PI controller for photovoltaic-fed novel multilevel inverter topologies

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ABSTRACT

This research describes the analysis and design of a unique 7-level and 9-level multi-level inverter topology with fewer DC power supplies and power switches, and a comparison using pulse width modulation (PWM). Comparisons of 7-level and 9-level multi-level inverters that analyze characteristics using optimal nearest level modulation (ONLM) technology are made using various PWM approaches such as nearest level modulation (NLM) technique, phase disposition (PD), phase opposition disposition (POD), and alternate phase opposition disposition (APOD). The output is evaluated based on a high Vrms, low total harmonic distortion (THD) harmonic profile. The controller is based on artificial intelligence (AI) and machine learning (ML) techniques. ONLM techniques are used to measure the voltage harmonics of the full load, several DC offset values are used. The control technology provided is validated using MATLAB/Simulink simulation tools and laboratory-based experimental testing.

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1. INTRODUCTION

Nowadays, renewable energy sources play a vital role in power generation, so we need power electronic devices that convert to AC charging current. During this project one of the most promising power electronics converters, a multi-level inverter is applied here. The multi-level inverter was introduced within the year 1975. It's a powerful device that converts DC to AC which it's utilized in both high and medium power situations [1]. Average multi-level inverters are used and supported the concept where electricity is employed in low power semiconductor devices to form the sequence voltage waveform intended for the merchandise that's why there are different applications are used under multi-level inverter topology settings like DC and AC high voltage power lines, electric drive, power factor compensation, and natural resources communications, etc. once we apply multilevel inverter in applications it's some advantages yet as disadvantages too [2]-[4]. So recently, multi-level inverters have mainly focused on reducing the number of switches, Improving DC performance by improving gate control circuitry, power quality, fault tolerance, and achieving overall reliability. To have the main target for these problems many techniques are used under multilevel inverters like pulse width modulation (PWM), space pulse width modulation (SPWM). PWM technique is employed which is additionally referred to as the pulse width modulation technique [5]-[7].

2. ARTIFICIAL INTELLIGENCE TECHNIQUES

2.1. Artificial intelligence control techniques

In this modern world Artificial Intelligence is occupying the world in all aspects. The linkage of the Artificial intelligence (AI) is based on various connections like machine learing and deep learning. AI is a wide-ranging branch and this technology is concerned with erecting smart machines. This can perform tasks and minimize the problem working and decision making that are generally required for mortal intelligence numerous Machine learning powers these systems. Some of them are deep learning, while others are rule-based [8], [9].

2.1.1. Artificial neural networks

Artificial neural networks (ANN) are biologically inspired systems. The neural network is predicated on the biological neural networks that construct the structure of the human brain like that ANN is made and therefore the neuron is interlinked to every other and various layers of the networks are formed and networks are thought of as nodes [10]. Neural network is employed for problem-solving; the output is also discrete value or real-valued or discrete-valued attributes, and problems in ANN are represented by attribute-value pairs. ANN can bear long training times counting on the factors required like weights, numbers, and the setting of varied algorithm parameters [11]-[13]. The training method is kind of robust to the noise which can show some errors in training examples but it doesn't affect the final output. Once the ANN learning method is completed, they don’t must be reprogrammed and it will be implemented in any application. Easy to build the models and less statical knowledge is required. Where the ANN is parallelizable.

2.1.2. Fuzzy logic system

The fuzzy logic architecture has a fuzzification module, knowledge base, inference engine, and defuzzification module, and these functions work on a set of variables. The system inputs are transferred into fuzzy sets within the fuzzification module, and the input is divided into five main parts large positive (LP), medium positive (MP), small (S), medium negative (MN), and large negative (LN), and also the knowledge base will store these rules provided by the experts, and the inference engine will simulate the method by performing fuzzy inference on the input, and the last one is defuzzification module which can transform inference engine into crisp value [14]-[16]. Many applications are used under the method of fuzzy logic systems (FLS) like automotive systems, consumer electronics goods, and domestic goods then on. The FLS is often easily constructed which is flexible and also allows modifications. These systems provide solutions to complex problems and also the logic is additionally really simple, robust, and might be modified consistent with the wants. The FLS coded requires only less data where the space requirements are additionally less during this logic [17]. The logic can handle different kinds of inputs at a time and the accurate decisions have been defined by the functions. When the feedback system fails within the logic system, it is often easily reprogrammed.

2.1.3. Genetic algorithms

The genetic algorithm (GA) may be a powerful algorithm supported by natural processes and natural genetics. GAs work with a group of binary sequences, trying to find many parallel vertices. By using genetic operators, they exchange information between vertices, thereby reducing the likelihood of reaching a neighborhood optimal point [18]. GA is more adaptable than most search techniques because they require only pieces of data regarding the standard of the answer generated by each set of parameters (values for the objective function) unlike many optimization methods [19]. Chemistry requires additional derivative information or knowledge of the structure and parameter of the problem. There are some areas within which genetic algorithms are frequently used: economics, optimization, vehicle routing problems, robot trajectory generation, etc. Genetic algorithm search from a population of points, not one point and supports multi-objective optimization, and uses transition rules, not deterministic rules [20], [21]. Genetic algorithms concept is straightforward to grasp and noise-free for the environment. Genetic algorithm works well on the mixed continuous and discrete problems, when compared to brute force, genetic algorithm is faster and more efficient [22].

