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Four Quadrant Operation of a Single Phase Improved Power Quality AC-DC Converters

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***Abstract*: This paper presents the four quadrant operation of a boost type single phase bidirectional ac-dc convertor via modeling and simulation. Improved power quality with unity input power factor has been achieved by adopting the hysteresis band current control technique. The simulation results confirm the efficacy of the hysteresis control that renders operation of the boost converter as the operating point transfers between the four quadrants at a unity power factor.**

***Index Terms*: Bidirectional ac-dc converter, improved power quality, boost convertors.**

I. INTRODUCTION

Solid state ac/dc conversion of electric power is widely used in a variety of industrial and other applications, such as adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs) etc. Moreover, these convertors are also used in utility interface with nonconventional energy sources such as solar PV, etc., battery energy storage systems (BESSs), in process technology such as electroplating, welding units, etc. [1],[2].

Traditionally solid state ac/dc converters are designed using diodes and thyristors to provide controlled and uncontrolled unidirectional and bi-directional ac/dc power conversion. They have problems of injected current harmonics, resultant voltage distortion and poor power factor at input ac mains and a rippled dc output at load end, low efficiency, and large size of ac and dc filters. In view of stringent requirements of power quality at the ac mains [3],[4] and their increased applications, a new breed of converters have been emerged using new solid-state self-commutating devices such as MOSFETs, IGBTs, GTOs, etc. Such converters are classified as boost, buck, buck-boost, multilevel and multi-pulse ac-dc converters and are referred to as improved power quality converters (IPQCs) [5],[6]. IPQC technology has matured at a reasonable level for ac-dc conversion with reduced harmonic currents, high power factor, low electromagnetic interference (EMI) and radio frequency interference (RFI) at input ac mains and well-regulated and good quality dc output to feed loads ranging from fraction of kW to MW power ratings.

Most of the researchers studied the system at steady state for only one quadrant operation [7-10]. However, studying the circuit with operation at transfer between different quadrants have not been given the important attention. This paper presents a study of the bi-direction boost type ac/dc power converter with improved power quality and unity power factor. Results of operating point transfer between different quadrants are studied and presented. The circuit employs power IGBT embedded four quadrant switches (4QSWs) [3]. The topology of the IPQC itself ensures variable bi-directional dc voltage and reversible current in boost [7] modes. Application of the hysteresis band current control (HCC) based closed loop pulse width modulation (PWM) technique renders operation of the converter in the mode at any power factor, in any quadrant, with an improved power quality at the ac interface by appropriately modifying the switching pattern of the 4QSWs.

II. CIRCUIT DESCRIPTION

The bi-directional boost converter is the IPQC version of the conventional thyristor dual converters. Their topology is derived from ac-ac matrix converters using four quadrant switches (4QSWs). Since no four-quadrant switch is currently commercially available these are realized by embedding a transistor inside a diode bridge or by inverse parallel connections of transistors as shown in Fig (1). Power IGBTs are employed because they have the advantages of high switching frequency and small pulse and notch widths. Topology of a single-phase bi-directional boost converter using type I 4QSWs is shown in Fig (2).

In the circuit shown in Fig (2), there are four 4QSWs, two in each limb. Each 4QSW comprises two 2QSWs (two quadrant switches), each two -quadrant switch consisting of a IGBTT with series diode, connected in inverse-parallel. The operation of the bi-directional boost converter in boost mode and in a particular quadrant in the V-I plane shown in Fig (3) is determined by the conditioning of the switching states of two sets (I and II) of devices. In the single-phase version each set comprises four IGBT s; set (A) IGBTs – T11, T22, T33, T44 and set (B) IGBTTs - T1, T2, T3, T4. corresponding to the four quadrants in the buck and boost modes pertaining to the rectification and inversion operations. Table (1) shows the modes of operation of the boost circuit.

