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RESEARCH ARTICLE

DESIGN OF SHUNT PASSIVE FILTER FOR HARMONIC MITIGATION

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ABSTRACT

This paper review the study of harmonics present in the system and harmonics filter of primarily used in electrical system. CFL loads Arc furnaces, converters, adjustable speed derives, switch mode power supplies and PWM modulated drives etc. are some of the non-linear loads that generate harmonics. In order to overcome harmonic related problems, passive filters have been used for a long time. The main aim of this paper is to monitorvarious power quality parameters of real time CFL load using power quality analyzer fluke 435 and designing of passive shunt type filter in the distribution system for harmonic mitigation of the load used in analysis.

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INTRODUCTION

In recent years, advancement in power electronics devices has increased the usage of non-linear loads to greater extent. Widespread use of non-linear loads deteriorates the power quality in power system to great extent. The ideal power quality is defined by electrical power energy consists of sinusoidal supply voltage waveform at a constant frequency and constant magnitude. In today's world, electronic loads are very sensitive to harmonics, sags, swells, etc. So power quality has become an important factor to take in to account. A number of solutions exist to reduce the undesirable effects of harmonics. The most conventional method is installing passive harmonic filters to remove harmonic currents which present a low cost solution possessing simplicity and efficiency characteristics.

Harmonics and its effects

Electrical loads which draw sinusoidal current from a sinusoidal voltage source are termed as linear loads. They consist of only resistive (R), inductive (L) and capacitive(C) passive elements. Whereas, non-linear loads draw non-Sinusoidal current waveform, from a input sinusoidal voltage source. In order to show the undesirable effects and adversity of these non-sinusoidal signals, harmonic definition and its limits was introduced by Institute of Electrical and Electronics Engineers (IEEE) in 1981. According to IEEE Std. 519 [2], Harmonic factor or distortion factor (DF) is define as the ratio of the root sum square value of all harmonics to the root mean square value of the fundamental as shown in eqn. (1). Another important term known as Total Harmonic Distortion is define as the addition of each harmonic components of the voltage or current waveform compared with respect to the fundamental component of the voltage or current wave shown in eqn.(3) as given below

$$\text{Harmonic Factor (Voltage)} = \frac{\sqrt{\sum_{h=2}^{\infty}(V_h^2)}}{V_1} \quad (1)$$

$$\text{Harmonic Factor (Current)} = \frac{\sqrt{\sum_{h=2}^{\infty}(I_h^2)}}{I_1} \quad (2)$$

$$\text{Total Harmonic Distortion (THD)} = \frac{\sqrt{\sum_{h=2}^{50}(V_h^2)}}{V_1} \text{X}100\% \quad (3)$$

$\mathbf{V_h}$: Magnitude of the voltage harmonic component of order "h"

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I_h: Magnitude of the current harmonic component of order "h".

The Total Demand Distortion (TDD) limit defines how much a load can assign the utility in terms of harmonic current, and it is directly proportional to the size of the load with respect to the ability of the utility at Point of common coupling.

$$\text{Total Demand Distortion (TDD)} = \frac{\sqrt{\sum_{h=2}^{\infty}(I_h^2)}}{I_L} X100\% \quad (4)$$

I_L= Maximum demand Load Current
I_h = Amplitude of the harmonic current of order "h"

Therefore, the load can inject harmonic current to the Utility at higher percentages as the size of the load decreases with respect to the capacity of the system. In Table II, current distortion limits for general distribution systems are shown

Harmonic Mitigation Techniques

A number of solutions exist to reduce the undesirable effects of harmonics. The most common and the conventional method are installing passive harmonic filters to remove harmonic currents which present a low cost solution.

Passive Filter

In order to solve the current harmonic related problems, passive filters have been used. They are used to inject a series high impedance to block the harmonic currents or to generate a shunt low impedance path to change the path of the harmonic currents. So, passive filters can be installed both in shunt connection or series topology.

Classification of Passive Filter

The classification of Passive filter is made on the basis of harmonic generation component present in the system and passive component such as resistor; inductor & capacitor connected in the system and are given in detail as

1. Passive series filter
2. Passive shunt filter
3. passive hybrid filter

Passive series filter

A passive series filter has property of purely inductive or LC tuned characteristics. The main circuitry of passive series filter is AC line inductor and DC link filter.