3. METHOD USED IN EXISTING TOPOLOGY

The heart of the any designed inverter is based on its PWM tehniques used in it. There are various PWM techniques like space vector, sine PWM, and NLM. NLM also known as nearest level technique is one of the PWM techniques and it is used to reduce total harmonic distortion (THD) value and increase Vrms value. NLM works on the fundamental frequency [23]. Pulse design for random switching position is very easy in the NLM technique.

3.1. Seven level inverter

Existing seven-level inverter and topology for this ONLM approach introduced with varied DC offset by adjusting the value DC versus reference value with two distinct voltage sources such as 100v and 200v and six insulated-gate bipolar transistors (IGBT) switches used S1, S2, S3, S4, Sa, and Sb where load resistors are linked to the switches in parallel and switchboards are displayed as shown in Figure 1. Seven-level inverter switching topology shows the functioning of switch both ON and OFF for positive and negative switching operations given in Table 1. Figure 2 represents the 7-level output waveform.

Table 1. Switching sequence for 7-level inverter

Digital	Sa	Sb	S1	S2	S3	S4
100	0	1	1	0	0	1
110	0	1	0	1	1	0
111	0	1	1	0	1	0
100	1	0	0	1	1	0
110	1	0	1	0	0	1
111	1	0	0	1	0	1

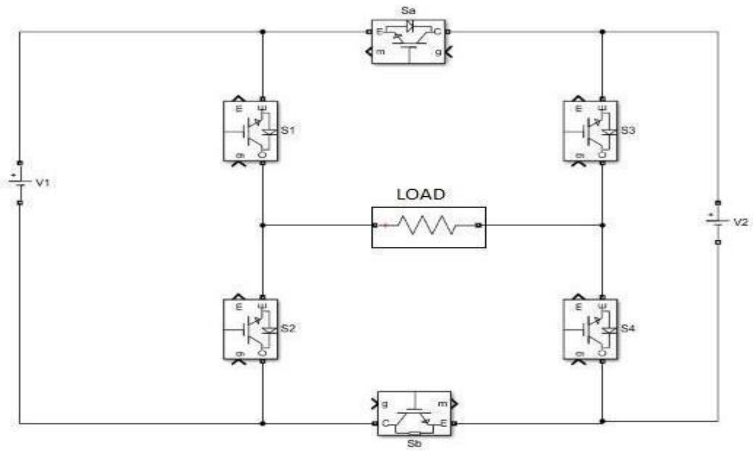

Figure 1. Circuit diagram for 7-level inverter

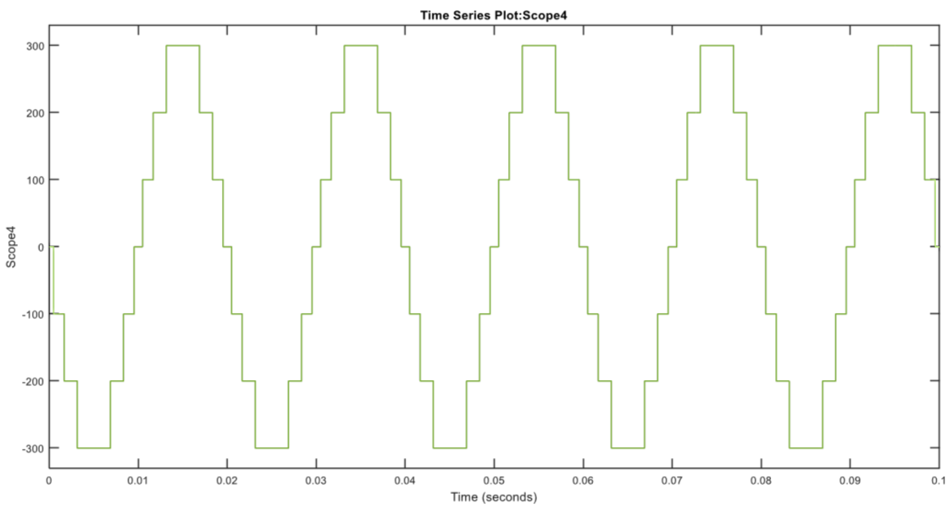

Figure 2. Seven level output waveform

The testing for THD represented in Figure 2 is done by the selected signal of generated 5 cycles this fast fourier transform (FFT) analysis is done for 2 cycle seven-level switching waveform with the frequency of 306 to the THD =12.27% based on the frequency of 50 Hz to the maximum frequency of 2,500 Hz range the peak voltage of 300 v in positive half and -300 v in a negative half cycle where the 0 is the start time point. This is 7-level in using the nearest level technique through the various dc offset value of 0.5 to 2.5 in positive and -0.5 to-2.5 in a negative cycle. Figure 3 represents the FFT analysis of 7 level inverters.

