Series Active Power Filter for Power Quality Improvement

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Abstract: - The paper discusses the theoretical framework and operating principles of the SAPF, including its control strategies based on instantaneous reactive power theory and synchronous reference frame theory. The design criteria for the SAPF components, such as the voltage source inverter, DC link capacitor, and coupling transformer, are also elaborated to ensure optimal performance. Simulation studies using MATLAB/Simulink are conducted to evaluate the effectiveness of the proposed SAPF under various power quality disturbance scenarios. The results demonstrate that the SAPF effectively compensates for voltage sags, swells, and harmonics, maintaining voltage stability and reducing total harmonic distortion (THD) to within acceptable standards. Additionally, a prototype of the SAPF is developed and tested in a laboratory environment, confirming the simulation results and showcasing the practical feasibility of the solution. The study concludes that the Series Active Power Filter is a robust and versatile solution for power quality improvement in modern electrical distribution systems. Future work may involve exploring hybrid configurations combining series and parallel active filters for comprehensive power quality management and the development of advanced control algorithms for enhanced performance under dynamic load conditions.

Key-Words: - Series Active Power Filter, Power Quality, Voltage Sags, Harmonics, Total Harmonic Distortion, MATLAB/Simulink, Power Electronics, Control Strategies.

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1 Introduction

Power quality has become a significant concern in modern power systems due to the increasing use of nonlinear loads, which introduce various power quality issues such as voltage sags, swells, harmonics, and flicker [1]. This research paper presents the design and implementation of a Series Active Power Filter (SAPF) aimed at improving power quality in electrical distribution systems.

The Series Active Power Filter is a power electronic device that is connected in series with the power line and works by injecting compensating voltages into the system to mitigate power quality disturbances [2]. Unlike traditional passive filters, the SAPF provides dynamic and selective compensation for a wide range of power quality issues, enhancing the reliability and efficiency of the power system.

In recent years, the proliferation of nonlinear loads such as variable frequency drives, uninterruptible power supplies, and other power electronic devices has led to significant challenges in maintaining power quality in electrical distribution systems. These loads introduce disturbances such as voltage sags, swells, harmonics, and flicker, which can adversely affect the performance of sensitive equipment, leading to operational inefficiencies and increased maintenance costs. Ensuring high power quality is essential for the reliability and efficiency of both industrial and residential power systems[3].

Power quality issues not only impact the end-users but also pose challenges to utility providers in maintaining stable and clean power supply. Traditional methods to mitigate these disturbances, such as passive filters and capacitor banks, often fall short due to their fixed compensation characteristics and inability to adapt to varying load conditions [4]. This has spurred interest in active power filters (APFs), which offer dynamic and selective compensation for power quality issues.

Among the different configurations of active power filters, the Series Active Power Filter (SAPF) has emerged as a promising solution. Unlike shunt APFs that are connected in parallel with the load, the SAPF is connected in series with the power line [5]. It operates by injecting compensating voltages into the system to counteract the voltage disturbances, thus ensuring that the load voltage remains within desired limits. This approach provides direct control over the voltage waveform and allows for effective mitigation of sags, swells, and harmonic distortions.

This paper presents a comprehensive study on the design and implementation of a Series Active Power Filter for power quality improvement. The objectives of the study include:

Theoretical Analysis: Understanding the fundamental principles and operational characteristics of the SAPF, including various control strategies for effective voltage compensation.

System Design: Developing a detailed design of the SAPF components, such as the voltage source inverter, DC link capacitor, and coupling transformer, to ensure optimal performance and reliability.

Simulation and Evaluation: Conducting simulation studies using MATLAB/Simulink to evaluate the effectiveness of the SAPF under different power quality disturbance scenarios and verifying the performance through key metrics such as total harmonic distortion (THD) and voltage stability.

Prototype Development and Testing: Constructing a laboratory prototype of the SAPF and conducting experimental tests to validate the simulation results and demonstrate the practical feasibility of the proposed solution [6].

By addressing the critical need for effective power quality management, this research aims to contribute to the development of more reliable and efficient power systems, thereby supporting the growing demand for high-quality electrical power in modern society.

2. MATLAB Simulation Model

The series active power filter is employed to compensate the supply facet disturbances like voltage sags, swells and conjointly harmonic distortions. during this configuration, the filter is connected nonparallel with the road being stipendiary [7].

Therefore, the configurations square measure usually brought up as a series active filter. The approach relies on the principle of injecting voltage nonparallel with the road through the injection electrical device to cancel the supply facet voltage disturbances and so it makes the load facet voltage curving [8]. Fig. 1 shows the MATLAB/ Simulink model of designed system.

