Research Article

PV-DG Synchronization model using PSCAD software under Partial Shading conditions

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We all know that electricity is a major part of our everyday life. The reserves of fossil fuels that currently power our society will fall shortly due to demand over the long term. We must save the electricity for our future generation. The only possible way is by using the renewable energy more efficiently. Even though solar energy can save lot of electricity it only works when the sun is shining. It also produces least energy power during night time it is a major drawback for the Photovoltaics (PV) system. In modern energy systems, integration of renewable energy has gained significant attention due to the need of sustainable energy solutions. This integration aims to maximise the benefits of both renewable energy and conventional energy sources while reducing their drawbacks. So, Disel Generators (DG) are used in PV system as auxiliary or backup power sources. The work proposed in this paper is to combine the integration of PV systems and DG so that this method offers promising solution to challenge the conventional fossil fuel-based energy and it will contribute more efficient and adaptable energy. The PV DG synchronisations focus the importance of managing power flow between PV and DG sources productively, especially during rapid changing environment based on real time conditions. All these are done by using advanced algorithms and clear communication systems. The algorithms are explored to optimise the power distribution and to ensure flawless integration. So, this synchronisation not only boost the power supply but also helps the operation of the DGs by minimising its runtime and reducing fuel consumption. We don't need to bother about the partial shading, unpredictable weather, solar variability and load fluctuations. Overall, this paper tries to overcome these complexities by synchronising the PV with DG which provides important benefits in ensuring consistent power supply, reliability, and overall performance of the energy system. The integration of DG sources also compensates for the shaded areas of PV arrays, resulting in improved power quality and it enhances the grid stability.

1. Introduction

The PV-DG involves in interdependent operation which boost the consumption, grid stability and production. For that sensors and monitoring devices are used to continuously to track and collect the data based on parameters such as solar irradiance, electricity demand grid condition and PV system output. Basically PV-Dg works based on set point values. As solar energy production minimises due to partial shading by clouds or the setting sun, the predefined set point will prompt the engagement of the DG. These set points are based on the energy demands and convenient level of backup power. The synchronisation system reacts dynamically to varying conditions and it can quickly adjust the level from PV system and DG to maintain stable. For example, sudden change in load or unexpected variation in solar irradiance. The main objective of this synchronisation is to minimise the runtime of DG and to provide stable efficient energy supply for the grid.

When comes into power the standalone DC microgrids are becoming very rare and it needs an additional source as a backup. Battery could be one of the sources, but it is very expensive. So, a Diesel generator could be one of the replacements as it offers very low cost and delay. To address this a novel control strategy is proposed between sources and loads. Various SDCMG were tested and validated with proposed control strategy [1]. The controller integrates the PV and auxiliary batteries. It uses the batteries when the grid is not there. It operates in two different modes: real and reactive power control (p-q) mode and voltage frequency control (v-f) modes. To improve the tuning a novel approach of firefly algorithm is used and validated in MATLAB and Simulink [2]. The synchronization issues are described in this paper and the synchronization criteria uses Lyapunov-Krasovskii functionals and reciprocal lemmas, which employs a delay partitioning technique. These techniques were used to solve the synchronization issues [3]. The synchronization of PV to the grid with the voltage, frequency, and power factor by using components like voltage, frequency and power factor detectors and the controlling is done by Arduino Board. The synchronizing is verified in the proteus simulations, and the voltage current graphs are verified [4]. Hybrid power generation system works by tracking the Intermediate Power Point (IPP) over Maximum Power Point (MPP). This method offers high accuracy and efficiency in partial shading condition which combines particle swarm optimization with novel algorithm for control setpoints, gives high voltage and lower current thereby reducing the power losses [5]. Renewable solar is major replacement for the conventional energy sources. But its efficiency is reduced, especially under partial shading conditions. A more optimal, intelligent and hybrid method of MPPT using sensors are proposed in this paper [6]. In Partial Shading Conditions (PSC), the solar cells in shading will create hotspots in the cells and leads to a power loss. The complexity increases when bypass diodes are used. This leads to the development of Improved Harmony Search Algorithm (IHSA) combined with Perturb and Observe (P&O) algorithm. This algorithm tracks the global peak instead of local peak [7]. PSC can be optimized using controls like Adaptive Takagi- Sugeno Fuzzy Inference System based Fuzzy logic control. This model simulated in MATLAB environment and various case studies was verified [8]. A PV system with Grid and Battery Energy Storage System (BESS) for office buildings is proposed in this paper. A dynamic programming algorithm is proposed to take care of the scheduling and switching of the grid and BESS system which will offers efficient controlling of the system and also takes care of the sensitivity analysis of electricity pricing also [9]. The control strategy of solar energy storage systems in the residential areas are proposed in this paper using Dynamic Programming algorithm which minimize the total cost of electricity for household loads. The DP algorithm control strategy is proposed and compared with the already existing control strategy which was implemented by using heuristic control techniques and the performance is verified [10]. The major issue in the power systems is the high cost of electricity, caused by some factors like market pricing, inflation, climatic conditions, etc. This paper combines the Diesel generator and Battery storage system together to tackle these challenges. So, an efficient DG is designed which is suitable for both renewable and non-renewable energy sources. This will improve the grid based intelligent control panels are designed in this paper. This microcontroller handles the switching of the solar, mains and DG. The DG starting and synchronizing is automatically done by the Auto mains failure controller [17].