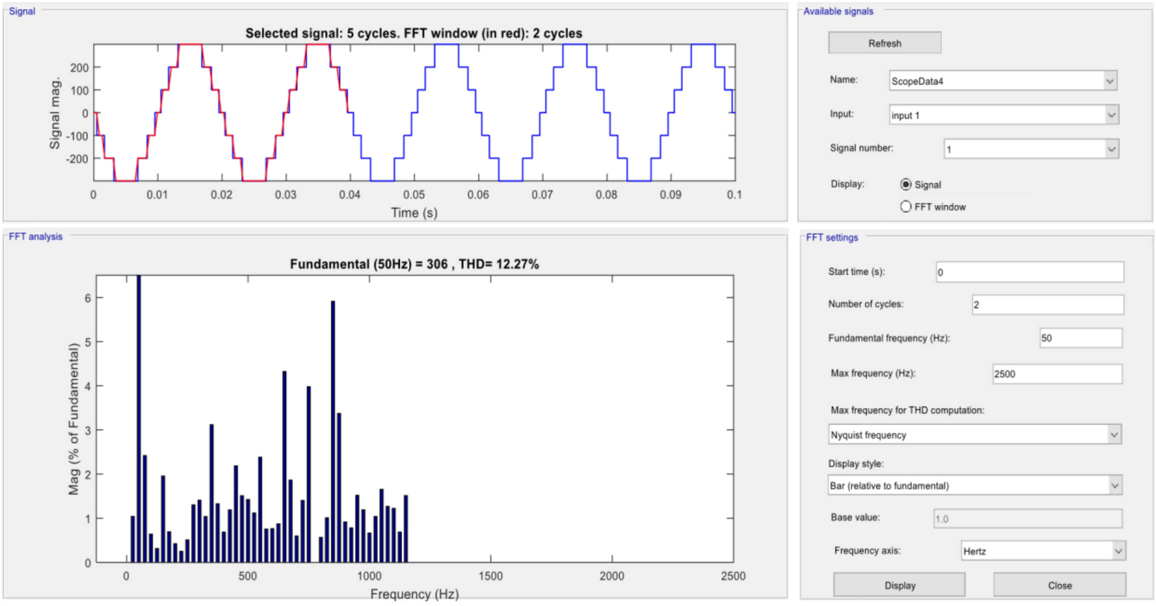

Figure 3. FFT analysis of 7-level inverter

3.2. Nine level inverter

The 9-level inverter used the existing topology with different asymmetric PWM techniques for this closest level technique is used as work using different DC offsets on each change DC value by comparing with sine wave value with three different DC sources like 100 v, 100 v, and 200 v and eight switches used S1, S2, S3, S4, S5, S6, Sa and Sb in that the active switch has been given in the table and the load resistor has been connected in parallel with the switches through a nine-level inverter we can reduce total harmonic distortion improved THD and reduce THD. In Figure 4, the circuit is like adding two then the 7-level switches are shown this S5 and S6 when connecting DC source V1 and V3, this is the voltage difference of 100 v and 200 v respectively. Table 2 shows the switching sequence of 9-level inverter. Figure 5 shows the 9-level output waveform.

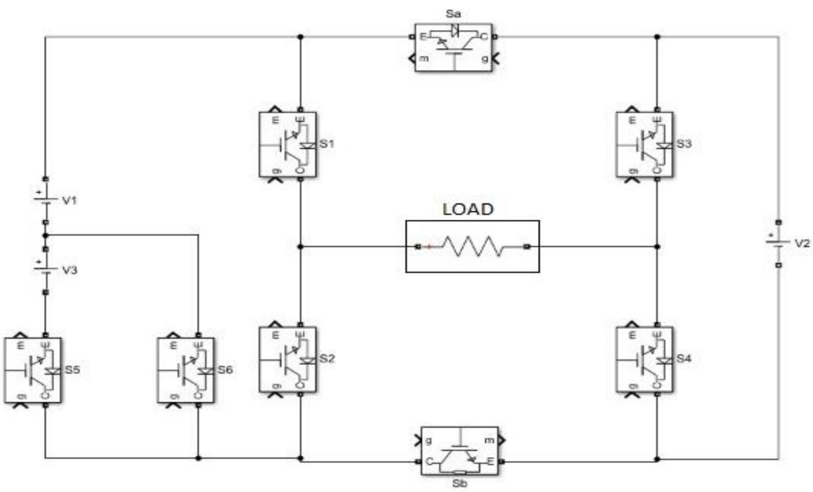

Figure 4. Circuit diagram of 9-level inverter

Table 2. 9-level switching sequence

Digital	Sa	Sb	S1	S2	S3	S4	S5	S6
1000	0	1	1	0	0	1	0	1
1100	0	1	0	1	1	0	0	0
1110	0	1	1	0	1	0	0	1
1111	0	1	1	0	1	0	1	0
1000	1	0	0	1	1	0	0	1
1100	1	0	1	0	0	1	0	0
1110	1	0	0	1	0	1	0	1
1111	1	0	0	1	0	1	1	0

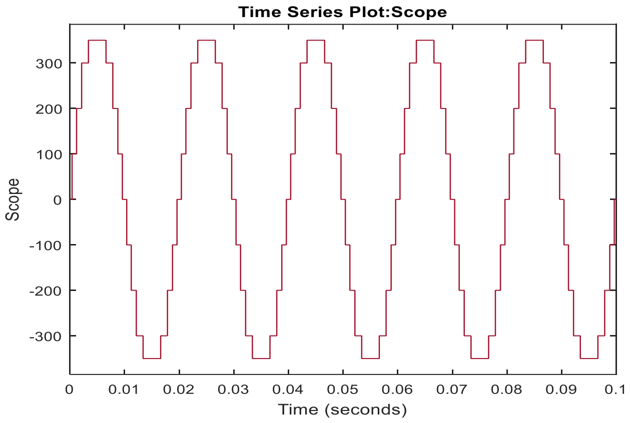

Figure 5. Nine level output waveform

The testing for THD represented in Figure 5 is done by the selected signal of generated 5 cycles this FFT analysis is done for 3 cycle 9-level switching waveform with the frequency of 376.7 to the THD = 10.08% based on the frequency of 50 Hz to the maximum frequency of 2,500 Hz range the peak voltage of 300 v in positive half and -300 v in a negative half cycle where the 0 is the start time point. Figure 6 is FFT analysis of 9-level in using the nearest level technique through the various dc offset value of 0.5 to 2.5 in positive and -0.5 to-2.5 in a negative cycle.

