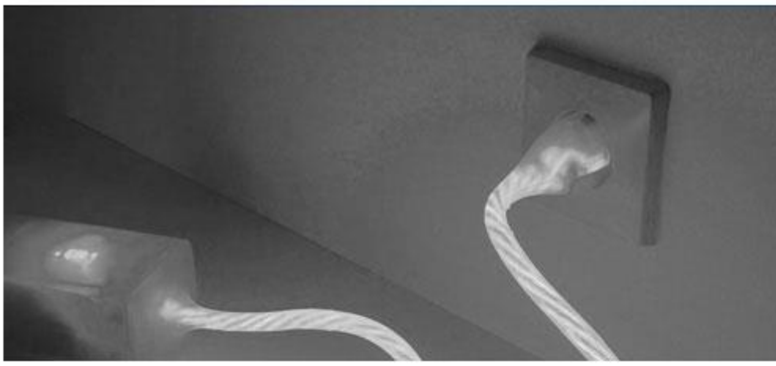


apqi ASIA POWER QUALITY INITIATIVE





A PQ Case Study

CS 36 HOSP 14

A Case Study OF Harmonics Mitigation in a Hospital and its Benefits

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Abstract

A leading hospital in southern India faced chronic problems in terms of humming noise in capacitor bank, its failure, high temperature in transformer, and disturbances on the monitor of ultra sound machine. In order to rectify these problems hospital management carried out power quality study. During the study it was observed that harmonic content were quite high. As suggested by the consultant hospital management decided to install one 120 amperes active harmonic filter at the PCC level.

Detailed measurement based study was conducted at the hospital to analyse benefits gained by the hospital. During the case study it was also observed that by reducing harmonic content, the hospital also reduced energy charges causing direct savings in energy cost.

Introduction

With the critical applicability of medical electronics equipment used in hospital and widespread use of microprocessor based equipment, it has become very important that power fed to such equipment is of high quality. Any deviation in power quality can result in malfunction of the medical equipment or failure of them. Failure of critical medical equipment in Operation Theatre during operation can have disastrous effect both on life and reputation. With rising cost of energy, reduction in energy consumption is also one of the important aspects that need address in a hospital. As many distribution companies like in Andhra Pradesh (India) are opting for kVAh based billing, presence of harmonics in the system will definitely increase consumer's electricity bill.

This case study illustrates typical power quality problems faced by a hospital, benefits achieved by the hospital by installing harmonic filter and scope of further improvement to maintain power quality as per standards.

About the Facility

The hospital is one of the major hospitals in Hyderabad with specialization in treatments of heart disease, neurology, neuro-surgery, cancer and other life threatening diseases. Diagnosis and treatment of these diseases require highly experienced doctors and medical professionals along with sophisticated machines and equipment. For diagnosis purpose, a doctor depends a lot on the results of these medical equipment and these sophisticated medical equipment become very important in terms of diagnosis of a particular ailment. Any error in the results can lead to wrong diagnosis and the life of a patient can be in danger.

The facility has opted for best available technology in terms of medical equipment and electrical distribution system. The facility receives power from state electricity board at 11kV which is stepped down to 415volts using a 690 kVA transformer.

Single line diagram below shows distribution system of the facility. The facility has installed an active harmonic filter of 125 Ampere capacity at the PCC level to reduce harmonics along with APFC panel of 650KVAr. From PCC, number of panels distributes power to each floor where it is distributed further. On each floor, typical distribution of load consists of lighting, split air conditioners and medical equipment.

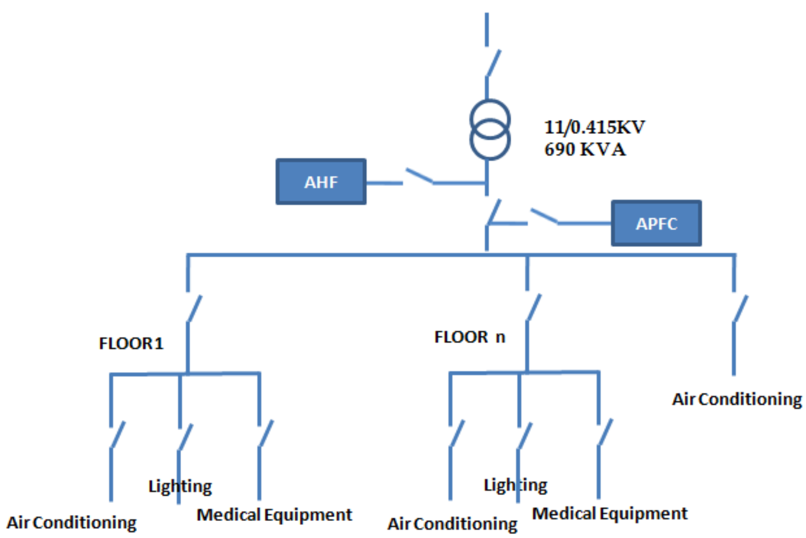


Fig.no.1 Single line diagram of facility

Problem Faced by the Hospital

The Hospital was facing following problems in the distribution system.

1. Higher temperature in the transformer 80-85 ^{o}C.
2. Humming noise in the capacitor bank
3. Higher energy charges as billing is based on kVAh
4. Disturbance on the monitor on ultra sound machine

In order to find root cause of above problems to avoid any breakdown, Hospital management decided to carry out detailed power quality study of the facility. Result of power quality study identified presence of high harmonics at PCC level. As per the study, total current harmonic distortions at the PCC level were up to 30%. Measurements and results below confirm presence of harmonic distortion beyond the limit prescribed by IEEE-519. Table – 1 shows harmonic limit as prescribed by IEEE-519.

