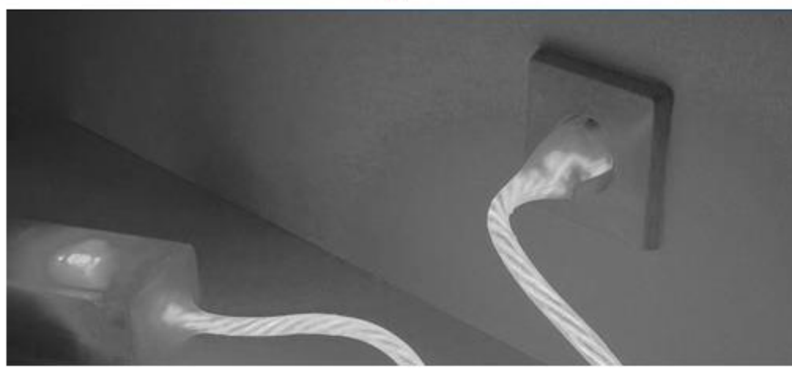
apqi ASIA POWER QUALITY INITIATIVE



A PQ Case Study

CS 37 CEME 14

Mitigation of Harmonic and Reduction in Operating Cost for a Cement Plant

37

Abstract

With rising cost of energy and environmental concerns, energy saving is need of the hour. In order to reduce operating cost installation of variable frequency drive on variable load is proven energy saving measure. VFDs in market are generally based on six pulse rectification topology. Due to the fact that these VFD's convert frequency to change speed, generation of harmonics cannot be avoided. Losses associated with harmonics increases apart from other issues like premature failure of motors, nuisance tripping of circuit breakers are also common. Case study below presents how a cement plant overcame these issues by mitigating harmonics using harmonic filters. The cement plant not only reduced harmonics, but also reduced losses associated with harmonics.

Background

Indian cement industry has both best and worst energy efficiency benchmark in the world today in terms of specific energy consumption per ton of cement. In order to achieve quality and minimum utilization of energy most of the Cement industries are now a day's opting for a variable speed drives to control speed of fans/blowers/pumps. The clinker cooler exhaust fan plays a very critical role in the cement making process. Raw material enters the kiln and is heated to around 1,500 degrees Celsius and in this process it is converted to clinker. The clinker is cooled to 100 degrees Celsius by the clinker cooler fans which blow cooling air through the clinker. By controlling the clinker cooler fan speed, it can be ensured that temperature and pressure in the kiln hood are constant. It does this by regulating the fan speed that draws cold air through the clinker cooler in relation to the hot air that is being drawn through the kiln.

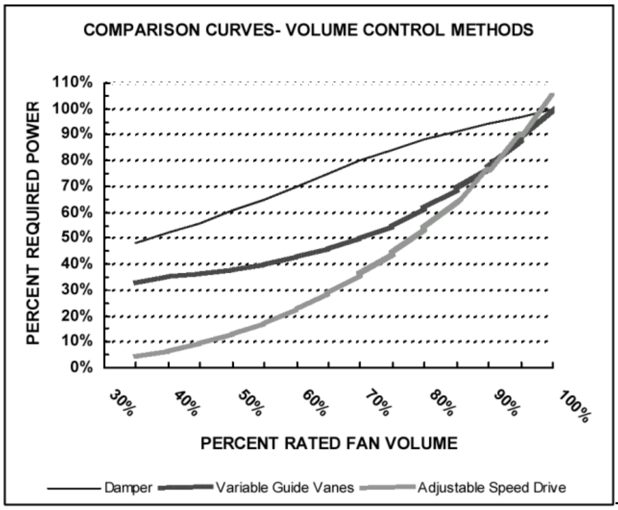
It is very important that proper temperature is maintained in the kiln to ensure the quality of cement. If the temperature is less, poorly burnt low quality clinker will be produced and if temperature is more, it can damage the kiln shell. VFD's are installed on cooler fans to control proper flow of air and constant pressure is maintained inside the kiln. There is always some gap in operating conditions considered for design and actual operating conditions. The plant and all auxiliary equipments including cooler fans are designed to meet peak operating load. However during normal operating hours, maximum production and rated capacity is not utilised. In case of fans flow of air can be controlled by damper or VFD. As per fan laws:

Air Flow α speed - Quantity of air flow is directly proportional to speed

Pressure α Speed^2 – Pressure of air is directly proportional to square of speed

Power Consumption α Speed^3 – Power consumption is proportional to cube of speed

By controlling air flow does not affect speed of the fan. Hence there is not much reduction in energy consumption. However, by reducing fan speed by 10%, air flow volume can be reduced by 10% and energy consumption can be brought down by 27%. Graph-1 shows various methods of controlling air flow and reduction in power consumption.



