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Push-Pull Converter Fed Three-Phase Inverter for Residential and Motor Load

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ABSTRACT

The proposed paper is an new approach for power conditioning of a PV (photo-voltaic) cell array. The main objective is to investigate an approach to provide and improve the delivered electric energy by means of power conditioning structures with the use of alternative renewable resources (ARRs) for remote rural residential or industrial non-linear loads. This approach employs a series-combined connected boost and buck boost DC-DC converter for power conditioning of the dc voltage provided by a photo-voltaic array. The input voltage to the combined converters is 100 V provided from two series connected PV cells, which is converted and increased to 200 V at the dc output voltage. Series-combined connected boost and buck-boost DC-DC converters operate alternatively. This helps to reduce the input ripple current and provide the required 400 Vdc on a sinusoidal PWM three-phase inverter. Analysis of the two series-combined DC-DC converters is presented along with simulation results. Simulations of the series-combined DC-DC converters are presented with an output DC voltage of 200 V and a maximum output load of Po=600 W.

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1. INTRODUCTION

The Application of Solar cell is employed as an Alternative Renewable Resource to provide clean electric energy to

1. Remote rural Residential load.
2. Small Industrial non-linear load.

Lack of electricity in some rural areas, along with the power quality concerns on providing the electric power to residential and industrial customers require paying attention on proposing alternatives to supply electricity to critical customers [1]-[3]. In supporting those customers, distributed power may be the long-term foundation of competition in electric power industry. Photovoltaic cells have been extensively used to generate electric energy as a way of distributed generation (DG).

Several approaches have proposed power conditioning structures to increase the voltage from PV cells and provide the proper ac voltages required by residential or industrial customers. DC-DC and DC-AC converters have been explored extensively to meet the required electric energy demands by those customers [4]-[7].

1. Power conditioning structure of a DC-DC boost converter along with a single-phase dc-ac converter (IGBT PWM inverter) to supply 120V to remote rural residential loads.
2. Power conditioning structure of a DC-DC push-pull converter along with a single-phase dc-ac converter (IGBT PWM inverter) to supply 120V to remote rural residential loads.

The First Approach is a typical DC-DC boost converter employed to increase the voltage generated by a PV cell module and convert it to an ac output voltage of 120 V_{rms}. The second approach is another well known topology, the dc-dc push-pull converter, which employs a high frequency isolation transformer to increase further the input voltage provided from the PV cell. However, these two approaches are limited in their performance due to the nature of each topology [8]-[10]. The dc-dc boost converter is limited by the duty cycle, where a limited output voltage of 170 V can be obtained from a 100 V, 600 W PV cell array. The dc-dc push-pull topology can be employed, which needs a high frequency isolation transformer to have an increased voltage.

A DC-DC combined converter is proposed to meet the customers electric demands and improve performance on this new proposed approach. The main objective is to investigate an approach to provide and improve the delivered electric energy by means of power conditioning structures with the use of alternative renewable resources (ARRs) [11]-[13]. Further, the proposed approach is also connected to a sinusoidal PWM three-phase inverter to investigate the performance of the complete DC-AC power conditioning structure.

2. CIRCUIT DIAGRAM AND DESCRIPTION

The proposed approach consisting of a DC-DC boost stage which converts the input dc voltage, V_{SC}=100V, from the PV cell, to a regulated dc output voltage, V_{dc}=200V.

