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Transient Response Improvement & Harmonic mitigation by Shunt Active Filter in Power System

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Abstract – Harmonics can be a major issue of concern as it can cause excessive heating and torque reduction in motors and generators, voltage stress may be increased in capacitors as well as heating effect and can cause misleading in operation of electronics based instruments or relaying commands. The conclusion is the harmonics can reduce the life of the equipment's and overall system. So a system should be properly designed considering the harmful effects of harmonics in the system.This work focuses on harmonic mitigation in power systems using a shunt active power filter (SAPF) to reduce harmonics within permissible limits. Nonlinear loads are the primary sources of harmonics, leading to power quality issues such as voltage sag, swell, flicker, and waveform distortion. To address these challenges, a SAPF is integrated into the modelled power system, and its performance is evaluated. The effectiveness of the SAPF largely depends on the employed control strategy, which plays a critical role in harmonic suppression. In this study, hysteresis current control and phase control methods are implemented as reference techniques for harmonic reduction. The complete system is modelled and simulated in MATLAB/Simulink to analyse performance and validate results.

Key Words: SAPF shunt active power filter, Phase control, Harmonics reduction, nonlinear loads, PCC point of common coupling. Total harmonic distortion (THD), FACTS Flexible AC Transmission system.

1. INTRODUCTION

In the recent years, Power quality (PQ) is emerging as an issue of major concern, (globally as well as nationwide) requiring accurate monitoring, in-depth analysis and adoption of planned PQ improvement initiatives. The present scenario has changed in our country, with a large proportion of the industrial, commercial and domestic load now turning out to be non-linear due to growing use of power electronics, automation, computers and information technology. Widespread use of non-linear loads degenerate the quality of power in both transmission and distribution systems. [1].

Classically, passive filters, consisting of tuned LC high passive filters are used to suppress the harmonics up to certain extent and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions.

Active power filters are considered as a viable alternative over the classical passive filters, to compensate source current harmonics produced by the non-linear loads. The objective of the active filtering is to meet the reactive power demand and maintain the harmonics according to IEEE Std. 519-1992.

Shunt Active Power Filter (SAPF) can be used with different current control strategy such as Synchronous reference frame method, Instantaneous reactive power theory, Unit vector template method, Fuzzy logic controller, Neural networks. Each control strategy has its own advantages and disadvantages in reducing the harmonics from the system. The paper mainly focus on the comparison of two different control strategies Instantaneous Reactive Power(IRP) theory and Modified Synchronous Reference Frame(MSRF) theory which reduces the harmonics under different source voltage conditions.

For generation of gate pulse signals Hysteresis Current Controller (HCC) is used which are given to drive the switches of the Shunt Active Power Filter and inject the required compensation signal. Proportional-Integral controller is used to compensate the losses of the SAPF.[2].

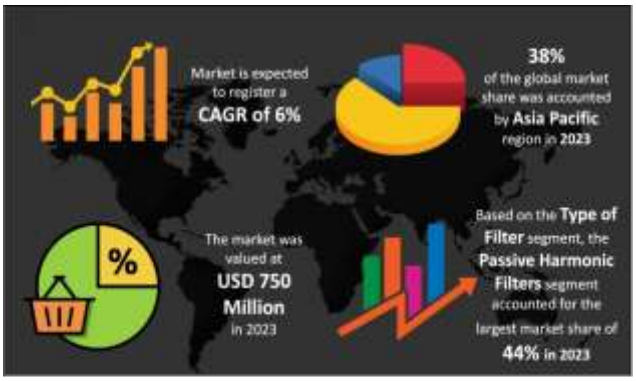

Fig -1: **Harmonic Filter Market**

The global harmonic filter market was valued at USD 1.18 billion in 2024 and is projected to grow at a CAGR of 9.1% from 2025 to 2030. The increasing reliability of sensitive electronics equipment in multiple industries is a key growth driver for this market. The growing use of variable frequency drives (VFDs) has increased harmonic distortion and sparked a larger demand for harmonic filters that can mitigate distortions in power systems.

