Analysis and Design of Closed Loop Control of a Three-Level Converter

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Abstract— MATLAB/Simulink based Three-Level Integrated AC-DC Converter with pulse width modulation (PWM) technique is presented in this paper. Internally the proposed converter has two individual converters, one is at input side (called as an input converter), which is for power factor correction purpose the and another one is at DC output voltage (called as output converter), which is for regulation purpose of the output DC voltage. The proposed converter with its two internal converters integrates the operation of the boost power factor correction and the three-level dc–dc converter and one more advantage with the input converter is prevents the dc-bus voltage from excessive voltages. The time constant for PFC controller should be faster in compare to output voltage controller. The resultant simulation waveforms justify AC-DC conversion operation efficiently.

Index Terms— AC-DC Power conversion, pulse width modulation (PWM), Power Factor Correction (PFC

I. INTRODUCTION

Advancement in the research of Power electronic converter is still increasing with the rapid demands in the industry. In search of better efficiency, cost, design flexibility, low harmonics in converters, many converters had been proposed so far. Besides multilevel converters plays a major role in increasing demands. Mostly the AC-DC Power conversion with transformer isolation are typically implemented with some sort of input power factor correction (PFC) to comply with harmonic standards such as IEC 1000-3-2 [1] . There are three techniques to satisfy these standards. One of them is adding passive filter elements to the traditional passive diode rectifier/LC filter input combination; the resulting converter is very bulky and heavy due to the size of the low-frequency inductors and capacitors [2].Another method is using an ac–dc boost converter in the front-end rectifying stage to perform active PFC for most applications.

Several single-stage ac–dc full-bridge current fed converters have been proposed [2]; these converters have a boost inductor connected to the input of the full bridge circuit. Although they can achieve a near-unity input power factor, they lack an energy-storage capacitor across the primary-side dc bus, which can result in the appearance of high voltage overshoots and ringing across the dc bus. It also causes the output voltage to have a large low-frequency 120-Hz ripple that limits their applications.The most common type of single-stage ac–dc full-bridge converter is based on some sort of voltage-fed single-stage pulse width modulation (PWM) converter [4].

With multilevel topologies, the dc bus voltage can be allowed to reach higher levels that are possible with a two-level topology as the converter components are exposed to half the dc bus voltage and, thus, have half the voltage stress[3]. Freeing up the allowable limit of dc bus voltage allows the aforementioned limitations on output and input currents to be eased so that the converter can be made to operate with an output current that has less ripple and an input current that is less distorted than that of a two-level converter[3].

The paper is organized as follows. In Section II, the designing procedure of the proposed converter and modes of operations of the proposed converter is presented. In Section III, the developed MATLAB/Simulink basedresults are discussed. Finally conclusion of the proposed hybrid system is presented in the Section IV.

II. PROPOSED THREE-LEVEL AC-DC CONVERTER

A Three-Level (TL) voltage-fed ac–dc single stage PWM converter is shown in Fig. 1. and Fig.2 shows the PWM to operate the converter.

The proposed converter is made to operate with the PWM technique. PWM signals are pulse trains which are applied to the gate of switches to perform the operation of converter. The pulse trains are fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the load depends mostly on the modulating signal. The control of output voltage is done using pulse width modulation.

As the input line frequency is much lower than the switching frequency, it is assumed that the supply voltage is constant within a switching cycle. It is also assumed that the input current is discontinuous, although there is no reason why the input current cannot be made to be continuous [8].

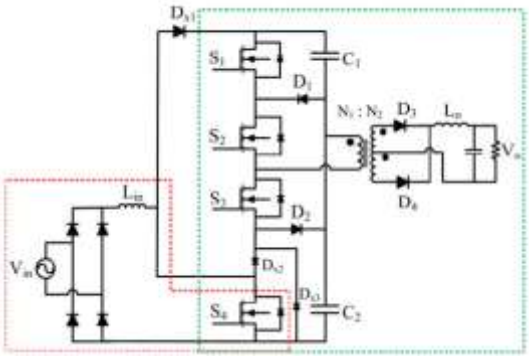

Fig.1. Proposed single-stage three-level AC-DC converter.

