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SIMULATION & ANALYSIS OF SERIES & SHUNT ACTIVE POWER FILTER USING MATLAB FOR POWER QUALITY IMPROVEMENT

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Abstract: This paper presents a structured design approach for a Shunt Active Power Filter (SAPF) and Series Active Power Filter to enhance power quality by mitigating current and voltage harmonics. Using a Proportional-Integral (PI) controller for DC-link voltage regulation and instantaneous reactive power theory for reference current extraction, the system employs hysteresis current control for voltage source inverter (VSI) switching. The series-shunt configuration addresses harmonic disturbances, improving voltage stability at the load side. MATLAB/Simulink simulations demonstrate SAPF effectiveness under balanced and unbalanced non-linear loads, significantly reducing total harmonic distortion (THD) and improving overall power quality.

Key words: Series Active Filter (SAF), Shunt Active Power Filter (SAPF), Power Quality Improvement (PQI), Voltage unbalance, DVR ,PI Controller.

Introduction

Power quality is a significant concern in modern electrical distribution systems, often affected by issues such as voltage unbalance, sags, swells, and partial or total phase loss. Voltage unbalance arises mainly from uneven single-phase load distribution across a three-phase system, causing damage to equipment, increased power losses, and communication interference. Power system components like cables, transformers, and machines are all impacted by poor voltage quality. Traditionally, passive filters have been used to mitigate harmonic distortion in industrial sectors, but they suffer from drawbacks like resonance, dependency on system impedance, and the potential to absorb harmonic currents, further propagating them throughout the system. Active power filters (APFs) have been introduced as a solution to these limitations, injecting harmonic voltages or currents to cancel out distortions. However, APFs face challenges like high costs and power losses, limiting their use in high-power systems. This paper explores the design and simulation of a three-phase series active filter to compensate for voltage unbalance using power vectorial theoryTop of the table, position-center

II. ACTIVE FILTER (SERIES & SHUNT)

Active filters offer a dynamic alternative to active filters, especially in conditions where harmonic orders vary in magnitude and phase angles. Unlike active filters adjust to fluctuating harmonic conditions, making them ideal for non-linear loads where harmonics change over time. Like series active filters, shunt active filters can be connected in series or parallel depending on the harmonic source in the power system. Their main function is to minimize harmonic currents by generating currents of equal amplitude but opposite phase to cancel out the harmonics created by non-linear load.Fig.1

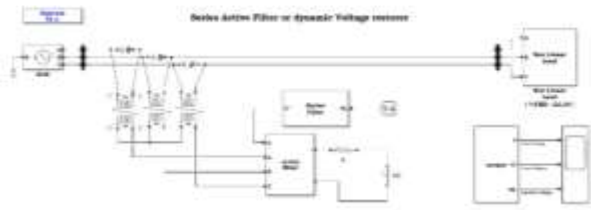

fig.1 series active filter

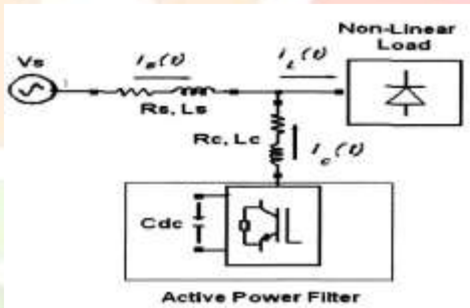

fig. 2 basic component principal active filter

Shunt Active power filters (APFs) are designed to draw or supply a control harmonic current, eliminating reactive and harmonic currents in the system, ensuring the total current drawn from the AC mains remains sinusoidal. In series configurations, APFs use PI Controller to inject a voltage & current that cancels out voltage harmonics and current harmonic on the load side. The inverter's output is filtered to remove high-frequency noise from switching actions, and the filtered current is injected through transformers to balance the current in three-phase systems, effectively eliminating supply current harmonics. fig.3