In this research, the complete PV-DG synchronization system is designed using PSCAD software and a novel and efficient control strategy is also designed which will increase the energy generation and reduce the unwanted losses. This design also uses control techniques like real power control and reactive power control is also designed using the PI controllers. This design also takes care of the partial shading condition at inverter level. So, if there is any shading in the panels the inverters will automatically adjust its parameters and match the power required to the load.

connectivity and efficiency of the system [11]. Traditionally DG will always run at the same speed even though a limited amount of energy is required and leading to a power loss and poor fuel efficiency. To tackle this a Variable Speed Diesel Generators (VSDGs) are designed which will vary their speed according to the power required. And, a comparison study of VSDGs and conventional DG is done in this paper [12]. This paper mainly focuses on optimizing the conventional PVDG system for Kuching and Malaysia by the approach of varying the PV array, Storage battery and DG. This approach provides a very low load loss and achieves very low cost. This system was designed and tested in MATLAB environment [13]. A novel control strategy for three phase three wire PV system which is in unbalanced and nor linear load scenarios is designed in this paper. This novel control approach uses multi-loop control technique, a multiple resonant harmonic compensator to reduce the total hormonic distortion and droop control for load sharing between the inverters. This model is designed and verified using MATLAB which offers 17.51% to 3% improved efficiency in nonlinear conditions [14]. A novel control strategy of PV- grid connected inverters tackles the issue of the inertia and damping capacity of the solar power plants using a model predictive control algorithm. This algorithm automatically adjusts its output current to suppress the oscillation of the output power. Thus, this simulation offers the effectiveness in damping power oscillations. This approach will also enhance the stability of the grid [15]. An Adaptive Neuro-Fuzzy Inference system based MPPT controller is designed to improve the power quality related issues at the point of common coupling in grid connected PV systems. This approach mainly focusses on the real power injection, reactive power consumption and the filtering of the harmonics. This system is designed and verified in the MATLAB Simulink [16]. An intelligent and efficient advanced microcontroller

In this paper, the second chapter explains about the general block diagram and principles behind PVDG synchronization. The third chapter explains the designing of PVDG synchronization system in PSCAD. The fourth chapter explains the control algorithm used in the design. And the final section explains about the simulation studies and results of the system.

2.PV-DG Synchronization

2.1. Block Diagram

Block diagram represents the actual PV-DG synchronization system available in market. It has some components like PV, DG, Grid, Bidirectional Energy meter, Inverters, Transformers, Breakers, PV-DG Synchronization controller. The PV is the major component when comes into production of energy on a large scale which is considered as the primary source. Grid and DG are the support or secondary sources which give the reference voltage and power when it is needed. Bidirectional energy meter is a device which is used to measure both the input and output power of any device. The breakers are used for controlling purposes of the system, especially open circuiting, and short circuiting of the system. Inverter plays a major role when comes to converting the DC to AC and controlling the output power of the PV. To control the output of the inverter the frequency of the IGBT is controlled.

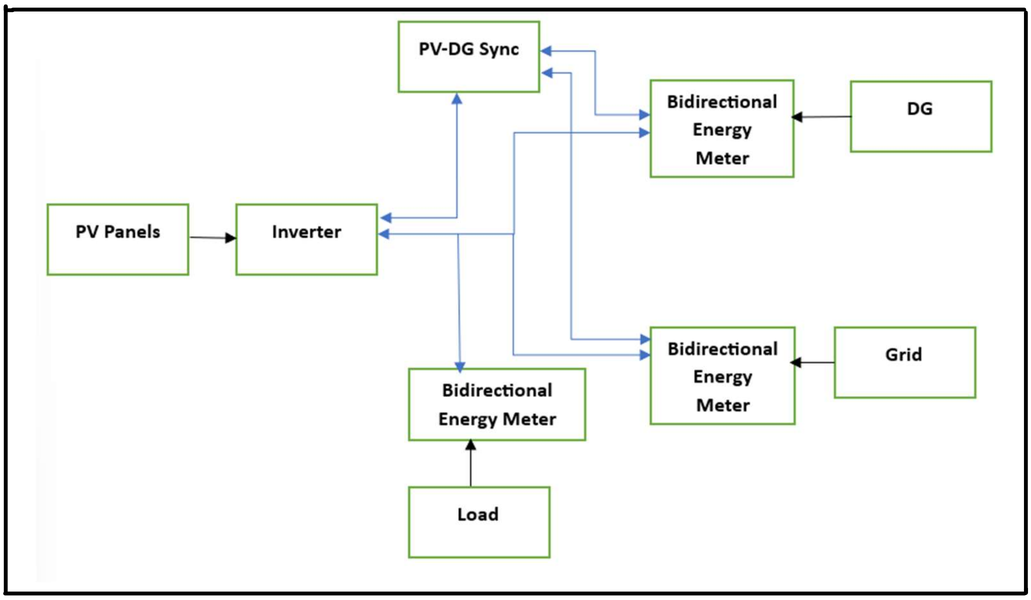

Fig.1 General Block Diagram of PV-DG Synchronization

2.2. PV-DG synchronization system

In a PV-DG system, PV is the major source to produce energy. It needs a reference voltage to supply the generated power to the grid. This reference voltage is generally taken from the grid. And if the generation of PV is not up to the demand from the load the grid will supply the remaining power to meet the demand from the load. If the grid is not available, then the reference voltage is not given to the PV and there will be a wastage of power. So, an alternative Source instead of grid is needed. One of the best alternative sources is Diesel Generator (DG). Now, the DG will automatically turn on and provide reference voltage and power if it is required to meet the demand. But the DG needs to be used efficiently.

2.3. Conventional PV-DG vs Proposed PV-DG

In conventional PV-DG, If the PV-DG system is running in Grid connected mode, Then the Load will run at 10% of the grid power and 90% of the power will be delivered by the PV source to the load. The inverter will get the reference voltage at 10% of the grid power. And if the grid is disconnected from the system, Then the system will start to run in DG connected mode, So the Load will run at 30% of the DG power and the 70% of the power will be delivered by the PV source. The inverter will get the reference voltage at 30% of the DG power. This will cause an issue in the system when there is a collapse of PV system, or the power generation is very less. As the grid or DG is allowed to provide only up to a limited power, so the load requirements are not meet.

In proposed PV-DG, if the system is running in the grid connected mode, the full power is delivered by the PV and the grid will provide only the reference voltage. When the load requirement is greater than the PV generation then the grid will provide power along with the reference voltage. when the grid is not available then the same operation will be done by the DG system. With this control strategy the PV power can be used effectively and the also the unwanted power loss is reduced.

