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HARMONICS AND ITS ILL EFFECTS OVER POWER QUALITY

S.Sayeenath[1] , S.ArunKumar[2]
Krishnasamy college of Engineering and Technology
sayee230@gmail.com arunnkumar1993@gmail.com

Abstract: **In little more than ten years, electricity power quality has grown from obscurity to a major issue. One of the most severe problems of power quality is harmonic distortion and its consequences. Particularly, the increasing penetration of power electronics-based loads (non-linear loads) is creating a growing concern for harmonic distortion in the AC power system. Then, electricity power quality is major issue for utilities and their customers and both are quickly adopting the philosophy and the limits proposed in the new international standards (IEC, EN, BS, IEEE). Consequently power-conditioning equipment is becoming more important for electric utilities and their customers. Up to now, various harmonic relief equipment or solutions have been proposed. Most of them are tuned passive filters, series reactors etc. New innovative equipment such as active harmonic conditioners or active filters also play an important role in compensating the power harmonics.**

***Key Words*: Harmonics, capacitor bank bursting, solution to the bursting problem.**

1. Introduction

A brief description of the project background can be given as follows. Lion Brewery Ceylon Ltd., one of the brewery manufacturing companies has faced a severe problem at their factory premises located at Biyagama. That is, their power factor correction capacitor banks had burst, once they were replaced after few weeks they were burst again giving rise to a situation to remove the capacitor bank form the distribution system. Total load of the factory is around 1000kW with a peak load of around 1600kW.

Around 50% of the peak comprised with Variable Speed Drives (VSD), which vary the supply frequency between 50 ~ 1 Hz.

On the request of the company the Demand Side Management Branch of the Ceylon Electricity Board had carried out a system monitoring. From that, they have found that a significant amount of harmonics is present in both voltage and load current.

Objective of the project was to carry out a complete system monitoring and find out the causes/reasons for capacitor bursting, harmonics and propose possible solutions to these problems.

Further we have simulated a model in the laboratory and designed the filters in a small scale. This can be extended to address the problem in the factory after more careful and in depth analysis.

2. Power System Harmonics

2.1 What are Harmonics?

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency (50Hz). Harmonics are created by non-linear loads that draw current in abrupt pulses rather than in a smooth sinusoidal manner.

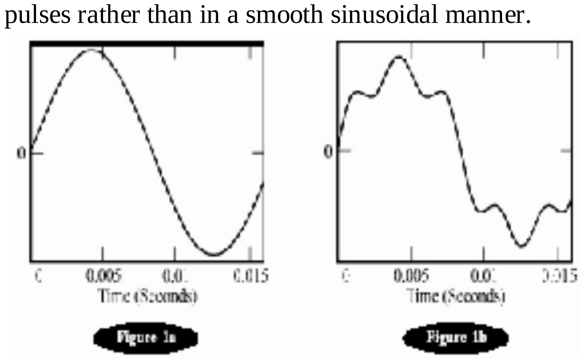

Figure 1 : Fundamental and waveforms containing harmonics

(a) Normal fundamental 50Hz Waveform.

(b) Waveform containing the fundamental plus third and fifth harmonics.

Power system voltage and currents are sinusoidal waves (See Figure 1a) Harmonics are sinusoidal components of a periodic wave that are integral multiples of the Fundamental frequency. Superposition of harmonics with fundamental will distort the original waveform (See Figure 1b).

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2.2 Harmonic Sources

Harmonics are generated in power systems by:

• **Arcing Devices -** Equipment that creates arcs as part of normal operation, such as electric arc welders.

• **Magnetic Circuits -** Magnetic devices such as transformers, produce distorted wave shapes when they are operated in their nonlinear regions.

• **Power Electronics -** The switching of such devices as Silicon Controlled Rectifiers (SCRs) and thyristors produce electrical wave shapes that are not sinusoidal in nature. These devices include **Variable Speed Drives (VSD)** or electronic power supplies.

2.3 Consequences of Harmonics

• **Exc e ssi ve Equipment Heating -** Increased heating is the result of increased copper and iron losses due to the increased frequencies present. Equipment ratings must take the presence of harmonics into account.

For example, the International Regulations requires that the size of neutrals be increased in circuits that serve loads that contain significant harmonics. The larger neutral is required to carry the added high frequency currents.

• **E l e c t r i c a l Interference -** Interference may take the form of loss of data, communication interference, or disoperation. Many electronic devices count on regular sinusoidal voltage waves for detection of peaks and/or zero crossings used in timing circuits.

• **O v e r voltage -** An over voltage is a voltage above the normal rated or maximum operating voltage of a device or circuit. Harmonic over voltages are caused by local circuit resonant conditions that can overstress equipment insulation.

