

Development of Solar Power Based Net-Metering System for Domestic Prosumers



A Thesis report presented to SONARGAON UNIVERSITY'S Department of Electrical & Electronics Engineering (EEE) in partial completion of the criteria for the Bachelor degree of Science in Electrical & Electronics Engineering.

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Candidates Declaration

It is declared hereby that this thesis paper or any part of this paper has not been submitted to anywhere else for the award of any degree.

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CERTIFICATION

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Also, thanks to our parents, friends and lab assistants who helped us and inspired us to do the best.

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ABSTRACT

With the increase of human population of the world and the rapid growth of the global economic, the demand of the energy resources especially electricity faced a tremendous increase. Countries across the globe are looking for some alternative sources of energy to cope up the depletion of fossil fuels. These alternative sources also help in minimizing the impact of climate change. Power generation through renewable sources like rooftop solar is considered as the best alternative. Solar has some drawbacks. Net-Metering is the solution for solving those drawbacks. Net metering is a policy by the virtue of which unconsumed energy is fed into the distribution network and is utilized by the nearby consumers, connected to the same distribution network. This paper, focuses on Grid connected solar photovoltaic electric system. The paper aims at modelling high performance Three Phase Single Stage Grid Connected Inverter and Bi-Directional energy meter. So as to achieve maximum output from the photovoltaic array, MPPT Tracking is connected. The conversion from DC output of photovoltaic array is done to AC so that it is fed into the grid, a IGBT based inverter is used which converts from DC to AC power and a Bi-Directional energy meter designed to measure the net energy. The Simulation model is developed in MATLAB Simulink and Proteus and the results are presented in the paper.

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Chapter1 INTRODUCTION

Electricity is an essential part of our modern life and important to the economy of Bangladesh. We use electricity for our day-to-day life. The sources of electricity of Bangladesh are- Coal, Hydro, Furnace Oil, Diesel, Natural Gas and Renewable energy (Solar & Wind). Coal based power plant is also responsible for our climate change world widely. The price of Furnace oil and Diesels are increasing day by day. For all of those reasons we have to look for some alternative sources of energy to cope up the depletion of thus problems. Solar energy is a blessing way to get energy naturally without any kind of risk like the impact of climate change. Hence, Bangladesh Govt. has set an ambitious goal of generating more than 4,100 MW of electricity from renewable energy sources by 2030 and Solar power will account for half of the energy, at 2,277 MW (According to SREDA). Now Bangladesh generating only 777.47 MW from renewable sources which representing about 3.52 per cent of the total electricity production. The government of Bangladesh has taken various initiatives to enhance generation of renewable energy as part of its efforts to ensure energy security keeping carbon dioxide emissions at a low level. The net metering system is a good initiative to promote the use of renewable energy. Here the "Net Metering" system or a policy mechanism that allows prosumers to export or import energy from grid. Net metering ensures the energy you generate at home doesn't go to waste. According to SEIA (Solar Energy Industries Association), Net metering allows residential and commercial customers who generate their own electricity from solar power to sell the electricity they aren't using back into the grid. For an emerging country like Bangladesh, it's a great way to minimize the demand of electricity for larger industries, Commercial users and also for the domestic users.

This paper focuses on the development net-metering system using solar power. Where the entire procedure of installing this modern technology using a grid-connected inverter and a bi-directional energy meter is described.

Chapter2 STATE OF ART OF NET- METERING

2.1 Innovation

Net metering originated in the United States, where small wind turbines and solar panels were connected to the electrical grid, and consumers wanted to be able to use the electricity generated at a different time or date from when it was generated. The first two projects to use net metering were an apartment complex and a solar test house in Massachusetts in 1979 when net metering was introduced for the first time in the US state of Massachusetts. Utilities in Idaho adopted net metering in 1980, and in Arizona in 1981. Massachusetts adopted net metering in 1982. By 1998, 22 states or utilities therein had adopted net metering. In 2005, all U.S. utilities were required to offer net metering "upon request". Excess generation is not addressed. As of 2013, 43 U.S. states have adopted net metering, as well as utilities in 3 of the remaining states, leaving only 4 states without any established procedures for implementing net metering. The first statewide net metering law was passed by the state of Minnesota in 1983. According to the National Conference of State Legislatures (NCSL) of the United States, as of October 2016, a total of 44 states, Washington DC and four other US territories have adopted net metering rules (Cleaveland and Durkay 2016). However, a 2017 study showed that only 3% of U.S. utilities offer full retail compensation for net metering with the remainder offering less than retail rates, having credit expire annually, or some form of indefinite rollover.

2.2 Worldwide Adoption

In present net metering system is being more popular for protect the world from global climate changes. Now US, Canada, Australia, Chania, Japan, India, Bangladesh and world-widely more than 66 countries using this system according to their own act. Net metering was slow to be adopted in Europe, especially in the United Kingdom, because of confusion over how to address the value added tax (VAT). Only one utility company in Great Britain

offers net metering. The United Kingdom government is reluctant to introduce the net metering principle because of complications in paying and refunding the value added tax that is payable on electricity, but pilot projects are underway in some areas.

