

Master Slave Topology for Parallel Operation of Renewable Energy based Distributed Generator



S. Sankar, K. Chandrasekaran

Abstract: This paper presents an effective control methodology to integrate multiple photovoltaic (PV) based distributed generator (DG) in microgrid. In general, the multiple PV based DG will operate in parallel and the rating of each PV unit is defined by the rating of the corresponding DC-DC converter. Each PV units operates independently with respective to the controller of the dc-dc converter and feeds power to the common bus. In this paper, a master slave control methodology is proposed to integrate multiple PV units with a single maximum power point tracking (MPPT) controller. In the proposed master slave approach, one PV unit is considered as master unit which is controlled through MPPT algorithm and voltage control method. Other PV units are considered as slave units and operate with current control without MPPT control. Compared with the traditional methods available in the literature, the proposed methodology reduces the complexity and controller cost of the parallel operation of multiple PV based DG system. Simulation and experimental results verify its feasibility.

Index Terms: Parallel operation of DG, PV system, Load sharing, Maximum power point tracking

I. INTRODUCTION

In recent years, the growth in electricity demand has been increasing day by day exponentially. The thermal power generation, leads to several environmental pollution causes life hazard to many inhabitants. The renewable energy sources found to be the environmentally friendly electricity generation among which solar energy is first. However, because of relatively high setup cost the PV systems inhibit to grow as a predominant power source. In addition, the weather conditions and peak sun-hours determines the PV power generation. To minimize the above effect, ensuring that the PV system is supplying the maximum power with reduced subcomponents cost.

The characteristic of a solar-panel is influenced by two factor i.e. irradiance and temperature. For the effective utilization of the existing energy, it is mandatory to operate the system at its maximum power point (MPP). The efficiency of the PV depends on the PV module operating point. MPPT is one of the vital algorithms that every PV system should include.

MPPT algorithms such as perturb and observe (P&O) [1] achieves an efficiency of 96.77% because of the continuous perturbation at MPP, however it varies for case to case, Variable step size P&O methods are used to improve the efficiency at MPP, incremental conductance (IncCond) [2] achieves an efficiency of 96.13 % [3].

Also, other methods such as fractional open-circuit voltage [4], fractional short-circuit current [4], ripple correlation control (RCC) [5], hill-climbing [6], neural network [7], optimization techniques to track MPPT under partial shading conditions [8], fuzzy logic [9], and sliding mode [9-10], techniques track MPP. In islanded mode, if the power generated from the distributed generator (DG) is higher than then the power consumed by the load and the battery unit, the DG units are forced to reduce the power generation to the value that the generated power equals to the power consumed, to maintain the grid voltage level to the nominal value. The above one haven't discussed about the parallel operation of PV unit. In a solar based PV-DG system, each array consists of many PV panels. Due to the defined power rating of DC-DC converter further increase in power is achieved by paralleling the unit with separate maximum power point controller (MPPT), sensors and DC-DC converter [11-12]. For parallel operation, a centralized unit is used to generate reference signal to the individual PV unit to operate. In some PV generation unit, the parallel PV units are separated from the centralized control, in such system, the dc bus voltage is maintained through droop control. However, in all the above methods PV voltage and current sensor, and microcontroller units are used for every parallel PV unit separately which incurred additional cost and maintenance to the system.

In this paper a new topology is proposed to reduce the controller cost by reducing the number of MPPT controller and sensors for the parallel connected PV system.

II. NOVEL TOPOLOGY FOR PARALLEL OPERATION OF DG

The most common method available in the literature for parallel operation of multiple photovoltaic (PV) based DG is shown in Fig. 1. Here, the P&O is used as an MPPT to track MPP of PV system. The voltage and current from the respective sensors are given to the MPPT controller, the power is computed in the microcontroller and the perturbation in duty cycle is generated based on the algorithm. To implement MPPT algorithm effectively minimum of 16-bit microcontroller is required with analogue to digital converter.

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Fig 1 shows the conventional method of parallel operation of PV unit. In this method, for each PV unit separate MPPT, sensors and DC-DC converter are needed to extract maximum power from the PV system. This method needs large number of sensors and MPPT controller to extract maximum power from the PV system.

In this paper, a proposed method is introduced to reduce the controller cost by reducing the number of MPPT controller and sensors for the PV system which is shown in Figure 2.

