Energy Conversion
Circuit Laboratory

A Novel Partial Shading Detection Algorithm Utilizing Power Level Monitoring of Photovoltaic Panels

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Abstract - **Maximum power point tracking (MPPT) under partial shading condition (PSC) is a challenging research topic in the PV array system. As the shaded PV module makes different peak patterns on the power versus voltage curve and misguides the MPPT algorithm, various kinds of global MPP (GMPP) detecting algorithms have been studied. Generally, too frequent execution of the GMPP tracking algorithm reduces the achievable power of PV module due to time spent on the scanning process. Thus, the partial shading detection algorithm is essential for efficient utilization of solar energy source. Based on the theoretical investigation of the characteristic curve patterns under various partial shading conditions, this paper presents a new detection algorithm utilizing power level monitoring. While conventional methods only focus on fast shading patterns, the proposed algorithm always shows superb performance regardless of the partial shading patterns.**

I. INTRODUCTION

Photovoltaic (PV) generation is going to be of immense importance due to its free energy with zero environmental pollution. To maximize the efficiency of the PV array utilization, maximum power point tracking (MPPT) algorithm is essential. The MPPT algorithm always attempts to locate the operating point on the power peak in the characteristic curve.

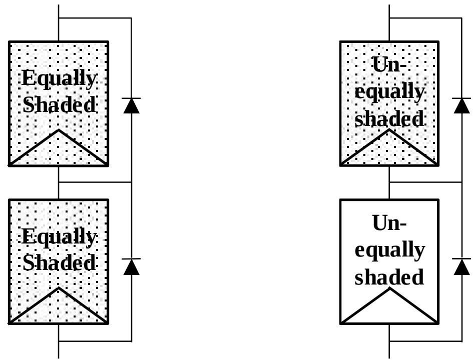
However, in the real environment, insolation shadows on the PV array are unavoidable and partial shading of PV array makes a considerable energy loss in PV system [1]. This is because multiple peaks can occur on the power vs. voltage curve (P-V curve) and obtainable output power may not be maximized without correct tracking of that peak. In this case, global MPPT (GMPPT) algorithm is required to select the highest peak among various local MPPs and give the new control reference to the MPPT algorithm.

There have been a few studies on the GMPPT algorithm [2-9]. To identify the occurrence of the partial shading condition (PSC), the PSC detection algorithm is used. However, conventional methods sometimes cause to the reduction of the system efficiency because they used to waste time on a sequence of repeated scanning of local MPPs, which hinders the optimal operation of PV module [2]. Hence, this study aims to investigate effective PSC detection in order to avoid such an unnecessary GMPPT and improve the system performance further. In this paper, a novel PSC detection algorithm is proposed and demonstrated. Finally, its advantages have been compared with conventional methods.

II. PRINCIPLE OF OPERATION

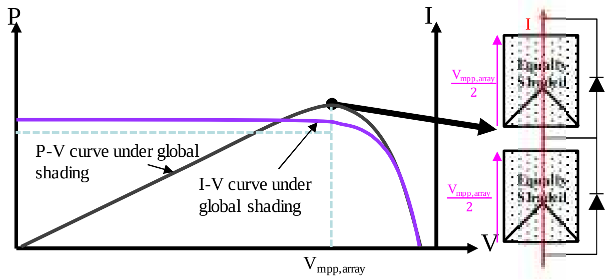
Basic concept

The PV arrays are engaged with different kind of shadings as shown in Fig.1. The global shading is shown in Fig.1 (a) and can be defined as the shading that can cover the entire PV array temporally. This kind of shading can be occurred due to large moving cloud. Likewise, a part of PV array can be covered by some shadows and it can be defined as PSC as shown in Fig.1 (b). In the real environment, the PSC detection algorithm should be able

