ENHANCEMENTOF POWER GENERATION AND POWER QUALITY FROM PV ARRAY UNDER PARTIAL SHADING CONDITIONS

R. Ramaraj[1], J.S. Sakthi Suriya Raj[2], Dr. D. PrinceWinston[3]

[1,2]M.E(Power System Engg) , [3]Associate Professor, Kamaraj College of Engineering and Technology, Virudhunagar, Tamilnadu (India)

ABSTRACT

In recent years, the utilization of renewable energy has become an attractive alternative to fossil fuels because of the growing concern on the environmental issues. Solar power generation has emerged as one of the most rapidly growing renewable sources of electricity. There are various factors that contribute to the reduction of output power from PV arrays. One of the major factors is partial shading. This problem not only failing the power generation, but also the power generation of the illuminated cells is dramatically reduced. However, in addition to PV cells and modules, power electronic inverters are also critical components for a PV system. In this proposed project a new technique is identified to configure the modules in the array so as to enhance the power generation from the PV array under partial shading conditions. An electrical array reconfiguration technique is proposed in which the connections of the modules are dynamically changed so as to maximize the power. This work also focuses on the requirement of copper conductor and bypass diode for all the type of system including the proposed system.In order to improve the power quality, efficient and reliable Photovoltaic energy conversion technologies a detailed analysis is conducted for Central and Micro-Inverter based PV Systems.

I INTRODUCTION

While a majority of the world's current electricity supply is generated from fossil fuels such as coal, oil and natural gas, these traditional energy sources face a number of challenges including rising prices, security concerns and etc. Solar power generation has emerged as one of the most rapidly growing renewable sources of electricity. It has several advantages over other forms of electricity generation: pollution-free and inexhaustible nature. The PV systems are frequently mounted on building roofs, facades, or urban environment, where partial shading can be frequent. Partial shading can be caused by the shadows of buildings, trees, antenna dish and poles. Shading is one of the most common causes of a lower actual energy yield of a PV system. Hence the annual electrical energy output of a photovoltaic (PV) system largely reduced due to this partial shading. PV cells are connected together through certain series and parallel connections, to provide a large amount of power. When one of the cells is shaded, the current in the whole module is limited by this failing cell. Because of this, not only the power of the failing cell is lost, but also the power generation of the illuminated cells is dramatically reduced.

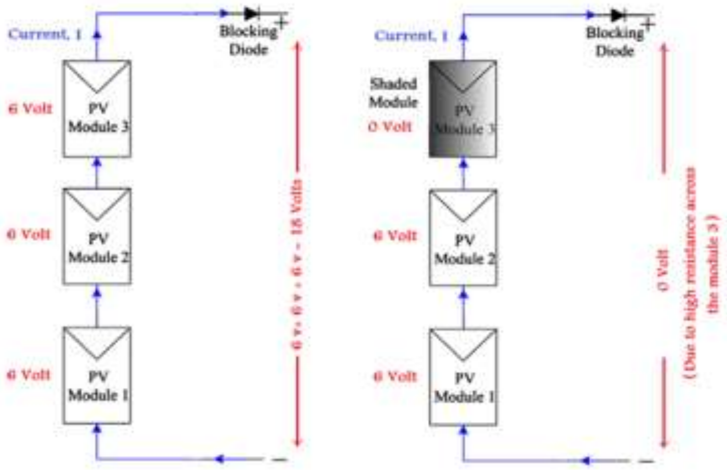


Figure.1 Explanation of Partial Shading

Hot-spot heating occurs when a large number of series connected cells cause a large reverse bias across the shaded cell, leading to large dissipation of power in the poor cell. The enormous power dissipation occurring in a small area results in local overheating, or "hot-spots", which in turn leads to destructive effects, such as cell or glass cracking, melting of solder or degradation of the solar cell.

A bypass diode is connected in parallel, but with opposite polarity to a solar cell. Under normal operation, each solar cell will be forward biased and therefore the bypass diode will be reverse biased and will effectively be an open circuit. Under partial shading conditions a solar cell is reverse biased then the bypass diode get forward biased and provide an alternative way for the current produced by the highest irradiated cells in the string, thereby allowing the current from the good solar cells to flow in the external circuit. The maximum reverse bias across the poor cell is reduced to about a single diode drop, thus limiting the current and preventing hot-spot heating that seems a system with low failure rates and long lifetime.

