

## SIMULATION AND CONTROL TECHNIQUE FOR SINGLE PHASE SUB MODULE INTEGRATED PV SYSTEM

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### ABSTRACT

The photovoltaic (PV) system that is based on sub module-integrated converters (subMICs) is capable of maximizing solar energy harvest by eradicating power losses due to intrapanel mismatch. Modeling and simulation of subMIC-based systems are important to study the effect of PV partial shading, prove new control strategies, analyze distributed system dynamics, optimize system configurations, and determine system parameters, etc. However, the simulation of such systems can be very challenging due to the large number of switching-mode power units, nonlinear nature of PV generators, and complication of the coordinating control. This project provides an effective solution to simulate and control single-phase grid-tied PV systems that are based on a practical subMICs configuration by sliding mode control. The approach includes the simplified PV cell model and averaged model for power converters, which consider all dynamic interactions among the maximum power point tracking (MPPT).

**INDEX TERMS:** DC/DC power conversion, energy harvesting, photo voltaic power system, simulation.

### I. INTRODUCTION

Photovoltaic (PV) array is usually composed of solar panels, which are connected in series-parallel combination to meet high input voltage requirement of the centralized power inverter for grid connection. However, significant power loss has been reported due to the unbalanced generation among PV panels, which is primarily caused by partial shading[1]-[4].The dc/dc power optimizer (DCPO), which incorporates a dedicated converter for every panel, has been proposed by researchers to minimize energy loss during mismatch conditions. Each DCPO performs independent maximum power point tracking (MPPT) to mitigate the mismatch effect among the series-connected solar panels. This configuration successfully eliminates the power loss

resulting from the inter panel mismatch but cannot mitigate the loss caused by inter panel mismatch. To increase solar energy harvest by eradicating intra panel mismatch, sub module integrated converters (sub MICs) have been developed. Both DCPO and sub MIC are similarly designed for cascaded structures where converter outputs are connected in series. Modeling and simulation of sub MIC-based systems are necessary to analyze the impact of partial shading, prove new control strategies, Optimize system configurations, and analyze system dynamics, etc. Furthermore, the evaluation of the system performance under uniform shading, partial shading, and non shading conditions can also be carried out using different modeling approaches.

Switching models of converters and equivalent circuits of PV units are commonly utilized to simulate centralized PV systems. The same technique is not suitable for the simulation of sub MIC-based PV systems using a standard desktop computer because of large numbers of subMICs and PV sub modules in the system configuration, and the high switching frequencies of the dc/dc converters. High switching frequencies aim to reduce the overall sub MIC size to utilize small size components, e.g., capacitors and inductors that can fit into the junction box of PV panels.

The PV module is the interface which converts light into electricity. Modeling this device necessarily requires taking weather data (irradiance and temperature) as input variables. The output can be current, voltage, power or other. However, trace the characteristics  $I(V)$  or  $P(V)$  needs of these three variables. Any change in the entries immediately implies changes in outputs. That is why, it is important to use an accurate model for the PV module. This paper presents a detailed modeling of the effect of irradiance and temperature on the parameters of the PV module. The chosen model is the single diode model with both series and parallel resistors for greater accuracy. The detailed modeling is then simulated step by step using MATLAB/Simulink software due to its frequent use and its effectiveness. All the aspects that show impact on

the power output are considered, which include double frequency ripple, temperature variations, uniform irradiance changes, uneven PV temperature distribution, and partial shading scenarios. Additionally, the model accounts for the effect of changes in grid voltage and

frequency and shows their influence on the dc-link and inverter input current. Furthermore, the discrete dc-link voltage control and PV submodule voltage regulation is applied, which emulates the actual digital control using microcontrollers in a real-world system.

