PV PANEL SOURCED MULTILEVEL INVERTER WITH BIO-INSPIRED CONTROLLING ALGORITHM

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Abstract

Multilevel Inverters (MLIs) are the very important and growing research in the field of power electronics, because of their notorious advantages and extensive applications in various fields. The main advantage of employing MLIs is that it is a high-frequency source stage i.e. it has many levels in the output approximate to the original sine wave. This advantage is the route to the crucial disadvantages of increased sources and switches in the circuit which, can result in high harmonic distortions and switching losses. These demerits can be improved by replacing the controller circuit in the conventional system with a Bio-inspired Monkey Grooming Algorithm to generate a pulse-width modulated signals and switching sequence and also in Maximum power point tracking. This paper proposed a nine-level inverter constructed with a Bio-inspired algorithm to achieve a reduction in THD and switching losses. The voltage control of Single-Phase Induction Motor for better performance is modeled and implemented in MATLAB / SIMULINK environment. The Simulation results are analyzed and the improvement has shown in the system.

***Keywords**:* Multilevel inverter, Monkey grooming, THD, Switching losses.

Introduction

The demandfor clean energy is pushing toward a large diffusion of electric generators supplied by wind, solar, hydro, and other renewable energy sources. This trend will continue during the next years because the energy produced by renewable sources is expected to satisfy 20% and 50% of the total needs in 2020 and 2050, respectively. A significant consequence of this situation is a change of the electric power system from the present one, consisting of a relatively low number of very high power ac generators, to a distributed one, characterized by an extremely large number of small-medium power DC and ac generators supplied by renewable energy sources connected to the grid through electronic power converters, the latter adopting the produced energy to grid specifications. This new scenario introduces many technical, economic, and political challenges because it is changing how the electrical energy resources (generators and transmission/distribution networks) are designed and managed. From the technical viewpoint, the use of electronic power converters introduces new and challenging issues, including increased topological complexity, additional power losses, and Electro-Magnetic Interferences (EMIs), thus reducing the overall quality of service, efficiency, and network stability.

In power electronics circuits, the Multi-Level inverter (MLI) is a potential topology to use in high-power applications since the MLI affords low Electro-Magnetic Interference (EMI) and high efficiency with low-switching-frequency control method (Kashihara and Itoh,2014). Hence the MLIs are used as power converters in grid-connected systems with PV and also used as an Uninterrupted Power Supply (UPS). Since the multilevel inverter can increase the number of levels, they can decrease the distortion of the output voltage. When many levels present in the output voltage, the waveform resembles the sine wave. By increasing the levels in the output voltage, a significant reduction in harmonic content can be achieved. Some more advantages are size reduction, the lower voltage stress on power switches, a decrease in change of voltage, reduced switching losses, and reduced harmonics. Regarding inverters, the conversion efficiency, size, and cost are dependants on some factors such as the output filter, the carrier frequency and the magnitude of current ripple. So based on the requirement, the values of these factors are selected and it becomes possible to design the multi-level inverter according to the needs. Because of these merits, various MLIs with different numbers of levels are proposed in many kinds of literature.

Initially, a three-level inverter was proposed by Nabae, which used a neutral point of DC line and the configuration has been known as Diode Clamped MLI (DC-MLI) (Nabae et al. 1981). The very popular multilevel inverter is a cascade type inverter diode-clamped multilevel inverter, and the clamp capacitortypes multilevel inverter (Rodriguez et al. 2009). In a cascaded MLI, every phase needs n-number of DC sources for $2n + 1$ levels. Because of the requirement of many DC sources, the employment of cascaded type inverter is impeded. Neutral Point Clamped (NPC) or Diode Clamped MLI (DC-MLI), Flying Capacitor MLI (FC-MLI), and Cascaded H-Bridge MLI (CHB-MLI) are the major three types of MLI (Rodriguez et al. 2002). There are major shortcomings in NPC MLIs such as the requirement of a capacitor voltage balancing control circuit for the level number greater than 3 and the high voltage across the clamped diodes. The FC MLI uses FCs as clamping devices, which has some appealing features like the transformer-less operation and redundant phase leg states that distribute the switching stresses equally between the switches (Mekhilef and Abdul, 2010). But the shortcoming is that they require many storage capacitors for higher voltage levels. To overcome this issue, a double FC multicellular inverter is proposed by employing two additional low-frequency switches in the FC MLI. The major benefits of this inverter are the amplification of the RMS value of the output voltage and the number of voltage steps two times and the removal of the midpoint of the DC source. In contrast, the additional switches should be operated at the peak value of the output voltage. Hence the employment of this type of inverter in high voltage applications is hampered. A significant problem in multilevel converter design is the complexity of their control and their pulse-width modulator. Many authors proposed different solutions (Sowjanya et al. 2013). In the case of converters for PV generators, another important issue is the achievement of the Maximum Power Point Tracking (MPPT).

The Hybrid and Asymmetric Hybrid inverter configurations are invented by employing various DC bus levels and by using different combinations of conventional MLIs. In asymmetric configurations, the magnitude of the DC voltage source is not the same and shows dynamic variation. This configuration decreases the size and cost of the converter along with the reliability enhancement because the number of switches and capacitors employed in this configuration is less. The hybrid multilevel inverter configurations are formed from the combination of different MLI topologies, mainly the two basic topologies of DC-MLI and FC-MLI, with different levels of DC voltage sources and different PWM methods. The employment of DC-MLI or FC-MLI instead of the H-bridge as the basic unit of the CHB-MLI is to decrease the number of the DC sources applied. The asymmetric hybrid MLIs produce the output voltage with reduced harmonic and increase the output levels with rational SDCSs (Du et al. 2007). The Voltage Source Inverter (VSI) is controlled by using the various kinds of feed-forward and feed-back PWM control methods. Among various PWM methods, the Sinusoidal PWM (SPWM) method is the more famous modulation technique. Then the PWM techniques are extended to multiple carrier waves of two types known as Level Shifted-PWM (LS-PWM) or phase disposition, and Phase-Shifted PWM (PS-PWM). Some other PWM methods are multilevel space vector and multilevel selective harmonic elimination (McGrath and Holmes, 2002). In the Hybrid Cascaded H-bridge Multi-LevelInverter (HCMLI) only a single DC source is used as the basic source and the other $n-1$DC sources are replaced by the capacitors (Du et al. 2006). The utilization of many single-level inverters to generate multilevel output voltage was previously implemented by phase-shifting the output voltage of these inverters and then performing vector addition to the voltages using the series-connected transformer coils. Still, this method cannot be employed when the number of levels is greater than 3, because of the increased size and the need for many coils.

