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Simulation Analysis of Multilevel Inverter for Renewable Energy Systems

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Abstract:

Renewable energy sources are not sustainable sources. These are having fluctuations in the output power. DC/DC converter is used in this paper before connecting source to inverter, it increases power rating. Switching losses in multilevel inverter overcomes by using bridge-less converter. The performance observed by integrating system with synchronous machine. The performance characteristics of the proposed converter are verified by MATLAB/ simulink software, they are described in simulation results section.

Index terms:

Low-power energy sources, single-stage boost converter, MPPT technology, Renewable Energy Sources, MLI's.

I.INTRODUCTION:

Multilevel voltage source inverter is recognized as animportant alternative to the normal two level voltagesource inverter especially in high voltage application[1]. Usingmultilevel technique, the amplitude of the voltage is increased,stress in the switching devices is reduced and the overallharmonics profile is improved. Among the familiar topologies,the most popular one is cascaded multilevel inverter. It exhibitsseveral attractive features such as simple circuit layout, lesscomponent counts, modular in structure and avoid unbalancecapacitor voltage problem. However as the number of outputlevel increases, the circuit becomes bulky due to the increase inthe number of power devices.

In this project, it is proposed toemploy a new technique to obtain a multilevel output using lessnumber of power semiconductor switches when compared toordinary cascaded multilevel inverter, which is suitable forrenewable energy source interfacing. Voltage source convertersare also required for various industrial applications, smart gridtechnologies etc. Due to high power requirement in theseapplications, using one power semiconductor switch directly isnot advisable. For high power and medium voltage applicationsmultilevel converters are introduced [2]. Using multilevelconverters renewable energy sources can be easily interfaced tothe grid. Using several low voltage DC sources such ascapacitors, batteries and renewable sources with series powersemiconductor switches high power converter can be achieved.

The rated voltage of the switches depends only upon the rating ofDC voltage sources to which they are connected. Theseconverters have several advantages over two level converters.Multilevel converters can generate the output voltages with lowdistortion and less dv/dt stresses. Small common mode voltagereduces the stress in the bearings of motor connected tomultilevel converter. Input current with low distortions, range ofthe switching frequency are further advantages of multilevelconverters. But due to large number of switches, each switchrequires its related gate drive circuit increase cost andcomplexity. Major multilevel converter structures are CascadedH bridge converter, Diode clamped converter, Capacitor clampedconverter. Different pulse width modulation techniquesdeveloped such as sinusoidal pulse width modulation (SPWM),Selective harmonic elimination (SHE-PWM), space vectormodulation (SVM) and so on[3]. In cascaded H bridge converter,depending on the number of voltage levels required, some single

The proposed converter configured by two dc capacitors, two diodes,and four power electronic switches. Two diodes are used to conductthe current loop, and four power electronic switches areused to control the voltage levels. The output voltage of thebasic diode-clamped multilevel inverter has three levels. Thevoltage difference of each level is Vdc/2 (the voltage on a capacitor).Since the voltages of two dc capacitors are used toform the voltage level of the multilevel inverter, the voltagesof these two dc capacitors must be controlled to be equal. Thecontrol for balancing these two dc capacitors is very importantin controlling the diode-clamped multilevel inverter, and it isvery hard under the light load.The voltage on each dc capacitor is controlledto be Vdc/2, and the output voltage of the basic flyingcapacitor multilevel inverter has three levels. The voltage differenceof each level is also Vdc/2 (the voltage on a dc capacitor).The paper is organized as follows: The section II describes the circuit design of multilevel inverter. The operating modes of five-level inverter are mentioned in section III.

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

II.CIRCUIT DESCRIPTION:

Circuit design of proposed five-level inverter interconnected with photovoltaic energy conversion system is shown in figure 1. 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.

