iPLON PROJECT INTERNSHIP REPORT

Project title

The PV-DG Synchronizing model using PS-cad tool on a live demonstration hardware.

Submitted to

iPLON India Pvt Ltd

Submitted by

Rishikumar NA

ASTRACT:

This research investigates the synchronization of Photovoltaic (PV) systems with Distributed Generators (DG) in the presence of partial shading, aiming to address the challenges of renewable energy integration. Partial shading scenarios frequently lead to mismatched power outputs and reduced overall system efficiency. By combining PV and DG resources, this study seeks to mitigate shading effects and optimize power generation. The integration of DG sources compensates for the shaded areas of the PV array, resulting in improved power quality and enhanced grid stability.

Through a comprehensive review of literature and case studies, this research emphasizes the potential benefits of PV-DG synchronization under partial shading conditions. It highlights the significance of managing power flow between PV and DG sources effectively, especially during rapidly changing environmental conditions. Advanced control algorithms and communication systems are explored to optimize power distribution and ensure seamless integration.

Furthermore, this research underscores the necessity for continued technological advancements in power electronics and energy storage systems to fully exploit the advantages of PV-DG synchronization. The findings contribute to a deeper understanding of renewable energy integration and offer valuable insights for engineers, policymakers, and stakeholders seeking to develop sustainable and reliable energy systems. Overall, PV-DG synchronization presents a promising avenue to overcome the challenges of partial shading, fostering a more resilient and eco-friendly energy landscape.

Introduction:

The growing global demand for sustainable and renewable energy sources has propelled significant advancements in Photovoltaic (PV) systems and Distributed Generators (DG). These technologies offer promising solutions to address the challenges of conventional fossil fuel-based energy generation and contribute to a greener and more resilient energy landscape. However, the intermittent nature of renewable energy sources, coupled with the detrimental impact of partial shading on PV arrays, presents considerable obstacles to their seamless integration into the existing power grid.

Partial shading occurs due to various environmental factors such as clouds, foliage, and nearby structures, leading to non-uniform solar irradiation on PV panels. This causes mismatched power outputs within the PV system, resulting in power losses and reduced overall efficiency. As a result, harnessing the full potential of solar energy under partial shading becomes a critical area of research.

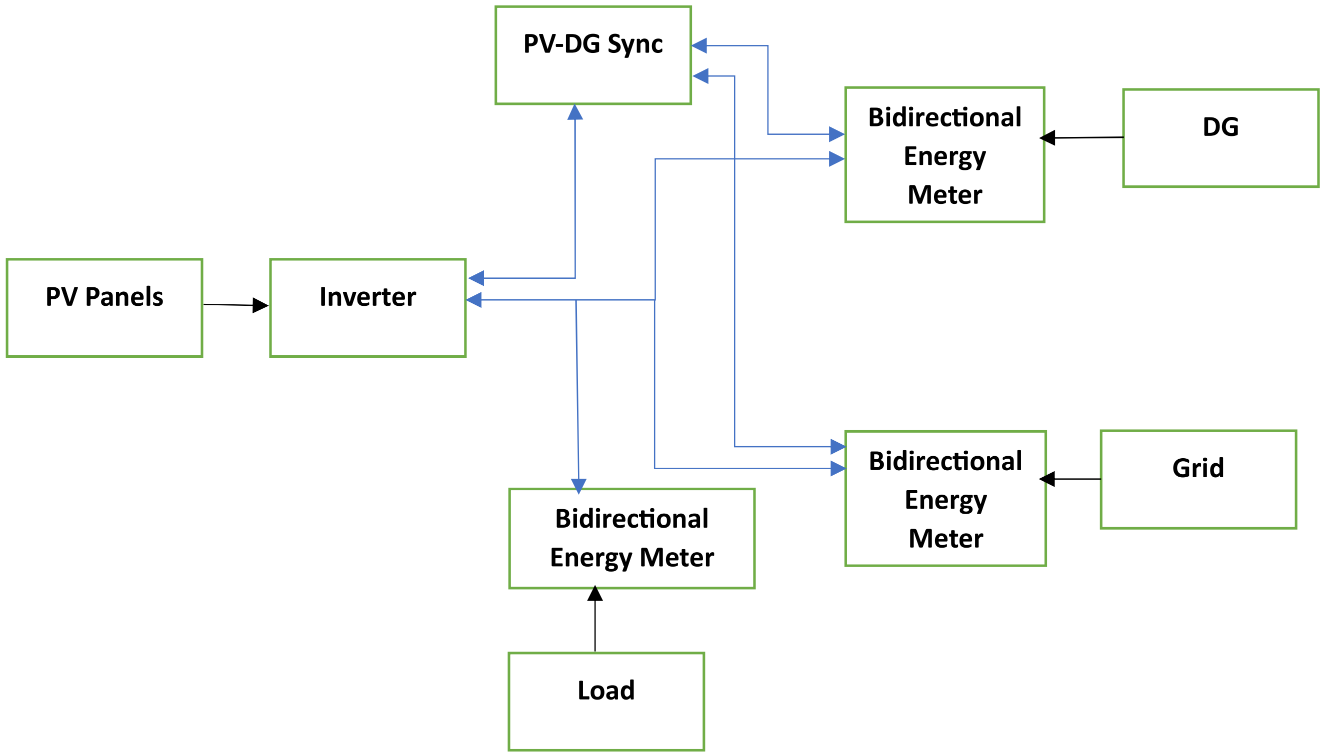
In recent years, researchers and engineers have explored the integration of DG resources with PV systems to alleviate the impact of partial shading and improve renewable energy utilization. DG sources, such as microturbines, fuel cells, and wind turbines, can provide stable power outputs, complementing the variable nature of PV systems. Synchronization of PV and DG sources aims to balance power generation and optimize energy utilization, thereby enhancing power quality and grid stability.

This paper presents an in-depth exploration of PV-DG synchronization under partial shading conditions. It examines the key challenges posed by partial shading and discusses how integrating DG resources can mitigate its adverse effects. The study emphasizes the significance of efficient control algorithms and communication systems to manage power flow between PV and DG sources during dynamically changing environmental conditions.

By conducting a comprehensive review of existing literature and relevant case studies, this research aims to shed light on the potential benefits of PV-DG synchronization and its role in achieving a more sustainable energy future. Moreover, the study aims to identify areas that require further technological advancements to maximize the advantages of this integration, ensuring a reliable and eco-friendly energy supply.

In conclusion, this research endeavors to contribute valuable insights for energy policymakers, grid operators, and renewable energy enthusiasts seeking to advance the integration of PV and DG technologies. By effectively addressing partial shading challenges through synchronization, we can pave the way for a more efficient and resilient energy system that capitalizes on the abundant potential of renewable resources.

BLOCK DIAGRAM:



Source:

The source is where the power is generated and transferred to the load to satisfies its demand. In PV-DG synchronization three sources are there. They are.

=>Solar (PV panels)

=>Grid

=>Diesel generator (DG)

Bidirectional energy meter:

This is a device which is used to measure the output and input power from any device and send the signal to the PV-DG synchronization controller.

Inverter:

Inverter Plays a major role in PV-DG synchronization. This inverter is responsible for controlling the output power from the PV source. As PV is the renewable source, so we need to use the maximum power from the PV. And need to use the minimum power from the other source. As the inverter is made of IGBTs, to control the output power, we need to control the frequency of the IGBT.

Theory:

PV-DG Synchronization:

Inverter won't generate power if there is no reference power from the grid or DG.

- If the PV-DG system is running in Grid connected mode, Then the Load will run at 10% of the grid power and the 90% of the power will be generated by the PV source. The inverter will get the reference voltage at 10% of the grid power.
- If the grid is disconnected from the system, Then the PV-DG system is running in Grid connected mode, Then the Load will run at 30% of the DG power and the 70% of the power will be generated by the PV source. The inverter will get the reference voltage at 30% of the DG power.

Control Technique:

The main aim of the PV-DG synchronization is to control the real power output from the from the source and the inverter.

There are many control techniques to control the real power output from the source.

Real power control Techniques:

- **Active Power Control:** Active power control involves regulating the real power output of the PV or DG system to match the grid requirements. This control mechanism ensures that the system provides the desired amount of real power and adjusts it according to the grid conditions. Active power control can be achieved using various techniques such as voltage and frequency droop control, power factor control, and power curtailment.

- **Reactive Power Compensation:** In addition to real power control, it is essential to manage reactive power in PV-DG synchronization. Reactive power compensation techniques, such as capacitive or inductive reactive power injection, help maintain a balanced power factor and regulate voltage levels. Proper control of reactive power ensures system stability and compliance with grid regulations.

Proportional Droop Control:

- **Principle:** In proportional droop control, the voltage deviation is directly proportional to the active power deviation.
- **Operation:** The droop controller adjusts the output voltage based on the difference between the measured output voltage and the reference voltage setpoint. The voltage deviation is multiplied by a proportional gain factor to determine the required adjustment.
- **Formula**: $\Delta V = Kp * \Delta P$, where ΔV is the voltage deviation, Kp is the proportional gain, and ΔP is the active power deviation.
- **Effect:** Proportional droop control provides a linear relationship between the voltage deviation and the power deviation. A higher gain value leads to a more significant voltage adjustment for a given power deviation.