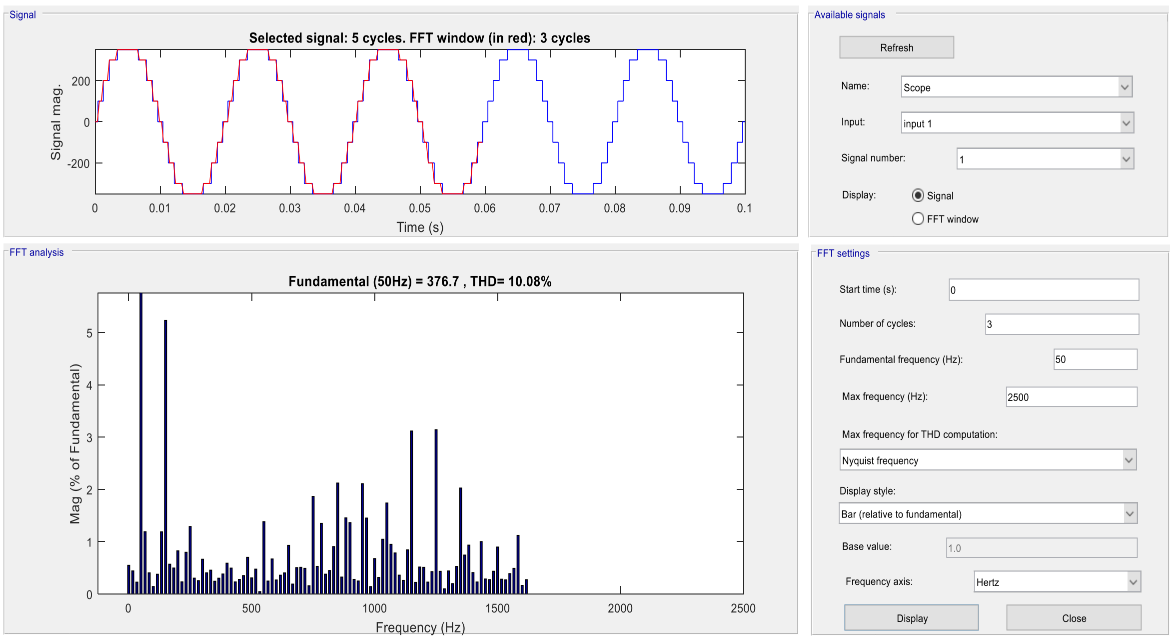

Figure 6. FFT Analysis of 9-level inverter

4. PROPOSED METHOD FOR CONTROLLER TECHNIQUE

4.1. Controller technique

The operational difference between the existing and the proposed system is based on the control system implemented. In the existing system conventional controllers are used. In the case of proposed system two controller techniques are implemented. The reason for choosing these techniques is, these techniques are having fast operating time and optimal control, such as proportional-integral controller and ANN-feedforward neural network.

4.1.1. Proportional-integral (PI) controller

PI controller is formed by combining proportional and integral control action. PI controller is a feedback control loop that reduces the amount of error when power is given to the supply. When two controllers are combined, they provide more efficiency, which removes any shortcomings connected with any of them. Many industrial applications are used under the PI controller for their reliable performance and are also reasonably simple to configure [24], [25]. The working of a feedforward neural network such that data enters through the network and each layer acts as a filter and filters outliers and following which it generates the final output. From language processing to route detection, in many applications feed-forward method, is used to solve complex problems [26].

4.1.2. Block diagram of controller technique

Figure 7 characterize the block diagram of the proposed topology. We represent the simulation of the multilevel inverter which is designed up to 31 levels using the NLM-PWM technique. Once the output waveform has resulted, a controller technique, is proposed in this system using the photovoltaic application in the source side (input) and grid in the load side (output). Two controller methods are used i.e PI controller which it is used as maximum power point tracking (MPPT) and ANN-feedforward neural network in the load to reduce the reactive power and increase the real power in the grid in the final output which it will increase the power quality and increase the efficiency with less circuit complexity. The proposed technique is implemented with fully looped closed system where all the control has been exhibited automatically.

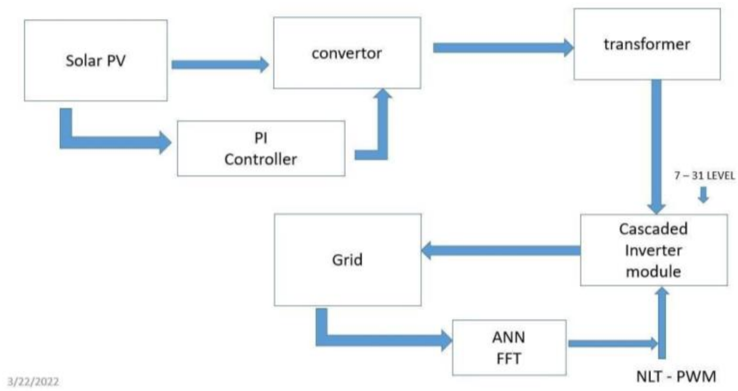

Figure 7. Block diagram of the proposed topology

5. SIMULATION OF PROPOSED CONTROLLER TECHNIQUE

5.1. Simulation of PI and feedforward neural network controller for 31-level inverter

This model was created by the following primary figure, who used the simulation program MATLAB simulation to allocate all of the components and build the system, and analyzed its overall performance, switching behavior, and power losses. The acquired results would be compared with the existing results. The solar photovoltaic (PV) is taken on the source side (input) which is used as an application in this paper. the work of a solar PV is to generate the DC voltage source. The dc voltage source is generated by changing the irradiance and intensity value The desired dc source is generated and fed into the PI controller. PI is also known as a proportional-integral controller. PI is one of the controller techniques which is works as an MPPT which is known as maximum power point tracking. When the dc voltage source is fed into the PI it will compare the Reference value which is already fixed in PI and the dc voltage source which comes from the solar PV when the maximum voltage source is trapped, the voltage source is transferred to the flyback converter.

