A New Technique of Solar Maximum Power Point Tracking System Useful For Agricultural Pump

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Abstract: **Solar water pumping system is a modern field proven means of pumping water in areas where the Grid is not reliable or where there is absence of Grid. The mechanism of such systems uses Photovoltaic (PV) cells to convert sunlight into electricity that not only improves the generation of electricity but also reduces the pollution due to fossil fuel. Broadly, this paper focuses on the overall development of circuit simulation model for Maximum Power Point Tracking (MPPT) evaluation of solar power that includes the involvement of Boost Power Converter. The MPPT plays an important role in Photovoltaic systems because it maximizes the power output from a PV system for a given conditions of solar irradiance and cell temperature, and therefore maximizes the array efficiency and minimizes the overall cost since the Maximum Power Point (MPP) varies. Algorithm was developed to track the MPP and maintain the operation of the system. MATLAB/SIMULINK is established by combing the models of solar PV module and DC-DC Boost Converter. Simulation results show that the Photovoltaic simulation system can track the Maximum Power Point accuracy.**

Keywords: **MATLAB/SIMULINK, Maximum Power Point Tracking (MPPT), Photovoltaic system, Solar Energy, Battery, Inverter.**

I. INTRODUCTION

To overcome the energy crisis and prompt consumption of conventional fossil fuel energy resources. The solar energy is the most desirable alternate among all renewable energy resources. Solar energy is one of the most important renewable energy sources because it is being environment friendly, sustainable and fuel cost free. Therefore, studies and applications related to PV system are increasing day by day. PV modules are semiconductor materials which are structures that convert solar energy into electrical energy.

Electricity is one of the most essential needs for humans in the present. Conversion method of solar energy into electricity not only improves generation of electricity but also reduce pollution due to fossil fuels consumption. The output power of solar panel of system depends on solar irradiation, temperature and load impedance. As the load impedance is depends on application such like, a DC-DC converter is used for improving the performance of solar panel. The solar irradiance and temperature dynamic hence an various types algorithm which dynamically computes the operation point of the solar panel is required. The efficient conversion method of solar energy is possible with Maximum Power Point Tracking (MPPT) algorithm. There are various MPPT algorithm are available but in the paper we are used incremental conductance method.

Photovoltaic PV generation assuring increased important such like as a RES (Renewable Energy Sources) application because of different advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts in the system, the solar energy characterize a clean, pollution free and inexhaustible energy source. In addition to these factors are the declining economic as a cost and prices of solar modules, an increasing efficiency of solar cells, manufacturing technology improvements and economies of scale. The increasing number of renewable energy sources and distributed generators requires new strategic condition for the operation and management of electricity grid in order to maintain or even to improve the power supply reliability and quality.

The voltage and current available at the terminals of PV device may directly supply through small loads. To involving a great deal of applications require electronic converters to process the electricity from the PV device. PV systems have to major problems: The conversion efficiency of electric power generation is very low (9% - 17%) especially under low radiation conditions, and the amount of electric power generated by solar arrays gradually changes day by day with weather conditions. Moreover, the solar cell V-I characteristic is non linear and the role whether parameters varies with irradiation and temperature. There is a unique point on the I-V or P-V characteristic called Maximum Power Point (MPP) at which the entire PV system which includes array, converter etc operates with maximum efficiency and produces its maximum output power (Peak Power).

To optimize the match between solar array, the use of the effective modern techniques for power control mechanism called Maximum Power Point Tracking(MPPT) algorithms has lead to the increase in the efficiency of operation of the solar modules and thus effective in the field of utilization of effective renewable source of energy.

II. DEIGNING COMPONENTS OF THE SYSTEM

1. Standalone PV System

The standalone PV system or direct coupled PV systems are designed and sized to supply DC and/or AC electrical load. It is called direct coupled systems because the DC output of a PV module or array is directly connected to a DC load. The Maximum Power Point Tracker (MPPT) is used between the array and load to help better utilized the available array maximum power output and also for comparing the impedance between of the electrical load to the maximum power output of the PV array. The solar PV array configuration to provide a battery charge stability and reliability, a DC load with battery backup, is essentially the same as the one without the battery except that there are a few additional components that are required. PV panels are connected in series to obtain the desired increase in DC voltage, such as 12, 24 or 48V. The charge controller regulates the current output and prevents the voltage level from exceeding the various peak values for charging the batteries. During the sunshine hours, the load is supplied with DC power while simultaneously charging the batteries. The controller will ensure that the DC power output from the PV array should be adequate to sustain the connected load while structuring as a sizing the batteries.

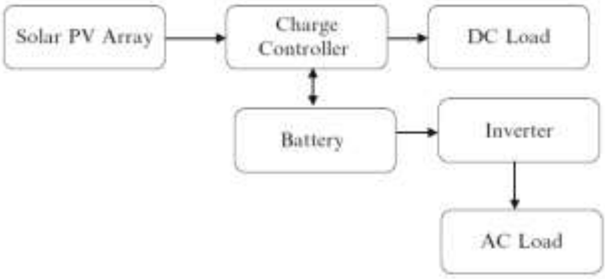

Figure 1: Block diagram of overall stand-alone PV system with battery storage

2. Solar Cell Modeling

Solar cell consists of a p-n junction fabricated in thin wafer or layer of semiconductors materials such as silicon to form electric field, whose electrical characteristics differ very little from a diode represented by the equation. Thus the simplest equivalent circuit of a solar cell is a current source in parallel with diode. The output of the current source is directly proportional to the light falling on the photocurrent Ipv cell.

The Maximum Powers of the PV module under Nominal Operating Cell Temperature (NOCT) rating, design under realistic operating conditions are given. Such as to consider whole a 'Peak' sunshine hours and it is based on some of the factors like light levels and ambient temperature. The solar array can provide specific amount of electricity under certain conditions. In order to determine array performance, following factors to be considered:

a) Characterization of solar cell electrical performance.
b) Degradation factors related to array design
c) Conversion of environmental consideration into solar cell operating temperature.
d) Array power output capability

The following performance criteria determines the amount of PV output
a) Power output: It is the power available at the charge controller / regulator specified either as a peak power or average power produced during one day.
b) Energy output: It indicates the amount of energy produced during a certain period of time.

