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Application of Active Power Filter for Power Factor Correction of Nonlinear Loads

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Abstract: - *Reduction of harmonics is one of the major needs for an ideal power system and it is demanded that it should ideally provide a balanced and pure sinusoidal voltage of constant amplitude to the loads. Loads should draw a current from the line at unity power factor .With the rapid development in power semiconductor devices, power electronics systems have matured and expanded to new and wide applications range from residential, commercial, aerospace to military and others. Power electronics interfaces, such as switchmode power supplies (SMPS) are now clearly superior over the traditional linear power supplies resulting in more and more interfaces switched into power systems. While the SMPSs are highly efficient, but because of their nonlinear behaviour, they draw distorted current from the line, resulting in high total harmonic distortion (THD) and low power factor (PF). To achieve a smaller output voltage ripple, Practical SMPSs use a large electrolytic capacitor in the output side of the single phase rectifier. Since the rectifier diodes conduct only when the line voltage is higher than capacitor voltage, the power supply draws a high rms pulsating line current. As a result high THD and PF are present in such power systems. Hence introduction of such devices in power system needed a solution for harmonic reduction and power factor correction.*

Keywords: - *Nonlinear loads, Harmonic distortion, Power factor, Active power filter, Current compensation.*

I. INTRODUCTION

The growing number of power electronics based equipment has produced an important impact on the quality of electric power supply. Both high power industrial loads and domestic loads cause harmonics in the network voltages. At the same time, much of the equipment causing the disturbance is quite sensitive to deviations from the ideal sinusoidal line voltage. Therefore, the power quality problem may originate in the system or may be caused by the consumer itself. Some of the power equipments causing power quality problems are adjustable speed motor drives (ASDs), electronic power supplies, direct current motor drives, battery chargers, electronic ballasts.

These nonlinear loads draws highly distorted current from the source, which consists of harmonic, active and reactive current components. Harmonic can be defined as sinusoidal component of periodic wave or quantity having frequency that is integral multiple of fundamental frequency. Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to applied voltage. A simple circuit as shown in fig.1 illustrates the concept of current distortion. In this case, a sinusoidal voltage is applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown [1, 2].

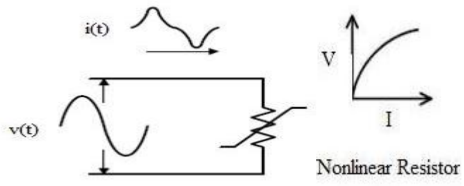

Fig. 1: Current Distortion Caused By Nonlinear Resistor

Nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). These harmonic currents can interact adversely with a wide range of power system equipment most notably capacitors, transformers, and motors causing additional losses, overheating and overloading [3].

For an increasing number of applications conventional equipment is proving insufficient for mitigation of power quality problems. Harmonic distortion has traditionally been dealt with the use of passive LC filters. However the application of passive filters results in parallel resonances with the network impedance, over compensation of reactive power at fundamental frequency, and poor flexibility for dynamic compensation of different harmonic frequency.

The increased severity of power quality in power networks has attracted the attention of power engineers to develop dynamic and adjustable solutions to the power quality problems such equipments generally known as active filters, are also called as active power line conditioners. They are able to compensate current and voltage harmonics, manage reactive power, regulate terminal voltage, suppress flicker, and improve voltage balance in three phase systems. The advantage of active filtering is that it automatically adapts to changes in the network and load fluctuations. They can compensate for several harmonic orders, and are not affected by major changes in network characteristics, eliminating the rise of resonance between the filter and network impedance. Another plus point is that they take up very little space compared with traditional passive components [4].

The concept of power factor in sinusoidal and in nonsinusoidal type of load is discussed in II. Operation of shunt power filter is given in III. Methodology for power factor correction of nonlinear load using single phase shunt active filter is given in IV.

II. CONCEPT OF POWER FACTOR

Power factor is ratio of useful power to perform real work i.e. active power to the power supplied by utility i.e. apparent power.

