

Simulation of Costumer Voltage Magnification due to Capacitor Switching Using EMTP

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Abstract-This paper presents the effect of switching a shunt capacitor banks at a utility's substation and the subsequent voltage magnification on a customer voltage bus. The magnification of transient phenomenon is produced when the natural frequency of the LC circuit formed by the switching capacitor banks and the system Thevenin's impedance is similar to the natural frequency of LC circuit formed by customer's shunt capacitor and the inductance between the two capacitors banks. The application of a capacitor banks is a usual practice of utilities and industrial plants to reduce energy cost; a shunt capacitor bank to correct the power factor is installed. This practice can result in an undesirable voltage magnification at customer bus.

The Electromagnetic Transients Program (EMTP) was used to simulate voltage magnification phenomenon. An example of a mitigation alternative is also provided.

KEYWORDS

Switching Transient, Capacitor Switching, EMTP, Voltage Magnification

I. NOMENCLATURE

The following notation is used throughout the remainder of the paper

f_1 = System frequency (Hz)

f_2 = Customer frequency (Hz)

L_1 = System Thevenin's inductance (H)

C_1 = Capacitance of Substation's Capacitor Bank (F)

L_2 = Equivalent inductance between transmission line and step down transformer (H)

Z_{LT} = Transmission Line Impedance (Ω)

Z_s = System Thevenin's Impedance (Ω)

C_2 = Capacitance of Customer Shunt capacitor (F)

C_L = Customer Load (MW)

II. INTRODUCTION

Voltage magnification occurring as a result of switching a shunt capacitor banks at a utility's substation is a phenomenon that it has been studied. It has been shown that the maximum overvoltage occurs when the natural frequency of both (utility and customer) are closely equal.

As utility customer power quality awareness increases, there is an increasing need to reduce or eliminate the effects of transients on customer electronic equipment [2].

Capacitor switching is one of the most common switching events on the utility systems. Capacitors are used to provide reactive power (vars) to correct power factor,

which reduces losses, and to support voltage on the system. They are very economical and generally trouble free means of accomplishment this. Alternatives such as rotation machines and electronic (vars) compensators are much more costly or have high maintenance cost [5]. Capacitor energizing is just one of the many switching events that can cause transients on a utility system. However, due to their regularity and impact on power system equipment, they quite often receive special consideration [9].

Voltage magnification phenomenon is related to two different LC circuits (the LC circuit formed by the switched capacitor and the system inductance and the LC circuit formed by the low voltage capacitor and the inductance between the two capacitor banks), it is important to consider the interrelationships between the different parameters. The level of power factor correction at the customer's low voltage bus is one of the most important parameter affecting the magnitude of the transient.

Transient overvoltages due to capacitor switching are generally just below the level at which utility surge protection, such as arresters, begins to operate. However, because of the relatively low frequencies involved, these transients will often be coupled through step-down transformers to customer loads. The frequent switching of transmission and distribution capacitor banks, coupled with the increasing application of sensitive customer equipment, has led to a heightened awareness of resulting secondary voltages. Typical transient magnitude levels range from 1.2 to 1.8 per-unit and typical transient frequencies generally rail in the range of 300 to 1000 Hz [9].

The EMTP is used to simulate electromagnetic, electromechanical, and control system transients in multiphase power systems. It was originally developed in the late 1960's by Hermann Dommel at Bonneville Power Authority (BPA). Since then, there have been significant developments by groups all over the world [9].

The EMTP is a general-purpose computer program for simulating high-speed transient effects on electric power systems. The program features an extremely wide variety of modeling capabilities encompassing electromagnetic and electro-mechanical oscillations ranging in duration from microseconds to seconds [9].

This paper presents a simulation of the voltage magnification at the customer bus due to switching capacitors at the utility, and a possible mitigation technique to reduce this impact.

III. EMTP SIMULATION OF CAPACITOR SWITCHING TRANSIENT

Voltage magnification impact due to a switching capacitor was simulated at the customer bus using EMTP. Firstly, the system to be studied was determined. A typical sub-transmission system of 38 KV at substation area was developed to determine the effect of switching a capacitor bank at the utility (20 MVAR) at the customer. Figure 1 shows a simplification of the system to be studied.

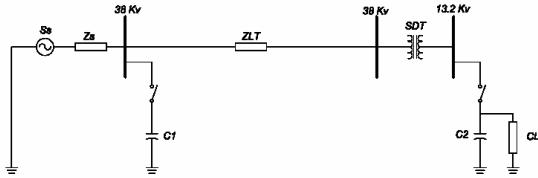


Figure 1. System one-line diagram showing 38KV substation and sub-transmission system to affect customer's utilization voltage bus.

