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Design of Optimal Power Point Tracking Hybrid Controller using Photovoltaic Power and Demand

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Abstract: *With the advent of grid-connected photovoltaic systems for energy generation, new technologies need to be created to maintain a continuous and stable balance between the supply and demand of generated electricity. Therefore, it is necessary to accurately predict the production and consumption of solar energy. Solar energy production and electricity demand are probabilistic and non-stationary in nature and are often incompatible. Imbalances in supply and demand can be costly and lead to long-term inefficiencies in power generation and distribution. The purpose of this work is to propose ways to balance the supply and demand of PV power generation and distribution systems. To achieve this, we will build and combine three different tools.*
1) Predictive model for predicting solar energy production,
2) Predictive model for forecasting demand, and
3) A real-time control algorithm that uses the output of a predictive model to adjust the output voltage of a PV system to maintain a balance between supply and demand.
Our prediction model is based on time series prediction tools and artificial neural networks. The control algorithm is called Optimal PowerPoint Tracking PowerPoint Tracking (OPPT) and is based on perturbation and monitoring algorithms. Use real-world data to evaluate the performance of a system that combines prediction and controller..

Keywords: OPPT(Maximum Power Point Tracking), SMC(Sliding Mode Control), SPWM(Switching Pulse Width Modulation), P&O(Perturb and Observe)

I. INTRODUCTION

Photovoltaic (PV) energy will be an integral part of our energy consumption and will soon be an integral part of our sustainable energy system. As better sensors are developed, module prices continue to fall, PV modules become more efficient, and solar energy is increasingly replacing other traditional energy sources. Economy around the world is ambitiously investing in grid-connected PV systems. [1], [2]. Unlike traditional power generation systems, PV power is unpredictable and depends on solar radiation and other meteorological factors such as temperature, humidity, precipitation, wind speed, and cloud cover.

The implementation of large grid-connected PV systems has brought important issues to the power grid, including system stability, reliability, and lack of power balance [3]. Predicting solar energy production is essential to maintain a stable energy supply from the PV grid. Accurate predictive models eliminate the effects of PV output uncertainty, improve system stability, and reduce maintenance costs for additional equipment [4]. Accurate modeling of the PV module is the first step in the simulation process. Many publications have already described different types of PV modeling techniques. However, these tasks were very complicated and time consuming. In addition, simulators based on MATLAB coding were used by most authors to visualize I-V and P-V curves [5, 6].

The problem with these simulators is that they cannot be used for different modules simultaneously. Herewith there exists some possibility of data manipulation. The proposed technique can be used to illustrate the characteristic curves of any specific model instantly.

Different types of **Optimal Power Point Tracking** algorithm such as hill climbing, voltage feedback, current feedback, perturb and observation, incremental conductance, fuzzy logic, and neural network have been discussed.

Among them, hill climbing and voltage feedback are quite easy to implement, but these algorithms are not efficient in tracking the maximum power with sudden variation in environmental condition.

The conventional (P&O) and incremental conductance are more popular because they show a better performance with environmental conditions, and implementation is also easy.Therefore, for this work a fuzzy logic based **Optimal Power Point Tracking** algorithm has been used. Some good works based on fuzzy logic has already existed. But in most of the works an extra gain block has been added with the fuzzy system for tuning the output [20, 21]. In this algorithm the gain block has been removed, and duty cycle has been calculated directly using seven rules based fuzzy system. The developed algorithm is able to track the maximum power with a convenient speed, and it shows a very dynamic response with sudden variations in environmental conditions. At the same time, the implementation of this algorithm is also possible with available components at a lower cost. Selection of an appropriate converter is another important issue when implementing a PV-**Optimal Power Point Tracking** system. Recent work has shown that various types of converters have beenused for different applications [22, 23]. In this work a boost topology has been selected with an intention to use the system for high voltage applications. Finally the developed PV module and **Optimal Power Point Tracking** technique has been connected with the boost converter to analyze the performance of the system.

II. LITERATURE REVIEW

In [2014-2016] addition to meteorological factors, non-linearity of voltage-current (V-I) characteristics of PV systems have a considerable impact on power delivery. The V-I characteristics of a PV module are a function of irradiation and temperature. For maximum utilization efficiency, Solar Cell Arrays (SCA) are accompanied by Maximum Power-Point Tracking (MPPT) controllers.

