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A THREE LEVEL INTEGRATED AC-DC CONVERTER WITH POWER FACTOR CORRECTION

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Abstract—In this paper, a three-level integrated ac–dc converter with power factor correction is presented. The proposed converter integrates the operation of the boost power factor correction and the three-level dc–dc converter. The converter is made to operate with two independent controllers—an input controller that performs power factor correction and regulates the dc bus and an output controller that regulates the output voltage. The input controller prevents the dc-bus voltage from becoming excessive while still allowing a single-stage converter topology to be used. The feedback system employed in this converter is to improve power factor by ZVS method in the PWM pulse generation to the switches. Experimental results obtained from a simulation are presented to confirm the output of the new converter.

I. INTRODUCTION

HIGHER power ac–dc converters are required to have some sort of power factor correction (PFC) capability to comply with harmonic standards such as IEC61000-3-2 Modern electronic equipment does not represent a completely passive load to the AC mains or powerline. Historically, loads have been fairly benign, having either resistive characteristics (light bulbs) or input currents that are sinusoidal but phase-shifted (AC motors). Most electronic systems now use one or more switch mode power converters that will tend to draw current from the power line in a non-sinusoidal fashion. This input current characteristic results in current and possibly voltage distortions that can create problems with other equipment connected to the power line and degrade the capability of the mains. These problems have led to the creation of design standards for the purpose of limiting the allowable harmonic distortion on the power line. Fortunately, solutions are available for meeting these standards. These solutions are referred to as Power Factor Correction (PFC) techniques.

. PFC methods can generally be divided into the following three categories:

1) *Passive PFC converters:* They use passive elements such as inductors and capacitors to filter low frequency input current harmonics and make the input current more sinusoidal. Although these converters are simple and inexpensive, they are also heavy and bulky and are thus used in a limited number of applications.
2) *Two-stage converters:* They consist of an ac–dc boost pre-regulator converter that shapes the input current and an isolated dc–dc full-bridge converter that converts the pre-regulator output into the required dc voltage. Two-stage converters, however, require two separate switch-mode converters (each with its own controller), and thus, can be expensive. Moreover, they have poor efficiency when operating under light-load conditions as there are two con-verter stages that are operating—each with its own set of fixed losses—while a small amount of power is actually transferred to the load. These fixed losses are dominant under light-load operating conditions.
3) *Single-stage converters:* They can perform PFC/ac–dc conversion and dc–dc conversion with just a single full- bridge converter. There have been numerous publications about single-stage PFC (SSPFC) converters particularly for low-power ac–dc fly back and forward converters. Research on the topic of higher power ac–dc single-stage full-bridge converters, however, has proved to be more challenging, and thus, there have been much fewer publications. Previously proposed single-stage ac–dc full-bridge converters have the following drawbacks:

a) Some are current-fed converters with 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.
b) Some are resonant converters that must be

controlled using varying switching-frequency control, which makes it difficult to optimize their design (especially their magnetic components) as they must be able to operate over a wide range of switching frequency.

c) Most are voltage fed, single-stage, pulse width modulation (PWM) converters with a large energy-storage capacitor connected across their primary side dc bus. These converters do not have the draw backs of resonant and current-fed SSPFC converters. They operate with fixed switching frequency, and the bus capacitor prevents voltage overshoots and ringing from appearing across the dc bus and the 120-Hz ac component from appearing at the output. Voltage-fed converters, however, have the following drawbacks:

i) The primary-side dc-bus voltage of the converter may become excessive under high-input-line and low-

ii) output-load conditions

This is because SSPFC converters are implemented with just a single controller to control the output voltage, and the dc-bus volt-age left unregulated. The high dc-bus voltage results in the need for higher voltage rated de-vices and very large bulk capacitors for the dc bus. For example, the converter in has a dc-bus voltage of 600 V.

iii) The input power factor of a single-stage voltage-fed converter is not as high as that of current fed converters. For example, the converter proposed in has an input current that is neither continuous nor discontinuous, but is semi continuous" with a considerable amount of distortion.

iii)The converter is made to operate with an output inductor current that is discontinuous for all operation conditions or some parts of operation conditions ,to try to prevent the dc-bus voltage from becoming excessive; output inductor current and dc-bus voltage are related, as shown in . Doing so results in the need for components that can handle high peak currents and additional output filtering to remove ripple.

