Do Not Mix Standard Shunt Capacitor Banks With Harmonic Filter Banks

Introduction

This technical note presents the reasons why shunt capacitor banks and harmonic filter banks should not be applied together on an industrial or utility power system when a voltage transformation or significant impedance does not exist between them. Such an application (actually miss-application) is shown in Figure 1 below. This system is utilized throughout this technical note to illustrate the problems that can occur.

Background

Shunt Capacitor Banks and Harmonic Filter Banks are often applied at the same voltage level in error for the following reasons:

- There is a misconception that the harmonic filter bank will absorb the harmonic currents away from the capacitor banks and prevent the harmful effects of harmonic resonance.

- The filters are applied to an industrial power system that already contains shunt capacitor banks. The capacitor banks may exist on the utility system (as pole-top capacitor banks) or on individual motors as illustrated in Figure 1. (Key Point – It is always important to check for existing capacitor banks before the application of harmonic filter banks).

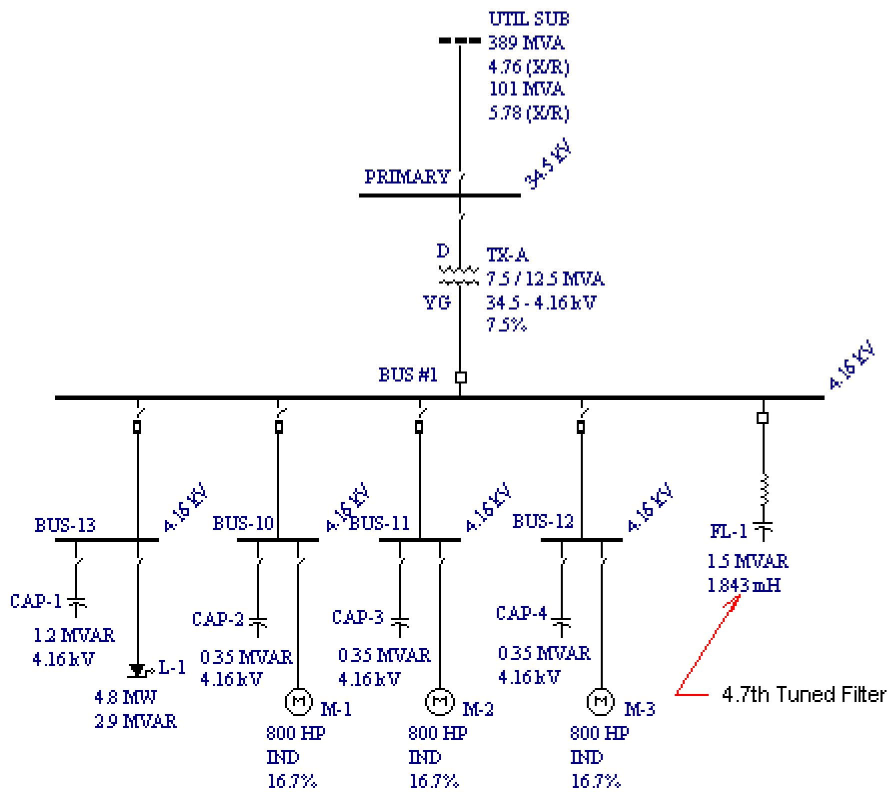

Figure 1 – Typical Industrial System Showing Miss-Application of Harmonic Filter and Shunt Capacitor Banks

System Description

Figure 1 shows an industrial power system that is fed from an electric utility at 34.5kV. The source has a 3-phase fault level of 389 MVA and a phase-ground fault level of 101 MVA. The voltage is transformed to the 4.16kV level for utilization by a 7.5/12.5 MVA transformer that has an impedance of 7.5%. Several large motors (800 hp) with capacitor banks connected at their terminals receive power from motor control centers located on Bus-10, Bus-11, and Bus-12. Bus-13 contains a shunt capacitor bank that corrects the power factor for a conglomeration of load while Bus- #1 is equipped with a 1.5MVAR (1,500 kvar) 4.7th tuned harmonic filter.

Harmonic Analysis – System Impedance Scans

A harmonic analysis program was utilized to show how this system would perform or behave under different operating scenarios. The following scenarios were investigated:

Scenario 1 – In this operating scenario, the harmonic filter bank FL-1 is left off line, while CAP-1 is left energized. Varying amounts of motors are energized to show the effects of the motor terminal capacitors.

Scenario 2 – The filter bank and CAP-1 are energized while varying amounts of motors are energized to show the effects of the motor terminal capacitors while the filter bank is online.

Scenario 3 – All standard capacitors are removed, and the filter bank is increased in size to compensate for the capacitors that were removed.

