Shading tolerance of Different PV Module Topologies

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Abstract

This paper analyzes the significance of solar cells interconnection in a module to improve the module shading tolerance. Different PV module configurations are considered in this paper – series, series-parallel and total cross tied. Corresponding PSpice models are developed to simulate the power loss for different module configurations. Simulations are performed for various shading patterns to understand the effect of cells interconnection scheme leading to higher power loss. Shading tolerance with respect to power loss, maximum reverse voltage drop and peak power dissipation in a shaded cell is analyzed and was observed that series configuration is more prone to power losses compared to series-parallel and total cross tied configuration.

Keywords: Partial shading, PV module configuration, solar cell, solar module, series connection, series parallel connection, total cross tied connection

1. Introduction

The demand for electricity has enhanced over the years depleting the resources and also causing harmful effects to the environment due to the release of greenhouse gasses. Among the available resources, solar has been one of the reliable solutions as it is available in abundance and is a natural resource. Wherever sunlight is available, solar panels can be deployed and the electricity can be extracted. This allowed the government to launch schemes leading to massive deployment of PV modules globally including urban environments. However, PV modules installed in urban environments are often subjected to non-uniform irradiation due to partial shading caused by birds, trees, buildings etc. Under non-uniform irradiation conditions, the performance of a PV module is significantly affected as the current generated by the solar cells is proportional to the incident irradiation. In the conventional modules, due to the series configuration, the module current gets limited by the cell that generates the least current. In the presence of bypass diodes, the mismatch in the current generation by different cells would lead to multiple peaks in the power curve. Though maximum power point tracking techniques try to maintain the module at peak power point, there is still some loss incurred due to the module configuration. Also, during partial shading, the cells receiving lower irradiation would develop hotspots and start degrading in the long term. Therefore, partial shading not only affects the PV module performance but also the reliability of the module. This implies that there is a need for mitigating the negative effects of the partial shading by deploying modules that possess high shading tolerance. This is important as it is very difficult to avoid shading in urban environments.

Several researchers are working on developing shade tolerant modules by modifying interconnection between the cells and bypass diodes in the modules. Numerous module topologies are listed in the literature like series-parallel, total cross tied etc. This might necessitate the complexity in the manufacturing process. However, the unavoidable shading from the structures in the surrounding, has a huge negative impact on the solar module peak power output. To understand the need for different configurations (Pannebakker et al., 2017) (Calcabrini et al., 2021), we aim to show the different configurations' shading tolerance with PSpice simulation results.

In this paper, the PSpice models are developed for the three configurations, then the simulations are performed for different shading scenarios. The power loss, reverse voltage and the power dissipation has been considered and compared for different shading layouts to analyze the significance of module configuration and its role in enhancing the module performance.

2. Solar Module Configurations

The interconnection of the cells in the module has a huge potential impact in degrading or improving the module performance. Based on the different interconnection layouts, three different configurations are considered – series connection (SC), series-parallel connection (SP) and total cross tied connection (TCT). The interconnection of the cells in all the three configurations is shown in fig.1. In series connection topology, all the 72 full size cells(6”x6”)

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are connected in series with three bypass diodes each across 24 cells as illustrated in fig.1(a). The series-parallel configuration has 144 half cut cells with two groups of 72 half cut cells. Each group has 72 half cut cells connected in series and the two groups are connected in parallel with three bypass diodes as shown in fig.1(b). Half cut cells are considered for SP configuration instead of full-size cells as the current would be doubled due to parallel connection of the two groups. Higher currents might be difficult to handle and would also lead to power loss near the connections. Therefore, half cut cells are preferred over full size cells in SP configuration. The other configuration is the total cross tied connection where all neighboring cell junctions are tied as shown in fig.1(c).