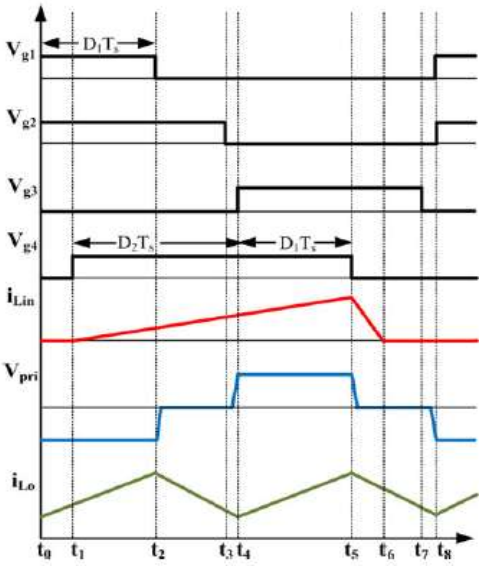

Fig.2. Key waveforms of proposed single-stage three-level AC-DC Converter

A. Modes of Operations of proposed single-stage three-level AC-DC Converter :

The gating signal of *S*1 , however, is dependent on that of *S*4 , which is the output of the input controller; how this signal is generated is discussed in in this section. The gating signals for *S*2 and *S*3 are easier to generate as both switches are each ON for half a switching cycle, but are never ON at the same time[1].

Mode 1 (*t*0 ≤*t*≤*t*1 *):* As shown in Fig.3,in this mode, switches *S*1 and *S*2 are ON and energy from dc-bus capacitor *C*1 is transferred to the output load.

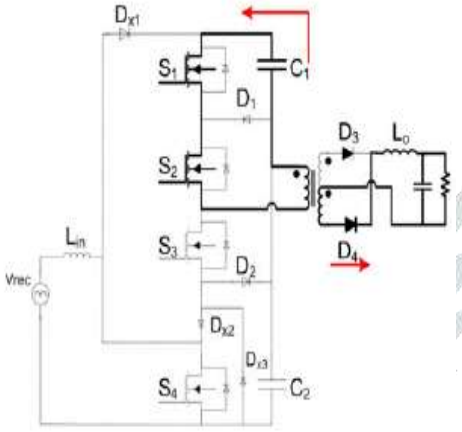

Fig.3. Equivalent Circuit of Mode 1 (*t*0≤*t*≤*t*1)

Mode 2 *(t*1 ≤*t*≤ *t*2 *):* As shown in Fig.4,in this mode , *S*1 and *S*2 remain ON and *S*3 turns ON. The energy from dc bus capacitor *C*1 is transferred to the output load.

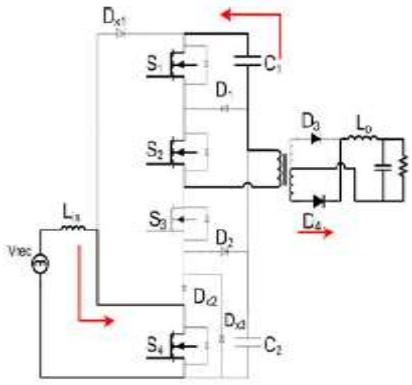

Fig.4. Equivalent Circuit of Mode 2 *(t*1≤*t*≤ *t*2)

Mode 3 *(t*2 ≤*t*≤ *t*3 *):* As shown in Fig.5,in this mode ,*S*1 and *S*2 remain ON and *S*3 turns ON. The energy from dc-bus capacitor *C*1 is transferred to the output load.

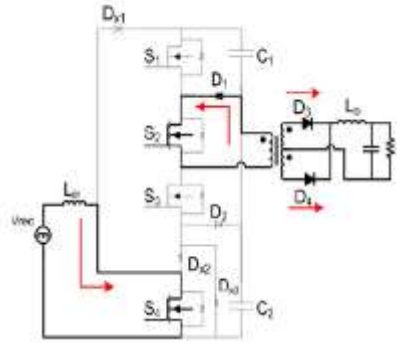

Fig.5. Equivalent Circuit of Mode 3 *(t2 ≤ t ≤ t3)*

Mode 4 *(t3 ≤t≤ t4):* As shown in Fig.6,in this mode*S*1 and *S*2 are OFF and *S*4 is ON.

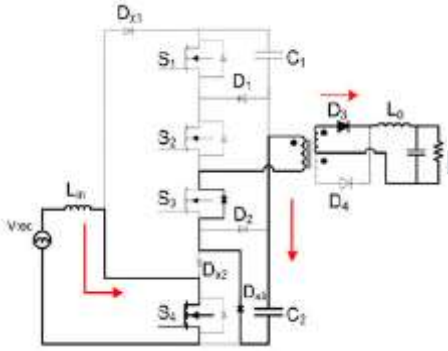

Fig.6. Equivalent Circuit of Mode 4 *(t3 ≤ t ≤ t4)*

Mode 5 *(t4 ≤t≤ t5):* As shown in Fig.7,in this mode,*S*3 and *S*4 are ON. Energy flows from capacitor *C*2 flows into the load while the current flowing through input inductor *L*in continues to rise.