Literature survey

Wu et al. (2015) argued about a new solar power generation system, which is composed of a DC/DC power converter and a new seven-level inverter. The DC/DC power converter integrates a DC-DC boost converter and a transformer to convert the output voltage of the solar cell array into two independent voltage sources with multiple relationships. This new seven-level inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade. The capacitor selection circuit converts the two output voltage sources of DC-DC power converter into a three-level DC voltage, and the full-bridge power converter further converts this three-level DC voltage into a seven-level ac 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. The salient features of the proposed seven-level inverter are that only six power electronic switches are used, and only one power electronic switch is switched at high frequency at any time. A prototype is developed and tested to verify the performance of this proposed solar power generation system.

Wu and Chou(2013) introduced a novel cascaded seven-level inverter topology with a single input source integrating switched capacitor techniques. Compared with the traditional Cascade Multilevel Inverter (CMI), the proposed topology replaces all the separate DC sources with capacitors, leaving only one H-bridge cell with a real DC voltage source and only adds two charging switches. The capacitor charging circuit contains only power switches so that the capacitor charging time is independent of the load. The capacitor voltage can be controlled at the desired level without a complex voltage control algorithm and only use the most common Carrier Phase-Shifted Sinusoidal Pulse Width Modulation (CPS-SPWM) strategy. The operation principle and the charging-discharging characteristic analysis are discussed in detail. With the switched capacitor techniques, the different H-bridges can share the input source; thus, the redundancy of the topology is enhanced. A 1kW experimental prototype is built and tested to verify the feasibility and effectiveness of the proposed topology.Edpugantiand Rathore, (2015) proposed a new optimal pulse width modulation technique for a cascaded seven-level inverter such that the maximum device switching frequency is limited to the rated fundamental frequency (50/60 Hz) and all power semiconductor devices operate at the identical switching frequency. Optimal switching patterns were determined off-line assuming steady-state conditions. Later, switching angles for each semiconductor device are determined and stored in an FPGA controller. A low power prototype of a seven-level cascade inverter has been developed to demonstrate the proposed modulation technique. The experimental results demonstrated that the proposed optimal modulation technique maintains the quality of machine stator currents, while device switching frequency is limited to the rated fundamental frequency.

A simplified Space Vector Modulation (SVM) technique is proposed for the seven-level Cascaded H-Bridge (CHB) inverter (Ahmed and Borghate, 2013). It is based on decomposing the seven-level space vector hexagon into several two-level space vector hexagons. The presented technique significantly reduces the calculation time and efforts involved in the SVM of a seven-level inverter; without any loss in the output voltage magnitude or increase in the total harmonic distortion content. A further simplified technique is also presented in this study, which significantly reduces the complexity and effort involved in the seven-level SVM. Simulation results for the seven-level CHB inverter using the proposed techniques are presented. The results are compared with results using sinusoidal Pulse-Width Modulation (PWM) and third harmonic injection PWM to prove the validity of the proposed techniques. The proposed technique is perfectly general and can be applied to all types of multilevel inverters and extended to higher-level inverters.

Low switching frequency modulation of multilevel inverters for medium-voltage high-power industrial AC drives is essential to reduce switching losses and thus improve the overall energy efficiency of the system. However, minimizing the switching frequency increase the Total Harmonic Distortion (THD) of machine currents. Synchronous Optimal Pulsewidth modulation (SOP) is an emerging technique for controlling multilevel inverters at low switching frequency without compromising on THD of machine currents. Edpuganti and Rathore, (2014) implementedthe SOP technique for controlling seven-level cascade inverter for an induction motor drive at an average device switching frequency limited to the rated fundamental frequency. First, optimal seven-level waveforms were obtained by off-line optimization assuming steady-state operating conditions. Then, the switching angles for each semiconductor device were obtained that ensure equal distribution of switching losses as well as unbalance in DC-link capacitor voltages. The proposed SOP technique is validated by experimental results obtained from the seven-level cascade inverter feeding a 1.5 kW induction motor

Lin et al. (2014) proposed a novel single-phase seven-level inverter. The topology of the proposed structure is composed of a DC source, a switched-capacitor circuit, and a coupled inductor. Compared to conventional seven-level inverter structure, numbers of switches and capacitors are reduced. The voltages of capacitors are self-balanced by using coupled inductors without complex control methods. Therefore, the output voltage total harmonic distortion can be reduced. Finally, the simulation and experimental results show the 350-V input voltage, 380-V_{ac} output voltage, and 0.52% output total harmonic distortion under 3kW output power condition to verify the feasibility of the proposed multilevel inverter. Sowjanyaet al. (2013) proposed two various transformer-based inverters. The proposed inverters consist of one center-tap transformer, two bidirectional switches,and three unidirectional switches. The proposed inverters are capable of increasing the input voltage according to the winding turn-ratio of the transformers and isolating input DC sources with the load, resulting in enhanced reliability. The performance of the proposed inverter has been compared to some of the commonly used transformer-based inverters from the literature in terms of the number of components and the overall performance. The proposed multilevel inverters have reduced the number of IGBTs and gate drivers and subsequently required a relatively simple control strategy for generating the desired output voltage. Finally, the performance of the proposed inverter has been simulated utilizing the PSCAD/EMTDC software package.

Wang et al (2017) suggested a Fuzzy Logic (FL) with genetic algorithms and neural networks, in the control of dc and ac drives and in the tuning of state observers, and introduced in the control loop for enhancing its behavior. Its use in power converter control and modulation was mainly in the field of DC/DC converters (Atallah et al. 2014). Besides several papers argued the use of FL in the control of ac converters chiefly for proportional-integral (PI) or sliding-mode current controller enhancement through gains adaptation. This situation probably depends on the high computational speed required by conditional and branch statements, typical of FLC. This drawback can now be overcome using Field-Programmable Gate Arrays (FPGA) in the replacement of microprocessors.

