International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 05, May 2017
ISSN: 2455-3778
http://www.ijmtst.com

Grid Connected Photovoltaic Multilevel Inverter Using Maximum Power Point Tracking Algorithm

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To Cite this Article
P.Manisankar, N.Satish Kumar and G.Balasubramanian, "Grid Connected Photovoltaic Multilevel Inverter Using Maximum Power Point Tracking Algorithm", *International Journal for Modern Trends in Science and Technology*, Vol. 03, Issue 05, May 2017, pp. 123-129.

ABSTRACT

In this paper presents a maximum power point tracking algorithm properly adapted by grid-tied photovoltaic multi level inverter. The inverter structure is based on a single-phase cascaded H-bridge inverter configuration, where each solar cell is supplied by an individual photovoltaic panel. The maximum power point tracking algorithm is based on a suitable hysteresis band, which defines the proper boundaries for maximum power point tracking references to ensure both stable inverter operation and maximum photovoltaic power extraction. The inverter control method is a mixed staircase pulse width modulation based on a sorting algorithm. The experimental tests have been performed by using a PIC 16F877A Microcontroller with single-phase five-level photovoltaic cascaded H-bridge inverter, which is controlled by real-time hardware platform. The experimental results confirm that the proposed control is able to efficiently track the maximum power point while assuring good performance in terms of harmonic distortion and power factor improvement in both standard and mismatch conditions.

KEYWORDS — *PV Panel, DC - DC Converter, Cascaded H-Bridge Inverter (CHB), Incremental Conductance MPPT Algorithm, PIC Microcontroller, Staircase Pulse Width Modulation.*

I. INTRODUCTION

In the last few years a slow, but gradual, revolution is coming out in the production of electrical energy from renewable energy sources. The feed-in tariffs policies adopted by many countries, especially in Europe, have supported the spread of photovoltaic (PV) energy resources. However, PV cells still show technology limitations in terms of efficiency, thus requiring significant improvements in the exploitation of PV systems. In particular, a grid-tied PV system should ensure the maximum power extraction, increasing the power delivered to the grid. As a consequence, a dedicated maximum power point tracking (MPPT) algorithm should be used to guarantee proper tracking of the maximum power point (MPP) while reducing losses and total harmonic distortion (THD). Moreover, a critical issue is the possibility of obtaining the previous performance both in normal and mismatch conditions because of different irradiation and temperature of the PV panels. Several power conversion circuits have been proposed with the aim of satisfying the aforementioned specifications.

In a review of the most popular circuital topologies was presented, and four main families can be considered: centralized topology, string and multi-string topology, and AC-module topology. Usually, the first three configurations present two power stages. In particular, the front stage is a boost DC-DC converter to obtain proper DC-bus voltage and/or a wider tracking range, while the second stage is an inverter to generate the desired AC grid voltage.

Instead of a boost DC-DC converter, a step transformer can be also used to meet the grid voltage requirement. Thus, the input of MPPT block is the PV current slope, while the output is the PV voltage reference [1]. This latter quantity is then used by the inverter control section. In fact, the adopted multi-level inverter control strategy is based on a mixed staircase–pulse-width modulation (PWM) technique, where a sorting algorithm determines the single power cell operating mode. The sorting is performed by considering the voltage error at each DC-link or rather the difference between the MPPT reference and measured voltage. This calculation allows identification of the cell, which must be in PWM mode, while the others are kept in a fixed state to synthesize the desired multi-level waveform.

The proposed approach represents a novelty with respect to traditional PWM techniques that have been successfully extended for multi-level converter topologies by using multi-carrier PWM methods. Each carrier can be associated to a particular cell thus control action is shared among the series-connected cells. In particular, the phase shifted technique provides an even power distribution, while the level shifted leads to an uneven lower distribution. The state of the art of distributed maximum power point techniques for photovoltaic systems is discussed. Modern applications of photovoltaic systems in urban context and to sustainable mobility require the proper facing of drawbacks due to partial shading and different orientations of the cells the photovoltaic source is made of.