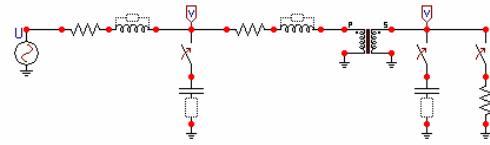
The inductance and capacitance, which determine the switching transient frequency, are represented in the source impedance (damping factors where taken in count). The transmission line connected to the substation bus is represented in term of the lumped equivalent impedance. The equivalent surge impedance serves to damp the energizing transient at the substation bus.

Capacitor Bank of 15 KVAR was installed at the customer to correct the power factor by 0.30 (from 0.60 to 0.90). The load at the customer's facility serves to damp the magnified switching transient voltage.

Tables 1 gives a summary of the base parameters used to calculate the required values in the simulation, and figure 2 shows the equivalent circuit used to simulate the transient phenomenon on EMTP.

Parameter	
System Thevenin's Source	38 KV
Short Circuit Current	32 KA
X/R	10
Switched capacitor Bank size	20 MVAR
Transmission Line	38 KV, 10 Km, Conductor: Amherst 195.7 Kcmil AAAC, Construction Pattern: 38-PC-7
Distribution Step Down Transformer	38/ 13.2 KV, 1.5 MVA, 5.5 % impedance
Customer-Voltage Bus Load	20 KW, P.F. 0.60
Customer Capacitor bank	15 KVAR
Power factor correction (Customer capacitor bank)	0.60 - 0.90
Transient Frequency	615.79 HZ

Table 1. Summary of the circuit parameters used for the simulation studies.



Model No. 1

Figure 2. Equivalent Circuit for the Capacitor Energizing.

Voltage magnification effect is present at the customer when the LC circuits (the LC circuit for the switched capacitor transient at the utility and LC circuit formed by the customer step down transformer and the low voltage capacitors) have similar frequencies $f_1 \approx f_2$. The frequency of the transient and the frequency of customer resonant circuit are given by equations below:

Switching Frequency

$$f_1 = \frac{1}{2\pi\sqrt{L_1C_1}}$$

Natural Frequency of Customer resonant circuit

$$f_2 = \frac{1}{2\pi\sqrt{L_2C_2}}$$

The transient frequency simulated at EMTP was 616 Hz.

The transient overvoltage obtained at the utility was 1.82 times bigger than the system voltage. Figure 3 shows transient overvoltage at the switched capacitor bank.

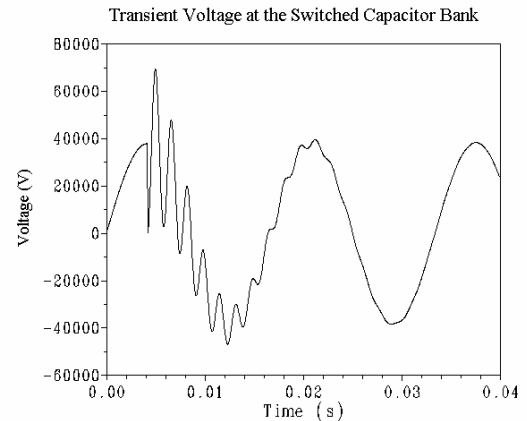


Figure 3. Transient Voltage at the Switched Capacitor Bank

As mentioned before these low frequency transients, can be magnified in a customer facility. Figure 4 shows a voltage magnification at the customer bus of 2.51 per unit. It was demonstrated that voltage magnification will be damaging electrical equipment if special analysis is not perform before the implementation of power factor correction capacitor bank.

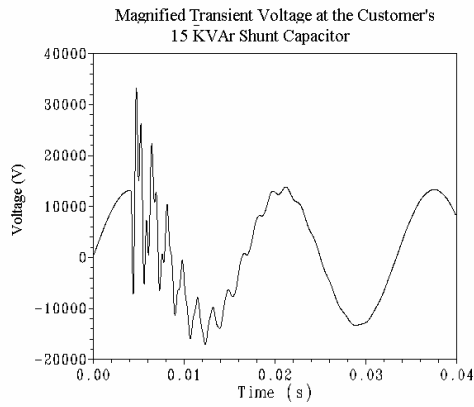


Figure 4. Magnified Transient Voltage at the Customer's Bus

IV. POSSIBLE MITIGATION TECHNIQUES

Voltage magnification can be controlled at the Utility Substation or at the Customer Facilities. Many of the following alternatives have been implemented to minimize voltage magnification.