Scenario 1 Results

Figure 2 shows three impedance scans from Bus #1. Each scan represents the system characteristic impedance as seen from Bus #1 with varying amounts of motors running (and motor terminal capacitors). The X-Axis shows the harmonic number while the Y-Axis shows the characteristic impedance. The peaks are referred to as a parallel resonance. At parallel resonant locations, harmonic voltage distortion can be very high and is equal to the product of the 4.16kV Bus Impedance in Ohms and the harmonic current injection in amps (Vn=In x Zn).

Figure 2 shows a near seventh resonance for the condition in which two motor capacitors are running. One amp of 7th harmonic load would result in approximately 27 volts of 7th harmonic voltage. This would be an unacceptable operating scenario. A 100 HP 6-Pulse drive, for example, would inject approximately 2 amps of 7th harmonic current and would result in a bus voltage distortion of 2.1% or 52 7th harmonic volts (Vn/VL-N x 100% = 52/2400 x 100% = 2.1%).

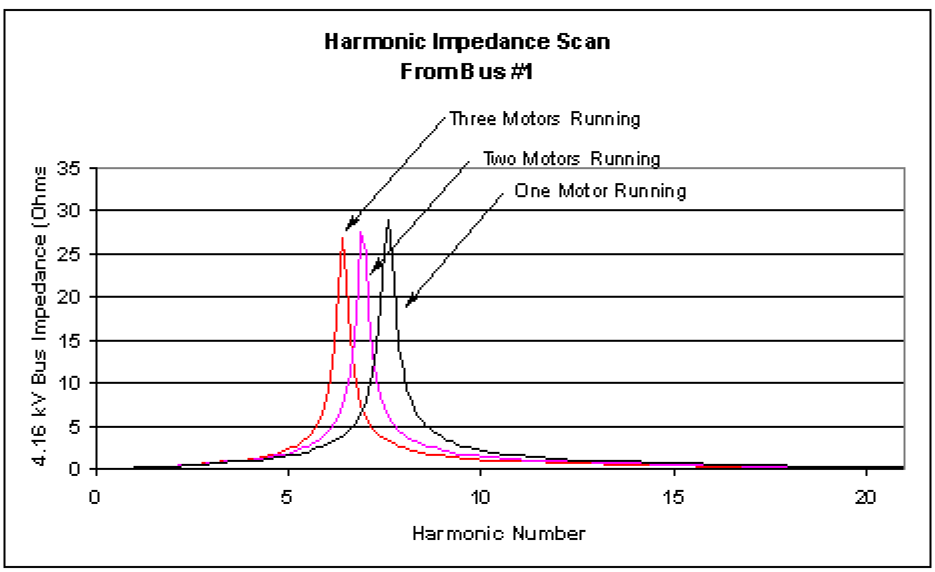

Figure 2 – Impedance Scan From Bus #1 Showing Effects of Motor Capacitors On System Resonance

Scenario 2 Results

Figure 3 shows and impedance scan for a scenario in which all capacitors are energized in addition to the harmonic filter bank. The tuning point, and parallel resonance from the standard capacitors and harmonic filter bank are illustrated. The following key points should be noted in regards to Figure 3:

- The parallel resonance created by the harmonic filter is not usually of concern because it occurs at a harmonic order where there are no harmonic currents being produced by the load. Therefore, without harmonic current, there will be no harmonic voltage. This resonant point is stable, and is primarily affected by the tuning frequency of the filter and short circuit impedance of the system. It will, however, always remain below the tuning frequency of the filter.

- The low impedance created by the 4.7th filter is determined by the filter and will remain stationary.

- The parallel resonance created by the standard capacitors is primary affected by the system short circuit impedance and the amount of kvar (number of motors in this case) that are on-line at a given time and the harmonic filter. The resonance will typically shift around with number of running motors and can create nuisance problems for industrial plants.

