RECONFIGURATION SOLUTION FOR EXTRACTING MAXIMUM POWER IN THE AGED SOLAR PV SYSTEMS

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Abstract: *Photovoltaics (PV) is a simple method of harnessing the sun's energy by using solar cells which directly converts the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long lasting. Because of the above natures we go for Solar PV. The problem behind solar PV is its efficiency. Efficiency of the panel is highly reduced because of the following (i) physical damage, (ii) improper maintenance and cleaning and (iii) aging. Aging is caused by the expose of solar PV panels to weather and wind for years. Because of this, output power of the individual panel varies due to dame and overheating of the panel. This leads to loss in their maximum efficiency. The rated power output of solar panels typically degrades at about 0.5% per year. In this paper the analysis and reconfiguration solutions for the aged or old solar PV panels for getting maximum power is proposed. This will be very much helpful for all solar power plants in the future.*

Keyword: *Solar PV, Aged Panel, Reconfiguration, Maximum Power Generation.*

1. INTRODUCTION

The energy and environment issues have become serious due to global warming. Increasing renewable energy based power plant is the best way to reduce the global warming effect. For this solar energy, as a kind of renewable energy, has a good application prospect. The Solar PV systems are designed either to feed the grid (several MW power) or for the residential applications (few kW power). The problem behind solar PV is its cost and efficiency. Efficiency of the panel is highly reduced because of the following temperature and physical damage. For the aged panels due to the expose of solar PV panels to weather and wind for years, overheating or damage may occur. Because of this, output power of the panel reduces and temperature of the panel increases, that leads to loss in their maximum efficiency. The rated power output of solar panels typically degrades at about 0.5% per year. PV panels are generally grouped or connected to match the voltage and current requirements by the grid or loads. This grouping can be done in many ways. The usual interconnections style to construct PV array using modules is as shown in Figure 2. In series–parallel (SP) connection modules are connected in series to form strings and then theses strings are connected in parallel. In total cross tied connection (TCT) the modules are first connected in parallel and then the parallel connected panes are interconnected.

As the panel getting older day by day, the output of the panel starts to degrade depends on the damage during that days. In an array all the panels are not equally damaged at same age. Hence, depending on the damage the panels are reconfigured at regular interval of years so that we can improve its efficiency.

In this paper, the performance of various types of solar cells against aging is given in detail in Section 2. Section 3 observes, analysis and reconfiguration of aged solar PV modules. Simulation and hardware implementation of the proposed work is shown is Section 4. Simulated and experimental results are presented in Section 5. Section 6 provides the summary and conclusions.

1.1. Related Works

Srinivasa Rao Potnuru, Dinesh Pattabiraman, Saravana Ilango Ganesan and Nagamani Chilakapati were discussed how to obtain maximum power even for a large size array by optimal Sudoku configuration without modifying TCT (Total Cross Tied) base connections [2]. Similar to that, Koray S_ener Parlak proposed a reconfiguration which is done by fixed and adaptive part along with the switching circuit and the short circuit current fed as the control signal for the controller, thus reducing number of connections [4]. Then, Abdulkader Tabanjat , Mohamed Becherif , Daniel Hissel made a dynamic reconfiguration by a switching circuit with formulations where a fuzzy logic controller and FL detector were used to detect the shading and thereby they made reconfiguration [3].

L. Fialho, R. Melicio, V.M.F. Mendes, J. Figueiredo and M. Collares-Pereira discussed about information of panel in terms of open circuit, maximum power point and short circuit conditions and simulation by heuristic method to find IV, PV curves in both normal and partial shading conditions [5]. Ahmed Fathy proposed a new optimization approach based on modified artificial bee colony algorithm which mitigates the power loss due to partial shading and shadow conditions by obtaining global maximum power point [6]. Vaibhav Vaidya and Denise Wilson developed a time based array reconfiguration to solve constrained objective function of PV module power loss and mitigate the shading effect [7].

All these techniques differ from each other in several aspects such as accuracy, complexity, convergence speed and efficiency but reconfiguration for the aged solar PV systems is not discussed.