The latest architectures proposed in literature are reviewed and their points of strength and weakness are discussed. Finally, the products that are currently available on the market are presented and their fields of application and features are overviewed. The Photovoltaic (PV) energy is one of the most important energy resources since it is clean, pollution free, and sustainable [2] [4]. Maximum Power Point Tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic output power, irrespective of the temperature and radiation conditions. In MPPT system, the PV output power is fed directly to dc/dc converter and the output of MPPT control is used to control the dc/dc converter in order to operate at the maximum possible power point (MPP) [3].

In this paper it is proposed to track the MPP in PV module using incremental conductance algorithm. boost converter is used as dc/dc converter to achieve the power/voltage level conversion. The MPPT system has been simulated using MATLAB/Simulink software to track the maximum output power from PV array and charge a battery bank. Simulation results show that the proposed MPPT system is capable of maximum power tracking of the PV array as desired [5]. The design and simulation for maximum power point tracking (MPPT) for photovoltaic system, which includes a high-efficiency dc-dc boost converter with a modified incremental conductance algorithm.

The converter can draw maximum power from the PV panel for a given solar irradiance and temperature by adjusting the duty cycle of the converter. The modeling procedure for the circuit model was presented using MATLAB/Simulink Sim-power. The MPPT system has been tested with solar panel ICO-SPC 100 W module under various operating conditions. The obtained results prove that the proposed MPPT can track even under sudden change in sunlight conditions and loading level. The Photo Voltaic (PV) cell which is a direct method of generating electricity using solar energy is used [6].

This paper is concerned with the optimal management of power in residential areas by using the energy generated by the PV when it is in full swing operation. By doing so the energy which is consumed under normal conditions that is electricity from the grid, a nonrenewable source of energy (FOSSIL FUELS) can be saved. The main idea of this project revolves around the fact of saving electricity from the grid which is nonrenewable source of energy to the maximum by generating electricity using PV that generates electricity using solar energy [7]. But even by using PV to generate electricity there is a small issue regarding the spillage or leakage that occurs. This spillage by using a boost converter in the circuit which boosts the voltage generated by PV to the required level of the voltage.

This paper is proposed to design a boost converter for photovoltaic (PV) system using microcontroller. Maximum Power Transfer in solar photovoltaic applications is achieved by impedance matching with a dc-dc converter with maximum power point tracking by the incremental conductance method. Regulation and dynamic control is achieved by operating with continuous conduction. It can be shown that under stable operation, the required output inductor has an inductance versus current characteristic whereby the inductance falls off with increasing current, corresponding to increasing incident solar radiation. This paper describes how a variable sloped air-gap inductor whereby the inductor core progressively saturates with increasing current meets this requirement and has the advantage of reducing the overall size of the inductor by 60% and increases the operating range of the overall tracker to recover solar energy at low solar levels.

The various topologies and controlling strategies used in multi level inverter. MLI are used to improve the waveform output of the inverter to be nearly to sinusoidal so that the harmonic injection by that inverter is minimum. In this paper implement a multi level inverter used in photo voltaic grid integration.

II. PV SYSTEM MODELLING

2.1 Photovoltaic Cell

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that photovoltaic effect. The photovoltaic modules current and power characteristics and different irradiation and temperature condition.