Graph-1 Volume control methods v/s power consumption
Source: Bureau of Energy Efficiency

It can be seen from the graph that adjustable speed drive or VFD is best available technology in terms of energy efficiency to control output of fan.

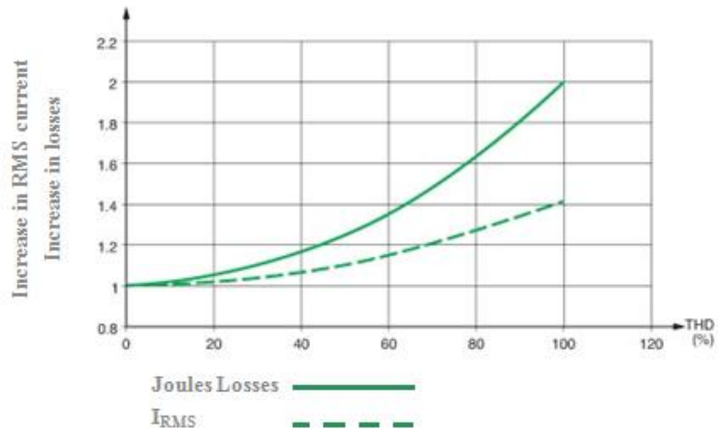
Thus installation of VFD's on cooler fan ensures that desired quality of cement is manufactured with minimum energy. However, in addition to above benefits, variable frequency drives are one of the major devices that generate harmonics. If these harmonics are not filtered out, they can cause various problems in the plant. The problems could be nuisance tripping, failure of motors, increased temperature in transformer windings, and failure of insulation with each failure causing loss in productivity. Apart from loss in productivity, there is also energy loss associated with harmonics. Various kinds of losses due to high harmonic current are described below.

Increased Losses in Conductor:

The active power transmitted through the conductors to the load is a function of RMS value of fundamental current of I1. With increased harmonic current, RMS value of fundamental current also increases which can be given by:

$$I_{rms} = I_1 \times \sqrt{1 + THD^2}$$

Where I_{rms} is RMS value of current inclusive of harmonics and $I_1$is the fundamental current. With presence of current harmonics in the system, there will be rise in RMS value of the current. Rise in RMS value of the current, causing increased heat loss, increases temperature of the conductor, which is also known as joules losses or ohmic losses. The increase in loss as compared to I_{rms} can be illustrated by below graph. As Joules losses are directly proportional to the square of the current, losses increases significantly with any rise in current. Graph-2 shows increase in RMS value of current (Y-axis, increase in RMS value of current and loss) as THDi increases (on x-axis). The graph also shows increase in joules losses with increase in THDi. For 100% THDi, RMS current is 1.4 times the fundamental current where as losses are increased by twice.



Graph-2 Increase in THD v/s Increase in losses / increase in RMS current

Increased Losses in Motors:

Presence of harmonic current can cause over heating in the motor due to higher copper losses. Presence of total voltage harmonic distortion equal to 10%, results in additional losses of 6%

Losses in transformers

Harmonic currents flowing in transformers causes an increase in the “copper” loss due to the Joule effect and increased “iron” losses due to eddy currents. The harmonic voltages are responsible for increased “iron” losses due to hysteresis. It is generally considered that losses in windings increase as the square of the THDi and that core losses increase linearly with the THDv. In distribution transformers, where distortion levels are limited, losses increase between 10 and 15%.

The case study below shows how a cement plant mitigated ill effects caused by VFD’s by installing harmonic filters. The plant not only continued to save energy and achieve consistent product quality by installing VFD, but they also reduced losses due to harmonics generated by VFD’s and avoided loss in productivity due to nuisance tripping and failure of motors.