Harmonic Current Limits for Non Linear load at the Point –of-Common-Coupling with Other Loads, for voltages 120-69,000 volts						
Maximum Odd Harmonic Current Distortion in % of Fundamental Harmonic Order						
I_{SC}/I_L	<11	11<17	17<23	23<35	35	TDD
<20	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

Table no.1 Harmonic limit as prescribed by IEEE 519

I_{SC}/I_L is the ratio of short circuit current value of the facility to the maximum load current.
TDD-Total Demand Distortion

Detailed measurement based study was carried out to find benefits gained by the hospital by installing harmonic filter.

Measurement

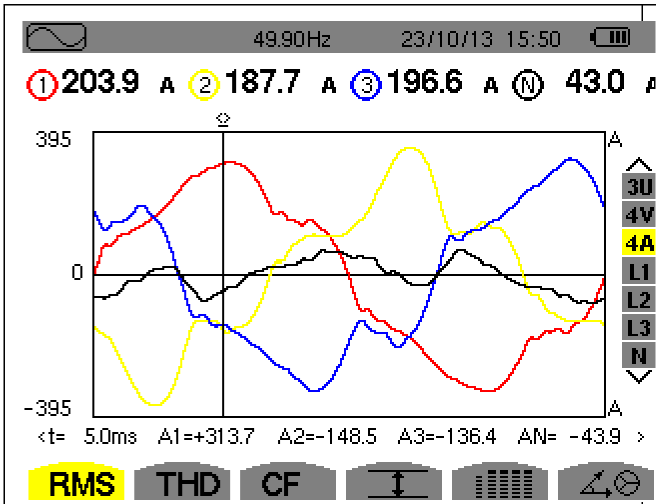
In order to carry out case study power analyzer suitable to carry out power quality study was installed at the PCC on transformer secondary side to record various parameters like harmonic order and percentage, power factor, power and demand. AHF was switched off for some time and measurements were recorded. Measurements were also carried out on HT side of the transformer as utility meter used for billing was installed on HT side.

Sections below shows effect of harmonic filter on various parameters like harmonics, power (kW), demand (kVA) and power factor.

Harmonics

Without AHF

Detailed measurements were carried out at the PCC level on LT and HT side of the transformer in the absence of harmonic filter.



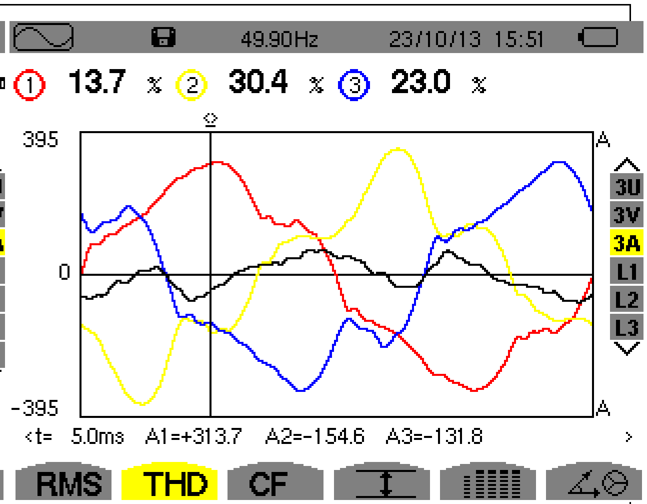


Fig.no.2 Load Current diagram of facility	*Fig.no.3 Total Harmonic Distortion - Current*

Figure 2 shows load current during normal operating hours. It can be seen from the snapshot that all phases of the wave form are distorted and are not close to a perfect sinusoidal wave form. Neutral current is 43 amperes which is quite high. Presence of harmonic current in the system distorts fundamental current wave forms. One of the reasons for high neutral current could be triplen harmonics Measurements for harmonics are shown in next section.

Figure 3 shows a snap shot for the total current harmonic distortion in the system. For each phase total current harmonic distortion is different. In R phase, THDi is 13.7%, Y phase 30.4% and in B phase THDi is 23%. Variation in the difference of total current harmonic for the phases is due to presence of lighting load that is connected on Y phase. Some single phase medical equipment are also connected in the same phase Presence of these harmonic current distort fundamental wave form and also peak value of the wave form is increased.

Snap shot below shows different order of harmonics present in the system in the absence of harmonic filter.

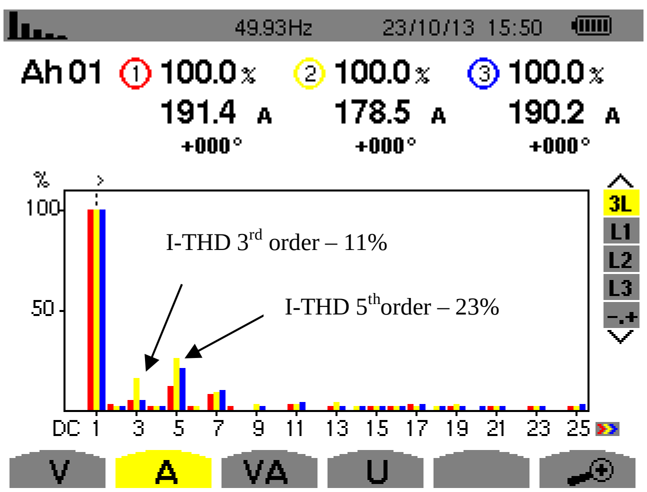


Fig.no.4 –Order of current harmonics

From the figure4 it can be seen that 3rd / 5th and 7th order of harmonics are predominant in nature where as harmonics were present up to 25th order and above. 3rd order harmonics were found to be up to 11% where as 5th order harmonics were up to 23%. High neutral current can be attributed to presence of triplen harmonics which are of the order 3rd , 9th and 15th. 3rd harmonic present in Y phase are up to 25 amperes. RMS value of 5th order harmonics was found to be up to 44 amperes.

