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Research Article

Design of an IoT based power monitoring system model for a grid connected solar PV

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Abstract
The new age of electricity generation is renewable energy. There is no other room, but to use renewable resources in energy generation to make the planet healthier, safer, and sustainable for the future. There are many different forms of renewable resources, but solar power is by far the most convenient. By utilizing solar panels, solar energy can be converted into electricity. Nowadays, solar panels are extensively utilized for the efficiency, availability, and simplicity of power production. This paper mainly represents the simulation of the compact design of a grid-tied solar system for energy production & internet of things (IoT)-based power monitoring using Matlab/Simulink. The main three sections of this design are; a fully optimized grid-tied model, IoT-based power measuring system, and optimized battery-based storage system. The model is also capable of working under load-shedding conditions. When irradiance is 1000, the integrated system can produce 2056W from the solar panels and it gradually decreases when the irradiance is less than 1000. Detail's structure and modelling of this system were discussed in this paper. The results found are promising which could be implemented in real life.

Keywords
Photovoltaics (PV) arrays, Grid-tied inverter, R-L loads, Utility grid, Battery, IoT-based monitoring system.

1.Introduction
The power consumption of every country of the world is increasing day by day. Most of the third-world countries are going through rapid industrialization, and with rapid industrialization, the electrical power consumption of the world in total is increasing every day. Most of this power comes from non-renewable fossil fuel sources. As of 2020, 66.17% of world electrical power consumption comes from fossil fuels [1]. However, using fossil fuels is unsustainable as these will eventually run out and impact the environment negatively. Today's primary motive for generating power is to use renewable resources. Every power generating company and research organization is now working on various renewable resources for generating electricity to ensure sustainable development in the power sector.

To make it possible, power management and measurement system are equally important for getting better outputs from renewable sources. In the present era of the rapid growth of renewable energy-based applications, community electricity demand management is a challenging issue while ensuring 24×7 energy security [2]. Thus, a renewable energy source is a must for long-term sustainability and to resist climate change.

Energy demand is increasing gradually. To satisfy this energy security demand and to ensure a cleaner environment, a renewable energy source integrated microgrid [3−8] system claims to be a potential community-scale solution. Considering the intermittency of renewable energy sources, multiple energy sources such as solar photovoltaic (PV), biomass, along battery energy storage systems forming a hybrid microgrid can be a potential solution. The most popular renewable energy source to generate large-scale power is hydropower. But hydropower is not suitable for every geographical area [9], and an individual person cannot install them.

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For this, PV systems are very popular nowadays as they allow users to generate power independently. According to the international energy agency (IEA), “more than 100 GW of solar PV projects were completed in 2019”. Solar-based power plants are growing up largely. An analysis report from the international renewable energy agency (IRENA) shows that, “total solar capacity has now reached about the same level as wind capacity thanks largely to expansion in Asia (78 GW) in 2020”. The transmission and distribution of power involve a high number of power losses. Solar-based energy sources are supported to reduce losses and reduce the volume spent on electricity transmission and distribution infrastructures. One of the major possibilities of solar power systems is to connect them to the local grid [10]. Multi-agent-based distributed control architecture for microgrid energy management and optimization has already been developed along with the control technique for enhancing the stable operation of distributed generation units within a microgrid [11, 12].

Moreover, solar systems connected with the mains or grid were simplified and often supported by incentives from utilities and/or governmental bodies [13]. The proposed model of this paper is an IoT-based power measuring system for a grid-connected solar PV. The IoT-based power monitoring system is the most advanced and widely used system for measuring various types of power nowadays. Conventional methods of power measuring are not capable enough to give real-time data, which is very important to show the outcome and advantages of renewable energy to the consumers. Also, there are many chances of doing unethical acts in the traditional metering system through billing policies. The proposed energy meter (kWh) section enables user to double check the electricity bill provided by the utility company, thus, forcing the utility company to be more transparent about their billing policy. If this data can be stored on a public server, the data can be accessed & acquired easily by government organizations, statistics bureau or power development authority in order to make easy assumptions about the power sector scenario of a country. IoT-based power measuring systems are now taking a valuable part in the power measuring sector [14]. Many big companies like Tesla are researching IoT-based energy monitoring systems [15]. The proposed power measuring system can show real-time data on both sides and merge both conventional and renewable power systems to give the maximum output combined at a time. One of the major concerns of solar technology is the efficiency factor. With the increased popularity and decreasing price, a lot of money is being invested in PV cell technology research and development. Some six junction solar cells have achieved efficiency as high as 47% in laboratory conditions [16]. In the proposed system, consumers and the equipment producers can see the real-time efficiency of their solar panels and can calculate their lifespan. It will add a competitive market for the producers to give their best product, and consumers can select the product based on their demands. One of the major features of this system is a backup system for load shedding or rainy weather. So, the backup system will send the necessary power to the load when there is any power failure on the grid or in the PV panel. In case of emergency, the system can work a certain period to handle the situation.

A bi-directional current flow is another essential feature of this system. The extra power that has been produced from the PV panels can be transmitted to the grid. On microgrid operation, control, and stability issues, many research publications have been published to date [17−32]. However, the dispersed generation is a very challenging task to implement and connected to the grid because a continuous change of frequency, voltage, control of active and reactive power, harmonic minimization etc. [28]. The proposed system can be worked as an individual powerhouse by this feature and connecting more of these will create a micro-grid. So, the power production from all the systems can be shared, which is one of the most advanced features of current times. The model has been implemented using MATLAB/Simulink to predict and verify whether the design is attainable and viable or not.

The remaining parts are organized in the following manner. Literature review is in section 2. Section 3 covers the methodology. Results have been discussed in section 4. Section 5 illustrated the discussion on the results. The paper is concluded in section 6.

2.Literature review

Till now many research models have been implemented on this topic. Samanta et al. has done a very similar work of designing a prototype of an IoT based power monitoring system [2]. However, instead of connecting with the national utility grid they have implemented a standalone micro grid. But the project lacks any energy (kWh) meter to measure the energy. Ciobotaru et al. introduced a paper with the design of a grid connected solar PV system [13].

Their purpose was to develop a control system for a single-phase single-stage grid-connected inverter. A complete structure of a grid-connected PV system has been presented. However, there is no load, and no backup power is connected with this system. This model lacks any IoT-based power monitoring system for remote access. Atiq and Soori [31] represent a model with a bidirectional power flow. The objective of the project was to develop a grid-connected PV system of 10.44 KW capacity. The system makes use of the PV array, boost converter, maximum power point tracker (MPPT), etc. technologies. The system is of three-phase, and a boost converter is needed. For lower capabilities, usage of the boost converter isn't enough convenient. The system has no energy storage facility, and it claims with reference that the systems with no battery have higher efficiency. The system is connected to a 2.75 KW load. So, it is generating more power than it consumes. As a result, it can supply excess power generated to the utility grid and when PV output becomes low, power can be imported from the utility grid. However, the simulation results focus on how the change in solar irradiance affects power generation more than temperature change. The system also has no IoT-based power monitoring system or a data logging system. Billah et al. represents a design of a grid connected solar PV with an energy storage system [33]. The project shows a grid-tied controller that will integrate with a PV system and an instant power supply (IPS) module to ensure uninterrupted power supply to load and supply excess energy to the grid. If the PV system generates more power than needed, the excess power is supplied to the grid. A rectifier is also used here to charge the battery from the grid in order to charge it when the PV system is not available. The output shows the flow of power, i.e., whether power is flowing from PV to battery or PV to grid. Mention of power consumed by the load is not available as well. No data for varying load is available in the paper. This project is not IoT based. Outputs are available only through a liquid crystal display (LCD), and no remote monitoring is possible here. Pyo et al. developed a system that can adjust the real and reactive power injection at the connection point of a grid and an inverter [34]. Parallel operation of the PV system in the distribution system significantly impacts the flow of power and voltage conditions. They tried to make a system that will not affect the grid negatively. The mentioned problem only arises when a great number of grid-connected PV systems work in parallel. Thus, their focus was on voltage regulation in the system. The paper completely ignores the power measurement systems and lacks an IoT-based platform. Maizana et al. represents a design of smart grid systems which uses the electrical energy sources through National grid, solar system and batteries as a backup [35]. The purpose of that model is to examine the efficiency of a smart grid system by influencing alternative sources. But in the model, there isn't any function to supply the excessive energy on the grid and by-directional current flow. Also, there are no IoT or remote monitoring features which is one of the major parts of our project. Chinnathambi et al. has created a research model on IoT-based smart residential building energy management system for a grid-connected solar photovoltaic-powered DC residential building [36]. The model mainly focused to shift from conventional AC distribution system to DC distribution system. Most of the household appliance and equipment's runs on AC power supply. The model proposed a general change to convert all the equipment's runs on DC power supply. But the system is not easily applicable to current scenarios. Also, all types of machines can't run on DC supply like an induction oven, which need AC supply and very much costly. A grid connected solar system which can operate on conventional power system is more reliable and cost effective.

