ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 2, Issue 9, September 2016

Extraction of Maximum Power from Series Connected PV Modules by using DPP Architecture

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Abstract— **In series connected Photo Voltaic (PV) modules (string), there is a higher possibility of mismatch of currents among modules during partial shading conditions. In order to overcome this problem various DMPPT (Distributed Maximum Power Point Tracking) architectures are studied and PV to Virtual bus DPP (Differential Power Processing) architecture is considered in this paper. The proposed technique is used for the extraction of maximum power from series connected modules under shading conditions. The MPP (Maximum Power Point) voltage values of all modules are obtained by using Resonant MPPT method. These MPP voltage values are given as reference voltages to the Bi-directional fly-back DC-DC converters, which are placed in parallel to each PV module. These converters are used for operating each module at their MPP by providing required compensation currents to the shaded modules in PV to Virtual bus architecture.**

Index Terms — **Bi-directional fly-back DC-DC converters, DMPPT, MPP, partial shading, PV modules, PV to Virtual bus architecture**

I. INTRODUCTION

Renewable energy is playing an important role in the generation of electricity. Solar energy is one of the best forms of renewable energy, as the earth receives large amounts of it in the form of sunlight. Generally solar PV modules are connected in series to meet the voltage specification of a particular standalone application. Improving the energy conversion efficiency of PV systems is an important research problem today. Apart from the inherent limitations of the PV modules, partial shading and other environmental conditions further restricts the conversion efficiencies of the PV systems. Partial shading conditions lead to mismatch of currents among modules and may result in the damage of PV modules. Use of by-pass diodes moderates this problem but multiple peaks will occur in the Power-Voltage (P-V) curve of the string or array [1]. Conventional MPPT algorithms to track the MPP will be ineffective when multiple peaks appear due to partial shading. This further requires intelligent techniques for tracking the global MPP [1].

Also, DMPPT is the latest research topic in solving the problems related to partial shading conditions in the rugged and also flexible type of PV Modules [2]. DMPPT architectures typically require a dedicated converter across each PV module. The DMPPT architectures are classified into two groups as shown in Fig-1 [3]. Full Power Processing (FPP) architectures are those in which the full power produced by individual PV modules is passed through the respective converters connected parallel to each PV module. Differential Power Processing architectures are those in which only the mismatched amount of power among the modules, under partially shaded conditions are passed through the converters. Losses are relatively high in case of FPP due to full power processing through the converters [4]. Further, different techniques exist in DPP architectures to extract maximum power from the PV modules with minimum converter losses [5]. The string voltage balancing technique has the drawback of lesser power extraction from the PV modules [6]. In this paper a technique is proposed for the extraction of maximum power from the PV strings by using the combination of PV to Virtual bus type of DPP architecture and resonance based MPP estimation.

Section-2 describes the proposed technique. In section-3, simulation studies were presented for validating the proposed technique.

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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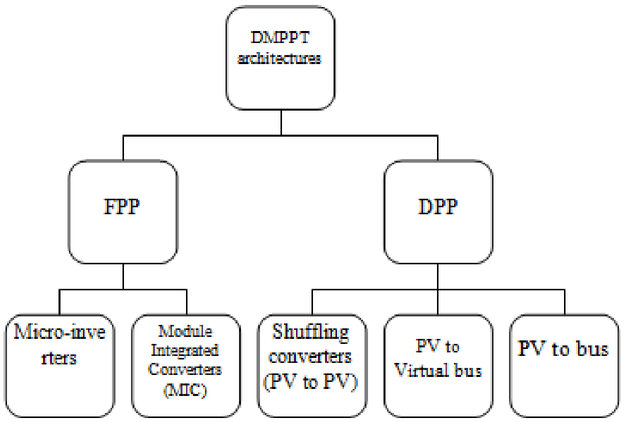