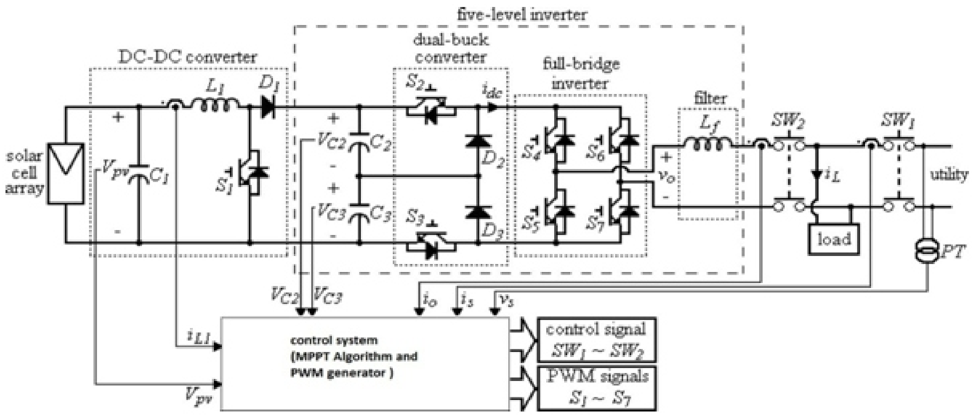

Figure 1: Circuit design of five-level inverter interfaced with PV energy conversion system

Five-level inverter is configured by two dc capacitors, a dual-buckconverter, a full-bridge inverter, and a filter. 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. The dcbus voltage of each full-bridge inverter is Vdc/2, and the outputvoltage of each full-bridge inverter can be controlled to beVdc/2, 0, and −Vdc/2. Thus, the voltage levels of the output voltageof the cascade full-bridge multilevel inverter are Vdc, Vdc/2,0, −Vdc/2, and −Vdc.

This topology has advantages of fewercomponents being required compared with other multilevel invertersunder the output voltage with the same levels, and itshardware circuit can be modularized because the configurationof each full bridge is the same.

III.OPERATING MODES:

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:

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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-levelinverter are Vdc/2.

Mode 3: Both power electronic switches S2 and S3 of the dual-buck converter are turned OFF. The current of the filter inductor flows through the utility, S7, D3, D2, and S4. Both output voltages of the dual-buckconverter and five-level inverter are 0.

Mode 4: Both power electronic switches S2 and S3 of the dual-buck converterare turned ON.DCcapacitorsC2 andC3 are discharged together through S2, S4, the filter inductor, and the utility, S7, and S3 to forma loop. Both output voltages of the dual-buck converter andfive-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-buckconverter can also generate three voltage levels Vdc/2, Vdc/2, 0,and Vdc, respectively. However, the operation of the full-bridgeinverter 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 willbe −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 areVdc, Vdc/2, 0, −Vdc/2, and −Vdc. The waveform of outputvoltage of five-level inverter is shown in Fig. 2.

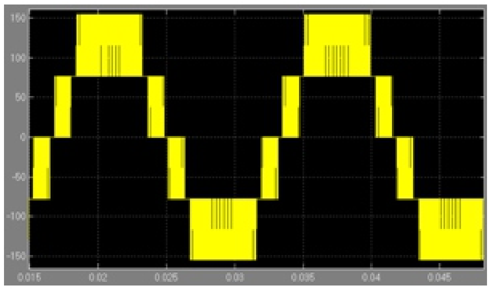

Figure 2: Output voltage of proposed inverter

DC-capacitors voltage balancing:

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.

IV.CONTROL SYSTEM:

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 extractthe maximum output power of the solar cell array.

MPPT LOGIC:

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 solarcell 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.