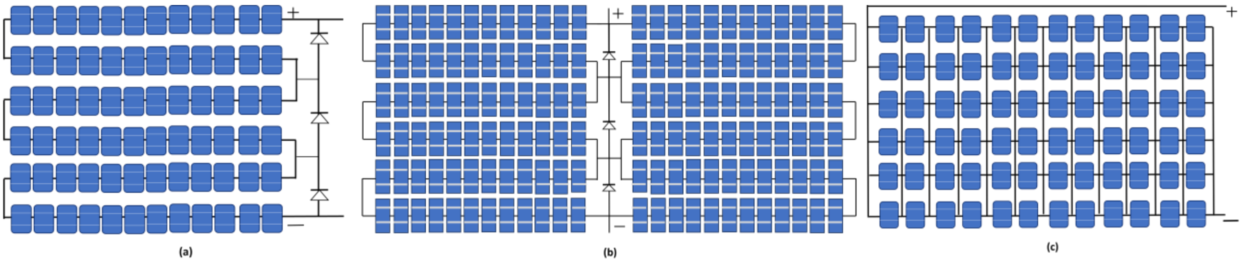
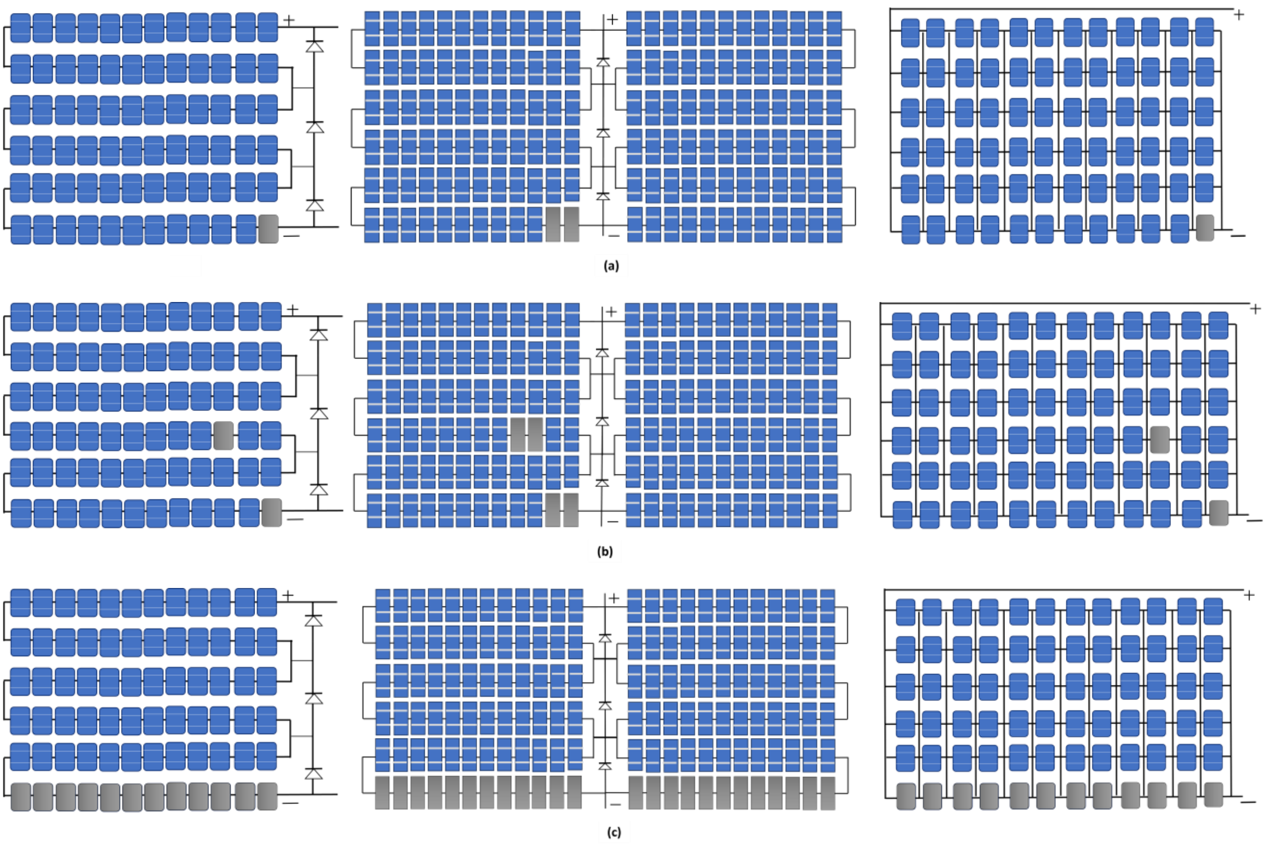
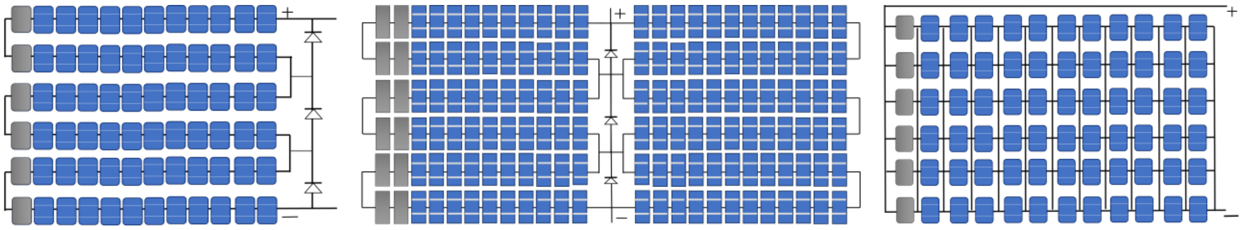