Fig -1: Classification of DMPPT

II. PROPOSED TECHNIQUE

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In this paper, a PV to virtual bus of DPP architecture is proposed to extract maximum power under partial shading conditions and also to achieve high conversion efficiencies. In DPP, the mismatch of currents in the series connected PV modules will be balanced by suitable shunt current compensation. But, it is necessary to determine the MPP parameters of individual PV modules before applying the compensation through the bi-directional DC-DC converters. Voltage balance is one of the techniques for this purpose [6]. Resonance MPP is another technique which determines the MPP parameters of individual PV modules more accurately [7]. In this paper, the resonant MPPT technique is considered for determining the V_{MPP} and I_{MPP} values of the individual PV module at the given partial shading condition. The PV to virtual bus configuration requires processing lesser power than other DPP architectures [8]. A combination of PV to virtual bus and resonant MPPT based MPP parameter estimation is proposed in this paper for an optimized PV power extraction operation.

Fig-2 shows the block diagram of the PV to virtual bus configuration. The arrangement consists of series connected PV modules, bi-directional fly-back DC-DC converters placed in parallel to each module and a central converter with P&O (Perturb & Observe) algorithm. An example case is considered in order to explain the functioning of the proposed technique. Fig-3 shows the block diagram of the example case. One of the PV modules is shaded with irradiation of 200W/m^2 and other is un-shaded with irradiation of 1000W/m^2. Initially the MPP voltage (V_{MPP}) and current (I_{MPP}) values of respective modules are obtained using resonant MPPT method. The values are 17.71V, 0.865A for un-shaded module and 16.22V, 0.168A for shaded module respectively. In the proposed technique, these MPP parameters of individual PV modules will be given as reference to the bi-directional fly-back DC-DC converters. The PV modules voltages are regulated by duty cycle control by using their respective MPP voltages as reference voltages. During this process, the criterion for compensation currents provided by the respective converters is explained in Fig-4

