Maximum Power Point Tracking Using Fuzzy Logic Controller for PV system Integrated with Internet of Things

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Abstract : *This paper presents the idea of integrating an IOT system to collect the real-time data of the PV system controlled by a Fuzzy based Maximum power point tracking logic controller. Solar energy is considered as one of the major sources of renewable energy, available throughout the globe and also free of cost. Solar photovoltaic (PV) cells are used to convert solar energy into unregulated electrical energy. These solar PV cells exhibit nonlinear characteristics and exhibits very low efficiency. Therefore, it becomes essential to extract maximum power from solar PV cells using maximum power point tracking (MPPT). The behaviour of MPPT schemes under continually changing atmospheric conditions is very important. The proposed Fuzzy MPPT scheme works fast and gives improved results under change of solar irradiation. Furthermore, the steady state oscillations are also reduced. This MPPT controlled PV system is then monitored by an IOT system which gives a real-time condition of the system and also backs up the data collected into the cloud for future use.*

IndexTerms - MPPT, Photovoltaic, perturb & observe, Power electronics, IoT.

I. INTRODUCTION

Global energy demand is increasing exponentially. This increase in demand causes concern pertaining to the global energy crisis and allied environmental threats. The whole world is running mostly on fossil fuels and other conventional fuels. These fuels not only are polluting the environment but are also depleting in an accelerated rate. The solution of these issues is seen in renewable energy sources. The most clean and efficient form of renewable energy is seen as solar energy. Since the energy is derived from the solar rays itself, It becomes an globally acceptable form of energy which can be tapped anywhere on the Earth. Being a semiconductor device, it is static, quiet in operation, does not cause any pollution while producing power and also has very low maintenance and operation costs. The major issue with solar energy is its efficiency due to the non-linear characteristics of the semiconductor materials used to make the solar panels. The solar panels vary their output drastically under varying environmental factors. So it becomes a necessity to create a PV system that is robust to environmental changes. Though other methods of power tracking are available, MPPT based on Fuzzy logic is more robust and reliable as it takes less time to converge to the maximum power point. Furthermore, the working conditions and other parameters of the system and environment are measured and monitored using an IOT system remotely. This system can backup data in cloud which can be tracked over a long period of time to study the reliability of the system and also to come up with better chances to reduce the down time of the system when it goes into faulty conditions.

II. MODELING OF PV SYSTEM

PV system which consists of PV array, DC-DC converter, MPPT controller and load. PV array generates the voltage and current depending upon the ambient conditions (irradiation and temperature). The current and voltage are varying due to changing atmospheric condition and so the DC-DC converter is used to make the output constant and available for the load/inverter. MPP tracker works as a controller for the DC-DC converter and accepts PV panel current (I_{PV}) and voltage (V_{PV}) as an input and provides with the desired change in duty cycle for the switching of the converter such that PV system works at the optimum point. Change in power and change in current is given as an input to the controller whose output is a change in duty cycle. The simulation of the system is done by making a mathematical model of the whole system in MATLAB SIMULINK.

2.1. PV Array

The photo-voltaic effect is a physical phenomenon of the creation of voltage or electric current in a semiconductor material upon exposure to light. Solar PV system works on the principle of photo-voltaic effect, direct conversion of solar energy to electrical energy using PV cells based. The power generated from these PV cells/arrays depends directly on the level of solar irradiation and the cell temperature. It is important to note that these installations require very high capital investment. Hence it is inevitable to make full utilization of the solar energy that falls on the panel surface. The PV panel is modeled in MATLAB SIMULINK to study the system under varying insolations. The mathematical modeling of Photovoltaic systems is based on the following equations:

Module photo-current:

$$Iph = [ISCr + Ki(T-298)]*\lambda/1000 \quad (1)$$

Module reverse saturation current – Irs:

$$Irs = ISCr /[exp(qVOC/NskAT)-1] \quad (2)$$

Relation between Io and temperature:

$$I_o=I_{rs}[\frac{T}{T_r}]^3 \exp[\frac{q*E_{g0}}{Bk}\{\frac{1}{T_r}-\frac{1}{T}\}] \quad (3)$$

Current output of PV panel:

$$I_{pv} = N_p*I_{ph} - N_p* I_o [\exp\{\frac{q*(V_{pv}+I_{pv}R_s)}{N_s AkT}\}-1] \quad (4)$$

