HARMONIC STUDY OF VFDS AND FILTER DESIGN: A CASE STUDY FOR SUGAR INDUSTRY WITH COGENERATION

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ABSTRACT
In majority of Sugar Industries, to achieve better efficiency of power, VFDs are extensively used. Initially D.C. Drives were used, but now these are slowly getting phased out and are replaced by A.C. Drives .In a case study of Harmonic Analysis of SAMARTH CO-OPERATIVE SUGAR FACTORY, ANKUSH NAGAR, MAHAKALA, JALNA it is commonly seen perception that, latest technology A.C. drives are having in built harmonic filters and hence do not produce harmonics / produce harmonics within prescribed tolerance limit. Because of variation in load pattern these drives still produce harmonics, which must be suppressed by using appropriate Harmonic Filter, otherwise it may result into malfunction of sensitive devices. It is more essential to suppress these harmonics, for SAMARTH CO-OPERATIVE SUGAR FACTORY, ANKUSH NAGAR, MAHAKALA, JALNA, as Sugar Industry has grid connected Cogeneration plant. The suggested method of filter design gives better result, reduces harmonic level (5th harmonics) to almost 10A from 154A. The values of load Kw, P.F., Voltage, current load inductance, capacitance, resistance are derived from average of readings actually available from site.

KEYWORDS: *Passive Harmonic Filter, Tuned Frequency, Cable Impedance.*

I. INTRODUCTION

In Co-generation Sugar Mills, Reduction in, specific power consumption increases power revenue by about Rs. 3 per ton cane [1]. In a sugar mill, one of the method of increasing power efficiency is to replace smaller low efficiency (25-30 %) mill turbines by better efficiency drives such as AC motors. Multistage steam turbines can operate at efficiency of 65-70 %. Hence equivalent quantity of steam saved by installation of AC motors, DC motor, Hydraulic drives can be passed through power turbines to generate additional power [2].

Modern Drive manufacturer proved the line reactor with the A.C. Drives only, but these line reactors produce high Voltage drop and does not provide the expected filtrations of harmonics. It is common perception among industries that these line reactors, use the harmonic filter and hence these Drives do not produce or produce harmonics within to tolerance limit. Because of variation harmonics, which must be supposed by Harmonic Filters otherwise it may result into malfunction of sensitive equipments. It is more essential to suppress these harmonics in case the Sugar Industry has the grid interconnected cogeneration power plant.

This paper discuss the case study of Harmonic Analysis of SAMARTH CO-OPERATIVE SUGAR FACTORY, ANKUSH NAGAR, MAHAKALA, JALNA, which confirms the presence of very high amount of harmonic current and the necessity of proper harmonic filter.

The organization of this paper is as follows

- In section II – The methodology of the case study is discussed
- In section III – The actual readings taken during the case study are presented
- In section IV – The filter design as per recommended method is explained

- In section V – The result of the installation of filter simulated with the help of matlab program is discussed.
- In section VI – The interpretation of the case study and the results derived is discussed as Conclusion
- In section VII – The future scope in the same research area of harmonic filter design for the Sugar Industry based co-generation plant is presented.

II. METHODOLOGY OF CASE STUDY

For the case study of harmonic analysis of SAMARTH CO-OPERATIVE SUGAR FACTORY, ANKUSH NAGAR, MAHAKALA, JALNA the methodology adopted is as follows

Initially the walk – in – audit of the entire plant was done.

The probable sources of generation of harmonics were identified, VFDs were came out as most probable sources of harmonics generation.

To confirm the current harmonics content generated by the VFDs, reading were taken for two VFDs for a time cycle of ten minutes each with the help of power quality analyser. [3]

Out of this two, the one which was generating more harmonic current was taken for the case study and case study is presented as below

III. CASE STUDY (ACTUAL READING)

An A.C. DRIVE OF 300 kW 3-Φ INDUCTION MILL DRIVE MOTOR

SAMARTH CO-OPERATIVE SUGAR FACTORY, ANKUSH NAGAR, MAHAKALA, JALNA

The Actual readings are kW consumed 261 kW.