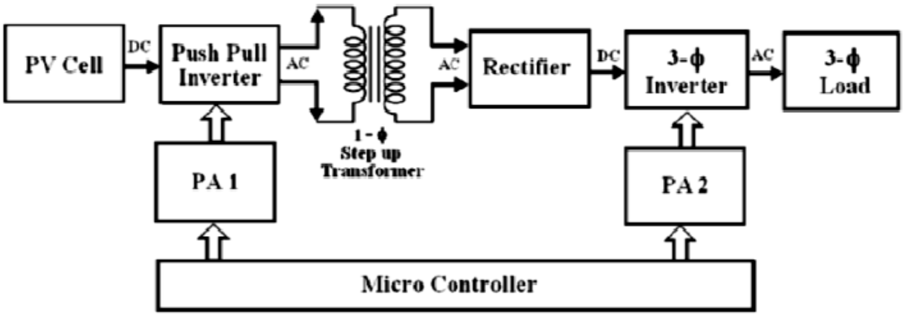

Figure 1. Proposed Block Diagram

The DC voltage from the Solar cell array is converted to AC by the inverter, which is converted in pushpull mode. The gating signals necessary to drive the push-pull inverter are provided by the control circuit. The controller circuit consists of AT89C2051 Micro Controller and a pulse amplifier.

The gating pulses with definite time delay of 5volt magnitude are not enough to drive the inverter switches. The pulse amplifier circuit (Stage 1) Power Amplifies the signals from the micro controller to nearly about 10volts, to drive the inverter switches. The alternative output of the push-pull inverter is fed to a high frequency ferrite core stepup transformer to boost the voltage levels. To drive the three phase load and to switch the three phase inverter, the boosted voltage is further converted to DC level, by the uncontrolled bridge rectifier circuit [14]-[17].

The micro controller and the pulse amplifier circuit (Stage 2) provide necessary gating pulses to the three phase inverter. The three phase inverter circuit which switching with definite time delay drive the three phase load.

The system mainly is comprised of a PV cell array with two modules (2 x 300 W, 2 x 50 V), a boost converter and a buck-boost converter. The two main inductors consists of a Boost inductor, L_{boost}, and the buck-boost inductor, $L_{buckboost}$, which can be configured as separate inductors, or they can be two coupled inductors. Two coupled inductors could improve the characteristics of the proposed approach that is, helping to reduce the input ripple current that is drawn by both DC-DC converters operating alternately.

The output of the Photovoltaic cell is inverted by using of Push-Pull inverter. It is stepped up and rectified by using an uncontrolled rectifier. The output of the rectifier is converted into Three Phase AC by using a Three Phase Inverter. The Pulses required by the Push-Pull inverter and the Three Phase Inverter are generated by using a Microcontroller. The advantages of this circuit are reduced Transformer size, reduced Filter size and availability of Three Phase output.

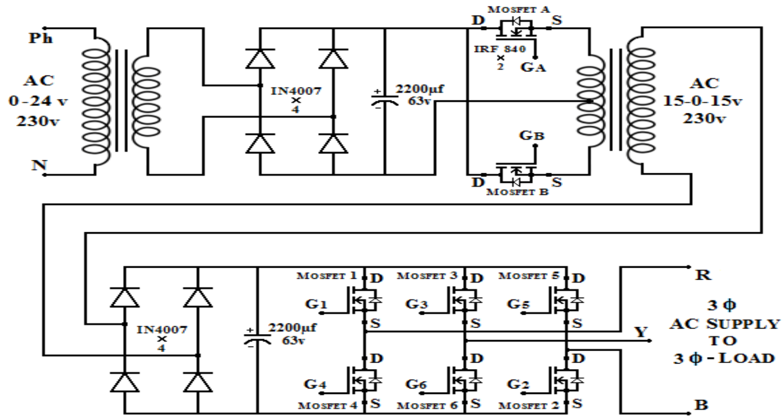

Figure 2. Push pull converter and 3 phase Inverter circuit

The second stage consists of a DC-DC buck-boost converter which operates alternatively with the boost converter. The buck-boost converter is also supplied from the voltage provided by the PV cell output voltage of 100 V. Both DC-DC converters are series connected and combined (alternate operation) to deliver the output power and voltage demanded by load.

