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Design of 31 Level Inverter Using Equal Area Criteria Switching Technique Interface with Standalone Photo Voltaic System

Adapala Tejasree[1], I. Siva Prasad[2], P. Sathish Kumar[3]
M.Tech (PEDR) [1], Academic Consultant[2], Assistant professor[3], Department of Electrical & Electronics Engineering, SPMVV-Andhra Pradesh

Abstract: Multilevel inverters have been an attractive topology for academia as well as industry in the recent decade for high power and medium voltage energy control. In this paper focused on the design of a single phase 31-level inverter by using eight switches and four separate DC sources from the solar panel. To get the maximum power from the panel artificial neural network technique can be used in the Maximum Power Point Tracking. The main objective of this paper is to increases the number of levels with a lower number of switches at the output without adding any complexity to the power circuit. The main advantages of the proposed method are to reduce the Total Harmonic Distortion, lower order harmonics and electromagnetic interference and to get high output voltage. To minimize the total harmonic distortion equal area criteria (EAC) switching technique is presented and it can enhance the output voltages from proposed work. The proposed method can be simulated by using MATLAB/Simulink.
Keywords— Standalone photovoltaic system, Artificial neural networks (ANN) MPPT, Multi-Level Inverter (MLI), Equal Area Criteria (EAC), Total Harmonic Distortion (THD).

I. INTRODUCTION

The massy usage of the fossil fuels, such as the coal, the gas and the oil, result in grave conservatory effect and pollute the surrounding, which has great effect the globe. Meanwhile, there is a big contradiction between the fossil fuels supply and the global energy claim, which leads to a high oil price in the world market recently. The major restrictions for the human development are energy deficiency and the atmosphere pollution. Photo Voltaic (PV) sources are one of the considerable players in the world's energy portfolio and will become the biggest contributions to the electricity generation among all renewable energy candidates by year 2040 because of it is clean, emission-free renewable energy technology with high reliability.

Stand-alone photovoltaic power systems are independent of the utility grid and it use solar panels with batteries because the demand from the load does not always equal the solar panel capacity and providing power to the loads throughout the day. The task of a Maximum Power Point Tracker (MPPT) in a PV energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions. while the solar array has a non-idyllic voltage–current characteristic and the conditions such as ambient temperature, insulation and wind that change the output of the solar array are changeable, the tracker must contend with a nonlinear and time-varying scheme. A lot of tracking algorithms and techniques has been developed. The Perturb and observer method [13] and the Incremental Conductance method as well as variants of those techniques are the most widely used. The Perturb and Observer method is known for its simple implementation. However when weather rapidly changes the Perturb and observer method fails to track the maximum power point successfully Keeping in mind all the negative points of the basic algorithms and the techniques to overcome their drawbacks, the present design is so designed to take head on challenges with the existing algorithms by Improved Maximum Power Point using Artificial Neural Network Algorithm[14] and the conceptual solution for high step-up conversion is proposed .The challenges in high step-up renewable energy applications are summarized to generate boost DC/DC converters. In a solar array having an inverter is necessary to convert the DC power which is produced from the solar array to the AC power which is required for our electrical and electronics equipment's. In this work, that contains the multilevel inverter for the conversion of DC-AC, because the total harmonics produced by the multilevel inverter is low while compared with other types of inverter.

The gate pulse to the multilevel inverter is fed through the Equal Area Criteria (EAC) technique [6] [13].The input of the multilevel inverter is fed through the boost converter. Because of step up the input supply from the PV module boost converter can be used. In this method, minimizing the value of THD compared with the conventional methods and reducing the number of switches. We know when devices are connecting in series the overall reliability of the system will reduces. To increase reliability we are using less series switches with asymmetrical voltage sources to get same number of levels. With less number of devices in the MLI the overall efficiency will increase, the size and cost also reduces.

II. STANDALONE PHOTOVOLTAIC SYSTEM

A stand-alone Photovoltaic system is an off-the-grid electricity system for locations that are not fitted with an electricity distribution system. Typical SAPS include methods of electricity generation, energy storage, and regulation. With Photovoltaic system using solar panels.

