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Embedded Controlled Solar Power Generation System Using Boost to Boost Converter and Seven Level Inverter

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ABSTRACT

This paper deals with simulation and implementation of embedded controlled seven level inverter system. The output of the solar system is boosted using a cascaded boost converter and the output of the boost converter is applied to a seven level inverter. Cascaded boost converter is proposed to increase the output voltage level of the PV system. The proposed system is modelled and simulated. The results of simulation are compared with those of experimental ones.

Keywords: Solar power, Embedded system, Open loop control, PI controller, Closed loop control, MLI, Boost Converter.

1. INTRODUCTION

THE extensive use of fossil fuels has resulted in the global problem of greenhouse emissions. Moreover, as the supplies of fossil fuels are depleted in the future, they will become increasingly costly.

Thus, solar energy is becoming more important since it produces less pollution and the cost of fossil fuel energy is rising, while the cost of solar arrays is decreasing. In particular, small-capacity distributed power generation systems using solar energy may be widely used in residential applications in the near future [1], [2].

The power conversion interface is important to grid- connected solar power generation systems because it converts the DC power generated by a solar cell array into ac power and feeds this ac power into the utility grid.

An inverter is necessary in the power conversion interface to convert the DC power to AC power [2]–[4]. Since the output voltage of a solar cell array is low, a DC–DC power converter is used in a small-capacity solar power generation system to boost the output voltage, so it can match the DC bus voltage of the inverter. The power conversion efficiency of the power conversion interface is important to in- sure that there is no waste of the energy generated by the solar cell array. The active devices and passive devices in the inverter produce a power loss. The power losses due to active devices include both conduction losses and switching losses [5]. Conduction loss results from the use of active devices, while the switching loss is proportional to the voltage and the current changes for each switching and switching frequency. A filter inductor is used to process the switching harmonics of an inverter, so the power loss is proportional to the amount of switching harmonics.

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The voltage change in each switching operation for a multi-level inverter is reduced in order to improve its power conversion efficiency [6]–[15] and the switching stress of the active devices. The amount of switching harmonics is also attenuated, so the power loss caused by the filter inductor is also reduced. Therefore, multilevel inverter technology has been the subject of much research over the past few years. In theory, multilevel inverters should be designed with higher voltage levels in order to improve the conversion efficiency and to reduce harmonic content and electromagnetic interference (EMI).

Conventional multilevel inverter topologies include the diode- clamped [6]–[10], the flying-capacitor [11]–[13], and the cascade H-bridge [14]–[18] types. Diode-clamped and flying- capacitor multilevel inverters use capacitors to develop several voltage levels. But it is difficult to regulate the voltage of these capacitors. Since it is difficult to create an asymmetric voltage technology in both the diode-clamped and the flying-capacitor topologies, the power circuit is complicated by the increase in the voltage levels that is necessary for a multilevel inverter. For a single-phase seven-level inverter, 12 power electronic switches are required in both the diode-clamped and the flying-capacitor topologies. Asymmetric voltage technology is used in the cascade H-bridge multilevel inverter to allow more levels of output voltage [17], so the cascade H-bridge multilevel inverter is suitable for applications with increased voltage levels. Two H-bridge inverters with a DC bus voltage of multiple relationships can be connected in cascade to produce a single- phase seven-level inverter and eight power electronic switches are used. More recently, various novel topologies for seven- level inverters have been proposed. For example, a single-phase seven-level grid-connected inverter has been developed for a photovoltaic system [18]. This seven-level grid-connected inverter contains six power electronic switches. However, three DC capacitors are used to construct the three voltage levels, which results in that balancing the voltages of the capacitors is more complex. In [19], a seven-level inverter topology, configured by a level generation part and a polarity generation part, is proposed.

