National Conference on Emerging Trends in Computer, Electrical & Electronics (ETCEE-2015)
International Journal of Advance Engineering and Research Development (IJAERD)
e-ISSN: 2348 - 4470 , print-ISSN:2348-6406,Impact Factor:3.134

Harmonics Mitigation from Non-Linear Load Connected with 11kV/440V Using Shunt Active Filter

Joshi Kaushal Himanshu[1], Bhatt Jigar Rajendra[2]

[1]*Scholar*
[1]*Ipcowala Institute of Engineering and Technology; Dharmaj, Dist.: Anand, Gujarat.*
[1]k.joshi.ec@gmail.com

[2]*Assistant Professor*
[2]*Leads Institute of Technology and Engineering; Matar, Dist.: Bharuch, Gujarat.*
[2]jigar.ee@gmail.com

***Abstract*— Harmonic Distortion in Electrical Distribution System is increasingly growing due to the widespread use of Non-Linear Loads and Power Electronics Switching Devices. Large considerations of these loads have the potential to raise Harmonic Current & Voltage in an Electrical Distribution System. To mitigate this distortion, we are interested in Active Power Filter technology. In this technology, we produce specific current components that cancel the Harmonics Current components caused by the Non-Linear Load. Particular "Shunt Active Power Filter" is mostly used as Active Power Filter. It has advantages of carrying only the Compensation Current plus a small amount of Active Fundamental Current supplied to compensate for system losses & also contribute to Reactive Power Compensation. Shunt Active Filter will be reviewed as a concept of solving certain types of problems related to Power Quality.**

***Keywords*— Power Quality, Non-Linear Load, Harmonics, Harmonics Mitigation, Shunt Active Filter, p-q theory, Clark Transformation.**

I. INTRODUCTION

Power Quality is main issue in all the categories of the power system those are Generation, Transmission, Distribution and Utilisation. Different Power Quality problems are Power Frequency Disturbances, Power System Transients, Electromagnetic Interference, etc. Many big industries, commercial and electrical industrial loads include power transformers; welding machines, arc furnaces, Induction Motor driven equipments such as elevators, pumps, variable frequency drives (VFDs) and Printing Machines etc., which are mostly inductive in nature. Poor power factor and generation of harmonics are two most important and serious power quality problems nowadays.

II. HARMONICS

The non-linear loads draw current in non-sinusoidal form which contains frequency components which are integer multiple of fundamental frequency. These frequency components are known as Harmonics. Harmonics are high frequency phenomena involving frequencies from 50/60 Hz to about 3000 Hz.

Harmonic number refers to the individual frequency elements that comprise a composite waveform. For example, for fundamental frequency of 50 Hz, then the fifth harmonic frequency is 5×50 or 250 Hz. Dealing with Harmonic numbers and not with Harmonic frequency is done for two reasons.

The fundamental frequency varies among individual countries.

Odd Harmonics have odd numbers (i.e. 3^{rd}, 5^{th}, 7^{th}, 9^{th}, 11^{th}...) and Even Harmonics have even numbers (i.e. 2^{nd}, 4^{th}, 6^{th}, 8^{th}, 10^{th}...). 1^{st} Harmonic assigned to the fundamental frequency component of periodic wave. 0^{th} Harmonic represents the constant of DC component of the waveform. The DC component is the net difference between the positive and negative halves of one complete waveform cycle.

Uneven current draw between the positive and negative halves of one cycle of operation can generate even harmonics.

III. SHUNT ACTIVE FILTER

An Active Harmonic Filter is something like a boost regulator. The concept used in an active filter is the introduction of current components using power electronics to remove the harmonic distortion produced by non-linear loads.

Active Filters have number of advantages over Passive Filters. It is used for reduce the harmonic in the system as well as it can compensate the reactive current in the system.

Shunt Active Filter is the most widely used and dominant form of active power filters to compensate the load current harmonics & the reactive power as well. It connects in shunt to the distribution supply at Point of Common Coupling (PCC) and it injects harmonic currents but having 180 degree phase shift to cancel out the load current harmonics and makes source current pure sinusoidal. This improves the power

For an increased range of power ratings, several Shunt Active Filters can be used together to withstand higher currents.

