Pre-insertion Resistor of Switching Shunt Capacitor Banks

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Abstract

This paper aims to reduce the transient overvoltages problem occurred in switching shunt capacitor banks by pre-insertion resistor. Capacitor banks installed in power system are used to compensate the reactive power demand for improving the network's voltage profile and decreasing the network's losses. Capacitor banks may be switched on and off frequently during a typical day according to certain load curves. The switching actions will produce large transient overvoltages. These transients may cause serious power quality problems. This paper compares the responses of several typical switching strategies by Alternative Transients Program (ATP) and some suggestions for reducing transients are proposed.

Keywords: transient overvoltage, power quality, ATP.

1. Introduction

Capacitor banks installed in reality power system is common method. Capacitor banks are used to compensate the reactive power demand for improving the losses of network. The most common way to install the capacitor bank is shunt with the customer on the identical bus. Because the capacitor voltage is unable to change suddenly, when the capacitor bank switch is operates, the bus voltage will plummet to zero, then the bus voltage will follow the high-frequency oscillation transient to recovery the voltage quickly that may cause to capacitor itself and near bus produce large transient overvoltage and inrush current, these transient phenomenon may lead to interfere or damage of the equipment and that has a very serious power quality problems. Finally, the transient phenomenon has became more and more concern day by day.

Before the capacitor bank energizing, there is a operating capacitor at the bus or nearby bus. The way of capacitor energizing is called back to back capacitor energizing. Under this condition, it will produce high oscillation frequency and a large inrush current. The model in this paper is belong to one kind of back to back capacitor energizing.

Figure 1 shows a typical LC two-loop power system, when the resonant frequency of the two loop very close, i.e. $L_1C_1 \cong L_2C_2$, it will cause the magnification overvoltage of series resonance phenomenon. The customer will become serious overvoltage situations. In the multi-voltage level of the power system, the low voltage side may be destroyed because of the magnification voltage, which causing the phenomenon of equipment insulation.

Since the seventies, the technology of pre-inserting resistor in the capacitor switch at both ends has been widely adopted. Before the capacitor switch operating, first switching of resistor, make to resistors and capacitors to form a series circuit. In order to avoid second switch in the duty cycle of the switching, it has to suffer a power frequency cycle, and then short the resistor, which provides additional damping to consume the energy of transient, and then short the resistor so that the capacitor will not consume energy. But the pre-component will increase the cost and the complexity of the circuit.

ATP is widely used in analyzing the electromagnetic transient phenomena of power system and the electromagnetic characteristics of the digital simulation programming system. This software can simulate a complex circuit, in addition to the calculation of transient analysis. ATP also has a number of expansion modules. And its function application is very powerful and practical

This paper used pre-insert resistor method and simulated with ATP to analysis for exploring how to reducing transient.

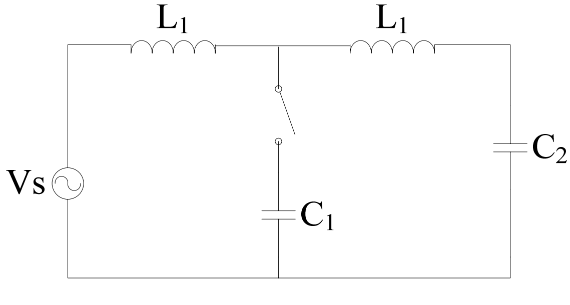


Figure 1. Typical two-loop power system.

2. Circuit Analysis

In order to explore the transient overvoltage phenomena of capacitor, this study assume the power voltage is 1 V, 60 Hz, $V_s = 1 \cdot \sin(2\pi t), 60Hz$.

