

# A compact Single-Phase Single stage AC-AC Impedance Source Converter

Jahangeer Ahmad, Santosh Sonar

**Abstract:** The paper presents a compact AC-AC single phase voltage regulator based on Impedance network. The proposed topology has ability to perform buck and boost operation in a single stage. The circuit is simple, highly efficient and more importantly reduced manufacturing cost due to its minimal number of active and passive components. The Impedance network has dual function of boosting and filtering. The proposed topology employs two bidirectional switches operating at high frequency PWM pulses. The high frequency switching reduces the size of the Impedance network. The gain of the system is controlled by controlling the duty cycle of the bidirectional switches. The operating mechanism of the proposed topology along with simulation and experimental results are presented.

**Keywords:** buck-boost, duty cycle, pulse width modulation

## I. INTRODUCTION

AC voltage control is one of the major factor of concern to both residential and industrial customers due to voltage swell-sag, oscillations, harmonic distortion, transient pulses and distortion. The switching on of large loads, short circuits or failures in the power grid leads to a voltage drop. If the voltage drop lasts longer than 2 to 3 cycles, sensitive loads may get damaged during this time. On the other hand, the voltage swell is caused by turning on the capacitor, relieving or shutting off heavy loads [1]. Both voltage drop and swelling cause interference in sensitive components such as computers, communication services, medical systems and prolonged power shutdowns [2]. These phenomena are extensively studied and many circuit topologies are being developed to reduce them. The most commonly used voltage regulators are made with thyristors that operate in phase-angle, integral-cycle, and tap changing transformers e.t.c [3]. The tap changer is used to convert the input voltage to a higher or lower magnitude. The transformer is generally employed in regions such as rural electrification, motor speed control etc. Voltage setting is not uniform and must be step change, the voltage regulation range is relatively narrow and the regulation is low. It is unlikely that the tap changing AC transformer will achieve fast and accurate voltage regulation [4] - [5]. Automatic voltage regulators rely on thyristor technology (Line-commutated ac controllers) due to reliability and high load capacity of the thyristor switches. However, such regulators have a slow response, a poor power factor, and require a large input-output filter to reduce large harmonics of low order in the line current [6]-[7].

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Line commutated ac controllers can be replaced by pulse width-modulated (PWM) ac choppers where the output voltage is regulated by changing the duty ratio of the control signal which is having better overall performance and all above problems associated with the line commutated voltage regulators can be improved[8]. The advantages are nearly sinusoidal input-output currents/voltage waveforms, improved power factor, reduced harmonic [9]-[11] current, a fast response speed and a smaller input filter size. In this paper, a simple single phase impedance network based ac-ac converter is explored with a dissimilar bidirectional switch. The proposed impedance network consists of one capacitor and one inductor which works as energy storage as well as filtering element in turns reduces the complexity of the system. It does not involve any additional circuitry for removing the harmonics from the output voltage. To obtain variable boost factor for surge operation a high frequency switching pulses generated from microcontroller are fed to the bidirectional switches. The paper is organised as : Section II of this paper deals with the mathematical modelling along with its operating principle. Section III presents the simulation and experimental results and section IV concludes this paper.

## II. PROPOSED TOPOLOGY

Fig. 1 proposes the single-phase AC-AC voltage regulator consists of two bidirectional switches S1 and S2 with inductor L and capacitor C connected at the output of converter to reduce output voltage ripple. The circuit directly operates from single phase line voltage over wide input range to regulate output voltage using PWM technique.

The circuit comprises of two bidirectional switches with each switch having two IGBT connected in common emitter mode. Each switch shares common driver circuit thereby simplifying the hardware design. The working principle is that during positive half cycle of the input ac the inductor gets charged and in the subsequent cycle inductor gets discharged to the output side. The equivalent circuit at each stage is depicted in the Fig. 2.

