Harmonic Measurements and Power Factor Correction in a Cement Factory

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Abstract

This paper presents a harmonic filter design to minimise harmonic distortion in a cement factory. In the applicational example, the power transformer feeds a rotary mill, which is driven by semiconductor devices generating harmonics in the power system. Experimental harmonic measurements have been recorded using a power and harmonic measurement device. By using the recorded data, a single tuned passive filter has been designed to reduce the fifth harmonic component caused by the power converter which was driving an induction motor in the factory. The solutions recommended in this paper can be used to increase power factor and reduce harmonics for improving the power quality and the plant productivity.

1. Introduction

Both the electric utilities and the end users of electrical power become more concerned about the quality of electrical power. The increasing numbers and power ratings of non-linear power electronic device loads produce harmonic currents in transmission and distribution feeder and distort voltage waveforms [1]. The effects of harmonics vary depending on the type of load. In some cases such as a resistance heating load all of the applied voltage does useful work. However, in most cases incorporating transformers and motors only the 50 Hz component of the voltage does useful work and the harmonic components dissipate heat energy ineffectively. Sensitive electronic control circuits, timers and logic circuits may be affected if the supply voltage is distorted.

Some of the methods used to solve harmonic problems are phase multiplication, harmonic injection, filtering [2]. The harmonic filtering is one of the solutions to prevent the harmonics. There are basically two types of filters [3];

i) passive filter where the filter components are passive elements such as resistor, inductor and capacitor,
ii) active filter where the filter has a controlled current or voltage source.

A number of authors devoted their studies to filtering out the harmonic currents. Heydt and Grady [4] used three simple filter structures; a single branch of series RLC (or single tuned filter) connected to the bus. The test system had several distributed non-linear loads. The dominant harmonic in this case was the fifth component and the proposed filter was single tuned to a frequency of 300 Hz. A fixed quality factor of 50 was used for filter inductor. Hammond [5] suggested the use of second order high pass filters. The advantage of second order is that it provides constant impedance to the harmonic currents above a certain corner frequency. It also helps in reducing commutation notches and it requires less total capacitance than the notch filter. The disadvantage is the significant power losses (both fundamental and harmonic) in the high pass resistor. In their interesting work, Montanari and Loggini [6] used the effectiveness of harmonic filters and transformer reactance in compensating the reactive power. The effectiveness of transformer reactance in reducing voltage notch and distortion factors was discussed. A smaller commutation angle, lead to higher harmonic components. The voltage notch dimensions were affected by location of filter and the ratio of protection and equivalent supply reactance. Makram and Subramaniam [3] investigated harmonic filters design to minimise harmonic distortion caused by drives. In their work, the steady state and transient analysis of harmonic filters has been presented. Andrews and Bishop [7] suggested the analytical technique used to correct power factor in modern steel manufacturing facility. Results of this work are reduced total harmonic distortion (THD) on the system, higher bus voltage, improved plant power factor and the elimination of power factor penalties.

In this paper, power system harmonic field measurements, power factor correction and harmonic analysis in the cement factory are considered to save electrical energy and to improve power quality. To this end, a harmonic filter design in order to minimise harmonic distortion and to correct power factor in the cement factory is presented. The harmonic measurements showed that the fifth harmonic is above the limit of the IEEE 519 standard. By using the experimental data, a single tuned passive filter has been designed to reduce the fifth harmonic caused by the power converter driving an induction motor. The proposed filter is single tuned to a frequency of 250 Hz. The result found in this paper increases power factor and reduces harmonics to improve power quality and therefore plant productivity.

2. Harmonic Standards

Certain international standards are presented. In USA an American Standard (IEEE) applies whereas in Europe a different standard (IEC) applies. Measured harmonics significantly higher than the recommended levels are considered unacceptable.
All of the standards make use of the total harmonic distortion (THD) voltage or current, defined as,

$$\mathrm{THD} = \frac{100\sqrt{\sum_{n=2}^{k} U_n^2}}{U_1} \qquad (1)$$

where U_1 is the fundamental component, U_2 and U_n are the harmonic components, respectively.