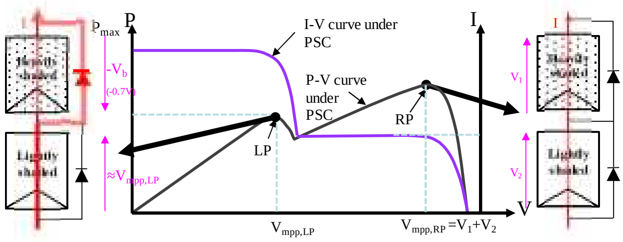


(a) Global shading condition (b) Partial shading condition

Fig. 1 Definition of shading



(a) Global shading condition



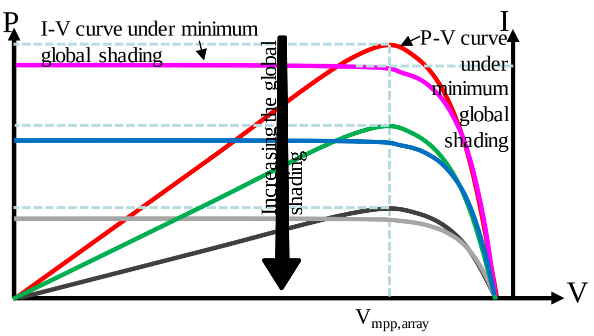
(b) Partial shading condition

Fig 2. P-V and I-V curves two equal panel (Ns = 2) to distinguish the shading condition.

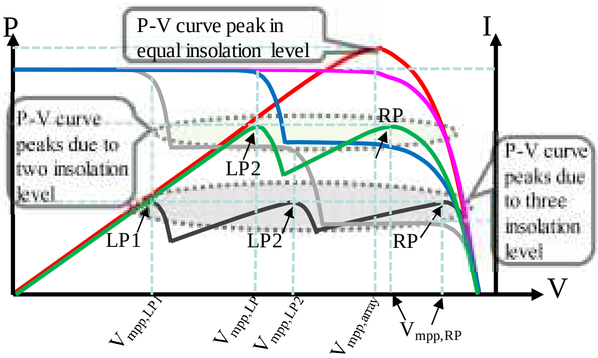
Figure 2 shows P-V and I-V curves of array with two identical modules which are connected in series configuration. According to Fig.2 (a), maximum MPP current and MPP power are delivered continuously under control of MPPT algorithm. When a global shading occurs, current and power are reduced without activating bypass diodes and new operating point is determined by MPPT. In the PSC, the behavior of characteristic curves is shown in Fig.2 (b). Here, the two peaks are appeared in the P-V curve as a left - side peak (LP) and the right-side peak (RP). The MPPT cannot sense other peaks on P-V curve and keeps the existing peak continuously. Thus, the PSC detection algorithm is important to select the operating point on correct peak by using global peak searching algorithm. The current flow through PV module is determined by selection of operating peak. When the RP is selected by GMPPT, both modules are contributed to the array power delivery and maximum array current is determined by shaded module. On the contrary, LP is selected, the shaded module is bypassed through the diode due to low current capability and array current is determined by minimally shaded module. Here, power is delivered by minimally shaded module along. Among those two peaks, the highest peak is defined as a global MPP (GMPP). According to the above behavior of characteristic curve, it is also known that the height of the RP is only affected by shading of global insolation [2] whereas the height of LP is always determined by minimally shaded module. The temperature effect due to change of shading is assumed as negligible.

This concept can be extended to multiple numbers of series module array. For an example, three modules array (Ns=3) is explained as shown in Fig.3. The behavior of global shading condition is shown in Fig.3 (a). Here, the current flow and voltage change follow a similar manner as Ns =2 system. However, PSC has two (generally (Ns-1)) possible scenarios as shown in Fig.3 (b). Here, maximally three peaks can be occurred, and the possible number of peaks is determined by the number of modules (bypass diodes) in series connected PV array [3]. In our study, peak occurring regions are defined as shown in Fig.3 (c). LP1 is occurred in “n=1” region and numbers of other regions are incremented according to the peak number. The location of “n=1” can be calculated by using Ns and V_{oc} of the module. When the array covered by one shadow, two peaks are occurred. Here, note that the area of the LP is in “n=2” region. (In Ns=2 system, the region of LP is “n=1”). If two shadows are covered the array, three peaks are appeared and named as LP1, LP2, and RP. The LP1 and LP2 are occurred due to minimally shaded module and module with next shading level, respectively. The RP is always occurred due to maximumly shaded module.

