Experimental Investigation of Hotspot Detection and Isolation in Shaded Photovoltaic Cells

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Abstract: In recent days utility of renewable energy sources is increased for various purposes and at varied locations under various conditions. While using solar panels for generation of power, many challenges are there. One of important challenge is partial shading of the panel and subsequent failure of PV cells due to hotspots. In the shading on the PV cell, the shaded part of the module operates at current levels higher than those of the non shaded PV cells, and affected cells are forced to reverse bias and start to dissipate power, consequently temperature increases due to overheating (hotspot) of the PV cells. Hotspot may also occur due to some manufacturing defects, impurities of the PV cell material etc. Based on these considerations an automatic detection scheme (KIT) is developed to identify the hotspot condition, and to isolate the PV panel which is under hotspot hence avoid the permanent damage of the cell and remove the power losses. If an error is detected (the current is reversed), the micro controller gives the signal to alarm circuit and relay circuit. Then the Alarm circuit gives an alarm sound and the affected panel is isolated by using relay circuit and restarts automatically if the error is removed. The removing of error is done by manual removing or panel tracking or automatic cleaning systems (depending on requirement).

Keywords: photovoltaic (PV) systems, current sensors, microcontroller, relays, reliability.

1. Introduction

The sun radiates the energy uniformly in all directions in the form of electromagnetic waves is called solar energy. Sun radiates the energy per year is 2.8*10^23 kw/year, but the earth receives the energy per year is 1.5*10^18 kw/year. "The rate at which solar energy arrives at the top of the atmosphere is called solar constant Isc. This is the amount of energy received in unit time on a unit area perpendicular the sun's direction at the mean distance of the earth from the sun"[1].

Photovoltaic Effect

The extraction of electromotive force as the result of the absorption of ionizing solar radiation is called as the photovoltaic effect and is first observed by Becquerel. The device which used to convert the solar radiation to electricity is called the solar cell or photovoltaic cell. The single cell can generate the power of 0.5watt at maximum irradiation of 1000w/m² per the area of 2×2cm [1].





Silicon semiconductor is used to make the solar cells. The combination of a p-type and n-type semiconductors constitutes a PV cell or solar cell. When a semiconductor absorbs photons from the sun, free electrons are created with high energies compared to the electrons by which bonding in the base crystal is provided. An electric field must be there, once free electrons are created to induce these high energy electrons to flow out of the semiconductor to do useful work. In most solar cells a junction of materials provides an electric field and they consist of different electrical properties [1]. When the shading occurs on the solar cell, there are consequent mismatches in the irradiation of the PV cells the in the module. Under this condition the diode part of the cell is reverse biased (voltage across cell is reversed) due to this the current flows in reverse direction in that particular cell and starts dissipate power, with a consequent temperature increase. This causes the overheating (hotspot) of the PV cells. This reverse current may be several times more than the normal maximum current (short circuit current) of the PV module [2], [3].

If the reverse current is not controlled in correct time there will be a chance to high power dissipation this causes the overheating of PV cell. When the temperature reaches critical value the cell is permanently damaged [4]. In this paper the hotspot is detected and affected panel is isolated. Whenever the shading is removed that panel automatically connected to the grid.

2. Literature Survey

In [5], simulation procedure had done on performance and working of partially shaded PV cells, as a result a 30% of reduction can be observed when total shadow occur on just a single PV cell. In [6], the hotspots are analyzed in crystalline silicon. According to this Hotspot occurs in a PV module when its operating current exceeds the reduced short circuit current of a shadowed solar cell or group of cells within it. The causes of reduced short circuit current are,

- Non uniform illumination of the PV panel
- Degradation of individual cell due to cracking
- Open circuits in series- parallel connections

These hotspot mechanisms are due to reverse bias in PV cells which lead to P-N junction breakdown. All hotspots are not the results of the P-N junction effect.

In [3] & [7], bypass diodes are used to limit the reverse voltage of PV cell but it has been proven that [4], the hotspots may still occur even if bypass diodes are used. In earlier a few approaches [8], [9] have been proposed to identify the hotspot condition based on current monitoring, followed by a theoretical comparison of current. The correct computation of the current theoretical value is however critical issue, given its strong depends on environmental parameters. In [10], the hotspot is detected by using hysteresis comparator, NOR gate, etc.

In this work an experimental investigation had done on hotspot detection and isolation of panel which is under hotspot to avoid the permanent damage of the cells. For this experiment the equipment required are hall effect current sensors, micro controller, relay circuit, alarm signal, LCD etc.. And I-V characteristics are obtained in mat lab programming.

Electrical Model of PV cells



Figure: 2. Electrical model for PV cells.

When the PV cell exposed to sunlight, it generates a photo current given by

Iph=(Jph.Acell.Girr)/GmaxGirr (W/m^2) = solar irradiation Gmax=1000(W/m^2) = max solar irradiation Jph=3.43(μ A/m^2) = max current density The current delivered to the load is Ipv = Iph-Id1-Id2-IrshId1 = saturation current due to the diffusion mechanism Id2 = saturation current generated by the recombination in the space charge layer. Irsh = leakage current of the PV cell Reverse breakdown current is given by $Ibd=a.(Vpv/Rsh).(1-(Vpv/Vbd))^{-m}$ a, m are the fitting parameters a=1.93, m=1.10

Mat lab result:



Figure: 3 I-V characteristics with different values of shunt resistance

The current Ipv increases with the decrease of Vpv, and strongly depends on the shunt resistance Rsh [10]. If the Rsh is diminishing, the current increases faster, and large power is dissipated on Rsh, this causes the temperature increase on that particular panel. It may cause the permanent damage of PV cell. To avoid this problem we proposed a hotspot detection scheme and isolation of PV panel which is under hotspot.