2.2.1 Canada

2.2.1.1 Ontario

Ontario allows net metering for systems up to 500 kW, however credits can only be carried for 12 consecutive months. Should a consumer establish a credit where they generate more than they consume for 8 months and use up the credits in the 10th month, then the 12-month period begins again from the date that the next credit is shown on an invoice. Any unused credits remaining at the end of 12 consecutive months of a consumer being in a credit situation are cleared at the end of that billing.

2.2.1.2 British Columbia

Areas of British Columbia serviced by BC Hydro are allowed net metering for up to 100 kW. At each annual anniversary on March 1 the customer is paid a market price, calculated as daily average mid-Columbia price for a previous year. FortisBC which serves an area in South Central BC also allows net-metering for up to 50 kW. Customers are paid their existing retail rate for any net energy they produce. The City of New Westminster, which has its own electrical utility, also allows net metering.

2.2.1.3 New Brunswick

New Brunswick allows net metering for installations up to 100 kW. Credits from excess generated power can be carried over until March at which time any excess credits are lost.

2.2.1.4 SaskPower

SaskPower allows net metering for installations up to 100 kW. Credits from excess generated power can be carried over until the customer's annual anniversary date, at which time any excess credits are lost.

2.2.1.5 Nova Scotia

In Nova Scotia, in 2015, 43 residences and businesses began using solar panels for electricity. By 2017, the number was up to 133. These customers' solar systems are net metered. The excess power produced by the solar panels is bought back from the homeowner by Nova Scotia Power at the same rate that the utility sells it to its customers. "The downside for Nova Scotia Power is that it must maintain the capacity to produce electricity even when it is not sunny.

2.2.2 Australia

Australian smart grid technologist, Steve Hoy, originated the opposing concept of "True Zero", as opposed to "Net Zero", to express the emerging capability to trace electricity through net metering. The meter allows consumers to trace their electricity to the source, making clean energy more accessible to everyone.

In some Australian states, the "feed-in tariff" is actually net metering, except that it pays monthly for next generation at a higher rate than retail, with Environment Victoria Campaigns Director Mark Wakeham calling it a "fake feed-in tariff." A feed-in tariff requires a separate meter, and pays for all local generation at a preferential rate, while net metering requires only one meter. The financial differences are very substantial.

2.2.2.1 Victoria

In Victoria, from 2009, householders were paid 60 cents for every excess kilowatt hour of energy fed back into the state electricity grid. This was around three times the retail price for electricity at that time. However, subsequent state governments reduced the feed-in in several updates, until in 2016 the feed-in is as low as 5 cents per kilowatt hour.

2.2.2.2 Queensland

In Queensland starting in 2008, the Solar Bonus Scheme pays 44 cents for every excess kilowatt hour of energy fed back into the state electricity grid. This is around three times the current retail price for electricity. However, from 2012, the Queensland feed in tariff has been reduced to 6-10 cents per kilowatt hour depending on which electricity retailer the customer has signed up with.

2.2.3 Malaysia

A net metering scheme guideline came into effect in Malaysia since October 5, 2016. The guideline was approved by the Suruhanjaya Tenaga Energy Commission (STEC), with an aim to cover 500MW by the end of 2020. Consumers are divided into three tariff categories, namely, domestic/residential, commercial and industrial consumers. The Malaysian net metering guideline differentiates between installed capacity limit and net energy export limit. Domestic solar photovoltaic systems shall not exceed 12 KWp for single phase and 72 KWp for three-phase. For commercial consumers, the limit will be either 1 MWp or 75% of the maximum demand of the current installation, whereas for industrial consumers it's either 60% of the fuse rating or 60% of the current transformer rating. The net export limit should be within the range of 1 KWp to 1 MWp. STEC has guided to conduct a mandatory pre-study before approving the application, the cost of which should be paid by the consumer and it varies depending on the installed KWp. The credit is allowed to roll for a period of 24 months. In Malaysia, the consumers who supply net electricity to the grid are allowed to submit an invoice to the utility to claim Goods and Service Tax as well (Tenaga 2016).

2.2.4 Pakistan

Pakistan introduced net metering regulations in 2015 (the “National Electric Power Regulatory Authority Distributed Generation and Net Metering Regulations, 2015”) to promote power generation from distributed Renewable Energy (RE) systems. The growth in net-metering installations is however slow, with only 815 licenses issued by December 2018, adding 17.28 MW to the country’s installed power generation capacity. Considering Pakistan’s RE potential, especially from solar PV installations, the slow growth in net-metering is a missed opportunity for the country. In order to develop the net metering market in Pakistan and to accelerate the proliferation of distributed generation (DG) technologies, this report provides an assessment of the regulatory and market barriers that are limiting the effectiveness of Pakistan’s net metering program and recommends specific interventions to address these barriers.

2.3 Worldwide Net-Metering Installation Capacity

Installing capacity of net metering system is growing day by day world widely. Some country forcing their industries and Govt. institutions to set this system to cope up the depletion of thus problems and to save the world from climate changes. Here, (Table 1) shows the installed capacity of net metering in different countries with approximate date.