The main components of the below system are as follows.
· Mains supply
· Nonlinear load
· Active Power Filter
- Voltage source inverter
- Interface reactor
- Reference voltage generator
- Hysteresis voltage controller

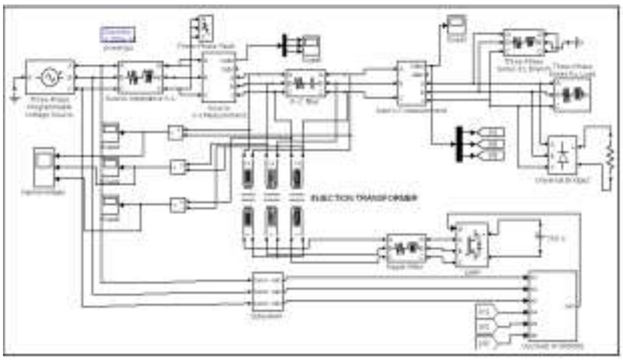

Fig -1: MATLAB simulation model of proposed series active power filter

3. MATLAB Simulation Results

3.1. Case 1 model

Fig. 2 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds, 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 0.4 p.u sag from 0.25 to 0.3 seconds , 0.9 sag from 0.3 to 0.4 seconds and 1p.u voltage from 0.4 to 0.5 seconds.

Table -1: Source Voltage parameters 3-phase (line-Ground)

Time (Second)	Voltage (pu)	Load
0 to 0.1	1	R = 50Ω; L = 1 mH
0.1 to 0.15	1.8	
0.15 to 0.2	1	
0.2 to 0.25	1.2	
0.25 to 0.3	0.4	
0.3 to 0.4	0.9	
0.4 to 0.5	1	

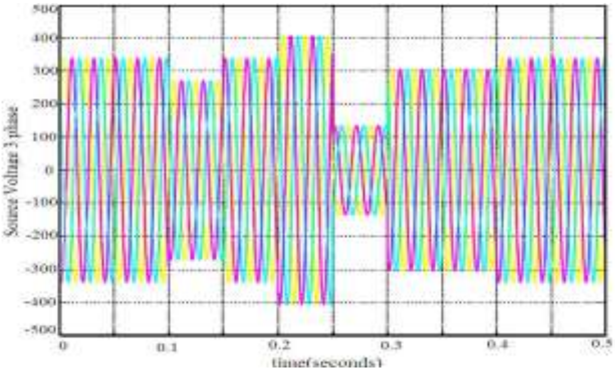

Fig -2: 3-Phase Source voltage (Line-Ground)

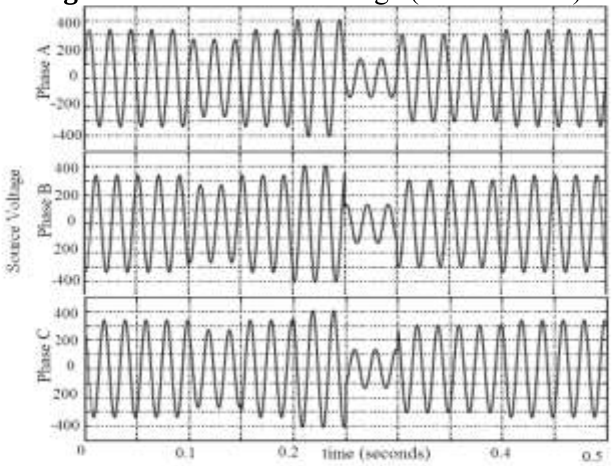

Fig-3: Source Voltage in each Phase

Fig. 4 shows the compensated voltage injected by each phases to cancel the source side disturbances present in the system.

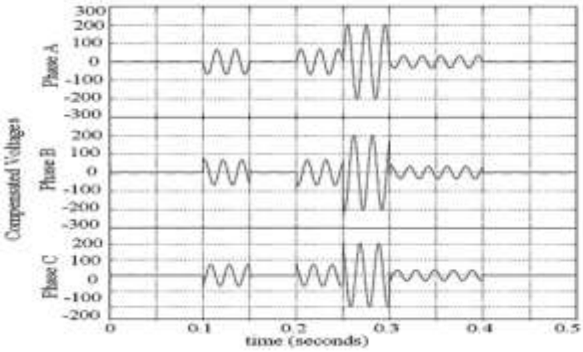

Fig-4: Compensated voltages injected for each phases

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in Fig. 5.

