International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

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# Simulated annealing MPPT based multilevel inverter for renewable energies

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International Journal of Science and Research Archive, 2025, 14(03), 504-510

Publication history: Received on 31 January 2025; revised on 07 March 2025; accepted on 10 March 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.3.0690

## Abstract

A seven level multilevel inverter for renewable energies is proposed. Photovoltaic array is used as the renewable energy source. The MPPT technique for the PV array under varying irradiance is implemented using the Simulated Annealing algorithm. The seven level ac output is generated using the carrier level shift sinusoidal pulse width modulation. Simulation results show decrease in the total harmonic distortion(THD).A laboratory prototype of the proposed model is implemented. Simulated and experimental results verify the operation of the model.

**Keywords:** Simulated Annealing; Photovoltaic array; MPPT; Multi-level Inverter; THD

## 1. Introduction

A multilevel inverter is used to produce a smooth and stepped output ac waveform. The harmonic distortion in the output waveform and dv/dt is low for a multilevel inverter which are supposed to be high in case of conventional two level inverters. Several multilevel inverter topologies are available. But all of these differ in the switching mechanism and the source of the input voltage. The existing groups of multilevel inverters are cascaded H bridge multilevel inverter, diode clamped multilevel inverter, flying capacitor multilevel inverter. The proposed multilevel inverter consists of an input voltage divider comprising three series capacitors. Four MOSFETS and four diodes are used to transmit the divided voltage to the H Bridge consisting of four MOSFETS.

At present multilevel inverters have been implemented up to 11-levels.Comparing to 2, 3 and 5 level inverters the proposed 7-level inverter has less THD i.e., below 5% which is the acceptable limit for THD. The higher level inverters show only small increase in the overall efficiency and a small decrease in the THD[1].

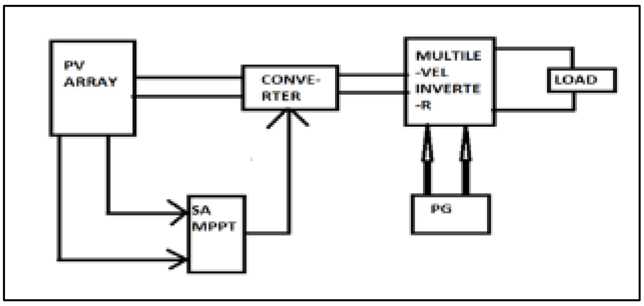


**Figure 1** Block Diagram of proposed system

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Taking into considerations, the number of power semiconductor devices used and simple construction, 7-level inverter proves to be more economical than other multilevel inverters[2]. A new type of multilevel inverter have contemplated in[3] which generates a seven level ac output waveform by using minimum number of switches. Due to the drastic increase in the population the energy demand is continuously increasing,the fossil fuels also will soon get exhausted . Renewable energy sources like PV panels and wind generators which are pollution free and reliable have to be widely used[4]. A 6W solar panel is used as the renewable energy source in this project.

5 level H-bridge simplified inverter have modelled using Field Programmable Gate Array (FPGA) programmable circuit in [5]. In [6] have used phase shift PWM technique to generate multilevel waveform. Since these techniques are quite complex carrier level shift sinusoidal PWM is used in this model as suggested in[7]. [8] solicited that Perturb and Observe MPPT technique is simple to implement and cost effective. But performance is poor under rapidly changing insolation. In the Particle Swarm Optimization (PSO) MPPT technique the best solution is arrived by allowing the particles to solve a problem conjointly[9]. It is based on the demeanor of schooling of fishes and flocking of birds. However the accurate Global Maximum Power point is not obtained by the above techniques. So Simulated Annealing method was proposed. Simulated annealing technique is based on the natural process of annealing in metals. Conventionally in the natural annealing process the minimum energy state is sought. Similarly for a PV system the global maximum power point is reached by seeking the maximum energy state[10].

## 2. Framework of 7-level inverter

A PhotoVoltaic module under varying irradiance is considered. The short circuit current of the PV panel is measured for each variation and is sent as the input to the MPPT coding and a suitable Vref value is obtained by performing various iterations. The Vref is compared with the nominal voltage and the compared output is given as the gate pulse to the MOSFET of the boost converter. This modifies the duty cycle of the boost converter in order to get the maximum possible output voltage. This is implemented as a separate PV subsystem. The PWM is generated using carrier level shift sinusoidal Pulse Width Modulation technique in a separate subsystem. The 8 switches in the 7-level inverter circuit are switched according to the switching sequence implemented using the comparator logic. The 7-level output waveform is verified using a scope. Using a spectrum analyser, the THD is measured.

