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A Novel Scheme for Harvesting Energy from Partially Shaded SPV System

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Abstract— In recent years, solar energy is the most promising and abundantly available renewable energy which could be absorbed easily with PV systems .So, we are at the verge of trapping the solar energy with high efficiency, reduced cost and improved energy capture. Shading effect is the major problem, since most of the power is lost. Conventionally, bypass diodes were used to avoid hotspot, which bypasses the shaded panel. So, the power available in that panel is unused. In order to capture that power also, a recovery scheme is proposed in this paper which bypasses the bypass diode and makes the maximum power available in the output. Also, a Maximum Power Point Tracking (MPPT) technique is used to draw peak power from the solar array in order to maximize the produced energy. Simulation has been done in Simulink/MATLAB and Embedded MATLAB function is used for embedding the code.

Index Terms- Partial Shading, Bypass Diode, Energy Recovery, Boost converter with Incremental Conductance.

1 INTRODUCTION

THE use of renewable resources has triggered a worldwide discussion about their effect on the environment. As a consequence, the number of photovoltaic (PV) power plants installed all over the world has steadily risen in the past few decades. However, the produced power is usually lower than their expected power.

This is because most of the power is lost due to variation in irradiation and temperature. If the temperature increases above a certain level say 35o, the performance of the panel degrades. Also, if there is a mismatch in irradiation of the panels connected power loss occurs. This is due to the shading effects which in turn is due to the trees, buildings, transmission lines etc. To study the shading effects, number of panels are connected in series. If one panel is partially shaded the overall voltage in the output side decreases. Also, the current in the shaded panel will be less when compared to the other panels. A methodology for the use of a detailed software tool that can accurately model both partial shading and electrical mismatch at the subpanel level in a PV array was developed and demonstrated in [1].

If the current from the healthy panel flows through the shaded panel hotspot will be created and the panel will be damaged. So, in order to avoid it normally we go for the bypass diodes. Normally a panel with 72 cells have two bypass diodes. This bypass diode shortcircuits the shaded panel and protects the panel from damage. Since the power in that panel is of no use, the effective expected output is not obtained. In order to obtain that power without damaging the panel the proposed circuit is used.

Also, the use of bypass diode will produce multiple peaks in PV and IV curves and if we use the MPPT algorithm in it the global peak cannot be determined effectively. The use of MPPT which has the bypass diode is ineffective.

In order to solve this problem, a novel Maximum Power Point tracking algorithm based on Differential Evolution (DE) that is capable of tracking global MPP under partial shaded conditions is discussed in [10]. The ability of proposed algorithm and its excellent performances are evaluated with conventional and popular algorithm by means of simulation.

2 PV MODELING

A solar cell is a semiconductor device that converters sunlight energy into electrical energy directly without going through any intermediate energy conversion steps. It is a fundamental block of solar photovoltaic (PV) technology. Many solar cells are connected together to form solar PV modules[2]. Several solar PV modules are connected together to make PV array in small power applications as well as in big power plant applications.

All of the model parameters can be determined by examining the manufacturer's specifications of PV products. The most important parameters widely used for describing the cell electrical performance is the open-circuit voltage and the short-circuit current . Since normally photo current is much greater than saturation current and ignoring the small diode and ground-leakage currents under zero terminal voltage , the short-circuit current is approximately equal to the photocurrent. The open circuit voltage parameter is obtained by assuming the output current as zero.

A model of PV module with moderate complexity which includes the temperature independence of the photocurrent source , the saturation current of the diode, and the series resistance is considered based on the Schockley diode equation . It is important to build a generalized model suitable for all PV cell, module , and array , which is used to design and analyse a maximum power point tracker. When illuminated with radiation of sunlight, PV cell converters part of the photovoltaic potential directly into electricity. A generalized PV model is built using Matlab/Simulink and mathematical modeling to illustrate and verify the non-linear V-I and P-V output characteristics of PV module [3]-[4] as shown in Fig 1.