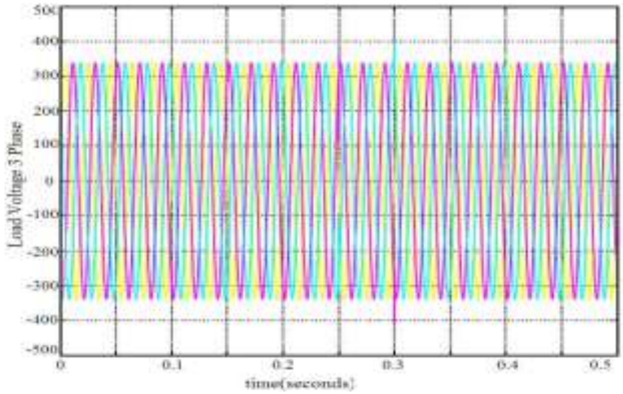

Fig-5: 3-Phase Load voltage (Line-Ground)

The Total harmonic distortion of source voltage is 1.64% and load voltage is 0.04 % as shown in Fig. 4.6 & Fig. 4.7 respectively.

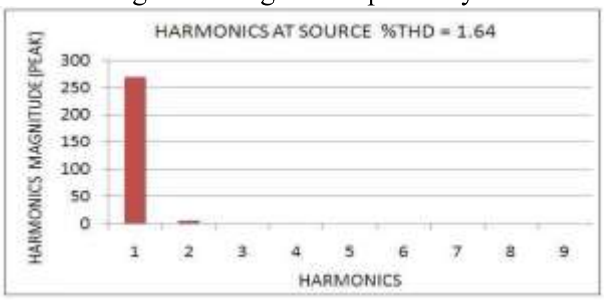

Fig-6: Source voltage harmonic spectrum

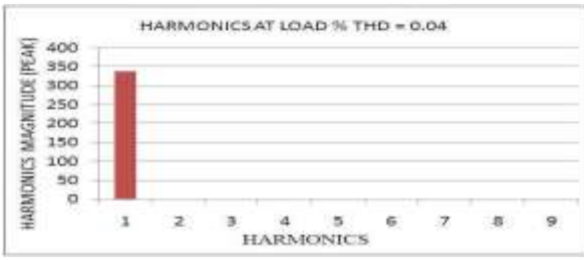

Fig-7: Load voltage harmonic spectrum

The SAPF is simulated with only interruptions in the form of Sag, Swell in the input side & the performance of SAPF is analyzed by taking the FFT analysis of the Source and load Voltages**.**

3.2. Case 2 model

Fig. 8 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 5th order harmonics of 0.4 p.u and 7th order harmonics of 0.2 p.u from 0.25 to 0.4 seconds , 0.9 sag from 0.4 to 0.5 seconds . the load is R=50Ω and L=10 mH.

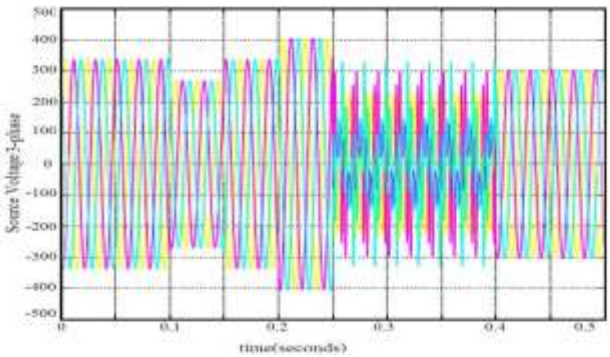

Fig-8: 3-Phase Source voltage (Line-Ground)

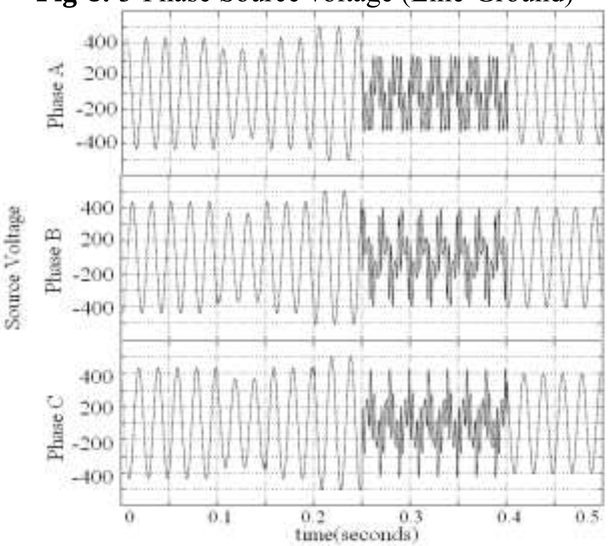

Fig-9: Source Voltages per phase

Fig. 10 shows the compensated voltage injected by each phases to cancel the source side disturbances present in the system.