The push pull configuration is derived from two forward converters working in antiphase. As such, the push-pull converter topology has the advantage over the forward converter in that the voltage across the transformer and hence, the peak collector voltage of the switching transistor is limited twice the input voltage. This is due to the symmetrical centre-tapped transformer with equal number of turns in the primary windings. Since the power supplied to the load is never stored in the transformer, more power can be handled at a greater efficiency and with a better regulation than the forward converter. The basic circuit diagram of a push-pull converter is shown in the Figure 2. It has two MOSFETs M1 and M2 and a transformer with mid-taps on both primary and secondary sides. An uncontrolled rectifier or any type of dc source feeds push-pull converter. Inductor L and capacitor C are the filter components.

When M1 is turned on, the input voltage is applied to the lower half of the primary transformer windings. As a result, voltage is induced in both the secondary windings. Voltage in the upper half of the secondary winding forward biases diode D1 and this will supply to the load. When M2 is turned on, the input voltage is applied to the upper half of transformer primary. As a result, voltage is induced in both the secondary windings. Voltage in the lower half of the secondary winding forward biases diode D2 and this will supply to the load.

3. MODES OF OPERATION

Three phase inverters are normally used for high power applications. Three single-phase half or full bridge inverters can be connected in parallel to form the configuration of a three phase inverter. The gating signals of single phase inverters should be advanced or delayed by 120º with respect to each other in order to obtain three phase balanced voltages. The three phase output can be obtained from a configuration of six switches and six diodes. Two types of control signals can be applied to the switches: 180º conduction or 120º conduction.

A. 180° Conduction

Each switch conducts for 180°. Three switches remain on at any instant of time. When switch 1 is switched on, terminal ‘a’ is connected to the positive terminal of the dc input voltage. When switch 4 is switched on, terminal ‘a’ is connected to the negative terminal of the dc source. There are six modes of operation in a cycle and the duration of each mode is 60°. The switches are numbered in the sequence of gating the switches 123, 234, 345, 456, 561, 612. The gating signals are shifted from each other by 60° to obtain three phase balanced voltages.

B . 120° Conduction

Each switch conducts for 120°. Only two switches remain on at any instant of time. The conduction sequence of switches is 61, 12, 23, 34, 45, 56, and 61. There are three modes of operation in a half cycle and the equivalent circuits for wye connected load are shown in Figure 3.

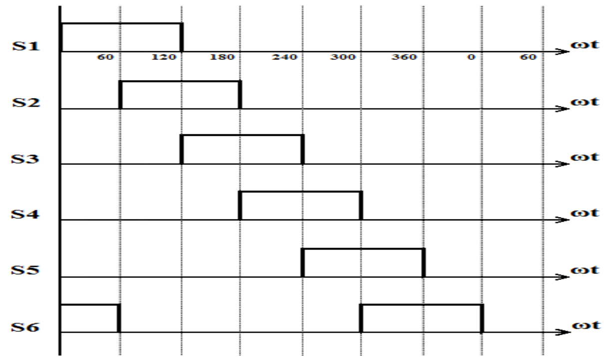

Figure 3. Waveforms of the switching pulses

During mode 1 for $0 \le \omega t \le \pi/3$ switches 1 and 6 conducts.

Van=Vs/2 Vbn=-Vs/2 Vcn=0

During mode 2 for $\pi/3 \le \omega t \le 2\pi/3$, switches 1 and 2 conduct.

Van=Vs/2 Vbn=0 Vcn=-Vs/2

During mode 3 for $2\pi/3 \le \omega t \le 3\pi/3$, switches 2 and 3 conduct.