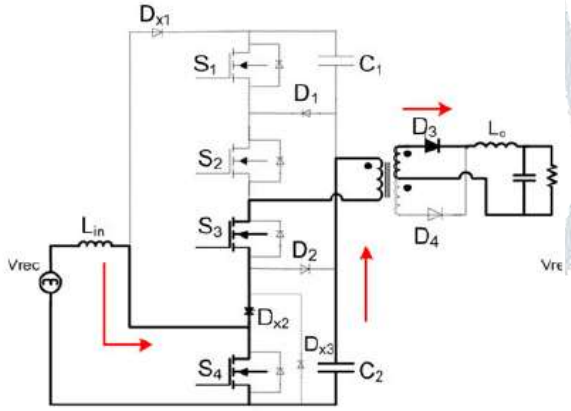

Fig.7. Equivalent Circuit of Mode 5 *(t4 ≤ t ≤ t5)*

Mode 6 *(t5 ≤ t ≤ t6):* As shown in Fig.8,in this mode , *S*4 turns off. The current in input inductor flows thorough the diode *Dx*1 to charge the capacitors *C*1 and *C*2. The current in the transformer primary flows thorough the *S*3 and *D*2. This mode ends when the inductor current reaches zero.

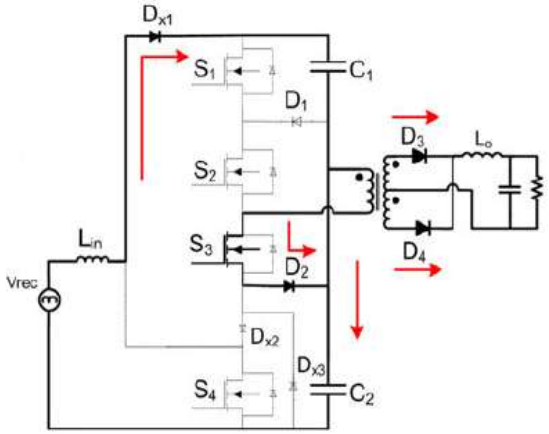

Fig.8. Equivalent Circuit of Mode 6 *(t5 ≤ t ≤ t6)*

Mode 7 *(t6 ≤ t ≤ t7):* As shown in Fig.9,in this mode , the load inductor current freewheels in the secondary of the transformer. This mode ends when the switches *S*3 turns off.

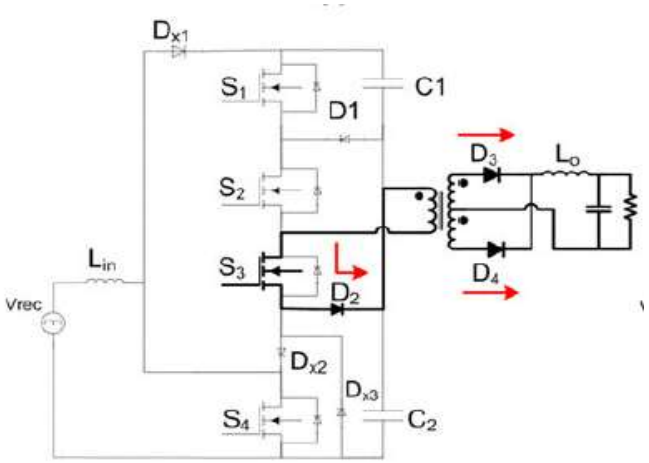

Fig.9. Equivalent Circuit of Mode 7 *(t6 ≤ t ≤ t7)*

Mode 8 *(t7 ≤ t ≤ t8):* As shown in Fig.10, in this mode *S*3 is OFF and the current in the primary of the transformer charges capacitor *C*1 through the body diodes of *S*1 and *S*2 . Finally, converter is in Mode 1.