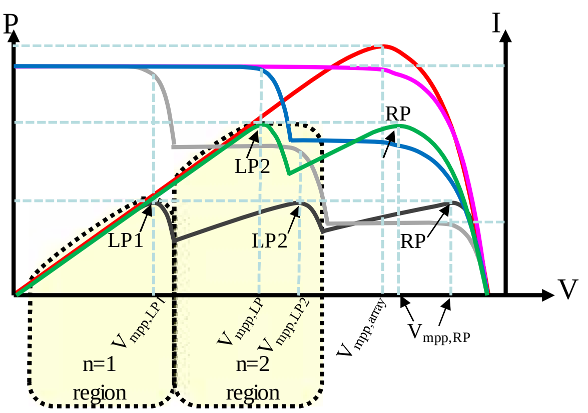
From our observations, the height of the LP can be calculated by using α% of the maximum output power (αP_m) and the ratio, α is determined by (1)



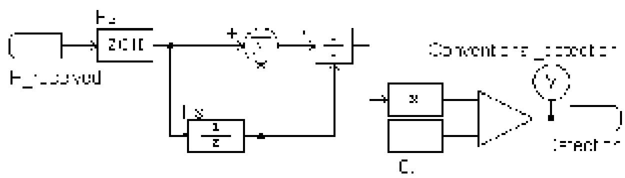
(a) Global shading conditions under 3 different equal insolation levels



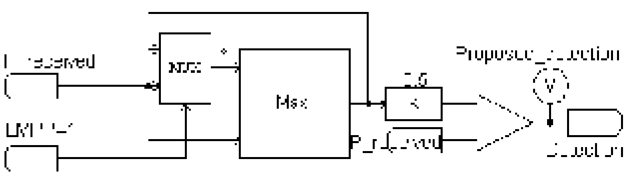
(b) PSC with different no. of peak



(c) PSC with different operating area of peak

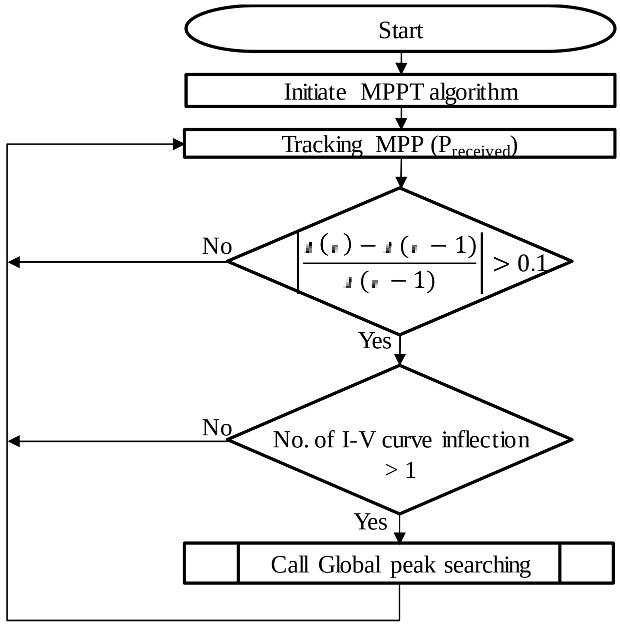


(a) dP/P based algorithm [2]

