SOLVING HARMONIC RESONANCE PROBLEMS ON THE MEDIUM VOLTAGE SYSTEM

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ABSTRACT

Harmonic problems are increasing on MV systems, especially with the application of power factor correction capacitors or extensive underground networks that resulting resonances close to the fifth harmonic. This paper describes two case studies of solving harmonic resonance problems on distribution systems with the design of harmonic filters that provide both power factor correction and harmonic control on the distribution system. The solution on the primary distribution system can be much more economic than trying to solve the problem within customer facilities. General guidelines for the application of harmonic filters on the primary distribution system are developed.

INTRODUCTION

Many distribution systems are experiencing increasing levels of harmonic generation and resulting harmonic voltage distortion. Harmonics are generated by all types of customers. Residential and commercial customers have more and more electronic load and industrial customers have a wide range of nonlinear loads that can be important. These can include ASDs, dc drives, process rectifiers, induction furnaces, welders and arc furnaces.

Harmonic limits for small loads (e.g. IEC 61000-3-2 [1]) and guidelines for harmonic injection from customer facilities (e.g. IEC 61000-3-6 [2], IEEE 519 [3]) provide some control of harmonic generation. However, the level of harmonic generation can still be significant and it becomes especially important when the distribution network can exhibit resonance conditions that magnify the harmonic currents and create high voltage distortion levels.

When these resonance conditions exist, it can be difficult to control the harmonics to acceptable levels using conventional methods of harmonic control in customer facilities. In fact, the resonance conditions on the primary distribution system can result in overloading of conventional harmonic filters and power factor correction within customer facilities. This paper describes two case studies of solving harmonic resonance problems on distribution systems with the design of harmonic filters that provide both power factor correction and harmonic control on the distribution system. The solution on the primary distribution system can be much more economic than trying to solve the problem within customer facilities. General guidelines for the application of harmonic filters on the primary distribution system are developed.

CASE STUDY 1 – RESONANCE CAUSED BY SUBSTATION CAPACITOR BANKS

The first case study involves a medium voltage (MV) distribution system that supplies a combination of industrial, commercial, and residential customers. A simplified one line diagram of the system is shown in Figure 1.

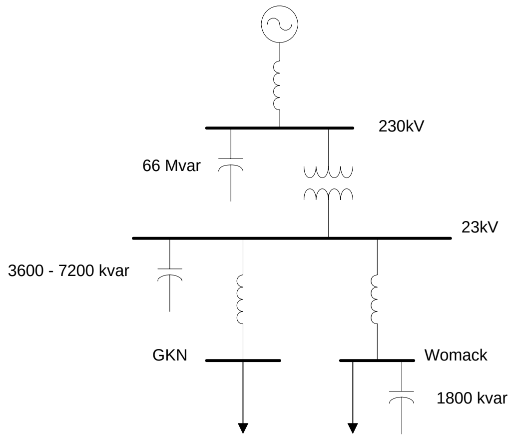

Figure 1. Simplified one line diagram for example 1.

This system was experiencing high voltage distortion levels. Figure 2 is an example of a plot of the voltage distortion showing distortion levels exceeding 9%. Even higher distortion levels were experiencing before limiting the size of the substation capacitors. Customers were experiencing problems with electronic equipment, UPS systems, and clocks.

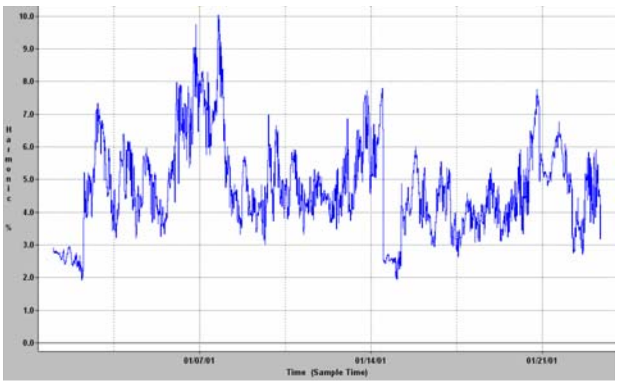

Figure 2. Plot of voltage distortion illustrating high distortion levels caused by resonance.

An investigation of harmonic current levels for industrial customers on the circuit found that none of the customers had harmonic injection levels that were exceeding the guidelines of IEEE 519. In fact, the harmonic current levels measured in the overall feeder currents at the substation were not excessive. The problem was being caused by resonance created by the substation capacitor banks at the 23 kV substation bus. This resonance was magnifying the fifth harmonic component in the currents from all the customers on this system, causing high voltage distortion levels. Figure 3 illustrates the resonance condition as a function of the size of the substation capacitor bank. The 7200 and 5400 kvar sizes in particular were causing very high distortion levels due to resonance that was close to the fifth harmonic.

