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Power Quality Improvement using Combination of passive filters & Active filters

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Abstract - *Poor quality of electric supply is normally caused by power line disturbances such as transients, notches, momentary interruptions, voltage sag and swell, over-voltage, under-voltages and harmonic distortions. Filters are used for improving the power quality. Active and Passive filters eliminate major fluctuating factors. Hybrid filters are the combination of active and passive filters. Conventional Active Filtering using PLL also reduces the harmonics. Total Harmonic Distortion (THD) can be reduced by implementing combination of active and passive filters. To design a hybrid power filter to reduce the harmonics for enhancing the quality of power. Also compare various topologies of filters to evaluate the best filter for power quality enhancement using MATLAB.*

Key Words: Harmonics; Hybrid Topology; Nonlinear Load; Power Quality (PQ);

1. INTRODUCTION

NONLINEAR loads cause significant harmonic currents with poor input power factor (PF), which create serious problems at the power supply system. Traditionally, passive filters have been used to eliminate current harmonics of the supply network. However, these devices suffer from resonance. Recently, thyristor-switched filters (TSFs), which contain several groups of passive filters, have been used to compensate reactive power . The compensation amount of TSFs can be adjusted with the variation of load power . However, the parallel and the series resonance could occur between TSF and grid impedance. Active filters were developed to mitigate problems of passive filters. They are more effective in harmonic compensation and have good performance. However, the costs of active filters are relatively high for large scale system and require high power converter ratings. Hybrid filters effectively soften the problems of the passive filter and an active filter solution and provide cost-effective harmonic compensation, particularly for high-power nonlinear loads. In proposed work a new combination of a passive filters and active filters is proposed to suppress current harmonics and compensate the reactive power generated from the load. The hybrid filter consists of a series connection of a small-rated active filter and a fifth-tuned LC passive filter. by this we can improve the filter characteristic

1.1 POWER QUALITY

There are several power quality difficulties in today's electrical systems, which are undergoing rapid change. The principal origins of these power quality issues can be categorized as either natural or artificial depending on whether they are measured in terms of current, voltage, frequency, etc. Weather factors, such as interference, lightning, and storms, and equipment failures are the most common natural causes of poor power quality. However, the majority of human reasons are due to load or system operation. Non-linear loads, such as saturated transformers and other types of electrical equipment, as well as loads with solid-state controls, such as steam lamp-based lighting systems, ASDs, UPS, arc furnaces, computer power supplies, and televisions, can be non-linear loads that contribute to load-related issues. Televisions and arc furnaces are two other common instances of load-related causes of power outages. Power quality issues that are caused by the operation of the system can be traced back to its transformers, capacitors, feeders, and switching at high loads. Typically, transitory power quality concerns are caused by natural factors, such as: B. Transient phenomena of voltage drop (dip), voltage distortion, expansion, and shock and vibration.

However, human causes are responsible for both temporary and permanent power quality problems. However, harmonics are one of the most significant power quality concerns. This can be caused by loads that do not operate linearly, including classic loads like transformers, electric machines, and furnaces, as well as innovative loads like rectifiers and steam lamps. Switch mode power supply (SMPS), ASD with AC-DC converter, cycloconverter, AC voltage regulator, HVDC transmission, VAR static compensator, and other similar devices. All affected utilities, customers, and manufacturers incur considerable economic losses owing to process interruptions and damaged equipment as a result of power quality concerns. The loss of production, the squandering of raw materials, the erasure of critical data, and other associated costs. Even a momentary drop or sag in voltage can cause significant problems in a number of contexts and applications, such as automated industrial processes, the production of semiconductors, the pharmaceutical industry, and banking, where it can disrupt operations for several hours and result in the waste of raw materials and other resources.

Some power quality issues impact the protection systems and lead to malfunctioning protective equipment. These disrupt several industrial operations and procedures and other organizations. Additionally, these attributes have an impact on a diverse set of measuring equipment, in addition to the metering of quantities like voltage, current, power, and energy. In addition, the monitoring systems of a significant quantity of major, critical, emergency, vital, and expensive equipment are impacted as a direct result of these problems.