3. PSCAD Design of actual PV DG model

3.1. solar panel design

The solar panel is designed based on Fig.3 specification which has been taken from the actual panel specification. The panel is designed to produce a maximum power of 3MW, maximum current of 1974A and a maximum voltage of about 1500V, to achieve these parameters 38 panels are connected in series, 200 panels in parallel. This complete design forms 1 set of panels which is given to one inverter.

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

Fig. 2 Solar panel Data

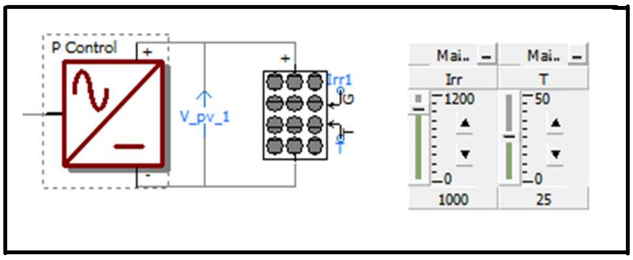

Fig.3 Solar panel Design

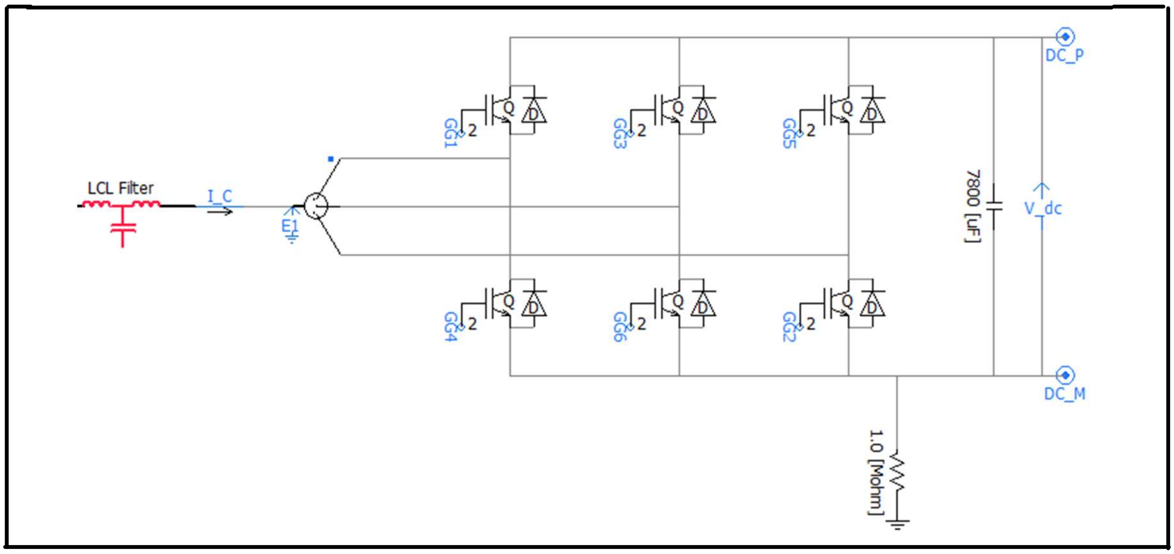

Fig.4 Inverter Design

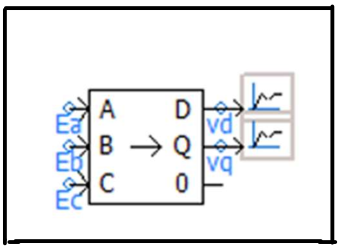

Fig.5 ABC to DQ frame of Voltage

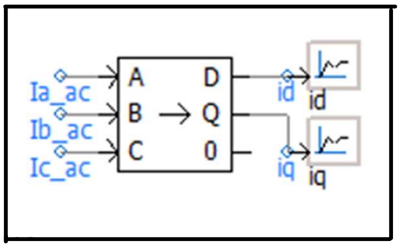

Fig. 6 ABC to DQ frame of Current

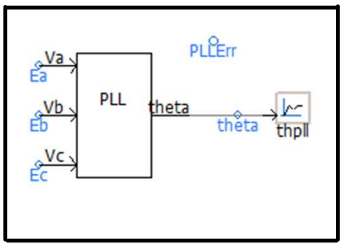

Fig.7 Phase locked loop

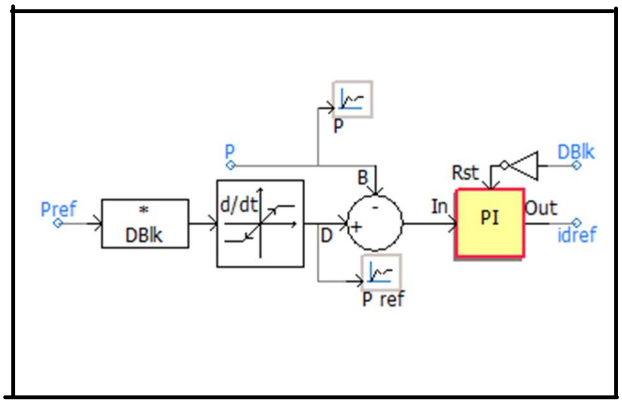