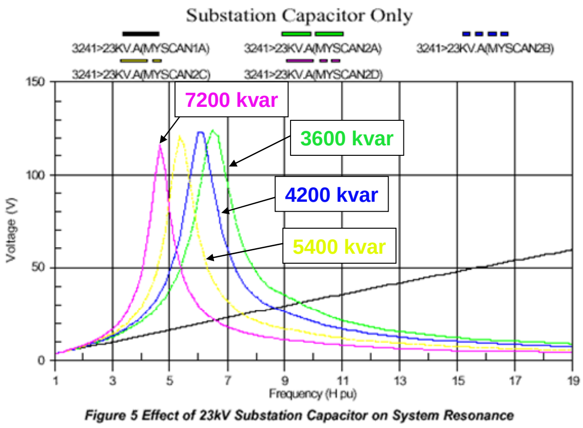

Figure 3. Resonance condition (system impedance vs frequency) at the substation for different substation capacitor sizes.

Since these capacitors were being used both for power factor correction on the distribution system and as voltage support for the transmission system, it was decided to convert the substation capacitor bank into a harmonic filter (Figure 4) rather than reduce the size of the compensation further. The effect of the tuned bank on the frequency response is illustrated in Figure 5. Finally, Figure 6 shows the effectiveness of the filter in reducing the voltage distortion. This has proven to be a very effective solution, providing the required power factor correction and voltage support while controlling the harmonic levels on the entire distribution system.

Additional scenarios were evaluated with a combination of tuned capacitors and untuned capacitor banks. Adding untuned capacitors banks at the substation has the potential to create a resonance near the seventh harmonic but this is not expected to create the type of distortion problems that were associated with the fifth harmonic resonance.

Figure 4. Tuned capacitor bank at the substation to control harmonic levels.

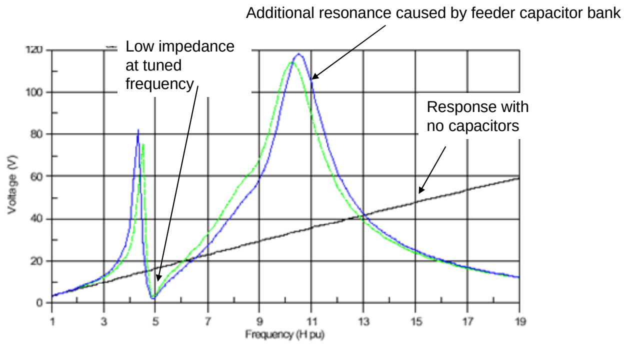

Figure 5. Frequency response with either 3600 kvar or 5400 kvar tuned bank at the substation (tuned to 4.9th harmonic).

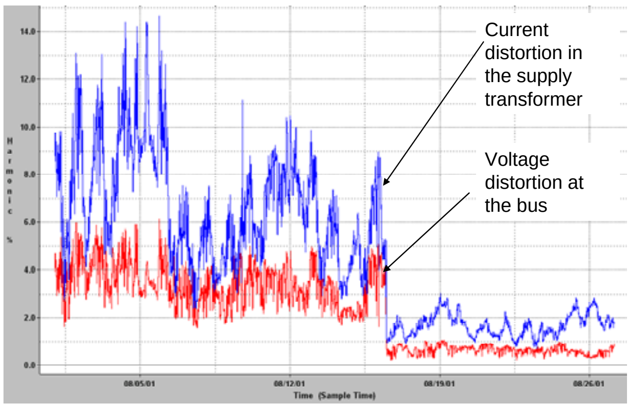

Figure 6. Reduction in both voltage and current distortion when the tuned capacitor bank is switched on.

CASE STUDY 2 – RESONANCE CAUSED BY DISTRIBUTED CAPACITOR BANKS

The first case study demonstrated the capability to control resonance problems with a large substation capacitor bank. The second case study evaluates resonance problems caused by capacitors distributed throughout the distribution system.

The one line diagram for this case is shown in Figure 7. It is a 12 kV distribution system that serves a few industrial customers but mostly residential customers. There are capacitor banks located throughout the four distribution circuits as shown on the diagram. The circled customer on the diagram has power factor correction within his industrial facility that has been installed as tuned banks but these banks were experiencing problems with fuses blowing shortly after they were put in service.

