



Five Level MCHB Hybrid Active Power Filter for Harmonics Mitigation

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Abstract— The presence of nonlinear loads significantly deteriorates power quality. With the rapid advancement of power electronics, particularly power semiconductor devices, the prevalence of nonlinear loads has expanded considerably. These loads generate harmonics in the power system and lower the power factor, thereby increasing the demand for reactive power. To address these issues, both active and passive power filters have been extensively implemented in distribution networks. A hybrid active power filter, which integrates the advantages of both filtering types, offers enhanced performance and effectiveness. At the core of this system lies a voltage source inverter, whose performance directly influences the overall efficiency of the filter. This paper proposes a modified cascaded H-bridge (MCHB) five-level inverter configuration for the realization of a hybrid active power filter. A MATLAB-based simulation model has been developed to validate the proposed control approach, which utilizes a instantaneous reactive power (pq) theory and PI controller. The simulation results demonstrate effective harmonic suppression and reactive power compensation. The proposed MCHB structure effectively reduces inverter size and cost of the hybrid active power filter.

Index Terms— hybrid filter, active power filter, harmonics, multilevel inverter, pq theory.

I. INTRODUCTION

Conventionally, passive (LC) filters are used for eliminating harmonics [1]. The capacitors are also deployed to improve the power factor. These passive filters comes with drawbacks of larger size, fixed tuning frequency, resonance issue and source impedance dependency [2]. The passive filters are designed for mitigating a specific harmonic contents. The passive filter design changes with changes in load characteristics [6]. Active power filters have several advantages over their passive counterparts, making them a preferred choice in many applications [3]. Active filters can rapidly adapt to changing load conditions, effectively mitigating harmonics and power quality issues. Active filters can be configured to meet specific power quality requirements, making them suitable for various applications [4]. Choosing between active and passive filters depends on specific application requirements, budget constraints, and desired level of power quality [5]. Active filters depends on source for meeting the DC power supply requirements and may put additional burden on the source. They have limited power and frequency range which is decided by the component selection during system design [7]. As a solution to this situation, the hybrid active power filters have been developed by combining active and passive filters together [8].

The main aim in the development of HAPF is to reduce the cost and rating of active filter by using passive filter that filters the dominant harmonics caused by non-linear loads and supplies reactive power requirement. The hybrid active power filters are configured as – series active shunt passive, shunt active series passive and shunt active shunt passive configuration [9].

The voltage source inverter (VSI) is a key component of active filter. The multilevel inverters [10, 11] have become popular in power industry. In high power and high voltage applications, they have some drawbacks such as switching loss and constraints of device ratings in operations. Multilevel structure can succeed high power and high voltage inverter without requiring higher ratings [12]. For harmonics mitigation with hybrid filter, instantaneous reactive power theory is used in [13] for reference current generation. To further enhance the performance, a proportional resonant controller [14] is included for calculating oscillating current component. For residential installation, single phase filter is recommended [15] whereas in industrial environment, multi tuned filters are recommended [16].

II. HYBRID FILTER DESIGN

A series-tuned harmonic filter consists of an inductor–capacitor combination specifically engineered to attenuate a targeted harmonic frequency. These filters are connected in parallel with the power system and are commonly referred to as shunt passive filters. The design process begins with determining the required reactive power compensation (kVar), which may be based on power factor correction objectives or the commercially available capacitor ratings. It is important to note that reducing the capacitor's kVar rating results in a larger reactor size for the filter. Therefore, an optimal balance between the inductor and capacitor parameters must be achieved during the design of a shunt passive filter.

Three basic steps are followed in design of single tuned passive power harmonic filter calculation.

- Determine the capacitor size Q_c (VAR) needed to meet the reactive power requirement of harmonic source.
- Determine capacitive reactance.

$$X_c = \frac{kV^2}{Q_c} \quad \dots (1)$$

Therefore the capacitor value becomes,

$$C = \frac{Q_c}{2\pi f kV^2} \quad \dots (2)$$

- If h_n is the harmonic order that is desired to be trapped, the value of inductive reactance needed is calculated using equation (3).

$$X_L = \frac{X_c}{h_n^2} \quad \dots (3)$$

Value of harmonic filter reactor is calculated as

$$L = \frac{1}{2\pi f X_L}$$

The details of system specification including load and calculated values of passive filter inductor and capacitor for third order and fifth order harmonics compensation are mentioned in Table 1.