Fig. 8 Id reference

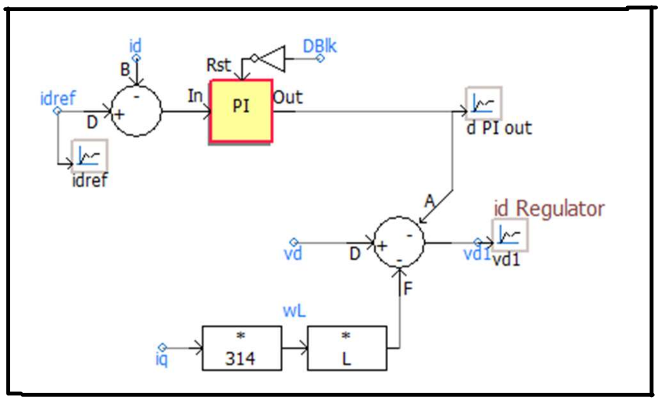

Fig.9 Vd generation

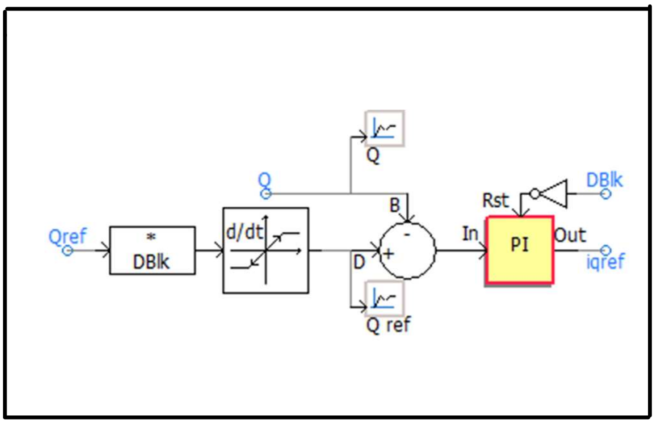

Fig. 10 Iq reference

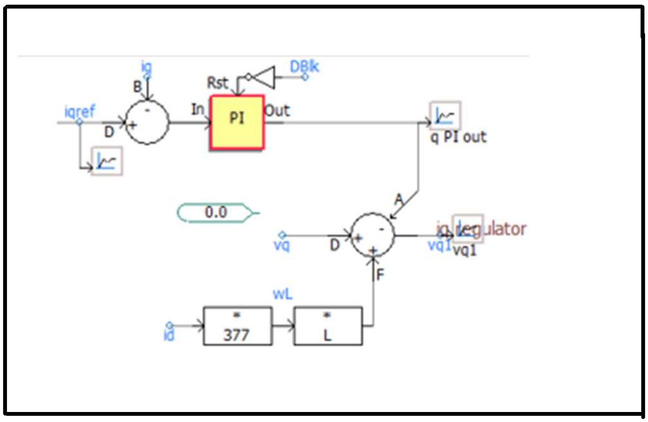

Fig.11 Vq generation

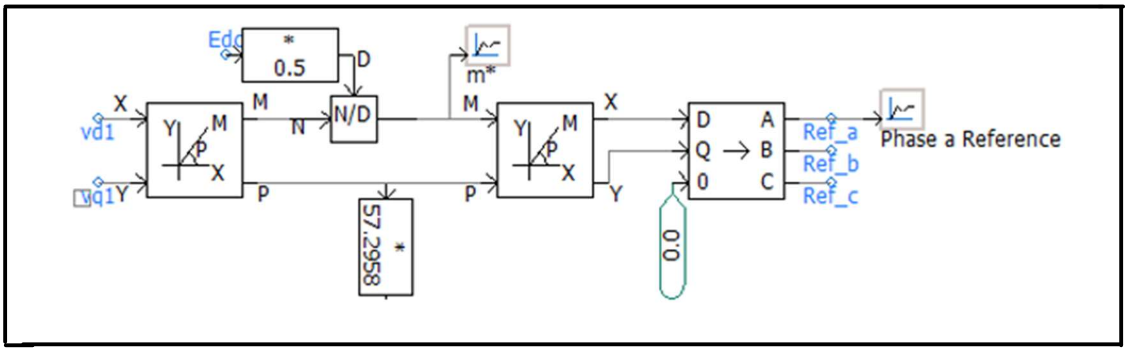

Fig. 12 Reference Phase generation

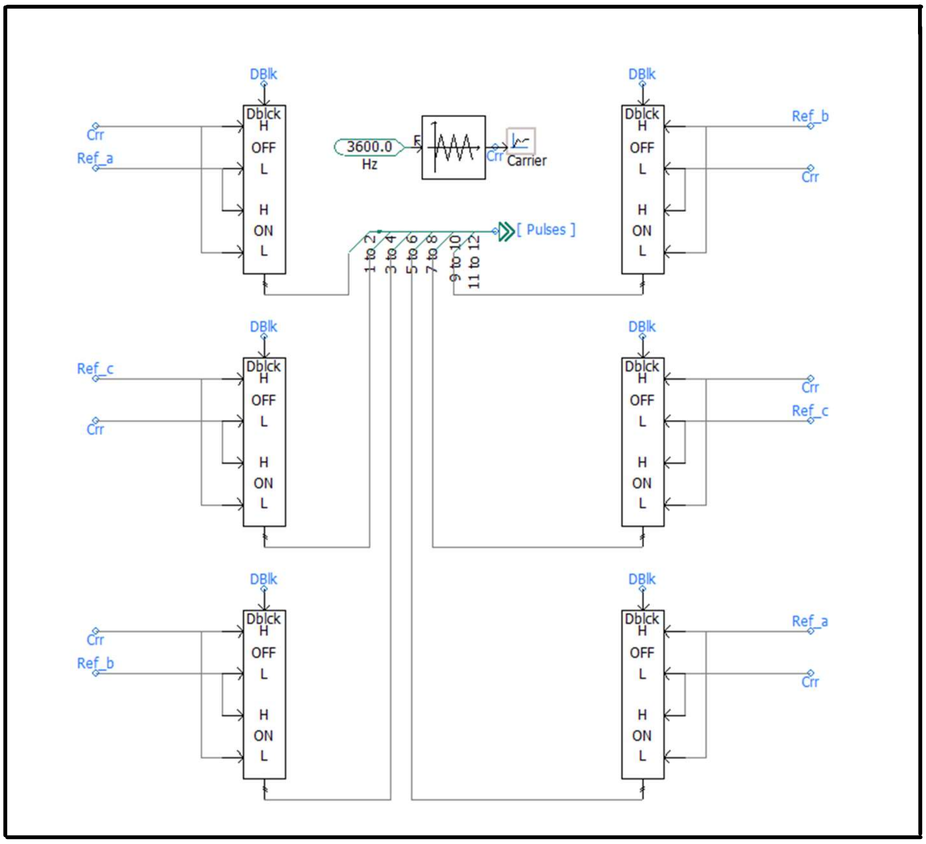

Fig .13 Gate pulse generation for IGBTs

3.2. Inverter design

Inverter plays a major role in the PV-DG synchronization. It involves in the controlling of real and reactive power of the system. The design of inverter is shown in fig. 4. The DC link capacitor is connected to provide more stable DC output. The IGBT are used for the controlling purpose of the inverter. IGBTs are controlled by using the gate pulse. That gate can be generated by the control technique as follows. And the LCL filter is used to reduce the harmonics and smoothens the output current and voltage.

