

Performance Characteristics of Miniature Photovoltaic Farm under Dynamic Partial Shading

Antonius Rajagukguk¹, Dedet Candra Riawan², Mochamad Ashari³

^{1,2,3}Department of Elect. Eng., Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia

¹Department of Elect. Eng., Universitas Riau, Pekanbaru, Indonesia

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ABSTRACT

This paper presents investigation of performance characteristic on a miniature photovoltaic farm under dynamic partially shaded condition. Effects of applying bypass diodes in each photovoltaics modul and the transient current of the diode is also investigated. The miniature of PV Farm consisting 4 photovoltaic panels, connected in series to form one string. The whole system comprises 5 photovoltaic strings, which are connected in parallel producing 30 volt and 60 watt peak power from miniature PV farm. Shading of 10%, 20 % up to 50 % with dynamically changed is applied. Result from both laboratory tests and simulations is investigated and show very similar.

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Corresponding Author:

Antonius Rajagukguk,
Department of Elect. Eng.,
Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia.
Email: antoniusrajagukguk@gmail.com

1. INTRODUCTION

The main problem of the utilization of photovoltaic (PV) as one of alternative energy generation is that the PV has low and changeable power as the weather changes [1],[2]. PV generated power optimization can be done through the mechanism of non-physical and physical-electrically method. Non-physical method conducted through Maximum Power Point Tracking (MPPT) method, either through conventional methods and algorithm-method based on *Artificial Intelligent Control* (AIC) [1], [2]. PV power optimization through MPPT with the conventional algorithm method can be done in several ways, such as *Perturbation and Observation* (P&O), *Hill-Climbing* (HC), *Incremental Conductance* (Inc Cond) [3], and PSO Algorithm [4]. All of these methods have advantages in terms of getting the maximum power point of PV. Many studies discuss the modeling and simulation of PV systems under shaded from various level of radiation intensity [4-7]. While some researchers have done research the impact of partial shading problem investigation, but their researches are limited to the photovoltaic module and the basic configuration of the PV array [8-13].

In the configuration of PV array, there are two type of diodes used. One is blocking diode and another one is bypass diode. Blocking diode is installed series with the string of PV, and bypass diode is installed paralel by each modul of PV. Bypass diode used to protection of PV when partially shaded of PV array occur. This research will discuss model characteristics and transient response of bypass diode on PV farm system under dynamically shading effect in implementation of PV farm miniature.

2. RESEARCH METHOD

2.1. PV Model

A single PV module consists of a number of PV cells in series and a PV cell is modeled as a current source shunted with a diode and represented by an equivalent circuit [1] shown in Figure 1. The equation relating the output current and the voltage of a PV module can be written as equation 1.

$$I_m = I_{ph} - I_0 \left[\exp\left(\frac{V_{pv} + R_s I_m}{A}\right) - 1 \right] - \left[\frac{V_{pv} + R_s I_m}{R_{sh}} \right] \tag{1}$$

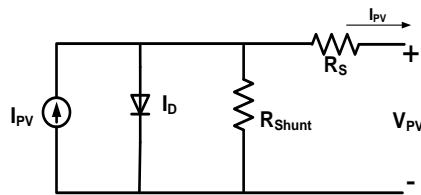


Figure 1. Equivalent Circuit of Photovoltaic

Where I_m is the current generated by the module, I_{ph} is the photoelectric current, I_0 is the saturation current, V_{pv} is the PV voltage $A = nkT/q$. T represents the temperature of the module in Kelvin, k is the Boltzmann's constant, q is the electric charge, n is the number of cells in series, R_s and R_{sh} are the series and shunt resistance respectively.

2.2. Block Diagram of Miniature PV Farm

The PV farm is combination of PV modules that connected in series and parallel in large quantities. The model of miniature PV farm is shown in Figure 2, is a representation of the actual PV farm with a capacity of 60 Wp, consist of 5 PV strings in parallel, and each PV string is composed of 4 PV modules in series. The PV panels using GH003M type, with maximum power of 3 Wp, maximum current of 0.334 mA and voltage open circuit of 11 Volts