The conversion efficiency is defined as energy output from array to the energy input from sun. It is also referred as power efficiency and it is equal to power output from array to the power input from the sun. The solar PV module the system contains various components as a battery charge controller, an inverter, MPPT controller and some of the low voltage switchgear components to gain the maximum output power.

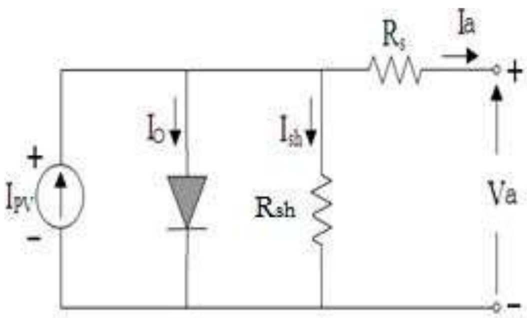

Figure 2: Equivalent circuit of PV cell

An ideal solar cell is modeled by a current source in parallel with a diode. So as per the current source Ipv represents the cell photocurrent, Rsh and Rs are used to represent the intrinsic shunt and series resistance of cell respectively. As per the configuration the value of Rsh is very large and that of Rs is very small as usually, hence they may be neglected to simplify the analysis. The PV mathematical model used to simplify our PV array is representing by equation. Output current of PV model is given by -

$$I_a = I_{pv} N_p - I_{rs} N_p \left\{ e^{\left(\frac{q}{AKT_c\left(\frac{V_a}{N_s}+\frac{I_a R_s}{N_p}\right)} - 1 \right)} \right\} - N_p/R_p \left(\frac{V_a}{N_s} + \frac{I_a R_s}{N_p} \right)$$

Where,
Ia: Cell output current
Va: Cell output voltage
Np: No. of parallel solar cells
Ns: No. of series solar cells
Ipv: Photon current
Io: Solar cells reverse saturation current
q: Electron charge
A: PN junction ideality factor
K: Boltzmann's constant
Tc: Solar cell operating temperature
Isc: Short circuit current at standard test condition
Ki: Cell temperature coefficient of the short circuit current
Tx: Solar cell absolute temperature at standard testing condition
Sx: Total solar reference radiation at STC 1000 W/m2
Sc: Operating solar radiation

From equation represent simulation of PV module can be done in the following manner, taking Rsh = infinity, Np = 1, Ns = 1 the equation becomes

$$I_a = I_{pv} - I_{rs} \left\{ e^{\left(\frac{q}{AKT_c(V_a + I_a R_s)} - 1 \right)} \right\}$$

During the performance of operation, the PV cell output voltage is a function of the photocurrent that mainly calculated by load current of the cell depending on the solar irradiation level of the atmosphere.

$$V_a = \frac{AKT_c}{q} \ln\left(\frac{I_{pv} + I_{rs} - I_a}{I_{rs}} \right) - R_s I_a$$

In operation, if the ambient temperature and irradiation levels are change, then the cell operating temperature also change resulting in a new output voltage and a new photocurrent value. The solar cell operating temperature varies as a function of solar irradiation level (S) and temperature (T). The variable ambient temperature Ta affects the cell output voltage and cell photocurrent.

$$I_{pv} = \left[I_{sc} + K_i (T_c - T_x) \frac{S_c}{S_x} \right]$$

3. Boost Converter

Boost Converters developed to maximize the energy harvest for photovoltaic systems hence it is called as power optimizers; it can be used as switching mode regulator to convert an unregulated DC voltage to a regulated DC output voltage. Due to that regulation is normally achieved by Pulse Width Modulation (PWM) technique at a fixed frequency and the switching device is IGBT. The minimum oscillator frequency should be above 100 times longer than the transistor switching frequency and thereby, the efficiency decreases. There are use the switching regulator as a Boost converter. The given circuit diagram of Boost Converter consist of a DC input voltage source Vin, Boost converter L, Controlled switch as IGBT, Diode D, Filter Capacitance C and the load resistance R

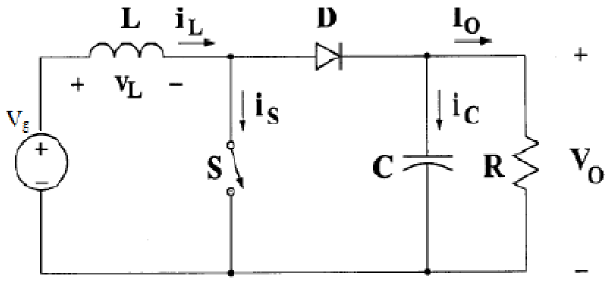

Figure 3: Circuit diagram of boost converter

ON STATE:

When the Switch S is in the ON state t=Ton, the current in the Boost inductor increases linearly and the diode D is OFF at that time.

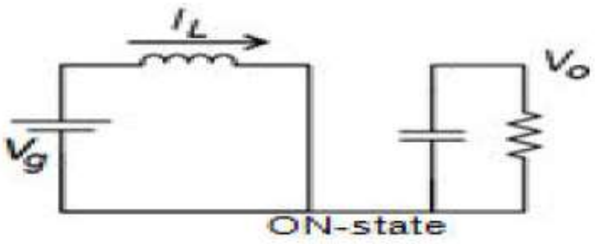

Figure 4: ON state diagram

OFF STATE:

When the switch is OFF state t=Toff, the current that was flowing through the switch would now flow through inductor L, Diode D, Capacitor C and load R. The inductor current iL falls until the switch is turned ON again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore output voltage is greater than the input voltage. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

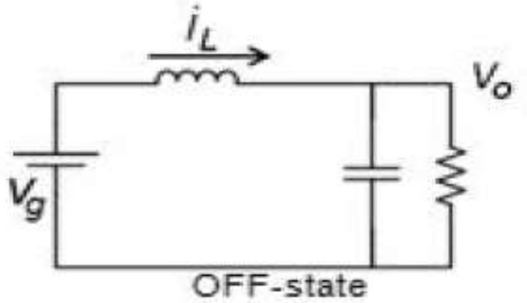

Figure 5: OFF state diagram

$$V_{out} = \frac{1}{(1-D)} * V_{in}$$

Where Vout is output voltage, D is Duty cycle and Vin is input voltage which in these case will be the so far panel voltage.

