Effect of Mismatch on the Conversion Efficiency of Solar Modules

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***Abstract*: - One of the major causes of power losses in the Photovoltaic module is mismatch effect. Mismatch losses are a serious problem in PV modules and arrays under some conditions because the output of the entire PV under worst case conditions is determined by the solar cell with the lowest output. This paper presents study on the effect of mismatch on the conversion efficiency of solar module connected in series and parallel. Some techniques of shadowing from a single cell to three cells and six cells both in series and parallel were employed. It was found that there is power lose in series than in parallel combination as a result of shadowing some cells on the module. The power loss in series combination was found to be between 21 to 73%; while in parallel combination power loss ranges from 33 to 52%. The overall voltage in series combination has lowered from 32-10V while the current in the same series combination remains 3.2A.But in parallel combination, the current decreases from 6.1 – 3.1 A and a slight decrease change in the voltage from 22 – 20V all to the non-shaded to the shadowing of one to six cells in the module. The study observed that the percentage loss in series combination is found to be more than that in parallel combination. The total power generated by the mismatching modules is less than the power produced by one module.**

***Keywords:* Photovoltaic Cells, Mismatch, Series, Parallel, Circuit**

I. INTRODUCTION

Energy Situation

For centuries, energy in its entire ramification has always been an essential input to all aspects of the human development especially for modern age. It is indeed the life wire for industries producing the fuel for transportation as well as manufacturing and for other conventional power generations and utilization [1].Global energy consumption has almost doubled in the last three decades. In 2012, about 87% of the primary energy consumption is from fossil fuels (33% oil, 24% natural gas, 30% coal), 4% from nuclear fuels, 9% from renewable resources, of which the main one is hydroelectric with7%, whereas the remaining 2% consists of non-commercial biomasses, such as wood, and other types of fodder, that in rural-economies still constitute the main resources [2].

The trend is not going to slow down giving the increasing rise of educated people with their attendant change in lifestyle which depends largely on energy for transportation, recreation and production. It is obvious from these figures that the major sources of the energy we consume today are from fossil fuels, which together account for 87%. Unfortunately, fossil fuels have been identified as having major negative impact on our environment as the primary agents of global warming as a consequence of their utilization in transportation producing gases such Carbon (II) oxide and other Green House Gases. For instance, In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded that "It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century [3].

The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) in the lowest emissions scenario, and 2.6 to 4.8 °C (4.7 to 8.6 °F) in the highest emissions scenario[4].

In view of the above, rising fears over the penalties of climate change may relentlessly limit future access to fossil fuels. This will precipitate mandatory choice between energy and environment which could hasten a major economic crisis, an environmental crisis, or both. Avoiding such a crisis will be hard, because fossil energy resources are an essential part of the world's energy supply and climate change is mainly driven by the accrual of carbon dioxide in the atmosphere. Carbon dioxide (CO_2) is the inevitable product of fossil fuel consumption. Therefore, the use of fossil fuels results directly into global environmental concerns. For these reasons, there is increasing interest in replacing fossil fuels with renewable energy sources as mitigation options. Renewable energy resources are available in both the developed and the developing countries in significant quantities [5].

As a result of the energy crises in the 1970's and the era of population explosion with growing public awareness on the cost of conventional energy, this has led to the search for various renewable energy sources. Renewable energy resources which include solar radiation, hydropower, wind, geothermal and biomass are available in both the developed and the developing countries in significant quantities. Among these renewable energy resources solar energy has availability almost everywhere, exhaustible and cannot be contaminated[6]. There's also easy maintenance because of the absence of moving parts.

Photovoltaic power system involves the conversion of sunlight into electricity and is achieved using materials known as semiconductors, which are formed mostly from silicon material when properly doped, solar cells are obtained whereby incident sunlight (photons) upon strike their surface with sufficient energy will cause the release of electrons[7]. Movement of the electrons from cells to the external circuit results in the production of electricity. The form of electric current generated is direct-current (dc) which could be used to charge batteries for storage and subsequent usage when there is no sunlight available. However, alternating current appliance could be powered with photovoltaic[8]. An inverter in this case is necessary to change the dc voltage into an alternating current type (ac) suitable for most commonly available appliances such as fluorescent lamps, fans and fridges. In most cases, charge regulators and other controls can be included to protect and ensure proper charging of the storage batteries[9].

Solar photovoltaic is currently being utilized in many places including Nigeria for a variety of applications such as village electrification, water pumping for both community water supply and irrigation, powering of microwave repeater stations and for powering of vaccine storage refrigerators in rural clinics. A practical example of the use of photovoltaic has been demonstrated at Kwalkwalwa village in Sokoto state in which about 50 households are served from a 7.2 kWp photovoltaic generator. The efficiency of a cell can be decreased by creating different short circuit current by shadowing one of the cells or by mismatch either through shadowing or crack of the module [10].The crack of the module really affects in such a way that the maximum power output cannot be met because of the crack. The main cause of mismatching between cells is partial shadowing which often occurs during module operation. Fortunately, practical cells do have larger leakage currents. The leakage current represented by the shunt resistor in the equivalent model of a solar cell, decreases the individual cell efficiency but makes the module performance much less sensitive to cell mismatching and shadowing effects[11].