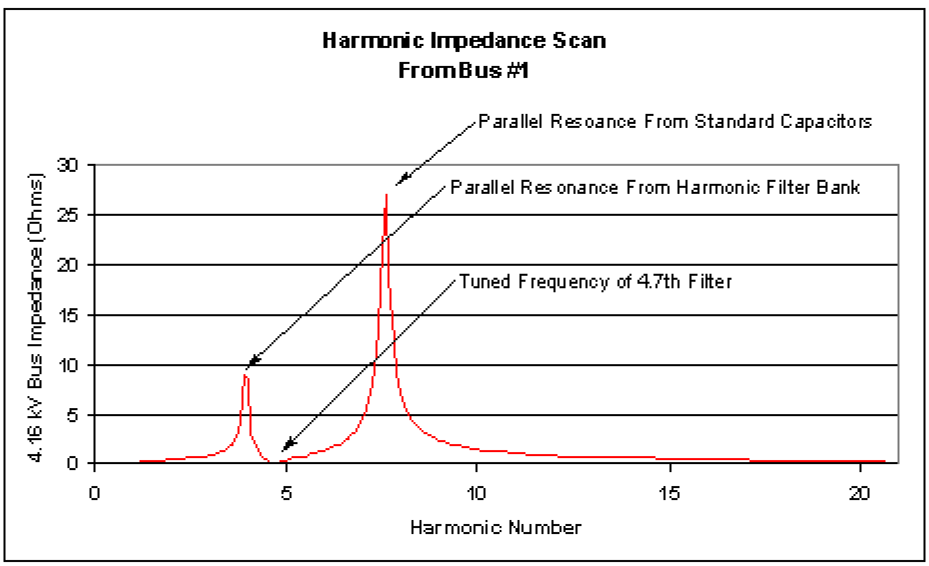

Figure 3 – Impedance Scan From Bus #1 Showing Parallel Resonant Points Created From the Filter Bank and Standard Capacitors

Figure 4 shows three different impedance scans for scenario 2. The figure clearly illustrates that the number of motor capacitors dramatically affects the parallel resonance created by the standard capacitors. A near 7th system resonance occurs for the case where there are three motors running. Under Scenario 1, it took only two motors. It is therefore evident that the filter bank impacts the performance of standard capacitors. The resulting system, however, is unacceptable.

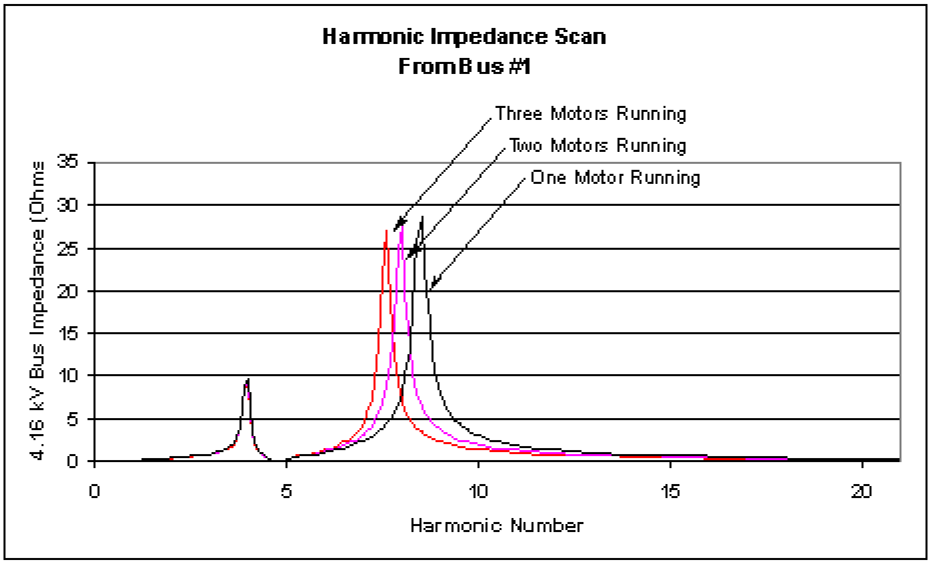

Figure 4 – Impedance Scan From Bus #1 Showing Effects of Motor Capacitors On System Resonance while a harmonic filter is on-line

Scenario 3 Results

Figure 5 shows an impedance scan with just the harmonic filter bank. The filter bank size has been increased to provide the vars lost by the motor run capacitors and CAP-1 on Bus-13. As can be seen in the plot, the impedance to harmonic currents above the tuning frequency of the filter (4.7th for this filter) is low. The result will be low harmonic voltages and acceptable system performance.

Key points about Scenario – 3 are as follows:

- The parallel resonance that results from the filter bank will always remain below the tuning frequency of the filter. For this reason, filters banks are normally tuned to a frequency below the most prevalent non-linear load harmonic (i.e. 5th harmonic).

- The parallel resonance will shift to the left or right by very small amounts. The shift is normally caused by a change in system short circuit impedance, or the size of the filter bank. In either case, this condition is not normally of concern.

- The low impedance part of the scan (tuned frequency of filter at 4.7th harmonic) is determined by the harmonic filter bank.

