

A Three Level AC-DC Converter Using Independent Controller

Jayachitra. T, Eassaki Muthu Pandi. A

Department of Electrical and Electronics Engineering, Vandayar Engineering College, Thanjavur, Tamil Nadu, India

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Abstract

Here an improved three-level incorporated ac-dc converter is presented. This converter improving or boosting power factor correction. And also this converter topology is advanced than previous ac-dc converters for the most part the converter is functioning with two independent controllers which are combined in a single converter. Input controller does PFC and regulates dc bus, output controller regulates the output voltage. Converter function is explained and power factor is improved in this paper. Finally the efficiency of the new converter is compared with that of previously proposed converter. Simulation results are obtained using mat lab.

1. Introduction

Advancement in the research of Power electronic converter is still increasing with the rapid demands in the industry. Normally high power ac-dc converters are required to have some power factor correction (PFC) capability. In search of better efficiency, expenditure, design flexibility, low harmonics in converters, several converters had been proposed so far. Besides multilevel converters plays a major role in increasing demands. Mostly the AC-DC converters are implemented with PFC to comply with harmonic standards like IEC 1000-3-2[1]. Based on this; PFC methods are of two types namely passive and active methods. Passive methods are simple and inexpensive which uses L&C components to filter low frequency input current harmonics & shapes input current to improve power factor. But this makes the converter huge and bulky in size which is less preferred. Due to this active PFC are used nowadays.

- 1) **Passive PFC converters:** These converters are using passive elements such as inductors and capacitors. These filters are used to get the sinusoidal input current. Although these converters are economical, weighty and bulky in size and these used for limited number of applications
- 2) **Two-stage converters:** They consist of an ac - dc boost pre-regulator converter and an isolated dc-dc full bridge converter. These Two-stage converters are required two separate switch mode converters and this can be increase the cost of the converter. Mainly these converters are having poor efficiency when operating under light load conditions. As there are two converter 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:** These converters 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 flyback 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 are having boost inductor connected to the input of the full-bridge. Any way these converters can achieve a near-unity input power factor, these converters are lack an energy-storage capacitor across the converter input side of dc bus, which can result in the appearance of high voltage over shoots we can observe across the dc bus. b) 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 are operating with fixed switching frequency, and the bus capacitor prevents voltage overshoots and ringing from appearing across the dc bus. However, have the following drawbacks:

- i) The primary-side dc-bus voltage of the converter may become excessive under high-input-line and low-output-load conditions. This is because SSPFC converters are implemented with just a single controller to control the output voltage, and the dc-bus voltage left unregulated. The high dc-bus voltage results in the need for higher voltage rated devices and very large bulk capacitors for the dc bus. For example, the converter in [9] has a dc-bus voltage of 600 V.
- ii) The input power factor of a single-stage voltage-fed converter is not as high as that of current-fed converters.
- iii) The converter is operating with an output inductor current that is discontinuous for all operation conditions. But some problems are also available in single -stage converters. This is excessive output inductor current and dc-bus voltages due to the lack of a dedicated controller to regulate these voltages, large output ripple, distorted input currents, and reduced efficiency. In the paper, a new single-stage ac-dc converter that does not have the drawbacks of previously proposed single-stage and two-stage converters is proposed.

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Corresponding Author,

E-mail address:

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introduces the new converter, explains its basic operating principles and its modes of operation, and discusses its features and its design. The feasibility of the new converter is confirmed with experimental results obtained from a prototype converter.

2. PWM Technique

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. But the width of the pulses changes from period to period according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turns off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal & consequently working of converter starts. 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. The commonly used techniques are

1. Single pulse width modulation.
2. Multiple pulse width modulation.
3. Sinusoidal pulse width modulation.
4. Modified sinusoidal pulse width modulation.
5. Phase displacement control

3. Operation of the Proposed Converter

Normally the proposed converter operation is simple. It integrates an ac-dc boost PFC converter into a three-level ac-dc converter. Here the operation of this converter is in three levels, in first level we are constructing a diode bridge with boost inductor L_{in} , boost diode D_{x1} . In second level we are using four switches along with two capacitors, named as C_1 and C_2 is used. In third level we are using multi winding transformer with half wave diode bridge and inductor L_o is used for dc generation. In first level we are converting input ac into dc by using the full bridge diode bridge operation in and second level we are converting this dc into ac, in this level we are using MOSFETs to convert dc into ac. Because MOSFETs are having high switching frequency

When S_4 is off, it means that no more energy can be captured by the boost inductor. In this case, diode D_{x2} prevents input current from flowing to the midpoint of capacitors C_1 and C_2 .

In this case we are using high switching frequency for MOSFETs i.e 50Khz. 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 signals to S_1 to S_4 . It should be noted that the control of the input section is decoupled from the control of the ac-dc section and thus can be designed separately.

