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Design and Simulation of an Improved PV-Array Energy Conversion System using Five-Level Multi-Boost Inverter

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Abstract:

Renewable energy sources are having better application in Micro-grid applications, but integration of RES systems to micro-grid requires step-up converters. Conventional converters are having disadvantage of two-stage conversion technique. The proposed converter is single-stage DC to AC converter with voltage boost technique. And it is multi-level converter of five-level.

The proposed converter is having improvedperformance in the generation of active power for mitigation of switching power losses and harmonic elimination with PV-Array as the input source. The five-level inverter is designed with two dc capacitors as input sources, a dual-buck converter, and full-bridge inverter. The five-level inverter output current is controlled to produce current in phase with utility voltage to inject into grid. The performance characteristics of the proposed converter are verified by MATLAB/simulink software, they are described in simulation results section.

Key words:

Renewable Energy Sources, Multi-level Inverter, single-stage boost converter, MPPT algorithm.

I.INTRODUCTION:

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect.

Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photo-Voltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free [1]. Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices.

The general power converters have to convert the input voltage at one level to another level. The output power controlling is depends on designing of switching circuit. Power conditioning units require a DC- DC converter followed by a DC- AC inverter to deliver the required power to the load.

RES systems are having in general low output power ratings, for integrating these systems to the micro-grid power systems they need to step-up the output power. Multi-Level Inverters (MLI) are the best solution for increasing output voltage levels.

MLI are having two or more inverters connected either in parallel or series for improving of output voltage and current levels based upon applications [2]. MLI's are having advantages of high-efficiency, and less switching losses when compared to the conventional half-bridge and full-bridge inverters.

Multi-level inverters are designed based upon following expression:

Level of inverter = (2n+1)

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Here n= number of inverters.
Basically MLI's are classified in to two types. They are (1) cascaded MLI's, (2) parallel MLI's

The single-phase conventional multilevel inverters are having different topologies, they are diode-clamped, flying capacitor, and cascaded H-bridge inverters.In the proposed paper a special five-level inverter is developed. The developed five-level inverter is having six power electronic devices, two capacitors and two high-frequency switching switches. The voltage balancing of capacitors is easier when compared to the other multilevel inverters.The controlling circuit is designed with Maximum Power Point Tracking (MPPT) Algorithm to the five-level inverter for getting of maximum output power from Photovoltaic power generation system. The circuit diagram of developed five-level inverter is shown in figure 1.

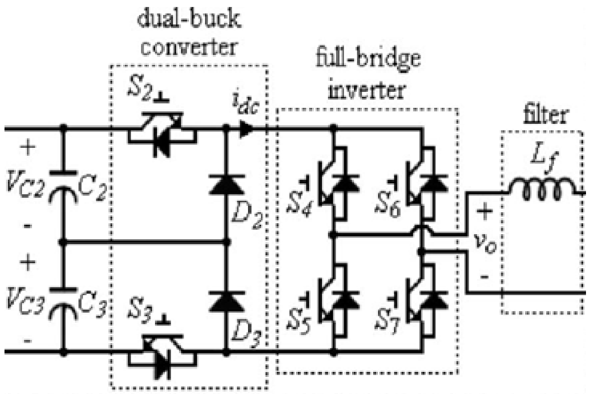

Figure1. Circuit diagram ofproposed five-level inverter.

The paper is organized as follows: The section II describes the circuit design of five-level inverter configured to photovoltaic power generation system. The operating modes and voltage balancing of five-level inverter are mentioned in section III.

Section IV describes the control system for five-level inverter. Simulation results are observed in section V, and finally conclusion mentioned in section IV.

II.CIRCUIT DESIGN OF PROPOSED SYSTEM:

Circuit design of proposed five-level inverter interconnected with photovoltaic energy conversion system is shown in figure 2. It is configured by a PV-Array, a dc–dc converter, afive-level inverter, two switches, and control circuit for the switching devices.

The switches SW1 and SW2 are used to connect or disconnect the photovoltaic power generation system fromthe utility system. The load is connected in between switches SW1 and SW2. The DC-DC converter is connected across output terminals of PV-array.