Table 1: Installed capacity of grid connected Net-Metering system in different countries

Installed capacity of Grid connected Net-Metering system		
Country	Installed Capacity	Approximate Date
China	48.2 GW	2021
India	24.4 GW	2021
Japan	11180.8 MW	2019
France	10072 MW	2020
Poland	7122 MW	2021
Spain	4,674 MW	2017
Canada	1553 MW	2021
Singapore	443.6 MW	2021
Sweden	398.47 MW	2020
UAE	298.7 MW	2021
Switzerland	241 MW	2017
Malaysia	108 MW	2020
Pakistan	56.86 MW	2021

Here, (Figure 1) shows the graph and the data where worldwide Net-Metering status was provided.

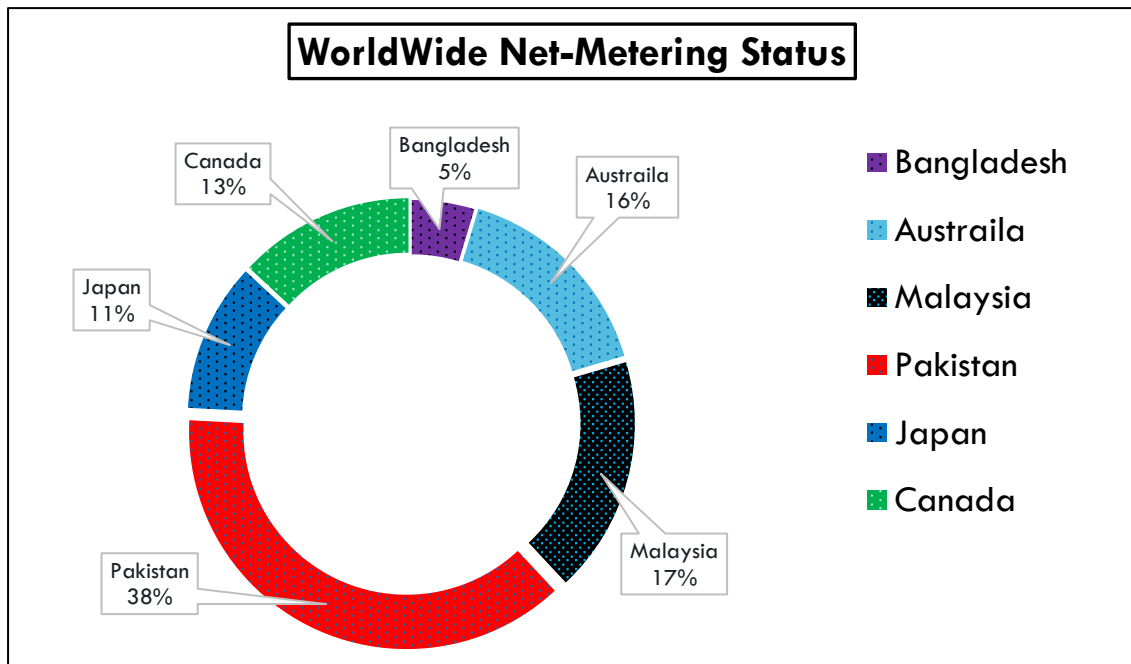


Figure 1: Worldwide Net-Metering Status

2.4 History of Net-Metering in Bangladesh

2.4.1 Innovation

The government has taken various initiatives to enhance generation of renewable energy as part of its efforts to ensure energy security keeping carbon dioxide emissions at a low level. The net metering system is a good initiative to promote the use of renewable energy.

In 26th February 2017, Japan International Cooperation Agency (JICA) has completed 360 KW Solar Net Metering project under Northern Electric Supply Company Ltd. (NESCO) at Adamdighi, Bogra, Rajshahi. It was the first net metering project in Bangladesh.

2.4.2 Launching Date

In July 2018, the Power Division of the MPEMR (Ministry of Power, Energy and Mineral

Resources) has launched the Net Metering Guidelines-2018 that aimed to incentivize installation of rooftop solar PV systems on a massive scale. The main idea behind net metering mechanism is that it allows consumers to become ‘prosumers’ by connecting their RE systems to the distribution grid via a bi-directional smart meter.

After launching “The Net Metering Guidelines-2018” Rajshahi University of Engineering & Technology, Rajshahi has completed 3KW SNMS project under (NESCO) in July and then the solar net metering system (SNMS) is gaining more popularity across the country as users, in addition to their own benefits, also enjoy rebates on total electricity bills.

2.4.3 Current Status

A total more than 1500 solar net metering system (SNMS) with the capacity of 34.34 megawatt (MW) of electricity have already been installed, and there is an upward trend. The SNMS enables surplus electricity produced from solar power to regulate and direct (surplus) electricity to the national grid. And to encourage the use of green energy in industries under which the industry owners can sell their surplus or unconsumed electricity to the grid and adjust their monthly bills.

2.5 Current Capacity of Renewable Energy and Net-Metering in Bangladesh

Analysis of the current status of all renewable energy and it’s capacity in Bangladesh is given in the table (Table 2) and (Figure 2) shows the flowchart of all renewable energies through a graph where Solar energy shares 543.48 MW which is 69% of total renewable energy in Bangladesh.

