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# Design Various MPPT Controller for Solar PV Water Pumping System

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***Abstract:***
The unavailability of grid connected electricity in remote areas and higher price of the diesel affects the fulfillment basic requirements of electricity. Because without electricity sustain of human life is a challenging assignment. The non-conventional solar PV technology can fulfill the demand of electricity, which can be used both electrification and water pumping system for both community drinking water and irrigation system. Based upon the solar PV technology, this paper presents various maximum power point tracking (MPPT) controller and compares with various parameters. Solar PV water pumping system is discussed in this paper and compares the results with and without using MPPT controller. This paper primarily represents the simulation model for solar pumping system. Comparing the controller under non-uniform irradiation is done. Water level with and without MPPT controller are analyzed in this paper. Result of optimum design of controller is presented along with various irradiance.

***Keywords:****Maximum power point (MPP), particle swarm optimization (PSO), photovoltaic (PV) system, maximum power point tracking (MPPT), solar pumping, simulink.*

## I. INTRODUCTION

The involvement of the energy is much essential for the world which is generally relay on resources like nuclear, fossil etc. However, they increase the risk of environmental pollution, which have drawn the attention for a different source of energy and generally a non conventional one. Solar system systems (PV) as a renewable resource is the most popular source of energy which is clean, safe and can be implemented with no fuel cost, less maintenance also with no noise and pollution [1].

The efficiency of the solar system is totally dependent on the MPPT controller strategy. However, the popular strategies like Perturb and Observe (P&O) and Incremental Conductance (I&C) fail to reach the global minima point at different irradiance condition [2]. Although, the P&O algorithm is a simpler approach for MPPT, it generally creates oscillations around the global minima point and this

generally fails for the rapidly altering environmental (temperature and irradiance) conditions. However, I&C algorithm has better performance for such environmental conditions while is much critical in nature. Other techniques like the constant voltage or/and the constant current approaches are also easy for implementation while they do not track the maximum point properly. On the contrary, the approach has good ability to tract MPP conditions but is computationally critical and needs a proper selection of factor [3]. The entire algorithm fails for partially shaded conditions. Hence, various strategies have also been developed which are discussed

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further and are scattered throughout the literature [1],[2].

Although some MPPT techniques are suitable for small scale solar systems, for large systems they fail due to the partial shedding condition. So, all the above said MPPT approaches are not suitable for reaching the global MPP for the partial shading conditions. Several approaches are the global tracking method under such condition, while they are not much acceptable comparing the efficiency also they have larger computational cost. A well known heuristic approach, named, Particle Swarm Optimization technique (PSO) is implemented in literature [3],[8],12]. It is a population based optimization approach which is a nature inspired approach. Here, everyone is assumed as particle. They represented as particular solution. PSO is considered for partial shading condition and variation of temperature. The implementation and the performances among P&O, IC and PSO presented and compared.

In the present context, as an initial attempt, solar modeling and their I-V and P-V characteristics are explored under both uniform and non-uniform irradiance conditions. For implementation of DC-DC converters buck and boost methods are analyzed and boost is implemented for MPPT [4], [5], [6]. Also the performance analysis of the boost converter is presented along with its experimental simulation results. Various approaches such as I&C, P&O, ANN and PSO are compared for MPPT tracking [7]-[10]. Also the solar MPPT is applied to water irrigation system and performance are evaluated.

## II. PV MODEL CHARACTERISTICS

The characteristics of the solar panel can be better visualized using a VI graph which perfectly display is the importance of the electrical characteristic of the solar panel. However the parameter $P_{max}$ is highly essential for calculating the overall performance of the solar panel and the solar efficiency [11].

The solar cell generally extracts power using the sun energy to generate the current or electricity with the help of semiconductors.

Solar system photo voltaic (PV) system commonly is a device with uses the solar light called as irradiance and converts to electricity with the help of semiconductors. While the irradiance of sun is absorbed by the semiconductor of the solar model, the electrons are generally being free and thus they generate the electricity [12].

Photovoltaic process is commonly utilized using the panel. Solar cells are mostly placed side by side and are placed on a frame or module. However, several frame also can be assembled to make an array, this also can be further scaled according to the power need of the user.

Major performance of the solar cell can be stated as the relationship within the electrical parameters i.e. the current and the voltage generated for a single PV cell and are represented by I-V characteristics curve. Mainly, the irradiance i.e. the intensity of the solar radiation hits the solar cell and it controls the solar generated DC current ( I ) and the resulting increase in the temperature of the PV panel and lowers the voltage ( V ). PV panels generate the direct current (DC). So by using power electronic devices, it can be converted from DC to AC.

