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Research paper

Analysis and Mitigation of Mismatch Errors in Rooftop Solar Panels

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Abstract

Harnessing maximum power from solar Photo Voltaic (PV) is possible only with less power loss in the PV system. Interconnection of PV cells or modules with different properties create Mismatch losses. Mismatch losses are the series problem in PV systems under specific conditions. The effects of current mismatch of single (PV) modules are analyzed in literature, but only few investigations dealt the mismatch losses of a PV system, which also dictate the overall power output. In this paper, the performance of solar panels has been discussed based on the losses occurred in various panels. The efficiency of the power produced by panels will be affected by the mismatch error. The power produced by the roof top solar plant is monitored by solar edge monitoring system. In addition, methods to reduce the mismatch error in the solar panels are presented.

Keywords : PV Arrays , PV system , mismatch error , PV losses

1. Introduction

Gone are the days, when people depended solely upon the non-renewable energy sources, which not only will soon be exhausted but also affect our nature. Nevertheless, with the advancement of technology in renewable energy harnessing, a new world is building up with much more care towards the nature; as such is solar energy. Looking at the history, the research on solar energy in a large scale started from 1970s when the oil crisis hit the major countries of the world such as The United States, Japan, Australia, Canada and New Zealand. Due to the surge of oil prices in these countries the economy of the above countries were affected adversely. Therefore, it led people to understand the great importance of an alternative energy source. Solar energy having great applications and advantages for remote areas easily got attention and further investigation over solar energy started.
The planet earth receives 174 Petawatt of solar radiation in the upper atmosphere. Even if half of it is converted, it is more than enough. According to the ministry of new and renewable energy (MNRE) reports, in 2016 the total installed capacity of solar power has reached to 8.6 GW which is a boom in Indian energy sector [1, 2].It is very crucial to improvise the method of harnessing the solar energy. One of the way of doing this is through reducing the losses that are involved in the process; one such loss is due to the mismatch error. Since the solar cell with the lowest output determines the output of the entire PV module under worst-case conditions, the mismatch losses are seen as a big problem [3-10].

The performance of PV Array (Fig 1) mainly depends on the variability of the modules that forms the array and PV cells that forms the modules. In addition, the arrangement of series and parallel connections of the PV modules in the network are shown in Fig 2[8-9].The mismatch losses occur in the PV system when the configuration and parameters of one solar cell are varying from the other cells. The amount of mismatch power loss depends on circuit configuration, Q point and parameters that are different from the rest of the solar cells. PV system that are being installed in rooftop and ground mount projects are generally very costly and for the PV system installed, and for it to be beneficial, it is essential to reduce the losses involved in it as much as possible, one of the major loss is mismatch loss[11].

The efficiency of the solar cells also depends greatly on the power electronic devices, which are being used. Due to the advancement of technology over the last decade the power output we receive has increased a lot, and also the current-

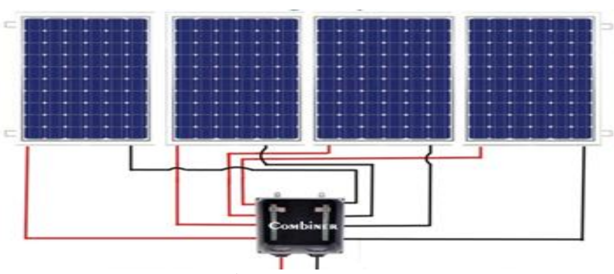

Figure 1: PV Array

voltage losses that include in the system has come down. But even then the working efficiency mentioned in the data sheets of the components in the PV system, it is not necessary that we will get the same efficiency in the normal weather conditions the components do not work at their best every-time.[11-12]Fabrication process of panels leads to mismatch in the PV arrays. The mismatch error must be addressed at the time of designing any solar PV system. Calculation of how much power is lost through mismatch is needed well ahead. Also after building the PV system there are many factors which affects the power produced. the interconnection of solar cells or modules which do not have identical properties or which are under different conditions from one another gives rise to Mismatch losses. [13]

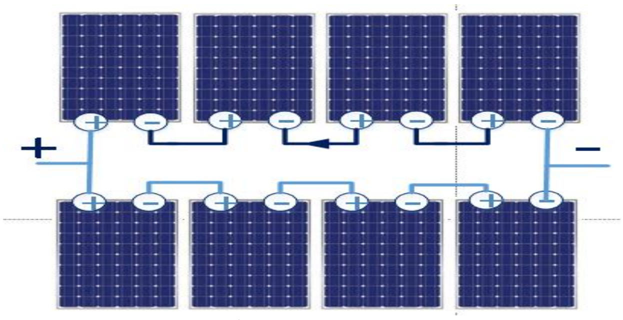

Figure 2: PV String

As most PV panels are series-connected(Fig 3), series mismatches are the most common type. In a series connected configuration with current mismatch, heavy power loss has been noticed when some particular cells supplies low current, because of effects such as shading than the maximum power point current of the good cells. In addition, if this combination is operated at short circuit or low voltages, the high power dissipation in the poor cell can cause permanent destruction to the PV panel.

