A Comprehensive Review of Harmonics Effects on Electrical Power Quality

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***Abstract* - This paper describes the concept of different method to reduce the harmonics in power system. In a power system harmonics caused by highly nonlinear devices degrade its performance. Thus harmonics is important to analyze and criticize the various harmonic problems in power system and acquaint the appropriate solution technique. Now day modern power systems are continuously being expand and upgraded to cater the require of ever growing power demand. Power quality (PQ) issue has attained considerable attention in the decade due to large going through of power electronics based load and microprocessor based controlled load. This project presents the effect of harmonics distortion of load voltage and current on distribution transformer. The synchronous d-q-o reference frame algorithm is also used to recognize and essence harmonic distortion. This project presents compensating reactive power and low order harmonics generated by three phases nonlinear load, three phase shunt active power filter with pulse width modulation technique to make the total input current drawn from the three phase AC main as sinusoidal.**

Keywords: Harmonics, Power Quality, three phases shunt Active filter

I. INTRODUCTION

In recent years both consumers and power engineers have being concentrate on the “electrical power quality” i.e. humiliate of current and voltage due to harmonics, low power factor etc. Importance to electricity to consumers at all levels of usage; Power quality is an issue that is becoming increasingly [1]. In network like excess heat and power losses, harmonics provide main problems. Limitation of harmonics seems to be vital.

Nowadays, in distortion recognition and elimination active power filter play effective role. Efficiency increment and dc offset elimination compare to bipolar PWM technique; Current control technique based on unipolar PWM provides better stability and compensation with loss reduction. The resulting of total current drawn from the ac main is sinusoidal when an active power filter is a device that is connected in parallel to and cancels the reactive and harmonic currents from a group of nonlinear load [2]. An active power filter converts the pulsating output of a rectifier into steady state dc level is known as filter. An active power filter out the undesirable ac component and allows only dc component to reach the load.

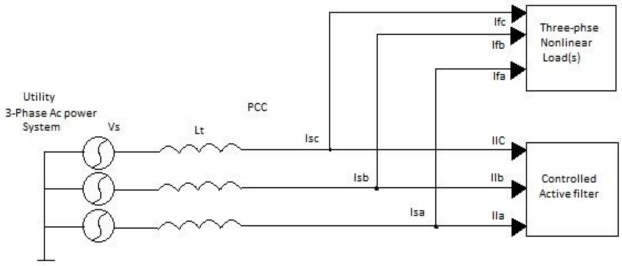

Fig.1: Block diagram of the system

II. DIFFICULTIES IN POWER QUALITY

Institute of Electrical and Electronic Engineers (IEEE) standard IEEE1100 defines power quality as “the abstraction of powering and grounding reactivity electronic equipment in a mode suitable for the equipment” [3].

2.1 Power quality problems

Nowadays, electronic equipment are widely use so that they are affected power quality. Power quality problems are given bellow:

- **Voltage sag (or dip) :**
  A decrease of normal voltage level between 10 and 90 % of the nominal rms voltage at the power frequency, for durations of 1/2 cycle to 1 minute. Causes of the Voltage sag are faults on the transmission or distribution network and also fault in consumer’s installation
- **Very short interruptions** :
  Total interruption of electrical supply for duration from few milliseconds to one or two second. Causes of very short interrupt are mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.
- **Voltage spike :**
  Very fast variation of voltage value for durations from a several microseconds to few milliseconds. This variations may reach thousand of voltage, even in low voltage. Causes of voltage spike are lightning, switching of lines or power factor correction

capacitors, disconnection of heavy loads.

- **Voltage swell :**
  Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few second. Cause of voltage swell are star/stop of heavy loads, badly dimensioned power sources, badly regulated transformers.
- **Harmonic distortion :**
  Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency. Causes of harmonics distortion are electrical machines working above the knee of the magnetization curve, arc furnaces, welding machines, rectifiers, and DC brush motor.
- **Noise :**
  Superimposing of high frequency signals on the waveform of the power-system of 0 to 30 Hz. Causes of noise are electromagnetic interferences provoked by hertzian waves such as microwaves, television diffusion, and radiation due to welding machine.