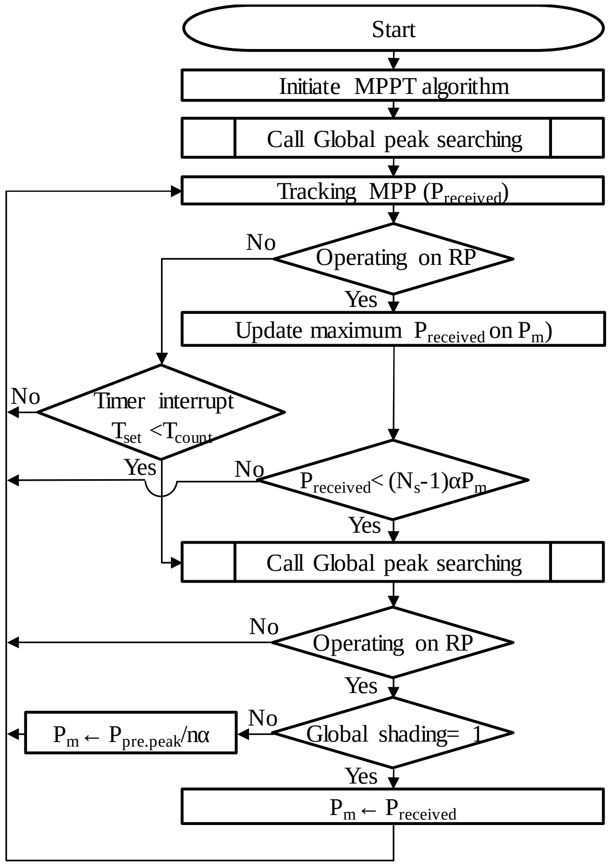


(b) Proposed ΔP based algorithm

Fig 4: Algorithm implementation in PSIM.



(a) dP/P based algorithm [2]



(b) Proposed ΔP based algorithm

Fig 5: Flow Charts of PSC detection algorithms.

$$\alpha = \frac{1}{N_S}, \qquad (1)$$

where N_S is the number of series connected PV modules and P_m is the stored maximum power value from instantaneous array power. It is found that GMPP searching beyond the αP_m power level is unnecessary and such a characteristic will be utilized in the proposed algorithm.

Conventional PSC method

Conventional PSC detection algorithm, shown in Fig.4 (a) and Fig.5 (a), monitors the power difference between consecutive two samples [2]. In a sudden change of insolation, dP/P can be considerably higher and if it becomes greater than a threshold which is assumed to be 0.1 in the literature, the algorithm triggers global peak searching. The problems of this method are that it could fail to detect PSC in a smooth change of insolation, or too frequent but unnecessary activation of global peak searching due to PSC detection may occur in a sharp change of insolation (under 0% to 50% shading).

Proposed method

Figure 4 (b) and Fig.5 (b) shows PSIM algorithm chart and the algorithm flow chart of the proposed method, respectively. To check the PSC at the start, the global peak searching subroutine is called and the maximum $P_{received}$ is obtained by MPPT tracking. If the operating peak is not on the RP, the algorithm flows through the timer interrupt loop and operates under the PSC. If the operating peak is on the RP, the maximum power information (P_m) is updated and the instantaneous power ($P_{received}$) is compared with (Ns-1)αP_m, continuously. If it gets lower than (Ns-1)αP_m, global peak searching subroutine is triggered and it calculates the number of peaks and re-locates the GMPP. If the operating peak is not on the RP, previous procedure was repeated. The number of peak is used to distinguish global shading from partial shading in the proposed algorithm. When the peak searching selects the GMPP as RP, but PSC still exist (no. of peaks > 1), the power of non-shaded array can be predicted by dividing the power of most left peak by nα. Here, "n" is the region of the last operated peak as shown in Fig.3 (c). If global peak searching does not identify another peak, it reflects that present operating point is RP and insolation can be changed without PSC (global shading) and the latest

