

Design & Simulation of Transformer less Universal Active Power Filter

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Abstract:—

MATLAB based transformerless universal active filter power quality in power system is presented in this paper. Compared with the conventional H-bridge topology, it only needs two additional asymmetrically distributed switches, and the system common-mode voltage can be kept constant with a simple modulation scheme. The proposed system is a combination of parallel and series active filters without transformer. It is suitable for applications where size and weight are critical factors. The model of the system is derived and it is shown that the circulating current observed in the proposed active filter is an important quantity that must be controlled. A complete control system, including pulsewidth modulation (PWM) techniques, is developed. Family of H6 transformerless inverter topologies with low leakage currents is proposed and highly efficient and reliable inverter concept (HERIC) topology is also presented in this paper. The proposed inverter can also operate with high frequency by retaining high efficiency which enables reduced cooling system. Finally, the proposed new topology is simulated by MATLAB/Simulink software to validate the accuracy of the theoretical explanation.

Keywords: Transformer less inverter; Common-mode voltage; Leakage current; Total Harmonic Distortion; Current Ripples; Switching control; PWM.

I. INTRODUCTION

The interest in renewable-energy sources is successively increasing because of rising demand of the world's energy and increasing price of the other energy sources, together with considering the environmental pollution. Many renewable energy sources are now available; among them, PV is the most up-to-date technique to address the energy problems. Photovoltaic (PV) power generation systems are received more and more attention in recent years. Due to the large-scale manufacturing

capability of the PV module, it is becoming increasingly cheaper during these last years. So the attempt to decrease the total grid-tied PV system cost is mostly depend on the price of grid-tied inverter [1-3]. Grid tied PV inverters which consists a line frequency transformer are large in size; make the entire system extensive and difficult to install. It is also a challenging task to increase the efficiency and reduce the cost by using high frequency transformer which requires several power stages [4, 5]. On the other hand, transformer-less grid-tied inverters have the benefits of lower cost, higher efficiency, smaller size, and weight [6-12]. However, there exist a galvanic connection between the power grid and the PV module due to the exclusion of transformer which form a CM leakage current. This CM leakage current increases the grid current harmonics and system losses and also creates strong conducted and radiated electromagnetic interference.

The universal active power filter (UAPF) [32]–[43] which is a combination of both, is a versatile device that operates as series and parallel active power filter. It can simultaneously fulfill different objectives like maintaining a sinusoidal voltage (harmonic free) at the load, source current harmonics elimination, load balance, and power factor correction. The cost and size associated with the transformer makes undesirable such a solution, mainly for office and home environments.

This paper proposes an universal active filter topology for single-phase systems applications without transformer, as shown in Fig. 1. In this case, the control of the circulating current becomes an important aspect in the converter design because this current may contribute to additional power loss and large circulating current may cause severe instability and also make damage to the circuit devices. A

complete control system, including pulse-width modulation (PWM) techniques, is developed. Comparisons between the structures are made from weighted total harmonic distortion (WTHD). The steady-state analysis is also presented in order to demonstrate the possibility to obtain an optimum voltage angle reducing the current amplitude of both series and parallel converters and, consequently, the total losses of the system. The operation principle, control strategy, steady-state analysis, simulated, and experimental results are presented to validate the theoretical considerations.

II. PROPOSED TOPOLOGY

The proposed configuration shown in Fig. 1 comprise the grid (e_g, i_g), internal grid inductance (L_g), load Z_l (v_l, i_l), converters S_e and S_h with a capacitor bank at the dc-link and filters Z_v (L_e, L_e , and C_e) and Z_h (L_h, L_h and C_h). Converter S_e is composed of switches q_e, q_e, q_e , and q_e . Converter S_h is composed of switches q_h, q_h, q_h , and q_h . The conduction state of all switches is represented by an homonymous binary variable, where $q = 1$ indicates a closed switch, while $q = 0$ an open one. The converter pole voltages v_{e0}, v_{e0}, v_{h0} , and v_{h0} depend on the conduction states of the power switches, that is