1.2 Modeling of PV Panel

A mathematical model is developed for 10W solar module (Panel) in MATLAB simulink. Figure 1 shows the equivalent circuit of single solar cell using 2 diodes. The I-V characteristic of the solar cell is derived from accurate two exponential diode model [12]. The current output of the solar cell can be derived as

$$I = I_L - I_0[exp^{\,q(v+IRs)/n_1kT} - 1] - I_{01}[exp^{\,q(v+IRs)/n_2kT} - 1] - \frac{V+IR_s}{R_p} \quad (1)$$

I_L -Light Induced Current

I_0 -Saturation Current of the First Diode

I_{01} -Saturation Current of the Second Diode

k -Boltzmann Constant

T -Device Operating Temperature

q -Elementary Charge on an electron

n_1 -Ideality factor of first Diode (Diode Emission Coefficient)

n_2 -Ideality factor of second Diode (Diode Emission Coefficient)

V -Voltage across the cell

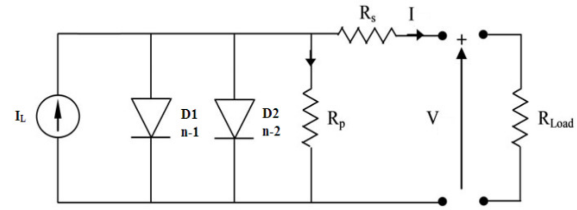

Figure 1. Equivalent circuit of single solar cell using 2 diodes

2. PERFORMANCE Vs AGING

Solar panel manufacturers put a lot of effort in making their solar panel. The panel's maximum output power not only depends on the amount of irradiation but also on the electrical connection of the panels. The maximum output power of the panel decreases year by year due to ageing. Table 1 shows the details for various materials.

Table 1. Loss in Output due to aging

Solar cell type	**Output loss in percent per year**	
	Pre installation	Post installation
Amorphous silicon (a-Si)	0.96	0.87
Cadmium telluride (CdTe)	3.33	0.4
Copper indium gallium selenide (CIGS)	1.44	0.96
Monocrystalline silicon (mono-Si)	0.47	0.36
Polycrystalline silicon (poly-Si)	0.61	0.64

However, thin-film solar panels (a-Si, CdTe and CIGS) degrade faster than panels that are based on mono and polycrystalline solar panels. In aged PV panels reconfiguration is very much essential, because low power and high power producing panels should be isolated to get the maximum power.

3. ANALYSIS AND RECONFIGURATION OF AGED PV's

3.1 Panel Specification

A 3x3 SP type (9 panels) PV array made up of Poly crystalline PV module is considered. The modules are of 10W power rating. Under Standard Testing Condition (STC), that is 1000W/m^2 of irradiance at 25^{o}C, each module has the open circuit voltage (V_{oc}) of 21.96V and the short circuit current (I_{sc}) of 0.59A. The three PV modules in each leg are connected in series and the three legs are connected in parallel as given in below Figure 2. MATLAB simulink is used to perform simulation of the conventional and proposed PV systems.

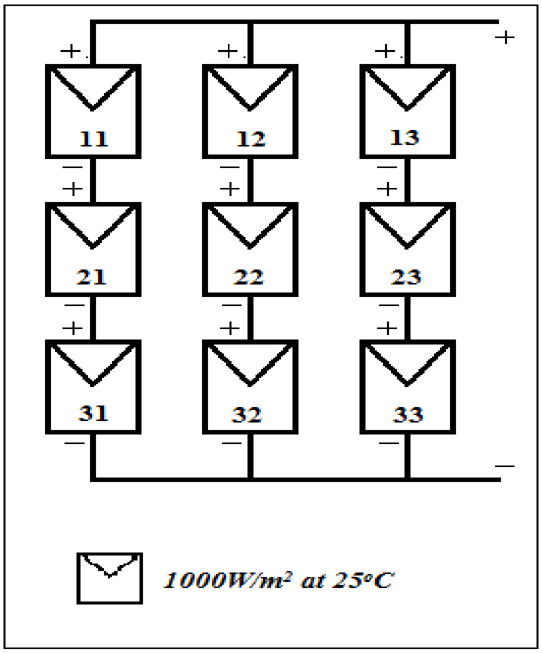

Figure 2. SP connection of selected modules at STC

3.2 Analysis of aged PV array

Considering the PV array is operated under STC with no panel (module) have any damage or overheating as shown in Figure 2. Under this condition the PV array produce a open circuit voltage (V_{oc}) of 65.88V and a short circuit current (I_{sc}) of 1.769A.

