Study of Capacitor Bank Switching Transient in Distribution Network

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Abstract. The power factor improvement has a great concern in the distribution system due to large motor installed in industrial system. The capacitor bank was installed to improve the power factor in the distribution system. Due to frequently capacitor bank switching has create transient phenomena in the distribution system and their effects the power quality. The aims of this research to study and simulate the effects of capacitor bank switching in the distribution system. The simulation has been conduct with PSIM software by modelled the system which contain of supply, load and three capacitor bank. The simulation was conducted with two conditions which are single bank and bank to bank switching. For single bank switching peak voltage of phase R reached about 60.9 kV and peak inrush current is reached about 6.7 kA. While for bank to bank switching the peak voltage of phase R reached as high as 59 kV and the peak inrush current is almost 8.2 kA.

1 Introduction

Along with the continuous increase in electricity demand in heavy industries caused by the installation of large motors in industrial systems involving increased reactive power consumption due to the typical power factor in steady conditions and as long as the motor is turned on. The result of this situation is the low power factor in the system. To overcome this problem, capacitor bank need install as a local source of reactive power. Three capacitors banks were installed in distribution substations system and these capacitors banks were designed to switch ON and OFF automatically based on power factor, voltage and volt ampere reactive in power system. The power factor itself will be fluctuation due to the load variations, so that the numbers of switching capacitor banks operations will be occur many times a day. Every switching event will cause the several impacts at distribution network like low frequency decaying, voltage and current distortion, resonance, inrush current and voltage transient [1]. The high magnitude voltage and current as well as high frequency transients can occurs during the switching of shunt capacitor banks, [2, 3, 4, 5]. Beside that, the capacitor banks paradoxically is an outlet source of harmonics. So that, the effect of capacitor bank switching transient on the distribution system must clearly understand. Voltage and current transients due to capacitor bank switching are often a concern for industrial and utility an engineer that are planning to install capacitors at distribution system, in this case is 20 kV.

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Depending on the size and rating, power capacitors are available installed at single phase or three phase circuit. Power capacitors are generally available in voltage rating up to 34,500 volts and 200 kVAR. Typically, the capacitor banks that applied in distribution substations consist of one to four banks. Individual units of power capacitor may be connected in series and multiples to provide banks of various capacities and voltage ratings [1].

This paper specifically was concentrated on the high frequency inrush currents and peak transient voltages that originated result of switching operation. The inrush current that occurs due to capacitor banks switching was becomes a big concern on these matters. Energizing of a capacitor bank that nearby fixed capacitor bank already in service produced a phenomenon called bank-to-bank switching [2]. It will be generated high frequency inrush currents in which the fixed capacitor bank charged the controlled bank. the According to IEEE Standard 18-2002, the shunt capacitors banks must withstand with 110% maximum continuous rms over voltage and 180% maximum continuous rms over current. This over voltage and over current includes both the fundamental frequency and any harmonic contributions. The standard also states that the VA rating of the capacitor cannot exceed 135%. [6]

2 Methodology

The system under study was included was included with the power source, three capacitor banks, three loads, feeder with overhead conductors and underground cables as shown in Fig.1. The capacitor banks are represented by cap. banks 1, 2 and 3 series with inductors. S_1 , S_2 and S_3 are represents the circuit breaker to switching ON and OFF the capacitor banks. To simulate this model, PSIM software was used. For the initial condition all these three capacitor banks are opened. To determine the impacts of capacitor bank switching in distribution networks, a study of principle of power system operations, energy stored in a capacitor which included how a capacitor been charging and discharging are need. The primary concern of this paper is typically with how the capacitor switching transients will affect to voltage and current nearby industrial and commercial loads. The inrush current and voltage transient are occurs during the charging and discharging of the capacitor. This transient phenomena will cause current and voltage distortion at distribution network. Simulation by using PSIM software program and calculation of peak inrush current and the frequency for this transient given by: [6]

$$I_{peak} = \frac{V_{peak}}{Z_0} \quad (1)$$

$$Z_0 = \sqrt{\frac{L}{C}} \quad (2)$$

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

Where, I_{peak} = peak inrush current, V_{peak} = peak voltage, f = transient frequency