Fig. 1: Solar module topologies (a) series connection (SC) (b) series-parallel connection (SP) (c) total cross tied connection (TCT)

3. Partial Shading Patterns

The partial shading in the urban environment can be of different types. Four shading patterns are considered in this paper- only one cell is shaded, two cells are shaded, a row of cells are shaded, a column of cells are shaded as shown in Fig.2. In this figure, all the shading patterns for the considered topologies are illustrated. Fig.2(a) depicts the situation when only one cell is shaded. For better comparison among the different configurations, two half cut cells are shaded whenever one cell is shaded. In order to analyze the effect of partial shading, when two cells from different sub-strings are shaded, a second shading pattern is considered as shown in Fig.2(b). In this situation, two bypass diodes would be activated in SC and SP configuration. TCT has no bypass diodes. In the presence of building structures or poles, there could be a long horizontal or vertical shading. This is examined by considering row of cells, column of cells as shaded as can be seen in fig.2(c) and fig.2(d). Simulations are performed for all these shading patterns in PSpice to observe the power loss for different configurations



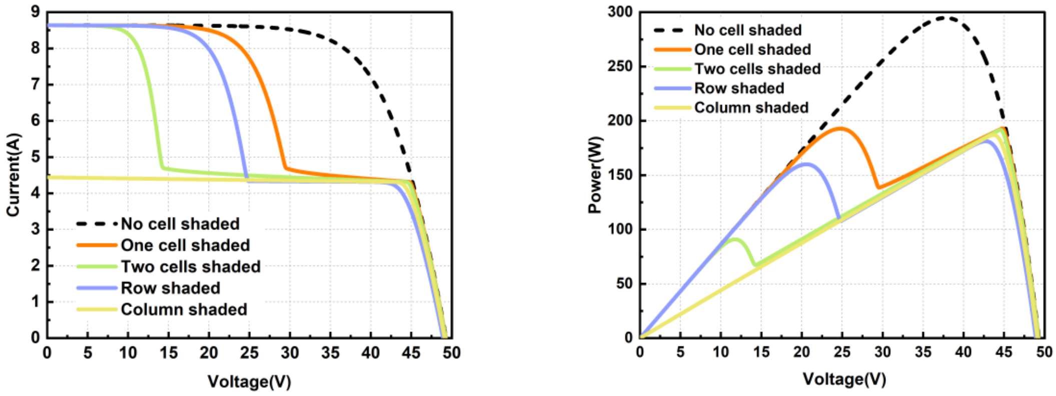


(d)

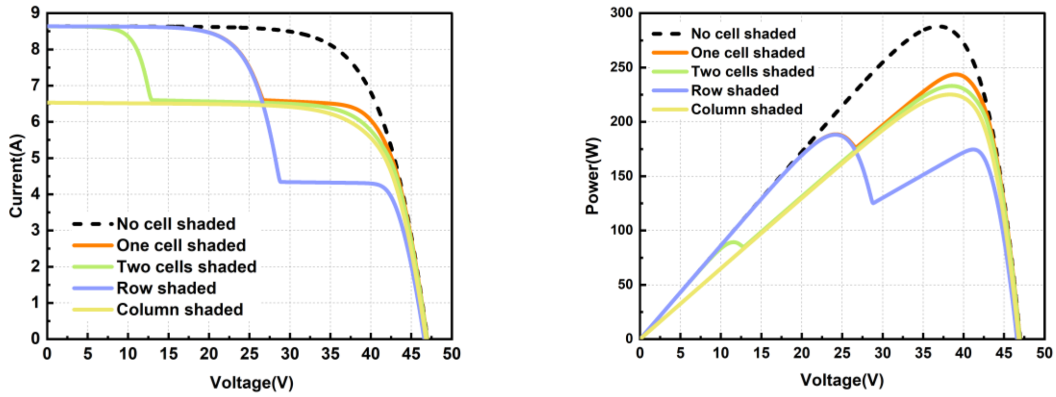
Fig. 2: Solar module topologies (a) one cell shaded (b) two cells shaded (c) a row of cells shaded (d) a column of cells shaded