Van=0; Vbn=Vs/2; Vcn=-Vs/2

The line to neutral voltages can be expressed in Fourier series as given bellow

Van=n=1, 3, 5 …

$\Sigma\ \infty\ 2Vs/n\pi \cos n\pi/6 \sin n (\omega t + \pi/6)$

Vbn=n=1, 3, 5 …

$\Sigma\ \infty\ 2Vs/n\pi \cos n\pi/6 \sin n (\omega t - \pi/2)$

Vcn=n=1, 3, 5 …

$\Sigma\ \infty\ 2Vs/n\pi \cos n\pi/6 \sin n (\omega t - 7\pi/6)$

4. SIMULATION RESULTS

The proposed work consisting of a DC-DC boost stage which converts the input dc voltage, V_{SC}=100V, from the PV cell, to a regulated dc output voltage, V_{dc}=200V. The second stage consists of a dc-dc buck-boost converter which operates alternatively with the boost converter. The buck-boost converter is also supplied from the voltage provided by the PV cell output voltage of 100 V. Both DC-DC converters are series connected and combined (alternate operation) to deliver the output power and voltage demanded by load. The simulation is done using Matlab simulink for Residential load and three phase motor load, the results are presented. Scope is connected to display the output voltage.

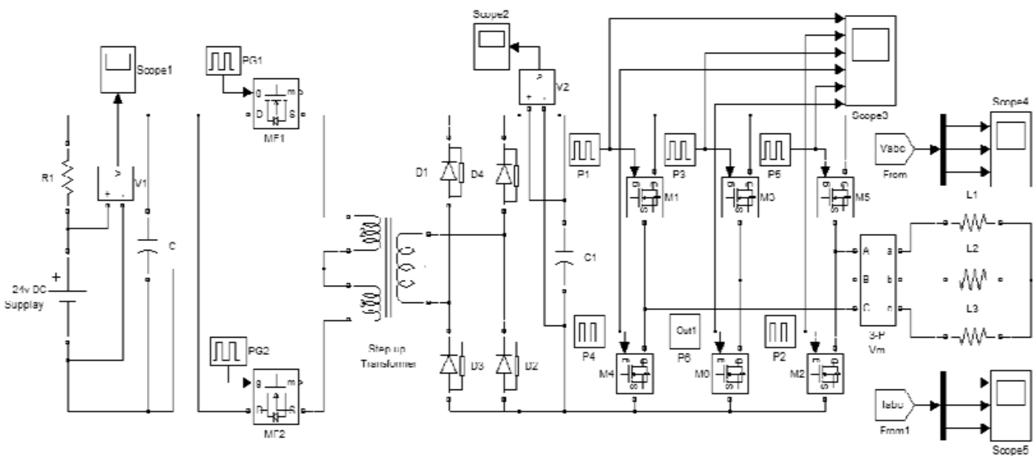

Figure 4. Simulation Circuit for push-pull converter fed Three Phase Inverter with Residential load