There, only power electronic switches of the level generation part switch in high frequency, but ten power electronic switches and three DC capacitors are used. In [20], a modular multilevel inverter with a new modulation method is applied to the photovoltaic grid-connected generator. The modular multilevel inverter is similar to the cascade H-bridge type. For this, a new modulation method is proposed to achieve dynamic capacitor voltage balance. In [21], a multilevel DC-link inverter is presented to overcome the problem of partial shading of individual photovoltaic sources that are connected in series. The DC bus of a full-bridge inverter is configured by several individual DC blocks, where each DC block is composed of a solar cell, a power electronic switch, and a diode. Controlling the power electronics of the DC blocks will result in a multilevel DC-link voltage to supply a full-bridge inverter and to simultaneously overcome the problems of partial shading of individual photovoltaic sources.According to the knowledge of authors, the boost to boost converter is not used between the PV system and multilevel inverter.

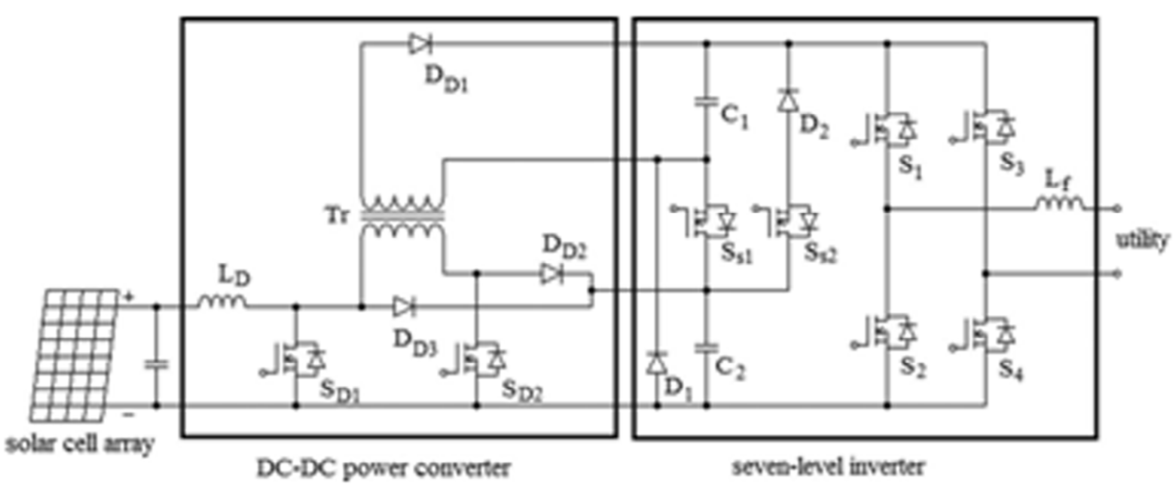


Figure 1: Configuration of the solar power generation system.

This paper proposes a cascaded boost converter for PV generation system. The proposed solar power generation system is composed of a DC/DC power converter and a seven-level inverter. The seven- level inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade. The seven-level inverter contains only eight power electronic switches, which simplifies the circuit configuration.

2. CIRCUIT CONFIGURATION

Fig.1 shows the configuration of the proposed solar power generation system. The proposed solar power generation system is composed of a solar cell array, a DC–DC power converter, and a new seven-level inverter. The solar cell array is connected to the DC–DC power converter, and the DC–DC power converter is a boost converter that incorporates a transformer . The DC–DC power converter converts the output power of the solar cell array into two independent voltage sources with Multiple relationships , which are supplied to the seven level inverter. The seven –level inverter is composed of a capacitor selection circuit and a full bridge power converter, connected in a cascade. The power electronic switches of capacitor selection circuit determine the discharge of the two capacitors while the two capacitors are being discharged individually or in series. Because of the multiple relationships between the voltages of the DC capacitors, the capacitor selection circuit outputs a three-level DC voltage. The full-bridge power converter further converts this three-level DC voltage to a seven-level AC voltage that is synchronized with the utility voltage. In this way, the proposed solar power generation system generates a sinusoidal output current that is in phase with the utility voltage and is fed into the utility, which produces a unity power factor.

3. DC-DC POWER CONVERTER

As seen in Fig. 1, the DC-DC power converter incorporates a boost converter and a current fed forward converter. The boost converter is composed of an inductor L_D, a power electronic switch S_{D1}, and a diode, D_{D3}. The boost converter charges capacitor C_2 of the seven level inverter. The current fed forward converter is composed of an inductor L_D, power electronic switches S_{D1} and S_{D2}, a transformer and diode D_{D1} and D_{D2}. The current fed forward converter charges capacitor C_1 of the seven level inverter. The inductor L_D and the power electronic switch S_{D1} of the current fed forward converter are also used in the boost converter.

