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INVESTIGATION OF PARTIAL SHADING EFFECTS ON PHOTOVOLTAIC SYSTEMS ACCORDING TO DIFFERENT CONNECTION TYPES

A.O. Kucuk [1] H. Gozde [2] M.C. Taplamacioglu [1] M. Dursun [1]

1. Department of Electrical and Electronics Engineering, Gazi University, Ankara, Turkey
aliosmankucuk@gazi.edu.tr, taplam@gazi.edu.tr, mdursun@gazi.edu.tr
2. Electronics and Communication Engineering Department, National Defense University, Military Academy, Ankara, Turkey, hgozde@kho.edu.tr

Abstract- The use of renewable energy is increasing daily as fossil fuels have limited reservoirs and damage the ecosystem. As a result, the need for maximum efficiency has become one of the most important topic of renewable energy sources. Besides using panels efficiently in solar systems, the studies is also made to reduce the losses caused by unwanted situations. One of the most important unwanted situation is partial shading conditions. Different types of connection topologies are used to reduce undesirable partial shadowing, and much research has been done on this. In this study, two different connecting topologies are simulated under partial shaded conditions and immunities against undesired conditions are compared to each other. In addition, for a chosen case the best connection topologies determined.

Keywords: PV Array, Connection Type, Serial-Parallel, TCT (Total Cross Tied), Partial Shading.

I. INTRODUCTION

The renewable energy sources have uncertainty and variable nature so, they have low efficiency. As a result of this, to achieve maximum energy from these sources become an important topic in order to satisfy the energy requirement. The efficiency of a photovoltaic module (PV module) is about 15%. In practice, however, this ratio is even lower for many reasons [1]. One of the main reason is the incompatible working conditions of the modules that make up a PV system. Especially, the partial shading condition is an important problem for solar energy systems. In this case, all series connected cells in the module carry the same current even if some cells are being subjected to the partial shading. The shaded cells in the module get reverse biased and act as a load. These cells take additional power from the fully radiated modules and exposed to the hot-spot damage [2]. Hot-spot may cause permanent damage to the module as it is shown in Figure 1.

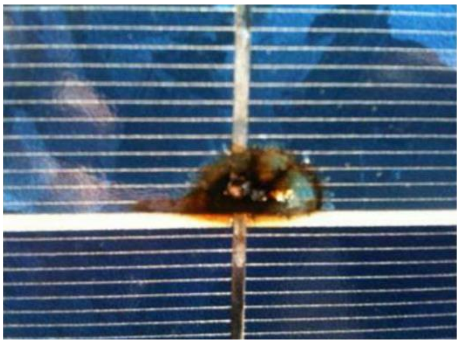


Figure 1. Hot-spot damage on PV-cell

The studies are still continuing to cope with this problem at present and different methods have been developed so far [3, 4]. Depending on all these methods, first application is to choose module connection types in order to decrease the loss effect of partial shading condition and increase the efficiency of the array in this condition. Different types of module connection are presented to the related literature by many types of researches [2-6].

In this study, two most commonly used connection topologies known as Serial-Parallel (SP) and Total Cross Tied (TCT) connections are simulated under partial shadow conditions. The immunities against undesired conditions are compared under standard test conditions and partial shading.

II. PARTIAL SHADING CONDITION

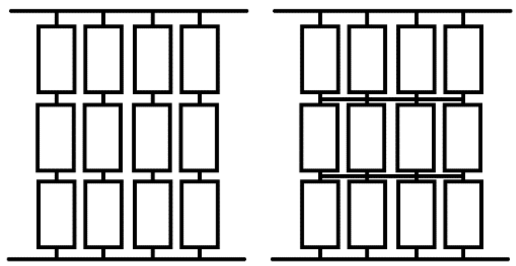
The partial shading effect is a condition that some cells series in the string connected with the same by-pass diode in the module are shaded for a while owing to different reasons such as cloudiness, trees or big buildings as depicted in Figure 2. These conditions are critically important detrimental factors that negatively affect productivity.

Figure 2. Partial shading condition [5]

Due to their reverse biased diode and internal resistors, the shaded cells act as a load to the other cells in the string. Owing to the by-pass diode of the string cannot make the short circuit the entire string due to the lack of full shading, following the shaded cells warm and go to the hot-spot damage. The other cells are forced to give additional current to the circuit as well. As a result of the partial shading condition, total power output decreases and the maximum power point of the module moves to the lower value on the *P-V* curve.

