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Single Phase Active Power Filter using ZVS Full- Bridge Inverter

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Abstract: Wide use of power electronics circuits resulted in harmonic distortion in power system in large extent. Traditional filters have poor dynamic response while harmonic component changes. Active power filters are used to improve power quality by injecting reactive and harmonic current, because of its better dynamic response in different load patterns. In this paper a conventional Zero Voltage Switching (ZVS) full-bridge inverter is investigated and reconfigured as Single Phase Shunt Active Power Filter (SAPF). Hysteresis current control scheme is employed because of its simplicity and ease of implementation. The ZVS scheme is incorporated with hysteresis controller followed by reference current generation. The simulation of the proposed SAPF is modelled and evaluated with desirable results in MATLAB/SIMULINK.

Keywords: Power Quality (PQ), Shunt Active Power Filter (SAPF), ZVS–Zero-Voltage Switching (ZVS) inverter, Hysteresis band control

I.INTRODUCTION

Power quality (PQ) is an important factor in Power system. It is an ability of a power system to deliver steady and secure power in all conditions. There are so many power quality issues faced by electrical engineers throughout the evolution of power system such as voltage sag, voltage swell, frequency variation, harmonics, etc. Harmonics are defined as multiple integral of fundamental frequency. In a linear load, the load current is always pure sinusoidal wave and doesn't contain any harmonics except the fundamental [1].A nonlinear load in power system is characterized by continuous current interruption due to switching. These distorted current waveforms include harmonics other than fundamental. Amplitude and frequency of these harmonics are dependent on the load and switching circuit. The harmonics and reactive power are the causes of various problems which includes increased neutral current, overheating of transformers, distortion of feeder voltage, poor power factor, damages to power electronic circuits and malfunction of the equipment [2]. These current distortions may lead to voltage distortions. When current harmonics flow through the power system network, additional distortions take place due to the transmission line impedance.

The increasing amount of nonlinear loads and unpredictable load patterns make so much undesirable effects in power system. In order to mitigate these effects several methods are adopted, which include passive and active filters. Passive filters are tuned to bypass particular harmonics, which means one tuned passive filter bypass only one or two harmonic contents depending upon design which are single or double tuned. When load change happens, amplitude of harmonic content also changes. Another tuned filter or switchable filters with feedback are employed to bypass harmonics. When harmonics in the line increases, the filter loading also increases. Frequency variation of source and tolerances in the filter components will affect the compensation characteristics of LC filters. If the system frequency varies considerable amount, components required for attaining tuned frequency become impracticable.

Unchangeable characteristics of traditional LC filter and unavoidable use of power electronic circuits makes a path for future research. A flexible solution for this harmonic problem is implementing an active filter. Unlike passive filter, active power filters injects power into the power system network despite bypassing it. Different type of active power filter topologies have been proposed, which includes Shunt active power filter (SAPF), series active topologies and hybrid schemes [3] [4]. SAPF is one among the various types of active filters proposed to improve power quality [5]. Hysteresis current control scheme is selected from various control methods because of quick current controllability and ease of implementation [6].

DC side ZVS full-bridge inverters [7] [8] have the simplest structure. With this advantage, this paper mainly focuses on improving the efficiency of SAPF by reconfiguring ZVS full-bridge inverter control circuitry to a hysteresis band controller. For the purpose of realizing the ZVS condition, a short-circuit stage controlled by the short-circuit pulse in each switching

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cycle is designed to reset the energy in the auxiliary resonant branch [9]. The hysteresis band control and current compensation of ZVS full-bridge inverter is investigated here.

II. SHUNT ACTIVE POWER FILTER

A. Principle of operation

The schematic diagram of shunt active filter power shown in Fig. 1 is a current controlled voltage source inverter (VSI), which is connected in parallel with the load. It is responsible for injecting compensating current into the network. Hence, it is controlled in such a way to generate compensating current to make the source to supply only the fundamental component of load current. All the reactive power could be loaded to SAPF, thus current distortion problem along the transmission line could be avoided.

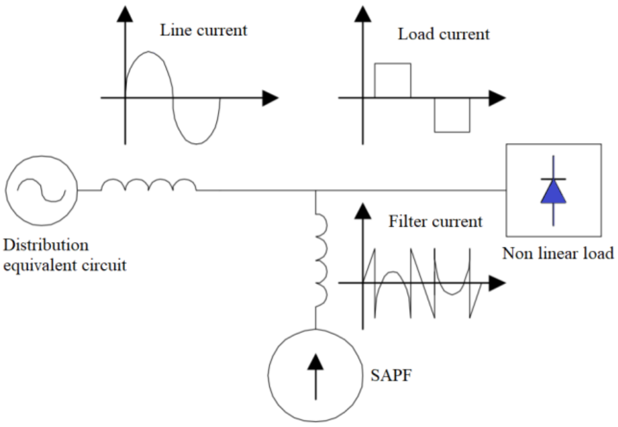

Fig. 1 Compensation characteristics of a shunt active power filter

B. Compensation Technique

The control technique computes the reference waveform for the compensation current to be injected by the SAPF. The choice of the control technique therefore decides the accuracy and response time of the active filter. The computation steps involved in the control technique have to be minimal to make the control circuit compact. The control scheme has an objective to sinusoidal source current at unity power factor. This objective can be realized if the the fundamental component of the distorted load current is accurately and instantaneously computed.