Fig. 2(a) shows the operating circuit of the DC-DC power converter when S_{D1} is turned on. The solar cell array supplies energy to the inductor L_D. When S_{D1} is turned off and S_{D2} is turned on, its operating circuit is shown in Fig.2(b). Accordingly, capacitor C_1 is connected to capacitor C_2 in parallel through a transformer, so the energy of inductor L_D and the solar cell array charge capacitor C_2 through D_{D3} and charge capacitor C_1 through the transformer and D_{D1} during the off state of S_{D1}. Since capacitors C_1 and C_2 are charged in parallel by using transformer, the voltage ratio of capacitor C_1 and C_2 is the same as the turn

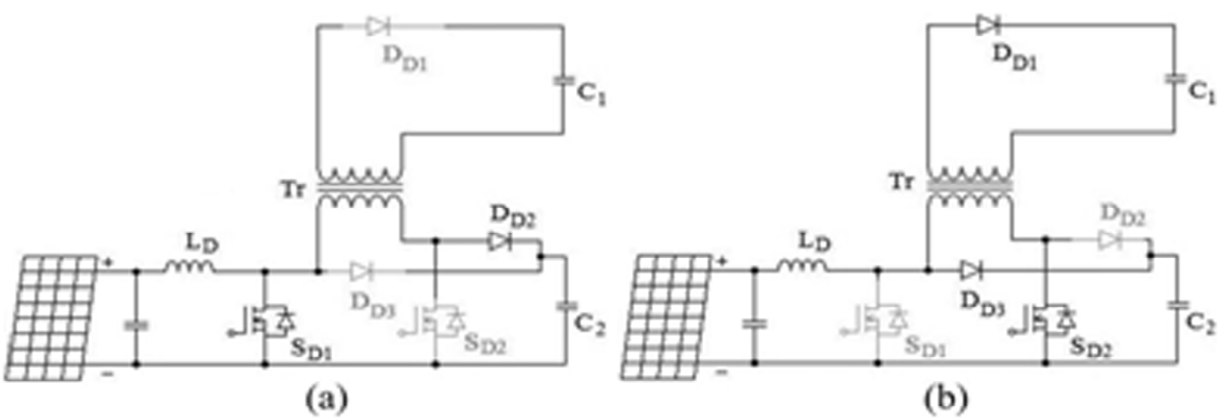


Figure 2: Operation of DC–DC power converter: (a) *SD* 1 is on and (b) *SD* 1 is off.

ratio of the transformer. Therefore, the voltages of C_1 and C_2 have multiple relationships. The boost converter is operated in the Continuous Conduction Mode (CCM). The voltage of C_2 can be represented as

$$Vc2 = \frac{1}{1-D}.Vs \tag{1}$$

Where Vs is the output voltage of solar cell array and D is the duty ratio of S_{D1}. The voltage of capacitor C_1 can be represented as

$$Vc1 = \frac{1}{2(1-D)}.Vs \tag{2}$$

It should be noted that the current of the magnetizing inductance of the transformer increases when S_{D2} is in the on state. Conventionally, the forward converter needs a third demagnetizing winding in order to release the energy stored in the magnetizing inductance back to the power source. However in the proposed DC-DC power converter, the energy stored in the magnetizing inductance is delivered to capacitor C_2 through D_{D2} and S_{D1} when S_{D2} is turned off. Since the energy stored in magnetizing inductance is transferred forward to the output capacitor C_2 and not back to the DC source, the power efficiency is improved. In addition, the power circuit is simplified because the charging circuits for capacitors C_1 and C_2 are integrated. Capacitors C_1 and C_2 are charged in parallel by using the transformer, so their voltages automatically have multiple relationships. The control circuit is also simplified.

