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RESEARCH ARTICLE

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SIMULATION MODEL OF SINGLE-PHASE SIMPLIFIED SEVEN-LEVEL INVERTER

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ABSTRACT

In the last years, new energy sources have proposed and developed due to the dependency and constant increase of costs of fossil fuels. On other hand, fossil fuels have a huge negative impact on the environment. In this context, the new energy sources are essentially renewable energies. It is estimated that the electrical energy generation from renewable sources will increase from 19%, in 2010, to 32%, in 2030, leading to a consequent reduction of CO2 emission. Among these renewable energy sources, solar photovoltaic energy is one of the fastest growing.

Multilevel inverters tender high power capability, associated with lower output harmonics and lower turn-off losses. This work informs a multilevel inverter for PV system using an H-bridge output stage with bidirectional auxiliary switches. The inverter is capable of producing seven levels of output-voltage levels (Vdc, 2Vdc /3, Vdc/3, 0, -Vdc/3, - 2Vdc /3 - Vdc) from the DC supply voltage. The control circuit necessary for multilevel inverter operation is implemented using an ATMEL AT89S52 Microcontroller, reducing overall system cost and complexity. Theoretical predictions are validated using simulation in MATLAB SIMULINK, and satisfactory circuit operation is proved with experimental tests performed on an experimental model

Keywords: Capacitor clamped, diode clamped, multilevel inverter**,** H-bridge, Simplified Seven-level Inverter (SSLI).

1. INTRODUCTION

The increasing energy demand, increasing costs and exhaustible nature of fossil fuels, and global environment pollution have generated huge interest in renewable energy resources. Other than hydroelectric power, wind and solar are the most useful energy sources to satisfy our power requirements. Wind energy is capable of producing huge amounts of power, but its availability can't be predicted. Solar power is available during the whole day but the solar irradiance levels change because of the changes in the sun's intensity and shadows caused by many reasons. Generally solar and wind powers are complementary in nature. Therefore the hybrid photovoltaic and wind energy system has higher dependability to give steady power than each of them operating individually. Other benefit of the hybrid system is that the amount of the battery storage can be decreased as hybrid system is more reliable compared to their independent operation.

PHOTOVOLTAIC SYSTEMS

Photovoltaic systems are composed of interconnected components designed to accomplish specific goals ranging from powering a small device to feeding electricity into the main distribution grid. Photovoltaic systems are classified. The two main general classifications as depicted in the figure are the stand-alone and the grid-connected systems. The main distinguishing fact tor between these two systems is that in stand-alone systems the solar energy output is matched with the load demand. To cater for different load patterns, storage elements are generally used and most systems currently use batteries for storage. If the PV system is used in conjunction with another power source like a wind or diesel generator then it falls under the class of hybrid systems. The balances of system (BOS) components are a major contribution to the life cycle costs of a photovoltaic system. They include all the power conditioning units, storage elements and mechanical structures that are needed. They especially have a huge impact on the operating costs of the PV system.

PV cell

PVs generate electric power when illuminated by sunlight or artificial light. To illustrate the operation of a PV cell the p-n homo junction cell is used. PV cells contain a junction between two different materials across which there is a built in electric field. The absorption of photons of energy greater than the band gap energy of the semiconductor promotes electrons from the valence band to the conduction band, creating hole-electron pairs throughout the illuminated part of the semiconductor [6].These electron and hole pairs will flow in opposite directions across the junction thereby creating DC power.

INVERTERS

DC to AC converters produces an AC output waveform from a DC source. Applications include adjustable speed drives, uninterruptable power supplies, active filters, Flexible AC transmission systems (FACTS), voltage compensators, and photovoltaic generators. Topologies for these converters can be separated into two distinct categories: voltage source inverters and current source inverters. Voltage source inverters (VSIs) are named so because the independently controlled output is a voltage waveform. Similarly, current source inverters (CSIs) are distinct in that the controlled AC output is a current waveform.