Table 2: Renewable energies in Bangladesh

Technology	Total (MWp)
Solar	543.48
Biogas to Electricity	0.69
Hydro	230
Wind	2.9
Biomass to Electricity	0.4
Total	777.47 MW

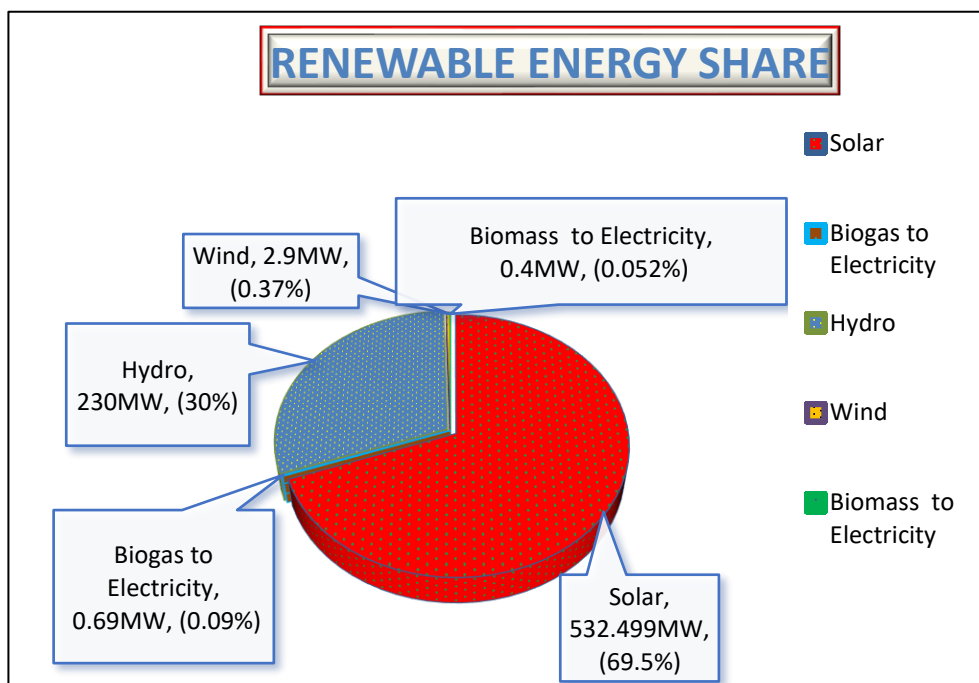


Figure 2: Renewable energies in Bangladesh

2.6 Share of Net-Metering in Bangladesh

Now Bangladesh producing more than 34.34 Mw electricity from Net-Metering system where total amount of solar energy share is 543.48 MW. Here, the table (Table 3) shows the data of net metering among solar energy.

Table 3: Net-Metering current status in Bangladesh

Technology	Total (MWp)
Solar	543.48
Solar Net metering	34.34

Here the figure (Figure 3) shows the flowchart of the sharing amount of electricity by Net-Metering which now generating from Solar energy.

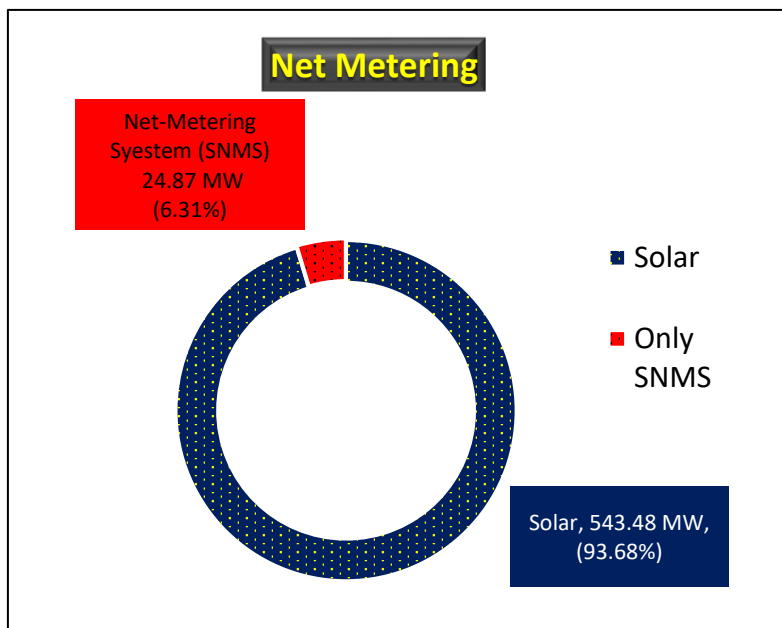


Figure 3: Net-Metering installed capacity in Bangladesh

Chapter3 METHODOLOGY

To set up a complete net-metering system, several rules and installation procedures must be followed step by step. To complete these procedures, we initially used a home load as an ideal load, which we computed using the steps listed in fig... The PV producing electricity by using sun power provide to the IGBT based inverter also tracking maximum power by MPPT (Maximum Power Point Tracker). The solar PV panels' DC power is not stored in batteries; instead, it is converted to AC power by an inverter, which is then connected to the grid immediately. When there is surplus power generation, it is fed into the grid, and when power is in short supply at the consumer end, it is drawn from the grid. The net metering system with grid connected inverter and bidirectional energy meter is depicted schematically in figure (Figure 4).