This method is used for the system with more than one PV unit. Among number of PV based DG, one PV unit acts a Master and all other PV unit act as slave. The Master PV unit is controlled by conventional P&O to track MPP whereas other slave PV units are controlled by simple PID current control with the reference current generated by the

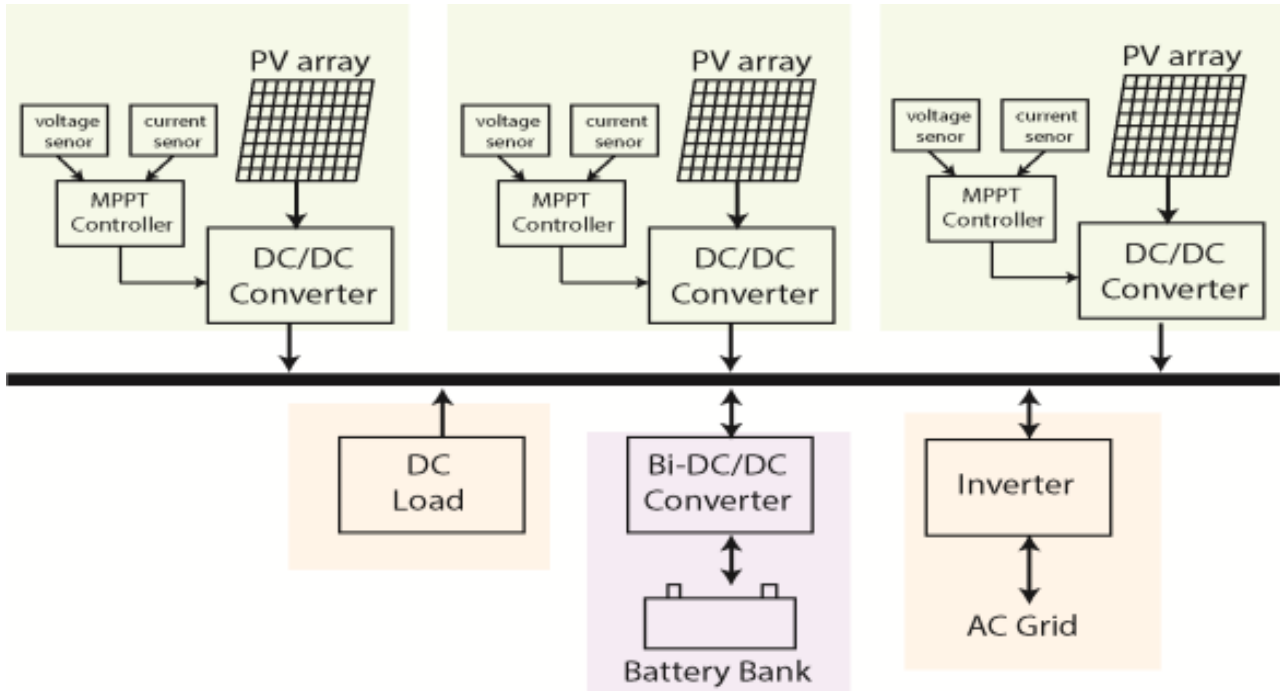


Fig 1 Conventional Grid connected PV system

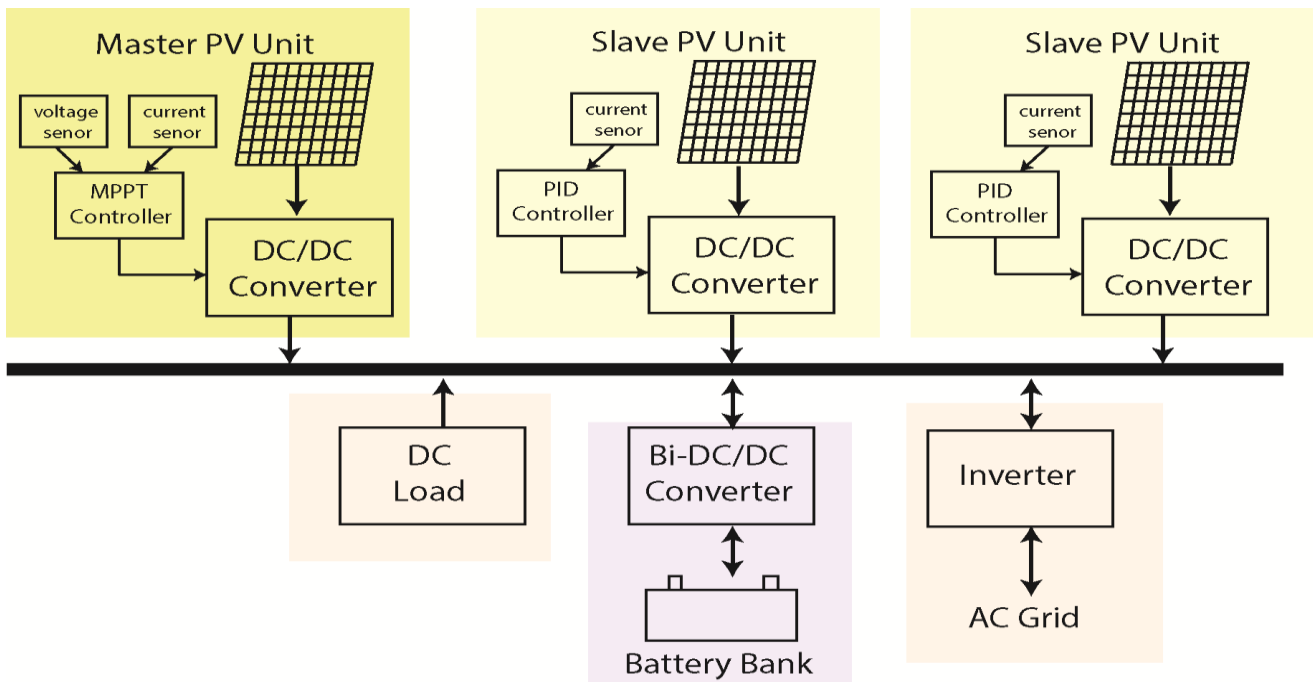


Fig. 2 Proposed Grid connected PV system

master PV unit is shown in Figure 2. Thereby, slave unit can operate at MPP at highest efficiency without MPPT controller.

III. PROPOSED CONTROLLER FOR DIFFERENT MODE OF OPERATION

In the proposed grid connected PV system, the PV system is subjected to operate under grid connected mode and islanded mode. The mode of operation of multiple PV system based on the grid availability, load and battery charge status is shown in Fig. 3.

