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# A Distributed Control Strategy for Coordination of an Autonomous LVDC System

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## Abstract

In this paper, the co-ordination of energy sources is attained to have a continuous power supply to a dc load. This co-ordination provides effective management between photovoltaic (PV) module and battery. The maximum power is drawn from the photovoltaic panel using the maximum power point tracking technique (MPPT). The algorithm used for Maximum Power Point technique is perturb and observe (P&O) method and it is implemented using the fuzzy logic controller (FLC). When sunlight is available, photovoltaic panel supplies power to the DC load. When PV panel becomes inactive i.e. at zero irradiation, the battery starts supplying power to the DC load. A DC-DC converter which works in bi-directional mode is used for charging and discharging the battery. The converter acts in buck and boost mode while charging and discharging the battery. Thus, the DC load gets continuous power supply without any interruption maintaining a constant DC voltage across the resistive load. A simulation platform is developed in MATLAB/Simulink, in which Photovoltaic and battery are selected as distributed renewable energy resource and energy storage device respectively.

**Keywords:** Photo-Voltaic Module, Maximum Power Point Tracking, Perturb and Observe, Fuzzy Logic Controller.

## Nomenclature

| | | |
|---|---|---|
| E | = | electron charge (1.602 × 10-19 C). |
| k | = | Boltzmann constant (1.38 × 10-23 J/K). |
| $I_c$ | = | cell output current, A. |
| $I_{ph}$ | = | photocurrent, function of irradiation level and junction temperature. |
| $I_0$ | = | reverse saturation current of diode (0.0002 A). |

$R_s$ = series resistance of cell (0.001 Ω).
$T_c$ = reference cell operating temperature (20 °C).
$V_c$ = cell output voltage, V.

## Introduction

An extensive dependence on thermal energy sources has elevated the $CO_2$ emissions which have serious impact on our environment. Renewable energy sources form a better alternative option in bringing down the level of $CO_2$ emissions. Building a new power transmission system in the remote places is difficult, expensive and time-consuming. Thus, the microgrid is constructed using these renewable energy sources in the places which are far away from mainland (Tamer Khatib et al, 2009). As microgrid is constructed near to the load, the transmission losses are also greatly reduced. As renewable energy sources are variable in nature, much sophisticated method is needed to give power supply to the load continuously. DC microgrid finds applications in areas such as data centres and telecommunication towers. DC microgrid is preferred over AC microgrid because of robustness, maximum efficiency, no synchronisation problems and no reactive compensation issues and also reliability and power quality. As renewable energy sources are variable in nature, for example, the output of the PV panel depends on the irradiation produced by the sunlight. Because of this, the stability issues or disturbance in the power flow to the load occurs. Thus, the energy management plays a much important role in the energy applications.

In India, many parts are very hot throughout the year. Thus, PV panel becomes a prominent source of energy. Maximum power is obtained from PV panel by P&O algorithm using fuzzy logic controller (Tamer Khatib, 2010). The energy storage element is also much important to assure the continuous power supply to the DC load. The important principle is to co-ordinate the operation of various energy elements to make the power flow continuously on the consumer side (Ahmad Razani Haron et al, 2012). Microgrid can supply power to the main grid as well as it can work as an autonomous unit. The concept of microgrid has encouraged the people to meet the shortage in energy needs.