3.Research methodology

In this research work a model of a grid tied solar PV system with IoT based power monitoring features has been implemented, so that the user can monitor and measure how much power is generated from solar PV, power transferred to the grid and received from the grid. Also, the user can approximate the usage of electricity for that measurement. Related theories and existing models were studied to complete the project and then potential specifications were selected as per the objective. After the design had been completed, the circuit was simulated using Matlab/Simulink 2020a to observe possible outcomes accordingly with the specifications. Lastly, the data was taken using Matlab/Simulink and ThingSpeak IoT server. *Figure 1* shows the block diagram of the main structure of the simulated model along with the design:

Figure 2 represents the full design for the modeled system of this project. A single stage single phase grid connected solar PV system has been designed for this project. The model includes necessary components like PV array, grid tied inverter, MPPT controller, phase locked loop (PLL), load, charge controller, battery, IoT based monitoring systems, etc.

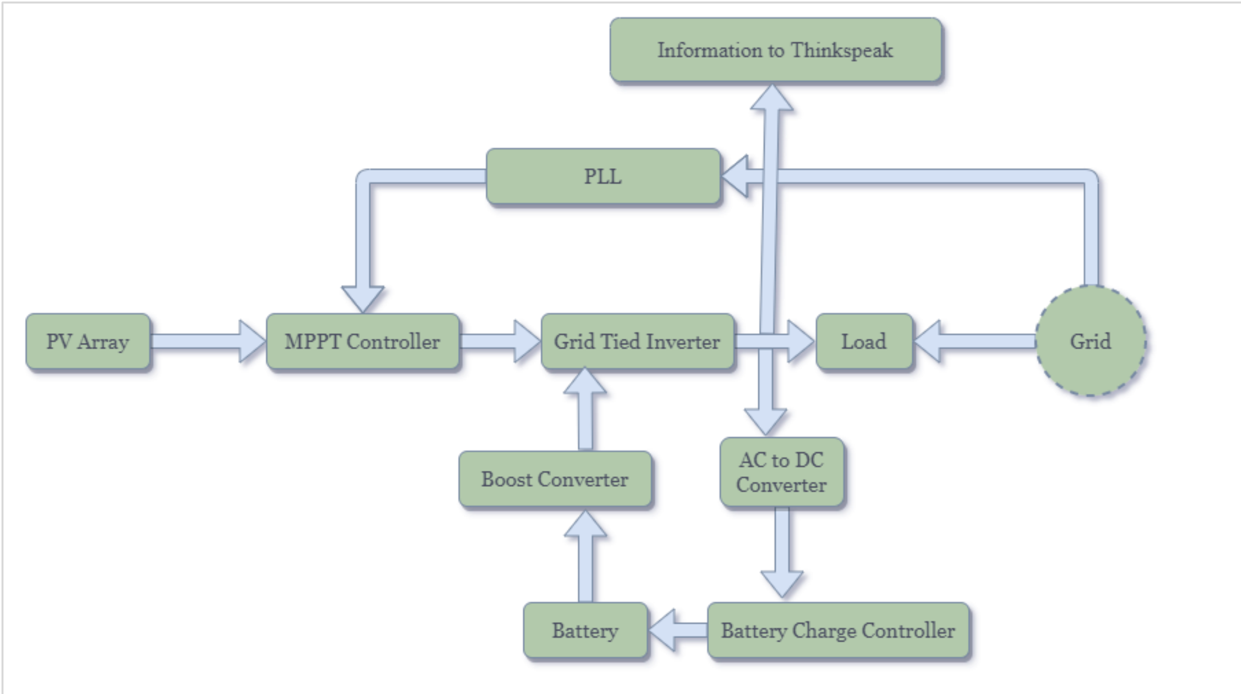


Figure 1 Schematic of system model

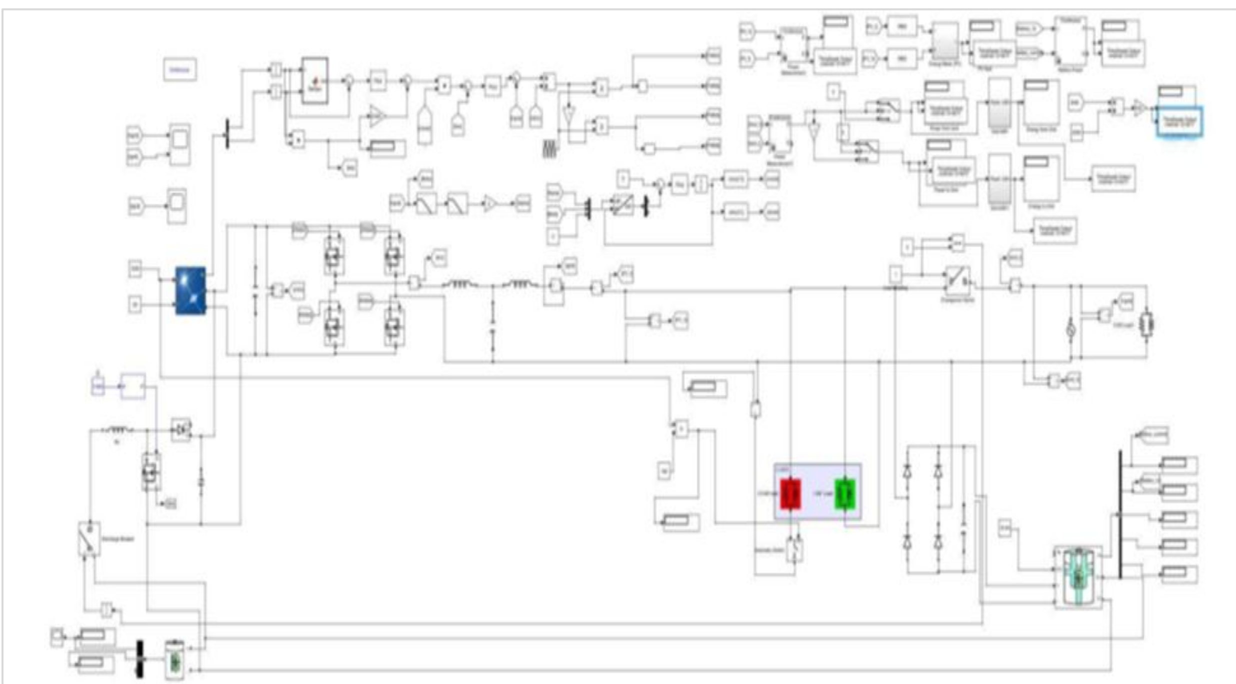


Figure 2 Implemented Simulink model of the system

3.1 System description

In this project, a 2091-watt grid-connected PV system with an energy storage system with an IoT-based power monitoring system is designed and implemented using MATLAB Simulink. The system frequency is set to 50 Hz, switching frequency of MOSFETS is set to 10 kHz, the output voltage is set to 230V RMS.

3.1.1PV Array

PV arrays produce DC power from the sun's rays. For designing a single-stage grid-tied system, the open-circuit voltage of the PV arrays must be greater or equal to the peak voltage of the grid. A total of 12 arrays (11 in series & 1 in parallel) has been used for this project. The peak capacity of each PV panel is 190 watts, and the open-circuit voltage of each array is 4.86 V. The peak capacity of the panels is 2.091 kW. The open-circuit voltage of the array is 493.5V, and the knee voltage is 415 V. The open-circuit voltage of the array is 493.5V. *Figure 3* explains these parameters through current-voltage (I-V) & power-voltage (P-V) curves of the used PV array. For PV arrays, Zytech Engineering Technology ZT190s model has been selected from the Simulink library. The grid voltage is 230V RMS, and the peak voltage is 325V. The frequency of the signal is 50Hz. The grid voltage is 230V RMS, and the peak voltage is 325V. The frequency of the signal is 50Hz. *Figure 3* explains the current-voltage & power-voltage curves of the used PV array.