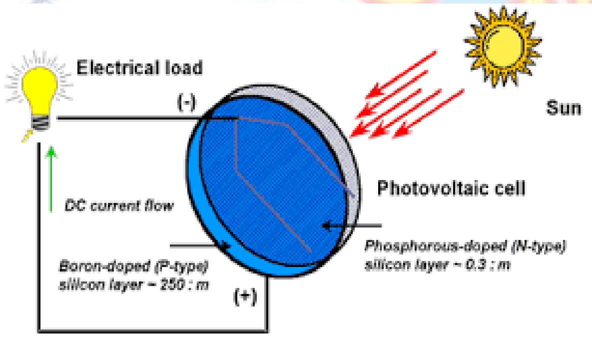

Fig.1: Photovoltaic cell

It can be observed that the PV module's short circuit current highly depends on the radiation. High radiation leads to leads to large short circuit current. The temperature impacts more on the open circuit voltage. High temperature leads to leads to small open circuit voltage, because of its *I*-V and P-*V* characteristics, Maximum Power Point Tracking(MPPT) is required to extract the maximum energy that the PV module can produce.

2.2 Solar Module and Array Module

A typical PV cell produces less than 2W at 0.5V approximately the cells must be connected in series-parallel configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuit to generate the required current and voltage .The equivalent circuit for the solar module arranged in parallel and series.

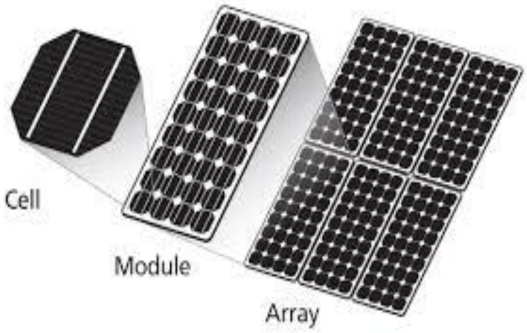

Fig. 2: Solar module and array module

The PV efficiency is sensitive to small change in RS but insensitive to variation. For a PV module or array, the series resistance becomes apparently importance and the shutdown resistance approaches infinity which is assumed to be open an appropriate equivalent circuit for all PV cell module, and array is generalized.

2.3 Characteristics of PV Module

The silicon solar cell gives output voltage of around 0.7 V under open circuit condition. To get a higher output voltage many such cells are connected in series. The typical characteristic curve of a PV solar cell is shown below.

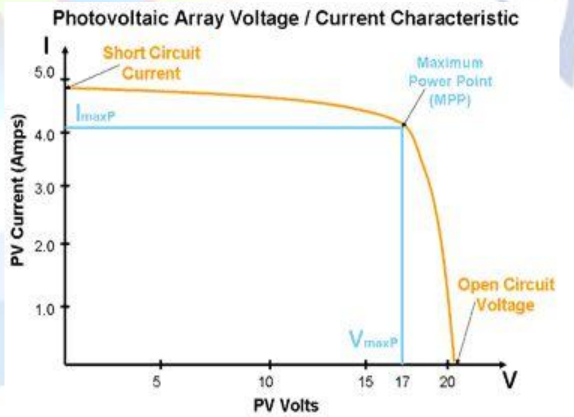

Fig. 3: Characteristics of PV cell

2.4 DC-DC Converters

DC-DC boost converters with MPPT control were used at the output of the PV array to provide power to the load. Boost converters are used in PV power applications because of its simple topology, fast transient response and continuous input current. For providing high output voltage dc-dc converters has to be operated at extreme duty cycle, which would subjects switching devices to short pulse which leads to reverse recovery and EMI (Electro magnetic interference) problems. Converters with coupled inductors can provide high output voltage and less switching voltage stress without extreme duty cycle. But the leakage energy loss in the coupled inductor reduces the efficiency of the converter.