In [2006-2010]A comprehensive list of 40 different MPPT techniques and their classification has been gathered by Karami et. al and can be found in [5]. Much work is available in the literature describing various MPPT algorithms and designs to improve the efficiency of PV system, including Perturb and Observe (P&O), variable step size P&O, distributed MPPT, Incremental conductance (INC), Fuzzy Logic Controller (FLC), Particle Swarm Optimization (PSO) based P&O method and Neural Networks (NN). All these methods vary in oscillation around the actual maximum power point, convergence speed, complexity, stability, cost and requirement of electronic equipment [6], [7], [8].

In [2016] Demand of electricity is also stochastic (though more predictable than the PV-based generation rate). The uncontrollable nature of solar energy generation and stochastic demand can lead to solar energy supply-demand imbalance. The generation rate must continuously meet the demand, but the surplus can be costly. For instance, in March 2017 the state of California produced excessive solar power on some days than required and had to pay the neighboring states to take the excess electricity to avoid overloading of power lines [9].

In [2018]This similar recurrent instances, germany has had to pay consumers multiple times in the past for disposing the excessive power supplied by the wind and solar farms [10].

In [2009-2010] Energy storage could be used to smooth PV MPPT power fluctuations for grid injection [11], but it is a very costly option. To better manage the demand-supply balance, power control algorithms have been proposed and used [12], [13], [14], but the applicability of these methods are limited to deterministic or non-stationary conditions.

In [2015-2019]The voltage base MPP tracking method uses the fact that the ratio between the maximum power voltage and the open circuit voltage under different weather conditions, are linearly proportional [15]. Since this method is based on an approximation of a constant ratio, the extracted power is most likely to be below the actual MPP, which results in significant loss of the available power. Moreover, this method fails to track the MPP if some of the PV array cells are partially shaded or damaged. A similar MPPT method, called current-based MPPT, has been proposed. This method approximates the ratio between the maximum power current and the short circuit current under different weather conditions [16]. The same limitations and disadvantages as the voltage base MPPT exist with this method

III. METHODOLOGY AND ALGORITHM

3.1 Mathematical Model for proposed PV Panel

The equivalent circuit of single solar cell is shown in Fig. 3.1. The solar panel for the required power rating is obtained by connecting number of solar cells in series and parallel. The equivalent circuit of the solar panel with Ns number of series connected cells and Np number of parallel combination of series string is shown in Fig. 3.2.

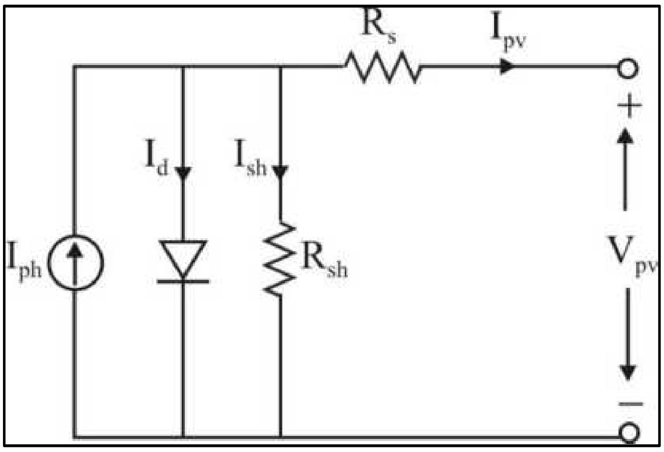

Fig. 3.1: Equivalent Circuit of Single Solar Cell

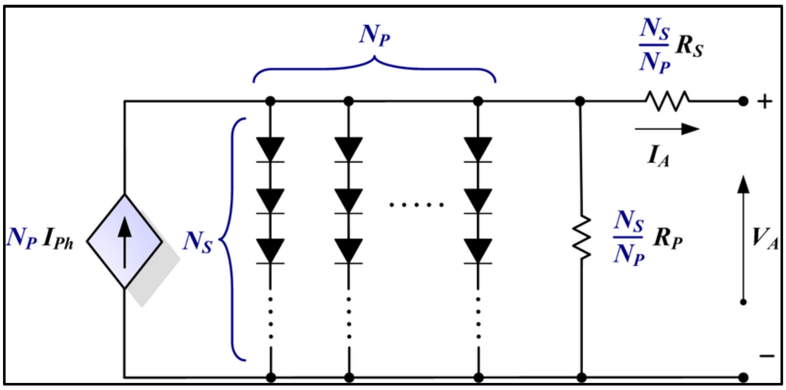

Fig. 3.2 Equivalent Circuit of Solar Panel.