Impedance Droop Control:

- **Principle:** Impedance droop control utilizes the concept of voltage droop and the impedance of the system to determine the voltage adjustment.
- **Operation:** The droop controller measures the output current and voltage, calculates the apparent power (V x I), and adjusts the voltage based on the impedance of the system.
- **Formula:** $\Delta V = (R + jX) * \Delta P$, where ΔV is the voltage deviation, R is the resistance component, X is the reactance component, and ΔP is the active power deviation.
- **Effect:** Impedance droop control considers the system impedance, allowing for more accurate voltage adjustment based on the power deviation. It helps maintain a stable voltage profile and reduces the impact of reactive power flow.

How the control the Output of the Inverter?

The output of the inverter is controlled by the controlling the IGBT of the inverter. The IGBT can be controlled by controlling the pulse width of the inverter. To reduce the output of the inverter the Pulse width needs to be reduced and to increase the output of the inverter the Pulse width needs to be increased. Here the PV-DG sync is sending the signal to the inverter to change the gate pulse of the IGBT.

The number of pulses per second from the IGBTs is known as carrier frequency.

Research papers:

Research paper -1:

Title: Effective Power management scheme for PV-Battery-DG integrated Standalone DC Microgrid

A new Power Management System is proposed in this paper to achieve the effective coordination and management of solar PV battery, and DG in the contemplated SDCMG configuration. Proposed strategy extracts maximum power from solar PV and utilises the same in all modes. In addition to this, PMS ensures minimum loading of DG when it is ON. Its execution begins by collecting total renewable power generation (pp) and load power (P) along with SoC of the battery (SoC) at some fixed intervals of time. All the source and load powers are fed to low pass filter (LPF) with a cut-off frequency of 10 Hz before dispatching them to PMS so that noise can be eliminated. Now, the supply-demand gap (Ap) is estimated from the data acquired. Based on the difference (Ap), three operating modes are classified as follows:

- Surplus mode
- Floating mode
- Deficit mode

If the power difference (Ap) is more than a positive threshold (P) then it drives SDCMG into a surplus mode where battery's SoC is estimated using Coulomb counting method

respectively After devising the SoC of battery, then it is checked against the lower and upper thresholds of SoC, so that corresponding operation mode is enabled. If it exceeds the upper threshold, then the battery enters an idle state. Meanwhile, solar PV shifts into DC bus regulation mode (ie. off-MPP). If SoC, drops below the lower limit, then the battery starts charging with the excess power. Similarly, if the power difference (Ap) falls below the negative threshold (M), then it enters power deficit side. SoC, is estimated using (1) to decide the sub operating modes. A power- sharing logic is introduced to distribute the required load power aiming the battery and DG efficiently depending upon SoC, value so that the minimum loading of DG is assured. Meanwhile, battery life is also preserved by not allowing it to feed the load demand when its SoC falls 20%

If the power difference oscillates between positive and negative thresholds, then SDCMG will operate in a floating mode where battery shifts to either charging or discharging state to maintain the DC bus voltage.

Research paper 2:

Title: **A new hybrid firefly optimized P-Q and V-f controller coordination for PV-DG–based microgrid stabilization**

An distribution network (with PV/ auxiliary battery energy storage system [BESS] and diesel generator) is considered to observe the dynamic performance of a microgrid during contingencies. This proposed multiple DG-based microgrid, which is considered as a weak network with short-circuit ratio (X/R) of nearly 0.13. The weak microgrid is considered to observe the stability improvement prominently. This PV system (consists of 4 parallel connected individual PV systems) with auxiliary BESS is considered as the primary DG unit and is designed according to IEEE 1547 and UL1741 standards. The PV system is considered with BESS to compensate the PV generation inconsistency, during grid synchronous operation. During islanding condition, the BESS is further operated for load management, where local load demand is compensated by the battery. A diesel generator with Padé approximation-based governor controller is considered at bus 8 for a multiple DG operation. The active power (P1) flow relies on the difference in voltage magnitude (Vi − V1), and reactive power (Q1) flow depends on power angle (δi − δ1) between VSC and PCC (bus 1) 19,20 for low voltage grids. The battery voltage is time varying in nature while subjected to DC link, and hence BESS control strategy is considered to decide the allowable charging/discharging limits. The primary DG is interfaced with 5 DC-DC conversion units (i.e., 4 boost converters-based PV systems: DC-DC1 to DC-DC4 and 1 bi-directional battery: DC-DC5). This paper considers insulated-gate bipolar transistor (IGBT) VSC switching with second order (ie, PI control) PLL grid synchronization. Instantaneous P1 and Q1 at the PCC and angular frequency (ωdig) at secondary DG are obtained as feedback variables to the VSC controller and diesel generator governor controller, respectively. The proposed optimization scheme is based on error dynamics of these DGs and their relationship with the distribution network. To understand the system stability limits and hazard of multiple optimal solutions, the dynamic design of the system is described later in this section.

Research Paper-3

Robust Synchronization of Phase-Varying Discrete-Time Grids

the authors focus on achieving accurate and stable synchronization between distributed power converters and the grid in the presence of phase variations. Phase variations can arise due to factors such as variations in the grid frequency or disturbances in the power system.

The authors propose a robust control strategy that considers the uncertainties and disturbances in the grid parameters. They develop a mathematical model to describe the phase-varying grid dynamics and derive conditions for synchronization stability. These conditions ensure that the power converters track and synchronize with the grid despite the phase variations.

To address uncertainties and disturbances, the authors employ robust control techniques. Robust control aims to design control systems that can tolerate uncertainties and disturbances and still maintain desired performance. By incorporating robust control into the synchronization scheme, the proposed approach provides resilience against uncertainties in the grid parameters and disturbances in the power system.

The effectiveness and robustness of the proposed synchronization scheme are demonstrated through simulations. The simulations show that the power converters can successfully synchronize with the grid, even under challenging conditions such as uncertain grid parameters or disturbances. This research contributes to advancing the understanding and implementation of phase-varying discrete-time grid synchronization in power systems, providing a more reliable and stable operation of distributed power converters.

Research Paper-4:

Simulation of synchronization photovoltaic system and low voltage grid

In this research, the synchronization between the PV system and grid designed with synchronization parameters are voltage, frequency, and phase angle difference. As a result, by using a synchronization system, the PV system and grid could be parallelized and supplying power into the load at the same time. The synchronization method used is zero-crossing detection because it is simple than the other method. The synchronization system consists of several components; voltage detector, frequency detector, phase angle detector, and switch controller which all of them are controlled using the Arduino board. The switch controller will be functioned based on input from the detector to do synchronization or parallelize the PV system and grid. Testing is done by simulating running in Proteus. Based on the result of the simulation, the system is successful to do synchronization between the PV system and grid, it can be observed from the grid and PV inverter voltage graph and current which is measured from load, grid, and inverter.

Zero-crossing detection

The Zero-crossing detection method is measurement of voltage and detects zero points of voltage when voltage changes from negative value (-Ve) into positive value (+Ve). Because used for switching, then there must be such a thing as harmonic Zero-crossing detection is also stated as a comparison, as shown in Figure 3, where zero-crossing detection uses a basic operational amplifier (Op-Amp) to compare two voltages simultaneously and change output according to the result of the comparison. Zero-crossing detection can be applied to the phase meter and time marker generator.

Voltage detector

The voltage detector is used to read the voltage of the grid and inverter. The measurement of AC voltage is conducted by decreasing voltage because Arduino is only able to measure the voltage between 0V-5V and it is not able to read negative voltage value. Source voltage can be decreased with the transformer and voltage divider circuit. The resistor on the voltage detector.

Frequency detector

Frequency on AC voltage can be calculated by measuring the time of the AC voltage wave. Time is the full-time wave, which means a half positive wave and a half of negative wave. To make it easier to detect and measure frequency, the diode rectifier is used as shown in Figure 9. Series to measure the AC frequency magnitude is shown in Figure 10, Optocoupler component is used as isolation for high voltage and low voltage from Arduino.

Phase angle detector

Phase angle detector is a circuit diagram to know the differences of the phase angle. Measurement of the difference of the phase angle between grid and inverter is the same with the measurement of power factor, but the difference is only on implementation. To measure phase angle, first decreasing voltage from both sources using a transformer, then utilizing Op-Amp to detect zero points of grid voltage wave and inverter. Op-Amp convert sinusoidal wave signal becomes square wave with 4V amplitude, which is then linked into XOR gate input and processed by Arduino. Moreover, the output of the XOR gate. For example, the calculating of phase angle difference.

Phase Synchronization:

To be parallelized between the PV system and grid, both phases should be the same and not allowed to synchronization of phase between PV inverter and grid must be conducted. The blue wave is grid voltage, red is inverter voltage, and green is PWM inverter wave. The yellow graph is the output of

the zero-crossing detection series, which can be seen as yellow graph remarks zero points of grid voltage wave.

Grid and inverter voltage

When the simulation process is conducted, delaying happens several seconds until the voltage produced by the inverter has stabilized and steady state so that it can be synchronized with the grid. From those graphs, grid voltage and inverter are synchronous when it is 160ms, it can be seen voltage is synchronous although there are little differences in phase angle.

Grid and inverter current

To ensure the inverter helps to supply electrical energy to the load, so current measurement of the inverter, grid, and load is conducted., it remarks the current percentage supplied from the inverter is not constant, it caused inverter only supply current to support grid in serving the same load, or known as load sharing, the condition of two or more generators operates in parallel to supply the same load.

Some of the Companies working in PV DG synchronization:

Company- Logics Power:

They are designing the Solar DG synchronization and they will also provide features like

- Smart control
- Flawless protection
- Graphical representation
- Remote monitoring
- Deemed generation

Working Principle

In case of Solar DG Synchronization, energy meter shall be installed at DG panel.When we get off status from the grid and ON status from DG meter or DG'S, the DG PV controller throttles the power of each Inverter as per building load. This will result in the minimum fuel consumption of DG along with reverse power protection and solar generation optimization.