## System Structure

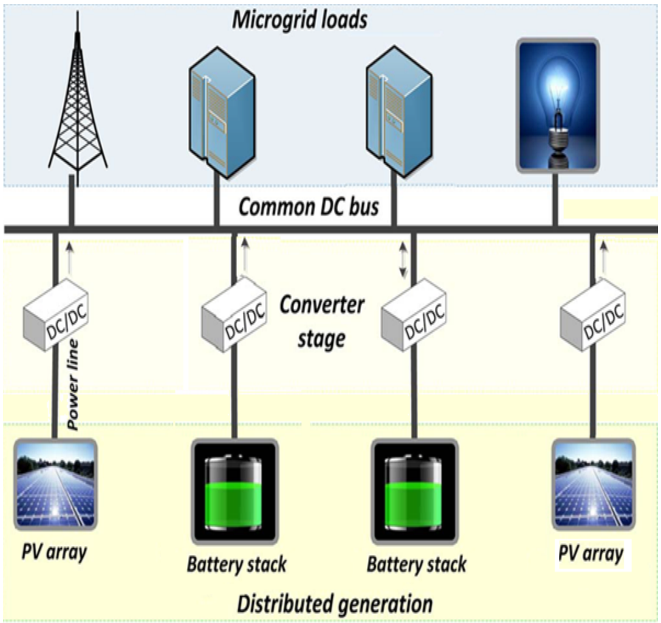



**Figure 1:** Structure of DC microgrid with PV array and battery

The structure of DC microgrid is shown in above fig. 1. The PV panel is used as the primary energy source and battery as the secondary energy source. A boost converter is used between the PV array and DC bus. A battery stack is connected to the DC bus through dual active bridge converter which acts as a bidirectional buck-boost converter. MPPT technique is utilized for extracting a maximum power from the PV source using FLC which adjusts the duty cycle of the boost converter(R. Balasubramanian et al., 2014). When PV panel is operating, it supplies power to the load demand as well as it charges the battery. When the PV panel attain zero irradiation, the battery comes into play to supply the energy demand of the DC load. A simple principle is used to govern these energy sources i.e. PV and battery (A. Yasin et al, 2011).

## Design of PV Panel

Solar cells are the building blocks of PV panel. Since voltage produced by a single solar cell is very less, a number of solar cells are connected in series or parallel to form a module. A number of modules are connected to get a solar array in order to get a considerable voltage rating.

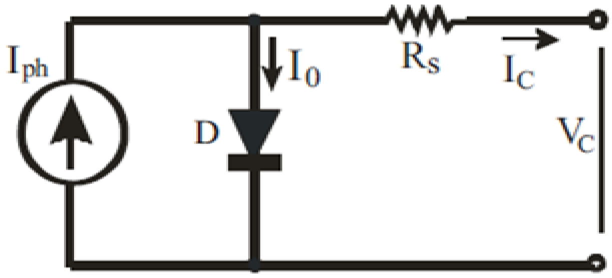



**Figure 2:** A single diode model of PV cell

## The Simplified-Equivalent of PV Cell Depends on The Following Equation

$$V_c = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - R_s I_c$$

## Maximum Power Point Tracking Technique Using P&O Based FLC

Different types of MPPT methods are developed by researchers. The VI characteristic of PV panel is non-linear. So, in order to get the maximum efficiency the load impedance matching is required. In order to achieve this, a separate power electronic converter with MPPT technique is used. In this paper, MPPT is implemented using P&O based Fuzzy Logic Controller.

Perturb and observe is the most famous and simplest of all other algorithms. It is chosen as it gives desirable results with fewer complexities. It involves the calculation of voltage and power at all instants. In this method, voltage is perturbed in one direction, if power at that instant is more than the previous instant, then the perturb continues. If power at that instant is less than the previous instant, then the voltage perturb in opposite direction. There is some oscillation occurs at MPP point. The voltage sensor is the only sensor that is used in this method so it is cost effective. Thus, this method involves less complication than other methods. MPPT can also be calculated using various other methods. The flowchart for P&O method is given in fig. 3