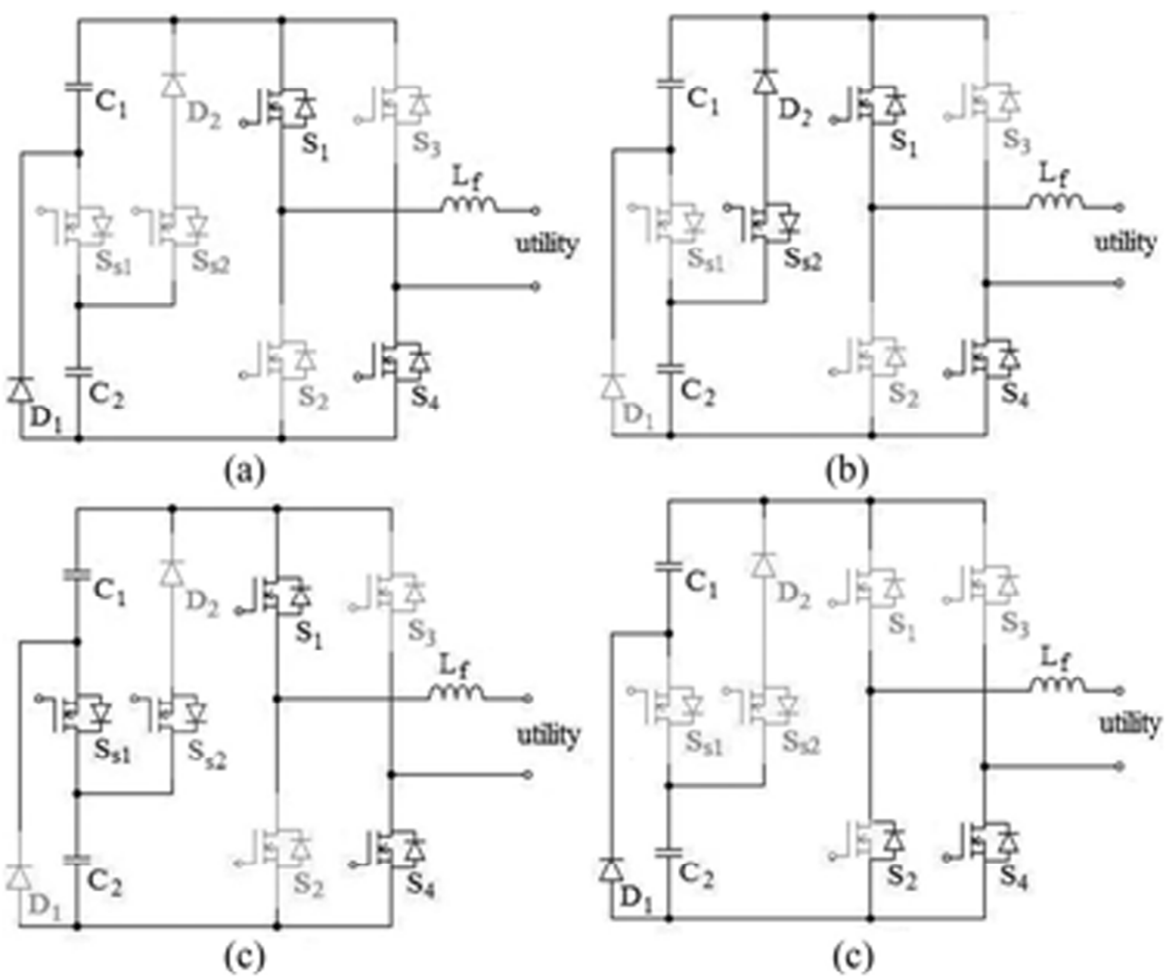


Figure 3: Operation of the seven-level inverter in the positive half cycle, (a) mode 1, (b) mode 2, (c) mode 3, and (d) mode 4.

4. SIMULATION RESULTS

The Seven level inverter based PV-Inverter system is modelled using the elements of Simulink. The boost converter-inverter system is shown in the Fig. 4(a) DC input voltage is shown in the Fig. 4(b) and its value is 70V. The output voltage of the boost converter is shown in the Fig. 4(c) and its value is 150V. The output voltage of the MLI is shown in the Figs. 4(d). The peak value is 140V.The switching pulses for the boost converter and inverter are shown in the Fig. 4(e).