Table 2 shows percentage harmonic content in each phase and table 3 shows RMS value of individual order of harmonic in each phase.

Order of Harmonics	% Harmonic Current		
	Phase R	Phase Y	Phase B
3rd	3.5	13.2	3.3
5th	10.8	23.5	19.4
7th	6.1	7.9	8.8
9th	0.1	1.7	0.8

Table no. 2 – Percentage of harmonic current

Order of Harmonic	RMS Value of Current		
	Phase R	Phase Y	Phase B
3rd	6.22	25.6	6.8
5th	21.38	44.0	38.0
7th	12.4	14.3	17.2
9th	0.19	3.3	1.5

Table no. 3 – RMS value of harmonic current

From the above measurements, it was evident that high percentages of harmonics were present in the system. In order to mitigate harmonics, hospital management decided to install 120 ampere active harmonic filter recommended by PQ auditor.

Installed Harmonic Filter at the Facility

Harmonics - With AHF

Figure 5 shows when harmonic filter was in line, distortion level of the wave forms was much lower as compared to the condition when harmonic filter was switched off. The waveform was close to sinusoidal waveform as compared to waveform in figure number 2. Also current in the neutral is significantly reduced from 43 amperes to 32.6 amperes.

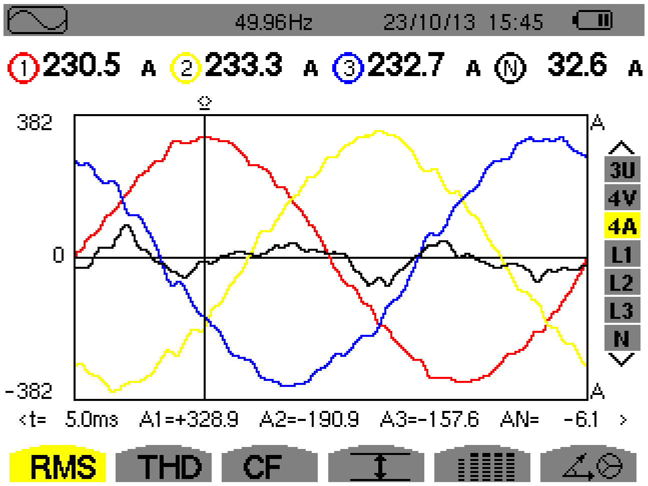


Fig.no.5 –Load Current

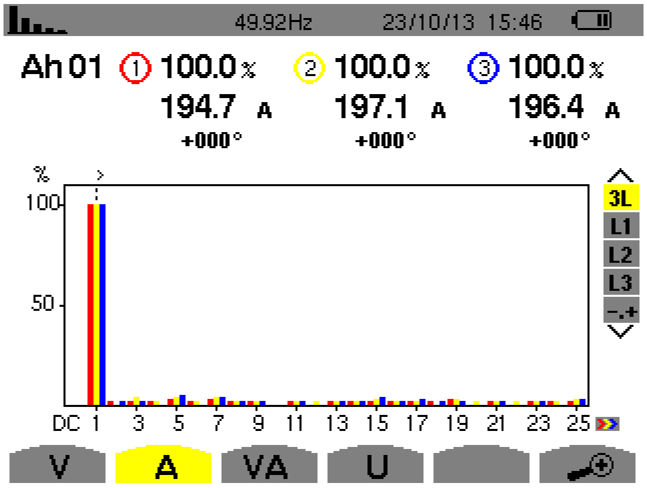


Fig.no.6 –Order of current harmonics

From the figure 6 it can be seen that 3rd / 5th and 7th order of harmonics are reduced to considerable extent. Reduction in triplen harmonics also reduced current flowing in the neutral of the system. After installation of harmonic filter 3rd, 5th, and 7th order of harmonics are reduced to 2.2%, 3.2% and 2.1% respectively.

Table number 4 and 5 shows percentage of individual order of harmonic and their RMS values.

Order of Harmonics	% Harmonic Current		
	Phase R	Phase Y	Phase B
3rd	0.7	2.2	0.7
5th	1.7	2.8	3.2
7th	1.8	2.1	2.1
9th	0.2	.01	0.9

Table no. 4 – Percentage of harmonic current

Order of Harmonic	RMS Value of Current		
	Phase R	Phase Y	Phase B
3rd	1.3	4.3	1.4
5th	3.3	5.5	6.3
7th	3.5	4.1	4.1
9th	0.4	0.2	1.8