The rapid pace of digital transformation in multiple industries backed by technology advancements and the emergence of artificial intelligence (AI) has led to the rising use of sensitive electronic equipment. This includes CMOS ICs, graphics ICs, laser diodes, plasma TVs, LEDs, high-precision resistors, and others. The dependability of these systems has developed vulnerability for industries and businesses, as any disruptions in power quality may lead entire infrastructure into an inoperative state and major equipment damage. This has created an inevitable need for harmonic filters, which can prevent or lessen the gravity of potential damages that distortions can cause.
Another key factor that has encouraged industries and organizations to invest in advanced harmonic filters proactively is stringent regulations and standards regarding connectivity with the power grids-in addition to increasing awareness regarding the benefits of power quality and uninterrupted operational workflows. A continuous rise in demand for power quality, growing dependency on equipment, increasing automation of industrial processes, and data-driven decision-making backed by the utilization of sensitive electronic devices are expected to generate an upsurge in demand for the harmonic filter market during the forecast period.

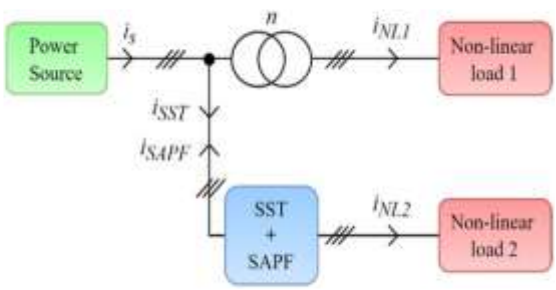

Fig 2- Filter connected with non linear loads

2. SHUNT ACTIVE POWER FILTER

A **Shunt Active Power Filter (SAPF)** is a modern power electronics-based device used to improve **power quality** in electrical systems by mitigating **harmonics, reactive power, and unbalanced currents** caused by nonlinear loads.

Working principle

Detection – The distorted load current is sensed and processed to extract the harmonic component.

Reference Current Generation – A control algorithm (like **p-q theory**, **SRF method**, or **hysteresis control**) generates the reference compensating current.

Inverter Action – A Voltage Source Inverter (VSI) with a DC link capacitor produces the compensating current.

Injection – This compensating current cancels out the harmonic and reactive components of the load current

3. CONTROL ALGORITHM

Hysteresis Current Control

This algorithm is used extensively due to its simple mechanism of implementation. The main operation is done by the comparison of the current error and the hysteresis band.In this method the error is placed between hysteresis bands. Whenever the error will increase from the upper limit or goes down below the lower limit the command will be sent to the control switch to control and

Reduce the error in order to reset the band for the production of reference current. This will make the ability of control very quickly with the high accuracy and not require any system information. The fixed band hysteresis will suffer from a high frequency variations which will cause switching losses and also noise.

To avoid this situation the band hysteresis algorithm with the variable hysteresis bands have been proposed in this work. The variation in band as per the desired reference current and to provide the active filter for the switching frequency. This method is very sensitive for the parameters and also calculations for the selected band increase the complexity of this approach.

PQ Theory algorithm

The harmonic extraction based on PQ algorithm is done by using a series of calculation of power in a three phase system. The calculations in ab frames where three phase voltage and currents are transformed to ab by using Clarke transformation and then applied for calculation of active and reactive powers of load. The P and Q component of instantaneous power will appear as a DC signal and harmonics appear as a ripple. Only active power needs filtered to obtain the desired component of harmonics. So a reference current is generated by using extracted harmonic components

The control structure of a PQ theory algorithm is shown in figure below. The algorithm is applied to the three phase systems with the sinusoidal voltage and balanced waveforms just like the SRF algorithm. This algorithm also shows the time delay in harmonic extraction from the fundamental due to the dependency on low pass filter.

SRF algorithm

The harmonic elimination based on dq synchronous reference theorem is accompanied by a series of mathematical calculations of the three phase load current which is done by a dq0 reference frame and to convert the three phase current from abc to dq0 frame the park transformation matrix has been used. DQ frames are determined by phase sin cos delivered by a synchronizer. The separation of fundamental component and harmonic component is done by a low pass filter. The reference current is produced by the eliminated harmonic component and figure below shows the control structure of a typical SRF algorithm.