The major importance of I-V curve is characterizing the performance of the solar panel over varying voltage how the solar panel reacts to its current with a constant loading condition. The resulting power curve also is most important there it has a maximum peak called as MPP.

From the Fig. 1, the I-V curve of a solar cell can be visualized. The I-V curve of a solar panel is characterizing the performance of the solar panel over varying voltage how the solar panel reacts to its current with a constant loading condition. The resulting power curve also is most important there it has a maximum peak called as MPP.

When the solar cell is not connected to any load, the voltage across the terminals is represented as $V_{oc}$.

On the other hand when the two terminals are shorted i.e. when the maximum current flows i.e. the voltage difference across the two terminals is zero then it flows the maximum amount of current called as the short circuit current $I_{sc}$.

Again, variation of the I-V characterstics ranges from ($I_{sc}$) for 0 output volts to zero current for the maximum open circuit voltage i.e. ($V_{oc}$).

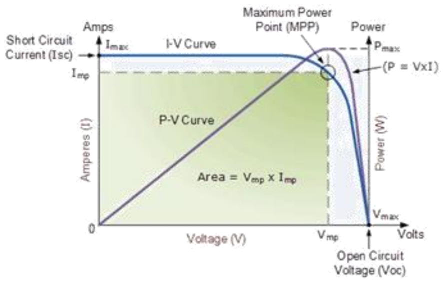


Fig. 1. I-V characteristics.

The I-V curve of a solar panel is the characterize the performance of the solar panel over varying voltage how the solar panel reacts to its current with a constant loading condition. The resulting power curve also is most important there it has a maximum peak called as MPP.

The MPP of the solar panel is generally having specific position in the I-V performance graph. Their respective $V_{mp}$ is calculated from open circuit (OC) voltage and $I_{mp}$ is calculated from short circuit (SC) current. Although, the MPP is being calculated still it can shift its value according to the temperature and irradiance impose on to the solar panel.

So different configured solar V-I curve is shown in the Fig. 3,

where one can be different MPP points under different configuration of the solar panels i.e. single, parallel and series connections.

According to the previous figure, the efficiency of the solar panel can be viewed in terms of obtained power along with the configuration of solar panels used in the panels. So, the PV panels can either be in series or parallel which may depend on the amount of current or voltage for MPP.

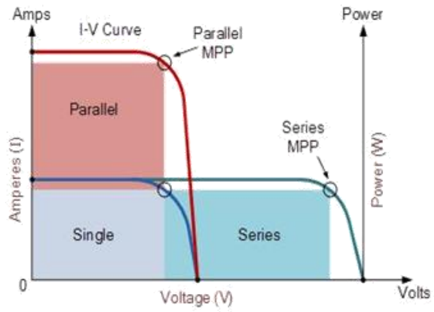


Fig. 2. Solar characteristics under different configurations

So according the power requirement, variation of load, variation of current and variation of voltage, the device need to be maintained and controlled with another external converter. However, an initial configuration is made with an assumption to configure the solar panel.

## III. FACTOR AFFECTING THE CHARACTERISTICS OF PV PANNEL

The factor affecting the solar panel characteristics are presented below. The factors affecting the characteristics are the vital parameters which are considered for a novel solar mathematical modeling. Temperature is a parameter which changes the output power of the panel to a great extent and is depicted in the figure. Not only temperature, but also the irradiance and the atmospheric condition like dust also have a major effect on the performance of the solar panel. If the temperature is high then there is a drop in the voltage and vice versa. However it should operate on a particular region satisfying the MPP to obtain. So any module under study should be analyzed closely as the materials and the temperature affects the performance to a greater extent.

The band gap in semiconductor reduces as the temperature increases resulting the $V_{oc}$ decreases. This in return effects the p-n junction voltage with the relation as seen for diodes as a factor of q=kT. Solar modules generally is related to a -ve temperature coefficient relating to $V_{oc}$. Along with this, the lowering power is also resulted because of

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the conventional battery set up which are generally driven with lower power.

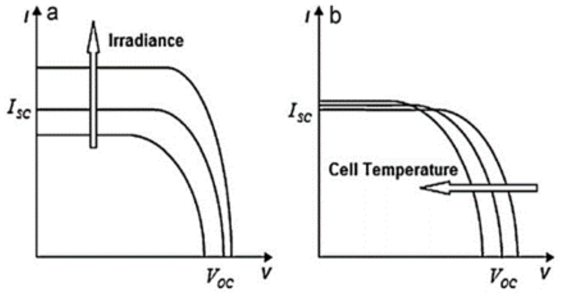


Fig. 3. Effects of the irradiation (left side) of PV cell and effect of cell temperature (right side) of PV cell.