III. CONNECTION TYPES OF SOLAR MODULES FOR PARTIAL SHADING

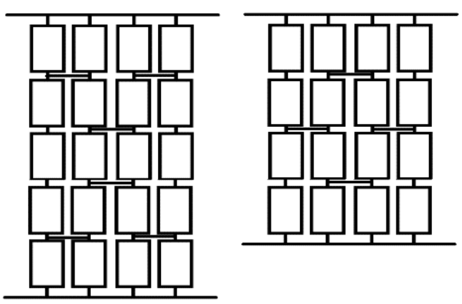
There are different module connection methods for the solar arrays used in PV energy systems. Each of these connection methods has its own unique characteristics. Most commonly used types are serial-parallel (SP) and Total Cross Tied (TCT) connections. These connection types are shown in Figure 3.



(a) Serial-Parallel (SP) (b) Total Cross Tied (TCT)

Figure 3. Simple connection of PV arrays

Apart from these connections, there are other types of connections that can respond to different needs derived from these two connections. Each connection type has advantages and disadvantages according to different usage areas and different conditions. Other connection types derived from SP and TCT connections are; bridge connection and honey-comb connection type. These connection types are also shown in Figure 4 [2].



(a) Bridge connection (b) Honey-comb

Figure 4. (a) Bridge and (b) Honeycomb connections

In the present study, the most commonly used connections like as SP and TCT connections are briefly explained below as follows:

A. Serial Parallel Connection

In this connection, all modules are connected in series (Figure 3a). The total voltage equals the sum of the voltages of the modules. Then, the series consisting of the serial connected modules are connected in parallel and the current level of the total sequence is increased to obtain the desired *V-I* characteristic in theory [6]. However, the SP has low immunity to undesired situations. The undesirable situation in any serial connected module affects the entire system. By-pass diodes are used to reduce the effect of disturbing the faulty module. However, since the total output is affected, there are many peaks at the *V-I* characteristic.

B. Total Cross Tied (TCT) Connection

In this connection, parallel connected modules are connected in series (Figure 3b). The TCT connection is more resistant to unexpected situations than the SP connection type. However, it increases the cost due to the cabling complexity. Additionally, TCT connection reduces the effect of incorrect mappings.

IV. CONNECTION TYPE ANALYSIS UNDER PARTIAL SHADOWS

In this study, the behaviors of SP and TCT connections are examined under partial shadowing effect. All simulations are studied on Matlab/Simulink environment. The 3×3 SP and TCT connections are compared under different shadowing scenarios to observe which connection type is more immune to this condition as represented in Figure 5.

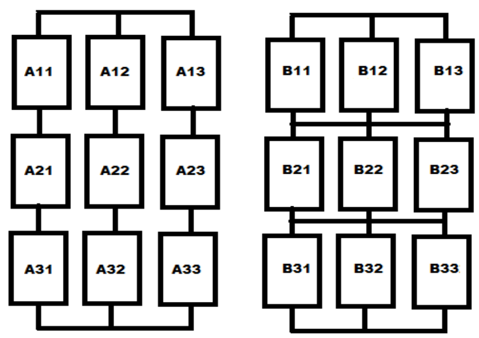


Figure 5. 3×3 SP and TCT connections

The *I-V* and *P-V* characteristics of the SP and TCT connections are examined in the following cases:

- Case-1: No-shading condition.
- Case-2: A11-B11 are 25%, A32-B32 are 35% and A23-B23 are 50% shaded.
- Case-3: A11-B11-A22-B22-A33-B33 are 25% shaded.
- Case-4: A11-B11 are 70%, A21-B21 are 60%, A31-B31 are 50%, A32-B32 are 40%, A33-B33 are 30%, A22-B22 are 25% and A13-B13 are 50% shaded.

V. RESULTS AND DISCUSSION

To obtain the simulation results, 3×3 SP and TCT connected PV-array models are created by using Matlab/Simulink tools as represented in the Figures 5 and 6. Following, five different partial shading cases are applied to these models as mentioned above.

At the end of the simulations, the *I-V* and *P-V* characteristics are examined as depicted in from Figure 7 to Figure 14. In these figures, the *I-V* graph is shown on the left and the *P-V* graph on the right. Voltages in the x-axis (Volts), current (Ampere) and power (Watts) in the y-axis are shown.