During the grid connected mode of operation, the maximum power will extract from all the PV unit and supplied to the

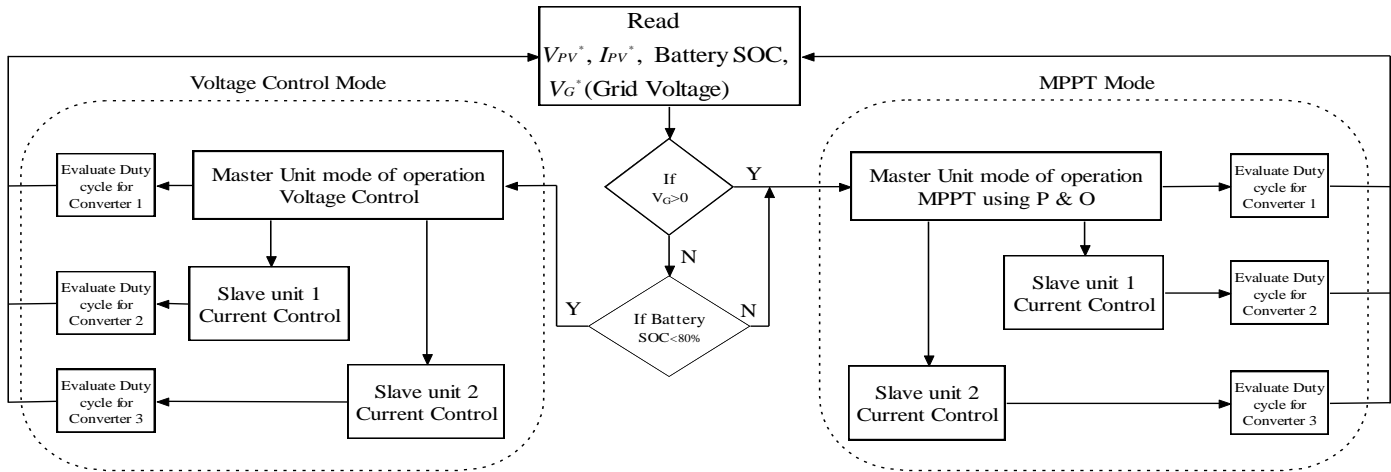


Fig. 3 Flowchart of proposed mode of operation

Then the value of m_1 will be equal to twice of m_2 . The generated reference current is given as an input to the subtractor of corresponding slave unit. The subtractor generates error signal $e(t) = i_{iref} - i_i^*$ by comparing the reference current to the measured current as shown in fig 9, and feed to the respective PID controller to generate duty cycle. In some cases, the power feed to the grid is limited due to the rating of the inverter, the surplus power generated causes the raise in DC bus voltage leads to voltage stress across the load and other converter which is not acceptable. Thus, the rating of the inverter is always designed based on the maximum power generation capacity. However, in such cases, the voltage control mode is operated to maintain the bus voltage, which is explained in islanded mode of operation.