Depending on the temperature, more irradiance is absorbed and a large charge flows from the valance-band to conduction-band. As a result a large current $I_{sc}$ for a given insulation the solar cells generally has a +ve temperature coefficient of $I_{sc}$.
Effect of temperature and the irradiance are illustrated in the Fig. 3. From the Fig. 3 (left) it can be observed that, the $V_{oc}$ increases logarithmically with the increase in the irradiance while, $I_{SC}$ increases linearly. Effect of the temperature upon the PV panel characteristics is presented in Fig. 3 (right).

## IV. EFFECT OF PARTIAL SHEDDING OF PV SYSTEM

Shedding is a practical problem faced to the larger solar array configurations. When there is a hundreds of solar panels placed in a larger spatial location, there can be an effect of difference in the solar irradiance to different panels. These results the panels are operating at different MPP which are not uniform throughout the array. This results a mismatch in the output power level of the solar panels resulting multiple peaks of MPP points. A similar pictorial representation (Fig. 4) with its performance (Fig. 5) is depicted below.

Fig. 4. Image of shedding on Solar panel

In real due to the varying weather conditions the chain formed solar panels (either in parallel or in series) different irradiance fall on to the solar panel. The Fig. 4 shows such a demonstration which results in the energy loss due to varied energy level of operation of the incorporated solar panels.

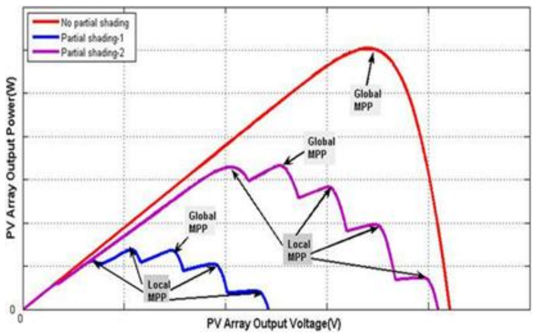


Fig. 5. PV characteristics of partial shedding on solar panel

## V. DC-DC CONVERTER

This is a general issue happens in urban or domestic solar configurations. Along with this the grid connected issues are also imposed and various researches are being carried out in this aspect. Various other configurations can be complied in parallel for central inverter integration for grid connection with the solar panels. The main limitation arises due to the inaccurate modeling of the MPP algorithms which may result in varying output power levels. This is generally an effect of the incident irradianceon panels differently at different locations. The integrated PV-converter modules incorporate the full use of the incoming irradiance levels and optimize the power by adjusting the DC-DC converter output by varying the PWM source. However, because of nonlinear characteristic observed in the solar panel power curve, it is very difficult to achieve the same. So proper alignment and arranging the solar panels are required in order to avoid the partial shading prior. If exists further an efficient algorithm is only the choice left behind. Also, the proper combination of converters may allow the integrated modules to operate with the global MPP point.

As like the buck converter the boost converter also have all these components, which are arranged differently (Fig. 6). In the case of boost, the switch Q1 operates with high frequency. The voltage of output can be regulated as per the variation in the duty cycle.

When the switch Q1 is switch on, the current (I) passes from the source to load L and to the Q1. The energy is stored in the inductor in the form of the magnetic field. As, current didn't passes through D1, the current of the load flows due to change of C1. While, switch Q1 turned off, the inductor (L) restricts the decrease opposes the drop in current (I) by suddenly altering EMF. This result an addition of voltage to the inductor. The step up voltage (V) generally due to the result of the boost operation, which can be represented as

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

Where, the reciprocal duty ratio 1-D is the proportion of the duty cycle that Q1 is off while making it on. Thus the resulting ratio can be presented as

$$\frac{V_{out}}{V_{in}} = \frac{T}{T_{off}} \qquad (2)$$

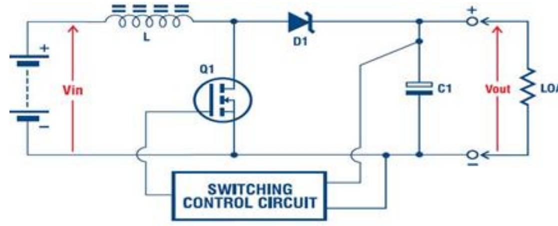


Fig. 6. DC-DC converter of Boost type

## VI. MAXIMUM POWER POINT TRACKING

In case of solar panels, the general characteristics of VI curve represent a specific region where the maximum power is observed. The resulting power operates with a specific voltage and current rating. However finding the perfect combination of the voltage and current is the basic need of an MPPT algorithm.Even if the PV has the principle applies to sources with over varying power it has variation due to different aspects of these parameters.Due to the differently configured PV systems, the reference with their relationship of the inverter systems, battery banks, external grids and/or industrial/domestic electrical loads. Although the sun falling on to the panel characterized the performance of the PV characteristics, still the other parameter as temperature also affects it much. Also the configuration of the solar panel has a greater impact on the performance. Prior to application, the parameters need to be perfectly analyzed in order to obtain the VI curve effectively. Again, according the loading conditions, the VI curve has different effect. So considering all the issues the algorithm should be able to track the perfect combination of the voltage and current.

