Study of different PV array configuration techniques to improve performance of solar photovoltaic array

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Abstract - **In this research paper, the study of different PV array configuration to find out the efficiency of connections in uniform as well as in partial shading conditions. To study the effect of PV array on non uniform shading the modules size 3*3 of series (S), parallel (P), series parallel (SP), total cross tied (TCT), bridge link (BL), honey comb (HC) have been classified. Result of such configuration have been study in terms of open circuit voltage, short circuit current, maximum power, maximum voltage, maximum current, VI characteristics, fill factor and efficiency can be calculated by using validate formulae.**

keywords - **Series (S), Parallel (P), Series Parallel (SP), Total Cross Tied (TCT), Bridge Link (BL), Honey Comb (HC).**

I. Introduction

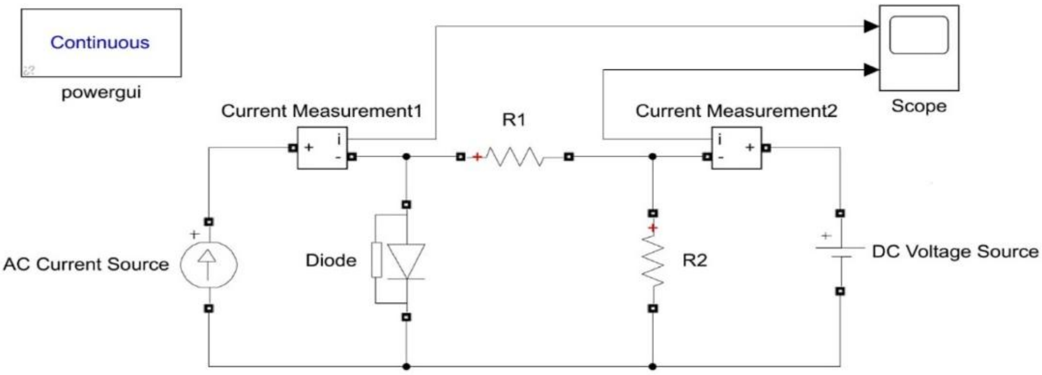
Solar energy is one of the major renewable energy resource which is having potential to solve many challenges which is facing the world. In market there is need to promote the renewable energy resource particularly solar energy. Solar energy having many benefits to the world and also to the environment. It is safe alternative that can interchange many fossil fuels like gas and coal for the production of electricity and from that we can reduce water, land and air pollution. If we use particularly solar renewable energy resources we can prevent the distraction of habitats. From that we are saving the trees which are very useful for our environment. By using solar energy we can stop simultaneously changes in weather pattern to leading effects. This energy is very useful for consumer because the production of energy by using small scale and consumer directly get the electricity that's why it is the greatest attraction for consumers.

The series and parallel which is the main combination for the formation of solar photovoltaic array and this is use to obtain desired output in terms of voltage and current. As we know increment of output voltage is done in series configuration and in parallel configuration increment of output current is done. By using series and parallel connection there are another four configuration which is formed by using the combination of series and parallel configuration. Throughout the simulation we had observed some parameters and by using that particular parameters we will find out fill factor and efficiency of the panel in uniform shaded portion as well as in non-uniform shaded portion. In non-uniform shaded portion we include different partial shading condition like row shading, column shading, diagonal shading, random shading.

II. PHOTOVOLTAIC MODULE

The photovoltaic cell it is also term as solar cell which helps to produce electric current and for there is, need to flow the electron in the same direction. It is help to produce the direct current and for the measurement of efficiency the combination of cells are formed and it becomes modules and when modules are combined formation of array occurred. In this given circuit the calculation are depend on changing the value of irriadance and temperature. This circuit is shown in figure.

Equivalent circuit diagram of ideal solar PV cell



Ideal PV & I-V characteristics equation

$$I = Ipv - Io\left[\exp\left(\frac{V+RsI}{Vta}\right) - 1\right] - \frac{V+RsI}{Rp} \qquad (1)$$

Where

I and IPV are the entire current and photovoltaic (PV) currents,

VT = NskT/q it shows thermal voltage of the array

where

Ns is cells number in series.

The saturation current (IPV) and photovoltaic (Io) can be given by:

$$Ipv = (Ipv,n + K1\Delta t)\ \frac{G}{Gn} \qquad (2)$$

$$Io = \frac{Isc,n+K1\Delta t}{\exp\left(\frac{Voc,n+Kv\Delta t}{aVt}\right)-1} \qquad (3)$$