III. ORIGIN OF POWER SYSATEM HARMONICS

The characteristic behavior of non-linear loads is that they draw distorted current waveform even through the supply voltage is sinusoidal. In general most apparatus only generates odd harmonics [4][5]. For each devices, the current distortion is changes due to the consumption of active power, background voltage distortion and changes in the source impedance.

In residential and industrial use single and three phases non-linear loads are common.

- **Single Phase Loads**
  - In general electronics equipment supplied from the low voltage power system, rectifiers the ac to dc power for internal use at different dc voltage levels.
  - Such equipment’s consist of :
    - small UPS
    - TV’s – Video recorders, computers
    - Printers, Microwave ovens
    - Adjustable Speed Drives, Fluorescent lighting etc.
- **Three phase Loads**
  - Higher power application, three phase rectifier are used. Capacitor for the lower power application the rectifier can either controlled or non-controlled and can consist of in most case. In generally larger rectifiers a smoothing inductor and capacitor are use. Industry application and in the power system mainly use three phase group rectifier. Some examples are :
  - Adjustable speed drives, Large UPS’s, Arc furnaces
  - SVC’s
- **Harmonics Generated by Transformers**
  - In power system, harmonics are largely produce by transformers. A transformer is basically designed to optimum use of magnetic core materials, resulting in a peak magnetic flux density in transformer steady state.
  - When causes saturation, with such peak operating magnetic flux design, the core materials may be subjected to large magnetic flux density. The magnetizing current has all the odd harmonics, when the converter transformer core is in saturation.
- **Harmonics Generated by Rotating Machine**
  - The practical and economical design electrical machines are also main harmonic contributors in power systems. In the distribution of windings

IV SHUNT ACTIVE FILTER

A shunt active filter is representation to be coupled with in parallel with the load [2]. It detects the harmonic current of load and introduce into the system a compensating current, indistinguishable with the load harmonic current but in facing phase. Therefore, the net current drawn from the distribution network at the point of combine of filter and the load will be a sinusoidal current of only fundamental frequency. Fig 2 shows the proposition of operation and the connection scheme of a shunt active filter.

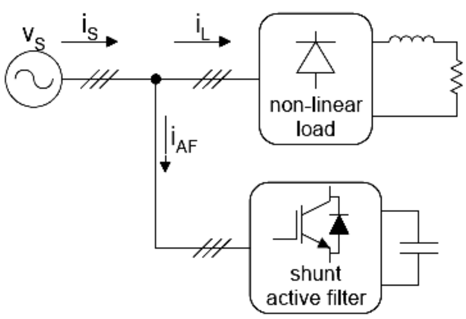

Fig.2: shunt active filter

Harmonic current and/or negative sequence current compensation and dc link voltage mandate between both active filters. The impetus of the shunt active filter is mainly to compensate current harmonics generated from the distributed lines. Thus, shunt active filter has to scrutinize the voltage at the point of installation and is controlled as to present infinite impedance for the fundamental frequencies and a low impedance for the harmonic frequencies. In order to accomplish other functions, as reactive power compensation, Flicker/imbalance compensation etc., the overall system must be equipped with other assessment or feed forward control loops.

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is delineate to operate, that combine with the fundamental voltage or current, and generate waveform distortion. It is prompt by nonlinear loads. Lower order harmonic is describe as the harmonic component whose frequency is nearest to fundamental one and its amplitude is greater than or equal to 3% of the fundamental component.