One most common form is the tuning of a circuit due to the addition of a capacitor. If such a harmonic resonance occurs capacitor banks can even be exploited.

The following equation can be used to determine if the system is tuned to a power system's characteristic harmonic:

$$h = \sqrt{\frac{kVAsc}{kVARc}}$$

where kVAsc – Short circuit available at the location in kVA
kVARc – Rating of the capacitor bank in kilovars
h – Harmonic number to which the circuit is tuned

3. Analysis of the Distribution System & Identification of Measuring Points

In order to analyze the distribution system, data were recorded using 'Data Loggers' and a 'Network Analyzer'. These equipment were provided by the Demand Side Management Branch (DSMB) of the CEB. Data recoding was carried out for four days.

Load points to which the data recording equipment are to be connected were decided by analyzing the distribution system. There are mainly five feeders coming from the main bus bar, which comprised with variable speed drives. Data Loggers were connected to the load ends of each of those feeders. Network Analyzer was connected to the main bus bar.

Recoded data, which was logged using the Data Loggers and the Network Analyzer, were analyzed with the help of following software.

ƒ Energy Logger (Elog) 99b

ƒ Power Vision 1.1

Following figures (Figure 2 - 5) refers to few samples which give the voltage & current profiles of the measuring points from which the data was recorded.

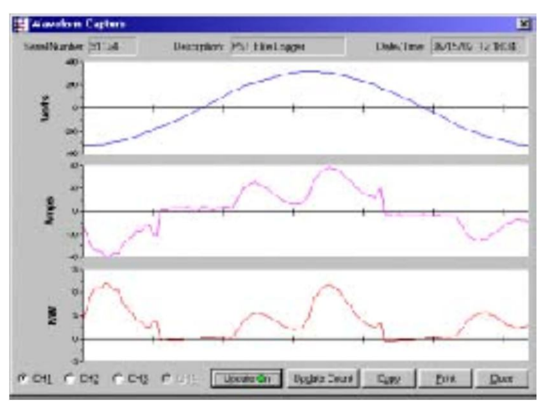

Figure 2: Voltage & Current waveforms obtained from a feeder connected to a VSD load

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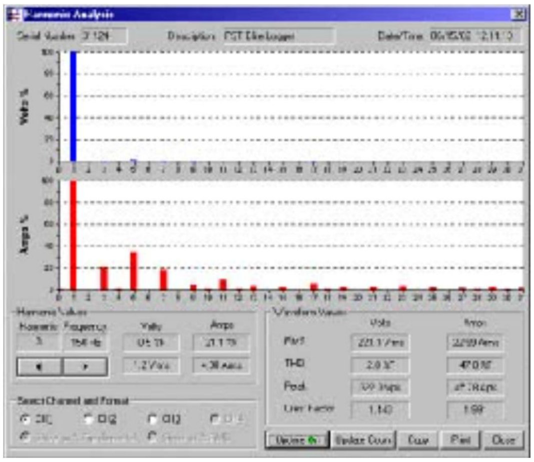

Figure 3: Voltage & Current spectrum obtained from a feeder connected to the VSD load

Phase Voltage/Current data

rms voltage : 223.3V

rms current : 22.99A

Voltage THD : 2.0%

Current THD : 47.8%

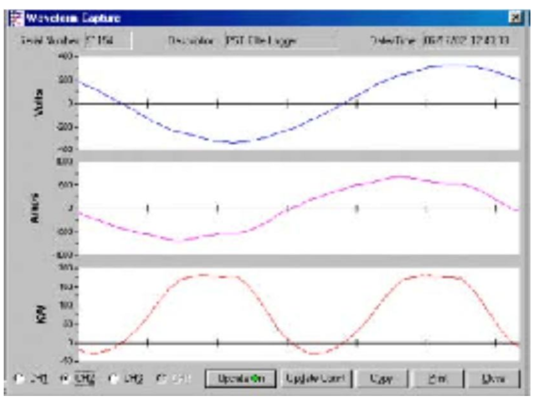

Figure 4: Voltage & Current waveforms obtained from the Main Bus bar

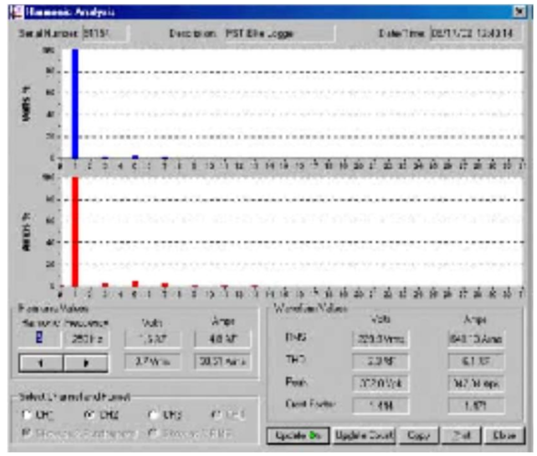

Figure 5: Voltage & Current spectrum obtained from the Main Bus bar

Phase Voltage/Current data

rms voltage : 229.9V

rms current : 641.13A

Voltage THD : 2.3%

Current THD : 6.1%

By analysing the recorded data we found that load taken form the feeder VSD-3 contains a significant amount of current harmonics.

