Power Quality Improvement of LV Systems using Active Power Filters

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***Abstract*—We live in a system where we give liberty to an ordinary power consumer to add in his personal power generation source (Domestic Generators, Solar plants, Wind Turbines etc) in to the National Grid. These scattered generation sources usually operate on switching devices such as AVRs, Inverters and Buck-Boost Converters. These switching devices cause a harmonic effect on fundamental and high switching frequencies inject frequencies that are multiples of the fundamental. These injected harmonics are severe for the system since they produce various problems like voltage fluctuations, increased THD etc. This work proposes a shunt active power filter for small scale consumers who also rely on alternative source of generation for their facility. The system is verified by simulation using MATLAB/SIMULINK simulation package.**

I. Introduction

The term power quality has become one of the most prolific buzzwords in the power industry since the late 1980s. It is an umbrella concept for a multitude of individual types of power system disturbances. Power quality is simply the interaction of electrical power with electrical equipment. As a general statement, any deviation from normal of a voltage source (either DC or AC) can be classified as a power quality issue. Each type of electrical equipment will be affected differently by power quality issues.

A load is considered non-linear if its impedance changes with the applied voltage. The changing impedance means that the current drawn by the non-linear load will not be sinusoidal even when it is connected to a sinusoidal voltage. These non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it. Harmonic problems are now common in not only industrial applications but in commercial buildings as well. This is primarily due to new power conversion technologies, such as the Switch-mode Power Supply (SMPS), which can be found in virtually every power electronic device (computers, servers, monitors, printers, photocopiers, telecom systems, broadcasting equipment, banking machines, etc.). Their proliferation has made them a substantial portion of the total load in most commercial buildings.

Several configurations [2][3][4] with different control algorithms have been presented. The APF proposed in this paper uses Unit vector to compensate the harmonic currents in the line.

II. Active Power Filters

A. A Brief Introduction

Active power Filters, also known as Active Line conditioners, are systems consisting of active devices such as power converters. These filters are used to compensate voltage and current harmonics, reactive power,reduce voltage fluctuations, improve voltage balance in polyphase systems and regulate line voltages.

B. Types of APF

There are three configurations of APF usualy, Shunt, Series and Hybrid.

1) Shunt Active Power Filter: Shunt Active Power filters are connected to power line in parallel. They cancel the current harmonics by injecting equal and out of phase harmonic compensating currents. In this configuration the APF can also cater for the power factor of load. The source takes up APF and Nonlinear load, combined, as a resistor and the source current becomes in phase with source voltage hence the source power factor improves. Fig 1a showshe shunt APF configuration.

2) Series Active Power Filter: Series Active Filters are connected in series to the power line through coupling transformers. They isolate the high frequency components of current by creating a high impedance path for them and forcing them to pass through the LC filter placed parallel between the harmonic insulator and load. The voltage that is needed to cancel the high frequency component is utilized as the high impedance pathfor the component. Fig 1b shows the series APF.

3) Hybrid Active Power Filter: Hybrid Active Power filters are implemented with a passive LC filter connected in series with an active filter as shown in Fig 1c. This system is connected to the power line through a coupling transformer. The high frequency currents are forced to circulate through the passive filter by imposing a high voltage. These filters were introduced in 80s to improve the characteristics of passive filters.

C. Advantages over Passive Filters

1. Adaptability to changes in network and system loadings is higher.
2. Unlike passive, a single APF can respond and eliminate several orders of harmonics.
3. Resonance between filter inductance and network is eliminated.
4. They are very compact as compared to traditional Passive Filters.