A. *Power factor in sinusoidal case*

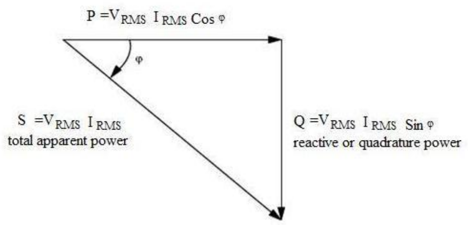

Fig. 2: Power Triangle in Sinusoidal Case

Active power P is commonly referred to as the average power or true power. It represents the useful power expanded by loads to perform real work i.e. to convert electrical energy to another form of energy. In electric power real work is performed for the portion of current that is in phase with the voltage. The active power is the rate at which energy is expanded, dissipated or consumed by the load. P can be computed by averaging the product of the instantaneous voltage and current i.e.

$$P = \frac{1}{T}\int_{0}^{T} v(t)\, i(t)\, dt \qquad (1)$$

This equation is valid for sinusoidal and nonsinusoidal conditions. For sinusoidal case there is only one phase angle between voltage and current. Since only fundamental frequency is present therefore power factor is known as Displacement power factor.

$$\text{Displacement Power Factor} = \frac{P_1}{S_1} = \frac{V_{rms} I_{rms} \cos\emptyset}{V_{rms} I_{rms}} \qquad (2)$$

Where S_1 is the apparent power is a measure of potential impact of load on the thermal capability of the system. P_1 defines how much active power being consumed while S_1 defines capacity of the system to deliver P_1. Q is the reactive power that does no real work and generally associated with the reactive elements. For example power appearing across the inductance sloshes back and forth between the inductance itself and the power system source producing no network. For this reason it is known as reactive power since no power is
dissipated or expended. It is expressed in the units of Vars.

$$Q = S \sin\emptyset = V_{rms} I_{rms} \sin\emptyset \qquad (3)$$

B. *Power factor in nonsinusoidal case*

In nonsinusoidal case the computation of active power must include contributions from all harmonic components, thus it is the sum of active power at each harmonic. Reactive power consists of the sum of the traditional reactive power value at each frequency. D represents all the cross products of voltage and current at different frequencies. D is the distortion power. Unit is volt ampere.

$$S = \sqrt{P^2 + Q^2 + D^2} \qquad (4)$$

In nonsinusoidal case the power factor takes into account the contributions from all active power including both fundamental and harmonic frequencies known as True Power Factor. The true power factor is simply the ratio of total active power for all frequencies to the apparent power delivered by the utility.

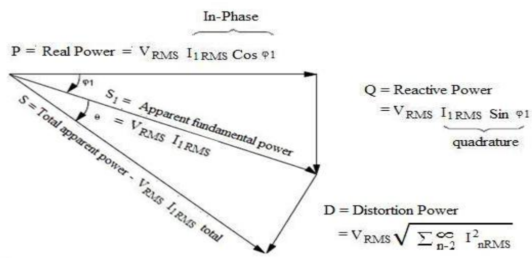

Fig. 3: Power Triangle in Nonsinusoidal Case

Assume that the main voltage is an ideal sinusoidal voltage waveform , its rms value is

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} \qquad (5)$$

If the current has a periodic nonsinusoidal waveform, the Fourier transform can be applied

$$I_{rmsTotal} = \sqrt{I_0^2 + I_{1rms}^2 + I_{2rms}^2 + --- + I_{hrms}^2} \qquad (6)$$

Where I_0 is the DC component of the current. $I_{1rms}$the fundamental component of the rms current and I_{2rms} to I_{nrms} the harmonics. For a pure AC signal

I_0= 0. The fundamental of the rms current has an inphase component I_{1rmsP} and a quadrature component I_{1rmsQ}. So the rms current can be expressed as

$$I_{rmsTotal} = \sqrt{I_{1rmsP}^2 + I_{1rmsQ}^2 + - - - + \sum_{h=2}^{\infty} I_{hrms}^2}$$

