PQSoft Case Study

Voltage Notching and Distribution Systems 1
Large Induction Motor Drive Example

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Author:	Electrotek Concepts, Inc.	Access Level	PQSoft Subscriber

Keywords:

Power Quality Category	Voltage Notching	Harmonics	Voltage Distortion
Solution	Detune System	Add Capacitor	Remove Capacitor
Problem Cause	SCRs	Resonances	Weak System
Load Type	6000 HP ASD	CSI	
Customer Type	Large Industrial		
Miscellaneous1	Fast Clocks	Failed Surge Capacitor	
Miscellaneous2			
References	IEEE Standard 519		

Abstract:

This case describes voltage notching associated with large adjustable speed drives. The notching is a normal characteristic of a phase-controlled rectifier but this paper illustrates problems that can occur on systems with low short circuit levels where the voltage notching can excite the natural frequency of the distribution system and cause significant distortion in the supply voltage. The notching characteristics and the interaction with the distribution system frequency response characteristics are described, along with possible solutions, An example problem and the corresponding solution associated with a large 6000 hp ASD is presented.

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RELATED STANDARDS

IEEE Standard 519

GLOSSARY AND ACRONYMS

ASD	Adjustable Speed Drive
CSI	Current Source Inverter

INTRODUCTION

Adjustable speed ac and dc drives are used with very large motors (e.g. 1,000-20,000 hp) for a variety of reasons. The drives can result in significantly improved efficiency when the driven load is variable. For large motor applications on weak systems, the drives may be required for motor starting to avoid high inrush currents.

Adjustable speed ac drives (ASDs) 1000 hp and larger typically use phase-controlled rectifiers (SCRs) and a large dc link inductor to supply a relatively constant dc current to the inverter. This is known as a current source inverter (CSI) configuration. The input rectifier may be configured as a six pulse, twelve pulse, or even higher pulse number rectifier, depending on harmonic control requirements. For dc drive applications, phase-controlled rectifiers are used to supply the dc current directly to the dc motor.

The voltage notching discussed in this paper is caused by the commutating action of the controlled rectifier. Whenever the current is commutated from one phase to another, there is a momentary phase-to-phase short circuit through the rectifier switching devices (SCRs, in this case). For a six pulse converter, this happens six times each cycle. The voltage notch is defined by its duration and its depth. The duration (commutation period) is determined by the source inductance to the drive and the current magnitude. The depth of the notch is reduced by inductance between the observation point and the drive (e.g. isolation transformer or choke inductance). An example waveform illustrating simple notches resulting from a drive operation is shown in Figure 1.

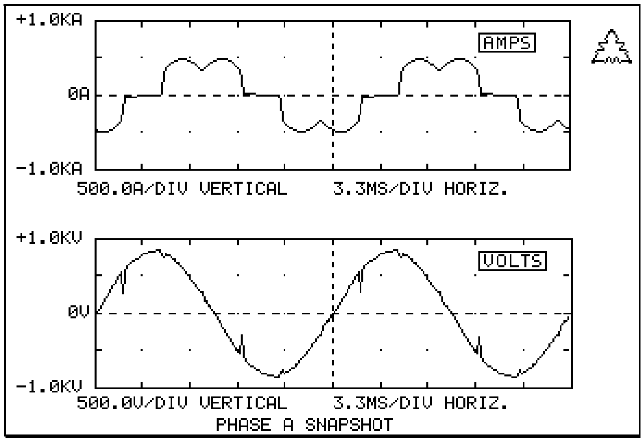

Figure 1 - Voltage Notches caused by Converter Commutation

PROBLEM DESCRIPTION

On most systems, problems with voltage notching can be minimized by applying sufficient isolation reactance at the drive. This limits the notch magnitude on the source side of the isolation reactance. However, on some systems, the notches that appear at the system level can still be significant. If there is not much resistive load on a system like this, the notches can excite the natural frequency of the distribution system (determined by the capacitance of lines, cables, and capacitor banks in parallel with the system source inductance) and cause significant distortion in the voltage waveform.

Numerous papers have described the voltage notching phenomena in industrial facilities and sizing isolation reactance to limit the notching effect on other loads [1-5]. However, there has been little literature describing the potential for voltage notching to excite natural frequencies of the distribution system. The high frequency oscillations that result can cause problems with communication interference and sensitive customer loads. This paper describes the concern and possible solutions using an example where a problem was encountered. The methodology for evaluating these problems and the solutions implemented should be valuable to anyone else encountering this problem.