1.2 POWER QUALITY PROBLEMS

Due to increasing problems associated with poor power quality, such as financial loss, lost output, wasted raw materials, and so on, numerous mitigation strategies have emerged in the previous quarter century to try to fix the problem. Capacitors, reactors, and other specialized power devices are examples of passive components. Power filters, better power quality AC–DC converters, and matrix converters are further examples of passive components. In many cases, however, such as in distribution systems, when problems with voltage regulation, low power factor, load unbalancing, excessive neutral current, and so on are found, it is possible that harmonics are not the primary cause of the power quality concerns.

This is because harmonics are a frequency-dependent phenomenon. By decreasing problems like low power factor resulting from reactive power demands, lossless passive devices like capacitors and reactors can improve power quality. Specialized power devices such as DSTATCOMs, DVRs, and UPQCs can also be used to improve power quality by reducing current, voltage, or both. In single-phase two-wire, and three-phase three-wire, and three-phase four-wire systems, it is common practice to retrofit power filters of various types, such as shunt, series, or a combination of both, in order to mitigate power quality concerns caused by harmonics and other power quality issues. There are numerous filter circuits, and the best filter configuration depends on the type of load being fed electricity: voltage-fed, current-fed, or a hybrid of the two. The use of PFC converters, also referred to as IPQCs, Multi-pulse AC-DC converters, matrix converters for AC-DC or AC-AC conversion, and others in the input stage of newly designed and developed equipment is the basis for power quality improvement techniques. By receiving clean power from the utility, PFC converters automatically alleviate some of the power quality disturbances that exist within them and across the supply system. Numerous circuits of the boost, buck, buck-boost, multilayer, and multi-pulse converter sorts are available for unidirectional and bidirectional power flow with and without isolation in single-phase and three-phase supply systems. These circuits can be used for extremely specific applications. These are used as input stage front-end converters and, in many circumstances, protect equipment from power quality concerns in the grid.

2. PROPSED METHODOLOGY

Harmonic suppression is the process of reduction or elimination or mitigation of the harmonics in power system networks.

This can be done through the basic filtering techniques namely,

- Passive power filter
- Active power filter

The two main approaches for reduction of harmonics in the power system networks and hence reduce the power quality problems related to it, are, active filtering approach and passive filtering approach.

The passive filtering approach deals with the introduction of filters in the power system networks, so as to reduce the number of harmonics produced by the non-linear load, from entering the grid. Advancement in passive filtering methodology is the Selective Harmonic Filtering technique (SHF), which helps in reduction of a particular band of harmonics from entering the grid. The Active filter approach is a process of reducing the amount of harmonic content produced by the non-linear load usage, which not only reduces the amount of unnecessary harmonic current drawn from the grid, but also reduces the amount of reactive power drawn. This is a comparatively efficient approach of reducing harmonics in power system networks and hence improve power factor as well as the quality of power drawn the non-linear loads used. These filtering techniques are discussed in detail in the following sections.

Passive Filters

Passive Filtering technique is the simplest conventional technique for reducing harmonics and is least expensive. It uses passive elements such as inductor, capacitor and resistor. They are tuned to a particular frequency to suppress the harmonic current of that frequency.

Basically, lower order harmonics will have a greater effect more power systems because these harmonics have higher current rating compared to the other higher order harmonics. Even though it is the simplest technique, it fails when the load is dynamically/randomly varying. Ex: Electric arc furnace, adjustable speed drive motors etc.

Active Filters

The complexity of the filtering circuit will increase as the size of the non- linear load increases and also, huge losses may be produced in case of the conventional passive filters. The passive filters also have a restricted capability to eliminate inter-harmonics and non-characteristic harmonics. These restrictions and drawbacks of passive filtering technique have encouraged the development of harmonic compensation by means of power electronic devices. This method of harmonic suppression is commonly referred to as Active Filters. The principle behind this harmonic mitigation technique is to generate equal and opposite current signals, that cancel the harmonic current produced by the non- linear load by utilizing the advanced power electronic switches, which finally leads to a sinusoidal source current with reduced amount of THD. The active power filter is basically a Voltage Source Inverter (VSI) along with a DC sided Capacitor. The active power filter (APF) is connected to the supply line at the point of common coupling (PCC), where the filtering action happens, according to the principle of operation. The APF hence has an ability to actively compensate the randomly varying harmonic currents.

The Active Power Filter (APF) has several functions in a single circuit which includes:

Active compensation of the randomly varying harmonic currents.