A. Utility Mitigation Options

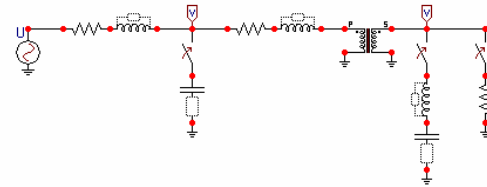
At the present, the devices available for transient overvoltage control attempt to minimize the transient overvoltage (or overcurrent) at the point of application, this is the ideal solution to the transient magnification problem. These devices include pre-insertion resistors and/or inductors (unfortunately the optimum size is not commonly available for sub-transmission switching device), synchronous closing control, also known as zero voltage closing (with solid state switch, actually only vacuum circuit breakers are fast enough to permit this implementation), and metal oxide varistors (MOV's) arresters. Previous researchers [6], [8] have suggested that the effectiveness of these control methods are system dependent, and that detailed analysis is required to select the optimum control scheme. Each of these methods has various advantages and disadvantages in terms of transient overvoltage reduction, cost, installation requirements, operating/maintenance requirements, and reliability.

B. Customer Mitigation Options

Customer has few options in controlling magnified transient related to utility capacitor switching, if it needs to add power factor correction. Low voltage arresters can be applied, but they must have high energy rating and may not coordinate with the withstand levels of the other customer's devices. The best option is to eliminate the magnification completely. In order to do it, it is recommendable to detune the LC circuit adding significant inductance in series with the power factor correction capacitor. If we use a harmonic filter as a power factor correction and tune it to control the common harmonic distortion levels (3rd and 5th harmonics), the resonance for the total series combination will be 256 Hz, not easily excited frequency by the utility's capacitor switching.

V. SIMULATE AN HARMONIC FILTER TO MITIGATE VOLTAGE MAGNIFICATION

Many techniques are available to mitigate the voltage magnification, but this paper will simulate only the effect of adding a harmonic filter at the customer. As a mentioned a harmonic filter can reduce the transient overvoltage to acceptable levels. A simulation of the circuit was made adding a harmonic filter at the customer. Figure 5 shows the equivalent circuit with a harmonic filter installed.



Model No. 2

Figure 5. Equivalent Circuit for the Capacitor Energizing with a harmonic filter Installed

Figure 6 shows that reconfiguring the low voltage capacitor as harmonic filter has eliminated voltage magnification at the customer bus. While the voltage transient in the utility's substation is 1.82 per unit, in the customer bus the transient is 1.74 per unit. This fact can reduce the energy dissipated in the MOV's arresters.

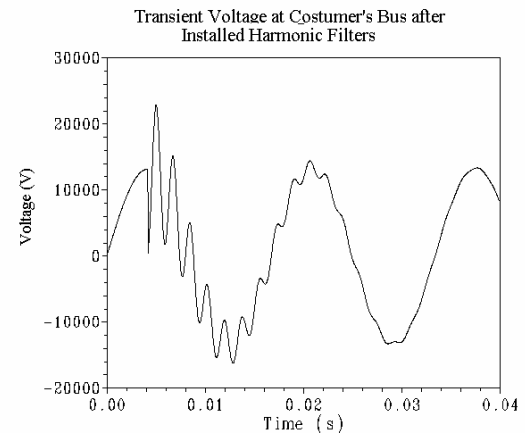


Figure 6. Transient Voltage at Customer's Bus with a Harmonic Filter Installed

Other mitigation techniques can be simulated in future studies.

VI. CONCLUSIONS

1. Power factor correction capacitors at low voltage buses can result in magnified transient voltages during capacitor switching on the primary distribution system. Magnified transients in the range over 2 per unit are possible. Problems with these transients depend on the sensitivity of the customer equipment. Some types of power electronic devices can be particularly susceptible to

these transients.

2. The most severe magnification cases occurs when the following conditions exist:
 - Utility's switched capacitor bank is much larger (KVAR) than the customer capacitor bank.
 - The frequency of oscillation, that occurs when the utility's capacitor bank is energized, is close to the resonant frequency formed by the customer's capacitor bank and the lumped inductance between the two capacitors banks.
 - There are few damping factors provided by customer's active load (normally motor's loads)
3. Voltage Magnification can be reduced by reconfiguring the capacitor bank (power factor correction) as harmonic filter.

VII. REFERENCES

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