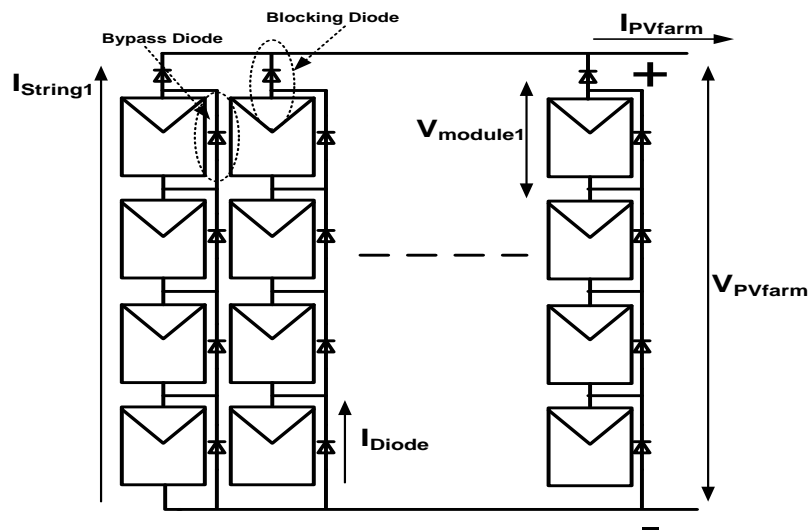


Figure 2. Model of Photovoltaic Farm

For implementation, we used the solar module (mono-crystalline silicone type) that made by Zhejiang Ganghang solar Technology, with specifications as shown in Table 1.

Table 1. PV module specifications

Model of PV Modules	GH003M
Standard Power W_p (Watts)	3
Break Working Voltage V_{mp} (V)	9
Best Working Current I_{mp} (A)	0.333
Open Circuit Voltage V_{oc} (V)	11
Short Circuit Current I_{sc} (A)	0.361
Number of modules per string	4
Total of PV string Farm	5

Bypass diode is used to protect PV Module during reverse bias condition. Reverse bias on the PV module is occur when each module in each string have various sun's radiation. Sun's radiation variation on the PV module's surfaces is called shading effect. To avoid damage because of shading effect, so each PV module is paralel-conected with bypass diode.

2.3. Data Collecting

In this research, data collecting is by observing the magnitude of current on the bypass diodes, magnitude voltage and current of each PV modules, on each PV string. Tests carry out by using software simulation and measurement directly in the PV miniature farm system. It also observing the maximum power of observation through the characteristic curve I vs V and P vs I.

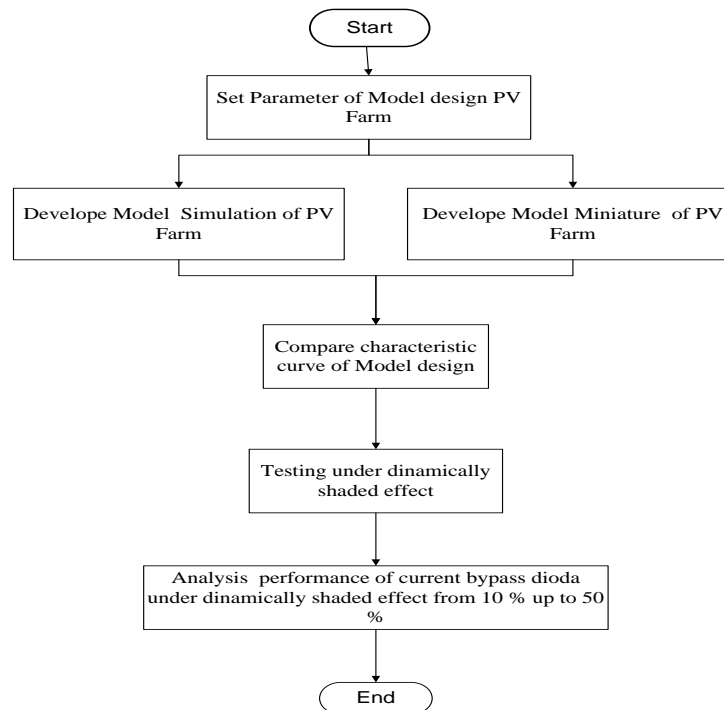


Figure 3. Flow chart of Research Method

Voltage V of PV farm with various dynamics shaded (10%,up to 50% dynamically shaded effect). This was done for presents investigation of performance characteristic on a miniature of PV farm under dynamic partially shaded. Effects of applying bypass diodes in each PV panel and the transient current of diode is also investigated. Figure 3, describes detailed information for this research method.