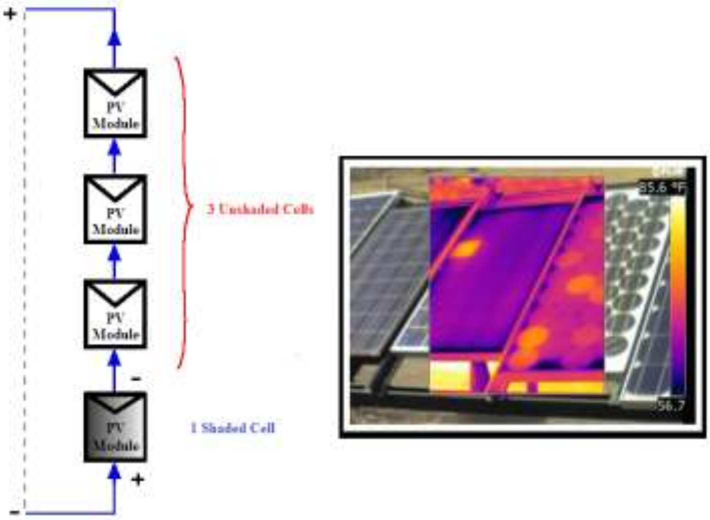


Figure.2 Effect of Hot-Spot Heating

The number of bypass diodes to be installed in a PV panel must be designed properly. A too high number would complicate the connection among the cells too much and would increase the costs. It has been found that one of the most sophisticated methods for maximizing available DC power is array reconfiguration where the connections of the modules are reconfigured without changing the physical location of panels. The different interconnection schemes such as Series–Parallel (SP), Total Cross Tied (TCT), Bridge Linked (BL), Honey Comb (HC) and recently Su Do Ku Puzzle pattern have been proposed.

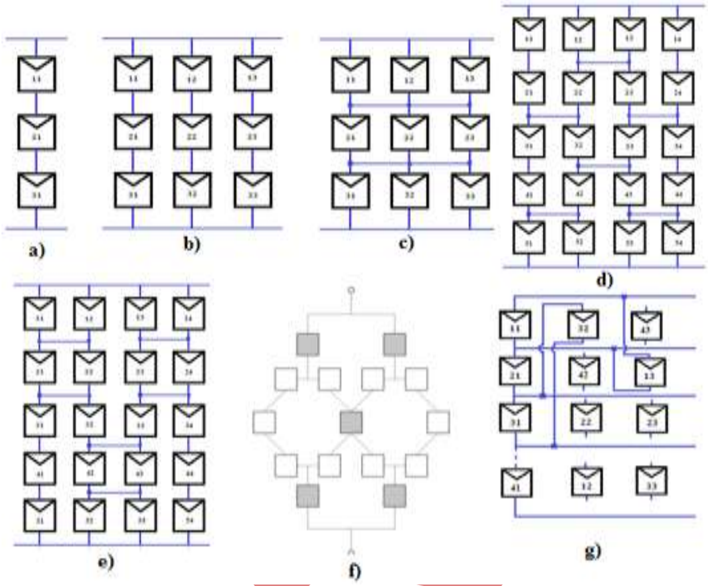


Figure.3 Review of different array configurations (a) Simple Series (b) Series Parallel, (c) Total Cross Tied, (d) Bridge Linked, (e) Honey Comb (f) Structure of Honey Comb Configuration and (g) Su Do Ku Puzzle pattern

In Bridge-Linked (BL) array all cells are interconnected in bridge rectifier fashion. BL configurations result in a 2.3% increase in MPP compared with the SP configuration. The modifications have been made in BL configuration to arrive at a new configuration called HC configuration. The advantages of TCT and BL configurations have been combined together in HC configuration. Total-Cross-Tied (TCT) array which is obtained from the simple Series-Parallel (SP) array (which has zero interconnection redundancy) by connecting ties across each row of junctions; it may be characterized as the scheme with the highest possible redundancy. The introduction of Total Cross Ties (TCT) almost doubles the life time of the system. Changing the interconnection schemes of the modules from SP to TCT increases the power by more than 3.8 % and the TCT configuration is considered as the best solution to mitigate the mismatch losses under partially shaded conditions. To enhance the PV power generation under partial shaded conditions, the modules are arranged based on the Su Do Ku puzzle pattern so as to distribute the effect of shading over the entire array without altering their electrical connection within the array.

Solar inverters, sometimes called PV inverters, are types of electrical inverters which are developed to change a DC (direct current) voltage from photovoltaic arrays into AC (alternating current) currents which in turn are used to power home appliances and some utility grids. These solar inverters are very popular nowadays as electricity costs continue to rise. Also, this helps conserve energy for future use.

II CLASSIFICATION OF SOLAR INVERTER

Solar PV Inverters may be classified into three broader types**:**

2.1 The Stand Alone Solar Inverter

These standalone solar inverters are called such because they do not need to be hooked up into a solar panel. Instead, it draws its direct current (DC) power from batteries which are charged by photovoltaic (PV) arrays. There are a lot of standalone inverters which integrate vital battery chargers to refill the battery coming from an alternating current (AC) source whenever possible. Because these inverters are isolated from utility grids, they do not require anti-islanding protection. Some of the most commonly used power converter types are briefly described according to their topology, function, efficiency, and the major global manufacturers.

2.2 Power Optimizer

Commonly known as a DC-DC power optimizer in solar PV markets, a power optimizer is a module-level power converter. It takes DC input from the solar module and gives either higher or lower DC output voltage. Such a converter is equipped with an MPPT technology to optimize the power conversion from the solar panel to the DC load or a battery or central inverter. It is also considered one of the most efficient power converters, delivering up to 99.5% efficiency. However, it needs DC cabling from the array. Some of the major players in this power converter market are ***SolarEdge*** and ***Tigo***Energy.

2.3 Micro-Inverter

Micro-inverter is also a module-level power converter. It takes DC input from the solar module and converts it into AC electricity, which is then ready to be connected to the load or single-phase main grid or to a central inverter. It is also equipped with MPPT technology to detect the maximum power point of each module. Even though it doesn't requires any DC cabling, it is more expensive than the power optimizer due to its advanced design. The efficiency of such a power converter is about 96%. The important players in this power converter market are ***Enecsys*** and ***Enphase***.

