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Modeling and Simulation of Inverter Based Photovoltaic Power Generation System for Various Applications

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Abstract- **The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable power. Owing to their initial high costs, PVSCs have not yet been a fully attractive alternative for electricity users who are able to buy cheaper electrical energy from the utility grid. A photovoltaic array (PVA) simulation model is developed in Mat lab-Simulink GUI environment. The model is developed using basic circuit equation of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. The new model was tested using a directly coupled ac load via an inverter. Test and validation studies with proper load matching circuits are simulated and result are presented. The Total harmonic distortion in output voltage with filter is 2.16 % which is under the IEEE standard.**

Keywords- **PV Cell, Boost Converter, Inverter, MPPT, THD, FFT and PWM.**

I.INTRODUCTION

Renewable energy sources play an important role in electric power generation. Various renewable sources such as solar energy, wind energy, geothermal etc. are harness for electric power generation. The main challenge in replacing legacy systems with newer more environmentally friendly alternatives is how to capture the maximum energy and deliver the maximum power at a minimum cost for a given load. Solar energy which is free and abundant in most parts of the world has proven to be an economical source of energy in many applications.

The solar energy receives by the earth from the sun is so enormous that the total energy consumed annually by the entire world is supplied in as short interval of time as in half an hour. On a clear day the sun's radiation on the earth can be 1000 watts per square meter depending on the location. The sun is a clean and renewable energy source, which produces neither green-house effect gas nor noxious waste through its utilization. The photovoltaic process is completely solid state and self-contained. There are no moving parts and no materials are consumed or emitted. Considering the advantages of photovoltaic systems have over competing power options.

A solar cell is a non-linear power source and its output power depends on the terminal operating voltage. The Maximum Power Point Tracker (MPPT) compensates for the varying voltage vs. current characteristics of the solar cell. The MPPT tracks the output voltage and current from the solar cell and determines the operating point that will deliver the most power. The proposed MPPT must be able to accurately track the constantly varying operating point where the maximum power is delivered in order to increase the efficiency of the solar cell.

In the near future, the demand for electric energy is expected to increase rapidly due to the global population growth and industrialization. This increase in the energy demand requires electric utilities to increase their generation. Recent studies predict that the world's net electricity generation is expected to rise from 17.3 trillion kilowatt-hours in 2005 to 24.4 trillion kilowatt-hours (an increase of 41%) in 2015 and 33.3 trillion kilowatt-hours (an increase of 92.5%) in 2030 [1]. Currently, a large share of electricity is generated from fossil fuels, especially coal due to its low prices.

However, the increasing use of fossil fuels accounts for a significant portion of environmental pollution and greenhouse gas emissions, which are considered the main reason behind the global warming. For example, the emissions of carbon dioxide and mercury are expected to increase by 35% and 8%, respectively, by the year 2020 due to the expected increase in electricity generation [2]. Moreover, possible depletion of fossil fuel reserves and unstable price of oil are two main concerns for industrialized countries.

To overcome the problems associated with generation of electricity from fossil fuels, renewable energy sources can be participated in the energy mix. One of the renewable energy sources that can be used for this purpose is the light received from the sun. This light can be converted to clean electricity through the photovoltaic process. The use of photovoltaic (PV)systems for electricity generation started in the seventies of the 20th century and is currently growing rapidly worldwide. In fact, many organizations expect a bright future for these systems. But there is a problem in using the PV system for generation process a bad efficiency of the system. The position of the sun is changes all time in day. So the output of the PV system get vary. For producing the high power here need of some tracking system which is known as Maximum Power Tracking System (MPPT). This is more beneficial for finding the point where maximum power achieve in the PV system.

In this paper discuss the different types of MPPT algorithm proposed by the researchers for increasing the efficiency of the solar system. Further a system model is developed based on P&O MPPT algorithm. The whole model is developed in MATLAB software for checking the performance of the proposed system.

II. REVIEW OF MPPT FOR PV SYSTEM

The solar irradiance and temperature are dynamic. Hence an online algorithm which dynamically computes the operating point of the solar panel is required. The efficient conversion of solar energy is possible with Maximum Power Point Tracking (MPPT) algorithm. In his section discuss the different authors work in the field of MPPT.