TABLE I: SPECIFICATION TABLE

Source	Voltage 230V (RMS)
Load	Full wave diode bridge rectifier driven $R = 5 \Omega$ $L = 10\text{mH}$
Active Filter	DC link Voltage = 440V Switching frequency = 5KHz Configuration: MCHB Capacitors = $C_1 = C_2 = 3000\mu\text{F}$ Control scheme: PQ theory Pulse Generation: SPWM
Passive Filter	Single Tuned 3 rd order $R_3 = 0.0325\Omega$ $L_3 = 3.45\text{mH}$ $C_3 = 326.21\mu\text{F}$

	Single Tuned 5 th order R ₅ = 0.0195Ω L ₅ = 1.2421Mh C ₅ = 326.21μF
Coupling Inductor	0.785mH

III. MATLAB SIMULATION AND RESULTS

The MATLAB Simulink model is developed with pq theory based controller for harmonics mitigation. In pq theory based control, the three phase AC quantities are converted into two rotating reference frames (alpha-beta) to simplify the analysis and control. The three-phase AC quantities (a, b, c) are transformed into two-phase quantities (α, β) using the Clarke transformation. The α-β frame is a rotating frame of reference, which simplifies the analysis of the system. The Instantaneous Reactive Power is calculated based on the pq components. The active power is associated with the real power flow, while the reactive power is associated with the flow of energy back and forth between the source and the load. By manipulating the pq components, it is possible to control the active and reactive power flow in the system. Here, voltages and currents are transformed from abc to αβ coordinates with Clark Transformation and then load power are computed to define the compensation power components. The reference currents are expressed in abc coordinates and compared with the actual currents. A PI controller is used for regulating DC-link voltage.

By applying Clark Transformation to V_{abc} and I_{abc},

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (5)$$

And

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (6)$$

The instantaneous active and reactive power are given by,

$$p = V_\alpha I_\alpha + V_\beta I_\beta \quad (7)$$

$$q = -V_\alpha I_\beta + V_\beta I_\alpha \quad (8)$$

The active power has two components which are average component ($\bar{p}$) and oscillating (p_{osc}) components.

$$\therefore p = V_\alpha I_\alpha + V_\beta I_\beta = \bar{p} + p_{osc} \quad (9)$$

Again, the reactive power has two components which are average component ($\bar{q}$) and oscillating (q_{osc}) components.

$$\therefore q = -V_\alpha I_\beta + V_\beta I_\alpha = \bar{q} + q_{osc} \quad (10)$$

A Butterworth high pass filter can separate the average and oscillating components of active and reactive power. A DC link controller is used to suppress the fluctuation in the DC-link voltage of the active filter. The error signal that drives the controller usually is obtained by comparing the reference DC voltage and actual DC voltage. Response obtained from the controller is referred as power loss component of active power (p_{loss}).

The estimated active power is estimated as,

$$p' = \bar{p} + p_{osc} + p_{loss} \quad (11)$$

and estimated reactive power is remain same as

$$q' = q \quad (12)$$

By separating the average and oscillating components of powers and obtaining the power loss component, the reference currents in α-β are obtained from,

$$\begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p' \\ q' \end{bmatrix} \quad (13)$$

The reference currents could be expressed in abc phase quantities by,

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{\alpha}^* \\ I_{\beta}^* \end{bmatrix} \quad (14)$$

This reference signal further generates sinusoidal PWM (SPWM) signals for triggering of the switching devices in the five level MCHB inverter configuration.

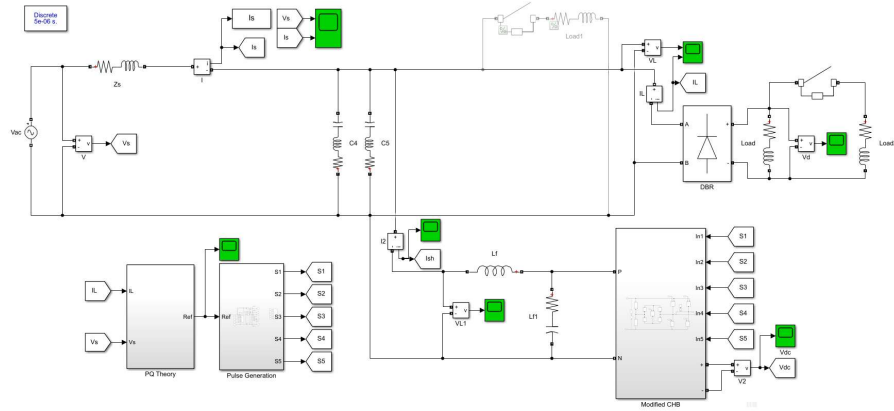


Figure 1: MATLAB model of single phase hybrid active power filter with five level MCHB