The Biologically Inspired Algorithms (BIA) are exposed to be tremendous methods in many fields of engineering design, industrial optimization, networking, image processing, power system optimization,and medical signal analysis (Lin et al. 2014). Many works have been performed in the research field of BIA from the last decade twentieth century. Many such algorithms have been developed for the last two decades and still, there is a vast space for the engineers since some of them yield better solutions to only certain problems; not for all.

System design

The proposed Nine-level inverter consists of a converter circuit and a controller circuit. The converter circuit comprises of PV panel, which acts as a DC source, DC-DC boost converter circuit to boost the voltage obtained from the solar. The Multilevel inverter uses the boosted voltage to produce 9 levels in its AC output with reducing THD. The output of the inverter circuit is filtered by the LC filter to give a pure sine wave to run the RL load.

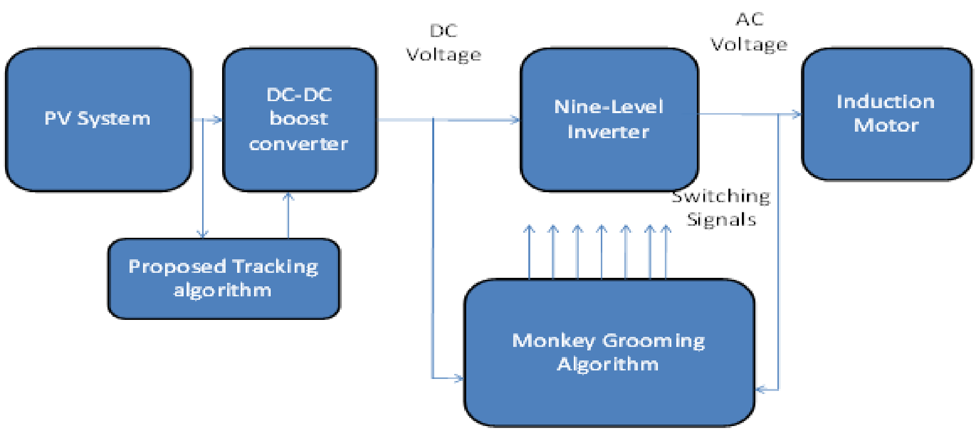

Figure 1: Block diagram of the overall system

The controller process is here replaced by employing the Monkey grooming algorithm. This controller does the process of producing constant DC voltage value and generatesa pulse-width modulated signal to produce nine levels in the output voltage.

Inverter circuit

The inverter circuit comprises a single-phase conventional H-bridge inverter, three bidirectional switches, and a capacitor voltage divider formed by C1, C2, C3, and C4, as shown in Figure 2. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via a DC-DC boost converter. The power generated by the inverter is to be delivered to induction Motor.

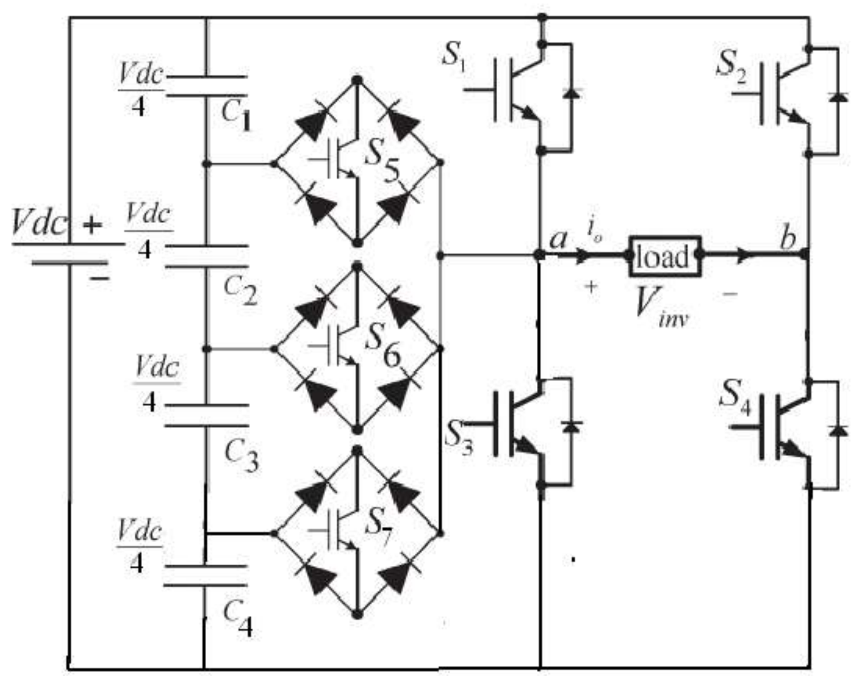

Figure 2: Topology of Single-phase nine-level inverter circuit

Proper switching of the inverter can produce nine output-voltage-levels (V_{dc}, $V_{dc}/2$, $V_{dc}/4$, $3V_{dc/4}$, $-V_{dc}$,$-V_{dc/2}$, $-V_{dc}/4$, $-3V_{dc/4}$)from the DC supply voltage. The proposed inverter's operation can be divided into nine switching states. The maximum positive output V_{dc} can be obtained by switching ON the Switch S1 and S4. The maximum negative output $-V_{dc}$ can be obtained by switching ON the switch S3 and S2. $3V_{dc/4}$ is obtained by activating the switch S5 and S4 ON and$-3V_{dc/4}$ obtained by activating the switch S7 and S2 ON. Half of the positive output $V_{dc}/2$ can be obtained by switching the S6 and S4 ON and its negative output $-V_{dc/2}$ obtained by switching S6 and S2 On. $V_{dc}/4$ and $-V_{dc}/4$ can be obtained by correspondingly switching S4 & S7 ON and S5 & S2 ON

These nine levels can be sequentially obtained in the output by sending the proper switching signals after each level. The part of the forming switching sequence is carried by the grooming algorithm in the control circuit and it was explained in the next section.