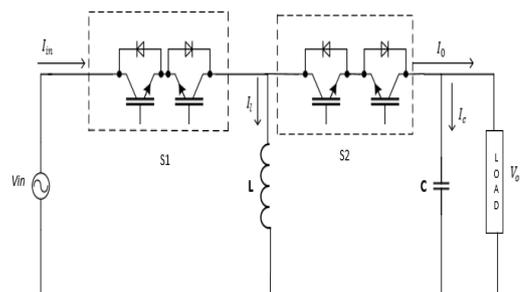
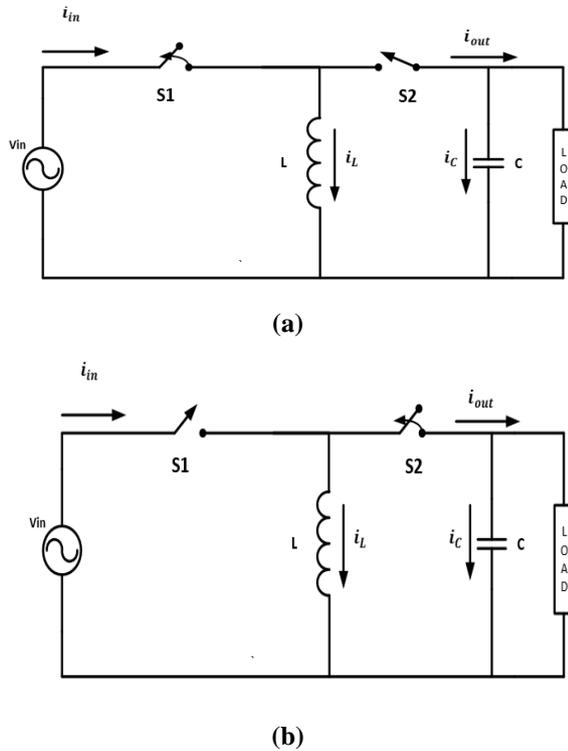


Fig. 1. Propose AC-AC converter topology

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**Fig. 2: Equivalent circuit (a) when S2 off and S1 on (b) when switch S2 on and S1 off**

Table.1 represents the different possible states of operation. The proposed circuit basically operates in two different states. Proper care is to be given to avoid the state one and four as given in Table 1.

**Table1: Different possible states of operation**

State	S1	S2	Remarks
1	0	0	No path for inductor current to flow. This state should be avoided.
2	1	0	Input voltage charges the inductor. Output Capacitors supplies the charge.
3	0	1	Inductor current charges the capacitor and load.
4	1	1	Shorts the input to output. This state also should be avoided.

During state 1, the inductor L stores electromagnetic energy from the ac source. Also, at the same instant switch S2 is kept off and the capacitor C discharges through the load. This state is presented as an equivalent circuit in Fig. 2(a). During state 2, when the switch S1 is off and S2 is on, then the deposited energy of the inductor delivers current to charge the capacitor C as well as provides load current through switch S2. The equivalent circuit for this state is shown in Fig.2 (b). The switch S1 is in the operating state 2 for an interval of  $T_{on}$  and off condition for the duration  $T_{off}$  in a complete time period T.

From Fig. 2(a),

$$V_L = V_{in} \quad (1)$$

where  $V_{in}$  =Input voltage,  $V_L$ =Inductor voltage

Now considering the state2 during off state, from the equivalent circuit Fig. 2(b) one has

$$V_L = V_O \quad (2)$$

Here,  $V_O$  is the load voltage.

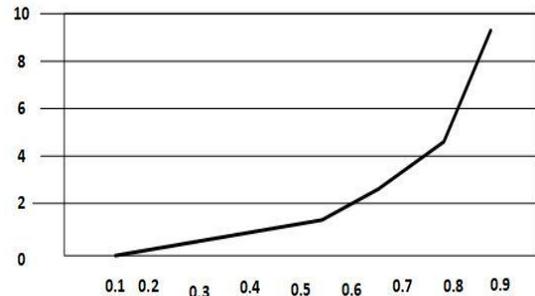
Applying volt-sec balancerule, The average inductor voltage over one switching period (T) should be zero in the steady state.

From (1) and (2)

$$\bar{V}_L = \frac{V_{in} * T_{on} - V_O * T_{off}}{T} = 0 \quad (3)$$

$$\text{So, } \frac{V_O}{V_{in}} = \frac{T_{on}}{T_{off}} = \frac{D}{1-D} = G \quad (4)$$

The output voltage is controlled using buck and boost operation performed with the help of duty cycle using PWM technique. Here D is the Duty ratio of the PWM signal applied to the switch S1 and G, open loop gain of the proposed converter. The open loop characteristic of the converter is plotted in Fig. 3.