4. METHODODLOGY

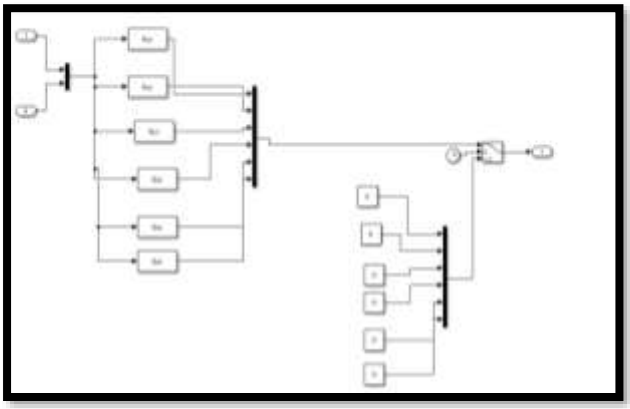

Fig -3: Hysteresis Control

Harmonic extraction based on the synchronous reference frame is accomplished by a series of mathematical calculations of three phase load currents which is conducted in dq0 direct quadrature zero reference frame. Park transformation is applied to convert three phase load current from abc frames to dqo frames. Here dq frames are determined by the reference phase which is delivered by a synchronizer. In dq frames fundamental component will appear as DC signal, and the harmonic component will appear as ripples. A low pass filter will be used for the separation of fundamental component and harmonic component. Finally the desired reference signal is generated by using extracted harmonic components.

