PQSoft Case Study

Industrial Harmonic Filter Design

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Abstract:

The industrial harmonic problem can be solved using a comprehensive approach including site surveys, harmonic measurements, and computer simulations.

Simple calculations are used to determine the system resonant frequencies and then the preliminary model development is completed. Initial estimates of voltage distortion levels are made based on the level of harmonic current injection and the frequency response characteristic.

This case study presents the configuration of low voltage power factor correction capacitors as harmonic filters to improve poor power factor and reduce excessive voltage distortion levels.

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RELATED STANDARDS

GLOSSARY AND ACRONYMS

ASD	Adjustable-Speed Drive
CF	Crest Factor
DPF	Displacement Power Factor
PF	Power Factor
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
TPF	True Power Factor

PROBLEM STATEMENT

The plastics manufacturer (refer to power factor correction case) is now experiencing equipment problems, such as several capacitor bank fuses blowing, and a capacitor can failure. The plant engineer believes that the problem may be related to harmonics. He measures the following bus voltage waveform (Figure 1):
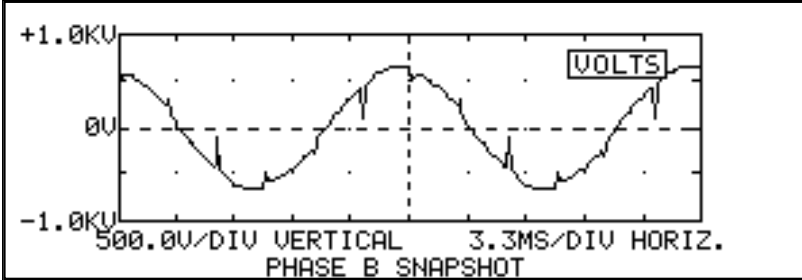

Figure 1 - Bus Voltage Waveform

Harmonic Evaluations

The industrial harmonic problem can be solved using a comprehensive approach including site surveys, harmonic measurements, and computer simulations. One general procedure used for a harmonic analysis study consists of the following steps:

- Preliminary analysis / model development

- Harmonic measurements

- Perform computer simulations

- Determine impact on equipment

- Evaluate harmonics with respect to limits

- Develop solutions (including filter design)

Simple calculations are used to determine the system resonant frequencies and then the preliminary model development is completed. Initial estimates of voltage distortion levels are made based on the level of harmonic current injection and the frequency response characteristic.

Model Development and Drive Characteristic

A simplified model, as illustrated in Figure 2, can be developed for the initial analysis. Harmonic measurements of the ASD indicated the following characteristic:

Drive rating:...500 HP
Drive voltage: ....480 V
Fundamental Current: ....600 A

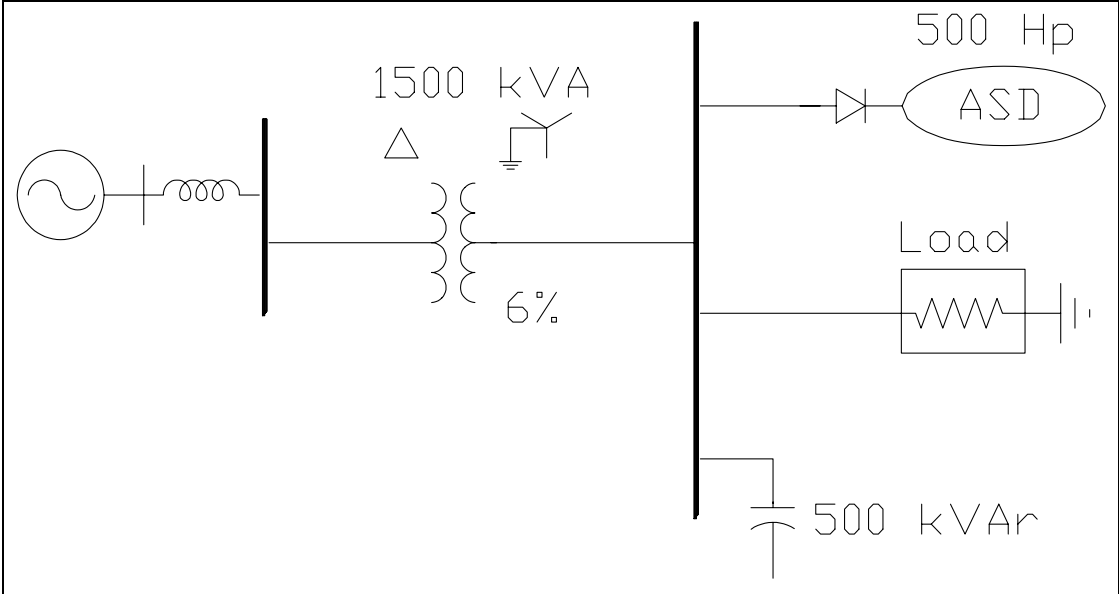| Harmonic Number	% of Fundamental	Amps
5	28	168
7	12	72
11	7	42
13	4	24
THD:	**31.5%**	