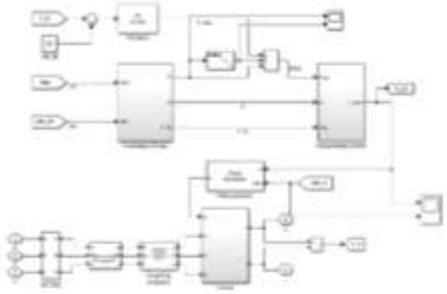

Fig.3 Diagram of proposed shunt active filter

Active filters have evolved significantly over the past three decades and are now widely used to compensate for current-based distortions such as harmonics, reactive power, and neutral currents, as well as voltage-based issues like flickers, sags, swells, and imbalances. They are categorized into single-phase and three-phase types. Single-phase filters address power quality problems from single-phase loads, while three-phase filters handle high-power nonlinear loads like adjustable speed drives (ASD) and AC-DC converters. Active filters can also be classified by topology: current source active filters (CSAF) use inductors for energy storage, while voltage source active filters (VSAF) use capacitors.

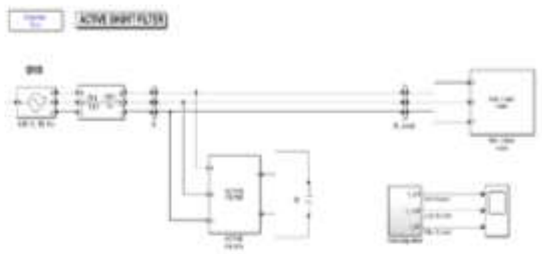

FIG.4 Shunt active filter

III. Modelling of Series and Shunt Active Filter

The series active filter is a type of active filter designed to mitigate voltage imbalances and harmonics in power systems. Various control methods are employed to regulate the operation of the series filter, with the choice of control algorithm directly impacting its accuracy and response time. In this context, power vectorial theory is applied for voltage imbalance compensation.

For optimal performance, the active filter ideally presents infinite impedance (k=∞). In this configuration, as depicted in, a passive LC filter is connected in parallel with the load and is tuned specifically to remove fifth and seventh harmonic components. At the fundamental frequency, this setup ensures better harmonic suppression.

$$\mathbf{i_{ref}=i_1-\frac{p}{v^2}v} \text{ ………………..(1)}$$

where

i_1-current vector of the load and active filter

$$p\text{-}\frac{1}{T}\int_0^T (U^T.i)dt \text{………………………………(2)}$$

u-voltage vector before active filter.

v-voltage vector before active filter.

V^2-norm of v defined by

$$v\text{-}\frac{1}{T}\int_0^T (v^T.v)dt \text{………………………………(3)}$$

$$\begin{bmatrix} v_{ref}\ a \\ v_{ref}\ b \\ v_{ref}\ c \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} -v_{ao} \\ 0 \\ -v_{a2} \end{bmatrix}$$

where va_0 is the zero sequence component and va_2 the negative sequence component.

Fig. 4 illustrates the control scheme for deriving the reference signal. The voltage compensation signal is produced by the PWM inverter. The gain \ (K_v \) represents the turn ratio of the series transformers, which is applied to the reference signal for voltage imbalance correction. The gain \ (K_i \) is the proportional constant used for addressing source current harmonics and determines the impedance magnitude at high frequencies. Consequently, the inverter must generate the compensation signal according to these specifications.

$$G_t(s)=\frac{i_{sabc}}{i^*_{abc}} \approx 1$$

The gating signals for the inverter are produced by comparing the resultant reference signal with the inverter's output using a bang-bang control approach. The core principle behind a shunt active power filter is to regulate the compensating current at the utility, aligning the source current with the source voltage by eliminating current harmonics on the AC side.

