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ADVANCED CONTROL STRATEGIES FOR EFFICIENCY ENHANCEMENT OF ACTIVE POWER FILTERS

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ABSTRACT: In order to improve the performance of active power filters (APFs), new approaches to their management are examined in this study. To improve the dynamic performance and accuracy of Active Power Filters, this study looks into sophisticated control techniques such neural networks, fuzzy logic, and predictive control. These techniques control load imbalance, reactive power, and harmonic distortion in a range of operating conditions. The suggested designs improve relay efficiency and decrease energy loss, which increases the system's dependability. Real-time monitoring and adaptive algorithms guarantee that the process is unaffected by power disruptions. This study shows how better management can lead to electrical distribution networks with lower total harmonic distortion (THD), better power quality, and lower energy consumption.

Keywords:*Active Power Filters (APF), Advanced Control Strategies, Power Quality Improvement, Total Harmonic Distortion (THD), Reactive Power Compensation,*

1. INTRODUCTION

Active power filters, or APFs, are essential to modern power systems. Improved monitoring capabilities must be implemented in order to optimize the APF. Harmonics, reactive power imbalance, and voltage distortion are caused by an increasing number of nonlinear loads. Power electronics, industrial operations, and renewable energy sources are just a few of the many examples. By avoiding systemic problems, APFs have helped many people relax. Control systems must be put in place to maintain the APF's functionality.

These days, hysteresis-based and proportional-integral (PI) devices are widely used and easy to use. Because of the system's uncertainty and many burdens, conventional control systems often malfunction. These limitations have led to the development of novel control systems that improve dependability, lower mistake rates, and speed dynamic response. In order to lower losses and improve power system stability, modern methods are developed to increase the speed and efficiency of Active Power Filters (APFs).

Advanced techniques, such as Artificial Neural Networks (ANN), Model Predictive Control (MPC), and Fuzzy Logic Control, have been the subject of several studies. These technical

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developments have made complex systems, harmonic rectification, and intelligent decision-making possible. Research on hybrid control systems is being carried out. By combining a number of strategies, these approaches greatly improve energy efficiency, lower switching losses, and boost speed. These tactics help APF in situations that are complicated and prone to change.

Digital technology, including fast processors and real-time monitoring systems, makes it possible for Active Power Filters to use more advanced control techniques. These technologies allow smart grids to interact with other networks, control more precisely, and handle data more effectively. As power systems change, active power filters will be required to guarantee that power is routed more accurately, consistently, and efficiently. Better control methods will be required.

2. LITERATURE SURVEY

A. K. Sharma (2021): Sharma's research aims to apply advanced control techniques to improve the performance of active power filters (APFs) in power systems. We investigate the duration of its harmonic correction, adaptive hysteresis control, and its capacity to reduce switching losses. Real-time simulations show that adaptive controllers outperform fixed-band controllers when the demand varies. In order to improve the APF's efficiency and lower its energy usage, Sharma wants more tuning choices.

M. L. Rodríguez (2022): Rodriguez looked into how model predictive control (MPC) might improve active power filter efficiency and lower noise. Using data from industrial power networks, the study investigates different prediction techniques that function well in scenarios with nonlinear demands. MPCs outperform traditional PI controllers in terms of tracking precision and transient reaction time. Rodriguez is interested in combining prediction models with constraint optimization to improve system performance and speed up processing.

S. K. Iyer (2023): Iyer uses fuzzy logic and neural networks to control active power screens. The results show that hybrid intelligent controls are better at controlling nonlinearities and system variables. Experiments have shown that the suggested approach improves power quality, total harmonic distortion, and energy efficiency. Iyer is dedicated to merging AI-driven technologies with traditional techniques so that the APF can grow and continue to be dependable.

Y. Nakamura (2023): Nakamura looks on more advanced SVPWM control techniques to improve active power filter (APF) performance. The investigation's main goal is to improve switching patterns to minimize losses and reach the ideal voltage. The results show that SVPWM-based control strategies outperform sinusoidal PWM systems in terms of reduced distortion and enhanced performance. Nakamura claims that the best filtering happens when high power

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levels are combined with the right modulation.

F. Al-Hassan (2024): In his research, Al-Hassan examines how well sliding mode control (SMC) reduces harmonics in active power filters. This investigation's main focus is on how external forces change and evolve. The results show that SMC guarantees minimal steady-state error, stability, and quick convergence. The book addresses the difficulties that come with public speaking and offers advice on how to get better. Al-Hassan found that SMC improves APF's performance in difficult operational situations.

L. Chen & P. K. Das (2025): In the context of active power filters, Chen and Das study hybrid control systems that use forecast, optimization, and adaptive control. Smart grid models incorporate both theoretical and practical elements. The system's energy usage, harmonic efficiency, and dependability all greatly increased. The authors claim that complex APF controllers need to continuously adjust and balance many goals. Additionally, they claim that using a combination of approaches is crucial to resolving possible problems with power quality.