4. Maximum Power Point Tracking

The MPPT operates solar PV module in such manner that allows the PV module to produce all the power they are capable of generating and transforming. MPPT is not mechanical packing system but it works on a particular tracking algorithm and it is based on a control system. MPPT can be used to connecting mechanical tracking system, but the two systems are completely different. MPPT algorithm is used to obtain the maximum power from the solar array based on the effect of variation in the solar irradiation and cell temperature.

The major principle of MPPT is to extract the maximum available power from the PV module that is MPPT calculates the output of PV module, compares it to battery voltage then fixes what is the best power and them to operate at the most efficient voltage(maximum power point).

When the PV module is directly connected to a load is shown in the given figure. The PV module operating point will be at the intersection of its I-V characteristics and the load line which is I-V relationship of the load. In general this operating point is not at the PV arrays MPP.

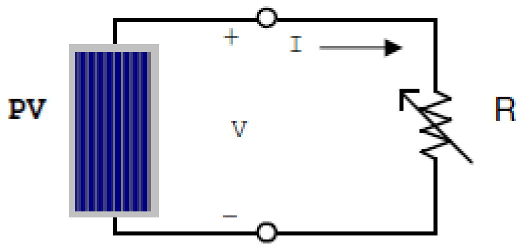

Figure 6: PV module directly connected to a (variable) resistive load

In a PV module the direct-coupled system with variable load, the PV array must usually be oversized to ensure that the loads power requirement can be supplied. This is lead to an overly expensive system. To overcome this problem, a switch mode power converter can be used to maintain the PV operation point at the MPP. The MPPT making this by controlling the PV arrays voltage or current independently of those of the load. However, the location of the MPP in the I-V characteristic is not known a prior. It must be located either through model calculation or by algorithm. The situation is further complicated by the fact that the MPP depends in a non-linear way of irradiation and temperature.

As per the various methods of algorithm, the incremental conductance algorithm uses two voltage and current sensors are used to sense the output voltage and current of the PV array. The array terminal voltage is adjusted according to the MPP voltage by sensing the voltage in the incremental conductance method. It is based on the incremental and instantaneous conductance of the PV module. In the PV curve of solar array the slope of the power curve is zero at MPP. Increasing on the left of the MPP and decreasing on the right hand side of MPP.

To the negative output conductance, the solar array will operate at the maximum power point. This method exploits the assumption of the ratio of change in output conductance is equal to the negative output.

Instantaneous conductance P= VI

At MPP, differentiate

$$I + V\frac{dI}{dV} = 0 \quad \text{- - - - - (1)}$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{- - - - - (2)}$$

If the operating point is the left side of MPP,

$$I + V\frac{dI}{dV} > 0 \quad \text{- - - - - (3)}$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{- - - - - (4)}$$

If the operating point is the right side of MPP,

$$I + V\frac{dI}{dV} < 0 \quad \text{- - - - - (5)}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{- - - - - (6)}$$

The above equation could be written in the term of array voltage V and array current I

The MPPT regulates the PWM control signal of the DC-DC boost converter until the condition is satisfied. In this method the peak power of the module is lies at above 98% of its in converter conductance. r maximum available power.

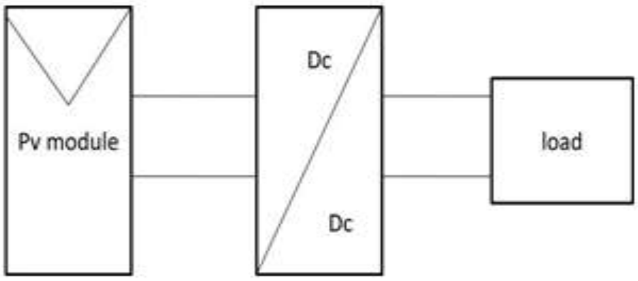

Figure 7: Block diagram of typical MPPT system

To deliver maximum available power, for that additional power extracted from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system.

In the PV curve of solar module, at the MPP increasing on the left hand side of the MPP and decreasing on the right hand side of the MPP. The basic equations of these methods are as follows.

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{At MPP}$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{Left of MPP}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{Right of MPP}$$

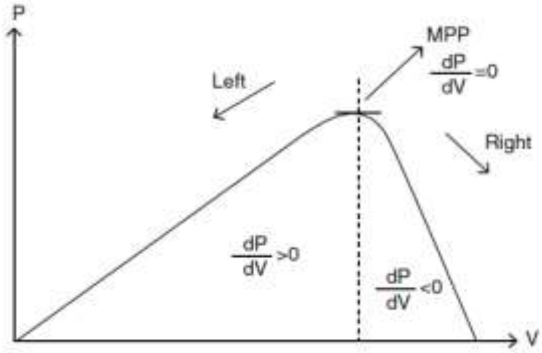

Figure 8: Basic idea of incremental conductance method on a PV curve of solar module

The flowchart shown in Figure 9 explains the operation of this algorithm. It starts with measuring the present values of PV module voltage and current. Then, it calculates the incremental changes, dI and dV, using the present values and previous values of voltage and current. The main check is carried out using the relationships in the equations (2), (4), and (6).

If the condition satisfies the inequality (4), it is assumed that the operating point is at the left side of the MPP thus must be moved to the right by increasing the module voltage. Similarly, if the condition satisfies the inequality (6), it is assumed that the operating point is at the right side of the MPP, thus must be moved to the left by decreasing the module voltage. When the operating point reaches at the MPP, the condition satisfies the equation (2), and the algorithm bypasses the voltage adjustment. At the end of cycle, it updates the history by storing the voltage and current data that will be used as previous values in the next cycle. Another important check included in this algorithm is to detect atmospheric conditions. If the MPPT is still operating at the MPP (condition: $dV = 0$) and the irradiation has not changed (condition: $dI = 0$), it takes no action. If the irradiation has increased (condition: $dI > 0$), it raises the MPP voltage. Then, the algorithm will increase the operating voltage to track the MPP. Similarly, if the irradiation has decreased (condition: $dI < 0$), it lowers the MPP voltage. Then, the algorithm will decrease the operating voltage.