Theoutput ports of the dc–dc converter are connected to the five-levelinverter input side. The DC-DC converter operated as boost converter, and it is fed by control circuit of maximum power point tracking algorithm to deliver maximum output power from solar cell array. Five-level inverter is configured by two dc capacitors, a dual-buckconverter, a full-bridge inverter, and a filter.

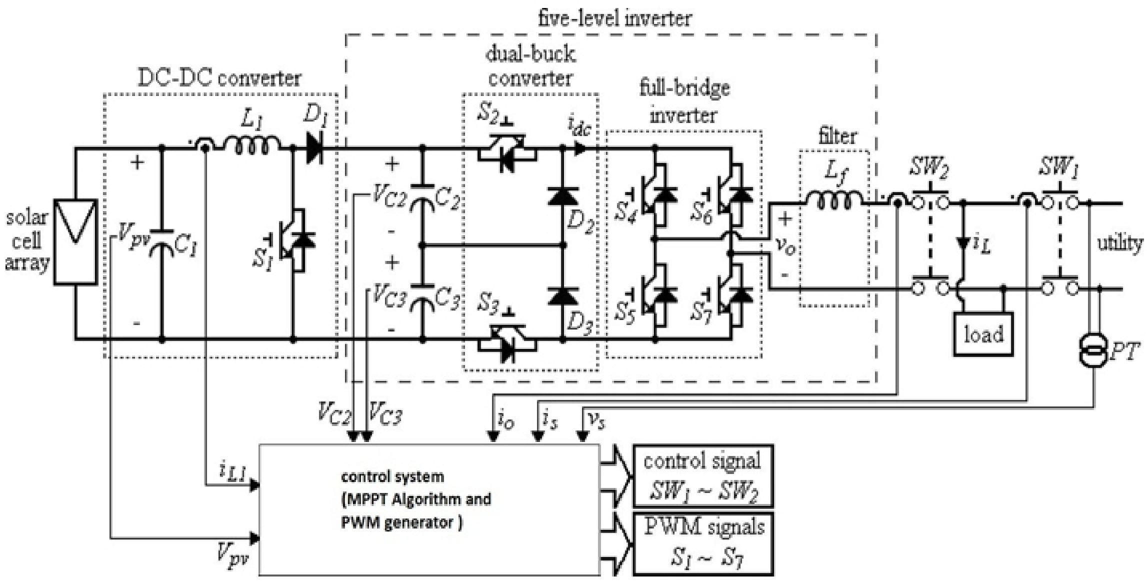

Figure2. Circuit design of five-level inverter interfaced with PV energy conversion system.

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The dual-buckconverter is configured by two buck converters. For the energy buffering between dc-dc converter and five-level inverter is done by connecting two dc capacitors [3].

The output of the dual-buck converteris connected to the full-bridge inverter to convert the dc voltage to ac voltage.

Thehigh-frequency switching harmonics are eliminated by connecting inductor at output of full-bridge inverter which is caused by buck converter.

III.OPERATING MODES OF FIVE-LEVEL INVERTER:

Operation principle of five-level inverter is explained in this section. The proposed converter is operated in eight (8) modes [4]. The positive half-cycle conversion is done in modes 1-4. And negative cycle in modes5-8.

The operation modes of this five-level inverter are explained as below:

Mode 1:

The power electronic switch of the dual-buck converter S2 isturned ON and S3 is turned OFF. DC capacitor C2 is discharged through S2, S4, the filter inductor, the utility, S7, and D3 toform a loop. Both output voltages of the dual-buck converterand five-level inverter are Vdc/2.

Mode 2:

The power electronic switch of the dual-buck converter S2 isturned OFF and S3 is turned ON. DC capacitor C3 is discharged throughD2, S4, the filter inductor, the utility, S7, and S3 to forma loop. Both output voltages of the dual-buck converter and five-level inverter are Vdc/2.