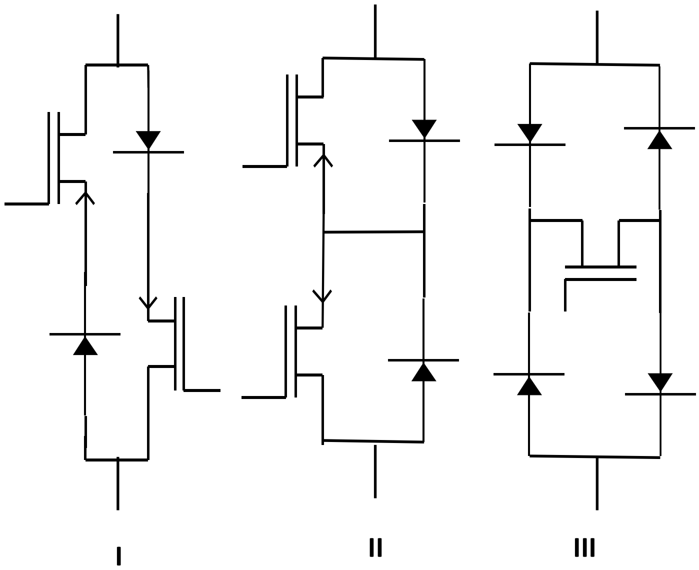
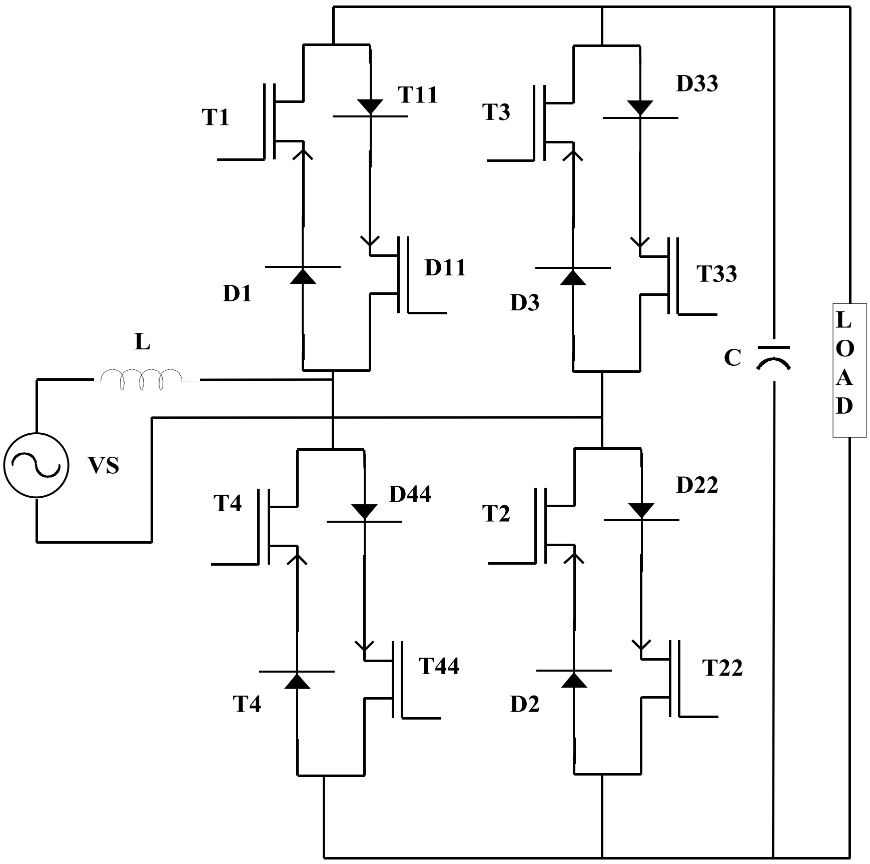