For controlling the real power, the real power output has been taken from the inverter output and given back as the power to the control part via feedback loop. And the reference power is also given to the control part. Both powers are compared, and the error signal has been given to the proportional Integral controller which will generates the Id reference as shown in fig 8. Proportional Integral controller (PI) is a controller which operates by the adjusting the error signal until it reaches the correct value.

The present Id, Iq is calculated by changing the current of three phase (ABC frame) to DQ frame as shown in fig. 6. Then Both the Id and Id reference are compared to find the error signal and given to another proportional Integral controller. The output from the PI controller and Iq are subtracted with the Vd which is generated by using the same technique ABC frame to DQ frame conversion. As an output the corrected Voltage Vd has been generated as shown in fig. 9. The same technique is followed to find the voltage Vq as shown in fig. 11. Then both the voltages Vd and Vq are rectangular to polar form. The radian value is then converted into the degree. The reference for all the three phases has been generated by changing it again to the rectangular form and converted it from DQ frame to ABC frame of reference as shown in fig. 12.

Then these three reference signals are given to the merger block which is then merges with the carrier signal to form a gate pulse. The carrier signal is generated by the pulse generator. These merged signals are then given to the respective IGBTs as a gate pulse signal. Then these gate pulses will take care of converting the DC signal to the AC signal. Here the real power and reactive power has been controlled by the PI controller. Hence the real and reactive power control is achieved as shown in fig.13.

Fig. 13 shows the Phase Locked Loop (PLL) which is control mechanism operates by getting the input from the feedback loop and automatically adjusts its signal to generate an output signal that exactly matches with the reference input signal. The generated signal will have the exact same frequency and constant phase difference. Here the PLL will takes the input signal from all the three phase voltages and generates an output signal with same exact frequency and voltage.

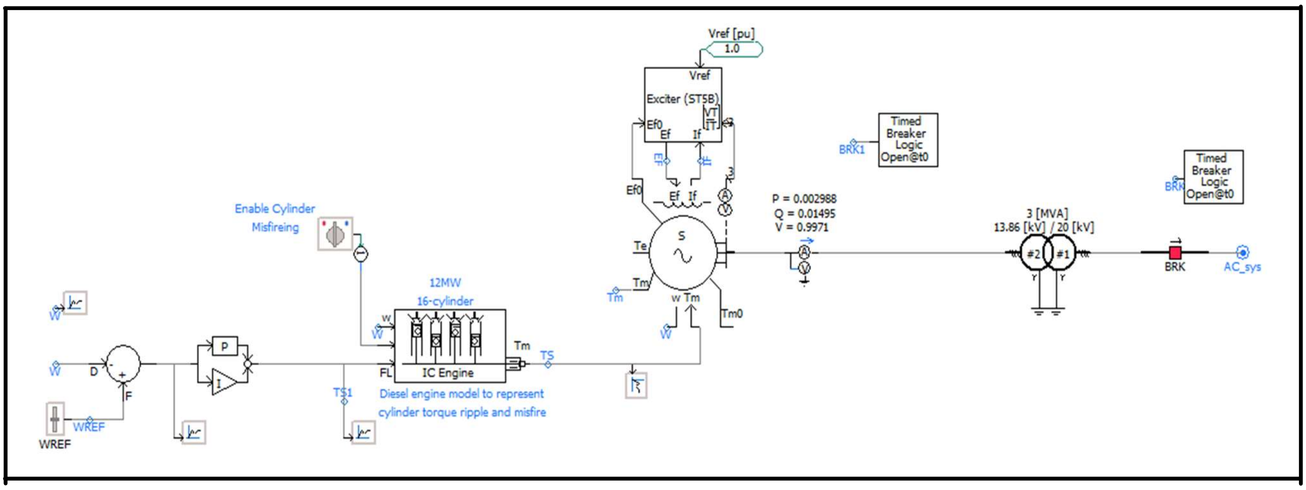

Fig. 14 Diesel Generator Design

3.3. Diesel generator design

The design of diesel generator is shown on the fig. 14. The diesel engine has mainly three parts namely an IC engine, a Synchronous generator, and an exciter. The present power is taken from the feedback loop of output. Then this power is compared with the reference power that needs to be generated and the error signal is given to the PI controller which will takes care of controlling the fuel injection into the IC engine. The IC engine uses that fuel and starts to produce torques. When the fuel injection increases the torque of the DG also increases. As the IC engine is connected to the synchronous generator, the generator also rotates at the same torque and produce power by the principle of electromagnetic induction. Here the synchronous generator is used because it offers easy synchronization with PV. The exciter will take care of the voltage maintenance in the diesel generator. The reference voltage is given to the exciter and the exciter will maintains the DG in that voltage. Then the transformer is used to step up the voltage to the grid voltage.

3.4. Partial shading design

The Partial Shading is achieved by using the per unit concept. As a default rating each inverter will generates the 3MW power. But in actual scenarios the inverter will handles different power generation capacity. To achieve that an additional parameter is introduced to the inverter by which the generation capacity can be controlled. Now for partial shading, the power setpoint is converted into the per unit power and given to the inverter. And inside the inverter the per unit value is multiplied with the inverter rating and given as the power set point to the inverter as shown in fig. 15 and 16. So, when the generation of one inverter decreases. The per unit value will automatically increases which results in increased power generation of other inverters.