Generally the PV panels has a typical relation within the varying temperature and the resistance which produces the non-linear effect in the output efficiency and this generally being analyzed using the VI curve. So, the MPPT approach should operate for a specific load for achieving maximum power in the environmental situations. Mostly the power trackers should be integrated with an electric power converter system which will provide the voltage and current conversion.

Not only conversion, but also the filtering and regulation with different loading condition Including the power grids, batteries or motors also may be an application objective where MPPT is a requirement.

With the help of V-I curve and loading conditions the MPPT needs to reach the maximum rich point.

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A. **Perturb and Observe (P&O) algorithm**

This is basically a search process where the voltage is being varied and in each step the voltage changes a particular level to obtain the best power. This can be termed as the hill climbing process as it is dependent on the gradient of the power level generally depicts like a hill. The P&O is the mostly used MPPT approach for its simplification. P&O method can only reach the global optimum if a proper strategy is being adopted.

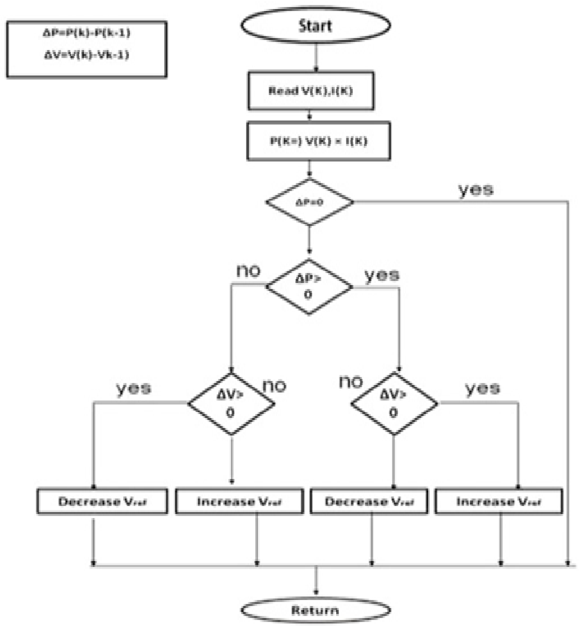


Fig. 7. Perturb and Observe algorithm

**Incremental Conductance algorithm**

This controller generally computes the incremental changes in a solar system for voltage and current for forecasting the impact of changing of voltage. However this has a higher computational cost as compared to the P&O approach, while it has better tracking capability under rapidly changing conditions. But, as like the P&O approach I&C approach also suffers from the oscillation problem. The I&C approach incorporates the incremental conductance (dI=dV) for the PV panel for calculating the sign of the gradient of the power w.r.t. the voltage.

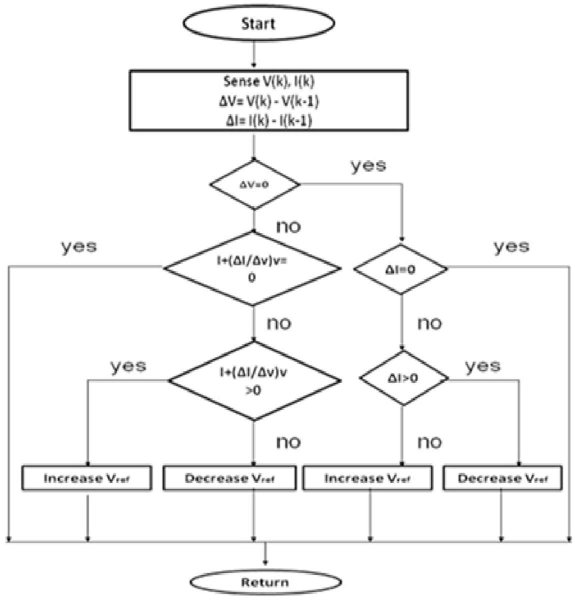


Fig. 8. Incremental conductance algorithm

The I&C approach computes the maximum power point by comparing the gradient in the incremental conductance (I= V) with the array conductance (I/V). While if they are same (I=V = I= V), the resulting output voltage is the global MPP voltage. The process is repeated till it attains the maximum peak. The I&C approach generally relay on the observation that, for MPP the dP=dV= 0. And thus P = IV. Resulting current can be presented as a function of the voltage: P = I (V) V. Hence, dP=dV = V dI=dV + I (V). Making is =0 yields: dI=dV = I (V) =V. So, the MPP is obtained for the incremental conductance is equal to the -ve of the instantaneous conductance.