Table no. 5 – RMS value of harmonic current

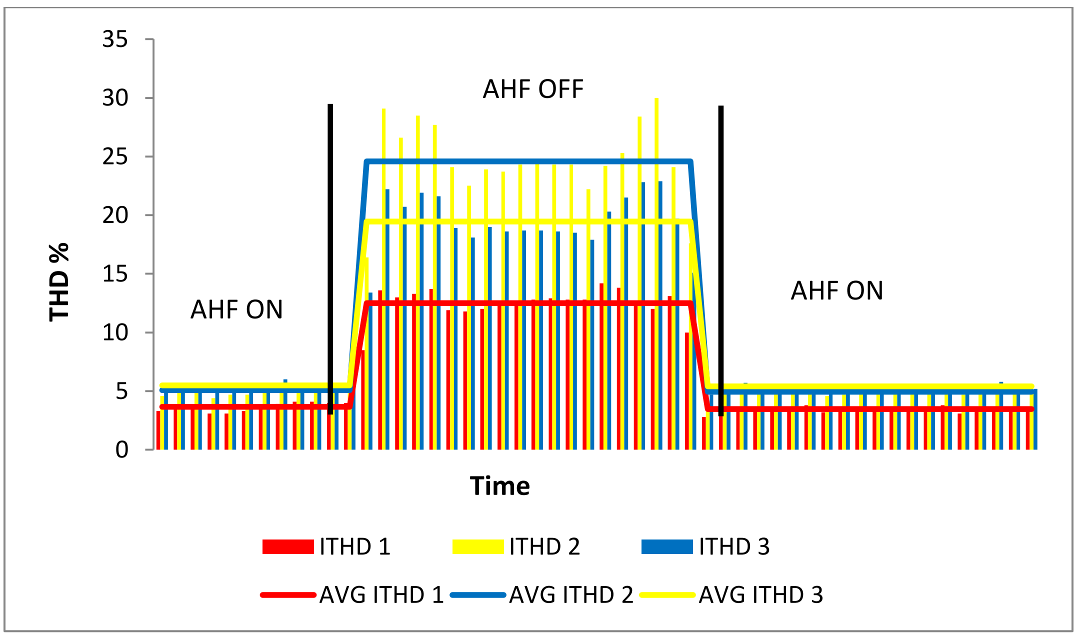
From the above table it can be seen that after installation of active harmonic filter, the harmonic current are reduced by considerable extent.

Benefits accrued by installing Active Harmonic Filter

In order to analyse benefits accrued to the hospital by installing active harmonic filter measurements, data was logged for longer duration of time. During this time active harmonic filter was switched off for some time. Sections below show affect of active harmonic filter on various parameters like harmonics, power factor, kW and kVA.

Current Harmonic Distortion

As the measurements recorded, graphs-1 below shows effects of harmonic filters in ON and OFF condition.



Graph-1 Total Current Harmonic Distortion with and without AHF

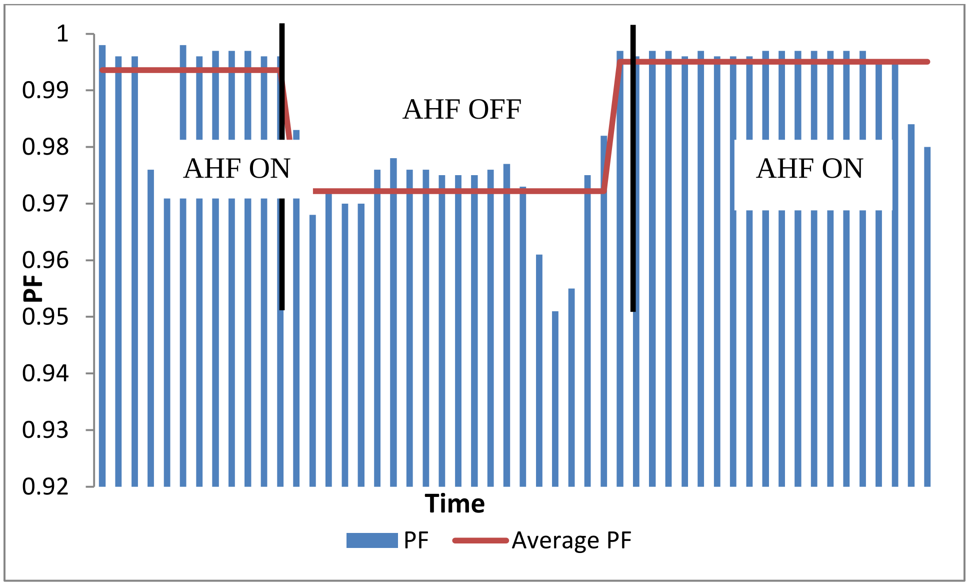
Graph-1 shows total harmonic distortion in percentage against time. It can be seen from above graph that when active harmonic filter was switched ON, there is drastic reduction in total harmonic distortion in current. When active harmonic filter is OFF, THD percentage is up to 25% but when active harmonic filter is switched ON, THD percentage is reduced to below 5%.

From the above measurements, it can be seen that by installing active harmonic filter, magnitude of harmonic distortion is reduced to considerable extent within the limits prescribed by IEEE and as desired by the hospital. The harmonics that are being fed to the upstream of the grid are within IEEE limits. As of now there is no penalty by the distribution company on the harmonic distortion, but in future if levied then the harmonics are within limits.This would enable customer to avoid any penalty imposed due to distortion in future by distribution company.