Summary of mathematical equations of the PV panel are given below: Module photo-current, Iph is given by,

$$I_{ph} = [I_{SC} + K_T\,(T - T_r)]\,\frac{G}{G_{ref}} \qquad (3.1)$$

Where, ISC - Short circuit current60

KT - Temperature coefficient of the cell (KT = - 3.7 * 10 - 3 / °C for mono and poly crystalline Si)

G - Solar radiation in W/m²

Gref - Solar radiation at reference conditions (Gref =1000 W/ m²)

T - Operating temperature

Tr - Reference Temperature

Module reverse saturation current, Irs is given by,

$$I_{rs} = I_{SC}/[e^{\frac{qV_{OC}}{N_s knT}} - 1] \qquad (3.2)$$

Where, q - Charge of an electron

VOC - Open-Circuit Voltage

Ns - Number of cells in series

k - Boltzmann's Constant

n - Identity Factor of Diode

$$I_o = I_{rs}\left(\frac{T}{T_r}\right)^3 e^{\frac{qE_{go}}{nk}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \qquad (3.3)$$

Where, Ego - Band gap energy of semiconductor

Rs - Series resistance of the cell

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Rsh - Shunt resistance of the cell

3.2 Simulation Model of PV Panel

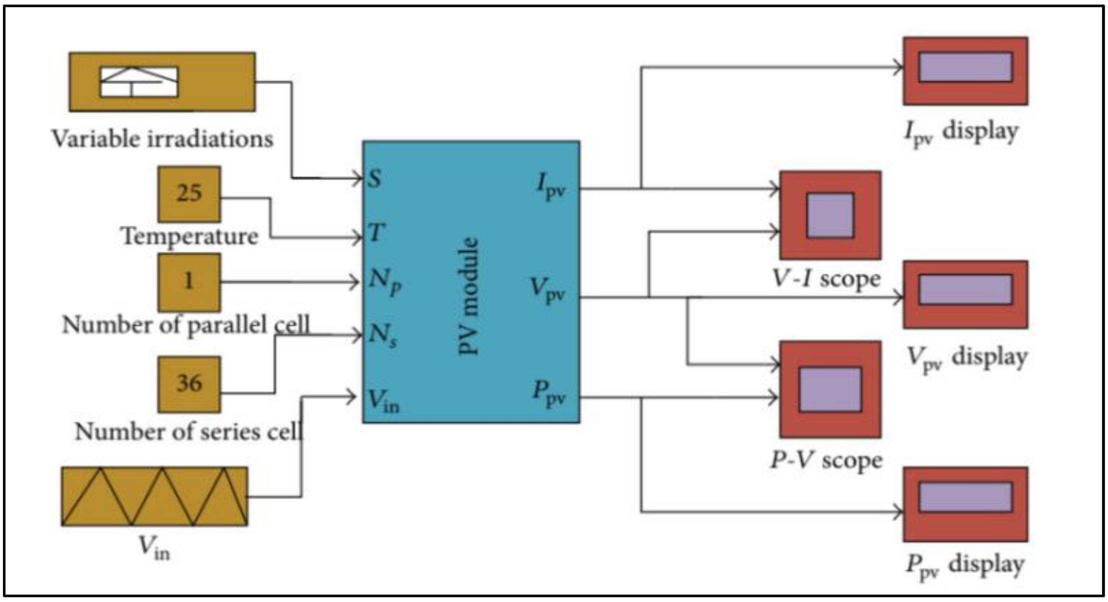

Fig. 3.3 Simulation model of PV panel system

Simulation model of PV panel system is show in Fig. 3.3. It is analysed for constant temperature and variable irradiance. The Power-Voltage characteristics and the Current-Voltage characteristics are plotted with a variable load so that the load current is varied from zero to short-circuit condition for various irradiance conditions. Also, the voltage output of the PV panel is studied for a fixed load at various irradiance conditions.