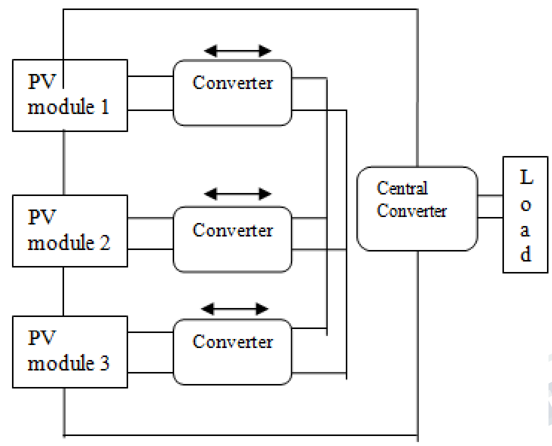

Fig -2: PV to Virtual bus layout

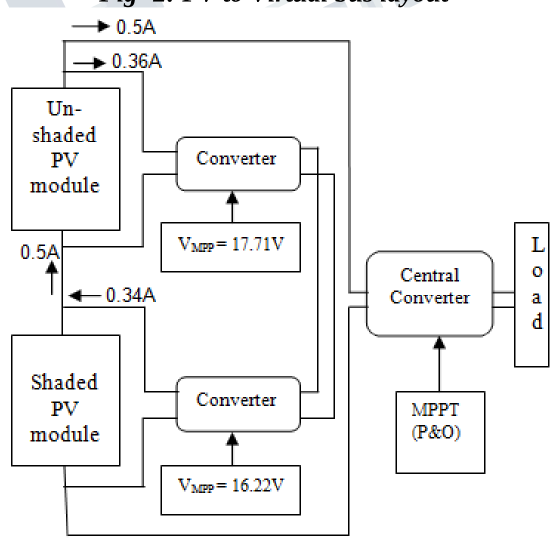

Fig -3: Block diagram of example case

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 2, Issue 9, September 2016

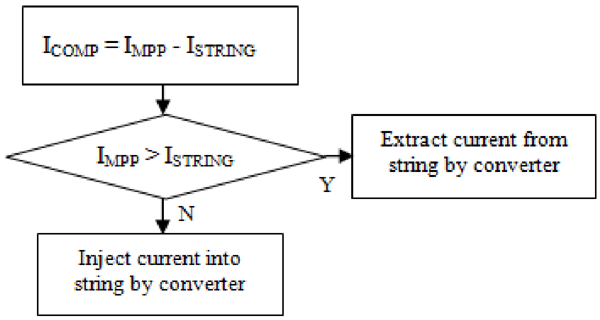

Fig -4: Shunt current compensation logic

The module MPP current 'I_{MPP}' of un-shaded one is greater than string current I_{STRING}, therefore the shunt compensation current I_{COMP} = 0.36A will be extracted by the DC-DC converter from the string. Since the I_{MPP} of shaded one is lesser than I_{STRING}, the shunt compensation current I_{COMP} = 0.34A will be injected by the converter into the string. In the above manner, the un-shaded module will be providing the required compensation current to the shaded one, in order to equalize the string current to 0.5A and at the same time consuming lesser processing power with the help of PV to virtual bus configuration.

Fig-5 explains the algorithm of the proposed technique. Whenever irradiation changes beyond an acceptable band, MPP voltage (V_{MPP}) values of all the modules at the instantaneous irradiation values are obtained by using resonant MPPT method and these MPP values are given as reference to the respective converters. Accordingly compensating mode starts and the un-shaded modules provides the required compensating currents to the shaded ones there by all the modules operates at their MPP respectively. The overall array converter also implements independent P&O. With the above technique, the respective modules and overall array can be maintained at maximum power point with minimum conversion losses in the process.

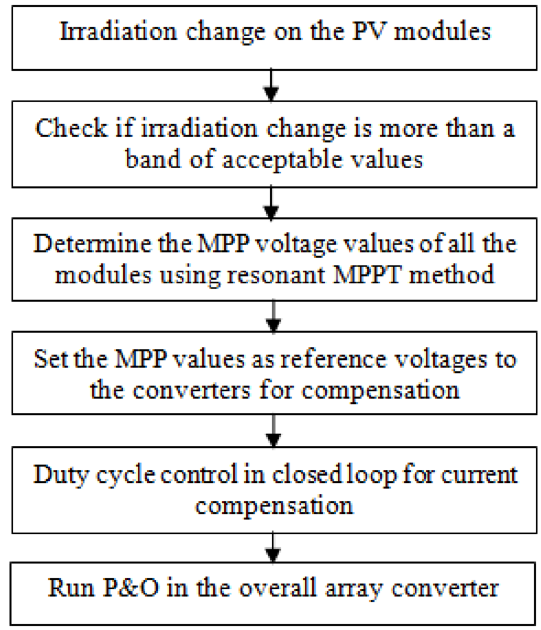

Fig -5: Flow chart of proposed technique

III. SIMULATIONS AND DISCUSSION

A PV module is modeled with open circuit voltage V_{OC} = 22V and short circuit current I_{SC} = 0.929A. Fig-6 to Fig-11 shows the simulation results of the PV module under various irradiation conditions and the obtained P-V and I-V (Current-Voltage) curves. These curves shows the PV module's power, voltage and current values at their MPP and the same are listed in Table-I.