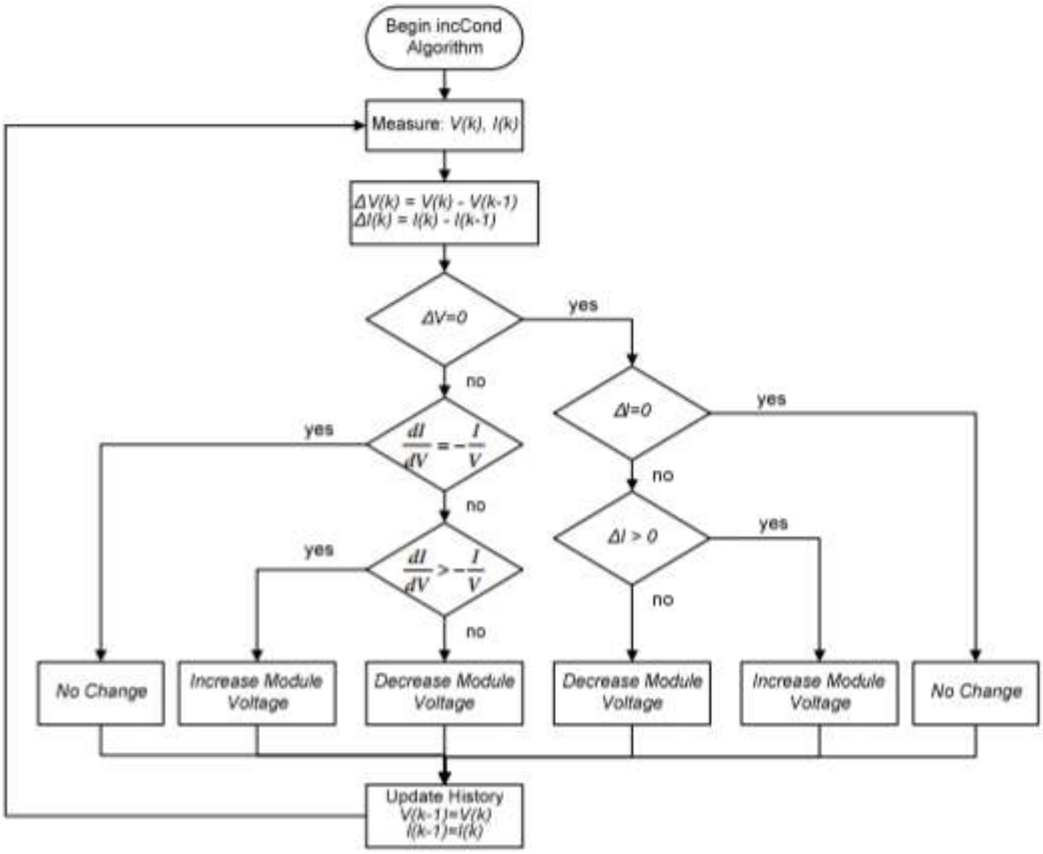

Figure 9: Flow chart of Incremental Conductance algorithm

5. Batteries in PV System

In a 12 V battery system the voltage vary between 10.5 and 14.4 V, depending on the actual state of charge of the battery, charge current, discharge current, type and age of the battery. When a normal full loaded battery and no charging or discharging current is flowing than the battery voltage is about 12.4–12.7 V, when charging current is flowing the voltages jump to a higher level e.g. 13.7 V (depending on the current), the PV module produces energy and the current is flowing into the battery so voltage level increases up to the range of 14.4 V. Then the overcharge protection starts the work. When the battery voltage level is 14.4 V, the charge controller is switched off the charging current or reduced it (by pulse wide modulation).

If the voltage of the system falls below 11.5 V for a period of minimum 20 s than the charge controller will be switched off for minimum 30 s. All loads which are connected to the controller is off. If the battery voltage increase above 12.5 V for more than 20 s than the charge controller will be switched ON the loads again for a minimum time of 30 s. The delay of 30 s is integrated to protect the system against a swinging situation.

When loads are switched on the voltage drops down to a lower level e.g. 12.0 V or 11.8 V (also depending on the current). For off grid and critical applications, storage systems are required, the most common medium of storage are the lead acid batteries. Presently researches are going on in the field of lithium ion batteries and to implement the concept of fuel cells in solar PV systems. One of the most expensive components in the PV systems is the battery. Under sizing the batteries will become more costly as the battery life cycle is significantly reduced at higher Depth of Discharge (DOD %). At a higher depth of discharge, expected average number of charge-discharge cycles of batteries. Further a higher current discharge than the rating will dramatically reduce the battery life. This can be avoiding by carefully sizing of battery according to the 'C-rating' during the system design. It signifies the maximum amount of current that can be easily and safely withdrawn from the battery to provide adequate backup in quality or quantity due to that no causing any damage. Selecting the suitable battery for a PV application depend on many factor. Battery selection depends on physical properties. In battery include the number of batteries in series and parallel, over current disconnect requirement and selection of proper wire sizes and types. The energy output from the solar PV system is generally stored in battery or in a battery bank depending on the necessary and requirements of the system to store the reliable power. Batteries are use as backup system in grid connected system. The primary function of battery in PV system are-

1. Energy storage capability and autonomy: To store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or when on demand.

2. Voltage and current stabilization: To supply the power to electrical load at stable voltage and current values, by suppressing or smoothing out transients and stability improvement of energy system in weak grid conditions.

