Power Factor Corrected by Buck-Boost Converter type Battery Charger Employing PWM Technique with Capacitor Bank

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Abstract: In this paper, a buck-boost type battery charger is developed for charging battery set with a lower voltage. This battery charger is configured by a rectifier circuit, an integrated boost/buck power converter and a switched capacitors circuit. A boost power converter and a buck power converter sharing a common power electronic switch are integrated to form the integrated boost/buck power converter. By controlling the common power electronic switch, the battery charger performs a hybrid constant-current/constant-voltage charging method and gets a high input power factor. Accordingly, both the power circuit and the control circuit of the developed battery charger are simplified. The switched capacitors circuit is applied to be the output of the boost converter and the input of the buck converter. The switched capacitors circuit can change its voltage according to the utility voltage so as to reduce the step-up voltage gain of the boost converter when the utility voltage is small. Hence, the power efficiency of a buck-boost type battery charger can be improved. Moreover, the step-down voltage gain of the buck power converter is reduced to increase the controllable range of the duty ratio for the common power electronic switch. A prototype is developed and tested to verify the performance of the proposed battery charger

DOI of the Article: https://doi.org/10.46501/GIETEE07

Available online at: https://ijmtst.com/icceeses2021.html

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To Cite this Article: N.Sowmya; M.Govindu Raju; S.Chandra Sekhar and Dr.D.Ravi Kishore. Power Factor Corrected by Buck-Boost Converter type Battery Charger Employing PWM Technique with Capacitor Bank. *International Journal for Modern Trends in Science and Technology* 2021, *7*, pp. 45-49. https://doi.org/10.46501/GIETEE07

Article Info. Received: 20 May 2021; Accepted: 25 June 2021; Published: 30 June 2021

INTRODUCTION

Portable electronic products and electric bikes have become more popular due to the progress of the battery industry in recent years. The performance of batteries significantly affects the operation of portable electronic products and electric bikes. The performance and lifetime of a battery is affected by the battery charger. Therefore, the operation of a battery depends on a battery charger with good controllability. Battery chargers for portable electronic products and electric bikes require a power source with a low DC voltage. However, distribution power systems supply a high AC voltage. Therefore, a battery charger acts as an interface between a distribution power system and the battery set. Conventionally, a diode rectifier with a filter capacitor is applied to convert AC power into DC power for charging a battery set due to its simple configuration and low cost [1]. Unfortunately, the output voltage of a diode rectifier cannot be regulated according to the state of charge (SOC) of the battery set, which will shorten the life of the battery set. In addition, its input characteristic is nonlinear, resulting in harmonic current and a poor power factor. The output voltage of the diode rectifier is about the peak value of the input AC voltage, and it cannot directly charge the battery set with a low DC voltage. A low-frequency transformer needs to be placed at the front of the diode rectifier, which will increase the volume and weight of the battery charger. For lowering and regulating the output voltage, a buck converter can be connected to the diode rectifier in cascade [2]-[4]. The diode rectifier outputs an absolute voltage of the utility voltage, and the buck converter converts the absolute voltage into a regular voltage with a low DC voltage. The power electronic switch of the buck converter can be controlled to regulate the output voltage according to the SOC of the battery set. It also corrects the input current of the diode rectifier to be approximately sinusoidal. However, the buck converter cannot work when the absolute voltage is lower than the output voltage, and the input current of the diode rectifier is zero. Hence, the input current will contain a zero-crossing distortion. In addition, the duty ratio of the power electronic switch will be small for obtaining a high step-down voltage gain, and it is difficult to precisely control the output voltage. To avoid zero-crossing distortion of the input current, the buck converter can be replaced by a flyback converter [5], [6] or a buck-boost converter [7], [8]. A high-frequency transformer is used in the flyback converter to increase the step-down voltage gain. Although the size of the high-frequency transformer is small, it will result in an extra power loss and it will increase the voltage rating of the power electronic switch. The power factor corrector, which is configured by a diode rectifier and a boost converter, can solve the problem of zero-crossing distortion [9]-[14]. The input current will be sinusoidal and in phase with the input AC voltage to achieve a unity power factor. However, the output voltage will be higher than the peak value of the input AC voltage, and it cannot directly charge the low-voltage battery set. An extra buck converter or a flyback converter, which achieves a high step-down gain, needs to be connected to the output of the power factor corrector for generating a low DC voltage. This is a two-stage AC-DC power converter and it complicates both the power circuit and the control circuit. In addition, the step-up voltage gain for the power factor corrector is very high when the amplitude of the utility voltage is low. In this paper, a five-level boost PFC rectifier has beenproposed using reduced number of active switches that affectsthe size of the manufactured box significantly. On the otherhand, *gaining from multilevel converter advantages* makes thepresented rectifier appealing to use in medium-voltage high powerapplications in which the switches suffer low voltagestresses and are operated at low switching frequency.Moreover, low harmonic content of the AC voltage andcurrent would be a promising result of employing this 5-levelPFC rectifier. To overcome the high switching frequency, a 4-carrier PWM technique has been adopted to modulate thereference signal and send associated switching pulses sincethis technique is still the most interesting method in industries.