The MATLAB Simulink model of single phase hybrid active power filter with 5 level MCHB inverter is shown in figure 1. The configuration of 5 level MCHB is shown in figure 2. The passive filter part is designed for mitigating third and fifth order harmonics. A nonlinear load of diode bridge rectifier feeding RL load having $R = 5\Omega$ and $L = 10\text{mH}$. The effective load KVAR value is 17.652KVar.

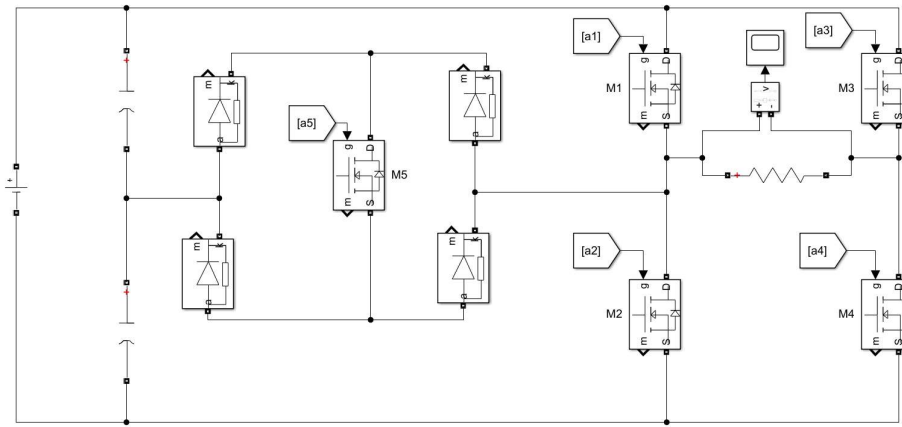


Figure 2: The MCHB configuration

The control scheme of hybrid active power filter based on PQ theory is shown in figure 3. It is used to generate reference signal for pulse generation. The system measures load current and source voltage which are converted into alpha and beta components with Clarke's Transformation. The alpha and beta components of load current and source voltage are used for estimating P and Q with standard PQ theory. The estimated P component is used to further determine the instantaneous power component p which is combined with DC link PI controller. The resultant instantaneous power is combined with estimated Q, V alpha and V beta to obtain the reference current component. This reference current is compared with the active filter current. This output is compared with a four triangular waves as shown in figure 4 to generate the required switching pulses for all the MOSFETs in inverter.