C. ZVS full-bridge inverter

The circuit diagram of the proposed ZVS full-bridge topology is shown in Fig. 2. It is composed of an auxiliary switch S_a, resonant inductor L_r, clamping capacitor C_c and resonant capacitor C_{ra}. The capacitors C_{r1} ~ C_{r4} are paralleled to the main switches. Before the commutation from body-diode to MOSFET in Fig. 2, the auxiliary switch S_a is turned off and the DC voltage V_{dc} across the inverter leg can be resonated to zero voltage by the resonant process. Therefore, the main switches in full-bridge achieve ZVS turn-on. PWM technique employed in this topology shown in Fig. 3. Gate pulse for auxiliary switch is represented as v_{gsa}. For each switching transition vgsa goes low. For bipolar switching operation, before each switching pulse goes low to high, the auxiliary switch will turn OFF and dead time provided to achieve ZVS operation. In that interval voltage across main switches will resonate to zero [10].

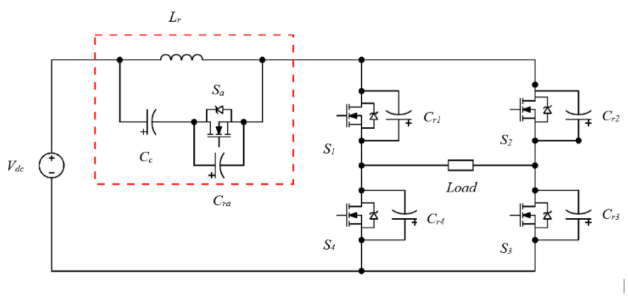

Fig. 2 ZVS full-bridge topology

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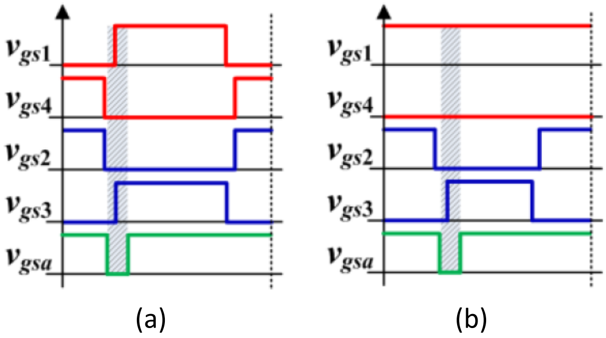

Fig. 3 v_{gsa} with (a) bipolar PWM (b) unipolar PWM

III. PROPOSED SYSTEM

Schematic diagram of soft switching full-bridge inverter used as SAPF as shown in Fig. 4. It is connected to the power system network parallel to load through an inductor (L_f), which helps to make desired slope for filter current waveform. Slope of current waveform determines the characteristics and switching speed of hysteresis band control. The current equation for the circuit is given as (1). The current injected by SAPF is determined by the control technique and it is determined by (2).

Reference current I_{ref} is generated by filtering harmonic components from the load current I_l except the fundamental. Hysteresis current control scheme track the error signal to stay within the band and this current will inject to the system.

$$I_s = I_l - I_f \quad (1)$$

$$I_f = I_l - I_{ref} \quad (2)$$

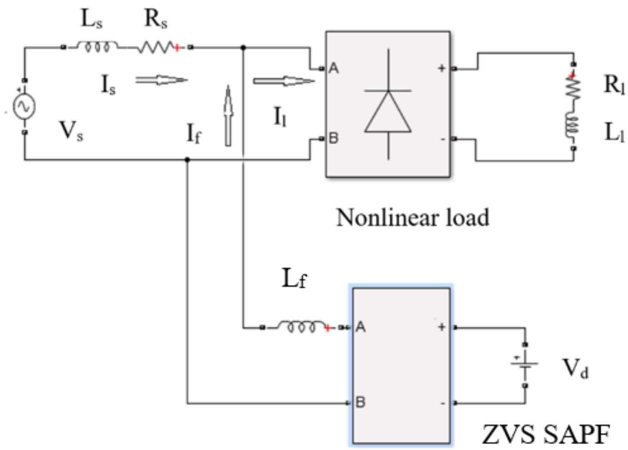

Fig. 4 Schematic diagram of ZVS-SAPF

IV. DESIGN OF CONTROLLER

A. Mathematical modelling

Reference current is generated by measuring load power and input voltage. The total power consumed by the load is calculated as (2):