2.4 Central Inverter

In large PV power plants (10 kW and higher), central inverters are used instead of string inverters. However, the central inverters' functionality remains the same (i.e, to produce a 3-phase high voltage output for grid integration), which is why this power converter is considered essential for connecting with the main grid. In many large PV power plants, central inverters are inevitable. But there are many losses within the PV system due to their large and complex configuration. However, to mitigate such losses, some of the manufacturers, like Siemens, have developed a master-slave arrangement, such that at low irradiance the system efficiency will increase.

2.5 Research Gap Identify

In Total Cross Tied scheme, when any one of the entire rows is partially shaded, the power generated in the reaming cell will not be available in the output. It requires more number of bypass diode (across the each cell) to eliminate this effect.

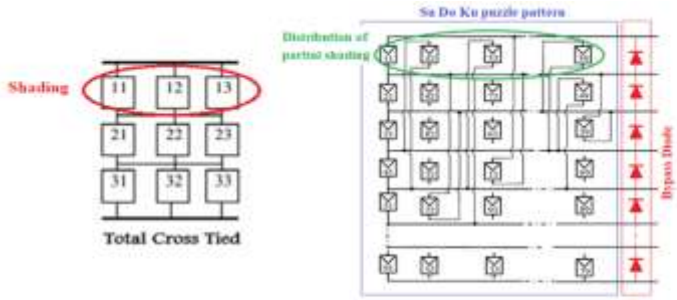


Figure.4 Drawback of partial shadingand Su Do Ku puzzle pattern

Su Do Ku puzzle pattern distribute the effect of partial shading. A bypass diode string improves the voltage profile and reliability. Considering the number of interconnections, the SP configuration has the minimum wiring, while the TCT configuration requires the maximum number of wires. The higher number of interconnections slightly increases the loss of the PV system due to the additional cable loss. However, the simpler pattern of TCT configuration for large PV arrays causes easier wiring process. Recently proposed Su Do Ku Puzzle made wiring complicated and requires more conductors. To enhance the power generation from the PV array under partial shading conditions, the bypass diode (Normal PN diode is replaced by Shockley diode which has more features than PN diode) will be implemented to extract the power from a single cell or module that seems a system with low failure rates and long lifetime. The modules will also be arranged to reduce of the effect of shading over the entire array without altering their electrical connection within the array.

III V-I CHARACTERISTICS

The V-I characteristics of schottky barrier diode is shown below. The V-I characteristics of Schottky barrier diode is steeper compared to V-I characteristics of normal PN junction diode due to high concentration of current carriers. Their blocking voltages, however, are limited due to the reverse currents which rise steeply when the temperature rises and their unipolar on-state character. Silicon based Schottky diodes are currently available with a blocking voltage of up to around 200 V. Those made of gallium arsenide (GaAs) are suitable for up to 300 V, while Schottky diodes made of silicon carbide (SiC) are available for up to 1200 V. The suitability of SiC for high blocking Schottky diodes is due to the material's breakdown field intensity, which is nine times higher than silicon. The forward voltage drop increases with the increasing doping concentration of n type semiconductor.

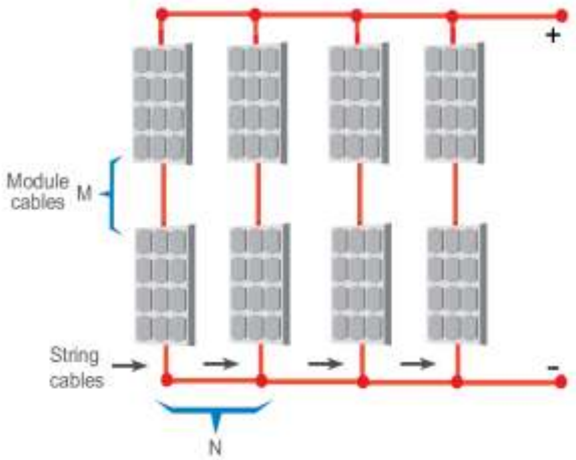
IV DESIGN OF WIRING CIRCUIT

The cables used for wiring the PV system need to be selected to ensure that they can withstand the extremes of the environmental, voltage and current conditions, under which they may be expected to operate. PV array formed from a number of strings, fault conditions can give rise to fault currents flowing though parts of the DC system. Two key problems need to be addressed are overloaded string cables and excessive module reverse currents, both of which can present a considerable fire risk. Hence, the string cables are suitably rated such that they may safely carry the maximum possible fault current. Hence to minimize the conductor loss (I^2R) and risk of faults, cables have to be chosen as short as possible.

General assumptions are made to calculate the requirement of conductor

- Module distance is 1 meter
- String distance is 2 meter

Where the distance between two adjacent modules is module distance, M and the distance between two adjacent string (or column) is string distance, N.



