Chapter 2

Maximum Power Point techniques

2.1 Introduction

A PV module may be used as any of three different sources i.e. current, voltage and power, depending on the location of operating point on the $I-V$ curve and the operating point at which the available maximum power can be extracted from the PV module is called maximum power point as shown in Fig. 2.1. A DC-DC converter is used as a impedance matching network to extract the maximum available power from PV system by controlling the duty-ratio (D) of the converter. The maximum power point tracking algorithms are developed using based on the $I - V$ and $P - V$ characteristics of the PV module. These algorithms can be implemented by using direct duty-ratio control or current reference control or voltage reference control. Maximum power point tracking algorithms can be classified into mainly two categories; first one is input parameter based and second one is output parameter based, depending on the measured parameters fed to the algorithm as described below.

2.2 Input Parameter Based MPPT Algorithms

In most of the PV system, the MPPT algorithms are developed by sensing the PV voltage (V_{pv}) or PV current (I_{pv}) or both. MPPT algorithms like fractional open circuit voltage [21] and fractional short circuit current [22] uses the V_{pv} and I_{pv} respectively. The general block diagram of PV system with input parameter based MPPT algorithm are shown in Fig. 2.2 [23]. The conventional MPPT algorithms such as perturb and observe

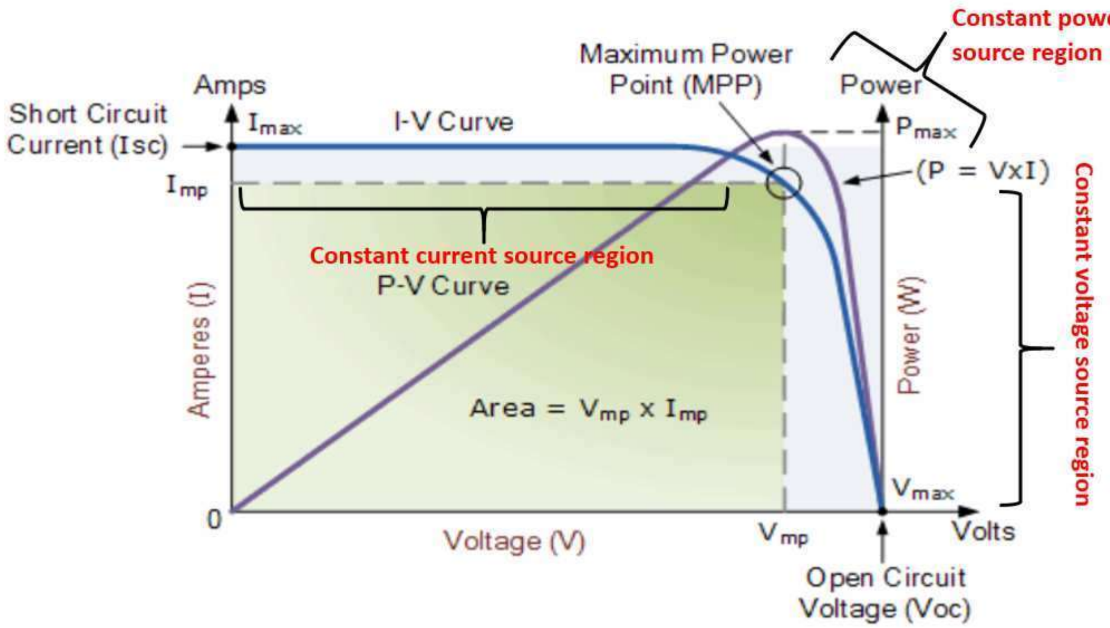

Figure 2.1: I-V and P-V characteristics curve of PV module.

(P&O) [24–26], incremental conductance (IncCond) [27–30], hill-climbing (HC) [31–33] and ripple correlation control (RCC) [34, 35] algorithms have been developed based on input parameter to extract maximum power from the PV arrays. Both P&O and IncCond algorithms are mostly used methods ease of implementation and increased efficiencies [36] under uniform insolation condition. However, for sudden changes in the insolation conditions causes these algorithms to drift away from MPP [20]. Other advance algorithms such as fuzzy logic (FL) [37–41], neural network (NN) [42–44], sliding mode control (SMC) [45–47] and particle swarm optimization (PSO) [48–50] shows improved performance, but they are not commonly used due to their complex nature and require expensive microcontroller [27, 36].