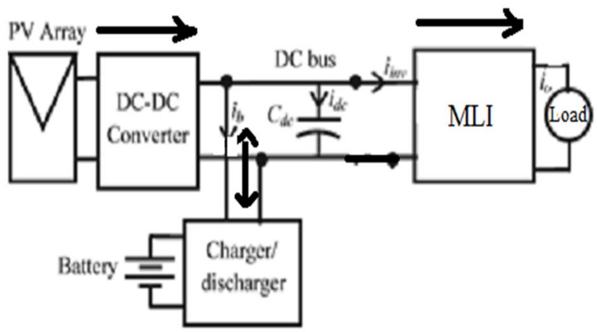

Figure.1 Stand-alone photovoltaic system

Storage is typically implemented as a battery bank. Power drawn directly from the battery will be direct current extra low voltage, and this is used especially for lighting as well as for DC appliances. An inverter is used to generate AC low voltage, which more typical appliances can be used with. Stand-alone photovoltaic power systems are independent of the utility grid and it use solar panels with batteries because the demand from the load does not always equal the solar panel capacity and providing power to the loads throughout the day.

A. Photovoltaic System

A PV system is a system which uses one or more solar panels to convert solar energy into electrical energy. It consists of numerous components, including the photovoltaic modules, and mountings that means of regulating and/or modifying the electrical output [13].

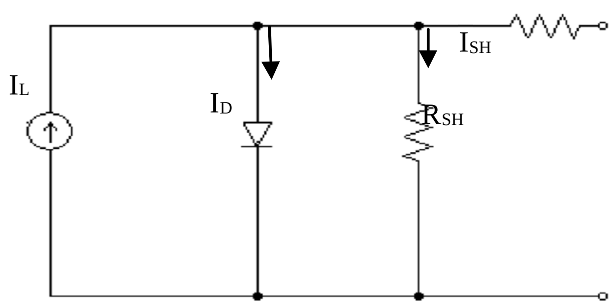

Figure.2 Equivalent Circuit of Solar Cell

The output current from the photovoltaic array is

$IL = I_{sc} - I_d$ (2.1)

$I_d = I_o\,(e^{qVd/kT} - 1)$ (2.2)

Where, I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant ($1.38 * 10^{-19}$ J/K) and T is the junction temperature in Kelvin (K)

From eq. 2.1 and 2.2

$IL = I_{sc} - I_o\,(e^{qVd/kT} - 1)$ (2.3)

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Using suitable approximations,

IL = Isc – Io (eq((V+IRs)/nkT) - 1) (2.4)

Where, IL is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n is the diode ideality factor

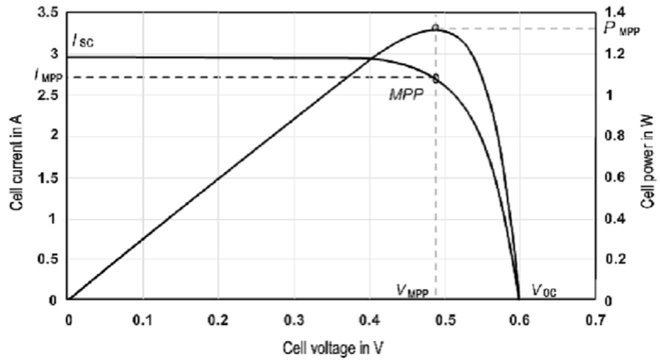


Figure.3 Output Characteristics of Solar Cell

In the Figure. 3 Shows the PV characteristics can be drawn for Current Vs Voltage and Voltage Vs Power. By this way got the Maximum power from the cell [13].

B. Artificial Neural Network MPPT

The Improved Maximum Power Point Tracking System using Artificial Neural Network is a modification of the classical Perturb and Observe Technique. A feed-forward propagation Artificial Neural Network based controller is added here which takes Ambient Temperature (T) and Solar Radiation (G), as two out of its total four inputs, and converts them into information based on the predicted values of the Instantaneous Optimum Voltage ($V_{Optimum}$) of the Photo Voltaic System in order to ensure the maximum power operation.

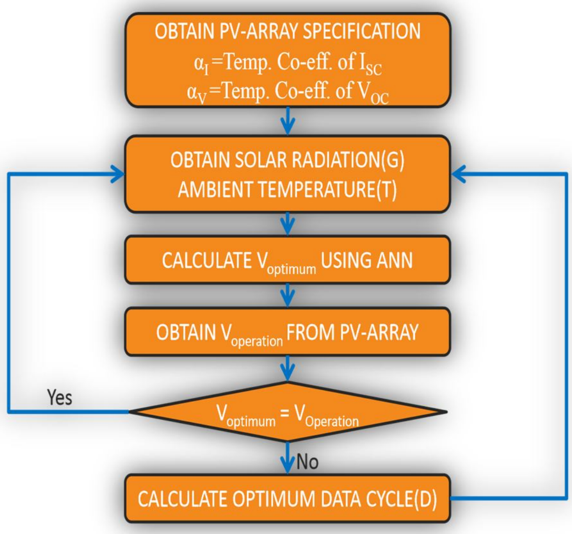


Figure.4 Flow chart of Artificial Neural Network

An artificial representation of the human body, the network tries to simulate its learning process through the various input fed to it during each cycle of data interpretation. It changes its structure based on the internal and external information that flows in and out of the network system. However the major advantage of using the network here is to make sure the response of the Proposed Maximum Power Point Tracking System is faster than the classical Perturb and Observe Algorithm so as to increase the tracking efficiency.