III. Three Phase Shunt APF

A. Basic Principle

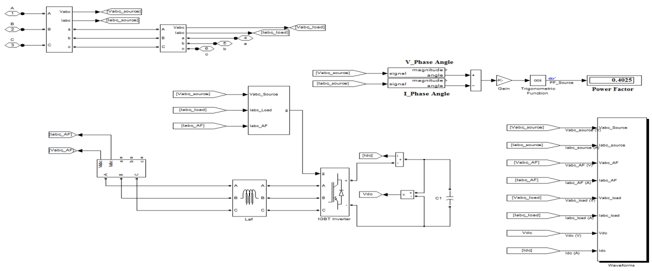
Shunt Active Power Filter is connected in parallel to power line. The detection unit absorbs the running load and measures the amount of harmonic currents and reactive power present in the load current. These harmonic currents when pass through source impedance they load the source. Upon detection of these harmonic currents, APF generates (utilizing the DC side capacitor) the same amount of current which is out of phase to the harmonic content present in the line. This out of phase current when injected into power line, it cancels the harmonic currents of the line and power factor is improved to ideal maximum, hence the source current is sinusoidal.[3]

B. Basic Dynamics

As shown in Fig 1, the APF comprises of a controlled voltage source inverter (VSI) with DC side as a capacitor. The VSI is used to $generate$ the harmonic content needed (determined by the system variables detected) and the DC side capacitor is available for provision of APF input ripple current and is the main storage of reactive energy. A PI controller could be used to provide a constant DC voltage at the inverter input. An interfacing inductor is used at the point of coupling to mitigate the switching frequencies.
The source current carries both load and harmonic currents drawn from source, $IS = IL + IH$, however after compensation from APF the source current carries only the active part of load current and harmonic part is cancelled by the APF.[3]

IV. PROPOSED SYSTEM

The system that has been taken under consideration is a power system that is feeding a certain amount of non-linear load. Harmonics are introduced in the line currents due to non-linearity of loads and as these harmonic currents pass through source impedance they load the source to produce reactive power hence degrading the power factor. Power factor degradation reduces system stability and affects the performance of the system.



A. LOAD UNDER CONSIDERATION

Since switching mechanisms are the basic reason of non linear impedance hence house hold and general daily life loads like Motors, Fans, Computers, Juicers, Iron press, etc are taken into consideration. For the purpose of larger picture and simplification, rectifiers feeding loads are used. In addition to this, two converter circuits, fed by three phase transformers, are also feeding RL loads. A passive linear load consisting of Resistive and inductive component is also realized.

PARAMETER	VALUE
Mains Voltage	1 p.u.
Load kVA	1 p.u.
Total Harmonic Distortion (THD)	26.55%
Power Factor	0.4

The APF proposed for the problem discussed in earlier sections is a three phase Active Power Filter that is connected to the power line through an interfacing inductor. The system prototype is given under along with the summary of parameters realized in simulation

V. THE DYNAMIC BEHAVIOR AND CONTROL

A. System Variables Detection

This is the first stage of active power filter working process. The system variables including source voltages and load currents are detected and then passed to the reference current generator stage.

B. Reference Signal Generation

It is responsible to generate the reference sine wave sin (wt) with unity amplitude and synchronous with the source voltage. The source voltage sensed in the variable detection stage is divided by its magnitude. This results in a unity amplitude sine wave which is in phase with the source voltage. The load current is processed through an RMS BLOCK to have its peak value.

$$\frac{V_m Sin(wt)}{V_m} = Sin(wt)$$

$$I_{L-RMS}(t) * \sqrt{2} = I_{L-MAX} = I_{RCM}$$

The unit amplitude sine wave obtained from source voltage is multiplied with the load current peak to have the reference current.

$$i_{rc}(t) = I_{RCM} Sin(wt)$$

C. Compensation Current Estimator

The reference current obtained from the reference current stage is then passed to compensation current estimator. Here the reference current is subtracted from the total load current to have the harmonic current which is flowing in the system. This harmonic content is the current that is to be compensated in the system.

$$i_{cc}(t) = i_L(t) - i_{rc}(t)$$

D. Hysteresis Controller

The current feedback path of active power filter brings the output current of APF in this stage and here it is subtracted from compensation current obtained from the previous block.

$$i_{HYS}(t) = i_{cc}(t) - i_f(t)$$

In this control scheme, a signal deviation (H) is designed and imposed on Icc (t) to form the upper and lower limits of a hysteresis band. The If (t) is then measured and compared with Icc (t); the resulting error is subjected to a hysteresis controller to determine the gating signals when exceeds the upper or lower limits set by (estimated reference signal + 2H) or (estimated reference signal - 2H). As long as the error is within the hysteresis band, no switching action is taken. Switching occurs whenever the error hits the hysteresis band.