Power Factor

Graph -2 below shows effect of harmonic filter on power factor. In the absence of harmonic filter power factor was close to 0.97 and when harmonic filter was switched on power factor improved to 0.995 and above. A major concern arising from the use of capacitors in a power system is the possibility of system resonance. This effect imposes voltages and currents that are considerably higher than would be the case without resonance. The reactance of a capacitor bank decreases with frequency, and the bank, therefore, acts as a sink for higher harmonic currents. This effect increases the heating and dielectric stresses.The result of the increased heating and voltage stress brought about by harmonics is a shortened capacitor life. One of the indicator of resonance is humming noise coming out of capacitor bank. This phenomenon was also observed at the facility. When harmonic filter were switched off, it was observed that there was a continous humming noise coming from capacitor bank. When harmonic filter was switched onthere was no humming noise coming from the capacitor bank.

Power Factor

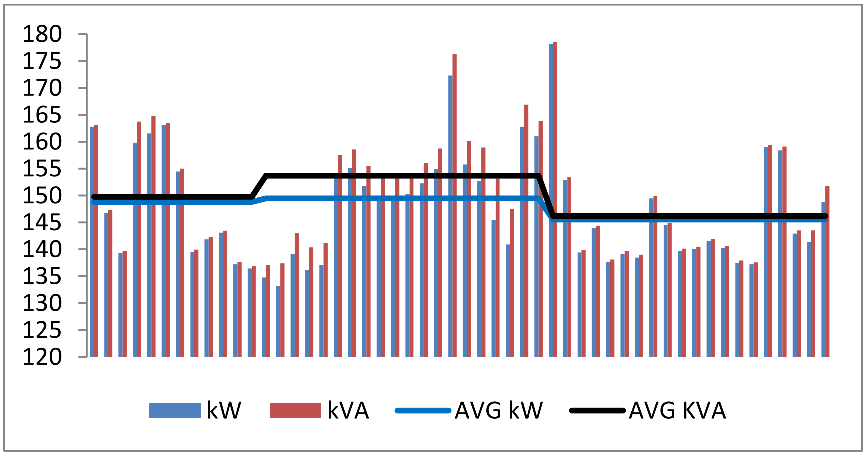


Graph-2 Power Factor With and without AHF

By reducing current harmonics, power factor is improved and humming noise is eliminated from the capacitor bank.Also it is reported that capacitor bank failure is heavily reduced.

Reduction in Energy Charges

Most of the utility boards are now opting for kVAh billing instead of kWh billing. In kVAh billing, harmonics distortion makes a great impact as compared with kWh billing. Graph-3 shows difference in kW and kVA when harmonic filter was switched ON and OFF.

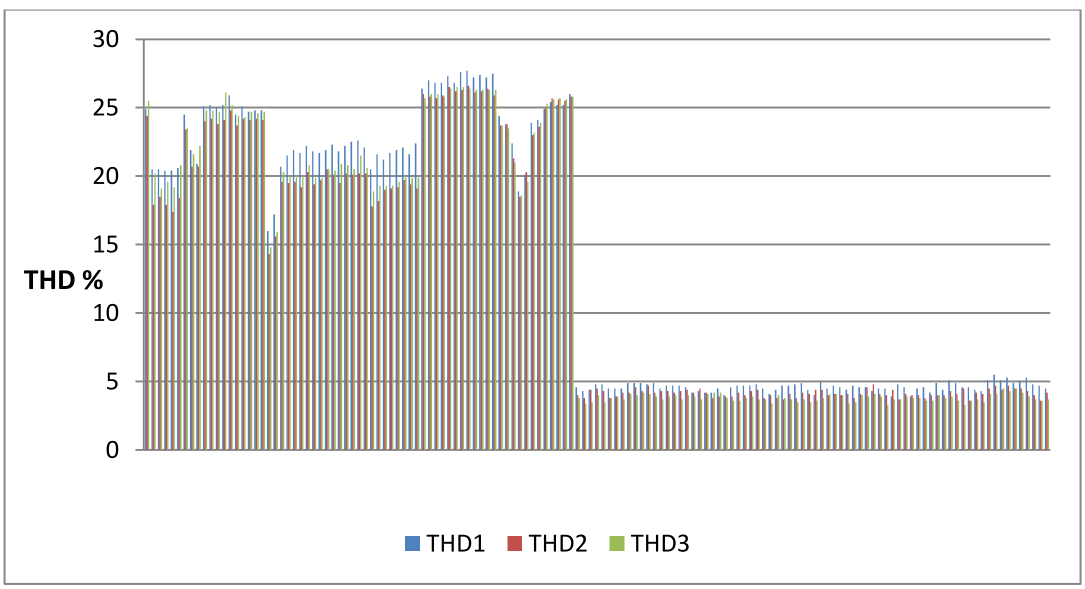


Graph-3 kW and kVA with and without AHF

From the graph it can be seen that in the absence of harmonic filter, average values for both kW and kVA has increased. When active harmonic filter was switched off, average value for load was 149.45kW. As soon as harmonic filter was switched ON, average load came down to 145.5kW. For kVA, average value dropped down to 146kVA from 153.6kVA when harmonic filter was switched ON. The average difference in kW was 3.94kW whereas average difference in kVA was 7.5kVA.

In order to include losses in transformer and overall effect on billing, measurements were carried out on HT of the transformer to find difference in kVA by filtering out harmonics.

