



Auto-Scaling Variable Step Size Incremental Conductance Maximum Power Tracking Control Algorithm for Photovoltaic System

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Abstract

Generally, most of the Maximum Power Point Tracking (MPPT) techniques are based on the fixed step size considering to its simplicity and easy execution. However, the fixed step size contributes to the high power oscillation around maximum power point for large step size and slow time response for small step size. In order to compromise between these two problems, the variable step size (VSS) method is proposed. Yet, there are some deficiency occurred in the conventional VSS between time response and power oscillation. Thus, in this research paper, Auto-Scaling Variable Step Size (AVSS) Incremental Conductance (INC) algorithm technique will be employed to improve the trade-off between time response and power oscillation.

Keywords: maximum power point tracking; variable step size MPPT; incremental conductance; auto-scaling.

1. Introduction

Renewable energy, especially solar energy is increasingly recognized due to unstable oil prices, shortage of fuel resources, over climate changes and enhancement of incentives and government supports. By taking advantage of the readily available energy, solar energy is the best choice of green energy technology to be applied to overcome the lack of non-renewable energy resources [1].

Photovoltaic (PV) system consists of PV module will generates DC power when sunlight shines onto it. The performance of the PV module subject to change with the weather changes, especially solar irradiance and temperature. Therefore, maximum power point tracking (MPPT) is used to obtain the maximum PV power output regardless the weather changes [2],[3].

The ability of MPPT to track the maximum power point (MPP) depends on the application of step size in the algorithm. Based on the study, there are two types of step size perturbation which are large step size and small step size. By using large step size contributes to fast tracking speed, but exaggerates oscillations in power. Opposite to this, by using small step size the power oscillation is reduced, but the tracking speed becomes slow. Thus, the VSS is proposed in the INC algorithm to compromise between higher power oscillation and tracking speed [4]. However, in the conventional VSS INC the fixed value of scaling factor is used for the step calculation [5]. Due to the fixed value of scaling factor, the issues of trade-off between power oscillation and tracking speed still exist. Besides that, the selection of scaling factor in the conventional VSS INC algorithm done by manually. The manual adjustment of scaling factor is tedious and results may be valid for a given system and operating condition.

2. Conventional Variable Step Size Incremental Conductance MPPT

In the conventional VSS INC, the step size is tuned according to the PV module characteristic [4],[6]. The step size is increased to enable fast tracking ability if the operating point is far from MPP and the size is automatically decreased if the operating point is near to the MPP [7],[8]. Through the variation of the step size, the accuracy and speed are accomplished.

The steps are determined by the scaling factor (N) and a ratio of slope of power (dP) and slope of voltage (dV) as in (1). The updating duty cycle (D) is obtained based on increment or decrement of calculating step and previous duty cycle (D_k) as shown in equation (2) [5].

$$step = N \times \left(\frac{dP}{dV} \right) \quad (1)$$

$$D = D_k \pm step \quad (2)$$

The N determines the performance of the MPPT which adjusts the step in the algorithm as shown in Fig. 1. The manual adjustment of N is tedious and the results may be valid only for a given system and operating condition [9]. Thus L.Fangrui et.al [5] proposed N calculation method by comparing large step size (ΔD_{max}) for fixed step size MPPT with the lowest value of step in (3). To ensure the convergence of the MPPT update rule, the variable step rule must obey the following:

$$\left| \frac{dP}{dV} \right|_{\text{fixed_step}=\Delta D_{\max}} < D_{\max} \quad (3)$$

Therefore, the scaling factor can be obtained as :

$$\frac{N < \Delta D_{\max}}{\left| \frac{dP}{dV} \right|_{\text{fixed_step}=\Delta D_{\max}}} \quad (4)$$

A VSS INC works with fixed step size with a large step size at ΔD_{\max} if the (4) is not satisfied. Otherwise a faster response is produced with larger N compare to smaller N . Although this method can be considered as a simple method for designing the scaling factor, it requires analysis of the system with fixed step size operation. A wrong design of N cause the algorithm operates as fixed step size instead of VSS which reduces the efficiency of the system [10]. The bad design of the N lead to worst dynamic response, but the selecting of appropriate N ensures the high efficiency tracking and acceptable transient and steady state performance [11].