3. Supply surge current: To supply high peak operating currents to electrical appliances.

6. PULSEWIDTH MODULATION (PWM)

The voltage obtained from a PV system is low, and a DC-DC boost converter is necessary to generate a regulated higher DC voltage. A voltage source inverter interfaces the PV module with the standalone application to provide an AC output voltage without transformer. For lower generating systems, the conventional pulse width modulated inverter is used because of simple and easy control mechanism. PWM inverters usually involve fast switching of semiconductor switches due to which high frequency noise gets generated. Also all PWM methods inherently generate harmonics that originate from the high dV/dt and dI/dt semiconductor switching transients. These drawbacks result in distorted output, and traditionally passive filters have been used to remove the harmonics from the line current. These filters improve the power factor of the system, but the passive filters have many drawbacks such as tuning problems and series and parallel resonance. Typical shunt and series active filter topologies along with passive filters are proposed to provide high quality power for a PV system.

This method uses solid states switch to apply pulses of current at reasonably high frequency but with a varying duty cycle to overcome the shortcoming of a slow charging time in distributed battery cells in pulse based charging method, such that battery receives a constant voltage charge from the array. This type of controller shows in series configuration. The power dissipation is reduced with PWM technology.

7. INVERTER

Inverters are used to convert DC current into AC currents in PV systems. Different types of inverters produce a different “quality” of electricity. So, the user must match the power quality required by your loads with the power quality produced by the inverter. The job of the inverter is to connect the systems with each other and to feed the solar power into the grid with the highest possible efficiency.

The ideal switches in the circuit can be selected depending on the power and voltage requirements. A simple control strategy to get the inverter output is to turn on and off the switches at the required AC frequency to obtain a square wave voltage but it consists of high harmonic currents and voltages. It can be reduced by using high frequency pulse width modulation techniques to diminish harmonic distortion and provide load voltage control. Because, harmonic can cause overheating in the case of motor loads due to higher copper losses as well as magnetic fields affecting overall operation. Sensitive electronic loads may also display erratic operation. Today, novel control schemes and creative ideas allow the creation of AC with very low harmonic distortion and noise; three phase designs are also possible by incorporating additional switches.

The intermediate DC-DC converter is built with an Insulated Gate Bipolar Transistor (IGBT) as main power switch in a standard unidirectional boost topology that employs an energy-storage reactor, a rectifier diode and a voltage smoothing capacitor C. The converter is linked to the PV system with a filter capacitor for reducing the high frequency ripple generated by the transistor switching. The DC-DC converter output is connected to the dc bus of the VSI. For modeling of voltage source inverter they used IGBT. The VSI structure is designed to make use of a three-level pole structure, also called Neutral Point Clamped (NPC), instead of a standard two-level six-pulse inverter structure this three-level inverter topology generates a more sinusoidal output voltage waveform than conventional structures without in-creasing the switching frequency. The additional flexibility of a level in the output voltage is used to assist in the output waveform This type of VSI has several advantages over the standard two-level VSI. s In the output voltage waveforms containing great number of levels, lower dV/dt, less harmonic distortion and lower switching frequencies. The main draw-back of this type of converter is the voltage imbalance produced in the capacitors of the DC-link when one of the phases is connected to the middle point or Neutral Point (NP).

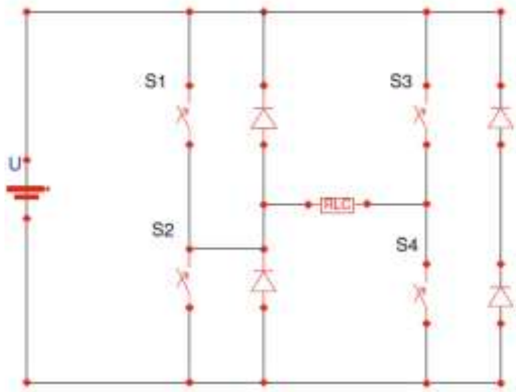

Figure 10: Inverter configuration with load

The Boost Converter boosts the voltage which is being used in MPPT system. The selection of converter is based on the load connected to the system. The ripple in DC voltage and current also influences the selection of converter. PWM inverters are used for standalone AC load. To improving efficiency of MPPT algorithms can encourage domestic generation of power using solar panels. The aim of the system is to achieve DC supply to AC supply which can be used for pumping application. The frequency of operation was set by using repetitive sequence to generate the pulse signal that was compared with the signal generated from the MPPT unit to feed the gating signal to the switch. When there is change in the solar irradiation and temperature, the Maximum Power Point changes and thus the required duty cycle for the operation of the model also changes. The various waveforms were obtained by using the plot mechanism in MATLAB by varying duty cycle to extract maximum power.

III. PROPOSED SYSTEM

The experimental water pumping system proposed in this paper is a standalone type with backup batteries. As shown in Figure 11, the system containing the PV module, a Maximum Power Point Tracker (MPPT), and DC water pump. The size of the system is intended to be small; therefore it could be built in the lab in the future. To extract the maximum power MPPT controller by control technique generates the pulses. The system including the subsystems will be simulated to verify the functionalities.