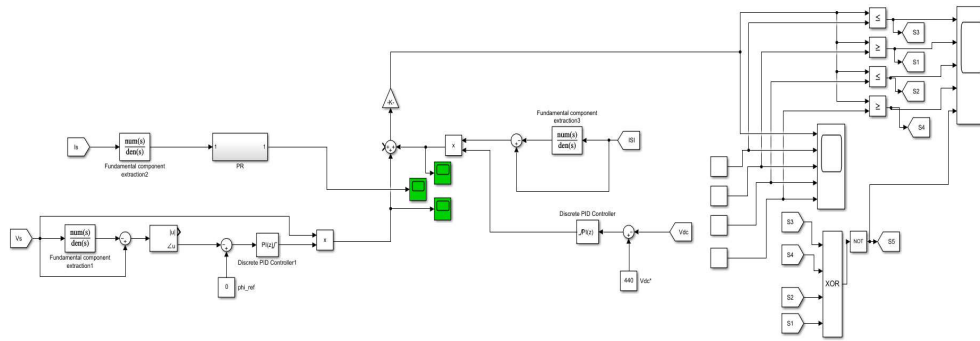


Figure 3: Control scheme with pq theory and PI controller

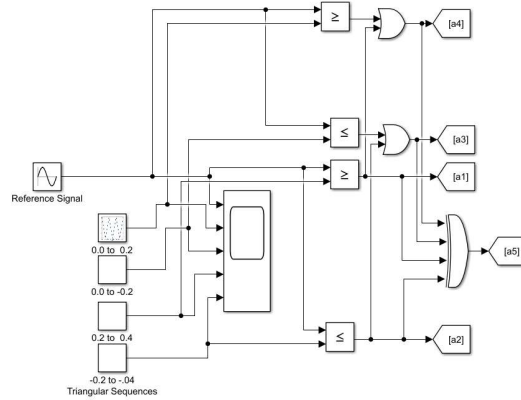


Figure 4: Switching scheme for five level MCHB inverter

The simulation model is set into execution for 1 second. The load switching is done at 0.5S. The DC link voltage waveforms are shown in figure 5. The link voltage is seen to be maintained constant at 440V. A small dip in DC link is seen during the load switching at time instance $t=0.5$ second. The source voltage and load current waveforms are seen in figure 6.

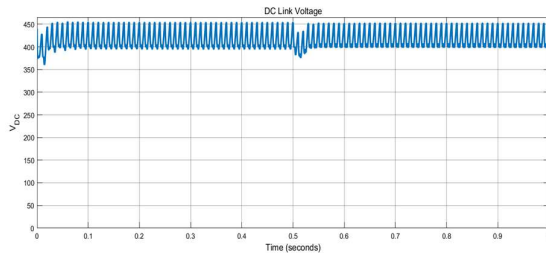


Figure 5: DC Link Voltage

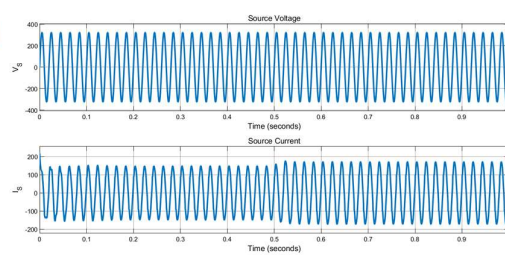


Figure 6: Source Voltage and Source Current

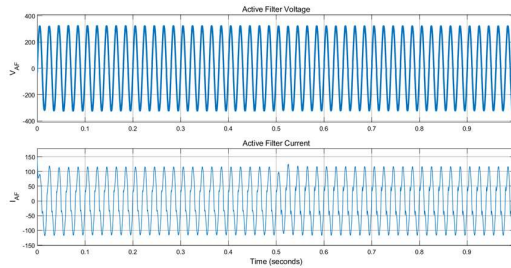


Figure 7: Active Filter Voltage and Current

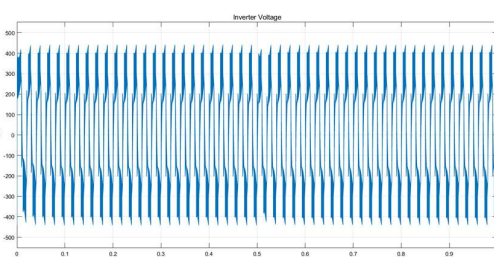


Figure 8: Inverter Output Voltage Waveforms

The waveforms of active filter voltage and current i.e. compensating signal are shown in figure 7. The variation are seen in the compensating current waveforms shape corresponding to the value load. The output voltage waveforms of the five level MCHB inverter are shown in figure 8.

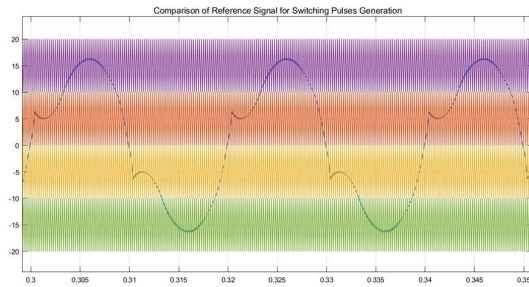


Figure 9: Gate pulse generation by comparing reference current with triangular waves

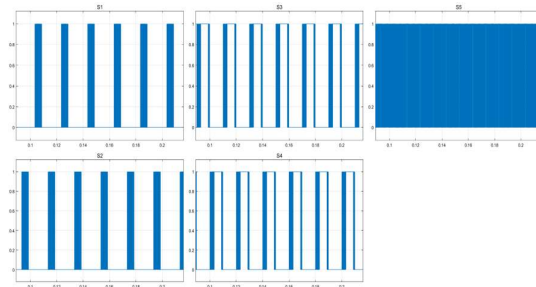


Figure 10: gate pulses of the switching devices

For generating the gate pulses for switching devices of the inverter, the compensating current waveform is compared with triangular waveforms with a logic circuit as shown in figure 4. The corresponding waveforms are shown in figure 9. The switching pulses of five MOSFETs of MCBH inverter are shown in figure 10.