Control circuit

In Multi-Level Inverter circuits, the controller circuit composed of the comparator, PI, PID, fuzzy controllers with PWM techniques (Nabae et al. 1981). They were used in switching and controlling the regulated voltage through the inverter circuit and the improvement has also achieved in the harmonic reduction and switching losses. To provide an optimized solution in THD better than the obsolete systems we are now going for the Bio-Inspired algorithm.

Proposed tracking algorithm

A common inherent drawback of PV and system is the intermittent nature of their energy source. Solar energy is present throughout the day, but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. These drawbacks tend to make these renewable systems inefficient. However, by incorporating Maximum Power Point Tracking (MPPT) algorithms, the systems' power transfer efficiency can be improved significantly.

Commonly in previous papers for MPPT Tracking, They used many obsolete methods to increase efficiency in tracking (Xiao et al. 2012). In this work, we have used the behavior of Monkey picking lice to develop an algorithm for maximum power point tracking. Monkey i.e., primates search for the lies in their kins body to make it socially hygienic. In the algorithm, the place where louse lies in the body of the primates can be considered as a Maximum PowerPoint in the solar PV panel. Monkey search first in the area denser with the louse and it intakes the lice as it is a protein source for them. Considering this attitude,

Step 1: The algorithm first makes the random choice of area to search for the maximum power points. On the chosen random point it calculates the power and we can denote it as P_{prev} .

Step 2: Then the algorithm will calculate the power at the points around the P_{prev} and it may denote as $P_{new\ 1}$, $P_{new\ 2}$, $P_{new\ 3}$,……..$P_{new\ n}$.

Step 3: The next step is to compare all the new find values to find the highest $P_{new\ high}$ value. Then the Highest values founded will be compared with the P_{prev} value.

Step 4: If P_{prev}<$P_{new\ high}$, tracking will move in that direction. Now take $P_{new\ high}$ as $P_{prev\ 1}$ and repeat from step 2 of calculating the power around the point P_{prev} 1 except P_{prev} to track in the direction of maximum power points.

Step 5: If P_{prev}>$P_{new\ high}$, Then repeat from step 2.

However, these techniques utilize many iterations in tracking maximum power but gives high efficiency in tracking.

DC-DC boost converter

The DC-DC boost converter was required because the PV arrays had a voltage that was lower than the single-phase voltage to drive the Induction Motor. The DC-DC boost converter was required because the PV arrays had a voltage that was lower than the single-phase voltage. High DC bus voltages are necessary to ensure that power flows from the PV arrays to the single-phase induction motor. Hence it is modeled.

Modeling of the DC-DC Boost converter

The boost converter is a power electronic circuit that gives the output voltage which is greater than the input voltage. It consists of DC input voltage source Vs, boosts inductor L, controlled switch S, diode D, filter capacitor C, and load resistance R.

Using Faraday's law for the boost inductor

$$V_s\,DT = (V_o - V_s)/(1-D)T \qquad (1)$$

From which the DC voltage transfer function turns out to be

$$M_v = \frac{V_o}{V_s} = \frac{1}{1-D} \qquad (2)$$

As the name of the converter suggests, the output voltage is always greater than the input voltage. The boost converter operates in the CCM for L >Lb where

$$L_b = \frac{(1-D)^2}{2f}DR \qquad (3)$$

Where d, is the duty ratio of DC to DC converter which is defined as the ratio of turn-on time to that of total time. The boost converter steps up the voltage from the PV array to the required value before feeding to the Nine-Level Inverter system.

Monkey grooming algorithm for forming switching sequence

Inspired by the grooming activity of the primates (i.e.) monkey. Here we have developed the Grooming algorithm for controlling the inverter circuit to provide optimized levels in the output. Social Grooming in primates serves two primary adaptive functions: hygiene and social bonding. Grooming removes dirt, insects, parasites, dead skin, tangled fur, &c., and generally help to keep an animal's skin and hair in good condition. The idea is an "altruistic" action done by one creature to benefit another will prompt either a beneficial response from the receiving animal. The benefits of the bond may not seem "direct," the bonding is a "response" from the receiving animal. Primates may also make different types of vocalization to indicate whether they want to groom or be groomed, so individuals can communicate their desires and assess others' intentions. Allo grooming occurring between lower-ranked and higher-ranked individuals. There is evidence that a lower-ranked individual is more likely to groom a higher ranked individual than an individual with the same or lower rank. The Main behavior in Monkey picking lies is that they pick lice in a sequence manner like shown in the picture below.

Figure 3: Monkey grooming algorithm

The first monkey on the left is the one which undergoes grooming and it is called groomee. The monkey who is doing the grooming is called the groomer. The middle one will act as a groomer and groomee too. The last one is doing grooming to the middle one. On the whole,they are doing the process of grooming to their previous one in the intention to remove parasite for them to be socially hygienic. Taking this behavior as the root Idea. We have developed an algorithm on the controlling process of the multi-level inverter.

The processes in controlling fall under-grooming algorithm. The first process is to compare the V_{dc} and $V_{dc\,ref}$ The process of acquiring actual and reference value can be related to the monkey picking lies from the first one and the comparing process is here related to grooming. Then the error in the V_{dc} value will be reduced to give a constant V_{dc} value to give as an input to the inverter. The output of the controller, also known as V_{ref}, goes through an anti-windup process before being compared with the triangular wave to produce the switching signals forS1–S6. Eventually, V_{ref}becomes V_{ref1}; V_{ref2} and V_{ref3} can be derived from Vref1 by shifting the offset value, which was equivalent to the amplitude of the triangular wave.