Problems associated with single-stage converters; excessive dc-bus voltages due to the lack of a dedicated controller to regulate these voltages, large output ripple, distorted input currents, reduced efficiency (particularly for low input line voltages due to a low dc-bus voltage generally exist for two-level single-stage converters, such as the ones shown in Fig.1 and three-level converters.

A new single-stage ac–dc converter that does not have the drawbacks of previously proposed single-stage and two-stage converters is proposed. The paper introduces the new converter, explains its basic operating principles and its modes of operation, and discusses its features.

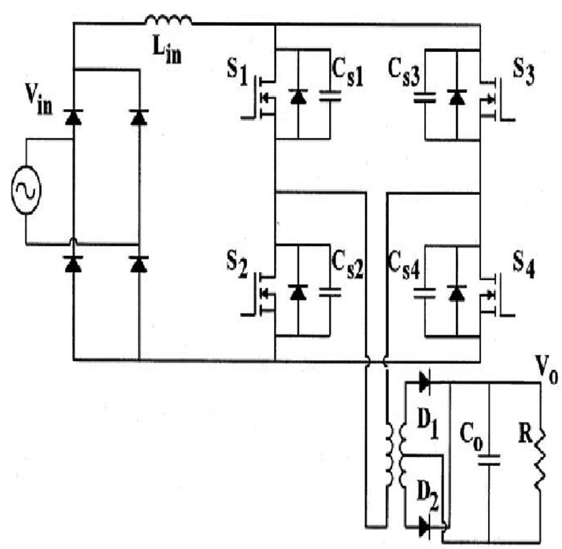

Fig 1.Single stage boost-based current-fedac–dc PWM integrated full-bridge converter

II.MODELLING OF THE CONVERTER

The proposed converter, which is shown in Fig. 3, integrates an ac–dc boost PFC converter into a three-level dc–dc converter. The ac–dc boost section consists of an input diode bridge, boost inductor L_{in} , boost diode $D_{x\ 1}$, and switch S_4 , which is shared by the multilevel dc–dc section. When S_4 is off, it means that no more energy can be captured by the boost inductor. In this case, diode $D_{x\ 2}$ prevents input current from flowing to the midpoint of capacitors C_1 and C_2 and diode $D_{x\ 1}$ conducts and helps to transfer the energy stored in the boost inductor L_{in} to the dc-bus capacitor.

Diode $D_{x\ 3}$ bypasses $D_{x\ 2}$ and makes a path for circulating current. Although there is only a single converter, it is operated with two independent controllers. One controller is used to perform PFC and regulate the voltage across the primary-side dc-bus capacitors by sending appropriate gating signals to S_4 . The other controller is used to regulate the output voltage by sending appropriate gating signal to S_1 to $S_{4.}$

It should be noted that the control of the input section is de-coupled from the control of the dc–dc section and thus can be designed separately. 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 detail later in this paper. 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.

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 if this is what is desired. The converter has the following modes of operation:

1) *Mode 1* ($t_0 \leq t \leq t_1$): During this mode, switches S_1 and S_2 are ON and energy from dc-bus capacitor C_1 is trans-ferred to the output load. In the output section, a positive voltage of (V_{pri} /n) – V_o (where n is the ratio of primary to secondary transformer turns) is impressed across L_o and the current through it rises.
2) *Mode 2* ($t_1 \leq t \leq t_2$): 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. At the same time, the diode bridge output voltage V_{rec} is impressed across input inductor L_{in} so that the current flowing through this inductor rises.
3) *Mode 3* ($t_2 \leq t \leq t_3$): 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. At the same time, the diode bridge output voltage V_{rec} is impressed across input inductor L_{in} so that the current flowing through this induc-tor rises voltage V_{rec} is impressed across input inductor L_{in} so that the current flowing through this inductor rises.