The main standards are the followings,

i) IEEE 519: This standard set limits for percentage "individual harmonic component distortion" and "THD". It limits both utility voltage and end user current distortions at the point of common coupling

ii) a)IEC 1000-2-4 (1994): It prescribes the compatibility levels for industrial and non-public networks. It applies to low and medium voltage supplies.
b)IEC1000-1-1 (1992): Definitions used in IEC1000
c)IEC1000-2-2 (1990): It defines the compatibility levels for individual harmonic voltages in public low voltage systems.

3. Applicational Example

Harmonic measurements have been taken at five different cement factories whose energy consumption were very high. The measurements have been taken at motor and unite. A typical example system where the measurements have been taken is shown in Fig.1

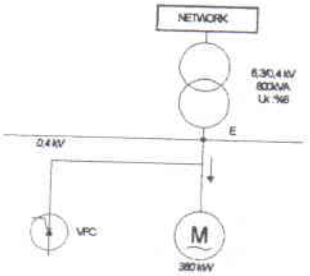


Figure 1. Sample system

i) Harmonic Measurement

Harmonic measurements have been recorded in the cement factory. One of the measurement sets has been taken at the power transformer low voltage side. This power transformer feeds a rotary mill, which is driven by semiconductor devices injecting harmonics into power system. These measurements have been compared to a standard to evaluate whether or not they are harmful.

The recorded current waveform having harmonic components is shown in Fig. 2.

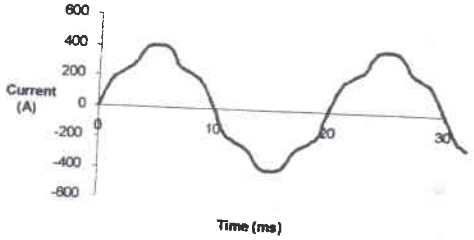


Figure 2. The recorded current wave form

The results of harmonic measurements are shown in Table 1. Nominal power of transformer is 800 kVA; seconder side voltage of transformer is 400/231 V and seconder load current is 1155 A. In the table Comp/Eff (%) is defined as ratio of harmonic component to effective value. THD_v and THD_A are the voltage and current distortions, respectively. Power transformers nominal value, harmonic values, which are found by the measurements and load conditions, are seen in Table 1. Second order harmonic components are zero because the power transformer has balanced load. As a result of harmonic measurements, the total harmonic distortion is found to be 12 %. This value is higher than 5 %, which is the limit value set in the IEEE 519 standard. Therefore, decreasing the harmonic effects is needed. Table 1 shows that the fifth order harmonic component is higher than the value defined by the IEEE-519 standard. Thus the fifth harmonic has to be filtered out to improve quality and saving of electrical energy.

ii) Power factor correction

Engineering analysis performed during the study showed that to correct the overall plant power factor to a value above 0.90 lagging, reactive compensation is to be added to the 0.4 kV bus. This action would increase the 0.4 kV bus power factor from an average value of 0.894 lagging to a value approximately of 0.95 lagging. The field measurements indicated that the power transformer load was approximately 171 kW with 0.894 lagging power factor. The incorrect reactive load is therefore 136,3 kVAr. To increase the power transformer power factor to 0.95 lagging the reactive load should be placed a capacitor bank with value 95.21 MVAr.

Table 1. Harmonic measurement results for the power transformer.

Harmonic order	Voltage (V)	Comp/Eff (%)	Current (A)	Comp/Eff (%)
01	235,9	97	285,2	92
02	0	0	0	0
03	0	0	3,8	1
04	0,4	0	0	0
05	3,9	2	21,8	8
06	0	0	0	0
07	0,4	0	13,5	5
08	0	0	0	0
09	0	0	0	0
10	0	0	0	0
11	1,1	0	9,9	3
12	0,7	0	0	0
13	0,8	0	7,6	3
14	0	0	0	0
15	0	0	0	0
16	0,4	0	0	0
17	1,6	1	10,6	4
18	0,3	0	0	0
19	2,1	0	11,6	4
20	0,3	0	0	0
21	0,5	0	1,6	1
22	0,3	0	0	0
23	1,8	1	6,8	2
24	0,3	0	0	0
25	1,7	1	5,5	2
Distortion	$THD_V = \% 2$		$THD_A = \% 12$	
One phase load	64,9 kVA	51 kW	39,2 kVAr	
f=50,1 Hz	236,8 V	274,1 A	PF= 0,786	
Three phase load	218,7 kVA	171 kW	136,3 kVAr	
	408,4 V	309,5 A	PF= 0,782	