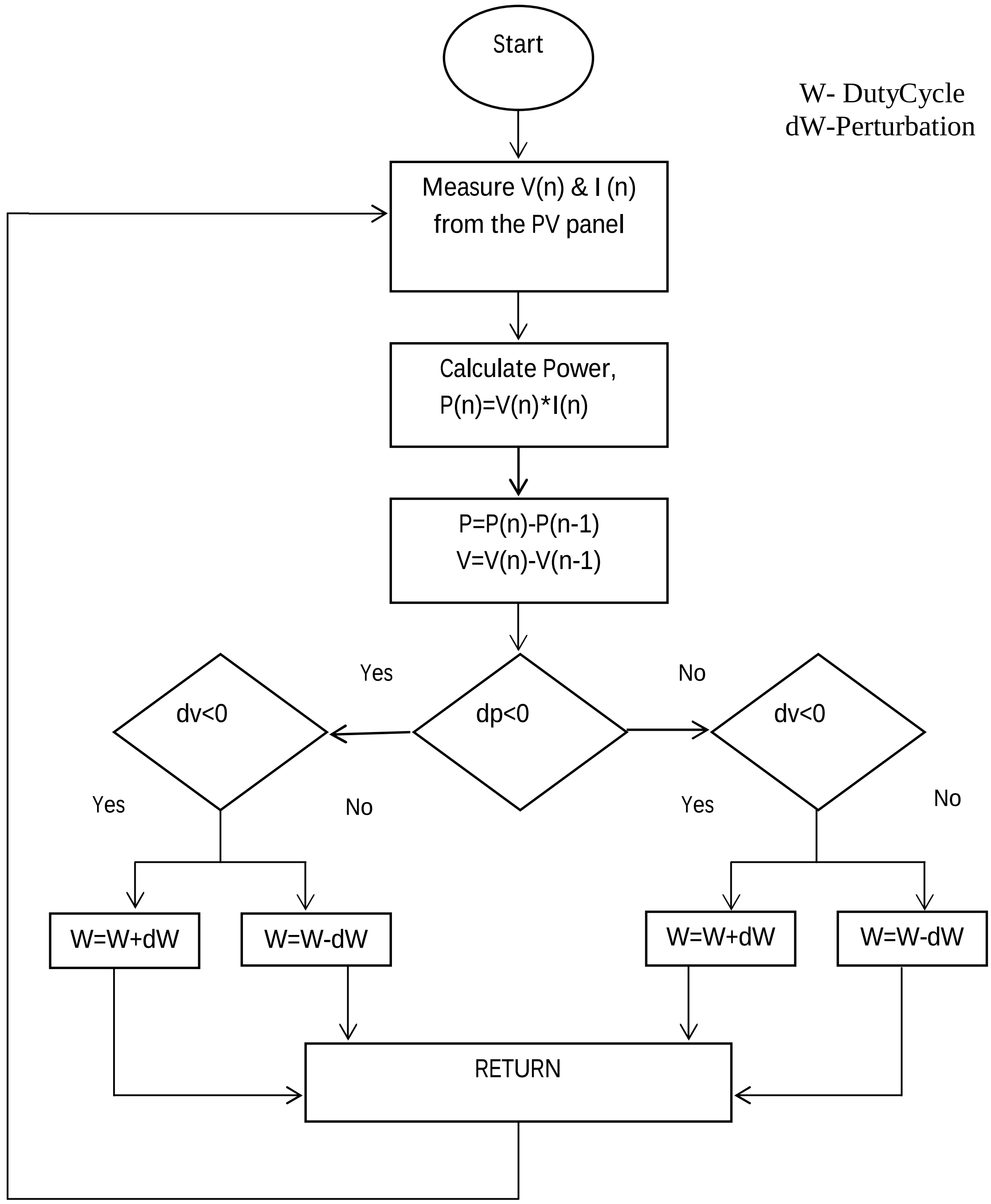



**Figure 3:** Flowchart of Perturb and Observe Algorithm

Fuzzy logic controller involves three methods fuzzification, interference and de-fuzzification. At first, the input and output variables are converted into fuzzy sets by introducing membership functions. After this, fuzzy rules are created based on this membership functions. Finally, all the fuzzy sets of values are converted into real time values in the process called de-fuzzification. In this paper, two input variables 'dp' (change in power) and ‘dv’ (change in voltage) are used. The duty cycle is taken as output variable. The membership functions for the fuzzy logic controller are given in fig. 4: a-c. and the rules are framed in table. 1.