Fig (1) Three types of Four-Quadrant Switch (4QSW) realizations



Fig(2)the power circuit diagram of a single phase bi-direction boost rectifier

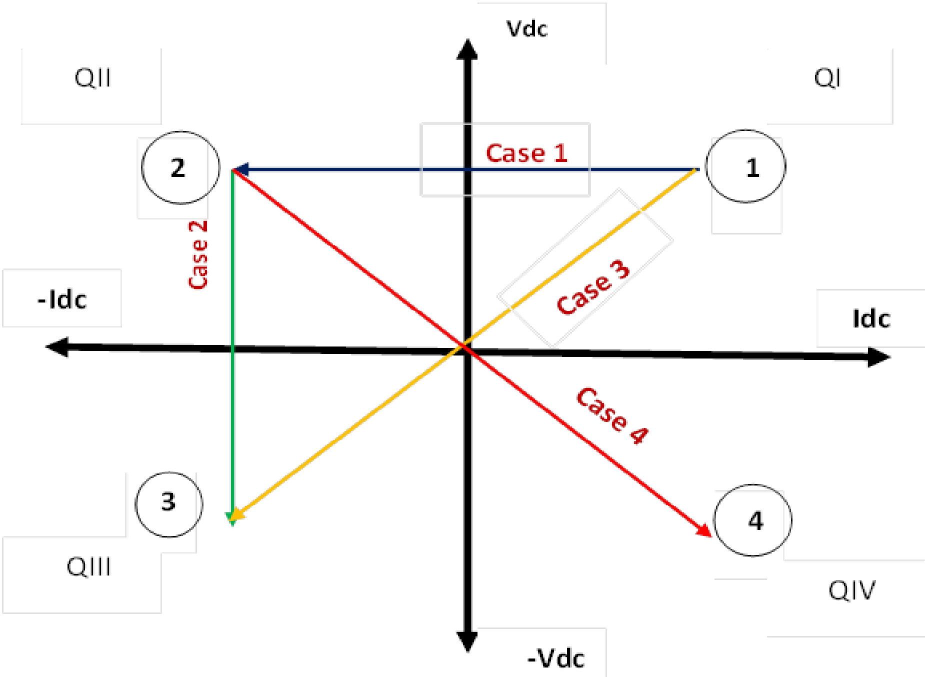


Fig (3) V_I plane for the quadrants

Table (1) Modes of boost circuit

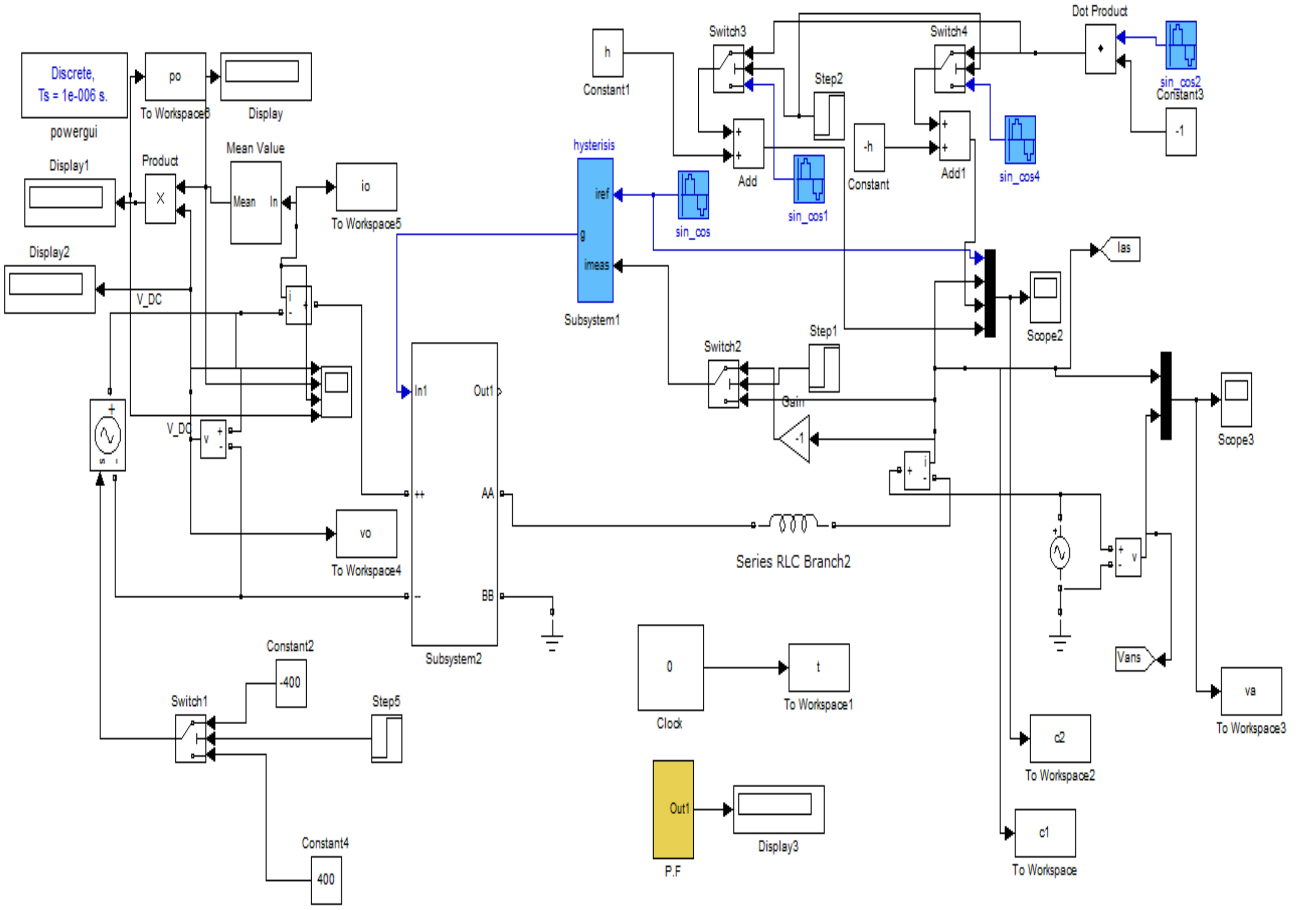
Operation	Quadrant	Set (A)	Set (B)
Rectification	QI	Switching pattern displaced by 180	OFF
Inversion	QII	OFF	Switching pattern displaced by 180
Rectification	QIII	OFF	Switching pattern displaced by 180
Inversion	QIV	Switching pattern displaced by 180	OFF

III. SIMULINK MODEL

Fig (4 a) shows the general PSB/simulink model for the ac-dc boost rectifier-inverter circuit. Fig (4 b) shows details of the subsystem1, i.e. power circuit of the bidirectional rectifier/inverter with its triggering block. Fig (4 c) shows details of subsystem 2, i.e. the hysteresis band controller where the controller accepts the actual input ac current and then compare it with a reference signal. This internally generated signal has zero phase shift with the ac supply so that a unity power factor is obtained. The amplitude of the reference signal is the required ac current, Its amplitude can be obtained mathematically if the required output power is known.