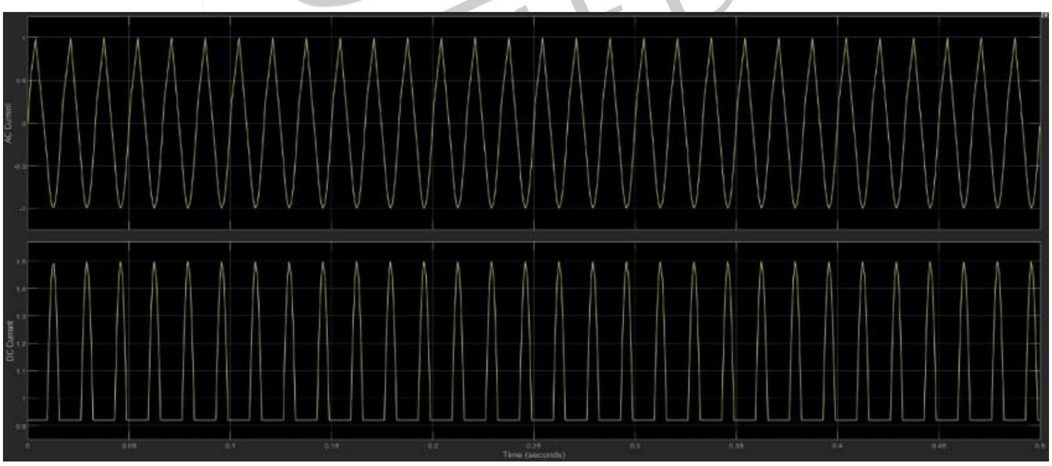
Where

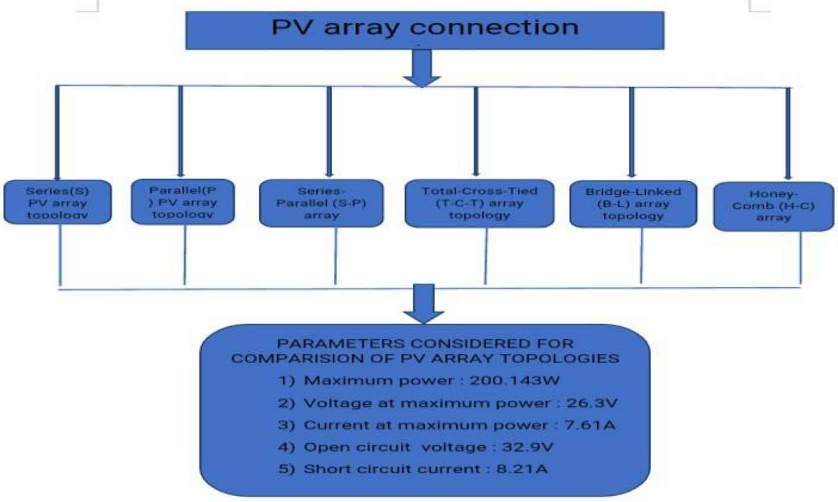
AT=T- Tn (T and Tn is the verified and nominal temperatures [in Kelvin], respectively),

G stands for irradiation in watts per square meters,

Gn is nominal irradiation, and Kl and KV is current and voltage coefficient respectively.

Output Waveform





III. PV Array Configuration

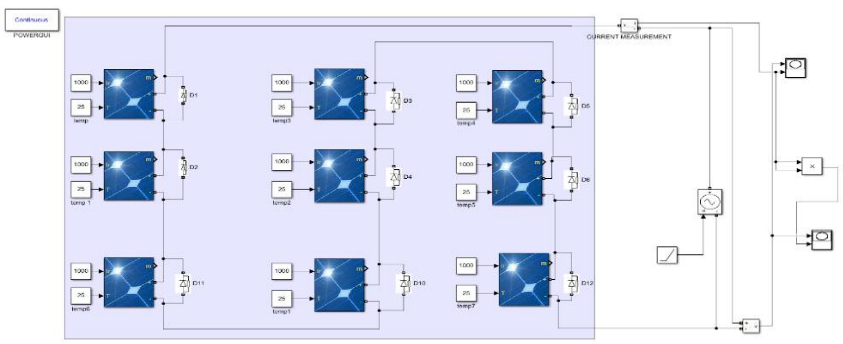
A. Series Configuration

In series topology the current throughout the panel or modules is same. To produce equal short circuit current in uniform and nonuniform shaded modules all the pv modules should be operate in reverse bias mode. To prevent the panels from hotspot effect bypass diode should be connected in antiparallel. In series connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 720.2 V short circuit current Isc is 15.3 A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 590.2 V current at maximum power point Impp is 13.09A. from this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

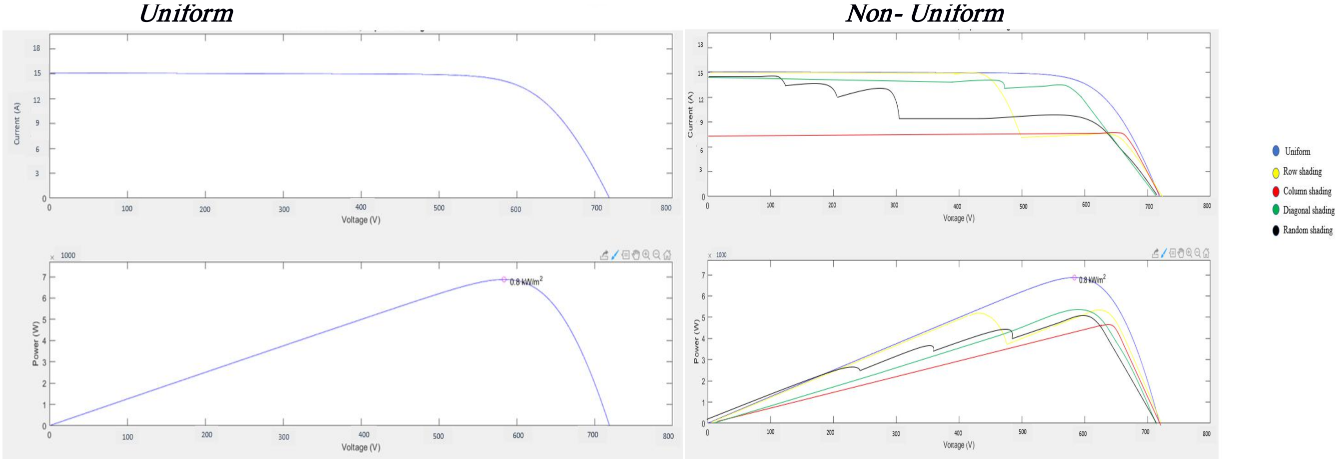
Efficiency = Vmpp*Impp/ I *A

So that fillfactor (%) is 63.53 and efficiency (%) is 63.53.



Simulink model of 3*3 series(S) PV array Configuration.