3.3 Perturb and Observe Algorithm

Perturb and Observe (P and O) searches for the maximum power point by changing the PV voltage or current and detecting the change in PV power output. The direction of the change is reversed when the PV power decreases. P and O can have issues at low irradiance that result in oscillation. There can also be issues when there are fast changes in the irradiance which can result in initially choosing the wrong direction of search. The designer has a choice of either changing the PV voltage or current. Tracking PV power by changing the PV voltage is less sensitive to changes in irradiance. This becomes more of an issue as the irradiance decreases as shown in Fig. So finding Imp will better locate the maximum power point particularly at lower insulation. Choosing the proper step size for the search is important. Too large will result in oscillation about the maximum power point and too small will result in slow response to changes in irradiance. To reduce the response to noise, averaging the PV power value is important when making a direction decision. Keep in mind that whenever the system is not at the maximum power point, it is not operating at the **Optimal Power Point Tracking** point.

We are proposing an OPPT controller that minimizes the difference between (predicted) P power generation and demand, rather than maximizing the power output of the SCA. This is achieved by gradually increasing or decreasing the duty ratio of the power converter according to the PV module output power versus the voltage curve. The controller operates on similar principles as the P&O algorithm and utilizes predicted values of available solar power and demand. Namely, it inspects the instantaneous predictions of supply and demand. If the demand exceeds the maximum available power, the controller operates similar to the MPPT P&O method, thus delivering maximum power. However, if the demand prediction is less than the maximum power available, the controller tunes the PV array voltage such that the output PV power closely matches to predicted demand. The adjustments are achieved through small perturbations in the output voltage as in Perturb & Observe. The output of P&O OPPT controller is fixed size duty cycle change. A schematic flowchart of the proposed OPPT P&O algorithm is shown in Fig 3.4. The voltage of solar cell array corresponding to optimal power point is denoted by Vref.