The model has been built so that it gives results in either mode (rectification or inversion) and after a specified some time it transfers to another mode (rectification or inversion), switching time between the modes is pre-specified within the program.

Fig (3) shows all possible operations of the circuit that is four quadrants on the V-I dc-dc axis. The operating point may be transferred from any quadrant to any quadrant as it will be shown in the following section.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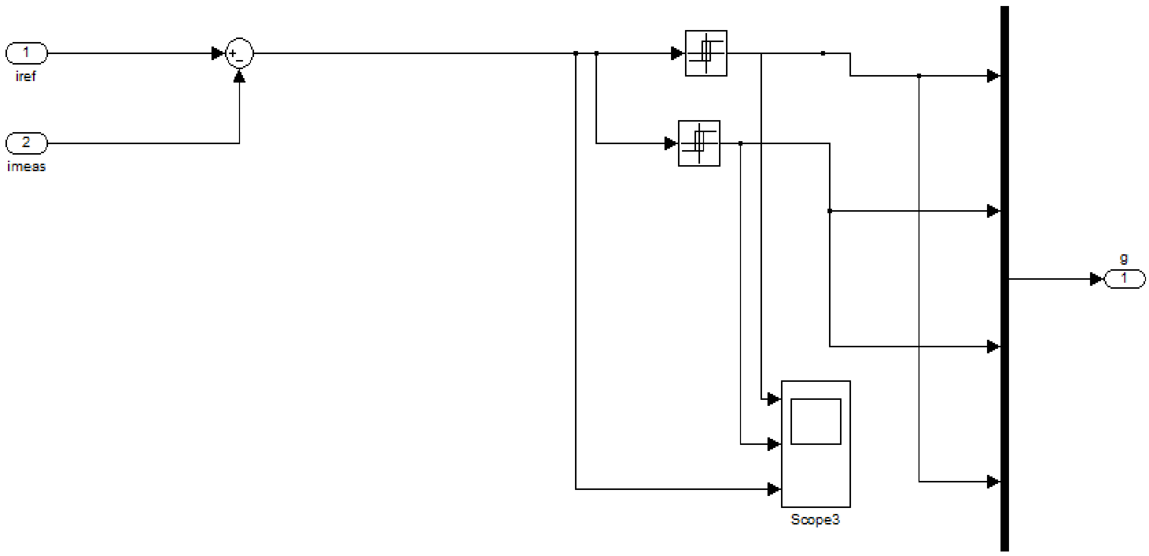
(a)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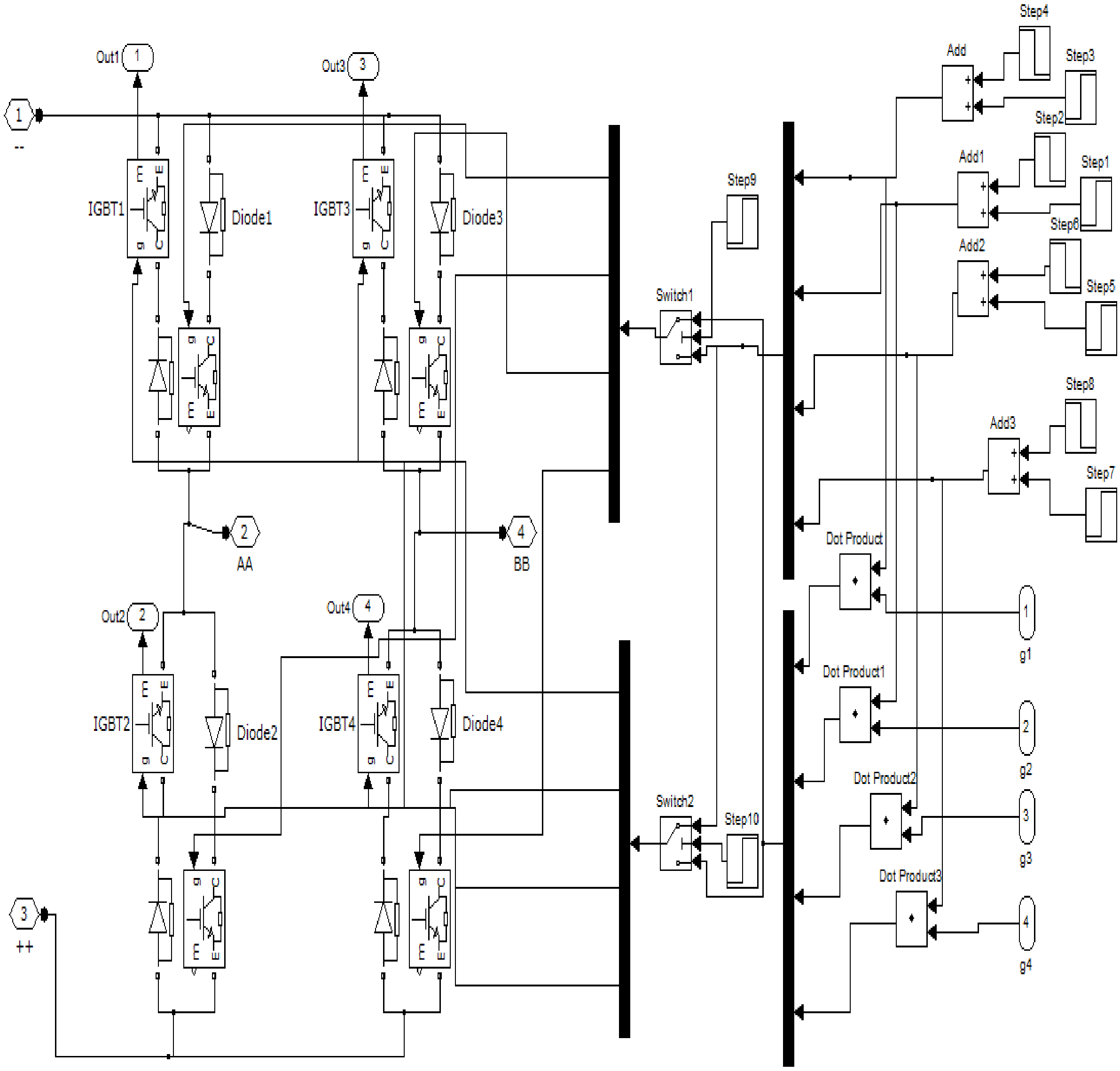