Table 1 Electrical Characteristics of PV System

Maximum power(P_{max})	60W
Voltage at maximum power(V_{mp})	17.1V
Current at maximum power(I_{mp})	3.5A
Open circuit voltage(V_{oc})	21.1V
Short circuit current(I_{sc})	3.8A

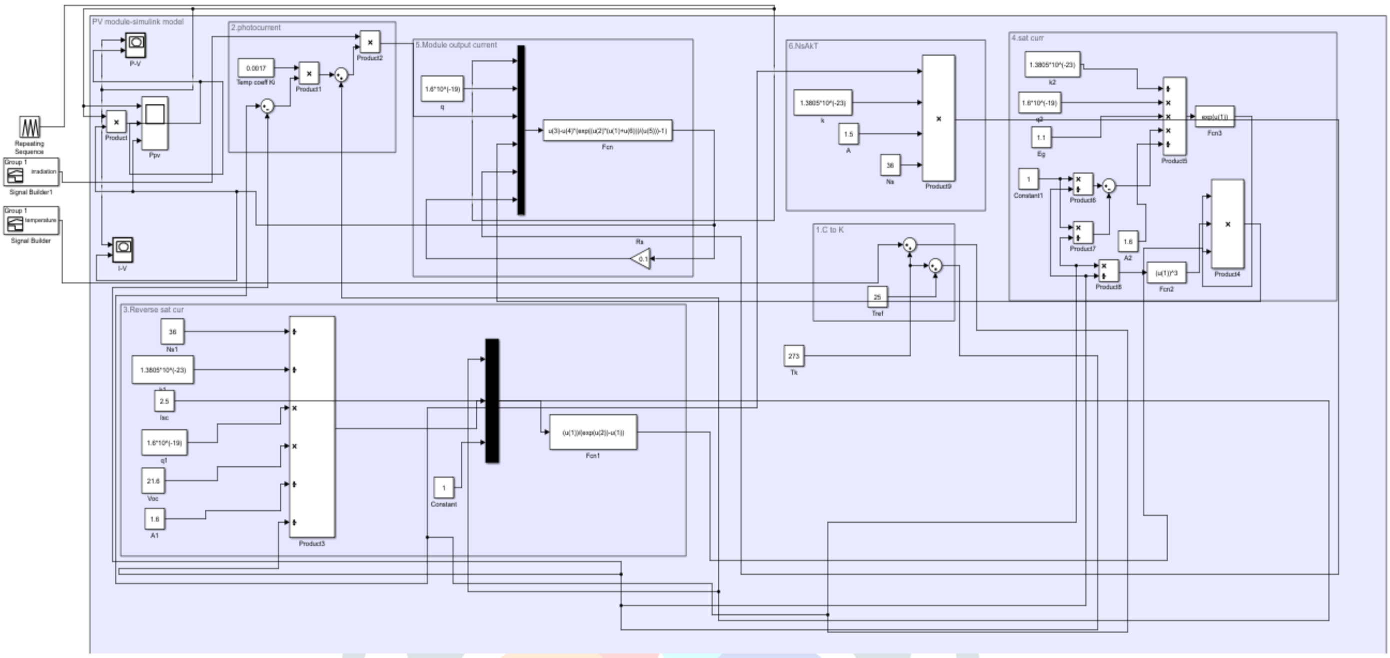

Figure 1 PV Array – MATLAB Model

2.2. DC-DC Converter

A DC-DC Boost converter consist of diode, inductor, capacitor, IGBT switch, Voltage source and load. Here the PV module acts as the source. Figure 2 shows the DC-DC boost converter. It performs two major tasks: it regulates the fluctuating input voltage coming from the PV array and maintains the maximum power point by adjusting the duty cycle.