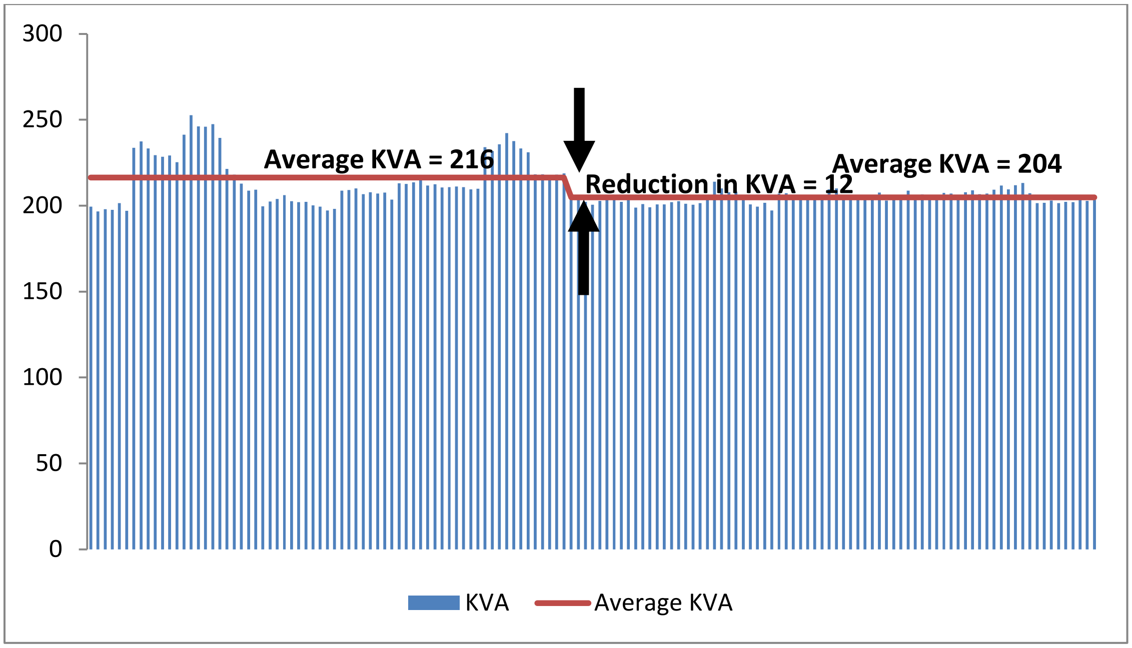
From the graph-4 it can be seen that harmonic content were in the range of 20-25% in the absence of harmonic filter. These measurements also indicate that harmonics were being exported to the grid. The harmonic contents are quite high as prescribed by the limits in IEEE 519.



Graph-4 THD level on HT side of Transformer

From the graph it can be seen that when AHF was switched ON, total current harmonic distortion which were being exported to the grid were reduced. In the absence of AHF, THD current were up to 25% but in the presence of AHF, THD current were reduced to below 5%.

Graph-5 below shows reduction in kVA in the presence of harmonic filter on HT side of the transformer. In the absence of harmonic filter average kVA value was 216 kVA. When harmonic filter was switched ON average recorded kVA value was 204 kVA. In the presence of active harmonic filter demand is reduced by 12 kVA. With energy cost of INR 7.5 per kVAh, annual cost saving by installing harmonic filter at the facility is around 788,400.00 Indian rupees per annum.



Graph-5 kVA on HT side of the transformer

Average reduction in kVA	-	12 kVA
Annual operating hours	-	8760 hours
Unit energy cost	-	INR 7.5 per kVAh
Annual saving	-	INR 788,400.00
Investment	-	INR 750,000.00
Payback	-	1 year

By installing active harmonic filter hospital management gained substantial monetary benefit in terms of reduced electricity charges. In other words it conserved energy. With an investment of around INR 750,000.00, energy charges are reduced by INR 788,400.00. Simple payback period for installation of active harmonic filter was just under one year.

Benefits gained by the hospital

As mentioned above in the measurement based case study, the hospital is getting benefits in following aspects.

1. Reduction in total harmonic distortion being injected in the grid thus avoiding any future penalty levied on THD limits by state electricity Distribution Company.
2. Reduced demand – Demand on transformer is reduced by 12 kVA
3. Reduced kVAh consumption – Monetary saving of INR 788,400.00 per year
4. Reduction in humming noise at the capacitor bank
5. Temperature of transformer was found to be around 45 ^{o}C

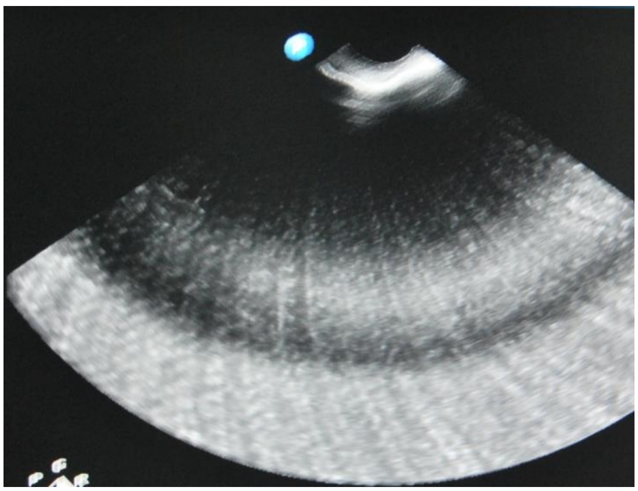
Problem still faced by the Hospital

Problem faced in the ultra sound machine for disturbance on the screen was still present even after installation of active harmonic filter. In order to find possible reason and solution to the problem, some more detailed measurements were carried out. As indicated in the above single line diagram, active harmonic filter was installed at the point of common coupling.