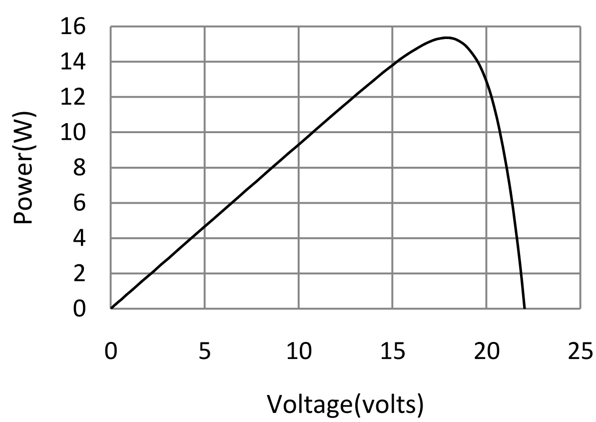

Fig -6: P-V curve of module at irradiation of 1000W/m²

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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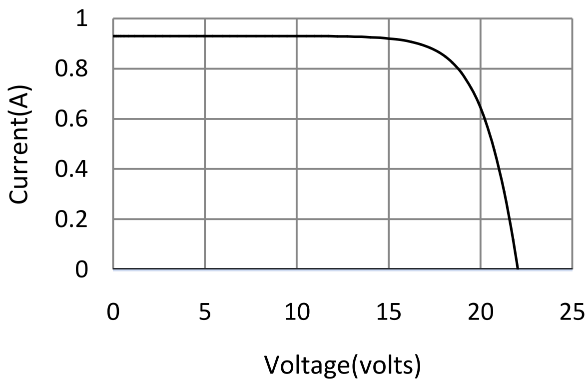

Fig -7: I-V curve of module at irradiation of 1000W/m^2

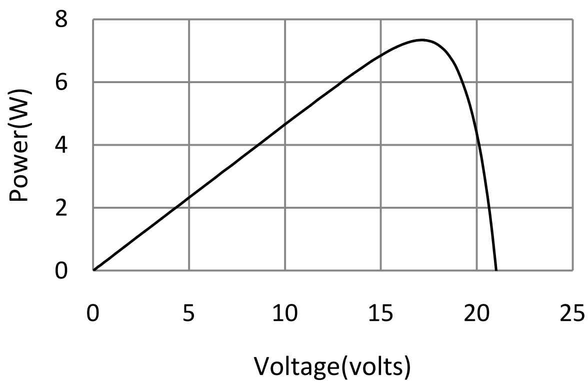

Fig -8: P-V curve of module at irradiation of 500W/m^2

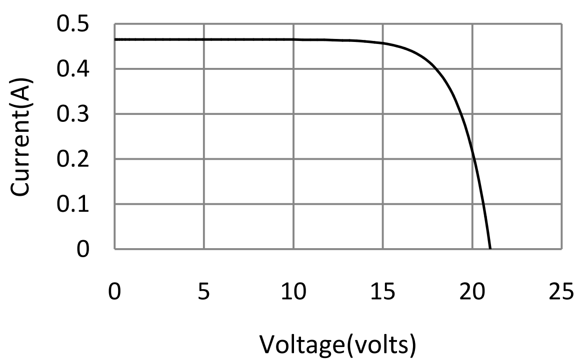

Fig -9: I-V curve of module at irradiation of 500W/m^2

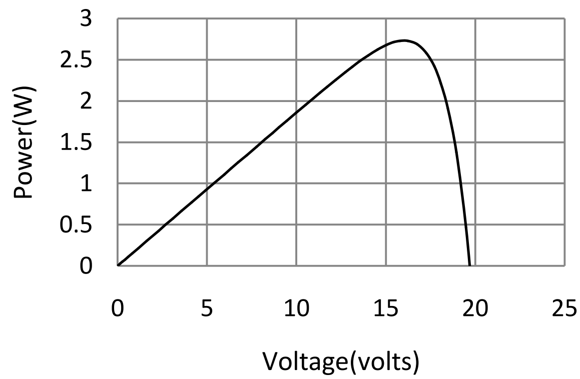

Fig -10: P-V curve of module at irradiation of 200W/m^2

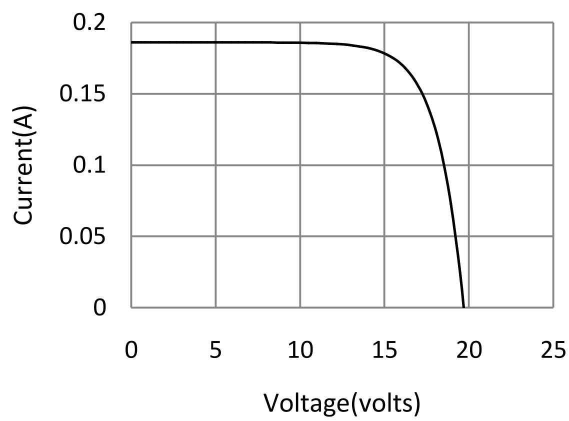

Fig -11: I-V curve of module at irradiation of 200W/m^2

Table -I: PV module Specifications

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 2, Issue 9, September 2016

Shading condition	No shading	Moderate shading	Dark shading
T(°C)	50	50	50
G_n(W/m²)	1000	500	200
V_{MPP}(V)	17.712	17.272	16.225
I_{MPP}(A)	0.865	0.424	0.168
P_{MPP}(W)	15.33	7.33	2.72