In input layer, reactive power is an error value that is fixed, in the output layer real power is implemented to get the power that is used by consumers, and in the hidden layer, reactive power error reference and iteration are fixed. The working of the feedforward neural network starts in the hidden layer where the iterations start their process and minimizes the error in the grid once the input layer reactive power matches with the hidden layer reactive power layer or iterations and acquired the output controller technique process gets to stops and gives the remaining efficiency to the output layer where the real power is implemented. In Table 3, ANN fuzzy neural network (FNN) training results are shown. Using this controller technique losses in the load will be reduced and real power is fully used by the consumers and also improves the power quality and increase the efficiency in the load. Figure 8 and Figure 9 are the block diagram and simulations of the proposed system in MATLAB module.

Table 3. ANN-FNN training results

Input layer	Hidden layer	Output layer
Reactive power	Reference value layer/iterations	Real power
10% (fixed)	50 layers (fixed)	90% efficiency

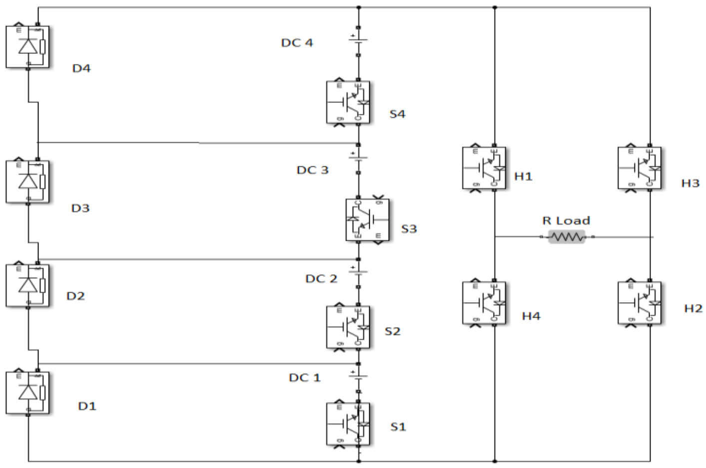

Figure 8. Block diagram of proposed system

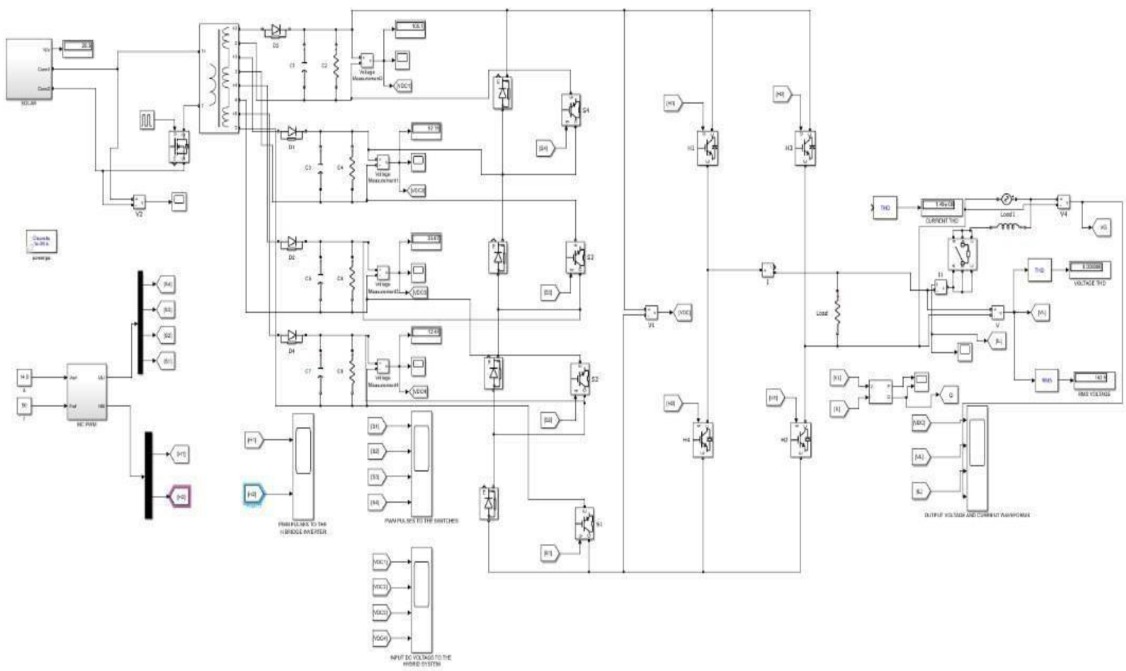

Figure 9. Simulation of proposed system in MATLAB module

5.2. Simulation results
5.2.1. Solar PV source block

The block diagram where the DC voltage source is generated represents in Figure 10. Figure 11 shows outputs that are generated from the solar PV source represent the intensity vs irradiance values on the X and Y-axis respectively. The below block Figure 12 represents the PI controller block as well as the design of switches and pulses to achieve the waveform of the 31-level inverter. Figure 13 refer the carrier and reference wave signal to the 31-level inverter and Figure 14 is 31-level output waveform.