1) Gate Pulse generator: The compared result from the hysteresis controller is passed to this stage. Here the current obtained from previous stage is limited to a unit value band using relays and the relay output is used as gating signals.

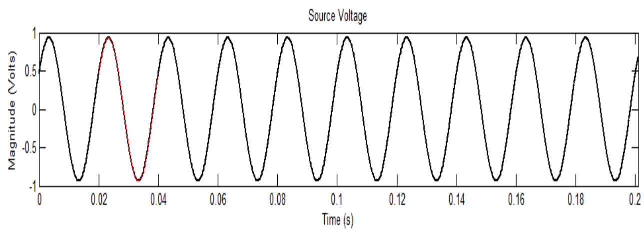
$$GateSignal = \begin{Bmatrix} 1 & if error >= H \\ 0 & if error < H \end{Bmatrix}$$

2) Power Inverter: The inverter block used is a 3phase IGBT based inverter which uses DC Bus of 440V. The Gating signals obtained are used as firing signals for the IGBTs. The inverter output is the current that is to be injected in the system to mitigate harmonics and improve the power factor.

VI. Simulation

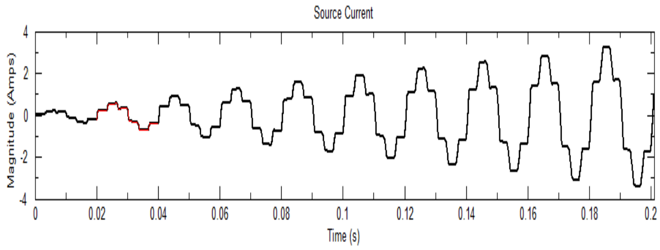
A. Before Compensation

The source voltage measured at source end:



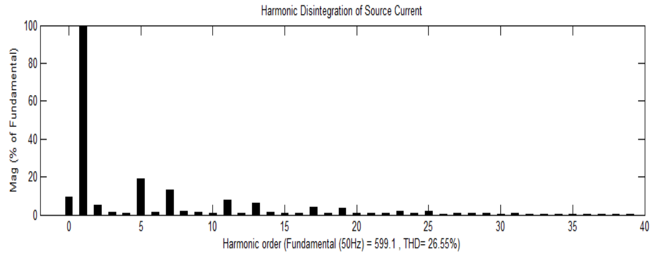
1. Source Voltage

The source current prior to compensation:



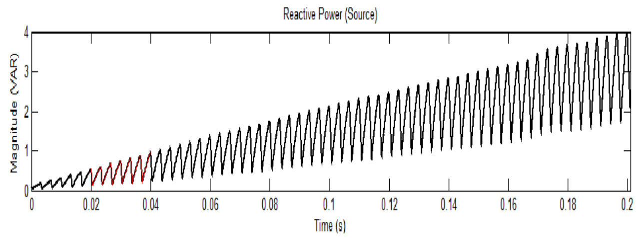
2. Source Current

The breakup of frequencies of fundamental multiples in Source current:



3. Source Current harmonic disintegration

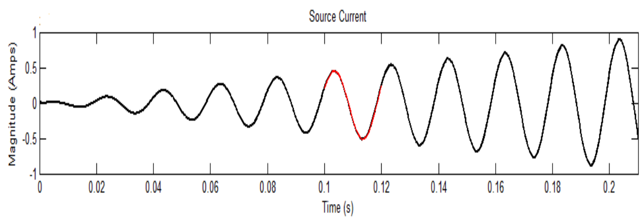
The reactive power supplied by source due to poor power quality:



4. Reactive Power drawn from Source

B. After Compensation

The source current after compensation:



