International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

VOLTAGE OSCILLATION TRANSIENTS CAUSED BY CAPACITOR BANKING ENERGIZING FOR POWER FACTOR CORRECTION IN THE POWER SYSTEM

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Abstract

As far as the power quality issues are concern, insertion of capacitor banks into the system needs to be understand for both power factor correction as well as for the voltage support. Whenever capacitance switching takes place, a transient overvoltage will be seen which can be hazardous for our power system's equipment. In this paper, voltage oscillation transients caused by the capacitor banking energizing for power factor correction in the power system has been discussed. The experiment is carried on a sample system which has been studied using the MATLAB/Simulink environment. The simulated results are the plots of the RMS values against the different intervals of the switching times of each phases and how the transient overvoltage occurs in a particular switching time and for how much duration is also shown.

Keywords **:** ***Capacitor bank energization,power factor correction, switchingovervoltages,*** **transients.**

I. INTRODUCTION

Being diversified and dynamic in nature the power system's state variables get deviate from there specified limits due to certain phenomenon.With the growing number of installation of capacitor banks and their frequently usage by the utility multiple times a day or hundreds of times per year which will be depending upon the system voltage need and reactive power to be fulfilled from the banks. [4] [13] As we know that the capacitors are there for power factor correction and voltage regulation. But these can cause parallel or series resonance problems and hence distorts the voltage and current waveforms. [1]. One of the most common operation in the electrical power system is the switching of the capacitor banks in distribution networks. [15] During its switching, a high frequency component of transient occurs. These over voltages can be of very high value that it can damage whatever the power electronic devices are present in the system. [1] [2] [16]these over voltages can be generated either at low frequency, medium frequency (capacitor energizing), or at high frequency (lightning and load switching). Even though the over voltages of shorter duration doesn't damage the electronics equipment but can cause the operation of protective devices of the drive's. [1].As far as power quality issue is concern, capacitor bank energizing transients should be studied. Shape and magnitude of these transients can vary with the system specification and network configuration. Along with this, it can also depend on circuit breakers operation and point-on wave at which switching transient starts. [4] [7] [9]

This paper presents how to estimate the switching over voltages caused due to the insertion of capacitor bank into the sample system for power factor correction in the power system by using MATLAB/Simulink.

This paper is divided in to the following sections: Section I consists of introduction, Section II gives the brief description of capacitance switching and energization, Section III contains sample model and in the last Section IV and Section V discusses the results and conclusion respectively.

II. CAPACITANCE SWITCHING AND ENERGIZING

It's well known that capacitors are there to provide reactive power (in units of Vars), for correction of the power factor in addition reduces losses and improves voltage profile of the system but it has its own disadvantage. In addition to it some capacitors can be energized all the time (a fixed bank) or be switched according to load levels. During the switching of shunt capacitor banks, high magnitude and high frequency transients can occur. The transient is characterized by a surge of current having a high magnitude and a frequency as high as several hundred Hertz. [5] [15] [17]

When the capacitor in Fig. 1 is energized by closing of the circuit breaker the voltage and current in this capacitor considering a discharged capacitor can be represented as: -

$$v_c(t) = v - v\sin\omega t \qquad (1)$$

$$i_c(t) = \frac{v}{z0}\sin\omega t \qquad (2)$$

where, v=circuit breaker voltage at closing instant; ω=natural frequency = ${}^{1}\!/\!_{\sqrt{LC}}$; Z_0= surge impedance= ${}^{\sqrt{L}}\!/\!_{\sqrt{C}}$

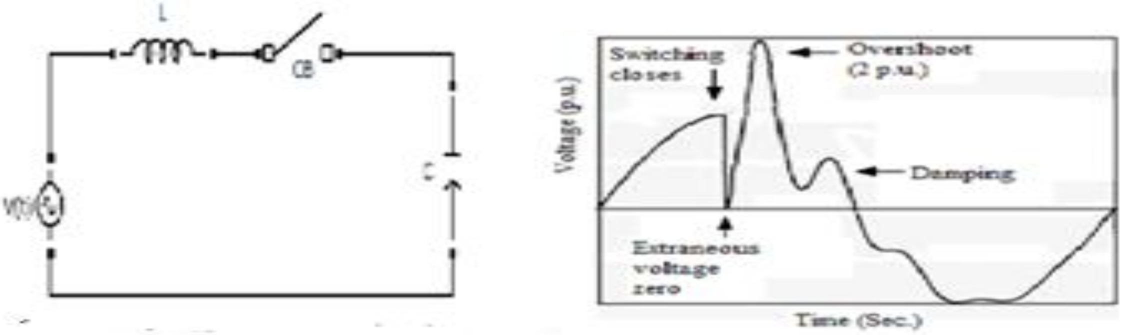


Figure 1: Capacitor energizing (Source)

Case1: - At the instant of capacitor bank insertion, a capacitor is a sudden short circuit, because the voltage across the capacitor cannot change suddenly, therefore it will dip severely. [12] This dip in the voltage & the step change in transient is a function of the source impedance behind the bus. Later on, voltage will then recover through a high frequency oscillation.