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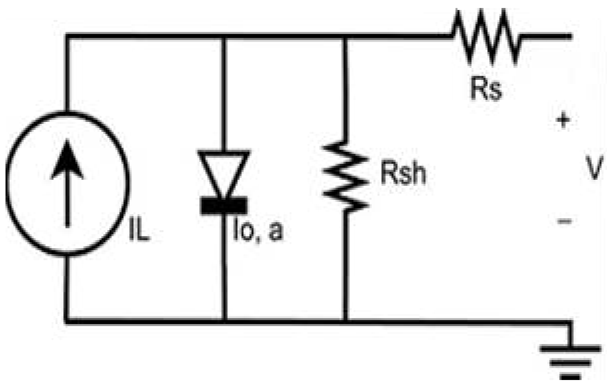

Fig 1. Equivalent circuit of PV cell

In order to study about the variation of PV and VI curves due to different temperature and irradiation a single panel with is taken and the curves are plotted for different irradiation and temperature in each instant. Fig 2 shows the PV model in MATLAB.

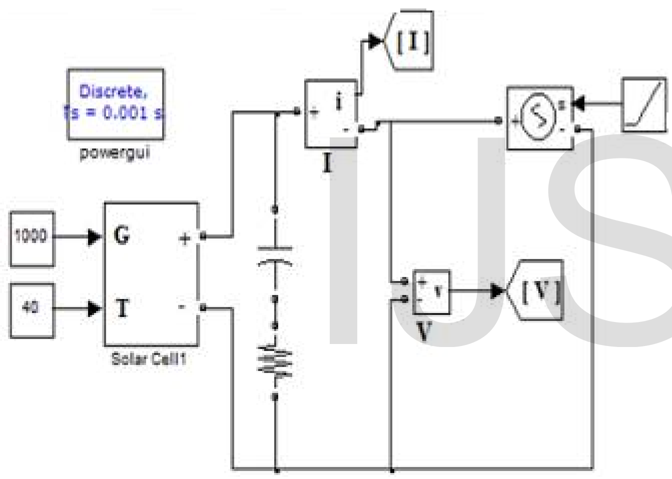

Fig 2. Modelling of Single Panel

The waveforms are obtained for the various insolations 1000W/m2, 800W/m2, 600W/m2, 400W/m2, 200W/m2 correspondingly with constant temperature and plotted which is shown in Fig 3a) and 3b). In the same module keeping the insolation constant the temperatures are varied which is depicted in the Fig 4a) and 4b).

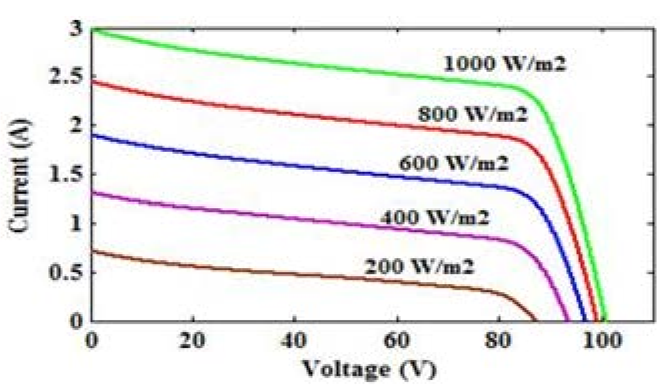

Fig 3a). VI characteristics for various insolation

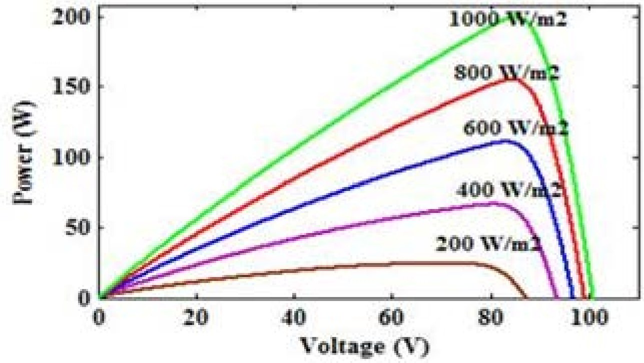

Fig 3b). PV characteristics for various insolation

From the Fig 3a) and 3b) it is inferred that as insolation increases, Current increases and voltage increases insignificantly. Hence, Power also increases correspondingly. Similarly, from Fig 4a) and 4b) it is inferred that as temperature increases, Current increases insignificantly and voltage decreases. Hence, Power decreases correspondingly.