It will be ensured that DG runs at 30% to 36% of its KW rating eg. DG will run in the range of 30 KW to 36 KW in case of 100 KW DG set.

The working principle is as follows-

1. Read Active Power frommeter

2. Is Active power > Max Set point? If yes, increase power oninverters

3. Is Active power < Min Set point? If yes, decrease power oninverters

4. Repeat from step1

Company- Pay per watt

DG synchronization with solar (DG PV synchronization system).

When the grid power isn't available, DG (diesel generator) can be used as reference power to an on-gird solar power plant. This type of PV DG synchronization can be possible with any make of grid-tie solar inverters. As long as connected load (kW) is lesser than power generated from on-grid solar power plant this DG PV synchronization is safe. But if gird-tie solar power plant generates any surplus power. This surplus power will reverse back to DG (generator) and damage it. DG PV controller is required solar dg synchronization.

DG PV controller

DG PV controller is the device used to protect DG (diesel generator) from the surplus power generated from the PV plant. DG PV controller is also known as Zero Export Device. DG PV controller enables solar system owners & operators to limit the amount of solar power that their systems export to the DG (diesel generator).DG PV controller limits the amount of energy generated by on-grid solar inverters by adjusting the set point of the gird-tie inverters. Inbuilt power analyzer of DG PV controller measure the total power at the point, DG couples (electrically couple) with the load and compares this with the set point of DG PV controller.When the load on DG (diesel generator) is above this set point, DG PV controller ramp up the solar power. And if the load on DG is below this set point, DG PV controller will ramp down the solar power. Continuous running generator at load lesser than 30% of its rated capacity affects it negatively. DG PV controller makes sure that DG is 30% loaded.

Company- Surya logics:

PV-DG controller:

- Protect DG from excess Solar Power and Maintains the Spinning Reserve of DG.
- To Optimize Solar Generation while Running with DG. Maintain Spinning Reserve at about 25-30% (when the load is less than Solar Power.
- To Monitor Solar, DG, and Load Parameters

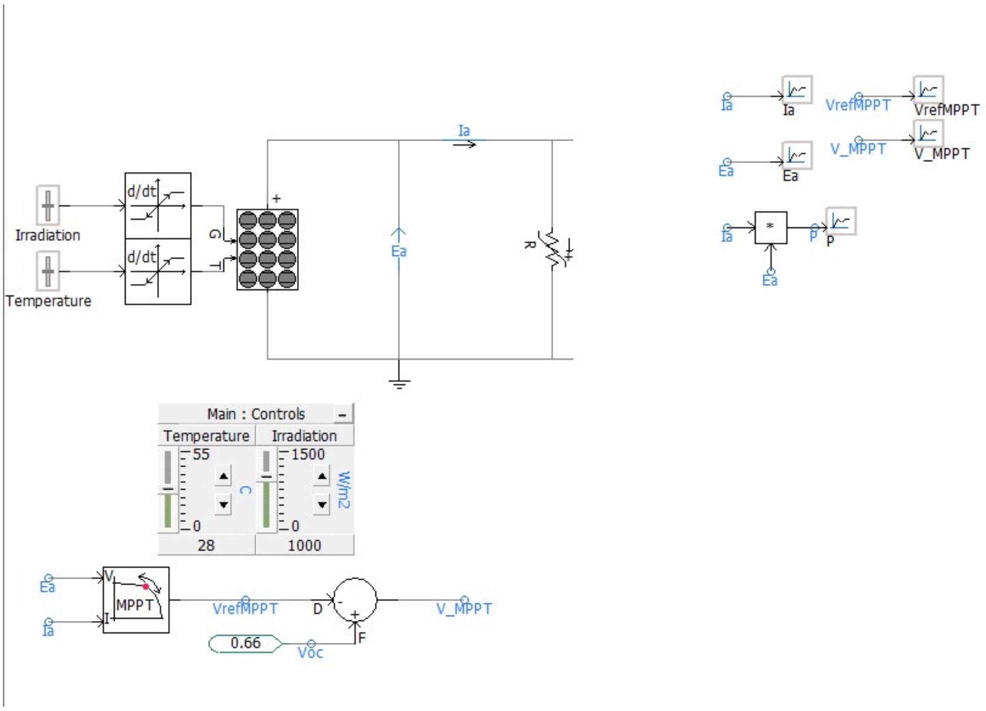
Master Slave Technique:

Whenever a Solar/Hybrid Power Plant is installed at Multiple Buildings and Multiple Wings are there, then you can use Master-Slave Communication. You can install Multiple SuryaLog Devices out of which one device will act as a Master Device and other Devices will act as a Slave or Sub-master Devices. The Master Device will Communicate with other Slave Devices which may be installed in each Wing so that you can get Wings Data at One Location. There are two default types that you can use for Master-Slave Communication namely, Wired and Wireless.

And many more companies we referred to.

Proposed Work:

SOLAR PANEL WITH MPPT TRACKING:



- On this day, I worked on the solar panel part of the PV-DG synchronization.
- In this I have used slider to control the Temperature and irradiance of the solar panel.
- These two are given to the inverter with the help of rate limiter.

  Rate Limiter:

- The Rate Limiter outputs a duplicate of the input function as long as the rate of change of the input (dx/dt) does not exceed the specified limits.
- If the rate of change does exceed the limits, the output falls ahead or behind the input, confining its rate of change within specified limits.

Then We give this to the solar panel block which is available in the Pscad.

iPLON® INDIA PVT. LTD.

Solar Panel Block:

This component can be used to model a photovoltaic (PV) source. The photovoltaic source is assumed to consist of several strings of PV modules connected in parallel, where each string can consist of a number of PV modules connected in series. All PV modules in the array are assumed identical.Then we calculated the power , Voltage of the panel , Current drawn from the panel

Solar Panel Parameter setting:

As said, we need to design the solar panel of 3MW, Voltage of 1.5KV

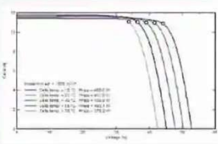
I decided the parameter based on that

The panel parameters we have taken are

Construction Features		Warranty
Type of Cell	PID Free/Mono Perc-Crystalline Si	10 Years - 90% of Power O/P
Glass	ARC coated, Tempered & Low Iron	15 Years - 80% of Power O/P
Encapsulate	PID Resistance Ethylene Vinyl Acetate	
Frame	>15 micron Anodized Aluminum	
Junction Box	Weather Proof Nylon IP 68	

S. No.	Description	Rating
1	Power (Pm) in Watts (nominal)	400 (0 ~+3%)
2	Open Circuit Voltage (Voc) in Volts	49.05
3	Short Circuit Current (Isc) in Amps	10.44
4	Voltage at Maximum Power (Vmp) in Volts	40.25
5	Current at Maximum Power (Imp) in Amps	9.94
6	Maximum System Voltage (Vdc)	1500
7	Solar Cells per Module (Units)	72
8	Length x Width x Thick (L x W x T) mm	1985 x 1000 x 40
9	Weight (Kg)	24
10	Mounting Holes Pitch (Y) - mm	1000
11	Mounting Holes Pitch (X) - mm	955
12	Junction Box with 1200mm Cable	3 DIODE IP68
13	Max. Series Fuse (A)	25
14	Module Efficiency (%)	20.06

I-V Curve at STC



Temperature Coefficient	
Voltage	-0.35% / °C
Current	0.10% / °C
Power	-0.47% / °C
NOCT	47+/-2 °C

The parameters of the total solar panel are

Series connection- 38

Parallel connection- 200

Power – 3MW

Current-1974 A

Voltage- 150V

Output inverter parameters:

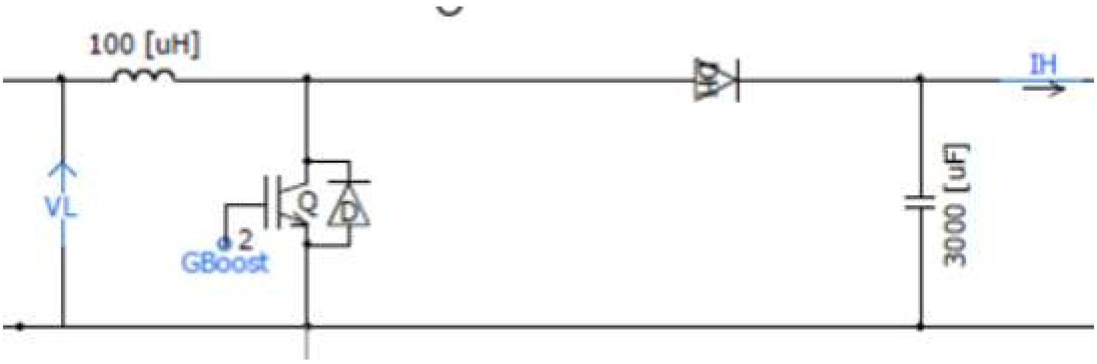
V- 800V

Transformer_Parameters:

Primary side- 800V

Secondary side- 33KV

Boost Converter:



The boost converter shown in Figure 8 consists of a low pass filter at the input side. The controller ,where the reference power (Pref) is compared to the dc link power (Pdc) and the error signal is given to a PI controller to generate the boost converter duty cycle (Ref_Boost). The PI controller coefficients (i.e. KpBoost and KiBoost) and its output limit (DmaxBoost) can be adjusted using the control panel

Maximum Power point Tracking:

The PV array is connected to a DC-DC converter (boost converter). The output power of the PV array is a function of the inputs namely irradiation and temperature.