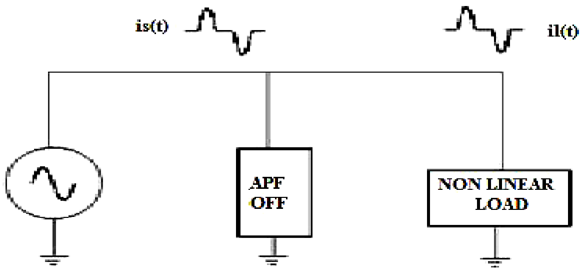

Fig.3: Block diagram of a simple power system with APF OFF

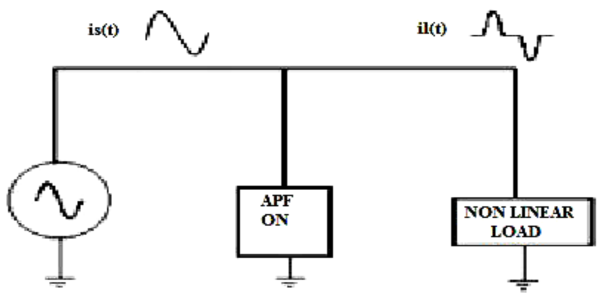

Fig.4: Block diagram of a simple power system with APF ON

The above diagrams narrate the function of Active Power Filter in a system. When the active power filter is OFF, the input current is deformed. When the active power filter is ON, the input current is sinusoidal and the distortions are reduced, active power filter will inject the harmonic currents 180 degree out of phase in to the Point of Common Coupling (PCC) as shown in Fig.1.

V. DISTORTION DETECTION BY REFERENCE FRAME D-Q-O

Different methods are used to recognize and extract harmonic distortions which are categorize as frequency, time and time frequency approaches. (FFT) Fast Fourier Transformer [6] and adaptive neural network [7] in frequency domain, Coexistent reference frame theory d-q-o (Synchronous Reference Frame) [8] and instantaneous active and reactive power theory (Procedure Qualification Record) [9] in time domain and the other methods such as proficiency of small wave and one-cycle control or objectivity with suitable digital or analogue filters have wide applications.

In this approach, reference frame algorithm is used due to simplicity in calculation and enactment. transformed to d-q-o by park equation , Having measured three phase currents in a-b-c orientation:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{4\pi}{3}\right) \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (1)$$

$$\theta = \theta_0 + \int_0^i \omega t dt$$

Lexicon rotates synchronous with fundamental currents. Therefore, time variant currents with fundamental frequencies would be abiding after transformation. Yet, harmonics with separate speeds remain time variant in this frame [2]. Thus, currents would be different simultaneously to DC and AC parts.

Diodes and IGBT are conduction and switching losses in inverters increase voltage wavelet in DC-link which affects the performance of the filter. These consequences are controlled by a feedback loop where PI regulator compares the DC-link voltage with a reference voltage to extract d component of current.

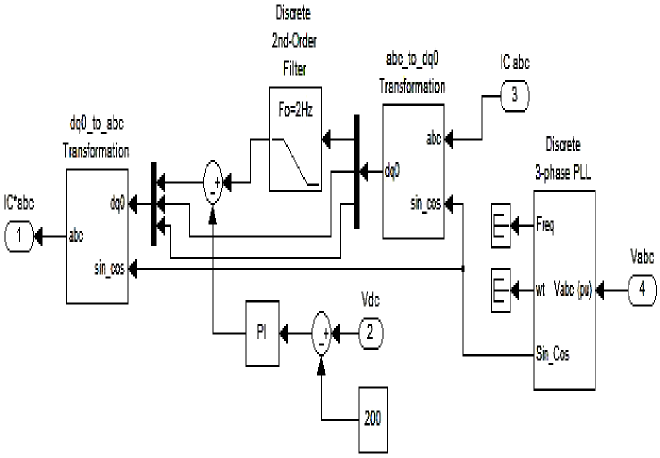

Fig.5 Synchronous d-q-o reference frame based compensation algorithm.

VI. UNIPOLAR PULSE WIDTH MODULATION

In the Fig.6 shows a full bridge Three-phase inverter diagram that is connected in parallel to a non-linear load. Unipolar PWM method can be controlled the inverter.