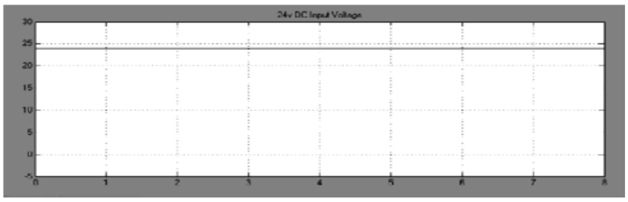

Figure 5. DC Input Voltage

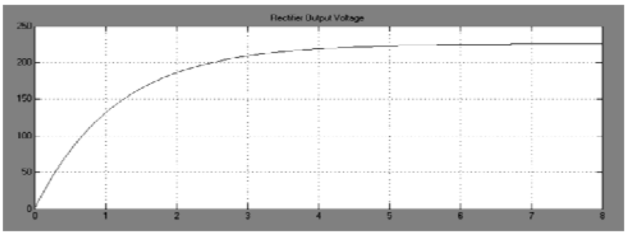

Figure 6. Rectifier DC Output Voltage

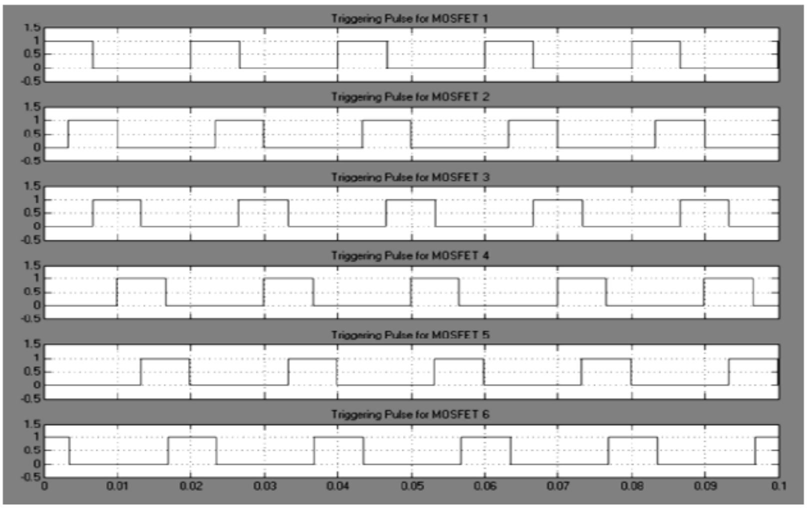

Figure 7. Triggering Pulses for MOSFET's 1 to 6

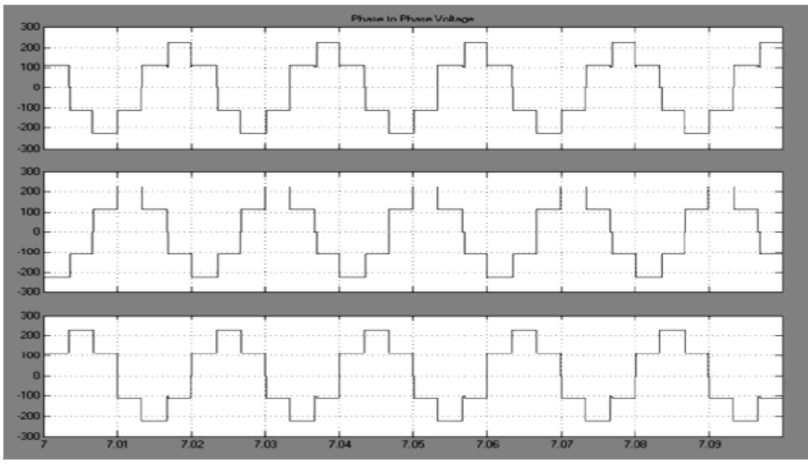

Figure 8. Output Phase Voltage

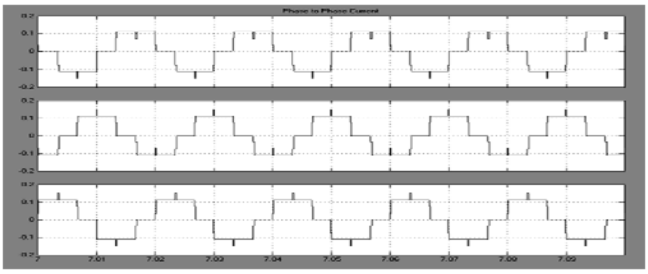

Figure 9. Output Phase current

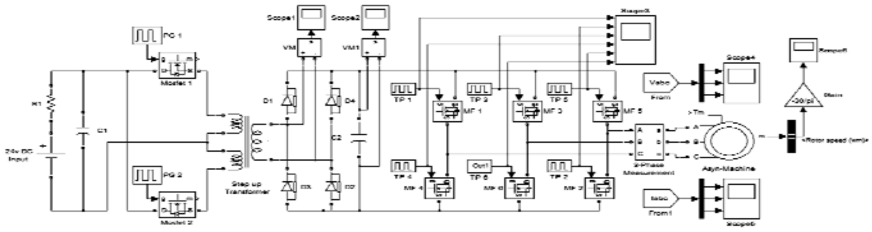

Figure 10. Simulation Circuit of push-pull converter fed three phase motor load

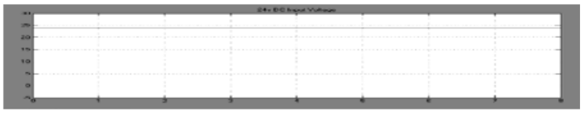

Figure 11. 24V DC input supply

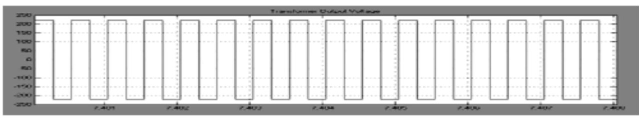

Figure 12. Transformer Output Voltage

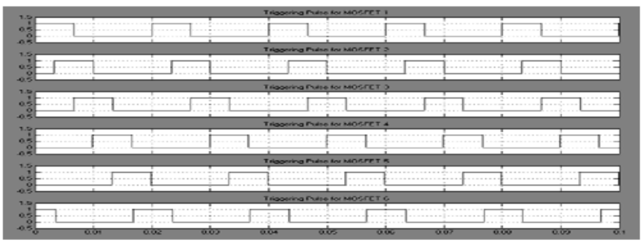

Figure 13. Triggering Pulses for MOSFET 1 to 6

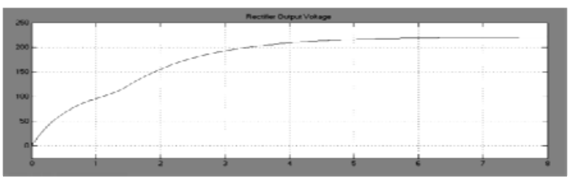

Figure 14. Rectifier Output Voltage

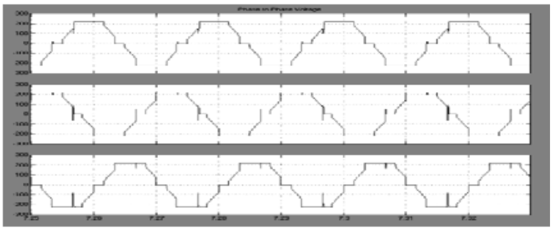

Figure 15. Output Phase Voltage

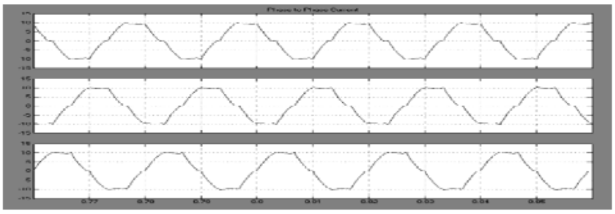

Figure 16. Output Phase current

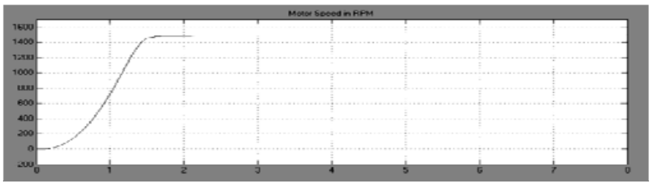

Figure 17. Motor Speed in RPM

5. CONCLUSION

In this proposed work a novel approach has been developed for the conversion of the generated DC output voltage of a PV cell array into a higher regulated DC voltage. This higher power conditioned DC output voltage is utilized by a typical sinusoidal SPWM three-phase inverter such that nominal line-to-neutral rms voltage, $V_{LN,rms}$=120 V and line to line rms voltage $V_{LL,rms}$=208V can be available to residential and/or industrial loads. Simulation results of the new series-combined converter show the feasibility of the proposed approach to obtain a higher dc-link output voltage, $V_{o,dc\text{-}link}$=200 V. The dc-link voltage regulation has been shown to be provided by the two output capacitors voltages which can be individually controlled. The ac output load can be unbalanced and/or non-linear. Furthermore, the inductor currents in the boost and buck boost schemes are shown to be within adequate rms and dc current quantities, which must be delivered by the PV cell module. The proposed converter is able produce a low input current ripple due to the alternate operation of boost and buck boost converters.

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