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Reduction in Harmonics in Marble Industry

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Abstract: Lower order harmonic are major problems in industries in India. This will get worse due to the increasing number of lagging power factor induction motors and harmonic generated non linear loads. During survey of Udaipur, Rajasthan (India) investigator found the poor condition of power quality in large number of marble, soft stone and minerals industries and took one marble industry for investigation of the power quality due to harmonic content in power supply. After measurement in Arihant Marble industry, Udaipur, Rajasthan (India), the investigator found that the 5th harmonic content was beyond the IEEE limits. Investigator then design the harmonic filter at Hercules Controls Panel Pvt. Ltd. Udaipur, Rajasthan (India), after installation of harmonic filter at Arihant Marble Industry and measurement were done again and found that 5th harmonic content was below IEEE limits. Investigator also calculate the kVA saving.

***Index Terms*—**Harmonic Reduction, Passive Harmonic Filter, Marble / Soft stone Industry.

I. INTRODUCTION

Highest power tariffs is paid by Indian industry in the world and the gap between supply and demand is expanding leading to poor quality and lower quantity of power resulting in loss of production and profits[2]. Unfortunately, in India, there is very less awareness of low power factor and harmonic pollution and the available solutions to curtail down it. “Poor power factor” was considered as the only parameter to measure the efficiency of electrical system in earlier days and hence, traditionally, more emphasis was given on the solutions to improve the power factor. The incentive schemes and imposition of penalty for maintaining the PF by Electricity Board’s has drawn user’s attention toward the PF improvement. But only PF improvement does not compete the challenge posed by high percentage of harmonics getting injected into the supply. Thus there is large need of energy saving in electrical systems i.e. there is need to improve system power quality for several different benefits like reducing peak kW billing demand ,increased system capacity, reduced system losses in electrical system, increased voltage level in electrical system and cooler, more efficient motors.

Harmonic: Power quality has caused a great concern to electrical system with the increasing use of sensitive and susceptive electronic and computing equipments and all nonlinear loads. The results are generation of harmonics. High level of harmonic distortion can create stress and resultant problems for the utility's distribution system, the plant's distribution system, as well as the plants equipments. .In electrical engineering harmonics are described as follows as per IEEE 1159-1995.[4]

The Total Harmonic Distortion (THD) is a measure of the effective value of harmonic distortion

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$$THD(\%) = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots\ldots\ldots\ldots + I_n^2}}{I_1} \times 100\%$$

Where: THD is the total harmonic distortion of the waveform in %,

I_1 is the magnitude of the fundamental component and

I_2, I_3, I_4 is the magnitude of the 2nd, 3rd 4th harmonic components.

Marble and soft stone industries are the largest consumers of electricity (approximately 60%) of the total industrial consumption of electricity of Udaipur, Rajasthan (India). Marble and soft stone industry has very poor power factor (0.4 to 0 .8) and they were penalized for that by Rajasthan State Electricity Board along with poor quality of power. Recently some industries used manually operated capacitor banks which are not effective and sufficient. Also a marble and soft stone industry uses non linear loads and various electronics loads which further degraded the quality of power supply by harmonic generation. That is why harmonic reduction is required.

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II. ENERGY SAVING TECHNIQUES

In the areas for improvement in electrical systems resulting in energy conservation/saving are:

(i) Power factor management
(ii) Demand side management.
(iii) Improvement in quality of power (Reduction in harmonics).

III. METHODS FOR REDUCTION OF HARMONIC DISTORTION

One of the ways to resolve the issue of harmonics would be using filters in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. With the increase of nonlinear loads in the power system, more and more filters are required. There are two types of filters (i) Passive Filters (ii) Active Filters.[6] [12] Inductors and Capacitors are commonly used in the active and passive filters for harmonics reduction. The passive filters are used in order to protect the power system by restricting the harmonic current to enter the power system by providing a low impedance path. Passive filters consist of resistors, inductors and capacitors. The active filters are mostly used in distribution networks for elimination/reduction of problem like sagging in voltage and flickering, where there are harmonics in current and voltages, etc. There is also a third type of filter which is used i.e. the hybrid filter. Hybrid filters are composed of the passive and active filters both. [2]

IV. DESIGN OF A PASSIVE HARMONIC FILTER (PHF)

A harmonic filter essentially consists of a power capacitor, a tuning reactor and its control gear. It will act in parallel with an untuned basic power factor improvement capacitor bank. For the designing purpose investigator collected some datas such as load details, existing power factor, required new power factor, total harmonic distortion, individual harmonic details etc. This data can be obtained from a harmonic analyzer.