(c)

Fig (4) PSB/simulink model for the ac-dc boost rectifier
(a) main model
(b) details of subsystem1
(c) details of subsystem2

IV. SIMULATION RESULTS

In this section results of the bidirectional rectifier circuit are presented, the circuit may operate as a boost rectifier and/or invertor. Fig (5) shows the voltage and current waveforms at the ac side of the circuit when operating as a boost rectifier (Quadrant I) for the first cycle , followed by a dead time for a half a cycle, then as a boost inverter (Quadrant II) for the rest of the figure. This corresponds to case 1(fig 3) where the operating point 1 in Q1 to point 2 in Q2. Fig(5) shows clearly how the operating point is transferred between the two quadrants very smoothly keeping the THD at 4.28 % at unity P.F at h=0.5 and the THD =1.98% at unity P.F. when h=0.2 , where h is the hysteresis band for the current.

Fig (6) shows the current and the power at the dc side for the same condition. It is clear from this fig. how the power changed its sign when the operating point is transferred between QI & QII.

Similar simulation results (Figs.7 & 8) are obtained for the system operating as an invertor (QII) then as a rectifier (QIII) . This corresponds to case 2 (Fig3) , where the operating point 2 in QII moved to point 3 in QIII .Fig. 7 shows that the power quality remains as good as in the first case .

Simulation results for all other possible cases are also presented in (figs.9-12) where (figs.9 & 10) are for the transferring of the operating point from (QI to QIII) (both rectification). This corresponds to case 3 (Fig3) , where the operating point 1 in QI moved to point 3 in QIII, And (figs.11 & 12) are for the operating point transferring between (QII to QIV) (both inversion) . This corresponds to case 4 (Fig3) , where the operating point 2 in QII moved to point 4 in QIV.

V. CONCLUSION

The performance analysis of a single phase bi-directional boost type improved power quality ac-dc converter (IPQC) based on four quadrant switches are presented. The ability of the circuit to operate as a bi-directional boost converter is confirmed via modeling and simulation. The simulations are conducted for rectification and inversion operations for boost model at unity displacement factor. The results confirm the efficacy of the pseudorandom switching strategy from the perspectives of power quality at the utility in terms of power factor and amenability of the line currents to wave shaping.