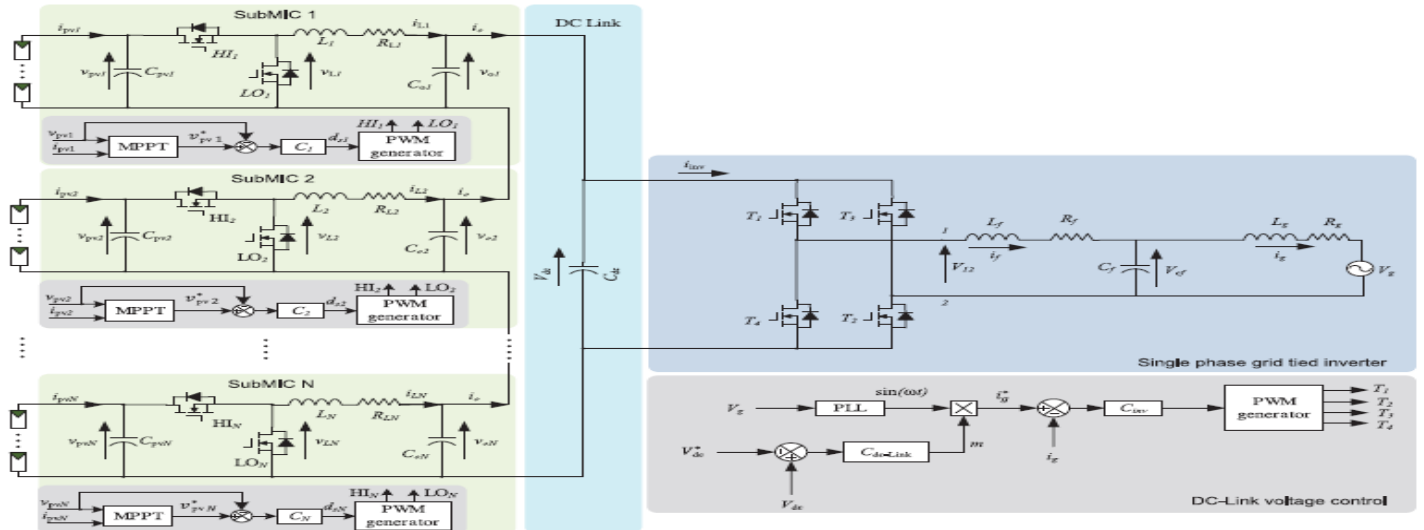


Fig.1 Diagram of subMIC-based PV system for single-phase grid connection

The proposed modeling and simulation is used to compare the performance of subMICs with a standard grid-tied system based on a centralized PV inverter under the real-world solar irradiance and various PV mismatch conditions, e.g., partial shading and uneven temperature distribution.

**II. MODELLING OF PV CELL**

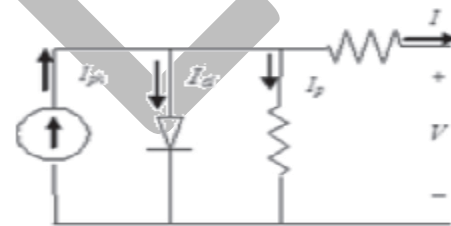
Among a variety of renewable energy sources, solar energy is predicted to become the largest contributors to world energy for its clean and no supply limitations characteristic. Over the past decade, PV technology has shown the potential by robust and continuous growth even during times of financial crisis.

The key technology of a PV system includes PV cell modeling, maximum power point tracking (MPPT) algorithm, DC/DC converter and grid-connected DC/AC inverter. Photovoltaic (PV) cell is a semiconductor device that absorbs and converts the energy of light into electricity by photovoltaic effect. Figure shows the equivalent circuit of PV Cell.

By applying Kirchoff law, current will be obtained by the equation:

$$I = I_{ph} - I_d - I_p$$

$I_p$ , is the current leak in parallel resistor.



Equivalent circuit of PV Cell

According to the equation, the output current of a module containing  $N_s$  cells in series will be:

$$I = I_{ph} - I_0 \left[ \exp \left( \frac{V + I R_s}{a} \right) - 1 \right] - \frac{V + R_s I}{R_p}$$

$$a = \frac{N_s \cdot A \cdot k \cdot T_c}{q} = N_s \cdot A \cdot V_T$$

**A. DETERMINATION OF THE PARAMETERS:**

The number of parameters varies depending on the chosen model and on the assumptions adopted by the searchers. It is considered that  $I_{ph}$ ,  $I_s$ ,  $R_s$ ,  $R_p$  and the factor ideality are five parameters that depend on the incident solar radiation and the cell temperature.

In this work the four parameters that have to be evaluated are also  $I_{ph}$ ,  $I_s$ ,  $R_s$ ,  $R_p$ .

**• DETERMINATION OF  $I_p$ :**

$$I_{ph} = \{ [(T_{op} - T_{ref}) \cdot K] + I_{sc} \} \cdot I_{rr}$$

Where,  $I_{rr}$ =Solar irradiance ( $W/m^2$ ),  $I_{sc}$ =Short circuit current,  $K$ =Temperature coefficient of short circuit

current,  $T_{ref}$ =Cell temp at STC=25+273=298K,  $T_{op}$ =Operating temp.