Harmonic Filter Design

Step-A: Investigator measured the electrical data of Arihant Marble with the help of energy meter and harmonic analyzer as follows:

a) Energy meter data:

Data was measured from the energy meter installed at Arihant Marble Pvt. LTD. Udaipur. From table 1 the maximum demand in HP = 57Hp, the maximum demand in kW = 53.15 kW, and Maximum load current =119.26 A.Design of harmonic filter is done at 30% of the load (kW)

Load in kW = 30% of 53.15 kW
=16 kW

Lowest Power factor measured = 0.60 lag

TABLE.I

Electrical Data of Marble Industry

S.No	Parameters	Value
1	Total load(HP)	57
2	Total load(KW)	53.15
3	Average monthly PF	0.79
4	Maximum load current	119.26 A

b) Data obtained from Harmonic Analyzer at 30% load:

Total harmonic current in power supply system THD = 5.6 A

5th harmonic current = 8.0 A----------------------------- (3)

During measurement investigators found that only 5th order harmonic was beyond the limit of harmonic and other orders were under limits.

Step-B Assuming required power factor to be 0.99, calculate the total kVAR required to raise the power factor from 0.60 to 0.99.

kVAR required = kW ($\tan Ø_1 - \tan Ø_2$) ---------------------- (4)

Lowest power factor $\cos Ø_1$ = 0.60 ∴ $\tan Ø_1$ = 1.333

Required power factor CosØ 2 = 0.99 ∴ tanØ 2 = 0.142

kVAR required = 16 (1.333 - 0.142) = 20 kVAR.

Thus 20 kVAR capacitor required to raise the power factor to 0.99. It can be seen that, ITHD is 5.6 but maximum harmonic current distortion as recommended by IEEE specifications C-519-1992 is = 4.0.

Out of 20 kVAR calculated from equation (4) to be installed we employ 30% kVAR towards filter duty and remaining kVAR for power factor correction. (Thumb rule).

Filter kVAR= 30% of 20 kVAR = 6 kVAR.

Step-C Design of filter: Investigators decided to design passive shunt harmonic filter. A 3-phase passive filter consists of 3 reactors and 3 capacitors in which capacitors are connected in star. Investigators have to calculate the reactor and capacitor value in mH/phase and µF/phase and also in kVAR value. For designing of reactor, investigator calculates the condition of resonance. Since investigator found during measurement of harmonic content, 5th harmonic level beyond the IEEE standard. Thus calculation of capacitive reactance at 5th harmonic frequency (5x50=250Hz) at resonance was done.

Inductive Reactance at 50Hz $X_{C50} = 1/2\pi fC = 1/2\pi \times 50 \times C$

Inductive Reactance at 250Hz $X_{C250} = 1/2\pi fC = 1/2\pi \times 250 \times C$

Using above two relation

$X_{C250} = X_{C50}/ 5$ ------------------------------------- (5)

For X_{C250}, first investigators calculated the capacitive reactance at 50Hz where

$X_{C50} = 1/2\pi fC$ -- (6)

Step-1 Capacitance per phase: For above relation capacitor value in µF/phase is required thus investigators using the following relation

kVAR per phase = $(kV^2 \times 2\pi fC \times 10^{-3})$

$C = \text{kVAR per phase}/ (kV^2 \times 2\pi f \times 10^{-3})$ ------------ (7)

Where kVAR per phase = kVAR for 3-phase/ No. of phase = 6/3 = 2kVAR

$kV_{ph} = kV_{line}/\sqrt{3} = 0.415/1.732 = 0.230$ kV

Capacitor C becomes using equation (7)

$C = 2/ (0.2309)^2 \times 2 \times 3.14 \times 50 \times 10^{-3} = 111.50$ µF /Ph.

Step-2 capacitive reactance at 50Hz: capacitor value obtained in step-1, calculated the capacitive reactance at 50Hz frequency using equation (6)

$X_{C50} = 1/ (2 \times 3.14 \times 50 \times 111.50 \times 10^{-6}) = 28.562\Omega$/Ph.

Step-3 capacitive reactance at 250Hz: Since only 5th order harmonic are beyond the limits of harmonic thus investigators calculated the capacitive reactance at 250Hz (5 X 50Hz) using equation (5)

$X_{C250} = X_{C50}/ 5 = 28.562 /5 = 5.712\ \Omega$ /Ph.

Step-4 Calculation of inductor: For resonance at 5th harmonic we should have,

$X_{L250} = X_{C250}$ --- (8)

$X_{L250} = 5.712\ \Omega$ /Ph.

Investigators calculated the inductive reactance at 50Hz using following relation

$X_{L50} = X_{L250}/5 = 5.712/5 = 1.142\ \Omega$ /Ph. ---------------- (9)

From equation (9) inductive reactance at 50Hz, calculated the value of inductance from following relation by putting the value of inductance obtained in step- 4.