It is important to note that the notching problem described should only exist with large adjustable speed drives with current-source inverter configurations or with dc drives. With other types of ASDs that use voltage source inverters (e.g. pulse width modulation), the rectifier does not have a constant dc current that needs to be commutated from one switching device to another. It is this current being commutated that that essentially looks like an injection of a disturbing current into the distribution system.

LARGE INDUCTION MOTOR DRIVE

The example system is illustrated by the one line diagram in Figure 2. The 25kV distribution system is supplied through a 10 MVA transformer from the 144kV transmission system. The customer causing the notching problems has a 6000 hp induction motor supplied through an adjustable speed drive. This drive is at a 4.16kV bus supplied through a 7.5 MVA transformer. Harmonic filters (5th, 7th, and 11th) are included to control the lower order characteristic harmonics of the six pulse drive.

Another customer on a parallel feeder supplied from the same 25kV bus has motor loads at both 4.16kV (800 hp motor) and 480 volts. The 800 hp motor includes surge capacitors for transient protection. The customer also has power factor correction capacitors at the 480 volt bus. These lower voltage surge capacitors and power factor correction capacitors have the potential to magnify the oscillations which occur on the distribution system.

Operation of the 6000 hp motor and drive resulted in significant oscillations on the 25kV supply system. These oscillations caused clocks to run fast at the customer with the 6000 hp motor (clocks were fed separately from the 25kV system) and failure of surge capacitors on the 800 hp motor at the customer located on the parallel feeder.

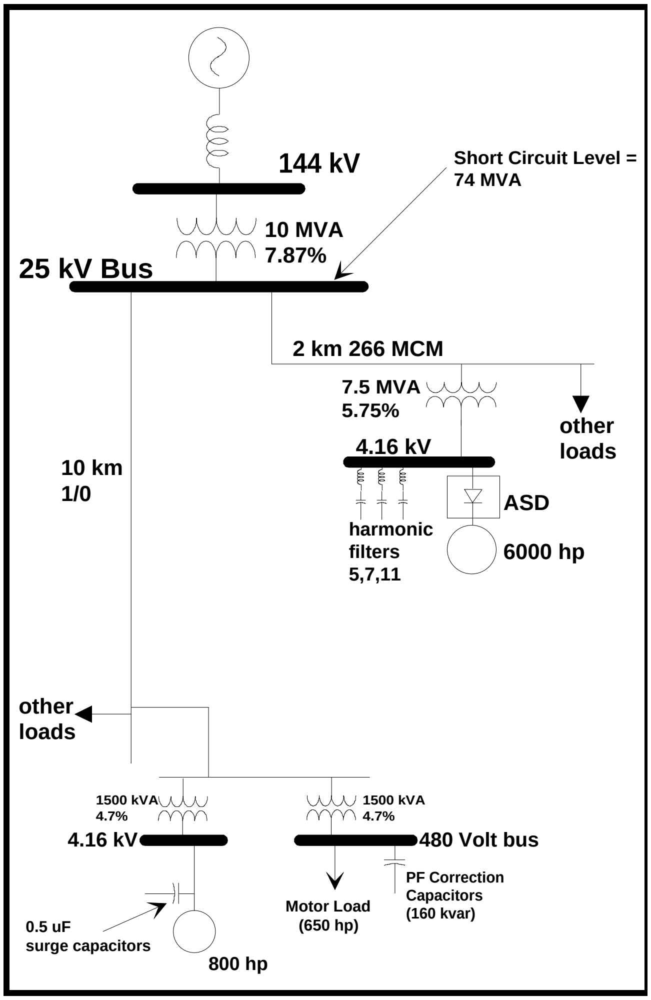

Figure 2 - Oneline Diagram for the System.

Figure 3 illustrates the measured waveforms on the 25kV supply system. The oscillations have a primary frequency component near the 60th harmonic. In this case, the natural frequency is the result of the line capacitance from approximately 12 km of overhead line in parallel with the system source inductance. Note that the oscillations are excited six times per cycle corresponding to the six-pulse operation of the drive.

System Frequency Response

A model was developed using the Electromagnetic Transients Program (EMTP) to evaluate the magnification at the surge capacitor location and to evaluate possible solutions to the problem. First of all, the steady state frequency response of the system was simulated to illustrate the natural frequency that can excite the oscillations illustrated above. Figure 4 shows the voltage on the 25kV system as a function of a 1 amp source at the 4.16kV bus where the drive is located. The system resonance just above the 60th harmonic is apparent in the figure. Note also the lower order series and parallel resonances caused by the harmonic filters.