2.3 Output Parameter Based MPPT Algorithms

The MPPT algorithms can also be developed by using output parameters i.e., load voltage (V_L) and load current (I_L) depending on the type of the load [23, 51, 52]. The general block diagram of PV system using output parameter are shown in Fig. 2.3 [23]. In [51], the MPPT algorithm is developed by using load current for a battery load. In most practical PV systems, batteries are used for energy storage, where the converter output

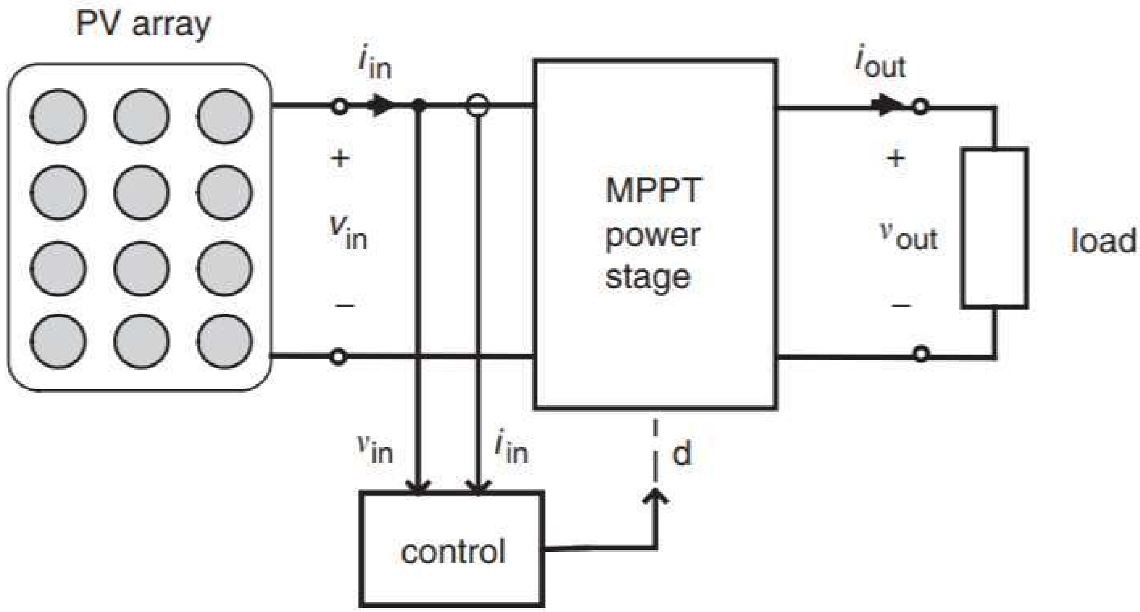

Figure 2.2: Block diagram of PV system with input parameter based MPPT controller.

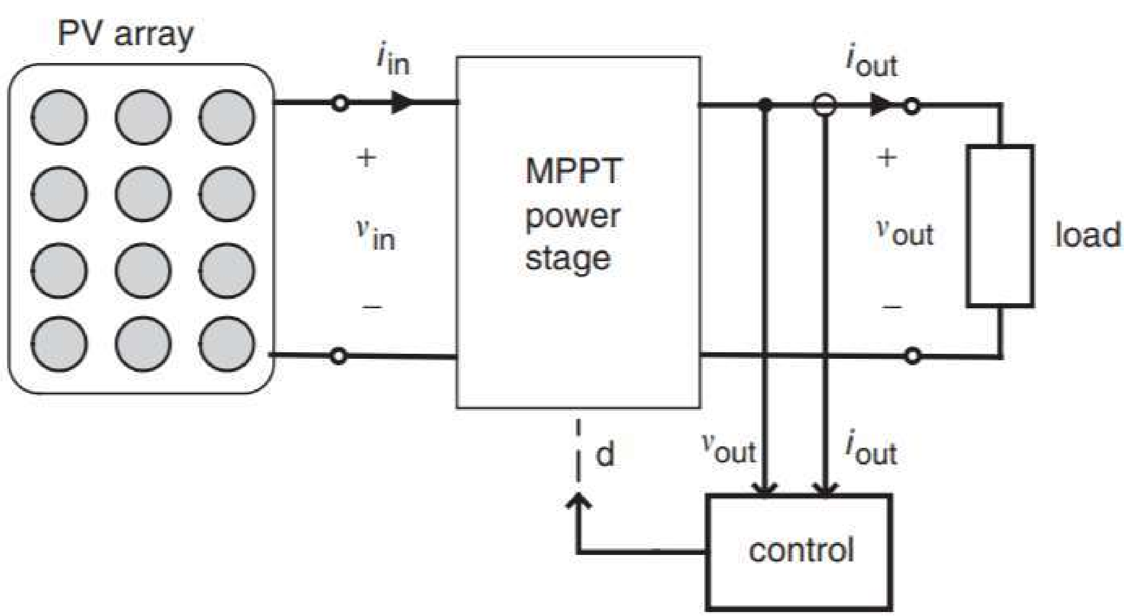

Figure 2.3: Block diagram of PV system with output parameter based MPPT controller.

voltage and current are already monitored for the protection of the batteries and charge control. Hence, with the same load measurements (V_L & I_L), the PV MPPT control and charge control of batteries can be achieved. As a results, the overall cost of the PV system is reduced. A comparison of different MPPT techniques [3,53], particularly in the perspective of number of sensor used, is shown in Fig. 2.4 and given in [54] Table 3.2.