3. RESULT AND ANALYSIS

3.1. Implementation of Miniature PV Farm

Figure 4 shown a miniature of PV Farm, with a total of 20 PV modules, with a maximum power of 60 watts at radiation of $1000 \text{ W} / \text{m}^2$, strings current $I_s = 0.336 \text{ Ampere}$, and strings voltage $V_s = 36 \text{ Volt}$.

Dynamic shading is implemented by covering the surface (part or full surfaces) of PV modules on the PV Farm. In this case study, the data obtained through measurement and simulation. The PV modules that used in this research have same characteristic (same I vs. V and P vs. V curve, relatively).



Figure 4. Miniature of PV Farm

3.2. Case of string PV on Miniature PV Farm

In testing using a single PV string module, it can be obtained the maximum power as $P_{max} = 10Wp$, the maximum voltage as $V_{max} = 30$ Volt, and the maximum current as $I_{max} = 0.355A$. It was obtained at the time of radiation of $600 W / m^2$, as shown in Figure 5.

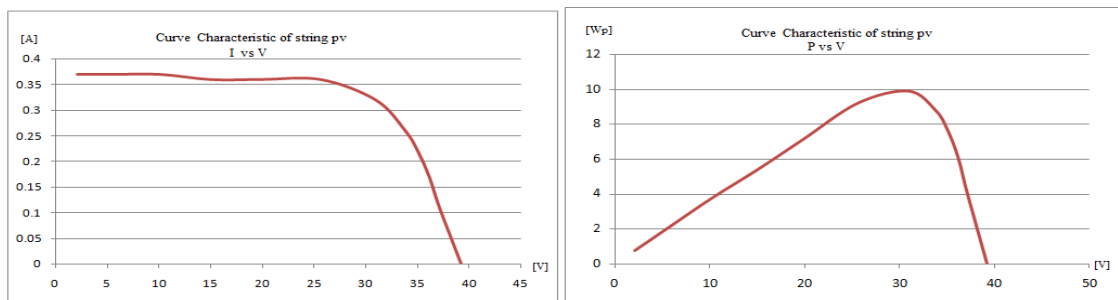


Figure 5. Characteristic Curve of Single Miniature PV string

Other results can be shown in Figure 6, by applying dynamic shading (for 25%, 50%, and 75% shaded).

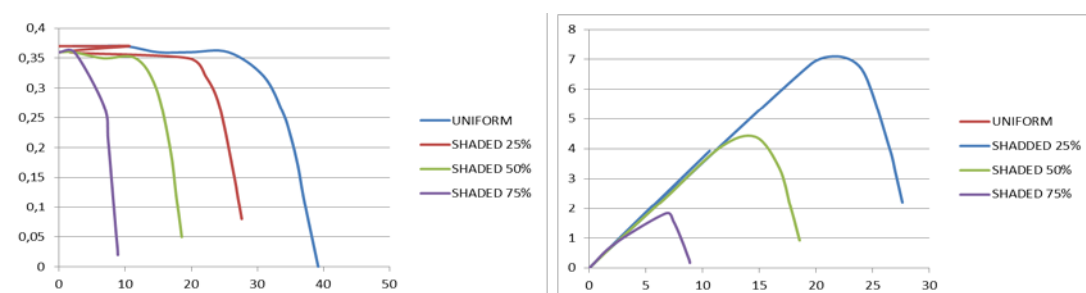


Figure 6. Characteristic Curve of Single Miniature PV String under Shaded (IvsV and PvsV)

3.3. Case of Miniature PV Farm.

The test result and measurement implementation reveals a pattern that relative within the limits of differences which is acceptable when compared to the results of the simulation on software. Significant differences occurred in the current reading. In this research, for simulation case we use $600 W/m^2$ radiation. The measurement data can be shown in Fig 7 a and b.