3. Experimental Setup

The experimental setup consists of four 50Wp PV panels, four 20A current sensors, micro controller, alarm, relay circuit, LCD display, connecting wires etc. The specifications of all these equipment are given below.



Figure: 4 Block Diagram



Figure: 5. Experimental setup of hotspot detection and isolation

Components Specifications:

PV panels Electricity performance of solar panel: Condition: 1000W/sq-m AM1.5 Temperature: 25i³ Model: MS1250, 50W

Table 1: Specifications of PV panels

Specifications	Ratings
S/C current Isc	3.285
O/C voltage Voc	22.298
Max power Pm	54.106
Max current Im	2.966
Max voltage Vm	18.241
Form Factor (FF)	73.87
EFF (%)	15.62
Series resistance Rs	0.740
Shunt resistance Rsh	123.52

Hall Effect current sensors

Table 2: Specifications of Hall Effect current sensors

Specifications	Ratings
Model name	Wcs2210
Amp ratting	10 amps
Voltage	60v
Туре	Non contact Hall's

Micro controller

Table 3: Specifications of Micro controller

Specifications	Ratings	
Model name	Arduino Nano	
Controller name	Atmega 328p	
Voltage	5v	
I/O pins	22	
Inputs	8 ADC 1024	
Outputs	14 Digital	
Memory	32Kb	
SRAM	2KB	

Relay circuit	
Table 4: Specifications of Relay cit	rcuit

¥		
Specifications	Ratings	
Model name	Hrs4h s dc 12 V	
Amp rating IN	100 amp	
Voltage IN	12V	
Amp rating OUT	10 Amp	
Voltage OUT	24 DC /230V AC	
Туре	EM Coil (non-solid state)	

LCD display		
ble 5: Specifications of LCD display		

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Specifications	Ratings		
Model name	20×4 Alpha numeric		
Operating voltage	5 – 5.5 V		
Operating mode	8 bits		

Alarm

Here piezo buzzer is used for alarm with operating voltage of 3 - 15 V. Here 5V is applied.

4. Operation of Hotspot detection Scheme



Figure 6: Circuit board of hotspot detection and isolation



Figure 7: Schematic diagram for single panel

When the PV panels are generating the power, the current of the panels are sensed by the Hall Effect current sensors, due to Hall Effect they give equivalent voltage signals to the micro controller [11]. The micro controller converts analog signal to digital values, then the voltage and current values of four panels are displayed in the LCD. Whenever the shading occurs on a cell of any PV module the cell is reverse biased and starts dissipating power [2],[3], then the micro controller gives the signal to an alarm and a relay circuit of respected panel [12]. Alarm is on and relay circuit trip the corresponding panel from the grid. LCD displays which panel is affected (the panel current is zero) and that panel starts working automatically after the hotspot is removed. This is all done by the micro controller by giving the related programs to the micro controller.

5. Results

It is implemented and validated the proposed hotspot detection and isolation for 3A of load; the three observations are given below fig 8, fig 9 and fig 10. Fig 8 is observed when there is no partial shading. At this time four panels shared the load equally (0.75 each), fig 9 is observed when partial shading occur on panel 4 without isolation, the reverse current is clearly observed in the 4th line of the LCD, and fig 10 is observed at same partial shading conditions with isolation on the same panel, it is clear that, the current from that panel is isolated so that the panel is protected from the hotspot.

Volt Volt Volt	19.12 19.12	Amp 0. Amp 0. Amp 0.	75A 75A 75A 75A
VOL	o tserv	mine or	i um

Figure 8: Without any partial shading condition

Тα

Volt	19.12	Amp	1.23A
Volt	19.25	Amp	1.23A
Volt	19.16	Amp	1.23A
Volt	14.20	Amp	-0.69
F igure 9: Wi	th partial sha	ding wit	thout isolation
Volt	19.12	AMP	1.00A
Volt	19.25	AMP	1.00A
Volt	19.16	AMP	1.00A

Figure 10: With partial shading with isolation

The experiment is conducted at 3A load, the result with isolation (fig 10) shows that, load draws 1 amp from 3 panels without any excess current. The partially shaded panel (4^{th}) is completely isolated, and then the current is zero in that panel. Whereas in fig 9 (without isolation) we can observe the excess current of 0.23 amps from each panel which is responsible for 0.69 amps reverse current in 4^{th} panel. In this case, the 4^{th} panel is not isolated which can cause permanent damage of the solar panel. Our hotspot detection and isolation project will help to improve the solar panel life and performance.

6. Conclusion

The following conclusions were drawn from the experimental work. Under partial shading condition the reverse currents are observed clearly. These reverse currents can cause the temperature increase; if the temperature reaches critical value (Hotspot) the cell is permanently damaged.

A model is proposed to detect hotspot and isolate panel which is under hotspot by using relay circuit. That panel starts working automatically after shading is removed. The panel parameters are observed for three conditions they are, (i) without any partial shading, (ii) with partial shading without isolation (iii) With partial shading with isolation. This helps to protect the solar panel from permanent damage and improve the reliability and performance of solar plant.

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