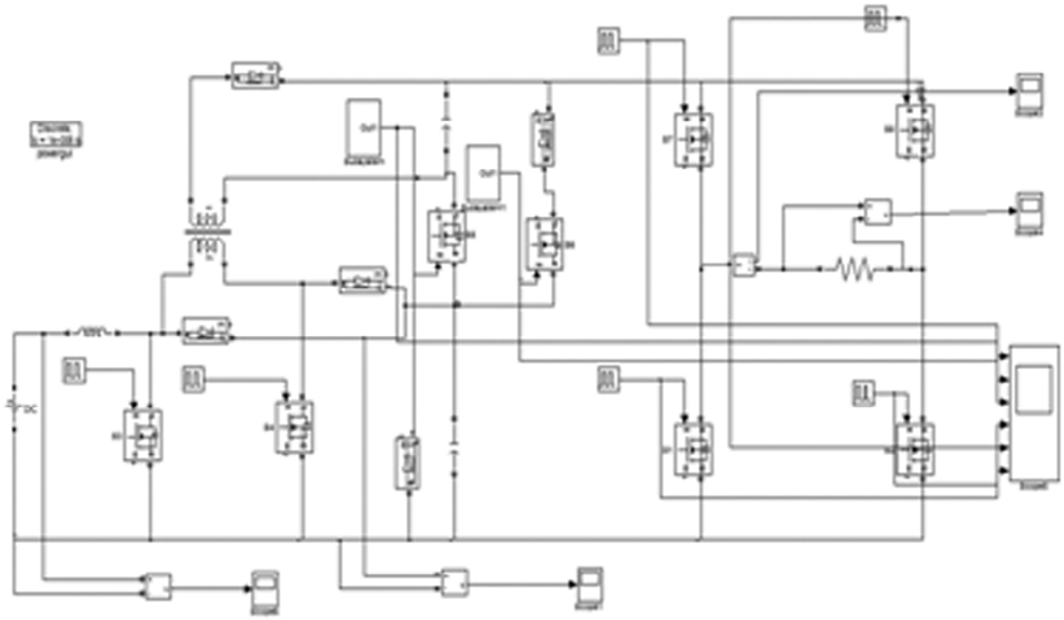


Figure 4(a): Circuit of Seven level MLI system

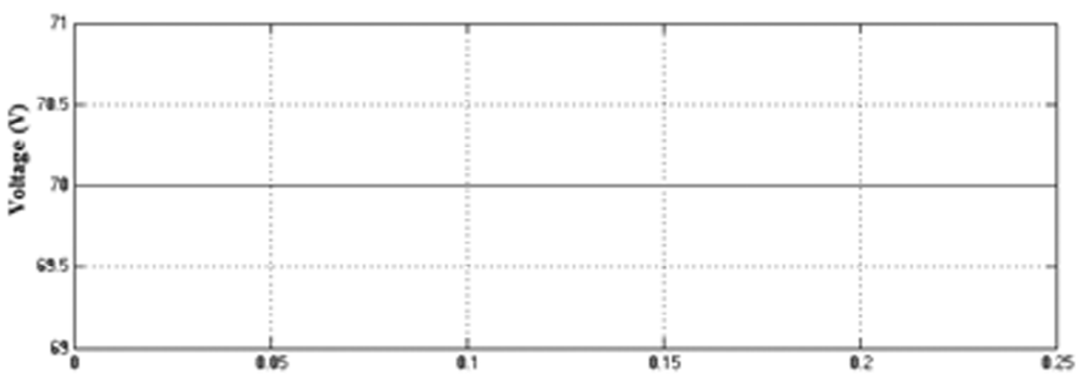


Figure 4(b): Input voltage waveform

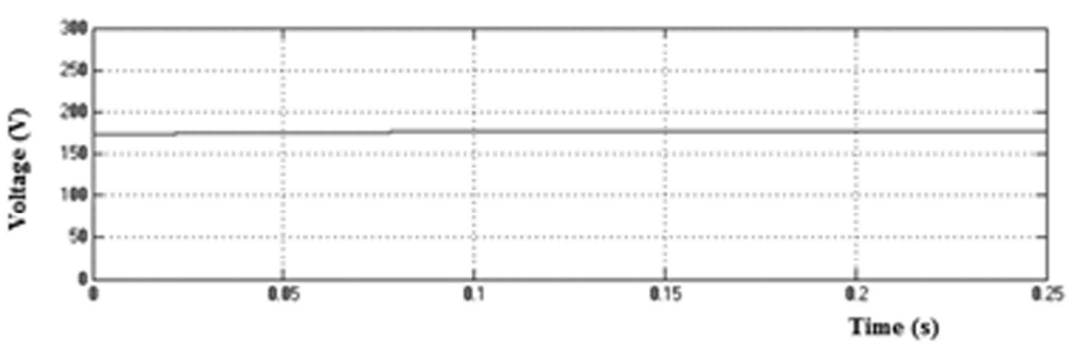


Figure 4(c): Output voltage of the Boost converter

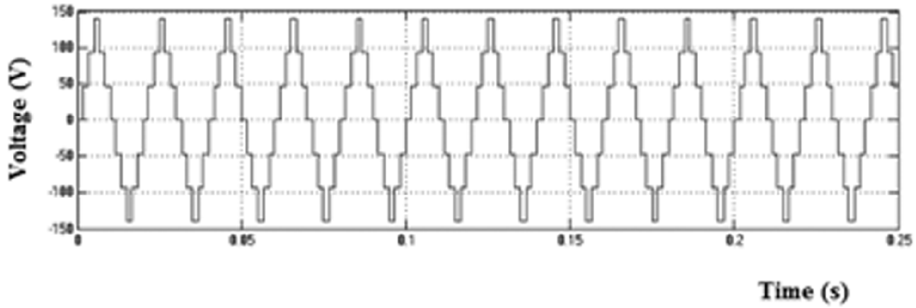


Figure 4(d): Output voltage waveform of the MLI

