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Cascade Operation of DC-DC Boost Converters in Solar PV System with Individual MPPT Controllers

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Abstract: This paper presents Cascade Operation of DC-DC Boost converters with the implementation of individual MPPT controller for each converter. These MPPT controllers track the maximum power from their respective solar photovoltaic panels operating at different irradiation levels. The output voltage of the Cascaded System is delivered to another DC-DC Boost converter which provides the output voltage of required level and reduced ripples. The level of the power delivered to load increases when the load is fed through another DC-DC Boost Converter. This paper also considers the flexibility of operating PV panels at different points and the effect of local panel shadings.

Keywords: PV Array, MPPT, DC-DC Converter, Cascade operations.

I. INTRODUCTION

With the increased focus on the use of Renewable Energy Systems as the conventional energy recourses getting depleted, the use of Power Electronic Converters in this regard is highly appreciated. The important information of Maximum Power Point (MPP), open circuit voltage, Short Circuit current etc can be obtained from the Parameters of the PV Array [2]. The system may not deliver maximum power to load when it is directly connected to it. The voltage and current values are different from values corresponding to Maximum Power Point (MPP). Instead of this direct connection, if it is done through a Boost Converter, the MPP can be achieved. Normally, the duty ratio of 0.5 is considered for the Boost converter. As the load is fed through the Boost Converter, the effective resistance seen from the input side of converter is

$$R_{effective\ \ input} = R_{OUT}/(1-\delta),$$

δ represents duty ratio of Boost Converter. The duty ratio is varied such that the voltage and current values corresponding to MPP are tracked[1]. The PV Array is connected to the load through Boost Converter having MPPT Controller. MPPT controller tracks the maximum power point. Hence maximum power is delivered by the PV Array to the load.

II. PV ARRAY MODELLING

Based on the theory of semiconductors, the basic equation that mathematically describes the I-V characteristic of an ideal photovoltaic cell is

$$\mathbf{I = I_{pv,cell} - I_{0,cell}[exp\left(\frac{qv}{aKT}\right) - 1} \qquad (1)$$

where $I_{pv,\ cell}$ is the current generated by the incident light which is directly proportional to the Sun irradiation, $I_{0,cell}$ [A] is the reverse saturation or leakage current of the diode, q is the electron charge [$1.60217646 \cdot 10^{-19}$C], k is the Boltzmann constant [$1.3806503 \cdot 10^{-23}$J/K], T [K] is the temperature of the p-n junction, and a is the diode ideality constant[2].

A few additional parameters are to be included in the equation (1) to represent the characteristics of practical photovoltaic cells. Figure 1 provides the model of a practical PV cell.

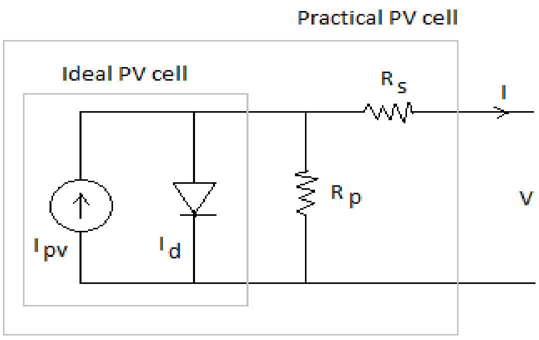

Fig.1. Equivalent Circuit Model of PV Cell

The current supplied by the practical PV cell is given by the equation

$$\mathbf{I = I_{pv} - I_0\left[exp\left(\frac{v+R_sI}{V_ta}\right) - 1\right] - \frac{v+R_sI}{R_p}} \qquad (2)$$

The above equation (2) describes the single-diode model presented in Fig.1 where I_{pv} and $I_o$are the photovoltaic

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and saturation currents of the array and v_t = NskT/q is the thermal voltage of the Array with Ns cells connected in series. The parallel connected cells increase the current and the series connected cells give greater output voltages. If the array is composed of Np parallel connections of cells the photovoltaic and saturation currents may be expressed as: $I_{pv} = I_{pv,cell}$ Np, $I_o = I_{ocell}$,N_p.