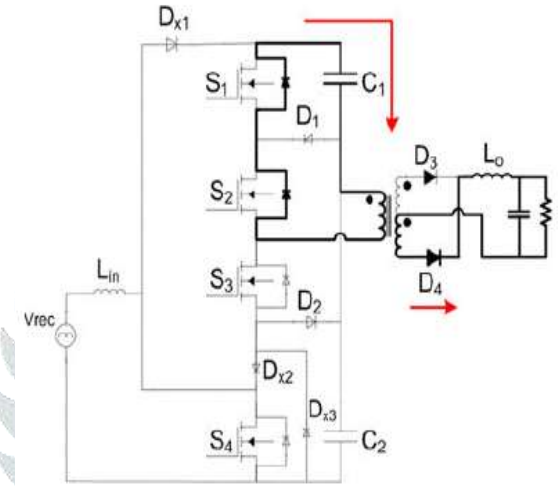

Fig.10. Equivalent Circuit of Mode 8 *(t7 ≤ t ≤ t8)*

III. *Designing Aspects :*

While designing the proposed single-stage three-level AC-DC converter the input inductance (Li) , Output inductance (Lout) and the main transformer trans ratio (N) which are shown in Fig.1 are the important consideration [1] . The following expressions are used to calculate those values and are given in Table.1

The value for *L*in should be low and is given by the following equation

$$L_{in,max} < \frac{[(V_{bus,min})]^2 * D_{max} * (1 - D_{max})^2}{2P_{o,max} f_{SW}} \quad (1)$$

Where, Dmax = Maximum Duty Cycle

fsw = Switching frequency

*V*bus,min =minimum primary-side dc-bus voltage

Po = Output power

The value for *L*out should be designed so that the output current is made to be continuous under most operating conditions and is given by the following equation

$$L_{o,min} \geq \frac{V_o^2}{0.5\ P_{o,max}} \frac{1 - D_m}{2} \frac{T_{SW}}{2}, \quad (2)$$

Where, Vo=Output voltage

Tsw=Switching period

The value for transformer turns ratio is given by the following equation

$$N \geq \frac{V_{bus,min}}{2V_o} \cdot D_{max} \quad (3)$$

Table .I. Simulation Parameters

Parameter	Rating
*L*in	80 μH
Lout	10 μH
N	5
*D*max	0.75
*V*bus	650 V
f sw	50kHz
Tsw	20 μs
*P*o,max	1.35kW
*V*in	90−265 *V*rms

IV. Simulation Results

By using the Table.1 calculated values and designing procedure with modes of operations of the proposed three-level AC-DC converter is simulated in MATLAB using Simulink and set tool boxes. The resultant circuit with masked blocks are shown by the Fig.11.

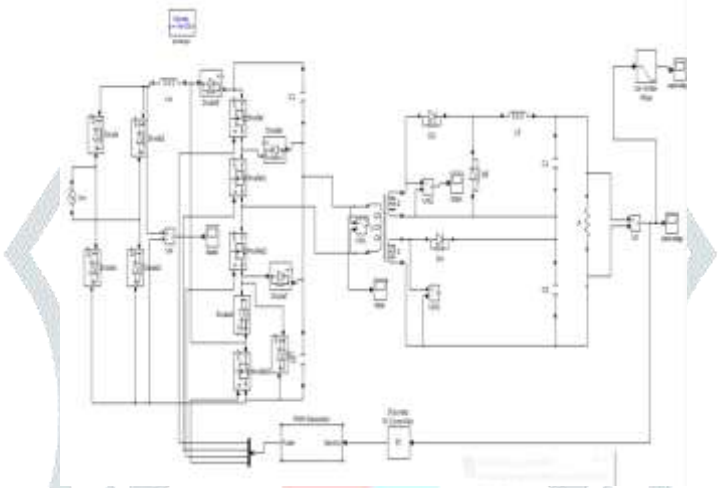

Fig.11. MATLAB based simulation diagram of proposed single-stage three-level AC- DC converter with masked blocks

MATLAB based switches pulses for the proposed converter active switches are given by the Fig.12