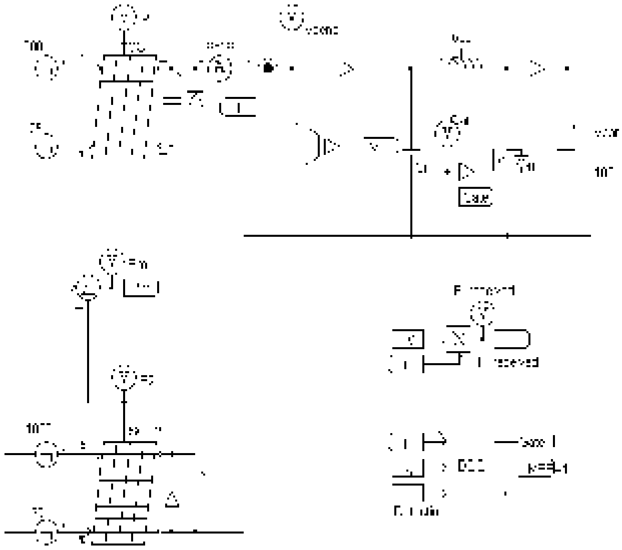
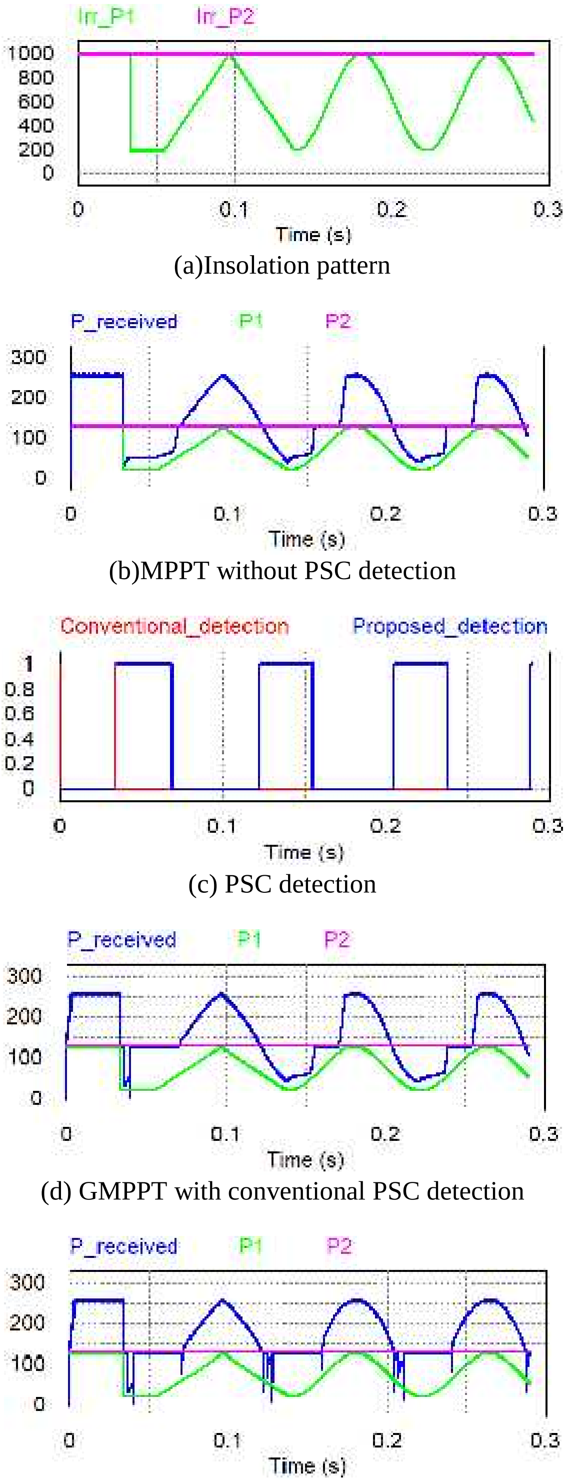
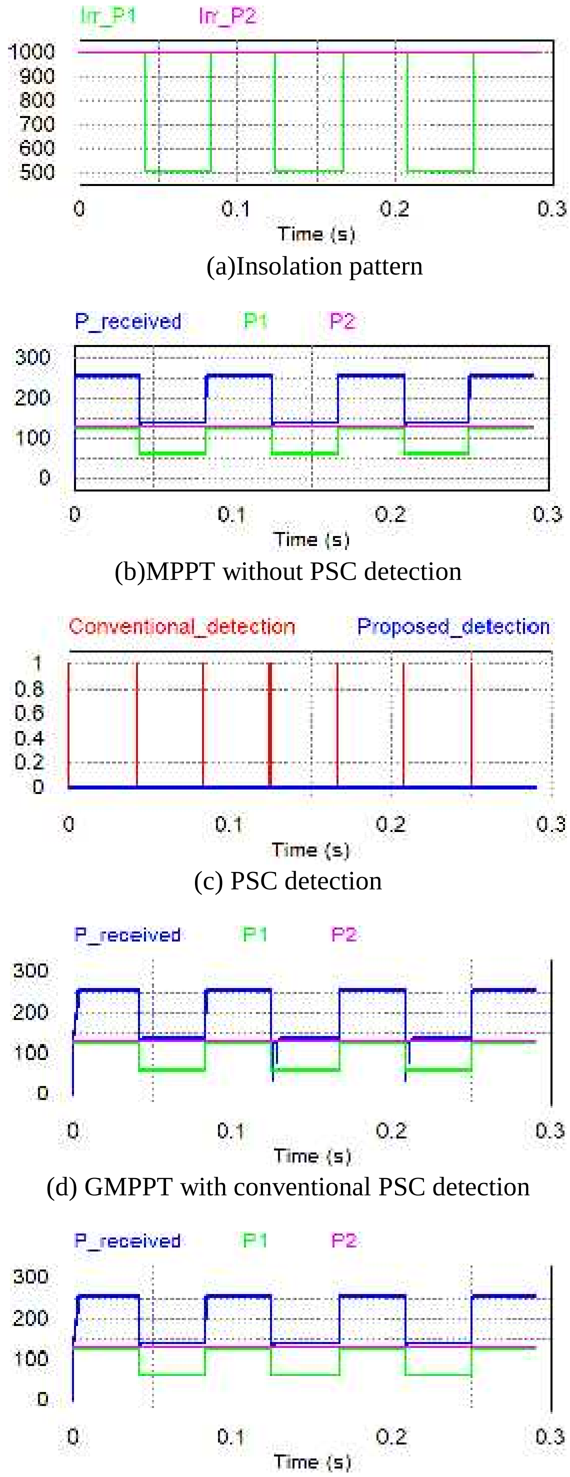