$$i_{iref} = m_i i_{iM} \quad (1)$$

In islanded mode during the failure of grid, the surplus or insufficient power is controlled through the battery system. Suppose if the battery is fully charged then all the PV generation units are switched from MPPT control to voltage control mode [10]. Here, the master unit will operate at voltage control. In which, the dc bus voltage v_{out}^* is sensed and compared with the reference dc bus voltage v_{DCref} to generate the error signal $e(t) = v_{DCref} - v_{out}^*$. The error signal is then given to the analyzer where the operating point of the PV unit is observed. If the operating point is at the right of the PV curve then the error is directly sent to the PID controller, else if the operating point is at the left hand side of PV cure then the error is multiplied with -1 before feeding it to the PID control of Master unit. The PID controller maintains the DC bus voltage by operating the PV voltage around the vicinity of MPP. The significant advantage of the

grid. Here, the master unit controller will track the maximum power using P&O based MPPT algorithm. The current with respect to maximum power is given as reference to slave units as shown in equation (1). The computed reference current from the equation (1) is given to slave units. The value m_i from equation (1) is defined based on the power rating of the converter. For instance, if the parallel PV unit connected with the power rating of 200w and 100w respectively.

proposed method is by implementing voltage control operation for equal power sharing without additional sensors and MPPT controller.

IV. RESULTS AND DISCUSSIONS

To verify the proposed methodology, simulation and hardware results are presented in this section. Here all the mater and slave unit are installed in the same plant.

A. Simulation Results:

The master and slave PV units specification considered in the simulation is shown in Table 1. The PV specification and converter specification is given in Table 2.

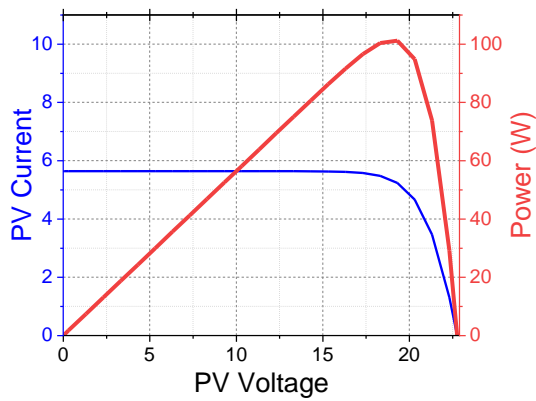
Table 1 Simulated system configuration

	Master PV unit	Slave PV unit 1	Slave PV unit 2
PV Configuration	2s0p	2s0p	2s2p
Power rating	100W	100W	200W

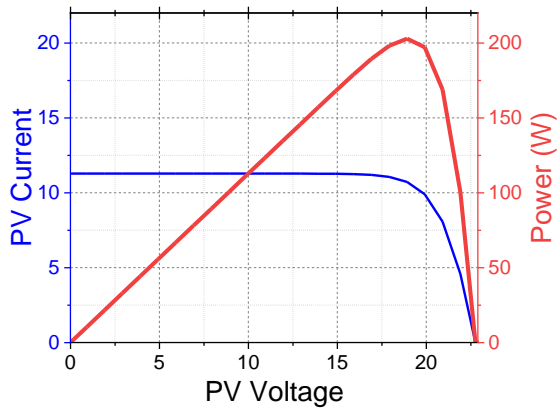
Here, in the simulation the master unit has three series and zero parallel PV array is defined as 3s0p configuration as shown in Table 1. Similarly, slave and 1 and 2 has 2s0p and 2s2p configuration. The PV and IV curve of the master and slave units are shown in Fig. 4.

Table 2 PV and DC-DC Converter Specification – Simulation Setup

PV module	Boost converter		
Maximum Power	50W	Switching frequency	4 kHz
Voltage at Maximum power	18.54 V	Inductor, L	4 mH
Current at Maximum power	2.7 A	Input Capacitor (C1) & (C2)	1000 μF



(a) Master unit and slave unit 1



(b) Slave unit 2
Fig. 4 PV Curve

From the Fig. 4, at the irradiance value of 1200 W/m^2 the Maximum power is achieved by the Master PV unit and the Slave PV unit 1 is 100W , and slave PV unit 2 is 200W . In general, the PV system broadly operates at two different modes of operation such as Grid connected mode and Islanded mode. The sub mode of operation in grid connected system and Island mode of operation is given below:

- Grid connected mode:
 1. Power consumed from Grid
 2. Power delivered to Grid
- Islanded mode
 1. Battery charging mode,
 2. Battery discharging mode
 3. Battery fully charged mode

By Comparing all the modes of operation, except battery fully charged mode in Islanded condition all other mode forces PV system to operate at MPPT. Therefore, the simulation results are obtained for only two different cases to validate the proposed method.