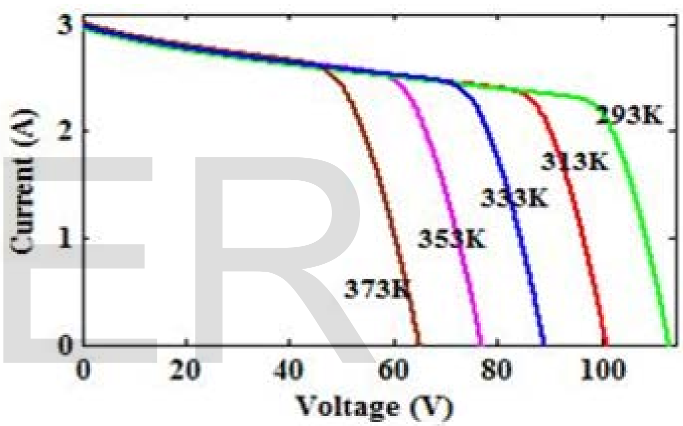

Fig 4a). VI characteristics for various temperature

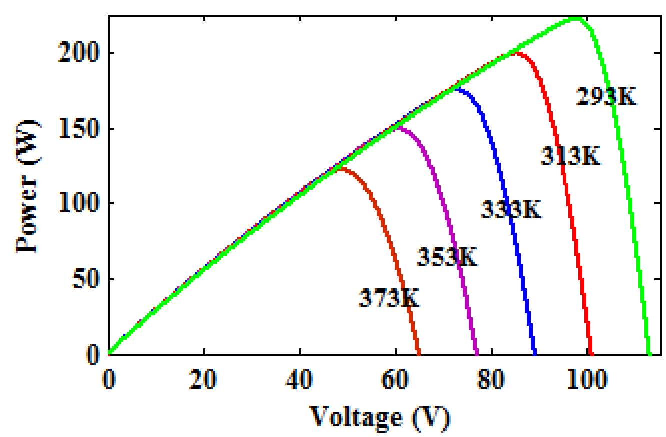

Fig 4b). PV characteristics for various temperature

3 Partial Shading And Its Effects

In the previous section different insolation is given for a single panel at a time. In practice we connect number of panels

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in series[5-8]. All these panels do not get the same irradiation all the time. The output voltage obtained will be the sum of individual panels. Obviously, the output power will also be the sum of individual panels. In Fig 2. Inside the solar panel subsystem, two panels are connected in series and the combined voltage is brought out. When one panel has 1000W/m2 and the other has 500W/m2, the power substantially reduces. This is shown in the Fig 5. Where red represents full insolation in both the panels, while the green represents one panel has less insolation than the other.

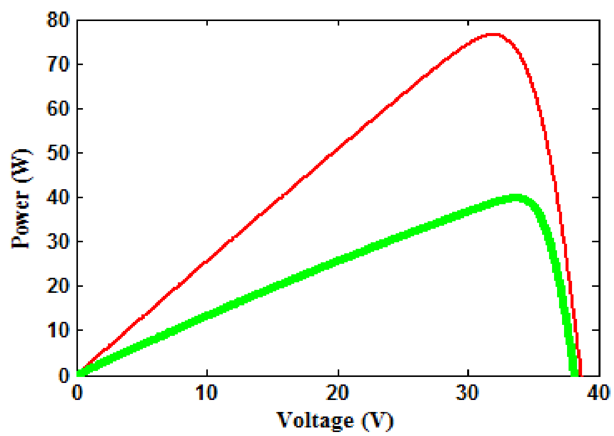

Fig 5. PV for panel having Partial Shading

In such cases like partially shaded condition, current in the non-shaded panel flows through the shaded panel also. This creates the hotspot and damages the entire panel [8]. To avoid this, a bypass diode is connected across each panel. Consequently, two peaks are found in the PV characteristics when we plot having the bypass diode in the circuit. This is depicted clearly in the Fig 6.