The operating principle of series passive filter is given by above described components which connected in series such that AC line inductor improves the magnitude of inductance in system which diverts the path of current drawn in the rectifier circuit. Thus system harmonic distortion will be going to reduced compare to previous amount of harmonic content.

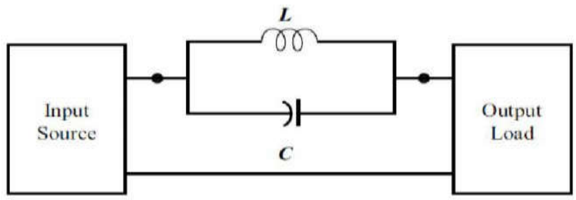

Fig 1. Series Passive Filter

Passive Shunt Filter

Passive Shunt Filter is the most common and effective method for the mitigation of harmonic current in the distribution system. Shunt type passive filter are connected in system parallel with load. Passive filter offer a very low impedance in the network at the tuned frequency to divert the path of all the related current and at given tuned frequency. As passive filter always have tendency to offer some reactive power in the circuit so the design of passive shunt filter always carried out for the two purpose one is the filtering purpose and another one is to provide reactive power compensation for correcting power factor in the circuit at desired level. The advantage of the passive shunt type filter is that it carries just a fraction of current so that system AC power losses are reduced as compare to series type filter.

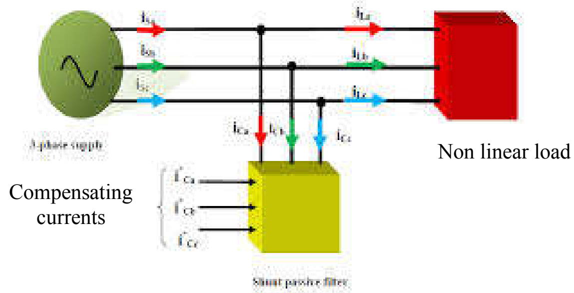

Fig 2. Shunt Passive Filter

The shunt connected passive filters are further classified as band-pass, high pass and C-type filters. Among these types, low pass and high pass filters are the most common types due to their design simplicity and low cost. In Figure 3 most common types of shunt passive filters and their circuit configuration is represented.

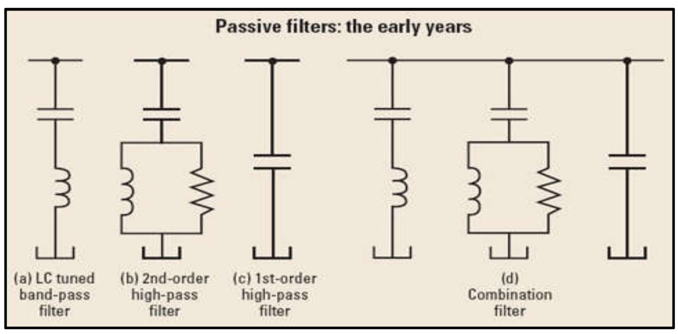

Fig. 3. Shunt Passive Filter

Single tuned filter

Single tuned filters are the generally the most common type of filter which are used in industry for the harmonic mitigation. The basic principle behind using passive filter is that at the tuned frequency filter will offer low impedance to current so that harmonic current will tends to divert in the system. Another important advantage of employing passive filter is that it provides reactive power compensation.

As discussed and easily can be seen from the figure that single tuned filter are the simply series connection of R-L-C component or L-C component. The equation of resonant frequency for the given single tuned frequency is given as:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (6)$$

$\mathbf{f_0}$= Frequency at resonant condition
L=inductance of Filter
C = Capacitance of Filter

Other important term which is mandatory to keep in mind is the design of filter Quality factor. The term quality factor is defined as the ratio of reactance at the resonant condition and resistance of the circuit as follows in the equation

$$Q_f = \frac{X_l or X_c}{R} \qquad (7)$$

Where
$\mathbf{Q_f}$= quality factor
R = resistance of filter

For a distribution system the value of quality factor ranges in between 15 to 80.