B. **PSO algorithm**

Particle swarm optimization (PSO) is the optimization process, which is proposed by Dr. Eberhart and Dr. Kennedy in 1995. This was mainly based upon general nature of flocking of bird or the schooling of fish.

PSO does have much similar nature with the evolutionary processes for the computation. A similarity is Genetic Algorithms (GA) but is highly non-linear in nature. Generally it finds (may/may not) the optima by updating generations as a global best outcome. The PSO has the capability through which the particles are updated in the search space with the help of other particles based on the current optimum particles. A summary of the approach is discussed further.In comparison to the GA, the advantages of the PSO are it is easier in implementation few hyper parameters are to be controlled. Several applications have been proven the importance of the heuristic approaches although they might not have strong mathematical justification.

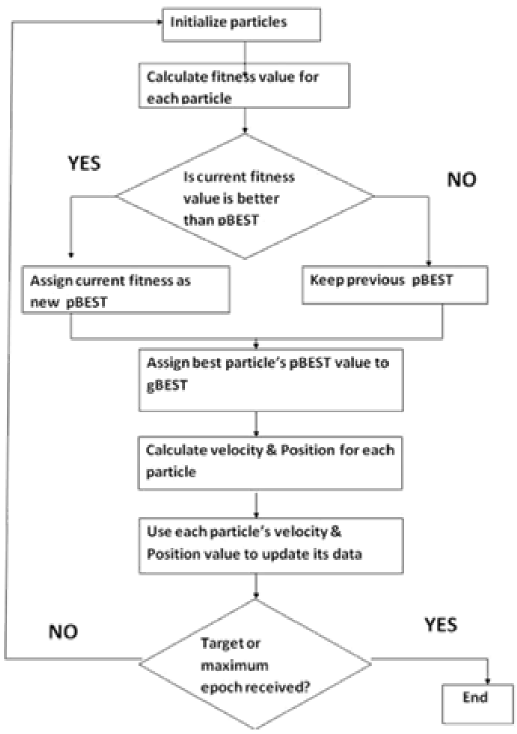


Fig. 9. Flow chart of PSO algorithm

## VII. SOLAR IRRIGATION SYSTEM AN APPLICATION OF MPPT

Irrigation is a vast field of application that the world demands. However, in the remote areas the pumping is a bit difficult due to the unavailability of the electrical resources. Such a requirement can be perfectly fulfilled by the help of the solar system. However, the design of the optimum controller to operate the solar pump is essential to obtain the maximum power output. Such an implementation is discussed in the further subsections.

### A. Motor control system

Brushless DC (BLDC) electric motors which can also be termed as the electronically commutated motor and the synchronous DC motors are the synchronous motors which are generally powered with a source DC with the help of inverters.

Generally the inverter produces the AC current for driving the motor in a closed loop form by a control mechanism. The algorithmic control maintains the speed of the motor by promising the torque to be stable and minimum loss to be occurred.

The architecture of a BLDC motor system is a specifically similar to a PMSM. While it can also be an asynchronous or an induction motor. BLDC motors are generally applied for pumping applications; fan or spindle drives for varying speed applications as having good torque response. Furthermore also they have controllable through remote access. As of the constructional configuration, the thermal stability and high energy efficiency have put it in high value. Feedback sensors are used in order to control the speed of the motor. Generally these sensors are Hall Effect sensors which find the position of the motor shaft/winding and calculate the rotational speed requirements. In the present study, the BLDC motor is used to generate speed which is further fed to the water pumping mechanism for the purpose of irrigation. The pumping system of water is described in details further.