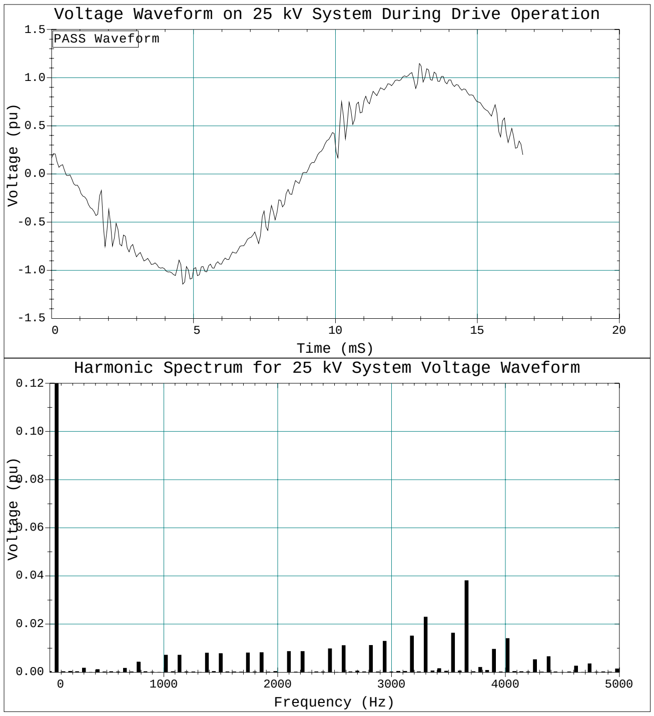

Figure 3 - Voltage Waveform and Spectrum on 25kV System

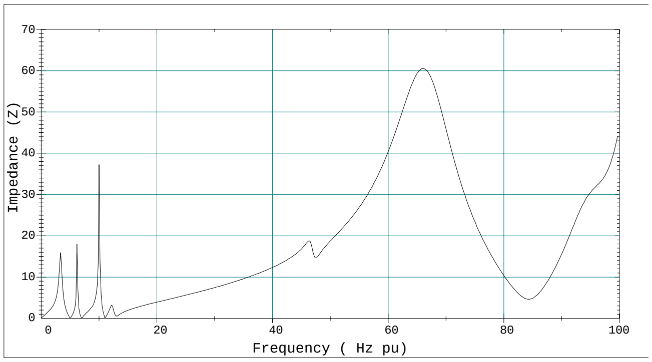

Figure 4 - Voltage vs. Frequency at 25kV Bus

Effect of Customer Low Voltage Capacitors

Next, the actual adjustable speed drive and motor load were represented to reproduce the notching oscillations observed in the measurements. The worst notching problems are associated with a firing angle at about 70% load. The simulated waveform for the 25kV bus voltage is shown in Figure 5 below. The oscillations at each commutation point are in good agreement with the measurement results.

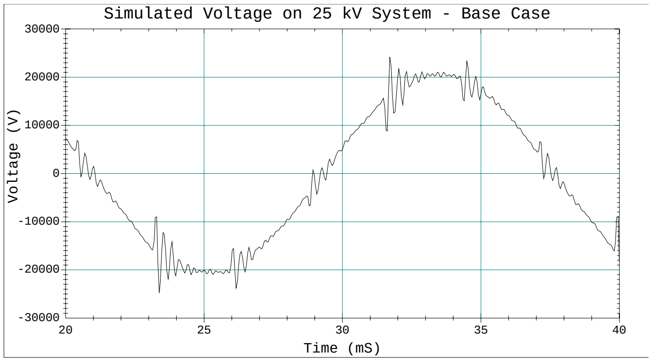

Figure 5 - Simulated 25kV Voltage with Drive Operating

The model was then used to evaluate the voltage waveforms at the customer bus located on the parallel feeder. Figure 6 illustrates the voltage waveform at the 4.16kV bus where the 800 hp motor surge capacitors cause magnification of the oscillations. The potential for problems at this location is quite evident. The surge capacitor failures typically occurred during startup of the drive when the firing angles went through this worst case condition. Figure 7 shows the waveform at the 480 volt bus where the power factor correction capacitors damp out the high frequency oscillation. The power factor correction capacitors are much larger than the surge capacitors and result in a much lower resonant frequency. No problems were encountered with loads on the 480 volt bus.