In the first step, the Photo Voltaic Array's specifications for Temperature Coefficient of Short Circuit Current I_{SC} and Temperature Coefficient of Open Circuit Voltage V_{OC}, are obtained and stored. The Artificial Neural Network now gets the values of Incident

Solar Radiation G and Ambient Temperature T. The controller calculates $V_{Optimum}$. Now collect the magnitude of $V_{operation}$ of the PV Array. If $V_{operation} \neq V_{optimum}$, then Duty Cycle is calculated and also controlled, else the flow switches on to get the next values of Solar Radiation and Ambient Temperature [14].

The Artificial Neural Network has been designed using the simple short circuit current I_{SC} and open circuit voltage V_{OC} equations which are described as:

$I_{SC} = I_{SC}^{*}(G/G^{*}) + \alpha_i (T-T^{*})$

$V_{OC} = V_{OC}^{*} + \alpha_v (T-T^{*}) - R\,(I_{SC} - I_{SC}^{*})$

Where,

I_{SC} = Short Circuit Current

V_{OC} = Open Circuit Voltage

G^{*} = Reference Solar Radiation

I_{SC}^{*} = PV I_{SC} at Ref. Solar Radiation

α_i = Temperature Co-efficient of ISC

T^{*} = Reference Temperature

V_{OC}^{*} = V_{OC} at Ref. Temperature

α_v = Temperature Co-efficient of V_{OC}

C. Design of Boost Converter

Boost converter is the best one for hybrid configuration. The only disadvantages of the other converters are harmonic current flow which will affect the overall system efficiency. It does not having any input filter, hence the size of the system reduces. To transferring power from the PV modules to a battery DC-DC boost converter is used. Output voltage can be regulated by changing the duty cycle of switches by using PI controller in converter, the circuit diagram of this converter is shown in Figure.5

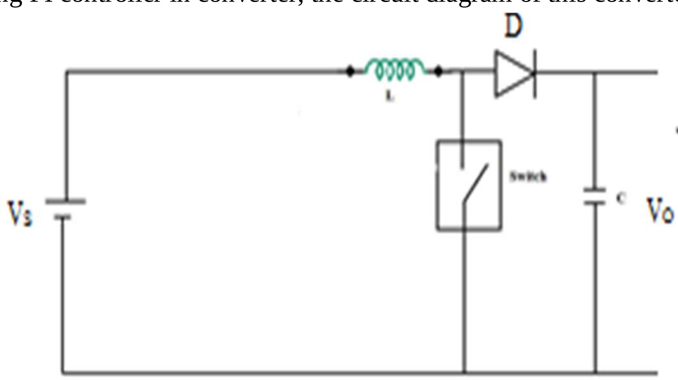


Figure.5 Design of the Boost Converter

The output voltage is given by

$V_o = \frac{Vs}{(1-D)}$

Where D =Duty Ratio

Vo =Output Voltage (volts)