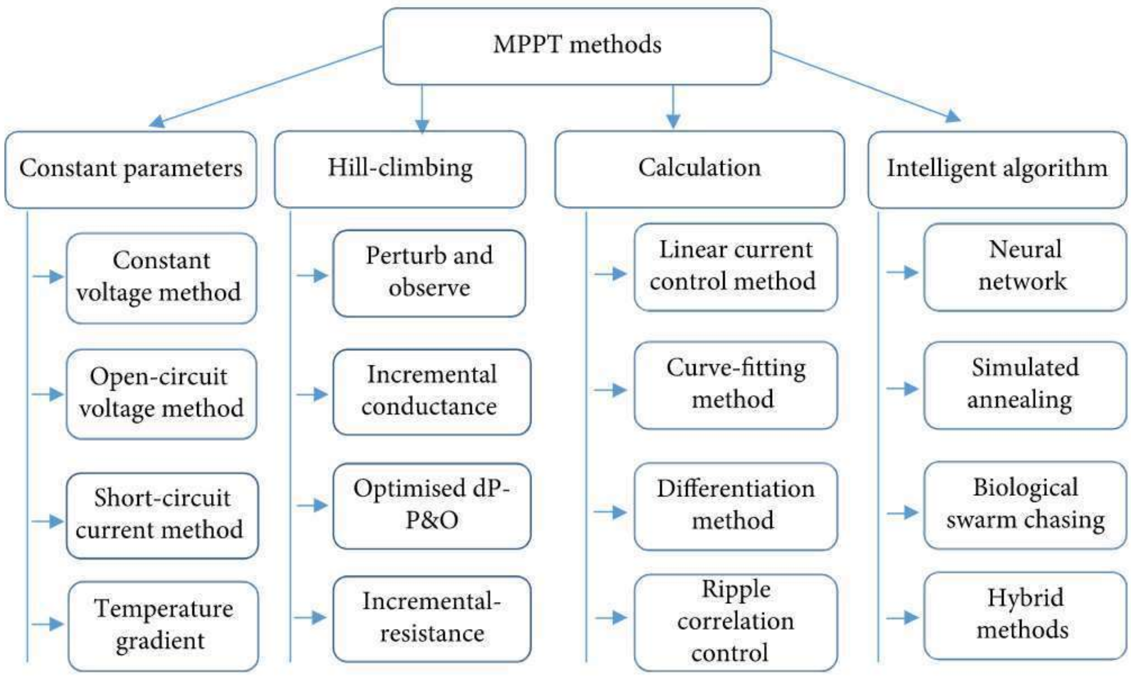

Figure 2.4: Types of MPPT methods.

Table 2.1: Comparison of MPPT techniques

Criteria	**P&O**	**IncCond**	**HC**	**RCC**	**FL**	**Output parameter based**
Sensed parameters	Both V_{pv} and I_{pv}	Both V_{pv} and I_{pv}	Both V_{pv} and I_{pv}	Both V_{pv} and I_{pv}	Both V_{pv} and I_{pv}	Only V_L or I_L
Tracking speed	Varies	Varies	Varies	Medium	Medium	Fast
Complexity	Medium	Medium	Medium	Medium	High	Low
Sensitivity	Moderate	Moderate	Moderate	Moderate	Low	Low
Implementation cost	Moderate	Moderate	Moderate	Moderate	High	Low

2.4 Distributed MPPT Techniques

A large-scale integration of PV system consisting of several series and parallel connection of PV modules have the problems of hot spotting and mismatching under partial shading conditions. These problems have been addressed by connecting a bypass diode anti-parallel to the each module as shown in Fig. 2.5. However, with this bypass diode multiple peaks appeared in the I-V and P-V characteristics of the PV array as shown in Figs 2.6 and 3.1, respectively. There are numerous conventional distributed MPPT (DMPPT) techniques available in the literature for tracking the global peak power, but they are complex and may fail in tracking the global peak power.