In (2) Rs is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. This equation originates the I-V curve seen in Fig.2, where three remarkable points are highlighted: short circuit $(0, I_{sc})$, maximum power point (V_{mp}, I_{mp}) and open-circuit $(V_{oc}, 0)$.

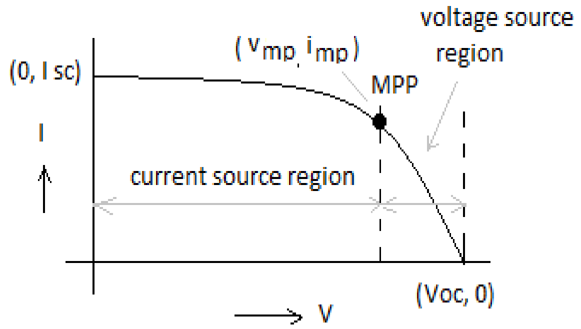

Fig.2. I-V Characteristic of a Photovoltaic Cell

The current generated by light in the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation (3)

$$\mathbf{I_{pv}} = \left(\mathbf{I_{pv,n}} + \mathbf{K_I \Delta_T}\right)\frac{\mathbf{G}}{\mathbf{G_n}} \qquad (3)$$

Where $I_{pv,n}$[A] is the light-generated current at the nominal condition (usually 25 ◦C and 1000W/m2),
T =T − T_n (being T and T_n the actual and nominal temperatures [K]), G [W/m2] is the irradiation on the device surface, and G_n is the nominal irradiation. Parameters of the adjusted model of the KC200GT solar array at nominal operating conditions are provided in table 1.

III. MAXIMUM POWER POINT TRACKING (MPPT) OF SOLAR SYSTEM

MPPT techniques are needed to operate the PV arrays at their Maximum Power Points. if the load is connected directly across PV cell, it may operates at power differs from the maximum Powers. Thus, a power conditioner or DC-DC converter is introduced between the Solar PV module and the load. This converter connects the load to the array so that load characteristics are transformed along locus of maximum points and maximum power is extracted from the array. The duty cycle of the converter is changed till the peak power point is obtained.

Table.1.Parameters of the KC200GT solar array model

I_{mp}	7.61 A
V_{mp}	26.3 V
$P_{max,m}$	200.143 W
I_{sc}	8.21 A
V_{oc}	32.9 V
$I_{o,n}$	9.825×10^{-8} A
I_{pv}	8.214 A
a	1.3
R_P	415.405 Ω
R_S	0.221 Ω
K_v	-0.1230 V/K
K_I	0.0032 A/K
N_s	54

There are different techniques used to track the maximum power point [4]. The most popular techniques are

1) Perturb and Observe (Hill Climbing Method)
2) Incremental Conductance Method

The choice of the algorithm depends on the time complexity. The algorithm considers tracking the MPP, implementation cost and the ease of implementation. Perturb and Observer algorithm is used to track MPP of the system. The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power *ΔP* is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If *ΔP* is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed [4].

If $\Delta P > 0$ and $\Delta V > 0$ then $D = D - \Delta D$
If $\Delta P > 0$ and $\Delta V < 0$ then $D = D + \Delta D$
If $\Delta P < 0$ and $\Delta V < 0$ then $D = D - \Delta D$
If $\Delta P < 0$ and $\Delta V > 0$ then $D = D + \Delta D$

IV. CASCADE OPERATION OF DC-DC CONVERETRS

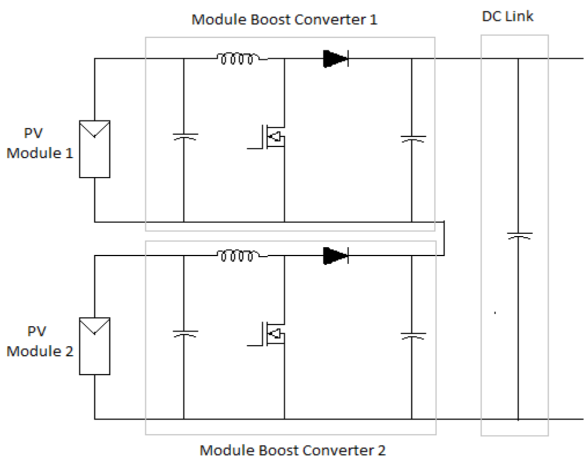

Fig 3.Cascaded DC-DC Converters

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The figure 3 shows Cascade operation of DC-DC converters every panel has its own converter. The outputs of the converters are pooled up in series to form a dc string and it is connected to load through other converter. It facilitates for Converter-per-panel approach. The Advantages of Converter-per-Panel approach are