Mode 3:

Bothpower electronic switches S2 and S3 of the dual-buck converterare turned OFF. The current of the filter inductor flows throughthe utility, S7,D3, D2, and S4. Both output voltages of the dual-buckconverter and five-level inverter are 0.

Mode 4:

Bothpower electronic switches S2 and S3 of the dual-buck converterare turned ON.DCcapacitorsC2 andC3 are discharged together through S2, S4, the filter inductor, the utility, S7, and S3 to forma loop. Both output voltages of the dual-buck converter and five-level inverter are Vdc.

Modes 5–8:

These operating modes for the negative half-cycle.The operations of the dual-buck converter under modes5–8 are similar to that under modes 1–4, and the dual-buck converter can also generate three voltage levels Vdc/2, Vdc/2, 0,and Vdc, respectively.

However, the operation of the full-bridge inverter is the opposite. The power electronic switches S4 andS7 are in the OFF state, and the power electronic switches S5 andS6 are in the ON state during the negative half-cycle. Therefore, the output voltage of the five-level inverter for modes 5–8 will be –Vdc/2, –Vdc/2, 0, and –Vdc, respectively.

Considering operation modes 1–8, the full-bridge inverterconverts the dc output voltage of the dual-buck converter withthree levels to an AC- output voltage with five levels which are Vdc, Vdc/2, 0, –Vdc/2, and –Vdc.

The waveforms of output voltage of five-level inverter and utility voltage are shown in Fig. 3.

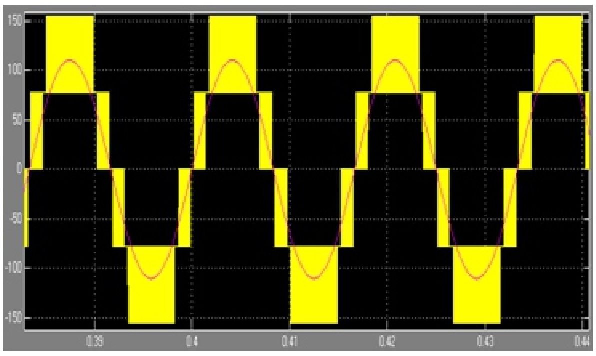

Figure 3: Waveforms of output voltage and utility voltage.

Voltage balancing of DC-capacitors:

The operation of the multilevel inverter is depends on controlling of dc capacitor voltages. Those voltages are represented as Vc2 and Vc3 and they are controlled by switches S2 and S3 easily [5].

If utility voltage is less than Vdc/2, one switch either S2 or S3 is switched in high frequency and other in OFF state.

If utility voltage is higher than Vdc/2, one switch either S2 or S3 is switched in high frequency and still in the ON state.

		Vs>Vdc/2	Vs<Vdc/2
$V_{c2} > V_{c2}$	S2	ON	PWM
	S3	PWM	OFF
$V_{c2} < V_{c3}$	S2	PWM	OFF
	S3	ON	PWM

Table: ON/OFF state of S2 and S3

The operation of switches S2 and S3 is shown in above table.

IV.CONTROL SYSTEM:

The proposed photovoltaic energy conversion system is having dc-dc converter and dc-ac five-level inverter. For these converters two different control strategies are performed. The MPPT control algorithm is used for dc-dc converter for generating switching signals and performs the MPPT to extract the maximum output power of the solar cell array.

MPPT Algorithm:

Maximum Power Point Tracking (MPPT) algorithm is used for getting of maximum power from solar array [6]. The output of the MPPT controller is the desired output voltage of the solar cell array, and it is the reference voltage of the outer voltage control loop. For the proposed system P&O (perturbed and observation) method is designed. The control block diagram of MPPT Algorithm is shown in figure 4.