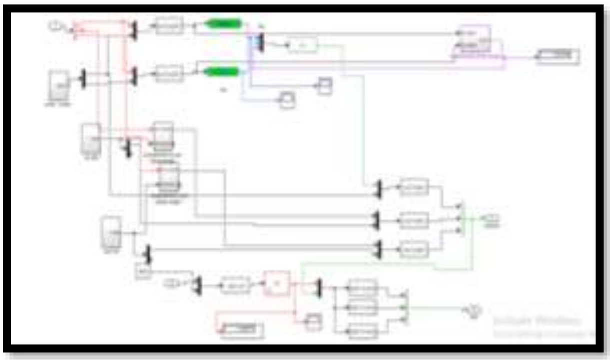

Fig -4: Fundamental CT and Phase control

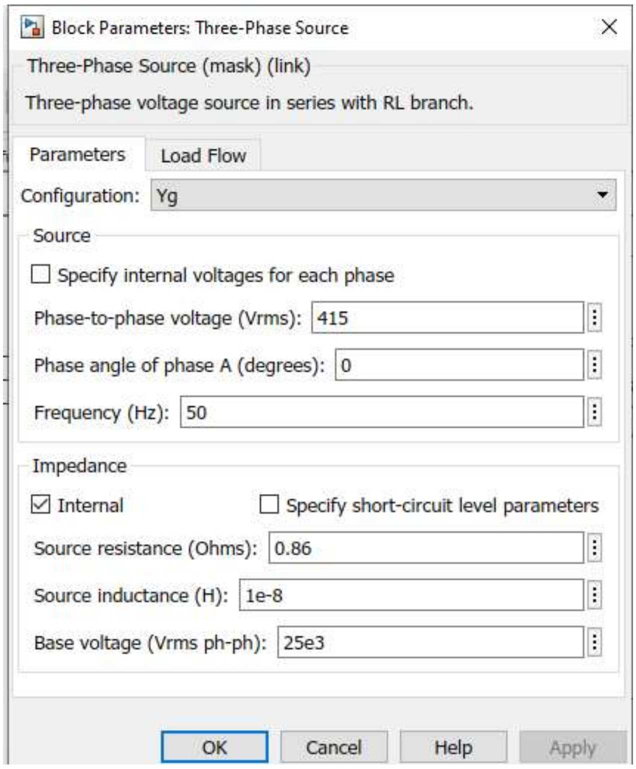

Fig -5 Three Phase Source

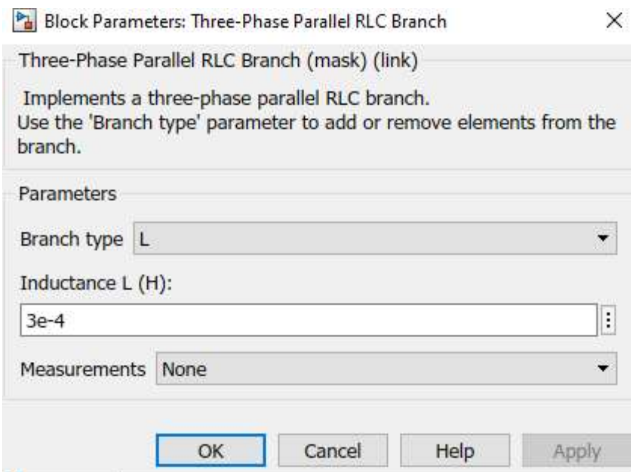

Fig -6: Inductor Filter Parameter imposed on filter

5. RESULTS

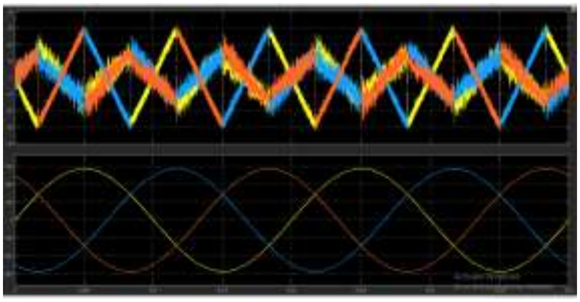

Fig 7: Voltage and current after filter

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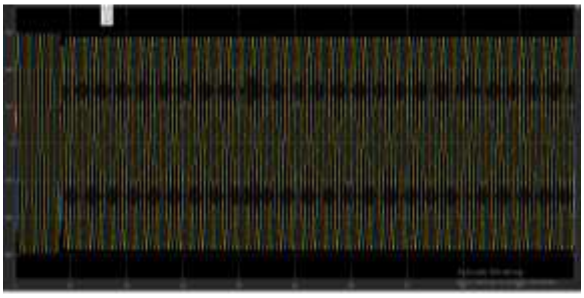

Fig -8: Voltage waveform after filter

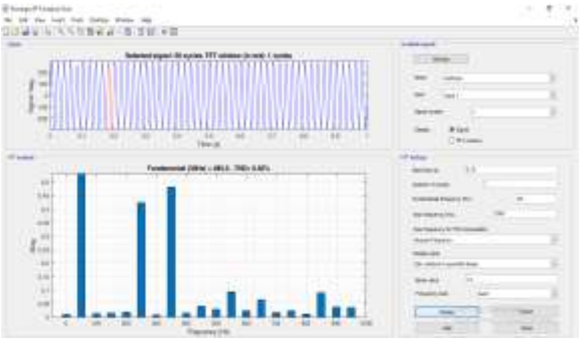

Fig -9: Voltage THD

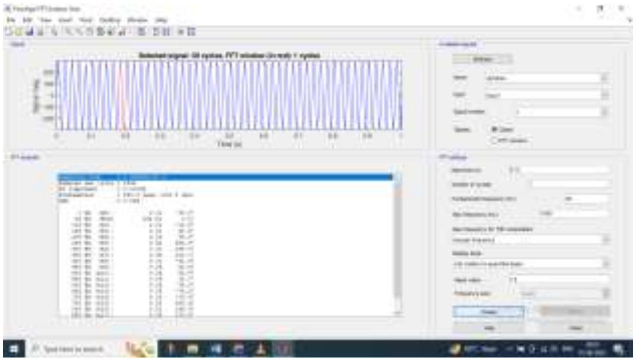

Fig -10: FFT Analysis frequency wise values

Fig -11: Current THD

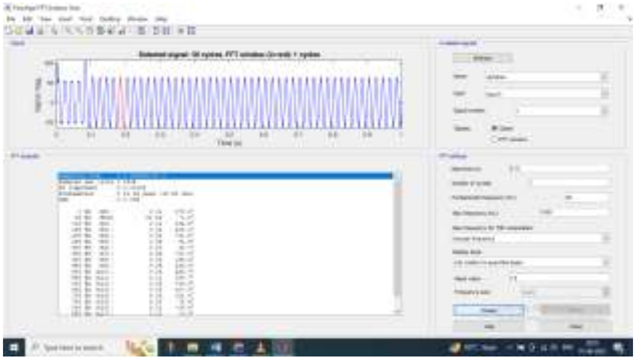

Fig -12: FFT Analysis frequency wise values

6. CONCLUSION

In this paper a shunt active power filter has been installed with synchronous reference frame theory for the better performance of a three phase three wire distribution system to improve the performance under non sinusoidal waveform condition. This method has the ability to reduce the harmonics in a specified controlled limit defined by IEEE and reduce the losses.

For the harmonic mitigation shunt active power filter proved to be one of the most effective solution. This model has been designed and modelled in Matlab Simulink software which is based on dq reference theory for the power quality improvement. It seems that the shunt active power filter improves the quality of power by harmonic reduction FFT analysis shows that implementation of filter improves the results by a much better smooth waveform.

7. FUTURE SCOPE

Further we can also work on power conditioning by using FACTS devices like statcom and all. We can work on various issues which I have discussed above .In our next generation the most important issue is to save nonrenewable energy resources such as fuel and to create a good environment. In such conditions the wind energy is the best option if it can be generated according to our desired output and that much quality of power it can provide as other energy resources give. Our main aim is to generate more and more power with good quality by using nonrenewable resources such as wind and solar energy.

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