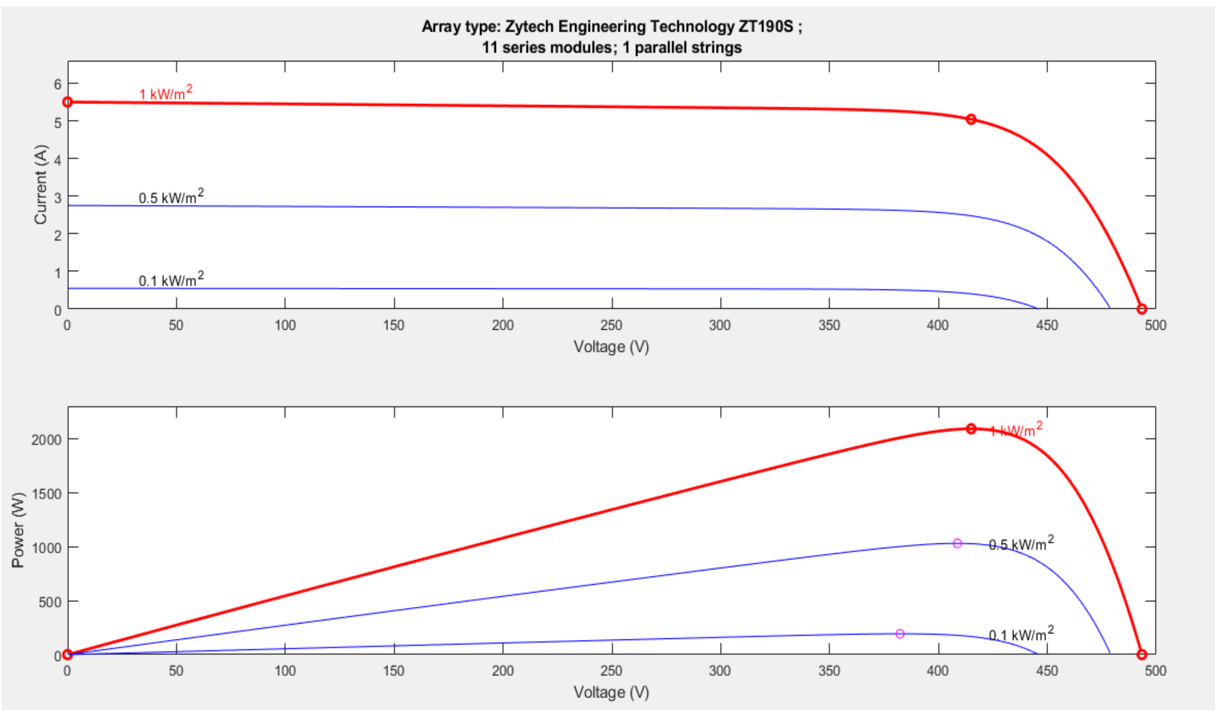


Figure 3 I-V & P-V characteristics of the PV array found in Simulink

3.1.2Phase lock loop

The PLL acts as the current controller in this project. To send active current to the grid, the inverter current must be in phase with the grid voltage. To generate this current, a reference is generated using the PLL. Here, the PLL uses the D-Q transformation theory to generate a reference signal that is in phase with the grid voltage. The PLL gives a unity power factor which helps the inverter output current (Ig) to be synchronized with the grid [13]. The input of the PLL is the grid voltage signal. The input signal is named Beta. The input signal is passed through two low pass filters and multiplied with 2 to make a 90-degree phase shift. The output is the alpha signal. Next, alpha-beta to D-Q transformation is applied, and the output is fed into a sum block to calculate the error. The error term is fed into the PI controller. The result is integrated, and a loop is created to feed the □ t port of the alpha-beta transformation block. The output is passed through the MATLAB fcn block, and Cos□ t & Sin□ t is generated. Cos□ t is used when active power is pushed to the grid, and Sin□ t is used when reactive power is pushed to the grid. The following *Figure 4* explains the working structure of the implemented PLL.

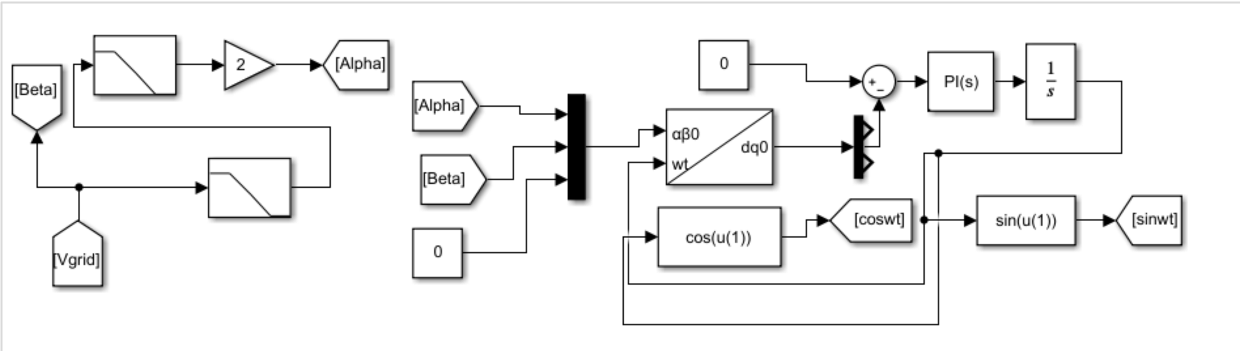


Figure 4 Structure of PLL designed in Simulink

3.1.3Maximum power point tracking

Maximum power point tracking (MPPT) is not a physical device, but a code embedded in the system. MPPT makes the PV array to operate in the maximum power region. System efficiency increases due to the implementation of MPPT. For this project, P&O algorithm based MPPT is implemented. MATLAB function is used to write & implement the MPPT code. An incremental conductance algorithm for MPPT has a slightly better performance compared to the P&O but P&O algorithm is used for its less complexity [13]. *Figure 5* explains the flow diagram of P&O algorithm used for this project.

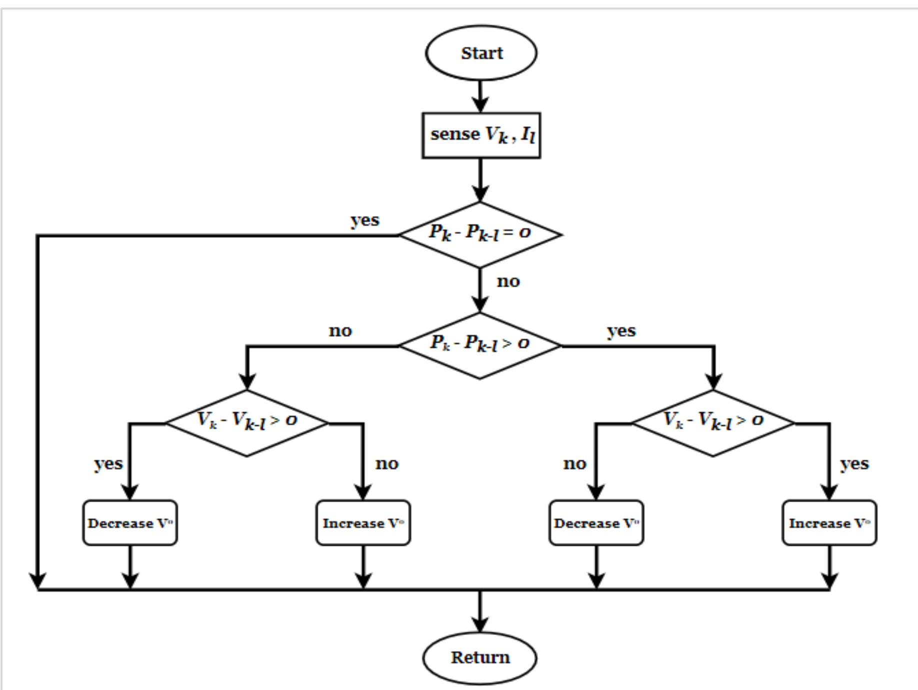


Figure 5 P&O algorithm flowchart [13]

3.1.4Control structure

This block serves two purposes. The MPPT makes sure that the PV panels are operating in the maximum power point region, and the control structure generates the pulse width modulation (PWM) signals required for the inverter. For MPPT implementation P&O algorithm was used. For generating PWM, the unipolar PWM generation method is used [26]. In this method, the output is switched between 0 and the positive peak voltage of the grid during the positive half cycle and 0 to peak negative voltage during the negative half cycle. *Figure 6* describes the working blocks of the MPPT & control structure.