After analyzing, the transient voltage equation can be determined:

$$V_{C2}(t) = 1 - \frac{\beta_2^2 \cos \beta_1 t - \beta_1^2 \cos \beta_2 t}{\beta_2^2 - \beta_1^2} \quad (1)$$

Natural angular frequencies of two-loop are designed β_1 and β_2 :

$$\beta_1 = \left(\frac{\alpha}{2} - \sqrt{\frac{\alpha^2}{4} - \beta} \right)^{\frac{1}{2}}$$
$$\beta_2 = \left(\frac{\alpha}{2} + \sqrt{\frac{\alpha^2}{4} - \beta} \right)^{\frac{1}{2}} \quad (2)$$

where

$$\alpha = \frac{1}{L_1 C_1} + \frac{1}{L_2 C_2} + \frac{1}{L_2 C_1}$$
$$\beta = \frac{1}{L_1 C_1 L_2 C_2}$$

3. Pre-insertion Resistor

This paper uses the pre-resistance method as showed in Figure 2. To shunt resistor before you close switch, the use of resistors to provide additional damping to reduce transient energy. As the resistor will consume the energy, it has to short the resistor after a power cycle in order to avoid consumes extra energy. This study assumes the current of L_1C_1 loop:

$$i_1 = I_m \cos(\omega_1 t)$$

Then the angular frequency ω_1 ,

$$\omega_1 = \sqrt{\frac{1}{L_1 C_1}} \quad (3)$$

And

$$I_m = -\frac{V_{sw}}{L_1 \omega_1} = -\frac{V_{sw}}{\sqrt{L_1/C_1}} = -\frac{V_{sw}}{Z_0}$$

Where the V_{sw} is the switch terminal voltage,

And the surge impedance Z_0 ,

$$Z_0 = \sqrt{\frac{L_1}{C_1}} \quad (4)$$

This study pre-inserts a resistor, which resistance is same to value of the surge impedance, to offset the energy of the surge impedance.

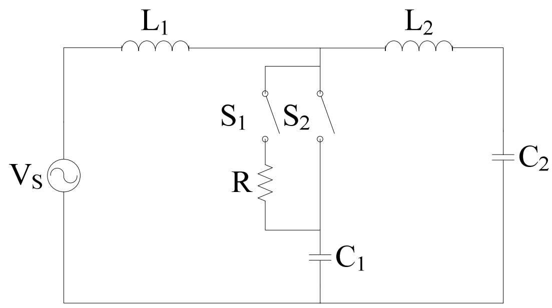


Figure 2. Pre-insertion resistor of voltage magnification circuit.

4. Case Study

This paper used alternative transient program (ATP) to simulate the circuit of Figure 2. The system parameter as showed below:

$$V_s = 1 \cdot \sin(2\pi t), 60Hz,$$
$$L_1 = 41\mu H, \; C_1 = 2600\mu F,$$
$$L_2 = 4100\mu H, \; C_2 = 26\mu F$$

The resistance of pre-insertion resistor can be calculated by the equation (4), $R \approx 0.1\Omega$

This article is divided into four cases to do simulation analysis. The former two cases are analyzed without pre-install resistor.

Case 1 : switch closing at T1.
Case 2 : switch closing at T2.
Case 3 : switch S1 closing at T2, and switch S2 closing at T3.
Case 4 : switch S1 closing at T2, and switch S2 closing at T4.

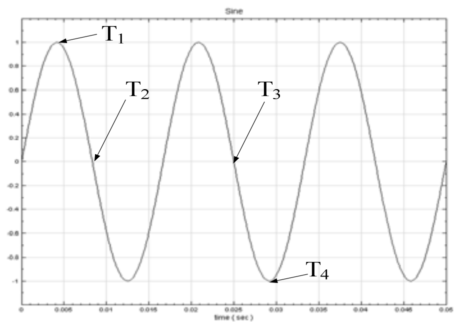


Figure 3. The switching time

In case 1, this study closes the switch at the voltage peak. Due to the switch closing, the voltage difference across the switch is the largest. According to Figure 4, the voltage of capacitor C1 is close to 2V. The voltage of capacitor C2 is enlarged and its transient overvoltage is nearly as high as 11V. There will be a obvious oscillation phenomena observe in the 400 ~ 600Hz by the spectrum, especially serious in the capacitor C2. Then this study can convert frequency into natural angular frequency which is identical when proving from equation (2).