4. PSpice Simulation Results and Discussion

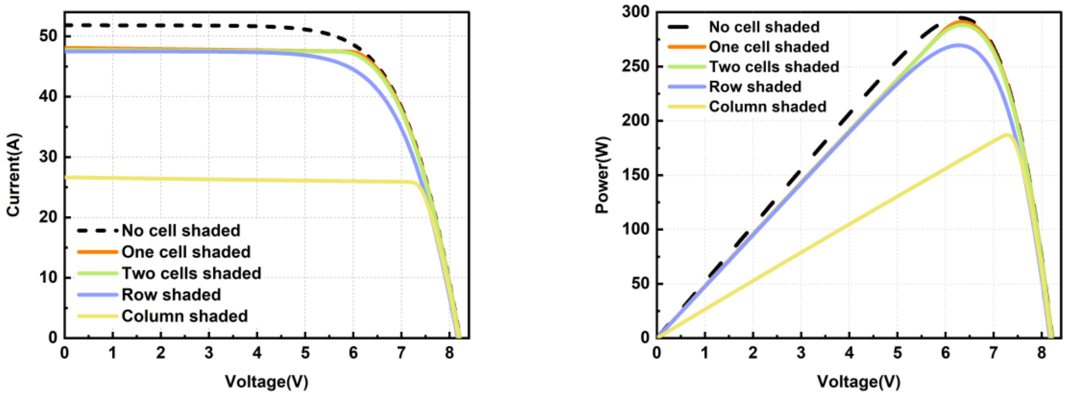
PSpice models are developed for all the different configurations and shading patterns mentioned in previous sections. In the PSpice models, the non-shaded cells are given 1000W/m^2 and the shaded cells are assigned 500W/m^2 i.e., 50% shading for better analysis based on the amount of shading. The IV and the corresponding PV curves for all the scenarios are illustrated in Fig.3. The bypass diodes of the sub-strings with shaded cells are activated and are indicated by the step in the IV curves. This led to multiple peaks in the PV curves as depicted in fig.3(a) and fig.3(b).



(a)



(b)



(c)

Fig.3. IV and PV characteristics of the different configurations for all the shading scenarios (a) series (b) series-parallel (c) TCT

Due to the absence of bypass diodes, TCT configuration doesn't show any step in the IV curve(fig3.(c)), thus no multiple peaks observed in the PV curve(fig.3(c)). To analyze the effect of different shading patterns, power loss for each shading pattern is calculated in percentage using eq.1 P_{no_sh} is the peak power generated by the module when no cells are subjected to shading and P_{sh} is the global peak power for a particular shading pattern. P_{sh} is calculated for all the different configurations subjected to different shading patterns.

Power loss(%) = $\frac{P_{no\_sh}-P_{sh}}{P_{no\_sh}}$ x100 (eq.1)

The power loss (%) results for all the scenarios is shown in Fig.4. It can be observed that the loss is more for all scenarios in the series configuration and is lowest is TCT configuration except for the column shading. This implies that TCT configuration modules have high shade tolerance in other shading patterns. However, it is important to note that under column shading, TCT module current is totally limited by the shaded cells as shown in the IV curve in fig.3(c). Since there are no bypass diodes, the total module current would drastically decrease if the column cells are totally shaded. This would lead to huge power loss. Apart from this, under uniform irradiation, TCT module current is also very large which might lead to power losses during the flow of current from cell to cell. Also, the busbars must be able to handle the higher currents which would enhance the complexity in the manufacturing process. Therefore, series-parallel configuration whose power loss is still comparatively less than series configuration can be considered as a better shade tolerant module over series configuration module. However, one disadvantage of SP connection is that, when a whole row of cells are shaded, SP would still result in nearly equal power loss as that of series connection. This is because the non-shaded half cut cells would generate less current than the non-shaded full-size cells.

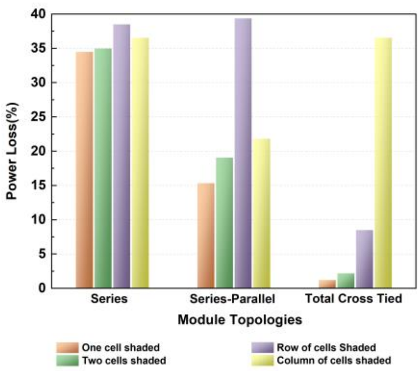


Fig.4. Power loss (%) for both the shading scenarios can be observed for all the three configurations

Along with power loss, the reverse voltage drop across the cells under short circuit condition is also observed for all the scenarios. Basically, the bypass diodes activate to prevent large amounts of reverse voltage across the shaded cells. Under high reverse voltage, the cell would get heated up, developing hotspots leading to permanent damage.

