Power Quality Enhancement using Passive Filters

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Abstract:- Power quality is becoming a major concern of power system. Harmonics play an important and major roll in deteriorating power quality-called harmonic distortion. Harmonic distortion is measured in terms of THD (Total Harmonic Distortion). This paper presents design and simulation of passive filter for harmonic reduction. Single phase rectifier is chosen as a non-linear load and implemented in real world. Performance characteristics of the same have been compared with the simulation model. Design and application of passive filter is carried out. Performance of the passive filter is evaluated in terms of harmonic reduction at point of common coupling. The simulation is carried out in MATLAB environment.

Keywords:- Power Quality, harmonics, non-linear loads, passive filter, rectifier.

I. INTRODUCTION

Nowadays, power quality has become a great concern for both utilities and customers. With the increasing use of non-linear load being connected to the power system, more studies are needed. The problems associated with high harmonic content in the power system do not only result in the poor quality of supply but also the operation of the system will get affected. The major sources of harmonics are from the three categories of equipment: power system equipments, industrial loads and domestic loads. Harmonic currents are generated to a small extent and low distortion level by generation, transmission and distribution equipments and to a larger extent by the industrial and domestic loads.

II. NON-LINEAR LOAD IMPLEMENTATION

Non-linear load simulation and implementation is done to verify the degree of severity of harmonic distortion the distribution system. There are number of solid state controlled non-linear equipments are used for domestic application such as electronic fan regulator, personnel computer, printer, etc. These non-linear loads inject harmonic currents in the network thus distorting supply voltage. In this paper single phase rectifier is chosen as non-linear load to be simulated and to be implemented. Actual harmonic measurement along with voltage and current waveform is carried out.

In carrying out harmonic measurement of practically implemented and designed model of bridge rectifier which is supplied by 24V DC. All the measurements are made at 230 V using harmonic analyzer. Harmonic spectrum for each load is plotted showing magnitude of each harmonic frequency that makes up a distorted waveform. The magnitude of each harmonic frequency can be expressed as a percentage of fundamental. Total harmonic distortion is defined from harmonic spectrum as the ratio of the RMS sum of all harmonic frequencies to the RMS value of the fundamental.

Mathematically THD is expressed by the following equations:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{n} (V_h)^2}}{V_1} \quad (1)$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{n} (I_h)^2}}{I_1} \quad (2)$$

Fig. 1 shows single phase bridge rectifier implemented in real world. Various system parameters are tabulated in Table VI of appendix.

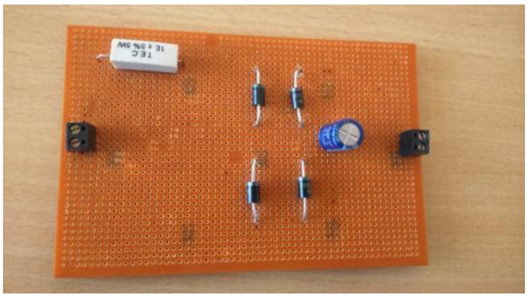


Fig.1: Single phase bridge rectifier implemented

Fig. 2 shows measured current waveform at PCC.

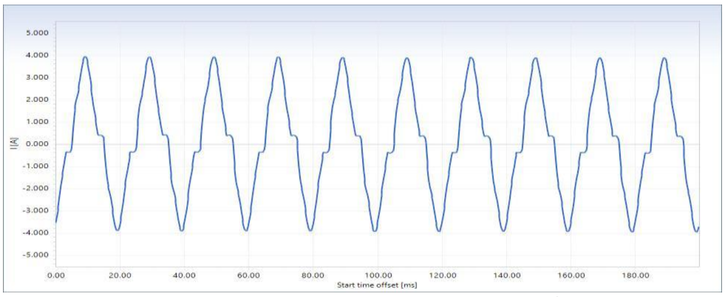


Fig.2: Measured current waveform at PCC

Fig. 3 shows measured harmonic spectrum for current at PCC.

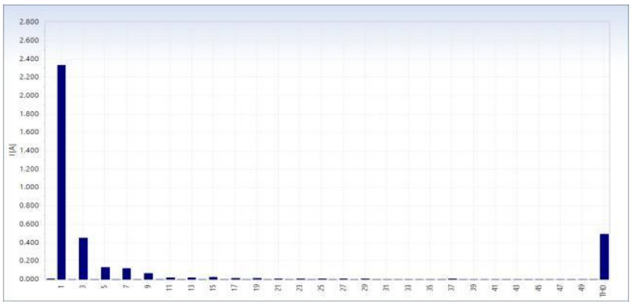


Fig.3: Measured current harmonic spectrum at PCC.