3. Auto-scaling Variable Step Size Incremental Conductance Algorithm

The proposed AVSS INC MPPT algorithm maintains a similar approach of conventional VSS INC algorithm. The modification of the classical algorithm is based on analysis of dP/dV slope which determines the selection of the scaling factor (N) involved in the step calculation. The difference between conventional algorithm and new algorithm is based on the value of N in the operation. The conventional VSS uses a fixed value of N , whereas the new algorithm uses multiple value of N . The new algorithm adapts the combination of high value of N (N_1) at the beginning and lower value of N (N_2) when the slope is reduced. The N_1 is applied at the beginning of the execution for faster response time. Meanwhile the second value of N_2 is used to stabilize the power oscillation of the system. The objective of this method is to achieve fast response time and minimize the power oscillation around MPP thus increase the efficiency. With multiple value of N , the step of increment/decrement is more strategic since the time response can be programmed to achieve faster MPP.

Initially, the system is tested with a conventional VSS INC algorithm. Based on the algorithm, the highest slope (HS) is obtained. The HS is applied and compared with the current value of slope dP/dV to determine the selection of N in the step perturbation. If the current slope dP/dV is higher than HS, a high value of N is applied. Otherwise, a small value of N is applied. The selection of N is shown in Fig. 2.

Fig. 3 shown the flowchart of the AVSS INC algorithm. Initially, the operating input current $I_{pv(k)}$ and voltage $V_{pv(k)}$ from PV module are measured. The system starts by initializing duty ratio at 75%, since it is most likely that MPP can be found. The incremental changes in dV and dI are approximated by comparing the most recent measured values for $V_{pv(k+1)}$ and $I_{pv(k+1)}$ with those measured in the previous cycle $V_{pv(k)}$ and $I_{pv(k)}$. The operating power $P_{pv(k+1)}$ is computed based on $I_{pv(k+1)}$ and $V_{pv(k+1)}$. Similarly with dV and dI , the incremental changes of dP are compared with the values of $P_{pv(k+1)}$ and previous $P_{pv(k)}$.

Once the selection of N is done, the value of N is applied in the step perturbation. If $dP/dV=0$ ($dI/dV = -I_{pv}/V_{pv}$) is executed, the system operates at the MPP and no change in duty ratio is necessary and current cycle ends. If otherwise, ($dI/dV > -I_{pv}/V_{pv}$) is used to determine whether the systems is operating at a voltage greater or less than MPP, hence increases or decreases the duty ratio. The

value of the increment or decrement of duty ratio is automatically calculated depending on the step perturbation.