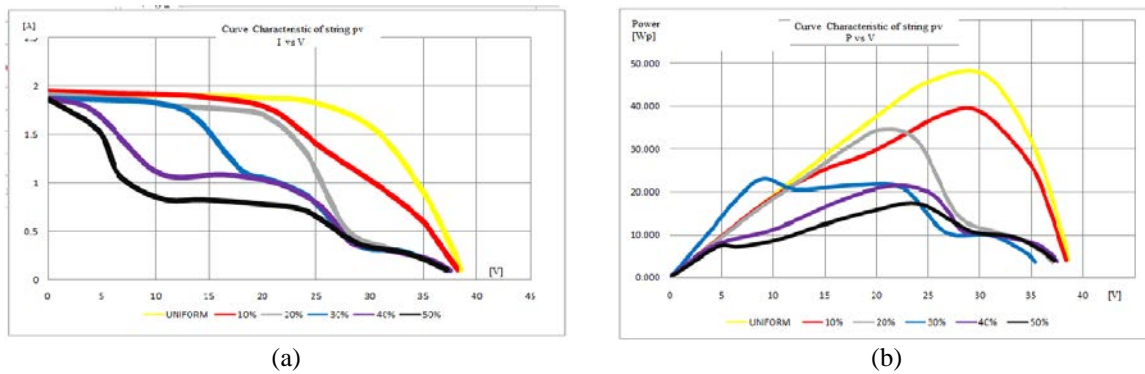


Figure 7. (a) I vs V Characteristic Curve of Miniature PV Farm under Shaded. (b) P vs V Characteristic Curve of Miniature PV Farm under Shaded

Irregularities were very strong at the current readings, it could lead to a relatively different power obtained by the power generated in the simulation. This is due to the tolerance of the measuring instrument, but in general the resulting data has a pattern, the number of the local point of optimal and data trends is relatively as same as the simulation.

3.4. V and I Performance of bypass diode under shaded.

The power that generated by the PV farm under dynamic shading is very dependent to the performance transient of bypass diodes, because without using the bypass diode, current will flow and harm the modules of PV when PV farm under dynamics shade effect. Figure 9 shows radiation signal as input of PV farm under shaded with 1 second of time. Radiation change at 1 second for forward or reverse from 600 watt/m² to 0 watt/m² and vice versa.

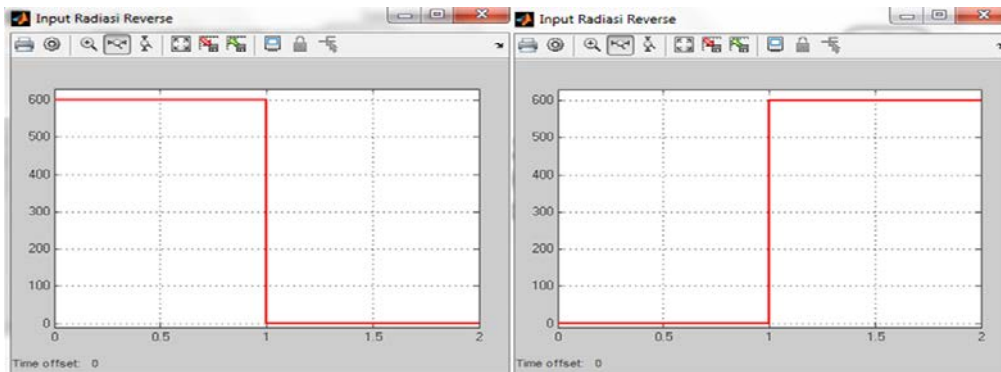


Figure 9. Input Signal of Module PV Under Shading Effect

This study presents of PV farm characteristic using the bypass diode under dynamic shading. Tests conducted on two conditions of PV string

1. The Simulation of module PV Farm shaded 30 % and 40 %.
2. The Simulation of module PV Farm shaded 50 % forward
3. The Simulation of module PV Farm shaded 50 % reverse
4. The Miniature PV modules shaded 50% forward and reverse.

3.4. The Simulation of module PV Farm shaded 30 %

In this case showing on Figure 10, simulations of module refer to Figure 2, Parameter illustrated are: I_{PVfarm} , V_{PVfarm} , I_{PV} , and V_{PV} , in the relationship between the current by-pass diode, current and voltage of PV module. The PV farm currently under shade, the magnitude of current by pass diode $I_d = 0$ A, in the event of dynamic shade 30%, the current I_d goes from zero ($i_d = 0$) becomes $I_d = 0.065$ A, and $V_{PV} = 9.5$ A, became

$V_{PV} = 0.7$ same with V_d short circuits. It shows that the bypass diode can work well in conditions under dynamically shade effect.