The author [1] discusses the method to track maximum power point for PV system. A high frequency PV for led acid battery is discussed in[2]. By The PV-PC imple mented by a boost current converter (BCC) is to eliminate sulphating crystallization on the electrode plates of the LAB and to prolong the battery life.

Hussein et.al [3] developed a new MPT algorithm to track maximum power operation point (MPOP) by comparing the incremental and instantaneous conduction of the PV array. A new method named CVT (Constant Voltage Tracking) is developed in [4]. In this paper a lower power PV system with simple structure has been designed.

Noppadol et.al [5] present adjustable self organised Fuzzy logic controller (SOFLC) for a solar power traffic; light system. The P & O method for MPPT is based on fuzzy system is designed in [6]. The introduction of artificial neural network based MPPT is developed in [7]. By applying a three layers neural network and some simple activation functions, the maximum power point of a solar array can be efficiently tracked.

S. Yuvarajan et al [8] proposed a fast and accurate maximum power point tracking (MPPT) algorithm for a photovoltaic (PV) panel that uses the open circuit voltage and the short circuit current of the PV panel.

Prof. Dr. IlhamiColak, et al [9] have modeled three separate solar farms that provide 15 kW power for each farm using Mat lab Simulink real-time analysis software. Energy conversion was performed with maximum power point tracking (MPPT) algorithms in each converter using Perturb and Observe (P&O) structure.

S. G. Tesfahunegn et al [10] designed a new solar/battery charge controller that combines both MPPT and over-voltage controls as single control function. A small-signal model of lead acid battery was derived in detail to design the employed dual-loop control configuration.

Yuncong Jiang et.al [11] present an analogue Maximum Power Point Tracking (MPPT) controller for a Photovoltaic (PV) solar system that utilizes the load current to achieve maximum output power from the solar panel.

Arash Shafie et al [12] proposed a novel MPPT algorithm mainly for battery charging applications which were considered constant voltage type loads. This was achieved mainly with output current maximization. This technique benefits from advantages such as very simple current controller and also circuit topology independency.

Ali F Murtaza et al [13] addresses this problematic behavior of P&O technique and hence presents a novel MPPT hybrid technique that was combination of two basic techniques i.e. P&O and Fractional Open Circuit Voltage (FOCV) technique in order to overcome the inherited deficiencies found in P&O technique. The proposed MPPT technique was much more robust in tracking the MPP even under the frequent changing irradiance conditions and was less oscillatory around the MPP as compared to P&O.

Weidong Xiao et al [14] introduce the performance analysis of photovoltaic modules in non-ideal conditions and the topologies to minimize the degradation of performance caused by these conditions. It was found that the peak power point of a module was significantly decreased due to only the slightest shading of the module, and that this effect was propagated through other non-shaded modules connected in series with the shaded one.

Jun Pan et al [15] present according to the output characteristics of photovoltaic (PV) array and battery charging characteristics, design of a PV charging system with maximum power point tracking (MPPT).

Sandeep Anand et al [16] proposed charged controller for limitation in battery life. They discuss in this paper in standalone dc system, dc-dc converter was used to interconnect solar photovoltaic (PV) and battery. To utilize solar PV to fullest, maximum power point tracking (MPPT) was incorporated in controller.

Mohamed Azab [17] proposed a new maximum power point tracking algorithm for photovoltaic arrays. The algorithm detects the maximum power point of the PV.

The computed maximum power was used as a reference value (set point) of the control system. ON/OFF power controller with hysteresis band was used to control the operation of a Buck chopper such that the PV module always operates at its maximum power computed from the MPPT algorithm.

Ashish Pandey et al [18] describe about the limitations of Perturb & Observe (P&O) method because of continuously changing environmental conditions. A variable step-length algorithm was proposed and the drift was minimized by evaluating the entire trend in a power versus voltage curve.

Ahmed k et al.[19] proposed a high performance adaptive P & O based MPPT system. In this paper, a modified P&O MPPT technique, applicable for PV systems, is presented. The proposed technique achieves: first, adaptive tracking; second, no steady-state oscillations around the MPP; and lastly, no need for predefined system-dependent constants, hence provides a generic design core.