Figure 2 - Simplified Model for Harmonic Analysis

Voltage Distortion and Harmonic Resonance Calculation

Hand calculations can be used to determine the voltage distortion level without capacitors. This value is then compared with measured quantity to determine the accuracy of the preliminary model.

The transformer impedance can be determined from:

$$X_{tx} = \frac{kV^2 * Z_{pu}}{MVA} = \frac{0.480^2 * 0.06}{1.5} = 0.0092\Omega$$

Table 1 - Voltage Distortion Calculation

h	I_h	$X_h = h * X_t$	$V_h = I_h * X_h$
5	168	0.046	7.73
7	72	0.064	4.64
11	42	0.101	4.25
13	24	0.119	2.87

The total harmonic voltage distortion (VTHD) is determined by:

$$V_{THD} = \sqrt{\frac{\left(7.73^2 + 4.64^2 + 4.25^2 + 2.87^2\right)}{277^2}} = 3.74\%$$

The customer has added 500kVAr of power factor correction at the 480 volt bus. The addition of a capacitor bank creates a parallel resonance condition. The parallel resonance occurs at the frequency where the shunt capacitive reactance is equal to the inductive source reactance and can be expressed in terms of the 60 Hz values as follows:

$$h = \frac{1}{2\pi\sqrt{L_s C}} = \sqrt{\frac{X_c}{X_s}} \approx \sqrt{\frac{(100*kVA_{tx})}{(kVAr_{cap}*Z_{tx(\%)})}}$$

[1]

where:

h .... parallel resonance frequency (x 60 Hz)

X_c ....shunt capacitive reactance (C - capacitance) (ohms)

X_{sc} ....short circuit reactance (Ls - inductance) (ohms)

kVA_{tx} .... step-down transformer rating (kVA)

Z_{tx} ....step-down transformer impedance (percent)

$kVAr_{cap}$ ....capacitor bank rating (kVAr)

This simple relationship provides an excellent first check to see whether or not harmonics are likely to be a problem. Almost all harmonic distortion problems occur when this parallel resonance moves close to the 5th or 7th harmonic, since these are the largest harmonic current components in loads like ASDs. However, the 11th and 13th harmonics can also be a problem when ASDs (PWM type) are a large percentage of the total load.

For the 500 kVAr power factor correction capacitor bank installation, the harmonic resonance is very near the 7th harmonic.

$$h \approx \sqrt{\frac{(100*kVA_{tx})}{(kVAr_{cap}*Z_{tx(\%)})}} = \sqrt{\frac{(100*1500)}{(500*6.0)}} = 7.08$$

assuming:

kVA_{tx} ....step-down transformer rating (1500 kVA)

Z_{tx} ....step-down transformer impedance (6%)

$kVAr_{cap}$ ....capacitor bank rating (500 kVAr)

The frequency response characteristic, determined from computer simulation, is illustrated in Figure 3.

The addition of the 500kVAr power factor correction capacitor increases the voltage distortion to 11.5% (determined from computer simulation).