1) Better Utilization of Modules
2) Possibility for mixing different Sources
3) Better Protection of Power Sources
4) Redundancy of Power Converters and Power Sources
5) Better data gathering
6) Greater Safety during Installation and Maintenance

V. RESULTS AND ANALYSIS

The PV Arrays are operated at different irradiances and the output is fed to load resistance of 10Ω. The powers delivered by individual PV panels along with their operating voltages and currents are shown in table 2.

Table 2. Power delivered by PV arrays without Boost Converters

	Irradiance (w/m^2)	Operating voltage	Operating Current	Power Delivered
PV Array 1	1000	31.2 V	3.1A	97 W
PV Array 2	800	30.6 V	3.06A	93.8 W

Instead of connecting PV Array directly to the load resistance, if a Boost Converters are placed before load, the power levels are found to be enhanced. The duty ratio of the Boost converter is taken as 0.5 in the analysis. The powers delivered by individual PV panels along with their operating voltages and currents with individual Boost Converters are shown in table 3. The power delivered, the operating voltage and current can be varied by varying the duty ratio of converters. This leads to concept of Maximum Power Point Tracking (MPPT).

Table 3.Power delivered by PV arrays with Boost Converters

	Irradia-nce	Operating voltage	Operating Current	Power Delivered
PV Array 1	1000	21.03V	8.12A	171W
PV Array 2	800	21V	5.7A	120W

Now, the converters are provided with MPPT controllers and the PV Array is connected to the load resistance through Boost Converter having MPPT Controller. The MPPT controller tracks the maximum power point. Hence maximum power is delivered by the PV Array to the load. The power delivered by the PV Array connected to the load resistance through Boost Converter having individual MPPT Controller for different irradiances is provided in Table 4.

Table 4.Power delivered by PV arrays with Boost Converters provided with MPTT controllers

	Irradia-nce	Operating voltage	Operating Current	Power Delivered
PV Array 1	1000	26.3V	7.61A	200.2W
PV Array 2	800	26.14V	6.1A	159.5W

The Simulation results of the Cascade Operation of DC-DC converters with MPPT control feeding into a DC link from different PV sources of irradiances $1000 w/m^2$ and $800\ w/m^2$ are shown in the following figures.

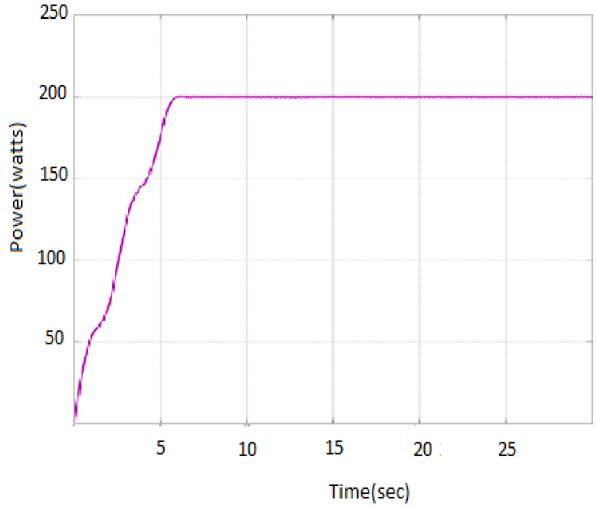

Fig.4 Maximum Power Delivered by PV Array having irradiation of 1000 $^{w}/_{m^2}$