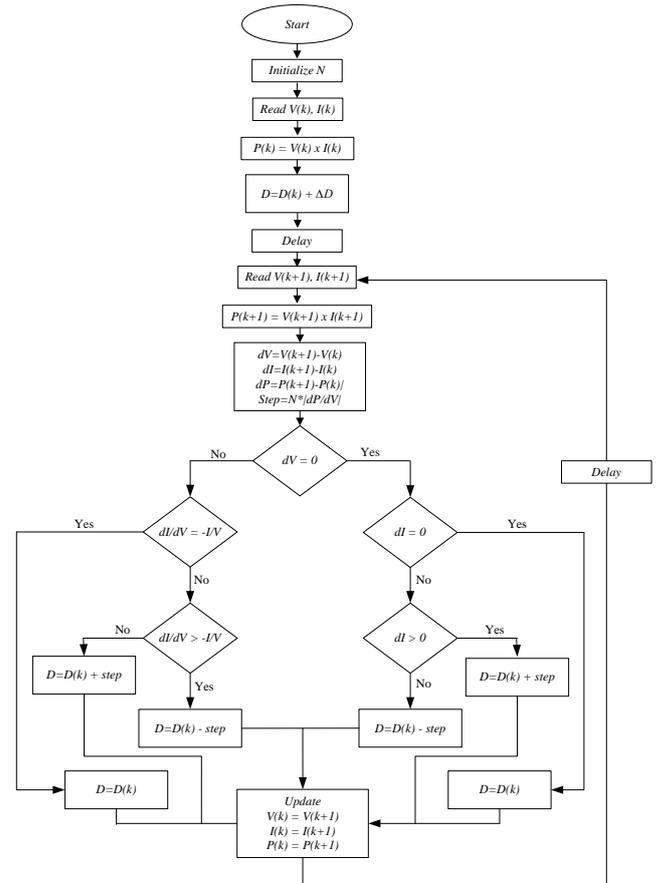


Fig. 1: Conventional Variable Step Size Incremental Conductance Algorithm

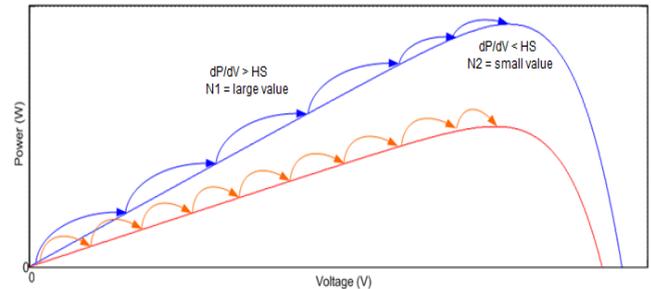


Fig. 2: Selection of N in the MPPT

If the system operates at the MPP during the previous cycle, the INC of the operating voltage is zero ($dV=0$). This would lead to a division by zero, $dI/dV = dI/0$, which is impossible to calculate. To avoid this, the condition $dV=0$ is checked first and it leads to another branch. Since the voltage $dV=0$, that means it has not changed. The only useful information about possible changes can be found from the current measurement. If $dI=0$, the operating conditions have not changed and therefore the adjustment of the system voltage is bypassed. If $dI > 0$, the duty ratio is increased and if otherwise, the duty ratio is decreased. The whole process is repeated until the MPP is reached.

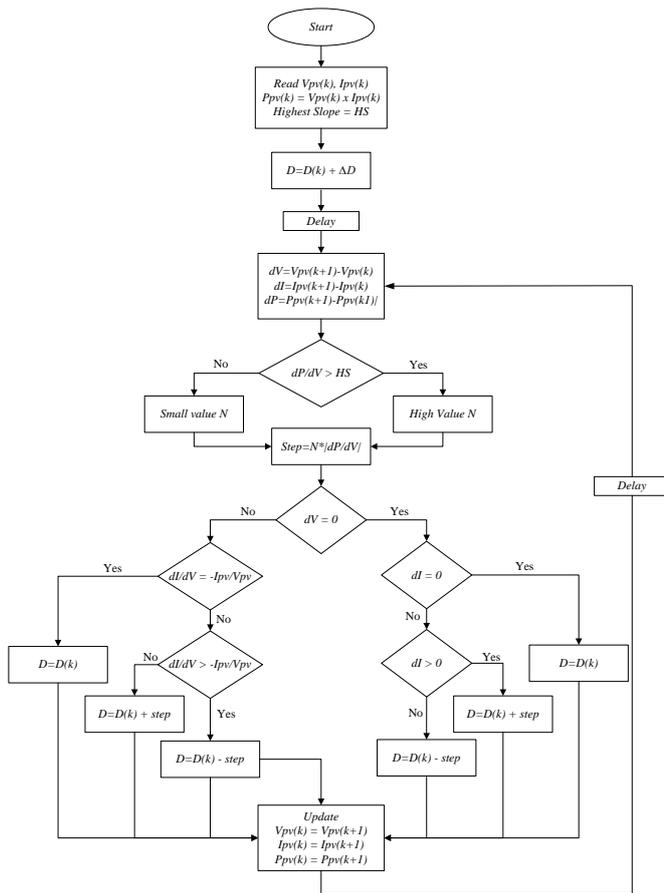


Fig. 3: Flowchart of AVSS INC Algorithm

4. Conventional Variable Step Size Performance

The approach to control the MPP performance based on the scaling factor N rate applied in the step parameter. To study the effect of N in the performance of VSS INC, three values of N are used. The different value of N is set manually with $N = 0.5, 1$ and 3 . The values are chosen by randomly with small value to a high value to observe the effect of tracking and power oscillation output.

Fig. 4 shows the effect of tracking speed and power oscillation by using small and high value of N in the step calculation. $P_{mp_calculated}$ is represented as dotted line. The $P_{mp_calculated}$ is calculated based on equation (5).

$$P_{mp_calculated} = Pmp_{stc} \times \left[1 + \left(\frac{\gamma_{pmp}}{100} (T_{cell} - T_{stc}) \right) \right] \times PSF \quad (5)$$

where,

- P_{mp_stc} is power output of module at STC, [Wp];
- γ_{pmp} is temperature coefficient of maximum power, [%/°C];
- T_{cell} is temperature of cell during operation [°C];
- T_{stc} is temperature of cell at STC [°C];
- PSF is peak sun factor;

Fig. 4(a) applies a small value of $N=0.5$ resulting lower steady state oscillations, 1.28 W but slows down the tracking speed to 50 s. By using $N=1.0$, the result shows the tracking speed to achieve MPP become faster to 20s, however the power oscillation increases to 1.32W. Compared with a higher value $N=3$, the tracking speed takes 7s to reach MPP nevertheless it is exhibiting large power oscillation 2.4 W.