Case(i): In the above case all the modules are healthy and produce rated output. Now it is considered that some of the modules are damaged which is shown in the below Figure 3. The damaged modules are shown in different colour (due to the damage average amount of irradiation received by the panel is varied). In this case the aged modules have no hotspot but the average irradiance receiving level may vary. Modules 11, 12 and 13 are equally damaged in the array which is connected parallel to each other. The average irradiance received by these modules is about 600W/m^2 at 25^{0}C. Similarly, modules 21 and 22 are equally damaged and the average irradiance received is about 800W/m^2 at 25^{0}C.

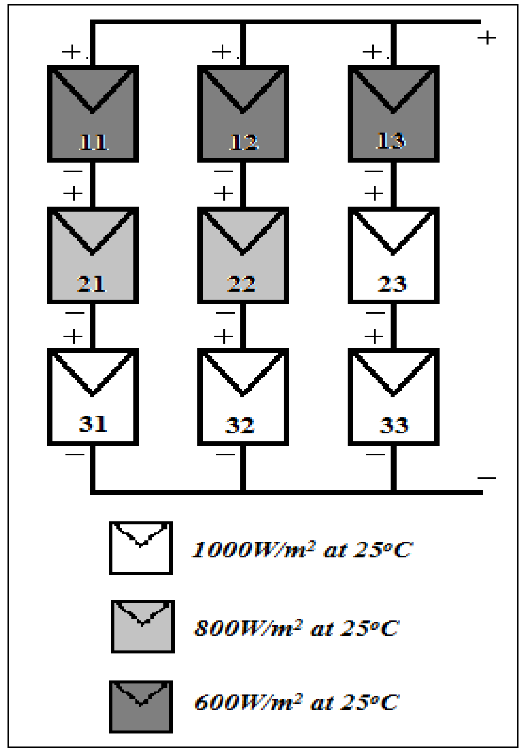

Figure 3. Connection of aged modules (different irradiance) in parallel legs

For the above case, the total open circuit voltage (V_{oc}) of the array is reduced to 31.8V and the short circuit current (I_{sc}) is also reduced to 1.39A.

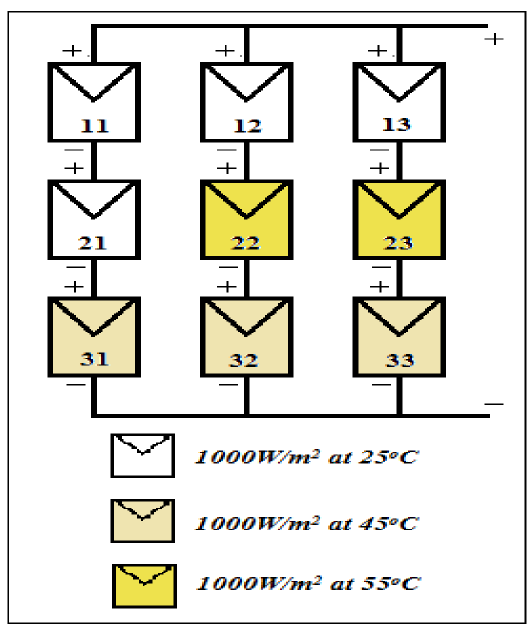

Figure 4. Connection of aged modules (different temperature) in parallel legs

Case(ii): In *case(i)*, the aged modules have no overheating but damaged. In this case it is considered that the panels are not damaged but the panels are over heated (temperature of panels get varied due to the ageing). Case ii is shown in the Figure 4. In that modules 31, 32 and 33 have same temperature of 45^0C and modules 23 and 22 have same temperature of 55^0C which is shown in different colours. All modules have same irradiance level of $1000W/m^2$. For the above case, the total open circuit voltage (V_{oc}) of the array is reduced to 38.9V and the short circuit current (I_{sc}) is also reduced to 1.55A.