Avg. Line Current = 406 A

P.F. = 0.88

Current Harmonics

I (h1) – 368.88 A I (h2) – 2.06 A

I (h3) – 28.363 A I (h4) - 0 A

I (h5) – 154.03 A I (h6) – 0 A

I (h7) - 59.543 A I (h8) – 0 A

I (h9) – 4.483 A I (h10) – 0 A

I (h11) – 26.33 A

Table 1 : R Current Harmonics

TIME	I1(01)	I1(02)	I1(03)	I1(04)	I1(05)	I1(07)	I1(09)	I1(11)	THDF_I1(%)
15:54:40	351.00	0.00	19.00	0.00	148.00	47.00	4.00	30.00	45.60
15:55:40	329.00	0.00	21.00	0.00	137.00	51.00	0.00	24.00	46.00
15:56:40	282.00	0.00	17.00	0.00	136.00	61.00	0.00	25.00	54.30
15:57:40	480.00	5.00	20.00	0.00	183.00	49.00	3.00	31.00	40.80
15:58:40	338.00	5.00	19.00	0.00	149.00	57.00	0.00	27.00	48.60
15:59:40	397.00	4.00	17.00	0.00	165.00	57.00	0.00	29.00	45.10
16:00:40	393.00	5.00	22.00	0.00	173.00	67.00	0.00	33.00	48.50
16:01:40	373.00	0.00	21.00	0.00	161.00	62.00	4.00	33.00	48.10
16:02:40	340.00	0.00	17.00	0.00	153.00	62.00	0.00	24.00	49.80
16:03:40	202.00	0.00	23.00	0.00	117.00	63.00	5.00	19.00	68.20
16:04:40	330.00	4.00	21.00	0.00	152.00	62.00	4.00	26.00	51.10

Table 2 : Y Current Harmonics

TIME	I2(01)	I2(02)	I2(03)	I2(04)	I2(05)	I2(07)	I2(09)	I2(11)	THDF_I2(%)
15:54:40	402.00	0.00	31.00	0.00	144.00	51.00	4.00	26.00	39.80
15:55:40	378.00	0.00	27.00	0.00	137.00	55.00	4.00	20.00	40.70
15:56:40	325.00	0.00	24.00	0.00	134.00	63.00	4.00	21.00	47.10
15:57:40	532.00	5.00	30.00	0.00	177.00	52.00	6.00	26.00	36.00
15:58:40	386.00	4.00	28.00	0.00	148.00	62.00	6.00	24.00	42.80
15:59:40	442.00	6.00	25.00	0.00	162.00	59.00	5.00	25.00	40.20
16:00:40	441.00	4.00	26.00	0.00	168.00	70.00	5.00	28.00	42.50
16:01:40	416.00	4.00	23.00	0.00	160.00	64.00	4.00	30.00	42.80
16:02:40	384.00	0.00	26.00	0.00	152.00	64.00	4.00	21.00	44.20
16:03:40	244.00	4.00	19.00	0.00	121.00	68.00	0.00	18.00	59.00
16:04:40	378.00	4.00	26.00	0.00	151.00	65.00	4.00	23.00	44.70

Table 3 : B Current Harmonics

TIME	I3(01)	I3(02)	I3(03)	I3(04)	I3(05)	I3(07)	I3(09)	I3(11)	THDF_I3(%)
15:54:40	377.00	0.00	41.00	0.00	155.00	49.00	8.00	30.00	45.80
15:55:40	349.00	0.00	42.00	0.00	146.00	54.00	7.00	25.00	47.30
15:56:40	301.00	0.00	35.00	0.00	144.00	63.00	7.00	26.00	54.60
15:57:40	503.00	0.00	44.00	0.00	190.00	49.00	9.00	32.00	41.00
15:58:40	361.00	0.00	40.00	0.00	157.00	59.00	8.00	28.00	48.80
15:59:40	416.00	4.00	38.00	0.00	172.00	57.00	8.00	29.00	45.40
16:00:40	412.00	0.00	40.00	0.00	178.00	68.00	7.00	32.00	48.20
16:01:40	387.00	5.00	38.00	0.00	168.00	63.00	7.00	33.00	48.60
16:02:40	361.00	0.00	39.00	0.00	160.00	63.00	7.00	24.00	49.70
16:03:40	213.00	0.00	36.00	0.00	126.00	66.00	6.00	21.00	70.50
16:04:40	350.00	5.00	41.00	0.00	159.00	63.00	8.00	26.00	51.30