The initial solution to the problem would appear to be the installation of a 7th harmonic filter. This would create a low impedance condition and reduce the 7th harmonic voltage distortion. However, the installation of the 7th harmonic filter create a new parallel resonance very near the 5th harmonic. Recalling the current spectrum for the ASD, the 5th harmonic component was higher than the 7th (168A vs. 72A), therefore the voltage distortion will actually increase. Figure 4 illustrates the simulated frequency response characteristic for this condition.
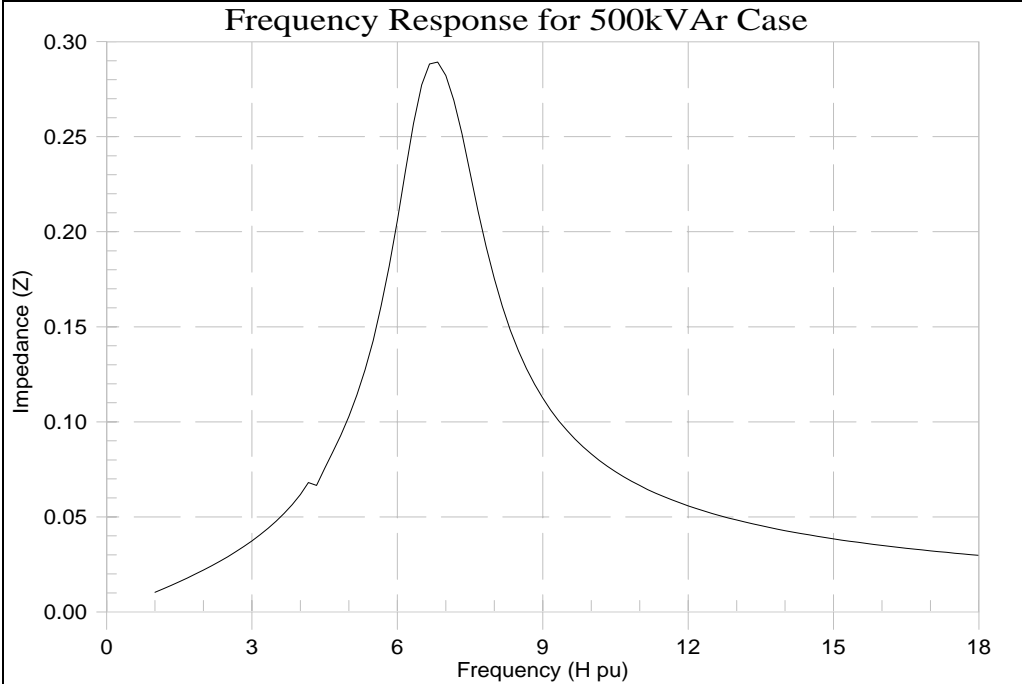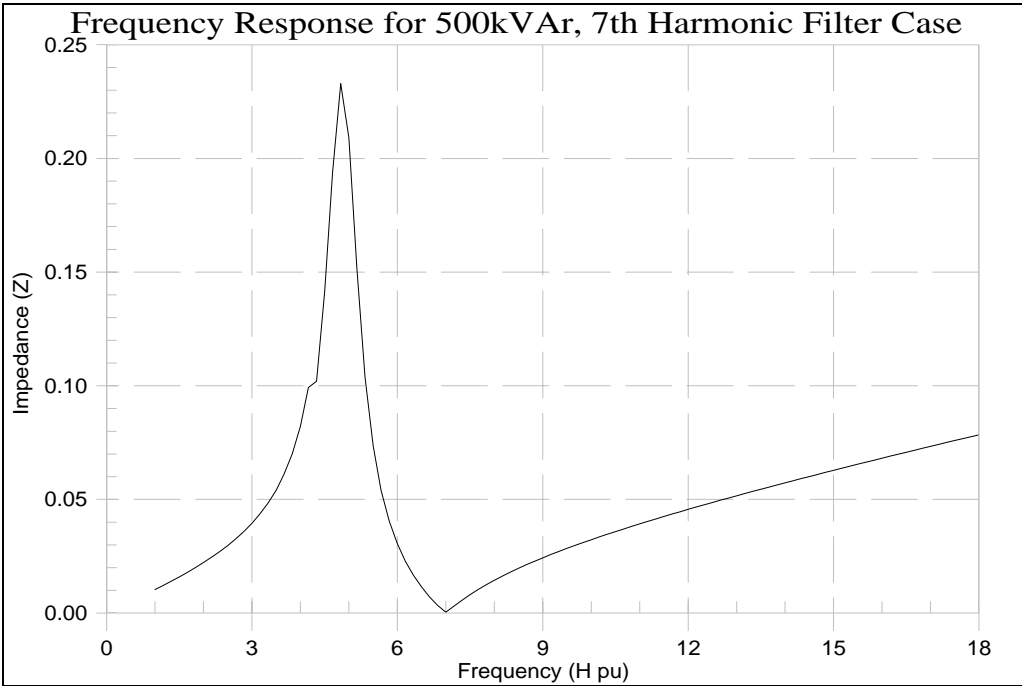
Figure 3 - Frequency Response Characteristic