Here, in shunt active filter; joint to PCC with coupling inductor & in SAF, consider voltage source inverter with DC link-capacitor.

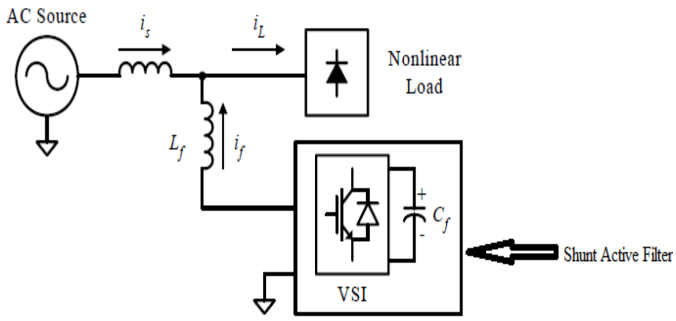

Fig. 1 Shunt Active Filter

Here,

$$I_s + I_f = I_L \quad (3.1)$$

$$I_s = I_L - I_f \quad (3.2)$$

For non-linear load;

$$I_L = I_{L,\,f} + I_{L,\,h} \quad (3.3)$$

Now,
By applying SAF it provides,

$$I_f = I_{L,\,h} \quad (3.4)$$

So, we get source current,

$$I_s = I_{L,\,f} \quad (3.5)$$

As per upper discussion, we can conclude that, source current is free from harmonics i.e. sinusoidal source current.

Now, for controlling this shunt active filter; there are two categories like as Frequency Domain Analysis & Time Domain Analysis. The time domain analysis is superior over the frequency domain and of great interest in recent years.

In time domain analysis, particularly p-q theory is most useful. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation.

IV. Instantaneous Power of the P-Q Theory

This theory is very efficient and very flexible in designing controller for power conditioner based on power electronics devices. In p-q theory, we use Clark Transformation for transform voltage & current from the abc to αβ0 coordinates.

After this transformation, we get the instantaneous power on these (αβ0) coordinates.

From Clark Transformation, we get V_α, V_β & V_0 from V_a, V_b & V_c respectively and same as I_α, I_β & I_0 from I_a, I_b & I_c

quality.

respectively. The advantage of this transformation is that to separate Zero-sequence from the abc-phase component.

Zero-sequence current does not exist in 3-Ø, 3-wire system, So, I_0 can be eliminated from the system and same as in 3-Ø, 4-wire system, voltages are balanced; no zero-sequence voltage is present, So that V_0 can be eliminated.

The p-q theory can be defined in three-phase systems with or without a neutral conductor. Three instantaneous powers, the instantaneous zero-sequence power p_0, the instantaneous real power p and the instantaneous imaginary power q are defined from the instantaneous phase voltages and line currents on the αβ0 axes are given in equation,

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (4.1)$$

In three phase three wire systems, i_0 value is zero. So, instantaneous power defined on the αβ axes exist, because $v_0\, i_0 = 0$, so, upper equation should be write as per following,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4.2)$$

From that,

$$p \text{ (Instantaneous real power)} = V_\alpha I_\alpha + V_\beta I_\beta \quad (4.3)$$

&

$$q \text{ (Instantaneous imaginary power)} = V_\alpha I_\beta - V_\beta I_\alpha \quad (4.4)$$

According to p-q theory, real & reactive power can be written as,

$$p = \tilde{p} + \bar{p} \quad (4.5)$$

$$q = \tilde{q} + \bar{q} \quad (4.6)$$

&

$$p_0 = v_0\, i_0 \quad (4.7)$$

Where,

p = The Active Power for a Three Phase System with or without Neutral Conductor & it represent the Total Instantaneous Energy Flow per second between Source and Load.

p_0 = Active Power due to Zero Sequence Components.