Fig 6: PSIM simulation schematic



(a)Insolation pattern
(b)MPPT without PSC detection
(c) PSC detection
(d) GMPPT with conventional PSC detection
(e) GMPPT with proposed PSC detection

Fig 7: Test 1 (Smooth insolation change)



(a)Insolation pattern
(b)MPPT without PSC detection
(c) PSC detection
(d) GMPPT with conventional PSC detection
(e) GMPPT with proposed PSC detection

Fig 8: Test 2 (Sharp insolation change)

$P_{received}$ need to be stored in P_m to adapt to the change of insolation.

Comparisons of dP/P algorithm and proposed one are done with simulation. Here, the proposed technique aims at reducing the time taken by a global MPP technique thereby increasing the efficiency. The proposed algorithm successfully overcomes this detection issue in both sharp and smooth insolation changing conditions.

III. ALGORITHM VERIFICATION BY SIMULATION

The existing dP/P PSC algorithm [2] and proposed algorithm are developed in PSIM as Fig.6. Two BP MSX 120 modules are serially connected as an array and a boost converter is used. Power P1 and P2 are the maximum obtainable power of each module. The present output power is calculated by the product of PV array voltage and current and then is assigned to $P_{received}$. To implement a partial shading, one of the two modules is supplied by the time-varying shading patterns and other modules are fed up with the constant insolation pattern of 1000W/m^2. P&O (perturb and observation) algorithm with 0.007 ΔD is used as an MPPT algorithm and developed in DLL block. The global peak searching algorithm in [4] is used for implementation. The simulation parameters are shown in Table 1.

A sawtooth and sinusoidal insolation patterns are used to simulate varying insolation. In Test 1, insolation is varied between 1000W/m^2 and 200 W/m^2 and the detection of PSC is monitored. In Test 2, insolation is varied in the range of 1000W/m^2 to 500 W/m^2. Under the insolation patterns in Fig. 7, dP/P based algorithm fails to detect smooth insolation changes. In a sharp change of insolation in Fig.8, the conventional algorithm detects PSC. However, such a detection causes a reduction of the overall system because such a small magnitude of insolation change cannot change the highest power peak. In Fig.7 (a) and Fig.8 (a), insolation pattern is shown. The insolation pattern of panel P1 is varied and P2 is kept in constant. The pattern of local MPPT without PSC detection is shown in Fig.7 (b) and Fig.8 (b), where this behavior is generated by P&O algorithm. Conventional and proposed PSC detection, according to the local MPPT are shown in Fig.7 (c) and Fig.8 (c). Here, logically high level, namely "1", indicates PSC detection and low level "0" denotes no PSC detection. When operated with the GMPPT, the behaviors of conventional and proposed PSC detection algorithms are shown in Fig.7 (d), Fig.8 (d) and Fig.7 (e), Fig.8 (e), respectively.

Key observations of the simulation are mentioned in Table 2. An example for the failure of the conventional algorithm is shown here. In such a sample of PV array power, dP/P based algorithm cannot be successfully handled the GMPP, but the proposed method could able to take the correct decision.