The Maximum power point is tracked by the MPPT tracker.

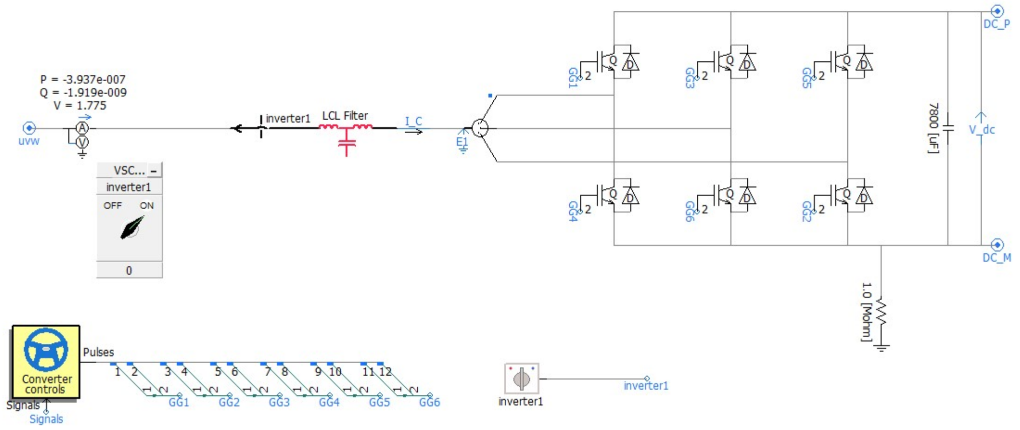
MPPT (Maximum Power Point Tracking) is a technique used in solar PV systems to optimize the power output of solar panels. It involves continuously adjusting the operating parameters of the panels to find and maintain the maximum power point (MPP), where the panel operates at its highest efficiency. MPPT tracking algorithms, such as P&O, incremental conductance, and constant voltage methods, are used to monitor and adjust the operating point to maximize power output. Modern MPPT controllers employ advanced algorithms and microcontrollers to achieve better tracking performance and improve the overall efficiency of PV systems.

- The MPPT tracker track the maximum power by taking the inputs as the Voltage and current of the solar panel and generates the reference voltage which is compared to the actual voltage and the error is identified by the addition /subtraction block and it is sent to the PWM generator which takes the reference voltage as input and generate the Pulse width which is then given to mosfet of the boost converter.

Then we discussed and come up with an idea of not using MPPT for PVDG synchronization because MPPT is already available in the inverter. So we planned to remove the MPPT

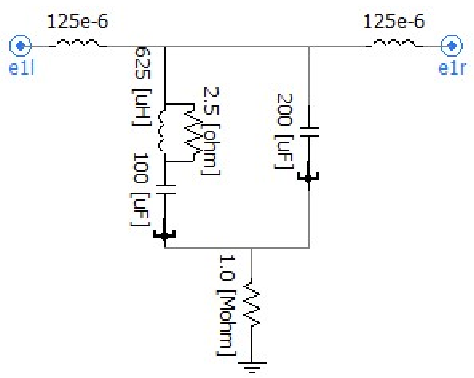
Inverter :

Then I decided to add the inverter to the solar model.



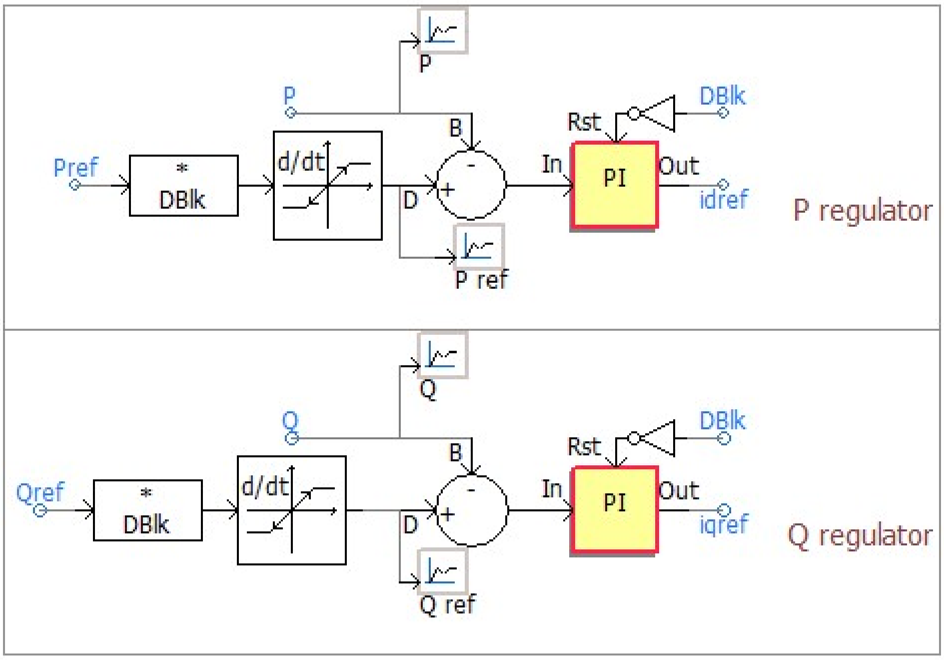
The ac side of the converter is supplied by a voltage source 3-phase 208V 60Hz. The VSC comprises 6 IGBT-diode pairs, which form a 2-level 3-pole bridge,

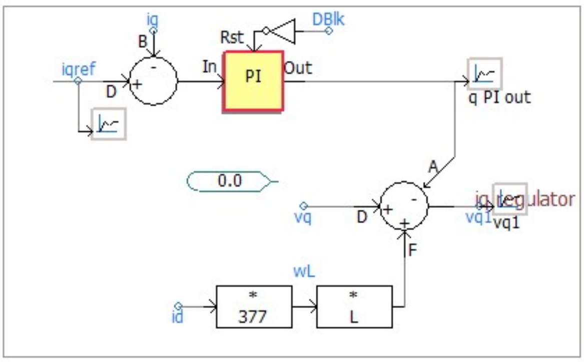
The dependent current source at the dc side represents the dc system, which can either absorb or produce power, depending on the sign of the signal Il. Sinusoidal pulse-width modulation (SPWM) switching technique was chosen in this example. The carrier frequency has been set to 7kHz. Designed for a cutoff frequency of 1.55kHz, the low-pass LCL filter unit at the ac side of the VSC eliminates high- frequency switching disturbances from the 60-Hz current and voltage waveforms.

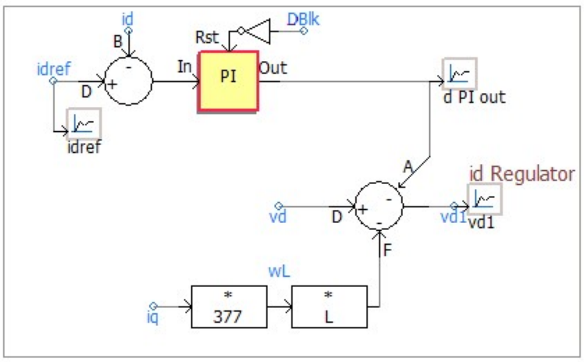


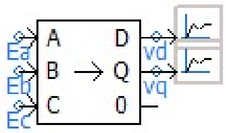
Control Algorithm

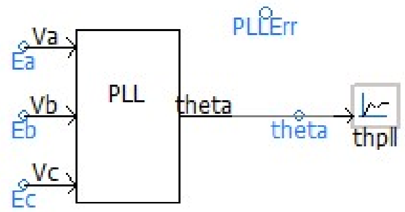
Vector control strategy is used in this example. In this technique, the ac current of the VSC is controlled to adjust active power exchange between the ac and dc sides, as well as the reactive power level at the ac terminals of the VSC [1]. The control system block diagram of the model can be found in the Rectifier Control function block in Figure2-1. The block diagram of the control strategy is presented in Figure 2-4-b. The ac current phasor of the VSC (I_C signal in Figure 2-1) is decomposed into direct (d) and quadrature components, which are in-phase with, and perpendicular to, the ac phase voltage E, respectively. The direct component of the ac current id regulates the active power transfer between the ac and dc sides. Hence, the dc link voltage can be adjusted by controlling id. The reactive power level at the ac terminals of the VSC can be regulated by controlling of the quadrature component iq.

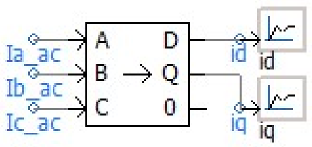












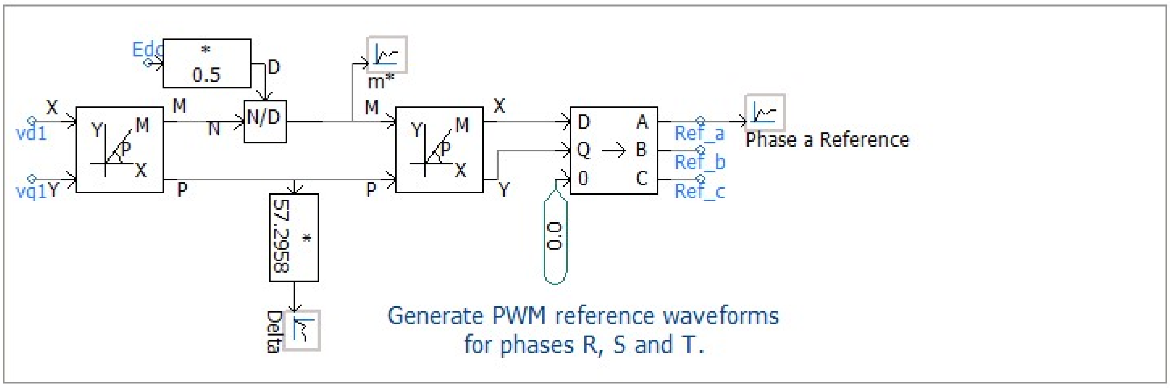
Decomposition of the ac current vector d and q components is carried out by applying the Park transform. The Park transform requires a reference phase angle to map 3- phase quantities onto the d-q coordinates. In this application, the ac phase voltage is chosen as the reference vector, whose phase angle information can be obtained using a phase-locked loop (PLL). Figure 2-5 shows the PLL block in PSCAD™. This block is available in Master Library\CSMF.

