



PQSoft Case Study

Voltage Notching and Distribution Systems II Large DC Drive Example

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Customer Type	Large Industrial		
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Miscellaneous2			
References	IEEE Std. 519		

Abstract:

This case study describes voltage notching associated with large DC 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 DC drive is presented.

TABLE OF CONTENTS

TABLE OF CONTENTS 2

LIST OF FIGURES 2

RELATED STANDARDS..... 2

GLOSSARY AND ACRONYMS 2

INTRODUCTION..... 3

PROBLEM DESCRIPTION..... 3

LARGE DC DRIVE APPLICATION 4

 EFFECT OF 34.5kV CAPACITOR BANK 7

SUMMARY 9

REFERENCES..... 9

LIST OF FIGURES

Figure 1 - Example of voltage notches caused by converter commutation 3

Figure 2 - Oneline diagram for the example system 5

Figure 3 - Measured voltage on 34.5kV system after installation of phase shifting transformers 6

Figure 4 - Voltage from 480 volt service entrance at new customer after installation of phase shifting transformers 7

Figure 5 - Effect of 34.5kV Capacitors on the System Frequency Response Characteristics 8

Figure 6 - Distortion profiles at the new customer service entrance with 900 kVAR feeder capacitor in service 8

RELATED STANDARDS

IEEE Std. 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.

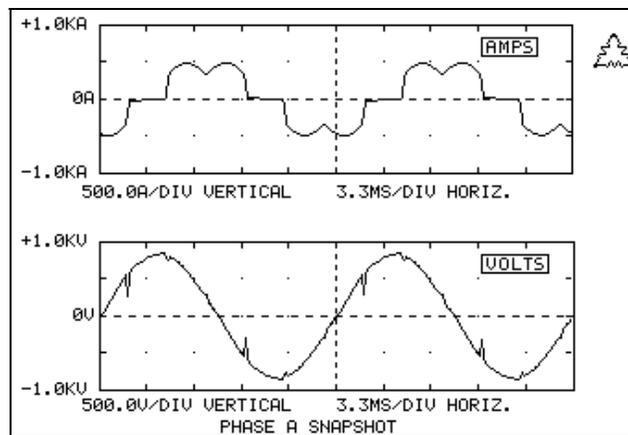


Figure 1 - Example of voltage notches caused by converter commutation

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 essentially looks like an injection of a disturbing current into the distribution system.

LARGE DC DRIVE APPLICATION

This example involves large dc drives used to pump a slurry in an industrial process. There are three sets of tandem 1000 hp dc drives used in the process. Initially, this customer was the only customer on the distribution system. Then, the distribution system was extended to supply a new customer with electronic controls for large gas turbine-driven compressors. When this new customer came on line, numerous problems were encountered, including motor heating and failures of control circuits. A one line diagram illustrating the system configuration is provided in Figure 2.

Measurements on the system indicated that harmonic distortion levels were unacceptably high on the 34.5kV system due to the operation of the dc drives. As a first step to try and solve the problem, the customer replaced the existing transformers supplying the dc drives with new transformers that had phase shifts designed to achieve 18 pulse operation for the overall facility (0 degrees, plus 20 degrees, and minus 20 degrees for the three transformers). This was effective in reducing the lower order harmonic components (when all three drives were operating) but it did not reduce the high frequency oscillation that was occurring as a result of a system resonance near the 35th harmonic. Figure 3 gives a measured waveform and spectrum from the 34.5kV system after the phase shifting transformers were put in service. Note that the distortion is spread over a range of harmonic components because the oscillation is not an exact multiple of 60 Hz. The corresponding voltage from the 480 volt service entrance at the new customer is given in Figure 4.