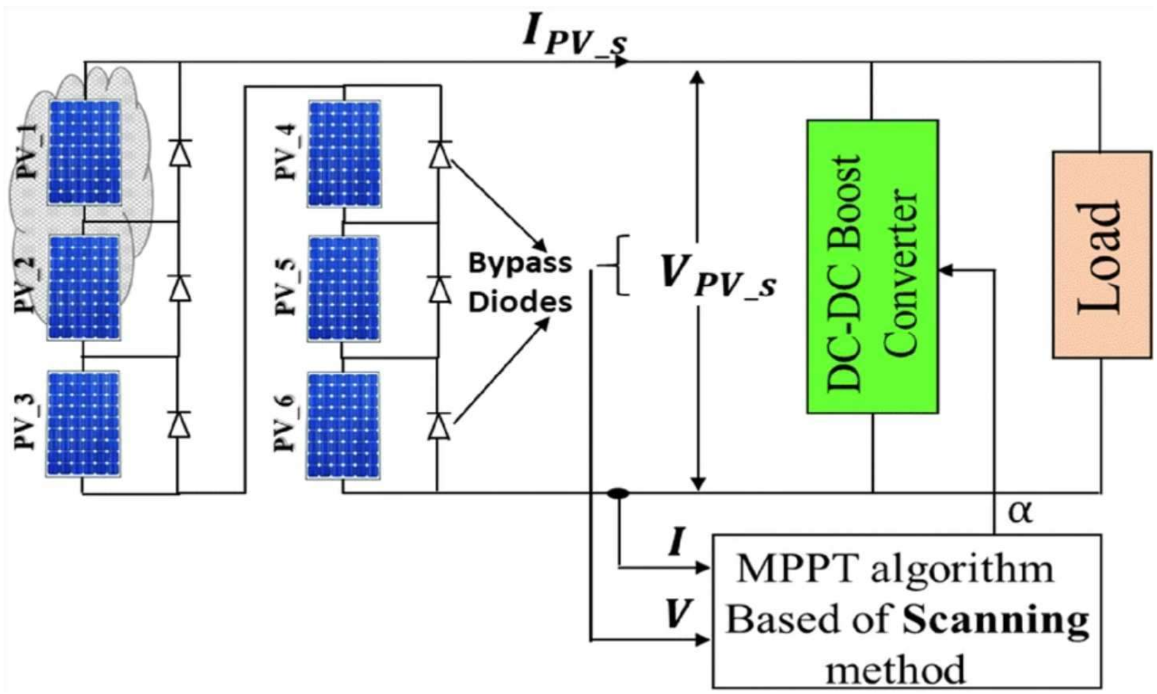

Figure 2.5: Distributed PV system.

In a DMPPT PV system, MPPT can be implemented by module level, sub-module level and cell level [55]. Theoretically, cell-level MPPT is the ideal one. However, it is not commonly used because it requires large number of power electronics converters, complexity and higher cost. Unlike cell-level MPPT, sub-module MPPT has gain much popularity in recent times. In this MPPT method requirements of bypass diode is eliminated, since each sub-module performs own MPPT and generates the maximum available power at the output independently. The advantage of sub-module MPPT technique is shown in [56]. however, the overall performance have been improved, but the cost of the system is increased since each sub-module has its own converter. Module level MPPT is implemented by PV optimizers and micro-inverters. Global MPPT becomes difficult when compared with sub-module level MPPT since multiple peak points occurs due to the presence of bypass diode under partial shading conditions [57].

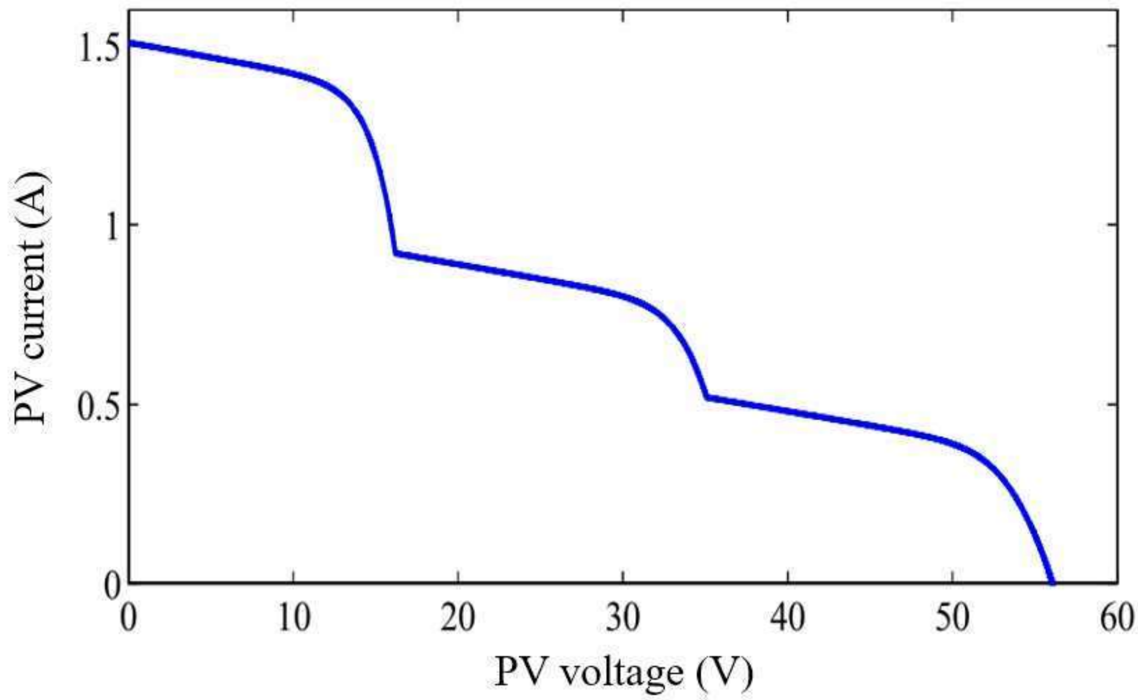

Figure 2.6: I-V characteristics of a PV array with three modules with different insolation.