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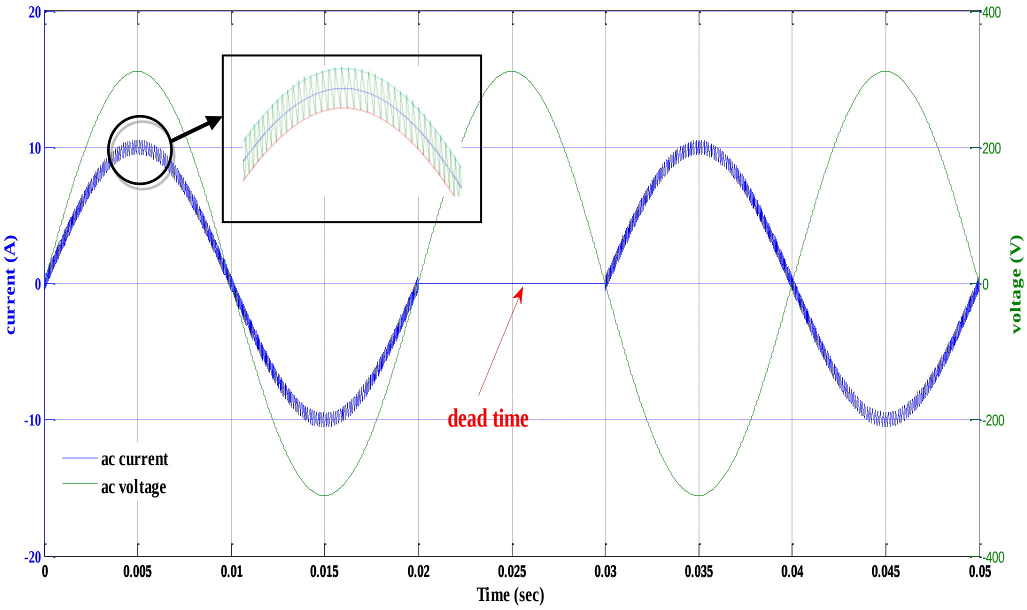


Fig.(5) voltage and current waveforms at the ac side when operating point transfer from QI to QII

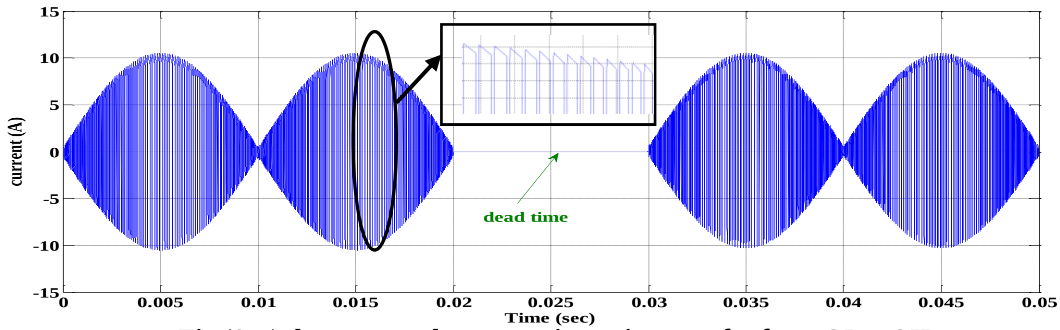


Fig.(6. a) dc current when operating point transfer from QI to QII

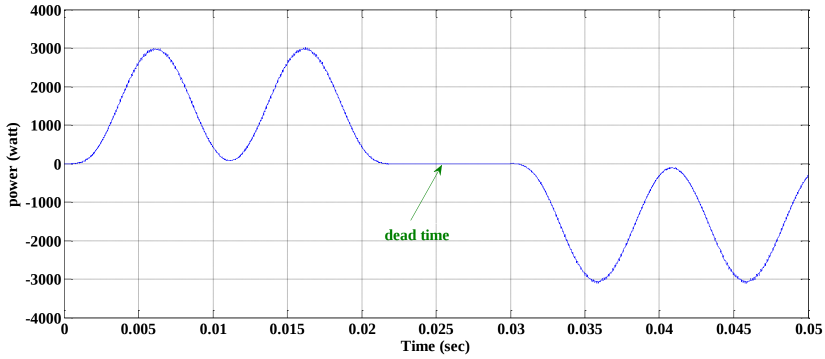
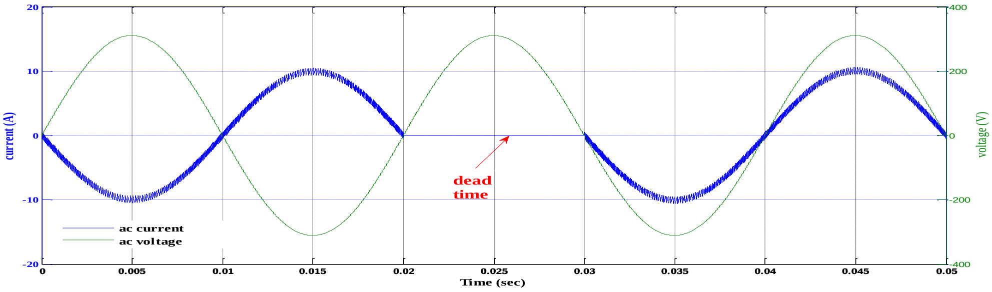