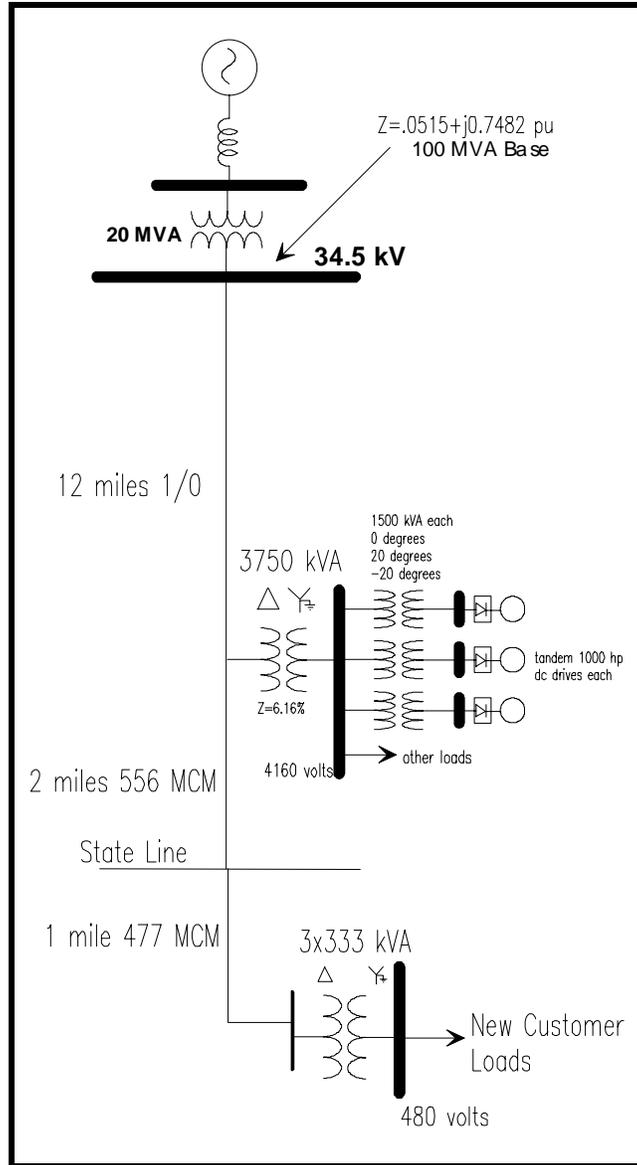
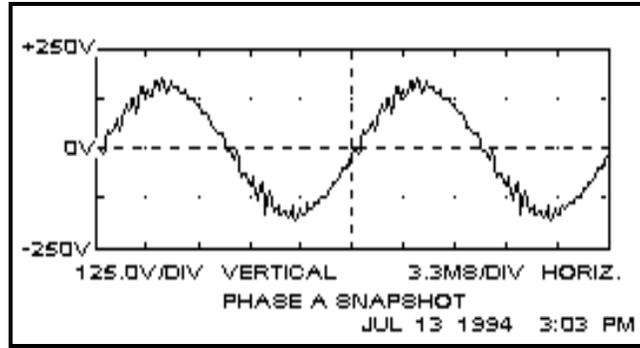


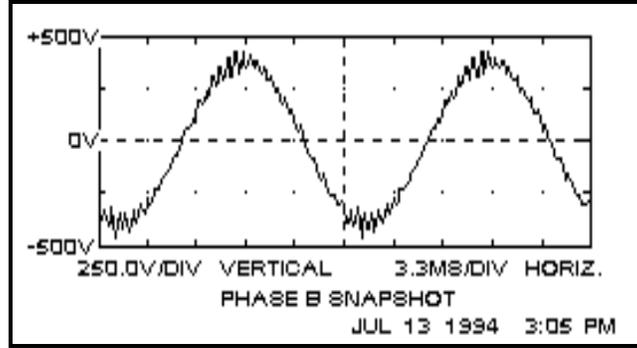
Figure 2 - Oneline diagram for the example system