Uniform *Non- Uniform*



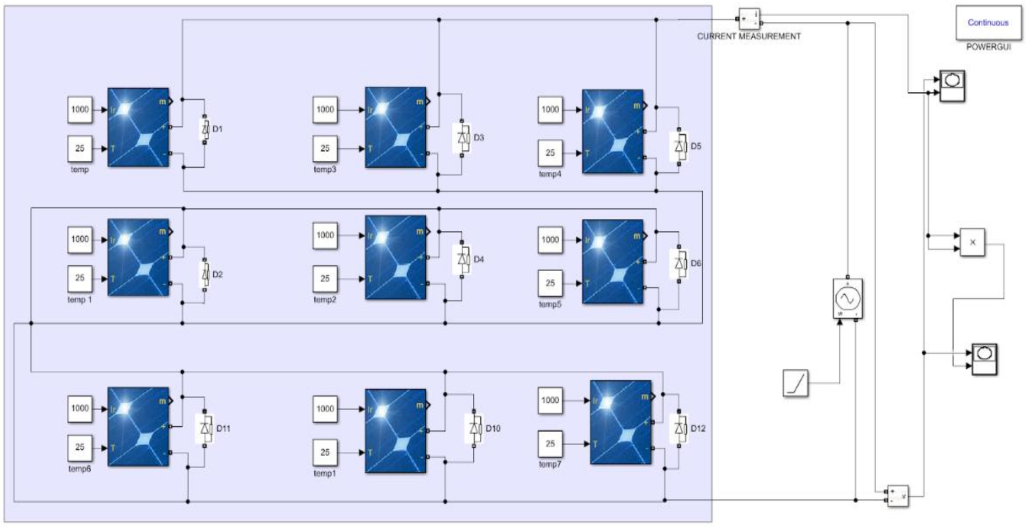
B. Parallel Configuration

In parallel topology, modules are connected in parallel manner. The voltage in each modules is same but there is variation in current throughout the modules. In this configuration the flow of generated current is limitless it is irradiance level depended. Parallel configuration is quite efficient than series configuration. It is very easy connection because if we want to add or subtract panel to form new connection it is smoothly working without affecting the modules. If there is any fault is occur then we can easily pass the current throughout the circuit using different paths. In parallel connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 73.5 V short circuit current Isc is 150.1A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 57.8V current at maximum power point Impp is 135.5A. from this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

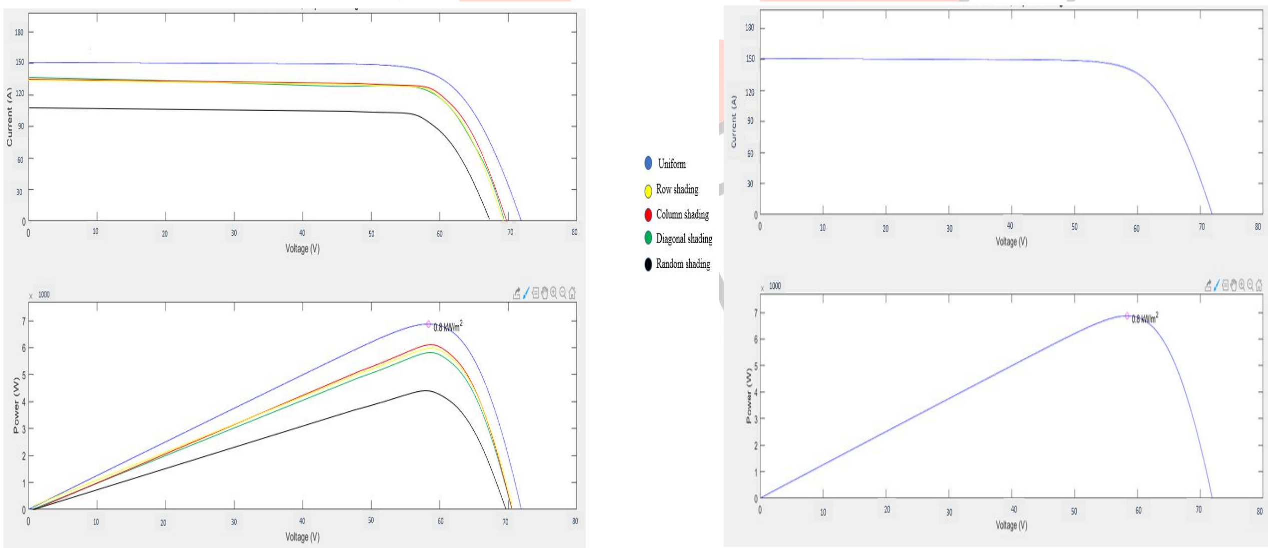
Efficiency = Vmpp*Impp/ I *A

So that fillfactor (%) is 63.49 and efficiency (%) is 63.49



Simulink model of 3*3 Parallel(P) PV array Configuration.

Uniform *Non-Uniform*



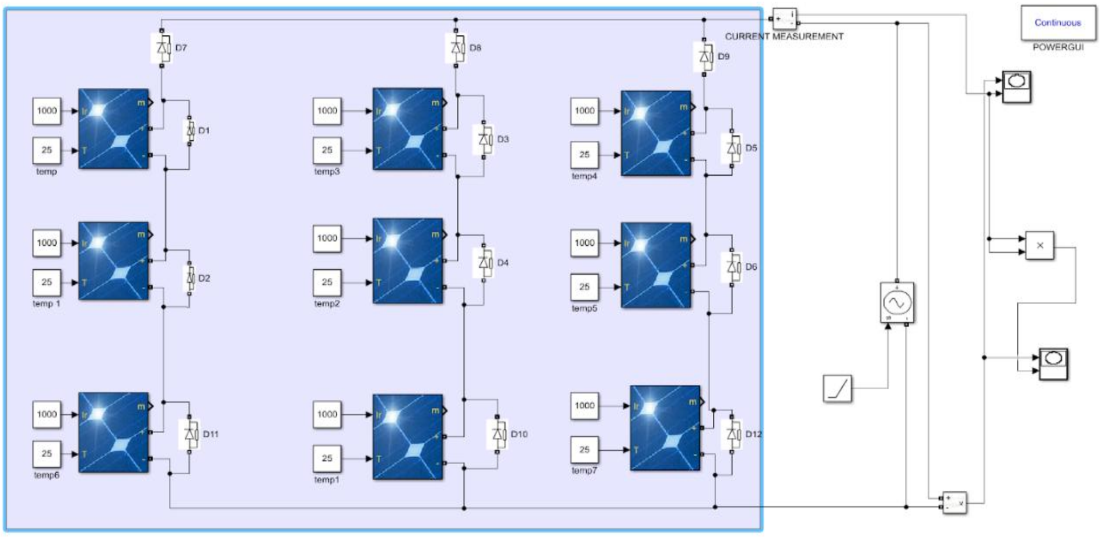
C. *Series-Parallel Configuration*

Series parallel configuration is most commonly used configuration. In this particular structure the modules are connected in series and that modules are again connected in parallel. In this particular configuration blocking diode plays an important role, blocking diode should connected in series for the protection of short circuit condition in pv module and it helps to prevent black flow of current in the string. The construction of this configuration is easy and comparatively it provides higher power than series and parallel configuration. In series parallel connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 220.1 V short circuit current Isc is 49.8 A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 178.5 V current at maximum power point Impp is 47.7 a from this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