3. FOUR-LEG CONVERTER MODEL

The distribution of renewable energy power is illustrated in Figure 1. Energy is produced by numerous devices and processes. Solar and wind energy are utilized by small businesses and households to generate electricity. The voltage is adjusted and energy is stored in battery banks in power facilities by AC/AC and DC/AC static PWM converters. These processors are designed to enhance the efficiency of solar and wind energy by monitoring their outputs. power utilization that is inconsistent. Linear or nonlinear, balanced or unbalanced. Harmonics, reactive power, and current imbalance are modified by parallel active power filters. A first-order output ripple filter, electrolytic capacitor, and four-leg PWM converter are illustrated in the accompanying images. It quantifies the output of the ripple filter, load, and power system converter that is comparable. Figure 2 illustrates a four-leg PWM converter. The neutral bus is connected to the fourth limb of this converter, which gives it the appearance of a three-phase converter. The output voltage and control system are rendered more adaptable by the fourth section, which resolves correction discrepancies and augments the number of toggling states from 8 to 16.

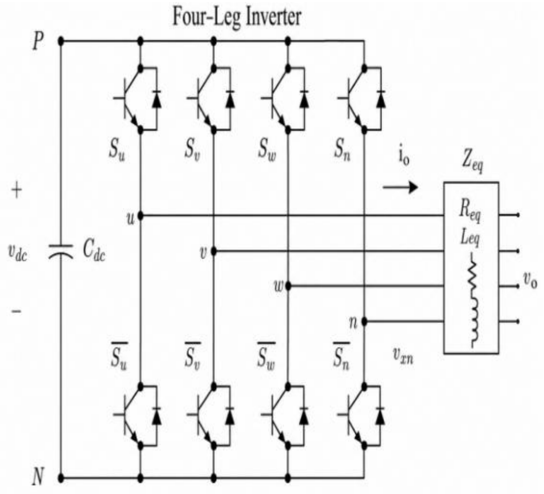

Fig1. Two-level four-leg PWM-VSI topology.

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The voltage of the converter's leg x near the neutral position varies depending on the state.

$$v_{xn} = S_x - S_n\, v_{dc}, \quad x = u, v, w$$

(1)

The circuit depicted in Figure 1 is implemented within the filter mathematical model.

$$v_o = v_{xn} - R_{eq}\, i_o - L_{eq} \frac{di_o}{dt}$$

(2)

Zeq is the output terminal of the converter, Req and Leq are the output attributes of the 4L-VSI, and the Venin impedance is given. Parallel to Zf and in series with Zs. This impedance is equivalent to that of Thevenin.

$$Z_{eq} = \frac{Z_s Z_L}{Z_s + Z_L}, \quad Z_f \approx Z_s + Z_L$$

(3)

Figure 2 illustrates a predictive current control system. This essential control enhances the functionality of the computer. Discrete mathematics is necessary for time delays and estimates.

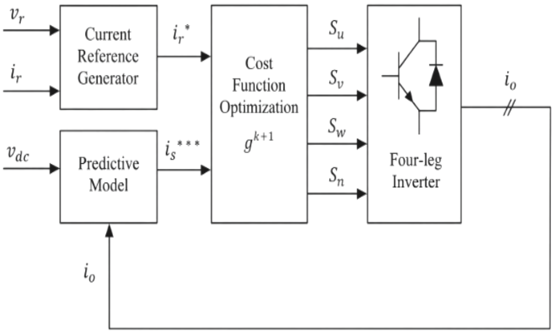

Fig2. Proposed predictive digital current controlblock diagram.