In the initial oscillation overshoot can result in a voltage that has a theoretical peak value of two times the maximum value of sine wave (crest voltage) as shown in Fig. 1 which can recover about ½ of a cycle.

Case2: - When a capacitor is switched off. Same effect is observed if re-strike occurs during the switching operation. [4]

III. SAMPLE SYSTEM MODELLING

The sample system considered for explanation of the proposed methodology is shown in Fig. 2. It consists of 33 kV, 30 MVA, 50 Hz three-phase source block feeding through 33 kV/0.4 kV, 3 MVA delta/Wye transformers to 200 kW resistive and 200 kVAR inductive load.

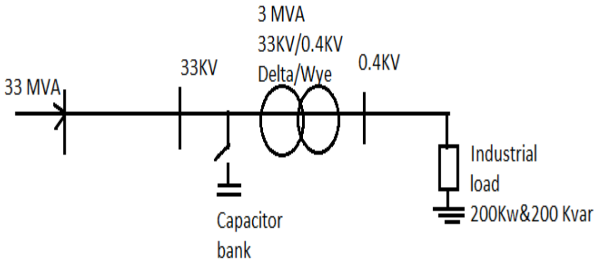


Figure 2. Single line diagram of the studied system before the insertion of the capacitor bank

The user friendly graphical interfaces of MATLAB/Simulink enable faster development for power system transient analysis.

The modelling of studied power system is detailed as below:-

A. 33 kV supply network

The system equivalent can be modelled by a three phase voltage source with amplitude equals to 33 × √2/√3 kV.

B. Transmission line model

Transmission line (OHTL or UGC) is described by PI cell, where the R, L and C parameters being derived from lumped-line models.

C. Transformer model

The substation transformer 33/0.4 kV is modelled by 3- phase, Δ-Y, with ground Y transformer where this model takes into account the winding resistances (R1, R2), the leakage inductances (L1, L2) as well as the magnetizing characteristics of the core, which is modelled by a resistance, R m, simulating the core active losses, and a saturable inductance, Lsat. The saturation characteristic is specified as a piecewise linear characteristic.

D. Circuit breaker model

Circuit breaker can be modelled by a resistance R_{on} when the breaker is closed and an infinite resistance when the breaker is open, where the opening and closing times can be controlled by external control signal

E. Load and capacitor bank model

The load is modelled as three phase Y connected constant impedances specified by active and reactive power. The capacitor bank is presented as three phase Δ connected reactive power generation units specified by the required reactive power for the system.

III. RESULTS

Case1: - When circuit breaker is continually kept closed, graphs will be as shown on fig. 7. This shows that the capacitor bank compensates for all disturbance present in the system.

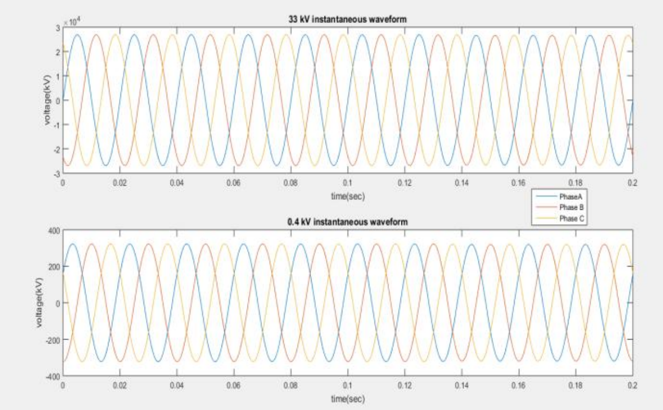


Figure 7: voltage wave forms on 33kV and 0.4kV Bus bar.

Case 2: - When switching time of circuit breaker is kept open at 0.01sec

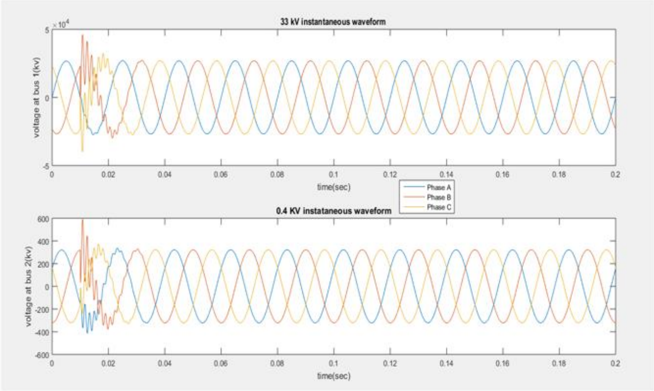


Figure 8: voltage wave forms on 33kV and 0.4kV Bus bar when capacitor is switched.