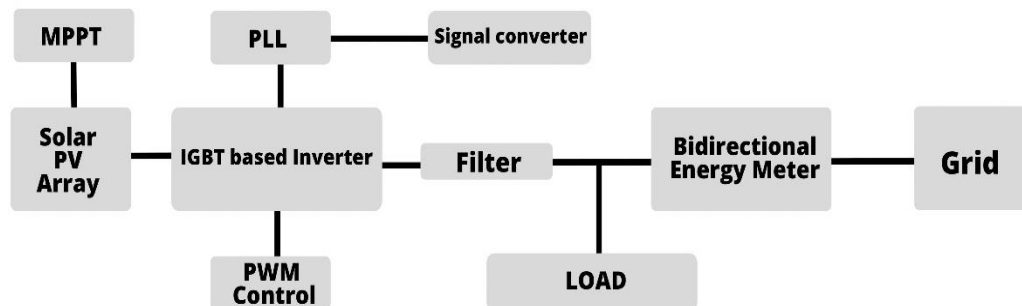


Figure 4: Block diagram of Net-Metering system with grid connected inverter

3.1 Load Calculation

Electrical Load calculation is very important because it determines how much money we are spending by using different types of appliances in a house. An on-grid power transmission system depends on the demand of prosumers. Prosumers can export 70% of electricity from their connected load. To calculate this demand, it's necessary to estimate the demand of the load. By using this information, an estimate provided below in table (Table 4).

Table 4: An ideal Domestic load calculation

Domestic Load Calculation														
APPLIANCE	POWER (WATT)	QUANTITY	0 to 2 am	2 to 4 am	4 to 6 am	6 to 8 am	8 to 10 am	10 to 12 pm	12 to 2 pm	2 to 4 pm	4 to 6 pm	6 to 8 pm	8 to 10 pm	10 to 12 pm
Ceiling Fan	80*4	4	640	640	0	640	640	640	640	640	640	640	640	640
Refrigerator	200*1	1	400	400	400	400	400	400	400	400	400	400	400	400
Desktop	200*1	1	0	0	0	0	400	0	0	0	400	0	400	0
LED TV	60*1	1	0	0	0	0	120	0	0	0	120	0	120	0
Electric Iron	1000*1	1	0	0	0	0	0	0	0	0	0	0	330	0
Laptop	100*1	1	0	0	0	0	200	0	0	0	0	0	200	200
Phone Charger	10*2	2	0	0	0	20	20	0	0	20	0	40	0	20
Light	30*8	8	0	0	0	0	0	0	0	0	0	480	480	480
Washing Machine	500*1	1	0	0	0	0	0	250	0	0	0	0	0	0
Water Pump	750*1	1	0	0	0	0	750	0	0	0	0	0	0	0
Load in W	3390		1040	1040	400	1060	2530	1290	1040	1060	1560	1560	2570	1740
Load in KWh	3.39		1.04	1.04	0.4	1.06	2.53	1.29	1.04	1.06	1.56	1.56	2.57	1.74
Total Load in KWh/Day						16.89								

Here, The total connected load = 3390W

Hence, Total load in kw = 3.39KW

And, Total load in kwh/day = 16.89

Maximum Demand = 2.57 KW/Hour

3.1.1 Load curve

Load curve or chronological curve is the graphical representation of load (in kW) in proper time sequence and the time in hours. It shows the variation of load on the power station. When the load curve is plotted for 24 hours a day, then it is called daily load curve. If the one year is considered then, it is called annual load curve. The load curve of the power system is not same all the day. It differs from day to day and season to season. The load curve is given below in table (Table 5). X represents time and Y represents the load in KW.

Table 5: Load Curve

Load Curve	
X	Y
12- 4 AM	1.04
4-6 AM	0.4
6-8 AM	1.06
8-10 AM	2.53
10-12 PM	1.29
12-2 PM	1.04
2-4 PM	1.06
4-8 PM	1.56
8-10 PM	2.57
10-12 AM	1.74