Effective Impedance of filter branch is given by

$$Z = R + j(\omega L \quad \frac{1}{\omega C}) \qquad (8)$$

Where =angular frequency (*2πf*) of power system and R, L, C are the resistance, inductance, & capacitance of filter branch respectively. If ***h*** is the ratio between fundamental frequency and harmonic frequency then the value of capacitance and inductance can be found out by following equation

$$X_{Lh} = \text{h x } 2\pi\text{f} \qquad (9)$$

OR

$$X_{Ch} = \frac{1}{h \times 2\pi f} \qquad (10)$$

Again at the tuning of filter the impedance value of filter must be low. It has been found that there is only one way to minimize the impedance of filter is to cancel out the two reactance connected in the circuit which is possible through the resonant condition that is

$$X_{Lh} = X_{Ch}$$

Now when we put the value of X_{Lh}&X_{Ch} inthe equation (11) we can easily get a relationship between harmonic and passive component which is thereby important for the designing of filter which is

$$h = \sqrt{\frac{X_{Ch}}{X_{Lh}}} \qquad (11)$$

Parallel resonant point

Whenever a single tuned harmonic filter is connected with the non- linear load there is some inductance present in the system prior to connected filter which is known as source filter (Ls). This source impedance has a tendency of affecting the resonant condition of system. This total source impedance will has that much impact that resonant condition of system will be just before the tune frequency and operate the filter with some neighboring frequency too. When there are multiple harmonic filters are connected in the system the resonance of filter circuit will be affected for each harmonic filter. When there is some source resistance is connected in the system then the filter operation will affect by this additive source impedance with filter inductance thus new resonant frequency will be given by as follows

$$f_{o(parallelload)} = \frac{1}{2\pi\sqrt{\frac{L_S+L}{C}}} \qquad (12)$$

Now when the graph between frequency & source impedance is drawn as shown in Figure 4

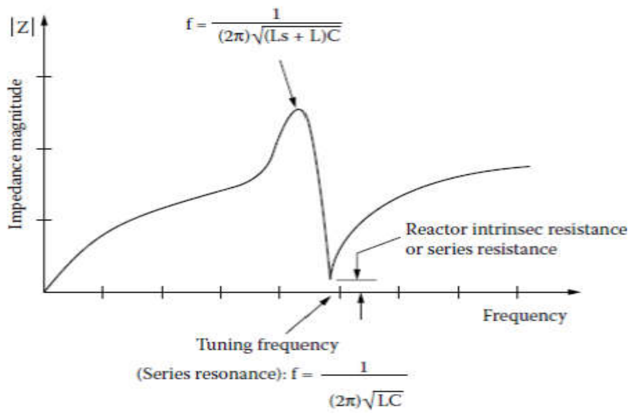

Fig. 4. Resonant point on a single tuned RLC filter

The frequency used for tuning of filter is normally taken below 3 to 5 percent of that of desired value. This will help in account of reducing the detuning effect of filter due to higher value of shift and allows providing low impedance path to harmonic current.

Quality factor

When the system have single tune filter the quality factor has the tendency to release the absorbed energy at the given tuned frequency .In an R-L-C series passive filter quality factor is given as the ratio of reactance present in the system either capacitive or inductive to the resistance of the filter at resonant condition.

$Q_C = \frac{X_L or X_C}{R}$ (13)

Bandwidth of filter

Bandwidth of filter is defined as ratio of harmonic frequency for which it has been designed or tuned frequency to the quality factor of the system at fundamental frequency.

$B = \frac{f_h}{Q_f}$ (14)

High pass filter

The single tuned harmonic filter is not much preferable as various harmonic frequency operated current are flowing in the circuit which forces the single tuned filter to design multi single tuned filter each having specific filtration attitude. For example if there is say 5th, 7th or 11th harmonic are present then for the mitigation single tuned methodology will require three harmonic filter of each respectively. This particular disadvantage of single tuned filter force to consider alternate of power harmonic current filtering technique, known as ***HIGH PASS FILTER.*** Various type of High pass filter arrangement is shown in figure [main]