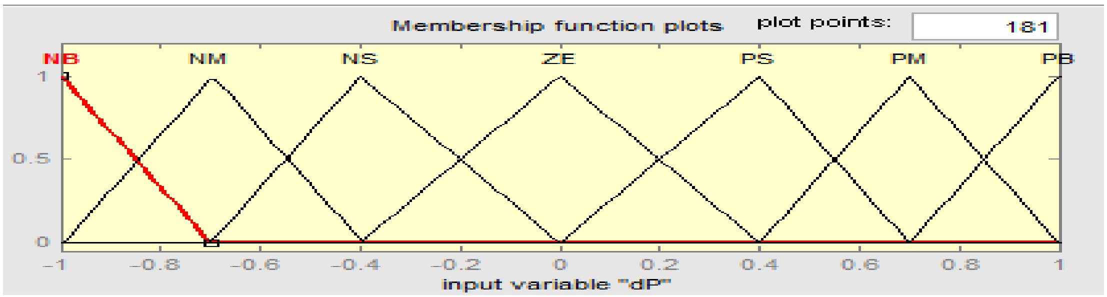



**Figure 4:** a) Member ship Function for 1st Input Variable ‘dp’

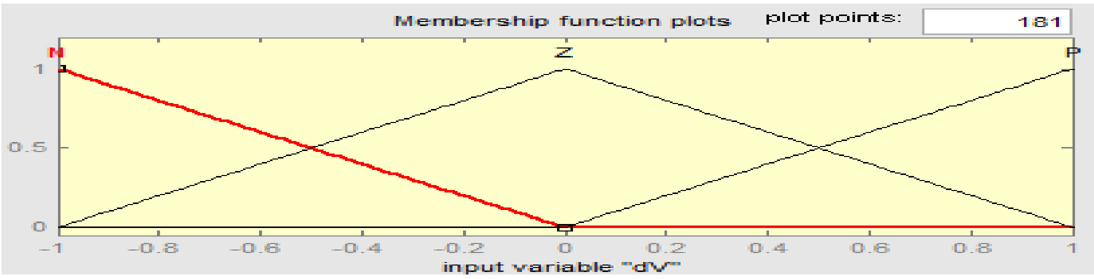



**Figure 4:** b) Member ship Function for2nd Input Variable ‘dv’

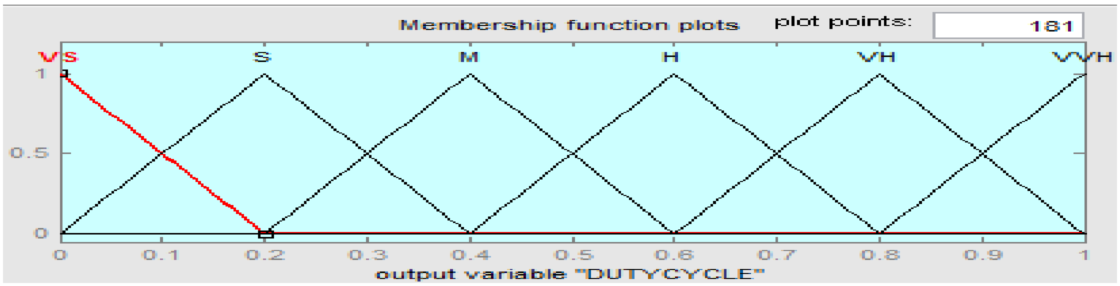



**Figure 4:** c) Member ship Function for Output Variable ‘duty cycle’

**Table 1:** Rules table for P&O based FLC to find MPPT

| dp / dv | N | Z | P |
|---|---|---|---|
| NB | VS | H | VS |
| NM | S | H | S |
| NS | M | H | M |
| ZE | H | H | H |
| PS | VH | H | VH |
| PM | VH | V | VH |
| PB | VVH | H | VVH |

## Dual Active Bridge Converter (DAB)

Dual active bridge converter shown in fig. 6 is preferred as it gives the maximum efficiency. It is connected between the PV panel along with the boost converter and the battery. This converter acts as a bi-directional converter. It acts a buck converter while charging the battery and as a boost converter when the battery discharges. It constitutes a high-frequency transformer with two DC-AC converters on both sides of it.