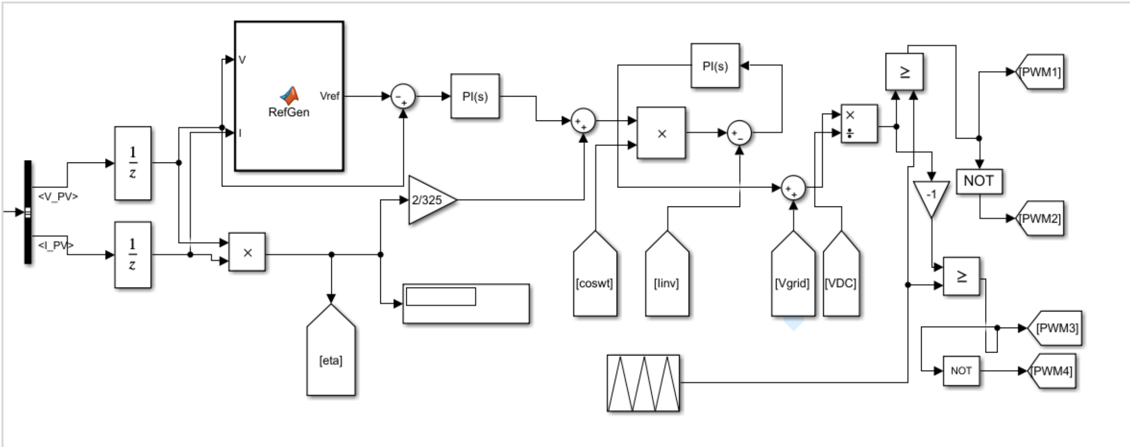


Figure 6 MPPT & Control structure designed in Simulink

The MPPT block senses the voltage & current generated by the PV array, and an output of this block is the reference voltage. The error is calculated using the sum block, and the error is supplied to a PI controller. The output of the voltage control PI controller is added with the input power control block. PI controller parameters are calculated using the Zeigler Nichols method where PV power is multiplied by 2/325 to implement the input power control structure [13]. The output of the sum block is multiplied by the active current component output of the PLL. The output of the product block is fed to a sum block, and error is calculated for the inverter voltage. The reference signal is fed to the PI controller of current control, and at the output of the PI controller, the signal is added to the grid voltage. Next, the error is divided by the DC voltage. The output of this block is the reference signal for the PWM generation. The reference signal is compared with the carrier signal, and PWM signals are generated for the gate terminal of the inverter. For the current control loop, PI controller parameters are calculated using according to reference [29] where, Kp is the proportional gain and Ki is the integral gain (Equation 1 and 2).

$$Kp = L/Ts \quad (1)$$

$$Ki = Kp/Ti \quad (2)$$

3.1.5Inverter

A full-bridge inverter is implemented using MOSFETs. The gate terminal signal is generated at the output of the control structure. The inverter output frequency is 50 Hz & the switching frequency is 10kHz. The output voltage is 230V RMS. *Figure 7* depicts the structure of a MOSFET based full bridge inverter.

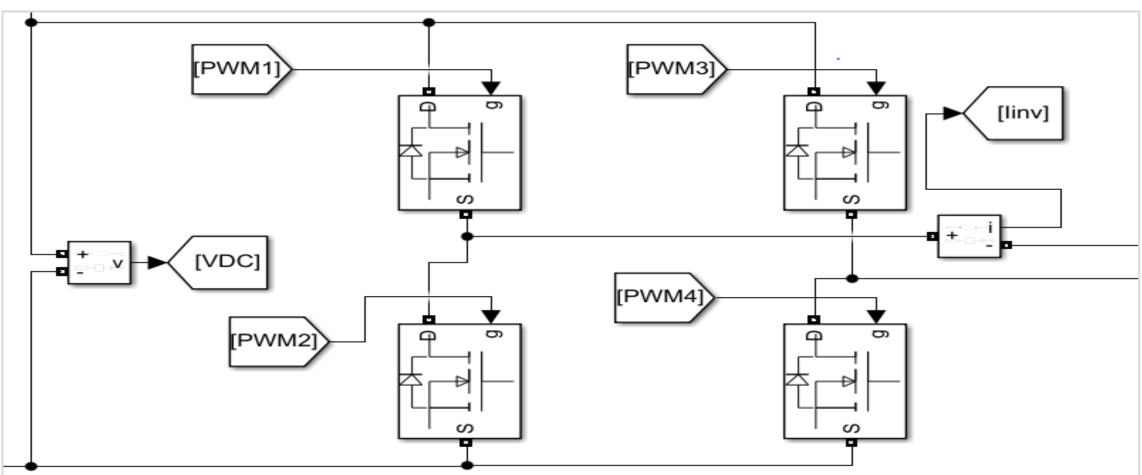


Figure 7 Full bridge inverter diagram designed in Simulink

3.1.6LCL Filter

The function of the less container load (LCL) type filter is to remove noise from the signal generated by the inverter. The capacitor of the LCL filter is designed based on the amount of reactive power (Q) it absorbs. Q absorbed by the capacitor is limited to 5% of the rated apparent power (S). The value of the inverter side inductor is selected based on the maximum permissible current ripple. The current ripple should be limited to 20% of the rated current. The total inductance is selected based on the maximum voltage drop across the inductor. The maximum voltage drop is limited to 10% of the rated voltage according to research shown in [32]. The filter parameters are calculated using the following formula (Equation 3, 4 and 5):

Capacitor, Q=V2/(1/2*pi*f*C) (3)

Inverter side inductor, L_1= $V_{DC}/4*F_{sw}*dI_{ppmax}$ (4)

Grid side inductor, L_2= 0.1*V2/S*2*Pi*f.-L_1 (5)

3.1.7Grid

AC voltage source is used as the grid in this project. The voltage of the source is 230V RMS & the peak voltage is 325V. The frequency is set to 50 Hz.

3.1.8Load

Two RL load is connected with the system. Loads are selected from the Simulink library. The total load is 1.5Kw & they are divided into 0.5 & 1 Kw. 1 kW is the constant baseload, and the 0.5 kW load is considered as a nonessential load. The non-essential load is disconnected automatically if irradiance drops below 250 W/m2 using a logic circuit. The battery is also being considered as a load. The battery consumes around 275-280 W of power.

3.1.9Battery

An 8.5 Ah lithium-ion battery is used to store the excess energy generated by the system, and it can supply backup power to the loads when power from the grid is unavailable. *Figure 8* depicts the setup of battery and connected displays used in this project.

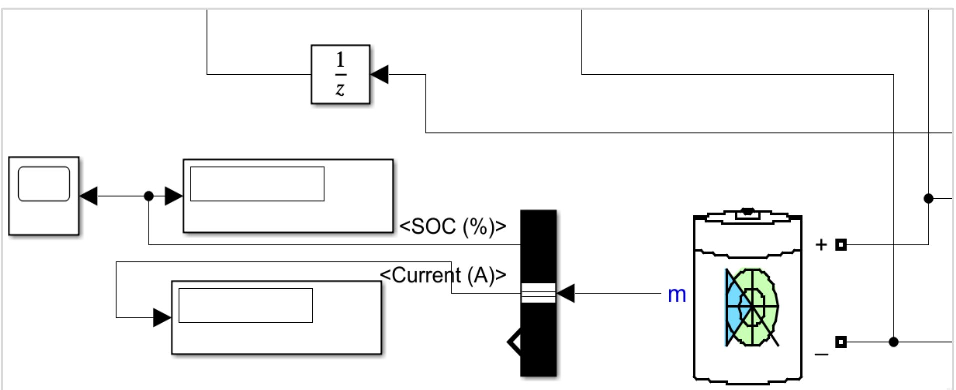


Figure 8 Battery structure designed in Simulink

3.1.10Battery charging

The constant current method is used for charging the battery. A constant current, constant voltage (CCCV) battery charger block is used to charge the battery. A rectified DC power is supplied to the CCCV block. A full bridge rectifier is used to convert the AC power into DC power. The battery is charged at 27V with a constant current of 10.44A. The output power of the charge controller is set to 275-280W. As sample time is set to 1 micro-second, it takes some time to saturate the power supplied to the battery. *Figure 9* shows the designed rectifier-based battery charging circuit used in this project.