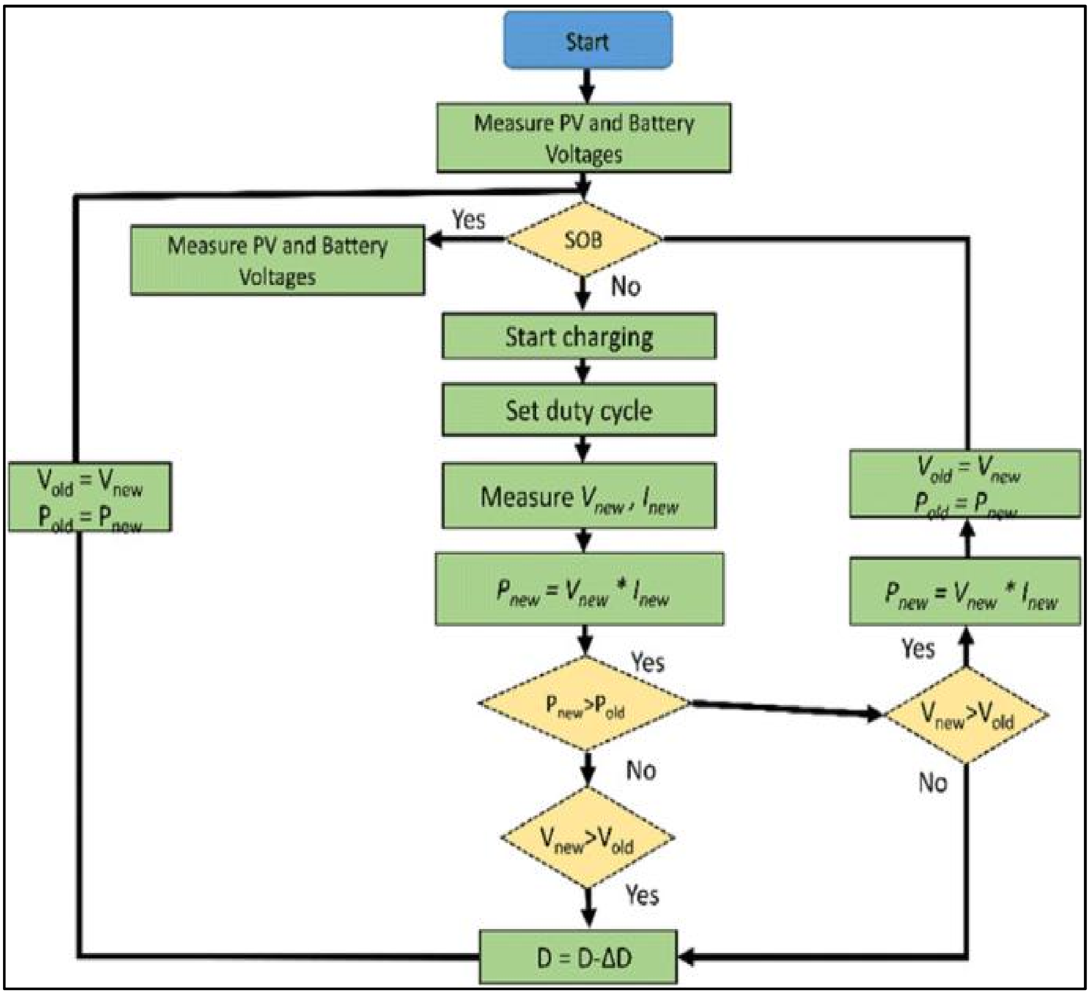

Fig. 3.4. P&O algorithm for Optimal power point tracking

IV. RESULT ANALYSIS

4.1 Implementation of Methodology by Using Simulation

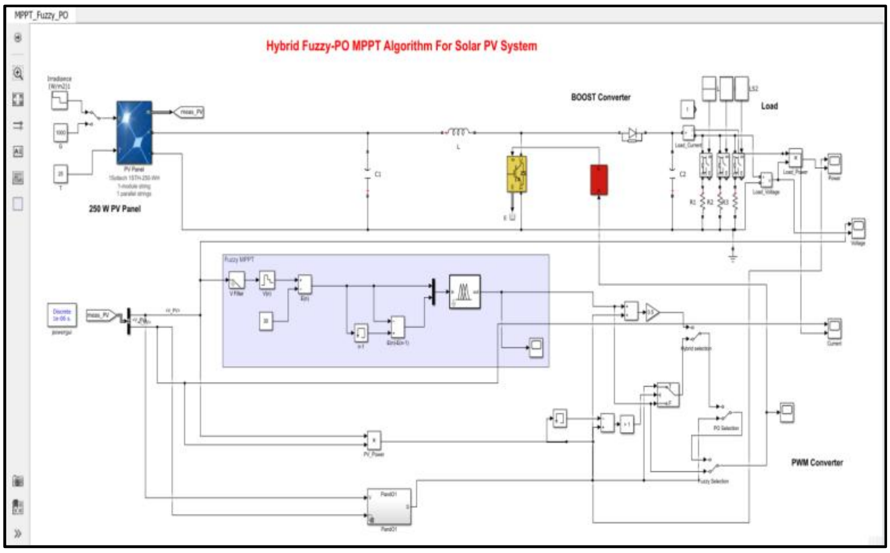

Fig. 4.1 Basic model for effective Optimal Power Point Tracking Controller Using Forecasted Photovoltaic Power and Demand

When PV systems are designed to match the peak loads, the power generated and the peak demand are incongruous. If the module always operates at MPP, it would produce more energy than demand during a significant period of the day. In the absence of adequate storage capacity, the excess power dumped in grids would result in situations like overloading of lines, islanding effects, negative pricing or unstable gridoperations. To prevent such situations, we can take advantageof the non-linear relation of Voltage-Current characteristic of PV array system by operating at an optimal power point rather than the maximum power point.