Y.Jiang et. al [20] present Adaptive Step Size With Adaptive-Perturbation Frequency Digital MPPT Controller for a Single-Sensor Photovoltaic Solar System. This paper presents a load-current-based maximum power point tracking (MPPT) digital controller with an adaptive step-size and adaptive-perturbation-frequency algorithm.

Venkata Reddy et.al [21] present a Simple and Efficient MPPT Scheme for PV Module Using 2-Dimensional Lookup Table. In this paper proposes a simple and efficient MPPTscheme using a 2-Dimensional Lookup Table. Venketa Reddy Kota et al [22] present a novel linear tangents based P & O scheme for MPPT of a PV system. In this paper first presents an overview on traditional Maximum Power Point Tracking (MPPT) algorithms.

Traditional algorithm can be easily implemented using analog or digital devices. As traditional algorithms suffer from low efficiency, oscillations in steady state power and poor dynamic performance, a novel MPPT scheme using Linear Tangents based Perturb & Observe (LTP & O) is proposed in this paper.

III. PROPOSED MEHODOLOGY

A PV array is used to convert the light from the sun into DC current and voltage as shown in fig.1. A DC converter is connected to the PV array to increase its terminal voltage and provide the means to implement an MPPT technique by controlling its switching duty cycle.

The output power from the array is stored temporarily in large capacitors to hold power before DC/AC power conversion. An inverter is then connected to perform the power conversion of the array output power into AC power suitable for the load. Pulse width modulation control is one of the techniques used to shape the magnitude and phase of the inverter output voltage. A harmonics filter is added after the inverter to reduce the harmonics in the output current which result from the power conversion process.

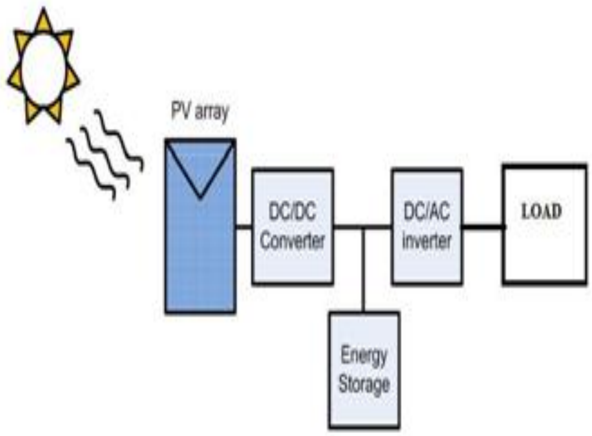

Fig 1. Block diagram of proposed methodology.

IV. PHOTOVOLTAIC CELL EQUIVALENT CIRCUIT MODEL

The equivalent circuit model of a PV cell is needed in order to simulate its real behavior. One of the models proposed in literature is the double exponential model [16] depicted in fig.2. Using the physics of p-n junctions, a cell can be modeled as a DC current source in parallel with two diodes that represent currents escaping due to diffusion and charge recombination mechanisms.

Two resistances, Rs and Rp, are included to model the contact resistances and the internal PV cell resistance respectively. The values of these two resistances can be obtained from measurements or by using curve fitting methods based on the I-V characteristic of the cell. The work done in [17] is an example of using curve fitting techniques to approximate the values of Rs and Rp.

The relationship between the PV cell output current and terminal voltage is governed by:

$$\mathbf{I = I_{ph} - I_{D1} - I_{D2} - \frac{V+IR_S}{R_P} \ldots 1}$$

$$\mathbf{I_{D1} = I_{01}\left[e^{(q(V+IR_S)/aKT)} - 1\right] \quad \ldots 2}$$

$$\mathbf{I_{D2} = I_{02}\left[e^{(q(V+IR_S)/aKT)} - 1\right] \quad \ldots 3}$$

Where

Iph is the PV cell internal generated photocurrent, I_{D1} is the currents passing through diodes D_1, a is the diode ideality factor,K is the Boltzmann constant (1.3806503 × 10^{-23} J/K), T is the cell temperature in degrees Kelvin, q is the electron charge (1.60217646 × 10^{-19} C), $\mathbf{I_{01}}$is the reverse saturation currents of each diode.