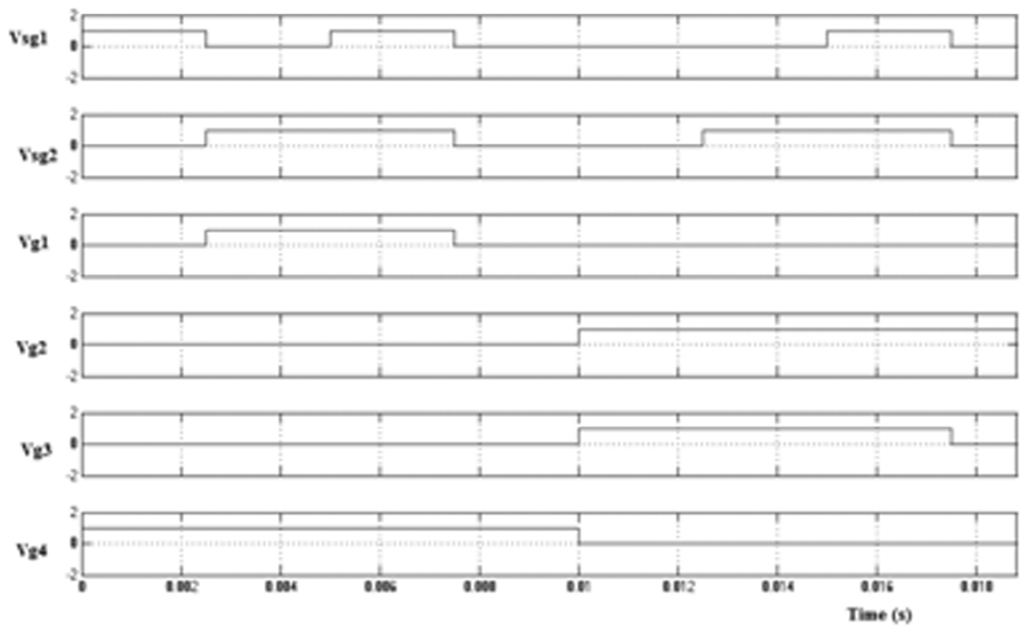


Figure 4(e): Switching pulses for M1, M2, M3 & M4

5. HARDWARE RESULTS

The hardware for the seven level inverter system is fabricated and tested in the laboratory. The hardware consists of PV panel, control circuit and power circuit modules. The snapshot of the hardware for the seven