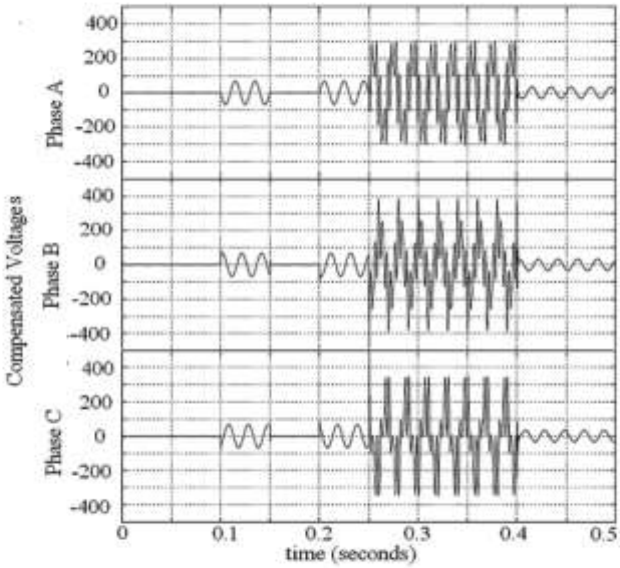

Fig-10: Compensated voltages injected for each phases

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal.

The Total harmonic distortion of source voltage is 64.37% and load voltage is 0.72 % as shown in Fig. 11 & Fig. 12 respectively.

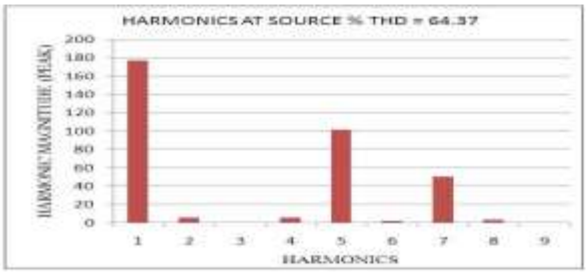

Fig-11: Source voltage harmonic spectrum

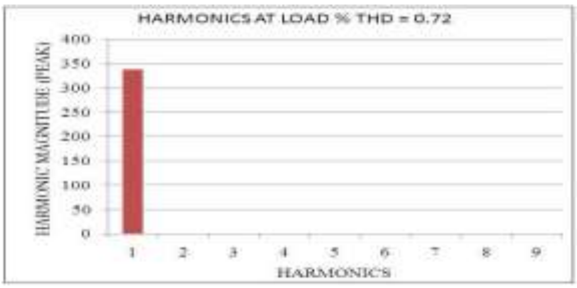

Fig-12: Load voltage harmonic spectrum

3.3. Case 3 model

Fig. 13 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 0.8 p.u sag from 0.25 to 0.4 seconds , 1 p.u voltage from 0.4 to 0.5 seconds . A L-G fault occurs in phase A from 0 to 0.2 seconds .The load is

R=10 Ω and L=1mH, a three phase diode rectifier bridge ,an inductive load of power factor (p.f) 0.894 lag (active power =1000W and reactive power = 500W).

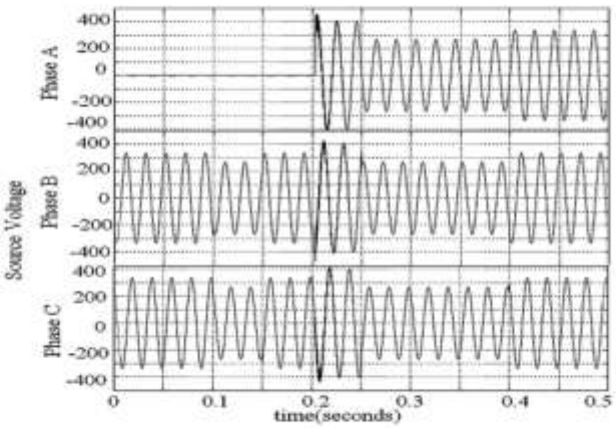

Fig-13: Source voltages in 3-Phases A, B & C

Fig. 14 shows the compensated voltage injected by each phases to cancel the source side disturbances present in the system.