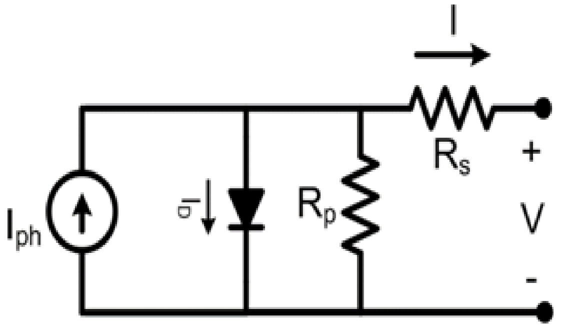

Fig 2. Simplified PV cell model.

This model provides a good compromise between accuracy and model complexity and has been used in several previous works and [13]. In this case, current I_{D2} can be omitted from (3) and the relation simplifies to:

$$\mathbf{I = I_{ph} - I_0\left[e^{(q(V+IR_S)/aKT)} - 1\right] - \frac{V+IR_S}{R_P}} \qquad \ldots 4$$

It is clear that the relationship between the PV cell terminal voltage and output current is nonlinear because of the presence of the exponential term in 1 and 4. The presence of the p-n semiconductor junction is the reason behind this nonlinearity.

V. SIMULINK MODEL & RESULTS ANALYSIS

The entire system has been modeled on MATLAB 2015 and Simulink. The masked block diagram of the solar PV panel, Circuit model and switching pulses are shown in fig. 3, fig. 4 & fig. 5. The inputs to the solar PV panel are temperature, solar irradiation.

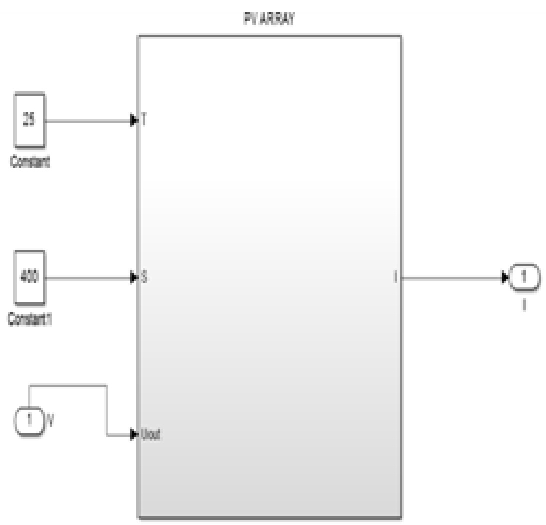

Fig 3. Masked block diagram of the modeled solar PV panel.

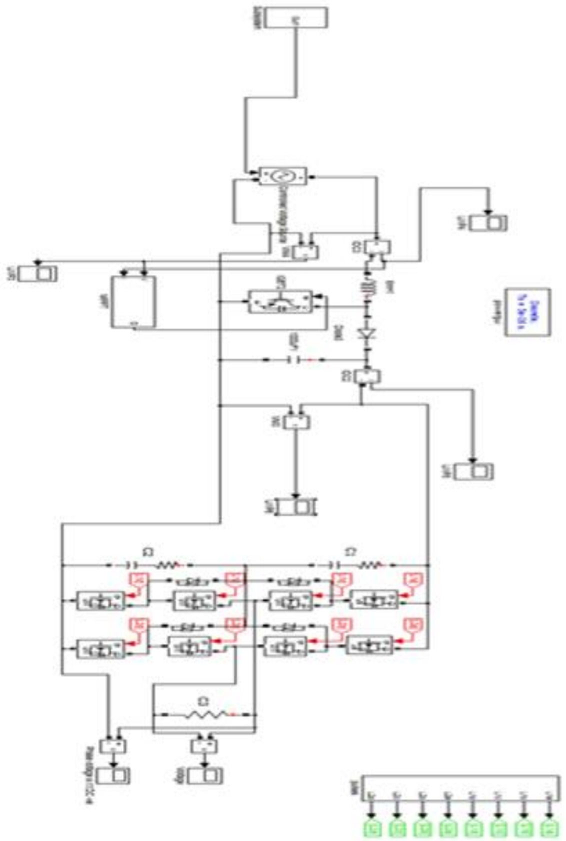

Fig. 4 Simulink model of PV system.