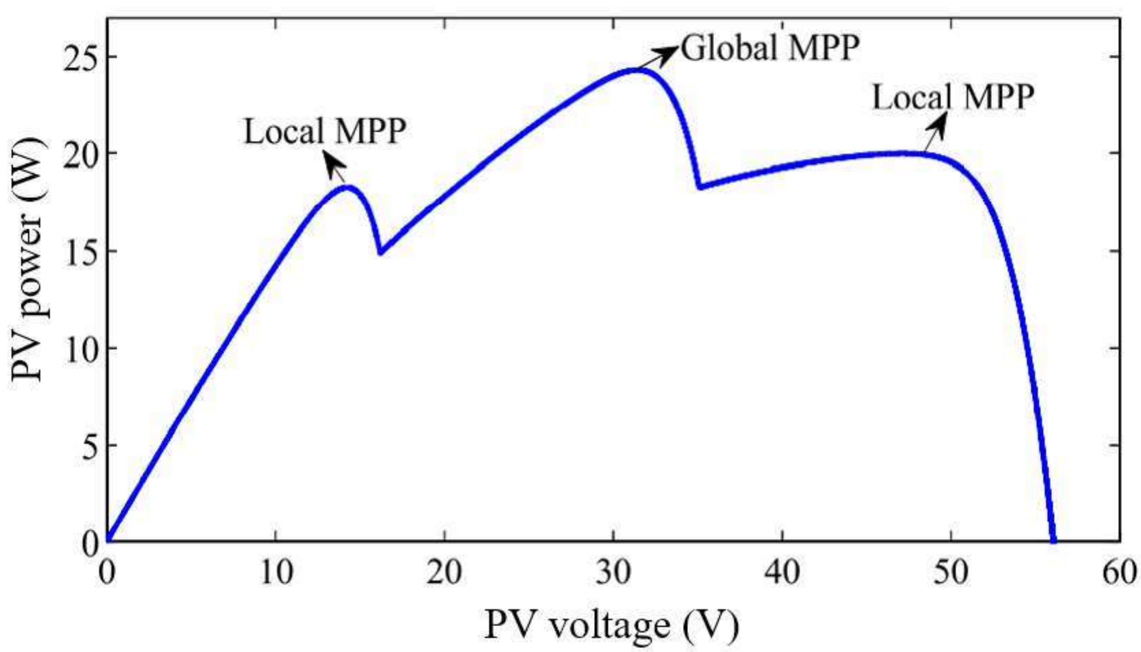

Figure 2.7: P-V characteristics of a PV array with three modules with different insolation.

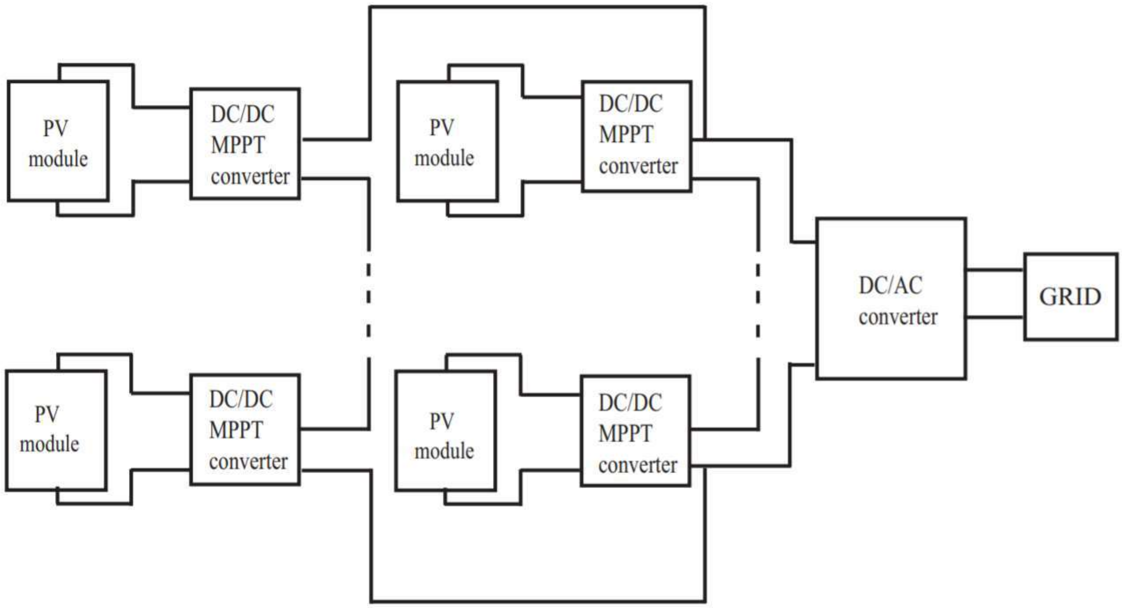

Figure 2.8: Grid connected DMPPT PV system with output ports connected in series.

For the extraction of maximum available power from the distributed PV system, the cascaded connection of DC-DC converters with the outputs of the converter in series connection has been developed in [58]. DMPPT technique is an effective method to reduce the problems of mismatching and partial shading conditions. In this method each PV module is connected with an independent converter and MPPT controller [59–63]. Series and parallel configuration of grid connected DMPPT PV system are shown in Fig. 2.8 and 2.9, respectively [64].