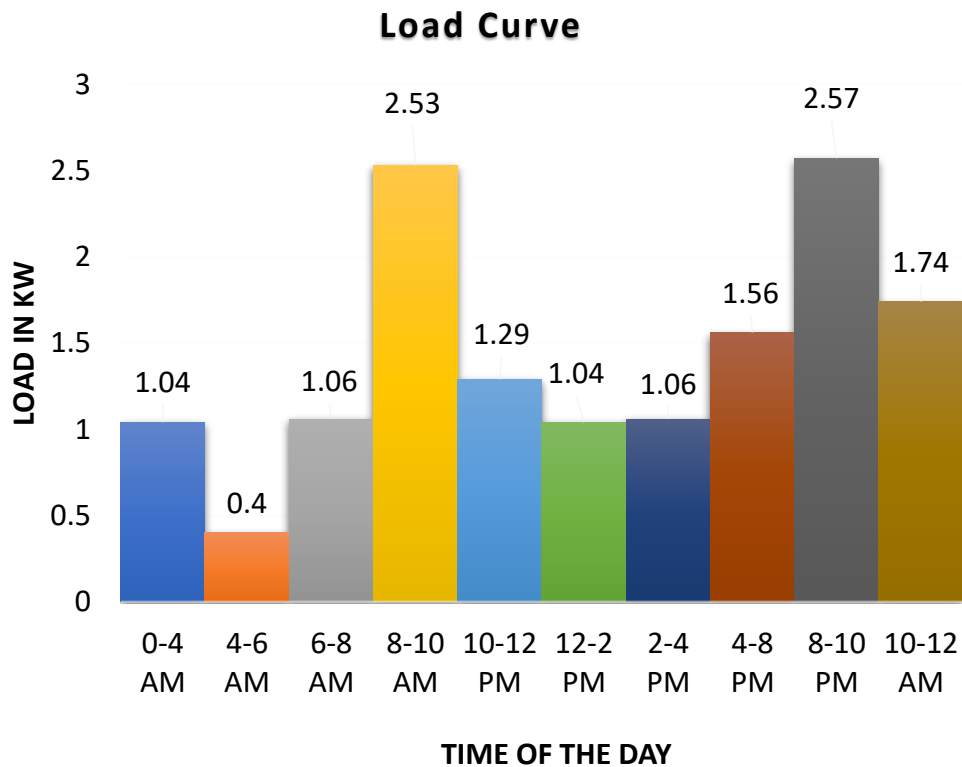


Figure 5: Load Curve

Here, figure (Figure 5) shows the load curve of the load with respect to time.

3.1.2 The Load Duration Curve

The load duration curve is defined as the curve between the load and time in which the ordinates representing the load, plotted in the order of decreasing magnitude with the greatest load at the left, lesser loads towards the rights and the lowest loads at the time extreme right. The load duration curve is shown in the figure below. This curve represents the same data as that of the load curve. The load duration curve is constructed by selecting the maximum peak points and connecting them by a curve. The load duration curve plotting for 24 hours of a day is called the daily load duration curve. Similarly, the load duration curve plotted for a year is called the annual load curve. In table (Table 6) load duration curve showed. Here, X represents the time duration and Y represent the load in KW.

Table 6: Load Duration Curve

Load Duration Curve	
X	Y
0-2	2.57
2-4	2.53
4-6	1.74
6-10	1.56
10-12	1.29
12-16	1.06
16-22	1.04
22-24	0.4

Here, from the fig (Figure 6) shows the maximum demand of total load is 2.57KW and minimum load demand is 0.4 KW.

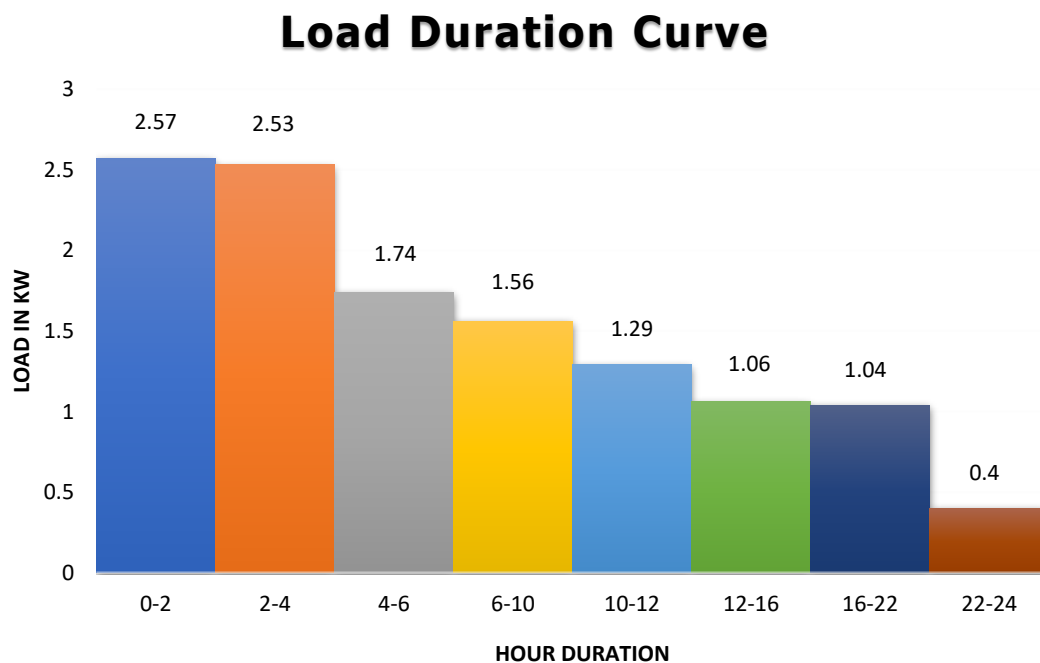


Figure 6: Load Duration Flowchart

3.2 Solar PV

When the sun shines onto a solar panel, energy from the sunlight is absorbed by the PV cells in the panel. PV converts light energy to electrical energy. This energy creates electrical charges that move in response to an internal electrical field in the cell, causing electricity to flow. The output of PV depends on the irradiance of sun power. Sun don't supply same or high light all time. Sun power varies in different irradiance. To complete this paper progress, we measured sun power or irradiance in the rooftop of Sonargaon University in Dhaka where the value of Sun Peak hour is 5 hour and for a better understanding of simulation and the value of irradiance shows Maximum= 1000, Lower Maximum=750, Minimum=500 and Lower Minimum=350 at 25-degree Celsius. And the PV setting angle was 23-degree. According to Load Calculation the PV selection and PV sizing given bellow;