Then the real power is given by $P = V_{rms} I_{1rmsP}$. As $\emptyset_1$ is the displacement angle between the input voltage and the inphase component of the fundamental current

$$I_{1rmsP} = I_{1rms} \cos \emptyset_1 \quad (8)$$

And

$$P = V_{rms} I_{1rms} \cos \emptyset_1 \quad (9)$$

$$S = V_{rms} I_{rms\,Total} \quad (10)$$

Then power factor can be calculated as

$$\text{Power Factor} = \frac{P}{S} = \frac{I_{1rms} \cos \emptyset_1}{I_{rms\,Total}} \quad (11)$$

One can introduce the k factor by $k = \frac{I_{1rms}}{I_{rms\,Total}} = \cos \theta$

Where θ is the distortion angle. The k factor is linked to the harmonic content of the current. If the harmonic content of $I_{rms\,Total}$ is approaching to zero. K→1. Finally Power Factor can be expressed by P.F.= $\cos \emptyset_1 \cos \theta$. Improving power factor means to improve both factors i.e. as $\emptyset_1$→1; $\cos \emptyset_1$→1 reduce phase lag between I and V, and as θ→1; $\cos \theta$→1 reduce harmonic components of line current I which can be achieved by means of active filtering effectively [5].

Then the problem can be formulated as, to design a single phase shunt active filter to drain harmonics and reactive component of a load current to improve power quality of the electric grid.

III. SHUNT ACTIVE POWER FILTER

This is most important configuration and widely used in active filtering applications. A shunt APF consists of controllable voltage or current source. The voltage source inverter (VSI) based shunt APF is the most common type used today, due to its well known topology and straight forward installation procedure. Fig. 4 shows the principle configuration of a VSI based shunt APF. It consists of a DC bus capacitor (C_f), power electronics switches, and interfacing inductors (L_f). Shunt APF acts as a current source, compensating the harmonic currents due to nonlinear loads. The operation of shunt APF is based on injection of compensating current which is equivalent to the distorted current. This is achieved by "shaping" the compensation current waveform (i_f), using the VSI switches. The shape of compensation current is obtained by measuring the load current (i_L) and subtracting it from a sinusoidal reference. The aim of shunt APF is to obtain a sinusoidal source current (i_s) using the relationship: $i_s = i_L - i_f$.

(7)

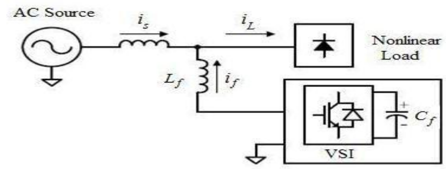

Fig. 4: Principle Configuration of a VSI Based Shunt APF

Suppose the nonlinear load current can be written as the sum of the fundamental current component ($i_{L,f}$) and the current harmonics ($i_{L,h}$) according to

$$i_L = i_{L,f} + i_{L,h} \quad (12)$$

then the injected current by the shunt APF should be

$$i_f = i_{L,h} \quad (13)$$

The resulting source current is

$$i_s = i_L - i_f = i_{L,f} \quad (14)$$

Which only contains the fundamental component of the nonlinear load current and thus free from harmonics. Fig. 5 shows the ideal source current when the shunt APF current completely cancels the current harmonics from the nonlinear load, resulting in a harmonic free source current. From the nonlinear load current point of view, the shunt APF can be regarded as a varying shunt impedance. The impedance is zero, or at least small, for the harmonic frequencies and infinite in terms of the fundamental frequency. As a result, reduction in the voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Shunt APFs have the advantage of carrying only compensation current plus a small amount of active fundamental current supplied to compensate for system losses. It can also contribute to reactive power compensation. Moreover, it is also possible to connect several shunt APFs in parallel to cater for higher currents, which makes this type of circuit suitable for a wide range of power ratings [6].

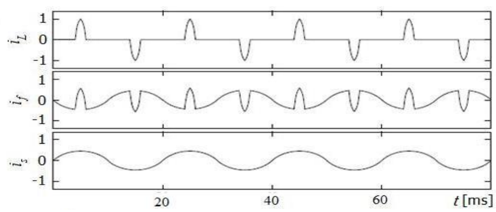

Fig. 5: Shunt APF Harmonic Filtering Operation Principle

IV. METHODOLOGY

The block diagram of the proposed system of shunt active filter for power factor correction on nonlinear load is as shown in fig.6

The converter which is used as the active filter is a full bridge voltage source inverter using IGBTs (IRGP4PC3OUD), due to its current reversibility characteristics. The full bridge inverter is connected in parallel with AC mains through a filter inductance LF and the DC side of the inverter is connected to the capacitor CF.