The output of the PLL (i.e.) is applied to the Park transform blocks. The 3-phase ac currents are mapped onto the d-q reference frame as depicted in Figure 2-6. The function blocks shown in this figure are user- defined components and are provided in the attached library file ABC_DQ_Transforms.psl'.

The three regulators in the control algorithm are implemented using PSCAD™ standard Master Library components, such as summation, PI controller, gain, etc. (see Figure 2-7). The Optimum Run feature of PSCAD/EMTDC can be employed to tune the parameters of the regulators.

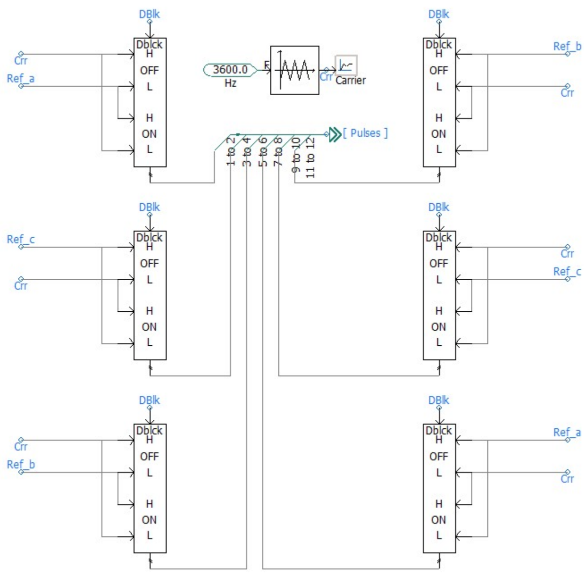
The regulators provide the set points vd* and vq*. Modulation waveforms Ref_a, Ref_b and Ref_c are obtained by applying Inverse Park transform to vd* which are subsequently applied to

inverse Park transform blocks to vd* and vq*,

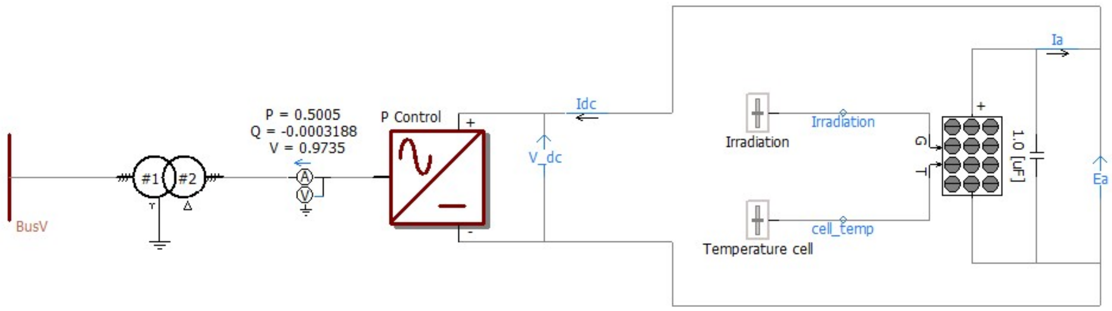


PWM switching pulses are produced by comparing the modulation waveforms (Ref_a, Ref_b and Ref_c in Figure 2-8) with a triangular carrier signal, through six 'Interpolated Firing Pulses' blocks, found in Master Library/HVDC_FACTS_PE. The 'Variable-Frequency Saw-tooth Generator' block (in Master Library/CSMF) produces the carrier signal.

Responses of the system to a few dc load disturbances are shown in Figure 2-10. In this simulation, the dc-link voltage has been set to 370V. In Figure 2-10-a, the VSC starts and raises the dc voltage to 370V. In Figure 2-10-b, a 28A load is applied to the dc link. It can be observed that the converter's control system restores the dc-link voltage. Similar response is presented in Figure 2-10-c, where the dc-side current switches from +28A to -28A, causing the VSC to transfer power from the dc link to the ac system. Again, one can notice that the dc-link voltage is maintained at 370V.



Solar Panel with Inverter:



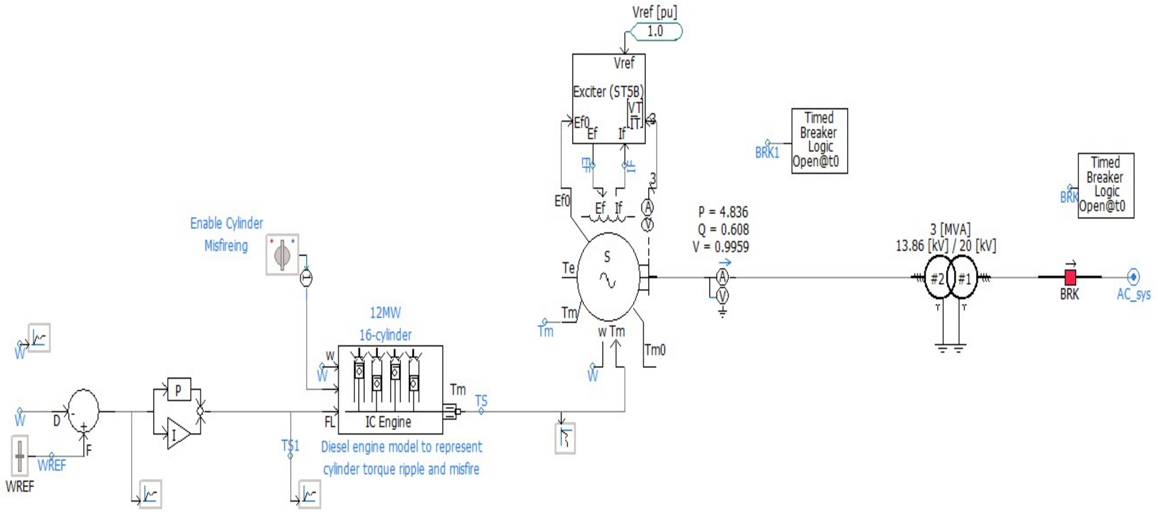
- Here I have connected the solar panel to the inverter and the inverter is connected to the transformer which transforms the 1.5K to 33KV
- I faced many errors while connecting this which was later rectified and built into an model.

Diesel Generator :

Then , the Diesel generator part will be implemented.

The power of the large ro-ro ship's generator is large and generated by diesel generating sets. Diesel generating equipment are mainly composed of diesel engine, governor system, synchronous generator and its exciter system.

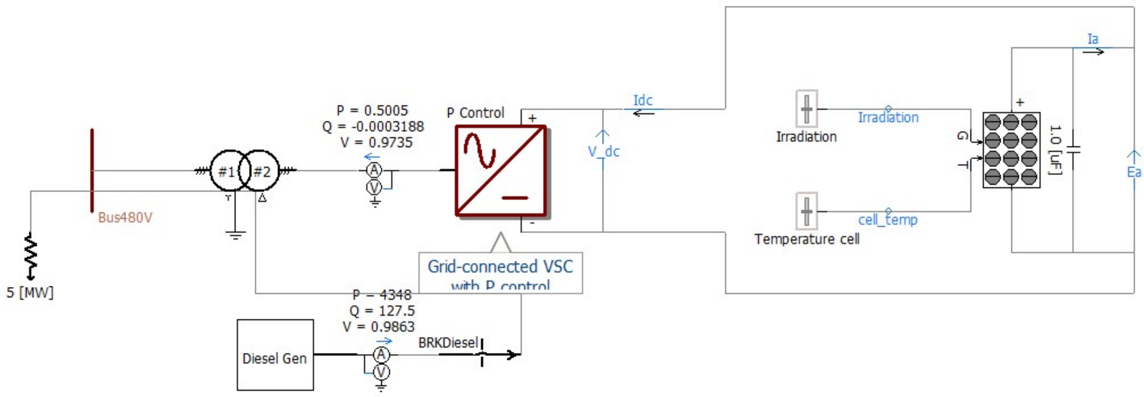
The basic function of governor system is to regulate the output power, maintaining the speed in the allowable range. Speed regulation system generally includes three main functions, speed measuring amplifier, signal conditioning, servo amplifier. In order to adjust the voltage of the generator, AC synchronous generator is equipped with auto-voltage regulator (A VR). This paper uses the built-in AC exciter module of PSCAD to simulate the self-excited constant-voltage control phase compound excitation system. In target ship, there are three generators. And the parallel operation of multiple diesel generators was used.



Solar with diesel generator:

Then I have connected the diesel generator model and the solar with inverter model to the busbar and I have also connected load to the bubsbar

And it was verified using the breakers:



Here the operation will function like

- The diesel generator will reach its full potential after 0.7 sec only. Until that the solar part and the diesel generator part needs to be disconnected from the busbar.