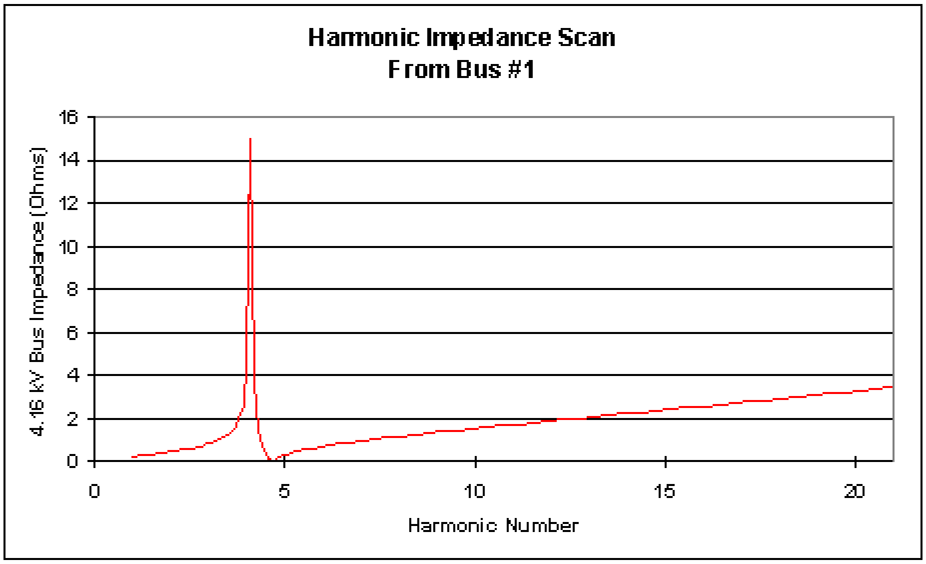

Figure 5 – Impedance Scan From Bus #1 Showing the System Characteristic Impedance With No Standard Capacitors On-line

Figure 6 shows how the parallel resonant point created by the harmonic can shift for a change in the short circuit impedance and the number of motors running (the motors actually change the short circuit impedance, and therefore changes the resonant location by a small amount). The plot is only shown for harmonics between the 3rd and 6th to more clearly illustrate the point. As can be seen, the parallel resonance only shifts between the 3.8 and 4.2 harmonic.

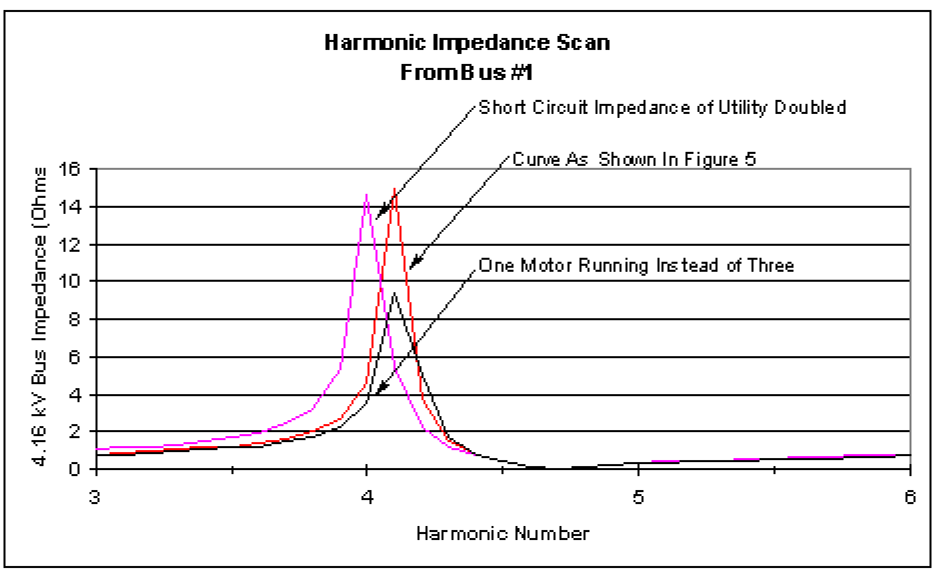

Figure 6 – Impedance Scan From Bus #1 Showing Effects on Filter Banks Parallel Resonance for Varying System Conditions

Harmonic Analysis – Voltage Distortion Calculations

In addition to developing harmonic impedance scans, it is also common to calculate the resulting total harmonic distortion, THD, based upon projected or measured harmonic current data. The following equation is utilized for calculating the Total Harmonic Distortion on Each Bus. The calculations are made for each operating Scenario above.

$$THD = \frac{\sqrt{\left(V_2^{2+} + V_3^2 + V_4^2 + \ldots + V_n^2\right)}}{V_1}$$

Table 1 – Total Harmonic Distortion Calculation results

Case Description	Maximum Calculated Voltage Distortion (%)
Scenario 1	22.2%
Scenario 2	18.9%
Scenario 3	1.7%

Conclusion

This Technical Note presented the reasons why standard shunt capacitor banks and harmonic filter banks should not be applied at the same voltage level without significant impedance between them. The significant impedance may consist of a transformer, or many miles of distribution line.

If you are planning on adding a capacitor bank or filter bank to your power system, it is important to recognize potential application problems. NEPSI has qualified, experienced, licensed power engineers that can guide and assist you with the specifics of your application.

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