Facility Description:

The facility under discussion is one of the major cement manufacturing plants with state of the art technology. It has two manufacturing lines and each line has 8 numbers of cooler fans, 4 ESP transformer and raw mill classifier. The facility receives power from state electricity board at 33kV level. In order to maintain quality of the product and optimize energy cost, all the cooler fans in the system were installed with variable frequency drive.

Power Distribution:

Each line is fed through two numbers of transformers 11kV/415V each of 2500KVA rating with loading on each transformer in the range of 50 to 70%. Figure-1 below shows section of single line diagram of the power distribution system to the cooler fans.

The facility receives power supply through state electricity board at 132KV level. The voltage is stepped down using a 132/6.9KV transformer of 35MVA. In order to feed to the lines, voltage is stepped down to 415 volts using 4 numbers of transformers each of 2500 kVA and 6.9/0.415 KV.

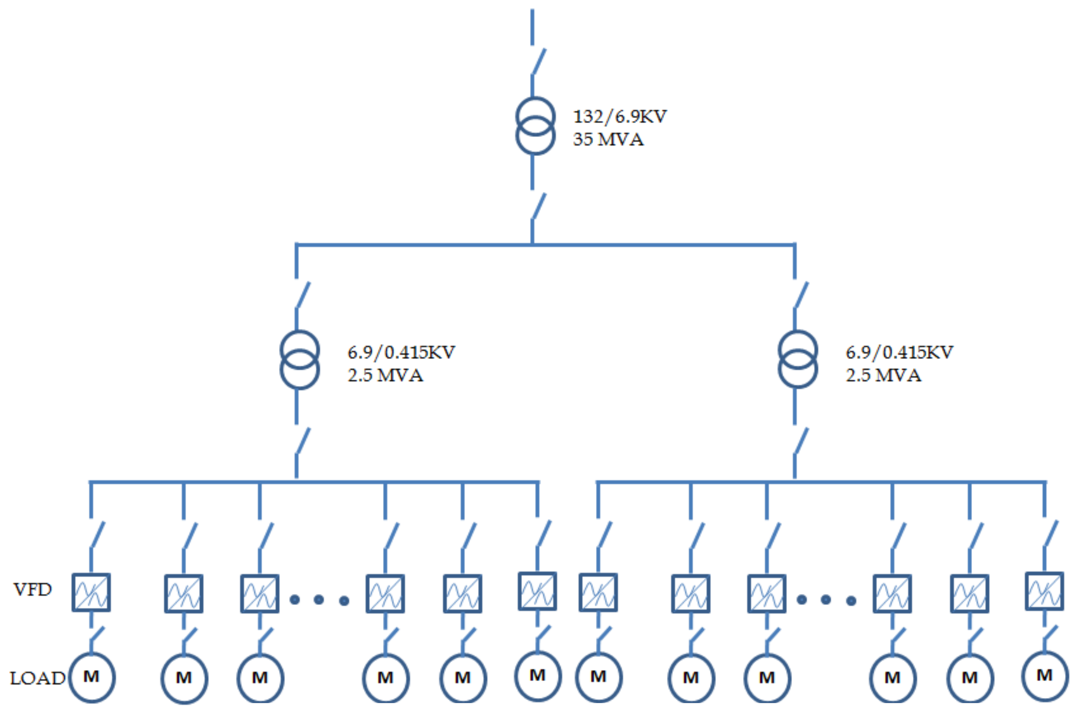


Figure-1 Single Line Diagram

Problems faced by the facility and Solution

In order to control speed of fan to reduce energy consumption and improve productivity and quality, the plant team decided to install variable frequency drives for the cooler fans. After installing variable frequency drives on all cooler fans, plant achieved objective of energy saving and control over quality. However the plant team started facing following problems post installation of VFD’s.