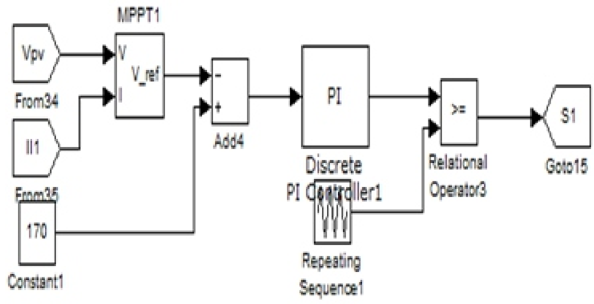

Figure 4: control circuit of dc-dc boost converter

The output voltage of the solar cell array is perturbed first, and then the output power variation of the solar cell array is observed to determine the next perturbation for the output voltage of the solar cell array. T

he output power of the solar cell array is calculated from the product of the output voltage of the solar cell array and the inductor current. Therefore, the output voltage of the solar cell array and the inductor current are detected and sent to a MPPT controller to determine the desired output voltage of the solar cell array.

The detected output voltage and desired output voltage of the solar cell array are sent to a sub-tractor, and the subtracted result is sent to a P-I controller. The output of the P-I controller is the reference signal of the inner current control loop.

The reference signal and the detected inductor current are sent to a sub-tractor, and the subtracted result is sent to an amplifier to complete the inner current control loop.

The output of the amplifier is sent to the PWM circuit. The output signal of the PWM circuit is the driving signal for the power electronic switch of the dc–dc converter.

Control circuit for five-level inverter:

The input of the five-level inverter fed from dc bus, which is connected to output of dc-dc converter [7]. The operation of the five-level inverter, to convert the dc bus voltage regulated to larger than peak voltage of utility system. The control block diagram of five-level inverter is shown in figure 5.

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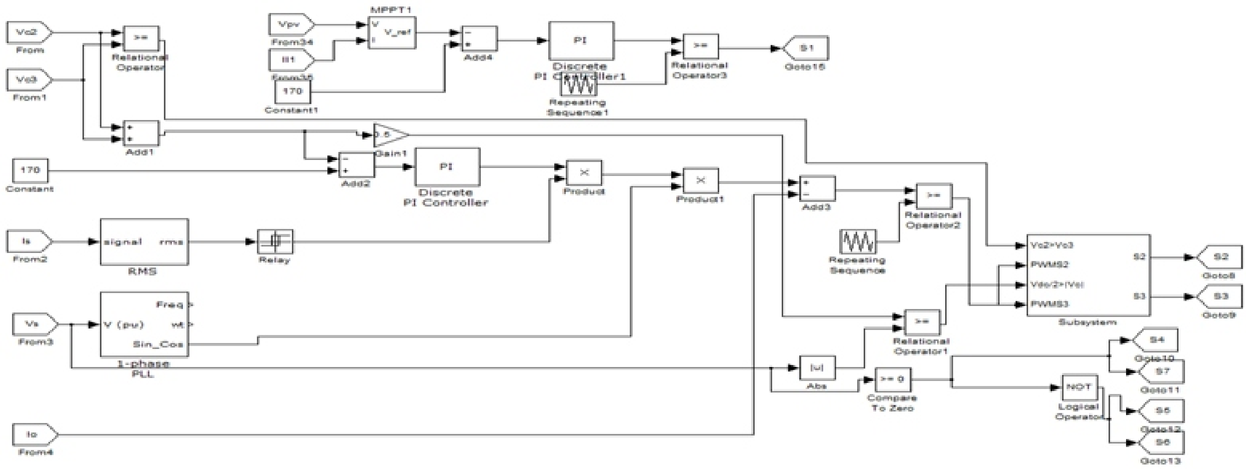

Figure 5: control circuit design for five-level inverter

The voltages of dc capacitors C2 and C3 are detected and then added to obtain a dc bus voltage Vdc. Resulting voltage is subtracted from setting voltage, and is sent to PI controller.

The utility RMS current is given to hysteresis comparator, and is sent to signal generator. The outputs of the PI controller and signal generator are sent to a multiplier, and the product of the multiplier is the amplitude of the reference signal.

The utility voltage is taken as input for PLL (Phase Locked Loop). The outputs of the multiplier and the PLL circuit are sent to the other multiplier. The output current of the five-level inverter is detected by a current sensor.