Fig.(6.b) dc power when the operating point transfer from QI to QII


current (A)
voltage (V)
Time (sec)
dead
time
ac current
ac voltage

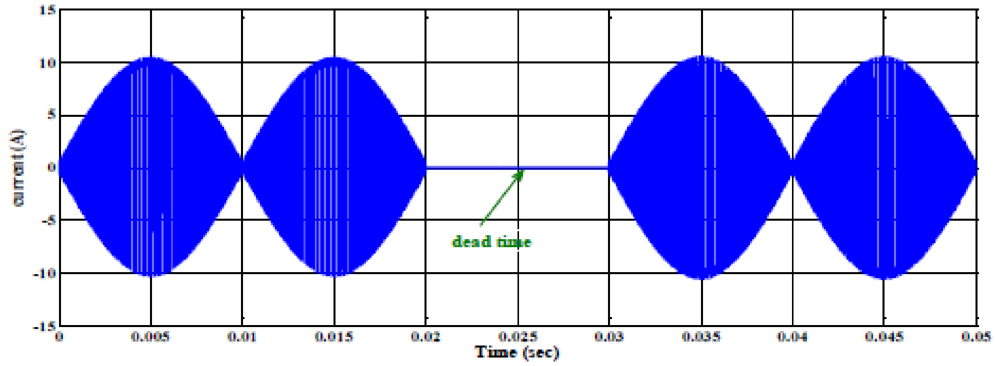


Fig.(8 a) dc current when operating point transfer from QII to QIII

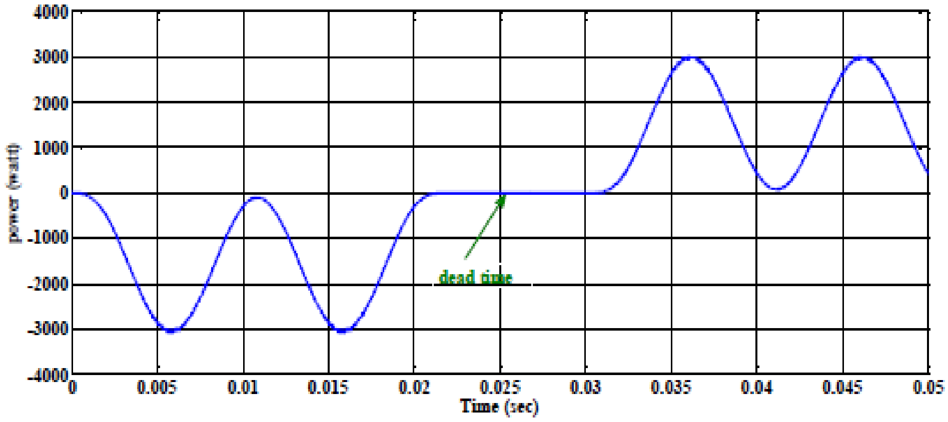


Fig.(8 b) dc power when the operating point transfer from QII to QIII

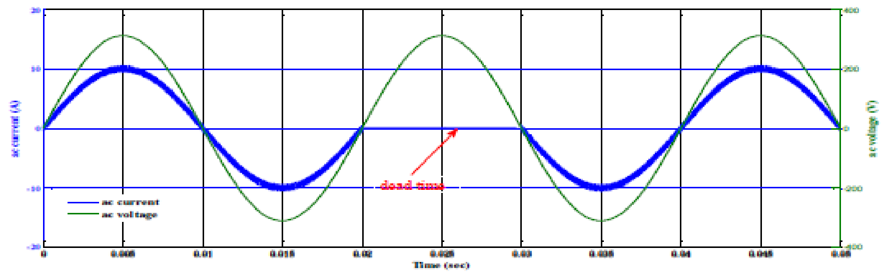


Fig.(9) voltage and current waveforms at the ac side when operating point transfer from QI to QIII