For a single bank switching, the amplitude of the inrush current will depend on the short circuit level at the point of common coupling (PCC) where the bank is connected. In this simulation the capacitor bank was switched into the feeder at the peak voltage of phase R to evaluate its effect on the feeder. To limit the frequency and magnitude of inrush current during the switching, the capacitor bank was equipped with 0.040 mH series transient inrush reactors. These reactors will increase the surge impedance magnitudes that will effectively reducing the peak inrush current. To study transient phenomena, the simulation has been done by single bank and bank to bank switching. For the single bank switching capacitor bank 1 has been turn ON at $t = 10$ ms, while for bank to bank switching the capacitor bank 2 has switching ON at $t = 50$ ms.

Fig 1: Typical utility substation showing a 4.5 MVAR capacitor bank and adjacent distribution loads.

2.1 Principle of energizing and de-energizing capacitor

If the capacitor is initially uncharged and there is no current flow to the circuit while switch is OFF. When the switch is closed at $t = 10\text{ms}$, charge begins to flow and setting up a current flow. At the same time, the capacitor begins to energize. During energizing of capacitor, the charge is transferred between each plate until the capacitor is fully charged. Once the maximum charge is reached, the current is zero because the potential difference across the capacitor matched that supplied by the source. The common phenomenon in the process of de-energizing capacitor banks is reignition. An electric arc is produced in the circuit breaker while a capacitor bank is disconnected. To produce an effective de-ionization, the electric arc will be extinguished when the current wave is zero crossing. At that time the capacitor bank will be at its maximum voltage.

3. Results and discussion

3.1 Single capacitor-bank switching

Single bank switching is while the transient (voltage and current) occur for the closing of the first capacitor bank, while other capacitor banks are still not energized. To simulate this system, it does begin with energizing capacitor bank 1 by closing switches S_1 . Fig. 2 (a) showed the three phase voltages distribution system for single bank switching. It shows the voltage before and after the switching operation. The frequency of the capacitor transient is equal to the system's natural frequency. Therefore, large capacitor banks will result in lower frequency decaying ring wave transients, while small banks will result in higher frequency ring wave transients. The capacitor bank switch is switching ON at peak value phase R voltage ($t = 10\text{ ms}$) with the peak voltage of phase R reached about 60.9 kV, more than its twice steady state value before the energized. This transient voltage can happen several times a day depending on the system power factor. This is a transient overvoltage, since the controlled capacitor bank was originally discharged and the voltage oscillated over the system voltage as high as it started below. Fig. 2 (b) shows the voltage according to harmonic frequency. For the fundamental frequency of 50 Hz, the peak transient voltage is 60.9 kV. For 300Hz frequency the peak amplitude voltage in phase R and S are 6.2 kV. This means the magnitude of the 6th order harmonic voltage is 6.2 kV or 10.18% of fundamental

frequency. The duration of the ring-wave transient is dependent upon the system X/R ratio at the capacitor bank. Transients associated with substation capacitor banks can last as long as at 10 ms to 30 ms.

Fig.2: (a) voltage waveform (b) maximum peak voltage, for single bank switching

Fig. 3: (a) current waveform (b) maximum peak current, for single capacitor bank switching

The inrush currents that happen for single capacitor banks switching were also the big concern. Fig. 3 (a) shows the inrush current when by energizing the capacitor bank 1 by closing switches S_1 . The peak inrush current value during of single bank switching is reached

about 6.7 kA, more than eight times of their steady state value before the energized. The current was zero before the switch was closed at ($t = 10$ ms). After approximately 40 ms the transient was disappeared and the current back to it's steady state value. Fig. 3 (b) shows the current according to harmonic frequency. For the fundamental frequency of 50 Hz, the peak inrush current is 6.7 kA. For 300Hz frequency the peak amplitude of inrush current in phase S and T are 4.8 kA. This means the magnitude of the 6th order harmonic current is 4.8 kA or 71.64% of fundamental frequency. This is a high enough harmonics that will affect of the power system quality.