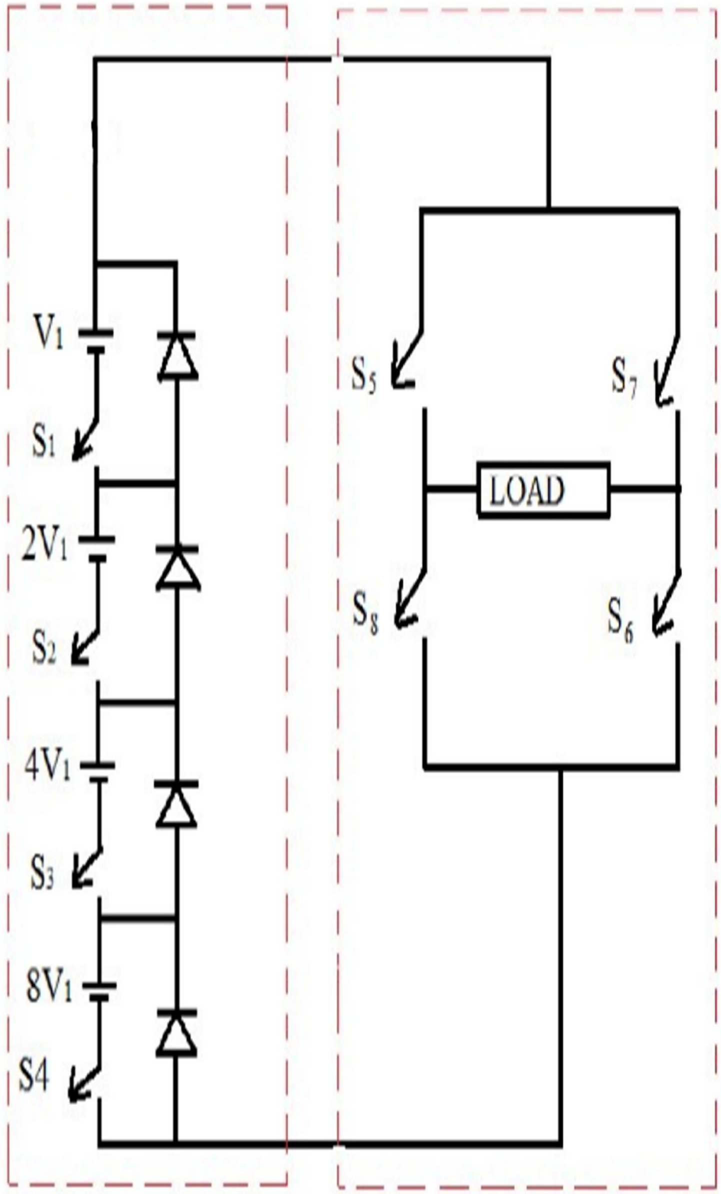
Vs =Input Voltage (volts)

D. Operation with Batteries

At night, an Off-Grid PV Power System uses batteries to supply power to its loads. Though the battery, when charged to its full capacity may have its operating voltage close enough to the PV Array's Peak Power Point.

III. PROPOSED MLI TOPOLOGY

The proposed topology has a set of asymmetrical voltage sources and combination of level generating and polarity generating cell. to get 31-level with less THD, we require only four power switches in level generation cell (LGC) and four in polarity generation cell ((PGC) i.e., H-bridge)) i.e, with eight switches we can generate 31-levels. The proposed 31-level inverter is shown in below Figure.6,



Level generating cell   Polarity generating cell
Figure.6 Proposed 31-level inverter

Here, V_1 is step voltage and the voltage ratio of asymmetrical voltage sources is given by, $V_1 : 2V_1 : 4V_1 : 8V1$
Here, we have two cells, they are level generating cell and polarity generating cell. The LGC generates number of output levels with the help of switching sequence and PGC generates +Ve and –Ve half waves for AC operation. The voltage across LGC is 31-level pulsating DC and the frequency of voltage wave is two times of output voltage frequency [6].

IV. SWITCHING TECHNIQUE

In this paper the simple technique called EAC is implemented to finding the initial values and these initial switching angles are enough to get minimum THD for any number of levels. The EAC is a natural method of finding the best switching angles [6], [7]. By dividing half of fundamental sine wave horizontally and vertically with step voltage and time (ms) respectively.