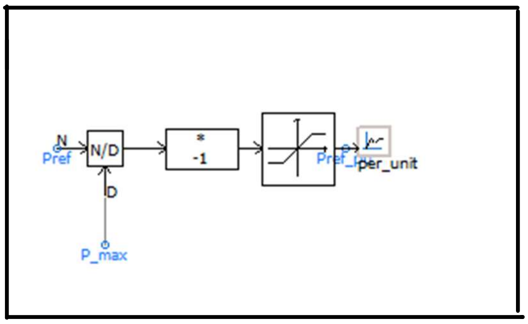

Fig. 15 Partial Shading control (Outside the inverter)

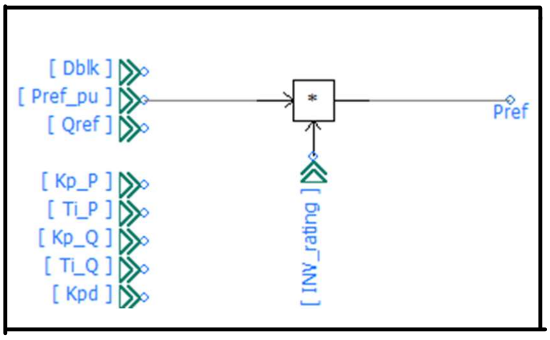

Fig. 16 Partial Shading control (Outside the inverter)

4. Complete design and Control Algorithm

4.1. Complete design

Totally four solar panel groups are designed which will gives a default power of 3MW which is then given to four different inverters. The generation capacity of each solar panel group is limited in the inverter, which is limited to 3MW, 2MW, 3.5MW, 1.5 MW summing to 10 MW in total. And all these inverters' generations are added and given to the transformer to step up the voltage. Then it is connected to the busbar via a multimeter which is used to measure the output power from the PV, and it is further used for feedback loop. Then the DG is connected to the busbar via another circuit breaker. The Grid and load are also connected to the busbar via breakers and multimeters.

4.2. Control Algorithm

The maximum solar power generation at that instant is declared as a local variable. And the power setpoint is taken as an input from the load dispatch centre (LDC) (here the user). As an initial condition all the circuit breakers are in open condition. The algorithm will first check whether the grid is available or not. If the grid is available, then it will close the circuit breaker of the grid. Then it will check whether the PV maximum generation limit is greater than the setpoint are not. If it is greater, then reference power will be the setpoint given by the LDC and the circuit breaker of the PV will be closed. If it is lesser, then the reference power will be the PV maximum generation and the inverter's circuit breaker is closed.

If the grid is not available, then the circuit breaker of the grid will be opened and the circuit breaker of DG will be closed. Here also the condition of whether the PV maximum limit is greater than the setpoint. And if greater, Then the reference power will be the setpoint of the LDC and the inverter's breaker is closed. And if lesser, Then the power reference will be PV maximum limit and the inverter's breaker will be closed. Here, the control algorithm is a closed loop control algorithm, so no human intervention required to control it.