- Case 1 - Grid connected Mode (MPPT control)
- Case 2 - Islanded mode (Voltage control)

(i) Case 1 - Grid connected Mode (MPPT control):

In this mode, all the PV units should operate at MPP, the surplus power is pushed to DC grid to maintain the DC grid voltage. The simulation results of case 1 are shown in Fig. 5-7.

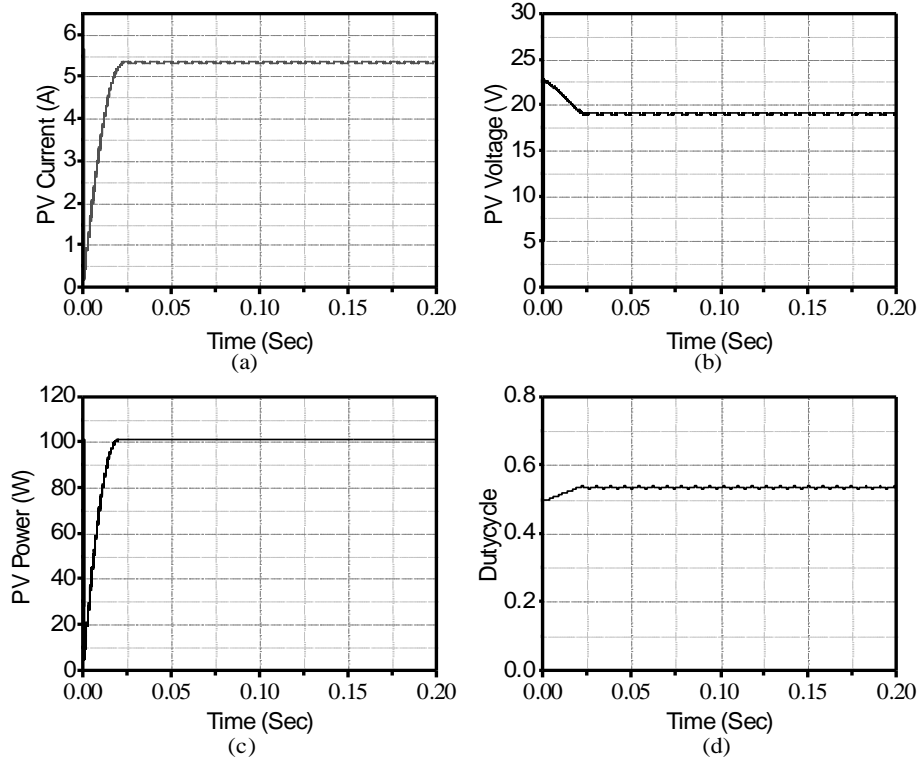


Fig. 5 Master PV unit (a) Array voltage (b) Array current (c) Array Power (d) Duty cycle

