(\omega 2 + r - \delta) \qquad (2)$$

When there is load across the line, the load resistance is very small and $\delta = 0$. The bornitz gives the following relationships:

$$I_e = -I_1 \left[cos^2\Phi + \left(\frac{\omega 2}{\omega 1}\right)^2 \sin^2\Phi\right]^{\frac{1}{2}} \quad (3)$$

$$V_e = -V_1 \left[\left(\frac{\omega 2}{\omega 1}\right)^2 cos^2\Phi + sin^2\,\Phi \right]^{\frac{1}{2}} \quad (4)$$

From this we get points:

4.1 A capacitor bank with a large KVAR has large capacitance C resulting in a small X_C. On the distribution lines, short circuit capacities are low. X_L is high. A small value capacitor (low C and thus high X_c) is switched across high short circuit capacity (low X_L) line. Then high ratio of $\omega 2/\omega 1$, high specific frequency. Result in sparking and explosion of capacitor.

4.2 A high specific frequency ω_2 means sharper rates of rise of current and voltage. This leads to sparking during switching. A lower specific frequency should not be so low that is coincides with the lower harmonics of the main frequency and result in the resonance.

4.2.1 When load increases a new capacitor bank joins as existing capacitor bank. Both are switched through a common switch. Total C increases and X_c decreases. This result ω_2/ω_1 and hence no sparking.

4.2.2 It is advisable to increase X_L by series inductor in series with a capacitor bank always on the HV and EHV circuit at the location closed to power generating station. This lower ω_2/ω_1 and reduces the danger. Standard percentage inductances are KVAR are 6% and 0.2% of the capacitor KVAR.

4.2.3 Phase angle of load has an influence on the peak magnitude of surge current.

$$I_e = -I_1 \left(\cos^2 \Phi + (\omega_2/\omega_1)^2 \sin^2 \Phi\right)^{1/2}$$

$\Phi = 0$ That is, power factor almost unity. Then $I_e = -I_1$

$\Phi = 90$ that is load is almost inductive with practically no power component. $Ie = -I1\,(\omega_2/\,\omega_1)$

4.3Effect of load on the surge current:

4.3.1 When there is no load, the step down transformer on the other side or the open lines have Φ of 90^0, giving the high possible value of Ie.so there may be flash over while testing capacitor under no load condition.

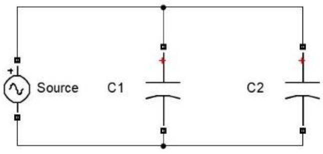
4.3.2 As the load increases, the power factor towards unity. It also absorbs the more and more of the surge energy being in parallel across the capacitor. The surge is rapidly damped down. Thus switching large capacitor bank of appropriate sizes when there is justified load is fairly safe.

4.4Influence of the switching instant:

4.4.1 Switching instant when the voltage passes through zero.

The sum of both stationary values and the exponential oscillatory values of the voltage and current naturally zero, since there is no voltage in the system. For both the system, the voltage and current will be 90 phase difference, with current leading the voltage wave. System1 will oscillate at the frequency 50 Hz steady voltage and current. System2 will oscillate at the specific frequency $\omega 2$ at decreasing values of the voltage and current. Thus under conditions of zero voltage crossing $I_1 = -I_e$ since they cancel out at start. Both are peak values since

V_e is zero. As per the equation. This implies Φ = 0.This gives $V_e = V_1(\frac{\omega 1}{\omega 2})$ as the maximum possible value. Since



the $\omega_2 > \omega_1$, $V_e < V_1$ and dies down quickly. The maximum instantaneous current will be less than $2I_1$ and the maximum instantaneous capacitor voltage will not exceed $V_1(1 + \frac{\omega 1}{\omega 2})$. Both these condition are favourable for the operation of a capacitor and its switching devices.

4.4.2Switching in at the instant when the voltage is at its peak value:

At the instant of peak voltage, the mains capacitor current, which is 90^0 out of phase will be zero. The instantaneous current will also start with a zero but will rise to its peak value within a quarter cycle of its specific frequency, which is normal quite high.

The peak value of the instantaneous current is given by $I_e = -V_1\sqrt{\frac{C}{L}}$ since the voltage is comman to both the systems $= -\frac{I1}{\omega 1C}\sqrt{\frac{C}{L}}$ (5)

$= -I_1\sqrt{\frac{1}{\omega 1\ L*\omega 1\ C}}$ (6)

$= -I_1\sqrt{\frac{XC}{XL}}$ (7)

V.PARALLEL SWITCHING OF A CAPACITORS:

When an additional capacitor bank C_2 is switched on across a bus where an existing capacitor bank C_1 is already energized, the bank C_2 has surge current drawn from two sources, the main and the already energized bank C_1.