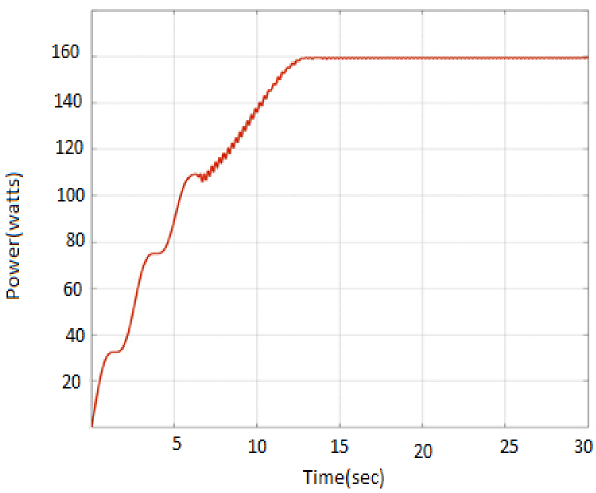

Fig.5. Maximum Power Delivered by PV Array having irradiation of 800 $^{w}/_{m^2}$

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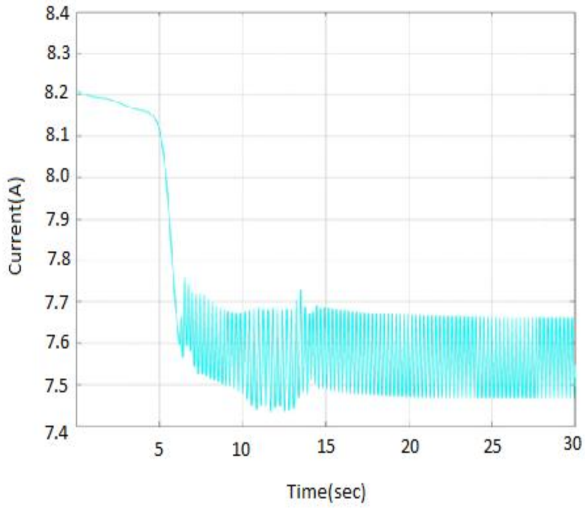

Fig.6. PV Array Current at maximum power point having irradiance of 1000 w/m^2

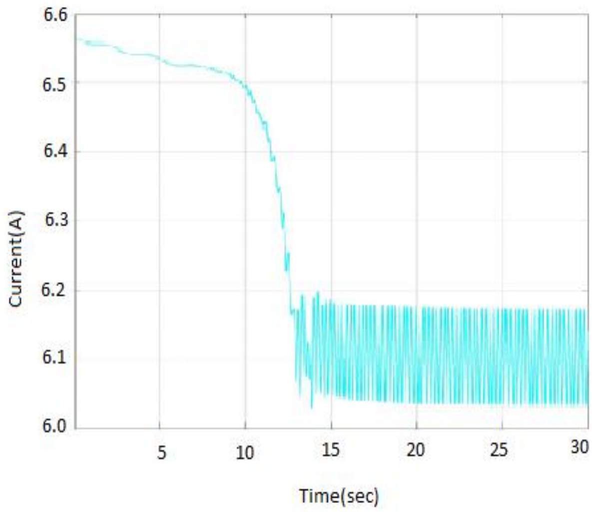

Fig.7. PV Array Current at maximum power point having irradiance of 800 w/m^2

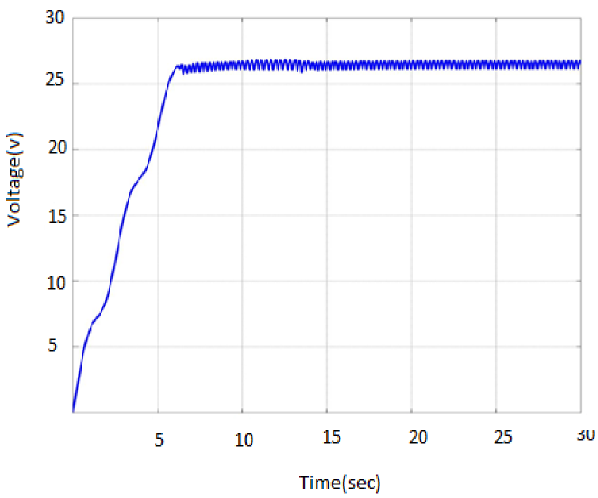

Fig.8 Voltage at Maximum Power Point of PV Array having irradiation of 1000 $^{w}/_{m^2}$