The effect mismatch may not result to the power loses but may also cause serious damage in the modules if precautions are not taken. This research intends to study the power loses or drops experienced on mounting solar modules connected in series and parallel combinations.

II. LITERATURE

2.1 Photovoltaic Cell

A photovoltaic power cell is the individual part of a solar module that converts sunlight directly into electricity[12]. The most widely used and technically developed type of solar cell is the silicon cell. Its popularity stems not from its scientific excellence but from the fact that it builds on the extensive solid-state technology and manufacturing experience of the semiconductor industry. Silicon is chemically stable and can yields upto 25% conversion efficiency[13].

2.1.1 The Equivalent Circuit

Figure 2.1 shows the equivalent of a typical solar cell. The equivalent circuit is used to show the variation of the open circuit voltage with the short circuit current if no external connections are made a voltage will build up across the circuit. At steady state the voltage produce will equal the photo current and the open circuit voltage (V_{oc}) condition will be established.

When the short circuit current is irradiated, the reverse saturation current will increase, in other words the I_{sc} is established [14].

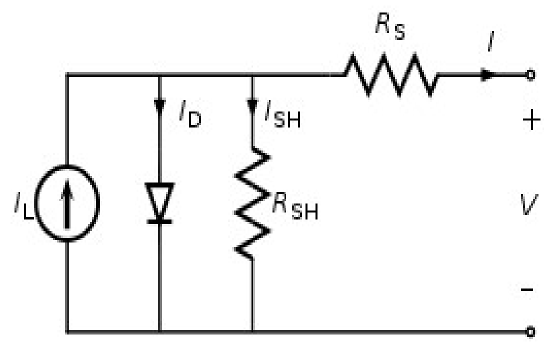

Figure 2.1: Equivalent circuit of solar cell (researchgate,net)

2.1.2 The I-V Characteristic Curve

Each photovoltaic cell, module, and array has its own unique current/voltage relationship, known as an I-V curve (an I-V cure is used to make sure a photovoltaic system is operating as close as possible to its peak power point) that can be graphically depicted as shown in the Figure 2.2. The graph shows the relationship between current (I) output, measured in Amps, and Voltage (V) output, measured in volts, from 0 volts at short-circuit current to 0 Amps at open circuit voltage, as the resistance of the load across the module is increased from short to open circuit. Short-circuit current (l_{sc}) is current flowing unimpeded from its source through an external circuit with noload or resistance factor; it is the maximum flow of current (amperage) possible. Open-circuit Voltage (V_{oc}) describes an open circuit with the absence of flowing current. The voltage potential across a photovoltaic cell (or module or array) in full sunlight in open circuit is the maximum possible voltage the device is capable of producing[15].

On every I-V curve, there is a point in the "knee" of the curve, roughly midway between short circuit and open circuit at which the relationship of voltage to amperage is ideal, - that is, where the product of the two, is the highest. This point is called the module's peak power point or maximum power point. The voltage at this point on the I-V curve is represented as V_m, the current as I_m and output power or wattage as P_m. [16].

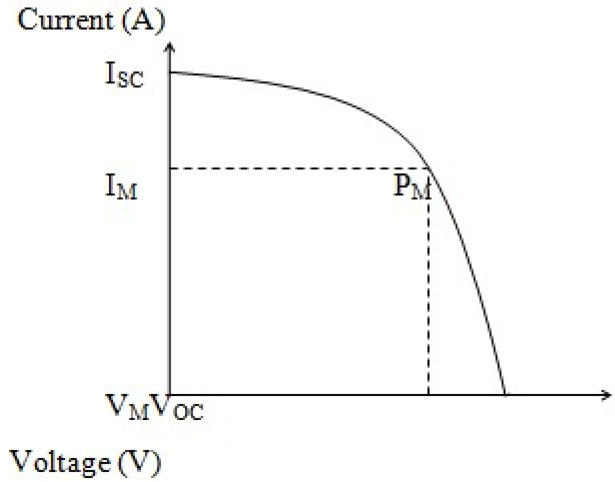

Figure 2.2: A sample I-V Curve showing the relationship between current and voltage.

Peak power is at the knee of the I-V curve. It is the point at which the product of voltage and current is at its maximum.

I-V Curve serves as useful design tools for a photovoltaic system designer and can be developed for cells, modules, panels or arrays.