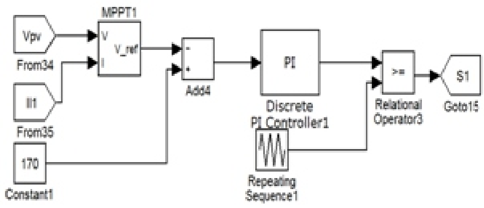

Figure 3: MPPT controller

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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. The 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, theoutput voltage of the solarcell array and the inductor current are detected and sent to aMPPT controller to determine the desired output voltage of thesolar cell array. The detected output voltage and desired outputvoltage of the solar cell array are sent to a sub-tractor, and thesubtracted result is sent to a P-I controller. The output of theP-I controller is the reference signal of the inner current controlloop.

The reference signal and the detected inductor currentare sent to a sub-tractor, and the subtracted result is sent to anamplifier to complete the inner current control loop. The output of the amplifier is sent to the PWMcircuit. The output signal ofthe PWM circuit is the driving signal for the power electronicswitch of the dc–dc converter.

Inverter controller:

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 4.The input of the five-level inverter fed from dc bus, which is connected to output of dc-dc converter [7].

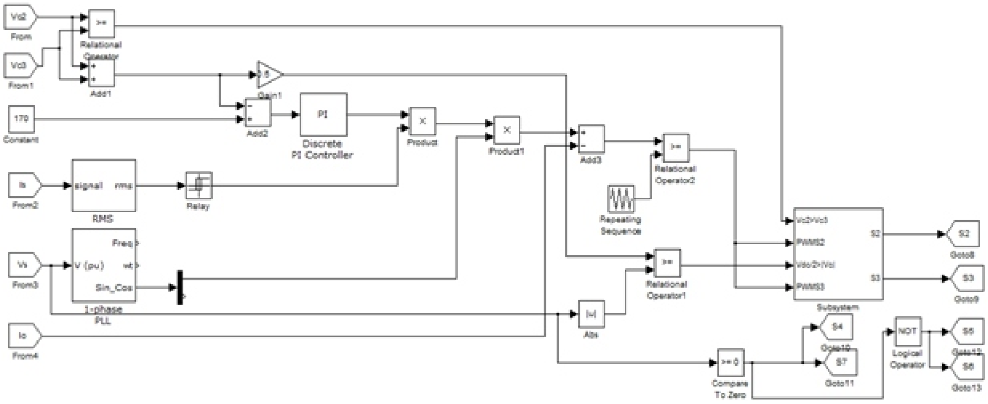

Figure 4: inverter control circuit

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 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 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. 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.

V.SIMULATION RESULTS:

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 5.

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.

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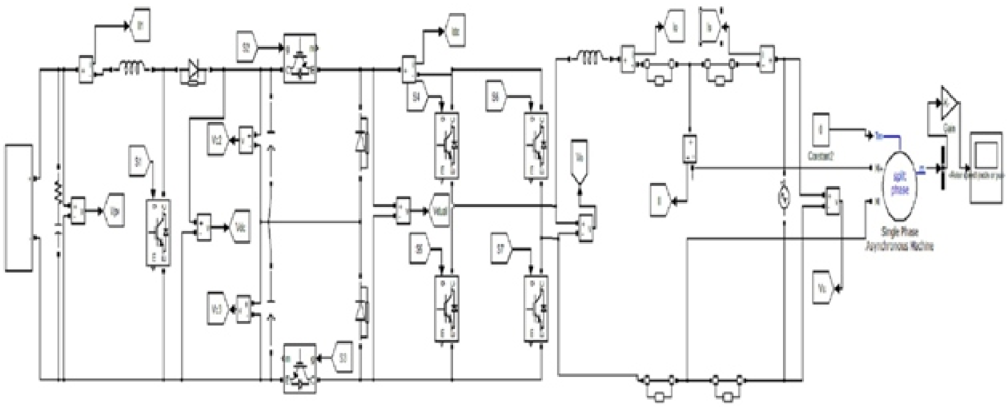

Figure 5: proposed converter with machine load

The simulation results of utility voltage, output current of five-level inverter, and DC capacitor voltagesV_c2,V_c3 are shown in figure 6. Simulation results of dc-dc converter are shown in figure 7. 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 8.