### B. Water pumping system [13]

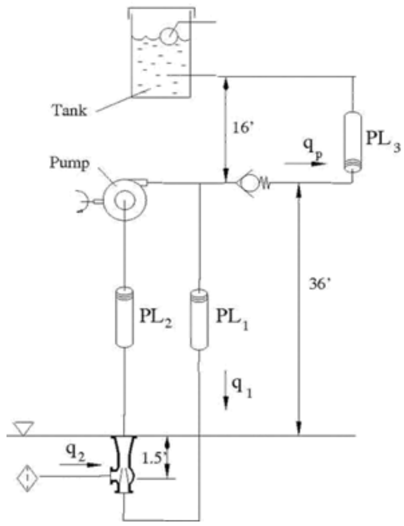


Fig. 10. Schematic representation of pumping system

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In the present application, the jet pump consists of a surface-mounted centrifugal pump which is installed in the well below the water surface. In the present case, the distance between the centrifugal pump and the water level is 36 feet. Below 1.5 feet, the jet pump was installed in the well whose schematic is presented in Fig. 10.At 20 psi pressure, the centrifugal pump discharges which are expected to reach around 130 gallons/min. The pipe have 2 inch diameter between the centrifugal pump output and the jet pump inlet. It is of 37.5 feet long. The 4 inches diameter of the pipe connects the jet pump output and centrifugal pump input which 36 feet long. The major two parts of the centrifugal pump are 1) one passes with the check valve into the tank, and 2) the rest is altered to the input of jet pump. The initialization parameters are based on the literature Karassic, I. J., et al (third edition, 2001) which are further modified according the requirements. However the motor speed and the water level are experimented in the present study with and without the MPPT approaches and presented further in the results section.

## VIII. SIMULATION AND RESULTS

The simulation parameters for solar panel, load and the DC-DC are presented inthe Table-I and Table-II.

### A. Solar Panel and its characteristics

As described before a single solar panel with uniform irradiance is modelled and is represented in Fig. 11 andits I-V characteristics are presented in Fig. 12.

The Fig. 12 and 13 clearly represents the I-V and also P-V behavior for a singlesolar panel with uniform luminance respectively.

Table- I: Solar panel parameter

| **Tata power solar systems TP250MBZ** | |
|---|---|
| $V_{oc}$(V) | 36.8 |
| $I_{sc}$ (A) | 8.83 |
| $V_{mp}$(V) | 30 |
| $I_{mp}$(A) | 8.3 |
| Temp.Coefficient $V_{oc}$(%/deg C) | -0.33 |
| Temp.Coefficient $I_{sc}$(%/deg C) | 0.0638 |

Table- II: DC-DC converter and load parameters

| **DC-DC converter** | |
|---|---|
| L1(*H*) | 1.15e-03 |
| C(*F*) | 4.68e-04 |
| $R_L$(Ω) | 53 |

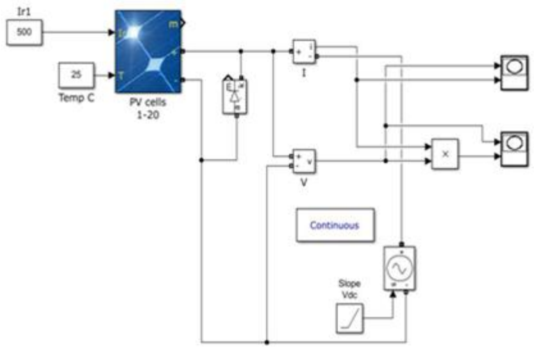

Fig. 11. Single PV panel setup

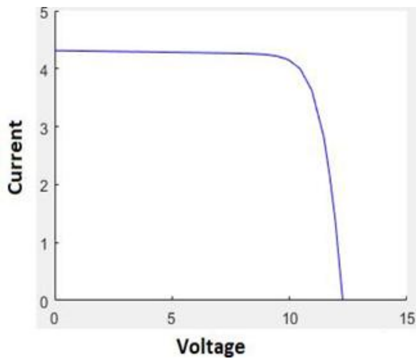

Fig. 12. Single PV panel I-V characteristics

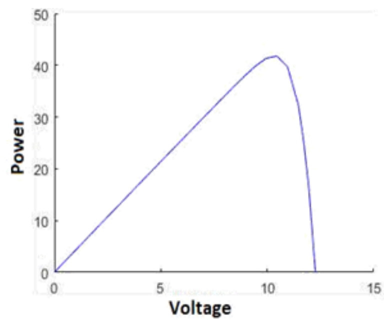

Fig. 13. Single PV panel P-V characteristics

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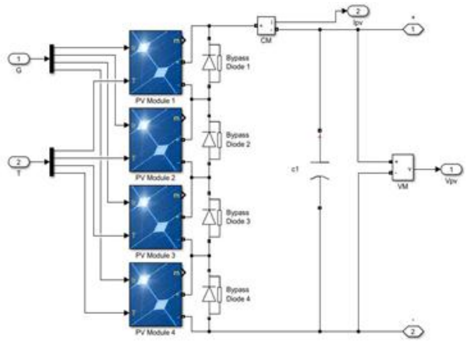