Being static power converters, the DC to AC power conversion is the result of power switching devices, which are commonly fully controllable semiconductor power switches. The output waveforms are therefore made up of discrete values, producing fast transitions rather than smooth ones. The ability to produce near sinusoidal waveforms around the fundamental frequency is dictated by the modulation technique controlling when, and for how long, the power valves are on and off. Common modulation techniques include the carrier-based technique, or pulse width modulation, space-vector technique, and the selective-harmonic technique.

2. POWER CIRCUIT

2.1 Power Circuit Advantages

A single-phase simplified multilevel inverter has the following merits over other existing multilevel inverter topologies.

- It consists of single-phase conventional H-bridge inverter, bidirectional auxiliary switches (number varies depending upon level) and a capacitor voltage divider formed by capacitors.
- Improved output waveforms.
- Smaller filter size.
- Lower electromagnetic interference (EMI) and total harmonic distortion (THD).
- Reduced number of switches employed.
- Less complexity of the circuit as the levels increase.
- Attains minimum 40% drop in the number of main power switches required.

Moreover, since the capacitors are connected in parallel with the main dc power supply, no significant capacitor voltage swing is produced during normal operation, avoiding a problem that can limit operating range in some other multilevel configurations.

2.2 Power Circuit Description

The proposed single-phase simplified seven-level inverter (SSLI) was developed from the five-level inverter in [1]-[12] . It includes a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by C" Cb and C3. The auxiliary switches, formed by the controlled switch S5 and S6 and with eight diodes, D, to Dg• The single-phase seven-level inverter power circuit with auxiliary switches is shown in figure.1. Proper switching of the inverter can produce seven output-voltage levels (Vdc, 2Vdc/3, Vdc/3, 0,-Vdc, 2Vdc/3,-Vdc/3) from the dc supply voltage.

3. POWER CIRCUIT OPERATION

The single-phase SNLI is capable of producing seven levels of output-voltage levels (V_{dc}, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}/3$, $-2V_{dc}/3$ $-V_{dc}$) from the dc supply voltage Vdc, shown in figure below.

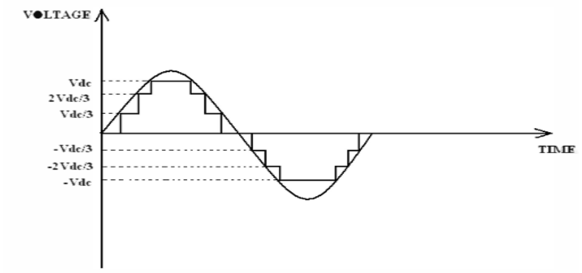

Fig. 1 Operation of Power circuit

3.1 Mode I Operation

The switch S I is ON, connecting the load positive terminal to Vdc, and S4 is ON, connecting the load negative terminal to ground. Remaining switches S2, S3, S5 and S6 are OFF; the voltage across the load terminals ab is V dc.

3.2 Mode II Operation

The bidirectional switch S5 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. Remaining switches Sl, S2, S3 and S6 are OFF; the voltage across the load terminals ab is 2Vdc/3.

3.3 Mode III Operation

The bidirectional switch S6 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. Remaining switches Sl, S2, S3 and SS are OFF; the voltage across the load terminals ab is Vdc/3.

3.4 Mode IV Operation

This mode of operation has two possible switching combinations. Either switches S3 and S4 are ON, remaining switches Sl, S2, SS and S6 are OFF or Sl and S2 are ON, remaining switches S3, S4, SS and S6 are OFF. In both switching combinations terminal ab is short circuited, hence the voltage across the load terminals ab is zero.

3.5 Mode V Operation

The bidirectional switch SS is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to Vdc. Remaining switches Sl, S3, S4 and S6 are OFF; the voltage across the load terminals ab is -Vdc/3.

3.6 Mode VI Operation

The bidirectional switch S6 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to ground. Remaining switches Sl, S3, S4 and SS are OFF; the voltage across the load terminals ab is -2Vdc/3.