Fig.2 Parallel switching of capacitor bank

Under the worst possible conditions, switching can take place when the main frequency voltage is passing through its peak. We will consider the two instantaneous current for C_2 separately.

The current drawn by C_2 from the mains will be

$I_{e1} = -V_{c1}\sqrt{\frac{C2}{Lmains}}$ (8)

The current drawn by C_1, which now is a source of supply will be given by

$I_{c2} = -V_{c1}\sqrt{\frac{C'2}{Lbus}}$ Where $C = \frac{C1\ C2}{C1+C2}$ (9)

These two current will have separate specific frequencies. However, these current will add up I_{e2} become very large, since the inductance of the bus system between the two capacitors is almost negligible.

VI.SIMULATION DETAILS

The MATLAB SIMULINK (2015b) software is used to simulate the circuit and to measure the inrush current and voltage.

Table 1 Parameters of circuit

Sr.No.	Parameter	Rating
1.	Transformer	3 phase, 11kv/415V, 630kVA, delta/star neutral point solidly grounded, 12 kA of short circuit rating, 4.89% impedance.
2.	Capacitor bank	50 KVAR (2 stages), 415V, rated operational current 72A, 3phase star bank.
3.	Load	440V 100 KVAR inductive load

Fig.3 Arrangement for the measurement of inrush

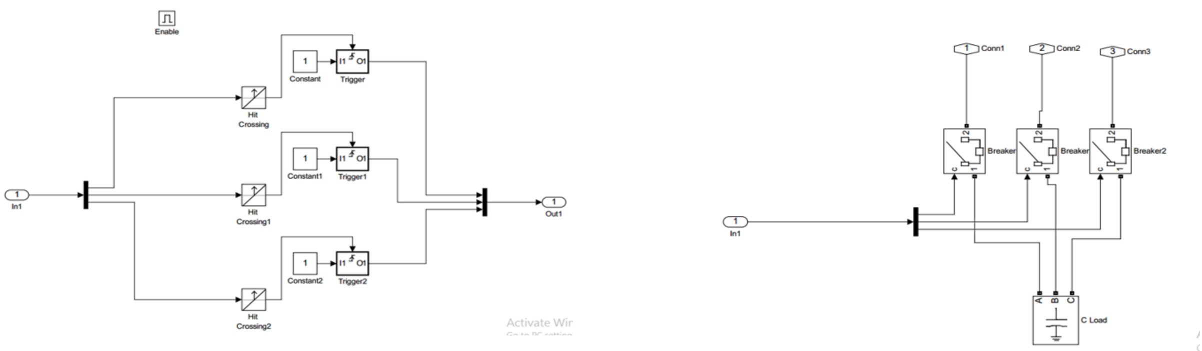
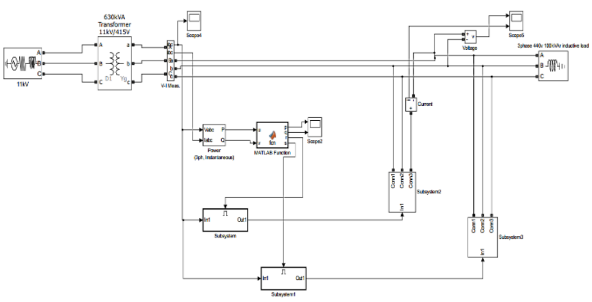


Fig.4 Subsystem1 CB switching signal generator and arrangement of capacitor bank with circuit breaker.

VII. RESULTS



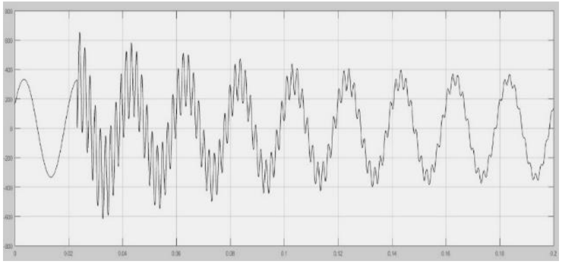
 ISBN : 978-93-87793-02-6

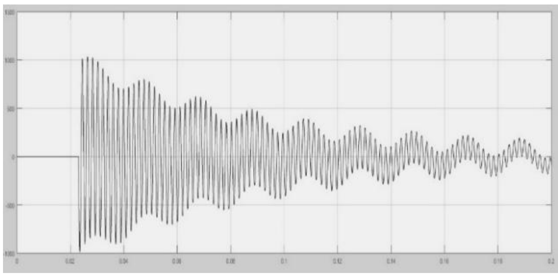
Fig.5 voltage and current transient at load side at random switching event respectively