It works effectively at low to medium voltage distribution level or at high voltage distribution level.

It has a special feature to measure harmonics and reactive power components of non- linear load and will take suitable actions.

PI Controller

PI Controllers provide control actions in terms of compensation based on present error input (proportional control) as well as depending on the past error signal (integral control).

As the term PI suggests, it comprises of two separate constant parameters, i.e. proportional constant and integral constant which are adjusted in order to get ideal, steady and faster response and to reduce the steady state error to zero or at least to a very small tolerance limit. Some of the disadvantages of PI Controllers are as mentioned below: Integrator wind up phenomenon: Integral or Proportional + Integral controllers are not stable. When there is a limit on the actuation capability, the controller output saturates leading to non-decaying errors. The integrator blindly accumulates the error and its output can grow to large values. Leads of Instability: Integral control leads to sluggish closed-loop response for a first order system. Integral PI control of higher order plants usually leads to instability of the systems.

Hysteresis Current Control (HCC) Technique

Current Control (CC) makes it possible to produce harmonic currents of Non-Linear Loads through inverters, so as to keep the Grid Supply sinusoidal.

1.Various Current Control techniques include:
2.Average Current Mode Control (ACMC)
3.System Management Control (SMC)
4.Hysteresis Current Controller (HCC)

The Hysteresis Current Control method allows non linearity, parameter variations, load disturbances, etc. for analysis. This method also proves to be suitable for VSI structure for STATCOM applications.

The required VSI switching frequency and dc source voltage are highly relevant to the current tracking method used. Hence in order to keep high safety and efficiency in APF operation, these aspects should be possibly low. However, switching frequency might fluctuate greatly.

Hysteresis Band (HB) is to provide lower and upper boundary for randomly varying current. Its magnitude should vary within this hysteresis band.

In HCC technique, the ON and OFF become well-known to force the current to stay inside a HB. ON/OFF condition occur when the error value go beyond the set magnitude of HB.

3. SIMULATION & RESULTS

This chapter investigates the performance of the shunt active power filter by employing vector control technique and HCC technique. The shunt active power filter consists of reference current extraction and PWM-VSI current controller. In chapter 4 and 5 reference current extraction methods and PWM-VSI current control techniques are discussed. This section is focused on simulation studies and analysis of the three-phase shunt active power filter.

Case 1: Three Phase Grid Feeding a Non-Linear load

The block diagram of a Grid feeding Non-Linear Load is as shown below in figure.

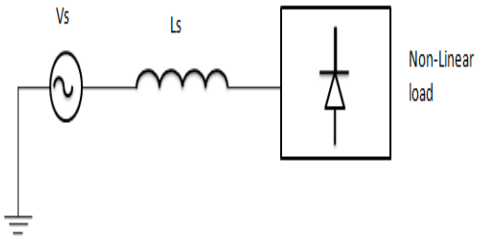


Fig. 3.1: Block Diagram of Three Phase Grid Feeding a Non-Linear Load.

Here, Vs is the voltage or the grid,

Ls is the source impedance. the voltage source here is a three-phase grid, while the linear load is a resistive load. The source impedance is the total impedance offered by the circuit elements, such as, transmission and distribution lines.

Based on the above block diagram, a circuit is simulated in the MATLAB Simulink Platform, as shown in the figure 3.2

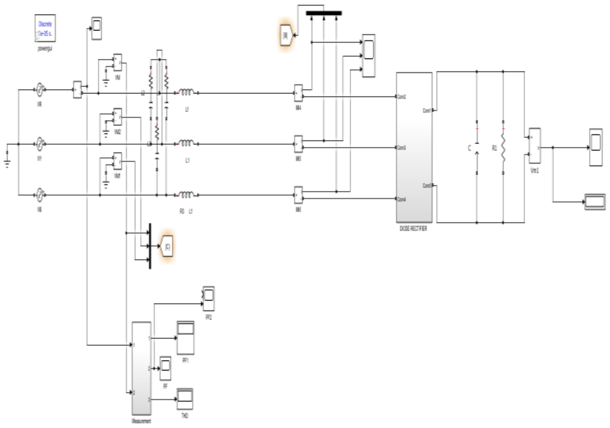


Fig. 3.2: Simulink Model of Three Phase Grid Feeding a Non-Linear Load.