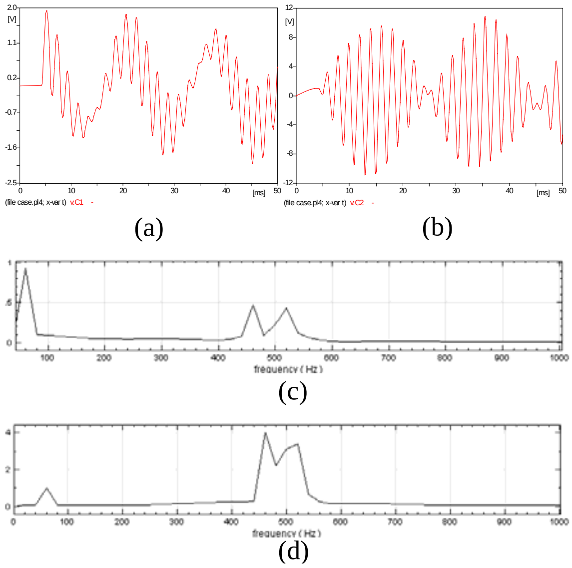


Figure 4. Case 1 (a) V_{c_1} (b) V_{c_2} (c) V_{c_1} spectrum (d) V_{c_2} spectrum.

In case 2, this study put the switch at the voltage zero and this method is the most commonly used in the past. When the voltage across the switch is zero, the transient overvoltage can be effectively reduced. According to Figure 5, the voltage of capacitor C1 had been reduced to near 1V. Although the C2 capacitor voltage has a obvious reduction, there are still some over-voltage of 2V. Compared to case 1, the oscillation also significantly reduces in the spectrum. Capacitors C1 and C2 capacitors in the part of the spectrum, the case of oscillation compared with Case 1 there is also a significant reduction.

Case 3 and Case 4 are examples of pre-inserton resistor. The S1 switch in Case 3 and Case 4 are closing when the voltage is zero, in order to avoid transient accumulation. The S2 switch in Case 3 is closing when the voltage is zero after a power cycle. The S2 switch in Case 4 is closing when the voltage peak after a power cycle.

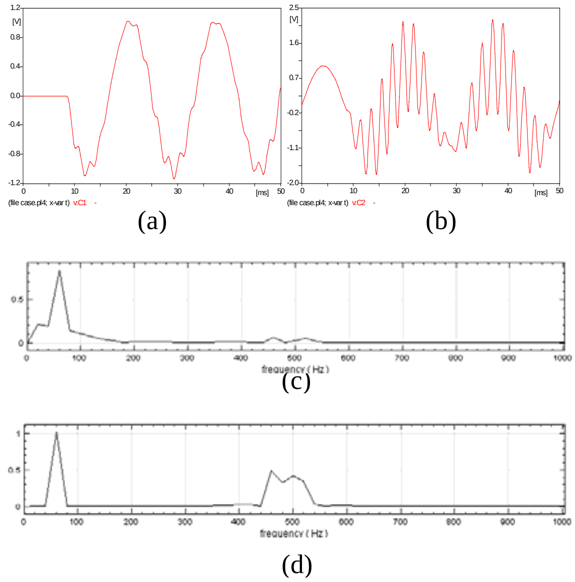


Figure 5. Case 2 (a) V_{c_1} (b) V_{c_2} (c) V_{c_1} spectrum (d) V_{c_2} spectrum

From Figure 6, this study can know the C1 capacitor voltage is significant reduce in case 3. Although the transient overvoltage is reduced, the second transient occur when S2 switch closing. There is less oscillation compared to case 2 in the spectrum.