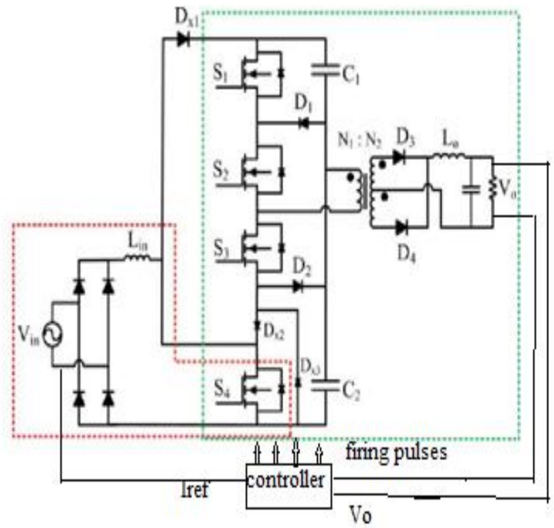

Fig 2 Proposed single stage three level converter with power factor correction

4) *Mode 4* ($t_3 \leq t \leq t_4$): In this mode, S_1 and S_2 are OFF and S_4 is ON. The current in the primary of the transformer charges capacitor C_2 through the body diode of S_3 and $D_{x\ 3}$.

5) *Mode 5* ($t_4 \leq t \leq t_5$): 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.

6) *Mode 6* ($t_5 \leq t \leq t_6$): In this mode, S_4 turns off. The current in input inductor flows thorough the diode $D_{x\ 1}$ 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. Also during this mode, the load inductor current freewheels in the secondary of the transformer.

7) *Mode 7* ($t_6 \leq t \leq t_7$): In this mode, the load inductor current freewheels in the secondary of the transformer. This mode ends when the switches S_3 turns off.

8) *Mode 8* ($t_7 \leq t \leq t_8$): 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 reenters Mode 1:The simplified

schematic of the power converter and the respective controllers are shown in Fig. 3. The decoupling of the input controller and output controller can occur because the crossover frequencies of the two loops are very different. The crossover frequency of the input controller, which performs in-put power factor correction and converts input ac into an intermediate dc-bus voltage (voltage across the two primary-side dc-bus capacitors), is much lower than that of the output controller, which converts the intermediate dc-bus voltage into the desired output voltage. Since the two crossover frequencies are far apart, it is therefore possible to consider the design of one controller to be separate from that of the other. Since the two controllers are decoupled, the standard designs for an ac–dc boost converter controller and a dc–dc full-bridge converter controller can be used.

Fig. 3 shows a simple diagram of the controller scheme that has two elements of control. One element is to control dc–dc conversion of the dc-bus voltage to the desired output voltage, and this can be done by controlling the gating signals of S_1 to S_4 through controlling duty cycle of D_1 . The other element is to control duty cycle of the switch S_4 to regulate the dc-bus voltage and to perform input power factor correction. This can be done by controlling D_2 and then adding duty cycle of D_2 to D_1 (where D_1 and D_2 are defined in Fig. 3); thus S_4 performs two tasks; one part (D_1) participate to control output voltage and another part (D_2) to regulate dc-bus voltage.

III. CONVERTER FEATURES

The proposed converter has the following features:

1) *Reduced cost compared to two-stage converters:* Although the proposed converter may seem expensive, the reality is that it can be cheaper than a conventional two-stage converter. This is because replacing a switch and its as-sociated gate drive circuitry with four diodes reduces cost considerably even though the component count seems to be increased—this is especially true if the diodes are or-dered in bulk numbers.a better input power factor for universal input line applications than a

2) single- *Better performance tha single-stage converter:* The proposed single-stage converter can operate with controller, single-stage because it does have a dedicated controller for its input section that can perform PFC and regulate the dc-bus voltage. The presence of a second controller also allows the converter to operate with better efficiency and with less output ripple as each section

IV. SIMULATION MODEL

The proposed new converter is simulated in the MATLAB/SIMULINK .The circuit diagram of the converter is shown below(fig). It mainly designed for DC bus bar voltage regulation. In this we can also improve the power factor by using controller. The output waveform of the converter is shown in the fig

In this output voltage and input current is measured and compared with the comparator. The error signal produced by the comparator is given to the PI controller. The PI controller produces control signal to the PWM generator,depends on this signal it produces gating signal to the switching devices.