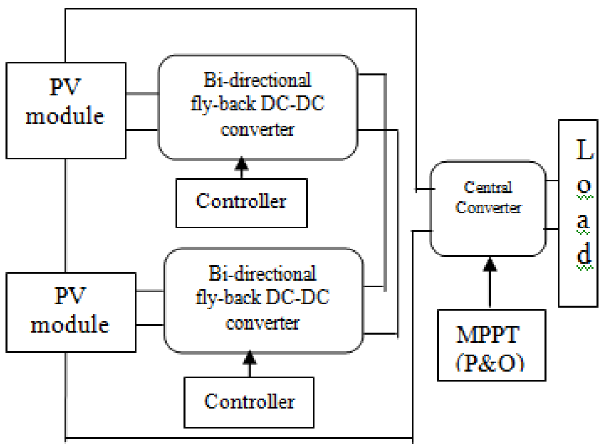

Fig -12: Simulation model of proposed technique

Fig-12 is the block diagram of simulated model for the proposed technique. In this simulation, bi-directional fly-back DC-DC converters whose schematic is shown in Fig-13 are used. In this converter, two MOSFET Switches (M1, M2) are used. One switch is on primary side and other on secondary side of the fly-back transformer whose turn's ratio is 1:n. Table-II lists the parametric values of various components in the converter. The bi-directional converter play an important role in the functioning of the proposed technique with PV to Virtual bus DPP Architecture and are used to inject current into or absorb current from the string there by enabling PV Modules to operate at their respective MPP's. The proposed technique is validated by simulating the same in SIMULINK®.

Table -II: Bi-directional Converter Parameter values

Parameter	Value
Range of converter primary side voltage (V_{pri})	(15-18V)
Range of converter secondary side voltage (V_{sec})	(30-36V)
Capacitor on primary side (C_{pri})	50μf
Capacitor on secondary side (C_{sec})	200μf
Switching period (T_s)	100μs

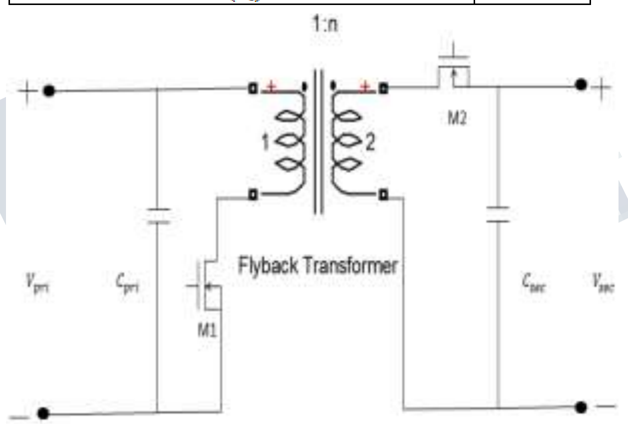

Fig -13: Bi-directional fly-back DC-DC Converter

IV. RESULTS AND DISCUSSION

The proposed technique is modeled in SIMULINK and functioning was validated by simulating the same for an example partial shading case. The case results are presented for two different partial shading conditions and are listed in Table-III. Fig -14 and Fig -15 shows the simulation results of the output voltage values for both of these cases.