$$v_{e0} = (2q_e - 1) \frac{v_c}{2} \quad (1)$$

$$v'_{e0} = (2q'_e - 1) \frac{v_c}{2} \quad (2)$$

$$v_{h0} = (2q_h - 1) \frac{v_c}{2} \quad (3)$$

$$v'_{h0} = (2q'_h - 1) \frac{v_c}{2} \quad (4)$$

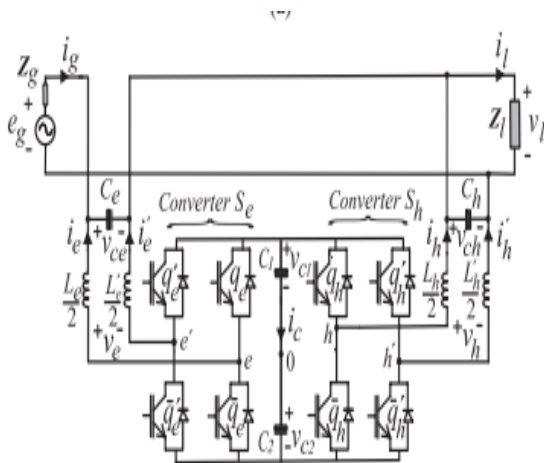


Fig.1. Proposed Transformerless Universal Adaptive Power filter

From the point of view of the controllers, the voltages: $v_e = v_{e0} - v_{e0}$ (converter S_e) is used to regulate and compensate for the load voltage $v_l, v_h = v_{h0} - v_{h0}$ (converter S_h) regulates and controls the grid current in order to maintain the power factor close to one and $v_o = v_{e0} + v_{e0} - v_{h0} - v_{h0}$ (converter $S_e + S_h$) is used to cancel or maintain the circulating current i_o near to zero.

In the balanced case, filter inductors are equal ($L_e = L_e$ and $L_h = L_h$) the circulating voltage model becomes

$$v_o = v_g + \left[\left(\frac{r_e}{2} + \frac{r_h}{2} \right) + \left(\frac{l_e}{2} + \frac{l_h}{2} \right) p \right] i_o. \quad (5)$$

This model is similar to the model of the conventional filter with an ideal transformer. Therefore, we can use $v_e = v_{e0} - v_{e0}$ (converter S_e) to regulate the load voltage and $v_h = v_{h0} - v_{h0}$ (converter S_h) to control the power factor and harmonics of i_g as in the conventional filter.

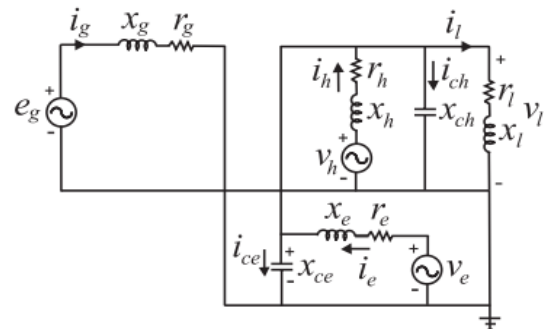


Fig.2. Steady-state circuit of the single-phase universal active filter without transformer.

III. PROPOSED TOPOLOGY FOR VOLTAGE LOAD ANGLE

The steady-state analysis of the proposed active filter is based on the circuit presented in Fig. 2. The phasor equations that describe the behavior of the proposed system are obtained in the complex form. In Fig. 2 is presented the grid (E_g and I_g), internal grid impedance (r_g and x_g), series voltage (V_e), series impedance (r_e, x_e and x_{ce}), series current (I_e), parallel voltage (V_h), parallel impedance (r_h, x_h , and x_{ch}), parallel current (I_h), and load impedance (r_l, x_l). Table I contains the parameters in p.u. used for the steady-state simulations. The power load S_l presents a inductive power factor (PF) equal to 0.85. The simulation results showing the behavior of the converter voltages are presented in Figs. 3 and 4.