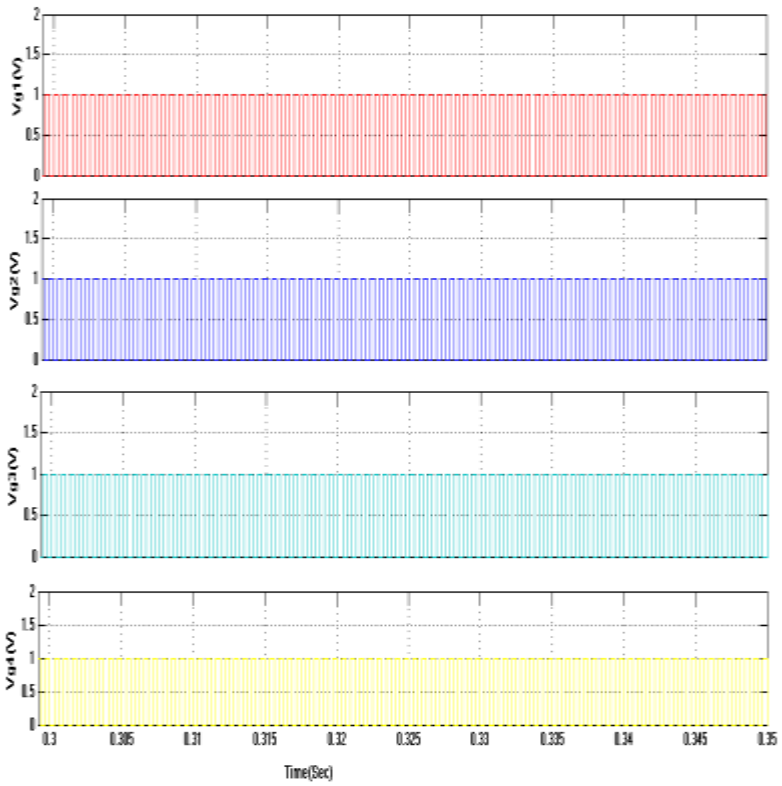

Fig.12.Switches pulses for actives switches of proposed converter

Fig.13 shows that proposed converter effectively converts the input AC in output DC. By using the first order filter harmonic content also reduces in the Fig.13.

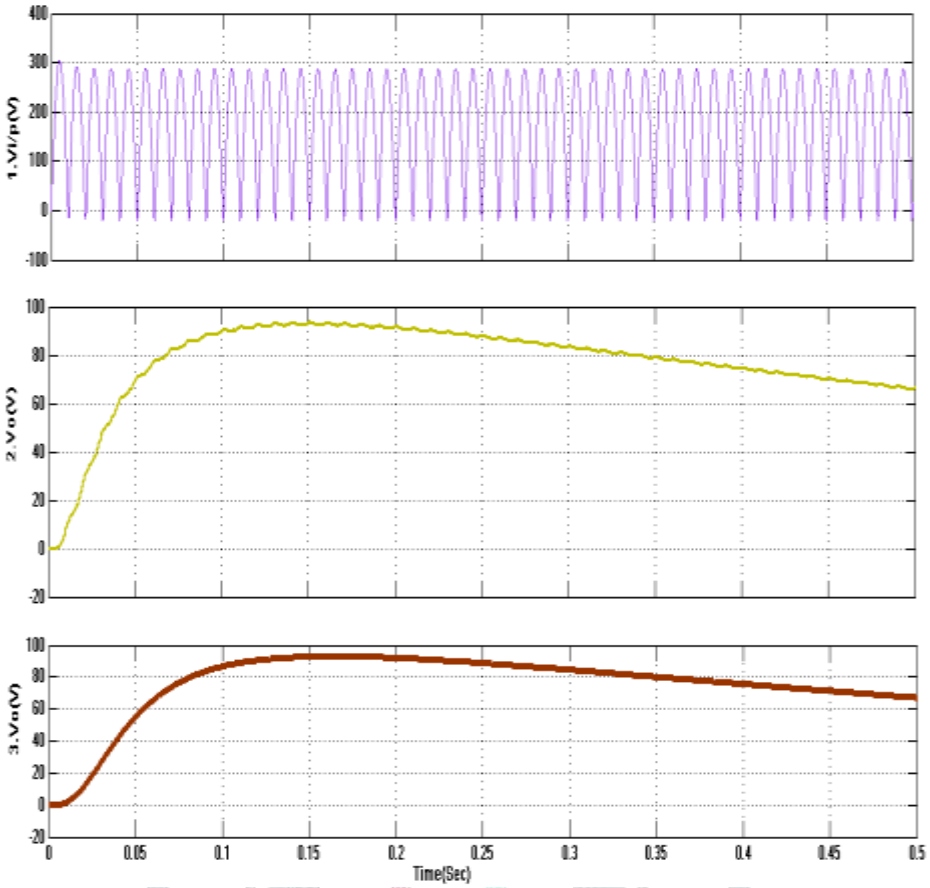

Fig.13. MATLAB based simulation graphs of 1.Input AC voltage (Vi/p) , 2.Output DC voltage (Vo) without filter and 3. Output DC voltage (Vo) with filter

V. CONCLUSION

An efficient Three-level AC–DC converter is presented in the paper. This converter is operates with two internal controllers, one controller that performs input PFC and a second controller that regulates the output voltage. The specific feature of this converter is that it combines the performance of two-stage converters with the reduction of cost of single-stage converters. This allows for greater flexibility in the design of the converter and ultimately improved performance.

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