Table 4 : The impedance from Generator to Mill – Motor

Sr.	**Cable size**	**R + j X L (Ω□k/m)**	**Length**	**Impedance / Length**	**No. of Runs**	**Total**
1	120 sq mm (L.T.)	0.3050 + j 0.0744	25	0.00762 + j 0.00185	4	0.0019 + j 0.00046
2	300 sq mm (L.T.)	0.1220 + j 0.0732	15	0.00183 + j 0.00109	10	0.00018 + j 0.00019
3	400 sq mm (H.C.)	0.10 + j 0.099	25	0.0025 + j 0.00247	1	0.0025 + j 0.00247
4	Transformer	0 + j 0.00338				0 + j 0.00338
5	Turbine	j 0.5377				0 + j 0 . 5377

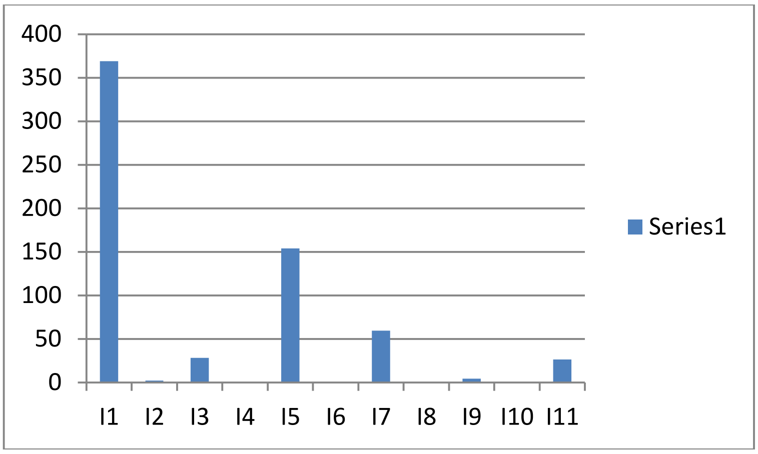

Figure – 1 Current Harmonic Spectrum

IV. FILTER DESIGN AS PER RECOMMENDED METHOD

The load is 261 Kw with 0.88 logging P.F. The fifth harmonic current produced by load is maximum that is 41.75 % of fundamental current. The system voltage is 422 V.
The fifth harmonic background voltage distortion on utility side of transformer is 0.5 %
Step 1 : Select a turned frequency for filter
The filter will be slightly tuned below the 5th harmonic frequency to allow for tolerances in the filter components and variations in system impedance. The filter is designed to be tuned to the 4.7th
Step 2 : Compute capacitor Bank size and Resonant Frequency.
Here it is assumed that P.F. is to be improved from 0.89 logging to 0.96 logging.
Reactive power demand for 0.88 logging PF

$$= 296.59 \times \sin[\cos^{-1}(0.88)] = 140.87 \text{ K}_{\text{var}} \quad \text{….. (1)}$$

Reactive power demand for a 0.96 logging PF

$$= 296.59 \times \sin[\cos^{-1}(0.96)] = 83.04 \text{ K}_{\text{Var}} \quad \text{….. (2)}$$