2.5 MPPT Algorithm Control Techniques

The MPPT algorithms can be implemented by controlling the reference voltage or reference current or duty-ratio as described below:

2.5.1 Reference Voltage Control

In this MPPT algorithm, the reference voltage (i.e. $V_{ref} \pm \Delta V$) is generated depending on the location of the operating point and then it is compared with present operating PV module voltage (V_{pv}) [65]. The error (i.e. $V_{ref} - V_{pv}$) voltage is processed by the controller to generates pulse width modulated (PWM) signal with the corresponding duty ratio as given in Fig. 2.10. This method is complex, it requires fine tuning of reference voltage so

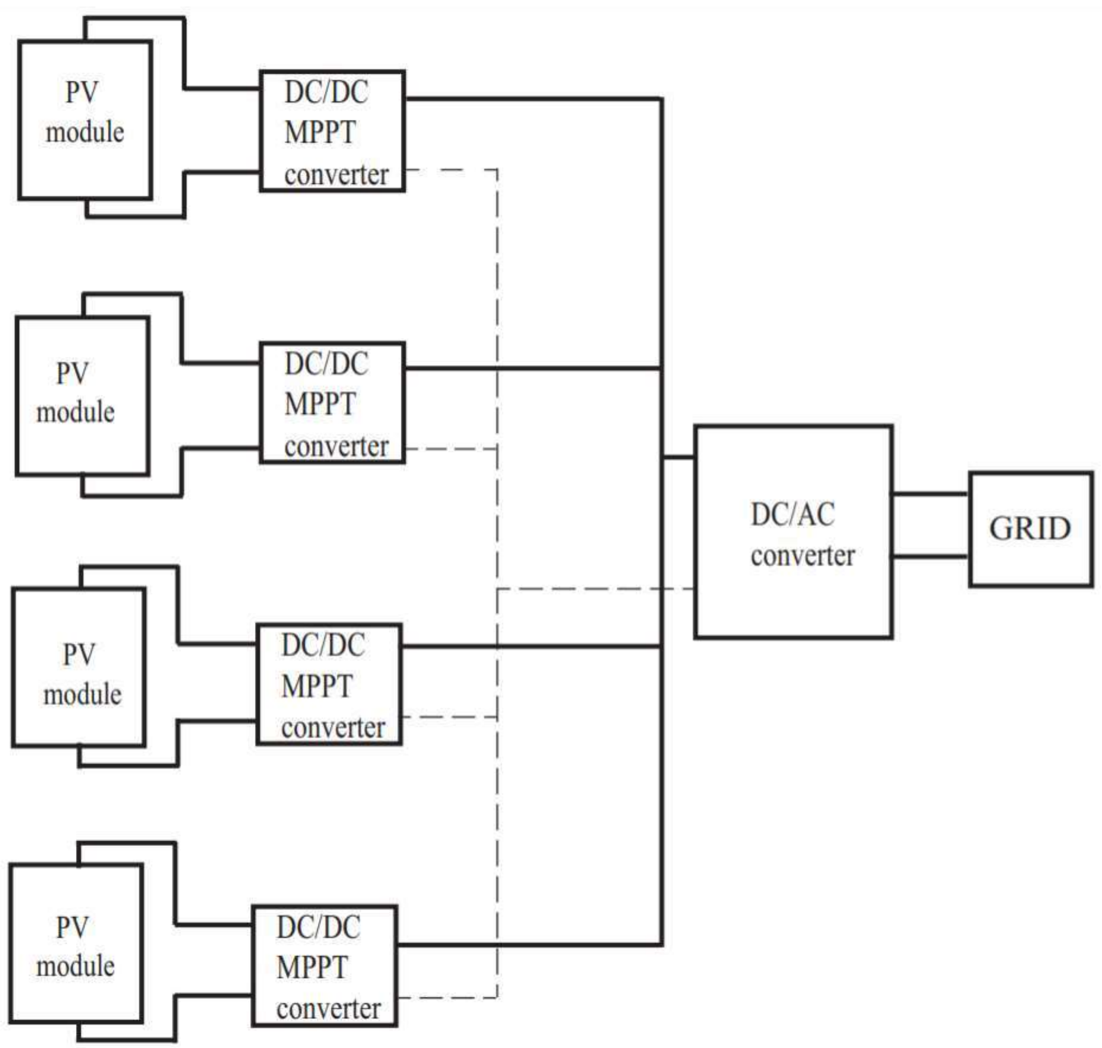

Figure 2.9: Grid connected DMPPT PV system with output ports connected in parallel.

that the error can be minimized.