2.2 Combination of Solar Cells

A solar cell is the individual part of a solar module that converts sunlight into electricity [17]. When a group of photovoltaic cells that are joined in a series or parallel configuration or both are combined into one sealed unit, what results is the PV module, the basic power-producing unit in all PV energy system. All of the PV modules that deliver electrical energy to the *same* load are collectively referred to *as* the PV arrays. A group of modules within the array connected and mounted together to form a single structural component is sometimes called a panel. The PV modules wired together to form one series circuit within a PV array are often called a series string or array string[18].

Photovoltaic arrays can be assembled across a very broad range of power requirements to closely match the needs of any specific application. Sometimes power spectrums are arrays that pump megawatts of power into the central distributing grids of some electric utilities. This is one of the important of photovoltaic that distinguishes it from all other sources of electricity and makes it so very appealing[19].

2.2.1 Series - Parallel Combination

The I-V characteristics of series interconnected cells can be found by adding, for each current, the different voltages of the individual cells, (modules). On the other hand, for parallel cells the current of the individual cells or module must be at each voltage.

In the case of more than one cell, (identical), the series and parallel connection of two cells illustrated in Figure 2.3; the maximum power generated by the two cells equals the sum of the individual developed powers. For series (Figure 2.3(a)) and parallel (Figure 2.3(b)) connection the optimum voltage and current equal the sum of the individual optimum voltages or currents respectively [20].

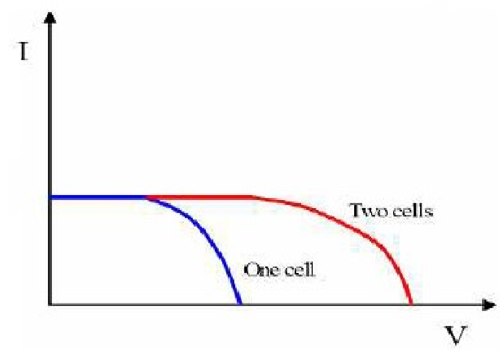

Figure 2.3(a): Series connection of identical cells.

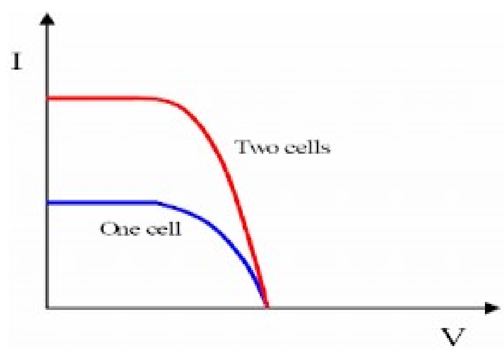

Figure 2.3(b): Parallel connection of identical cells

III. EXPERIMENT

Two36 cells polycrystalline type modules were used in practical with the ratings of Voc = 22.5V, I_{sc} = 3.6A, P = 60W, the two modules were identical and the same model. At first the reading was observed in series with the following circuit connection.

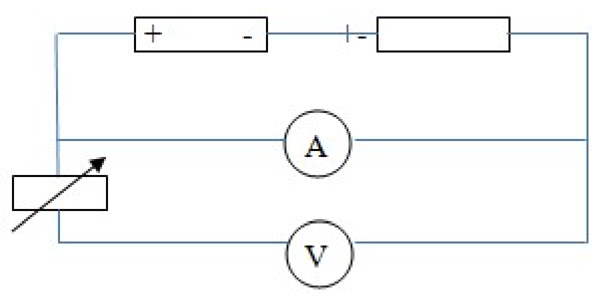

Figure 3.1(a): Series combination cct.

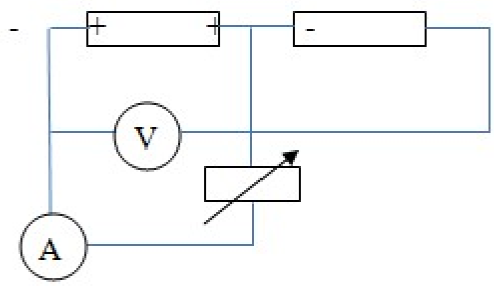

Figure 3.1(b): Parallel combination cct.

When connecting in series, the terminals are joined in the way (+ -) and positive terminal from the module is connected to resistance box or rheostat while the other terminal which is negative to the volt metre. In between the voltage and rheostat was a bridge in which the positive terminal of the ammeter was connected to the terminal leading to the rheostat and the other polarity head i.e. negative to one linking the voltmeter. I_{sc} and V_{oc} are then varying with varying the rheostat.

In parallel combination, the polarities were changed and therefore positive terminal of the second module. The same with the negative terminals, but in this case instead of getting the voltmeter directly, it was changed to ammeter and the positive output of the module to the rheostat making the voltmeter to be at the bridge to obtain current variation.