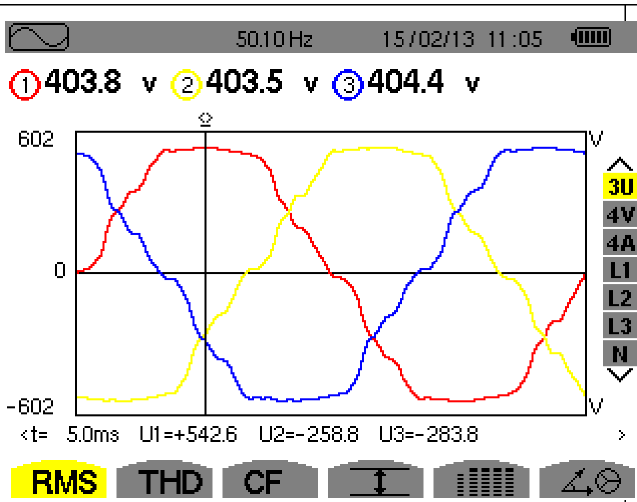
1. Nuisance Tripping of circuit breakers
2. Failure of motor winding due to high temperature.
3. Increased temperature of transformer, though loaded at 27-30% level, windings.

In view of above problems, the plant team decided to carry out power quality study of the plant. A detailed power quality study particularly for harmonics was carried out at the facility. After carrying out power quality study it was observed that both current and voltage harmonics were up to 32.5% and 7.4% respectively. These values are more than the limits specified by IEEE-519 standard. As suggested by the power quality consultant, the cement plant team opted to install active harmonic filters at all locations where they have installed variable frequency drives.

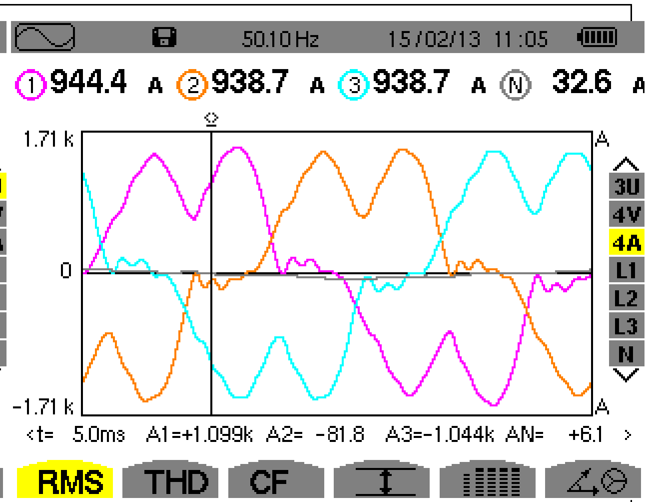
In order to ascertain the benefits gained by installing active harmonic filter, plant team once again carried out measurements at different locations. In order to find difference with and without AHF, all active harmonic filters were kept on bypass mode and measurements for harmonics were carried out. After carrying out measurements at all locations without active harmonic filter in line, measurements were carried out again by taking all active harmonic filters in line. Section below shows summary of measurements and their comparison.

Harmonic measurement at Line – 1 Transformer – 1

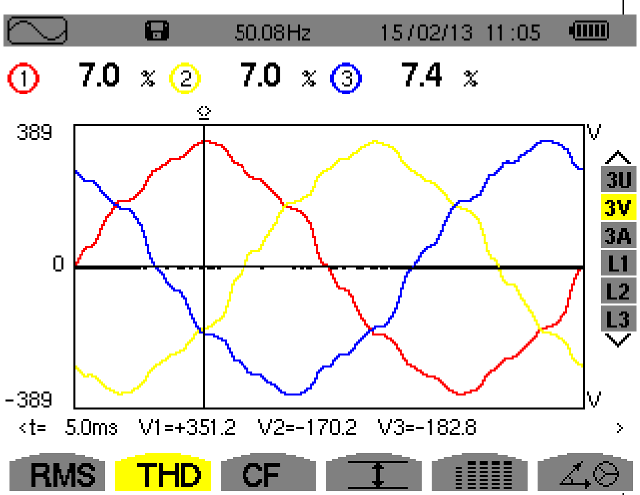
Snapshot 3 and Snapshot 4 shows RMS voltage and current measured at transformer 1 of line 1. Snapshot 5 and Snapshot 6 shows total harmonic distortion for voltage and current respectively.