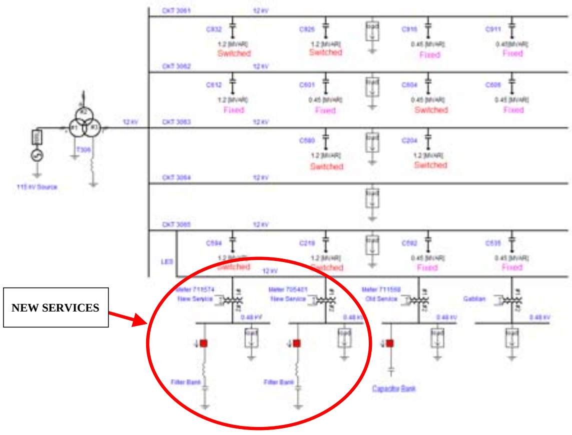

Figure 7. One line diagram for example 2.

Simulations of the system frequency response characteristics were performed with different combinations of feeder capacitors. The results are shown in Figure 8. It is clear that the resonance can be close to the fifth harmonic for some capacitor configurations.

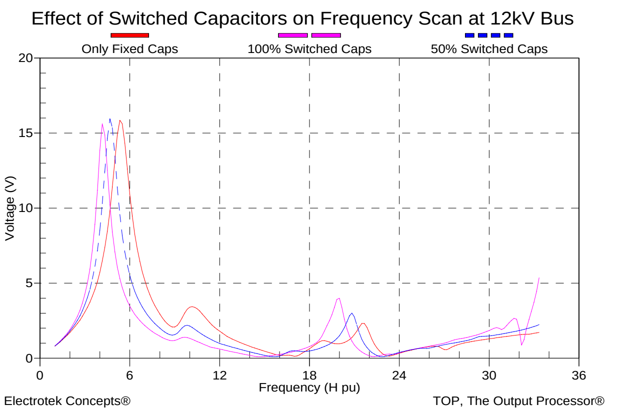

Figure 8. Frequency response to harmonics injected near the substation for different configurations of feeder capacitors.

Measurements of voltage distortion levels over time further confirmed the potential for magnification of the fifth harmonic voltage when certain configurations of capacitors occurred during the day (as the capacitors are switched in and out to control the voltage and the power factor). Figure 9 is an example of the voltage distortion levels. Step changes in the distortion levels occur at times that capacitor banks are switched in and out of service on the feeder circuits.

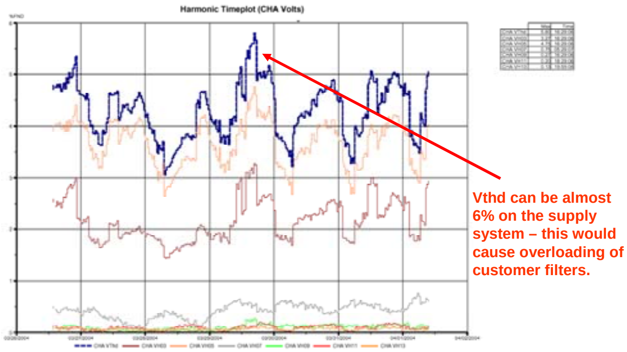

Figure 9. Plot of voltage distortion (and individual harmonic components) vs time showing the changing harmonic levels with capacitor bank switching.

These harmonic voltage distortion levels are not generally considered to be excessive. However, in this case they were causing customer filters to be overloaded. It would have been possible for the customer to redesign his filters to handle the higher loading from the supply system. In fact, they should have been designed with this margin originally [4,5,6,7]. However, this was going to be a very expensive solution for the customer and the utility decided to look at solutions that could be implemented on the MV system as a more economical approach to the problem.

A solution of converting one power factor correction bank on the distribution system into a filter bank was evaluated. In order to maximize the benefit for the customer with the tuned power factor correction, a bank close to this customer was selected. The filter installed on the overhead poles is shown in Figure 10.

Figure 10. 1200 kvar filter bank installed near the sensitive customer for power factor correction and harmonic control.

The filter proved to be very effective in controlling the distortion levels. The fifth harmonic voltage throughout the distribution system is controlled to very low levels as a result of the filter (less than 1.5%). However, the filter can create a resonance near the third harmonic that causes the third harmonic voltage to be in the range of 3% distortion for some system conditions. This has not been a problem on the circuit. The solution has allowed the customer to use his power factor correction without problems of fuses blowing or capacitors failing and has reduced the distortion levels experienced by all other customers.

CONCLUSIONS

The widespread use of nonlinear loads by all types of customers results in unavoidable harmonic generation throughout distribution systems. Power factor correction practices and underground cable capacitance can resulting resonance conditions that magnify these harmonic currents and cause high voltage distortion.

In many cases, it may be more economical to control the voltage distortion experienced by all customers by changing the frequency response of the system. This can be accomplished with a tuned capacitor bank on the MV system. Two examples were presented where fifth harmonic filters on the MV system solve resonance problems and reduce harmonic voltage distortion for all customers.

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