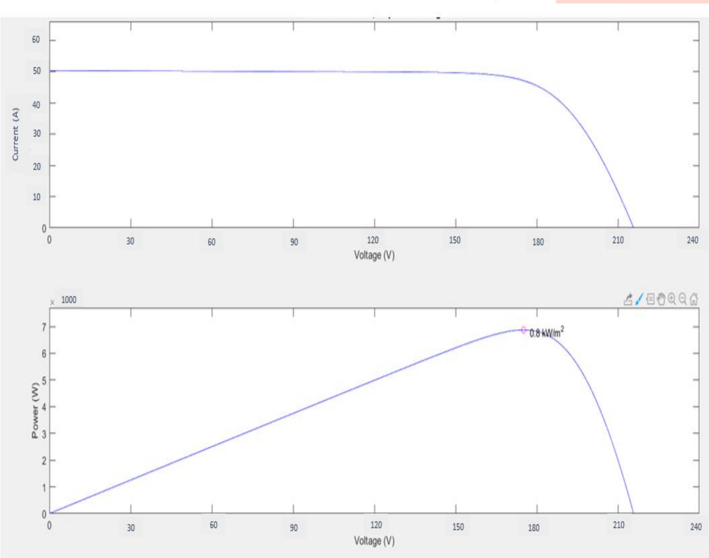
Efficiency = Vmpp*Impp/ I *A

So that fillfactor (%) is 63.86 and efficiency (%) is 63.86

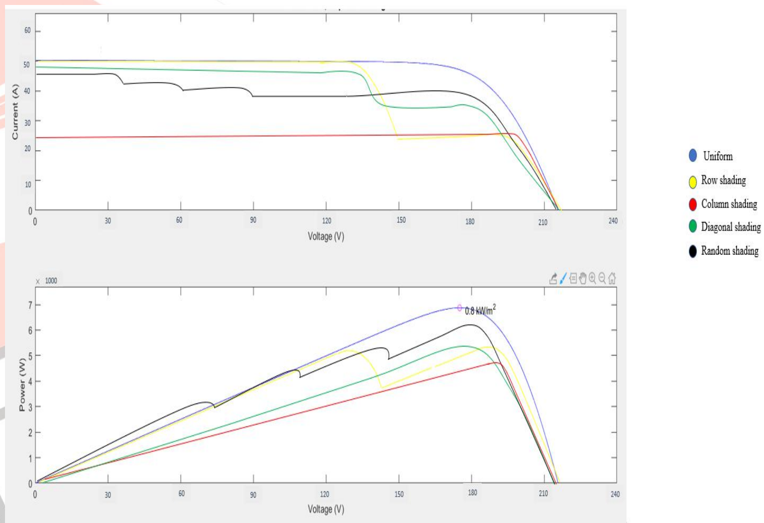


Simulink model of 3*3 series-Parallel(S-P) PV array Configuration.

Uniform



Non-Uniform



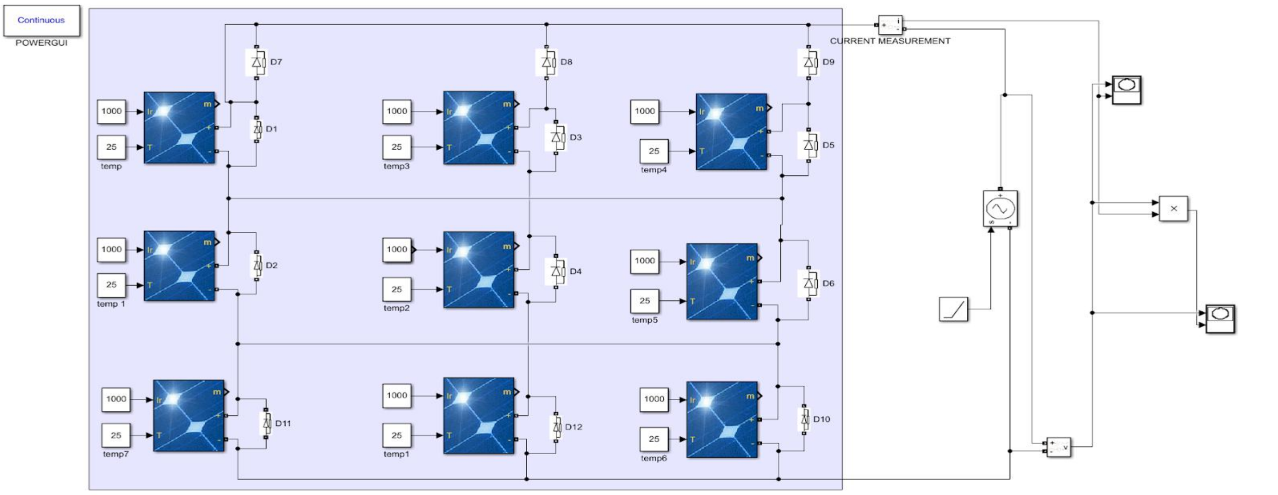
D. Total Cross Tied

Total cross tied configuration is the derivative of series parallel configuration. The connection of modules is exactly opposite than series parallel configuration i.e the modules are connected in parallel and that parallel modules are again connected in series manner. It is more efficient configuration. This is the best configuration because it produce the maximum power output than the rest of the configuration. If we use the partial shading condition we obtained maximum power throughout the panel. In this configuration we reached at highest efficiency and fill factor in uniform as well as in shading pattern. In total cross tied connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 221.6 V short circuit current Isc is 49.4 A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 178.8 V current at maximum power point Impp is 48.2 A. from this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