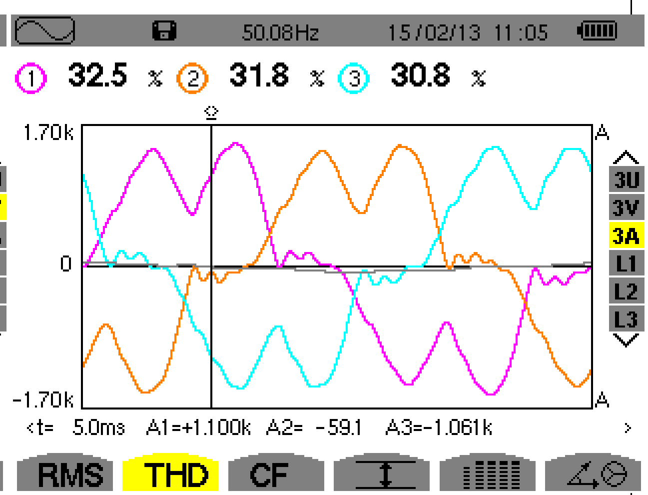
Snapshot-3 RMS Voltage



Snapshot-4 RMS Current



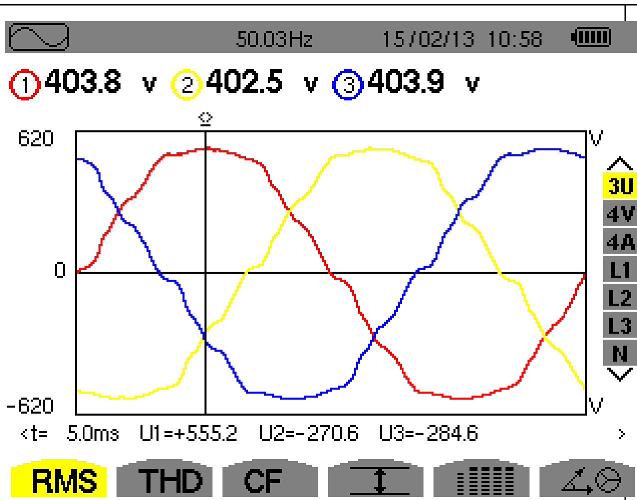
Snapshot-5 Total Harmonic Distortion – Voltage



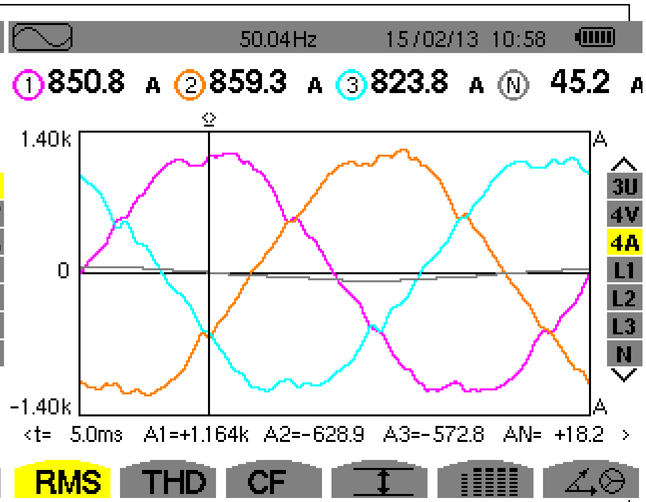
Snapshot-6 Total Harmonic Distortion - Current

From the above snapshot it can be seen that total voltage harmonic distortion were up to 7.4% where as total current harmonics distortions were up to 32.5%. Both these voltage and current harmonic distortion were above permissible limit prescribed by IEEE – 519. It can also be seen that the current waveform is distorted and is no way close to a sinusoidal waveform.

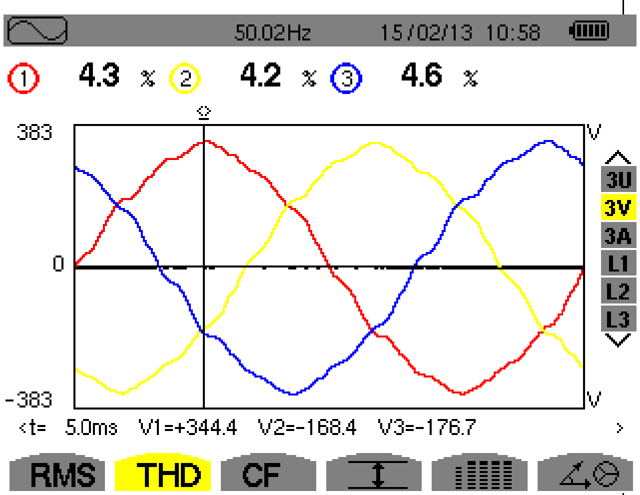
After taking the measurements at the transformer without any harmonic filter all active harmonic filters were taken in to line. Snapshot 7&8 shows RMS value of voltage and current. Snapshot 9&10 shows total harmonic distortion for voltage and current.