The maximum reverse voltage under short circuit condition for all the configurations subjected to different shading patterns is shown in fig.5. The reverse voltage drop is the highest for series configuration and is the lowest for TCT when all the cells in a row are shaded. Since, voltage across the cells in a column in TCT configuration would be the same, there won't be any negative voltage drop in this condition. Since, the maximum reverse voltage drop would be equal to the number of columns in this configuration, there would be at most 8V reverse voltage drop across a shaded cell which is less than cell breakdown voltage. Therefore, there is no need for bypass diodes in TCT configuration. SP configuration also shows less reverse voltage drop across its cells for this considered shading level and the shading patterns.

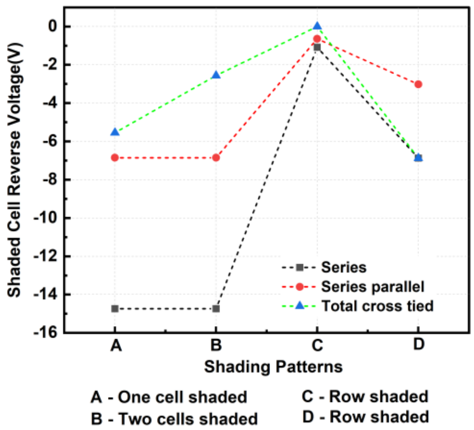


Fig.5. Reverse voltage drop across the shaded cell under short circuit condition for all module configurations subjected to various shading patterns

Though the reverse voltage drops are low, it is important to calculate possible peak power dissipation in the shaded cells. In order to find the peak power dissipation, the module current must be at its peak current (Imp). Thus, the cell must be shaded by an amount to generate Imp current. By following the procedure mentioned in (Jyothi et al., 2022), peak power dissipation for all the scenarios is calculated and plotted in fig.6. Even here, series configuration leads to highest peak power dissipation in its shaded cells. Whereas, SP and TCT configurations show lower peak power dissipations in the shaded cells. But, as already mentioned, the voltage across a column of cells in TCT configuration would be the same. This implies, if a cell in a row is shaded, the non-shaded cells would also be maintained at a negative voltage due to the interconnection scheme. It was observed that the non-shaded cells in this row would still be generating higher current as per the incident irradiation i.e., 8.63A(Isc) for 1000W/m2. This implies, the non-shaded cells in this row would dissipate larger power than the shaded cells. Since, the maximum reverse voltage is less than 8V, the power dissipation would be less than 64W. Though the power dissipation is less, the cells are subjected to high power dissipation though they are not shaded. Considering all the results based on power loss, maximum reverse voltage drop and peak power dissipation, SP would be a better shade tolerant module. TCT also might be a good shade tolerant module, but the complexity in the manufacturing process is more for TCT configuration than SP configuration.

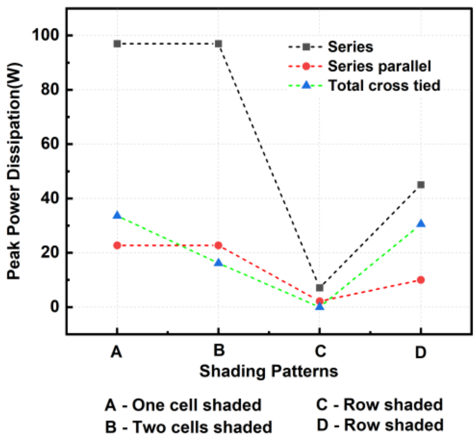


Fig.6. Peak power dissipation over the shaded cells in all module configurations due to various shading patterns

3. Conclusion

In this paper, three different configurations of solar modules are considered whose simulation results are compared to understand the shading tolerance of each configuration. Four shading patterns were considered and the PSpice simulations are performed for all the configurations to analyze the peak power reduction compared to uniform illumination condition. Also, the maximum reverse voltage drop across the shaded cell is observed. Along with this, the maximum power dissipated was obtained through simulations. In comparison, it was noticed that TCT configuration outperforms other configuration with respect to shading tolerance except when a column of cells are shaded. However, there are complexities involved in the manufacturing process due to high module current and also some limitations are observed when a column of cells are shaded leading to huge power loss. Therefore, series-parallel configurations seem to be a better shade tolerant module with lower power loss, maximum reverse voltage drop and peak power dissipation.

4. References

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