With the same circuit connection, shadowing 1, 3 and 6 cells respectively, observation was taken of the effect of shadowing in series combination. The same procedure for parallel was also observed.

The case of mismatch or shadowing which is my case study has relatively large effect on the performance of solar cell/module. The effect has been placed and the result of the effect observed.

IV. RESULTS

Comparison Table

Table 1 (a): SERIES COMBINATION

Series	I_m	V_m	Max, Power	Power Loss%
No shadowing	2.4	27.6	66.24	
Shadowing	3.0	17.4	52.2	21%
Shadowing 3 Cells	2.8	6.8	19.4	47%
Shadowing 6 Cells	2.7	6.3	17.6	73.%

Table 1 (b): PARALLEL COMBINATION

Series	I_m	V_m	Max, Power	Power Loss %
No shadowing	3.8	20	76	
Shadowing 1 cell	4.2	12	50.4	33%
Shadowing 3 Cells	2.9	16	46.4	38%
Shadowing 6 Cells	2.6	14 I	36.4	52%

(I) Series Combination

The I-V characteristics of the result of series combination of non-shaded solar module to shadowing of one, three and six cells in the module respectively. The maximum load current(I_m), maximum voltage(V_m), maximum power (P_m) are all indicated in Table 1a. However, we couldn't measure the open circuit voltage because of the influence of the resistance of connecting wires used. No change in the open circuit current (I_{sc}) because cells with equal short circuit current were put in series.

The output voltage decreased with the number of cells shadowed in the module leading to the higher losses in the maximum power output from 66.24 to 17.6W which represents loss between 21% to 73%. It was observed that after shadowing of one cell in the module, the values of maximum voltage reduced, maximum current fluctuates and that of the output power drops as follows; V_m from 27.7 – 17.4V, I_m from 2.4 – 3.0A, and P_m from 66.24 – 52.2W.By shadowing three cells, the maximum voltage decreased to 6.8V, while the I_m and P_m decreased to 2.8A and 19.4W, respectively. In order to further examine the photovoltaic efficiency of the panels under partial shadowing, and understand their performances, six cells were also shaded. It was noticed that by increasing the area of shading, the photovoltaic parameters kept on decreasing, such that the V_m, I_m, and P_m all decreased to 6.3V, 2.7A and 17.6W, respectively.

The significant decrease in voltage with the number of cells shadowed may be due weakest cells (i.e. shadowed cells), becomes a load to the strongest cells, yielding a strong mismatching loss, the voltage over this cell becomes negative, and therefore the voltage of the shadowed cells will be subtracting from the total voltage of the cells[21]. The voltage (V_{oc}) was in the range of 32– 10.8V, and the current (I_{sc}) 3.2 – 3.2Afrom no shadowing, to shadowing of 1, 3 and 6 cells respectively in the module.

(II) Parallel Combination

The observations of the results for parallel combination also without shadowing, by shadowing 1, 3 and 6 cells respectively were made. The open circuit voltage, maximum voltage the maximum current and the maximum power are all measured. By shadowing one cell in the module in parallel combination, the value of maximum voltage(V_m), maximum current (I_m) and maximum power (P_m) were decreased to 12V, 4.2A and 50.4W, respectively. This is ascribed to the fact that only parallel cells have been shaded, which gives rise to the change in the parallel internal resistance of the panel instead of the series resistance. As such, the current can find the non-shaded cells and does not pass through the parallel shaded cells. Shadowing three cells in the module, the photovoltaic characteristics showed highly decreased value of the panels parameters; I_m = 2.9A, V_m =16V and P_m= 46.4W.However, loss of power continued to increase with the shadowing of six cells as I_m, V_m and P_m dropped further to 2.6A,14V and 36.4W respectively representing 52% power loss.

The current output decreases with the increasing number of cells shadowed in the module which also lead to the decrease in power output of the module as shown in Table l (b). Also, the decrease in the current may be due to leakage current. The result of the leakage current of the module may well add to the decrease in the current because the result will be less loss with the leakage current, in the module. The decrease in current (I_{sc}) was from 6.1 - 3.1A and voltage (V_{oc}) 2.2 - 2.0V in parallel from no shadowing to shadowing 1, 3 and 6 cells respectively.

V. CONCLUSION

Series combination mismatch has no effect on the short circuit current, but the voltage drops with the number cells shadowed in the module because the weakest cell voltage will be negative, thereby subtracting from the total voltage of the module. This yields the decrease in the voltage of module, giving the percentage of power loss of 21 to 73%.

i. Little change in voltage and no change in short circuit current when one cell was shadowed in parallel combination. Three and six cells reduced the short circuit current (I_{sc}) to almost half of its value. This may not be connected to shadowing only but also to the leakage in the current yielding the power loss between 33 to 52%.
ii. In general, percentage power loss in series combination was found to be more than in parallel combination which was less than the power produced by a single module when there is no shadowing.

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