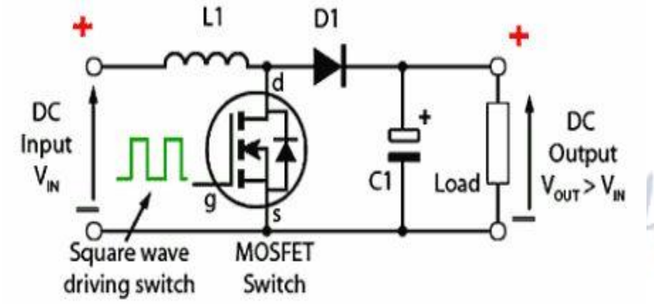

Fig.4: Circuit Diagram of DC-DC converter

2.5 Cascaded H-Bridge Inverter

The H-Bridge topology requires one DC source along with four MOSFET switches and one balancing capacitors. In order to obtain consequent levels we need a same set of topology which increases the number of components needed which in turn creates design complexity and increases the cost and number of components used. It is also found that the maximum output voltage cannot exceed the sum of voltage of individual sources which becomes the major setback of this topology.

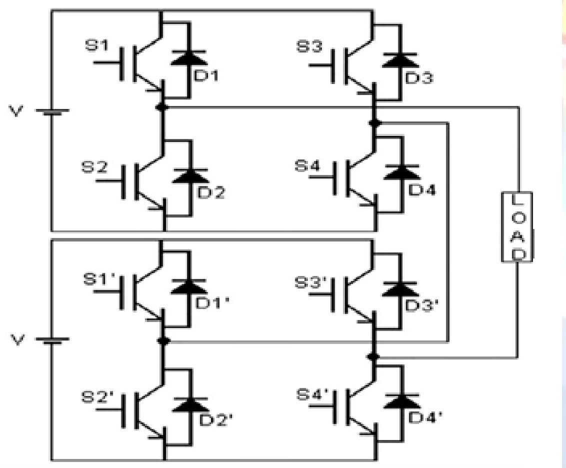

Fig.5: Five Level Cascaded H-Bridge Inverter

Fig.5 shows a five level cascaded H-bridge multilevel inverter. The converter consists of two series connected H-bridge cells which are fed by independent voltage sources. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs. The output voltage is given by V=V1 +V2, Where the output voltage of the first cell is labeled V1 and the output voltage of the second cell is denoted by V2. There are five level of output voltage ie 2V, V, 0, -V, -2V.

The main advantages of cascaded H-bridge inverter is that it requires least number of components, modularized circuit and soft switching can be employed. But the main disadvantage is that when the voltage level increases, the number of switches increases and also the soures, this in effect increases the cost and weight. The cascaded H-bridge multilevel inverters have been applied where high power and power quality are essential, for example, static synchronous compensators, active filter and reactive power compensation applications, photo voltaic power conversion, uninterruptible power supplies, and magnetic resonance imaging.

Furthermore, one of the growing applications for multilevel motor drive is electric and hybrid power trains.The one point of that supply is connected to the rectifier bridge, which is used for the polarity protection. Other terminal of supply is connected to the 7805 voltage regulator it can be regulate the voltage, across that regulator two capacitor are connected for smoothening purpose.

The RF 433 Transmitter uses to generate the radio waves for communication between these whole assemblies. The range of the radio waves is about 3 KHz to 300 GHz. The RF 433 Receiver uses to receive the radio waves. The encoder is used to convert the parallel input signal of 4 push button into the serial output. The decoder is decoding that signal and gives to the microcontroller. Microcontroller PIC16F877A is used to control the duty cycle of the pulse and simultaneously the terminal voltage is varying and also the speed will be varied.

2.6 Mathematical Model of Multilevel Inverter

The general single-phase configuration of a grid-tied PV CHB inverter. Each phase leg consists of a generic number *N* of H-bridge cells connected in series and permits both a string or module connection to the grid. Each power cell of the CHB inverter can generate three voltage levels (0, $+vpvi$, $-vpvi$) determined by four different states of the switching devices. By assuming the switch state as a binary signal (*i.e.*, switch *on* corresponds to 1, while switch *off* corresponds to 0), the inverter phase voltage *vin*is defined as

$$vin = \sum_{i=1}^{N} Vhi = \sum_{i=1}^{n} (Si1 - Si3)vpvi = \sum_{i=1}^{n} hivpvi$$