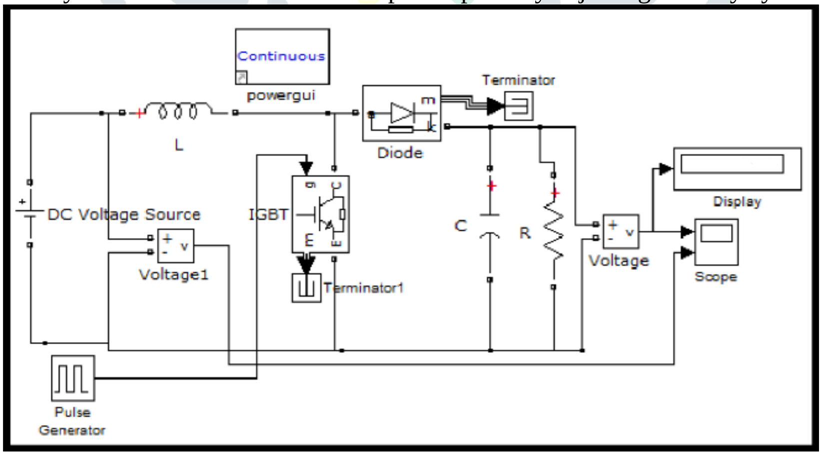

Figure 2 DC-DC Boost Converter – MATLAB model

The DC voltage gain of DC-DC boost converter is represented by the following equation

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \quad (5)$$

Where, V_o is Output Voltage

V_{in} is Input Voltage

D is Duty cycle used to control IGBT

$$D = \frac{t_{on}}{t_{on}+t_{off}} \quad (6)$$

Control of the boost converter is done by MPPT controller that will vary the duty cycle of the IGBT switch and deliver the maximum possible power from the PV array to the load.

III. Need For MPPT

The capital cost of installation of solar panel systems is very high. The duration for which solar rays hit on the panel making power is also not around the clock. Typical solar cells operate with a sub-standard efficiency of 12-15%. Owing to these factors, it becomes an absolute necessity to make the panels generate as much power as it practically can to increase the reliability of such systems without increasing the cost considerably. A lot of researches are going on worldwide to provide new technological developments that can maximize this factor of utilization of Photovoltaic systems.

IV. MPPT Techniques

PV arrays exhibit a non-linear I-V and P-V characteristics but always have one optimum point of operation called maximum power point (MPP). This Maximum power point can be easily hindered by the surrounding conditions which keep changing with time. Therefore maximum power point tracking controller is of great importance and it is connected to PV arrays to track their maximum power point and extract maximum possible power from the array.

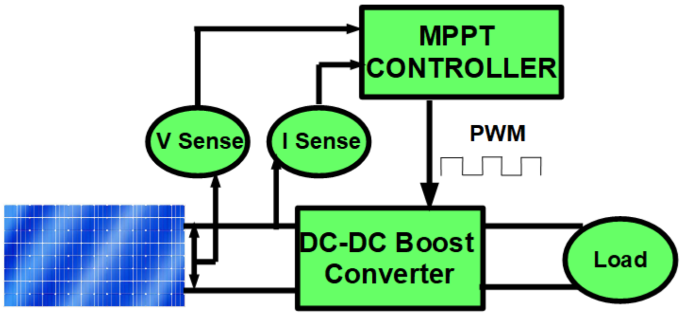

Figure 3 Implementation of MPPT

The concept of MPPT is not new, many methods of MPPT are currently in use which improve the tracking efficiency. These techniques vary in cost, complexity, convergence speed and sensors required. Perturb and Observe (P&O) method and Hill Climbing method are most popular because of their simplicity and low cost. Both of these methods work on the same principle of perturbing the PV system and observing its effect on the power output. The only difference between these both methods is that in the method of P&O, the output voltage/current is perturbed while in the hill climbing method, duty cycle of the dc-dc converter is perturbed. Incremental conductance is another famous method of Maximum power point tracking which over comes the limitations of the P&O method by using the PV arrays incremental conductance for tracking the MPP without a perturbation.

V. Fuzzy Logic Controller

The fuzzy logic controller makes use of the fuzzy logics to make decisions and to control the output of the controller. In the recent years, fuzzy logic controllers have been widely developed for tracking the MPP in solar systems. They prove to be more robust and comparatively simpler to design as they do not requires the knowledge of the exact model of the system. It does require the complete knowledge of operation of the PV system. Fuzzy logic controllers have the advantage of working with imprecise inputs, and does not need an accurate mathematical model of the whole system and it can handle non-linearity easily.