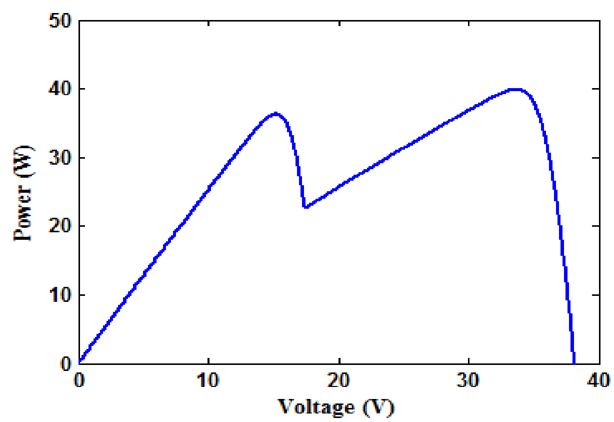

Fig 6. Partial shading with bypass diode

4 Recovery Circuit

4.1 General block diagram

The block diagram of the entire circuit in which each PV module has the bypass diode and the proposed circuit called recovery circuit is connected in between the source and the load is shown in Fig 7. The boost converter is used for increasing the voltage in the output side with the duty cycle as 50% [9,10]. The inductor and capacitor values are 220µH and 470µF respectively.

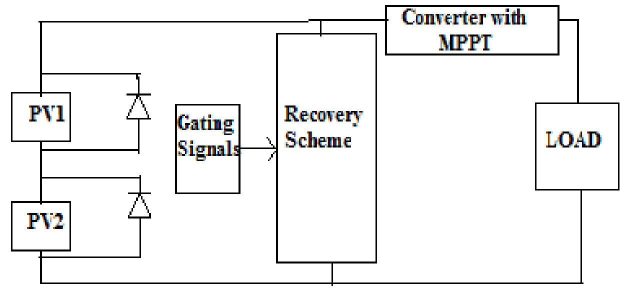

Fig 7. Block diagram with Recovery Scheme

The maximum power point tracking is used capture the peak power [11,12]. The main problem lies here when bypass diode is used for the partial shading. Since, several peaks occur due to the use of diodes the MPPT will not be able to track the global peak. In order to avoid this recovery scheme is introduced where only one maximum curve occurs, hence easy to track.

4.2 Gating Signals

The gating signals which are nothing but the pulse given to the switches used in the circuit. The pulses are given in such a way that it is controlled using the MATLAB program. The pulses are generated only when there is a partial shading in the panel and the recovery circuit across that panel alone works. The coding is given in such a way that when insolation reads below 1000W/m2 which is considered to be as full insolation, the pulses gets generated and the pulses are given to the circuit and it's shifted pulse is given to the switch in it's counterpart circuit. In this way, the switches are made to on and off during partial shading. The coding is done in the MATLAB which is depicted in TABLE 1.

TABLE 1.
Switching Of Pulses

PV Panel	Insolation Level	State of Switches			
		S1	S2	S3	S4
PV1	1000	OFF			
	<1000	ON		OFF	
PV2	1000	OFF			
	<1000	ON		OFF	
PV3	1000	OFF			
	<1000	OFF		ON	
PV4	1000	OFF			
	<1000	OFF		ON	

When the recovery circuit works , the bypass diode across the shaded panel will be bypassed and hence, the several peaks in the characteristic curve does not occur.

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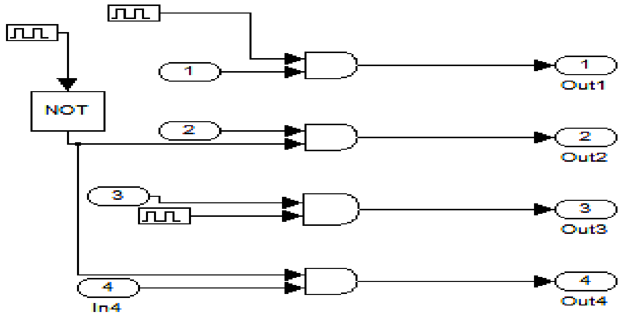

Fig 8. Gating signals to switches

In the Fig 8. the input values 1to 4 is obtained from the coding which along with the pulses is given to the AND gate and is given to the MOSFET switches. The pulses will be given whenever it is required.

4.3 Recovery Circuit

The recovery circuit is designed for four panels in the previous section and it can be extended to 8 or 16 etc. if needed [14]. The input insolation is given using timer in such a manner that it varies with time for each panel, so that the recovery circuit turns on automatically for the particular panel when the shading occurs. Table 2. shows the insolation condition for the each intervals of time.