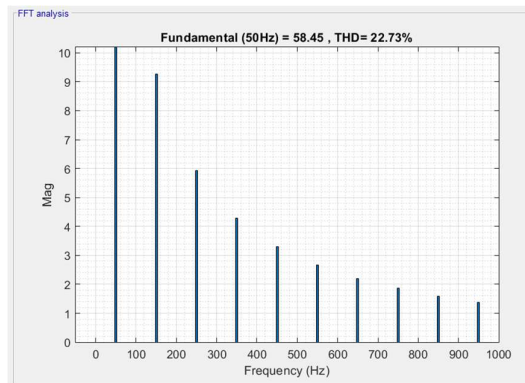


Figure 11 (a): THD without Filter

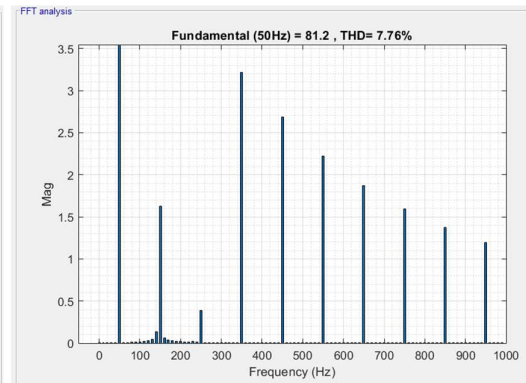


Figure 11 (b): THD with Passive Filter Only

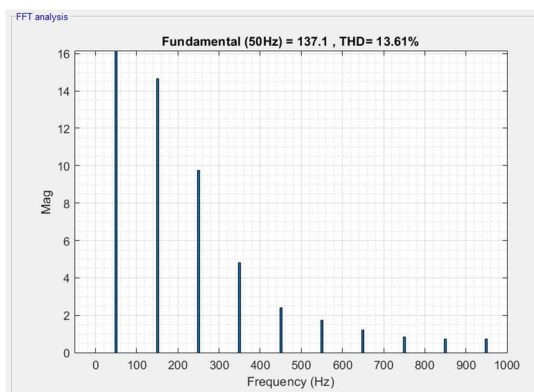


Figure 11 (c): THD with Active Filter Only

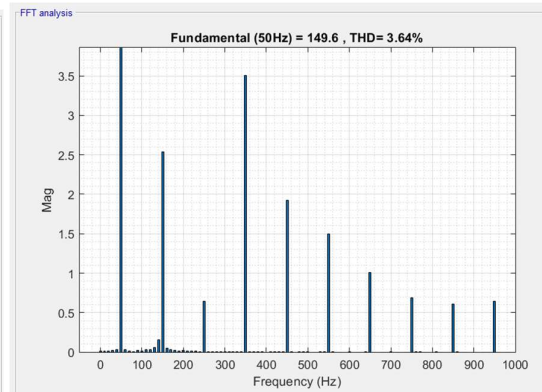


Figure 11 (d): THD with Hybrid Filter

The harmonics analysis is carried out in four parts. At first the harmonics produced by the nonlinear load are measured be 22.73% as seen in figure 11(a). When only passive filter is introduced, the percentage harmonics are reduced to 7.76% as seen in figure 11(b). Upon compensation with active filter only, the corresponding percentage harmonics are 13.61% as seen in figure 11(c) and the compensation with active and passive filter together, i.e. hybrid filter, the percentage harmonics are recorded to be 3.64%.

IV. CONCLUSIONS

The five level MCHB inverter-based hybrid active power filter has emerged as a promising solution for harmonic mitigation. Integrating a multilevel inverter within the hybrid active power filter configuration provides a reliable and efficient approach to improve overall power quality. The single-tuned passive filter effectively suppresses the targeted third and fifth-order harmonics, while post-compensation analysis using the hybrid active power filter indicates a THD of 3.64%, which is well within the permissible limits specified by the IEEE 519 power quality standard. The authors can conclude on the topic discussed and proposed. Future enhancement can also be briefed here.

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