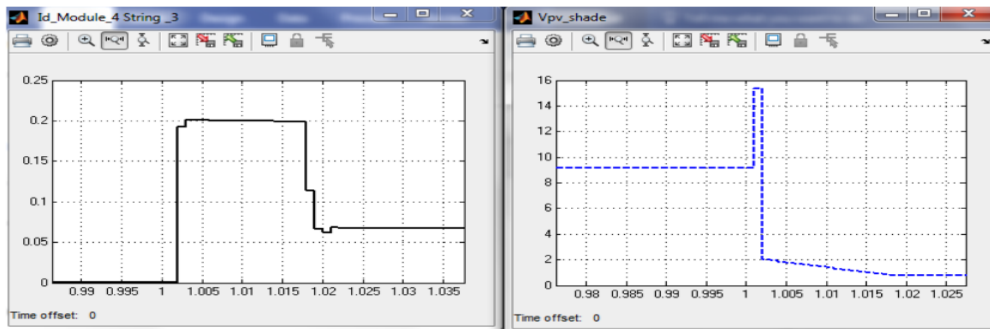


Figure 10. Transient, I_{pv} , V_{pv} Curve of PV Module during shade 30 %

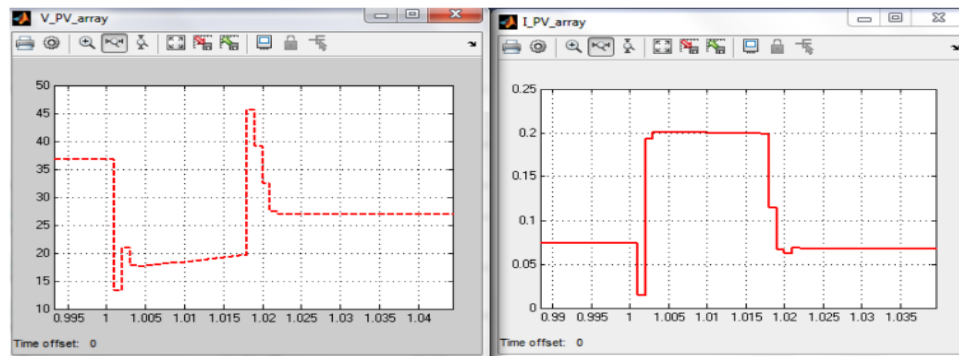


Figure 11. Transient, I_{pv} , V_{pv} Curve of Array PV Farm during shading 30%.

Figure 11, shows the magnitude current and voltage of Array PV farm under dynamically shaded effect. The magnitude of the current at the uniform conditions is $I_{pv_farm} = 0.075$ A and on the condition of shading 40% the magnitude of current $V_{pv_farm} = 36.6$ V. At the moment of dynamic shaded the magnitude of current I_{pv_Array} PV Farm = 0.758 A with current overshoot 0.2A A. Likewise on the on the case of voltage V_{pp} Farm for of dynamic shade overshoot voltage = 30 Volts before steady state condition.

3.5. The Simulation of module PV Farm shaded 40 %

The current and voltage of PV farm under dynamically shaded effect 40 % forward condition, can be seen in figure 12. In this case time of transient current diode I_d , and V_{pv} with shaded 40 %.