- **DETERMINATION OF  $I_s$ :**

$$I_s = I_{rs} \cdot \frac{T_{op}^3}{T_{ref}^3} \cdot e^{\frac{1}{T_{op}} - \frac{1}{T_{ref}}} \cdot \frac{q \cdot E_g}{K \cdot n}$$

Where,  $I_{rs}$ =Reverse saturation current at operating temperature,  $q$ =Charge,  $E_g$ =Material band gap energy=1.12eV for Si.

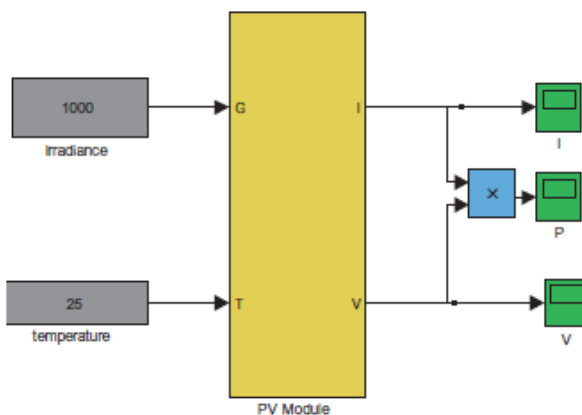


Fig. Presentation of PV Model

### III. SUBMODULE INTEGRATED CONVERTERS

Under the small-scale mismatch conditions, the sub MIC based PV system is superior to the systems of DCPO and centralized configuration in terms of solar energy harvesting. It is shown that the sub MICs offer an effective solution to maximize the utilization of PV power by employing MPPT on the sub module level. The sub module is a section of a PV panel consisting of 15 to 24 PV cells in series connection.

Advantage of sub MICs systems lies in the utilization of distributed MPPT to the sub module level to eradicate mismatch among sub modules. Therefore, the sub MICs-based system shows higher energy yield in comparison with the centralized inverter, DCPO, and micro inverter configurations. In a quantitative comparison of PV energy harvesting architectures of string, power optimizer, micro inverter, and sub MICs is presented. The 30-year prediction of solar energy harvest showed that the sub MIC-based system produces more energy than other system approaches with the consideration of various types of installations including ground-mounted power plant, rooftop installation, facade PV, and electric vehicles. 90% of the mismatch loss can be recovered by applying a unified control approach, which controls three sub-MICs connected to each PV panel. In [9], a subMIC product is developed, which reports 20% more energy harvesting in comparison with the DCPO under specific shading conditions. The study in [10] compares the performance

of the sub MIC solution with centralized PV system and reports 6.9%–11.1% more annual energy output. Furthermore, the sub MIC-based system have been proved to be low cost and high efficiency [9].

In sub MIC architecture, the inputs of dc/dc converters are connected in parallel to sub modules to perform MPPT, whereas the outputs are connected in series. The series connection of sub MICs delivers a voltage stack to achieve the required dc-link voltage, which is the input of a centralized grid-tied inverter. The voltage stack provides the flexibility to operate each sub-MIC at relatively low conversion ratio, which results in higher efficiencies compared to the solution of micro inverters. A typical micro inverter is required to boost the voltage from the PV module level of 22–45 Vdc to the grid level of 220 Vrms or 240 Vrms in ac [8]

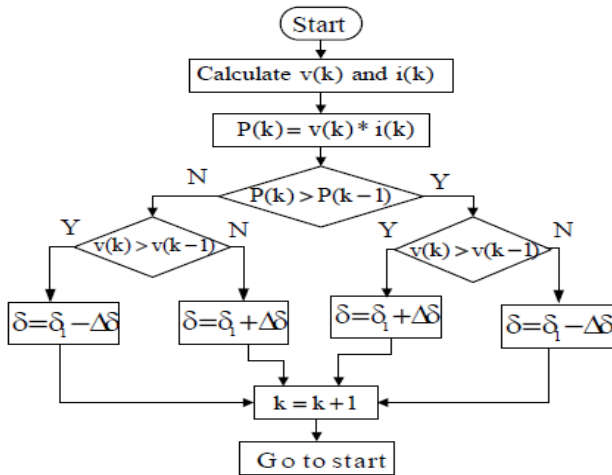
### IV. MAXIMUM POWER POINT ALGORITHM

To improve the efficiency of the solar panel MPPT is used. According to maximum power point theorem, output power of any circuit can be maximize by adjusting source impedance equal to the load impedance, so the MPPT algorithm is equivalent to the problem of impedance matching. In present work, the Boost Converter is used as impedance matching device between input and output by changing the duty cycle of the converter circuit. Output voltage of the converter is depend on the duty cycle, so MPPT is used to calculate the duty cycle for obtain the maximum output voltage because if output voltage increases than power also increases. In this Perturb and Observe (P&O) and constant duty cycle techniques are used, because these require less hardware complexity and low-cost implementations