3.1.11Battery discharging

A network of switches and a boost converter is used to discharge the battery. Discharging is done through a 24V-500V DC boost converter. The switching frequency of the boost converter is set to 25kHz. *Figure 10* shows the design of the battery and boost converter circuit used as the discharge circuit. According to research [30], boost converter parameters are calculated using (Equation 6,7 and 8):

Duty ratio, D= 1-V_s/V_O (6)

Inductance, L_{min}=$D(1-D)^2R/2F_{sw}$ (7)

Capacitance, C= D/ R*(dV_o/V_o) *F_{sw} (8)

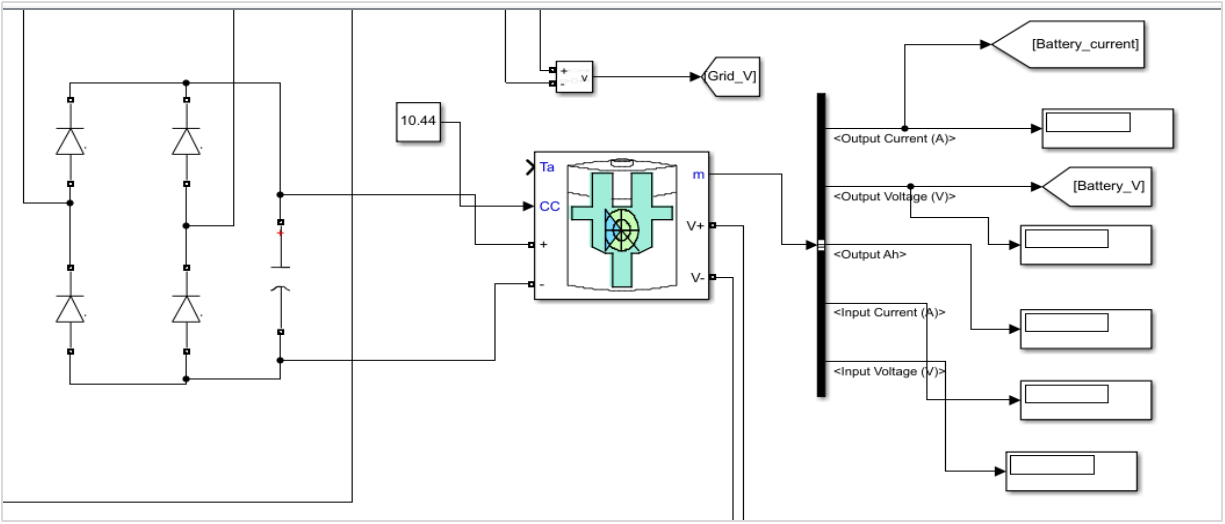


Figure 9 Battery charging circuit designed in Simulink

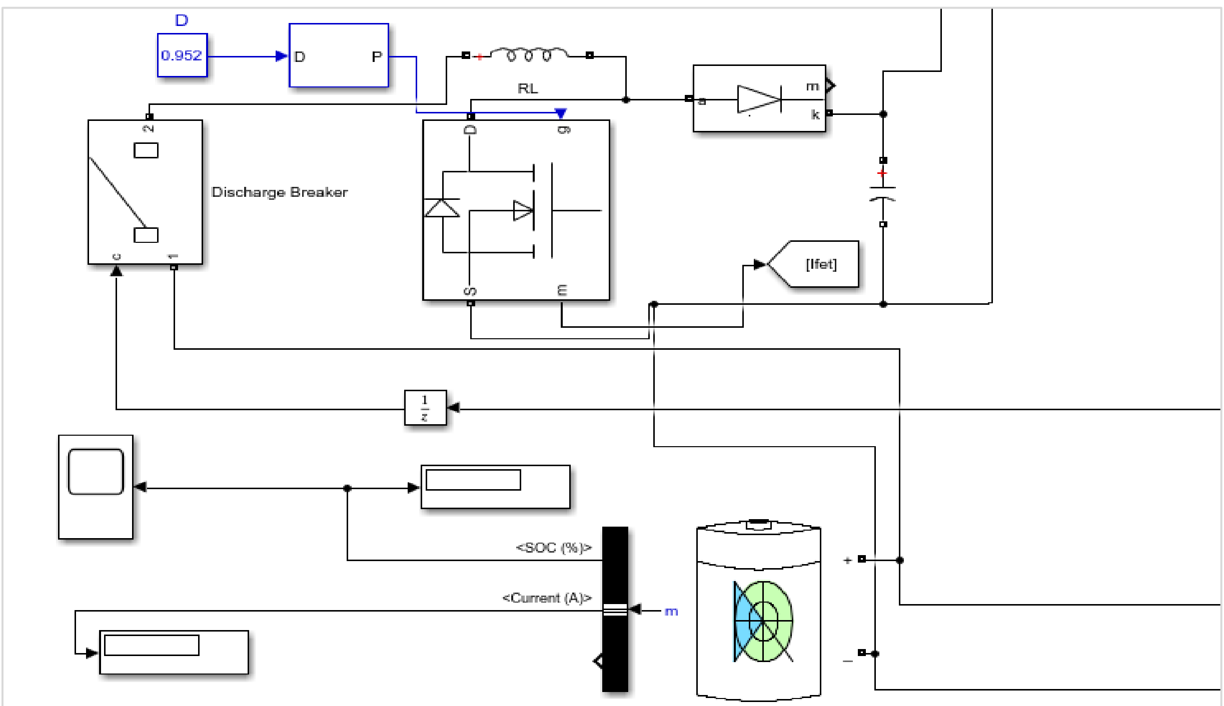


Figure 10 Boost converter circuit as discharge control designed in Simulink

3.1.12Switching

Total three switches are implemented in this project. The changeover switch is implemented to disconnect the PV system from the grid. When the PV system is disconnected from the grid, the system acts as a standalone system and takes power supply from the battery. The battery discharge switch is connected to a logic circuit. The switch is normally open. Whenever the changeover switch is opened, the battery discharge switch is closed, thus allowing the battery to be discharged. The switch with the load is connected to another logic circuit. Whenever the irradiance drops below 250 W/m2 the switch is opened.

3.1.13 Measurement & IoT

Voltage sensors, current sensors, and power measurement blocks are used to measure the power. The power measurement block calculates the power if the voltage and current are given input. The power factor is calculated automatically by the block. For grid power flow calculation, routing is designed using "as if" block. Whenever the value drops below zero, the data is diverted to another display and multiplied by -1. Thus, we can measure power & energy to and from the grid separately. PV efficiency is measured by dividing the DC power output by the rated capacity. All the outputs are connected to a ThingSpeak output block. Firstly, the Thingspeak channel was created, fields were added and then the block is connected with measured outcomes. This block transmits the data from Simulink to a cloud server. *Figure 11* shows the blocks that were used to monitor and collect data for the project.

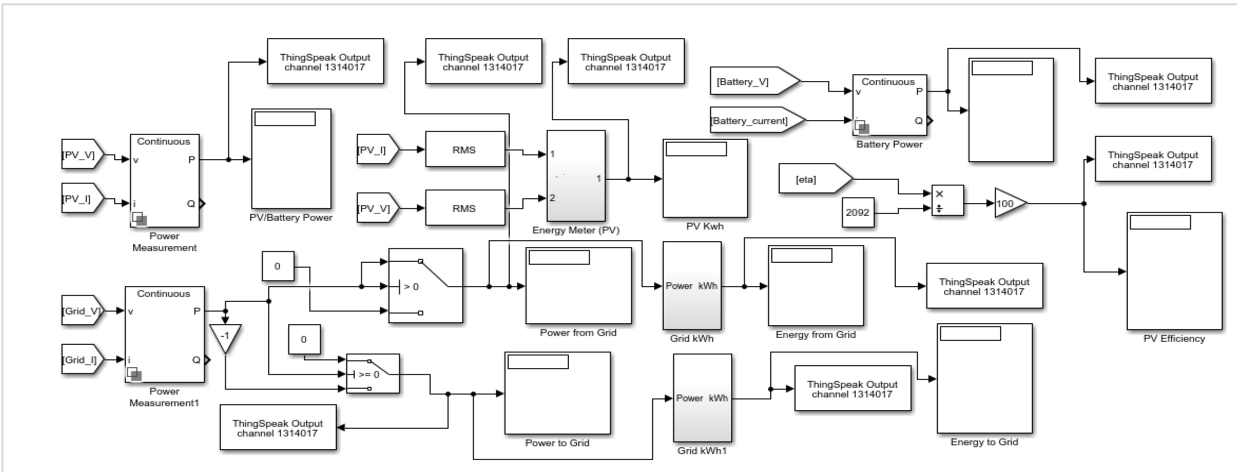


Figure 11 Measurement & monitoring blocks designed in Simulink

3.1.14Energy meter

The energy meter is not a default block of Simulink. The subsystem is created to measure the energy in kWh. The meter can hold its value throughout the simulation runtime if the reading is not changed. The meter gives output based on the frequency [21]. *Figure 12* contains the blocks that we used to implement the energy meter subsystem.