When each phase is taken serparetly we observe the folowing phenomenas as shown on the figure below.

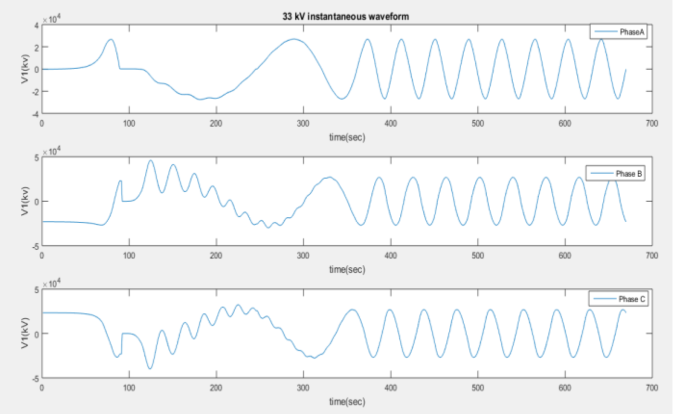


Figure 9: voltage wave forms on 33kV Bus bar when capacitor is switched taken independtly.

By obeserving the wave forms on figure 8 and 9 we can see some transient at the switching time, the duration of the transients depend on the peak value of the first strike. The table below shows different values of trasient duration depending on voltage disturbance initial time and ending time.

TABLE 1: ANALYSIS WITH DIFFERENT SWITCHING TIME

SW/time	$T_{V.D\ int.}$	$T_{V.D\ end.}$	$T_{D.D}$
0.01	0.01	0.031	0.021
0.03	0.03	0.055	0.025
0.05	0.05	0.074	0.024
0.07	0.07	0.095	0.025
0.09	0.09	0.114	0.024
0.11	0.11	0.135	0.025
0.13	0.13	0.155	0.025
0.15	0.15	0.175	0.025
0.17	0.17	0.194	0.024
0.19	0.19	0.214	0.024

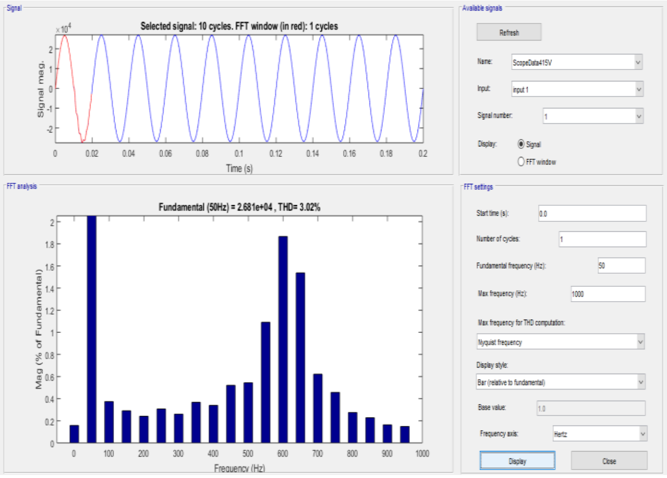
Where, $T_{V.D\ int.}$ = voltage disturbance initial time
$T_{V.D\ end.}$ = voltage disturbance final time
$T_{D.D}$ = disturbance's duration time

A. Total harmonic distortion (THD) Analysis

As known the harmonic distortion is caused by nonlinear devices in the power system, the total harmonic distortion (THD) is a measure of effective valuesof the harmonic components of a distorted waveform [3] [6] [18]. The difference between a harmonic and a transient must be discussed before making any analysis on the system.

Even though transient disturbances have high-frequency components, transients and harmonics are strictly different phenomena and analyzed differently [8] [11].

- Transient waveforms show high frequencies only for short duration after there has been an abrupt change in the system. The frequencies are not necessarily harmonics; they are the natural frequencies of the system when switching operation is done and have no relation with the system fundamental frequency.
- Harmonics, by definition, are observed in the steady state and are integer multiples of the fundamental frequency.
- After analysis using MATLAB/Simulink we found that the THD=3.02% as shown in the figure below. This value of THD shows that the high-frequency components caused by the transient as not affected strongly the fundamental frequency component of the system.



Name: ScopeData415V
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.0
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 10: THD analysis of the system

B. RMS value calculations

The THD is related to the root min square (RMS) value of the waveform as follows:

$$\mathrm{RMS} = \sqrt{\sum_{h=1}^{h_{max}} M_h^2} = M_1\sqrt{1+\mathrm{THD}^2} \qquad (3)$$

Where, M_h is the RMS value of harmonic component h of the quantity M.