#### A. PERTURB & OBSERVE MPPT ALGORITHM :

A photovoltaic (PV) array under uniform irradiance exhibits a current-voltage characteristic with a unique point, called the maximum power point (MPP), where the array produces maximum output power.

The P&O MPPT algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed.



Flow chart of P&O MPPT

It is the simplest method of MPPT to implement. In this method only voltage is sensed, so it is easy to implement. In this method power output of system is checked by varying the supplied voltage. If on increasing the voltage, power is also increases then further 'δ' is increased otherwise start decreasing the 'δ'. Similarly, while decreasing voltage if power increases the duty cycle is decreased. These steps continue till maximum power point is reached. The corresponding voltage at which MPP is reached is known as reference point (Vref).

**V.DC/DC CONVERTER**

A DC/DC converter serves the purpose of transferring maximum power from the solar PV cell to the load. A DC/DC converter acts as an interface between the load and the PV cell. By changing the duty cycle, the load impedance is varied and matched at the point of the peak power with the source, so as to transfer the maximum power.

There are Four basic topologies for DC/DC converter: Buck, Boost, Buck-Boost and Cuk.

**A. REASON FOR CHOOSING BOOST CONVERTER:**

Chosen the classical boost converter to implement the MPPT algorithm for the following reasons.

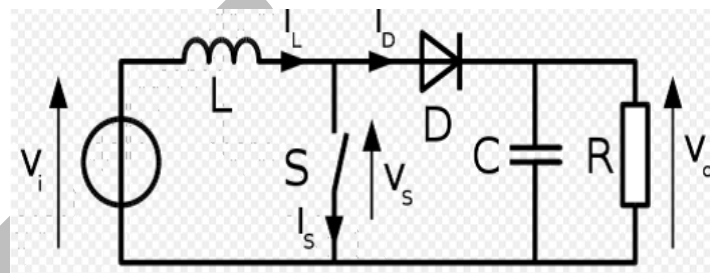
- 1) For Boost Converter, the output voltage is always higher than the input PV cell voltage, which is convenient for the PV cell to be connected to the grid later.
- 2) The topology for Boost Converter is simple, easy to implement, and has high efficiency.
- 3) The Boost Converter is easy to be controlled to minimize fluctuation and increase tracing accuracy.

**B. OPERATING PRINCIPLE OF BOOST CONVERTER:**

Below Fig shows the topology of Boost converter. For this converter, power flow is controlled by means of the on/off duty cycle of the switching transistor. When the

switch is On for  $t_{on}$  seconds, current flows through the inductor in clockwise, and energy  $V_i \cdot I_L \cdot t_{on}$  is stored in the inductor. When the switch is Off for  $t_{off}$  seconds, current will be reduced for increasing impedance. The only path of the inductor current is through diode D to the capacitor C and load R. The polarity of inductor will change. And the energy accumulated in the inductor during the On-State will be released,  $(V_c - V_i) \cdot I_L \cdot t_{off}$ .