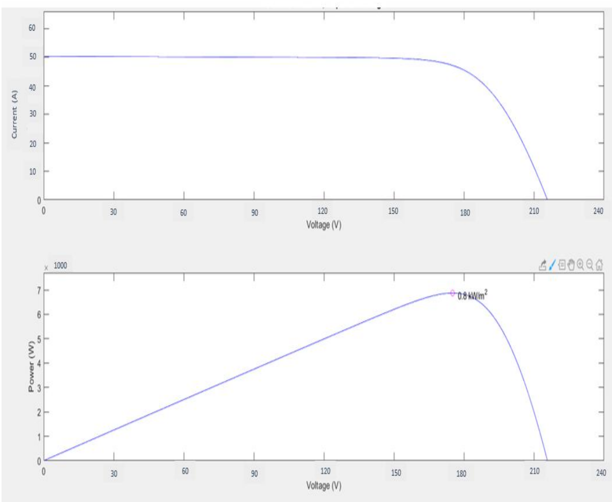
Efficiency = Vmpp*Impp/ I *A

So that fillfactor (%) is 63.95 and efficiency (%) is 63.95

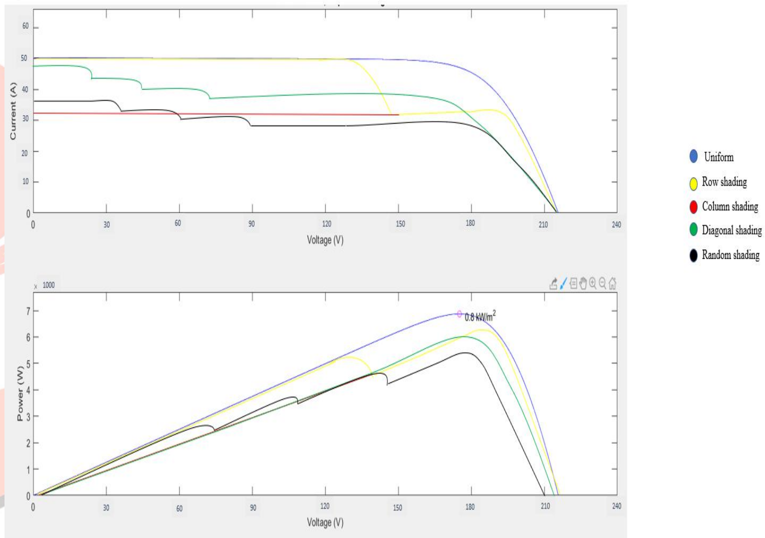


Simulink model of 3*3 Total-cross-tied(T-C-T) PV array Configuration.

Uniform



Non-Uniform

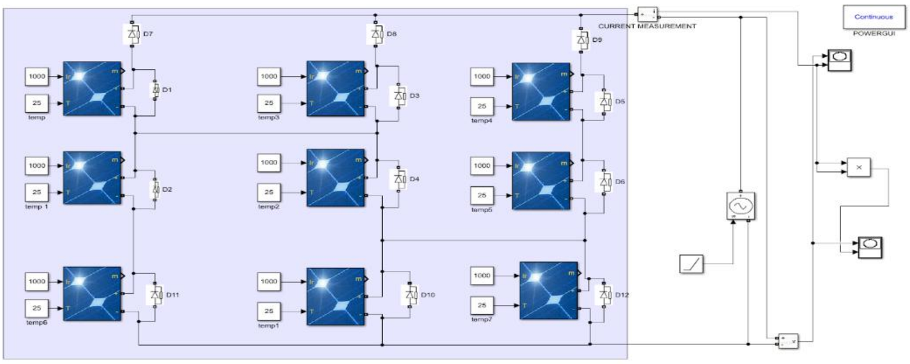


E. Bridge Link Configuration

Bridge link configuration having more connection as compared to series parallel configuration. Therefore when the number of connections are more there is production of power loss in higher amount. To reduce this power loss the modules should be connected in bridge rectifier architecture and hence if we connect this architecture we obtain the desired values if output i.e. Current as well as voltage. In this configuration because of using tied the number of connections are less as compared to series and series parallel. Power loss is also less than the series and series parallel configuration. In bridge link connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 220.1 V short circuit current Isc is 49.8 A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 177.4 V current at maximum power point Impp is 48.2 A. From this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

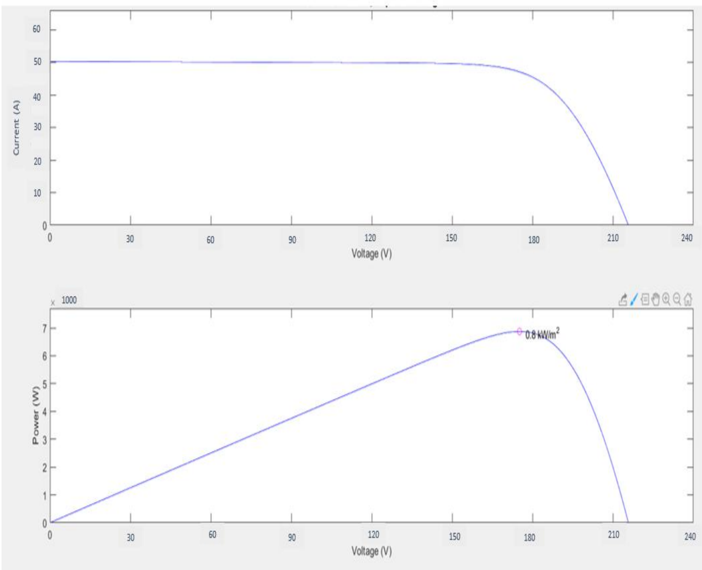
Efficiency = Vmpp*Impp/ I *A

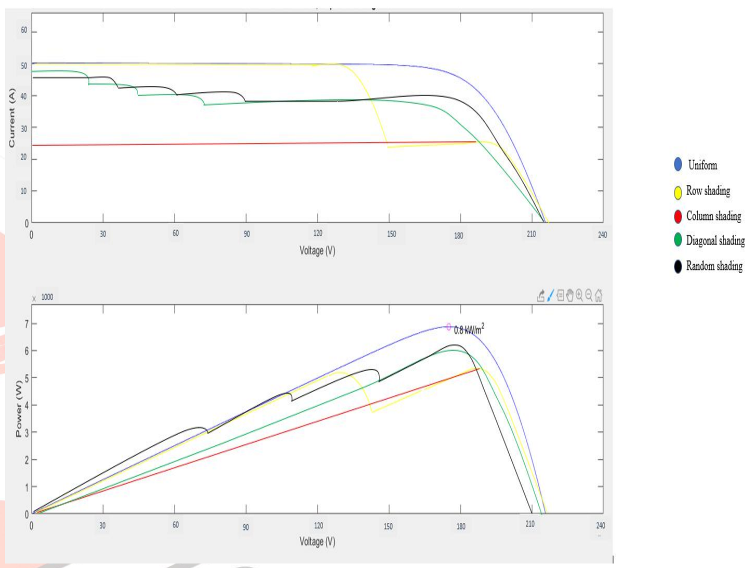


So that fillfactor (%) is 63.86 and efficiency (%) is 63.86

Simulink model of 3*3 Bridge Link (B-L) PV array Configuration.