- When the diesel generator reaches its full potential then we need to turn on the breaker of the diesel generator
- When the breaker is turned on the PLL control block will receive the voltage and frequency.
- According to that the inverter's PLL logic will adjust the voltage and frequency and gets synchronized with the diesel generator.
- Once it is synchronized , then we need to give the power reference to the inverter.
- And wee need to turn on the breaker so that the power will be limited to the range and if we need any remaining power required , it will be delivered by the Diesel generator.
- If there is any problem with the power generation of the solar , or any issue with the inverter suddenly the diesel generator will take on and supply the power to the load.
- Then I have connected this system with the grid and another one breaker was introduced in the grid side which operates using the same method.

Coding of the component:

```
#LOCAL REAL voltage_grid
#LOCAL REAL Solar_max_limit
voltage_grid = ($V_grid) * 1000;
Solar_max_limit = ($p_max);

$grid_BRK = 1;
$BRKDiesel = 1;
$inverter1 = 1;


if ($grid_check.EQ.0) then
    $grid_BRK = 0;
```

```
        if (Solar_max_limit.GT.$setpoint) then
                !Delay(100);
                $Pref = $setpoint*-1;
                $inverter1 = 0;
        end if;

        if ($setpoint.GT.Solar_max_limit) then
                $Pref = Solar_max_limit*-1;
                $inverter1 = 0;
        end if;
end if;

if ($grid_check.EQ.1) then
        $grid_BRK = 1;
        !Delay(1000)
        $BRKDiesel=0;
        !Delay(100)
        if (Solar_max_limit.GT.$setpoint) then
                !Delay(1000);
                $Pref = $setpoint*-1;
                $inverter1 = 0;
        end if;

        if ($setpoint.GT.Solar_max_limit) then
                $Pref = Solar_max_limit*-1;
                $inverter1 = 0;
```

```
    end if;
end if;
```

Explanation of coding:

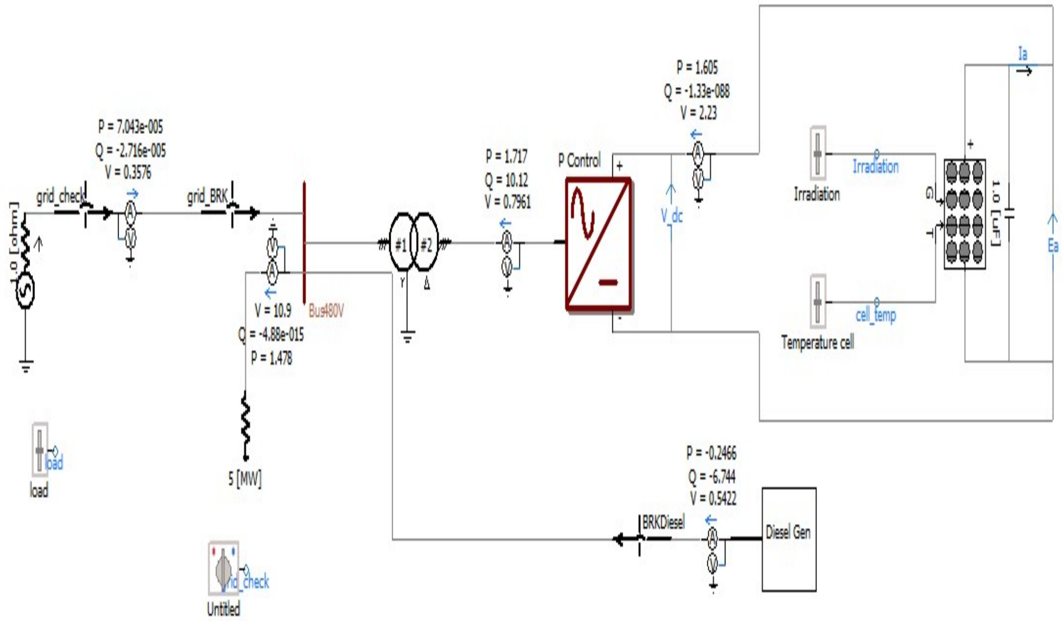
- The local variables for the grid voltage and the maximum solar generation limit are declared.
- Here the voltage of the grid is converted from KV to V and is assigned to the local variable called voltage_grid.
- Then the maximum solar generation limit is assigned to the local variable called solar_max_limit.
- Then we need to initialize the breakers condition like grid breaker = 1,Diesel breaker= 1,inverter breaker = 1 . here 1 means the breaker are in on condition (the breaker disconnects the line).
- Then we are moving to grid mode. Here we need to check the grid is available or not, if the grid is available then we need to connect the grid to the busbar .
- And if the solar maximum limit is greater than the setpoint of the power from the station, then we need to set the reference power value as the (setpoint*-0.5). Because we are having two inverters, so we need to share the power between these two inverters
- If the solar maximum limit is less than the setpoint of the power from the station, then we need to set the reference power value as the (maximum solar power generation *-0.5).
- Then we are moving to diesel generator mode. Here again we need to check the grid is available or not, if the grid is available then we need to disconnect the grid breaker and we need to connect the diesel generator breaker.
- And if the solar maximum limit is greater than the setpoint of the power from the station, then we need to set the reference power value as the (setpoint*-0.5). Because we are having two inverters, so we need to share the power between these two inverters
- If the solar maximum limit is less than the setpoint of the power from the station, then we need to set the reference power value as the (maximum solar power generation *-0.5).
- Then we end the if loops and check for errors and rectify it.

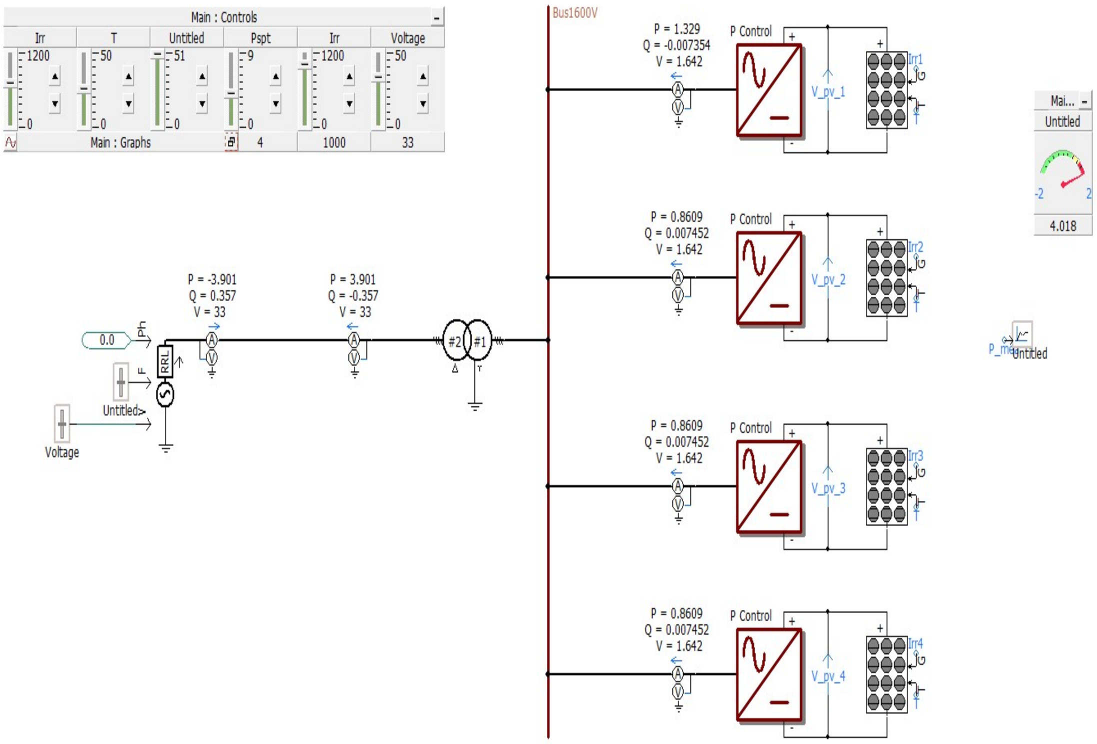
Then build and run the pscad model to verify the automation process is working are not.

Component Building:

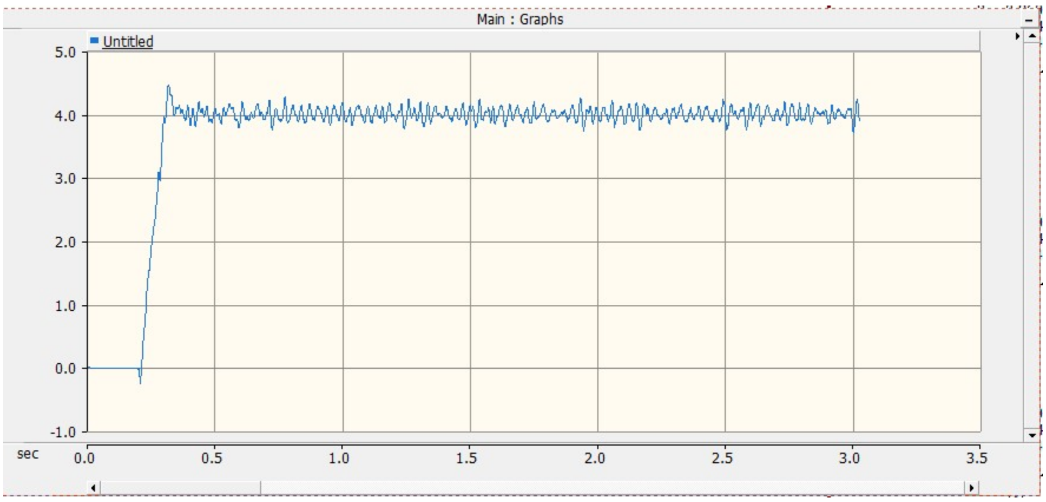
- After completion and verification of the pscad model manually, the controlling part must me automated.
- So for the automation process, I have built a component using component wizard (PPC).
- I have given the input parameters and output parameters and parameters.
- After developing the component I have done the automation via coding.
- The coding part is explained further.