Table 1: Simulation parameter

Category	Parameter	Value
PV panel BP MSX 120	P_{max}	120W
	V_{mpp}	33.7V
	I_{mpp}	3.56A
	V_{oc}	42.1V
	I_{sc}	3.87A
	Shunt res.	1000Ω
	Series res.	0.0015 Ω
Power circuit	C	22uF
	L	56uH
	V_o	48V
	f_{sw}	100kHz

Table 2: Key observations of Simulation

Power (W)		PSC detection		Status	
1st sample	2nd sample	Conv.	Proposed	Conv.	Proposed
250	225	1	0	Fail	Success
130	120	0	1	Fail	Success

IV. CONCLUSIONS

In this paper, a new PSC detection algorithm is proposed. According to the analysis of the P-V curve, the proposed power level detection algorithm prevents improper global peak searching from occurring, and thus provides a clear distinction between partial shading and global shading. For verification, the algorithm was tested by simulator with complex shading patterns.

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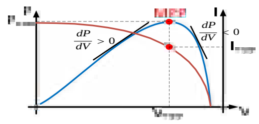
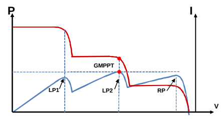
Research Motivation

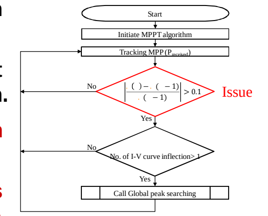
- ✓ To maximize the efficiency of solar energy utilization, a maximum power point tracking (MPPT) is needed.
- ✓ In the partial shading condition (PSC), many peaks can appear in the P-V curve and global maximum power point should be selected.
- ✓ The energy efficiency is reduced for checking process of global maximum power point.
- ✓ Thus, the proper PSC detection technique is essential.

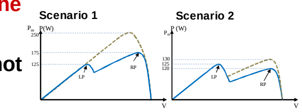




Conventional Method

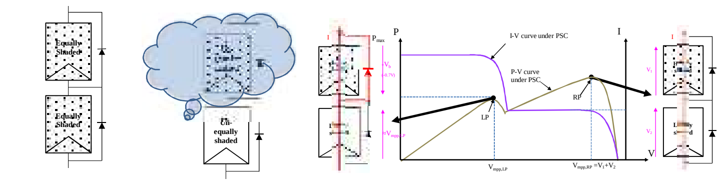
- ✓ It monitors the power difference between consecutive two samples.
- ✓ If it is greater than decided value (10%), it calls the global peak searching algorithm.
- ✓ It triggers unnecessary detection in sharp insolation change as scenario 1.
- ✓ In a smooth shading change such as scenario 2, it misses the calling for the global peak searching algorithm.
- ✓ Thus, the conventional method does not successfully detect the PSC.





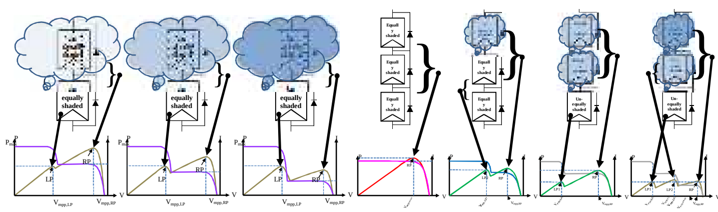
Proposed Method

- ✓ The proposed method is based on the comparison of operating point power.



Global shading condition   Partial shading condition (PSC)   Current flow according to the selection of operating points

➢The behavior of characteristic curve in different shading level



➢Proposed algorithm

- ✓ The height (power) of the left peak (LP) can be calculated by using αP_m.

$$\sim = \frac{1}{N_S}$$

N_S = number of series connected PV modules.

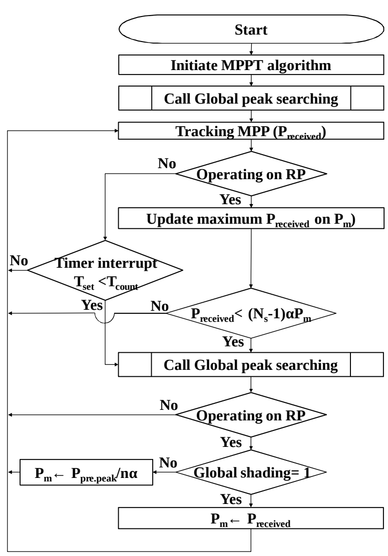
P_m = the stored maximum power value.