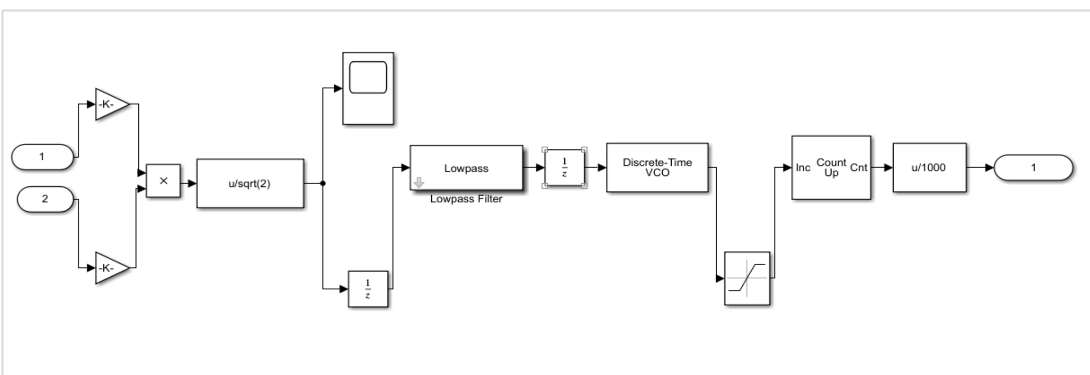


Figure 12 Energy meter subsystem designed in Simulink

4.Results

The simulation was run for 6 seconds in Simulink with a step size of 1 microsecond. As the step size was very small, it took approximately 32 minutes to take data of 6 seconds in Simulink. Thus, ThingSpeak recorded data for approximately 32 minutes. The designed grid-connected system was tested by varying the irradiance. The temperature was kept constant throughout the simulation runtime. The results were taken from the ThingSpeak server. A load shading scenario is provided to test the battery at the end of the simulation by cutting off the PV system from the grid and running the system as a standalone system with batteries.

Figure 13 confirms that the inverter is synchronized with the grid. The top graph represents the grid voltage Vg, and the bottom graph represents the grid current Ig (output waveform of inverter current). The two graphs are completely in phase, confirming that the inverter is synchronized with the grid and sending active power to the grid.

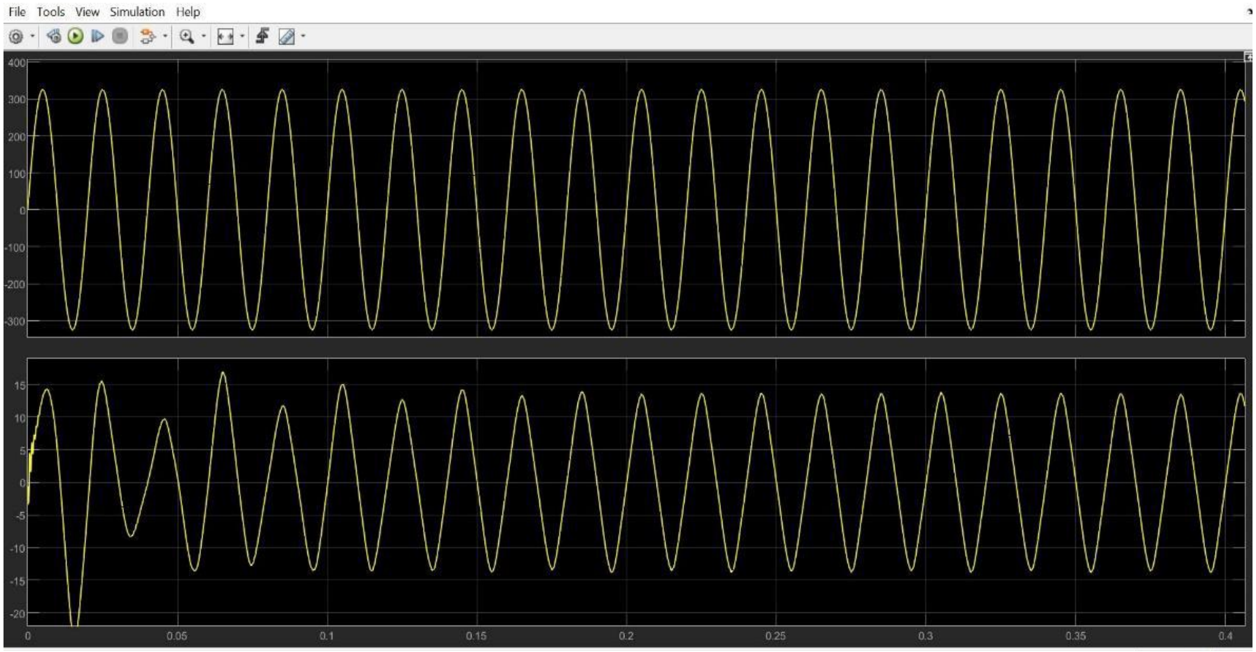


Figure 13 Verification of grid synchronization found in the model simulation

Figure 14 shows the change of SOC of the battery throughout the simulation period. The initial state of charge of the battery was set to 45%. As the simulation started, the state of charge begins to rise and reaches 45.12% at t=5 sec. As load shading was applied at t=5 sec, the battery begins to discharge and drops to 44.575% by the end of the simulation. This indicates that the battery charging & discharging system is working correctly. Obtained IoT results from ThingSpeak server are shown from *Figure 15 to Figure 17*.

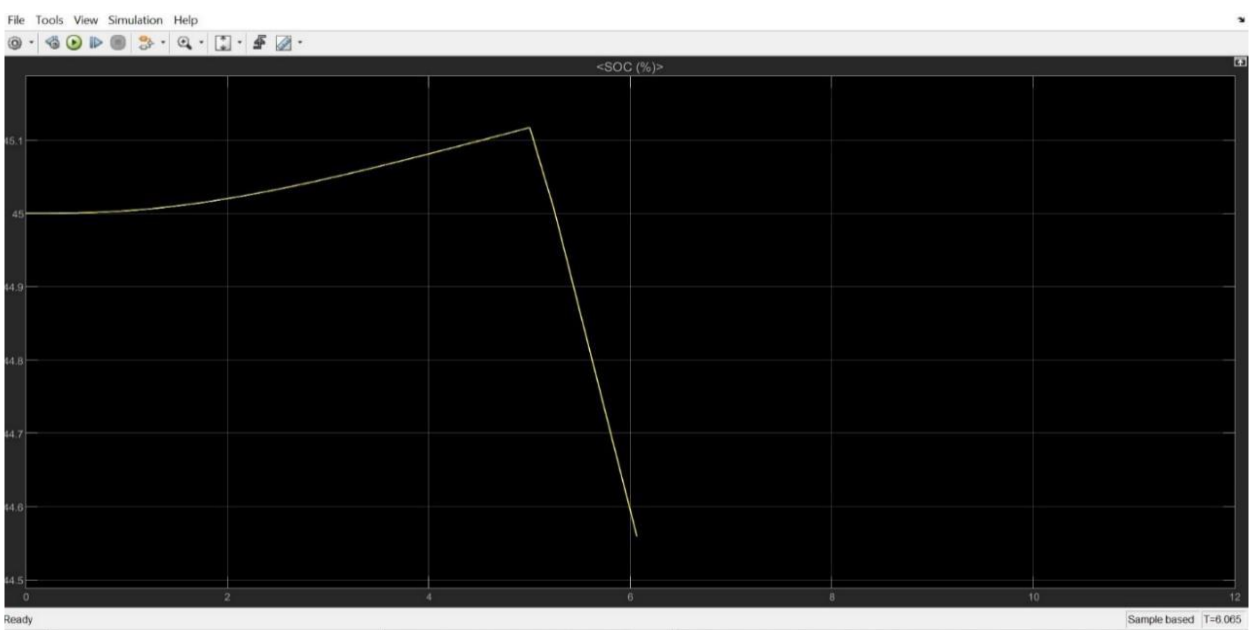
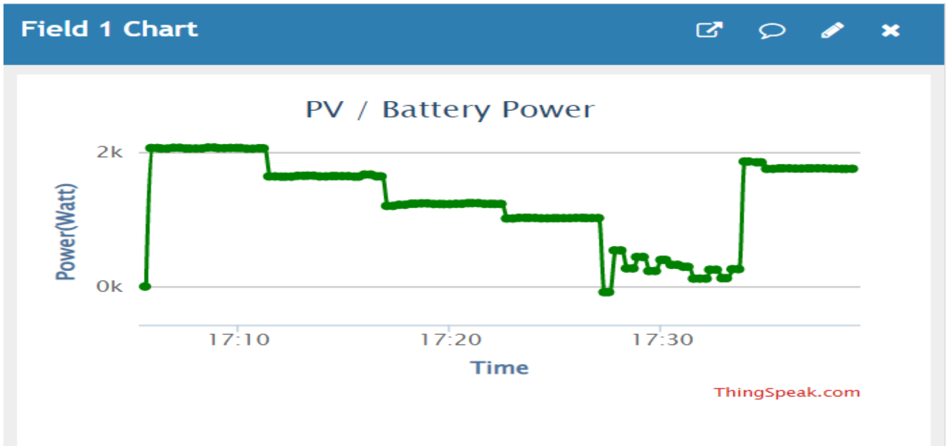