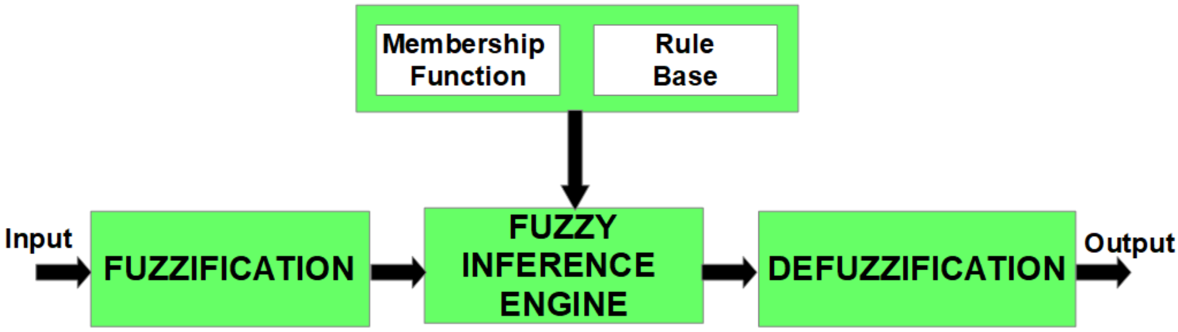

Figure 4 Fuzzy Logic Controller

As shown in the figure 4, The fuzzy logic controller has three stages, namely, fuzzification, rule base inference and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function. The membership functions are made less symmetric where there is a requirement to give more importance to specific fuzzy levels. The inputs to fuzzy logic controller is usually an error E and a change in error ΔE. After the calculation of E and ΔE, the change in duty ratio of the power converter which is the FLC'c output can be looked up in a rule base table as specified by the designer. In the defuzzification stage, the fuzzy logic controller output is converted from linguistic variable to a numerical variable using a membership function. This process produces the analog signal which controls the power converter to maintain power delivery at MPP.

VI. Implementation

Fuzzy logic is an advanced variant of soft computing multivalued logic. It is well fit for dealing with reality estimations of factors that might be any real number between 0 and 1. Fuzzy logic proves its worth in MPPT by its exceptional quality to handle the concept of partial truth , where the truth value might range between completely true and completely false. This feature of fuzzy logic controllers can be used to successfully implement maximum power power point tracking in PV systems.

The Fuzzy logic controller for MPPT has two inputs, namely, Error (E(n)) and change in error (CE(n)), as calculated below

$$E(n)=\frac{P(n)-P(n-1)}{V(n)-V(n-1)} \quad (7)$$

$$CE(n)=E(n)-E(n-1) \quad (8)$$

Where P(n) and V(n) are the instantaneous PV panel power and panel voltage. Error measures the position of operating point, whether the current operating point lies towards the left or right side of the MPP and change in error measures the direction of movement of this operating point.

The second stage of operation of FLC, Inference, is performed in accordance with the rules in table 2 making use of the Mamdani's method.

Table 2 Fuzzy Rule Table

E & CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	ZS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

The fuzzy membership functions named in the rule table are defined as: NB – Negative big, NS – Negative small, ZE – Zero, PS – Positive small , PB – Positive big. The membership functions defined for Error, change in error and duty cycle are shown in figure 5

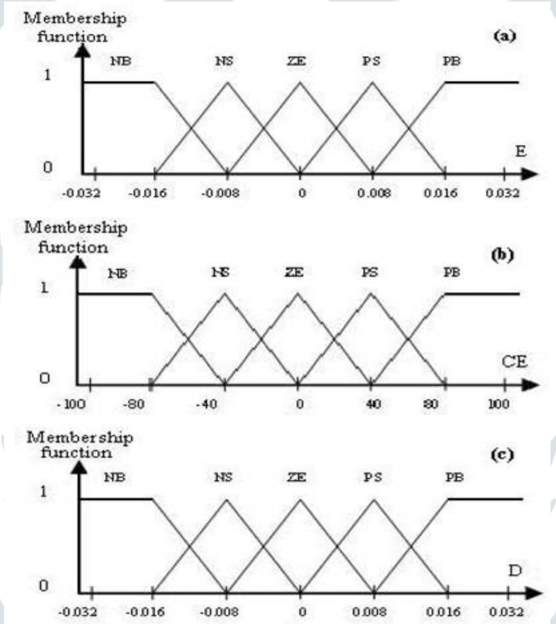

Figure 5 Membership Functions

The output from the fuzzy logic controller is changing the duty ratio which acts as the switching pulses for the chopper switch in the Boost converter. This switching action of boost converter allows it to converge the operation of the system to MPP.