V.SIMULATION RESULTS:

The reference signal and detected signal for the output current of the five-level inverter are sent to a subtractor. The subtracted result is sent to a current-mode controller. The output of the current-mode controller is sent to a PWM circuit to generate a PWM signal.

The performance of the proposed photovoltaic energy conversion system is verified by MATLAB/simulink software. The proposed photovoltaic energy conversion system consists of a dc–dc power converter and the five-level inverter.

The simulation circuit of proposed system is shown in figure 6. The environmental temperature and radiation levels are 35.7 deg.C and 944 W/m2, respectively. The temperature of the solar module is 55.3 deg. C. The maximum output power of the solar cell array is about 900W.

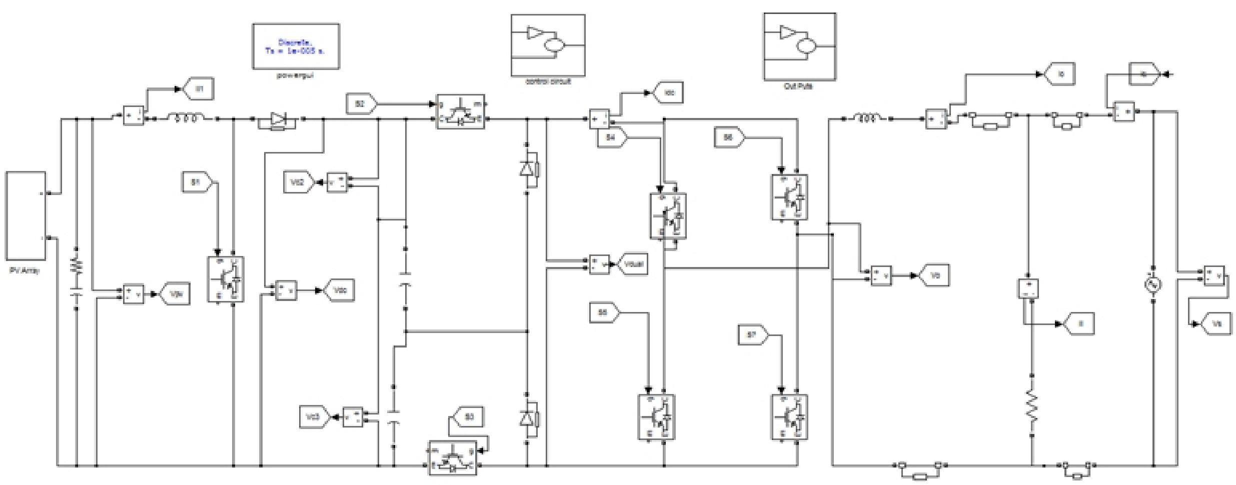

Figure 6: simulation circuit of proposed photovoltaic energy conversion system

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The simulation results of utility voltage, output current of five-level inverter, and DC capacitor voltages V_c2,V_c3 are shown in figure 7. Simulation results of dc-dc converter are shown in figure 8. The simulation results of Output current (i_o), and input current (i_dc) of the full-bridge inverter, (c) Driver signal of S4, Driver signal of S5 are shown in figure 9.

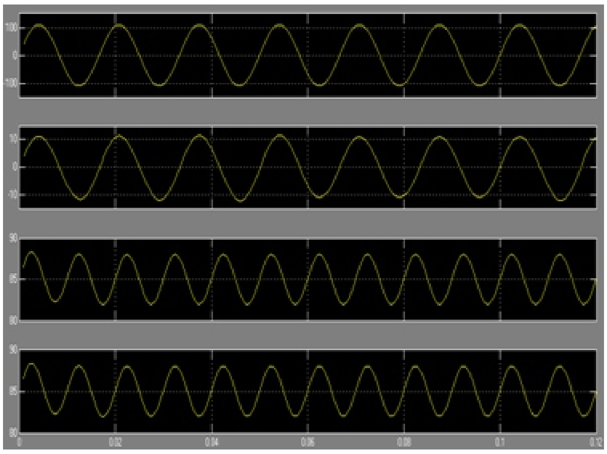

Figure 7: simulation results of the five-level inverter. Utility voltage, Output current of the five-level inverter, DC capacitor voltageV_c2, DC capacitor voltageV_c3.