Where *hi* are the switching function that modulates the *vHi*voltage on the *I*-the DC-link capacitor (*Ci*), and the possible discrete values of *hi* are +1, −1, and 0. Moreover, replacing *him* with a continuous switching function $\bar{h}_i$, bounded in the interval [−1, +1], the dynamic behavior of the circuit can be easily described as follows

$$\frac{di_{in}}{dt} = \frac{v_L}{L} = \frac{v_{grid} - v_{inv}}{L} = \frac{v_{grid} - \sum_{i=1}^{N} \bar{h}_i v_{pvi}}{L} \qquad i = 1, .., N,$$
$$\frac{dv_{pvi}}{dt} = \frac{1}{C_i}(i_{pvi} + \bar{h}_i i_{in})$$

Where *l* is the inductance of the output filter inductor, and *iin*is the inverter input current (in phase opposition with grid current*igrid*).

2.7 MPPT Algorithm

The proposed MPPT algorithm is performed by considering the derivative of PV current with respect to PV voltage and by establishing a boundary range (hysteresis band) within which the steady-state PV operating point is confined. The lower boundary of hysteresis band *a*1 (*i.e.*, lower boundary of the MPPT range) is the derivative of the PV current with respect to PV voltage properly evaluated to avoid voltage range overruns in the flat region of the I-V curve. The observance of the previous condition ensures stable system operation. Thus, the lower boundary is chosen with the aim of establishing a lower MPPT voltage threshold by bearing in mind the temperature and irradiance range as well as the AC voltage fluctuations at the DC-link. Moreover, the minimum value of PV voltage (*i.e.*, DC-side voltage) must be defined also to obtain a proper synthesis of the AC-side multi-level waveform by ensuring a total DC-side voltage higher than the grid peak voltage. As consequence, the value of *a*1 must accomplish the above requirements to assure both stable and proper operation of the inverter.

2.8 Incremental Conductance MPPT

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module [8].

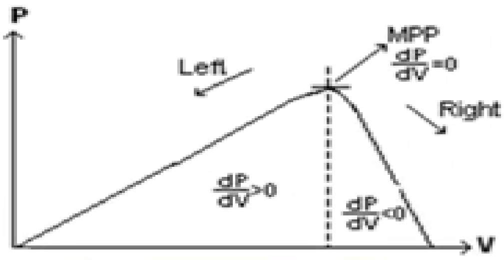

Fig. 6: Basic idea of incremental conductance method on a P-V Curve of solar module

The slope of the P-V array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The PV system is modeled using Power System Block set under Matlab/ Simulink.

2.9 Incremental Conductance MPPT Algorithm

This method exploits the assumption of the ratio of change in output conductance is equal to the negative output Conductance Instantaneous conductance. We have,

P = V I

Applying the chain rule for the derivative of products yields to

∂P/∂V = [∂ (VI)]/ ∂V

At MPP, as ∂P/∂V=0

The above equation could be written in terms of array voltage V and array current I as

$$\partial I/\partial V = -I/V$$

The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: (∂I/∂V) + (I/V) = 0 is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance [8]. The Flow chart of incremental conductance MPPT is shown below.