The results of the presented graphs are listed in the Table I. From the result, it is observed that $P_{mp_calculated}$ is slightly higher than $P_{mp_measured}$ of the system. This is due to the fact that in real condition, there are power losses occurring in cables, dirt on the surface of PV module and losses in switching component such as MOSFET

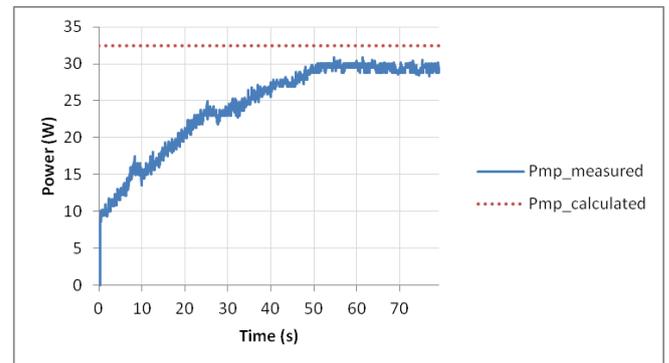


Fig. 4(a): N = 0.5

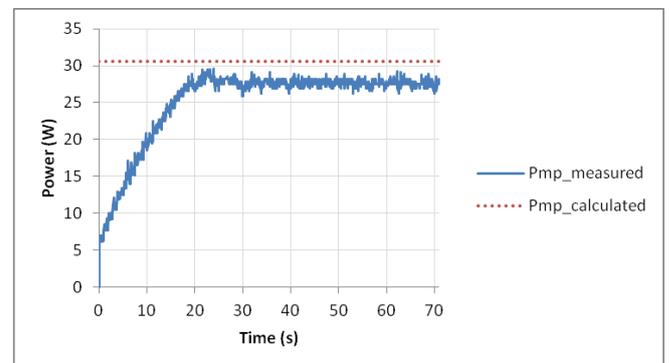


Fig. 4(b): N = 1.0

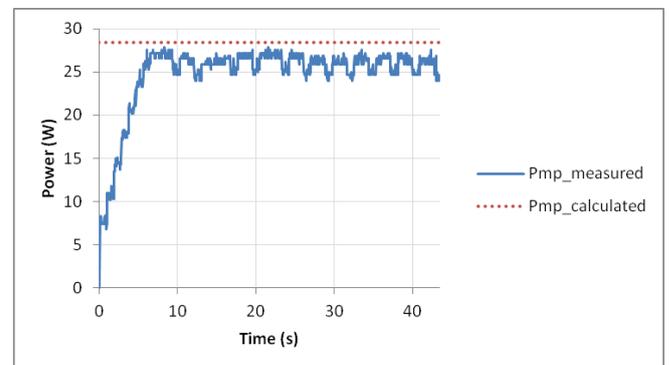


Fig. 4(c): N = 3.0

Fig. 4: Performance of Conventional VSS INC

Table 1: Tracking Performance of Conventional VSS INC Algorithm

Scaling Factor (N)	0.5	1.0	3.0
Irradiance, (W/m ²)	850	820	800
Temperature, (°C)	47	51	53
$P_{mp_calculated}$ (W)	32.5	30.5	28.4
$P_{mp_measured}$ (W)	29.5	27.5	25.5
MPP tracking speed (s)	50	20	7
Power Oscillation (W)	1.28	1.32	2.4

5. Auto-scaling Variable Step Size Incremental Algorithm Performance

In order to study the performance of the developed AVSS INC algorithm, three sets of N combination (N_1 and N_2) have been used in the algorithm. The same value that has been used in the conventional VSS INC is applied in the AVSS INC. The combinations

are chosen based on the possibility arrangement between $N = 0.5, 1$ and 3 . However, in order to improve the tracking speed, the value of N_1 is chosen higher compare to the value of N_2 . In addition, the small value of N_2 contributes to the stabilization of the power oscillation.

Fig. 5 presents the result of the AVSS INC algorithm with a combination of multiple of N . The arrangement of N value is set with combination A: $N_1 = 1$ and $N_2 = 0.5$, combination B: $N_1 = 3$ and $N_2 = 0.5$, and combination C: $N_1 = 3$ and $N_2 = 1$. It shows that by using Combination A, the tracking speed is 16 s and power oscillation 1W. Combination C produces 2W power oscillation, but the tracking speed becomes faster to 3s. However, Combination B has shown the best result in term of tracking speed 2s and power oscillation 3W.