Simulation:

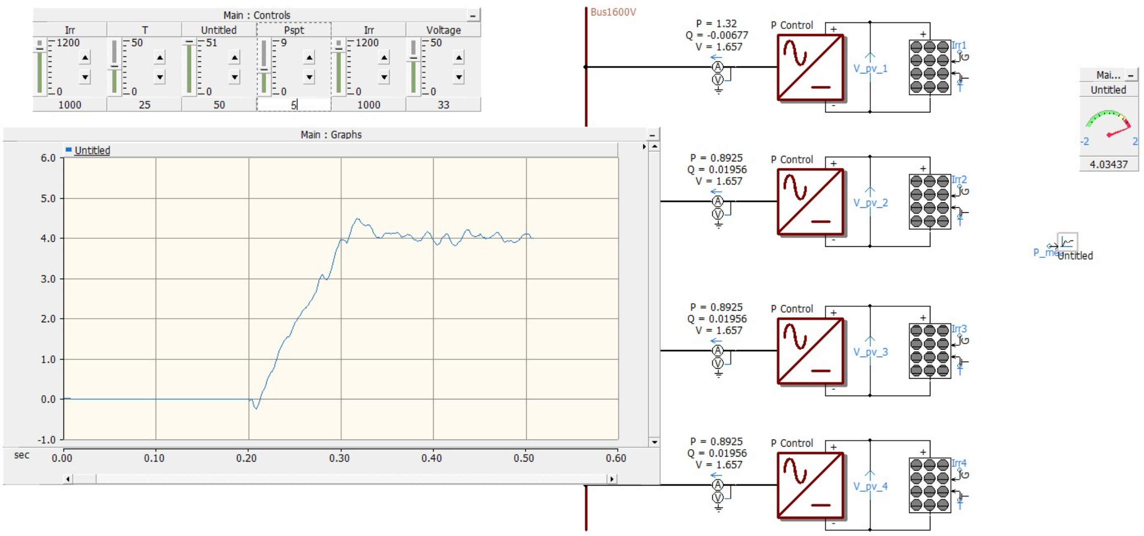




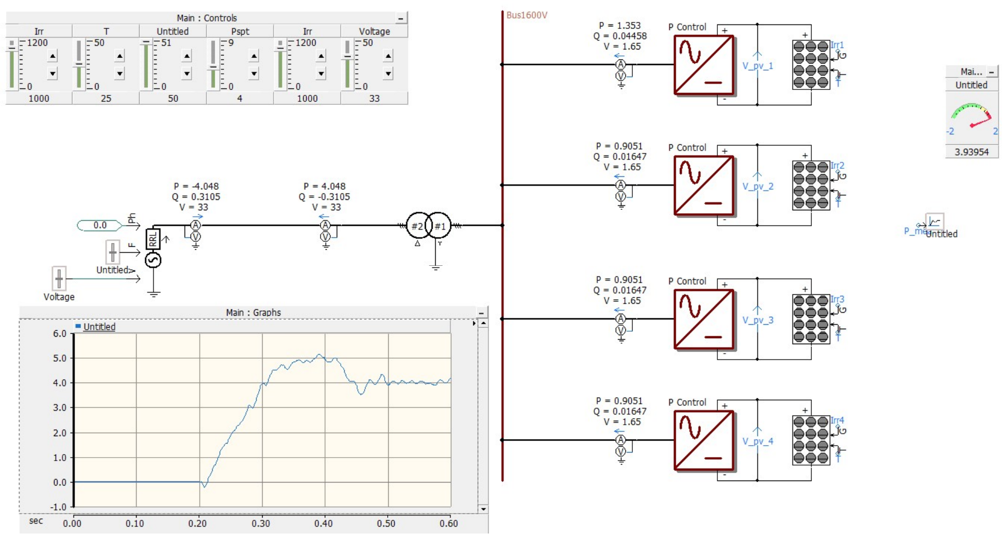
Results:



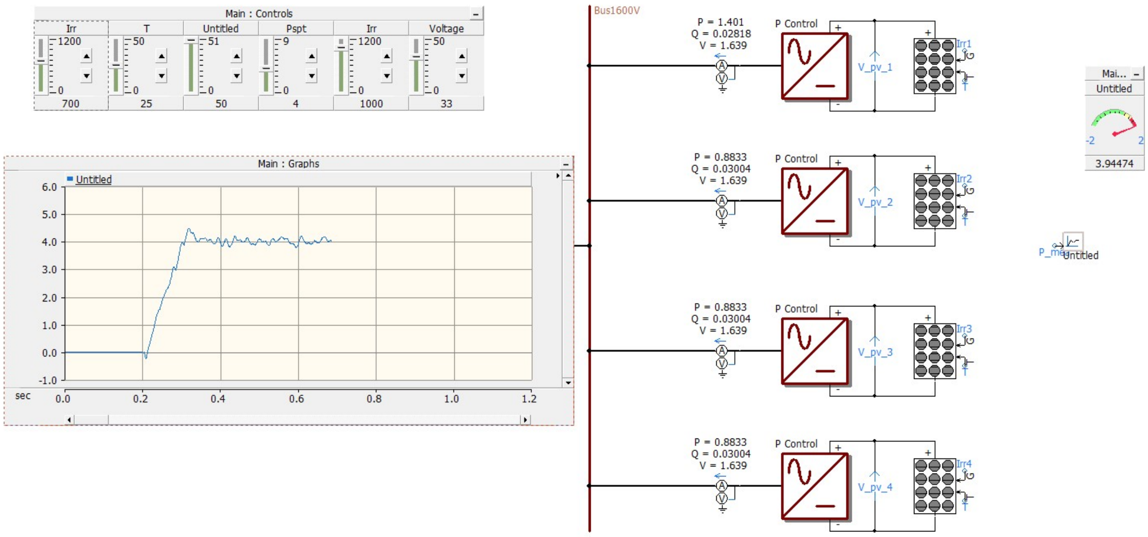
This photo indicates that the solar plant is giving the output of 4 MW as the maximum generation of the power plant is 4 MW. so the remaining power will be delivered by the grid.



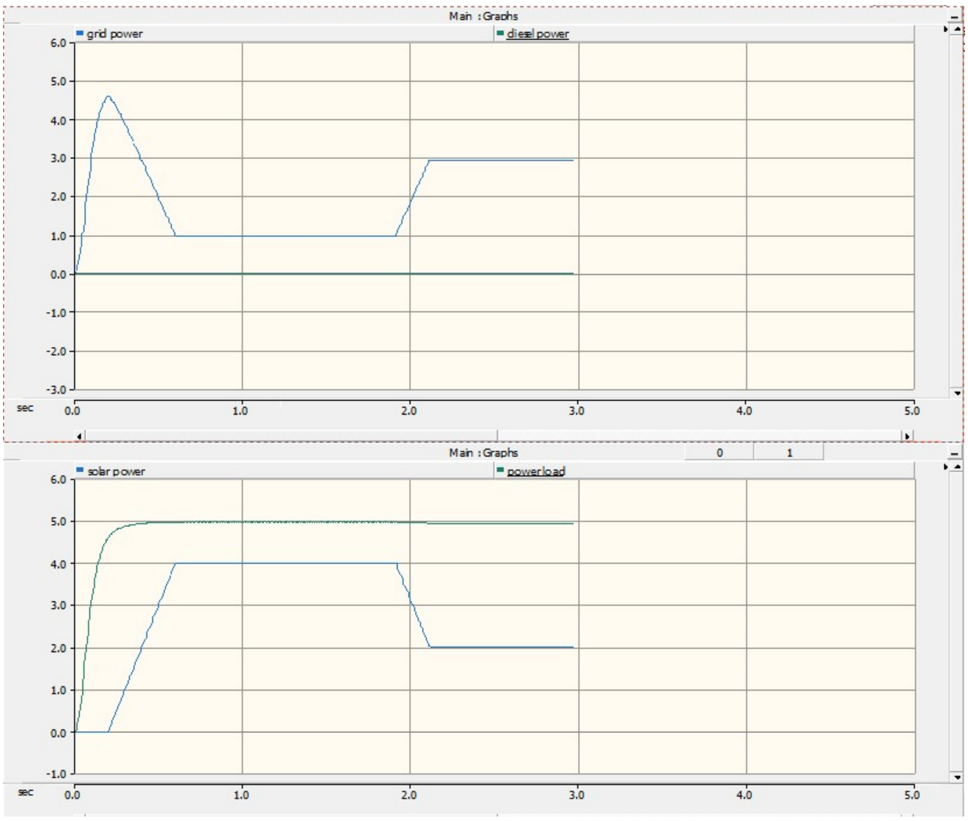
In this photo, the setpoint is given as 4MW and the panels of different reting are managing its production and gives the power of 4 MW. This can be done by per unit calculation.