4. Filter Design

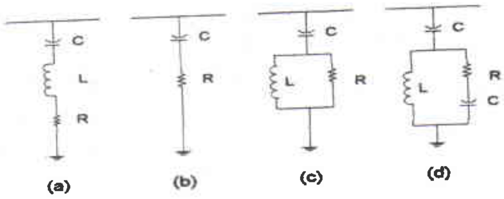
Undesired harmonic currents may be prevented into power system by one of two following methods [2],

i) Use of a high series impedance to block them,

ii) Diverting them by means of a low impedance shunt path.

Series filters must carry full load current and be insulated for full line voltage. But, the shunt filters carry only a fraction of the current that the series filter must carry. Given the higher cost of a series filter, and the fact that shunt filters may supply reactive power at the fundamental frequency, the most practical approach usually is to use shunt filters.

The most common shunt filters are the single tuned filter and the high pass filter. These two filter types are the simplest to design and the least expensive to implement. The general layout of shunt filters is shown in Fig.3.



(a) Single- tuned filter
(b) First order high-pass filter
(c) Second order high-pass filter
(d) Third order high-pass filter

Figure 3. Shunt filters

The single-tuned filter, or notch filter, is the most common shunt filter in use. The general layout of the filter is as shown in Fig.3.

One group of single tuned filters that was designed is connected to the system as shown in Fig.4.

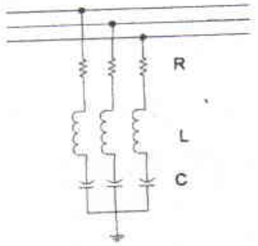


Figure 4. One group of single tuned filter

The impedance of the filter branch is given by [2],

$$Z = R + j[\omega L - 1/(\omega C)] \tag{2}$$

The resonance occurs when the imaginary part is equal to zero at which time the impedance is limited by the value of R. The frequency for which the filter is tuned is given by the value of ω that results in series resonance. This frequency is given as,

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

Defining the harmonic number n as the frequency of the harmonic divided by the fundamental system frequency allows the impedance of the inductive and capacitive reactances to be stated as,

$$X_{Ln} = n\omega L \tag{4}$$

$$X_{Cn} = 1/(n\omega C) \tag{5}$$

The capacitors are defined by reactive power of the motor. Thus, they can make compensation at the nominal frequency. L is selected as to make resonance with C at the tuned frequency. R is calculated from quality factor, which is a measure of the sharpness of tuning. The quality factor denoted by Q is defined as,

$$Q = \frac{\sqrt{L/C}}{R} = \frac{X_{Lr}}{R} = \frac{X_{Cr}}{R} \qquad (6)$$

where the reactances at the resonance frequency are given by X_{Lr} and X_{Cr}. Q can be chosen between 10-25.

The design constraints used in this paper are as follows;

i) Generally, switching filters can be adopted to the load variations. When the load is increasing, the groups are connected to the system sequentially. In this paper the filter has nine groups with equal powers.
ii) The filter used is a single- tuned 4.7 th harmonic filter,
iii) No harmonic current contribution below the fifth harmonic is considered,
iv) No other capacitors are in the system.

Filter Component ratings are given in Table 2.

Table 2. Filter Component Ratings

Q (Quality Factor)	15
C (Capacitance)	200 μF
L (Inductance)	2.29 mH
R (resistance)	0.226 Ω

5.Conclusion

A properly designed electrical supply system is necessary for reliable and efficient operation of cement factory. The paper has presented harmonic filter design for actual cement factory.

The field measurement has been useful in the analysis, providing input data and information for design a single tuned filter.

The designed filter has reduced THD on the system, higher bus voltage and improved plant power factor.

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