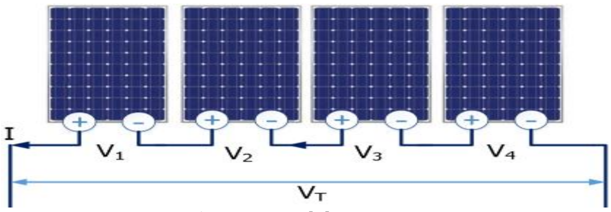

Figure 3: Modules in series

This paper focuses on the mismatch error produced in the system with reference of an experiment conducted to find mismatch error between four different modules, with a simple formula devised by basic mathematics. It will also include discussion on various problems related to mismatch error and their remedies. In addition, an estimate of the mismatch losses and solution has been provided to reduce the mismatch losses.

1.1 Equivalent Circuit

A PV cell is basically a PN junction that converts light energy into electricity. A set of PV cells connected to each other in different combinations for a specified outsput voltage is called PV module. A solar cell circuit can be treated as a current source. Fig 4 illustrates the equivalent circuit of PV cell. The DC current source connected in shunt with a diode, shunt resistance R_{sh} and series resistance. In Fig 4, R_{sh} , R_s and I_{ph} are the shunt resistance, series resistance and the cell photocurrent respectively. To simplify the analysis, the value of R_{sh} and R_s are ignored. The mathematical model of PV array using a set of equations has been derived from carrying out the simulation as in [14-15]

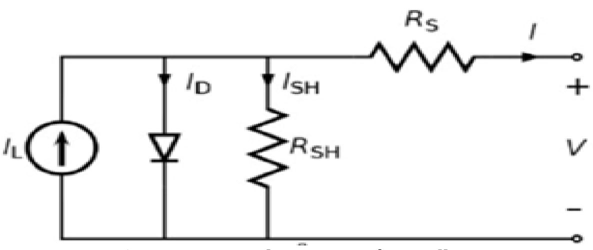

Figure 4: Equivalent circuit of PV cell

The expression of the PV array power is given by Eq. 1,

$$P = VI = n_p I_{p\square} V - [exp(\frac{qV}{kTAn_s}) - 1] n_p I_{rs} V \quad (1)$$

By putting dP/dV = 0 in Eqn(1), V_{max} can be found by Eq. 2,

$$[exp(\frac{qV_{max}}{kTAn_s})][(\frac{qV_{max}}{kTAn_s}) + 1] = \frac{I_{p\square}+I_{rs}}{I_{rs}} \quad (2)$$

From (2) it can be seen that V_{max} will be a function **of** I_{ph} and I_{rs}, solar radiation (S) and the cell temperature (T)[5].
The following paper is divided into sections, first one gives a brief about the technologies that have been used in the experiment conducted to find the mismatch error, than the procedure of the experiment conducted has been discussed and how it was conducted, in the end it gives an estimate on the average mismatch losses, conclusion, and solutions.

2. Brief about Major Technologies Used

2.1 Module Used for the Experiment:

Trina solar TSM-250PA05 modules. It uses Poly-Si, as a which is a raw material for the solar photovoltaic.The parameters of the PV Panels used are represented in Table 1.

2.2 Inverter

SolarEdge is a leading company in Photovoltaics. The SolarEdge DC/AC photovoltaic inverters are devices are very simplified, only task of these inverters is to carry out the function of DC-AC conversion, rest of the work including MPPT is carried out by the optimizers. It is a very cost-efficient, energy efficient(~98% weighted efficiency) and a robust device. Also, the long period warranty adds up to the advantage of using it (12 years).

Table 1. Module Specification

Specifications	Values
Peak power watts (W)	245
Max. Power output voltage (V)	30.2
Max. Power current	8.13
Open circuit voltage(V)	37.5
Short circuit current(A)	8.68
Module efficiency(%)	15
Glass	High transparency solar glass(0.13in.)
Connectors	Original mc4
J-box	Ip65 rated
Noct	45*c

It is also user friendly, if the solar plant needs maintenance then as a safety measure, the power output is reduced to zero to minimise the risks. These inverters also include data monitoring receiver, which is being used to get the data in this particular paper. It also has Advanced European safety standards and is certified to IEC 60947 and VDE 2100-712.

2.3 Power Optimizer [Solar Edge Op-700]

The SolarEdge power optimizer is a device connected to all the PV modules of a solar power plant for DC/DC conversion.The function of the SolarEdge power optimizers include maintaining the energy output from the panels by keeping a track of the maximum power point tracking from each module.

In rooftop projects where there are a large amount of PV modules and one of the module stops working efficiently, it is very difficult to find that module, but with the help of the monitoring system it makes it very easy to find it and further it can be corrected. It has a special safety feature where it can reduce the DC voltage to 0 when the inverter are made to shut down, it proves to be helpful during installation and maintenance. They are compatible with a wide variety of the module types like C-Si , Thin film. and the long period of warranty adds to its advantage(25 years).