**Fig.3: Gain vs duty ratio graph of ac-ac voltage regulator**

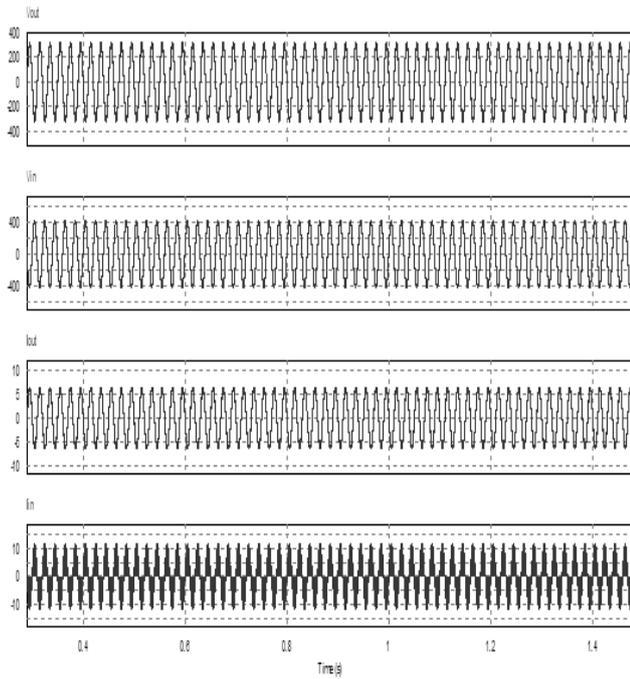
### III. SIMULATION AND EXPERIMENTAL RESULTS

The proposed topology is simulated in PSIM 9.0 environment. The parameters used for simulation is given in Table2.

Parameters	Values
Output voltage	220V
Input Voltage	90V-300V
IGBT	IXYB82N120C3H1
Switching frequency	20 kHz
Inductor	8mH
Capacitor	5uf
Load	1kW

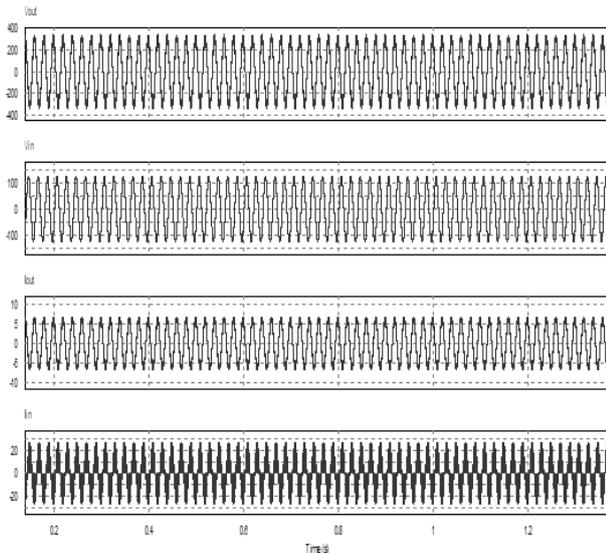
**Table 2. SIMULATION PARAMETERS**

The Closed loop is implemented in simulation based on feed forward mode, by sensing the input voltage through. The reference value is the desired voltage, it is divided by the input voltage and duty cycle is calculated mathematically. The two bidirectional switches are operated at frequency of 20khz. The duty cycle is automatically adjusted using closed loop. The waveforms of input voltage, input current, output voltage and output current for boost operation at input voltage of 90V is shown in Figure 4.



**Fig.4: Waveforms during sag condition of Input voltage , Output voltage ,input current and Output current**

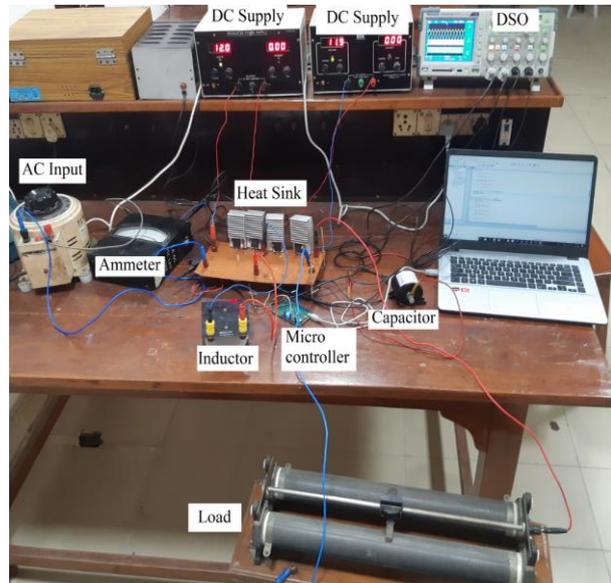
The waveforms of input voltage, input current, output voltage and output current for buck operation is shown in Fig.5