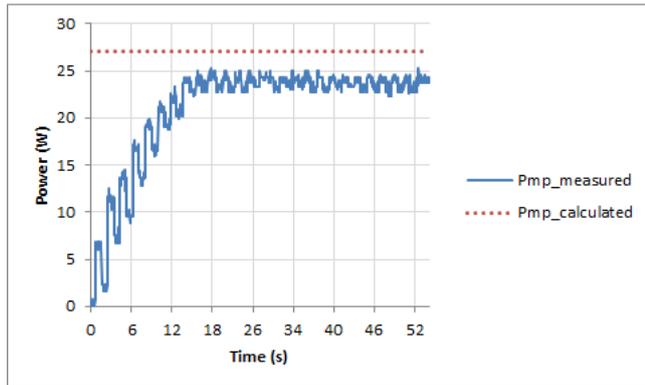


Fig. 5(a): Combination A: $N_1 = 1$ & $N_2 = 0.5$

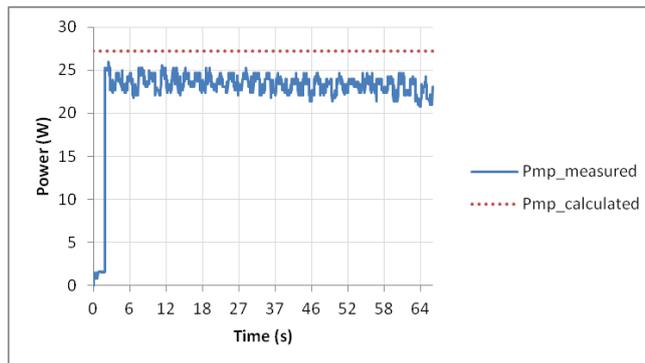


Fig. 5(b): Combination B: $N_1 = 3$ & $N_2 = 0.5$

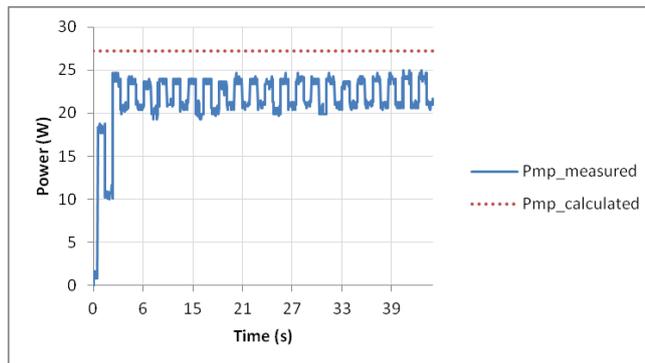


Fig. 5(c): Combination C: $N_1 = 3$ & $N_2 = 1$

Fig. 5: MPPT Performance of Auto-Scaling VSS INC Algorithm

The results of the presented graph are listed in the Table II. By the comparison result of AVSS INC performance and the result of the conventional VSS INC, it shows that the MPP tracking speed and power oscillation has been improved. The tracking speed of AVSS INC becomes faster and power oscillation is reduced. It shows that the high value of N_1 used at the beginning of the execution improves the tracking speed and a small value of N_2 reduces the power oscillation. Similar to the conventional VSS INC, it is ob-

served that $P_{mp_calculated}$ is slightly higher than $P_{mp_measured}$ of the system.

Table 2: Tracking Performance of AVSS INC Algorithm

Combination	$N_1 = 1$ & $N_2 = 0.5$	$N_1 = 3$ & $N_2 = 0.5$	$N_1 = 3$ & $N_2 = 1$
Irradiance, (W/m ²)	750	750	750
Temperature, (°C)	56	56	56
$P_{mp_calculated}$ (W)	27	27	27
$P_{mp_measured}$ (W)	23.5	23.75	22
Tracking speed (s)	16	2	3
Power Oscillation (W)	1	3	2

In order to analyse the performance of the AVSS INC MPPT algorithm during fast changing irradiance, the algorithm perturbation is tested based on sign of the derivative of the PV power with respect to the PV voltage, dP/dV . The result for short time duration is captured as presented in Fig. 6.