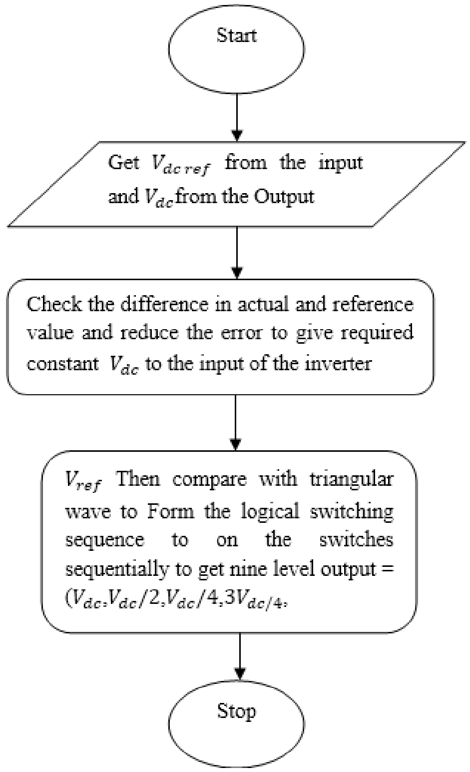

Figure 4: Flowchart of monkey grooming algorithm

On the whole, there is three comparison process, first, one comparing the actual and reference V_{dc} to provide constant V_{dc} to the grid. And the third one is comparing the V_{ref} compare it with the triangular wave to form pulse width modulated signals to generate nine levels and logical switching signals sequence. The below table shows the switching sequences of different output voltages. The processes in controlling fall under-grooming algorithm. The first process is to compare the V_{dc} and $V_{dc\,ref}$. The process of acquiring actual and reference value can be related to the monkey picking lies from the first one and the comparing process is here related to grooming. Then the error in the V_{dc} value will be reduced to give a constant V_{dc} value to give as an input to the inverter. The output of the controller, also known as V_{ref}, goes through an anti-windup process before being compared with the triangular wave to produce the switching signals forS1–S6. Eventually, V_{ref}becomes V_{ref1}; V_{ref2} and V_{ref3} can be derived from V_{ref1} by shifting the offset value, which was equivalent to the amplitude of the triangular wave.

Table 1: Switching signals sequence of the inverter circuit, 1-ON state of the switch, 0-OFF state of the switch

Vo	S1	S2	S3	S4	S5	S6	S7
V_{dc}	1	0	0	1	0	0	0
$3V_{dc/4}$	0	0	0	1	1	0	0

$V_{dc/2}$	0	0	0	1	0	1	0
$V_{dc/4}$	0	0	0	1	0	0	1
0	1	1	0	0	0	0	0
$-V_{dc/4}$	0	1	0	0	1	0	0
$-V_{dc/2}$	0	1	0	0	0	1	0
$-3V_{dc/4}$	0	1	0	0	0	0	1
$-V_{dc}$	0	1	1	0	0	0	0

Modeling of LC-Filter

In filter designing, the first step is finding the best filter. The second step is calculating the designed impedance from the lowest voltage (V_{min}) divided by the highest current (I_{max}) where is R_d. The third step is equating the inductor (L) and the capacitor (C) values from the second step using the following equation.

The design impedance form can be calculated by using the below equation

$$R_d = \frac{V_{min}}{I_{max}} \quad (4)$$

The inductance (L) and the capacitance (C) values of the filter can be calculated by

$$L = \frac{Rd}{2\pi f} \quad (5)$$

$$C = \frac{1}{2\pi f Rd} \quad (6)$$

Results and discussions

A) Simulation results

To validate the performance of the multilevel inverter, the system is designed with the source modeling in MATLAB /Simulink and the experimental waveforms are obtained. The performance of the inverter is studied under steady-stateconditions. The performances of the inverter are validated with the models to their efficiency conditions.

The first part of the simulation consists of a PV panel source with a DC-DC boost converter circuit to boost the voltage obtained from the panel to give as input to the inverter

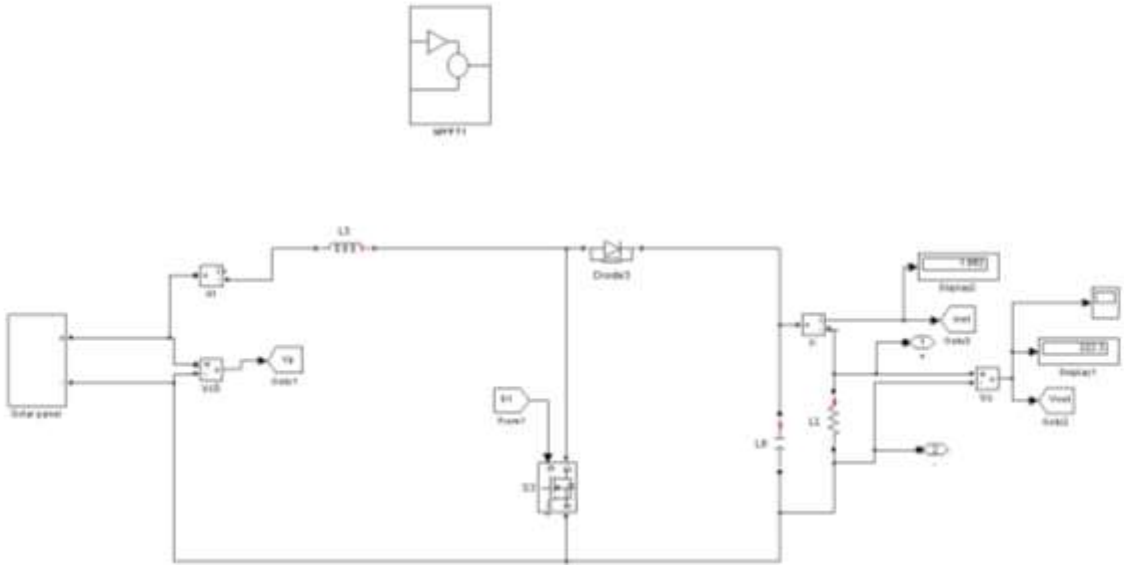

Figure 5: Simulation diagram of the panel with a boost converter

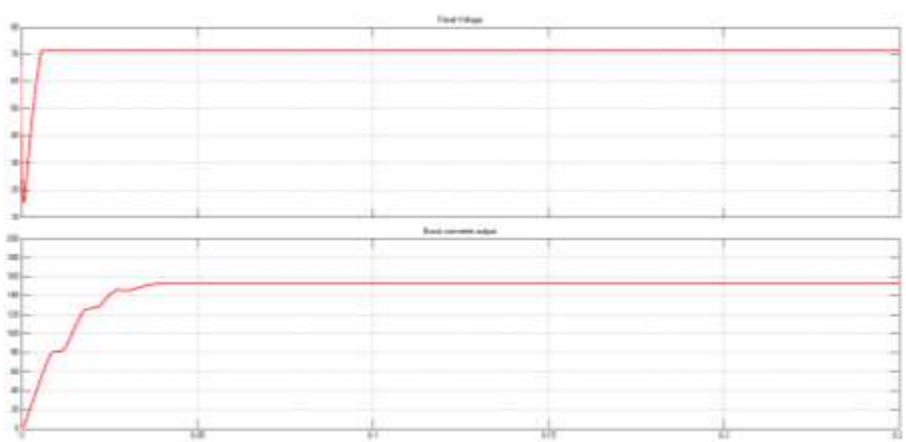

Figure 6:The panel voltage and boost converter output voltage.