It is observed in the Fig. 3(a) the behavior of the voltages converter as a function of the load angle δl (phase angle between the grid voltage e_g and the load voltage v_l). The voltage amplitude of the series converter increases considerably as δl moves away from $\delta l \approx -4^\circ$, which is the point of

smallest voltage amplitude. The amplitudes of currents in the series (I_e) and parallel (I_h) converters and in the grid (I_g) are shown in Fig. 3(b). It can be seen that currents I_e and I_h assume the smallest values for $\delta l \sim -40^\circ$ and $\delta l \sim -30^\circ$, respectively. The grid current remains constant.

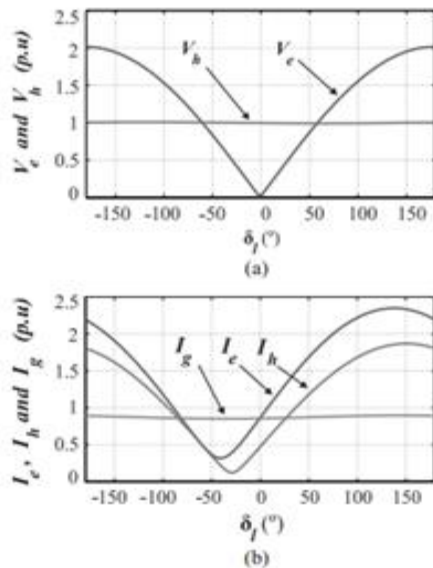


Fig.3. Steady-state analysis of the single-phase universal active filter without transformer (a)efficiency and (b) power of the ac grid

IV. CONTROL STRATEGIES

Fig. 4. presents the control block diagram of the system. The capacitor dc-link voltage v_c ($v_c = E$) is adjusted to a reference value by using the controller R_c , which is a standard PI (proportional-integral) type controller. This controller provides the amplitude of the reference current I_g^* . For the power factor and harmonic control, the instantaneous reference current i_g^* must be synchronized with voltage e_g . This is performed by the block $GEN-g$, from a phase-locked loop (PLL) scheme. From the synchronization with e_g and the amplitude I_g^* , the current i_g^* is generated. The current controller is implemented by using the controller indicated by block R_i which the input reference voltage v_h^* used to compose the PWM strategies for grid's current compensation.

The instantaneous reference load voltage v_l^* can be determined by using the rated optimized load angle δl plus the information θ_g from block SYN and the defined load amplitude V^* . The block $GEN-l$ uses the input information to generate the desired reference load voltage v_l^* . From the difference between the voltages v_l^* and v_l the block of control defined as R_e generates the reference voltage signal

v_e^* to be applied to the PWM strategies in order to to compensate for the load voltage. The homopolar current i_o is controlled by controller R_o , that determines voltage v_o^* responsible to minimize the effect of the circulating current i_o , maintaining this current near to zero. The controllers are of type double-sequence digital controllers employed in [14] and all these reference voltages v_h^* , v_e^* , and v_o^* are applied to the PWM block to determine the conduction states of the converter's switches

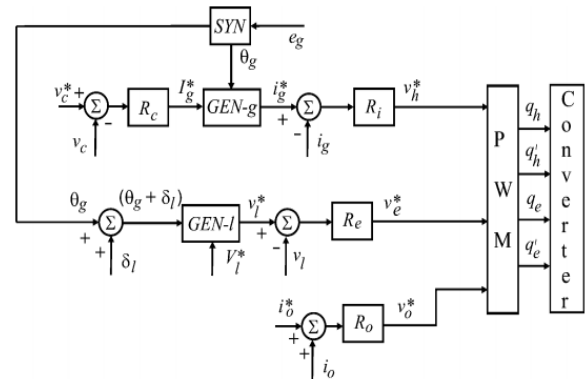


Fig.4. Control Strategy of Proposed system

V. MATLAB BASED SIMULATION & RESULTS

The proposed configurations do not use a transformer in the series connection and consist of four-leg converter. The capacitors of the dc-bus voltage and the switching frequency were, respectively, selected as $C = 2200 \mu F$ and 10 kHz. In order to demonstrate the feasibility of the proposed configuration, two different kinds of simulated results are presented. The first one comprises a linear load and the other one is by nonlinear load.