$\bar{p}$ = Average value of the Instantaneous Real Power & transferred from the power source to the load. It is due to fundamental active current.

$\tilde{p}$ = Alternating value of the Instantaneous Real Power. It is related to Harmonic Currents.

$\bar{q}$ = Average term of Instantaneous Imaginary Power and it is related to fundamental Reactive Power.

$\tilde{q}$ = Alternating term of the Instantaneous Imaginary Power which is must be compensated. It is also related to Harmonic Currents.

In this work, the adopted compensation strategy is Harmonics Compensation (compensation of oscillating Real & Reactive Power) and Reactive Power compensation (compensation of average value of Reactive Power) which is constant Active Power compensation strategy. In terms of Real and Imaginary Power, in order to draw a constant Instantaneous Power from the source, the Shunt Active Filter should be installed as close as possible to the Non-Linear Load and should compensate the oscillating Real Power of this Load. A three-phase system without neutral wire is being considered, and the zero-sequence power is zero.

Therefore the compensator has to select the following powers as a reference to follow the control strategy.

Instantaneous reactive power supplied by the compensator,

$$q_c = -q \tag{4.8}$$

Instantaneous active power supplied by the compensator,

$$p_c = -\tilde{p} \tag{4.9}$$

The mean value of oscillating active powers on α & β axis is zero but sum of both at every instant is not zero so capacitor has to supply energy when oscillating active power is positive and absorb energy when it is negative.

In addition to the reference active power in equation (4.9), compensator has to draw some active power from the distribution source called $\bar{p}_{loss}$ to make up for the switching losses of the voltage source inverter and to maintain constant voltage across the capacitor at a prescribed value. The power converter of the Shunt Active Filter is a boost-type converter. This means that the dc voltage must be kept higher than the peak value of the ac bus voltage so equation (4.9) will become,

$$p_c = -\tilde{p} + p_{loss} \tag{4.10}$$

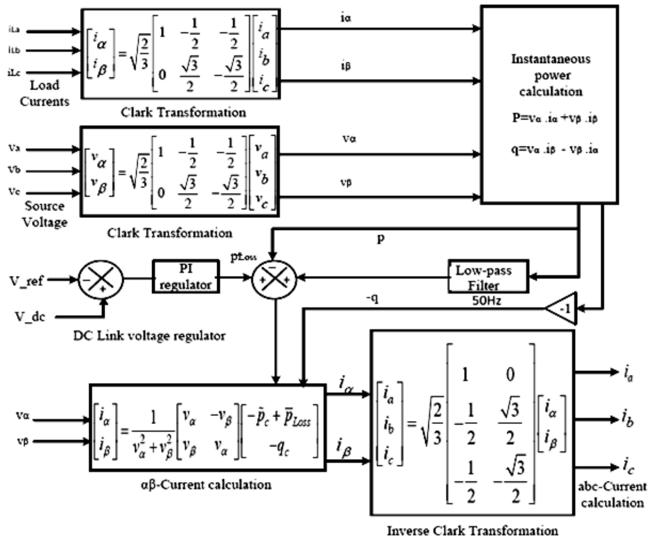

Fig. 2 Resulting Algorithm for the Calculation of Reference Currents of the Compensator for the Constant Active Power Supply

From this we have to calculate the compensator reference currents in α-β domain,

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} p_c \\ q_c \end{bmatrix} \tag{4.11}$$

$$\text{Where,} \quad \Delta = \frac{1}{V_\alpha^2 + V_\beta^2} \tag{4.12}$$

In a-b-c domain currents will be become,

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} \tag{4.13}$$

This operation takes place only under the assumption that the three-phase system is balanced and that the voltage waveforms are purely sinusoidal. This abc domain current is compensated current which is totally out of phase by 180 degree from the non linear load current.

V. SIMULATION RESULT OF 11KV/440V DISTRIBUTION SYSTEMS WITH NON-LINEAR LOAD

By using MATLAB-Simulator R2010a, 32 bit, simulation has been done for 11 kV/440 V distribution system with Shunt Active Filter. Here, these simulation circuits', parameters of non-linear load & waveforms are presented. Also mention the result of Individual Harmonic Distortion (IHD) for odd harmonics from 3rd to 31st and Total Harmonic Distortion (THD) value with & without Shunt Active Filter.