Configuration	Required Conductor in meter
SP	104
TCT	200
HC	136
BL	104
Su Do Ku	986
Proposed	512

Fig.5 Calculation of conductor requirement Table.6 Conductor requirement of different configuration

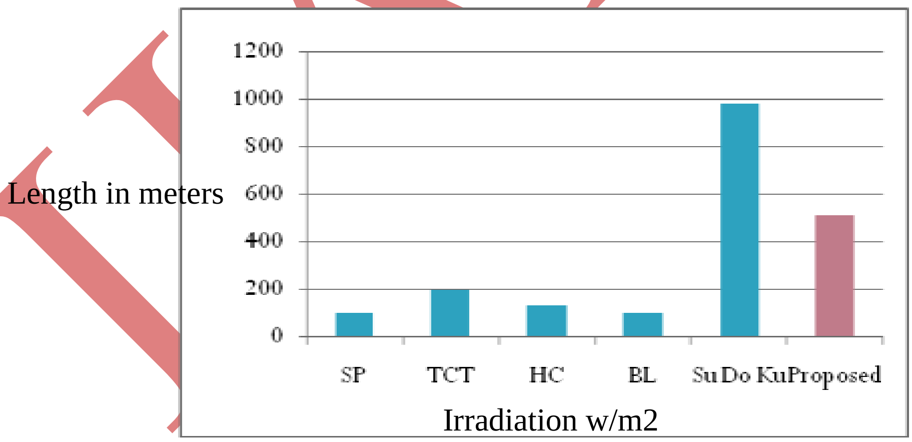


Figure.7 Comparison of Conductor requirement of different configuration

4.1 Central Inverter

A single inverter is used to Invert the entire PV array is called as Central inverter. String sizing is an important step when designing a PV system with a central inverter. This is important in system design in order to make sure the sum of the solar panel DC voltages isn't more than the inverter can handle or greater than the residential limit.

Additionally, when sizing an inverter to an array, one must work off the worst-case scenario for highest voltage and current to ensure that the equipment is never damaged.

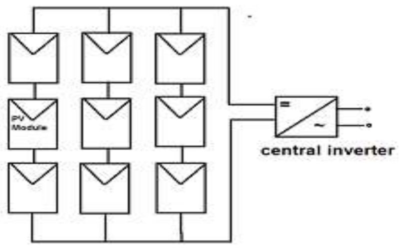


Fig.8 Block diagram of Central inverter

The primary disadvantage of the central converter configuration is that a large power loss may occur in the energy harvest when mismatch or shading happens among the PV panels within the array. Normally, a bypass diode is applied to a PV module. However, the recent development of the micro-inverter has enabled arrays that don't require complicated string sizing calculations and can be much more flexible for the market segment that values expansion options.

4.2 Micro-Inverter

A Micro-inverter is a much smaller device than a central inverter, and is mounted under an individual PV panel. It is then connected in parallel to the other Micro-inverters in an array. The Micro-inverter and panel are often referred to as an AC module. A Micro-inverter can accomplish the same tasks as a central inverter, including efficiently inverting DC to grid-synced AC, preventing system islanding, boosting efficiency through a MPPT, and meeting the standards. The maximum number of potential connections is stated for each model, so no string sizing is required. Moreover, Micro-inverters allow modules to be independent power producers, optimizing each panel regardless of how the rest of the array is functioning. This means that systems can be more flexible, because panels can gradually be added over time as budget allows. Panels can also be mixed and matched among different brands and models. The basic typology of a Micro-inverter is similar to that of many central inverters.

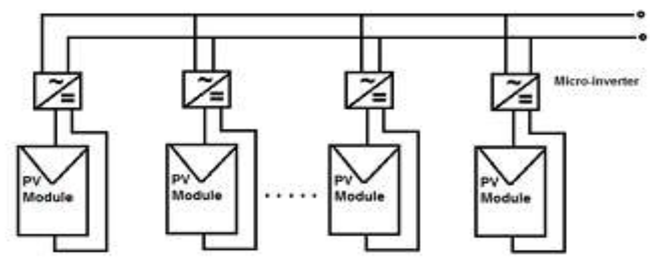


Fig.9 Block diagram of Micro Inverter

Micro-inverters have several advantages over conventional string inverters. The principal advantage is that shading of any one solar panel, or a panel failure, does not disproportionately reduce the output of an entire array of panels. Each micro-inverter can act as a maximum power point tracker for the Solar PV panel it is connected to.

Their primary disadvantages are that they are generally more expensive per peak watt than the equivalent power in a string inverter and are normally located on the panel, where they are harder to maintain.

A simulink model of the entire system of Central and Micro-Inverter are designed using MATLAB/Simulink.By varying the Irradiance of the PV Module the Partially shaded property is obtained.At various Irradiance (Shaded) condition the Quality of Power is evaluated by calculating THD using FFT analysis.

V RESULTS AND DISCUSSIONS

5.1 Different Shading Scenarios

To evaluate the performance of the proposed method, a 9 x 9 PV array connected in TCT configuration is subjected to three different shading patterns namely (a)Partial Shading (b) Uniform Shading and (c) Non-uniform Shading. Here in this case, only one bypass diode across a group of cells (one bypass diode per row) has been considered.