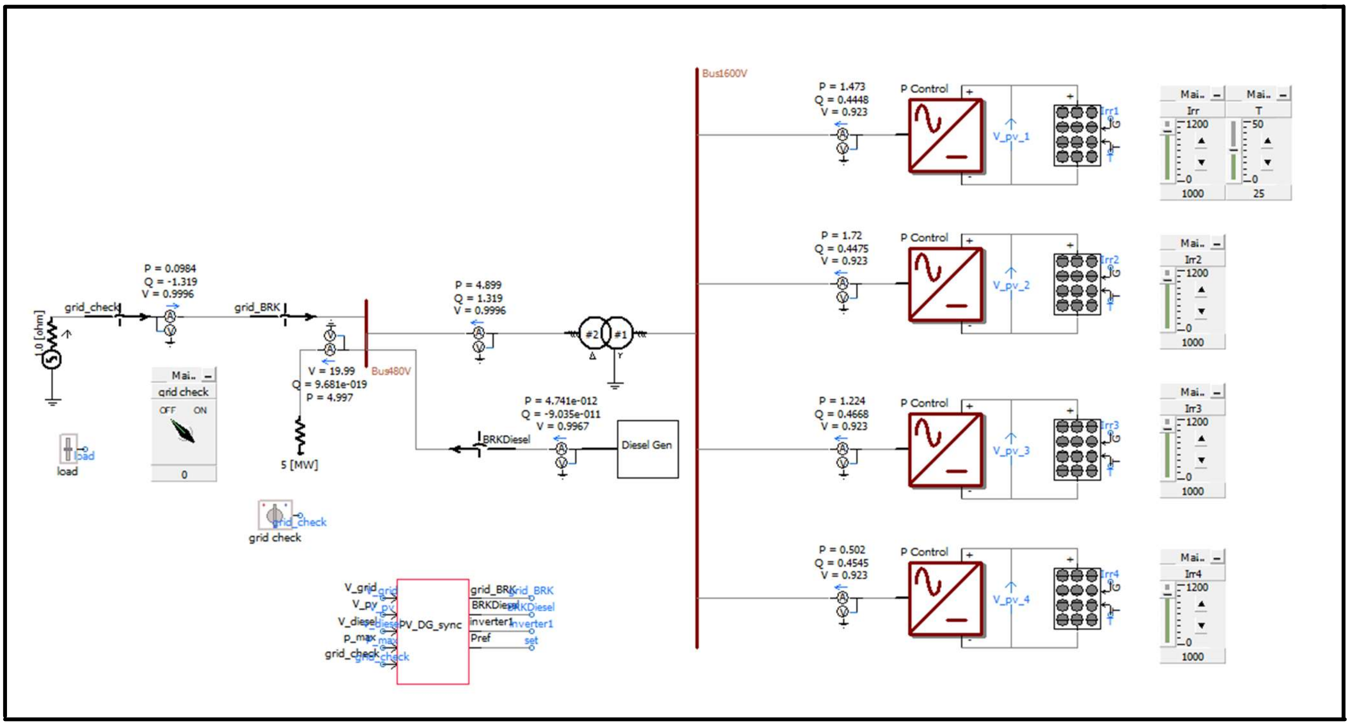

Fig. 17 Complete Design of PV-DG Synchronization

5. Simulation result and Analysis

5.1. simulation results

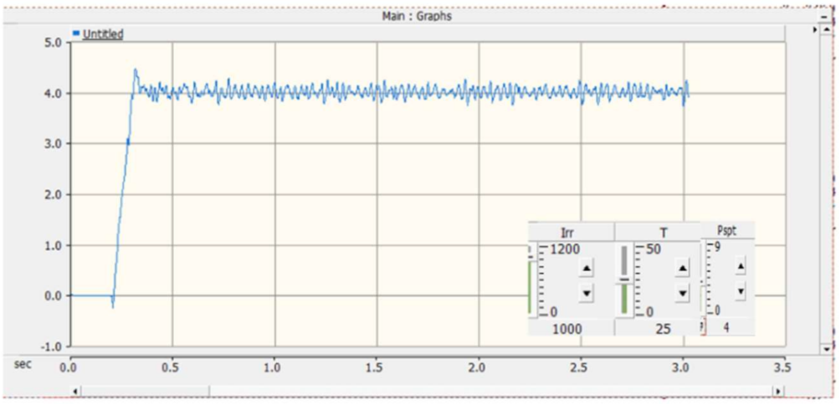

Fig. 18 Grid Available and set point is constant

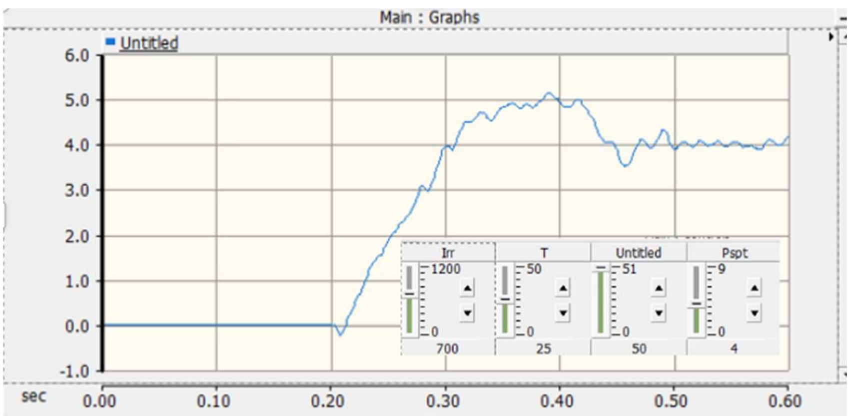

Fig. 19 Grid Available and set point is varying and under partial shading conditions