PHASE A VOLTAGE SPECTRUM 3:00:51 PM
Fundamental volts: 67.6 Vrms
Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	0°	2nd	0.9%	87°
3rd	0.4%	170°	4th	0.3%	35°
5th	0.2%	167°	6th	0.2%	95°
7th	0.4%	62°	8th	0.6%	-51°
9th	0.1%	-69°	10th	0.7%	-63°
11th	0.4%	-40°	12th	0.4%	-158°
13th	0.9%	-142°	14th	1.6%	18°
15th	0.6%	107°	16th	1.3%	-36°
17th	1.6%	-37°	18th	1.0%	-48°
19th	1.0%	-80°	20th	0.6%	158°
21st	0.9%	-46°	22nd	0.5%	176°
23rd	1.1%	-102°	24th	1.7%	157°
25th	0.9%	175°	26th	2.7%	44°
27th	1.5%	-87°	28th	4.0%	-32°
29th	1.6%	107°	30th	1.6%	-27°
31st	1.0%	69°	32nd	3.3%	-36°
33rd	4.1%	59°	34th	3.2%	-68°
35th	3.6%	-54°	36th	2.8%	172°
37th	0.6%	-121°	38th	0.3%	-147°
39th	0.6%	169°	40th	0.7%	136°
41st	0.3%	17°	42nd	0.3%	155°
43rd	0.3%	20°	44th	0.4%	50°
45th	0.4%	35°	46th	0.5%	11°
47th	0.5%	72°	48th	0.2%	7°
49th	0.2%	-34°	50th	0.5%	-35°
ODD	6.7%		EVEN	8.2%	
THD:	9.2%				

Figure 3 - Measured voltage on 34.5kV system after installation of phase shifting transformers



PHASE B VOLTAGE SPECTRUM 3:03:01 PM
 Fundamental volts: 280.2 Vrms
 Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	-120°	2nd	0.3%	-143°
3rd	0.1%	-4°	4th		
5th	0.4%	54°	6th		
7th	0.3%	-91°	8th	0.1%	94°
9th	0.1%	-7°	10th	0.4%	142°
11th			12th	0.2%	-132°
13th	0.3%	-49°	14th	0.7%	179°
15th	0.1%	22°	16th	0.8%	-137°
17th	1.0%	150°	18th	0.3%	-146°
19th	1.3%	-154°	20th	0.3%	-47°
21st	0.6%	-86°	22nd	0.7%	56°
23rd	1.1%	90°	24th	0.2%	63°
25th	0.9%	159°	26th	1.1%	-120°
27th	0.5%	36°	28th	1.9%	-111°
29th	0.1%	-28°	30th	2.2%	-115°
31st	2.8%	2°	32nd	3.4%	-100°
33rd	2.3%	9°	34th	7.5%	-147°
35th	1.2%	-80°	36th	3.6%	166°
37th	2.0%	124°	38th	0.6%	-109°
39th	0.6%	-152°	40th	1.3%	57°
41st	0.4%	-32°	42nd	0.9%	40°
43rd	0.6%	155°	44th	0.5%	149°
45th	0.8%	-148°	46th	0.4%	-124°
47th	0.5%	-74°	48th	0.1%	-120°
49th	0.2%	-52°	50th	0.2%	-160°
ODD	5.1%		EVEN	9.8%	
THD:	10.1%				

Figure 4 - Voltage from 480 volt service entrance at new customer after installation of phase shifting transformers

Effect of 34.5kV Capacitor Bank

The best solution to eliminate the high frequency oscillations that are excited by notching from the dc drives is to change the frequency response of the distribution system. This is most easily done by adding a shunt capacitor bank at the 34.5kV level. Figure 5 gives the base case frequency response characteristic showing a resonance near the 35th harmonic, along with the response for three different capacitor sizes added to the 34.5kV system near the customer with the dc drives.

At this facility, the dc drives are not always operated together. During lighter load pumping requirements, there may only be one or two of the tandem dc drives in service. During these conditions, cancellation of the lower order harmonic current components is not achieved and resonances at the 5th, 7th, 11th, or 13th harmonics could be excited. For this reason, it is important that the capacitor addition at the 34.5kV level not cause a resonance near one of these characteristic harmonics.