Case(iii): In this case, the aged modules have overheating as well as damage. Case iii is shown in in the Figure 5. In that modules 11, 12 and 13 have same damage and overheating due to aging. It is having temperature of about 45^0C and the average irradiance is of about $600W/m^2$. Similarly, modules 21, 22 and 23 have 25^0C and $1000W/m^2$ and modules 31, 32 and 33 have 55^0C and $1000W/m^2$. For the above case, the total open circuit voltage (V_{oc}) of the array is reduced to 33.72V and the short circuit current (I_{sc}) is also reduced to 1.319A.

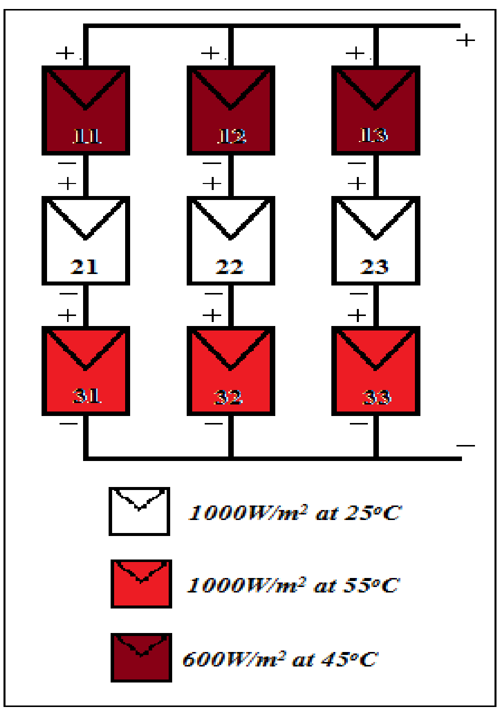

Figure 5. Connection of aged modules (different irradiance and different temperature) in parallel legs

3.3 Reconfiguration solution of aged PV array

The only solution for aged PV plants to produce maximum output power is by the Reconfiguration technique. Reconfiguration is the rearrangement of solar PV panels, thereby obtaining the maximum output power. In all the above cases, the similar aged panels are connected in parallel or any other position in the array. As a result, the output power is highly reduced. All the above three cases in analysis section are reconfigured which is explained below to get the maximum power output.

Case(i): As mentioned earlier in this paper, the similar damaged panels which are connected in different position is now connected in one leg. Figure 6 shows the reconfigured diagram for *case(i)*.

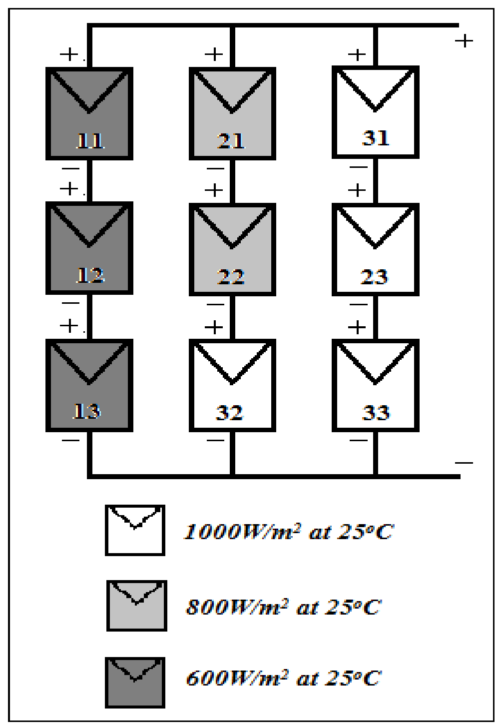

Figure 6. Reconfiguration of aged (different irradiance) solar modules

For this reconfigured array, the total open circuit voltage (V_{oc}) of the array is improved to 35.8V and the short circuit current (I_{sc}) is also improved to 1.93A.