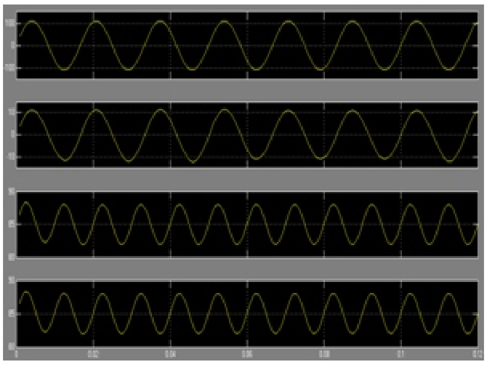

Figure 6: simulation results of the five-level inverter. Utility voltage, Output current of the five-level inverter, DC capacitor voltageV_c2, DC capacitor voltageV_c3.

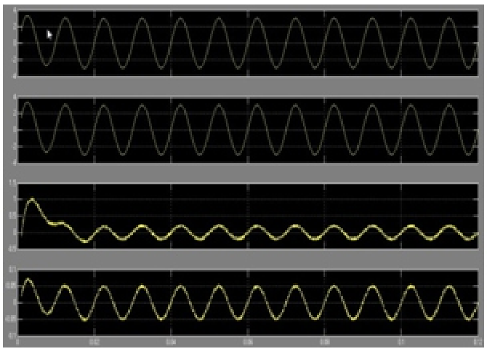

Figure 7: simulation results of (a) Voltage ripple of dc capacitor C2, Voltage ripple of dc capacitor C3, Output voltage ripple of solar cell array, Inductor current ripple of dc–dc converter

Comparison simulation waveforms of utility voltage, inverter output voltage, and output voltage of dual-buck converter are shown in figure 9.The proposed five-level inverter fed with solar energy conversion system is connected to machine load. The performance of the inverter is verified with single-phase asynchronous motor. And finally operation of proposed converter is satisfied with resistive load and machine.

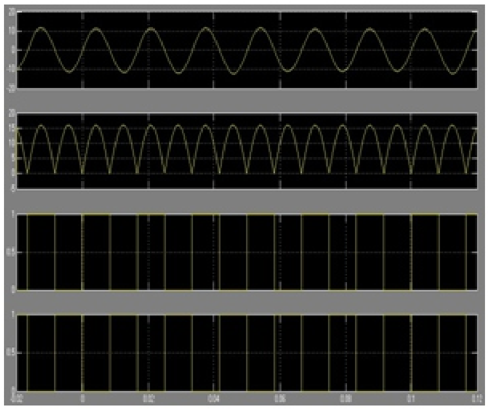

Figure 8: Simulation results of Output current of the full-bridge inverter, Input current of the full bridge inverter, Driver signal of S4, Driver signal of S5.

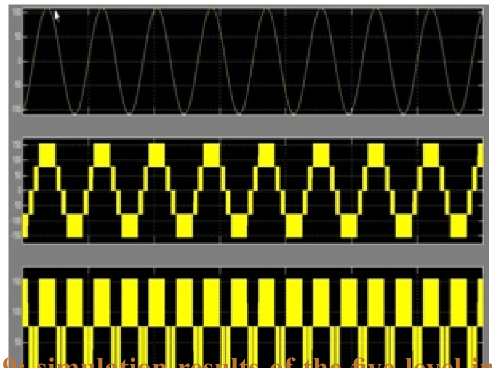

Figure 9: simulation results of the five-level inverter: Utility voltage, Output voltage of the full-bridge inverter, Output voltage of the dual-buckconverter.

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V.CONCLUSION:

An improved solar energy conversion system with five-level inverter asynchronous machine load is proposed in this paper. For increasing of power rating of PV array MPPT controller has employed. The performance of proposed inverter topology is verified with resistive load and asynchronous machine, can be observed in the simulations results section. The voltage balancing of capacitors connected to input of inverter.

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