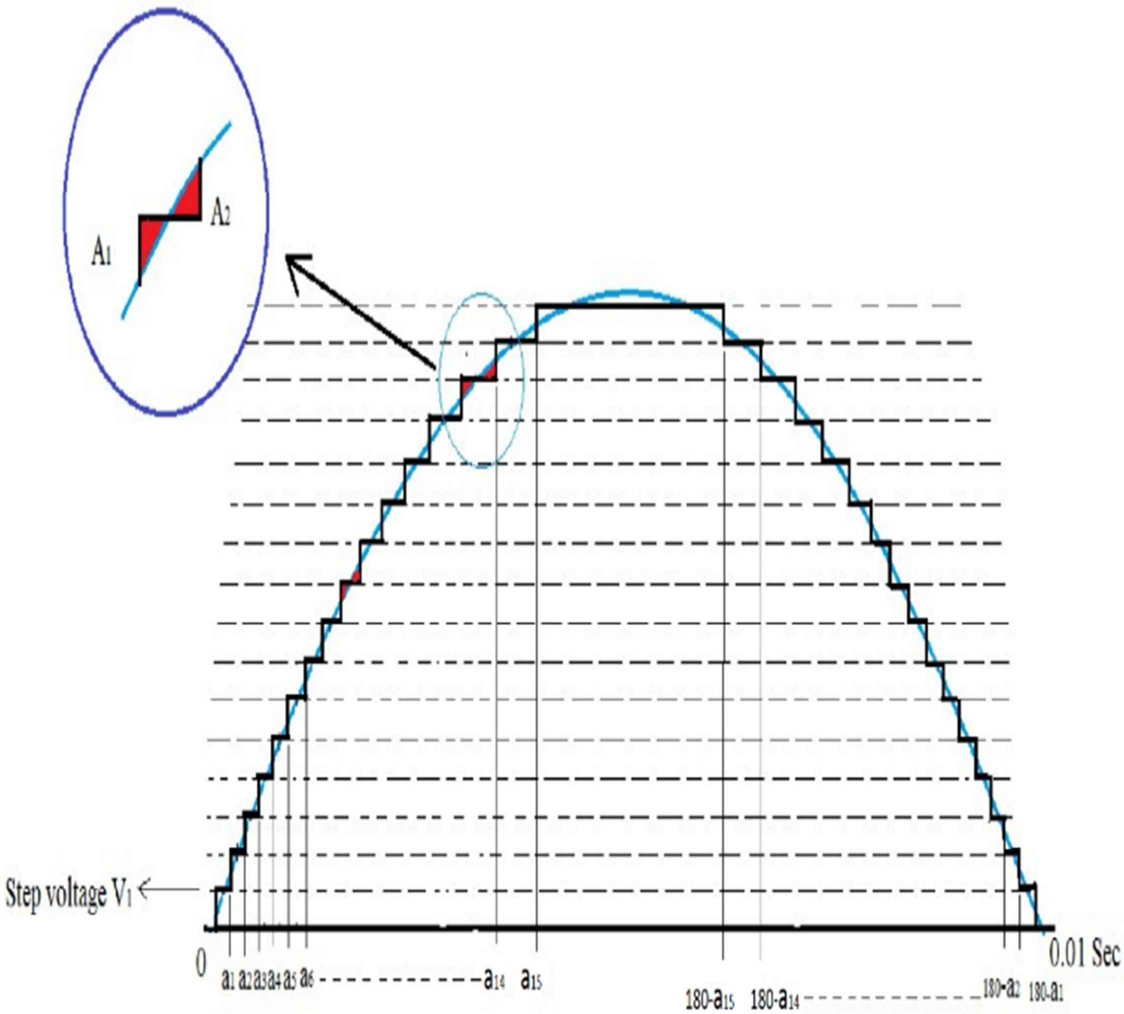


Figure.7 Equal Area Criteria (EAC) switching technique

Here, A_1 and A_2 are the areas shown in above figure. To get minimum THD the areas of A_1 and A_2 should be equal. The fundamental switching frequency is taken as 50Hz [6].

Here, $a_{1,}$ $a_{2,}$ $a_{3,}$ . . . . a_n are the switching angles for N-level MLI. All the angles should be $<90^0$.

$0<a_1<a_2<a_3<a_4<a_5<a_6<a_7$ - - - - $a_n<90^0$

Number of switching angles for N-levels = [(Number of levels-1)$_{/2}$]

A. *Mathematical formula for angle calculation*

N^{th} switching angle a_n (deg.) = [Time at which the N^{th} vertical line touches the time axis (x-axis)] x [2 x fundamental frequency]] x 180^0

The switching angles for 31-level is given below, $a_1=2^0$, $a_2=6^0$, $a_3=10^0$, $a_4=14^0$, $a_5=18^0$, $a_6=22^0$, $a_7=26^0$, $a_8=30^0$, $a_9=35^0$, $a_{10}=40^0$, $a_{11}=45^0$, $a_{12}=51^0$, $a_{13}=57^0$, $a_{14}=64^0$ $a_{15}=74^0$

By using above formula we can calculate switching angles for N number of levels. These angles can also be useful for initial guess in NR. With the above switching angles the THD of 31-levels is 2.85%. Here the sinusoidal pulse width modulation technique (SPWM) can be used for controlling H-bridge switches [6].

In order to obtain integral multiple of +Vdc levels in the output voltage, switches S5 and S6 should be turned ON and for –Vdc levels switches S7 and S8 should be turned ON. For zero level simultaneously either S5&S6 or S7&S8 should be turned ON. The switching pattern for different levels of 31-level inverter is shown in tabular form given below.