Required Compensation from filter
$140.87 – 83.04 = @60\,\text{K}_{\text{var}}$
For a nominal 422 V system, the net wye equivalent filter reactance (capacitive) X_{Filt} is determined by

$$X_{Filt} = \frac{KV^2\ (1000)}{K_{Var}} = \frac{(0.422)^2\ (1000)}{60} = 2.9680\,\Omega, \quad \text{….. (3)}$$

$$X_{Filt} = X_{Cap} - X_L \quad \text{….. (4)}$$

For tuning at 4.7th harmonic

$$X_{Cap} = h^2\ X_L = (4.7)^2\ X_L \quad \text{….. (5)}$$

Thus, desired capacitive reactance can be determined by

$$X_{Cap} = \frac{X_{Filt}\ h^2}{h^2 - 1} = \frac{2.968(4.7)^2}{(4.7)^2 - 1} = 3.1087\,\Omega \quad \text{….. (6)}$$

To achieve this reactance at a 422 V rating the capacitor would have to be rated

$$K_{var} = \frac{KV^2\ (1000)}{X_{Cap}} = \frac{(0.422)^2 \times 1000}{3.1087} = 57.28\ K_{var} = @\ 50\ \text{K}_{\text{var}} \quad \text{….. (7)}$$

Now the filter will be designed using 422 V capacitor rated $60\,\text{K}_{\text{var}}$. For this capacitor rating. $X_{Cap} = 2.968\ \Omega$
Step 3 : Compute Filter Reactor Size
The filter reactor size is computed from the wye – equivalent capacitive reactance as follow

$$X_L\,(Fund) = \frac{X_{Cap(wye)}}{h^2} = \frac{2.968}{(4.7)^2} = 0.134\ \Omega \qquad \text{….. (8)}$$

$$L = \frac{X_{L\,Fund}}{2\pi \times 50} = \frac{0.134}{2\pi \times 50} = 0.427\ \text{mH} \qquad \text{….. (9)}$$

Step 4 : Computation of Fundamental duty requirements

a) The apparent reactance of combined capacitor and reactor at fundamental frequency is

$$X_{Fund} = \left|X_L - X_{Cap(wye)}\right| = \left|0.134 - 2.968\right| = 2.834\ \Omega \qquad \text{….. (10)}$$

b) The fundamental frequency filter current is

$$I_{Fund} = \frac{KV_{actual}/\sqrt{3}}{X_{fund}} = \frac{422/\sqrt{3}}{2.834} = 85.97\ \text{A} \qquad \text{….. (11)}$$

c) The fundamental frequency operating voltage across capacitor bank is

$$V_{L\text{-}L}\ Cap_{(Fund)} = \sqrt{3} \times L_{fund} \times X_{Cap\ (wye)} = \sqrt{3} \times 85.97 \times 2.968 = 441.95\ \text{V} \qquad \text{….. (12)}$$

This is nominal fundamental voltage across the capacitor. It should be adjusted for any contingency conditions and it should be less than 110 percent of capacitor rated voltage.

d) actual reactive power produced is

$$K_{var\ Fund} = \sqrt{3} \times I_{fund} \times KV_{actual} = 62.83\ \text{K}_{\text{var}} \qquad \text{….. (13)}$$

Step 5 : Computation of harmonic duty requirements

a) The 5th harmonic current produced by load is $Ih_{(amps)} = 154.03$ A

b) Fundamental frequency impedance of service transformer

$$X_{T\,(Fund)} = Z_T\ (\%)\ \frac{KV^2_{actual}}{MVA(Xmer)} = 0.06\ \frac{(0.422)^2}{2} = 0.00534 \qquad \text{….. (14)}$$

$$X_{T\,(harm)} = hX_T\ (Fund) = 5 \times 0.00534 = 0.0267\ \Omega \qquad \text{….. (15)}$$

The harmonic impedance of capacitor bank is

$X_{Cap\ (wye)}$, $harm$ = 0.5936 Ω

The harmonic impedance of reactor is

$X_{L(harm)} = h \times X_{LFund} = 5 \times 0.134 = 0.67\Omega$

The fifth harmonic current contributed to filter from source side would be

$$I_{h(utility)} = \frac{V_{h(utility)(pu)} \times KV_{actual}}{\sqrt{3} \times (X_{T\,(harm)} - X_{Cap\ (wye)\ harm} + X_L\ (harm))} \qquad \text{….. (16)}$$

$$= \frac{0.005 \times 422}{\sqrt{3}\ (0.0267 - 0.5936 + 0.67)} = 11.81\ \text{A}$$

c) The maximum harmonic total current $I_{h(total)} = 154.03 + 11.81 = 165.84$

d) The harmonic voltage across capacitor

$$V_{Cap\ (L\text{-}L\ rms\ harm)} = \sqrt{3}\ I_{h(total)} \frac{X_{Cap\ (wye)}}{h} = \sqrt{3} \times 165.84 \times \frac{2.968}{5} = 170.50 \qquad \text{….. (17)}$$