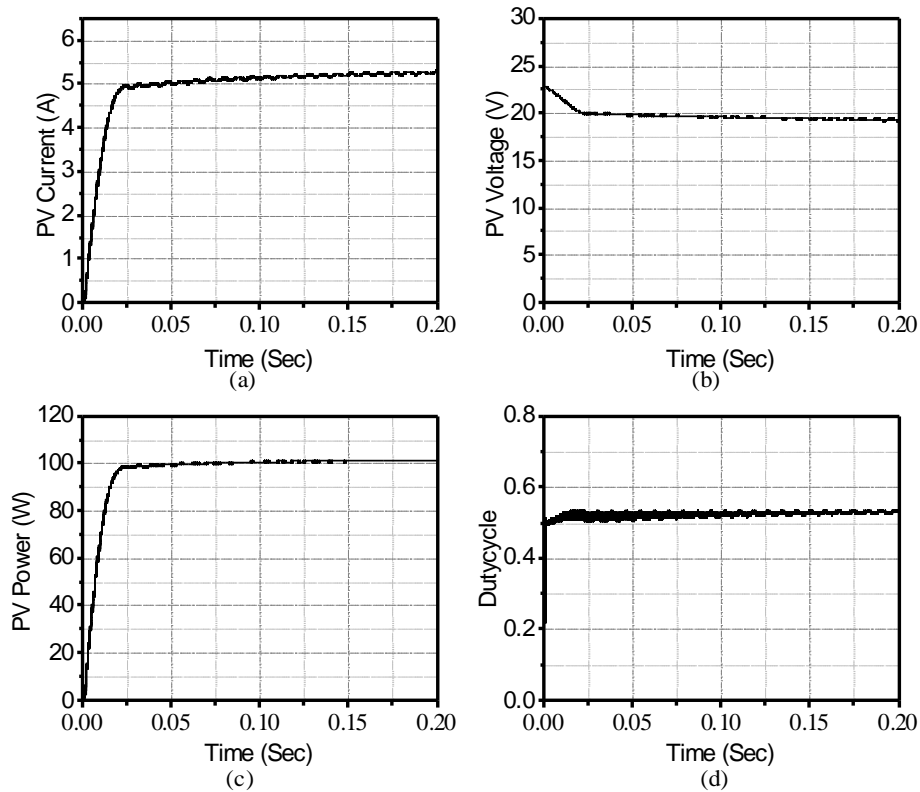


Fig. 6 Slave PV unit 1 (a) Array voltage (b) Array current (c) Array Power (d) Duty cycle

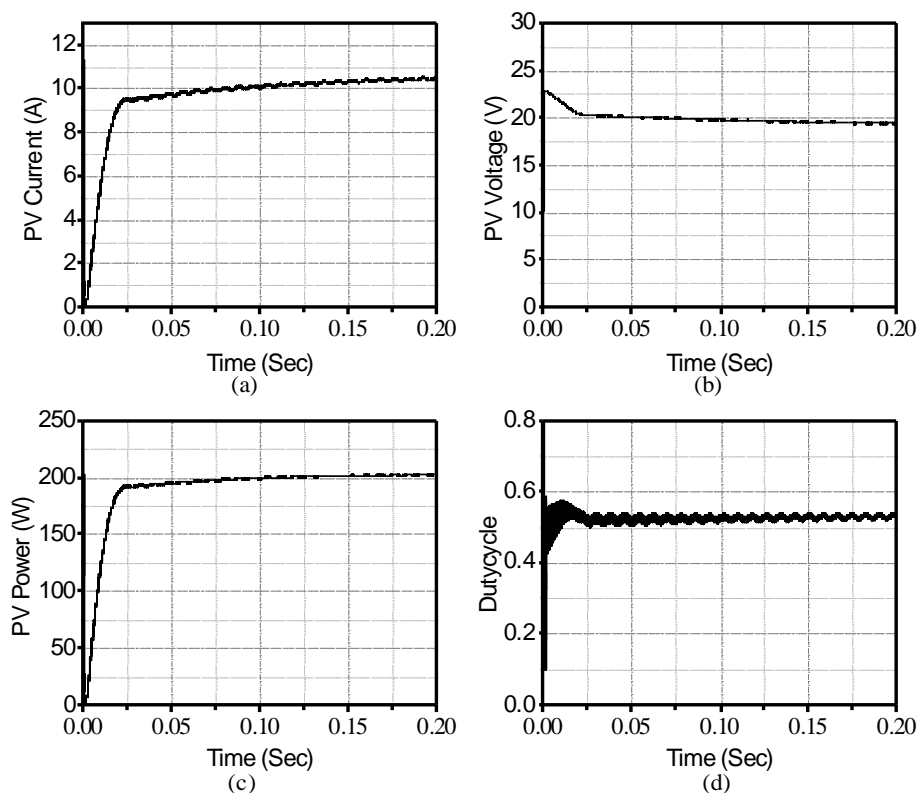


Fig. 7 Slave PV unit 2(a) Array voltage (b) Array current (c) Array Power (d) Duty cycle

Fig. 5 shows the PV voltage, PV current, PV power and duty cycle of Master unit. The maximum power generated by the master PV system is 100watts and corresponding voltage, current and duty cycle is shown in Fig. 5. Here, in the master PV unit the P&O based MPPT algorithm is implemented to

extract maximum from the master PV unit. The current with respect to maximum power is given as reference to slave unit 1 and 2.

The slave PV unit 1 is controlled by simple PID current control with the reference current generated by the master PV unit and extracts the maximum power from the slave PV unit. Fig. 6 shows the PV voltage, PV current, PV power and duty cycle of slave unit 1. The PV specification of master PV and slave 1 PV unit is same, the output power generated by the slave 1 unit is 100watts. Fig. 7 shows the PV voltage, PV current, PV power and duty cycle of slave unit 2. The PV specification of slave 2 PV unit is double the master unit. Hence the current reference generated by the master unit is multiplied based on the configuration and given as input to the slave 2 PV unit. The corresponding output power generated by the slave 2 PV unit is 200watts. The main advantage of operating slave units in PID current control method instead of MPPT controller is that the efficiency of slave PV unit is increased than the master PV unit since the slave units deliver constant power without perturbing. Also, the number of sensors in the slave unit and cost of the controller is less compared with master unit. Therefore, overall cost of the system can be reduced significantly with improved performance.