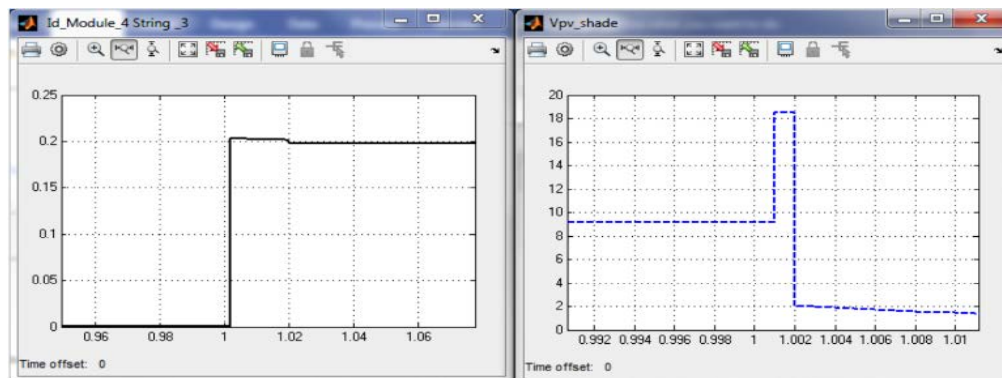


Figure 12. Transient, I_{pv} , V_{pv} Curve of PV Module during Shade 40 %

Figure 13, shows a large current and voltage of Array PV farm under dynamically shaded effect. The magnitude of the current at the PV farm uniform conditions is $I_{pv_farm} = 0.075$ A and on the condition of shading 50% the magnitude of current $V_{pv_farm} = 36.6$ V. At the moment of dynamic shaded the magnitude of current I_{pv_Array} PV Farm change from $I_{pv_Array} = 0.2$ A to I_{pv} array = 1.9 A. Likewise on the on the case of voltage V_{pp} Farm for of dynamic shade overshoot voltage = 30 V before steady state condition with change $V_{pv} = 36.6$ V to $V_{pv} = 20.5$ V

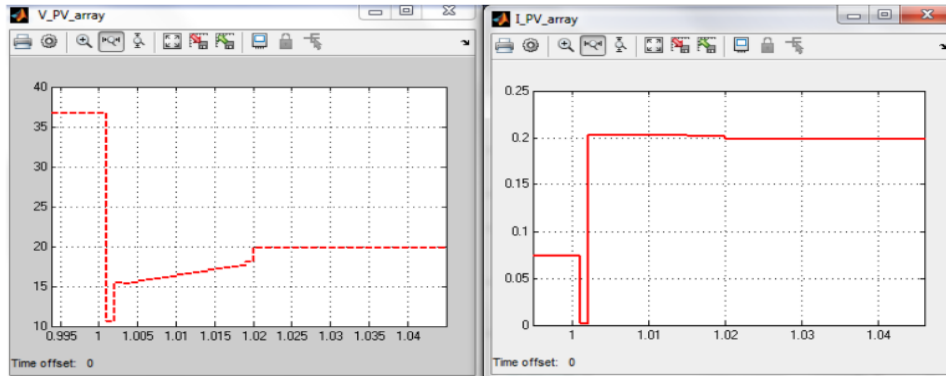


Figure 13. Transient, Ipvf, Vpvf Curve of Array PV Farm during Shading 40%.

3.6. The Simulation of module PV Farm shaded 50 %

Figure 14., shows the current and voltage of PV farm under dynamically shaded effect 50% from under shaded to without shaded conditions. In cases shade 50 % V_{pv} array change from 20 V to 36.6 V and I_{pv} array from 0.2 A to I_{ppv} 0.075 A. For all case have settling time (t_s) for all cases equally with 0.02 second. Figure 15 Shows that the the magnitude of currents overshoot increased sharply to 0.32 A, as well as voltages overshoot is increase from 25 volt up to 32 Volt. It can be potential into a problem on switching process by pass diode.