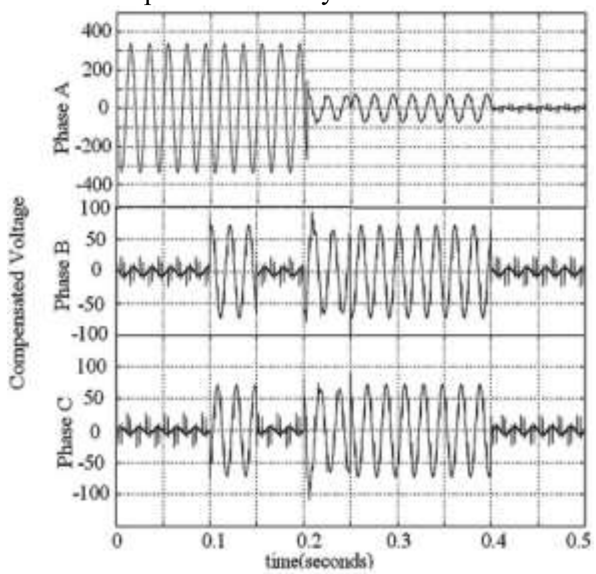

Fig-14: Compensated voltages injected for each phases

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig. 15

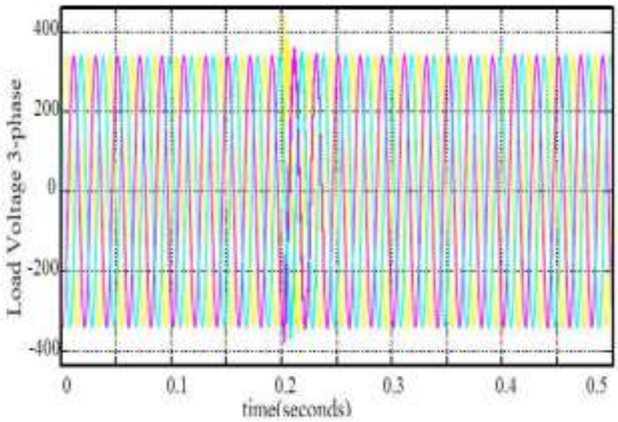

Fig-15: 3-Phase load voltage (Line-Ground)

The Total harmonic distortion of source voltage is 3.52% and load voltage is 1.09 % as shown in Fig. 16 & Fig. 17 respectively.

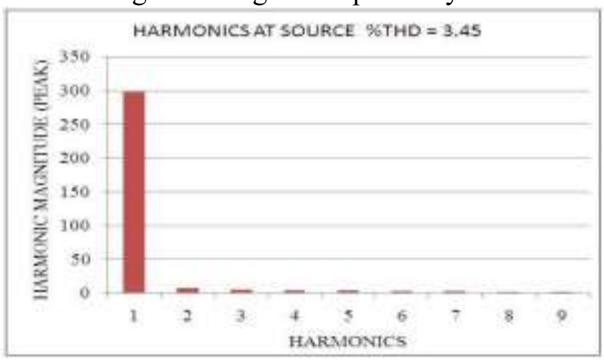

Fig-16: Source voltage harmonic spectrum

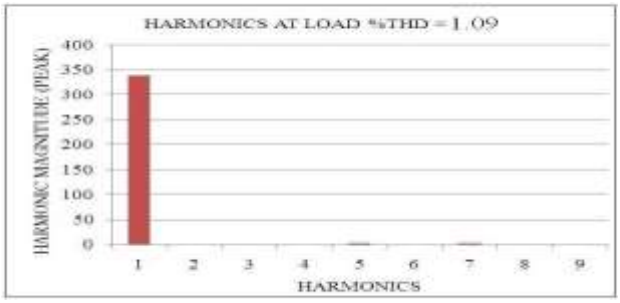

Fig-17: load voltage harmonic spectrum

The SAPF is simulated with interruptions in the form of Sag, Swell, LG fault in the input side on phase A & the performance of SAPF is analyzed by taking the FFT analysis of the Source and load Voltages**.**

Conclusion

A Series active power filter has been investigated for power quality improvement. Numerous simulations area unit administrated to research the performance of the system. Physical phenomenon controller primarily based Series active power filter is enforced for harmonic and voltage distortion compensation of the non-linear load. The Simulation is even extended for abnormal faults occurring on the ability system like L-G & L-L faults.

This section presents an summary of series active filter, its principle of operation and its management theme to come up with reference load voltage and physical phenomenon voltage controller to administer pulses to the series filter to inject the voltage through electrical device asynchronous with the road and also the simulation waveforms for supply voltage, salaried voltage and cargo voltage area unit planned. The doctor's degree of the load voltage with the inclusion of the active filter is well below five-hitter that is that the harmonic limit obligatory by the IEEE 519 standards.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.