Figure 4 - Frequency Response with a 7th Harmonic Filter

The installation of the 7th harmonic filter increased the voltage distortion to 16.2% (determined by simulation). The proper solution to the problem is the addition of a 5th harmonic filter. Configuration of the power factor correction capacitor as a 5th harmonic filter reduced the voltage distortion to 3.2% (determined by simulation). In general, it is best to apply harmonic filters at the lowest generated harmonic frequency. The filter configuration for this case is illustrates in Figure 5.
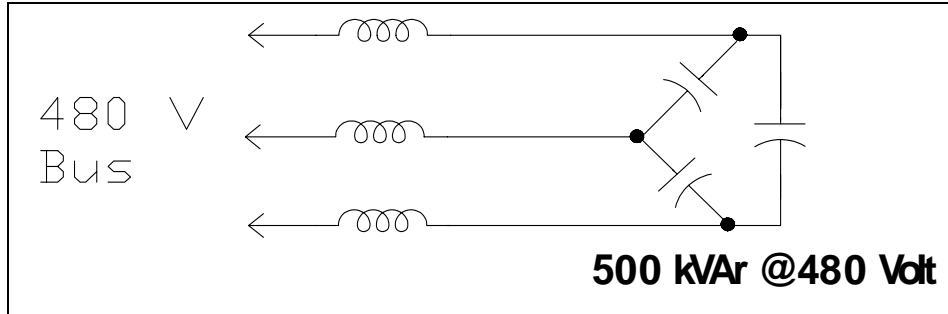
Figure 5 - 5th Harmonic Filter Configuration

Filter Design Methodology

The harmonic filter, illustrated in Figure 5, provides a low impedance path for harmonic currents, thereby minimizing harmonic voltage distortion problems. The filter is tuned slightly below the harmonic frequency of concern. This method allows for tolerances in the filter components and prevents the filter from acting as a short circuit for the offending harmonic current. This allows the filter to perform its function of providing low impedance at the harmonic frequency while helping to reduce the duty on the filter components.

The general method for applying filters is as follows:

- Apply one single-tuned shunt filter first, and design it for the lowest generated frequency.

- Determine the voltage distortion level at the low voltage bus. The commonly applied limit of 5% was introduced in IEEE Std 519-1992.

- Vary the filter elements according to the specified tolerances and check its effectiveness.

- Check the frequency response characteristic to verify that the newly created parallel resonance is not close to a harmonic frequency.

- If necessary, investigate the need for several filters, such as 5th and 7th.

SUMMARY

The industrial harmonic problem can be solved using a comprehensive approach including site surveys, harmonic measurements, and computer simulations.

Simple calculations are used to determine the system resonant frequencies and then the preliminary model development is completed. Initial estimates of voltage distortion levels are made based on the level of harmonic current injection and the frequency response characteristic.

A harmonic filter provides a low impedance path for harmonic currents, thereby minimizing harmonic voltage distortion problems.

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