The Measurement block is used to measure the values of active power supplied to the load, reactive power drawn from the load and the power factor

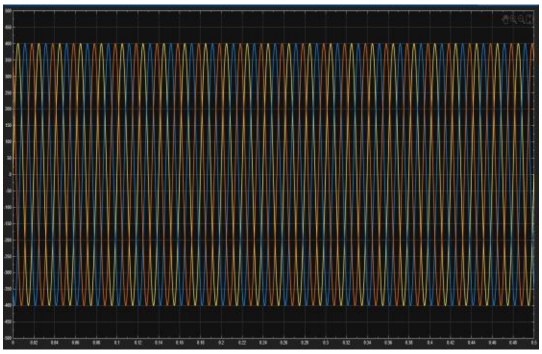
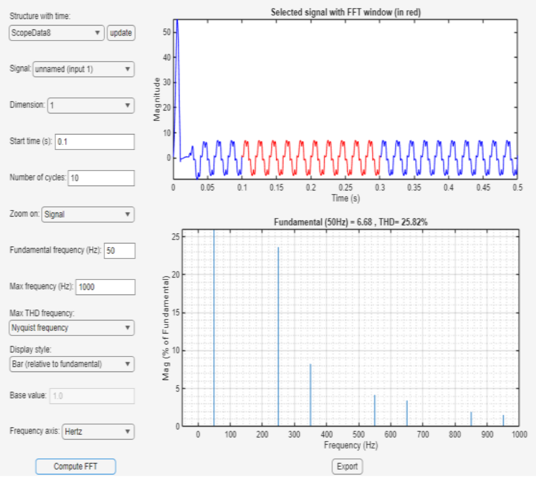


Fig. 3.3: Source Voltage waveform



Structure with time: ScopeData8
Signal: unnamed (input 1)
Dimension: 1
Start time (s): 0.1
Number of cycles: 10
Zoom on: Signal
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max THD frequency: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig. 3.4: Harmonic Spectrum of Source Current due to nonlinear load

The output window for FFT analysis with the Bar Graph representation corresponding to the maximum frequency, at the source end is shown in the figures 3.4 Total Harmonic Distortion at the Source End: 25.82 %.

Case2 : Three Phase Grid Feeding a Non-Linear Load with Shunt Passive Filter and Shunt Active Power Filter (SAPF) with Hysteresis Current Controller (HCC):

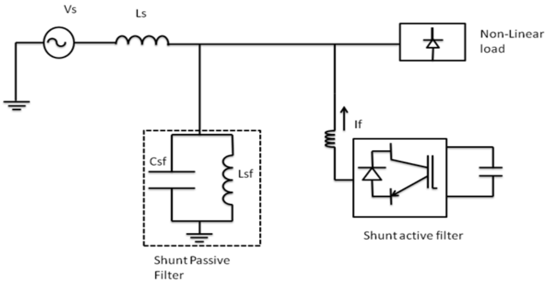


Fig. 3.5: Block Diagram of Grid Feeding a Non-Linear Load with Shunt Passive Filter and Shunt Active Power Filter (SAPF) with Hysteresis Current Control (HCC).

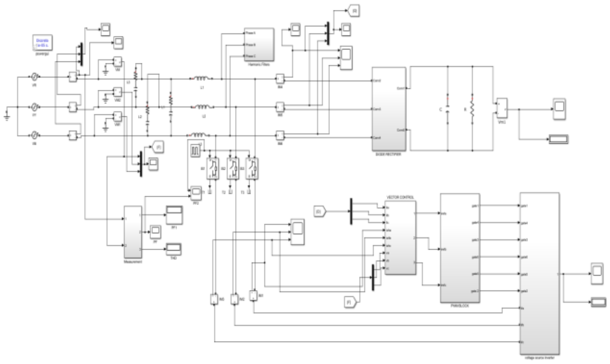


Fig. 3.5: Simulink Model of Three Phase Grid Feeding a Non-Linear Load With active and passive filters.

The block diagram and simulated circuit of Grid Feeding a Non-Linear Load with Shunt Passive Filter and Shunt Active Power Filter (SAPF) with Hysteresis Current Control (HCC) is shown in figure 3.4 and 3.5 respectively.

