In this paper the mismatch losses in solar photovoltaic system have been discussed. The mismatch losses occur between the interconnection of two or more modules inside an array and large amounts of energy has been generated. This mismatch can be caused by partial shading and homogeneous shading of the modules. This paper discussed the mismatch losses of photovoltaic modules under varying atmospheric conditions and some techniques used to reduce this problem. Firstly, we discussed the mathematical modelling of the photovoltaic module under different irradiance and temperature. The performance of photovoltaic string configuration is based on maximum power point tracker in terms of mismatch losses. Some techniques which are used not only to reduce these mismatch losses but also increase the efficiency and reliability of systems under mismatch conditions such as active bypass, AC-Modules, power optimizers and distributed maximum power point has been discussed.

II. MODEL OF SOLAR PHOTOVOLTAIC ARRAY

The simple equivalent circuit and I-V characteristics of solar PV array have been shown in Fig. 1 and Fig. 2 respectively. A solar cell is a p-n junction semiconductor device. It receives energy from the sun and converts it into electrical energy. Solar photovoltaic array is the combination of series ($N_s$) and parallel cells ($N_p$).

![Equivalent circuit of solar cell](image)

The photo-generated current ($I_{ph}$) depends on both irradiance and temperature. It is measured at some reference conditions such as reference temperature $T_{ref}$, reference radiation $G_{ref}$ and reference photocurrent $I_{ph,ref}$ and related as follows [1].

$$I_{ph} = \frac{G}{G_{ref}} (I_{ph,ref} + I_{sc} (T - T_{ref}))$$

(1)

where $G$ is the actual solar radiation (W/m²), $T$ the actual operating temperature of cell (K), and $I_{sc}$ the manufactured supplied temperature coefficient of the short circuit current (A/K).
The diode current is given by the Shockley equation [1].

\[ I_D = I_0 \exp\left(\frac{e(V_c)}{\eta KT_c}\right) - 1 \]  
(2)

Where \( V_c \) is the voltage across diode (V), \( I_0 \) the reverse saturation current (A), \( \eta \) is the diode ideality factor, \( R_s \) the series resistance (\( \Omega \)), \( e \) the electron charge \( 1.602 \times 10^{-19} \) C, and \( K \) the Boltzmann constant, \( 1.38 \times 10^{-23} \) J/K.

The reverse saturation (\( I_0 \)) current is given by [1]

\[ I_0 = I_{0,ref} \left(\frac{T_{c,ref}}{T_c}\right)^3 \exp\left[\frac{eE_c}{\eta KT_c}\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \]  
(3)

Whereas the shunt current \( I_{sh} \) is given by

\[ I_{sh} = \frac{V}{R_p} \]  
(4)

where \( R_p \) is the shunt resistance (\( \Omega \)).

Eq. (1) can be written as

\[ I = I_{ph} - I_0 \left(\exp\left(\frac{e(V + IR_s)}{\eta KT_c}\right) - 1\right) - \frac{V + IR_s}{R_p} \]  
(5)

In the terms of voltage, the equation (5) can be written as [1]

\[ V = N_s \lambda \ln\left(\frac{I_{ph} - I + N_p I_0}{N_p I_0}\right) - \frac{N_p}{N_s} R_p I \]  
(6)

\[ \lambda = \frac{\eta KT}{q} \]  
(7)

Where \( N_s \) is the number of cell connected in series and \( N_p \) is the number of such cell connected in parallel.

Employing equation (1-6), a non-linear equation involving photo generated current (\( I_{ph} \)), diode reverse saturation current (\( I_0 \)), shunt resistance (\( R_s \)) and load resistance (\( R_p \)) is obtained, which has been solved for \( V_c \) to supply an initial assumed value of \( V_c = 0 \).

The above solar PV array model has been implemented in MATLAB. The solar irradiance level and ambient air temperature are 1000 W/m² and 25°C, respectively.

The incident solar radiation has larger effect on short circuit current, while the effect on open circuit voltage is rather weak. The solar PV array will generate more power when the irradiance is higher. With an increasing temperature the array voltage drops at high voltages. Operating the cell in this region leads to a power reduction at high temperature. If irradiation increased with reduced temperature then the results are higher module output.

II. MISMA

Mismatch losses are caused by the interconnections of solar photovoltaic cells or photovoltaic modules in series or parallel. Mismatch losses are a very serious problem in photovoltaic modules and arrays because it causes the lower output power so the system efficiency and performance become lower.

In photovoltaic module the mismatch losses occur when the configuration and parameters of one solar cell are different from the other cells. The impact of power loss due to mismatch depends on circuit configuration, operating point and parameter which are different from the remaining of the solar cells.

Fig. 2. I-V Characteristics of solar PV Array

Solar cells are connected in series, there are two mismatch losses occur through series mismatch that are open circuit voltage and short circuit current. A mismatch loss occurs in open circuit voltage of series connected cell that the current of the two cells are same and the voltage of the two cells are added of two voltages and the power and efficiency of the cell is reduce. The mismatch effect occurs in short circuit current of series connected cells are relatively minor as compare to open circuit voltage.

II. DIFFERENT TYPES OF MISMATCH LOSSES

The mismatch losses occur from static mismatch, dynamic mismatch, environmental stress and shadow problem. The static mismatch is related to manufacturing tolerance, aging of the module and some weather conditions. The dynamic mismatches occurs when the modules operates far from its maximum power point. The PV modules connected in parallel or in series cannot operate in their individual maximum power point because the voltage or current is forced to be equal in all the modules of the string.