$$P = V_{load} * I_{load} \quad (2)$$

This power can be decoupled into two parts

$$P = P_{fund} + P_{har} \quad (4)$$

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P_{fund} (Fundamental component of active power) is the power contributed by fundamental component of current and voltage. P_{har} (Harmonic power delivered) is the power consumed by the load due harmonic components. In order to achieve hysteresis band control, reference current free from harmonics have to be generated. By filtering harmonics component of load current, reference can be generated synchronous with source voltage. In Fig. 5 mean values of load voltage and load current multiplied to get apparent power. The peak value of reference current calculated by (5).

$$I_{peak} = \frac{V_{load} * I_{load}}{V_{peak}} \qquad (5)$$

Peak value calculated using (1) is multiplied with fundamental component of source voltage waveform having unity magnitude. The steady state output of reference current block always pure sinusoidal with unity power factor.

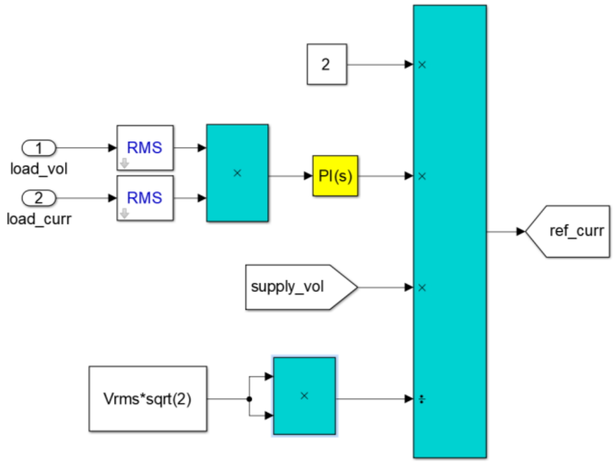

Fig. 5 Reference current generation

B. Hysteresis current controller

The hysteresis band current controller is used to generate switching pulses for an inverter. There are several current control methods already developed, but quick current controllability and ease of implementation make hysteresis current control method much more superior than other control methods. Some of the better properties possessed by hysteresis band current controllers are robustness, better dynamics and fastest control with minimum hardware.

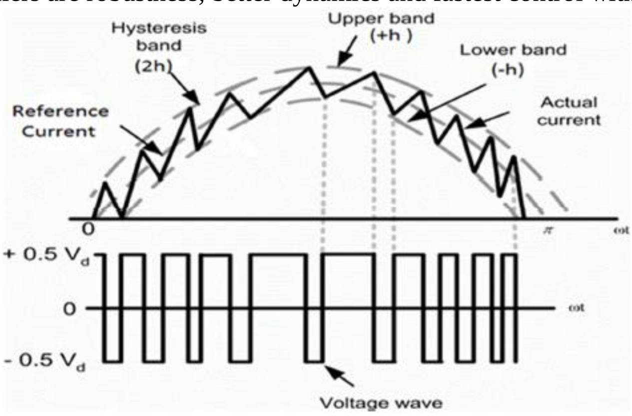

Fig. 6 Hysteresis logic

This method switches the MOSFET when the current error fed to it exceeds the fixed band. Smaller the band width provides better accuracy. If current becomes more than the upper band limit, the switch in the upper part of the inverter leg becomes turned off and the switch in the lower arm becomes turned on. Hence, the current starts to decrease with a desired slope. While decreasing, if the current cross the lower limit of the hysteresis band (-h), the upper switch becomes turned on and the lower switch of the inverter leg becomes turned off. Consequently, the current get reflects between the upper and lower limit of hysteresis band. Operating principle of hysteresis current controller is shown in the Fig. 6. Variable switching frequency is the major disadvantages of this method.

$$I_{error} = I_{load} - I_{ref} \quad (6)$$

The error signal for hysteresis current controller is computed using (6). This error signal shifts +h and –h in order to generate a hysteresis band. Complementary output from S-R flip-flop is connected to gate terminals of main switches in inverter. Dead time and gate pulse for auxiliary switch is generated using logic operations as shown in Fig. 7.