CIRCUIT CONFIGURATION

Fig. 1 shows the proposed five-level boost PFC rectifier in which three active switches and six diodes have been used as a slight modification to a similar topology that includes four switches requiring more gate drives and consequently more space on the manufactured board [29].As is clear in Fig. 1, a bidirectional switch has been connected between leg b and midpoint of DC capacitors to provide different paths for current in order to produce five voltage levels at the output including •±Vdc, •±Vdc/2 and 0 where Vdc is the output DC voltage generated by the rectifier. The bidirectional switch is made by four diodes and one active switch instead of using two active switches to shrink the rectifier size and to reduce the switching losses. The full switching states are listed in table I along with the associate generated voltage level.

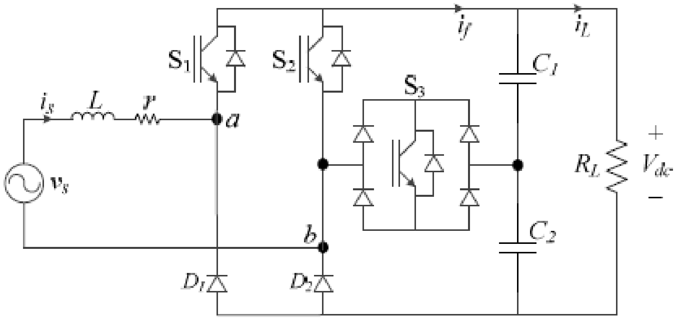


Fig. 1. Proposed five-level boost PFC rectifier with reduced number of switches

TABLE I
SWITCHING STATES AND PRODUCED VOLTAGE LEVELS OF PROPOSED FIVE-LEVEL RECTIFIER

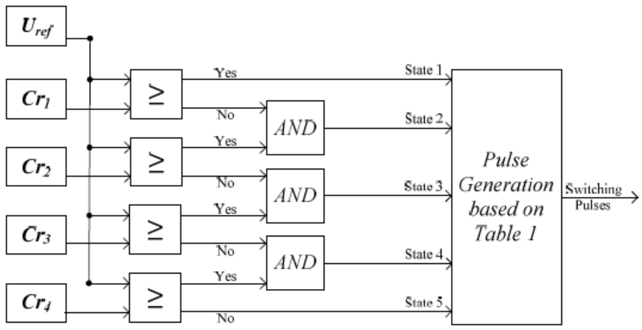
Switching States	i_s	S_1	S_2	S_3	V_{ab}
1	>0	1	0	0	$+V_{dc}$
2	>0	1	0	1	$+V_{dc}/2$
3	≥ 0 & ≤ 0	1	1	0	0
4	<0	0	0	1	$-V_{dc}/2$
5	<0	0	1	0	$-V_{dc}$

Noticing table I, it can be said that based on current direction, different voltage levels would be produced by firing necessary switches. If the current is positive, turning ON the switch S1 leads to conducting the diode D2 so +Vdc will be appeared at Vab and both capacitors (C1 & C2) are charged up. In next switching state, by firing switches S1 and S3 simultaneously, a low impedance current path would be provided through C1 and bidirectional switch S3 so the upper capacitor would be charged and Vab will have the voltage level of +Vdc/2. The zero level would be generated by a short circuit between points a and b using switches S1 and S2. For negative current direction, D1 is mostly responsible to prepare required current path. Hence, by turning ON the S3, the current will pass through only the lower capacitor C2 and charges it up while D1 is conducting and the negative voltage level –Vdc/2 would be generated at the rectifier input. Finally, during negative current direction, if switch S2 is fired, then diode D1 conducts and Vab would be equal to –Vdc. Having no redundancy switching states is the most important problem of this topology which makes the dc capacitors voltages balancing very difficult.

PROPOSED CONTROLLER AND MODULATION TECHNIQUE

Cascaded Control Design

Using hysteresis current control can help shaping the grid current into a sine wave but imposes switching problems such as high and variable switching frequency which makes annoying noises and increasing power losses in the hardware implementation [29-32]. In order to make this rectifier topology appealing and useable by industries, a simple controller including two cascaded loops have been designed in which the outer loop is voltage regulator and the inner one is the current controller. Initially, the AC line average current is modeled as shown by equation (1) [33].