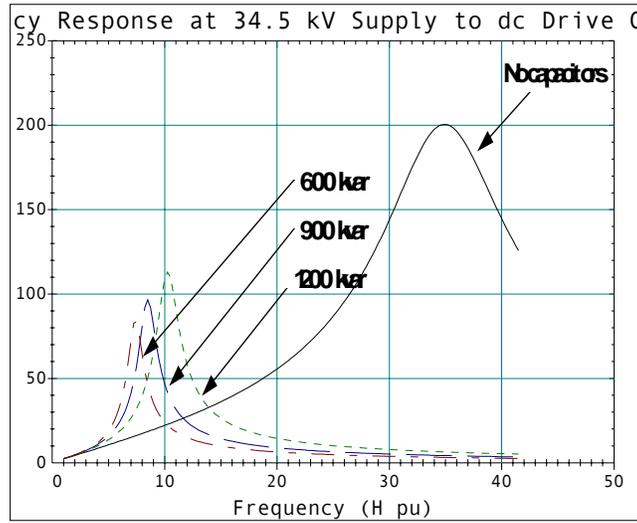


Figure 5 - Effect of 34.5kV Capacitors on the System Frequency Response Characteristics

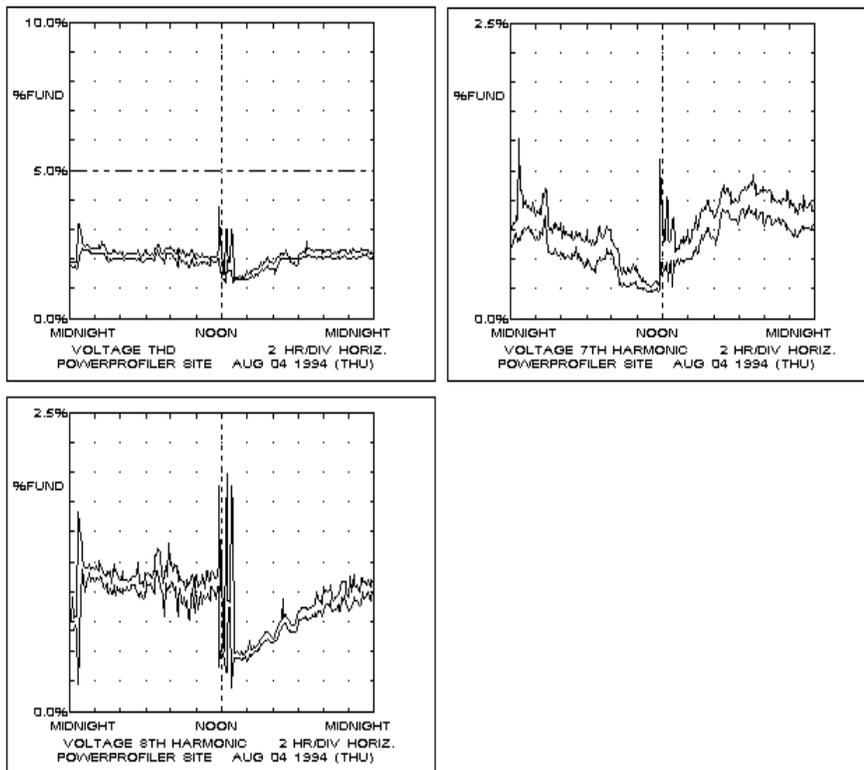


Figure 6 - Distortion profiles at the new customer service entrance with 900 kVAr feeder capacitor in service

A capacitor size of 900 kVAR was selected because it results in a resonance between the 7th and 11th harmonics (see Figure 5). This capacitor is most effective when the drives are operating in the full three pump mode and there is cancellation of the lower order harmonics. When in the two pump mode, generation of lower order harmonics increases the distortion on the system but the total harmonic distortion is still less than 5%. Plots of typical profiles of the total harmonic distortion, 7th harmonic component, and 8th harmonic component over a 24 hour period are shown in Figure 6. Note that the total harmonic distortion is normally less than 4%.

With this configuration, the new customer has been able to operate without problems. However, a better long term solution would involve the addition of 5th, 7th, and 11th harmonic filters at the 4.16 kV bus supplying the dc drives. These filters would prevent resonance problems at the low order harmonics during two pump operation, even if system changes in the future (e.g. another capacitor bank added to the distribution system or at a customer location) change the 34.5kV system frequency response characteristics.

SUMMARY

The paper 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.

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