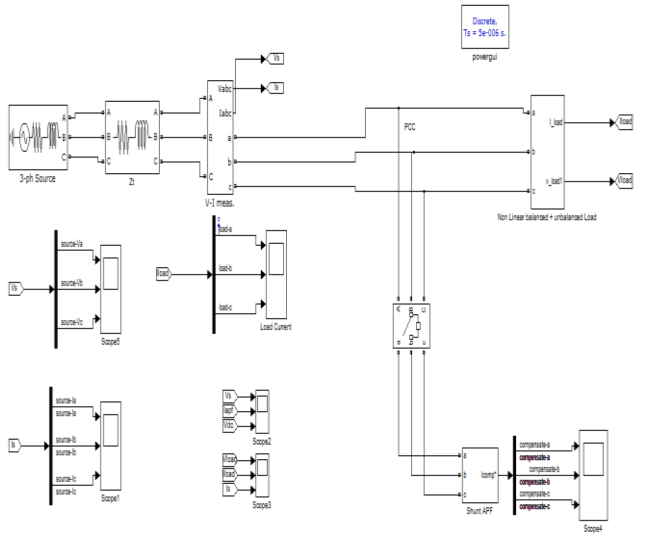

Fig. 3 Simulation Circuit of 11kV/440V Distribution System with Shunt Active Filter

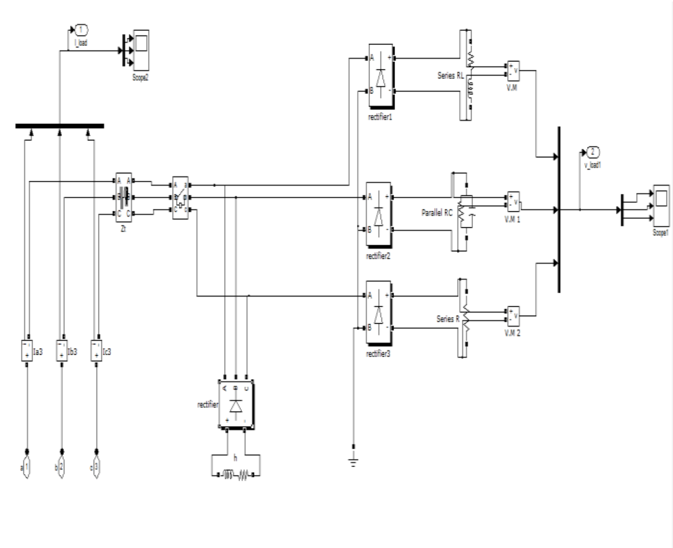

Fig. 4 Three Phase Non-Linear Balanced & Unbalanced Load design for 11 kV Distribution Line

TABLE I
SIMULATION PARAMETERS FOR NON-LINEAR LOAD SIDE (11KV)

Parameters		Symbols	Values
Balanced Load (Rectifier)	Universal Bridge circuit (No. of bridge arm =3)	Snubber Resistance R_s	10 KΩ
		Snubber Capacitance C_s	Infinite
		R_{on}	1 mΩ
		L_{on}	0 H
	Series R-L load connect with Rectifier	R	50 Ω
		L	0.003H
Un-Balanced Load In each phase (Particular One Unit is provided)	Universal Bridge circuit in each phase (No. of bridge arm = 2)	Snubber Resistance (R_s)	10 KΩ
		Snubber capacitance (C_s)	Infinite
	Series R-L Load	R_a	50 Ω
		L_a	0.01H
	Parallel R-C Load	R_b	50 Ω
		C_b	1 µF
	Series R Load	R_c	50 Ω