VII. Simulation

The simulation of the proposed system is done using MATLAB SIMULINK. The fuzzy toolbox which is already present in MATLAB is used to plot the input and output membership functions as depicted in figure 6. The FIS file containing the data about the membership function is imported into the solar PV system by the use of the Fuzzy logic controller.

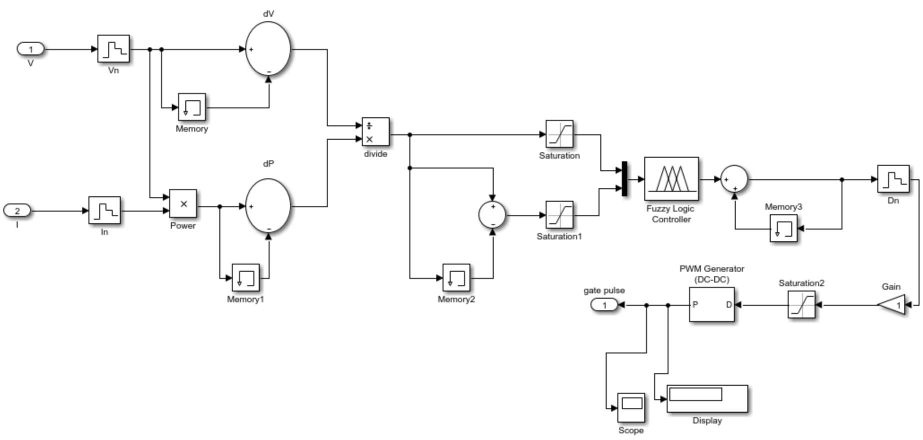

Figure 6 MPPT Fuzzy logic controller - MATLAB model

The MATLAB model shown in figure 6 is then coupled with the solar module model as shown in figure 1. The output gate pulse from the FLC MPPT controller is given as input to the IGBT switch in the boost converter which is already integrated with the output of the solar panel array.

The MATLAB model is allowed to execute and the performance characteristics are plotted at different irradiation levels; 400W/m^2 from 0 to 1st second , 600 W/m^2 from 1st to 2nd seconds , 800 W/m^2 from 2nd to 3rd second, and 1000 W/m^2 from 3rd to 4th second.

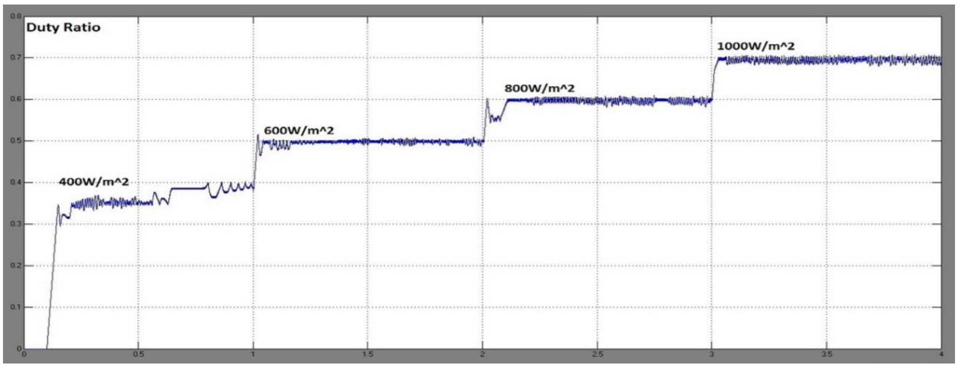

Figure 7 Change in Duty ratio (for changing irradiation)