Uniform *Non-Uniform*





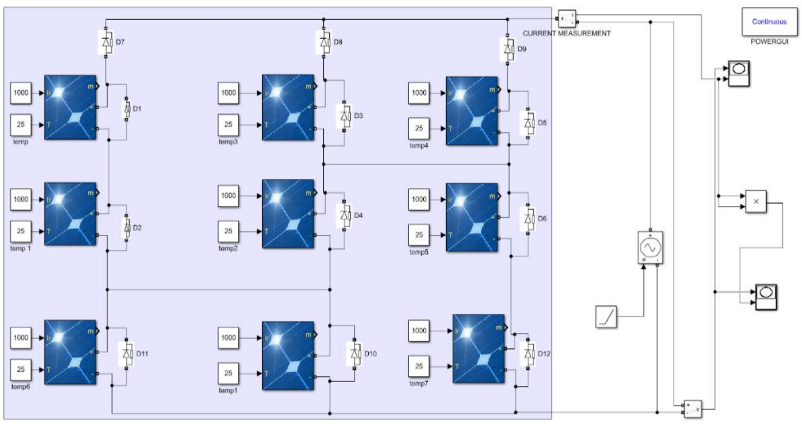
F. *Honey Comb Configuration*

Honey comb configuration is the new configuration which is the modification of bridge link configuration. This configuration is efficient than series and series parallel configuration and the modules are connected in hexagonal shape to form the honeycomb architecture. In this configuration less number are connection are required compared to series and series parallel hence the power loss is less than series and series parallel. In honey comb connection, under uniform shading we had calculated some parameters to find the efficiency of configuration. From the above graph the open circuit voltage Voc is 220.2 V short circuit current Isc is 50.0 A maximum power Pmpp is 7000.7 W voltage at maximum power point Vmpp is 178.8 V current at maximum power point Impp is 47.7 A. from this obtained value we have calculated the fill factor and efficiency by using the formula