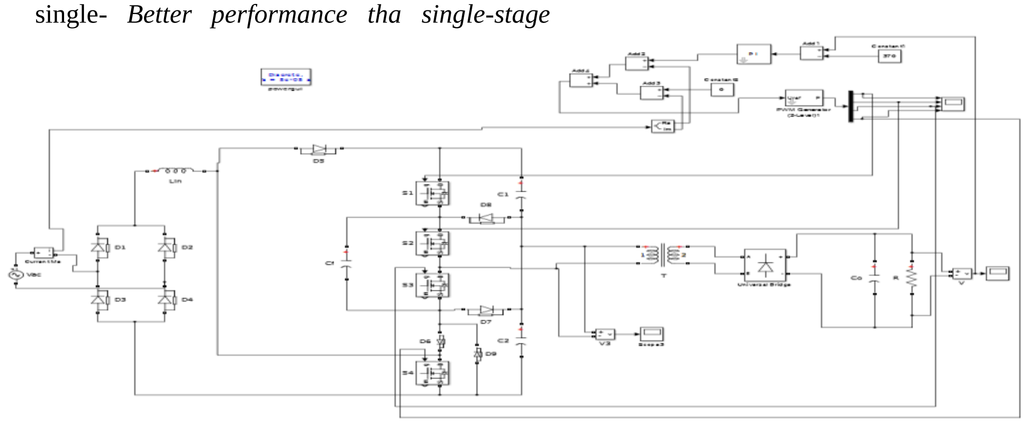

Fig 3.Simulation model of single stage three level AC-DC converter

OUTPUT VOLTAGE WAVEFORM :

The figure below shows the DC regulated output voltage.It plotted for time in x axis and voltage in the y axis.From this we can see that the output DC voltage is almost constant.

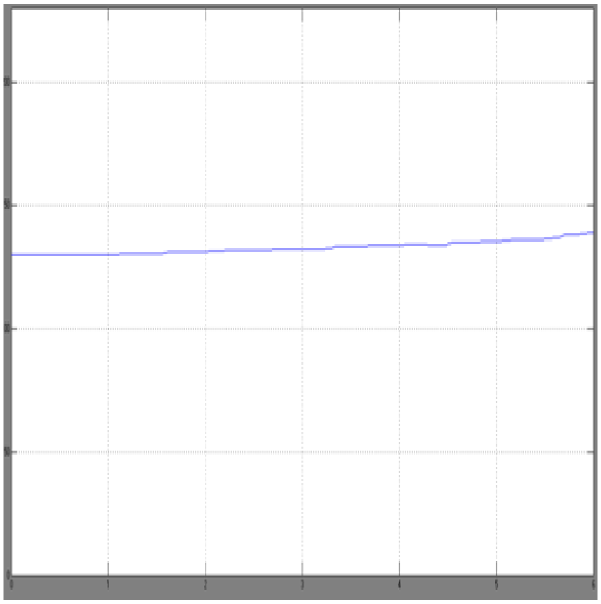

Fig 3.1 DC regulated output Voltage

WAVEFORM FOR THREE LEVEL OUTPUT:

The figure(3.2) shows the output voltage of the converter and it is measured at the primary of the transformer.

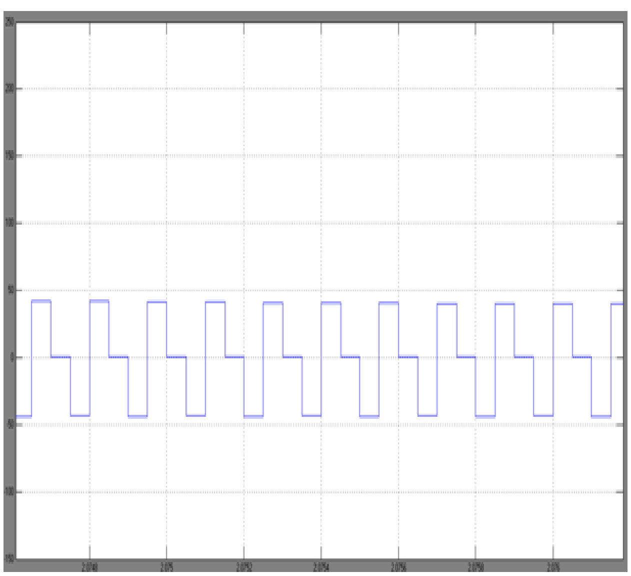

Figure 3.2 Three level output voltage at the converter

WAVEFORM FOR PULSE OUTPUT:

The below plot shows the gating signal to the switching devices. It is the outcome of the PWM generator.

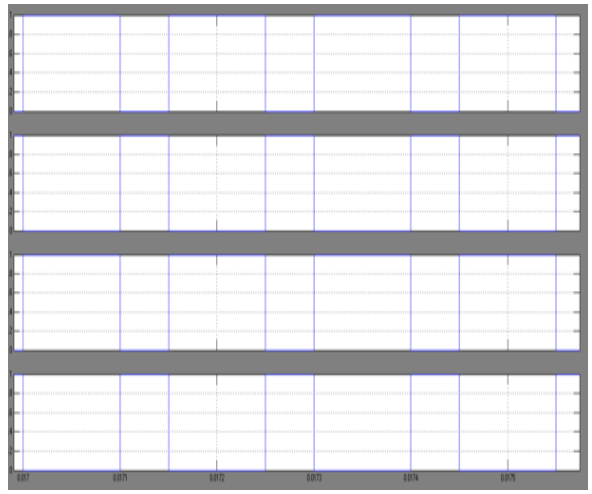

Fig 3.3 Pulse output of the PWM generator.

The input voltage and current is plotted with respect to time.It shown in the figure (3.4).

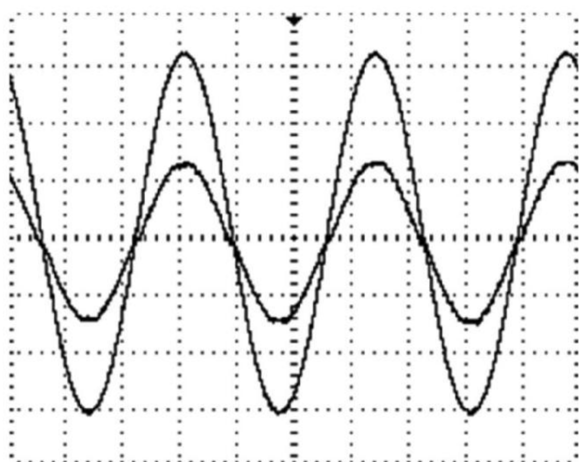

Fig 3.4 Input voltage and current waveform

V. EXPERIMENTAL RESULTS

A proposed converter is designed with the input voltage V_{in} = 90–265 V_{rms} .The input inductance is L_{in} = 80 μH, L_o = 10 μH, and C_1 and C_2 = 2200 μF. The main transformer ratio was 5:1.

Typical converter waveforms are shown Fig.3.3 shows typical gating voltage waveforms of the top switches.Fig3.4 shows the voltage across the primary side of the main transformer. It can be seen that the proposed converter manages to impress a standard square voltage wave-form across the transformer primary. Fig. 3.4 shows the input voltage and input current after filtering; it can be seen that the input current has no dead bands like those found in single-stage converter input currents, and thus, it has a near unity input power factor.

The experimental efficiency at different value of output power. It should be noted that the dc-bus voltage was regulated for 650 V for the experimental results.

VI. CONCLUSION

A new multilevel single-stage ac–dc converter is proposed in the paper. This converter is operated with two controllers— one controller that performs input PFC and a second controller that regulates the output voltage. The ZVS technique is used to operate the switches and it is achieved by the controller. Form the output we identify power factor improvement. The outstanding feature of this converter is that it combines the performance of two-stage converters with the reduction of cost of single-stage converters. The paper introduces the proposed converter, explains its basic operating principles and modes of operation, and it is applicable for regulating different dc-bus voltages.

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