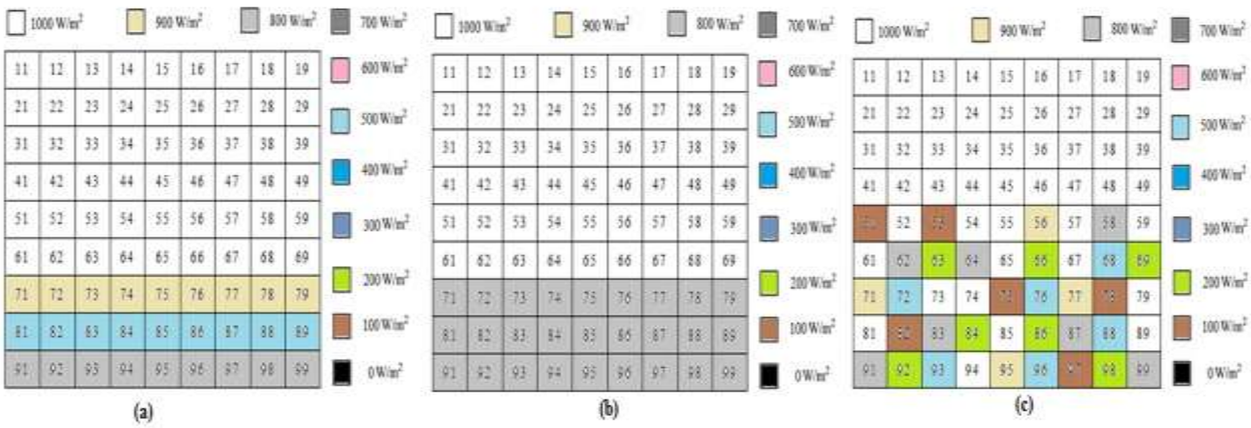


Figure.10 a) Partial shading arrangements b) Uniform shading arrangements c) **Non-Uniform shading arrangements**

A simulation study was carried out to compare the different shading pattern with the proposed PV system under complex illuminations.

5.2 Simulation Results

TABLE.7 PARTIAL SHADING

W/m^2	OUTPUT POWER IN WATTS									
	TCT		BL		SP		Su Do Ku		HC	
	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass
800	5260	14460	5260	7872	5260	11350	14100	14100	5260	8533
700	5260	8184	5260	7561	5260	8188	12300	12300	5260	7153
600	5260	5260	5260	5366	5260	5388	10700	10700	5260	5365
500	5260	5260	5260	5260	5260	5260	9165	9165	5260	5227
400	3314	3314	3314	3314	3314	3314	3314	3314	3314	3291
300	1835	1835	1835	1835	1835	1835	1835	1835	1835	1822
200	802	802	802	802	802	802	802	802	802	797
100	197	197	197	197	197	197	197	197	197	196

TABLE.8 UNIFORM SHADING

W/m²	OUTPUT POWER IN WATTS									
	TCT		BL		SP		Su Do Ku		HC	
	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass
800	7721	17790	0.019	2814	0.019	17800	16010	16010	0.019	9052
700	2247	14650	0.019	2814	0.019	17600	12260	12260	0.019	4782
600	588.8	11330	0.019	2263	0.019	11350	9012	9012	0.019	3044
500	141.5	8171	0.019	2261	0.019	8185	6262	6262	0.019	1964
400	30.96	5373	0.019	1008	0.019	5385	4011	4011	0.019	1150
300	6.03	3077	0.019	1008	0.019	3085	2260	2260	0.019	520
200	1.01	1375	0.019	307	0.019	1380	1007	1007	0.019	358
100	0.14	338	0.019	307	0.019	335	254	254	0.019	307

TABLE.9 NON UNIFORM SHADING

W/m²	OUTPUT POWER IN WATTS									
	TCT		BL		SP		Su Do Ku		HC	
	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass	Without bypass	With bypass
800	3314	7949	3314	5135	3314	7951	11590	11590	3314	4633
700	197	10480	197	2733	197	10490	10750	10750	197	2464
600	197	7693	197	1899	197	7121	8020	8020	197	1199
500	197	4491	197	2307	197	5260	5495	5495	197	1899
400	197	4658	197	1238	197	4664	3616	3616	197	639
300	448	3271	448	1031	448	3271	1885	1885	448	933
200	7.79	801	7.79	320	7.79	801	802	802	7.79	318
100	7.79	287.5	7.79	130	7.79	288	251	251	7.79	110