After calculation of RMS values using MATLAB of each phase in 10 intervals of switching time, the following results have been found:

When switching time of CB (Circuit breaker of capacitor bank) is 0.01sec then RMS value = 1.0e+04

Similarly, for rest of the switching times of the circuit breaker, the RMS value of the waveform in total will remain the same. We have made the switching time varies in step of 0.02 from 0.01 sec to 0.19sec.

But the RMS value in each phase varies as the table 2 and 3.

The plotting of RMS values of each phase with respect to the switching time is shown on the figure 11a and 11b for 33kV and 0.4kV bus bar.

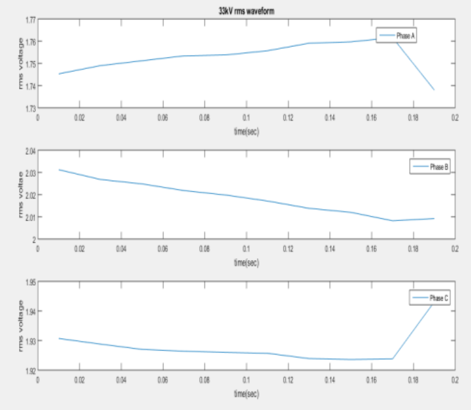


Figure 11a: Plotting of RMS values 33kV.

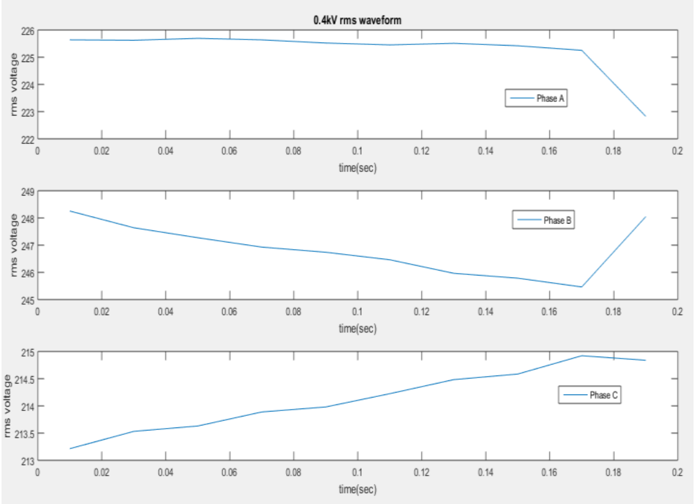


Figure 11b: Plotting of RMS values 0.4kV

TABLE 2: RMS VALUE VARIATIONS IN EACH PHASE FOR 33 KV

Phase/ SW Time	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19
A	1.7453	1.7490	1.7512	1.7534	1.7538	1.7557	1.7591	1.7597	1.7616	1.7380
B	2.0312	2.0268	2.0248	2.0218	2.0198	2.0171	2.0138	2.0120	2.0082	2.0092
C	1.9307	1.9288	1.9270	1.9264	1.9260	1.9257	1.9239	1.9236	1.9238	1.9431

TABLE 3: RMS VALUES VARIATION IN EACH PHASE FOR 0.4 KV

Phase/ SW Time	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19
A	225.6385	225.6220	225.6939	225.6373	225.5211	225.4522	225.5105	225.4199	225.2523	222.8230
B	248.2544	247.6399	247.2729	246.9288	246.7389	246.4630	245.9650	245.7858	245.4634	248.0466
C	213.2134	213.5320	213.6305	213.8884	213.9806	214.2245	214.4829	214.5856	214.9223	214.8388

C. Transient and Capacitor energizing

There is a net difference between a capacitor energizing transient and a transient caused by any fault in the system. Two types of transients are there among which capacitor energizing falls under the category of oscillatory transients. This difference must be shown out because when calibrating of the protective device is being done, it should be able to distinguish the two phenomena. [10]

- Transient (impulsive)

  Having the following characteristics; 5ns to 0.1 ms rise of spectral content with a duration of <50ns to >1ms, the magnitude component is very high in this case.

- Capacitor energizing (oscillatory transients)

With the following characteristics; a frequency from 500kHz to 5MHz with a duration of 5µs to 50ms and the magnitude is almost 1.5pu of the original magnitude. [10] [12]

IV. CONCLUSION

The aim of this paper was to design, simulate and analyze all aspect of voltage oscillatory transient caused by capacitor banking energizing for power factor correction in a power system. It has been observed that:

- There is a net difference between a transient when capacitor is switched in a system and when a fault occurs in the system, so that the protective device can be well calibrated.
- The difference between the harmonic caused by switching of a capacitor and the THD present in the system.

By analyzing different switching time of capacitor bank we have observed the duration of transient, the rise of magnitude of the voltage component in each phase, RMS values at each instance was shown and the THD of the system was also analyzed. The results shown in this paper can serve as base for analyzing power quality and calibration of a protective device when capacitor bank is inserted in a power system.

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