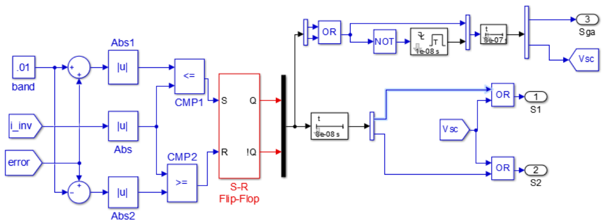

Fig. 7 Hysteresis band controller with switching pulse generation

Table 1 Simulation parameters

Parameter	Symbol	Value
DC voltage	V_{dc}	400V
Grid voltage	V_s	230V
Source inductance	L_s	1mH
Filter inductance	L_f	5mH
Resonant inductor	L_r	7.2μH
Clamping capacitor	C_c	20μF
Parallel capacitor	C_{rn}	1nF

V. SIMULATION RESULTS

The proposed system is modeled and evaluated in MATLAB/Simulink. Source voltage and current waveforms with nonlinear load is shown in fig. 6. The current THD is about 29.10% without any filter. In simulation, the SAPF is set to switch at time instant 0.04 sec. before the instant of switching source current and load currents are exact same having higher THD.

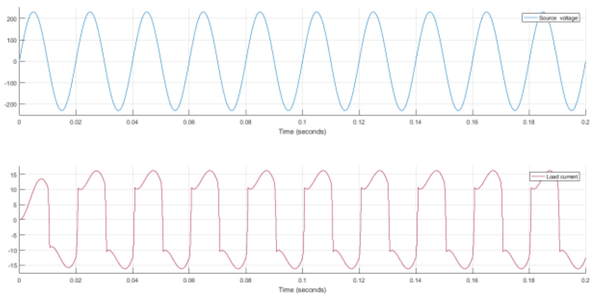

Fig. 8 Source voltage and current without filter

After the instant of filter switching the source current become nearly sinusoidal within one cycle shown in Fig. 8. After 0.04 sec the filter starts to inject current to the network. After 0.06 sec the source current tracks unity power factor. The load current and injected current waveforms are shown in Fig. 9

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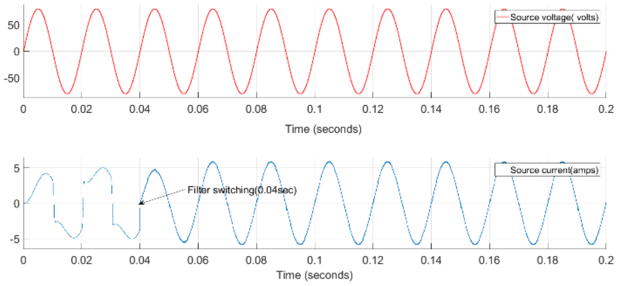

Fig. 9 Source voltage and current with filter

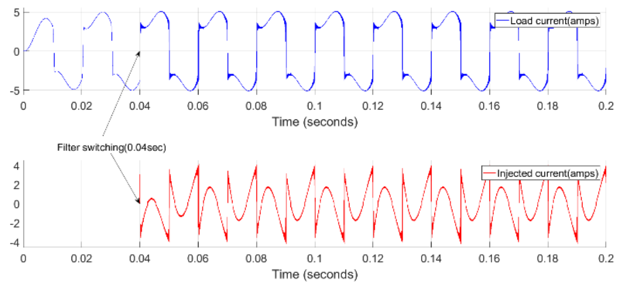

Fig. 10 Load current and injected current by SAPF

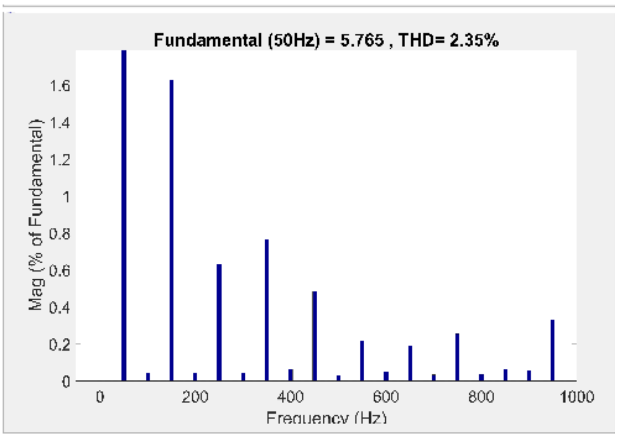

Fig. 11 THD analysis of source current

FFT analysis of source current waveform was done. Without filter THD is about 29.1%. THD after injecting compensating current is 2.35%. DC components almost eliminated.

VI. CONCLUSION

Conventional ZVS full-bridge inverter is reconfigured as single phase shunt active power filter (SAPF). The simulation of proposed system have been carried out. Switching pulses are generated using hysteresis band control and the reference waveform is generated by measuring load current and voltage. The reactive power consumed by nonlinear load is compensated by injecting current using SAPF and source current become almost sinusoidal. The THD is reduced from 29.10% to an acceptable value 0f 2.35%. The simulation results show that the reactive power injection and harmonics elimination of SAPF is satisfactory and it is effective to meet IEEE 519 standard on harmonic levels in source current.

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