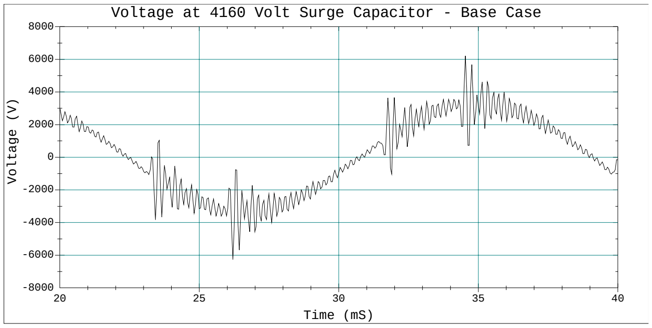

Figure 6 - Simulated Voltage at Surge Capacitor

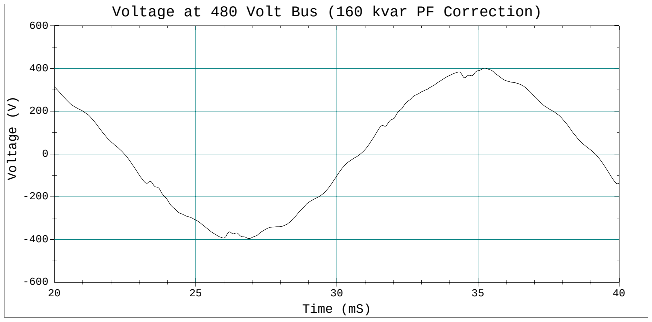

Figure 7 - Simulated Voltage at Power Factor Correction Capacitors

Possible Solutions

A number of possible solutions to the high frequency oscillation problem were evaluated. These included:

1. A larger choke inductance at the input to the adjustable speed drive. This approach could be effective if the choke impedance was included as part of the drive's initial design. As a retrofit, it is impractical because the size required would cause voltage regulation problems at the drive.

2. Larger surge capacitors at the 800 hp motor of the parallel customer. This approach is feasible to protect the individual motor and surge capacitors of concern. However, large surge capacitors would be required and they do not eliminate the oscillations on the 25kV system that are the source of the problem. Note that the surge capacitors were removed as a temporary solution for the parallel customer.

3. Modification of the filtering at the adjustable speed drive to include a high pass filter instead of just tuned branches at the 5th, 7th, and 11th. This approach proved to be ineffective because the high pass filter cannot provide sufficient damping at the higher frequency resonance.

4. Addition of a capacitor bank on the 25kV system. This approach has the advantage of being the least expensive and the most practical to implement. Simulations show that this solution can be effective.

Effect of a 25kV Capacitor Bank

Adding a capacitor bank to the 25kV system changes the system frequency response to prevent the high frequency oscillation shown on the previous waveforms. However, the capacitor bank creates a new system parallel resonance at a lower frequency that could result in magnification of the lower order harmonic components created by the adjustable speed drive.

The first capacitor bank size tried was 1200 kVAr. This created a resonance that magnified the thirteenth harmonic component on the system if the power factor correction capacitors at the parallel customer were out of service. Figure 8 gives the measured voltage on the 25kV system for this condition. Note that the notching oscillation problem is solved (no high frequency components) but the thirteenth harmonic component in the voltage is approaching 5%.

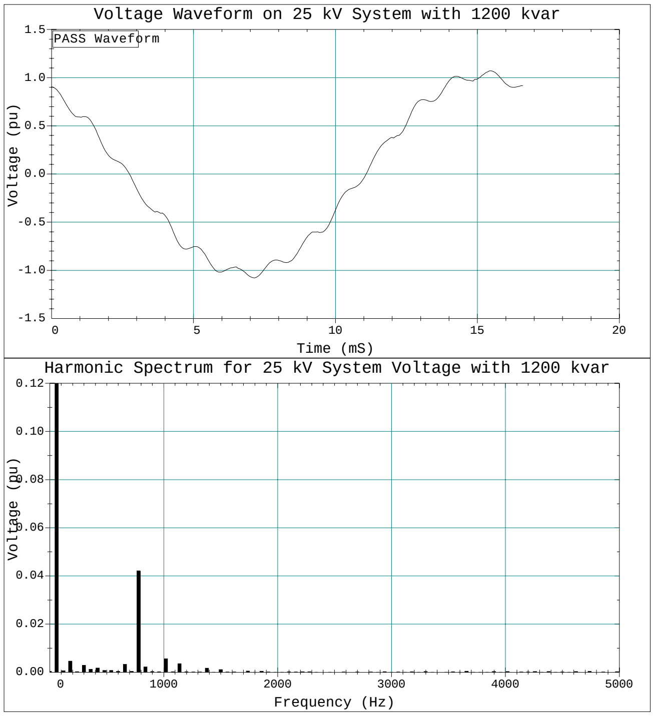

Figure 8 - Voltage on 25kV System with 1200 kVAr Capacitor bank

After examination of the system frequency response with the drive filters and the existing load power factor correction capacitors, the capacitor size was increased to 2400 kVAr to solve the thirteenth harmonic resonance problem. Figure 9 illustrates the frequency response at the 25kV bus for a 1 amp source located at the 4.16kV drive location.