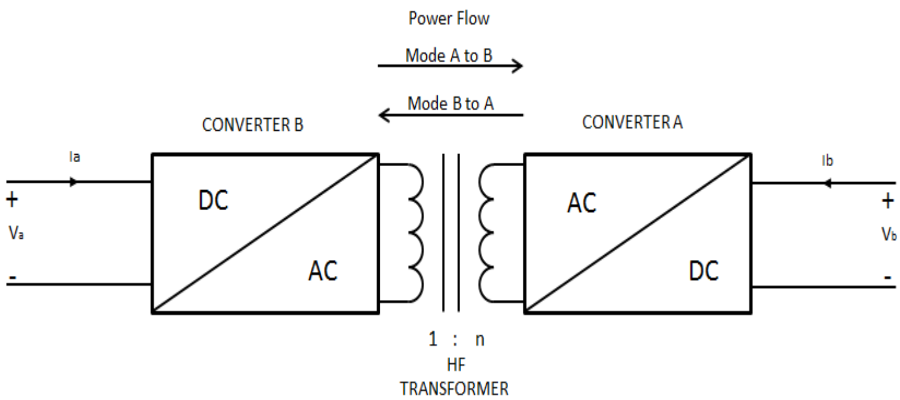



**Figure 5:** Basic Diagram of DAB converter

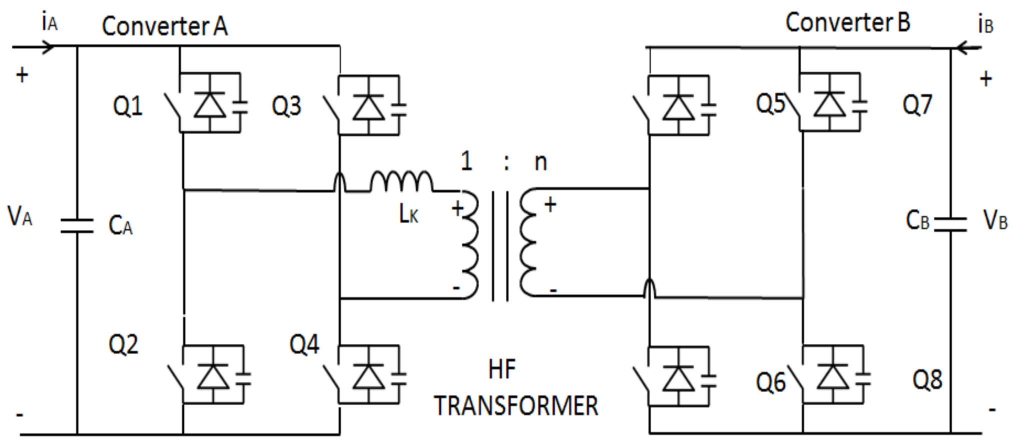



**Figure 6:** Topology used in DAB Converter

The advantages of using a DAB converter are 1. It can operate at a wide voltage ratio and also at a wide voltage range, 2. The structure is symmetrical on both sides of the high-frequency transformer.

## Energy Management

In this paper, two cases are simulated using MATLAB/SIMULINK tool.

**Case 1**: The PV panel is connected to the DC load through a boost converter. The Fuzzy Logic Controller is used to find the MPPT based on P&O algorithm. The maximum power is extracted from PV and given to the DC load.

**Case 2**: Along with PV panel a battery is connected to the DC load through a Dual Active Bridge converter.

## Simulation and Results

**Case 1:**

The fig. 7 shows the Simulink diagram of PV panel with boost converter using P&O based Fuzzy Logic technique. The boost converter parameters are inductance 47e-3H, capacitance 2200e-6F and load resistance 100 Ω. The MPPT for various irradiations is shown in fig. 8: a-c.