3.2 Bank-to-bank switching

Fig. 4 (a) voltage waveform for bank, (b) maximum peak voltage for bank to bank switching

When a number of capacitor banks are used in parallel, the banks are not switched in at the same time. Some of the capacitor bank may be switched in later than others. Bank to bank switching is switching transients occur when a capacitor bank is energized in close proximity to capacitor bank that is already energized. During charging of the uncharged capacitor bank, the adjacent charged capacitor bank dumps a high frequency high and magnitude of current into the uncharged capacitor bank and this current is called inrush current. After capacitor bank 1 is closed and in steady state condition, then switch S_2 closed at time ($t = 50$ ms), so that the capacitor bank 2 will be charged. The result shows, the voltage transient happen at phase R, S and T. The phase R peak voltage increased as high as 59 kV is about twice of it steady state value. Voltage at phase S and T were increased as well, but not as high as the increase voltage in phase R as shown in Fig. 4 (a). Fig. 4 (b) shows the voltage amplitude phase for R and S for harmonic frequency of 150 Hz is 8 kV. This means the magnitude of the 3rd order harmonic voltage is 8 kV or 13.6% of fundamental frequency. Fig. 5 (a) shows very large inrush current flow due to bank to bank switching. The peak inrush current is

almost 8.2 kA occurs for phase R, which more than 5 times its normal or steady state conditions. While the peak inrush current that occurs in phase S and T for frequency of 150 Hz as high as 7.8 kA. This means the magnitude of the 3rd order harmonic current is 7.8 kA or 95.1 % of fundamental frequency. So, the switching of capacitor bank besides causing transients will result in the emergence of current and voltage harmonics on the system as well, that will affect of the power system quality Furthermore, a high frequency transient component will arise, leading to further problems, especially with sensitive electronic loads.

Fig. 5 (a) current waveform, (b) maximum peak current for bank to bank switching

4. Conclusion

After doing this research and analyzing it carefully, then can be made conclusions as follows: During the switching of the capacitor bank within the distribution substation, the transient voltage and inrush current occurs. The level of transient voltage that occurs in the distribution system due to capacitor bank switching, depend on the system itself. The switching transient can be occurs for single bank switching and bank to bank switching. Both switching has significant effects to the distribution system like voltage transient and inrush current. The resulting transient over voltage can reach a peak value about 60.9 kV and inrush current can reach about 8.2 kA. Due to this phenomenon happen in several times a day, it will have significant effect to the power system stability and quality. Besides the transient problems, capacitor banks switching will have other problems such as harmonics that will reduce the quality of quality.

References

1. Technote Series, *Practical Aspects of Shunt Capacitor Switching Transients*, Northeast Power Systems Inc. Queensbury, New York www.nepsi.com, (2012).

2. IEEE Standards 18-2012 (Revision of IEEE Std 18-2002), *Collection on Power Capacitors*, ISBN 1- 55937-416-0, (2012).
3. A. Greenwood, *Electrical Transients in Power Systems*, 2nd Edition, John Wiley&Sons Inc., (1991).
4. John H. Brunke, *Application of Power Circuit Breakers for Capacitive and Small Inductive Current switching*, Application of Power Circuit Breakers, IEEE Tutorial Course 93 EHO 388-9-PWR, (1993).
5. *Modeling and Analysis of System Transients Using Digital Programs*, IEEE PES Special Publication TP-133-0 (Ch.4 – Modeling Guidelines for Switching Transients).
6. M.F. Iizarry Silvestrini and T. E. Vélez Sepúlveda, *Mitigation of Back-to-Back Capacitor Switching Transients on Distribution Circuits*, Department of Electrical and Computer Engineering (2006): 1-8.