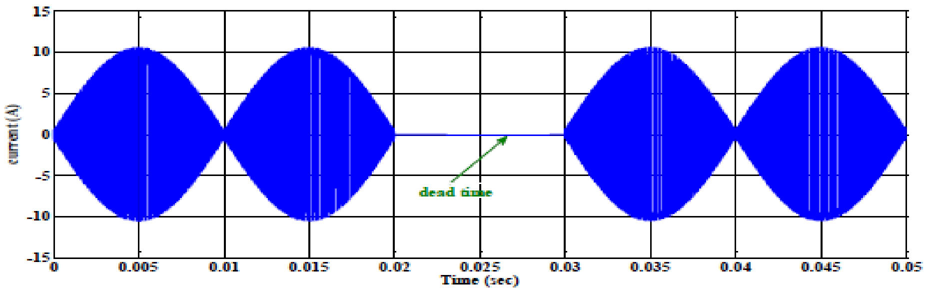


Fig.(10 a) dc current when operating point transfer from QI to QIII

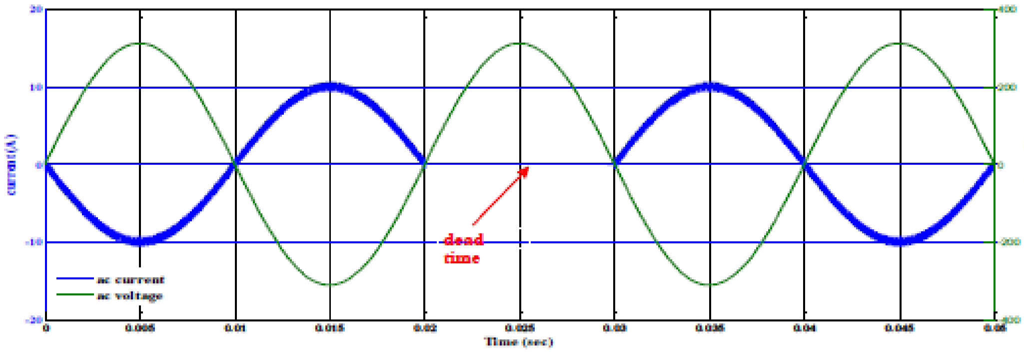


Fig.(11) voltage and current waveforms at the ac side when operating point transfer from QII to QIV

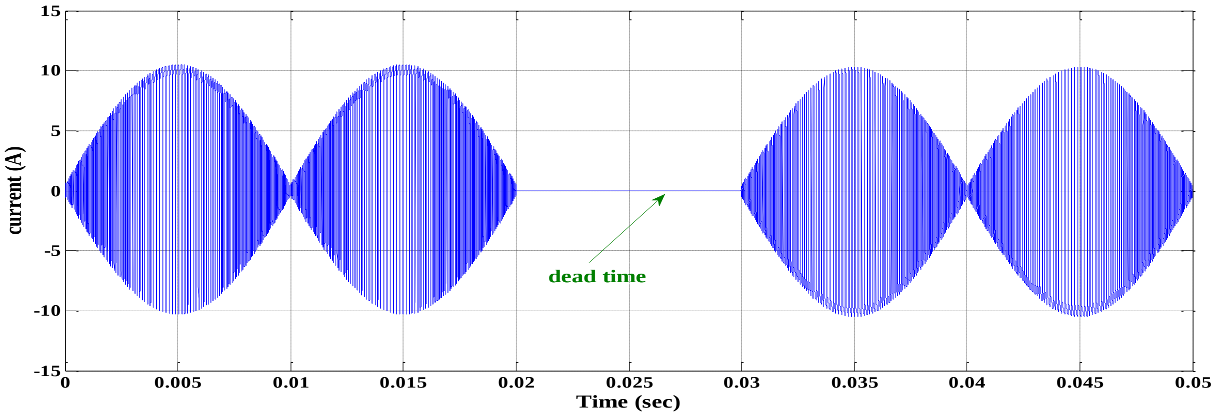


Fig.(12 a) dc current when operating point transfer from QII to QIV

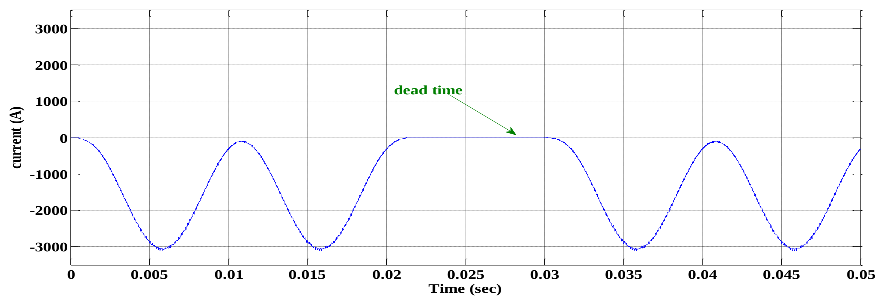


Fig.(12 b) dc power when the operating point transfer from QII to QIV