Single-Phase Hybrid Active Power Filter Using Single Switch Parallel Active Filter and Simple Passive Filter

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Abstract - This paper presents an implementation of hybrid active power filter for minimizing the input current distortion in a single-phase system feeding a non-linear load. In this method, the active power filter is injecting equal but opposite current to mitigate the distortion current shape the supply current to a sinusoidal form and in phase with the supply voltage. In this work, the single-switch parallel active power filter is used to reduce switching stress, losses and also the cost. Studies are performed to evaluate the performance of this topology in conjunction with a simple passive filter in a hybrid arrangement using two components; a parallel active power filter and a passive filter for removing both high order and low order harmonics. The passive filter uses simple LC configuration; whilst the parallel active filter uses a single-switch topology typically used in boost rectifier circuit. Theoretical, simulation and experimental result are presented to prove the validity of this arrangement.

Keywords- Hybrid Active Power Filter (HAPF), Boost circuit, Active Current Wave Shaping

I. INTRODUCTION

The application of power electronic in power conversion shows drawbacks that lead to power quality problems which could relate to harmonics affecting communication interference, heating, solid-state devices malfunction, resonance and others [1]. Solutions involve several techniques that include the use of passive and active power filter (APF). A more advance approach is the use of hybrid filters amongst other involves the use of both the passive filter and shunt APF in combination. They are being used to eliminate both the lower order and higher order harmonics. The passive filter is normally designed to eliminate the bulk of load-current harmonic [2] leaving the more complex problems to be solved by the APF.

Shunt APF normally operates using pulse width modulation (PWM) inverter techniques to inject the required non-sinusoidal current requirements of nonlinear loads [3] but is complex with the number of switches in use [4]. Another approach is the use of series active power filter that uses basic bridge-diode circuit, boost circuit and an inductor [5].

In this work, a new hybrid APF topology is proposed that employs only one power switch [6] as a parallel active power filter[PAPF] and the use of simple passive filter is studied. The proposed system introduces an active current wave-shaping technique to mitigate the distortion input current by injecting equal and opposite input current to shape the supply current to a sinusoidal form; in time and phase with the supply voltage.

The time-domain approach is used to control the power switch of proposed PAPF during compensation process. This approach is based on the principle of holding the instantaneous current within some reasonable tolerance of a sine wave [7]. The error is computed from the difference of instantaneous actual current signal with its reference signal, normally pure sine wave. This error is then conditioned and processed to obtain the required switching pattern known as the pulse wave modulation (PWM) wave. A simple proportional integral control method is implemented to aid response from the control which uses a supply current detection to accomplish shunt APF tasks. A simple LC filter is used in conjunction to study its effects.

II. PROPOSED HYBRID ACTIVE POWER FILTER

The new proposed hybrid APF consists of two types of filter; simple LC passive filter and a PAPF for removing both high order and low order harmonic components. Fig. 1 shows the arrangement of proposed hybrid APF and in
The PAPF is used to inject equal but opposite current into the system to mitigate the distortion current to a sinusoidal form; in phase and time with the voltage supply. The new proposed PAPF topology only consist a single active power switch (IGBT) in order to simplify the compensation circuit and reduce the switching stress.

The SCCL (fig.1) is used to monitor the supply current waveform and make corrections by current compensation techniques. If the supply current is distorted, the SCCL will respond by providing switching signal to the IGBT that will inject the current compensation from the PAPF circuit to the mains to compensate the distorted supply current into a sinusoidal form. Unipolar switching is proposed due to the use of one power switch in the system.

The compensation circuit uses a boost and PWM technique to generate the injected current into the system as described in [6]. In this work, active PWM also known as active current wave shaping is used for switching control. This technique allows active comparison of the error signal with the carrier signal to ensure error is kept within the boundaries of the carrier peaks at all times [8]. The active PWM operates by comparing the corrected signal with the carrier signal to produce the required PWM control. When sinusoidal signal has magnitude larger than or equal to the carrier signal, the comparator output (PWM sequence) is higher. A proportional integral (PI) control algorithm is used to regulate the error.

III. OPERATION OF SHUNT APF

The operation of the PAPF is best described by the illustration as shown in Figure 4 to inject the required current into the system. When switch is turned ON (Figure 4(a)), diode D5 is reversed biased. Thus the output stage is isolated from the system. The input supplies energy to the boost inductor that causes inductor current to increase linearly with ramp behaviour. The energy stored in the inductor can be used for compensation purposes.

When the switch is turned OFF, diode D5 is forward biased as shown in the equivalent circuit of Fig. 4(b). There exists a change in current. Since the inductor cannot change instantaneously, the voltage in the inductor reverses its polarity to maintain constant current. In this stage, the current will flow through the inductor, diode D5 and the compensating load.