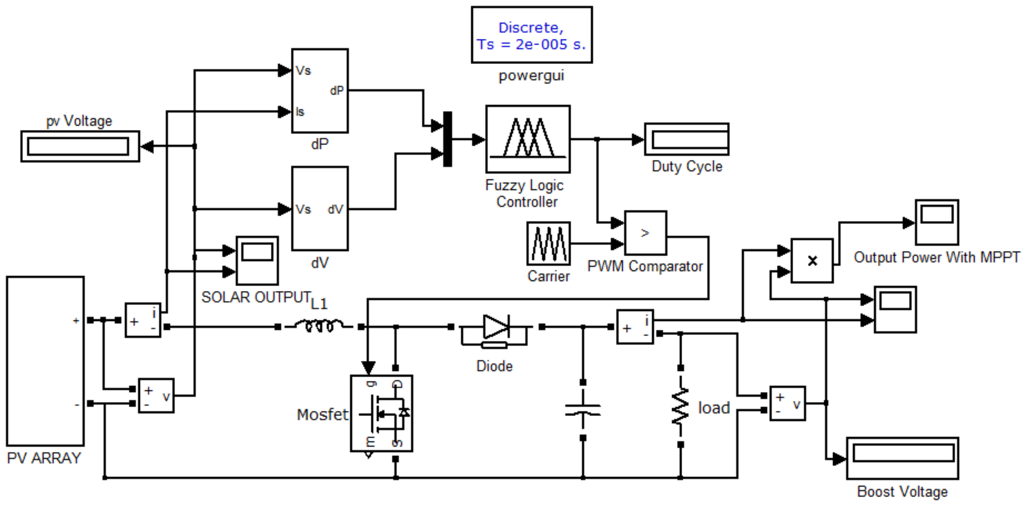



**Figure 7:** Simulink Model of PV Panel with MPPT Using P&O based FLC technique

**Output Power across the Resistive Load Obtained Using MPPT by P&O Based FLC under Various Irradiation Conditions**

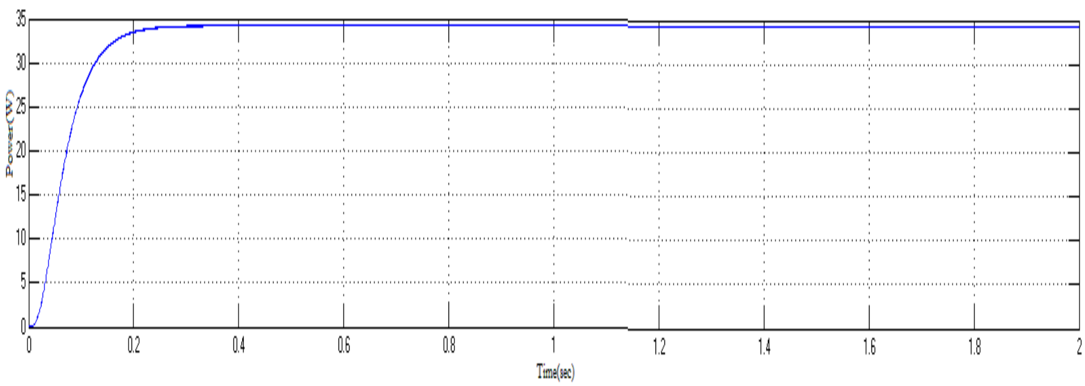



**Figure 8a:** Output Power with MPPT Using P&O based FLC technique for 500 W/$m^2$

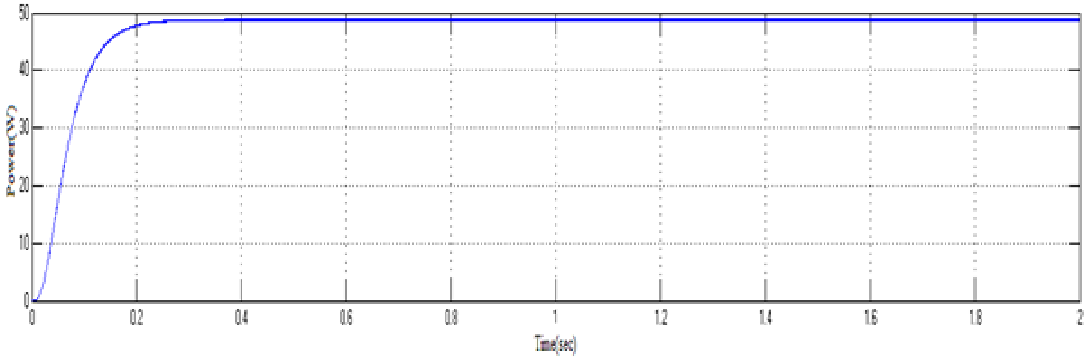



**Figure 8b:** Output Power with MPPT Using P&O based FLC technique for 750 $W/m^2$

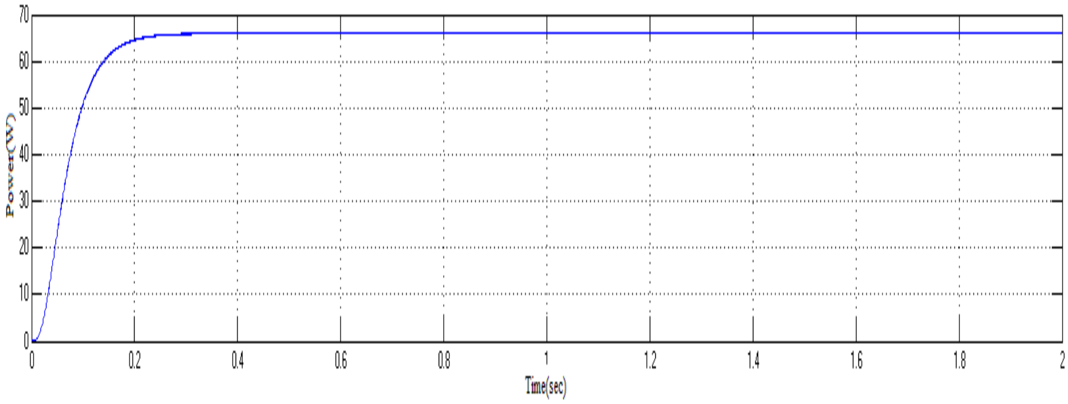



**Figure 8c:** Output Power with MPPT Using P&O based FLC technique for $1000W/m^2$

## Results Obtained

**Table 2:** Efficiency of Boost Converter Obtained Under Various Irradiation Conditions

| Irradiation | Duty Cycle | Input Power of Boost Converter | Output Power of Boost Converter | Efficiency |
|---|---|---|---|---|
| **(w/m2)** | | **(W)** | **(w)** | **%** |
| 250 | 0.6191 | 69.75 | 66.01 | 94.64 |
| 500 | 0.619 | 50.8067 | 48.82 | 96.09 |
| 750 | 0.6165 | 36.21724 | 34.23 | 94.25 |
| 1000 | 0.612 | 23.57751 | 22.22 | 94.24 |