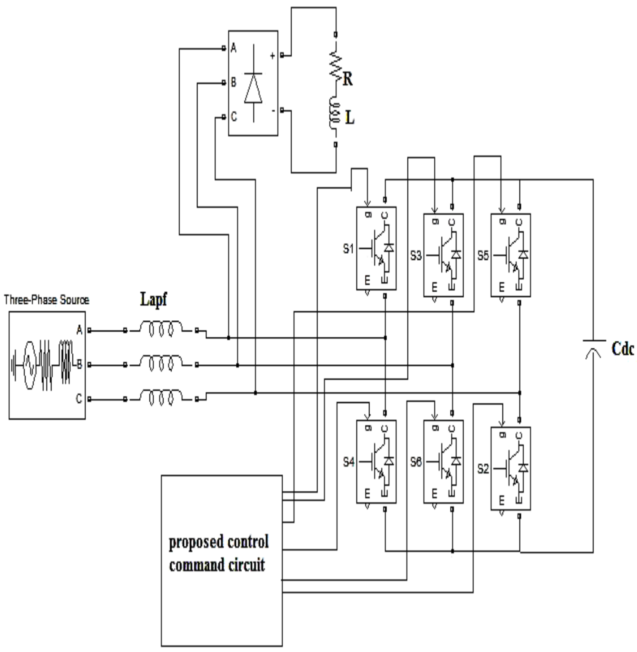

Fig.6: Typical shunt Active Power Filter connected in parallel with nonlinear load.

A. Unipolar control

In this approach have four switching states. In unipolar control, when Vg>0 (reference current in flourishing slope (dic/dt>0), S1 and S2 turn on and off periodically in switching cycles, S3 is on in the reference current half cycle. At that time V0 and zero voltages generate between P and N so error signal slope is negative in hysteresis band and periodically decreases and increase. Originated different current in reference current half cycle is as follows:

$$\frac{di_c}{dt} = \frac{1}{L}\left(\left|v_g\right| + \left|v_0\right|\right) \text{First half cycle of switching}$$

$$\frac{di_c}{dt} = \frac{1}{L}\left(\left|v_g\right|\right) \quad \text{Second half cycle of switching}$$

So that output voltages have three levels, +V0,-V0 and zero, the two switching states (similar to bipolar) cannot control the load current sufficiently. In this case to achieve different switching state more bands are required corresponding to different output voltages. As shown in Fig.5, when the reference current has a positive at that time dic/dt from 0- 90° and the load current can follow the reference current based on two voltage levels, +V0 and zero volts and when the reference current has a negative dic/dt, the output voltage of inverter has to be different in such a case to generate negative dic/dt for the load current, thus more band are required to change the voltage level from +V0&0 to
–V0&0. Variation of Current in the second half cycle of the reference current is:

$$\frac{di_c}{dt} = \frac{1}{L}\left(-\ \left|v_g\right| -\ v_0\right) \quad \text{First half cycle of switching}$$

$$\frac{di_c}{dt} = \frac{1}{L}\left(-\ \left|v_g\right|\right) \quad \text{Second half cycle of switching}$$

VII. HARMONIC REACTION ON TRANSFORMER LOSSES

IN this section is describing the contribution made by harmonic currents to different loss components of the transformer. The loss elment get affected by the harmonic current loading are the *I2R* loss, winding eddy current loss and the other stray losses.

a) **Harmonic current effect on I2R loss**
If I2R loss will be increase, the rms value of the load current is increased due to harmonic component.

b) **Harmonic current effect on Pec**
Winding eddy current loss (*P*ec) in the power frequency gamut tends to be proportional to the square of the load current and the square of frequency. In transformers supplying load currents Harmonic current characteristic that can cause excessive winding loss and hence abnormal winding temperature rise.

c) **Harmonic current effect on Posl**
It is identify that other stray loss (*P*osls) in the core, clamps, and structural parts will also increase at a rate proportional to the square of the load current. However, rate of proportional to the square of the frequency these losses will not increase, as in winding eddy current losses. Studies at developer and other researchers have shown that the eddy current loss in bus bars, connecting and constitutional parts increase by a harmonic proponent factor of 0.8 or less [10].