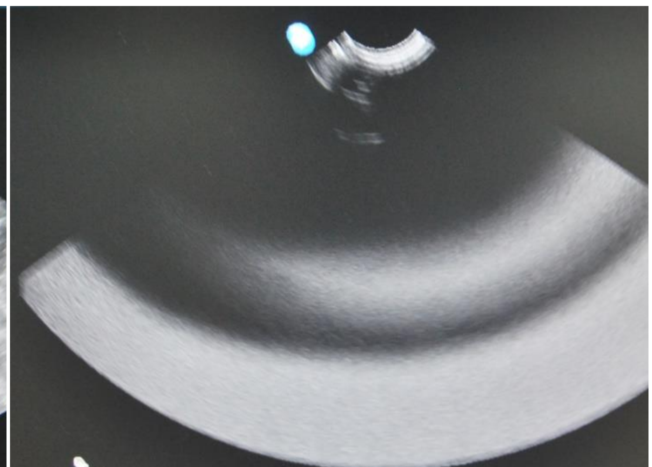
Measurements were carried out at the MCC in the distribution system from which supply to particular ultra sound machine was fed through sub feeders. The load on that particular MCC was hospital equipment like ultrasound machine, lighting load other diagnostic equipment.

The particular ultrasound machine is fed through a single phase supply to a 2 kVA single phase UPS. Output of UPS is connected to the ultra sound machine. The machine is operated on the electricity board supply. There is a disturbance on the screen of the ultra sound machine making diagnostic a bit difficult. Photograph - 1 below shows the disturbance on the screen. When power supply from EB is switched off but the plug of the machine is still in the socket, and ultra sound machine is operated on UPS, the problem persists. When the power supply is switched off and plug was still in the socket, neutral and earth was still connected, hence the circuit was not completely isolated from the main system.

However, when the supply from electricity board is completely isolated by taking out plug from the socket, then image is clear. This is shown in photograph -2. In order to find cause of the problem, measurements were taken from the distribution board till UPS.



Photograph-1: Image quality when supplied through EB power and when supplied through UPS but plug still in socket



Photograph-2: Image quality when supplied through UPS and plug is disconnected from socket

When measurements were taken at the particular MCC feeding the floor on which ultra sound machine is placed, it was found that harmonic content were quite high. Although a harmonic filter is installed, but this filter is only filtering out harmonics from going to the grid. However harmonic current generated by different load are still present in the system and needs to be filtered out from re-circulating in the system. Following graphs shows content of harmonic distortion at the feeder.

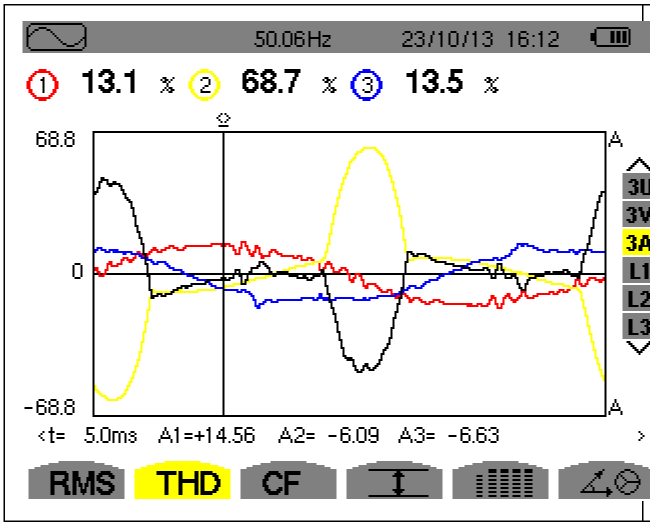


Figure – 7 Total Harmonic Distortion at MCC

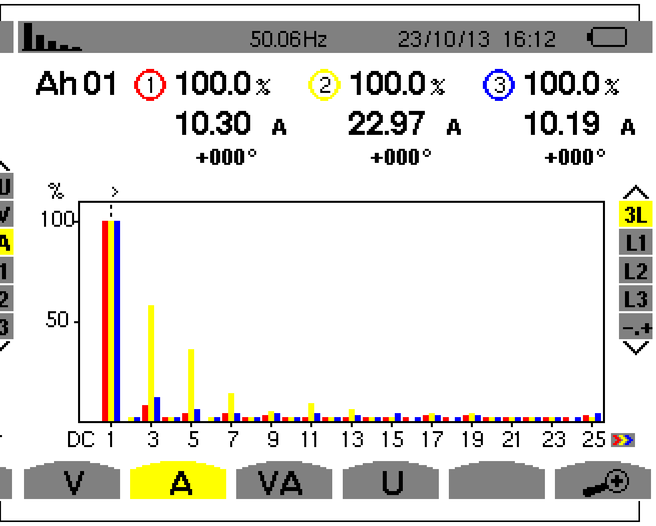
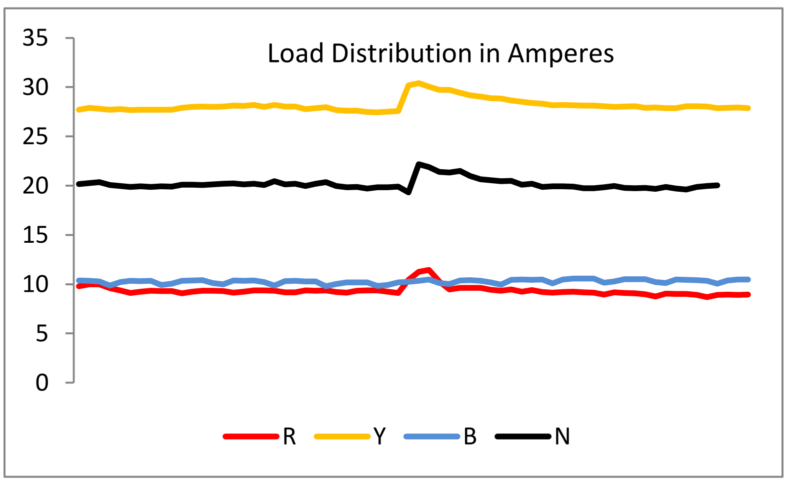