Fig.5. shows the MATLAB based simulation diagram of proposed system.

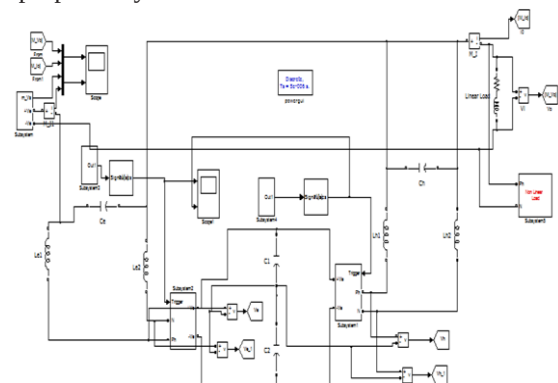


Fig.5. MATLAB based simulation diagram of proposed system with masked diagrams

Fig.6. shows the MATLAB based simulation output voltage & current diagram of proposed system.

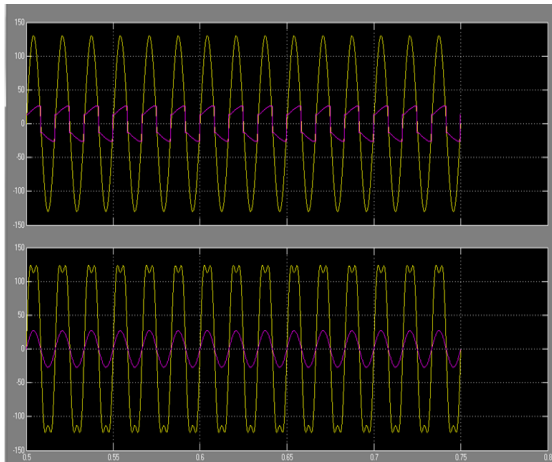


Fig.6. MATLAB based simulation output voltage & current diagram of proposed system.

Fig.7.shows the MATLAB based simulation diagram of with Inductive load (L) proposed system.

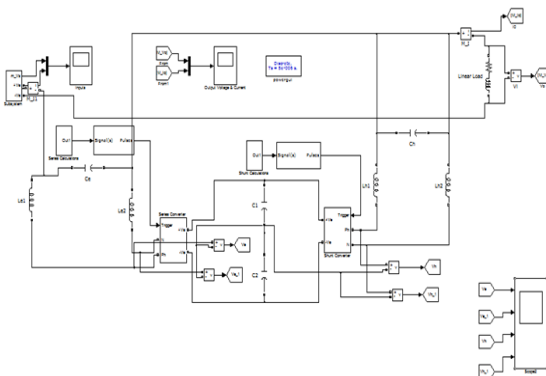


Fig.7. MATLAB based simulation diagram of with "L" Load proposed system

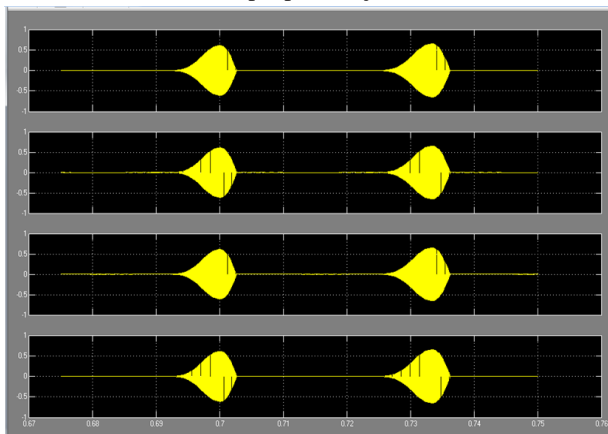


Fig.8. MATLAB based simulation current waveform diagram of proposed system with Inductive Load