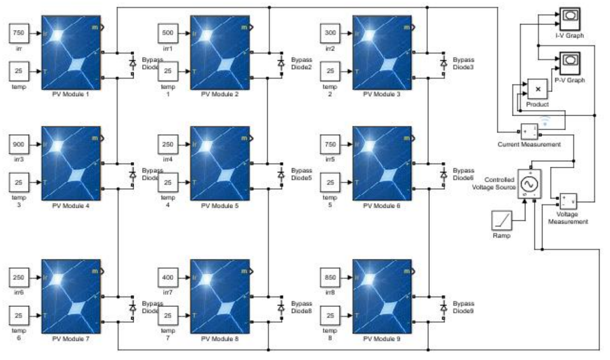


Figure 6. The Simulink model of SP connection

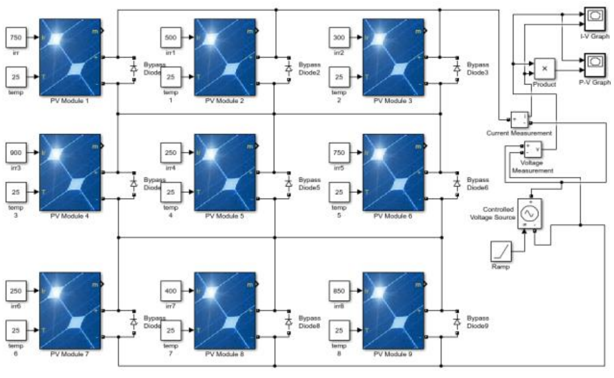


Figure 7. The Simulink model of TCT connection

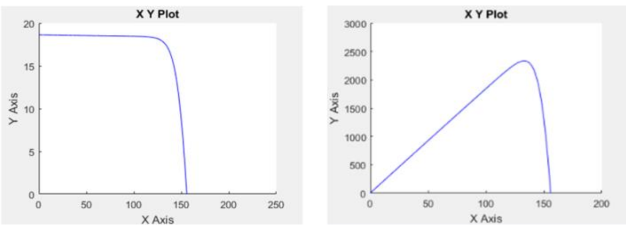


Figure 8. Case 1: SP connection, *I-V* and *P-V* curves

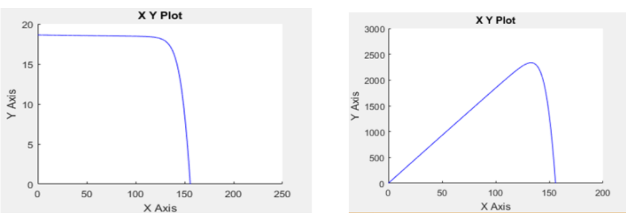


Figure 9. Case 1: TCT connection, *I-V* and *P-V* curves

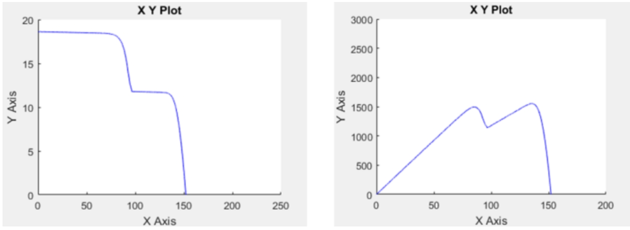


Figure 10. Case 2: SP connection, *I-V* and *P-V* curves

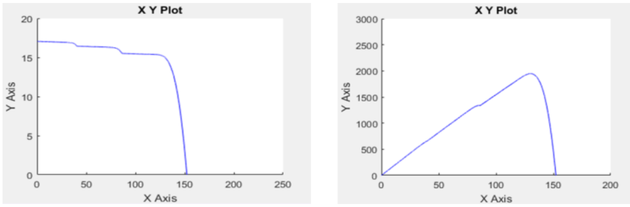


Figure 11. Case 2: TCT connection, *I-V* and *P-V* curves

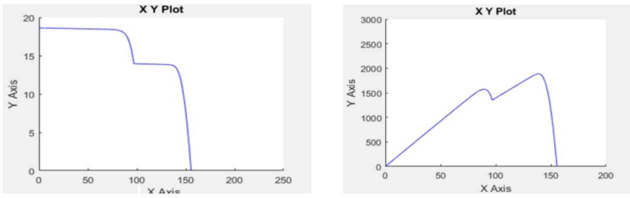


Figure 12. Case 3: SP connection, *I-V* and *P-V* curves

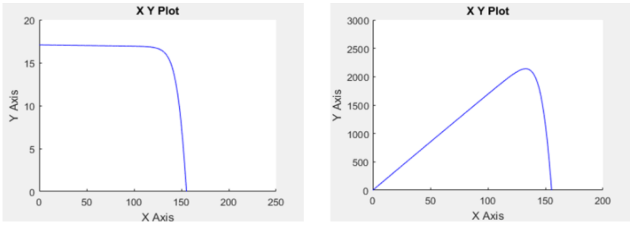


Figure 13. Case 3: TCT connection, *I-V* and *P-V* curves

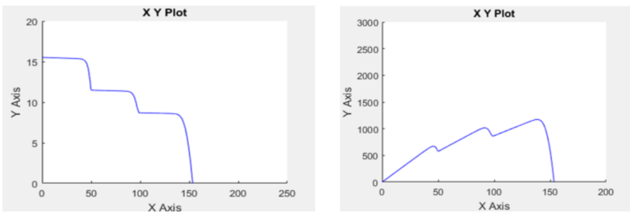


Figure 14. Case 4: SP connection, *I-V* and *P-V* curves

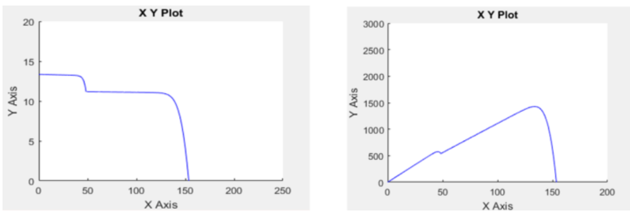


Figure 15. Case 4: TCT connection, *I-V* and *P-V* curves

It is clearly observed from these figures that, the TCT connection for any partial shading conditions is more immune and robust. Case-2 is performed to show unequal shading conditions for different modules. In this condition, while the *P-V* curve changes greatly in SP connection, the curve of TCT connection maintains its shape as depicted in Figure 10 and 11.

The same behavior is observed in case-3 as well, which shows the equal shading distribution as presented in Figures 12 and 13. Case-4 has harder shading condition than the others. In this condition, TCT connection is more robust and immune, too. This condition is given in Figures 14 and 15.

In the TCT connection, the currents are summed when the modules in the row are connected in parallel. Therefore, the shaded panel has fewer effects on the overall system. However, in the case of the SP connection type, since the panel in the column is connected in series, any shadowed panel limits the current in the other panels and this causes a lower power output. For this reason, rather than connecting parallel columns in series, connecting parallel rows in series allows the better immune system to be achieved.

In practice, because the TCT connection type leads to extra cabling, the cost-benefit analysis should be done as well. SP connection types reduce installation costs. In theoretical studies, it is possible to switch between two connection types using switching matrices. For future studies, designing PV systems operating at maximum efficiency can be designed by using switching matrices by using artificial intelligence algorithms.

VI. CONCLUSIONS