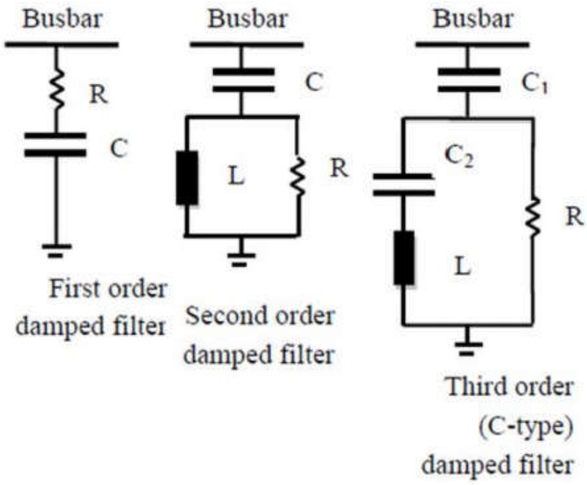

Fig. 5. Different types of high pass filter arrangement

Impedance

Impedance of filter branch at harmonic cut off harmonic frequency is given as

$Z_F(\ ) = \frac{jRhX_L}{R + jRhX_L} \quad j\frac{X_C}{h}$ (15)

Where, X_C = capacitor reactance at the fundamental frequency and given by the equation (15). Now the value of the capacitor reactance at fundamental frequency can be found by given formula

$X_C = \frac{K_V^2}{Q_c}$ (16)

Now the next step is calculate the reactor size trapping the $h_n$thharmonic

$X_l = \frac{X_C}{h_n^2}$ (17)

Calculate the reactor resistance for a specified quality factor (Q)

R=X_n * Q (18)

Where Q varies from 0.5 to 5.

The characteristics reactance is given by

$X_n = X_{cn} = X_{Ln} = \sqrt{X_l \times X_c}$ (19)

Again this can be furthered given as

$X_n = \sqrt{\frac{l}{c}}$ (20)

Now the size of filter is given as

$Q_{filter} = \frac{h_n^2}{(h_n^2 - 1)} Q_c$ (21)

Now the filter impedance is given by

$Z_f(\ ) = \frac{jRhX_l}{R + jRhX_l} \quad j\frac{X_C}{h}$

Or (22)

$Z_f(\ ) = \frac{jR(hX_l)^2}{R^2 + (hX_l)^2} \quad J\left[\frac{R^2 hX_l}{R^2 + (hX_l)^2} \quad \frac{X_C}{h}\right]$

Above discussed method are largely utilized in the passive filter designing calculation for the simple system harmonic mitigation process. These methods are also useful in power factor correction calculation for the power system where power compensation is required.

Real time analysis

The real time analysis is carried out by using non linear load comprising two CFL lamps of rating 23 W and 15 W connected parallel across the supply with the help of power quality analyzer Fluke 435.

Power quality analyzer fluke 434

POWER QUALITY ANALYZER FLUKE 435 isversatile instrument for carrying out Vigilance checks, Surveys, Audits and Periodic Visits for checking at Industrial and Consumers end. The measurements can be done on Live loads.

It is able to do almost all the analysis for single and three Phase supply and capable of analyzing standby Power consumption to the Maximum Demand of Factory.

Fig. 6. Power Quality Analyzer Fluke 435

Experimental Setup, Data Analysis and Design Parameters

Experimental Setup: The main objective of this chapter is to identify the harmonics generated in a non linear load in power system. The configuration of the experimental system block diagram is shown in Figure 13.

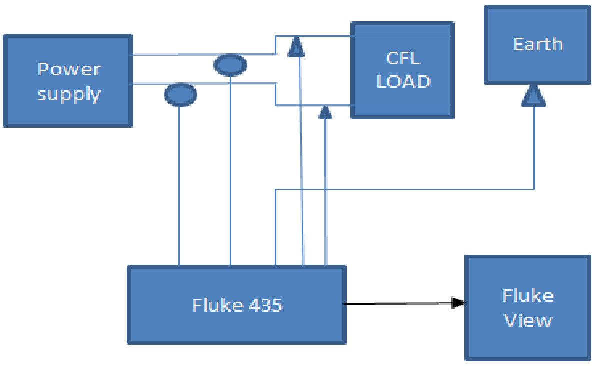

Fig. 7. Experimental Set Up

All experimental data has been collected in power electronics lab of EE Department, NITTTR Chandigarh. This lab has a 23W, 15W parallel connected CFL load set-up.