Figure 14 Change of Battery SOC during the model simulation



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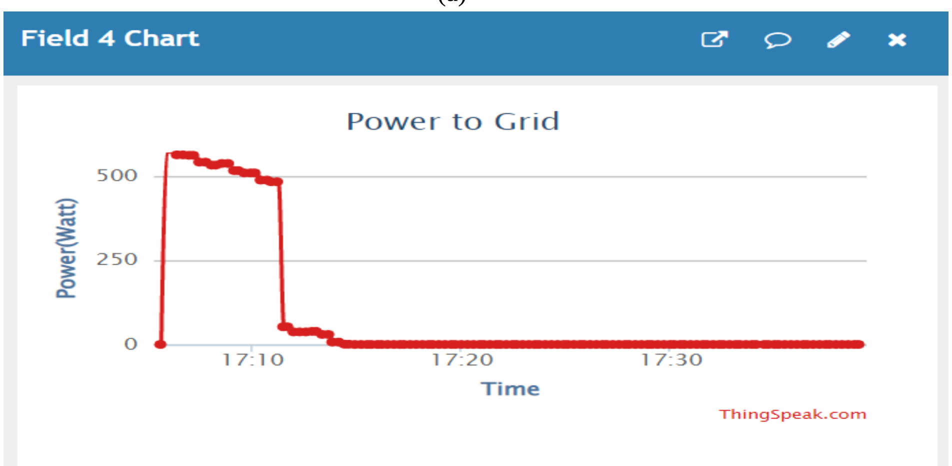

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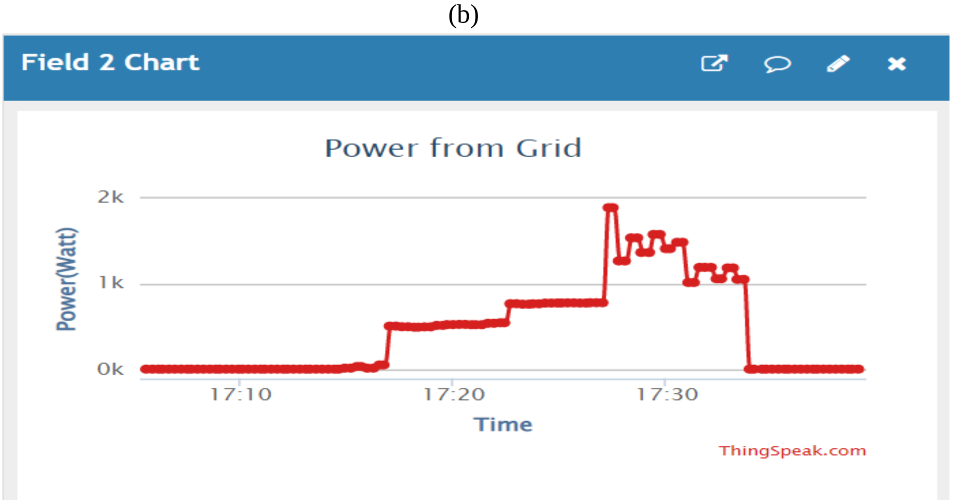
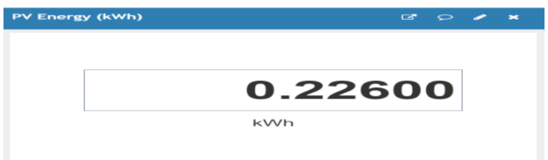


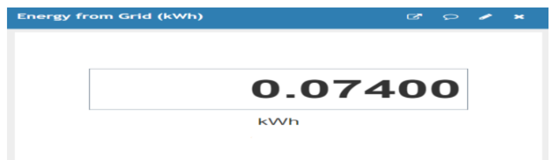
(c)

Figure 15 Generated Power from PV array and Battery (a), amount of power supplied to the grid (b) and imported power from the grid (c)

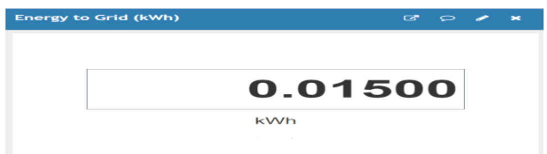
The irradiance is varied from 1000 W/m^2 to 100 W/m^2 gradually. As the irradiance decreases, the output from the PV array also decreases. At I=100 W/m^2 a load shading is applied. As the system becomes disconnected from the grid, the battery is connected with the inverter, and the battery supplies the power to the load. As the battery begins to supply power to the grid, the output of the system increase, and the inverter starts to work as a standalone system. When irradiance is high, over 560 watts of power is supplied to the grid. As the irradiance drops gradually, the amount of power supplied to the grid also decreases gradually. From I=400 W/m^2 the loads start to import power from the grid. Thus, the meter becomes zero and remains in this condition for the rest of the time. As simulation starts with the irradiance of 1000 W/m^2, the PV system generates enough power to supply the load and supplies excess power to the grid. Thus, the initial value of this field is zero as the irradiance decreases gradually, power generated by the PV arrays decreases and the amount of power imported from the grid increases accordingly. When irradiance drops below 250 W/m^2 the non-essential load is disconnected automatically, and the power consumption from the grid decreases. When irradiance becomes too low a ripple is seen during that time. As irradiance drops to 100 W/m^2 a load shading is applied. The system is disconnected from the grid, and power consumption from the grid becomes zero.



(a)



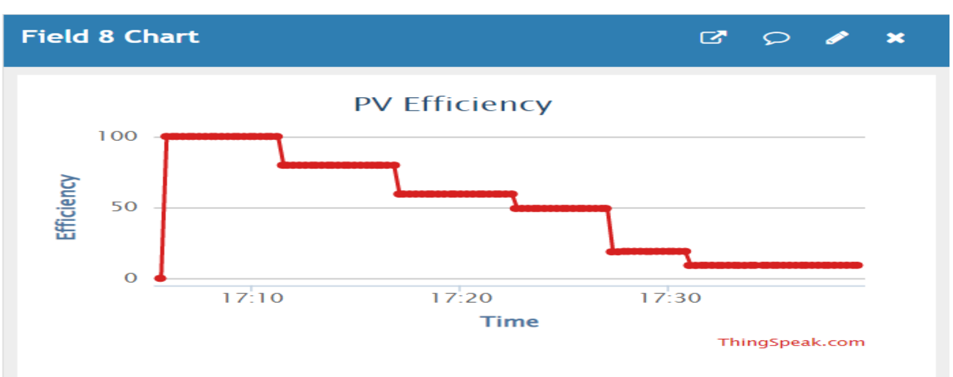
(b)



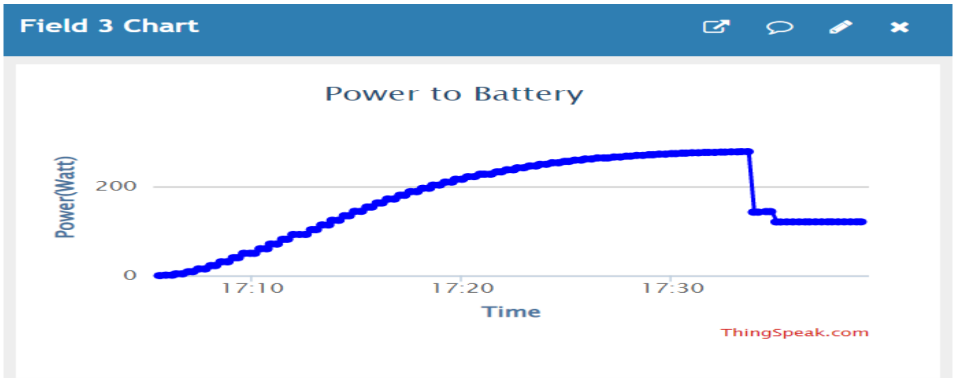
(c)

Figure 16 Energy generated from PV system (a), imported energy amount (b) and exported energy amount to grid (c)

Energy generated by the PV system during its 6 seconds run time. The block updates every 15 seconds, and the final reading after the completion of the simulation is 0.226 kWh. As irradiance is high at the beginning of the simulation, no energy is being imported to the load. As the irradiance begins to drop, energy import from the grid starts and gradually increases. When a load shading given at the end of the simulation, the energy meter stops and hold its value. The final value of the energy imported from the grid is 0.07400 kWh. As energy is high in the initial stage of the simulation, surplus energy is exported to the grid. As the irradiance drops below a certain value, the energy export to the grid stops and the meter hold its value. The final reading from the meter is 0.015 kWh.