A. Static Mismatch

For silicon based modules the manufacturer tolerances is below 1%. For thin film modules the manufacturing tolerances are higher. For the fractional power loss due to manufacturing tolerances is about 2%. In series strings for aging the mismatch losses may rise up to 12% and in parallel string the mismatch losses become reduce. Thus the expected mismatch even in consideration of aging effects is in the range of 0.3 to 2.5% [2,3].

B. Dynamic Mismatch

Dynamic mismatch are of four types that are module manufacturers employ with bypass diodes, without bypass diodes, partial shading and homogeneous shading.
Module manufacturing with bypass diodes is used to prevent shaded cells, the performance of other cells which are connected in series, reduced array voltage and to minimize hot spot heating, the potential for cell failure when shaded and reducing the power production of the whole string, bypass diodes are usually placed in reverse biased direction to series connected cells.

Bypass diode reduce the power losses through the module and it will allow passing current around shaded cells. If the photovoltaic module becomes shaded, then bypass diode becomes forward biased and begins to conduct. All the current greater than the shaded cells, new short circuit current is bypassed through the diode. It bypasses the photo generated current more than that of shaded cell and it reduces some amount of heating at the shaded area.

When the by-pass diodes are not connected in series current-voltage characteristics of photovoltaic module is affected. If the number of solar cells is connected in series without by-pass diodes and out of which one cell is shaded partially to different levels then the output power is decreases and partial shading have to obtain the resultant characteristics of the whole module.

By adding the corresponding voltage of shaded cell and non-shaded cells the current the voltage has to be calculated. The shaded cell acts as load, which dissipating power on itself which may lead to hot spot conditions and damages the cells. When single cell is shaded to 99% the reduction in irradiance falling on the module is less than 3% but maximum power output in watts is reduced by more than 86% [3].

Partial Shading, for solar photovoltaic module the partial shading is very dangerous. It can reduce the power output. When partial shading occur bypass diodes is used to reduce performance. The single cell of a module is shaded to 25%. If the shaded module is connected in series with other non shaded module, then mismatch losses occurs. The shading effect results in degraded string output because the current of series connected string in module is affected by shaded cell. When the modules are connected in series and diode conduct to bypass the shaded cell string, the peak power becomes high, which is higher than all cell strings. It means it is more efficient to completely remove the compromised cell than to have it operate at partial capacity and degrade the performance of other cells in string.

Homogeneous Shading, in the string when all the modules do not receive equal amount of irradiance this effect is known as homogeneous shading. According to this phenomenon when modules are connected in series has different tilt angle so that they can receive different irradiation. In this condition, the string has different current flow when bypass diodes conduct in the modules. This may cause mismatch effect. Further, the power and efficiency of the string will be reduced. The module based maximum power point tracker can harvest more energy than conventional string because of individual maximum power point tracking.

**III. REDUCTION TECHNIQUES OF MISMATCH LOSSES**

There are many different techniques used to reduce the mismatch losses that are as follows, Active Bypass, During partial shading conditions the bypass diodes are very useful but it has many disadvantages that are the forward voltage of the bypass diodes are the order of 0.5 to 1 V and it depends on the type, junction temperature and the current. It also have many problems that are due to the forward voltage drop the excessive heat developed, normal failures due to over voltages, energy losses in the form of leakage currents and failures due to lighting surges, switching surges etc. These limitations are overcome by active bypass diodes; it is also called an active electronic smart circuit because it has a maximum voltage drop which corresponding reduction in heat dissipation. Active diodes are thin and integrated in PV-lamination. If the voltage drop is low, then power will be dissipated. Active bypass diodes can also used for monitoring or active enhanced short circuiting of the module for safety. In active bypass the conduction losses in mismatch situations can be mitigated.

AC-Modules, when modules can be connected in parallel then this ac-module are used. The output of the module is in ac form so it called ac-module. To achieve the highest output power every solar module is continuously operated at maximum power point. This can be reached by using module-integrated inverters. The current mismatch occur a larger impact on the power than the voltage mismatch, it is to be expected that the system connected in parallel PV-modules have a higher power. Module-integrated inverters lead to higher especially with solar modules that are partially shaded with different angles. The advantages of ac-modules that are the design of the PV system is flexible and that it can easily be expanded; in addition, cost is also less. The performance of AC-modules will be same as module based maximum power point tracker. However, it does not avoid shading problem completely. The voltage of AC modules with similar performances and reliability as larger PV systems with central or string inverters is significant.

Power Optimizers, This is used to reduce mismatch losses in string. It is provided for each module so that input and output voltage of each module is independent and maximum power point voltage can be individually set for each module. This can monitor and maximize the power of each individual solar panel. The modules which have problem of shading because of existing trees, chimneys etc are provided with power optimizers. This configuration helps to reduce mismatch losses in string because of predictable shading sources. Distributed maximum power point tracking is same as AC-modules in which each module can operate to its maximum power point. DMPPT can be useful to reduce shading. Mismatch losses are eliminated but power conversion and losses are increased because of additional electronic circuit. If only the part of the module is shaded, then the power of the shaded part across bypass diodes will be reduced.

**IV. CONCLUSION**

The different mismatch losses and their reduction techniques have been discussed in this paper. The study and comparison between the static and dynamic losses in which bypass diodes are connected or not, partial shading and homogeneous shading
in solar photovoltaic system have been studied. The mismatch losses occur when the configuration and parameters of one solar cell are different from the other cells and it also caused by the interconnections of one or more solar photovoltaic cells or by shading. Active bypass diodes which are used in strings may also increase the energy output slightly because conduction losses are minimised. Module based maximum power point tracker decouples the power generation of each module so that mismatch losses are restricted to the shaded modules has been discussed.

REFERENCES