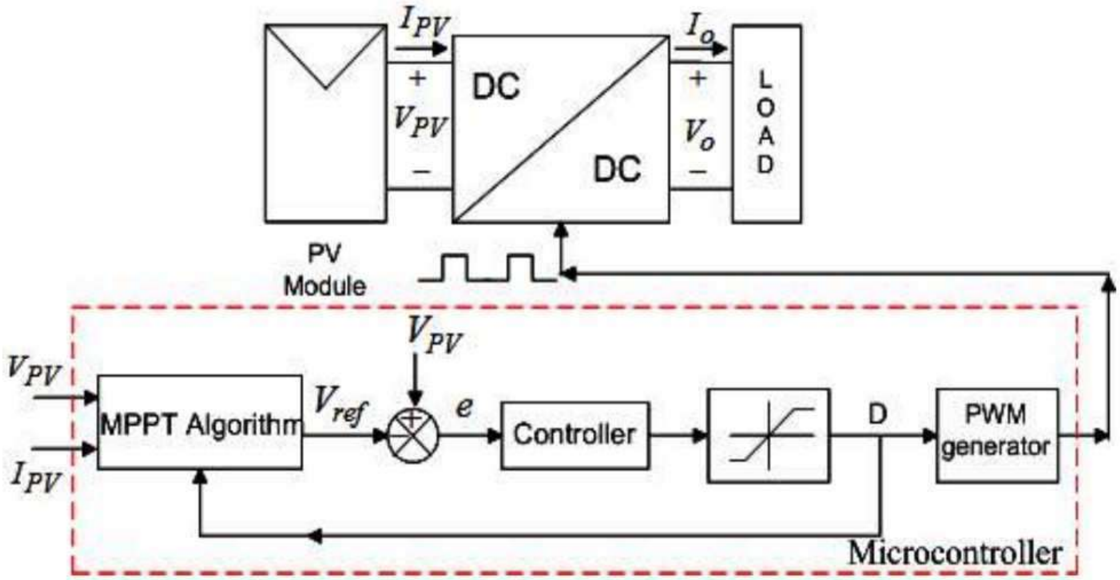

Figure 2.10: Reference voltage control MPPT technique for PV system.

2.5.2 Reference Current Control

In this technique, the MPPT algorithm generates the reference current (i.e. $I_{ref} \pm \Delta I$) [66] depending on the location of the operating point and then compared with the present operating PV module current (I_{pv}). The error (i.e. $I_{ref} - I_{pv}$) is processed by the controller to generate PWM signal with corresponding duty-ratio as shown in Fig. 2.11. This method is similar to reference voltage control method and it is also complex.

2.5.3 Direct Duty-Ratio Control

In the direct duty-ratio control MPPT technique, the duty-ratio (i.e. $D \pm \Delta D$) is directly generated depending on the location of the operating point as given in Fig. 2.12. The perturbation step-size (ΔD) can be fixed or adaptive. The fixed/adaptive step-size MPPT methods generates ΔD as a function of either derivative of power to duty-ratio (dP/dD) [67] or derivative of power to voltage (dP/dV) [68] to improve the transient and steady-state response. This method is simple and efficient.

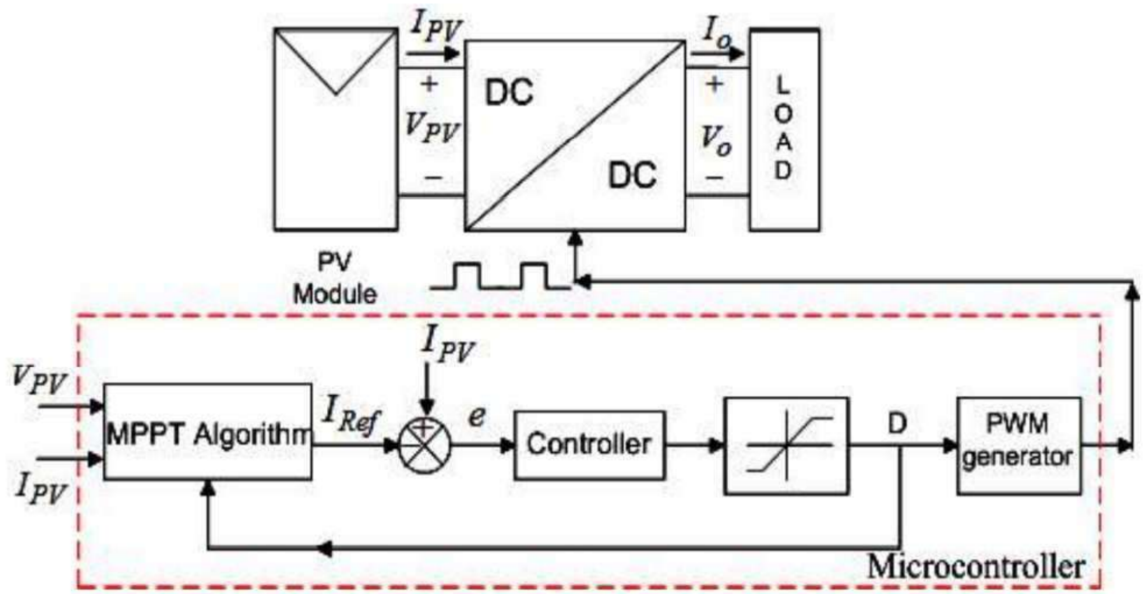

Figure 2.11: Reference current control MPPT technique for PV system.