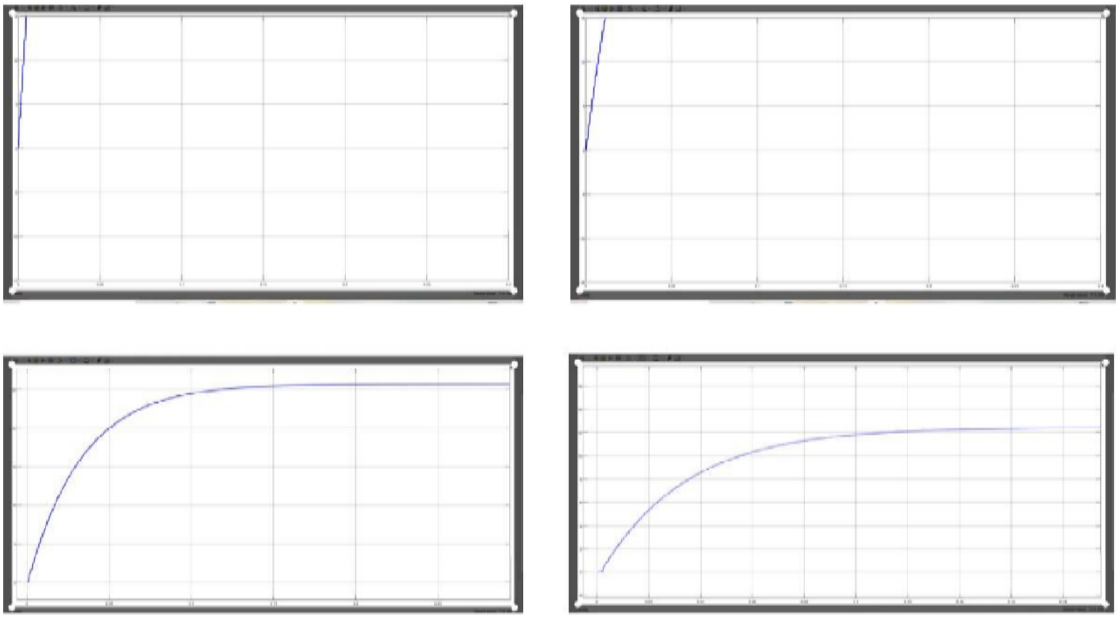

Figure 10. DC outputs simulation from the solar panel

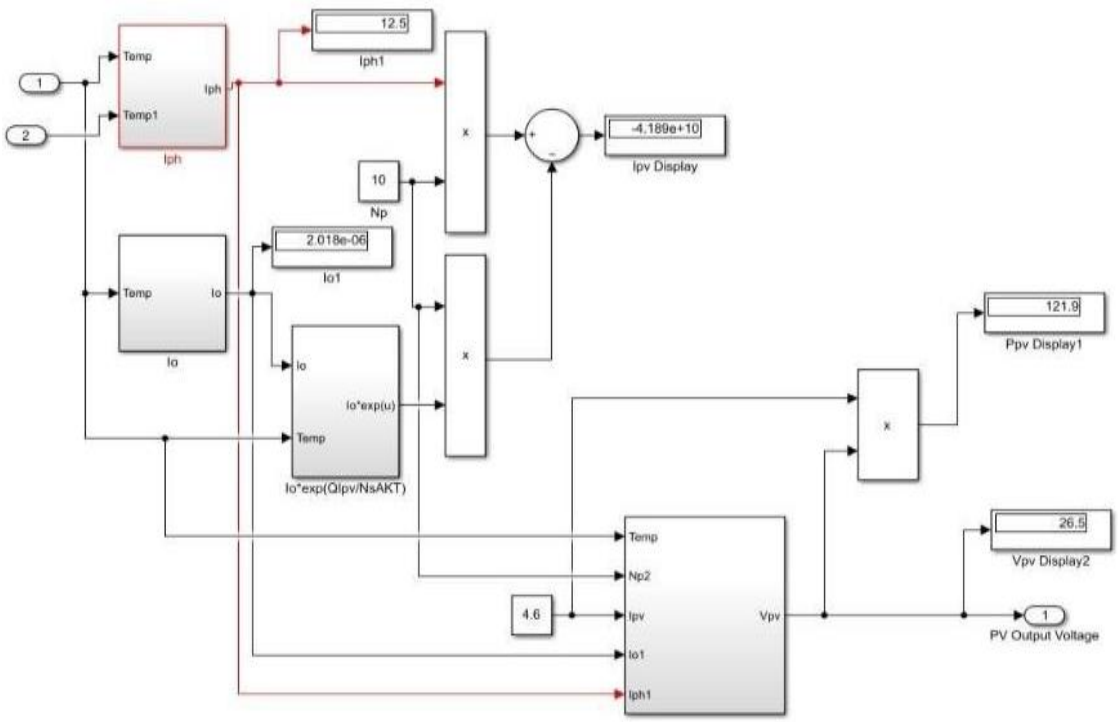

Figure 11. DC outputs generated from solar

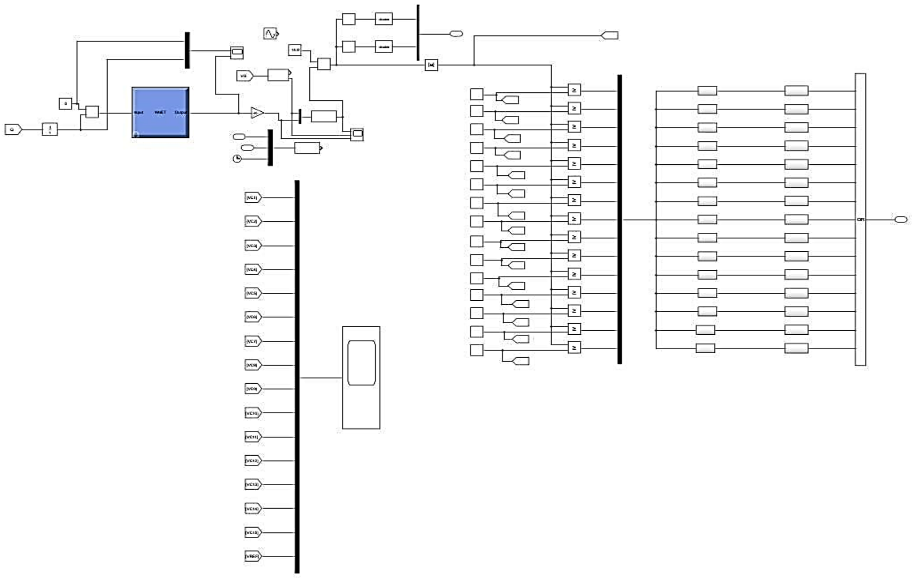

Figure 12. PI controller block

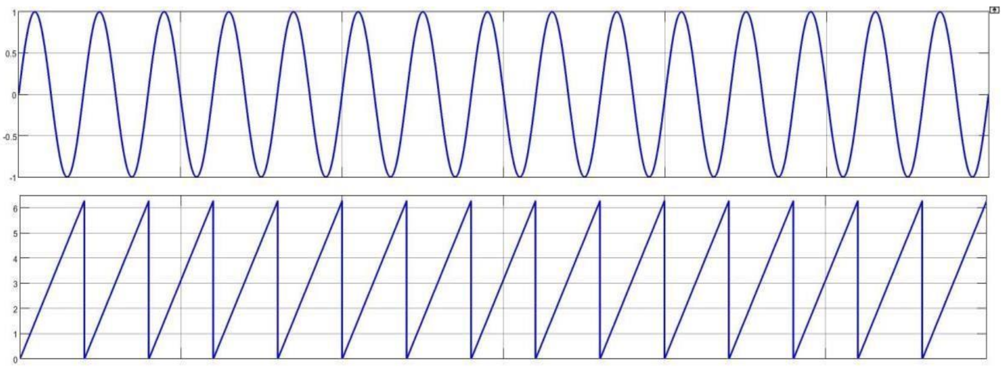

Figure 13. Carrier and reference wave signal to the 31-level inverter

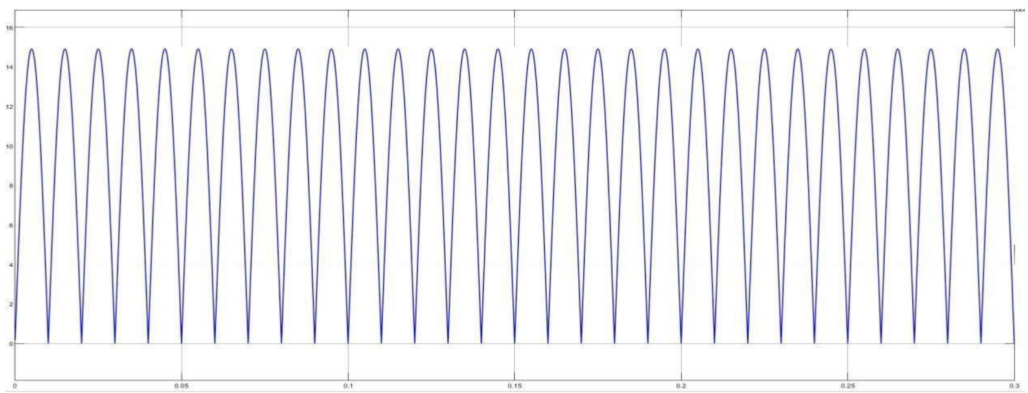

Figure 14. Thirty-one level output waveform

5.2.2. PWM pulses to the cascaded inverter module

The graph represents the ON and OFF times of the pulses in the cascaded inverter module as shown in Figure 15. Figure 16 represents the pulses when the source is converted from DC to AC supply in the polarity changer. Figure 17 it the input DC voltage to the system. In Figure 18, the first scope represents the flyback converter waveform when the constant voltages are fed into the isolated transformer. The Second scope describes the 31-level output voltage waveform which is applied with an LC filter. The third one is about the 31-level output load current waveform which is implemented from the pure resistive load. The last scope is about duty cycle waveform where the output voltage and load current waveform move in a synchronization waveform.