Table-1: Switching sequence for proposed 31-level inverter

S.NO	S1	S2	S3	S4	S5	S6	S7	S8	Output voltage(if V1=1v)
1	1	1	1	1	1	1	0	0	15V
2	0	1	1	1	1	1	0	0	14V
3	1	0	1	1	1	1	0	0	13V
4	0	0	1	1	1	1	0	0	12V
5	1	1	0	1	1	1	0	0	11V
6	0	1	0	1	1	1	0	0	10V
7	1	0	0	1	1	1	0	0	9V
8	0	0	0	1	1	1	0	0	8V
9	1	1	1	0	1	1	0	0	7V
10	0	1	1	0	1	1	0	0	6V
11	1	0	1	0	1	1	0	0	5V
12	0	0	1	0	1	1	0	0	4V
13	1	1	0	0	1	1	0	0	3V
14	0	1	0	0	1	1	0	0	2V
15	1	0	0	0	1	1	0	0	1V
16	0	0	0	0	1	1	0	0	0V
17	1	0	0	0	0	0	1	1	-1V
18	0	1	0	0	0	0	1	1	-2V
19	1	1	0	0	0	0	1	1	-3V
20	0	0	1	0	0	0	1	1	-4V
21	1	0	1	0	0	0	1	1	-5V
22	0	1	1	0	0	0	1	1	-6V
23	1	1	1	0	0	0	1	1	-7V
24	0	0	0	1	0	0	1	1	-8V
25	1	0	0	1	0	0	1	1	-9V
26	0	1	0	1	0	0	1	1	-10V
27	1	1	0	1	0	0	1	1	-11V
28	0	0	1	1	0	0	1	1	-12V
29	1	0	1	1	0	0	1	1	-13V
30	0	1	1	1	0	0	1	1	-14V
31	1	1	1	1	0	0	1	1	-15V

In the table representing switching patterns for 31-level, ‘1’is treated as “ON” and ‘0’ as “OFF” [2].
The output voltage waveform has 31-levels: ± 15Vdc, ± 14Vdc, ± 13Vdc, ± 12Vdc, ± 11Vdc, ± 10Vdc, ± 9Vdc, ± 8Vdc, ±7 Vdc, ± 6Vdc, ± 5Vdc, ± 4Vdc, ± 3Vdc, ± 2Vdc, ±Vdc and 0 level. Switching sequence for 31-level inverter is shown in Table-1.

B. THD Calculation:

In general, the Fourier series expansion of the staircase output voltage waveform is given by

$$V_{an} = \sum_{K=1,3,5,}^{\infty} \frac{4V_{dc}}{k\pi} \left(\cos(k\alpha_1) + \cos(k\alpha_2) + \ldots + \cos(k\alpha_s)\right)\sin(kwt) \qquad \text{(i)}$$

Where *s* is the n^th^ switching angle and *k* is order of harmonic components. Among *s* number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (*s*-1) switching angles are used to eliminate certain predominating lower order harmonics.

From equation (i), the expression for the fundamental voltage in terms of switching angles is given by

$$\frac{4V_{dc}}{\pi} \left(\cos(\alpha_1) + \cos(\alpha_2) + \ldots\ldots\ldots + \cos(\alpha_s)\right) = V_1 \qquad \text{(ii)}$$

From the above two equations (i) and (ii), the percentage value of THD is given by

$$\%THD = \frac{\sqrt{\sum_{n=2,3\ldots}^{\infty} V_n^2}}{V_1} \times 100$$

V. SIMULATION AND RESULTS

The Proposed 31-level inverter simulation circuit with resistive load is as shown below