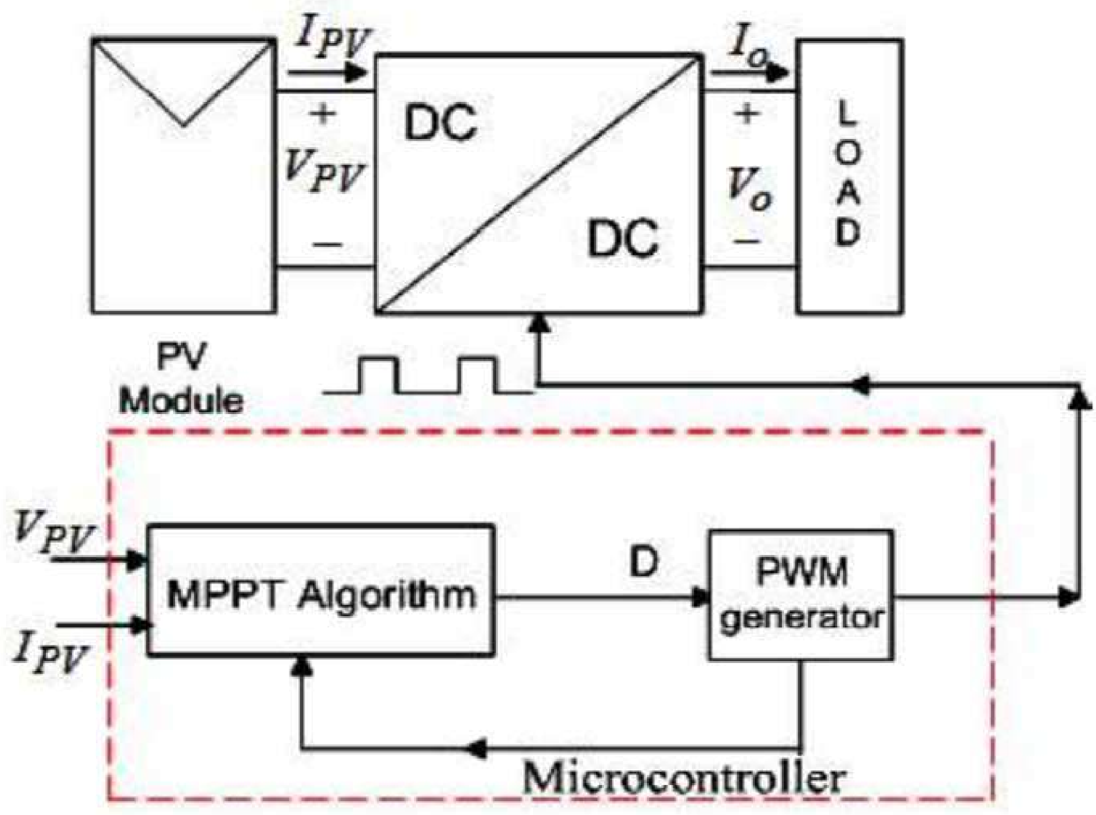

Figure 2.12: Direct duty-ratio control MPPT technique for PV system.

2.6 Maximum Power Point Tracking Parameters

The two important parameters in any MPPT method are perturbation time T_s and perturbation step-size ΔD. The selection criteria for these parameters are described below:

2.6.1 Selecting Proper Perturbation Time T_s

To insure the minimum number of oscillations, the perturbation time T_s should be higher than the settling time of the system for a step change (ΔD) in duty-ratio [20]. The perturbation time is proportional to the ΔD, as the ΔD will be maximum during transient state with adaptive techniques to minimize the tracking time. The time T_s should be chosen such that it is greater than the settling time for a maximum step change (ΔD_{max}) in duty-ratio.

2.6.2 Selecting Proper Perturbation Step-Size ΔD

The perturbation step-size ΔD can be selected by considering transient and steady-state performance. The MPP tracking time and perturbation step-size are directly proportional to each other. The maximum value of step-size ΔD_{max} improves the dynamic performance, whereas the minimum value of step-size ΔD_{min} improves the steady-state performance [20]. The value of ΔD_{min} should be chosen based the tracking accuracy at steady-state and analog to digital converter (ADC) resolution of the microcontroller used in the system [69]. The general DC-DC converter intrinsically contains some switching ripple on PV voltage, hence an optimum value of ΔD chosen, such that the voltage variation due to perturbation of D should be greater than the amplitude of the switching ripple of the PV voltage.

2.7 Convergence Response of MPPT Algorithm

The convergence response of any MPPT algorithm is mainly depends on three parameters as discussed below:

2.7.1 Convergence Time

Convergence time is the time required to reach the MPP for any change of insolation or load variation. The convergence time can be reduced by selecting the adaptive perturbation step-size MPPT techniques, such that the output PV power can be improved.

2.7.2 Convergence Response

The transient and steady-state response of the PV system can improved by the selecting the proper values of T_s and ΔD. The efficiency of the PV system is decided by the number of levels of operation (i.e. 3-level or 2-level) during the steady-state.

The linearity of PV current with insolation, developments of switching function for SEPIC, Buck and Boos converter, a novel adaptive 2-level current sensor based MPPT technique, design of SEPIC converter are explained in Chapter-3 and validated through simulation and experimental results.