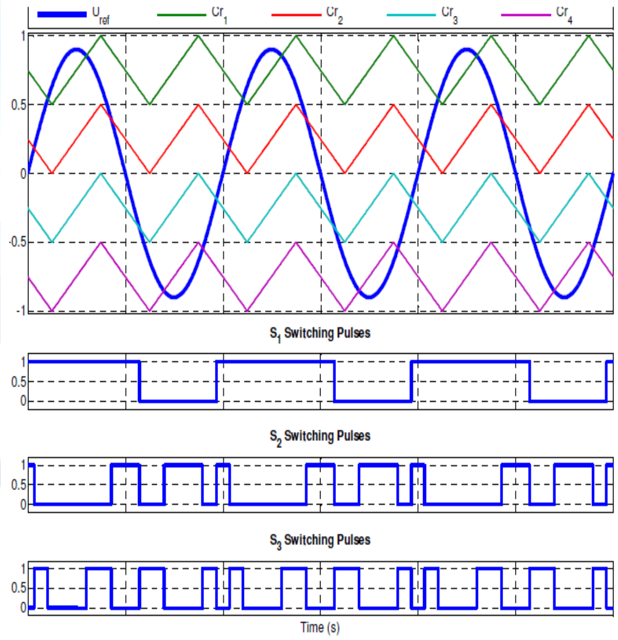


Fig. proposed multicarrier PWM technique for low and fixed switching frequency purposes

Multicarrier PWM Technique

In order to have low and fixed switching frequency to be suitable for high power and industrial applications, the PWM method should be used to generate required switching pulses [35, 36]. It should be noted that other switching techniques like hysteresis has variable switching frequency which makes annoying audible noises. As illustrated in Fig. 5, four carriers (Cr1, Cr2, Cr3 and Cr4) are shifted vertically to modulate the calculated reference signal (Uref). Each carrier is responsible of producing pulses for associate voltage level and switching states as shown by logic blocks. Moreover, corresponding switching pulses for three cycles of the modulated waveform (Uref) have been depicted in Fig. 5 to demonstrate the fixed switching frequency in each cycle The proposed method ensures low and fixed switching frequency functionality of the 5-level converter aims at low switching losses and high efficiency compared to other topologies.

SIMULATION RESULTS:

To show the good dynamic performance of the proposed rectifier as well as the implemented controller and modulation technique, it has been simulated in MATLAB/SPS toolbox using parameters listed in table II. The simulation mode was FixedStepDiscrete and sampling time was set at 20µs which makes it applicable on real-time controllers.