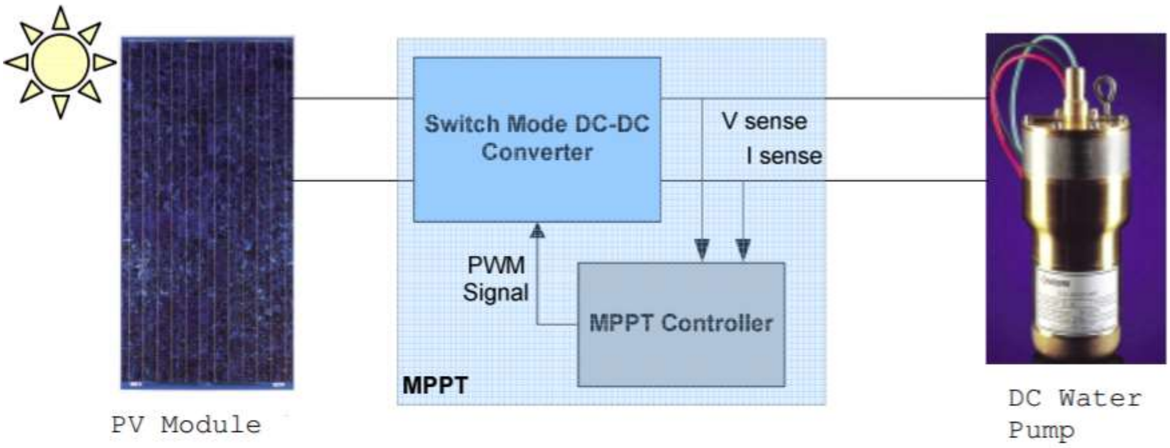

Figure 11: Block diagram of the proposed PV Water Pumping System

IV. SIMULATION SCENARIOS

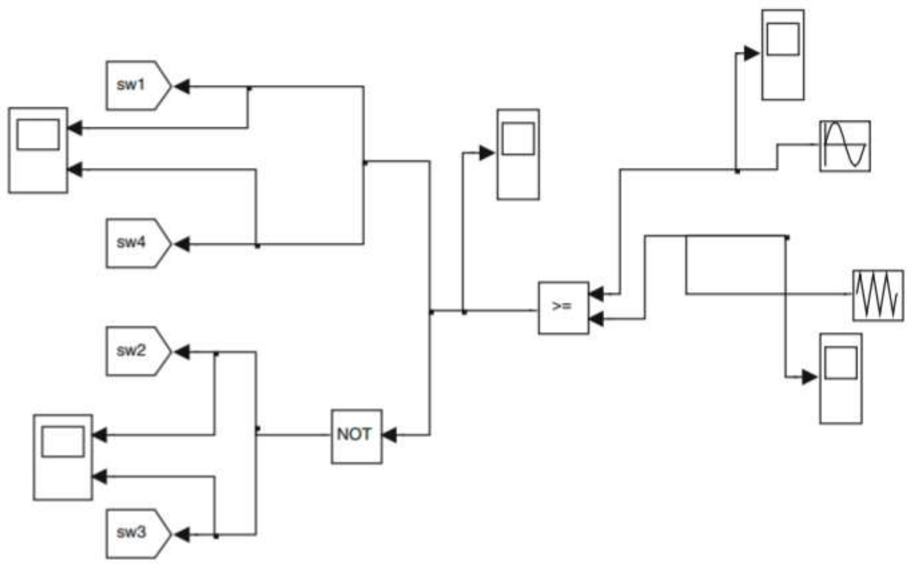

Figure 12: Pulse generation circuit

The inverter circuit provides the required components such as a full-bridge, batteries, resistors, inductors, capacitors etc. The pulse generation circuit is modeled as shown in Figure 12 generate the pulses and compare with PWM signal.

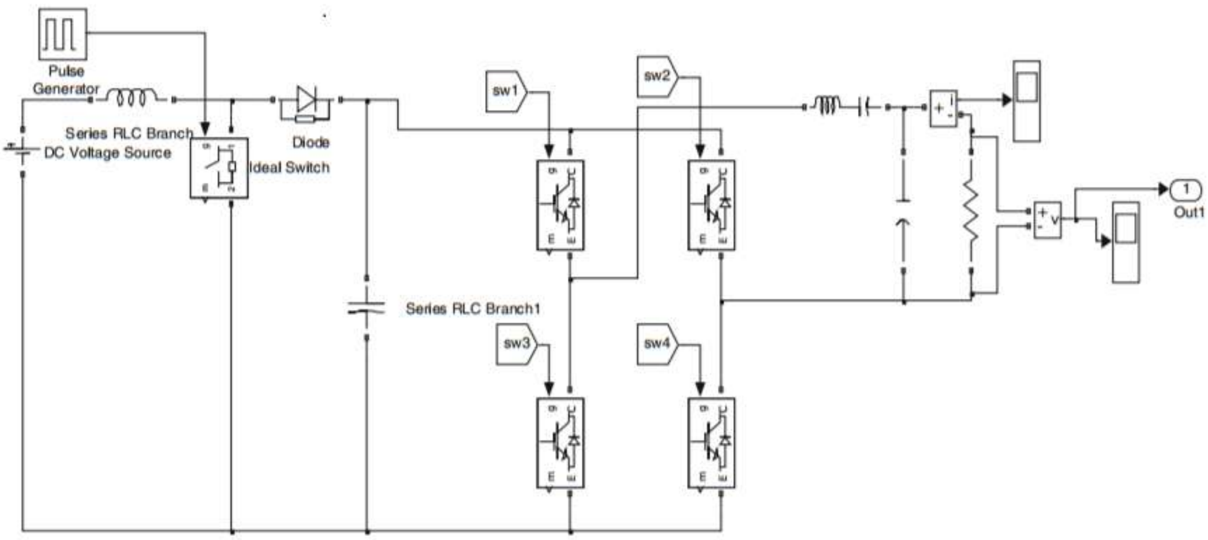

Figure 13: Boost Converter and single phase inverter circuit

The single phase inverter designed using IGBT, diode and ideal switch is presented in Figure 13. The PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25 degree Celsius, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day. The major principle of MPPT on the basis of load variation, temperature and irradiance is to extract the maximum available power from PV module by making them operate at the most efficient voltage by various control technique. MPPT Algorithm is based on the simple logic that, MPPT calculates the output of PV module, compares it to battery voltage then fixes what is the optimum power that PV module can produce to charge the battery and converts it to the optimum voltage to get maximum current into battery. When it is connected directly to the battery it carries the power to DC load. MPPT is mostly useful during cloudy days and when the battery is deeply discharged.