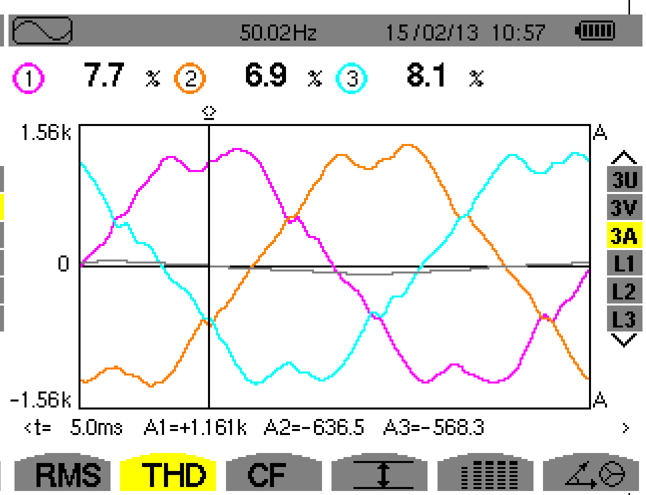
Snapshot-7 RMS Voltage



Snapshot-8 RMS Current



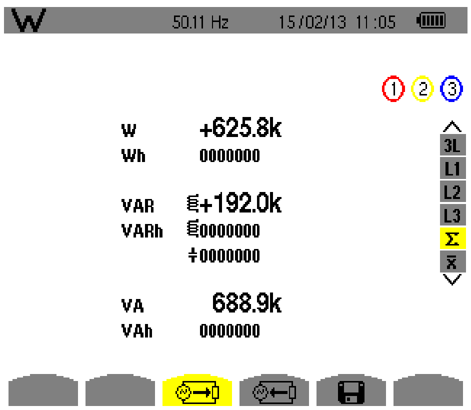
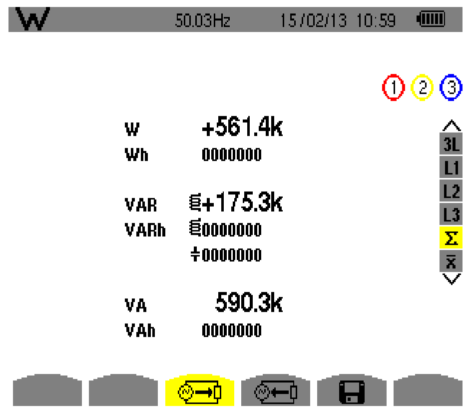
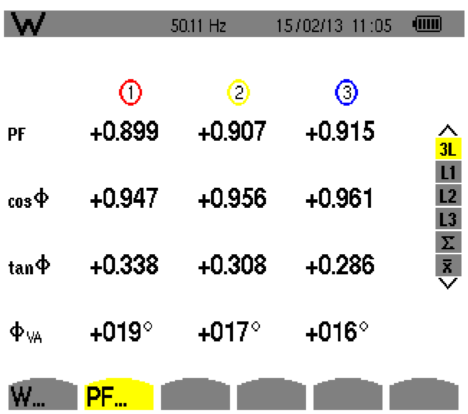
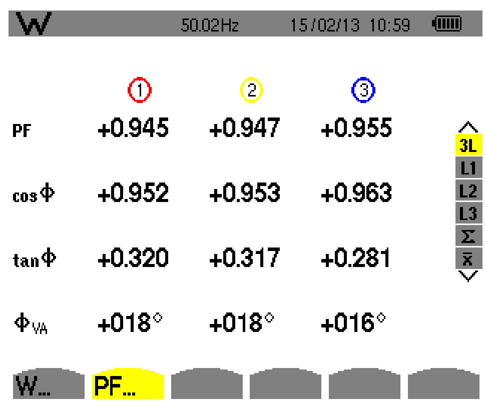
Snapshot-9 Total Harmonic Distortion – Voltage



Snapshot-10 Total Harmonic Distortion – Current

After taking active harmonic filter in line total voltage harmonic distortion were reduced to 4.2 – 4.6 % and current harmonics were reduced to 6.9 – 8.1%. Apart from reduction in harmonics, RMS value of current is also reduced to an average value of 844.6 Amperes from earlier average value of 940.6 Amperes. Apart from parameters mentioned above, power factor and power consumption parameters were also measured. Snapshots below show snapshot 11 of the measurements.