## 3. Simulated annealing MPPT technique

The technic which is used generally with wind turbines and Photovoltaic solar system to maximize the power elicitation under wavering climatic conditions is called Maximum Power Point Tracking. Photovoltaic cells have a convoluted relationship between temperature and total resistance whose output efficiency is non-linear which can be analysed based on the I-V curve. The MPPT system samples the output of the PV cells and designates the suitable resistance to secure maximum power for any given climatic conditions. An electric power converter system that provides current or voltage conversion, filtering and regulation for driving various loads are combined into Maximum Power Point Tracking devices. Solar inverters convert the DC power to AC power and may incorporate Maximum Power Point Tracking. The above inverters sample the output power from solar modules and apply proper resistance so as to obtain maximum power. The resulting power of MPP is the product of its voltage and current.

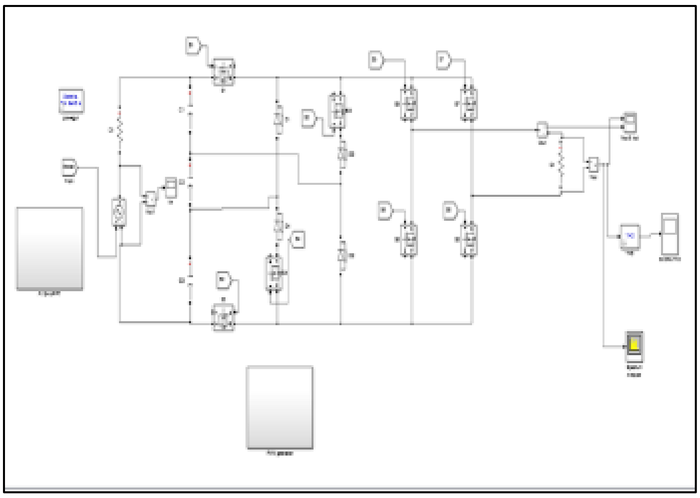

**Figure 2** Multilevel inverter block in MatLab Simulink

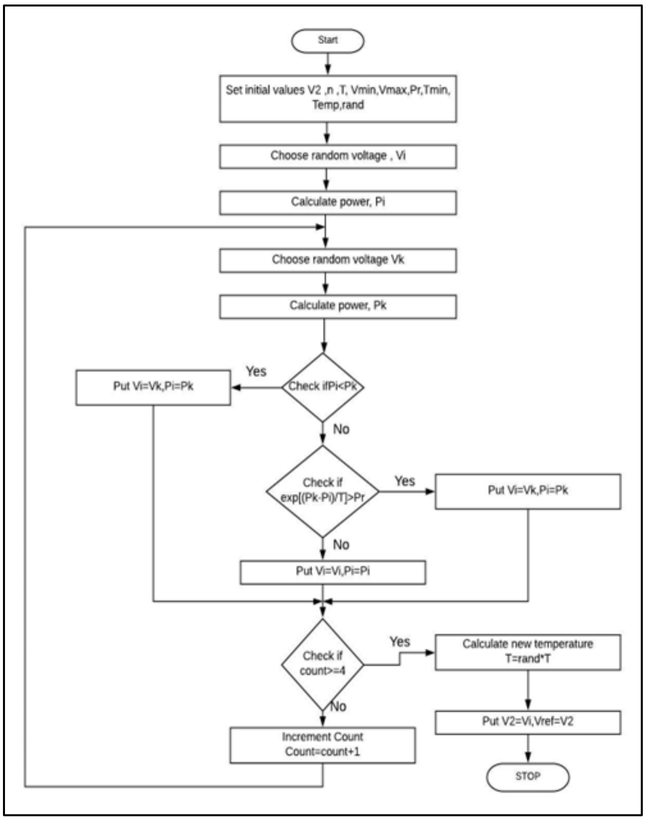


**Figure 3** Flowchart of SA MPPT

The algorithm for SA MPPT is:

- Step 1: Set the initial values of V2,n,T, Vmin, Vmax, Pr, Tmin, Temp, rand
- Step 2: Choose the random voltage Vi
- Step 3: Calculate the power Pi using the formula Pi=Vi*Ir
- Step 4: Choose the random voltage Vk
- Step 5: Calculate the power Pk using the formula Pk=Vk*Ir
- Step 6: Check if Pi<Pk
- Step 7: If yes Put Vi=Vk, Pi=Pk and goto step 11
- Step 8: If no check if exp[(Pk-Pi)/T]>Pr
- Step 9: If yes Put Vi=Vk, Pi=Pk and goto step 11
- Step 10: If no Put Vi=Vi ,Pi=Pi
- Step 11: Check if count>=4
- Step 12: If yes calculate the new temperature value, T=rand*T goto step 14
- Step 13: If no, then increment count, count=count+1, and goto step 4 and continue the process
- Step 14: Put V2=Vi , Vref=V2
- Step 15: Stop the process

## 4. Switching Sequence & PWM Generation

### 4.1. Switching combinations

- For the output voltage level to be 1/3 Vdc, the switches S1, S5 and S8 are turned ON.
- For the output voltage level to be 2/3 Vdc, the switches S1, S4, S5 and S8 are turned ON.
- For the output voltage level to be Vdc, the switches S1, S2, S5 and S8 are turned ON.
- For the output voltage level to be -1/3 Vdc, the switches S2, S6 and S7 are turned ON.
- For the output voltage level to be -2/3 Vdc, the switches S2, S3, S6 and S7 are turned ON.
- For the output voltage level to be –Vdc, the switches S1, S2, S6 and S7 are turned ON.
- For the output voltage level to be 0V, the switches S5 and S7 are turned ON.

**Table 1** Switching Combinations for seven-level inverter

| 7 Voltage Lvel | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| 0V | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| 1/3 Vdc | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 2/3Vdc | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| Vdc | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 2/3Vdc | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 1/3Vdc | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 0V | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| -1/3Vdc | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| -2/3Vdc | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| -Vdc | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| -2/3Vdc | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| -1/3Vdc | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0V | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

### 4.2. PWM generation

The PWM technique used is Carrier Level Shift Sinusoidal Pulse Width Modulation. A sinusoidal waveform of peak voltage 3V is generated. Six triangular waveforms each of magnitude 1 V which are level shifted are generated.

The method to determine switch signals are as follows:

- vs < 0 and vs > vt2 → S2 is turned on
- vs > vt4 → S4 is turned on
- vs < vt8 → S7 is turned on
- vs > vt8 → S8 is turned on
- vs > 0 and vs < vt1 → S1 is turned on
- vs < vt3 → S3 is turned on
- vs > vt6 → S5 is turned on
- vs < vt6 → S6 is turned on

The designed switching signals are sent as gate pulses to the respective MOSFET switches of the 7-level inverter. The corresponding switches for a particular output voltage level are switched ON according to the switching sequence. The figure shows the operation of various switches.