Case(ii): Figure 7 shows the reconfigured diagram for *case(ii)*. Here, the reconfiguration is done by connecting the overheated solar modules having same cell temperature in series combination. For this reconfigured array, the total open circuit voltage (V_{oc}) of the array is improved to 53.24V and the short circuit current (I_{sc}) is also improved to 1.828A.

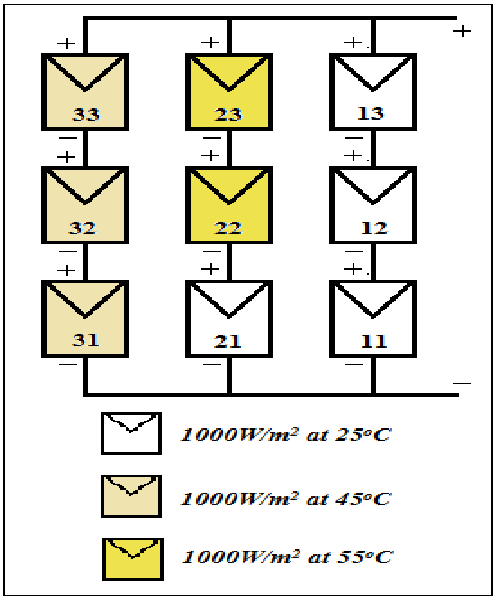

Figure 7. Reconfiguration of aged (different temperature) solar modules

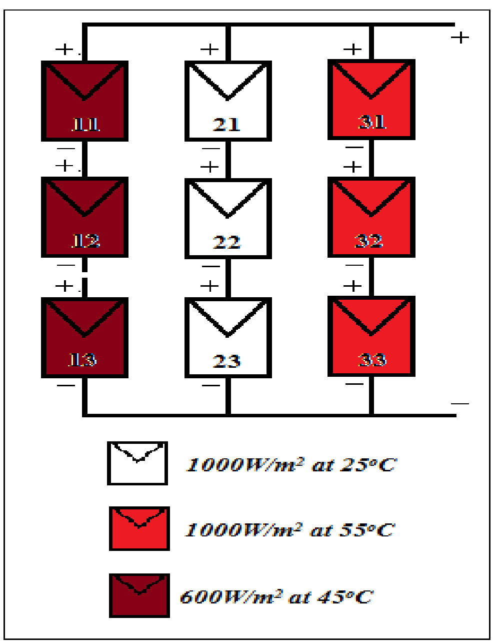

Figure 8. Reconfiguration of aged (different irradiance and temperature) solar modules

Case(iii): Figure 8 shows the reconfigured diagram for *case(iii)*.This case is evolved by incorporating the reconfiguration techniques of the above two cases which is shown in Figure 8. In this case, the reconfiguration is made by connecting equally damaged or overheated modules (having same irradiance and same temperature) in same leg. For this reconfigured array, the short circuit current (I_{sc}) is 1.585A and the open circuit voltage is (V_{oc}) 33.72A.

4. SIMULATION AND HARDWARE IMPLEMENTATION

4.1 Simulation of proposed work

All the above cases are simulated by using MATLAB/SIMULINK. Mathematical model is used for modelling of Solar PV panel (module). Figure 9 shows the simulation of 3*3 solar PV array for measuring open circuit voltage (V_{oc}) and short circuit current (I_{sc}) at different irradiance and temperature.