4.2 Simulation Results and Discussion

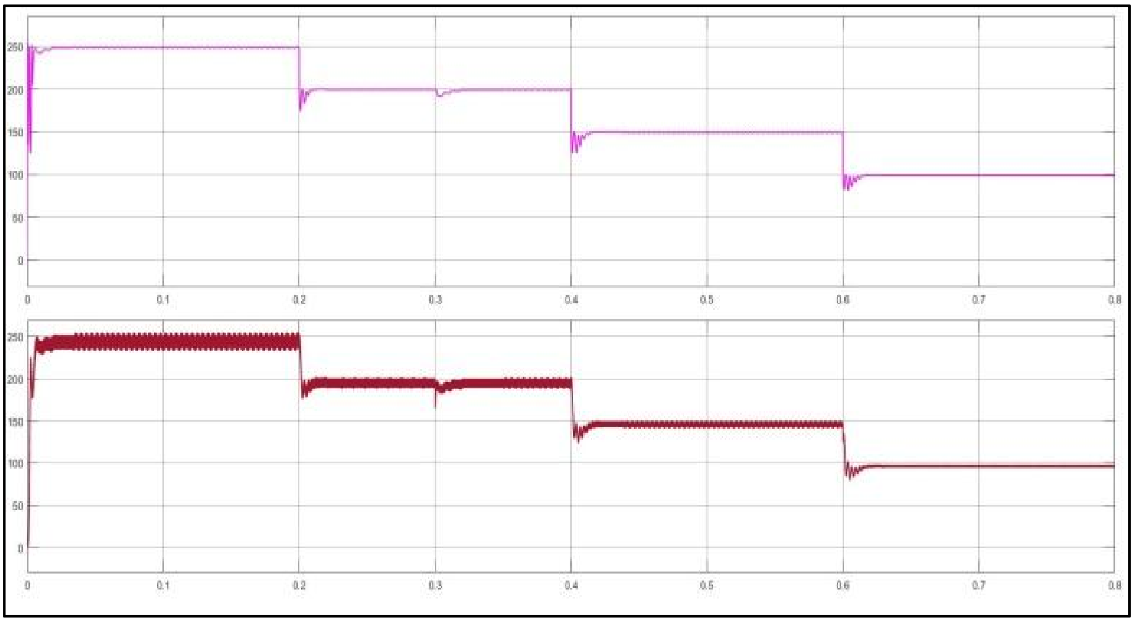

Fig.4.2 Optimal Power Point Tracking Using Fuzzy Logic Controller

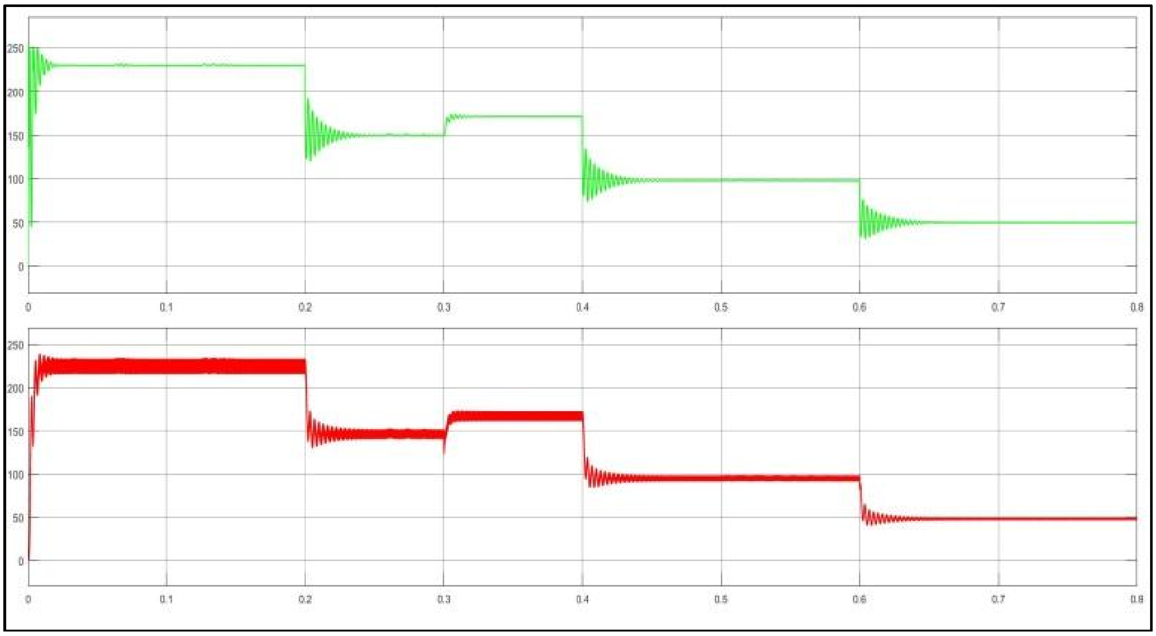

Fig.4.3 Optimal Power Point Tracking Using P & O Algorith