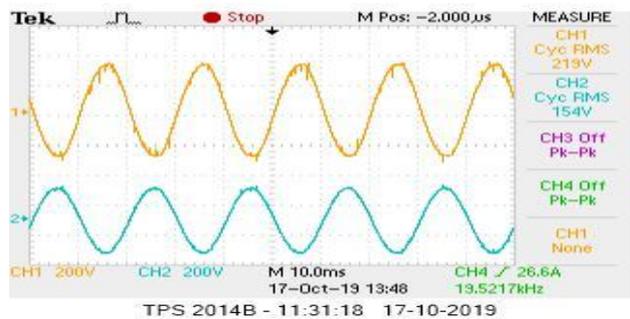
**Fig.5. Waveforms during surge condition of Input voltage , Output voltage , input current and Output current**

A prototype model of the proposed circuit is developed in lab as shown in Fig. 6. It is presented to validate the simulation results in open loop condition. The experimental results for both buck and boost is illustrated in Fig.7 and 8 at different input voltage. The experimental results agreed with simulation result. The circuit is tested in open loop condition. The complementary pulse are generated using STM microcontroller STM32F070RB as shown in Fig. 9. The program is written in keilMicro vision software. The complementary pulse is generated using two PWM pin PA8 AND PA9. Through these pins of microcontroller two

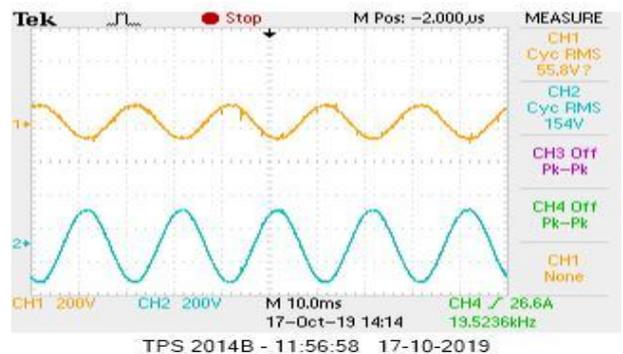
complementary pulses are generated at 20kHz frequency. The duty cycle can be varied in the program itself. Since the prototype was tested in open loop, the duty cycle is directly changed in the program in accordance with the input voltage. The duty cycle of generated switching signals are varied to test the circuit. The two complementary signals generated from the microcontroller pin are given to two switches S1 and S2 by means of two driver circuit connected to each switch. The two drivers are isolated DC supply voltage.



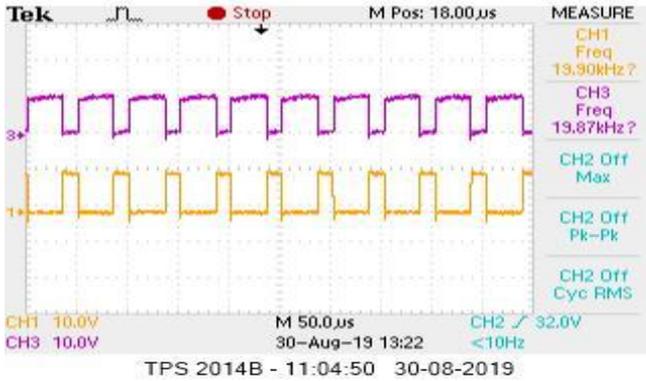
**Fig. 6. Experimental Setup**



**Fig.7: Surge results (resistive load,  $D = 0.70$ ). Waveforms of  $v_{out}$ ,  $v_{in}$**



**Fig.8: Sag results (resistive load,  $D = 0.30$ ). Waveforms of  $v_{out}$ ,  $v_{in}$**



**Fig.9: Complementary pulses generated from the Microcontroller**

## IV. CONCLUSION

An AC-AC single-phase compact voltage regulator based on impedance network is presented. The converter has ability to buck-boost the input voltage. The circuit is simulated in Psim 9.0 .To verify the suitability of the proposed converter,buck boost result are presented.. To verify the proposed system the simulation of the converter is performed and an experimental prototype is made to validate its operation in open loop. The converter has low harmonics, low component count, quick response, high power factor. The system operation is performed for the resistive load only.

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