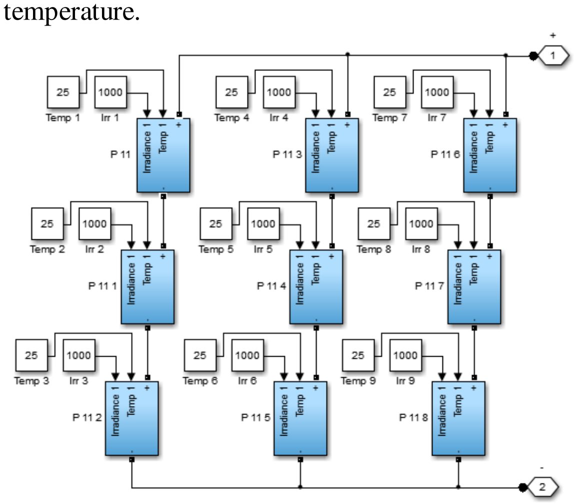

Figure 9. Simulation of 3*3 Solar PV array

4.2 Hardware implementation of proposed work

As mentioned earlier, the hardware model is implemented by taking the same rating used in the MATLAB simulation. The hardware setup of the proposed work is shown in 10.

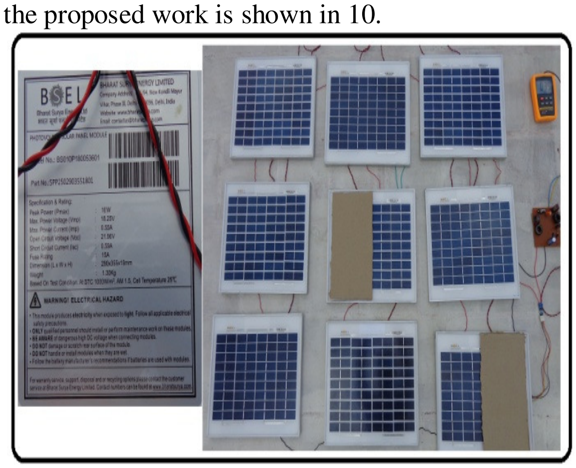

Figure 10. Hardware setup of proposed work

5. RESULTS

The simulation and practical results for the various cases are summarised in the Table 2 and 3. The simulation and hardware results for the same cases are compared in the table 4 with respect to power output of the array. From the table 4 it is clear that the simulation readings are on par with the practical reading. For creating the damages panels are shaded by card board sheet. For variation in panel's temperature, corresponding panels are cooled, because at environment temperature panels are heated up to 55^o C.

Table 2. Simulation Results

CASES	Simulation Results					
	Before Reconfiguration		After Reconfiguration		Before Reconfiguration	After Reconfiguration
	V_{oc}(V)	I_{sc}(A)	V_{oc}(V)	I_{sc}(A)	Output Power (W)	Output Power (W)
Case(i)	31.8	1.39	35.8	1.93	34.0	53.2
Case(ii)	38.9	1.55	53.24	1.82	46.4	74.6
Case(iii)	33.72	1.31	33.72	1.58	34.0	41.0

Table 3. Hardware Results

CASES	Hardware Results					
	Before Reconfiguration		After Reconfiguration		Before Reconfiguration	After Reconfiguration
	V_{oc}	I_{sc}	V_{oc}	I_{sc}	Output Power (W)	Output Power (W)
Case(i)	33.1	1.45	36.1	1.99	37.0	55.3
Case(ii)	37.6	1.52	53.1	1.78	44.0	72.8
Case(iii)	32.5	1.25	32.6	1.54	31.3	38.7

Table 4. Comparison Simulation and Hardware Results

CASES	Simulation Results after Reconfiguration	Hardware Results after Reconfiguration
	Output Power (W)	Output Power (W)
Case(i)	53.2	55.3
Case(ii)	74.6	72.8
Case(iii)	41.0	38.7

6. CONCLUSION

In this paper, a new reconfiguration method is proposed for the aged solar PV systems. The proposed method generates maximum power from a 3×3 PV array under various cases. In this method, total panels in the array are connected in series parallel type (SP). The proposed method is implemented in both simulation and practical setup for the 3×3 PV array. In simulation, damages in panel are created by varying the irradiation of the panels in the array. In practical setup, damages in panel are created by hiding the panels in the array by cardboard sheet. For achieving various temperatures panels are cooled using conventional methods. The obtained practical results are on par with the simulation results. Both the simulation and practical results shows that the power generation is maximum after the reconfiguration. This paper concludes that every solar power plant should be reconfigured once in a year to extract maximum power.

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