Snapshot – 11 Power and power factor – with and without harmonic filter

Parameter	AHF in bypass mode	AHF in inline
Power Factor		
Power		

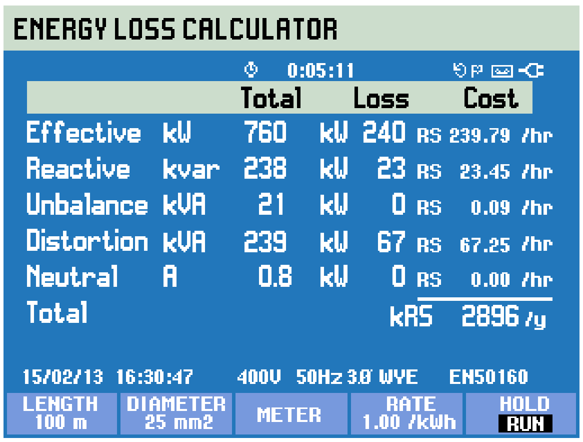
From the above snapshots it can be seen that power factor has improved from average value of 0.9 to an average value of 0.95. Although unity power factor was maintained at PCC level, improvement in power factor at distribution transformer level contributed to reduction in line losses.

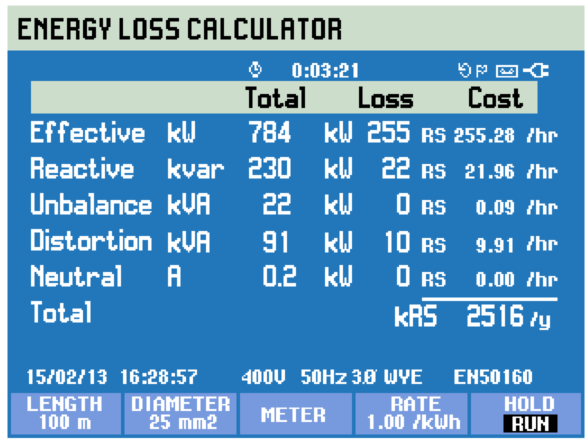
Energy Loss at the site by measurements

From above snap shots it can be seen that after taking active harmonic filter in line and keeping all other operating conditions same power consumption has decreased to 561.4kW from earlier value of 625.8kW. Reduction of power consumption by 64.4kW has substantial financial effect. Reduction of power consumption by 64.4kW has substantial financial impact. With unit cost of INR 6per kWh and 8000 operating hours, monetary saving would be INR 3,091,200.00 annually.

In order to record more realistic saving, all distortion energies were taken in to consideration. As the installed meter used for harmonic measurement has a feature of measuring harmonic distortion energy component and energy loss. Snapshot 12 shows snapshot of energy loss calculator with and without active harmonic filter. Table -2below shows difference in lost energy. As measurements for loss were carried out at different time, reading in power consumption has changed due to change in operating load.

ithout AHF	With AHF





Snapshot 12 Energy Loss with and without AHF

Parameters	AHF OFF	AHF ON	Unit of Measurement
Effective kW	240	255	kW
Reactive kVAr	23	22	kW
Unbalance	0	0	kW
Distortion	67	10	kW
Neutral	0	0	kW
Total	330	287	kW
Saving	43		kW
Cost per kWh	6		INR
Annual kWh saving	344,000.00		kWh
Cost saving per year	2,064,000.00		INR

Table -1 Energy saving

From the table-1 it can be seen that loss due to harmonic distortion is more in case when AHF was on by pass mode as compared to when AHF was in line mode.

On the same above lines measurements were carried out at individual load end and transformer level. Summary of these measurements are shown below in table-2.