Control is required to ensure that the inductor does not completely discharge the energy. Thus, when the power switch is turned on, the current ramp rides on a pedestal with a magnitude proportional to the residual energy stored in the core. Energy stored in the inductor is then used for charging the output capacitor and hence energy stored is transferred. Due to this requirement in operation, the boost voltage must be greater than the DC voltage since the APF is intended to inject an opposite reactive current into the system. For the proposed system the maximum peak to peak ripple current, \( I \) is set to 8% following reference [8] from the line current and the value of boost inductor can be determined by using where \( V \) is the supply voltage, \( I \) is the permitted peak to peak ripple current and \( f \) is the switching frequency.

In practice, due to losses and parasitic elements associated with the converter, the voltage conversion ratio declines as the duty cycle approaches unity, thus a very high duty cycle is impractical. During the inductor energizing period, all the output current must be supplied by discharging the output capacitor, resulting in considerable output voltage ripple. The ripple at the output voltage is given by [9].

\[
\frac{dV_{load}}{V_{load}} = \frac{\delta T}{RC}
\]  

(1)

where \( R \) is the load resistance and \( C \) is the capacitance.
Fig. 4: Equivalent circuit of the system when (a) power switch is turn “ON” and (b) power switch is turn “OFF”.

Fig. 5 shows the waveform of the desired supply with the compensation current from boost technique. During switching on, the inductor is linearly ramping while when switching is off, energy from inductor and from supply will transfer to the load. Therefore the current from inductor will decrease linearly.

IV. SIMULATION MODEL

In this work, MATLAB/Simulink was used to analyze the behaviour of the proposed system. Fig. 6 shows the proposed system that consists of a simple LC filter with PAPF shunt-connected with the non-linear load and main supply. The block diagram of control algorithm is shown in Fig. 7.

V. HARDWARE SETUP

The hardware setup consists of three major parts; non-linear load, passive filter and shunt. This experimental test-rig was constructed to verify the operation on the proposed hybrid APF and are as shown in Fig. 8; with the compensation circuit and boost inductor connected in series with diode bridge rectifier feeding a resistor connected in parallel with a capacitor.
device. A gate drive circuit was used to boost the small PWM signal into an appropriate level for turning ON of the IGBT and to provide physical isolation between the power and electronics section [10].

![Diagram](image)

**Fig. 8: Experimental set-up**

In this proposed system, both analogue and digital techniques were applied for the control electronic. The analogue system comprises a peak detector, multiplier, reference signal and absolute circuit whilst the digital system consists of a peripheral interface controller (PIC) that contains algorithms for the operation of a subtractor, PI controller and a comparator.

The peak detector used an operational amplifier (UA741CN) complemented with diode (IN 4007) to provide only the positive cycle and a capacitor at the output. Capacitor is used to reduce the signal ripple thus providing a stable measurement of required magnitude. An AD633JN amplifier and capacitor was used to implement the multiplier circuit. In this system, two resistors in series across the output of step-down transformer and a variable resistor were used to provide the reference signal in sine wave. The absolute circuit comprises of three operational amplifiers (UA741CN).

The digital system was implemented using PIC 16F877 microcontroller for its real-time control. This chosen microcontroller chip is an advanced version with high performance and low power consumption. This microcontroller is able to observe and convert the analogue signal into a digital form by using a built-in analogue to digital converter (ADC). This digital signal is then processed with appropriate control algorithm to generate discrete active PWM. An external 20 MHz external crystal oscillator provides the system clock for the PIC, sufficient to produce a 10 kHz switching required in this work.

**VI. RESULT AND DISCUSSION**

Selected simulations and experimental results on the operation of the proposed hybrid active power filter arrangements are presented. The behaviour of the supply subject to non-linear load is investigated in four modes of operation; without filter, b) with passive filter c) with APF and d) with hybrid. Fig. 9 show results obtained from simulation and hardware verification on individual components.

From the result, it can be seen that the supply current was pulsating (discontinuous) and not in phase with the supply voltage for uncompensated system and is measured with approximately 150.32% at a power factor of 0.59 leading due to the capacitive nature of the load. During compensation, current from APF was injected into the system to mitigate the distorted current to a sine wave supply current that in phase with the supply voltage as in the result. After compensation, the supply current has a sinusoidal waveform that is in phase with the voltage supply. The THD level was reduced to 3.50% (less than standard THD specified by IEEE 519) with almost unity power factor (0.99 lagging). Behaviour of system can be observed from subsequent Figures of 10. The final paper will discuss further results in stages reflecting various contributions.

**XI. CONCLUSION**

This work has illustrated that the single-switch could be used to effective to improve the performance of a passive filter using hybrid APF arrangements that is equally capable of reducing harmonic components in the current supply and achieved unity power factor operation in a single-phase system feeding a non-linear load. Expected sinusoidal supply current that in phase and time with the supply voltage can be obtained by injecting equal but opposite current to shape the pulsating supply current into a sinusoidal form and in time and phase with the supply voltage. The system employs only one control loop to generate appropriate active PWM switching signal, thus minimized the control requirement and reduce switching stress and losses.

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Fig. 9: Supply Voltage and Current without Any Filter (a) Simulation (b) Experimental; with Passive Filter (c) Simulation and (d) Experimental; with APF (e) Simulation (f) Experimental
REFERENCES