OUTPUT GRAPHS

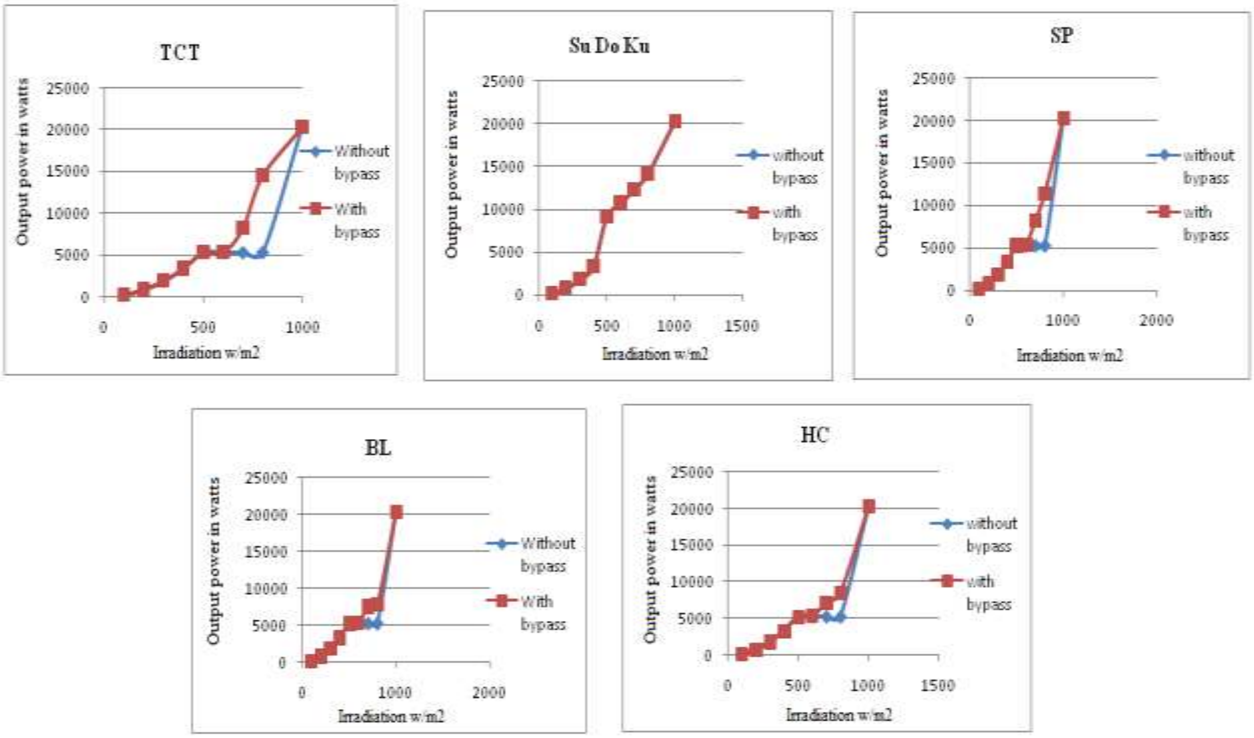


Figure.11 Partial Shading

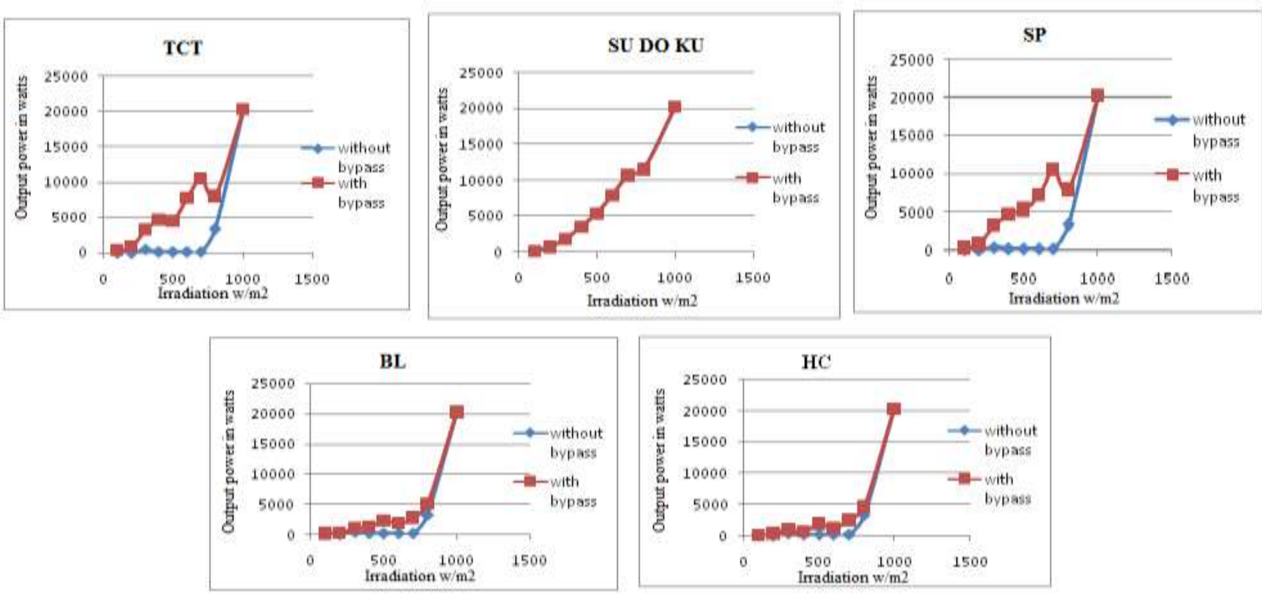


Figure.12 Uniform Shading

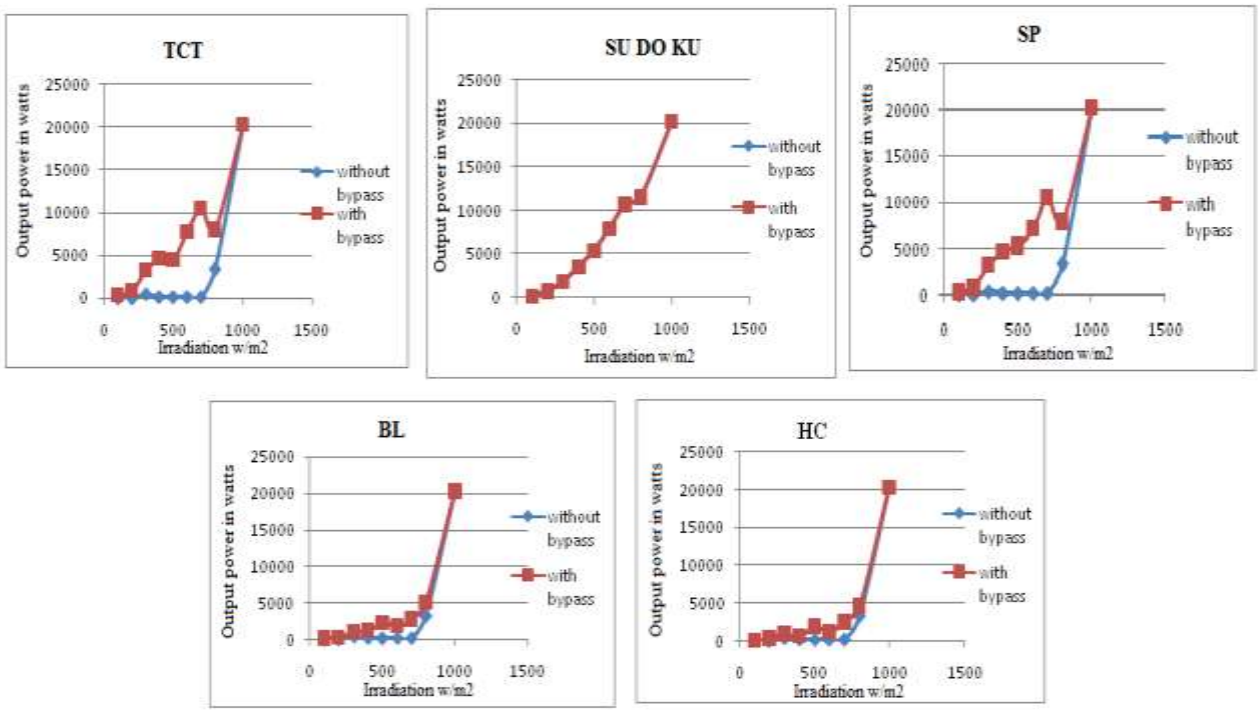


Figure.13 Non Uniform Shading

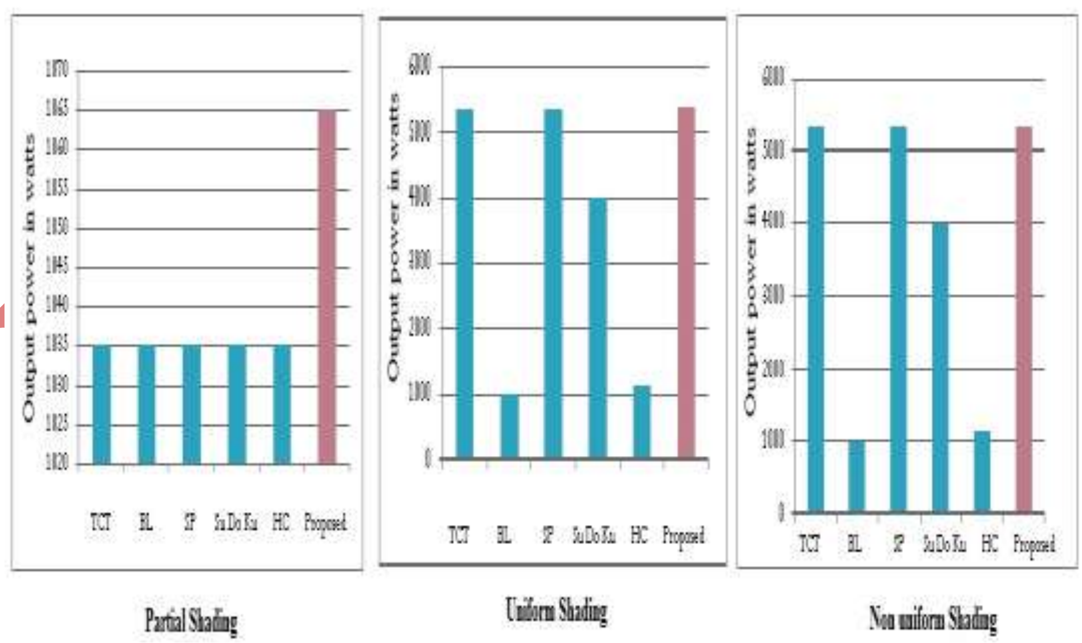


Figure.14 Comparison of output power of different configuration

VI THD VALUE UNDER DIFFERENT SHADING SCENARIOS

Total Harmonic distortion value for Central and Micro inverter under different shading conditions are tabulated below.

Irradiance 1000 W/m^2	THD (%)	
	Central Inverter	Micro-Inverter
1000	1.22	4.44
800	1.35	4.44
600	2.31	4.49
400	6.15	6.86
200	13.22	13.97

Table.10 THD value under different shading condition

The above Table 7.1 gives the values of THD under constant shading condition for all panel varied from 1000W/m^2 to 200W/m^2.