Measurements at Line – 1													
	Without AHF						With AHF						Saving Per year – INR
Location	V	I	kW	PF	V THD%	I THD%	V	I	kW	PF	V THD%	I THD%	
Transformer													
Cooler Transformer – 1	404	944	625.8	0.91	7.4	32.5	403	859	561	0.95	4.6	8.1	2,260,080
Cooler Transformer-2	412	1257	802	0.9	8.4	24.2	411	1239	804	0.92	6.5	9.2	1,629,360
Individual Load													
Cooler Fan1	406	230	145.7	0.9	6.8	43	408	219	149	0.96	6	7.4	240,199
Cooler Fan2	402	247	154	0.91	7.4	40.8	401	234	156	0.96	6.2	7.5	173,448
Cooler Fan3	403	254	159.6	0.92	8.7	30.7	404	239	160	0.96	6.2	7.1	315,360
Cooler Fan4	403	216	134	0.91	7.4	42.3	402	206.5	136	0.96	7.1	5.5	187,113
Cooler Fan5	408	211	132.5	0.89	6.6	45.3	407	196.8	134	0.97	6.2	7.6	192,895
Cooler Fan6	404	299	186.5	0.9	8.9	42	401	281	189	0.99	7.9	5.8	210,240
Cooler Fan7	411	300	185.8	0.89	7.2	46.4	411	287	192	0.97	6.2	7.5	404,712
Cooler Fan8	403	190	122.6	0.92	8.7	33.2	403	185	125	0.97	8.2	5.4	198,151
ESP Trans -1	401	15.4	0.893	0.2	7.6	147.8	403	11.1	0.588	0.26	7.4	9.3	-525*
ESP Trans -2	401	58.9	6.11	0.28	8.7	104.4	401	43.4	7.28	0.43	7.8	7.7	8,935
ESP Trans -3	401	57	5.63	0.28	8.9	107	400	43.1	5.95	0.35	8.7	6.4	5,781
ESP Trans-4	400	55.6	5.63	0.27	8.8	107.1	398	40.6	6.51	0.41	8.4	6.4	1,156
Raw Mill Classifier	408	104	55.7	0.74	3.2	88.2	408	85.6	57	0.97	3	8.3	159,256

**For ESP transformer 1 saving was in negative as there was no load on the transformer at the time of measurements.*

Table – 2: *Result of AHF at load and transformer end*

It can be seen from table-3 that at individual load level energy loss is reduced due to lesser harmonic and voltage distortion. Also at transformer level, the losses are reduced due to reduction in no load losses and copper losses.

Cost Benefit Analysis

By installing active harmonic filter plant team successfully mitigated harmonics. In the process of mitigation of harmonics plant team also got benefited by reduced losses in the system due to harmonics. Energy lost in the losses associated with harmonics was saved by the plant team. Table-3 shows cost benefit analysis of the project.

Parameter	Value	UoM
Annual Monetary Saving	5,986,161	INR
Investment	22,000,000	INR
Payback	44.10172	Months

Table-3 – Financial benefit

As shown in table-3, by mitigating harmonics, plant team not only avoided ill effects of the harmonics but also saved energy. Annual energy saving for line 1 is to the tune of INR 5,986,161 per year with investment being paid up in less than 4 years.

Conclusion:

By installing active harmonic filters, the plant team reduced harmonic level by considerable level. This has resulted in overall reduction in RMS value of current, thus reducing line losses temperature. Benefits gained by the plant can be summarized as:

- Monetary benefit of around 5,986,161.00 per year
- Reduction in RMS Current
- Resulting in Reduction in kVA , this will lower the Electricity bill towards lesser kVA demand & lesser kVAh .
- Reduction in losses at motors, distribution system and transformers giving direct energy savings.

- Avoided any nuisance tripping of circuit breaker
- Reduction in Failure rate of sensitive electronics, lesser production Downtime & lesser production Waste.
- Improved efficiency of transformer as load losses is reduced.

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Mr. Sunil Kumar S. K. completed his electrical engineering from Bangalore University in the year 1990. Mr. Kumar has around 22 years of experience with rich and versatile experience in power quality management and mitigation of power quality issues. He is successfully completed various projects related to power quality in the sectors like cement, hospitals, pharmaceutical and metro. Mr. Sunil Kumar is currently working as Business Development Manager and heading Indian operations of Schaffner Emc Pte Ltd., Singapore.

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