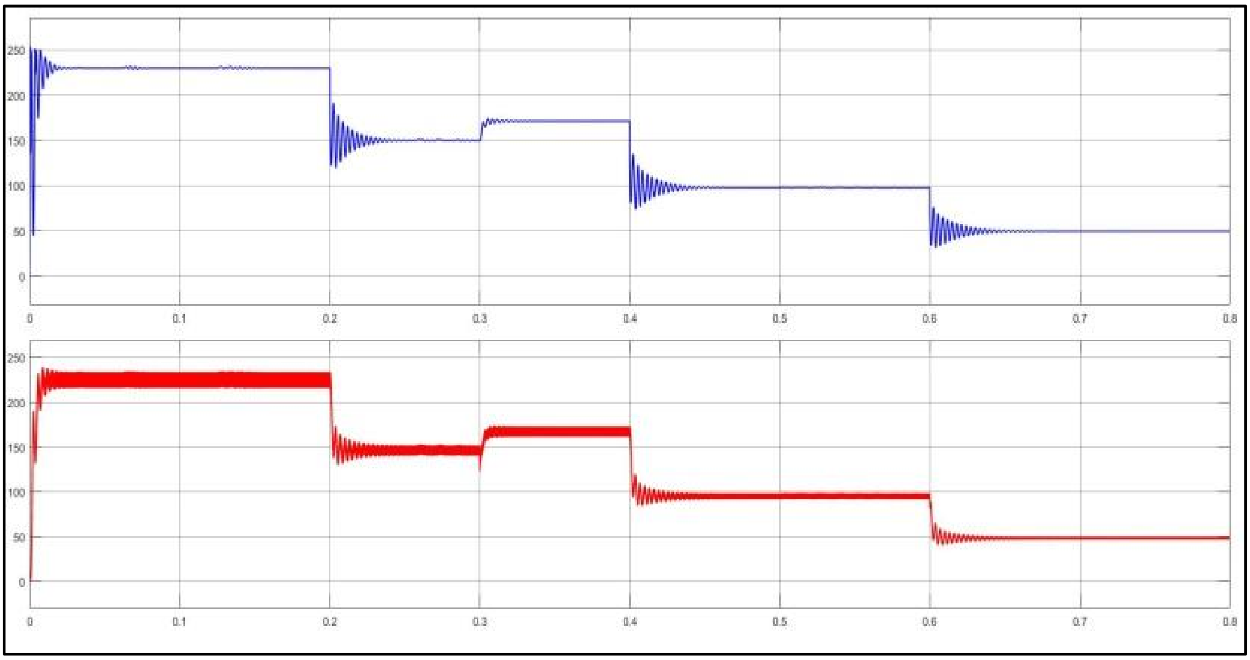

Fig.4.4 Optimal Power Point Tracking Using Hybrid System

Case: 1: Irradiation was held constant at 1000 W=m2 between 0 2 secs. At 2 sec, it was decreased to 800 W=m2. After every 2 sec, irradiation was decreased by 200 W=m2.