d) **DC Components of load current**
Harmonic load currents are customarily accompanied by a dc component in the load current. Slightly the transformer core loss increase a dc component of load current will increase, but will increase the magnetizing current and audible sound level more substantially. Comparatively small dc components (up to the rms magnitude of the transformer excitation current at rated voltage) are anticipate to have no effect on the load carrying capability of a transformer determined by this recommended practice. Higher dc current components may adversely affect transformer capability and should be avoided.

e) **Effect on top oil rise**
For liquid-filled transformers, the top oil rise (θto) will increase as the total load losses increase with harmonic loading. Any increase in other stray loss (*P*osl) will primarily affect the top oil rise.

VIII. DUAL INSTANTANEOUS POWER THEORY

The based on generalized p-q theory is used the proposed to control algorithm. Dual instantaneous power may be applied to both harmonic voltage injection and harmonic current injection. In this algorithm, the compensation voltage references are extracted directly. Therefore, the reckoning of the compensation voltage reference will be much simpler than for other control algorithms. In further, the difficulty of finding the voltage reference gain disappears.

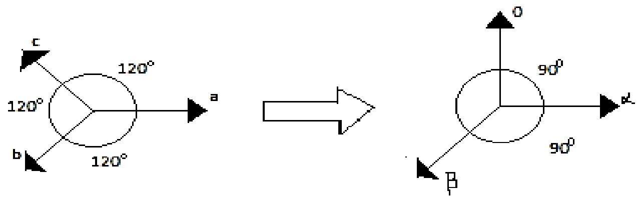

Fig 7 Three phase to two phase conversion

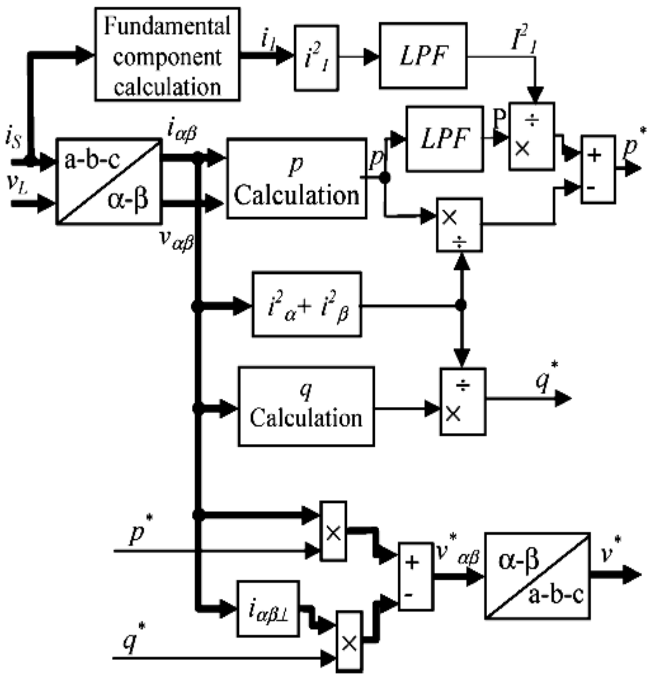

Fig 8 Dual instantaneous power theory

IX. CONCLUSION

In electrical power systems Flexible Alternating-current Transmission System (FACTS) is recent technological development. FACTS construct on the great many proceed in high-current, high-power semiconductor device technology, digital control and signal gained with commissioning and over many decades, may have provided the driving forces for searching deeper into the use of emerging power electronic equipment and techniques.

As we all know that nowadays the most efficient way to compensate reactive power and low order harmonics the active power filter technology is used, which has been generated due to nonlinear loads of the systems. So eventually synchronous reference frame theory for distortion detection and three phase shunt active power filter with unipolar pulse with modulation technique to compensate reactive power and low order harmonics which has been generated by the three phase nonlinear loads of the system has been successfully implemented. So that the final total current drawn from the three phase ac main is sinusoidal, Thus problems like power losses and Excess heat caused by the harmonics in network has been controlled and solved

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