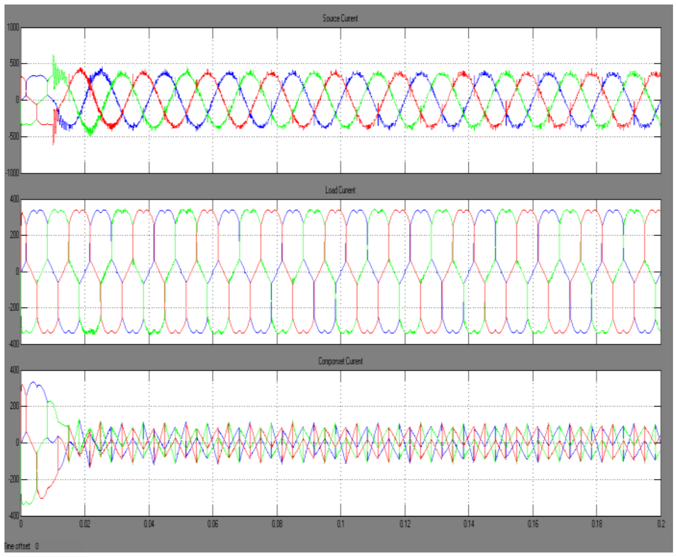

Fig. 5 Source Current, Load Current & Compensation Current for 11 kV Distribution Line

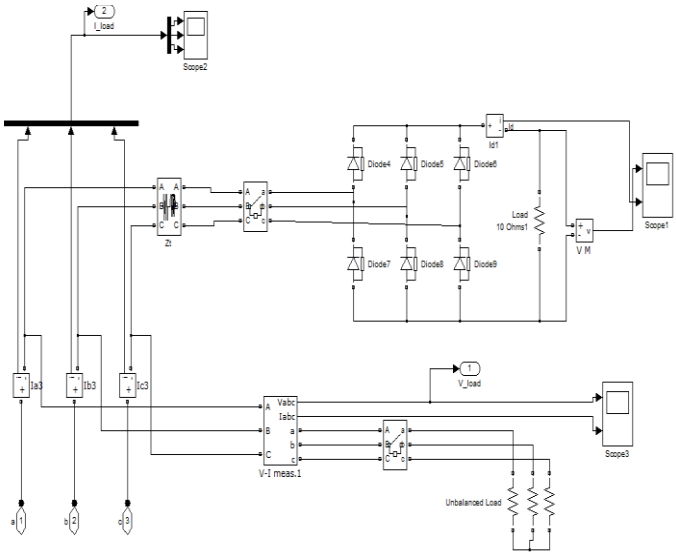

Fig. 6 Three Phase Non-Linear Load and Unbalanced Load designed for 440V Distribution Line

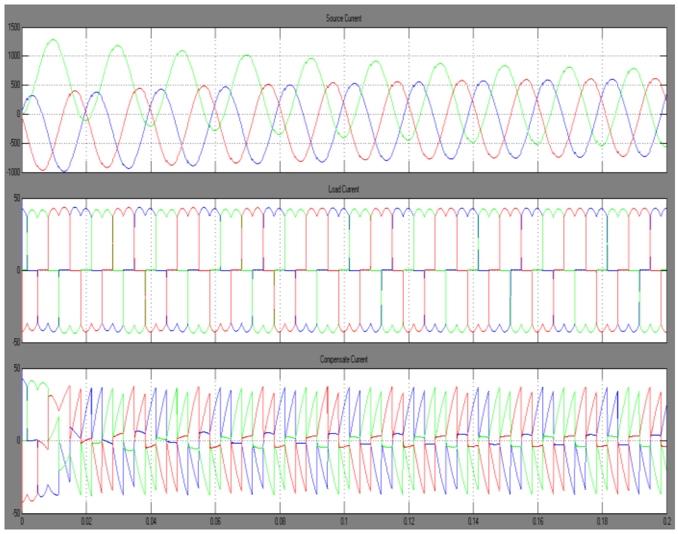

Fig. 7 Source Current, Load Current & Compensation Current for 440V Distribution Line.