Step 6 : Evaluate total rms current and peak voltage requirement

a) $I_{rms\ total} = \sqrt{I^2_{Fund} + I_{hutility}} = \sqrt{(85.97)^2 + (170.50)^2}$ = 190.94A ….. (18)

b) The maximum peak voltage across capacitor

$$V_{LL}\ Cap_{(max.\ peak)} = V_{LL} Cap_{(Fund)+}\ V_{Cap} \qquad \text{….. (19)}$$

= 442 + 170.5 = 612.5

c) The rms voltage across capacitor

$$= \sqrt{(442)^2 + (170.5)^2} = 473.74\,\text{V} \qquad \text{….. (20)}$$

d) The total K_{Var} seen by the capacitor is

$$K_{Var}\ \ Cap_{(wye)}\ total = \sqrt{3} \times 190.94 \times 0.47374 \qquad \text{….. (21)}$$

= 156.67 K_{var}

Capacitor Rated for high voltage must be

$$60 \times \frac{(600)^2}{(422)^2} = 121.29 \text{ K}_{var} .$$

Table : 5 Comparison able for Evaluating Filter Duty Limit

Duty	Definatio	Limit %	Actual Values	Actual Value %
Peak voltage	$\frac{V_{LL}\ Cap_{(max.\ peak)}}{\text{KV rated}}$	120	612.5 / 600	102
RMS voltage	$\frac{V_{LL}\ Cap_{(rms\ total)}}{\text{KV rated}}$	110	473.74 / 600	80
RMS current	$\frac{I_{rms}\ .\text{total}}{\text{I cap rated}}$	180	190.94/ 116.71	164
Kvar	$\frac{Kvar\ Cap\,(wye\ total)}{\text{K var rated}}$	135	156.67/ 121.29	129

V. RESULT

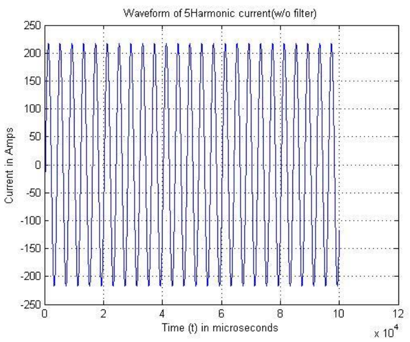

Figure – 2 Waveform of 5th Harmonic Current (w/o filter)

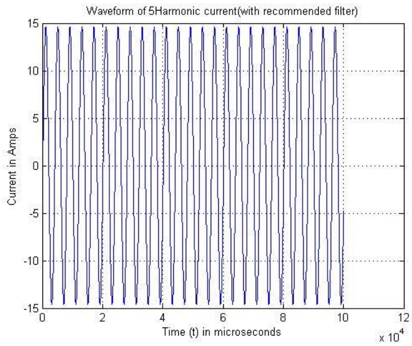

Figure – 3 Waveform of 5th Harmonic Current (with recommended filter)

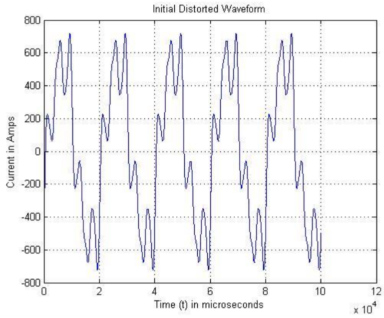

Figure – 4 Initial distorted Waveform (w/o filter)

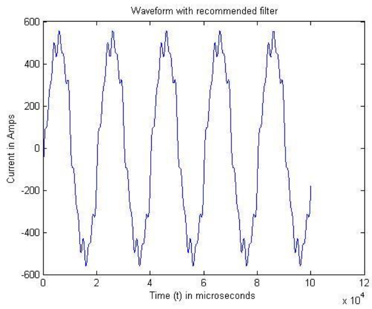

Figure – 5 Distorted Waveform (with recommended filter)

Table : 6 Result Of Performance Of Filters Designed By Recommended Method.