Fig. 14. Partially shaded PV panel setup

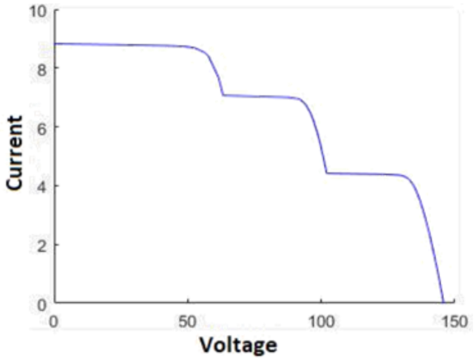


Fig. 15. Partially shaded PV panel I-V characteristics

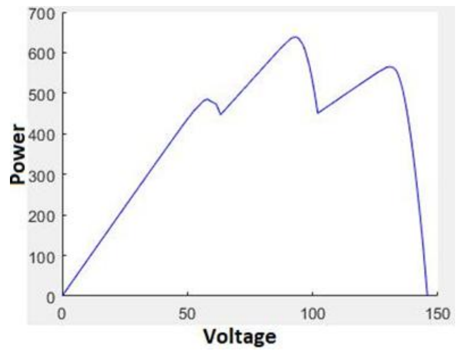


Fig. 16. Partially shaded PV panel P-V characteristics

## B. Various MPPT Controllers Performance

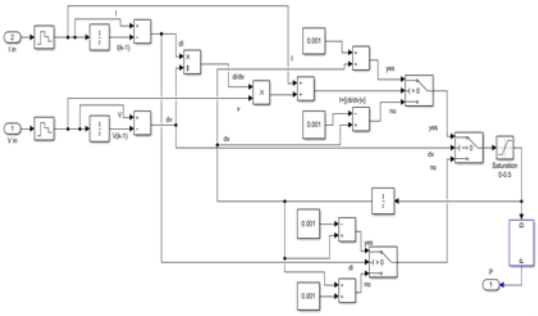

Fig. 17. P &O MPPT algorithm implementation using simulink

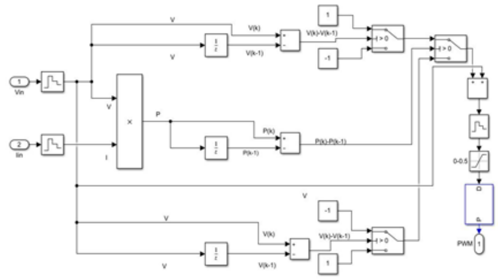

Fig. 18. IC MPPT algorithm implementation using simulink

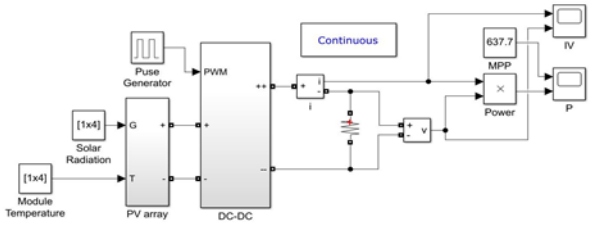


Fig. 19. Without MPPT total solar model for partially shaded condition

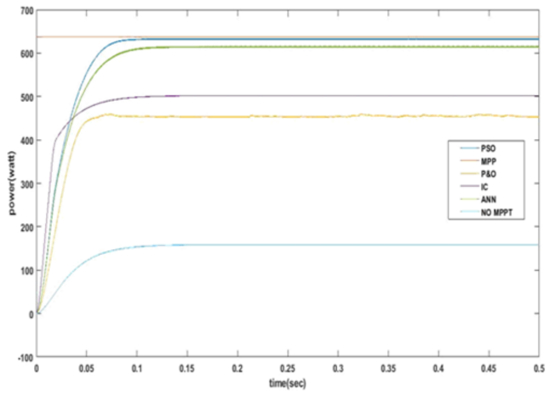


Fig. 20. Comparing the algorithms under uniform irradiance

## C. MPPT for Irrigation System

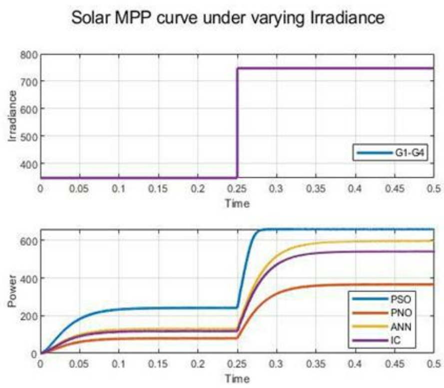


Fig. 21. Comparing the algorithms under non uniform irradiance

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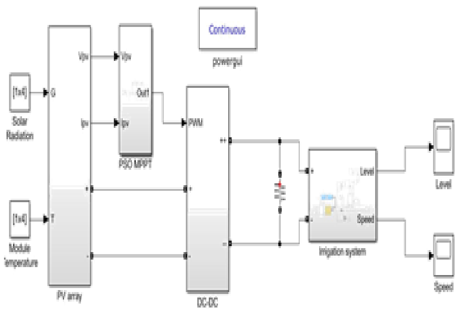