By appropriate control of the full bridge switches (IGBTs), the filter current cancels the harmonic component of the nonlinear loads, resulting in a sinusoid input current in phase with the AC main voltage.

The control block consists of two loops. The outer voltage loop consists of comparison of voltage across DC bus i.e. electrolytic capacitor with a reference voltage. The resulting error is injected in an appropriate voltage controller. The output of voltage controller is multiplied by a sinusoidal signal proportional and inphase with the input voltage. The result of this multiplication keeps the voltage across the DC bus capacitor constant. The inner current loop consists of the comparison of reference current obtained from band pass filter tuned at fundamental frequency and the line current. The resulting error is injected in an appropriate current controller which consists of PI controller. The output of this controller is compared with a triangular signal, generating the drive signals to the switches. The control strategy of the active power filter allows the compensation of the harmonics and phase displacement of the input current for the nonlinear load .

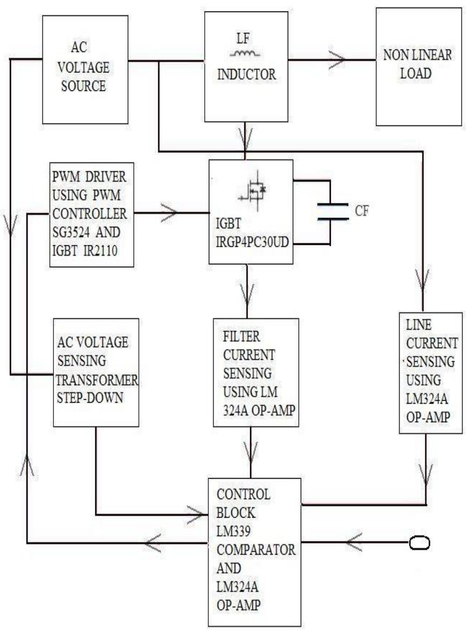

Fig.6: Block Diagram for P.F. Improvement using Shunt APF

V. CONCLUSION

A block diagram is designed for power factor correction of nonlinear load as a prototype model in this study. The compensation effectiveness of an active power filter depends on its ability to follow with a minimum error and time delay, the reference signal calculated to compensate the distorted load current. Hence decide control scheme for APF is the main task also deciding power circuit topology to give lossless and fast switching response for compensation current is equally important.

REFERENCES

[1] Rahul Virmani, Prerna Gaur, Himanshu Santosi, A.P.Mittal, Bhim Singh, "Performance Comparison of UPQC and Active Power Filters For A Nonlinear Load ", 978-1-4244-7781-4110, *IEEE* 2010.

[2] Mikko Rautimo, Mika Salo, and Heikki Tuusa, "Comparison of Voltage source And Current source Shunt Active Power Filters", *IEEE Transaction on Power electronics,*vol.22, No.22,March 2003.

[3] Roger C. Dugan, "Electrical Power Quality".2nd ed.,Chap.5 and 6,PP167-294, Tata McGraw Hill, Professional Engineering.

[4] J.G.Pinto, Pedro Neves, Ricardo Pregitzer, Luis F.C. Monteiro, Joao L.Afonso,"Single Phase Shunt Active Filter With Digital Control" *POCTI/ESE* 48242/2002.

[5] L. Wuidart , Application note on "Understanding Power Factor", *AN824/1003*.

[6] Tan Perng Cheng , "A Single Phase Hybrid Active Power Filter with PhotoVoltaic Application", *PSZ 19:16* (Pind. 1/97).

[7] P. M. Sonwane, B.E. Kushare, "Capacitor Placement for Loss Reduction in 132 kV Raymond Substation Using DigSilent", *NPATS Nashik,,* December 2/3, 2011.