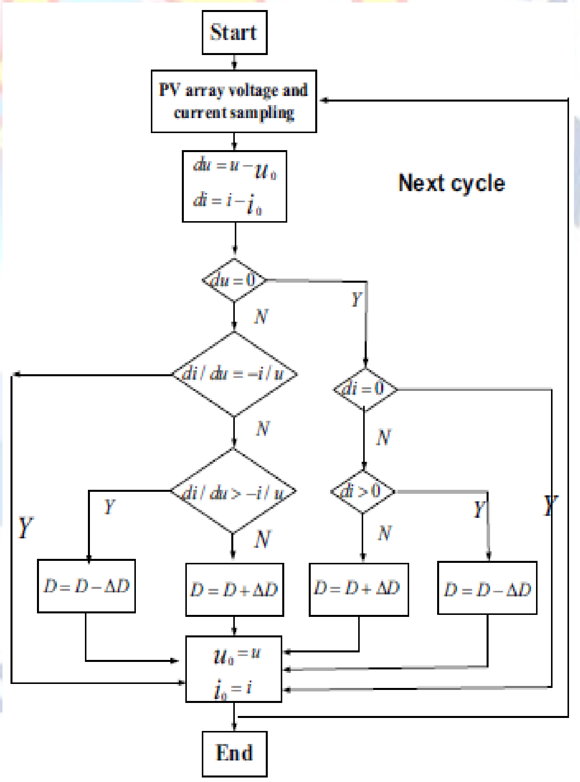

Fig. 7: Incremental conductance MPPT Flow chart

2.9 Block Diagram

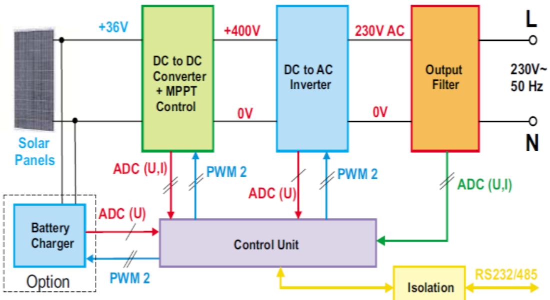

Fig. 8: Block Diagram Representation

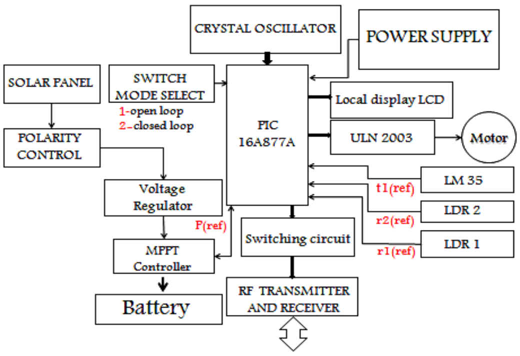

Fig. 9: PIC with PV panel Block Diagram

2.10 Block Diagram Description

All the electronic components starting from diode to Intel IC's only work with a DC supply ranging from _+5v to _+12. We are utilizing for the same, the cheapest and commonly available energy source of 230v-50Hz and stepping down, rectifying, filtering and regulating the voltage. The Photovoltaic (PV) systems have a structure containing solar cells (SCs), connection, protection, and storage components and some additional elements depending on load characteristics. The most important element of these systems, the solar cells, also has distinctive features especially on the initial investment cost and the quality and quantity of other elements. Therefore, in the initial installation stage, it is very important to design for operating of SC under the best conditions and effectively.

2.11 Circuit Diagram

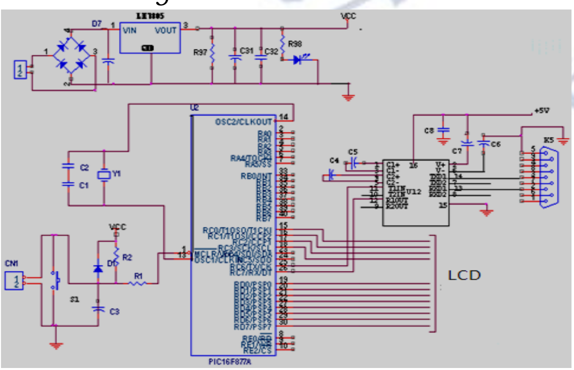

Fig. 10: Circuit Diagram

2.12 PIC Microcontroller

PIC stands for peripheral interface controller; it is a type of microcontroller component that is used in the development of electronics, computers, robotics and similar devices. The PIC was introduced by Microchip Technogy and is based on Harvard computing architecture where code and data are placed in separate registers to increase input/output throughput. PIC microcontroller was widely used for experimental and modern applications because of its low price, wide range of applications and high quality, ease of availability.