For the two module circuit with and without recovery circuit during partial shading condition is well differentiated in the Fig 9. It is observed that the power obtained with the recovery circuit will be higher than that of the circuit with bypass diode alone. The red colored curve represents the shaded modules without bypass and recovery scheme. The power will be much lesser in this case. The green color curve represents the circuit with bypass diode alone and it depicts the presence of two peaks. The blue colored curve is the one with the recovery circuit which bypasses the bypass diode and retrieves the maximum power. The difference is well depicted in the Fig 9. Same difference can be viewed in the VI characteristics also. The output power and voltage of the circuit shown in Fig 10. varies with respect to insolation in that particular time. It represents the overall power and the voltage.

TABLE 2 :
SHADING CONDITIONS FOR EIGHT MODULES

	Insolation (W/m²)			
Duration(s)	0	0.5	1	2
PV1	1000	500	600	1000
PV2	1000	500	500	500
PV3	1000	1000	1000	1000
PV4	1000	200	500	800
PV5	1000	100	600	1000
PV6	1000	500	1000	0
PV7	1000	500	600	1000
PV8	1000	200	600	1000

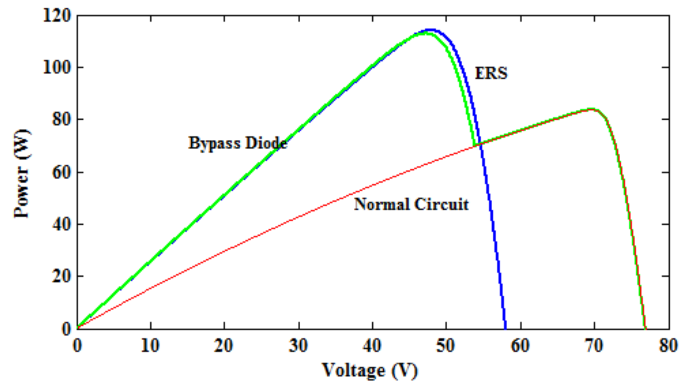

Fig 9. PV curves obtained with bypass diode and ERS

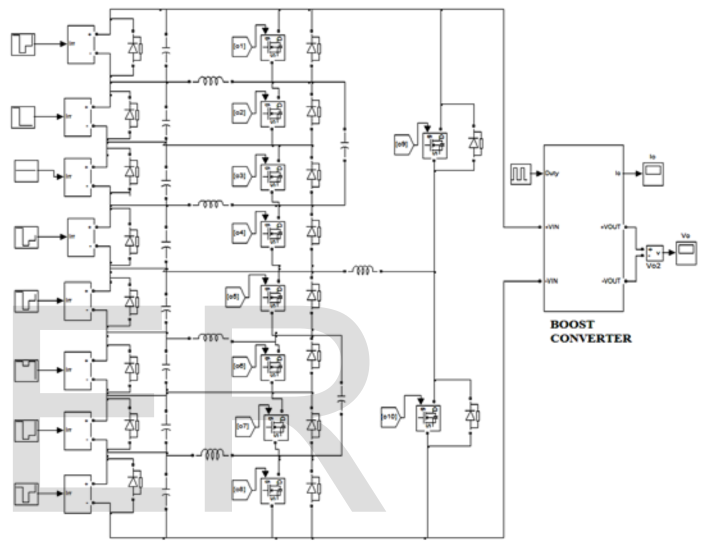

Fig 10. PV system with recovery circuit

4.4 Operation of the Recovery Scheme

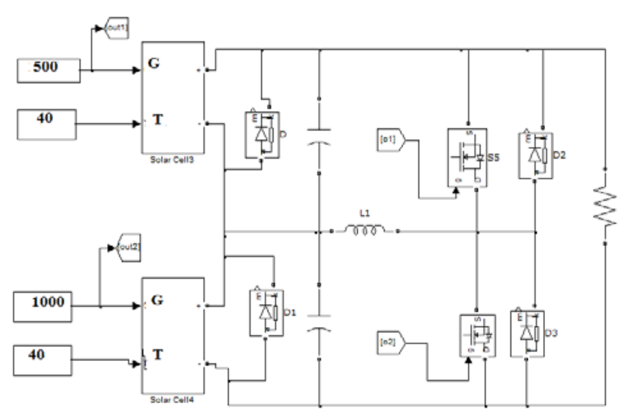

Fig 11. Recovery scheme for 2 panels