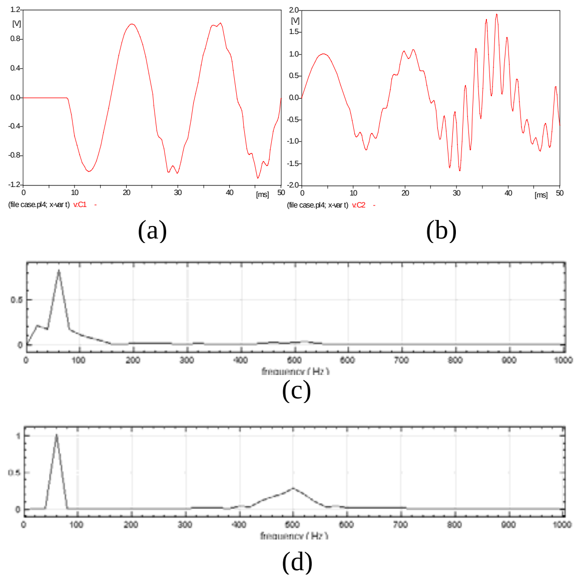
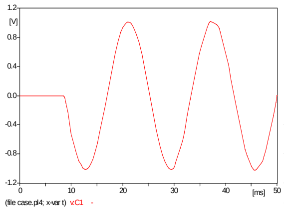
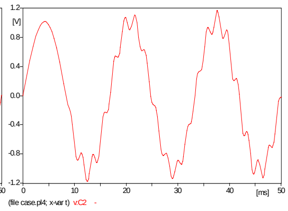


Figure 6. Case 3 (a) V_{c_1} (b) V_{c_2} (c) V_{c_1} spectrum (d) V_{c_2} spectrum

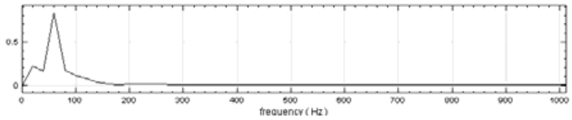
From Figure 7, it can be observed the C1 capacitor voltage has reduced to 1V and its waveform approaches to the sinusoidal in case 4. The C2 capacitor voltage is reduced to 1.2V. In the spectrum, only the C2 capacitor has a slight oscillation.



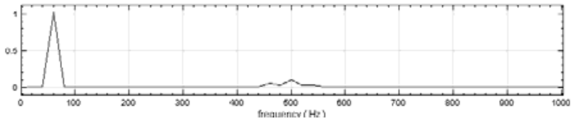
(a)



(b)



(c)



(d)

Figure 7. Case 4 (a) V_{c_1} (b) V_{c_2} (c) V_{c_1} spectrum (d) V_{c_2} spectrum

Observed in Table 1, the C2 capacitor may have a overvoltige colse to 11V in the circuit magnificated voltage, as showed in case 1, without any inhibition. The method used in Case 3 and Case 4 can reduce transient overvoltage to the extent that this study can accept, but the method used in Case 4 is more effective.

TABLE 1: Closing Transients in Four Cases

	C1 Maximum Voltage (V)	C2 Maximum Voltage (V)
Case 1	1.95	10.86
Case 2	1.14	2.2
Case 3	1.11	1.92
Case 4	1.02	1.17

5. Three-phase System Analysis

In order to take into account the effect of the phase angles difference of phase voltages on transient overvoltages, this paper simulate and analysis the three-phase system.

Figure 8 and Figure 9 show as it can be observed out that both the C1 and C2 three-phase voltage in case 1 has serious overvoltage situations.

Figure 10 and Figure 11 show as, although the strategy of voltage zero closing can effectively inhibit the overvoltage in phase A, the capacitor voltages in phases B and C still have serious overvoltage situations.