3.2.1 Sizing Of Solar PV Panels

$$\text{Daily Consumption} = 16.89 \text{ KWh/Day}$$

$$\text{PV power} = 16.89 \text{ KWh}$$

$$\text{Average sun peak Hours} = 5 \text{ h}$$

$$\text{PV power} = (\text{Daily Consumption}) / (\text{Sun peak Hours})$$

$$= (16.89 \text{ KWh}) / (5 \text{ h}) \times 1.3$$

$$= 4.3914 \text{ KW}$$

$$\text{No. of PV panels} = (\text{PV power in W}) / (\text{PV rated power})$$

$$= (4.3914 \text{ KW} \times 1000) / 250\text{W}$$

$$= 17.56$$

$$= 18 \text{ pieces}$$

For 4.39 KW \propto 4.4 KW PV panel and here 250W panel considered as per panel power and total 18 pcs panel required. Here, the simulated figure for total 18 pcs PV connected in series on MATLAB/SIMULINK then the result given figure (Figure 7) and (Figure 8).

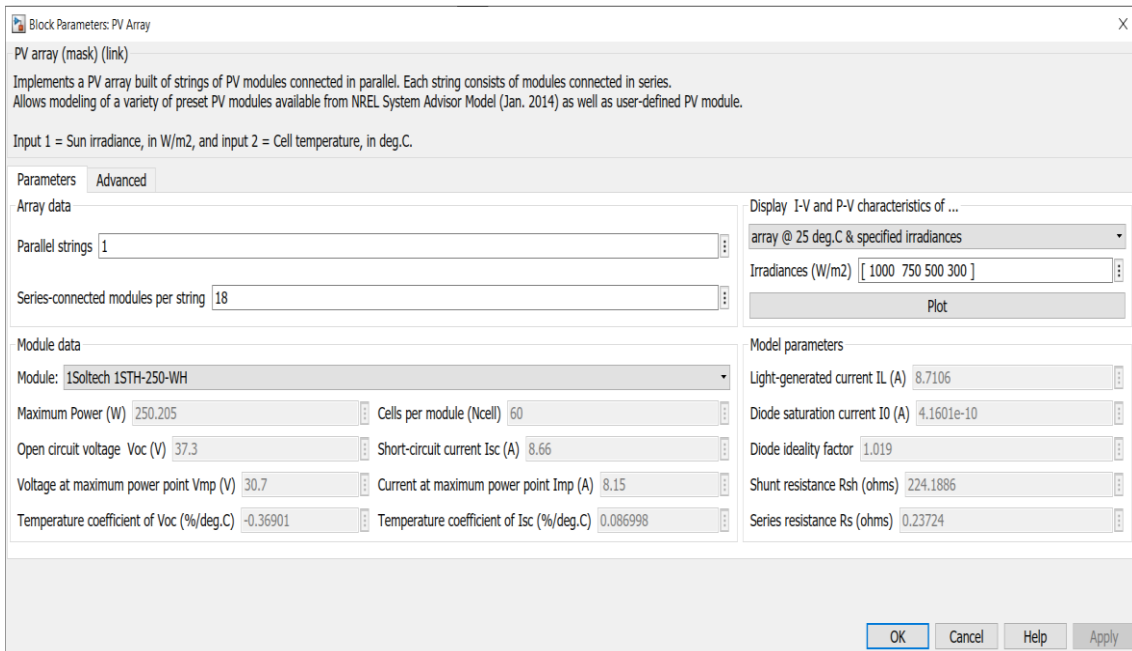


Figure 7: PV array selection and parameter for different irradiance on MATLAB/Simulink