TABLE II
SIMULATION PARAMETERS FOR NON-LINEAR LOAD SIDE (440 V)

Parameters		Symbols	Values
Load side series R-L branch		R	0.001 Ω
		L	1 MH
Balanced Load	Universal Bridge Circuit (No. of bridge arm=3)	Snubber Resistance Rs	1000 Ω
		Snubber capacitance Cs	1 µF
		R_{on}	0.1 Ω
		L_{on}	0 H
	Parallel R load	R	10 Ω
Un-Balanced Resistive Load	Parallel Resistive Load is provided in each phase with different value	R_1	2 Ω
		R_2	4 Ω
		R_3	6 Ω

TABLE III
IHD & THD VALUE OF SOURCE CURRENT (WITH & WITHOUT SAF)

Harmonic Number	Without SAF IHD (%)		With SAF IHD (%)	
	400V	11KV	400V	11KV
3	0.00	0.17	1.85	0.30
5	22.63	14.47	0.44	0.51
7	11.30	7.22	0.36	0.61
9	0.00	0.15	0.01	0.14
11	9.03	5.88	0.37	1.23
13	6.44	4.25	0.39	0.17
15	0.00	0.13	0.03	0.16
17	5.62	3.54	0.39	0.61
19	4.49	2.84	0.39	0.66
21	0.00	0.11	0.01	0.12
23	4.07	2.71	0.36	0.70
25	3.44	2.33	0.41	0.19
27	0.00	0.09	0.03	0.14
29	3.18	2.00	0.39	0.54
31	2.78	1.76	0.42	0.67
THD	**29.33**	**18.83**	**2.22**	**2.10**

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contributors of ETCEE-2015 & Atmiya Institute of Technology and Science (AITS), Rajkot, Gujarat. All made valuable comments and suggestions during the review process that improved the quality of this paper.

VI. CONCLUSIONS

In distribution system voltage 400V & 11kV, Harmonics will be generated by Non Linear Loads. The value must be below 3% for Individual Voltage Distortion (IHD) and below 5% for Total Harmonic Distortion (THD) which is mentioned by IEEE-519-1992 Standards for distribution systems having Bus Voltage at PCC ≤ 69 kV. Using Shunt Active Filter, we compensate the Harmonics component from the system. So, finally Source current is in pure sinusoidal form. For control of Shunt Active Filter, instantaneous active power theory is use its complex than other methods but if supply voltage contain unbalanced and containing harmonics at that time this method is very useful.

REFERENCES

[1] João Afonso*, Maurício Aredes+, Edson Watanabe+, Júlio Martins* , * University of Minho - Industrial Electronics Dept , + Federal University of Rio de Janeiro – COPPE/UFRJ, "Shunt Active Filter for Power Quality Improvement", International Conference UIE 2000 – "Electricity for a Sustainable Urban Development" Lisboa, Portugal, 1-4 Novembro 2000, pp. 683-691

[2] João Afonso, Carlos Couto, Júlio Martins, Departamento de Electrónica Industrial, Universidade do Minho, 4800 Guimarães – Portugal, "Active Filters with Control Based on the p-q Theory", IEEE Industrial Electronics Society Newsletter vol. 47, nº 3, Sept. 2000, ISSN: 0746-1240, pp. 5-10

[3] Thomas M. Blooming, P.E[#], Daniel J. Carnovale, P.E[$],# Eaton Electrical Asheville, North Carolina,$Eaton Electrical Pittsburgh, Pennsylvania, " Application of IEEE STD 519-1992 harmonic limits", Conference Record of the 2006 IEEE IAS Pulp and Paper Conference..

[4] Emílio F. Couto, Júlio S. Martins, João L. Afonso, Department of Industrial Electronic, University of Minho, Campus de Azurém – 4800-058 Guimarães (Portugal), "Simulation Results of a Shunt Active Power Filter with Control Based on p-q Theory".

[5] Hirofumi Akagi, Edson Hirokazu watanabe, Mauricio Aredes "Instantaneous power theory & applications to power conditioning" IEEE press series on power engineering, Wiley-inter science A John wiley & sons Inc; Publication.