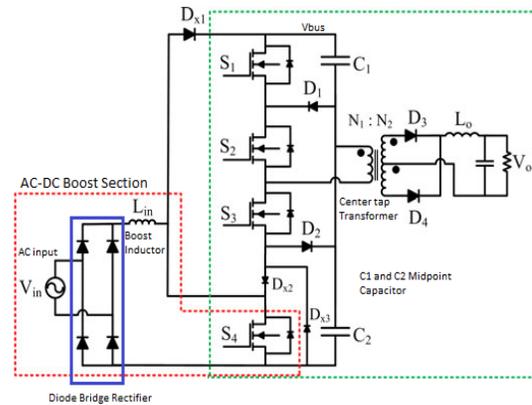


Fig. 1. Proposed three-level converter

4. The Proposed Converter Has Eight Modes of Operations

- 1) **Mode 1** ($t_0 < t < t_1$) [fig 4(a)]: During this mode, switches S_1 and S_2 are ON and energy from dc-bus capacitor C_1 is transferred 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** ($t_1 < t < t_2$) [fig 4(b)]: In mode 2, 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** ($t_2 < t < t_3$) [fig 4(c)]: In mode 3, 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 raises voltage V_{rec} is impressed across input inductor L_{in} , so that the current flowing through this inductor rises.
- 4) **Mode 4** ($t_3 < t < t_4$) [fig 4 (d)]: In mode 4, 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_{x3} .
- 5) **Mode 5** ($t_4 < t < t_5$) [fig 4(e)]: In mode 5, 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** ($t_5 < t < t_6$) [Fig 4(f)]: In mode 6, S_4 turns off. The current in input inductor flows through the diode D_{x1} to charge the capacitors C_1 and C_2 . The current in the transformer primary flows through 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** ($t_6 < t < t_7$) [Fig 4(g)]: In mode 7, the load inductor current freewheels in the secondary of the transformer. This mode ends when the switches S_3 turns off.
- 8) **Mode 8** ($t_7 < t < t_8$) [Fig 4(h)]: In mode 8, 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 re-enters Mode 1.

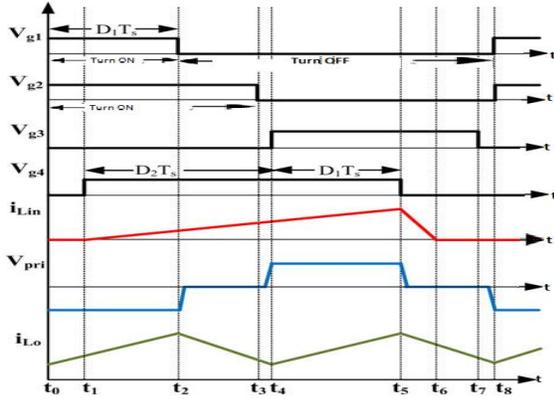


Fig. 2. Waveforms explaining of operation of converter

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 associated 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 ordered in bulk numbers.
- 2) **Better performance than a single-stage converter:** The proposed single-stage converter can operate with a better input power factor for universal input line applications than a single-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 of the converter can be made to operate in an optimal manner.
- 3) **Improved light-load efficiency:** The proposed converter can be designed so that it has a conventional dc-bus voltage of 400 V. Since the converter is a multilevel converter, a 400 V dc bus means that each switch will be exposed to a maximum voltage of 200 V. Having 200 V across a MOSFET device instead of 400 V (as is the case with two-level converters) results in a 75% reduction in turn on losses when the converter is operating under light-load conditions and there is an insufficient amount to current available to discharge the switch output capacitances before the switches are turned on.
- 4) **Increased design flexibility:** Since the converter is a multilevel converter, it can be operated with high dc-bus voltage (800 V), standard dc-bus voltage (400 V), or any dc-bus voltage $400\text{ V} < V_{bus} < 800\text{ V}$. There are advantages to operating with high dc-bus voltage or with standard dc bus voltage. The fact there is flexibility in the level that the dc bus voltage is set means that there is considerable flexibility in the design of the converter. This gives the designer options as to how to optimize the design of the converter for other factors such as efficiency profile and cost (i.e. cost of switches based on voltage rating considerations

and availability). It should be noted that this design flexibility makes the design of the three-level converter to be much simpler than that of a single-stage two-level converter or that of a single-controller three-level single-stage converter as the dc-bus voltage can be fixed to a desired level that is considered appropriate.

It should be noted that although the proposed converter has the aforementioned advantages over the conventional two-stage converter, it will have lower heavy-load efficiency because of increased conduction losses as switch S_4 must conduct both the input current and the full-bridge current. As a result, when determining whether to use the proposed converter versus a conventional two-stage converter, the main trade off that needs to be considered is lower cost and improved light-load efficiency versus heavy-load efficiency.