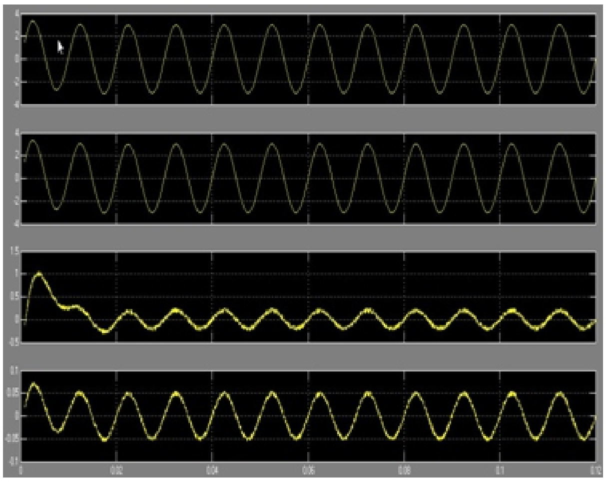

Figure 8: simulation results of (a) Voltage ripple of dc capacitor C2, Voltage ripple of dc capacitor C3, Output voltage ripple of solar cell array, Inductor current ripple of dc–dc converter

Comparison simulation waveforms of utility voltage, inverter output voltage, and output voltage of dual-buck converter are shown in figure 10.

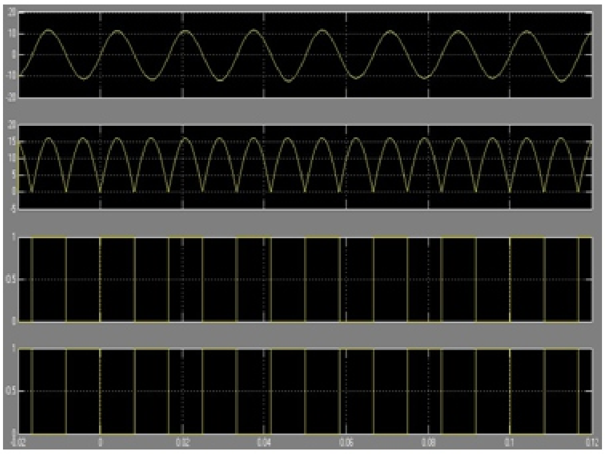

Figure 9: Simulation results of Output current of the full-bridge inverter, Input current of the full bridge inverter, Driver signal of S4, Driver signal of S5.

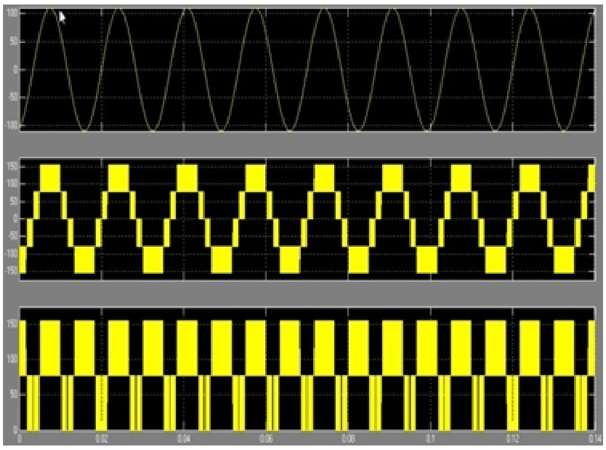

Figure 10: simulation results of the five-level inverter: Utility voltage, Output voltage of the full-bridge inverter, Output voltage of the dual-buck converter.

VI.CONCLUSION:

An improved photovoltaic energy conversion system with five-level inverter is proposed in this paper. The output power rating of the solar array is increased. Dc-dc boost converter with MPPT control algorithm is proposed for getting maximum output power from solar cell.

Five-level inverter is performs the function of dc input power into high-quality ac output power and dc balancing capacitors proposed at input of utility system. The performance characteristics are verified by MATLAB/ simulink software.

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