- ✓ Predicted P_m can be calculated as $P_{pre.peak}/n\alpha$.

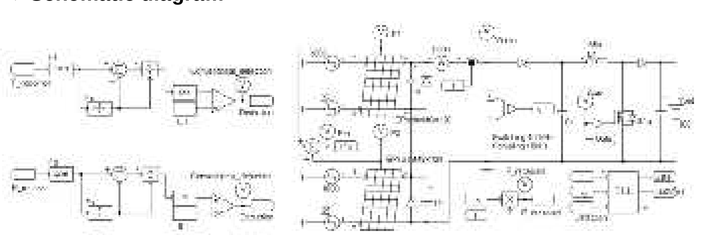
$P_{pre.peak}$ = Height of last operated LP.

n = region of the last operated peak.

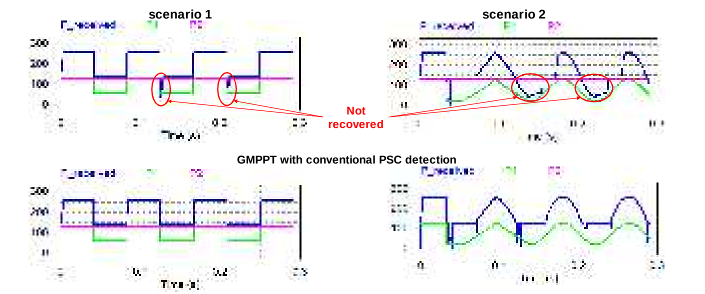
- ✓ P&O is used for Local MPPT



➢Schematic diagram



➢Simulation



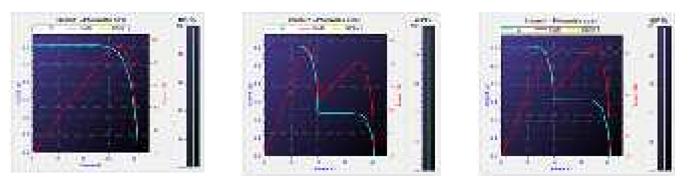
GMPPT with conventional PSC detection

GMPPT with proposed PSC detection

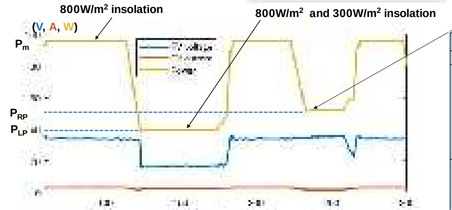
Key observations of Simulation						
Scenario	Power (W)		PSC detection		Status	
	1st sample	2nd sample	Conv.	Proposed	Conv.	Proposed
1	250	130	1	0	Unnecessary	Success
2	130	120	0	1	Missing	Success

- ✓ Conventional method was unsuccessful in the above scenarios, but the proposed method can take the correct decision.
- ✓ The behavior of algorithm is confirmed by the simulation

➢Experimental results



800W/m² insolation   800W/m² and 300W/m² insolation   800W/m² and 400W/m² insolation



Hardware parameters		
Category	Parameter	Value
PV panel BP MSX 60	P_{max}	60W
	V_{mpp}	16.8V
	I_{mpp}	3.56A
	V_{oc}	21.0V
	I_{sc}	3.87A
	T.C. of I_{sc}	(0.065±0.015)
	T.C. of V_{oc}	-(80±10)
Power circuit	C	22uF
	L	56uH
	Vo	48V
	f_{sw}	100kHz

➢Conclusion

- ✓ In this study, shadow changing rate independent PSC detection algorithm is proposed.
  - The LP height is calculated by using the present operating power and it is not changed due to partial shading level.
  - The RP is always changing with the PSC.
  - This relationship is used to avoid the unnecessary global peak searching and detect missing PSC.
- ✓ The partial shading and global shading can be distinguished by new PSC detection algorithm.
- ✓ Thus, the new algorithm has a successful PSC detection capability.