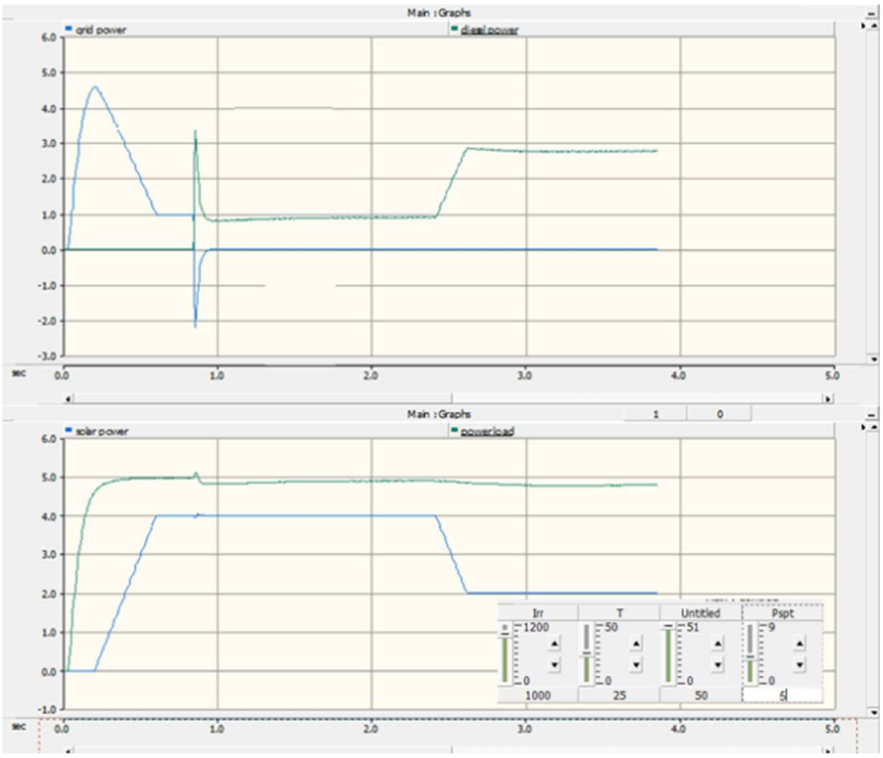

Fig. 20 Grid Available and set point is varying

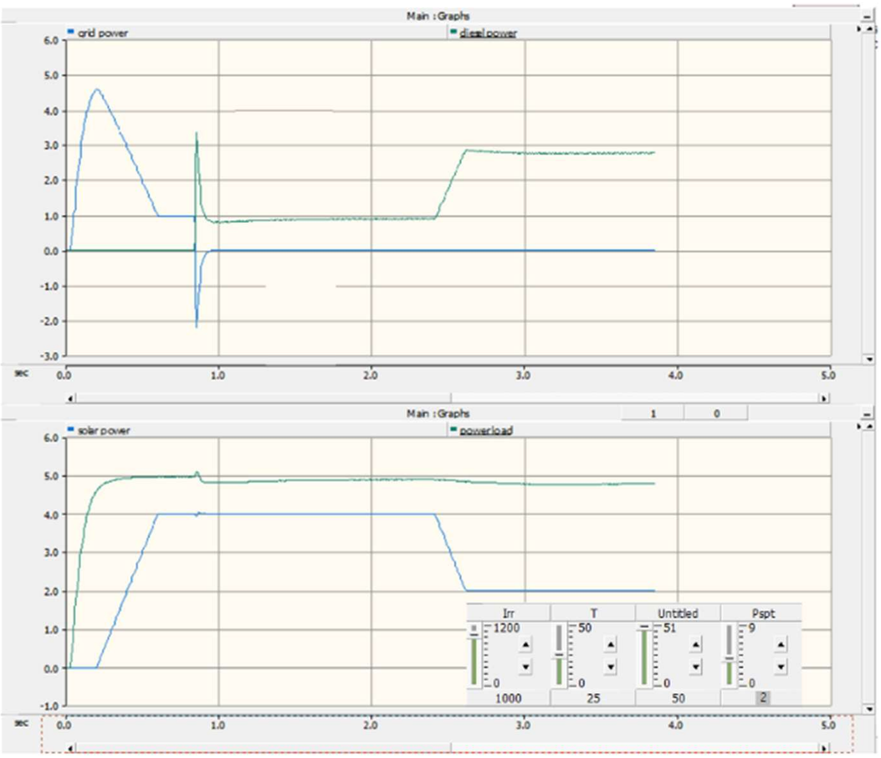

Fig. 21 Grid not Available and DG is On with varying setpoints

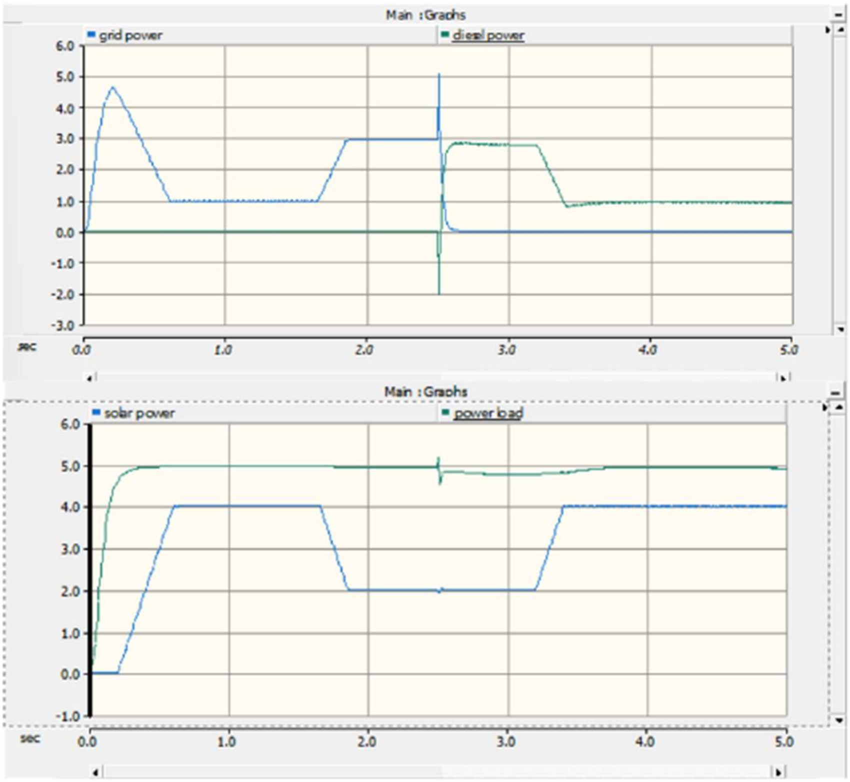

Fig. 22 Graph of Grid power, DG power, PV power and load power under all the conditions

Fig. 18 indicates that the PV is giving an maximum output 4MW, As the power set point is lower than the maximum power generated from the PV. Here the grid is available and providing only reference voltage to the PV.

Fig. 19 shows the PV generation under partial shading condition. Here when the Irradiance of 2.5 MW solar panel group decreases, the per unit value of reference power increases which will increase the generation of power in other inverters. So, it will manage to give the maximum possible power. Here, it is generating the power of around 5MW. Then the power setpoint is decreased to 4MW, which automatically adjust its power and reduced to 4MW.

Fig. 20 shows the result of PV generation, DG generation, power from grid and power delivered to load when the availability of grid while adjusting the set point given by the LDC. Here the set point is initially given as 4MW and then reduced to 2MW, The PV also reacts to this change and delivers 4MW at first and then switched to 2MW when it changed and settles at 2 MW. The PI controller inside the inverter inside the inverter will takes care of switching. Here as the circuit breaker of DG is opened, there will beno power generation across DG.

Fig. 21 shows the result of PV generation, DG generation, power from grid and power delivered to load when the grid is not available and the setpoints are also adjusted. When the grid is not available the system will automatically turn to DG mode and the reference voltage will be provided by the grid. Here when the grid is not available, and the set point is 4MW, and the load is 5MW. So, the DG is generating 1MW of power along with the reference voltage and the remaining 4MW was provided by the PV as usual. When the setpoint is reduced to 2 MW the DG power generation automatically increases to 3MW and the remaining 2MW was supplied by the PV. At all the time the load is receiving full power of 5MW.

Fig. 22 shows the complete operation in all the modes in one single graph. The output of PV-DG while operating in grid connected mode and DG connected mode is shown and it also indicates that the control algorithm is closed loop and no humans are required to control it.

5.2. Future scope

In future, a better performing and advanced control algorithm can be designed to improve the efficiency and reduce the loss of power. Each solar panel can be manufactured with the bypassing diode, so that when there is a shading or hotspots, the efficiency of the panel won't be lost, in practical case if one solar panel's generation is reduced then the whole strings generation will be reduced. An energy storage system can be integrated to reduce the wastage of solar power when the setpoint given by the LDC is lesser than the PV maximum generation. While designing this system lot of challenge have been faced will finding the Kp and Ki gain values of the PI controllers, so a modern algorithms like particle swam algorithm, firefly algorithm can be introduced. Machine learning algorithm and automation can be done in the area of power plant monitoring.

5.3. Conclusion

Adding Diesel Generator (DG) to the Photovoltaic systems to synchronize the voltage under nominal and partial shading condition when the grid is not available shows some promising results and improve the overall efficiency of the system. The combination of Grid, PV and DG optimizes the total power generation and minimizes the power losses caused by partial shading. As the PLL is taking care of synchronizing the PV, the frequency and voltage mismatch becomes rare which results in the improved power quality and grid stability. And also a maximum power can be generated at a very low investment of cost.

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