$$V_i \cdot I_L \cdot t_{on} = (V_c - V_i) \cdot I_L \cdot t_{off}$$

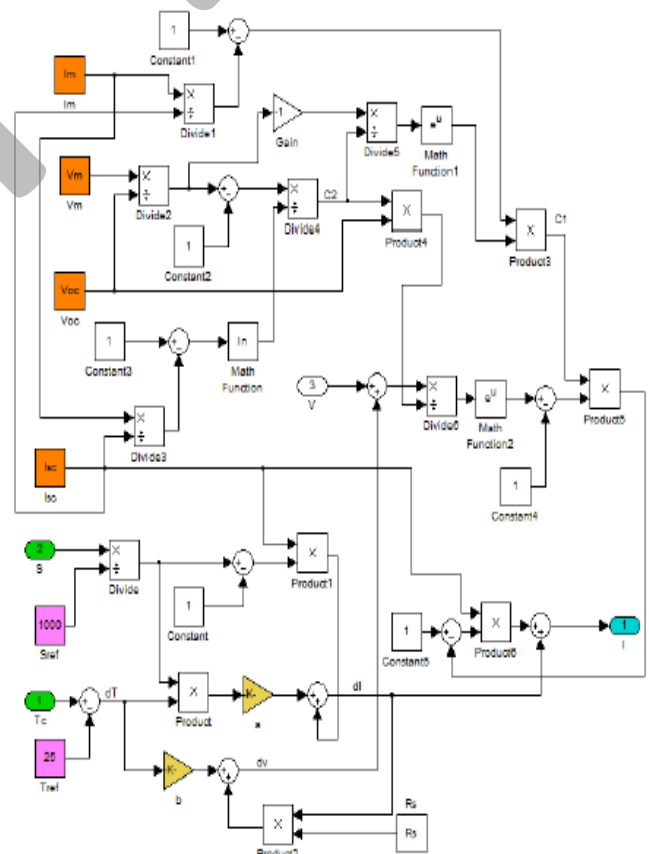


Topology of Boost Converter

**VI. SIMULATION & RESULTS**

**A. MODELING AND SIMULATION OF PV CELL IN MATLAB/SIMULINK:**

Figure shows the simulation structure of the PV model and the packaged model in MATLAB/Simulink according to the improved PV cell model.



Simulation structure of PV Cell

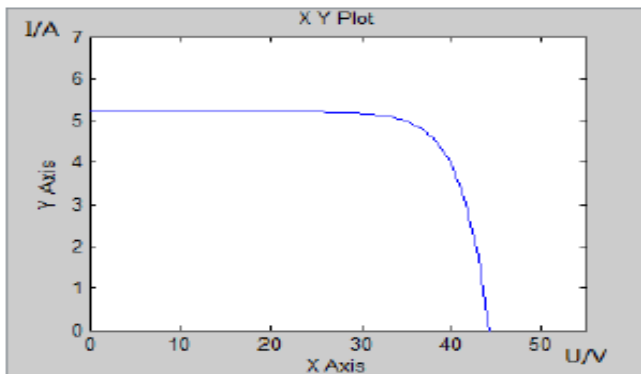


Fig.1 I-V Characteristic Curve of PV Cell

The simulation result is shown in Figures. Figure 1 shows the I-V characteristic curves of the PV cell. Figure 2 shows the P-V characteristic curves. The model curves exactly match with the experimental data at three remarkable points: short-circuit, open-circuit, and maximum power point. It can be seen that when the output voltage is less than a threshold value, the change of output current is very small with the changing of voltage. PV cell acts like a constant current source; when the output voltage exceeds a threshold value, the current declines sharply with increasing voltage. PV cell acts like a constant voltage source.

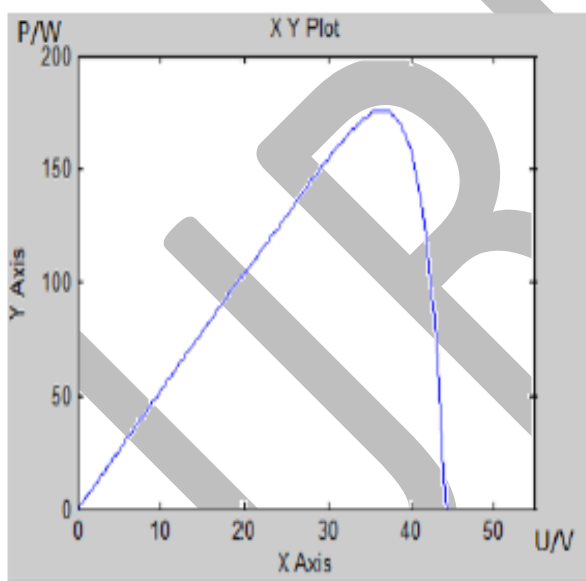


Fig.2 P-V Characteristic Curve of PV Cell

The I(V) characteristics are presented in by varying irradiance from 200 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> and taking The STC temperature.