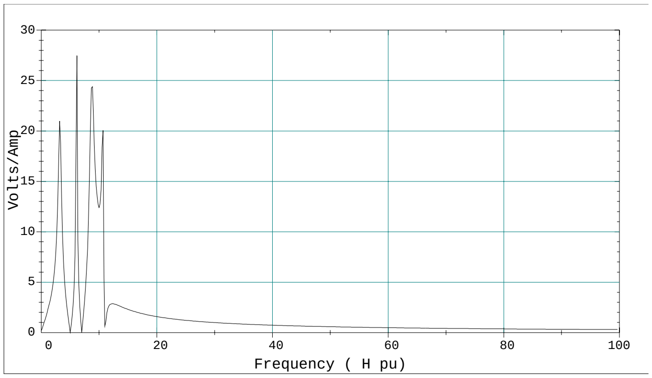

Figure 9 - Frequency Response on 25kV System with 2400 kVAr Capacitor Bank

With a 2400 kVAr capacitor bank, all of the system resonances that could cause magnification are located below the eleventh harmonic and are at frequencies that are not characteristic harmonics of the drive. Figure 10 gives the measured voltage waveform and harmonic spectrum with the 2400 kVAr capacitor operational. The voltage distortion is less than 2% with the 2400 kVAr capacitor in service.

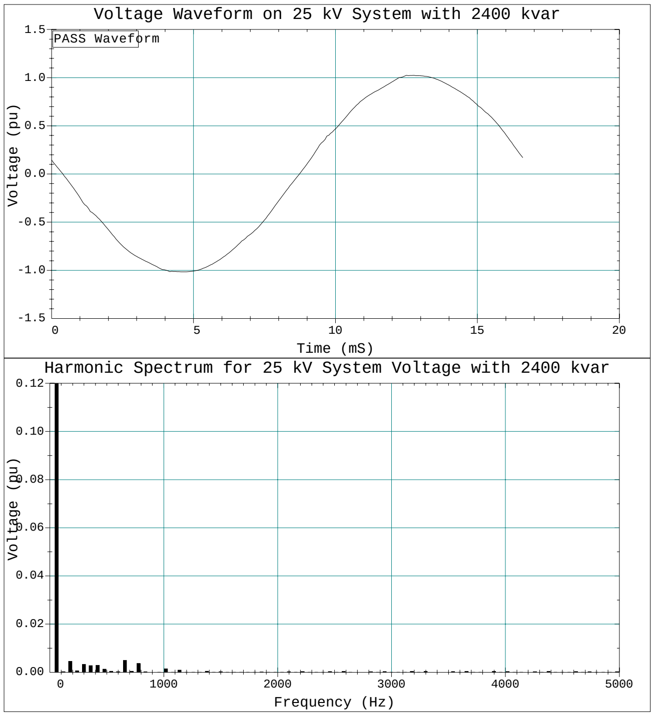

Figure 10 - Voltage on 25kV System with 2400 kVAr Capacitor Bank

SUMMARY

The case study illustrates the characteristics of high frequency oscillations that can result from the commutation notches of large adjustable speed ac or dc drives operating on systems with relatively low short circuit levels.

The system oscillations can be magnified at customer locations where low voltage capacitors exist. Small capacitors, such as motor surge capacitors can be a particular problem. Even capacitors in the power supplies for electronic loads or smaller adjustable speed drive rectifiers can be affected by these oscillations.

The problem can be solved by careful selection of a capacitor size for the primary distribution system. The capacitor should not introduce a new resonance at one of the characteristic harmonics of the adjustable speed drive. The interaction of the proposed capacitor with other system capacitors and harmonic filters must be evaluated.

REFERENCES

1. J.C. Read, “The Calculation of Rectifier and Converter Performance Characteristics,” Journal of the IEE, vol. 92, pt. II, 1945, pp 495-509.

2. E.F. Christensen, et. al., “Analysis of Rectifier Circuits,” AIEE Transactions, vol. 63, 1944, pp. 1048-1058.

3. R.A. Adams, et. al., “Power Quality Issues Within Modern Industrial Facilities, “IAS Textile Film and Fiber Meeting, Atlanta, GA., 1990.

4. D.A. Jarc and R.G. Schieman, “Powerline Considerations for Variable Frequency Drives, “ IEEE Transactions on IAS, vol. 1A-21, no. 5, 1985.