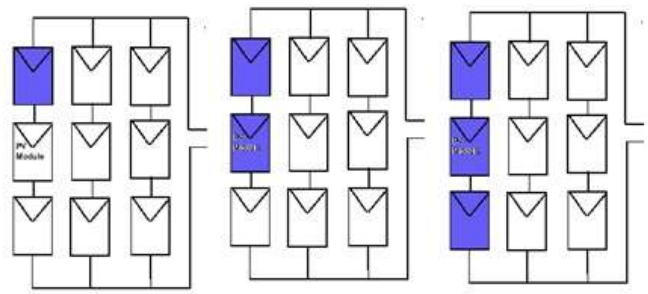
Input	Irradiance (W/m^2)	THD (%)	
		Central Inverter	Micro-Inverter
Linearly Decreased	1000 to 200	1.22	4.44
Linearly Increased	200 to 1000	23.05	22.42
Step Input	1000-200-1000	1.22	4.43
	200-1000-200	1.36	4.41

Table.11 THD value under linearly varied shading condition

The above Table gives the values of THD under linearly varying condition for every PV module varied between 1000W/m^2 to 200W/m^2.

6.1 Partially Shaded Column

The PV Modules P_1, P_2, P_3 are made partially shaded by keeping the Irradiance level as 200W/m^2



(a)

Irradiance 1000 W/m²	THD (%)	
For Shaded PV panel 200 W/m²	Central Inverter	Micro-Inverter
P1	1.39	7.75
P1,P2	1.42	16.03
P1,P2,P3	1.49	20.48

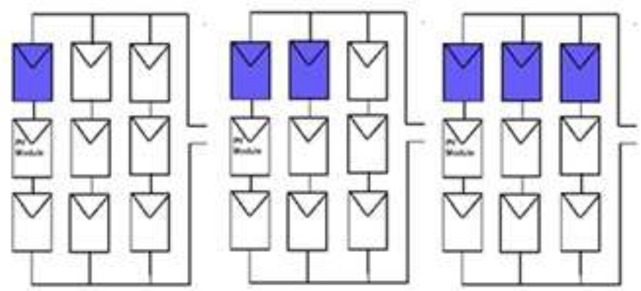
(b)

Figure.14 a) Partially Shaded Column b) value obtained by FFT analysis

The above table shows the THD value obtained by FFT analysis under Column wise Partially Shaded condition.

6.2 Partially Shaded Row

The PV Modules P_1, P_4, P_7 are made partially shaded by keeping the Irradiance level as 200W/m^2



a)

Irradiance 1000 W/m²	THD (%)	
For Shaded PV panel 200 W/m²	Central Inverter	Micro-Inverter
P1	1.39	7.75
P1,P4	2.90	16.03
P1,P4,P9	5.47	20.48

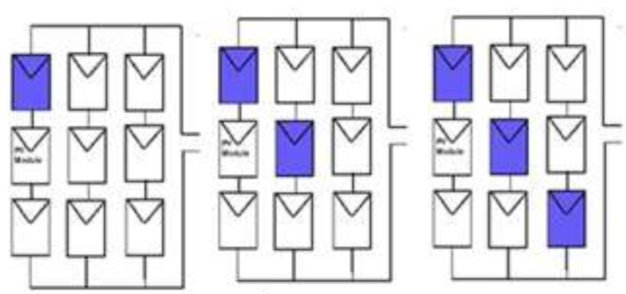
b)

Figure.15 a) Partially Shaded Row b) value obtained by FFT analysis

The above table shows the THD value obtained by FFT analysis under Row wise Partially Shaded condition.

6.3 Partially Shaded Diagonal

The PV Modules P_1, P_4, P_7 are made partially shaded by keeping the Irradiance level as 200W/m^2



a)

Irradiance 1000 W/m²	THD (%)	
For Shaded PV panel 200 W/m²	Central Inverter	Micro-Inverter
P1	1.39	7.75
P1,P5	2.90	16.03
P1,P5,P9	5.47	20.48

b)

Figure.16 a) Partially Shaded Diagonal b) value obtained by FFT analysis

The above table shows the THD value obtained by FFT analysis under Diagonal wise Partially Shaded condition. Micro inverter has high Efficiency than central inverter in partially shaded condition. It also has Low transmission loss. In Micro Inverter configuration the capacity of the generating Plant can be increased easily. Shading caused in one panel will not affect the Power generated by the adjacent panel. In Micro-Inverter increase in large number of PV arrays significantly increases the number of semiconductor switches, making them cost prohibitive.

VII CONCLUSION

Partial shading in solar modules posts a great problem in generating power. After analyzing the various configurations for different random shading patterns, it is observed that in most cases, the proposed method will have higher power output than the Su Do Ku and other configurations. It is also identified that conductor requirement is also very low for the proposed system compared to the other configuration. It also inferred that Central inverter has very low THD value when compared with Micro inverter under various partially shaded conditions. Although Micro-inverter has many advantages than central inverter its quality of the output power is low. Thus for the system which is located near to the load, Centralized inverter can be preferred. If it is located too far from the load, Micro inverter can be preferred. Proposed configuration is comparatively less susceptible to the effects of partial shading.

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