The voltage generated from the panel is about 70 V which is boosted to 150V. The next part of the simulation is the nine-level inverter. The boosted voltage will give as an input to the inverter. The nine-level inverter with reduced switch count is proposed which comprises a single-phase conventional H-bridge inverter, three bidirectional switches, and a capacitor voltage divider formed by C1, C2, C3, and C4. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels.

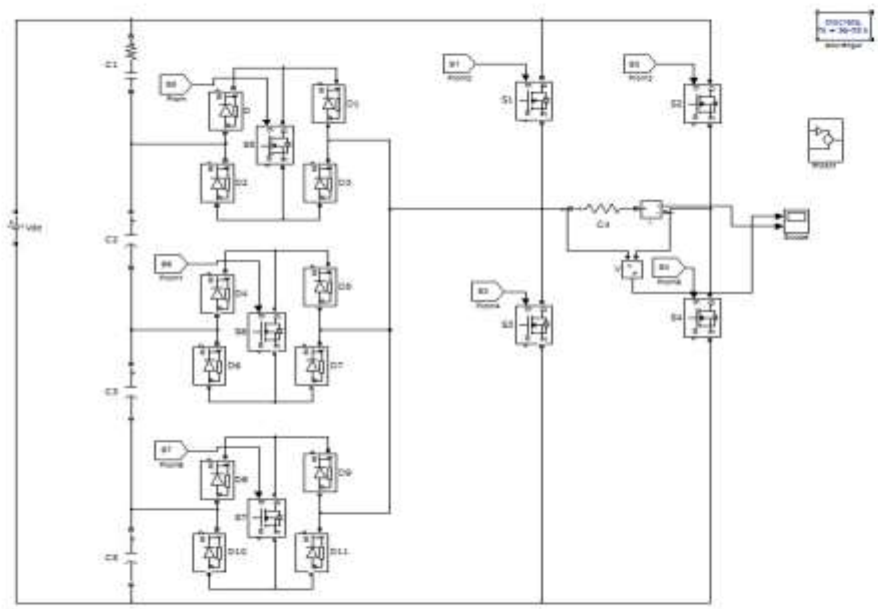

Figure 7: Simulation diagram of the nine-level inverter with a switched capacitor.

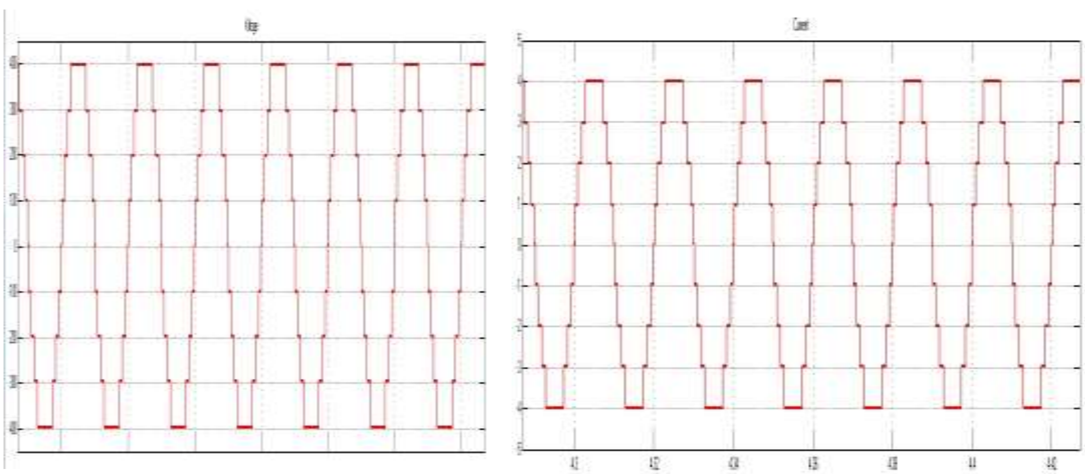

Figure 8:a) Nine-level voltage waveform output b) nine-level current waveform output.

After the simulation, the output voltage waveform results will undergo through FFT analysis to measure the Total Harmonic Distortion (THD). After this analysis, it is compared with the conventional system results to show the improvement in the proposed system results.

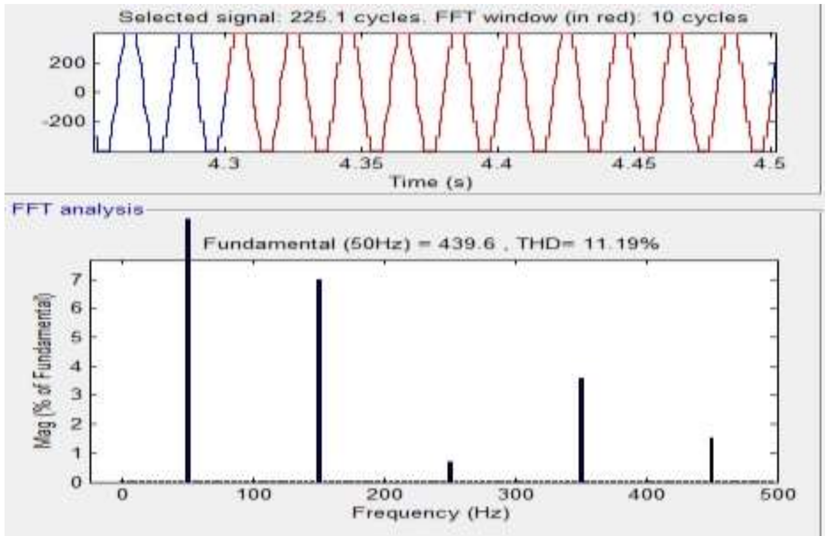

Figure 9: Total harmonic distortion of the nine-level output voltage.