3.7 Mode VII Operation

The switch S2 is ON, connecting the load negative terminal to Vdc, and S3 is ON, connecting the load positive terminal to ground. Remaining switches Sl, S4, SS and S6 are OFF; the voltage across the load terminals ab is -Vdc.

Table 1: switching combination require to generate the seven-level voltage waveform

V_o	S_1	S_2	S_3	S_4	S_5	S_6
V_{dc}	On	Off	Off	On	Off	Off
$2V_{dc}/3$	Off	Off	Off	On	On	Off
$V_{dc/3}$	Off	Off	Off	On	Off	On
0	Off	Off	On	On	Off	Off
0*	On	On	Off	Off	Off	Off
$-V_{dc/3}$	Off	On	Off	Off	On	Off
$-2V_{dc}/3$	Off	On	Off	Off	Off	On
$-V_{dc}$	Off	On	On	Off	Off	Off

4. SIMULATION RESULTS

The simulation model of the single-phase simplified Seven-level inverter (SSLI) using MATLAB Simulink tool box is shown in Fig.2.This model, developed using the Simulink power system block set, comprises of components such as power electronic devices (MOSFETs) and elements such as capacitors and resistors.

The PWM signals for each of the switching devices in the power circuit come from the PWM block. This block includes all the PWM signals required for switches are multiplexed on a single bus to the Seven -level inverter power circuit.The switching sequence required to generate seven levels of output voltage for the simplified Seven-level inverter (SSLI) circuit is shown in Fig. 3.

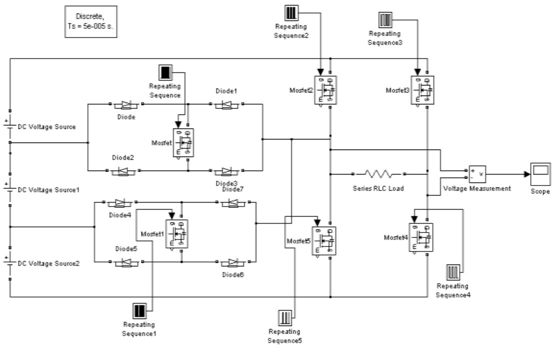

Fig 2: Single-phase SSLI Simulation circuit.

Switching Sequence for Switches: S1-S6

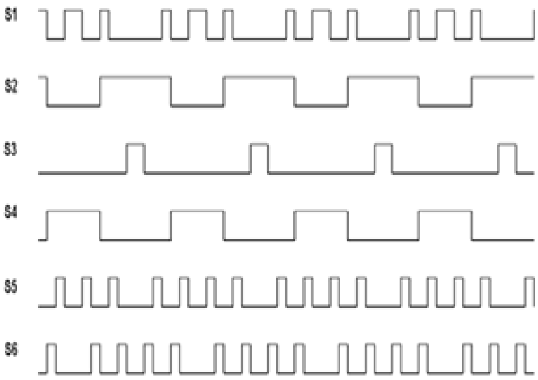

Fig 3: Switching sequence required for SSLI circuit.

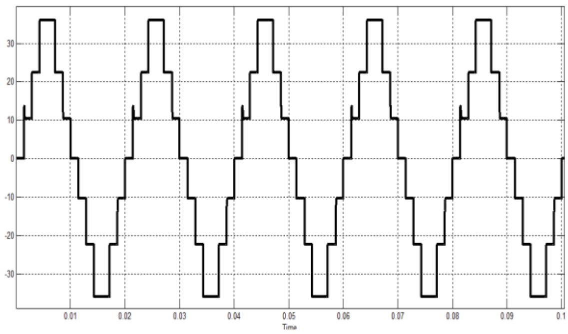

Fig 4: Simulated output voltage waveform of the simplified Seven-level inverter (SSLI) circuit

It is clearly visible that the simulated output waveform is very close to the ideal output defined for a simplified Seven-level inverter (SSLI) circuit.