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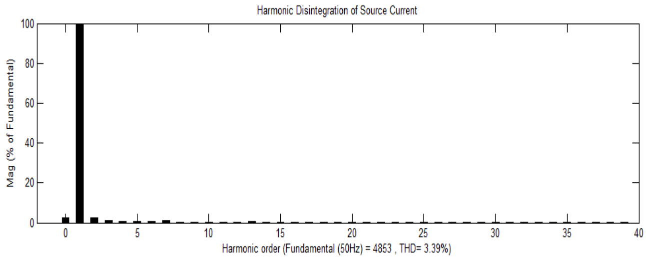
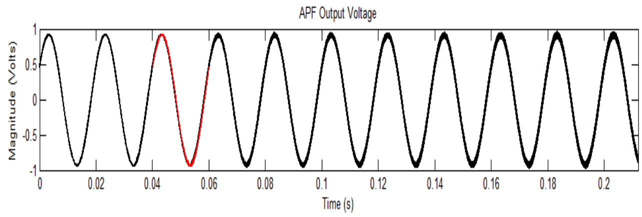
5. Source Current

The breakup of frequencies of fundamental multiples in Source current after compensation:



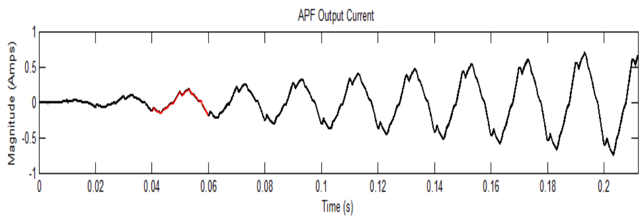
6. Source Current Harmonic Disintegration

The output voltage of APF



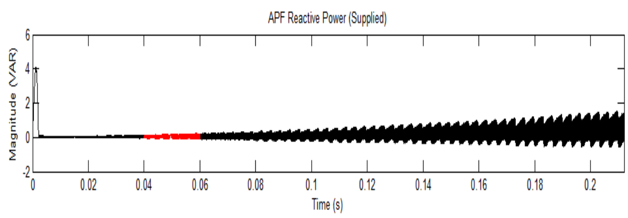
7. APF Output Voltage

The output current of APF:



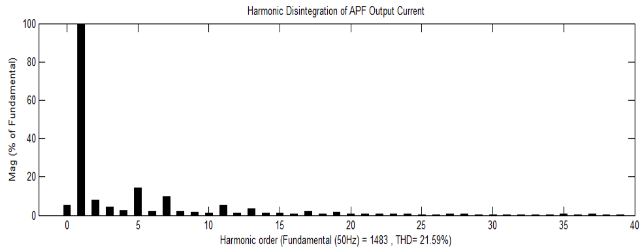
8. APF Output Current

The reactive power supplied by APF:



9. APF Reactive Power

The frequencies disintegration of APF output current. It can be seen that major portion of harmonic content is being neutralised by APF.



10. APF Output Current Harmonic disintegration

VII. Results

The objectives of having Sinusoidal source current and reduced Total Harmonic distortion are achieved. As shown in Fig 5 the source current has become sinusoidal which was extremely disturbed as shown in Fig 2. One more observation is the peak of source current before and after compensation. The source current is having both load and harmonic currents before compensation since the source supplies to both, the actual load and the harmonic load. But it is evident from the results that after compensation the peak of source current has dropped because the harmonic content is being supplied by the shunt APF. Total Harmonic Distortion is reduced to the permitted bound of 5% as shown in Fig 6 and harmonics are mitigated. In parallel, reactive power supplied $(Fig9)$ by APF has improved the power factor to 0.9 from 0.3. The improved power factor is an inevitable fact that source current is in phase with the source voltage hence improving the power quality.

VIII. Conclusion

The proposed APF system reduces THD of system from 26.6 to 3.39 which is well within the limits defined by IEEE. The APF is adaptive to load changes and has improved system efficiency. The analytical and simulated outcomes have shown that harmonics are being mitigated resulting in improved power factor. The DC side of inverter could be capacitor or a battery voltage.The proposed APF system is adaptive to load changes and has improved system efficiency. The analytical and simulated outcomes have shown that harmonics are being mitigated resulting in improved power factor. The DC side of inverter could be capacitor or a battery voltage.The proposed APF system is adaptive to load changes and has improved system efficiency. The analytical and simulated outcomes have shown that harmonics are being mitigated resulting in improved power factor. The DC side of inverter could be capacitor or a battery voltage.

IX. Refernces

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