The THD of the output voltage is 11.19%.

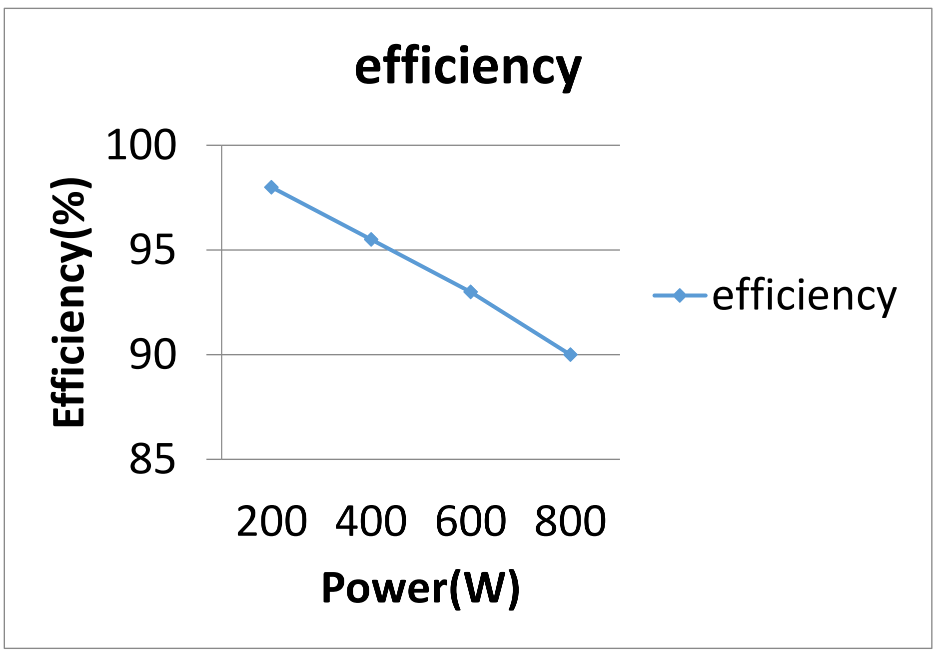

Figure 10: Power Vs efficiency waveform

Table 2: Existing Vs proposed comparison

	Existing	**Proposed**
Number of switches	9	7
Level	9	9
Efficiency	94%	98%

THD	11.9%	11.19%

The above table clearly shows that with a reduced number of switches in the circuit, the proposed system gives a higher efficiency of 98%. The THD reduced by 0.71%. The below figure shows the complete simulation circuit of PV panel sourced nine-level inverter with RL load. The output of the inverter voltage will be filtered by the LC filter to give a pure sine wave as in Figure 11.

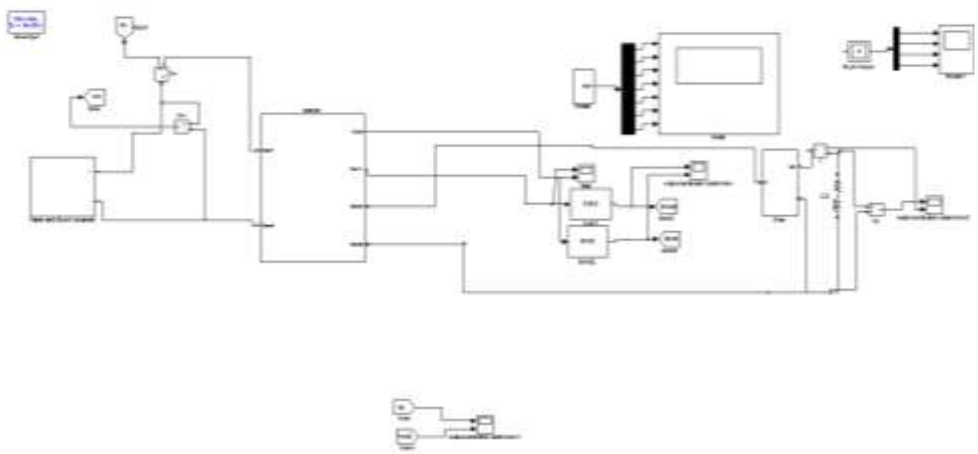

Figure 11: SIMULINK model for an overall solar, nine-level inverter with RL load

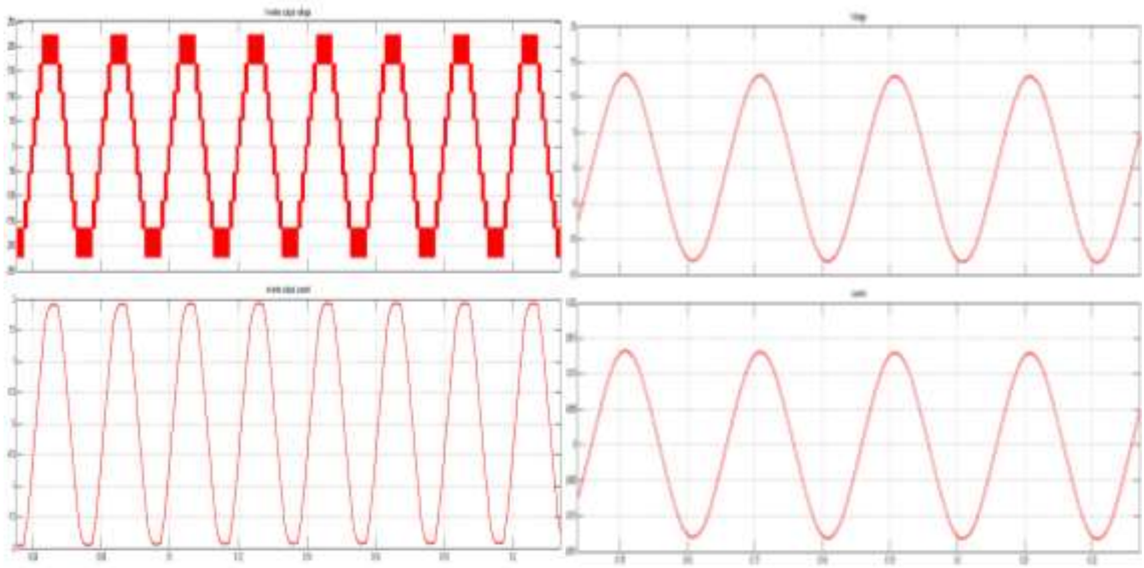

Figure 12: Nine-level inverter output voltage and current waveform before filtering. b)Nine-level inverter output voltage and current waveform after filtering.