Simulation results are explore the behavior of the model by running a simulation. MAT LAB simulation model and simulation results for above simulation model using different controlling topology are demonstrated by MATLAB R2015 a software module. Table: 1 shows the parameter used for simulation of the proposed system.

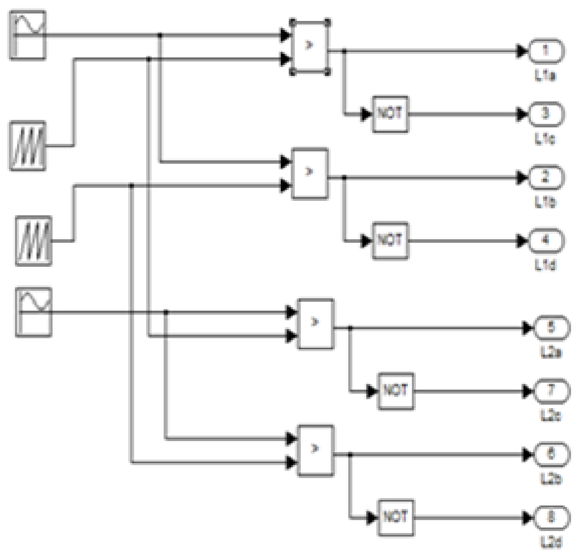

Fig 5. Simulink model of switching pulses of converter system.

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Table 1. Simulation Parameter.

Parameter	Value
PV Module	
Number of Series Connected Cell	96
Open Circuit Voltage (V_{OC})	(70-90) V
Short Circuit Current (I_{SC})	10 A
Series resistance	0.20 Ω
Shunt Resistance	350 Ω
Number of Module in Series	2
Number of Module in Parallel	2
PV Side Capacitance	450 µF
Output Power (W) of PV Array	700 W
Boost Converter	
Series Inductance	10 mH
Shunt Capacitance	47 µF
Resistance	60 Ω
OutPut Voltage	240 V
Inverter	
Output voltage	240 V
Output Current	4.7 A
Output Power (W) across load	500 W

The simulation was run for a total of 2 seconds and IV & PV Characteristic was recorded which is shown in fig.6 and 7.

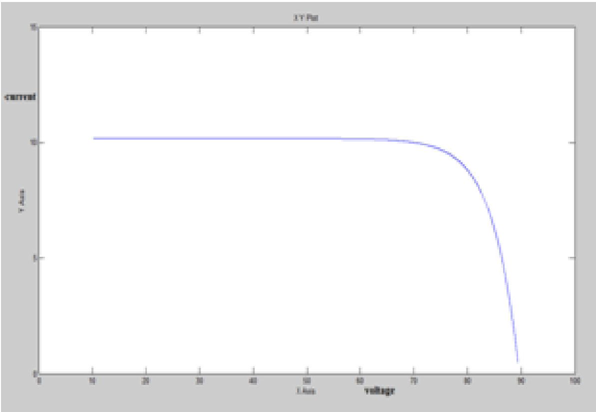

Fig 6. Characteristic solar PV panel.

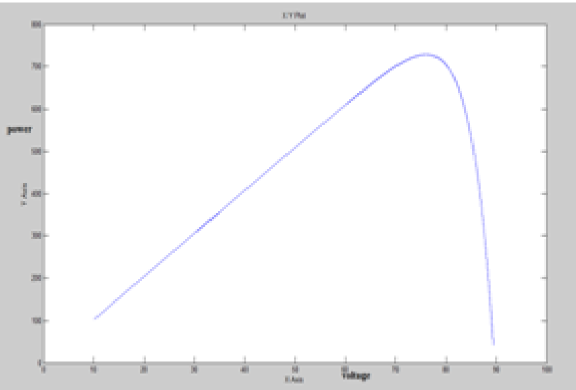

Fig 7. PV Characteristic solar PV panel.