Fill factor (%) = maximum power / Voc * ISC

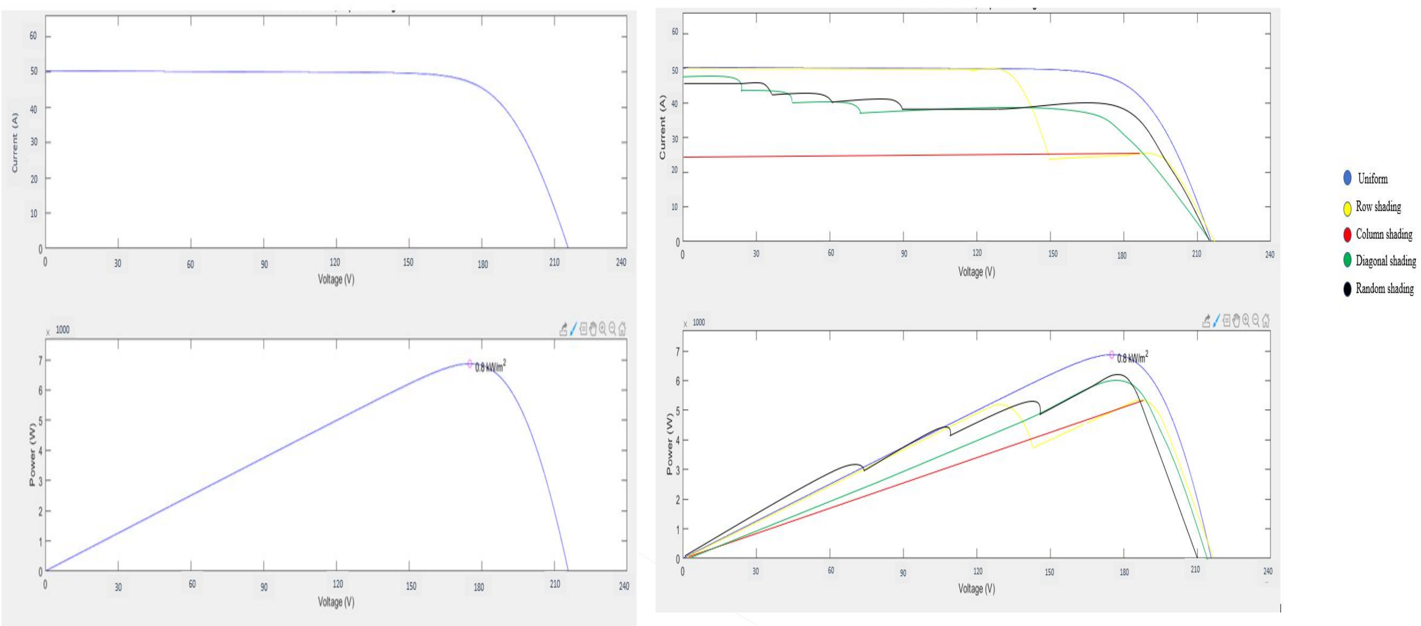
Efficiency = Vmpp*Impp/ I *A

So that fillfactor (%) is 63.58 and efficiency (%) is 63.58

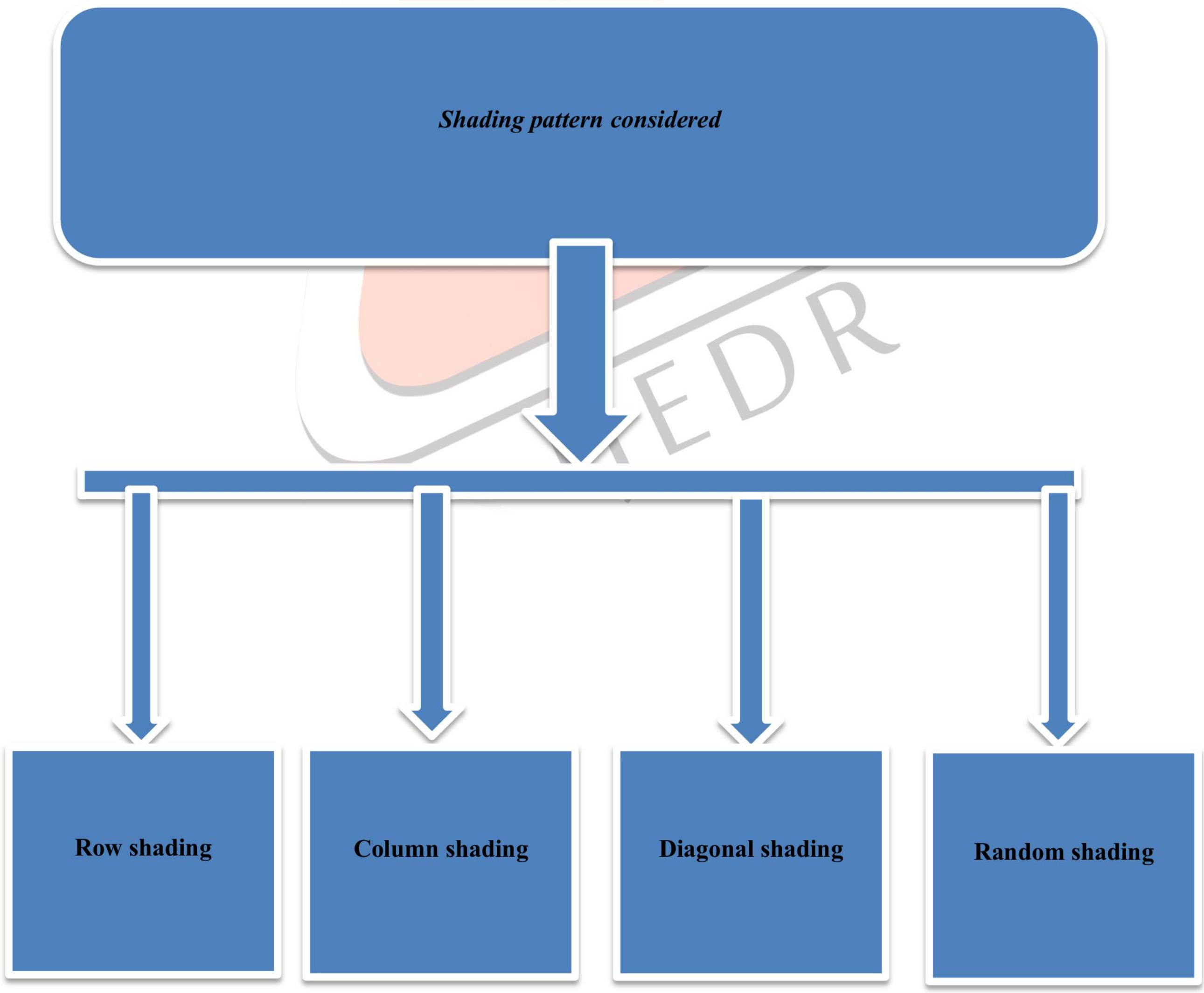


Simulink model of 3*3 Honey comb (H-C) PV array Configuration.

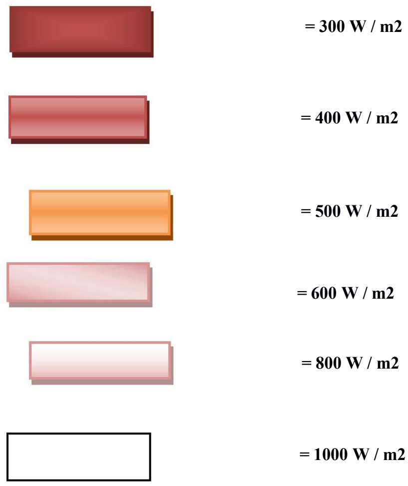
Uniform *Non-Uniform*



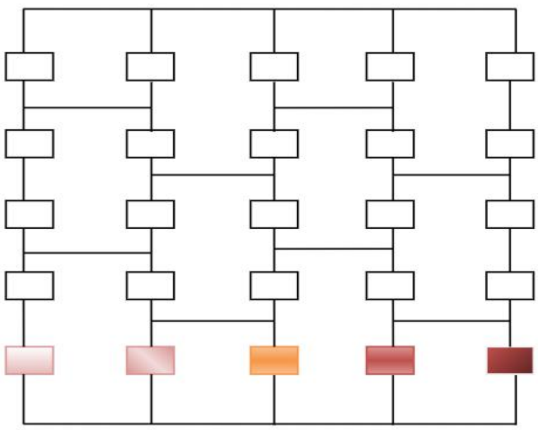
IV. SHADING PATTERN CONSIDERED UNDER DIFFERENT IRRADIANCE LEVEL



DIFFERENT IRRADIANCE LEVEL CONSIDERD

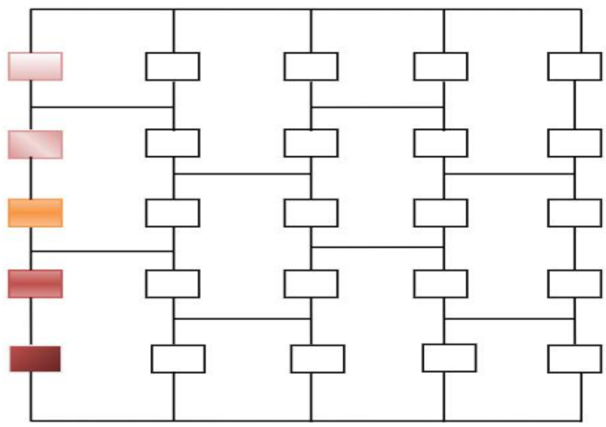


Row shading



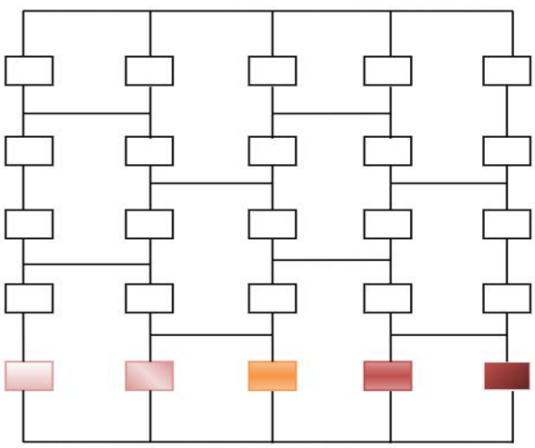
In this pattern only last one row of PV array is shaded and receiving different irradiance level.