As an example if the 5th harmonic of the current waveform is considered;

Fundamental rms current : 20.79 A

rms of 5th harmonic : 7.07 A as

a % of fundamental : 34.15%

If the main bus bar-1 is considered 5th harmonic of the current waveform;

Fundamental rms current : 635.63 A

rms of 5th harmonic : 30.51A

as a % of fundamental : 4.80%

4. Elimination of Harmonics

Current harmonics are often treated as a local problem at least for one feeder in the distribution network. The impedance of the distribution network dampens the harmonic propagation. Therefore, harmonic filtering should be performed nearby the source of the current harmonics for the best results. If this is done, other equipment will be unaffected by the harmonic producing load. Harmonic filtering or compensation is accomplished by the use of passive filters (PF), active filters (AF).

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5. Possible Solutions

5.1 Passive Filters

Passive filters for harmonic reduction provide low impedance paths for the current harmonics. The current harmonics flow into the shunt filters instead of back to the supply. A typical shunt passive filter and the resulting equivalent impedance seen from the load are shown in Figure 6. The passive filter consists of series LC filters tuned for specific harmonics in combination with a general high pass filter used to eliminate the rest of the higher order current harmonics.

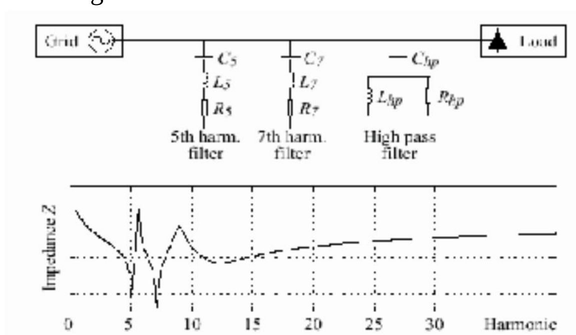

Figure 6: Typical passive filter for reduction of current harmonics and the equivalent impedance seen from the load.

The performance of a passive filter is strongly dependent on the system impedance at the harmonic frequencies. The system impedance depends on the distribution network configuration and the loads. Therefore, design of passive filters involves thorough system analysis in order to obtain adequate filtering performance of the filter.

In order to simulate the real situation a three phase diode converter followed by a dc load was used as the load with three single phase transformers. Resistors were used to represent the line impedance. Voltage control of the load was achieved by the having a chopper circuit in series with the dc load.

Passive filters were constructed for 3rd, 5th & 7th harmonic components separately. For simplicity filters were designed only for one phase. A high pass filter was used to eliminate the higher order harmonic components.