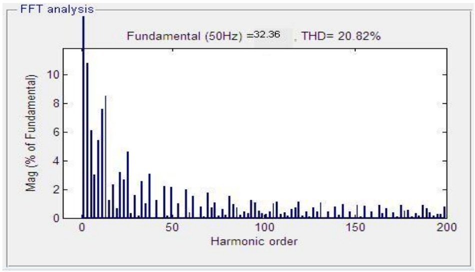

Fig 5: Total Harmonic Distortion for CSLI

The Total Harmonic Distortion (THD) of theconventional seven- level inverter is observed that 20.82% and fundamental voltage is 32.36V(50Hz) that has been illustrated in Fig.5.

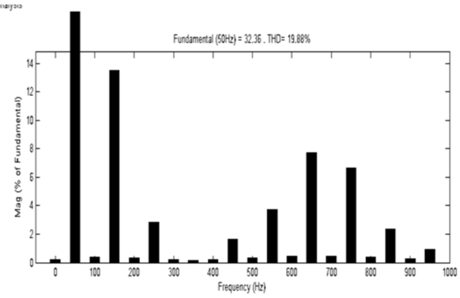

Fig 6: Total Harmonic Distortion for SSLI

The Total Harmonic Distortion (THD) of the simplified seven- level inverter is observed that 19.88% and fundamental voltage is 32.36V(50Hz) that has been illustrated in Fig. 6.

The proposed topology has the advantage of its reduced number switches and harmonics are reduced with THD value of 19.88 at 32.36 V is achieved. For proposed harmonic spectrum of the simulation system is as shown in the fig.6.. The results of both output voltage and FFT analysis are verified by simulating the main circuit using MATLAB

5.HARDWARE RESULTS:

5.1. BLOCK DIAGRAM OF KIT

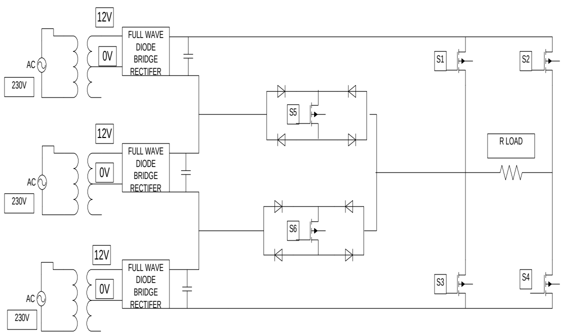

Figure 7: Block diagram of power circuit

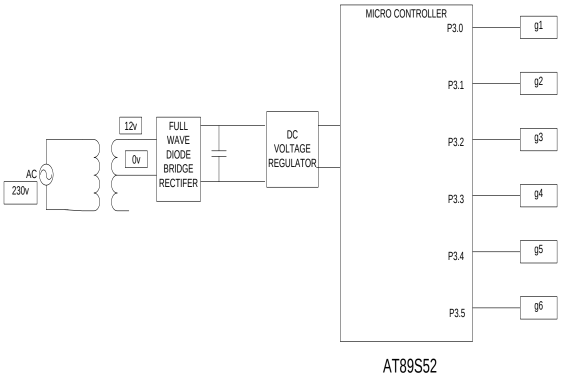

Figure 8: Block diagram of control circuit

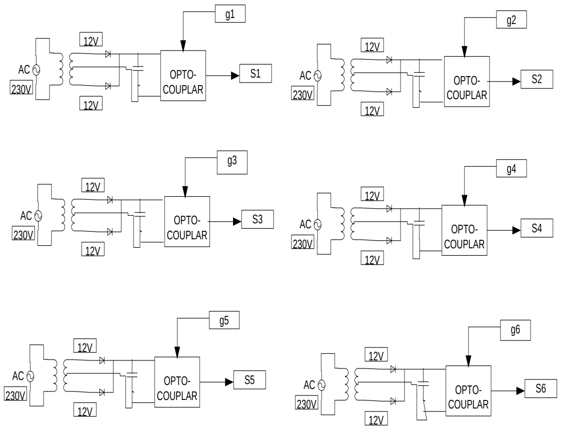

Figure 9: Block diagram of gating circuit

The proposed inverter is constructed in hardware and the results are obtained as follows.