The beneficial feature of active and passive shunt filter is combined to develop a hybrid filter where both the compensator function in tandem to eliminate the distortion issue due to harmonics.

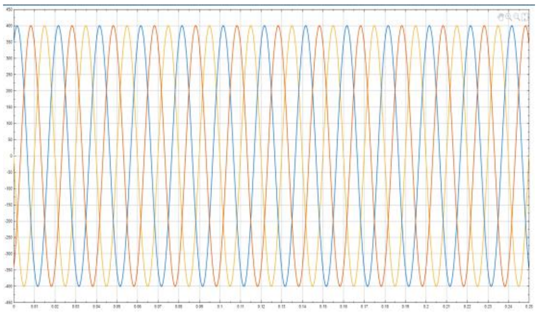


Fig:3.6 Source Voltage waveform

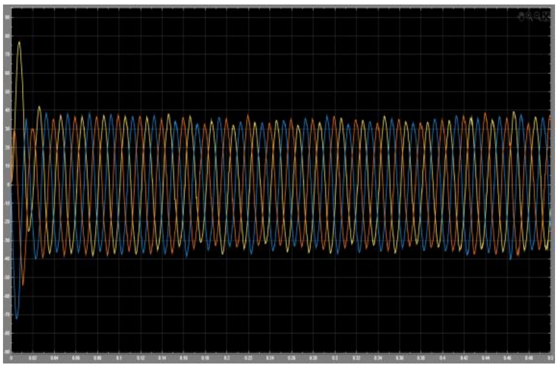
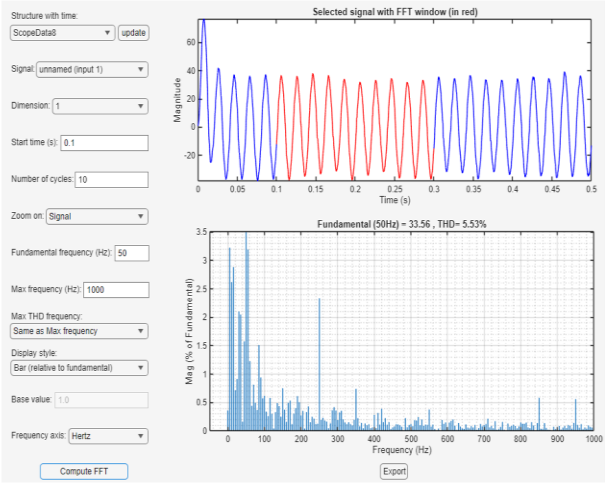


Fig:3.7 Source Current waveform



Structure with time: ScopeData8
Signal: unnamed (input 1)
Dimension: 1
Start time (s): 0.1
Number of cycles: 10
Zoom on: Signal
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max THD frequency: Same as Max frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig :3.8 Harmonic spectrum of waveform

The combined results of active and passive shunt filter is displayed in the figure 4.20, The FFT analysis carried out on the source current is as displayed in the figure 4.20, the results obtained revealed the reduction of current THD form about 28% to 5.53%, also the effect of lower order harmonics is reduced showing the effectiveness of tuned shunt active filter in mitigation of the LOH significantly and reducing the THD as per the prescribed IEEE standard limits. also it is observed that the performance of hybrid filter is slightly superior in comparison with passive filter as the THD is reduced to 5.53% in comparison of 8.53% in passive filter. however, the performance of hybrid filter is slightly inferior in comparison with active filter as the THD is increased to 5.53% in comparison.

4. CONCLUSIONS

This thesis presents the performance evaluation of different filter topologies clearly highlights the critical role of filtering techniques in improving power quality in electrical systems. Without any filtering, the system suffers from extremely high Total Harmonic Distortion (THD) of 25.82%, indicating severe waveform distortion caused by nonlinear loads. This not only reduces system efficiency but also poses risks such as overheating, equipment malfunction, and increased losses. Additionally, the power factor of 0.9311 reflects suboptimal utilization of electrical power.

The hybrid filter, which combines both passive and active filtering approaches, offers the most balanced and optimized performance. It reduces THD to 5.53%, which is significantly lower than the passive filter and close to the active filter's performance. More importantly, it achieves the highest power factor of 0.9971, nearly unity, indicating excellent reactive power compensation and maximum energy utilization. This combination leverages the strengths of both filtering methods while minimizing their individual limitations.

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