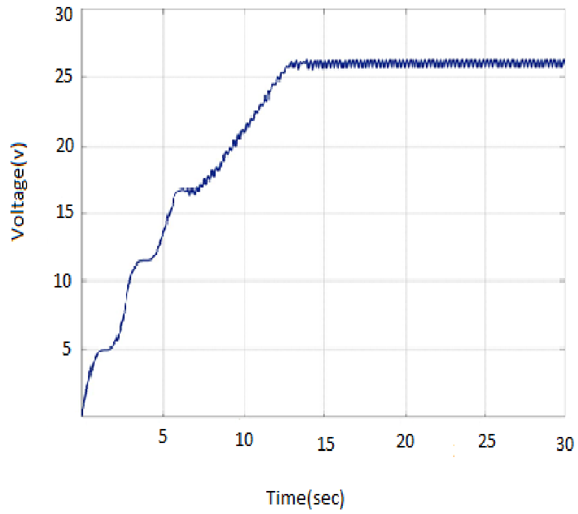

Fig.9 Voltage at Maximum Power Point of PV Array having irradiation of 800 $^{w}/_{m^2}$

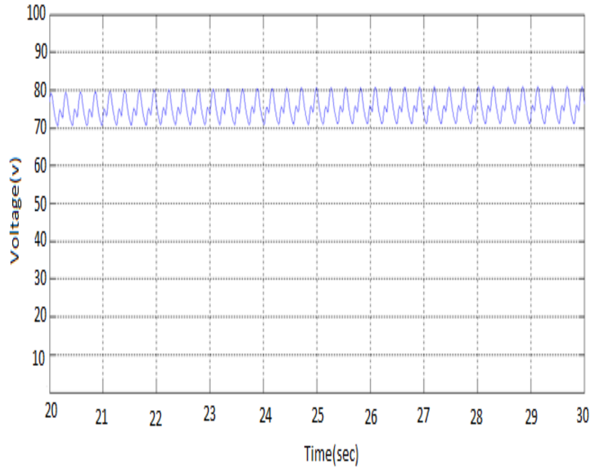

Fig.10. Output Voltage across the Cascaded DC-DC Boost Converter

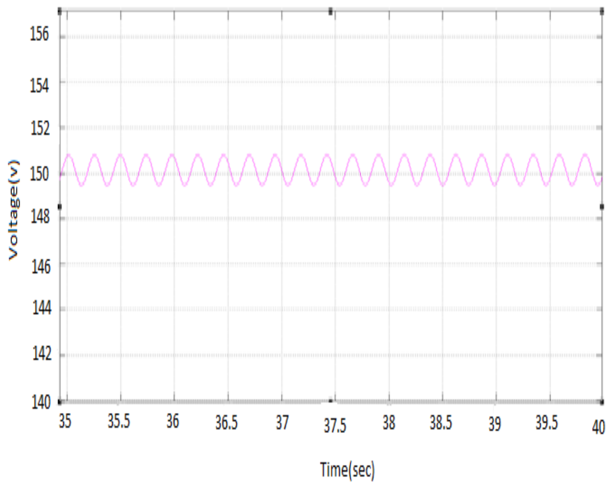

Fig.11.Output Voltage across Boost Converter connected to the cascaded DC-DC Converter with reference voltage of 150V.

IV. CONCLUSION

The Cascade operation of DC-DC Boost converters with the implementation of individual MPPT controllers for each converter is presented. The PV Arrays are modelled in the MATLAB environment. The Maximum powers are tracked from the converters using the MPPT controllers being their respective solar photovoltaic panels placed at different irradiation levels. Thus, this paper highlighted the flexibility of operating the panels at different orientations and convenient points. It opened up new possibilities in architectural applications. The effect of localized shadings of panels is also considered. The significant hike in power levels is observed when the load is fed through another DC-DC boost converter. This arrangement also provides the output voltage of required level and reduced ripples.

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BIOGRAPHIES

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