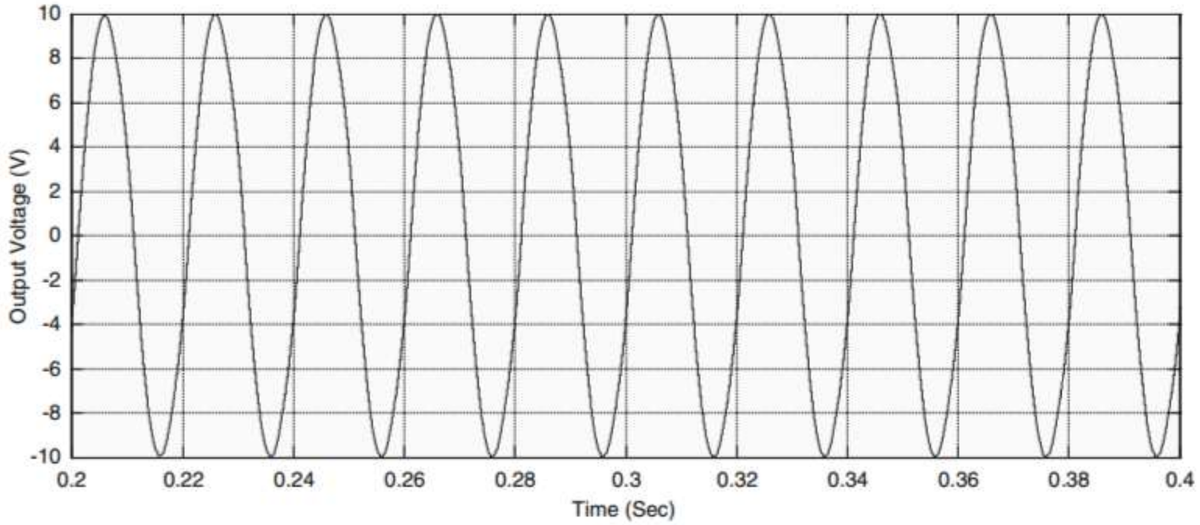

Figure 14: Scope output for Inverter model

The output voltage waveform is shown in Figure 14. The boost converter was designed for a 2 input voltage from solar PV panel with L in mH and C in µF. A single phase full-bridge inverter (PWM) circuit was used to convert the boosted DC voltage to alternating voltage. The inverter system modeled with MATLAB/SIMULINK was achieved using the power system and standard SIMULINK block sets. The system was analyzed by comparing the pulses with PWM signals, which allowed for analysis and design of the inverter mode.