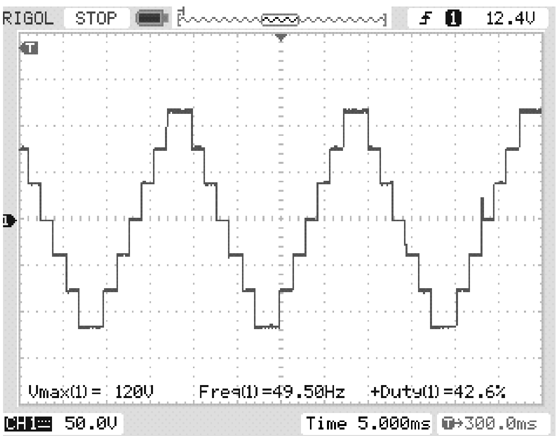

Figure 10: Output of Inverter

The gating pulses of each switch are obtained as follows.

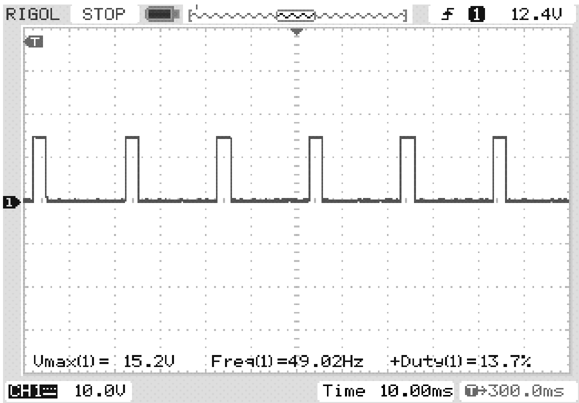

Figure 11: Gating Pulse of Switch1

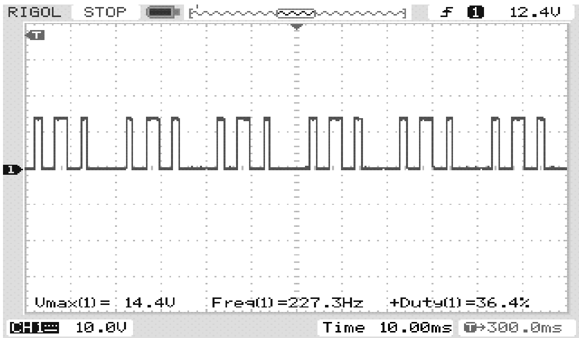

Figure 12: Gating Pulse of Switch2

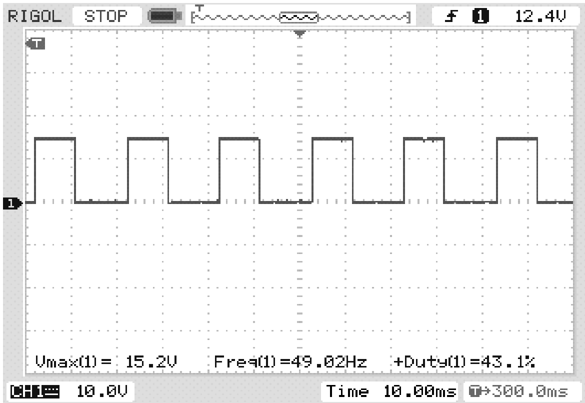

Figure 13: Gating Pulse of Switch3

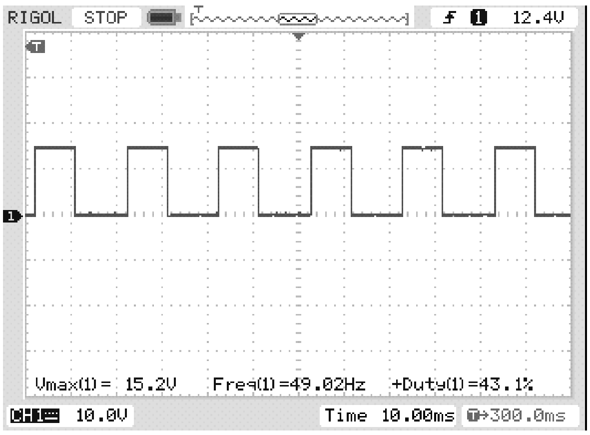

Figure 14: Gating Pulse of Switch4

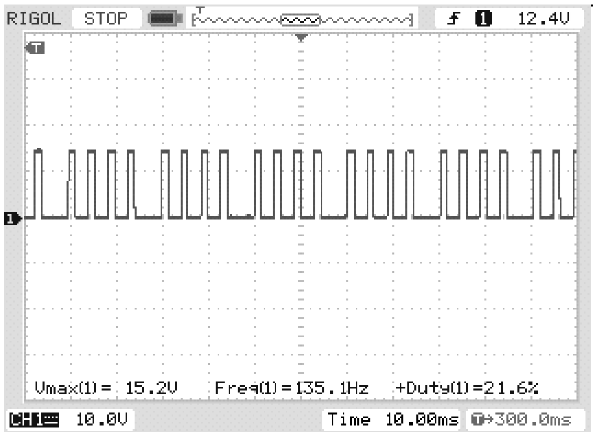

Figure 15: Gating Pulse of Switch5