2.4 Web Monitoring System

A weather monitoring system was also used in the site to predict the possible output. SolarEdge monitoring is an user friendly application used for tracking the power produced in a photovoltaic system, for this there should be optimizers installed on every module. Using this, the performance of modules in a photovoltaic system are analyzed. On the site a solar edge inverter and optimizers were installed which is necessary for the monitoring of the various elements like current produced, voltage, the power output. The output parameters recorded by the monitoring system are used to calculate the total power produced per day.

3. Method

The mismatch error is calculated using the formula by comparison method. This method is adopted for making the calculations and analysis simple. The mismatch error (E_m) is given as in (3)

$$E_m = \frac{(P_m - P_n)}{P_n} \quad (3)$$

Where, P(max.) is the maximum Power produced in modules connected in series (taken as reference)
P_n = Power produced in n^{th} module
Mismatch error in percentage = Mismatch error * 100%

3.1 Experiment

For finding the power produced this experiment was done in which, the power produced by four specific solar modules from morning 6 o'clock to evening 6 o'clock was taken; and the power produced was calculated for 3 consecutive days. The power produced from the modules were observed and noted with the help of solar edge monitoring system for three consecutive days and then mismatch error was calculated as per equation (1).The readings are being presented in below in Fig. 5,6,7.

- **First Day:**

Module No.	P4.1.25 P (W)	P4.1.26 P (W)	P4.1.27 P (W)	P4.1.28 P (W)
Power	10.4512	9.8015	9.8153	9.9775
Mismatch Error	0	6.21	6.08	4.53

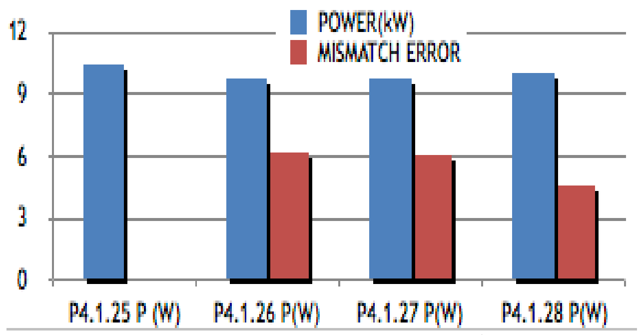

Figure 5: Power produced and mismatch on first day

- **Second Day:**

Module No.	P4.1.25 P (W)	P4.1.26 P (W)	P4.1.27 P (W)	P4.1.28 P (W)
Power	8.5811	9.2092	9.6600	9.2327
Mismatch Error	11.17	4.66	0	4.42

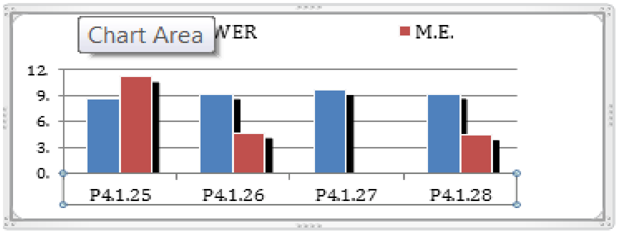

Figure 6: Power produced and mismatch on second day

- **Third Day:**

Module No.	P4.1.25 P (W)	P4.1.26 P (W)	P4.1.27 P (W)	P4.1.28 P (W)
Power	11.8025	10.1538	10.7648	11.4138
Mismatch Error	0	13.96	8.79	3.29

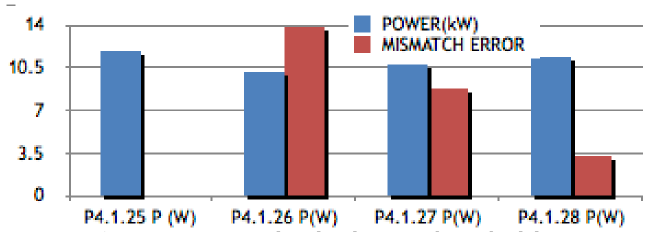

Figure 7: Power produced and mismatch on third day

The modules having their mismatch error as zero are those having maximum power and therefore have been used as reference power, since power produced and maximum power is same so the mismatch error is zero.

4. Results

Mean of mismatch error (%) for all modules for day1, 2 and day 3 are 4.208753, 5.064994 and 6.513605 respectively.Mean for all Three days is found to be 5.262451 %
The experiment shows the average value of mismatch error that modules have in natural conditions. Most of the modules have the same mismatch error, i.e., 5% (app.).Like in case of solar cells blocking diodes and bypass diodes may be used, which is being used in most panels but can be improved more with advancing technology. Mismatch losses may occur due to failure of a particular solar panel (even a small crack in the panel may lead to a great loss in the entire array). The soiling loss can also cause a great deal of mismatch losses, so the solar panels must be cleaned and maintained properly.Weather conditions also dictates the power loss that cannot be avoided. However, with the help of weather stations, the amount of approximate power, which will be produced, can be judged.

5. Conclusion

In small solar projects, it might not show much effect but when huge ground mount projects and rooftop projects are considered, it is essential that losses like these must be reduced as much as possible. Using MPPT and Optimizers may improve a lot, the above results for mismatch error shown are done using optimizers, and still there is an average of 5.264% of mismatch, which shows that using only MPPT will not help. So, further steps are needed to be taken for improving the result.

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