(a)



(b)

Figure 17 PV efficiency (Output/Capacity) (a), Power supplied to battery (b)

As at the beginning of the simulation, the irradiance was high, the efficiency of the PV array was high, as irradiance drops gradually, the efficiency of the PV array drops as well. At the end of the simulation, load shading is applied. At that time, the PV power meter shows a higher value due to the discharge of the battery, but the efficiency meter remains low as the DC output of the PV array remains low. The battery must be charged in a controlled way; the battery does not consume its rated power right at the beginning. The power supplied to the battery is increased gradually and saturates to around 275 watts. It takes approximately 5 seconds (while step size is 1 microsecond) to reach the saturation point. The power consumption of the battery drops as the load shading is applied, but the charging of the battery cannot be completely shut down due to software limitations.

4.1Summary of the results

Figure 18 represents the summary of the results that were collected from the ThingSpeak server. The x-axis represents the irradiance scenario, and the y axis represents the power generated, imported & exported. As at the beginning of the simulation, irradiance was high, power generated from the PV array was high also. Thus, power imported from the grid is zero in this stage, and extra power is exported to the grid. As with time irradiance decreases, power generated from the PV array also decreases and power imported from the grid increases over time. At the end of the simulation, the PV system is cut off from the grid to simulate a grid failure scenario. During this time, the PV system acts as a standalone system, and all the power generated from PV and battery is supplied to the load, and no power is imported or exported from the grid.

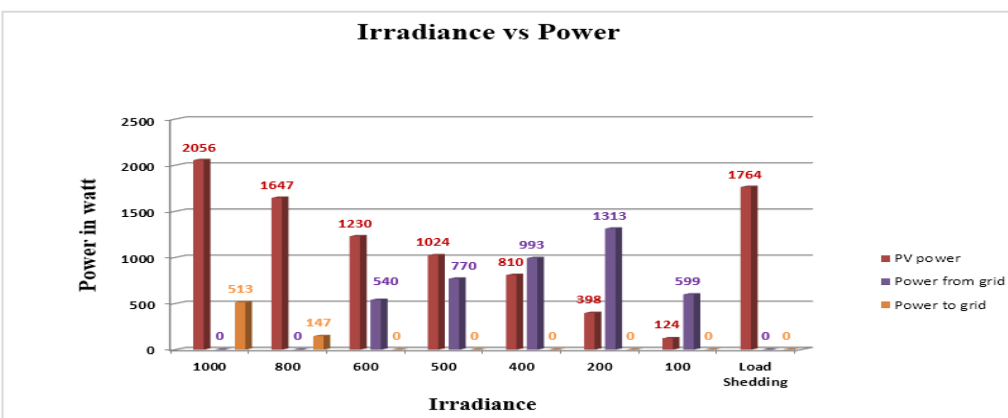


Figure 18 Graphical view of results

4.2Feasibility of the implementation of the model

Currently the model contains only the simulation method & results to observe is it possible to make or not. For this reason, Only the simulation-based part was discussed on this paper. But a prototype can be implemented using below components mentioned in *Table 1* to see the actual feasibility analysis based on different environment and situation:

Table 1 Equipment's price

SL	Item	Unit Price (USD)	Quantity	Total Price (USD)
1	Solar Panel (190 Watt)	253.53	12	3042.38
2	Grid Tied Inverter	370.00	1	370.00
3	Current Sensor	2.56	3	7.69
4	Voltage Sensor	5.38	1	5.38
5	Solar Charge Controller	19.01	1	19.01
6	Battery (50 Ah)	52.66	1	52.66
7	Boost Converter	55.63	1	55.63
8	ESP32 (Microcontroller)	8.89	1	8.89
9	Arduino Mega Microcontroller	11.59	1	11.59
10	Relay (As switch)	1.46	3	4.39
			Grand Total	3577.61

Microcontrollers are needed to measure & monitor the collected data. Current transformer (CT) & voltage transformer (PT) have to be connected to Arduino Mega and necessary codes regarding power and energy measurement has to be uploaded to the microcontroller to implement the measurement system. IoT based monitoring will become possible using serial communication between Arduino and Node micro controller unit (MCU).

4.2.1Advantages

Through this project, a user will be able to monitor the total consumption of power separately from the renewable system and conventional grid system. This will help a user to calculate how much power they can save if they install or expand a grid-connected solar PV system. This may encourage people to install grid-connected solar systems in mass. Thus, increasing power generation from renewable energy sources and decreasing a nation's carbon footprint. The proposed energy meter (kWh) section will enable user to double check the electricity bill provided by the utility company thus, forcing the utility company to be more transparent about their billing policy. If this data can be stored at a public server, the data can be accessed & acquired easily by government organizations statistics bureau in order to make easy assumptions about the power sector scenario of the country. If the data can be accessed by the manufacturers of PV panels & other components, they will be able to evaluate the performance of their components in long run.

5. Discussion

In this paper, a simulation of an IoT-based power monitoring system for a grid-connected solar PV system with an energy storage system is developed. The system works in combination with the utility grid and the solar plant, has a peak capacity of 2.091 kW. A lithium-ion battery-based energy storage system has been added to this project to supply power during grid failure or load-shading. For the collection of data, scenarios of high irradiance, low irradiance & load shading are considered. IoT-based monitoring of various parameters has been implemented through the "ThingSpeak Read" block of Matlab/Simulink. A Matlab/Simulink simulation study has been done to complete the whole process. The experimental result demonstrates that the design is working and viable. The results show that the simulation system can measure and monitor the power consumed from the PV array, battery, and grid, the export of extra power to the grid, change of power generated with respect to the change in irradiance, scenarios of power failure from the grid side with the help of IoT. It has also been observed that during the grid outage scenario, the backup power scheme works as expected and can meet the peak power demand. This feature ensures energy security for developing countries where load shading is a widespread occurrence.

5.1Limitations

The designed model uses a single stage topology for the grid tied inverter. Although the topology has higher efficiency than of a double stage design, the initial cost is slightly higher for small scale projects. Thus, higher initial cost and long return time on investment might not attract all kinds of investors. A complete list of abbreviations is shown in *Appendix I*.

6. Conclusion and future work

The IoT-based real-time monitoring system is done to ensure the capability and remote access of a system. Thus, the proposed IoT based power monitoring scheme and the backup power storage solution presented in this paper are scalable and claim to be very useful for providing real-time power and energy consumption and supply monitoring, and the backup power supply scheme satisfies the uninterrupted power supply to the user under both on-grid and standalone scenarios. To remain relevant in the competitive market, constant improvement of any product is mandatory. For the IoT-based monitoring system, better graphics and a single line diagram can be implemented for the ease of understanding of the client. Currently, the project uses a free cloud server to store and monitor the data. This has a limited customization option and poses a cyber-security risk to the user. Thus, a customized server can be implemented to make the user experience safer and more user-friendly.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Md. Ikramul Islam Nuhin: Investigation, writing- original draft, writing–review & editing, conceptualization, analysis. **Md. Ahnaf Shariar:** Conceptualization, design, simulation, data collection. **Jafrin Monsur Khan:** Data representation, Interpretation of results. **Tanjum Naeem Kongkon:** Literature review, conceptualization, surveys. **Mohammad Hasan Imam:** Supervision, conceptualization, investigation on challenges.

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Appendix I

S. No.	Abbreviation	Definition
1	AC	Alternating Current
2	CCCV	Constant Current Constant Voltage
3	CT	Current Transformer
4	DC	Direct Current
5	IEA	International Energy Agency
6	IoT	Internet of Things
7	IPS	Instant Power Supply
8	IRENA	International Renewable Energy Agency
9	LCD	Liquid Crystal Display
10	LCL	Less Container Load
11	MCU	Node Micro Controller Unit
12	MPPT	Maximum Power Point Tracker
13	PLL	Phase Locked Loop
14	PT	Voltage Transformer
15	PV	Photovoltaics
16	PWM	Pulse Width Modulation