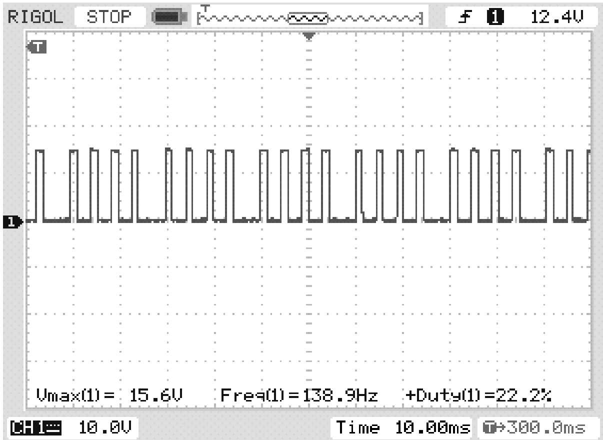

Figure 16: Gating Pulse of Switch6

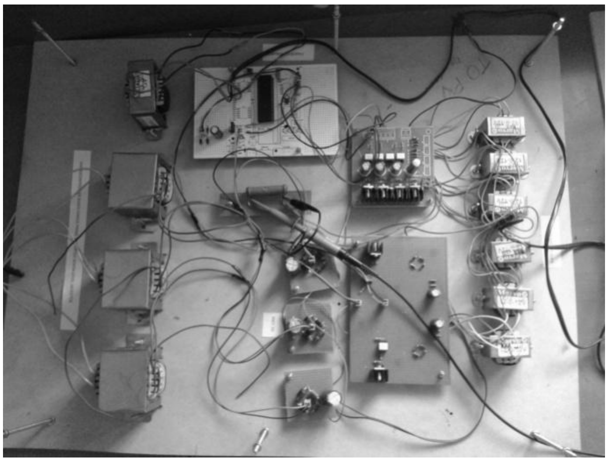
Figure 17: Hardware kit view

6.CONCLUSION

The concurrence between the simulated results and the experimental results show clearly that the single-phase SSLI works as expected, generating the required seven-level output voltage from the PV array .A further development of the 1-phase SSLI is able to be applied to any number of voltage levels for PV applications.

7. ACKNOWLEDGMENTS

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