5. Simulation Results

Here we are doing the operation for getting the output dc of 48V. With input of 230V AC, for this we giving high switching frequency of 50KHz for MOSFETs and also The input inductance is $L_{in} = 80\ \mu\text{H}$, $L_o = 10\ \mu\text{H}$, and C_1 and $C_2 = 2200\ \mu\text{F}$. The main transformer ratio was 5:1. The switching wave forms of voltages and primary voltage of center tapped transformer and also output DC voltage at load section are shown in above all figs. And input voltage & input current also we can observe in this converter. With the help of this converter we can rectify all drawbacks of single stage converter with nearly unity power factor.

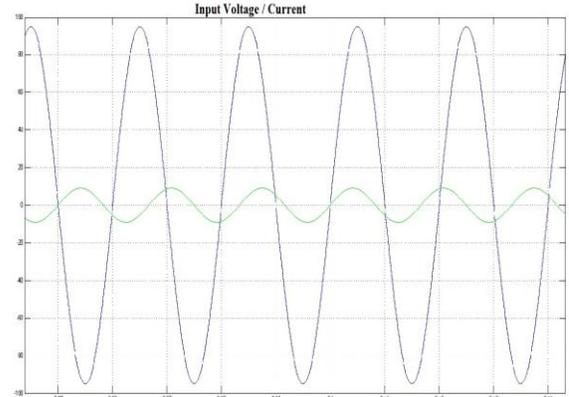


Fig. 3. Input Voltage and Current

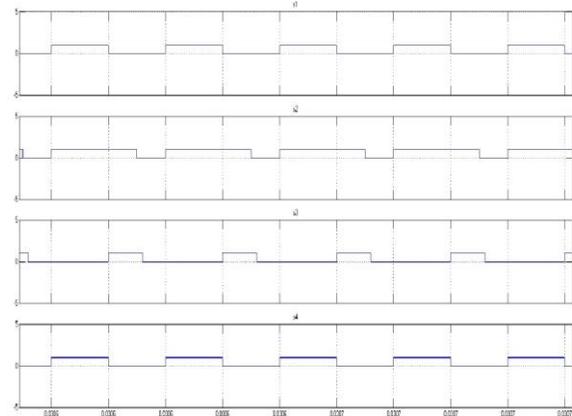


Fig. 5. PWM used in simulation circuit. (S1, S2, S3 & S4)

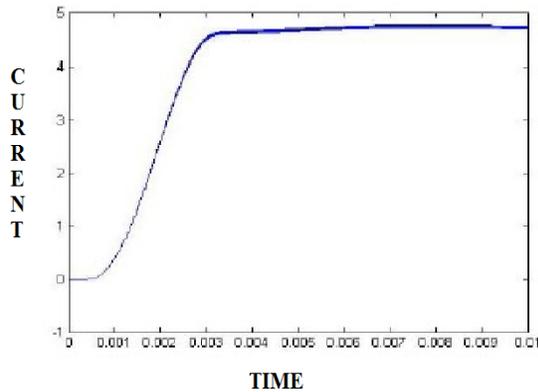


Fig. 6. Output Current

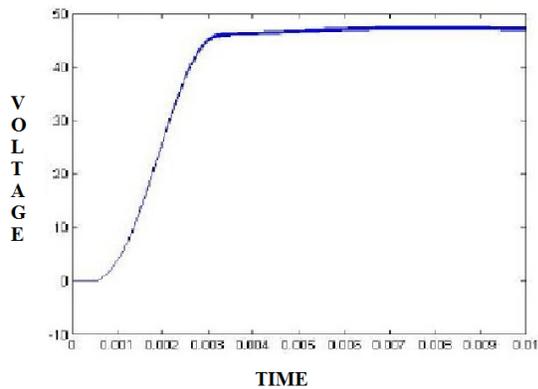


Fig. 7. Output Voltage

6. Results and Discussion

It is assumed that the input current is discontinuous, 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 is much lower than that of the output controller, which converts the intermediate dc - bus voltage into the desired output voltage. As 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

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designs for an ac – dc boost converter controller and a dc – dc full - bridge converter controller can also be used.

The simplified schematic of the power converter and the respective controllers are shown in Fig. 5. 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 input 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.

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 S1 to S4 through controlling duty cycle of D1. The other element is to control duty cycle of the switch S4 to regulate the dc-bus voltage and to perform input power factor correction. This can be done by controlling D2 and then adding duty cycle of D2 to D1 (where D1 and D2 are defined in Fig. 3); thus S4 performs two tasks; one part (D1) participate to control output voltage and another part (D2) to regulate dc-bus voltage.

7. Conclusion

A new multilevel single-stage ac–dc converter is proposed in the paper. This converter is operated with two controllers, first 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. Besides design complexity also much reduced unlike resonant converters. This converter provides constant output voltage with improved power factor. This allows for greater flexibility in the design of the converter and ultimately improved performance. Simulation results that confirm the feasibility of the converter

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