Fig. 4 and Fig. 5 show measured voltage waveform and measured voltage harmonic spectrum respectively at PCC.

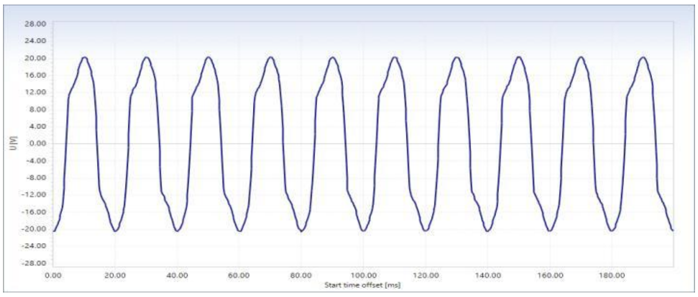


Fig.4: Measured voltage waveform at PCC.

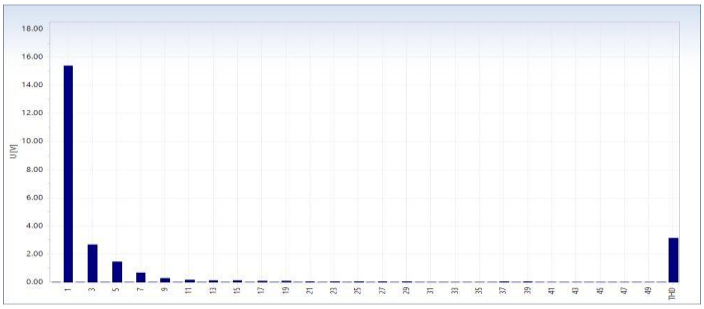


Fig.5: Measured voltage harmonic spectrum at PCC

Harmonic distortion introduced due to single phase bridge rectifier is tabulated in Table I.

Table I: Harmonic Distortion due to Bridge Rectifier at PCC

Sr. No.	Non Linear Load	THDV%	THDI%
1.	Rectifier	9.56	85.43

The IEEE 519-1992 [12] has imposed limits on total harmonic distortion (THD), as shown in Table IV of appendix. Table I shows that measured THD values for voltage and current at PCC are violating IEEE norms. Hence corrective actions are required to be taken. Passive filters are proven to be one of the reliable solutions in reducing harmonics and thus enhancing power quality at PCC. Single phase tuned passive filters are chosen for the same. While analyzing current harmonic spectrum of simulated non-linear load, it found that 3rd, 5th and 7th odd harmonics are predominant. The subsequent subsection describes the procedure for designing single tuned passive filter for elimination of above said harmonics.

III. DESIGN OF SINGLE TUNED PASSIVE FILTERS

The single tuned filter is designed to trap 3rd, 5th and 7th harmonics by adding reactor with $X_L = X_C$ at the tuned frequency $(n \times f)$. The data required for the single tuned passive filter and the required procedural steps are described below:

A. Data required for the design:

1. Reactive power consumed : Q in VA
2. Supply Voltage : V_S in Volts
3. Supply frequency : f in H_Z
4. Natural Frequency : f_n in H_Z
5. Harmonic order : h Number
6. Quality Factor : Q_L Number

B. Procedural Steps:

1. $X_C = \frac{V_S^2}{Q} \cdot \frac{h^2}{(h^2-1)}$

2. $C = \frac{1}{(2 \times \pi \times f \times X_C)}$

3. $X_L = \frac{X_C}{h^2}$

4. $L = \frac{X_L}{(2 \times \pi \times f)}$

5. $R = \frac{h \times X_L}{Q_L}$

Designed circuit parameters of single tune passive filter for 3rd, 5th and 7th harmonic order are tabulated in Table VI of appendix.

IV. SIMULATION OF NON-LINEAR LOAD AND PASSIVE FILTERS

Single phase bridge rectifier chosen as non-linear load (sources of harmonic) has been simulated using in MATLAB environment. Full wave Diode Bridge feeding a capacitor and a resistance in parallel is designed to simulate a non-linear load as shown in Fig. 6.