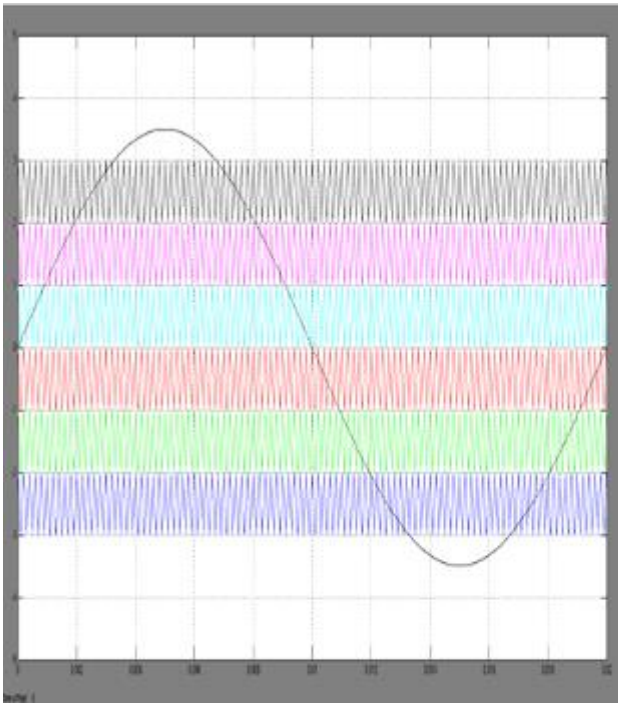

**Figure 4** Carrier level shift sinusoidal PWM

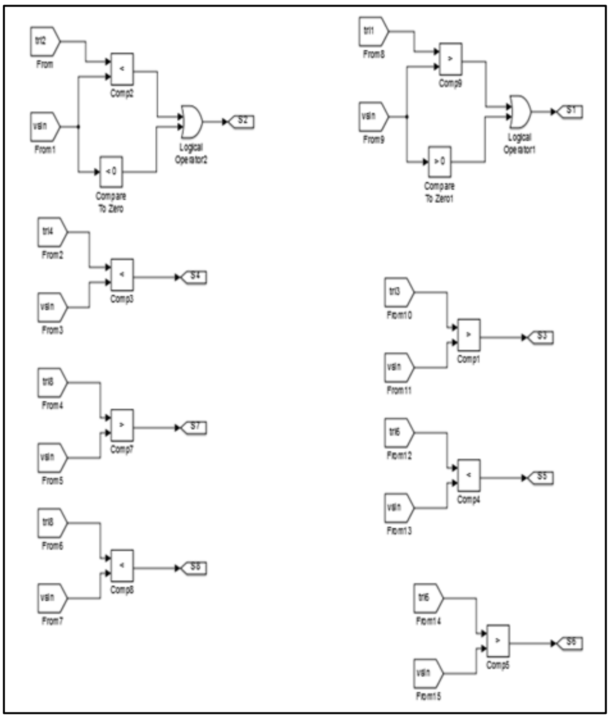

**Figure 5** Designing of switches

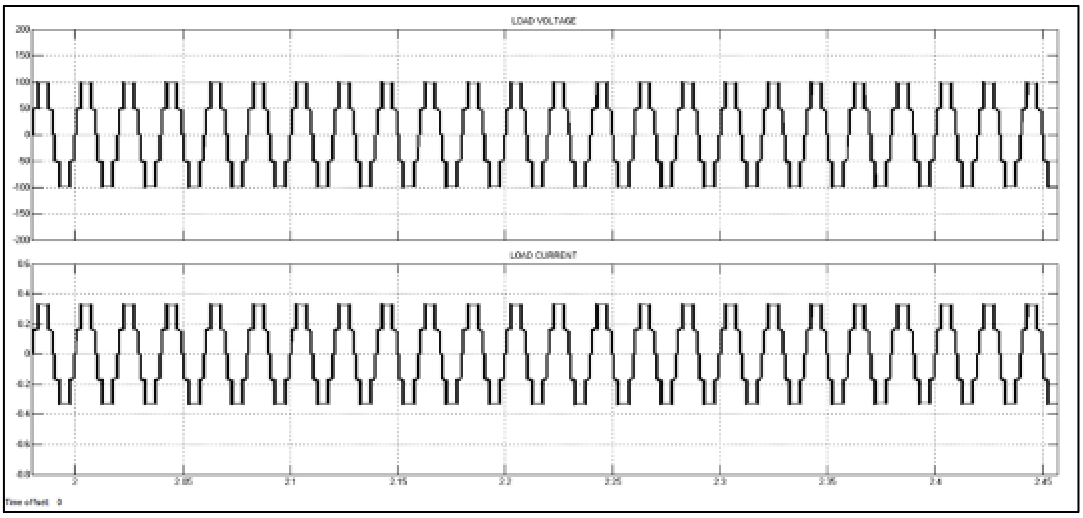


**Figure 6** Simulated Load Voltage and Current of 7-level inverter

## 5. Experimental setup

The multilevel inverter circuit consists of 8 MOSFET switches and four diodes. The main source of input is from a 5 watt photovoltaic array. It is directly fed into the boost converter. The SA MPPT algorithm is programmed in the 16F877A PIC microcontroller. It varies the duty cycle of the boost converter under varying irradiance and various atmospheric conditions in order to get the maximum voltage output. The boost converter output is given as the input to the multilevel inverter. Three capacitors are used to divide the input voltage. The 8 opto-couplers get their inputs from the PWM generation circuit through two buffer circuits. Based on the switching sequence programmed in the microcontroller MOSFETs are switched accordingly to generate a 7-level output waveform across a resistive load. The 8 opto-couplers are powered from 8 centre-tapped 230/12KVtransformers. The seven-level output waveform is checked using Digital Storage Oscilloscope(DSO).