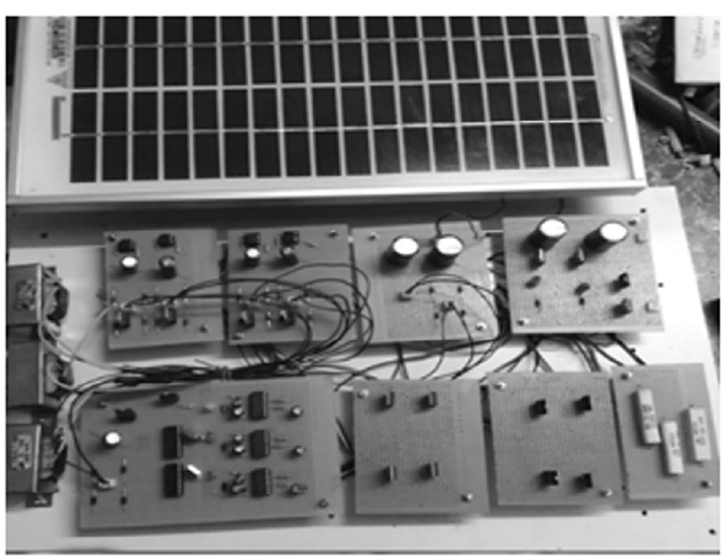
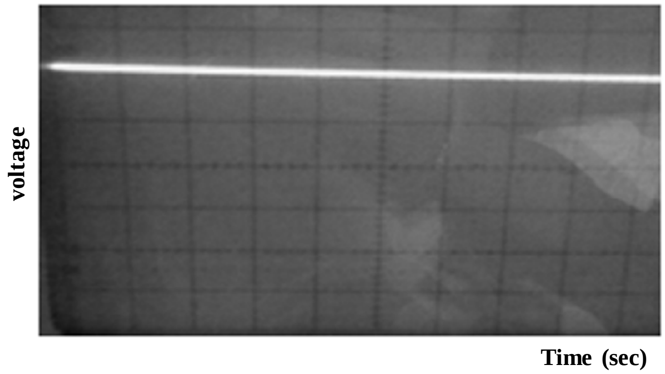
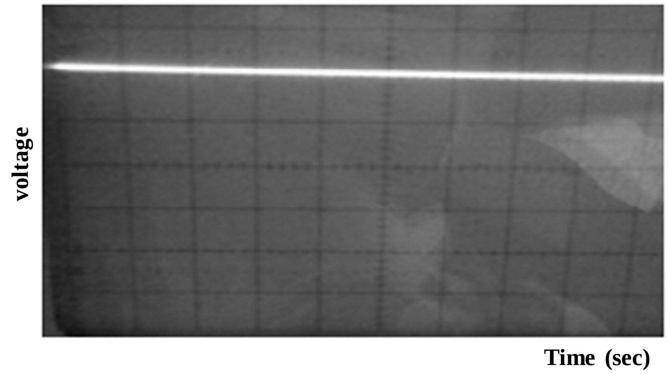


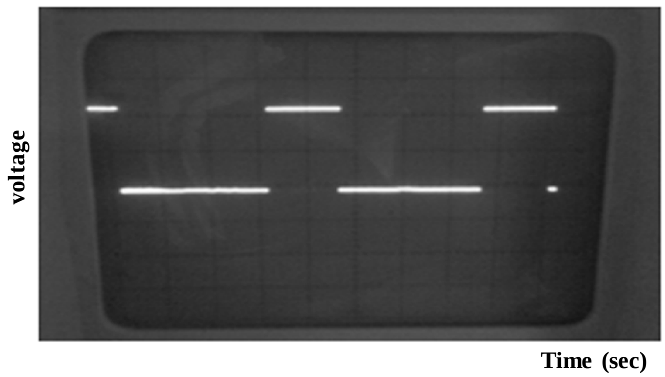
Figure 5(a): Hardware snapshot of the seven level inverter system