Fig. 8. CFL load

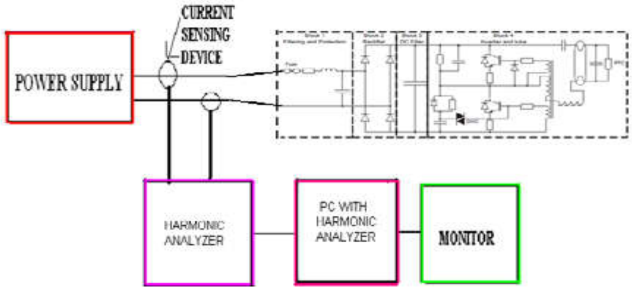

Fig 9. Block diagram of physical set-up for CFL load

Data analysis

Menu displays a Meter screen with important numerical measuring values.

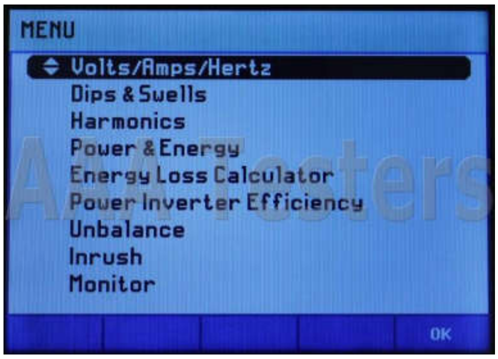

Fig. 10. FLUKE MENU

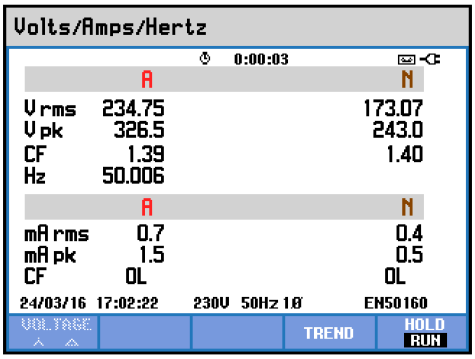

Fig. 11. Volts/Amps/Hertz

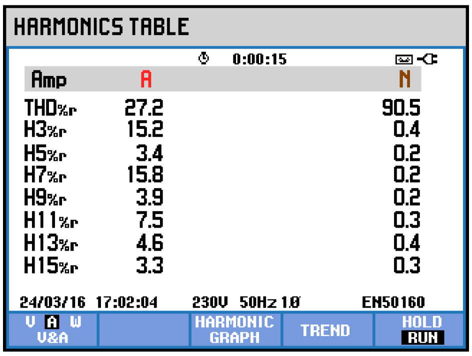

Fig. 12. Harmonic Table

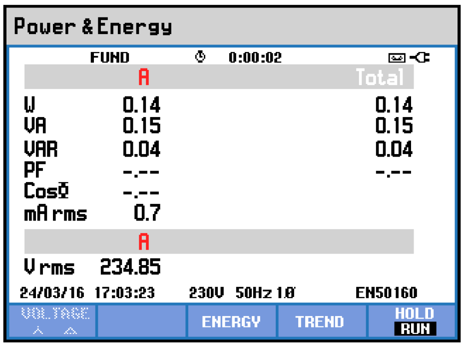

Fig. 13. Power and Energy

Design parametrs of shunt passive filter

Depending on the nominal voltage, harmonic spectrum of the supply current and reactive power measurements the passive filters designed are low pass filter tuned for 5th order harmonic frequency. The subsystem named shunt filter consists of 5th harmonic frequency. Based on the design carried out the filter component values are L=168mH, C=2.5μF, R=1.7Ω.

Conclusion

This paper has presented a brief idea about harmonics and their consequences on the distribution and transmission system. Here we also study the basic harmonic mitigation technique and the designing process of passive shunt filter for two types of passive filter analogy that is single tuned filter and high pass filter. Further real time load comprising two CFL lamp connected in parallel is taken in to consideration for calculating reactive power, harmonic spectrum, etc. using power quality analyzer. Hence Shunt passive filter is thus designed for the given load to mitigate harmonics.

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