Parameter	Without Filter	With Filter
Power Factor	0.88	0.968
2nd Harmonics	2.06 A	2.14 A
3rd Harmonics	28.363 A	14.237 A
4th Harmonics	0	0
5th Harmonics	154.03 A	10.3128 A

6th Harmonics	0	0
7th Harmonics	59.543 A	26.33 A
8th Harmonics	0	0
9th Harmonics	4.483 A	3.375 A
10th Harmonics	0	0
11th Harmonics	26.333 A	27.239 A

Finding of results

1) Figure 1 and 3 represent the current wave form of fifth harmonic current and the total rms current generated by the VFD before installation of the proposed harmonic filter.
2) Figure 2 and 4 represent the current wave form of fifth harmonic current and the total rms current generated by the VFD after installation of the proposed harmonic filter, simulated with the help of MATLAB program. It is seen that the originally distorted wave forms as observed in figure 1 and 3 are smoothened in figure 2 and 4 respectively, which clearly indicates the effective performance of proposed passive harmonic filter
3) The table 5 reveals that the power factor of load is improved, third, fifth, seventh and ninth harmonic current generated by the load are minimized with the incorporation of the proposed passive harmonic filter. It is seen that the fifth harmonic current for which the filter is designed, as it is the major harmonic contributor current, is drastically reduced from 154.03 A to 10.3128 A.
4) It is also seen from table 5 that eleventh harmonic current is increased marginally due to incorporation of the proposed filter.
5)The even harmonic currents that is second, fourth, sixth, eighth and tenth harmonics are absent in both the cases with filter and without filter

VI. CONCLUSIONS

This paper explains the design of harmonic filter by a method which is generally not followed by industry. The recommended method designs a filter which caters all requirement of the filter as shown in table 5.

i) The recommended filter suppresses 5^{th} harmonic current from 154.03 A to 10.3128 A.
ii) A Filter tuned for frequency 235 Hz is designed by considering 0.96 power factor gives all duty requirements within acceptable limits as per IEEE Standard18-1992, IEEE Standard for Shunt Power Capacitors

VII. FUTURE WORK

By this method filters tuned for different frequencies can be designed but for every frequency the cost of filter as well reduction in %THD of current changes. Filters can be designed for different power factors, but for different power factors the cost of filter as well reduction in %THD of current changes. An optimized approach is necessary for the optimum design of the filter to give the most cost effectiveness subjected to the better % THD of current and power factor of the system. Research is necessary in this area. A program can be designed to get this optimum result.

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REFERENCES

[1] Efficient Cogeneration Scheme For Sugar Industry. M.Premalata, S.Shanmuga Priya, V. Sivaramakrishnan Journal of Scientific and Industrial Research. Vol 67,March 2008,PP 239-242

[2] Energy Conservatin in Sugar Mills.All India Seminar on “Ethanol & Cogeneration 2003,Nainital,Uttaranchal
[3] IEEE Recommended Practice for Monitoring Electric Power Quality, 1159.
[4] Electrical Power Systems Quality, Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, H. Wayne Beaty, Tata McGraw-Hill Publication, Second Edition, pp-264-270.
[5] Harmonic Minimization In Sugar Industry Based Cogeneration Plant.S.M.Shinde ,W.Z.Gandhare IEEMA Journal December 2013 pp-122-125
[6] Modeling Variable AC Drives And Harmonic Distortion Erika Twinning, Ian Cochrane Department Of Elctrical and Electronics Engineering The University Of Melbourne ,Australia
[7] IEEE Standard18-1992, IEEE Standard for Shunt Power Capacitors

BIOGRAPHY

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