**Case 2:**

The fig.9 shows the simulation of PV panel with boost converter using P&O based Fuzzy Logic technique. The boost converter parameters are inductance 47e-3H, capacitance 2200e-6F and load resistance 100 Ω. The battery parameters are 12V, 7 Ah and 80% SOC. The PV panel conducts when sunlight available and battery conduct at zero irradiation on the PV panel. The simulation results are obtained in fig. 10(a-c).

**Simulink Model of The Battery Connected PV Source based on P&O Fuzzy Logic Controller**

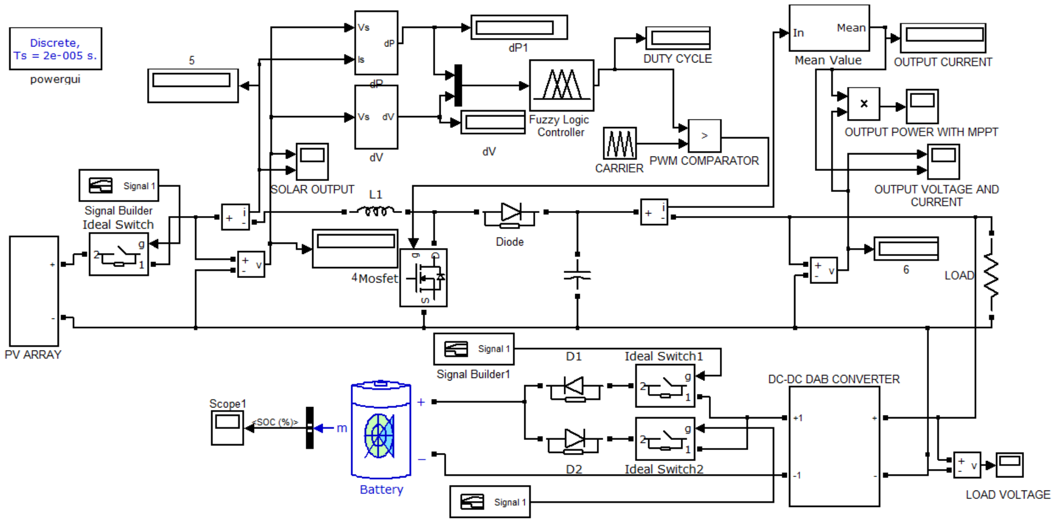
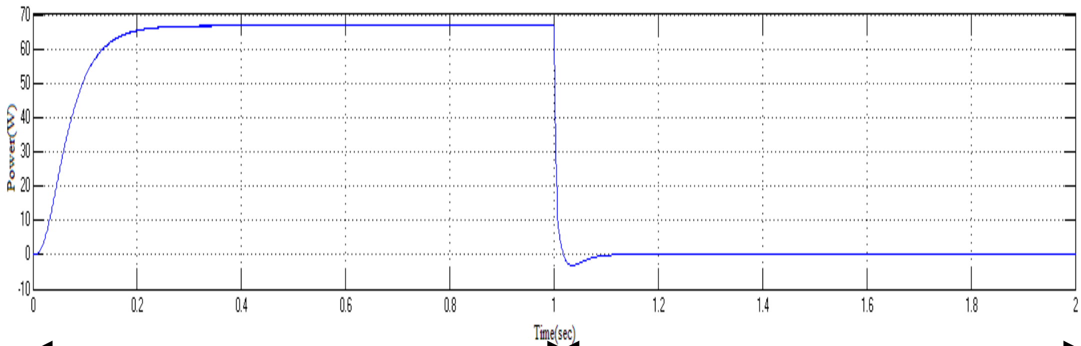



**Figure 9:** Simulink Model of PV Panel and battery with MPPT Using P&O based FLC technique

**Output Power across Resistive Load due to PV Panel**

The fig. 10-a shows the maximum power obtained from PV panel when the irradiation is at 1000 W/m[2]




Output power across the Resistive load due to PV Panel

PV panel becomes inactive at zero irradiation

**Figure 10a:** Output power across DC load due to PV panel

**Output Voltage across the Resistive Load Due To PV Panel and Battery Acting Simultaneously**

The fig. 10-b shows that DC voltage of 80V is maintained across the resistive load when PV panel or battery is conducting simultaneously.