$X_{L50} = 2\pi f L$

$L = X_{L50}/2\pi = 1.142/314 = 3.6$mH---------------------- (10)

After calculated the values of inductor, Investigators calculated the values of inductor in terms of kVAR.

Step-5 kVAR rating of Reactor: kVAR of inductor calculated by following relation kVAR $=V_L \times I_{RMS}$--------------------------------------- (11)

Where V_L = Voltage across reactor and given by relation

$V_L=V_{L50} + V_{L250}$--- (12) and

I_{RMS}= Resultant rms current due to fundamental and 5th order harmonics and given by following relation

$I_{RMS} = [I_{50})^2 + (I_{250})^2]^{½}$ ------------------------------------ (13)

(a) V_{L50} = Voltage drop across reactor due to fundamental Current and is given by following relations

$V_{L50} = I_{C50} \times X_{L50}$---------------------------------- (14)

Where I_{C50} = Capacitor current at 50 Hz and is calculated by following expression

I_{C50} = kVAR/ (1.732 x line voltage) ----------------------- (15)

= 20/ (1.732 x 0.415) = 27.82 Amp

Putting the value of I_{C50} from equation (15) and value of X_{L50} from equation (9) in equation (14)

$V_{L50} = I_{50} \times X_{L50}$

= 27.82 x 1.142 = 31.77 V. -------------------------- (16)

(b) V_{L250} = Voltage drop across reactor due to 5th harmonic current and is obtained by relation

$V_{L250} = I_{250} \times X_{L250}$ --- (17)

Where I_{250} = current at 250Hz and X_{L250} is Inductive reactance at 250Hz. Putting the value of I_{250} from equation (3) and value of $X_{L\ 250}$ from equation (8) in equation (17)

V_{L250} = 8.0 x 5.712 = 45.696V. ------------------------- (18)

Putting the value of V_{L50} from equation (16) and value of V_{L250} from equation (18) in equation (12)

$V_L= V_{L50} + V_{L250}$

= 31.77+45.69 = 77.466 Say 78 V. ------------- (19)

(c) RMS current:- For calculating the resultant rms current due to fundamental and 5th order harmonic, putting the value of current at 50Hz from equation (15) and value of current at 250Hz = 8 Amp from equation (3) in equation (13)

$I_{RMS}= [(27.82)^2 + (8)^2]^{½}$ = 28.94Amp. ------------------- (20)

kVAR rating of Reactor: For kVAR rating of reactor, putting the values of V_L from equation (19) and values of IRMS from equation (20) in equation (11)

kVAR $= V_L \times I_{RMS}$ = 78 x 28.96

= 2243.41 VAR/Ph. = 2.243kVAR/Ph ------------------ (21)

kVAR rating of capacitor. As per maximum demand of plant, investigator found the total value of capacitor was 20 kVAR. Out of 20 kVAR, 6 kVAR were used in filter and remaining was used in P.F correction. Thus 6kVAR was used for 3 phase i.e 2 kVAR/phase was used in harmonic filter. The voltage rating of capacitor was calculated as follows.

$V_C = V_{C50} + V_{C250}$ --- (22)

Where V_{C50} (Phase) = Line voltage/√3

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= 415/1.732= 239.6 V. ------------ (23)

V_{C250} = I_{250} x X_{C250}

= 8 X 5.712. (From equation (3) and step 3)

= 45.696V. -- (24)

Total voltage across capacitor $V_C = V_{C50} + V_{C250}$

= 239.6+45.696 (From equation (23) and (24)

= 285.296 V (ph voltage) = 494.13 V (line voltage) = 500 V

After designing the harmonic filter, the fabrication of the harmonic filter has been done at Hercules panel Pvt. Ltd. Udaipur (India).

V. INSTALLATION OF HARMONIC FILTER AND MEASUREMENT

During the measurement of harmonic content in supply system using harmonic analyzer, investigator found that only 5th order of harmonic is beyond the limit of harmonic as per IEEE specifications C-519-1992 and limit is 4%. To reduce the 5th harmonic content, above 5th order harmonic filter was installed and again measurement was done by harmonic analyzer. Investigator tabulated all lower order harmonic values with and without filter shown in Table 4 and graphically in fig.I

VI. RESULTS OF HARMONIC MEASUREMENT

The following observations were made:
(1) Input current reduced from 52 to 44 A / Ph
(2) kVA demand reduced from 50.51 to 43.18
(3) Input PF is improved from 0.79 to 0.85
(4) 5th harmonic level is reduced from 7.1% THD to 3.5% THD.

VII. CONCLUSION

From installation of harmonic filter at Arihant Marble Industry following conclusions were made:
(1) The 5th harmonic component was found 3.5%.
(2) The line current and the line losses were reduced and heating of cables were avoided.
(3) Harmonic filter improved the supply voltage waveform
(4) The overall efficiency of the plant increases and overall maintenance cost of plant reduces.
(5) Noise, EMI and RFI in the plant are eliminated.
(6) Generator and transformer heating issues were resolve.