In the case of partial shading of the PV systems, this study examines the behavior of the most preferred types of SP and TCT compounds. According to the obtained results, TCT connection type has emerged as more immune and robust connection than the SP connection. It is evaluated that TCT connection should be used in the new PV systems even if increasing costs in order to increase total system efficiency. To gain benefit-cost, both connection type can be used together in the same system. In further studies, maximum efficiency can be achieved by using a combination of different connection types by using switching matrices with help of artificial neural networks.

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BIOGRAPHIES

Ali Osman Kucuk graduated from Department of Electrical and Electronics Engineering, Ataturk University, Erzurum, Turkey in 2010. Currently, he is a Ph.D. student in Electrical and Electronics Engineering Department in Gazi University, Ankara, Turkey. He currently works on renewable energy systems and applications of wave energy to produce electrical energy.

Haluk Gozde received the B.Sc. degree in Electrical and Electronics Engineering from Karadeniz Technical University, Trabzon, Turkey in 1997. He received the M.Sc. and the Ph.D. degrees in Electrical and Electronics Engineering from Gazi University, Ankara, Turkey in 2004 and 2010, respectively. He is an Assoc. Prof. of the Electrical and Electronics Engineering since 2016. His main research area consists of power system dynamics and control, renewable energy systems, smart grid technologies, artificial intelligence-based control methods, and swarm intelligence-based optimization algorithms.

M. Cengiz Taplamacioglu graduated from Department of Electrical and Electronics Engineering, Gazi University, Ankara, Turkey. He received the M.Sc. degrees in Industrial Engineering from Gazi University and also in Electrical and Electronics Engineering from Middle East Technical University, Ankara, Turkey. He received his Ph.D. degree in Electrical, Electronics and System Engineering from University of Wales, Cardiff, UK. He is a Professor of the Electrical and Electronics Engineering since 2000. His research interests and subjects are high voltage engineering, corona discharge and modelling, electrical field computation, measurement and modelling techniques, optical HV measurement techniques, power systems control and protection, lighting techniques, renewable energy systems and smart grid applications.

Mahir Dursun received the B.Sc., M.Sc. and Ph.D. degrees from Gazi University, Ankara, Turkey in 1993, 1996 and 2002, respectively. He is currently a Professor at the Department of Electrical and Electronics Engineering, Technology Faculty, Gazi University. His research interests are motor design, modeling, motor control, switched reluctance motors, linear switched reluctance motors, brushless DC motors, DC-DC converters, matrix converters, FLC, artificial neural network, elevator motors, motor and centrifugal pump drivers, DSP, PLC, microprocessors and microcontroller programming, serial and parallel active power filters, and photovoltaic systems, photovoltaic irrigating systems, RF control and communications.