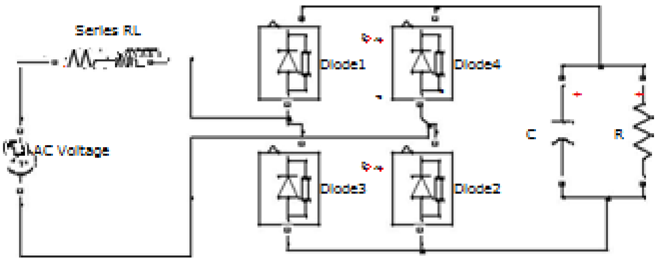


Fig.6: Non-linear load simulation using MATLAB

Following above said procedural steps (1 to 5 given in Section III) for passive filter design, three single tuned passive filters are designed to take care 3rd, 5th and 7th harmonics and implemented in MATLAB with the simulated diode bridge non-linear load shown as shown in Fig. 7.

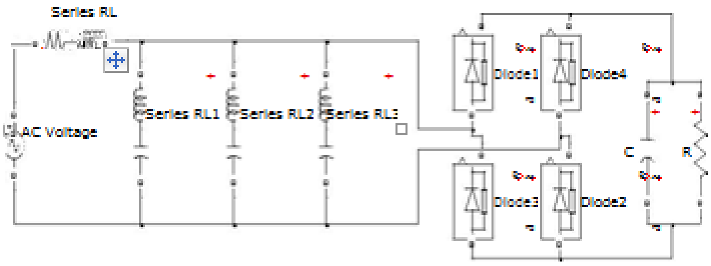
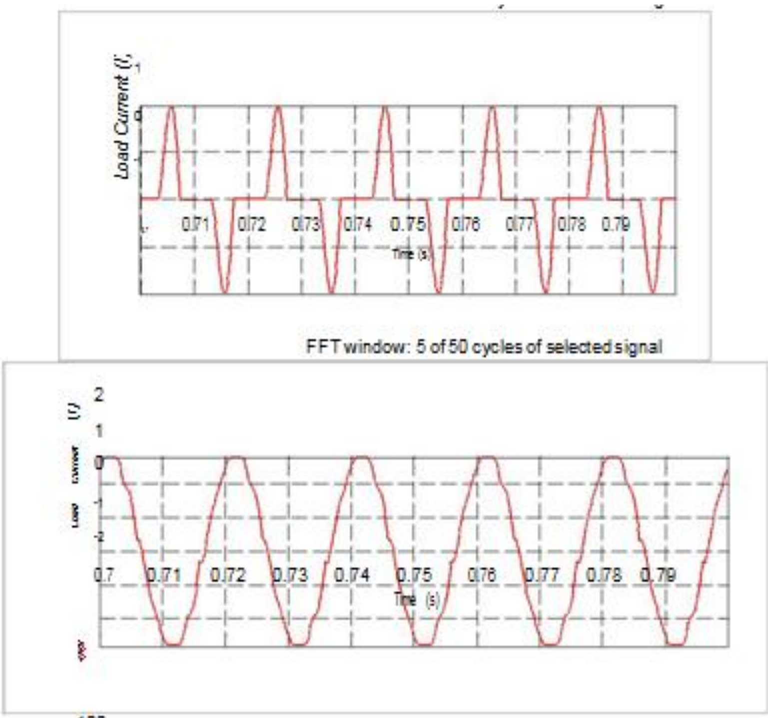


Fig.7: Passive filter simulation using MATLAB



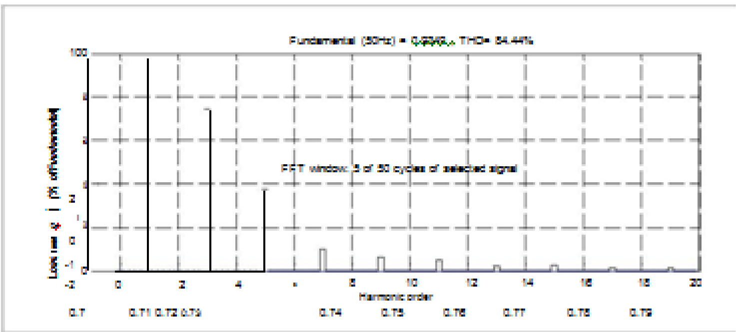
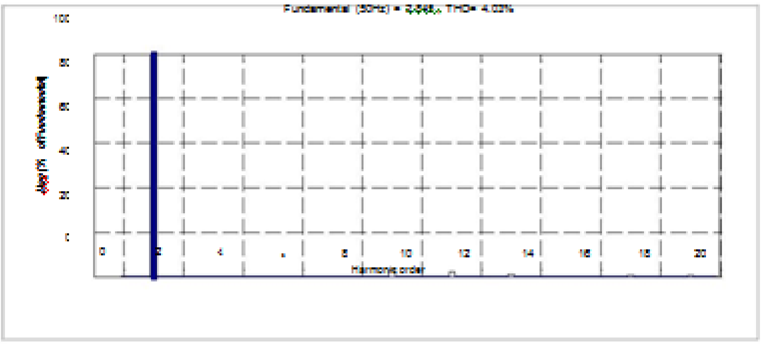


Fig.10: Current harmonic spectrum Time at(s) PCC without passive filter



which shows that IEEE limits for current harmonic distortion Time(s) limits are violated. This value reduces to 4.03 % after passive filter application at PCC.