TABLE II
Measured Harmonics by Harmonic Analyzer

S.No.	Order of Harmonics	Harmonics in % without filter	Harmonic in % with filter
1	5th	7.1	3.5
2	7th	2.5	2.5
3	9th	3.5	3.5
4	11th	2.5	2.5

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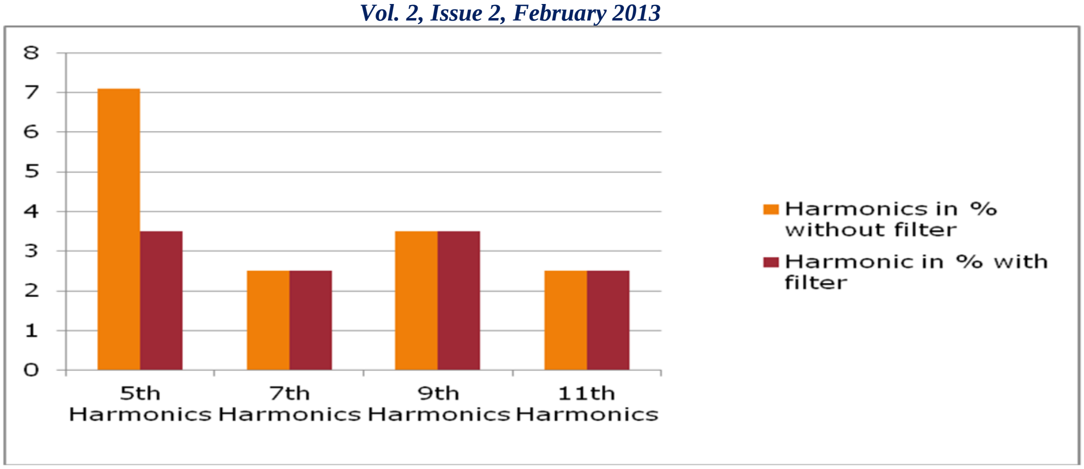

Fig. I Variation of Different Harmonic Order

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Biography

Mr. Prakash Sundaram is presently working as Assistant Professor and Head, Electrical Engineering Department, Vidya Bhawan Polytechnic College, Udaipur (Rajasthan). He has 20 years of experience out of which 17½ years are of teaching and 2½ year is of Industrial. Mr. Prakash Sundaram earned his AMIE Degree in Electrical Engineering from The Institution of Engineers (India), Kolkata. And pursing his Master of Instrumentation and Control from Electrical Engineering Department, NITTTR Chandigarh. Up till now he has guided more than 50 students for Polytechnic. He has 3 Research Articles to her credit. His areas of specialization are Energy Management, Non conventional Energy sources and Electrical Machines etc.

Mrs Shimi S.L is presently working as Assistant Professor, Electrical Engineering Department, and NITTTR Chandigarh. She has 10 years of experience out of which 9 years are of teaching and 1 year is of Industrial. Mrs. Shimi S.L earned her Bachelor of Electrical and Electronics Engineering from J.J College of Engineering and Technology, Trichy, Tamil Nadu and Master of Power Electronics and Drives from Saranathan College of Engineering, Trichy, Tamil Nadu and pursing her Ph.D from PEC University of Technology, Chandigarh. Up till now she has guided more than 20 students for BE and 10 students for Masters Degree. She has more than 25 Research Articles to her credit. Her areas of specialization are Power Electronics, Digital Electronics, ANN, Fuzzy, ANFIS etc. Mrs. Shimi S.L is a Member of IEEE (USA).

Dr. S. Chatterji is presently working as a Professor and Head, Electrical Engineering Department, NITTTR Chandigarh. He has 37½ years of experience out of which 35½ years are of teaching and 2 years are of Industrial. Dr.S.Chatterji earned his Bachelor of Electrical Engineering from Bhopal University, Master of Electrical Engineering from Allahabad University and Ph.D from Panjab University, Chandigarh. Up till now he has guided more than 100 students for Masters Degree and 10 students for Ph.D. He has more than 150 Research Articles to his credit. He has also authored 3 books in the field of Electronics, 4 Lab Manuals in Electrical and has produced a series of 21 Video films in Power Electronics. His areas of specialization are Power Electronics, Digital Electronics, Electrical Power, ANN, Fuzzy logic applications, Soft Computing Techniques etc. Dr.S.Chatterji is a Fellow member of Institution of Engineers (India), Member of IEEE (USA) and Life member of ISTE. He is also a adjunct professor of Instrumentation and Control, Manipal University. He is also a member of BOS for large number of Universities.