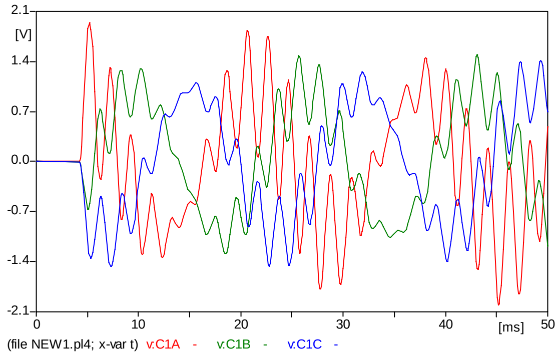


Figure 8. The Three-Phase V_{c_1} of Case 1.

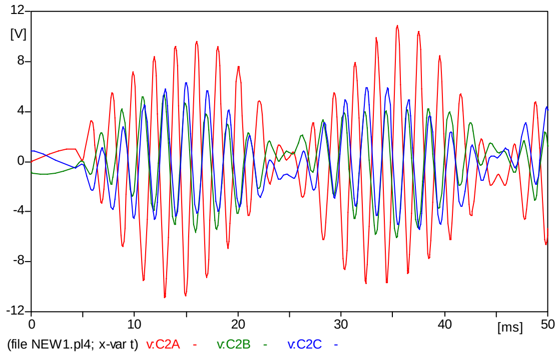


Figure 9. The Three-Phase V_{c_2} of Case 1.

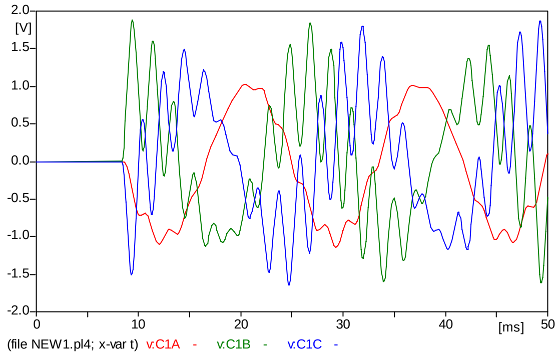


Figure 10. The Three-Phase V_{c_1} of Case 2.

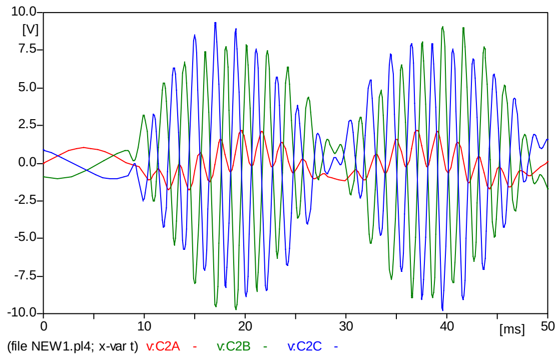


Figure 11. The Three-Phase V_{c_2} of Case 2.

Figure 12 and Figure 14 show as the strategy of pre-insertion resistor in this paper, the three-phase voltages of C1 are obviously reduced to about 1V.

Figure 13 and Figure 15 show as C2 capacitor voltage in phases B and C of Case3 and Case4 are also obviously reduced to the extend this study can accept.

The second transient phenomenon of the voltage in phase A can be significantly reduced by closing S2 switch at voltage peak used in case 4.

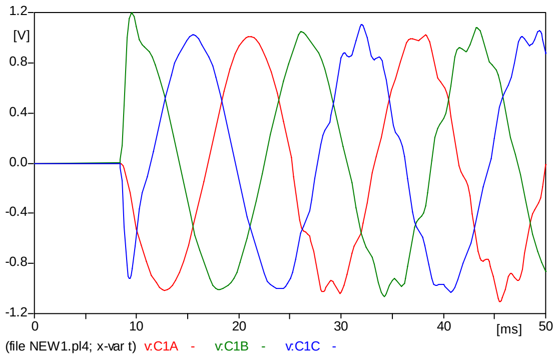


Figure 12. The Three-Phase V_{c_1} of Case 3.