FFT window selected for 5 of 50 cycles of selected current and voltage signals. Total harmonic distortion in current was reduced to 4.03 % from 84.44 % after passive filter installation. Whereas voltage harmonic distortion is reduced to 3.96 % from 9.54 % after passive filters installation.

Moreover considerable reduction in the total harmonic distortion in the respective order of harmonic is noticed, tabulated at the end of this section, shown in Table II & III.

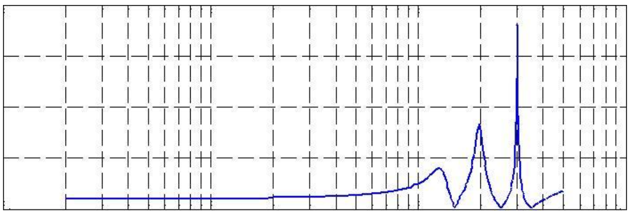


Fig.16: Impedance v/s Frequency**Phase**(Hz)plot of Passive Filter

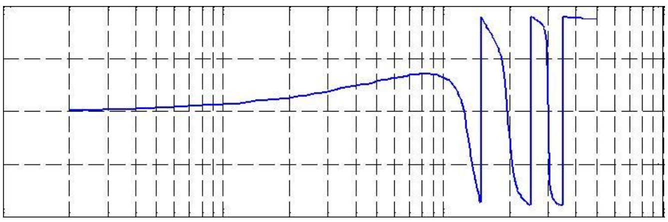


Fig.17: Phase v/s Frequency plot of Passive Filter

Fig. 16 describes almost zero impedance offered for the 3rd, 5th and 7th ordered harmonics. Fig. 17 shows phase relationship at the 3rd, 5th and 7th harmonic frequencies.

TABLE II: IMPROVEMENT IN LOAD CURRENT THD

	Before PF (%)	**After PF (%)**	**% Reduction**
3rd	74.78	0.14	95.36%
5th	38.73	0.08	99.79%
7th	10.59	0.05	99.52%
THDi	85.43%	3.96%	99.36%

TABLE III: IMPROVEMENT IN LOAD VOLTAGE THD

	Before PF (%)	**After PF (%)**	**% Reduction**
3rd	6.68	0.04	99.40%
5th	5.41	0.03	99.44%
7th	2.07	0.03	98.55%
THDv	9.56%	4.80%	49.79%

V. CONCLUSIONS

Harmonic is the predominant power quality issue. Non-linear domestic loads connected in the distribution system inject considerable current harmonics in the supply system resulting in harmonic distortion violating the limits specified by IEEE 519 for current harmonic distortion. Passive filtering is one of the solutions to prevent the harmonic from entering the rest of the system. Implementation of single tuned passive filter taking care of 3rd, 5th and 7th harmonic, suppresses the THD_I by 99.36 % and THD_V by 49.79 %.

VI. APPENDIX

Table IV: Harmonic Voltage limits by IEEE 519

Bus Voltage in KV	THD_V **in %**
69 & above	5.0
115-161	2.5
>161	1.0

Table V: Harmonic Current limits by IEEE 519

SCR	THD_I **in %**
<20	5.0
20-50	8.0
50-100	12.0
11-15	20.0

Table VI: Designed circuit Parameters used for Simulation of Non-linear Load

Parameter	V_S	f	R_S	X_S	C_L	R_L
Value	15 VOLTS	50 H_Z	1 Ω	2.2 MH	100 µF	40.5 Ω

Table 7: Designed circuit Parameters used for Simulation of Passive Filters

For 3rd Harmonic		**For 5th Harmonic**		**For 7th Harmonic**	
R Ω	1.06	*R* Ω	0.63	*R* Ω	0.45
C µF	100	*C* µF	100	*C* Mf	100
L mH	11.26	*L* mH	4.05	*L* Mh	7.4

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