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ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 2, Issue 9, September 2016

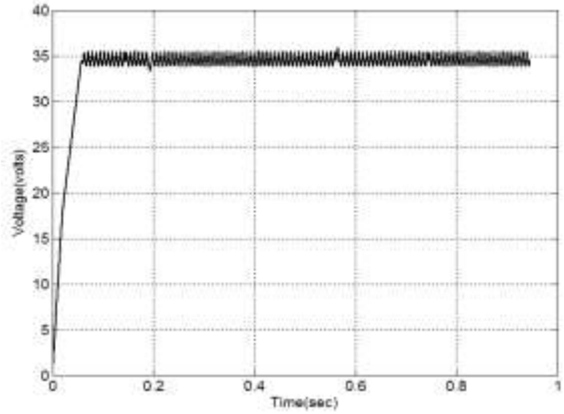


Fig -14: Output Voltage=34.5V of 2X1 string for the case (1000W/m^2, 500W/m^2)

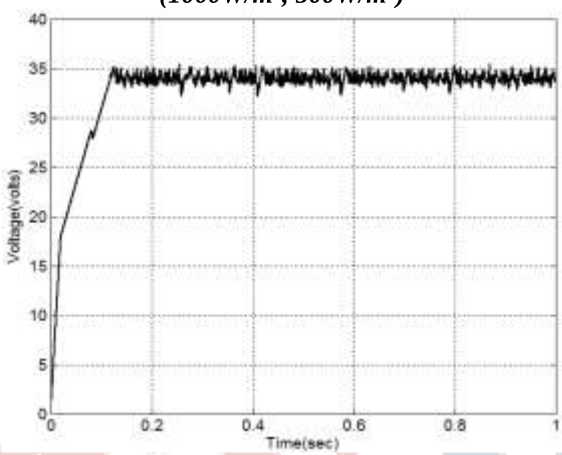


Fig -15: Output Voltage =33.9V of 2X1 string for the case (1000W/m^2, 200W/m^2)

Table -III: Results of 2X1 String for different shading conditions

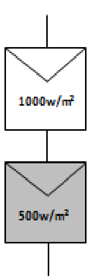
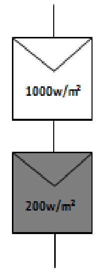
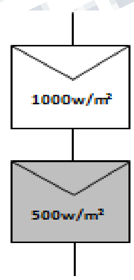
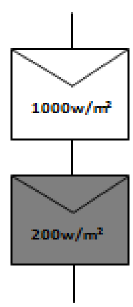
SHADING PATTERN OF PV MODULES	OUTPUT POWER (P_o)	OUTPUT VOLTAGE (V_o)	STRING CURRENT (I_{string})	UN SHADED MODULE (I_{comp})	SHADED MODULE (I_{comp})
	21.6	34.55	0.63	0.23	0.21
	17	33.93	0.5	0.36	0.34

Table -IV: Comparison of proposed technique with others

SHADING PATTERN OF PV MODULES	OUTPUT POWER P_o (W)		
	NORMAL ARRAY WITH BYPASS DIODES	PROPOSED TECHNIQUE	ACTUAL MPP POWER VALUES
	14.2	20.6	22.66
	14.2	17	18.05

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 2, Issue 9, September 2016

The output power obtained from the proposed technique is also compared with the case of PV module with by-pass diodes. A comparison is also presented in Table-IV to validate the efficacy of the proposed technique with respect to the ideal MPP values and the results obtained are found to be satisfactory.

V. CONCLUSION

In this paper, a technique to extract maximum power from series connected PV modules under partially shading conditions by using PV to Virtual bus DPP Architecture is proposed. The MPP parameters of the individual PV modules under a given partial shading condition have to be obtained by using resonant MPP technique. The bi-directional converters are used to inject current into or extract current from the string there by enabling the PV Modules to operate at their respective MPP values. The proposed technique will have lesser conversion losses and also will ensure the extraction of maximum power under various partial shading conditions. The proposed technique was validated by simulation based approach and the results observed confirm the relative advantage of the technique.

Acknowledgement

The authors would like to specially acknowledge Aswani U, Scholar, IIT Bombay for providing help in understanding various technical issues related to this work.

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