A critical phase in controlling the shunt active power filter is maintaining a stable DC voltage at the DC side of the voltage source inverter, achieved through DC-link voltage regulation. Typically, power filters using voltage source inverters to produce harmonic reference currents rely on DC-link capacitors for energy storage. Ideally, the capacitor's voltage remains steady with no real power exchange between the filter and the AC grid. In practice, however, the voltage source inverter uses a small amount of real power for switching operations. As a result, a proportional-integral (PI) controller is used to maintain a constant DC-link voltage and properly compensate the harmonic current. The DC-link capacitor voltage (vdc) is compared to a reference DC voltage (vdc_ref), and the resulting error (vdc − vdc_ref) serves as input to the PI controller, which minimizes steady-state error in reference current signal tracking.

This process is depicted by the inner current control loop and outer voltage control loop of the DC voltage PI controller. The gains GPI (s) and GVSI represent the PI controller and VSI transfer functions, respectively. When the VSI switches operate at high frequencies, the source currents (iSa, iSb, iSc) closely match the reference currents ($i*a$, $i*b$, $i*c$). Therefore, it's assumed that the closed-loop current controller's transfer function is approximately unity:

$$G_i(s)=\frac{i_{sabc}}{i^*_{abc}} \approx 1$$

where i_{Sabc} represents the three-phase source currents, and $i*_{abc}$ denotes the three-phase reference current. The proportional (Kp) and integral (Ki) gains of the PI controller can be determined based on the closed-loop system's step response. Consequently, the transfer function of the DC voltage-controlled closed-loop system is derived as follows:

$$\frac{v_{dc}}{v_{dc\_ref}} = \frac{\frac{k_p.k_i}{c}}{s^2+\frac{k_p}{c}.s+\frac{k_p.k_i}{c}}$$

Here, vdcvdc stands for the DC voltage, vdc_refvdc is the reference DC voltage, Kp represents the proportional gain, Kiki is the integral gain, and C symbolizes the capacitor. Since the DC voltage closed-loop control is a second-order system, Kp and Ki can be determined by comparing the open-loop transfer function to a general second-order system expression.

(15)

$$H(S) = \frac{W_n^2}{s^2+2\zeta w_n s+w_n^2}$$

Where w_n is the damping natural frequency,and ζ refers to the damping facts by euation (14) and experssion (15):

$\frac{k_p}{c} = 2\,\zeta w_n$ and $\frac{k_{p}.k_i}{c} = w_n^2$

Hence

$k_p = 2\,\zeta w_n c$ and $k_i = \frac{w_n}{2\zeta}$

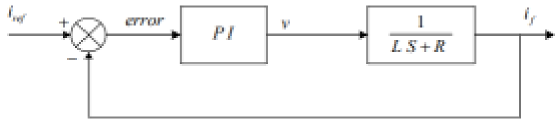

Figure 5: PI controller for current control

V. SIMULATION & RESULT

The three phase source of 15kVA, 440 V, 50Hz system supplying to a non-linear load of thyristor converter fed RL load (R=5.66 Ω, L=97mH) is considered for simulation analysis. The simulation has been performed under filter and without filter source supplying to non-linear load. Fig.7 shows the terminal voltage of without thyristor fed RL load filter which becomes Fig.7.