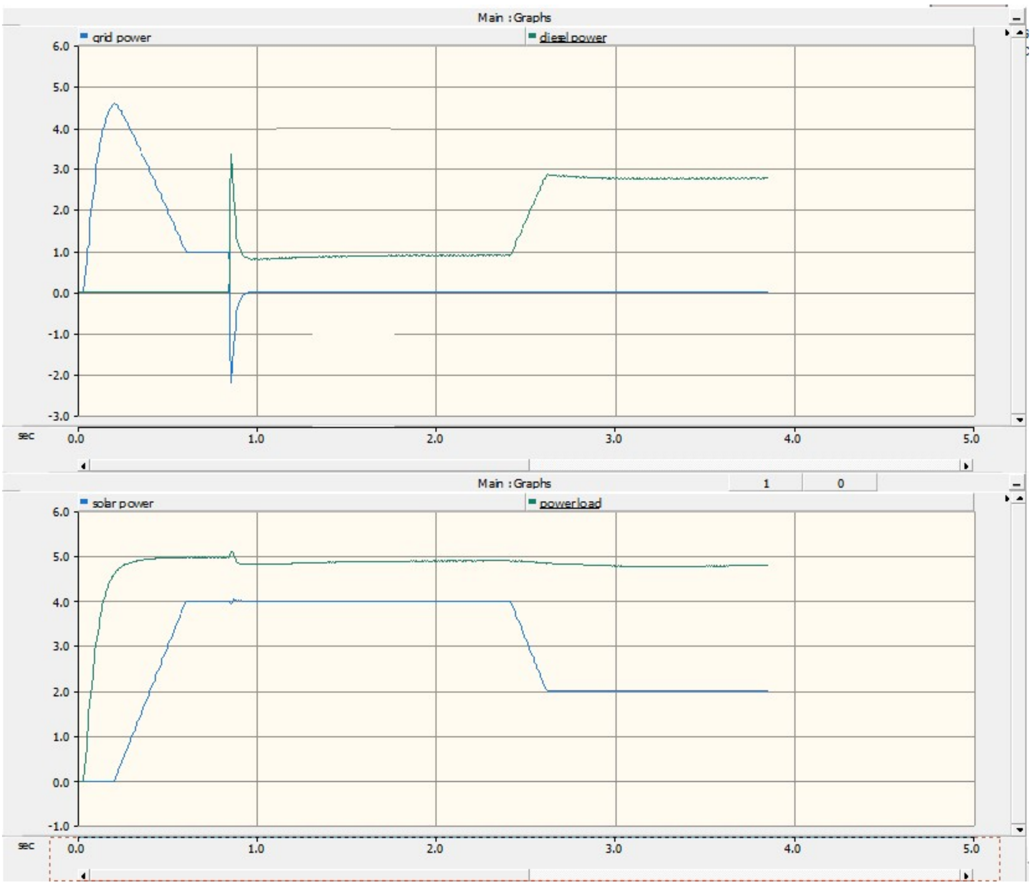
In this photo, if we notice , the power plant generates 5MW at first and after adjusting the set point from 5MW to 4MW the power plants follow the command and reduces its production to 4MW. Here in this, the inverters are automatically adjusting its power delivery and comes to the setpoint of 4MW. Here the interesting thing is the panels in the power plant are of different rating.



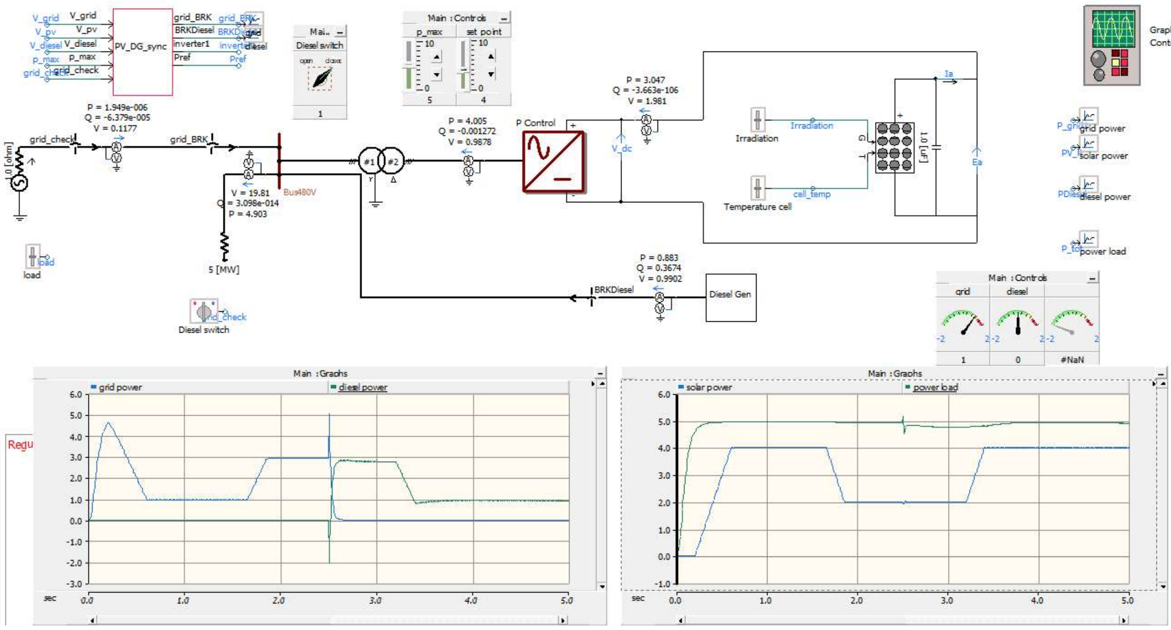
In this photo, I recreated the condition of partial shading . Here the irradiance of the second, third and fourth panels are given as 700(partial shading), so the inverters are automatically adjusting its power delivery and gives the output of 4MW.



In this photo, first the diesel generator switch is opened and the maximum generation point and the setpoint are given. Now the setpoint is set as 4 and so the power plant is automatically adjusted and gives the maximum power of 4MW and the remaining 1MW will be given by the grid. After some point the set point is decreased to 2. so the remaining power of 3MW will be delivered by the grid.



In this photo, first the diesel generator switch is closed and the maximum generation point and the setpoint are given. Now the setpoint is set as 4 and so the power plant is automatically adjusted and gives the maximum power of 4MW and the remaining 1MW will be given by the DG. After some point the set point is decreased to 2. so the remaining power of 3MW will be delivered by the DG.



This photo represents the whole output image of both the conditions (Grid mode and the DG mode).

Conclusion:

Incorporating Distributed Generators (DG) with Photovoltaic (PV) systems to synchronize under partial shading conditions shows promising results in mitigating shading effects and enhancing overall system efficiency. The combination of PV and DG resources optimizes power generation and minimizes losses caused by shading, leading to improved power quality and grid stability. However, addressing control and management challenges is crucial to ensure seamless integration and effective power flow between the two sources. Continued research and technological advancements will be essential to maximize the benefits of PV-DG synchronization, fostering a reliable and sustainable energy future.

Research Papers:

- **Effective power management scheme for PV-Battery-DG integrated standalone DC microgrid**, Sanjeev Pannala, Narayana Prasad Padhy, Pramod Agarwal First published: 10 September 2020 https://doi.org/10.1049/iet-epa.2020.0140

- **A new hybrid firefly optimized P-Q and V-f controller coordination for PV-DG–based microgrid ,stabilization** Prachitara Satapathy, Snehamoy Dhar, Pradipta Kishore Dash ,First published: 17 May 2018,https://doi.org/10.1002/etep.2568
- **Synchronization criteria of discrete-time complex networks with time-varying delays and parameter uncertainties**, P. Balasubramaniam and L. Jarina Banu, doi: 10.1007/s11571-013-9272-y
- **Simulation of synchronization photovoltaic system and low voltage grid**,M K Akbar1, S Syukriyadin1, R H Siregar1 and S Syahrizal1,Published under licence by IOP Publishing Ltd, IOP Conference Series: Materials Science and Engineering, Volume 1087, The 10th Annual International Conference on Science and Engineering (10th AIC 2020) 15th -16th October 2020, Banda Aceh, Indonesia

- **"A Review on PV-Diesel Hybrid System with Energy Storage for Power Quality Improvement under Partial Shading Conditions",** M. Khalid, M. A. Hassan, M. S. Hossain, M. J. Hossain, and M. J. Hossain, Renewable and Sustainable Energy Reviews
- **"Analysis of Photovoltaic System Integration with Distributed Generation under Partial Shading Conditions",** H. A. Kazem, M. M. Radzi, N. M. Adam, S. A. Aljunid, and S. F. Abd Rahman, IOP Conference Series: Materials Science and Engineering
- **"Enhancement of Grid Power Quality with DG in Presence of PV Systems under Partial Shading Conditions",** R. Ranjan, A. Kumar, and R. K. Jha, Journal of Cleaner Production
- **"Dynamic Programming Approach to Optimal Sizing of Photovoltaic and Distributed Generation with Battery Storage for Load Demand in Partial Shading Condition**", K. S. Rajpurohit, H. R. Pota, and K. C. Tseng, Applied Energy
- **"Investigation of Synchronization Techniques for PV-Diesel Hybrid System under Partial Shading Condition**", S. Khatib, A. Ghosh, and V. Agarwal, Energy Procedia
- **"Optimization of Distributed Generation Allocation and Sizing Considering Photovoltaic Units with Battery Storage in a Distribution Network under Partial Shading Conditions",** F. C. Freitas, E. A. S. Oliveira, and R. R. Saldanha, Renewable Energy