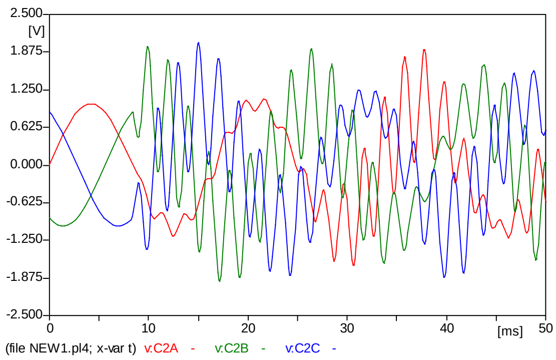


Figure 13. The Three-Phase V_{c_2} of Case 3.

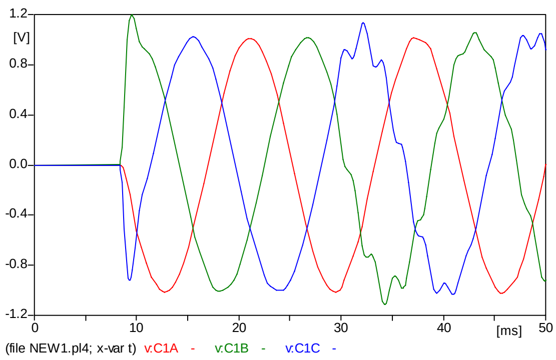


Figure 14. The Three-Phase V_{c_1} of Case 4.

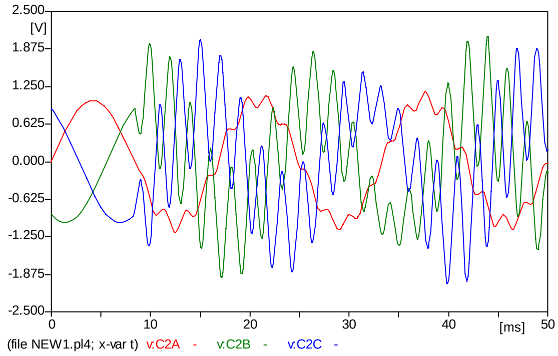


Figure 15. The Three-Phase V_{c_2} of Case 4.

Table 2 shows three-phase maximum voltages of four cases. It can be observed that pre-insertion resistor may effectively reduce the transient overvoltage. The method used in case 4 only effectively reduce secondary transient voltage in phase A, and maximum voltages in other phases are somewhat serious than in case 3. Both transient overvoltages of above two cases are on our allowable range.

TABLE 2: Closing Transients of Three-phase

	C1 Maximum Voltage (V)	C2 Maximum Voltage (V)
Case 1	2	10.86
Case 2	1.88	9.73
Case 3	1.2	2.03
Case 4	1.2	2.09

Due to the switch may not be accurately closed, this study insert the S1 switch delay 1ms in case 3 and case 4. As show in TABLE 3, the transient overvoltages in case 3 and case 4 are still to meet limit 2.2V [9].

TABLE 3: Closing with Timing Deviations

	C1 Maximum Voltage (V)	C1 Maximum Voltage (V)
Case 3 with 1.0ms late	1.24	2.18
Case 4 with 1.0ms late	1.24	2.13

6. Conclusions

Four ways are described in this paper to close the capacitor switch. Due to the effect of the phase angles difference of phase voltages on transient overvoltages, there will be serious overvoltage condition in other phases. So it is necessary to do three-phase analysis.

The resistance of pre-insertion resistor is the value of surge impedance this study calculated. After simulation analysis, this study can indicate that the method of pre-insertion resistor used in this paper can effectively reduce the transient overvoltage. Although the switch may not be accurately closing, even inserting the switch delay 1ms, the strategy used in this paper is still effective to reduce transient overvoltage within the range of the IEEE Std 18-1992.

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