Fig.6 simulation of without filter

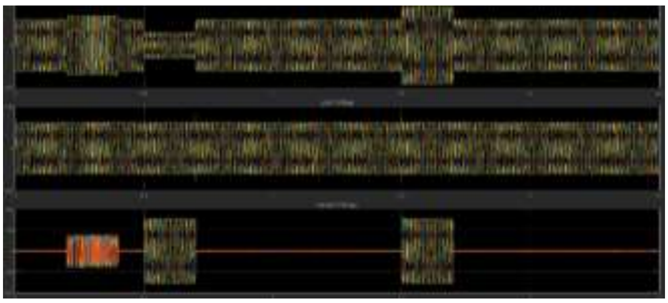

Fig.7 simulation of series active filter with filter

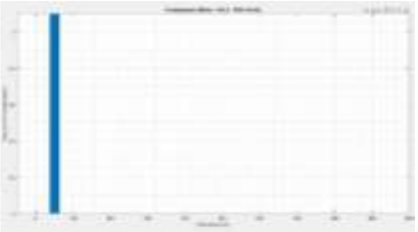

Fig.8 simulation of THD% Grid voltage Series Active Filter

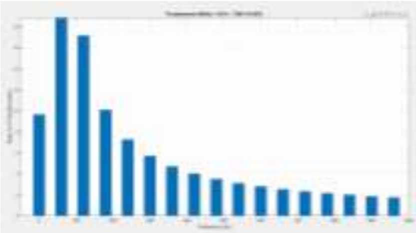

Fig.9 simulation of THD% Load voltage Series Active Filter

From THD for line current and load current without filter as shown in Fig. 12,14. it can be said that the effectiveness of the active filter in compensating for harmonic components will reduce the. This means that the

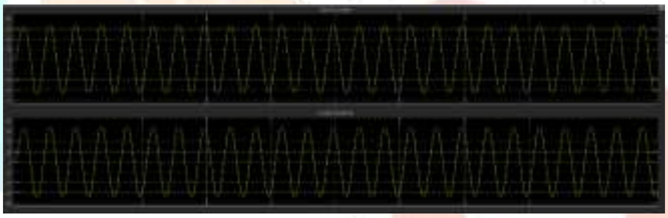

Fig.10 Simulation of Shunt Active Filter Without Filter

From THD for line current and load current as shown in Fig. 12 and Fig. 15, it can be said that the effectiveness of the active filter in compensating for harmonic components will reduce the THD. This means that

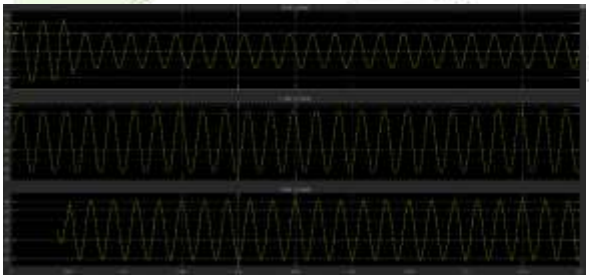

Fig.11 simulation of shunt active filter with filter

Fig:12 THD% of Grid Current (Shunt Active Power Filter)

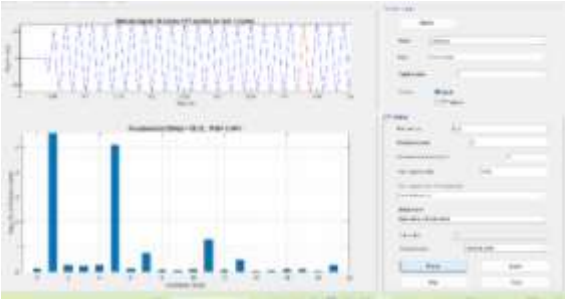

Fig:13 THD% of Filter Current (Shunt Active Power Filter)

THD values of the balanced & unbalanced source voltage & current

Table .1 THD Value of Voltage Harmonic

S.NO	THD% GRID SO8URCE	THD% LOAD SOURCE	THD% FILTER SOURCE
Without Series Active Filter	38.6%	38.2%	Filter not connects
With Series Active Filter	30.35%	24.55%	15.81%

Table .2 THD Value of Current Harmonic

S.NO	THD% GRID SOURCE	THD% LOAD SOURCE	THD% FILTER SOURCE
Without Filter	12.35%	12.35%	Filter not connects
With Active Filter	7.09%	2.26%	6.34%

Conclusions

In conclusion, the thesis presented in this paper underscores the effectiveness of series and shunt power filters as viable solutions for reducing THD and improving power quality in electrical power systems. The insights gained from this study pave the way for the widespread adoption of harmonic mitigation techniques, ultimately leading to more efficient and reliable power distribution infrastructure.

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