Fig. 22. Simulation model for solar pumping system

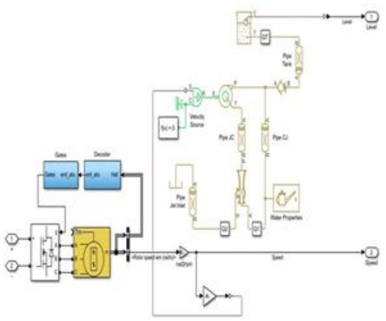

Fig. 23. Simulation model for pumping system with BLDC motor control

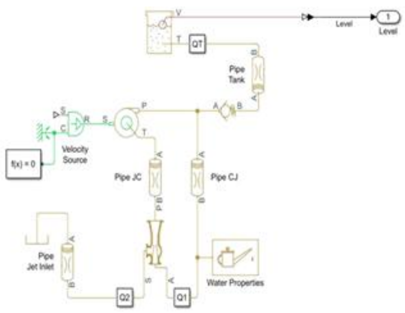


Fig. 24. Simulation model for pumping system

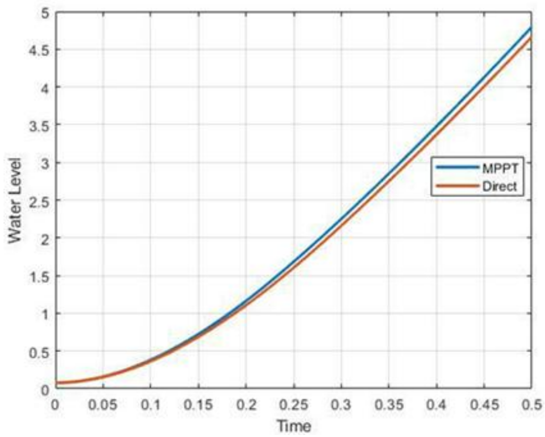


Fig. 25. Comparison of water level with and without MPPT controller

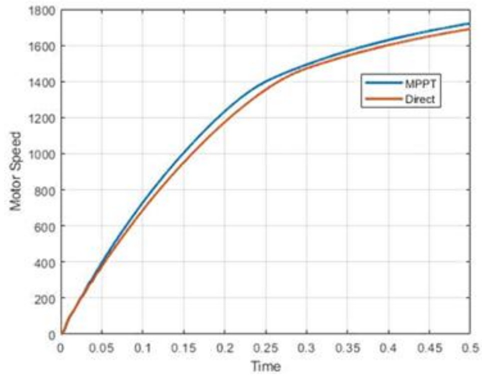


Fig. 26. Comparison of speed of the motor with and without MPPT controller

Fig. 15 and Fig. 16 clearly shows the I-V and P-V behavior of multiple solar panel with non-uniform luminance respectively. Fig. 17 represents P&O MPPT algorithm implementation using simulink and Fig. 18 represents IC MPPT algorithm implementation using simulink. Without implementing MPPT total solar model for partially shaded condition are represented in Fig. 19. Under uniform irradiance, comparisons of various algorithms are mentioned in Fig. 20 and Fig. 21 represented for non-uniform irradiance. Simulation model of various pumping system are represented from Fig. 22 to Fig. 24. Comparisons of water level with and without MPPT controller are presented in Fig. 25 and Comparison of speed of the motor with and without MPPT controller are presented in Fig. 26.

## IX. CONCLUSION

The analysis, design of solar panel is carried out to find their respective V-I characteristics with partially shaded conditions. The results of the characteristics reveal the importance of optimization algorithms, which cannot be solved by the other state-of art approaches, such as P &O and IC. The same can also be clearly convinced from the obtained results (figures). As of uncertain in nature of the irradiance, the solar panel characteristics cannot be pre-assumed. So, heuristic approaches like PSO can be a best solution to the above said problem. A similar implementation is carried out and results are obtained. Also solar irrigation is implemented and their system performances are presented in the form of water level and speed of the motor. This also strongly suggest that the proposed PSO based MPPT is capable of extracting ample portion of power in comparison to the other approaches. Multilevel inverter can also be implemented for getting the optimum output of the solar PV pumping system.

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