Column Shading



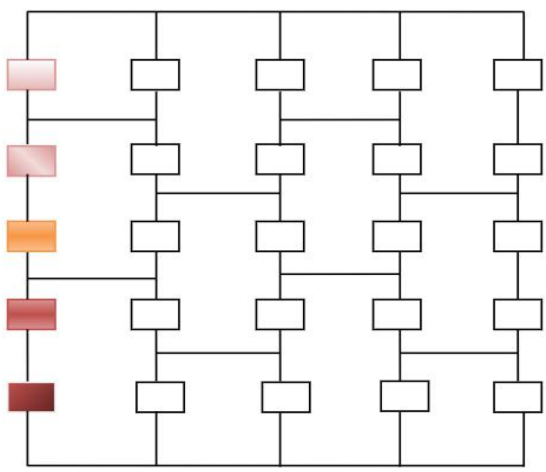
In this pattern only first one column of PV array is shaded and receiving different irradiance level.

Diagonal Shading



In this pattern the five diagonally placed module in PV array subjected to different irradiance level.

Random Shading



Here the PV module in an array receive irradiance level randomly.

Parameters variation of PV array under uniform shading

Sr . no	*Topologies*	*Voc*	*Isc*	*Pmpp*	*Vmpp*	*Impp*	*Fill factor*	*Efficiency*
1	Series	720.2	15.3	7000.7	590.2	13.09	63.53	63.53
2	Parallel	73.5	150.1	7000.7	57.8	135.5	63.49	63.49
3	Series- parallel	220.1	49.8	7000.7	178.5	47.7	63.86	63.86
4	Total-Cross-Tied	221.6	49.4	7000.7	178.8	48.2	63.95	63.95
5	Bridge-link	220.1	49.8	7000.7	177.4	48.2	63.86	63.86
6	Honeycomb	220.2	50.0	7000.7	178.8	47.7	63.58	63.58

Parameters variation of PV array topology under row shading

Sr . no	*Topologies*	*Voc*	*Isc*	*Pmpp*	*Vmpp*	*Impp*	*Fill factor*	*Efficiency*
1	Series	718.5	15.1	5132.9	630.5	7.2	47.31	11.349
2	Parallel	68.2	131.5	6225.8	55.2	110.6	69.42	15.262
3	Series- parallel	218.6	51.9	5281.6	196.2	24.8	46.55	12.164
4	Total-Cross-Tied	220.8	50.10	6599.7	188.7	32.6	59.66	15.379
5	Bridge-link	220.1	49.8	5145.5	182.6	24.8	46.94	11.321
6	Honeycomb	220.2	50.0	5123.3	182.4	24.4	46.53	11.126

Parameters variation of PV array topology under column shading

Sr . no	*Topologies*	*Voc*	*Isc*	*Pmpp*	*Vmpp*	*Impp*	*Fill factor*	*Efficiency*
1	Series	718.1	7.9	4825.9	630.8	7.6	85.06	5.9926
2	Parallel	69.1	132.8	6499.8	53.2	110.6	70.83	7.354
3	Series- parallel	218.5	25.6	4863.7	104.1	24.8	86.95	3.2271
4	Total-Cross-Tied	220.8	32.4	5289.4	182.2	32.8	73.93	7.4702
5	Bridge-link	220.1	25.0	5145.5	181.5	24.8	93.51	5.6265
6	Honeycomb	220.2	25.0	4986.2	183.1	24.8	90.5	5.6885

Parameters variation of PV array topology under diagonal shading

Sr. no.	*Topologies*	*Voc*	*Isc*	*Pmpp*	*Vmpp*	*Impp*	*Fill factor*	*Efficiency*
1	Series	714.6	14.7	5122.9	578.2	10.86	48.76	7.849
2	Parallel	58.2	132.9	6100.8	57.2	120.6	78.87	8.622
3	Series- parallel	218.4	49.5	5199.6	178.2	36.3	48.09	8.085
4	Total-Cross-Tied	220.6	48.8	6488.3	185.5	37.8	60.27	8.764
5	Bridge-link	220.1	48.6	5977.5	179.4	32.6	55.88	7.310
6	Honeycomb	218.6	48.6	5997.6	179.7	34.6	56.45	7.772

Parameters variation of PV array topology under random shading

Sr. no	*Topologies*	*Voc*	*Isc*	*Pmpp*	*Vmpp*	*Impp*	*Fill factor*	*Efficiency*
1	Series	713.2	14.8	5031.8	602.8	8.56	47.67	10.3199
2	Parallel	66.8	114.6	4225.9	57.2	120.6	55.20	13.796

3	Series- parallel	218.5	45.2	5999.6	180.8	35.3	60.74	12.764
4	Total-Cross-Tied	220.6	36.7	5289.4	178.9	38.8	65.33	13.886
5	Bridge-link	220.1	47.7	6148.3	179.2	35.7	58.56	12.794
6	Honeycomb	220.1	47.6	5986.2	178.9	35.8	57.13	12.809

V. Conclusion

Solar energy is most favorable energy source. We analysed different configurations like series (S), parallel (P) ,series parallel (SP), total cross tied (TCT), bridge link (BL), honey comb (HC). It has observed that as the increment in series connection power loss is also increased so by using the bypass diode power loss is controlled. It is observed that the characteristics in terms of IV and PV of various configurations under different shading conditions are analysed. It is observed that in uniform shading pattern there is no difference in output characteristics but when we observe non uniform shading pattern there is significant difference is occurred. Overall it is observed above from the data sheets TCT configuration gives maximum efficiency in different shading patterns as compared to rest of the configuration.

Appendix

Parameters of PV Module

Sr. No.	*Parameters*	*Values*
1	Maximum power	213.15W
2	Voltage at maximum power-point	29V
3	Current at maximum power	7.35A
4	Open circuit voltage	36.3V
5	Short circuit current	7.84A
6	Temperature coefficient of Voc	-0.36099 %/ deg.c
7	Temperature coefficient of Isc	0.102 %/ deg.c
8	Number of cell per module	60
9	Series resistance	-0.39383ohm
10	Shunt resistance	313.3991 ohm
11	Diode ideality factor	0.98117

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