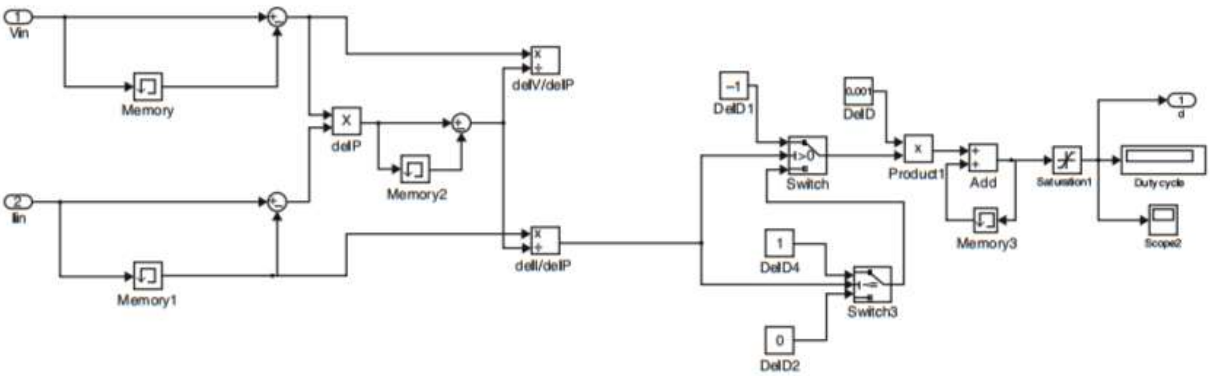

Figure 15: SIMULINK model for Incremental Conductance method

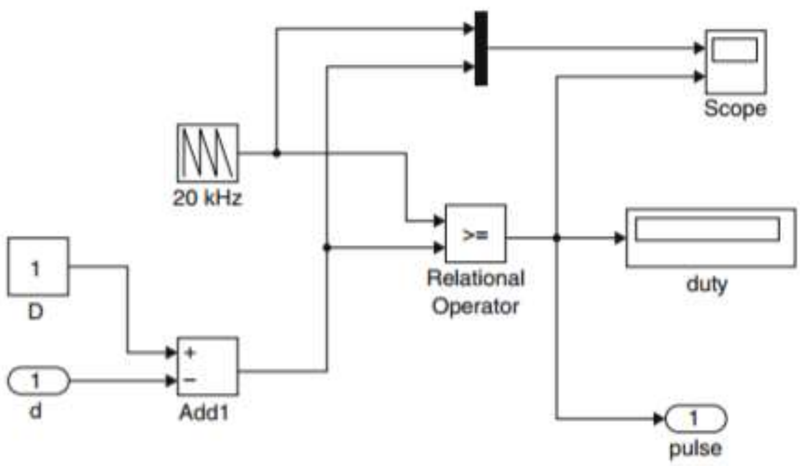

Figure 16: SIMULINK model for adjusting duty cycle

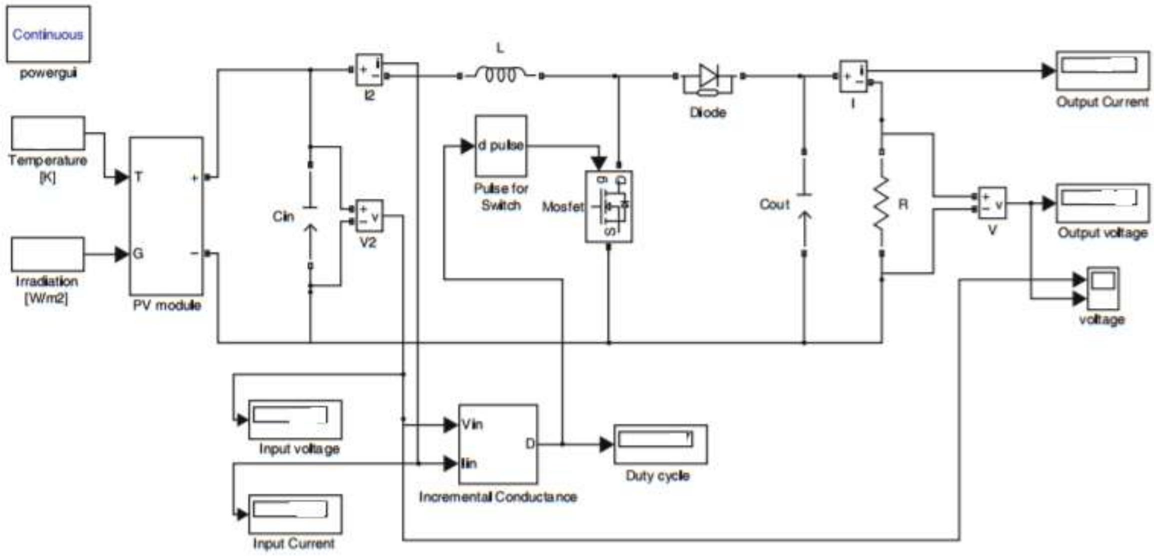

Figure 17: Overall SIMULINK model

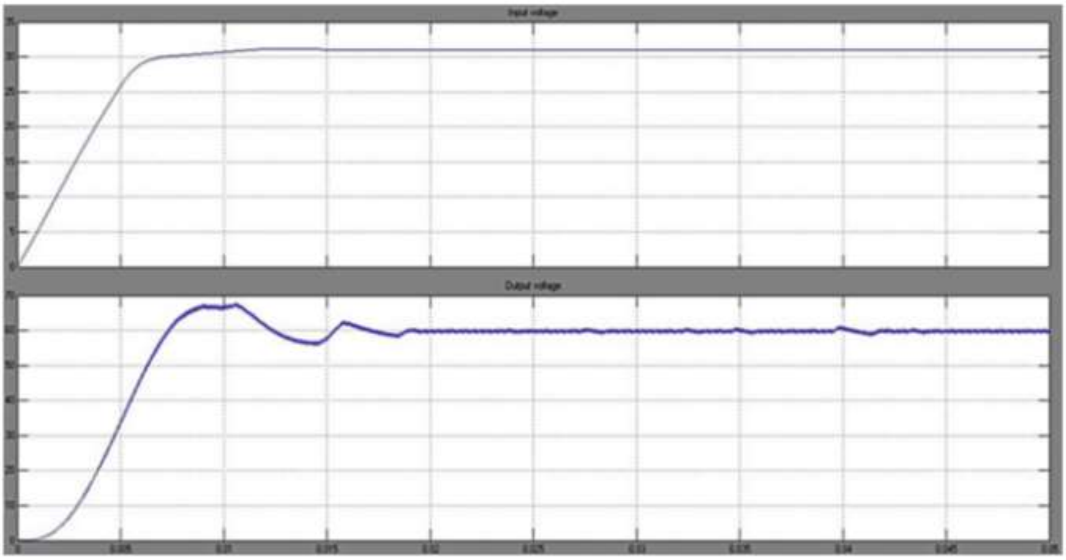

Figure 18: Voltage versus Time curve without MPPT technique with temperature and solar irradiance

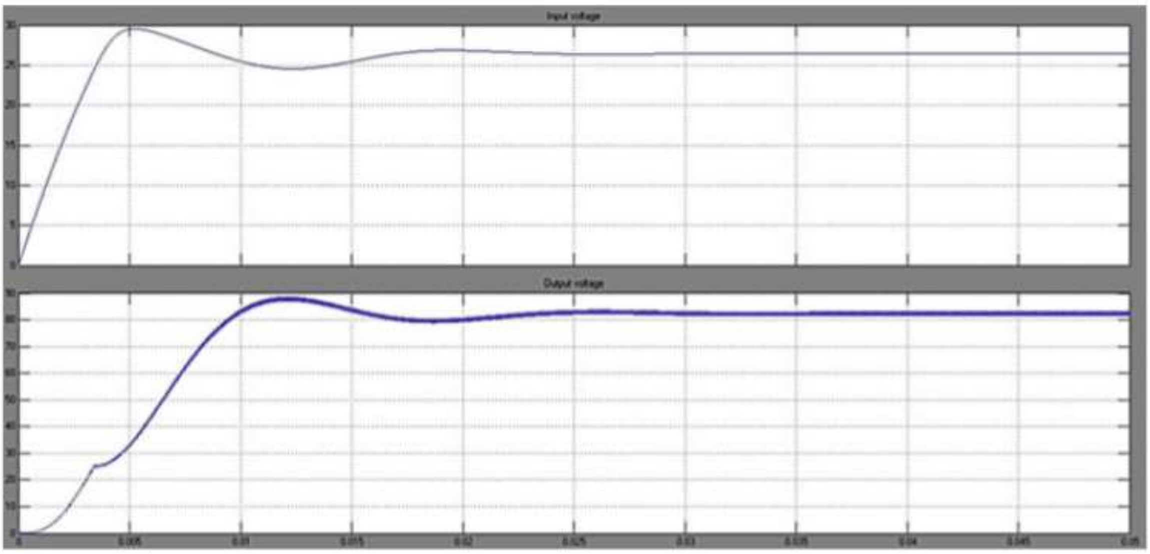

Figure 19: Voltage verses Time curve with Incremental Conductance MPPT technique with temperature and solar irradiance

Figure 18 show the voltage versus time curve without the MPPT technique at temperature 25C with irradiation levels 1,000 W/m2. The P&O method was applied it is inferred that using the perturb and observe technique, when the irradiation is constant, it oscillates around the MPP value. The amplitude of the oscillations depends directly on the solar irradiance and size of increment in the reference voltage, ΔVref. The corresponding MPP voltage is reached after a delay, which depends on the size of ΔVref. The P&O block was replaced using the Incremental Conductance technique and the output was observed as shown in Figure 19. The results are almost practically the same. Figure19 shows the Voltage versus Time curve with Incremental Conductance MPPT technique. In this case the tracking is adequate with necessary irradiation step changes challenge to the various algorithms and are not suitable for testing MPPT.

V. CONCLUSION

In this paper, the accuracy of any of these module is usually depends on the location where it is being installed. The pros and cons of MPPT algorithm state that incremental conductance is superior to all other MPPT algorithm. The efficiency remains high in these methods.

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