(ii) Case 2 Islanded mode (Voltage control):

In this mode, based on the control algorithm shown in Fig. 4, the voltage control is implemented to maintain specified grid voltage. Fig. 8 shows the power output waveform for master and slave units. Here, the system load is 260watts. Hence power generated from master and slave unit will share the load of 260watts. The simulation result for case 2 is shown in Fig. 8. From the figure, it is observed that the PV units share the 260W load power proportionally to the power rating of the PV source. Here, the Master PV unit 1 and slave PV unit 1 generates 65W from the maximum power capability of 100W and the slave PV unit 2 generates 130W from the maximum power capability of 200W. The sharing of load is achieved with less cost and improved efficiency.

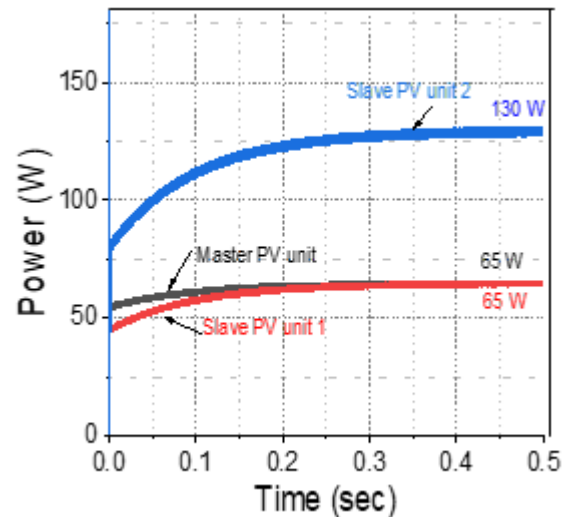


Fig. 8 Equal power sharing during voltage control

B. Experimental Results:

The proposed method is implemented in the experimental setup with specification of 1 kW PV system.

The master and slave unit are configured as 2s0p configuration and rating is given in Table 3. The specification of PV module and boost converter is shown in Table 4.