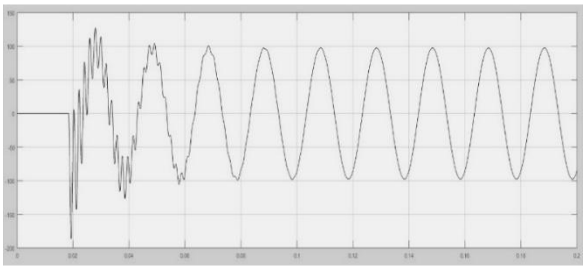
Fig.6 inrush current of bank C1 and C2 respectively

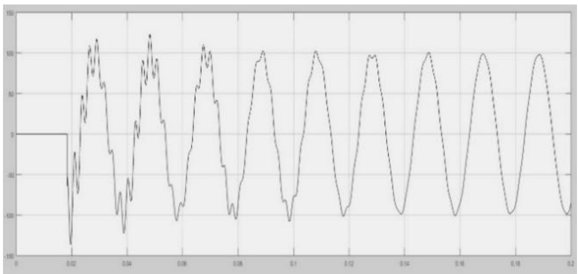
VIII.CONCLUSION

In this paper characteristics of transients, which originated from capacitor bank switching were studied. Moreover, the factors that influence the intensity of such transients were investigated in order to identify the condition in which these effects can be determined. The MATLAB/SIMULINK is used to simulate the inrush current in back to back switching of capacitor bank.









REFERENCES

[1] Alexander W.,Synchronous Closing Control for Shunt Capacitors,IEEE Trans. Power Appl. Syst., Vol. 104, No. 9, Pp.2619–2626, September1985.

[2] Meghana Ramesh, Hebbale Nagasimhaiah Nagamani, Venkatasubramanian Vaidhyanathan And Gururaj S. Punekar, Inrush Current Parameter Associated With Back To Back Switching Of Capacitor Bank,Taylor And Francis, Electrical Power component And Systems, 279-287,2017

[3] Chang-Chou Hwang, J. N. Lou, Transient Analysis of Capacitance Switching For Industrial Power System by PSpice, Elsevier, Electrical Power System Research, 45(1998) 29-28

[4] Denis V. Coury, Claudio Joes Dos Santos,Mario Oleskovicz, Maria Cristia Tavares, Transient Analysis Concerning Capacitor Bank Switching In A Distribution System, Elsevier, Electrical Power System Research 65 (2002) 13-21

[5] Schroeder, T. W., and Bloomquist, W. C., Automatic control and switching equipment for capacitor banks and its application, Electr. Eng., Vol. 63, Issue 9, pp. 649–654, 1944.

[6] Van Sickle, R. C.,Influence of resistance on switching transients, AIEE Trans., Vol. 58, pp. 397–404, 1939.

[7] Van Sickle, R. C. and Zaborszky Capacitor switching phenomena,AIEE Trans., vol. 70, pt. I, pp. 151–159, 1951.

[8] Porter, F. M. and Zimmerman, C. P., Application of shunt Capacitors at transmission and distribution stations, AIEE TRANS., Vol. 70, I, pp. 112–120, 1951.

[9] Boehne, E. W. and Low, S. S., Shunt capacitor energization with vacuum interrupters a possible source of overvoltage,"IEEE Trans. Power App. Syst., Vol. 88, No. 3, pp. 1424 – 443,September1969.

[10] Carnovale, D. J., Power factor correction and harmonic resonance: A volatile mix," EC & M Mag., Vol. 102, No.6, p. 16, June2003.

[11] Bohmann, L. J., Demler, J. R. and Barna, B. A., "Back-to-back capacitor energization transient's mitigation: comparison of preinsertion inductors versus surge reactors on a 46 kV subtransmission system, "Eectr. Mach. Power Sys. Vol. 25, No. 9, pp.1023–1034, 1997.

[12] D. M. Tagare, accessories for high tension capacitor banks (TATA McGraw hill publishing company limited, 2003)