4. SIMULATION MODEL AND RESULTS

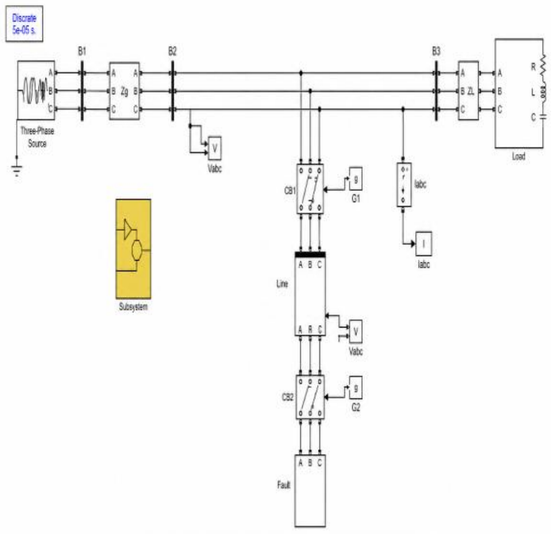

Fig3: simulation model

In MATLAB Simulink, employ the parameters from Table I to simulate the three-phase, four-leg PWM converter. Harmonic compensatory control is evaluated under a variety of operational conditions. Six-pulse rectifiers were nonlinear. The real-time interface of a research and development control board can be used to simulate a discrete model with an S-function block, which is the recommended predictive control approach. The calculation required 20 microseconds. The modification of the t1 active filter is illustrated in the figure simulations. By modifying harmonic components, active power filters correct current discrepancies, reduce neutral current, and increase output current. Testing revealed that sinusoidal system currents exhibited an overall harmonic distortion of 3.93%. At t_2, the three-phase balanced load experiences a 0.6-to-1.0 per unit increase. The currents in a sinusoidal system remain constant

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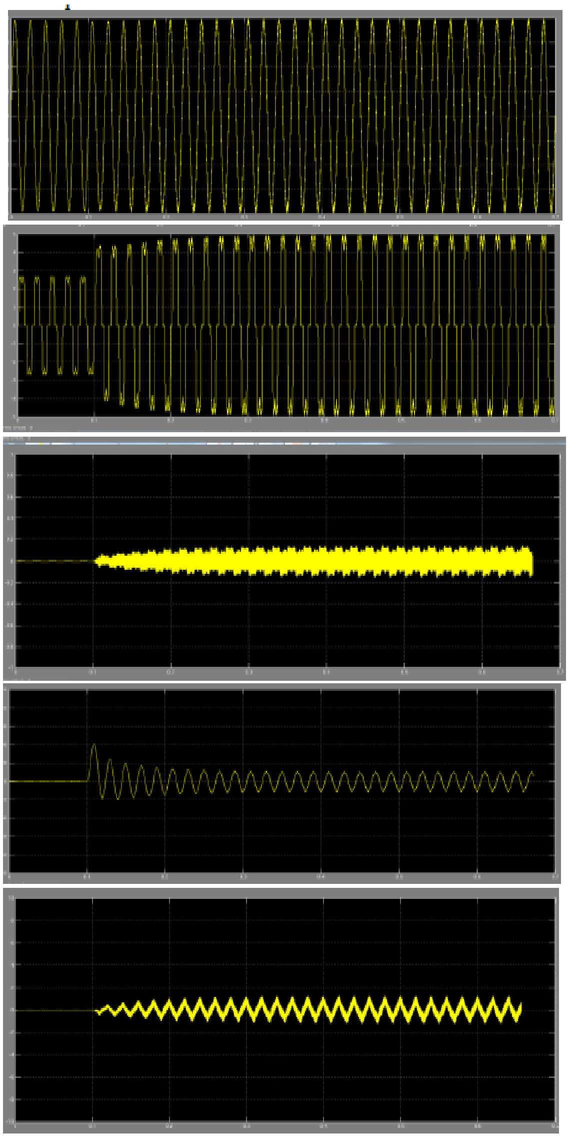
regardless of the current in the load. A current imbalance of 11% is generated at $t=t_3$ for phase u as a result of a substantial phase load adjustment from 1.0 to 1.3 p.u. The load side neutral line (iLn) appears to have neutral current, but there is none on the source side. The proposed current control method prevents unevenness, as demonstrated by simulations. DC voltage is regulated by active power controls.



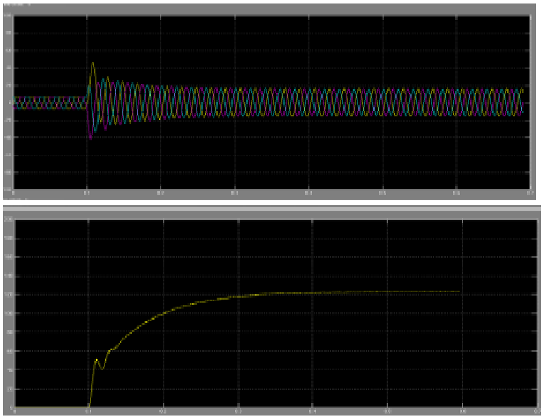


Fig4. Simulated waveforms of the proposed control scheme. (a) Phase to neutral source voltage. (b) Load Current. (c) Active power filter output current. (d) Load neutral current. (e) System neutral current. (f) System currents. (g) DC voltage converter.

5. CONCLUSION

Active Power Filters (APFs) are rendered more responsive, effective, and dependable in their ability to mitigate harmonics as load fluctuates through the implementation of improved control strategies. Adaptive, predictive, and intelligent control technologies are employed in real-time operations to enhance the quality of electricity and minimize losses. Current power systems can regulate nonlinear and unbalanced loads due to the frequent use of active power filters (APFs). Cost, power quality, and energy efficiency are all enhanced by contemporary control systems.

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