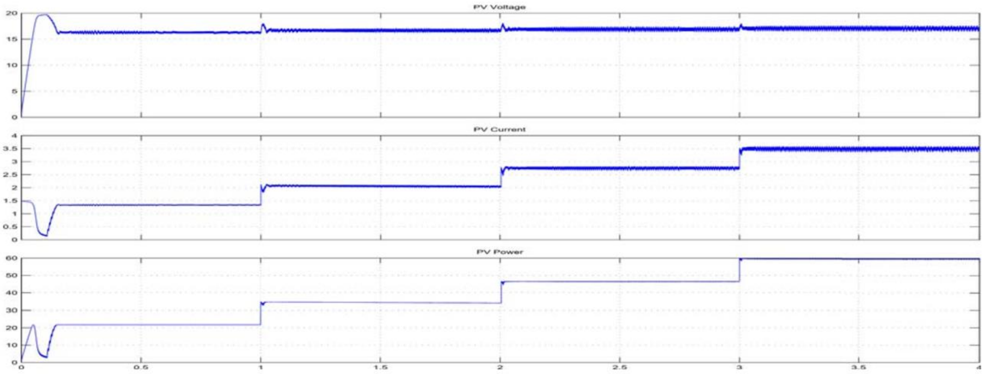

Figure 8 Solar Panel voltage, Panel current and Panel power

Figure 7 shows the change in duty ratio with the variation in solar irradiance levels. This duty cycle is fed as gate pulse to the boost converter which tracks the MPP. From Figure 8, It can be clearly seen that the panel voltage, current and power get varied for different irradiation levels to match the MPP. At standard insolation, It is seen that the panel generates 60W which is the maximum power. It is also interesting to note that the PV voltage remains almost a constant, while PV current varies according to the changing solar irradiation.

VIII. INTEGRATION WITH IOT

Internet of things (IoT) is the Futuristic vision in which the internet is incorporated into real world and enables easy access of everyday objects. IoT facilitates objects to be sensed and controlled remotely over network infrastructure which creates new opportunities for improving the efficiency, reliability, accuracy and economic benefits with the added advantage of reduced human intervention. The improvement in solar integration with Iot is a great stance towards sustainable smart cities. Harnessing the power of the IoT can help us resolve the most common challenges that we deal in complex energy grids and makes it easier to manage solar systems and monitor energy output. For solar energy based companies, installing an IoT system will help them meet their customer's demands and improve overall efficiency. The most common problem with integration solar panels with the grid is the unpredictable output of the panel but with the IoT installed with the solar system, the instantaneous outputs can be remotely monitored and the grid can be easily maintained. Installation of an IoT system with solar system will lead to a plethora of opportunities to improve the utilization factor of the system.

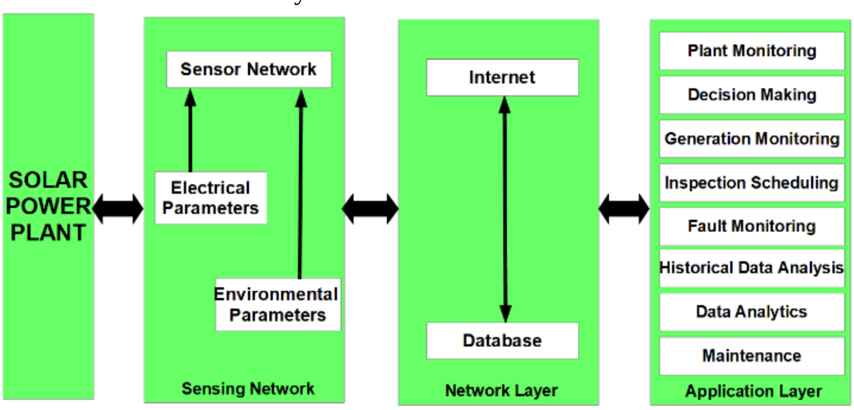

Figure 9. Implementation of IoT

IX. Conclusion

The conventional sources of energy are getting exhausted whereas the energy demand of the world is getting increased beyond limits. The only way forward are the renewable sources. PV systems seem to be the ultimate eco-friendly power source which has very less limitations and a huge deal of advantages when compared to any other form of renewable energy. So it becomes necessary to improve the efficiency of such system to make it more reliable. The fuzzy logic MPPT proposed in this paper has proved to be one of the fastest converging MPPT technique and also more robust and less sensitive to atmospheric conditions. This MPPT solution allows us to tap the maximum possible power from the solar panel. Even though the maximum power is tapped, it is also necessary to properly connect the solar system to a grid and deliver the loads. To improve the reliability of such a system, installation of IoT system with the solar system is proposed which can lead to proper management of the whole system. It also can help with the maintenance in the case of solar fields thereby reducing human labor. The sensor data from the IoT system can be analysed over time to understand more details about the behavior of the system such that better algorithms can be made that can further improve the efficiency of the solar systems.

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