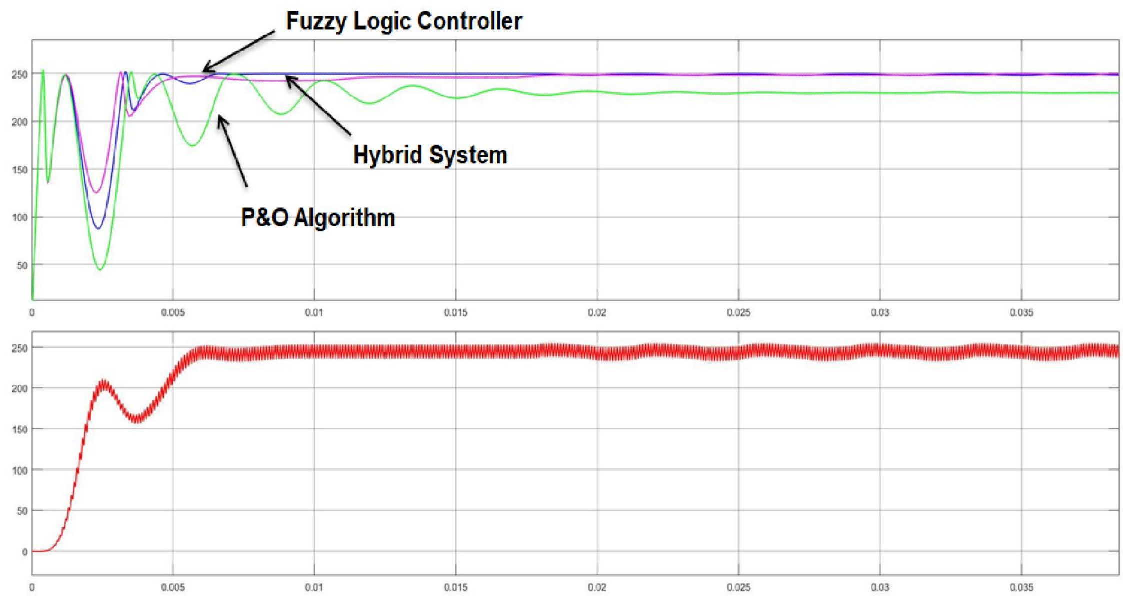

Fig.4.5 Case 1: Comparison of Optimal Power Point Tracking Using Hybrid System, Fuzzy Logic Controller, P&O Algorithm

In order to validate the model performance, the following simulations were performed with different combinations of solar irradiation and demand profiles with both controllers: P&O controller with fixed step sizing change of duty cycle and fuzzy logic controllers with adaptive step sizing change of duty cycle.is shown in fig.4.6

Case 2: Irradiation was constant at 1000 W=m2, Demand is kept constant at 1500 W.

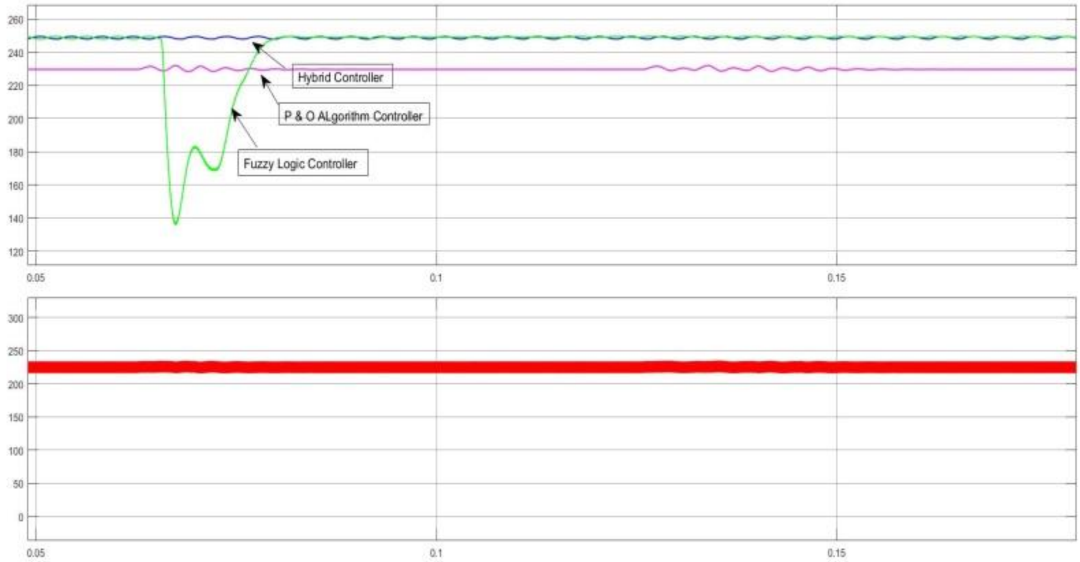

Fig.4.6 Case 2: Comparison of Optimal Power Point Tracking Using Hybrid System, Fuzzy Logic Controller, P&O Algorithm

V. FUTURE SCOPES

1. Hybrid of OPPT with mechanical tracking will give more efficiency, project can be extended in this direction.
2. Battery output is directly utilized to feed power in the dc grid which can be used for charging electronic devices like laptop, mobile directly.
3. By adding wifi module we can record our data in the system and optimize the data for better use.
4. Solar panel installed on urban and sub-urban areas with modified technology will lead in saving of our bill.

VI. CONCLUSION

A simple framework was proposed to balance the demand-supply equation for PV systems designed for peak-load. The framework comprises of predictive models for solar energy and load and real-time controllers. The predictive models were designed using the nonlinear autoregressive neural network with exogenous input (NARX) including time and weather parameters. OPPT controllers were designed using a modified Perturb and Observed algorithm and Fuzzy Logic to control the power flow between SCA and the load. Simulation results showed that the controller results in realistic source-load balance. With the designed P&O OPPT controller, tracking is more reliable than the fuzzy logic controller.

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