**Figure 7** Multilevel Inverter-Experimental Setup

## 6. Performance and result analysis

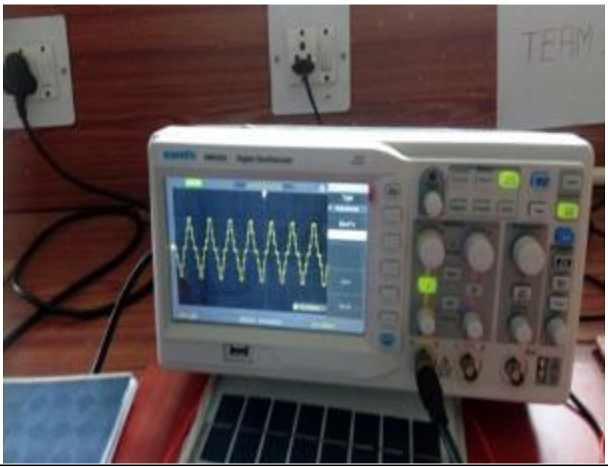

**Figure 8** a) Sevenlevel inverter output

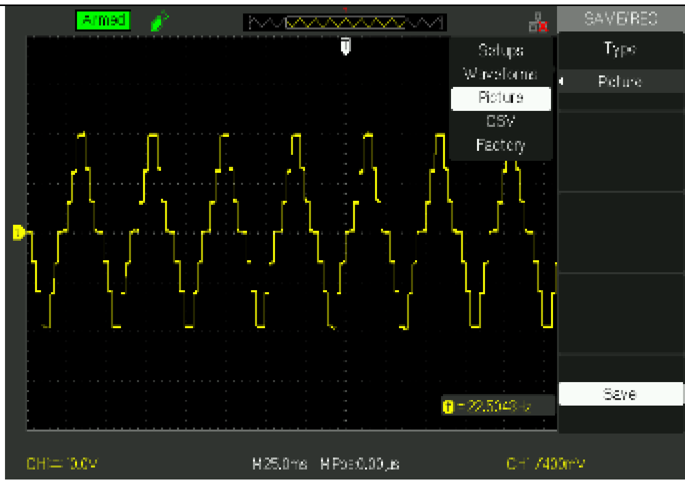


**Figure 8** b) Clear View output

**Table 2** Comparison of SA MPPT and P and O MPPT

| Case Study | Techniques | Vin | Vout |
|---|---|---|---|
| Case 1: Irradiation 75% | SA MPPT | 38.31 | 150 |
| | P and O MPPT | 38.31 | 75 |
| Case 2: Irradiation 50% | SA MPPT | 25.69 | 100 |
| | P and O MPPT | 25.69 | 50 |

**Table 3** Comparison of THD seven level inverter with2 Level and 5 Level inverter

| Investigation Parameter | 2 level inverter | 5 level inverter | 7 seven level inverter |
|---|---|---|---|
| THD | 99.65% | 12.35% | 3.68% |

## 7. Conclusion

An examination of multilayer inverter topologies is presented at the end, beginning with a summary of their importance in modern power electronics and renewable energy applications. The foundation for developing the perfect answer was laid by a comprehensive analysis of the literature, which described the advantages and disadvantages of the existing inverter designs. The study showed that conventional inverter topologies often have large switching losses, increased complexity, and worse energy efficiency, highlighting the need for a more effective design process.

The simulation of multilevel inverter is carried out in MATLAB/ Simulink, to verify the total harmonic distortion in its output in different scenarios. The proposed design is simple in its outlook with very few components. The carrier level shift sinusoidal pulse width modulation gives better result with less switching losses. The novel 7-level multi-level inverter has lower THD compared to conventional symmetric and asymmetric topologies. The Hardware results are presented and analyzed. The simulation results coincide with the output of the Hardware. The THD is found to be 3.683% from the simulation output which is within the permissible limit i.e, 5%.For the high-power applications and the renewable energy applications, the proposed multilevel inverter topology will be a better choice.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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