Figure – 8 Harmonic order and content

From the above two figures it can be seen that total harmonic distortion in the Y phase is more than 50%. Also 3rd and 5th orders were predominant harmonics present in the system.



Graph-6 – Load distribution on the floor

Graph-6 shows load in terms of amperes in the particular floor. From the graph it can be seen that:

1. High degree on unbalance in terms of load distribution
2. Current in the neutral quite high

Lighting load was fed through Y phase for that particular floor where as all other loads were fed through remaining two phases.

Due to presence of triplen harmonics and unbalance in the load, current in the neutral is quite high. All neutral conductors in the distribution system were half size. As harmonic current, particularly triplen harmonic has a tendency to flow in the neutral of the conductor; temperature of neutral conductor was high.

High current in neutral will constantly heat up the conductor and can lead to fire. It is recommended to go for a full size neutral conductor..

Measurements were also carried out at the supply of ultra sound machine. Figure-9 shows current in phase (Red colour), neutral (yellow colour) and leakage current (blue). Figure 10 shows current in neutral when switch was switched off but plug was still in the socket, there was flow of current in neutral even when supply was switched off.

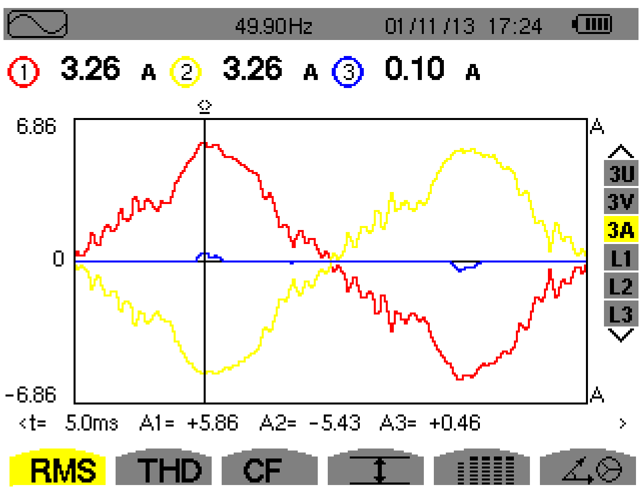


Figure – 9 Current in phase, neutral and leakage

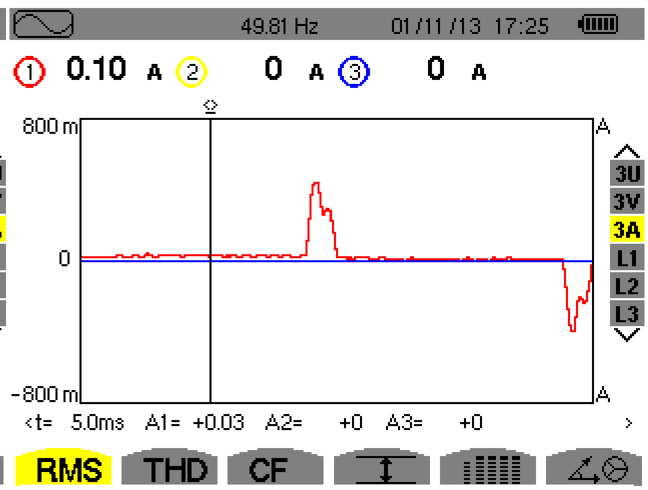


Figure-10 Current in neutral

As there was no protection or mitigation measure adopted to filter out harmonics generated by different loads, some of these harmonics were flowing in the system and rest were going in the upstream of the network to the grid. It is recommended to install an isolation transformer at the incomer of ultra sound machine. Isolation transformer will ensure that electrical noise will not be transferred to the ultrasound machine by creating a floating neutral.

Conclusion

By installing active harmonic filter, the hospital is being benefited by:

1. Reduction in total harmonic distortion being injected in the grid thus avoiding any future penalty levied on THD limits by state electricity distribution company.
2. Reduced demand – Demand on transformer is reduced by 12 kVA
3. Reduced kVAh consumption – Monetary saving of INR 788,400.00 per year
4. Reduction in humming noise at the capacitor bank and its failure
5. Operating Temperature of transformer was found to be around 45 ^{o}C, a healthy condition

However, the problem in the ultrasound machine is not due to harmonics. The problem is due to noise present in the neutral cable and this can be mitigated by isolating neutral using an ultra isolation transformer. The high neutral current if allowed to be persistent can cause fire accidents over time due to deterioration of insulation and eventual failure. This can be addressed by using full size neutral or eliminating triplen harmonics through filters etc that is generally costly compared to over sizing neutral option. The problems arising due to harmonics are taken care by active harmonic filter.

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