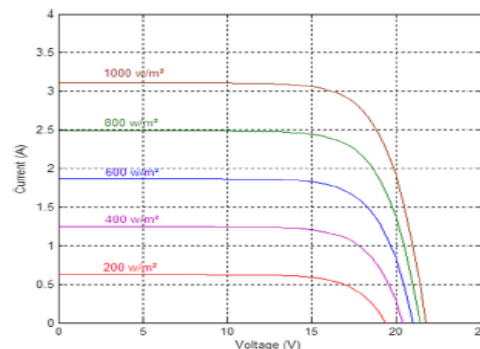
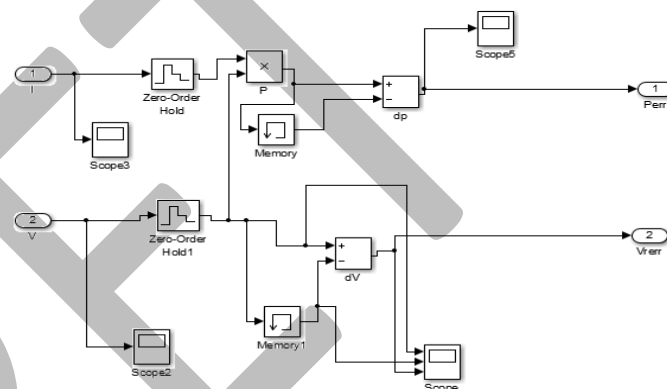
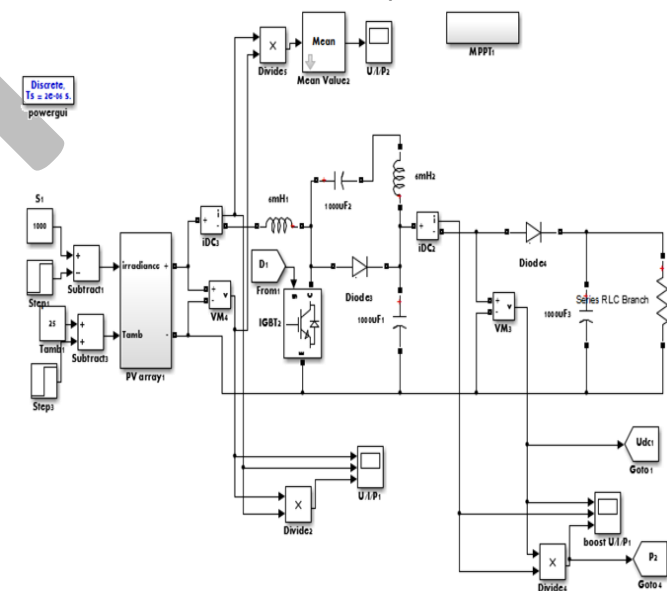


Fig.3 I-V characteristic of varying irradiance

**B. SIMULATION MODEL FOR P&O MPPT ALGORITHM:**

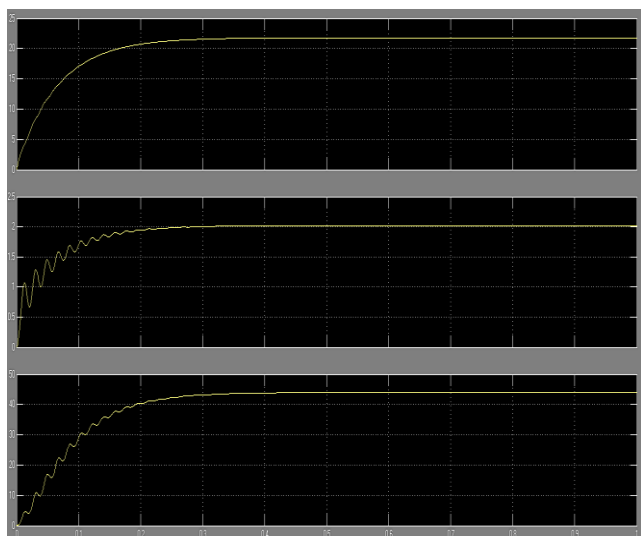


**C. SIMULATION MODEL FOR DC/DC CONVERTER:**



Below Waveforms represents the Current, voltage & Power of PV Cell.





Waveform of V/I/P

## VII. CONCLUSION

In this project, an efficient and fast simulation technique is presented to simulate sub MIC-based grid-tied PV systems, which is a difficult problem due to the significant number of PV sub modules and sub MICs. A comprehensive control strategy is also developed to coordinate the control of Distributed Maximum Power Point Tracking, PV sub module voltage regulation, dc-link voltage regulation, and grid-tied current injection. The simulation model is developed using the averaging technique of power converters in combination with the simplified PV model, which illustrates the dynamic interaction among DMPPT, PVVR, and DCLVR during various partial shading conditions.

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