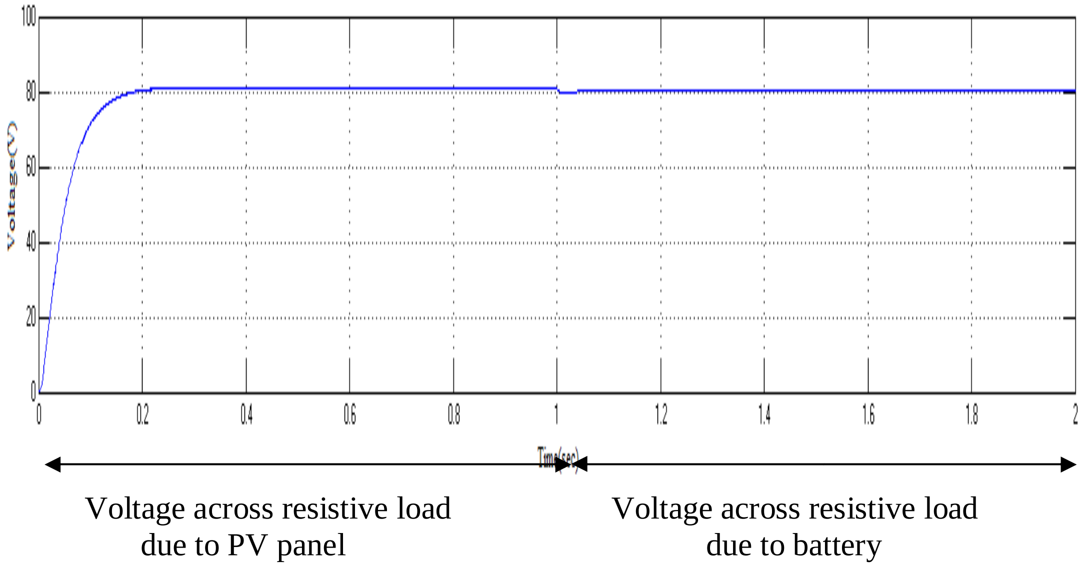



**Figure 10b:** Voltage across the Resistive Load Due To PV Panel and Battery

**Charging and Discharging Characteristics of the Battery**

The fig. 10-c shows **t**he battery charges by PV panel when irradiation is present and discharges at zero irradiation.

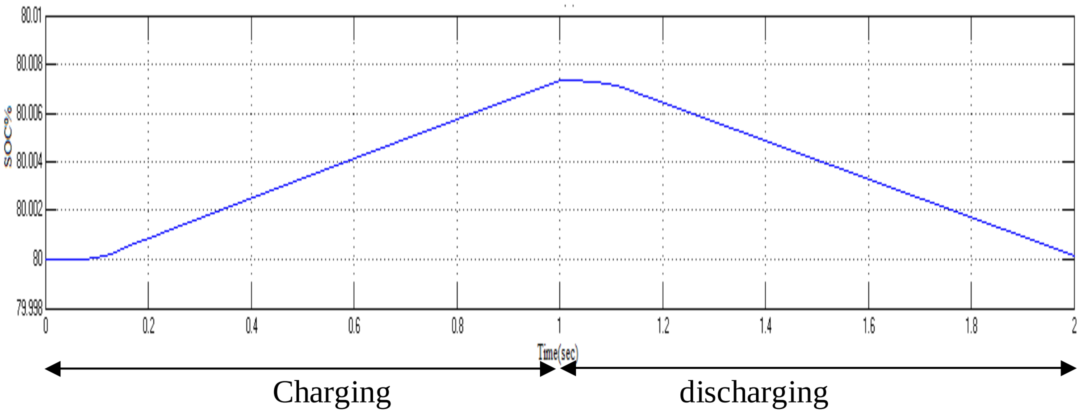



**Figure 10c:** Charging and Discharging Characteristics of Battery

## Conclusion

The energy management is achieved by governing the operation of PV and battery sources using P&O based FLC method. The results obtained shows better performance when compared to other conventional methods. The P&O based FLC helps in supplying the maximum power that PV panel has obtained to the resistive load. The energy can be tapped either from PV panel or from the battery according to the availability of irradiation on PV panel using a control strategy. Thus, the energy management plays an important role in the effective operation of DC microgrid and also enhances the better performance of DC microgrid.

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