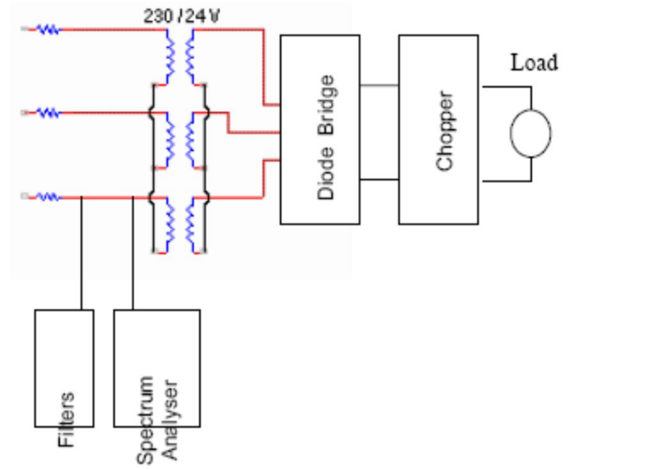

Figure 7: Basic circuit diagram of the simulation

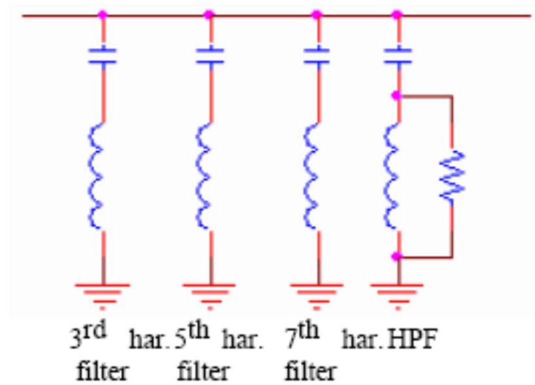

Figure 8: Expansion of the Filter block

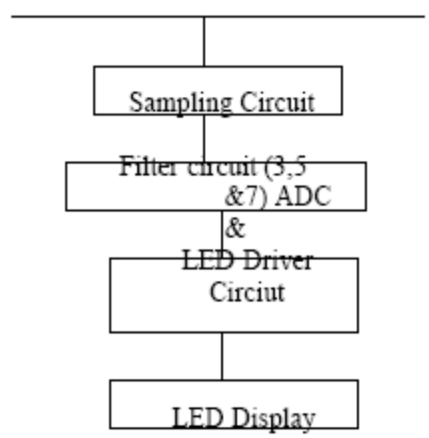

Figure 9: Expansion of the Spectrum Analyzer block

5.2 Detuning inductors with capacitor bank

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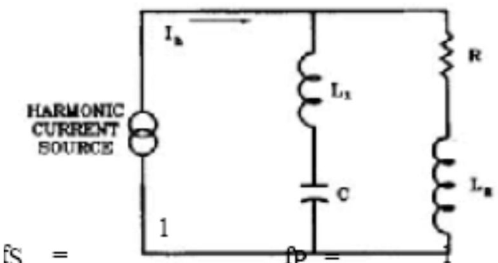
This method consists of series tuning capacitor bank to the lowest offending harmonic, i.e 5th. This is done by introducing an inductor in series with the capacitor as shown Figure 10.



$$f_S = \frac{1}{2\pi\sqrt{L_1.C}} \qquad f_P = \frac{1}{2\pi\sqrt{(L_1+L_2).C}}$$

Figure 10: Equivalent per phase circuit of the system with detuning inductors

Once detuning inductors are installed there will be two resonance frequencies.

f_P = tuning parallel frequency

f_S = tuning series frequency

Detuning Inductor should be selected in such a way that, parallel resonance occurs at a frequency which is below the lowest offending harmonic (most severe harmonic in magnitude) and series resonance occurs at a frequency closer to the lowest offending harmonic. In this case it is 5th harmonic. Hence harmonic currents generated at or near the series resonance frequency will flow to the trap harmlessly provided the capacitor and the inductor are sized properly to withstand the additional stresses. ie. series resonance circuit acts as a filter to the most offensive harmonics. Capacitor is **detuned** with inductor since the resonance frequency does not coincide with harmonic of the mains frequency. This results in a protection of the capacitors against resonance and high currents.

5.3 Multi-pulse methods and Transformers

Multi-pulse methods involve multiple converters connected so that the harmonics generated by one converter are cancelled by harmonics produced by other converters. By these means certain harmonics, related to the number of converters, are eliminated from the power source. Multiple pulse converters give a simple and effective technique for reducing power electronic converter harmonics. Multi-pulse methods are characterized by the use of multiple converters or multiple semiconductor devices, with a common load.

Phase shifting transformers are essential ingredients and provide the mechanism for cancellation of harmonic current pairs, for example, the 5th and 7th harmonics, or 11th and 13th and so on. This method might not be cost effective due to requirement of phase shifting transformers.

6. Conclusion

By analyzing the logged data of the distribution system it was found that there are significant amount of current and voltage harmonics in the load side and hence in the supply side. 5th and 7th harmonics are most severe harmonic components in the load current. Development of passive filters with simulated model revealed that there would be several practical issues to be addressed when developing such a filter system in large scale or even in small scale.

Proposed solutions are submitted to the factory management of the Lion Brewery Ceylon Ltd for their consideration and the prototype would be extended to a real passive filter system for the factory in the future if necessary.

7. Acknowledgment

The project group wishes to thank the staff of the Demand Side Management Branch (DSMB) of the CEB for giving us a valuable project and lending the data recording equipment. Also, the group wishes to extend our sincere gratitude to Prof. J.R.Lucas-Head of the Department, Prof. M.P. Dias -Supervisor of the project, Dr. N Nanayakkara- coordinator of the project and the staff of the Department of Electrical Engineering for facilitating us to do the project. Further, the project group would like to appreciate the kind co-operation of the staff of the Lion Brewery Ltd. especially Lalith Chandrasiri -Chief Engineer and Mangala Dharmarathne - Electrical Engineer.

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