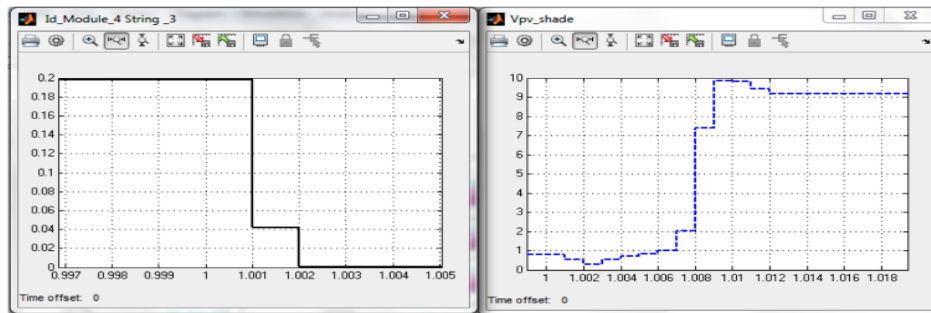


Figure 14. Transient, I_{pv} , V_{pv} Curve of PV Module during shade 50 %

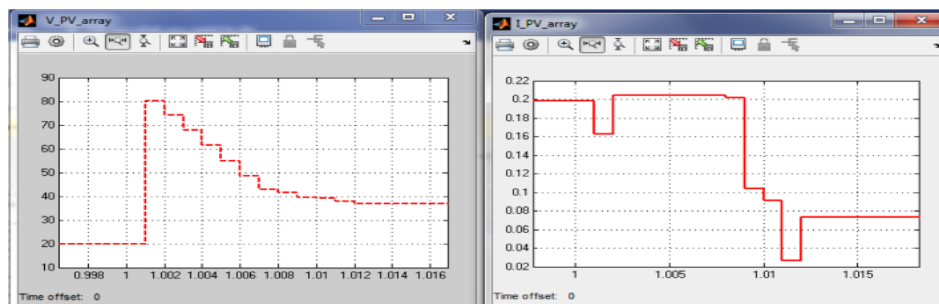


Figure 15. Transient, I_{pvf} , V_{pvf} Curve of Array PV Farm during shading 50%.

3.7. The Miniature PV Farm modules shaded 50% forward and reverse

Testing case miniature PV module, using a measuring instrument oscilloscope Tektronix TPS2014B. Variations shaded used are uniform to 50% and The measurement results shown in Figure 16.a and 16.b. Which is a test case C for the forward and reverse conditions on miniature PV module. Channel 2 shows the output string current I_s , channel 3 shows the voltage module PV (V_{pv}), and channel 4 shows the diodes current I_d . The measurement results are shown in figure 16.a and 16.b, when prose miniatures received and regardless of the shade (forward and reverse shade conditions), on channel 2 is seen going springboard current (overshoot current) up to 250%, both for the condition forward and reverse shaded. The differences lie in the forward going 1 oscillation condition but the reverse is no oscillation. In the same case channel pad 3, looks great Vpv voltage of 5 volts to 0.7 volts to change, or equal to the break over voltage of the diodes. Otherwise the image 15.b, changed from 0.7 volts to 5 volts. for both conditions seem to occur relatively small voltage oscillations. At channel 4 looks "diode current" I_d , when the condition of forward, there is a current overshoot and settling time but in a relatively small scale. But for the reverse case it is not visible.

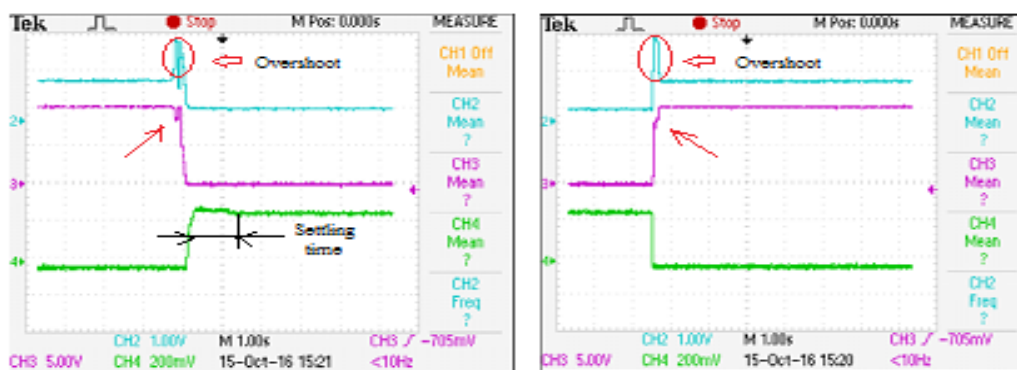


Figure 16. Measurement result, (a) Forward Bias Test Case, (b) Reverse Bias Test Case

4. CONCLUSION

Based on the examination of the implementation of miniature PV Farm and the simulation, it can be concluded: The design of diodes in PV farm miniature, can be work properly perform blocking of module PV from reverse bias effect. The reverse bias on module PV, is as of dynamic shaded effect. Based on testing from both laboratory test and simulations show, for all case, have equally settling time of current bypass diode $I_{d,ts} = 0.02$ second. Based on testing of simulation models and miniatures of PV farm, the greater dynamics shade from case miniature PV Farm, could potentially cause greater overshoot on current string pv (I_s) up to 250 %. To avoid failure by pass diode from overshoot of current and voltage, then The PV Farm miniature system require components that can to reduce the overshoot. Result from both laboratory test and simulations show very similar.

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