2.13 PIN Diagram

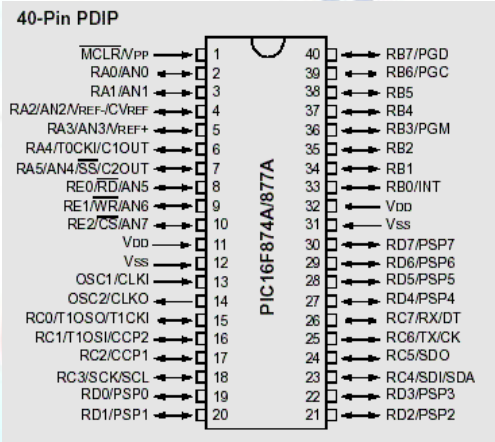

Fig.11: Pin diagram of PIC 16F877A

Features of PIC16F877A

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input DC - 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program emory,
- Interrupt capability (up to 14 internal/external)
- Eight level deep hardware stack
- Direct, indirect, and relative addressing modes
- Power-on Reset (POR)

III. HARDWARE IMPLEMENTATION

Fig.12: Photograph of Hardware

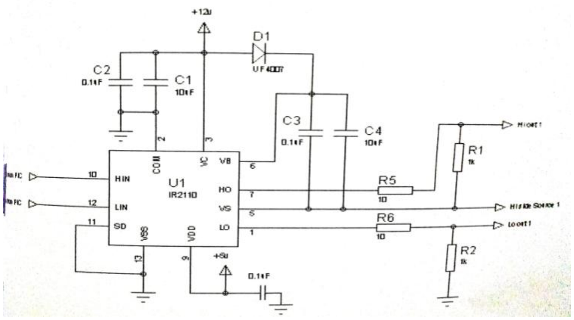

Fig. 13: Circuit Diagram of MOSFET Driver Circuit

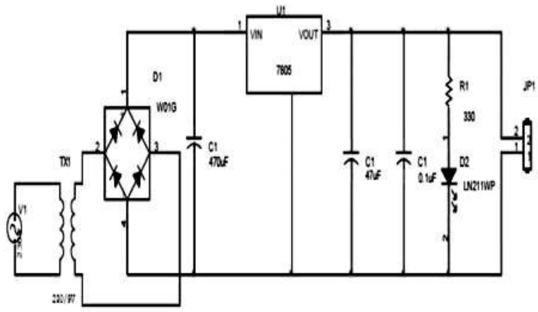

Fig.14: Power Circuit for Microcontroller

Table 1: Parameters

Sl.No.	Specifications	Values
1.	Open Circuit Voltage (Voc)	12 V
2.	Short Circuit Current (Isc)	0.083 A
3.	Output Power	1 W
4.	Temperature	75°

IV. CONCLUSION

This paper has focused on the control strategy for a grid tied PV multilevel inverter. The converter topology has many advantages in terms of modularity, power quality, and capability of controlling each DC-link voltage separately. The adopted MPPT algorithm features good tracking and efficiency performance while ensuring a stable circuit operation by defining a suitable hysteresis band. The modulation technique based on a hybrid staircase–PWM allows reduction of switching losses and achievement of the extraction of the maximum available power from each power cell separately by performing a proper sorting algorithm. As a consequence, the proposed control strategy ensures an individual track of MPP, thus improving the system efficiency even in mismatch conditions. The tests have been conducted on a laboratory prototype of a single-phase five-level grid-tied PV multilevel inverter. Furthermore, good MPPT efficiency has been kept over a wide range of input power, with a minimum value of 95.4% reached at 46% of the nominal power. The experimental results have highlighted stable circuit operation (even in mismatch conditions) and a fast individual tracking of MPPT. Further developments will be performed to optimize the MPPT voltage range by an online calibration of the hysteresis boundaries, thus resulting in adaptive MPPT control approach.

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