The system captures data starting at 11:06. After one minute of execution, the positive dP/dV is obtained at 11:07. In order to get operating point moving towards the MPP, the system decreases the duty ratio (increases the reference voltage). The irradiance has continuously increased to 800 W/m² until 11:09. At this time, the dP/dV is still in positive and the operating voltage has continuously increased to 15.3V. With the continuous increase of the irradiance, the current has increased to 1.7A which produces 26W of P_{mp} .

However, at 11:10, the irradiance drops to 680 W/m². With the drop of irradiance after the increase of operating voltage, the system calculates dP/dV as negative. Thus the system has to decrease the voltage to get the MPP at this level of irradiance. At this point, the operating voltage is reduced at 15.25V. With the 1.8A of current, the 27W of P_{mp} is obtained.

From the result, it shows that the increment and decrement of operating voltage are directly proportional to the sign of derivative of PV power and PV voltage. The system is perturbed in the right direction as in order. This shows that the AVSS INC algorithm has successfully performed under rapid irradiance changes.

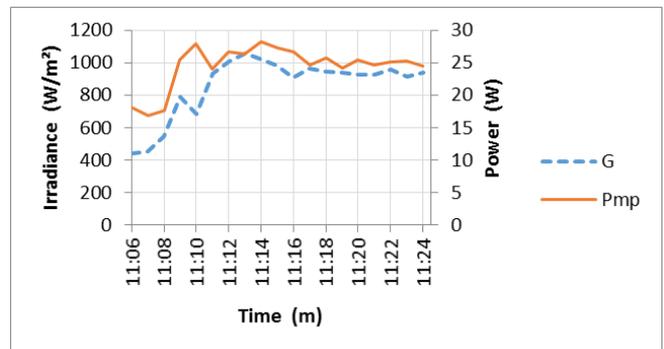


Fig. 6(a): Irradiance Data and Maximum Power

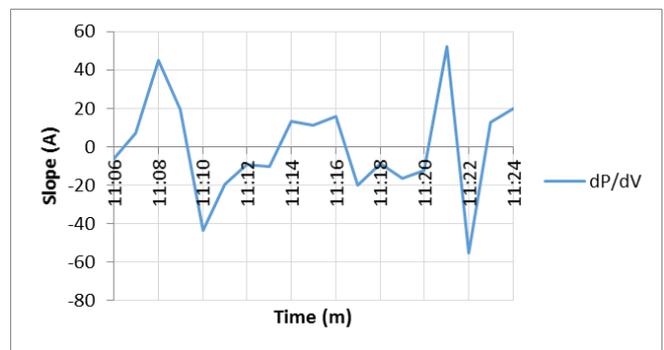


Fig. 6(b): dP/dV Slope

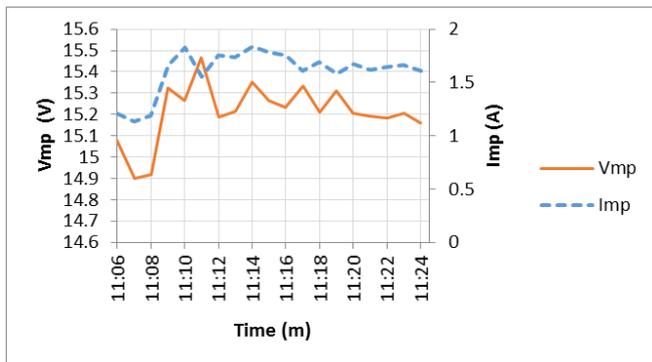


Fig. 6(c): PV Module Operating Voltage and Current

Fig. 6: Auto-scaling VSS INC Algorithm Performance under Rapid Irradiance Changes

6. Conclusion

The AVSS is successfully being carried out and the objectives were achieved. AVSS INC algorithm proposed in this research paper which uses two values of scaling factor has shown a great improvement between power oscillation and MPP time response. The results shown that, by applying a combination of large values of N at the beginning and lower value of N when the slope is reduced; the time taken to achieve MPP is faster and smaller power oscillation is observed around the MPP. This additional attribution has increased the efficiency of the MPPT. In addition, the AVSS INC shows favorable results under rapid change in irradiance. The algorithm is tracked with the right direction in the searching of MPP. For the future works, the result can be enhanced further for tracking speed less than 1 second and power oscillation almost zero by varying step and time response at transient and steady-state level.

Acknowledgement

The authors would like to thank to the Green Energy Research Centre (GERC) & Solar Photovoltaic Energy Conversion Technology Research & Application (SPECTRA), Universiti Teknologi MARA for the use of their equipment's in completing this research.

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