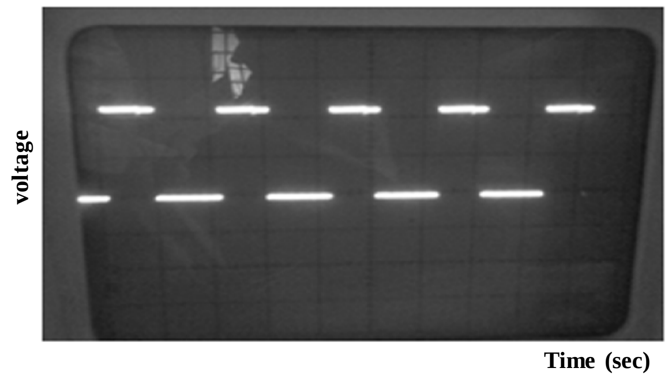
X-Axis 1 unit = 1ms
Y-Axis 1 unit = 5V
Figure 5(b): Output voltage of the PV panel



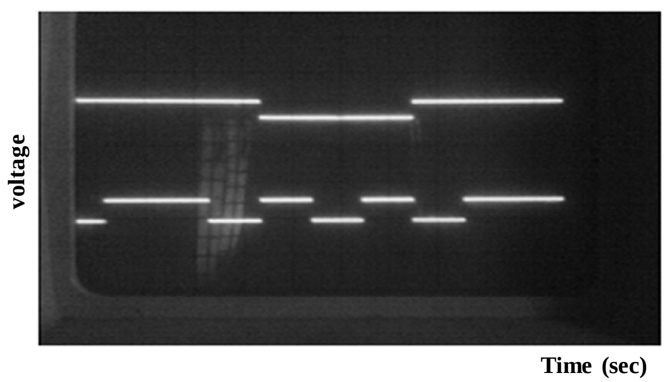
X-Axis 1 unit = 1ms
Y-Axis 1 unit = 20V
Figure 5(c): Output voltage of the Boost Converter



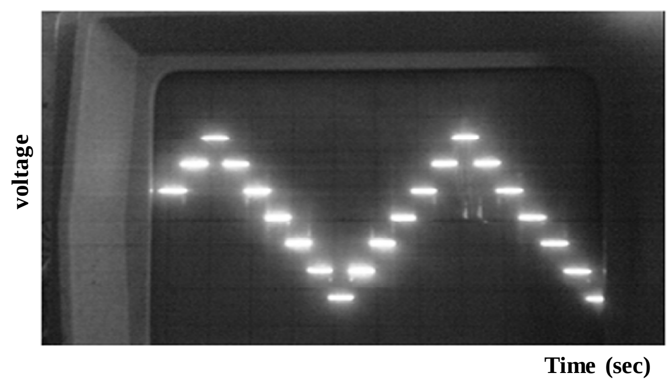
X-Axis 1 unit= 1ms
Y-Axis 1 unit= 5V
Figure 5(d): Switching pulse for M1



X-Axis 1 unit = 1ms
Y-Axis 1 unit = 5V
Figure 5(e): Switching pulse for M2



X-Axis 1 unit = 1ms
Y-Axis 1 unit = 5V
Figure 5(f): Switching pulse for M3 & M4



X-Axis 1 unit = 1ms
Y-Axis 1 unit = 40V
Figure 5(g): Output voltage of the Inverter

level inverter system is shown in the Fig. 5(a). The output voltage of the PV panel is shown in the Fig. 5(b). The output voltage of the boost converter is shown in the Fig. 5(c). The switching pulses for M1 and M2 are shown in the Figs. 5(d) and 5(e) respectively. The switching pulses for M3 and M4 are shown in the Figs. 5(f). The output voltage of the multilevel inverter is shown in the Fig. 5(g). The simulation results match with the experimental results as can be seen from Figs. 4 & 5.

5. CONCLUSION

Solar power generation system with seven level inverter that can supply AC energy was modelled, simulated and implemented. The comparison of results indicates that the hardware results are close to the simulation results.

The advantages of the proposed system are high boost ratio and reduced number of switches. The disadvantages of the system is that it requires two capacitors and a coupled inductor.

The scope of this work is the implementation of open loop system. The closed loop hardware will be implemented in future.

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