Table 3 Hardware configuration

	Master PV unit	Slave PV unit
Configuration	2s0p	2s0p
Power rating	1kW	1kW

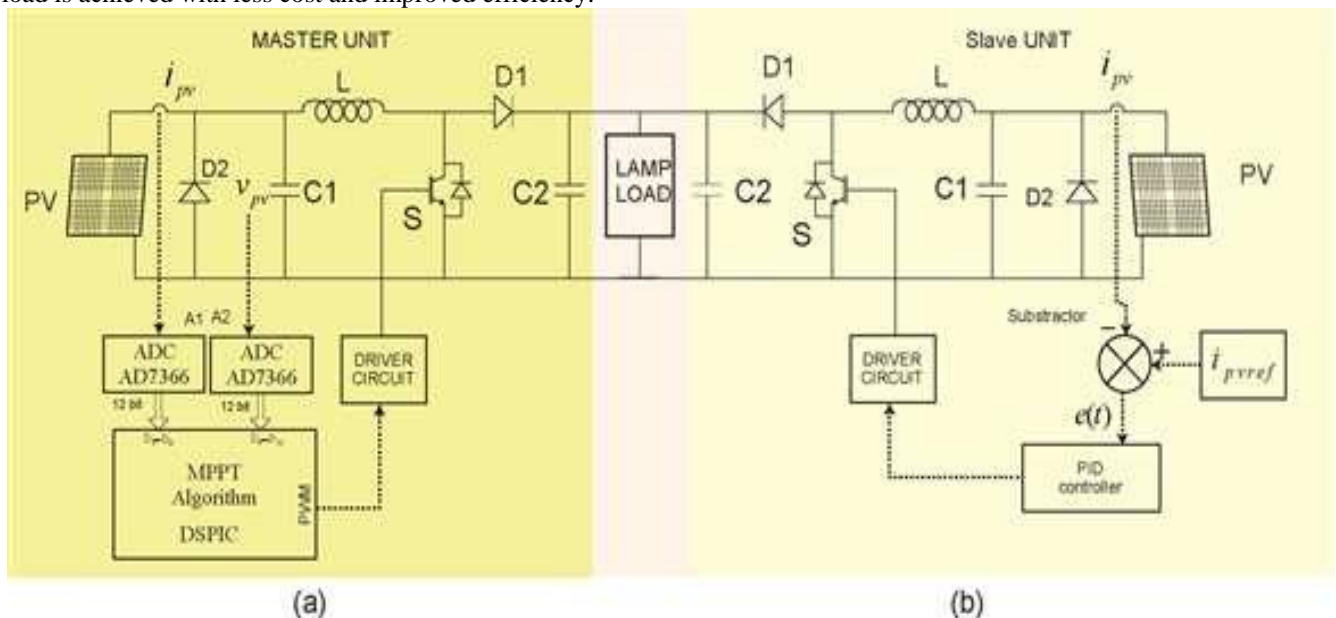


Fig. 9 Hardware setup a) Master unit and b) slave unit

Table 4 PV and DC-DC Converter Specification – Simulation Setup

PV Module		Boost converter	
Peak Power	250 W	Switching frequency	20kHz
Maximum Voltage	28.8 V	Inductor	1mH
Open Circuit Voltage	36 V	Input Capacitor (C1)	1000µF
Maximum Current	8.68 A	Output Capacitor (C2)	1000µF
Short Circuit Current	9.38 A	Resistive Load	2kW

The experimental setup of proposed for Master unit and Slave unit is shown in Fig. 9. The MPPT algorithm is programmed in PIC DSPIC 30F4011 based on the algorithm shown in Fig. 4. Here, to validate the experimental result, the duty sweep method is executed to obtain the voltage and current wave form of the slave PV unit which is shown in Fig. 10. The hardware result of case 2 is shown in Fig. 11. Fig. 11 shows the voltage and current of slave PV unit during current control mode. It is observed from the fig 11 a, and b, the slave unit follows the master unit successfully in current control method.

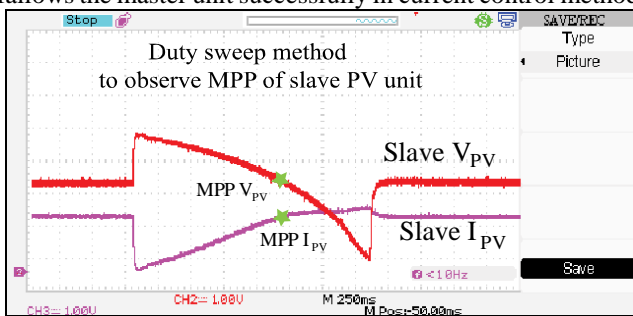
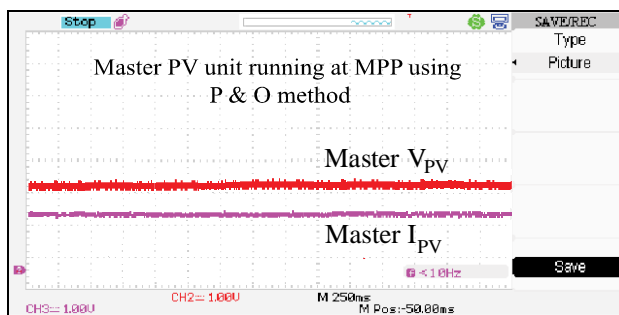
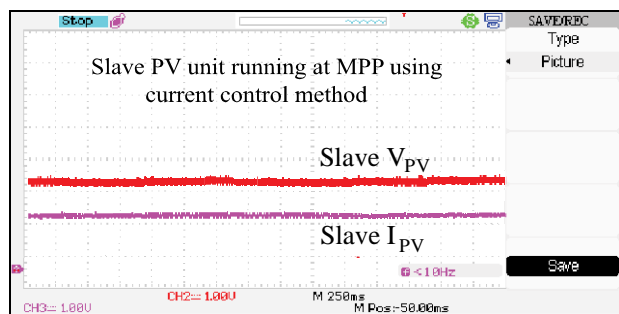


Fig. 10 V-I curve of slave unit using duty sweep method.



(a) Master PV unit



(b) Slave PV unit

Fig. 11 V-I curve – Experimental results

Also the operating point of voltage and current of slave unit is at the MPP is validated from the MPP operating point shown in fig 10 of slave unit. Hence it is concluded that the proposed method effectively tracks the maximum power during normal irradiance condition and with improved efficiency and less hardware cost.

V. CONCLUSION

A novel control methodology is implemented to integrate multiple photovoltaic (PV) based distributed generator (DG) in DC Microgrid. Here, multiple PV based DG are integrated with a single MPPT controller which reduce the hardware requirements and reduce the complexity of the system. The proposed master slave approach effectively tracks the maximum power from the PV system and maintain the DC bus voltage which share the load efficiently. The simulation results are carried out on grid and off grid condition to validate the proposed approach. The hardware setup is developed on CPRI project fund and results are validated. Since the proposed system is economical, it has large application in power industries.

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