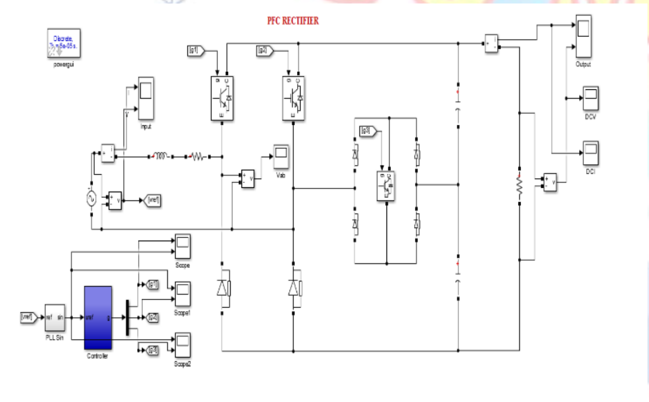


Fig: Simulation diagram of proposed circuit

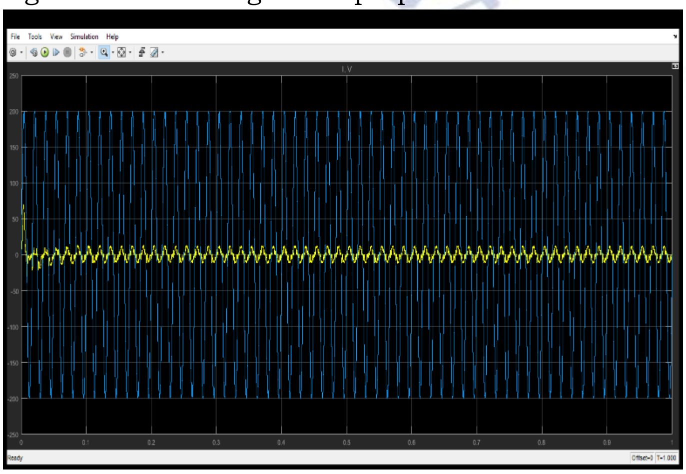


Fig: Input I and V

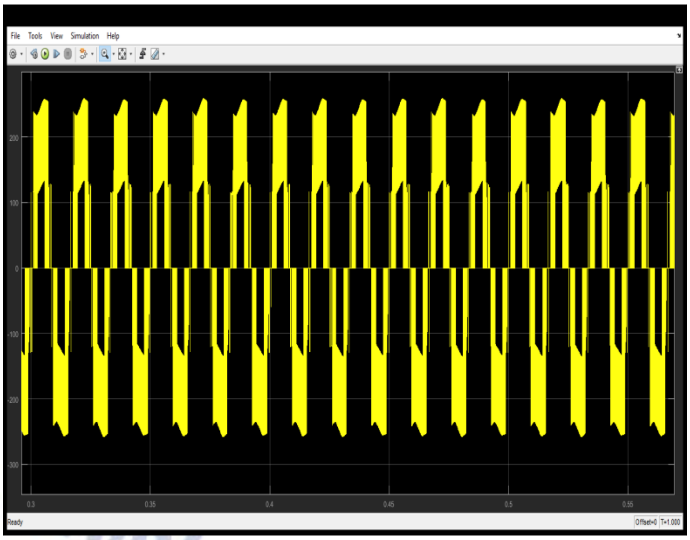


Fig: Rectifier AC link Voltage

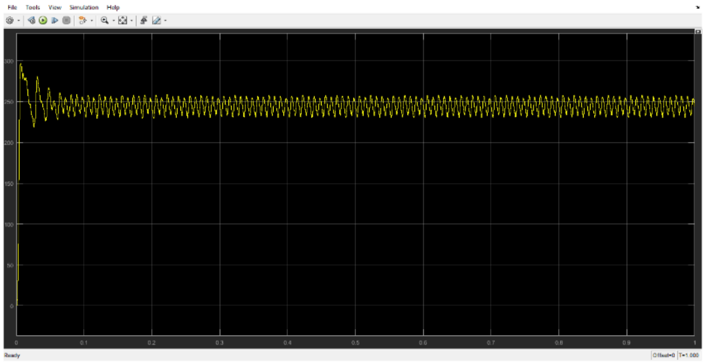


Fig: DC Voltage

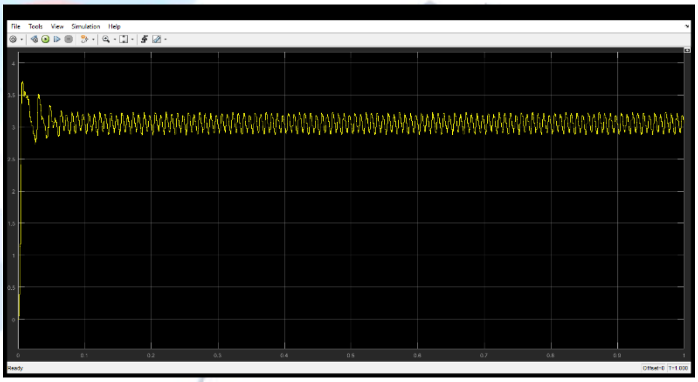


Fig: DC Current

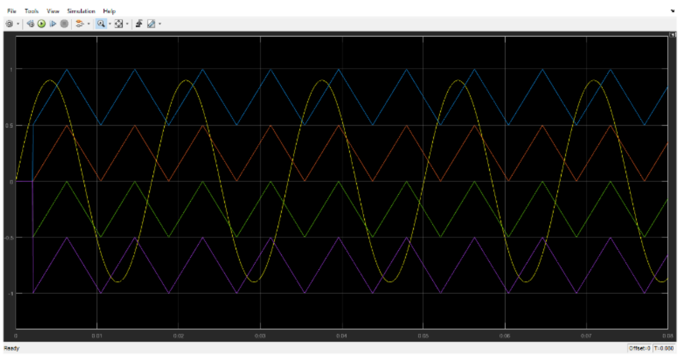


Fig: Switching Pattern

CONCLUSION:

In this paper a reduced switch count 5-level boost PFC rectifier has been presented. A cascaded PI controller has been designed to regulate the output DC voltage and to ensure the unity power factor mode of the input AC voltage and current. Moreover, low harmonic AC current waveform has been achieved by the implemented controller and employing a small inductive filter at the input line. One of the main issues of switching rectifiers is the high switching frequency that has been reduced in this work using PWM technique through adopting multicarrier modulation scheme. Moreover, DC capacitors middle point has not been connected to the load that had required splitting the load to provide a neutral point. Using a single load with no neutral point makes this topology practical in realistic applications. Comprehensive simulations cases including change in the load, AC voltage fluctuation and generating different DC voltage values have been analysed and performed to ensure the good dynamic performance of the rectifier, adopted controller and switching technique.

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