The operation of the energy recovery circuit is explained briefly using the two panels for simplicity as shown in Fig 11. Let us consider that first panel is shaded and it carries a current of 3A and the healthy panel carries the current of 10A. In mode 1, the 3A from 2nd panel flows through the panel 1 and then to the load. The remaining 7A circulates through the inductor and the second switch. In mode 2, 3A from the first panel and 7A stored in the inductor flows through the body diode of the switch 1 to the load. Thus, the entire current is made available to the load without damaging the shaded panel.

5 Output Waveforms

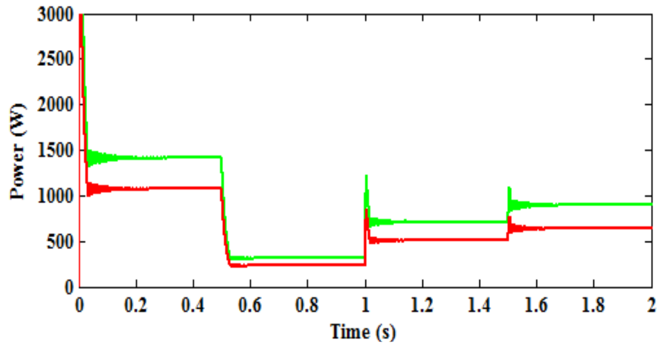

Fig 12. Output Power varying with respect to time

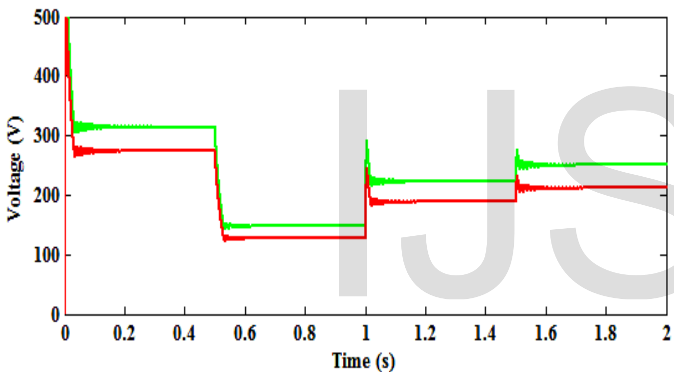

Fig 13.Output Voltage varying with respect to time

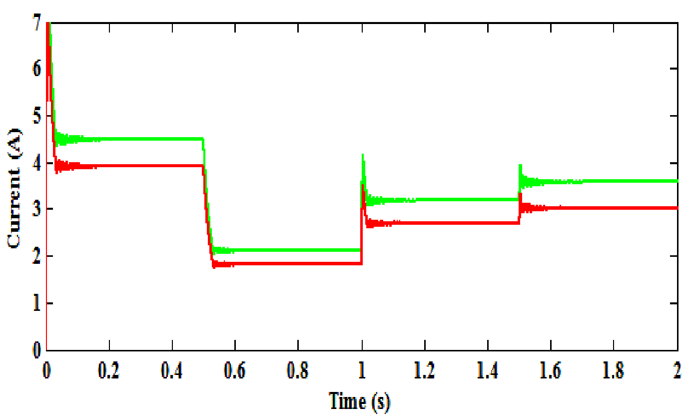

Fig 14. Output Current varying with respect to time

In the Fig 12.,Fig 13., and Fig 14. green color waveform represents variation of power, voltage and current with respect to the insolation level with energy recovery circuit as shown in Table 2. and for the same conditions the red color waveform is depicted without energy recovery circuit, with only bypass diode.

6 Conclusion

A novel method for effectively tracking the power from the shaded panel has been simulated and studied for various conditions. It is observed that it extracts the extra power which is wasted when a bypass diode is used. It also avoids the damage caused to the panel when the bypass diode is not used. Hence, the proposed circuit is used for extracting the higher power and also for protection purpose as it maintains the current in all the panels to be having the current which is flowing through the shaded panel.

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