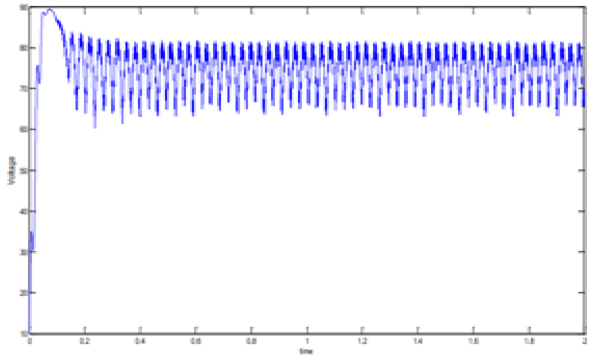

Fig 8. Output voltage of PV Array.

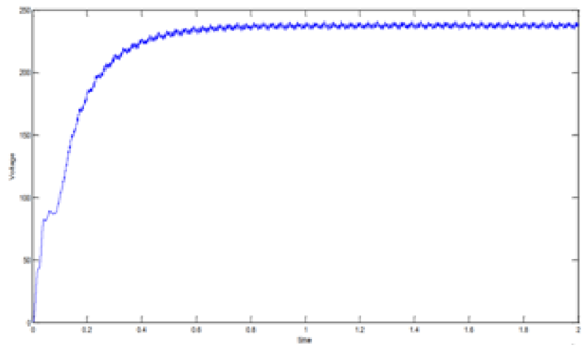

Fig 9. Output voltage of Boost converter.

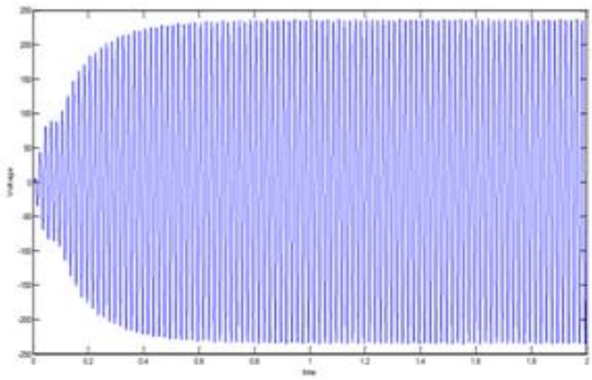

Fig 10. Output voltage of inverter.

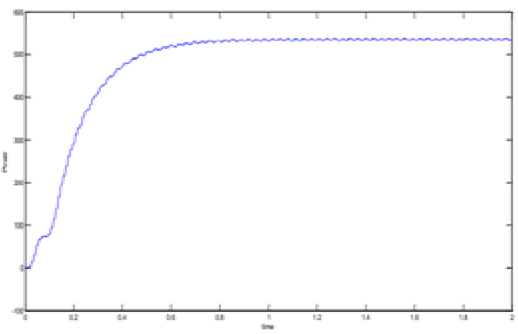

Fig 11. Output Power across load.

THD of output voltage of the inverter is 2.16% with the used of filer.

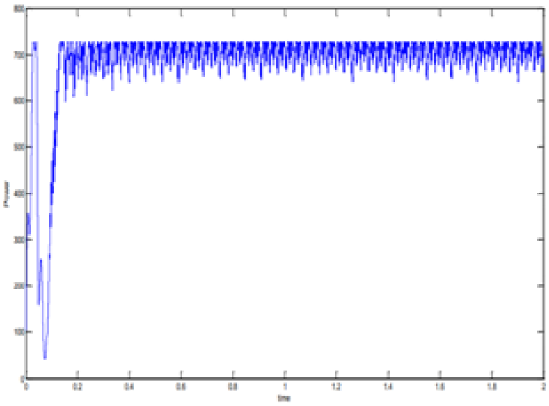

Fig 12. Output Power of PV Array.

VI . CONCLUSION

On the basis of literature review, simulations results and the performed experiments in Mat-Lab, We can be conclude as The PV array was simulated and its characteristics are obtained at varying temperature and irradiation condition. The MPPT method used here is found to be more simple and efficient than other MPPT methods and hence better results are obtained using the Perturb and observe method. The simulation results obtained of the inverter voltage and DC voltage are as per the system design and are having minimum harmonics. The Total harmonic distortion in output voltage with filter is 2.16%. Which is under the IEEE standard.

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