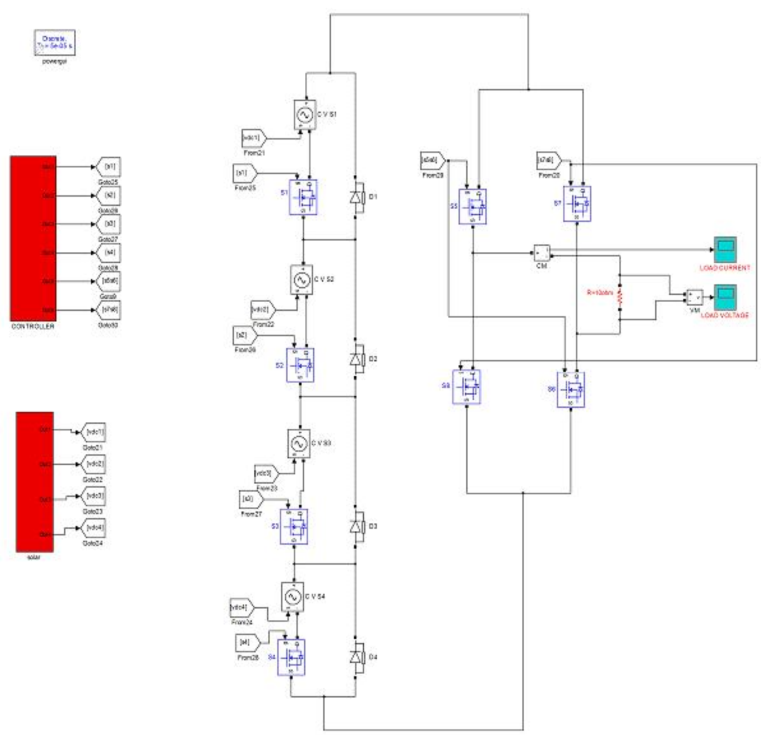


Figure.8 Simulink model of proposed 31- level inverter

After calculation of switching angles we used pulse generators for LGC to Switch ON the switches at calculated switching angles and for H-bridge SPWM. The value of THD is observed with the help of FFT analysis using MATLAB/Simulink software for 31-

level with resistive load of 10ohms. We achieved The THD value of the above levels is 2.85%. The output voltage wave form, gate pulses for switches and FFT analysis of output voltage are shown in below figures.

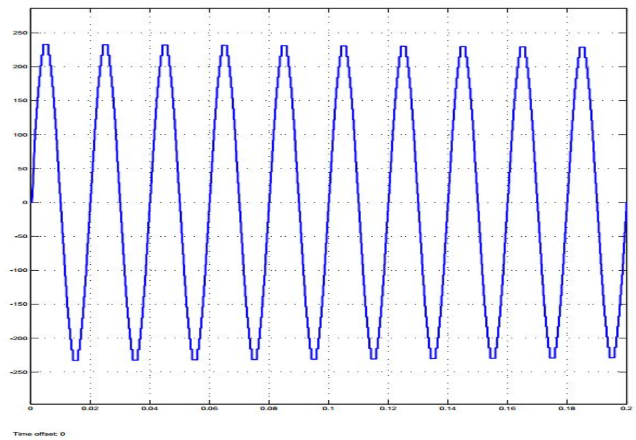


Figure.9 Output voltage wave form of 31-level inverter

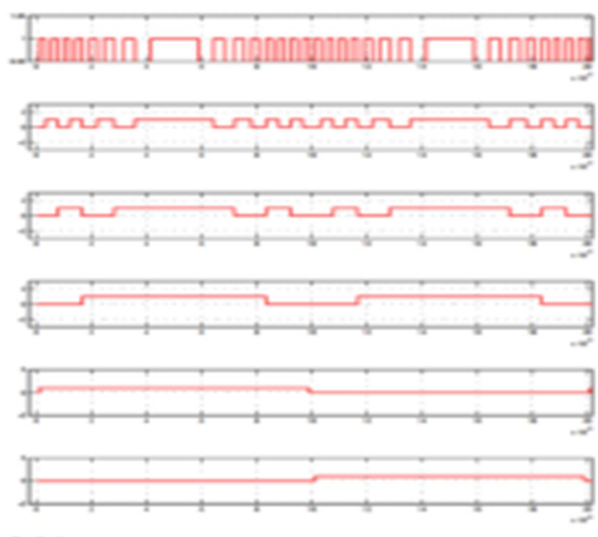


Figure.10 gate pulses for switches in 31-level inverter

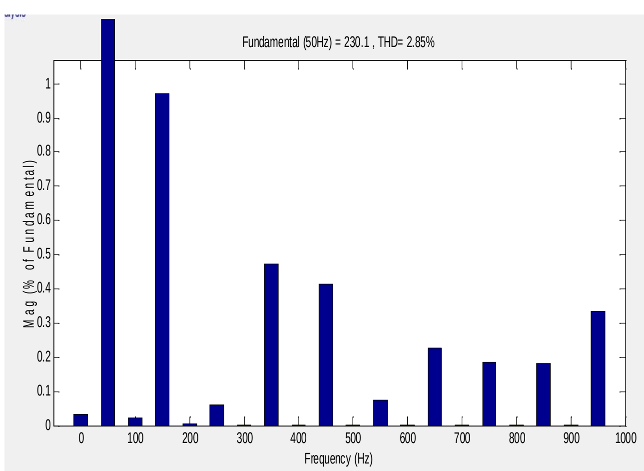


Figure.11 FFT analysis of 31-level inverter output voltage

VI. CONCLUSION

In this paper, ANN technique is used in MPPT scheme to get the maximum power from the panel and it improves the panel efficiency and here using batteries for standalone PV application. In the proposed method EAC switching Technique can be used to find the switching angle for MLI. At the instant, MLI can be used to reducing the number of switches, LOH and reducing the lower THD. Here the THD decreases with increasing the number of levels, developing the efficiency of the scheme, losses and cost of inverter is less compared to conventional MLIs. With this simple method we can easily calculate the best switching angles, No need of solving complex non-linear equations, No need of writing the MATLAB program for GA and NR and No need of guessing initial angles. With this EAC technique we achieved 2.85% THD with resistive load for 31-level without filter which is within limits specified by IEEE 519 standards.