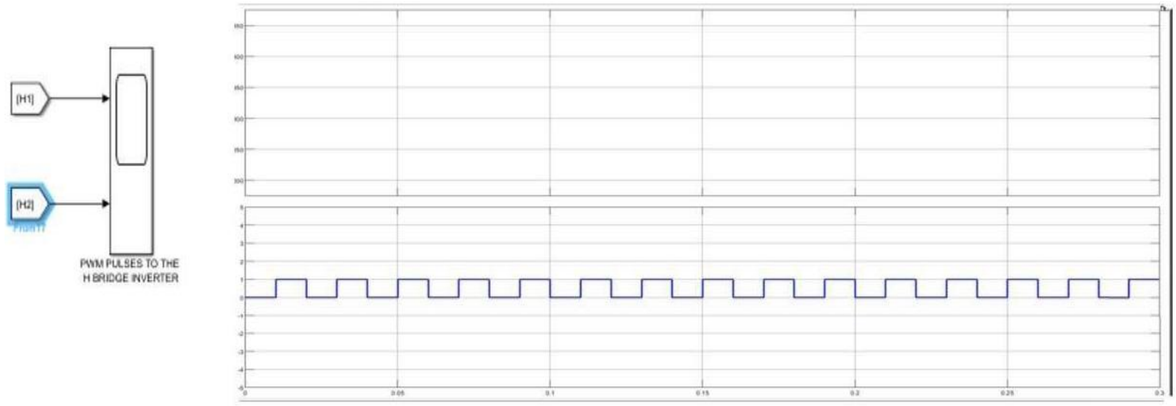

Figure 15. Pulses to the cascaded inverter module

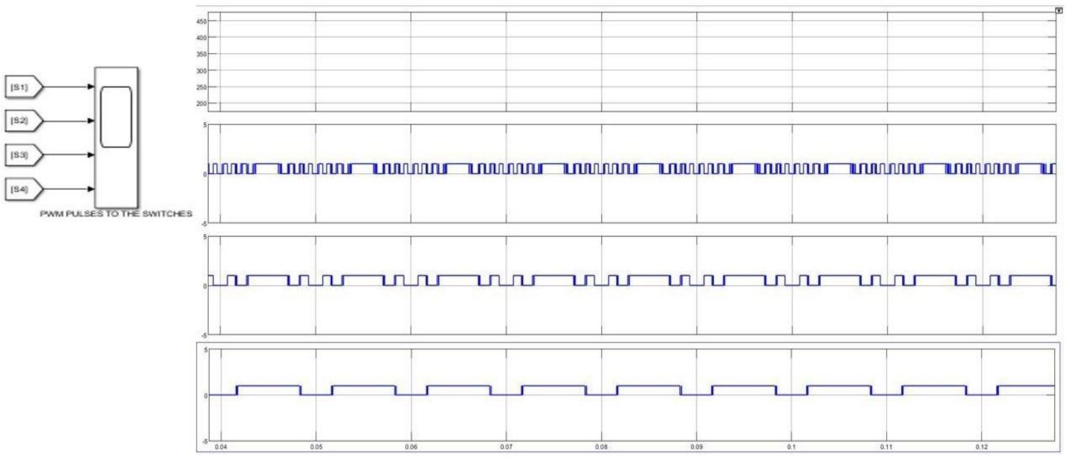

Figure 16. Pulses of the polarity changer

Figure 17. Pulses to the DC voltage

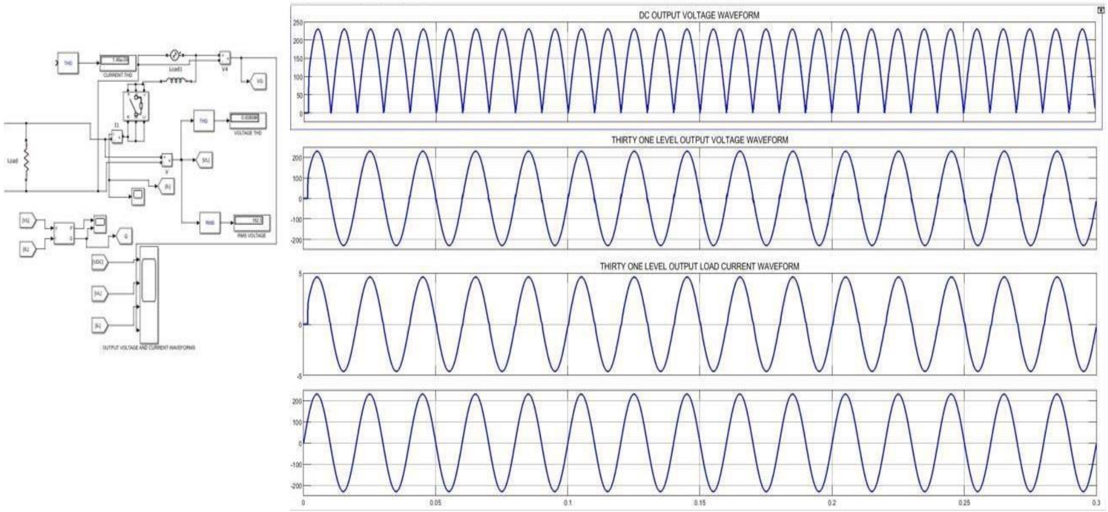

Figure 18. Thirty-one level output voltage and load current waveform with LC filter at the grid side

5.2. Results and discussion between topologies

Table 4 represents the comparisons of results from the existing topology versus the proposed topology. From this Table 4 we can understand the comparision properties of No level, Vrms, THD, and controller. This comparison which gives us idea about the positivity of the prposed design.

Table 4. Comparison between existing topology and proposed topology

S. No	Properties	Existing system	Proposed system
1	Level	7 and 9	Up to 31 levels
2	VRMS	227.5V	235V
3	THD	11.45	9.45
4	Controller	NA	PI &ANN
5	PWM	SPWM	ONLT
6	Load	R	Grid
7	Real and reactive power control	NA	ANN controller
8	MPPT	NA	PI controller

6. CONCLUSION

The suggested system was tested with up to 31 levels using PI and ANN controllers in this article. This system includes advantages such as fewer DC power supplies and low THD power switches. It improves power quality and efficiency while requiring less circuit complexity. The outcomes are summarised with properties such as level, Vrms, THD, and controller. The outcomes we acquired are quite effective and efficient, and they have also been compared to hardware outcomes. Seven-level and nine-level MLI were tested and simulated in MATLAB/Simulink, and the results for R loads are displayed. PWM approaches of many types can also be employed for analysis.

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