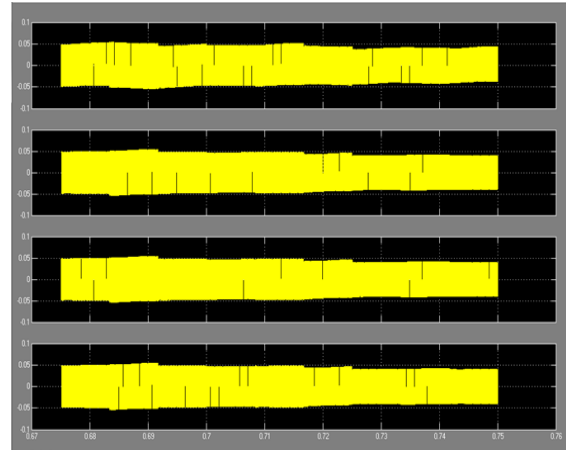


Fig.9. MATLAB based simulation waveform diagram of proposed system

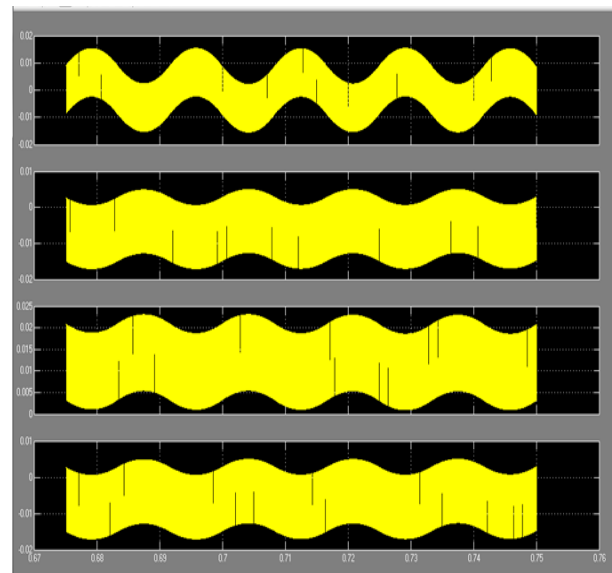


Fig.10. MATLAB based simulation waveform diagram of proposed system with no load

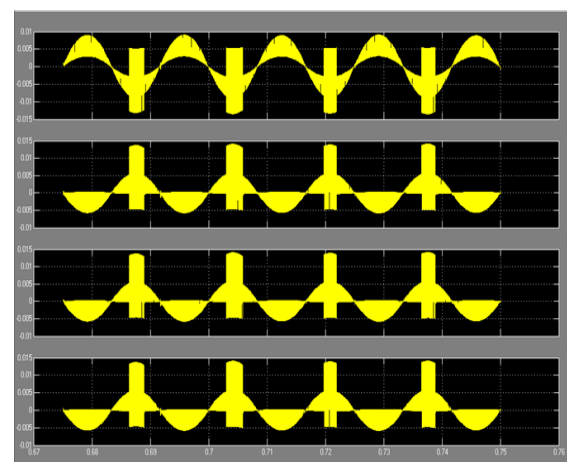


Fig.11. MATLAB based simulation waveform diagram of proposed system with no load

Table.1 shows the simulation parameters for the proposed system

TABLE1.SIMULATION SPECIFICATIONS

Parameter	Rating
Inductive filters	7mH
Filter capacitance	70 μ F
Linear load	5 Ω
Source frequency	60 Hz
Harmonic frequency	180 Hz
Grid voltage	110 $V_{rms} \pm 20\%$
Power system	1.2 kVA
Load voltage	v_l : 50 V_{rms} and 100 V_{rms}

VI. CONCLUSION

Transformerless inverter topologies are being used to overcome the deficiencies of inverters with transformers. A suitable control strategy, including the PWM technique has been developed for the proposed UAPF. In this way, it has been shown that the proposed configuration presents low *WTHD*, whose value is, however, higher than that of conventional configuration. This is because of the need to compensate the circulating current i_o via voltage v_o . Experimental results verify the validity of the novel circuit and show high efficiency. Furthermore, the switching voltages of all commutating switches are half of the input dc voltage and the switching losses are reduced greatly. Finally, theoretical analysis and performance evaluation results indicate that the proposed topology can effectively reduce the leakage current to an acceptable level.

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