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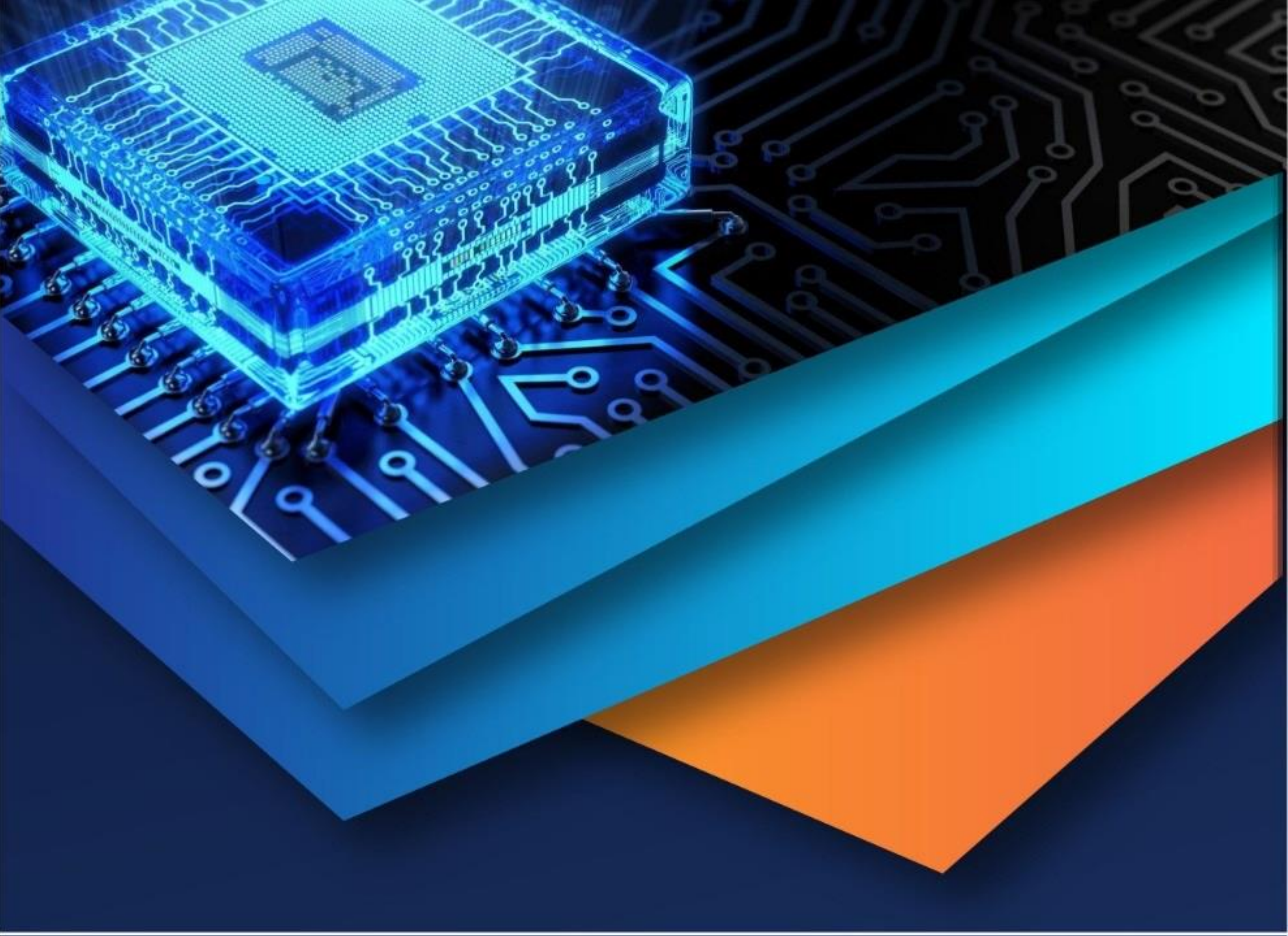

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