The simple LC filter used here helps in reducing second order harmonics and in generating pure sine wave as shown in Figure 12.

B) Experimental setup results

The output of the experiment results is shown in the figures below.

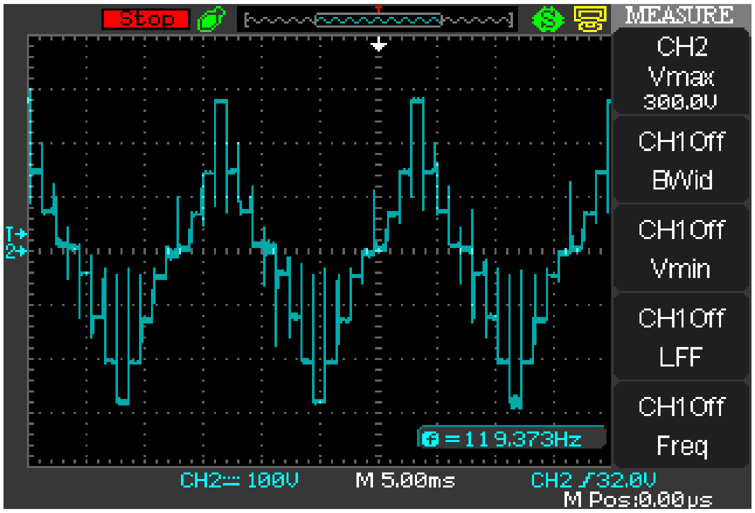

Figure 13: Nine level output voltage

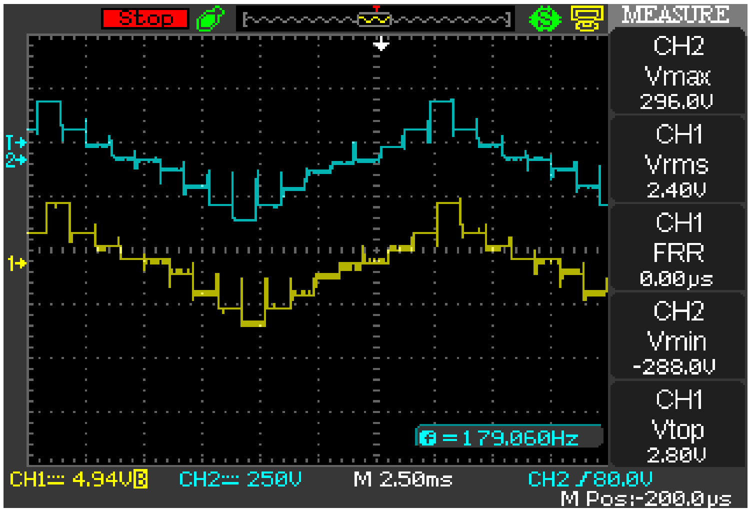

Figure 14: Nine level output voltage & current

Figure 15: Capacitor voltages

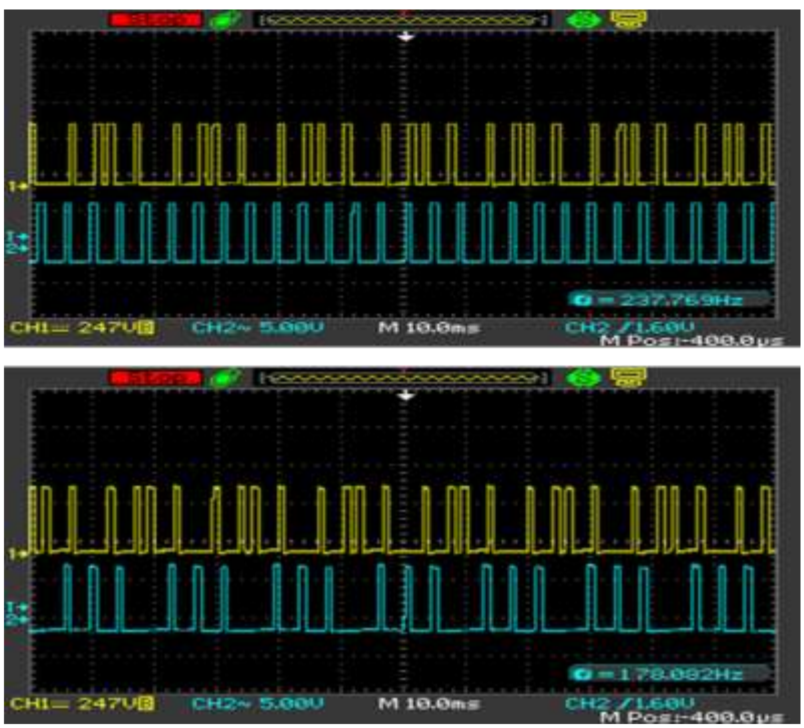

Figure 16: PWM waveforms

Conclusion

A multilevel inverter that operates in a single DC and the minimum number of switches have been proposed. This inverter uses a single DCsource and reduced number of DC sources which are minimal compared to the existing schemes, and also it can provideadditional space to modify the number of levels without touching the main circuit, As the system has the minimal switches the requirement of the hardware drivers are being reduced. Also,a Bio-inspired monkey grooming algorithm has proposed to generate pulse width modulated signals and switching sequence to invoke an inverter circuit to produce nine levels in the output. This proposed system has shown improvement in the reduction of THD and increment in the efficiency over the obsolete methods. Therefore, the construction cost of the proposed multilevel inverter is lower and it is not bulky.

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