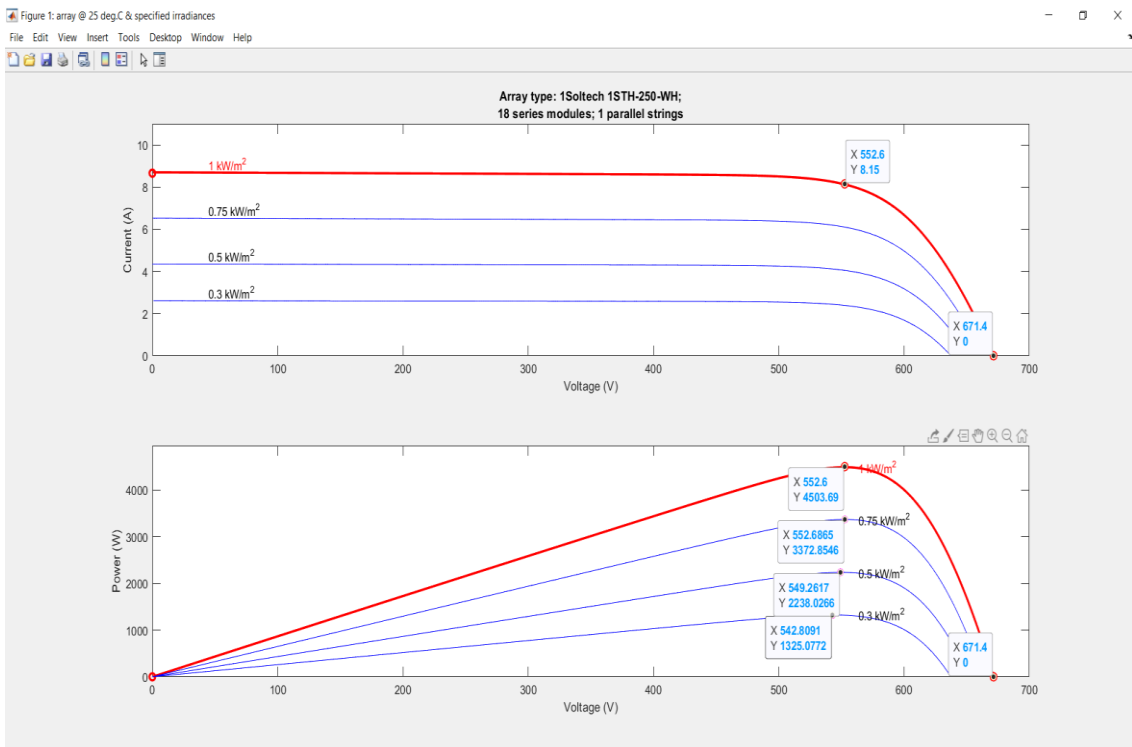


Figure 8: Figure 8: I_V Characteristics of PV output curve in different Irradiance on MATLAB/Simulink

The current-voltage (I-V) curve represents a PV cell graphically. An I-V curve tracks the performance of a PV cell and emphasizes key characteristics such as Voc, Isc, and Pmax. A PV cell will follow this curve indefinitely. The greatest power point is captured using a power curve. The voltage is plotted along the horizontal axis and the power is plotted along the vertical axis in a power curve. When this is placed on the I-V curve for the same cell, the maximum power point becomes quite evident.

According to the figure (Figure 7) and figure (Figure 8) the parameter of the PV or the Characteristics of the PV is given in Table (Table 7) .

Table 7: PV Specifications

250W PV panel specification	
Maximum Power	250 W
Open Circuit Voltage	37.8V
Short Circuit Current	8.7A
Maximum Voltage	31.5V
Maximum Current	7.94A
Module Efficiency	15.3%

3.3 MPPT

Due to the high initial investment and short lifespan of a photovoltaic (PV) array, the user must extract maximum power from the PV system. The introduction of maximum power point tracking (MPPT) to the system is further necessitated by the nonlinear $i-v$ characteristics of the PV array and the rotation and revolution of the earth around the sun. Solar cells, as non-linear devices, cannot always deliver continuous power in a Solar Grid connected system. As a result, getting the most electricity out of the solar panel is essential. Irradiance and temperature on any given day change for any Solar Panel, causing solar power output to shift as well. Even under changing temperature and irradiance conditions, it's essential to track the maximum power. MPPT may be implemented using a variety of methods and algorithms. P&O, IC, and fuzzy logic controller methods are only a few examples. P&O technique is employed in this project. If the power grows, the P&O controller changes the voltage from the array by a tiny amount and measures it; if the power increases, more modifications in that direction are made until the power no longer increases. To implement MPPT, we will employ PV voltage and current. The MPPT's output is the reference voltage. The inaccuracy is calculated by comparing the reference voltage to the actual PV voltage. The PI Controller is then informed of the mistake. The PI controller's output will create the needed duty ratio for PWM generating.

3.3.1 MPPT Code

The code which given below for MPPT on MATLAB/SIMULINK to perform properly.

```
function Vref = RefGen(V, I)
Vrefmax = 552.4;
Vrefmin = 0.0;
Vrefinit = 542;
deltaVref =1;
persistent Vold Pold Vrefold;
datatype = 'double';
if isempty(Vold)
    Vold = 0;
    Pold = 0;
    Vrefold = Vrefinit;
end
p = V*I;
dV = V-Vold;
dP = p-Pold;
if dP ~= 0
    if dP<0
        if dV<0
            Vref = Vrefold + deltaVref;
        else
            Vref = Vrefold-deltaVref;
        end
    else
        if dV<0
            Vref = Vrefold - deltaVref;
        else
            Vref = Vrefold + deltaVref;
        end
    end
else
    Vref = Vrefold;
end
if Vref >= Vrefmax || Vref <= Vrefmin
    Vref = Vrefold;
end
Vrefold = Vref;
Vold = V;
Pold = p;
```

3.3.2 MPPT Algorithm

Here, figure (Figure 9) when MPPT sense power from PV then 1st MPPT measure the voltage (V_{pv}) and current (I_{pv}) of PV and calculate the power of PV (P_{pv}) called initial power of PV by the initial voltage $V_{pv}(k)$ and initial current $I_{pv}(k)$. When the difference of initial power and Reference power $P_{pv}(k-1) > 0$ or more than 0 then MPPT increase, otherwise decrees. At the same time when the difference is not more than 0 then it works to stable the value of Voltage by changing the value of current I_{mppt} .

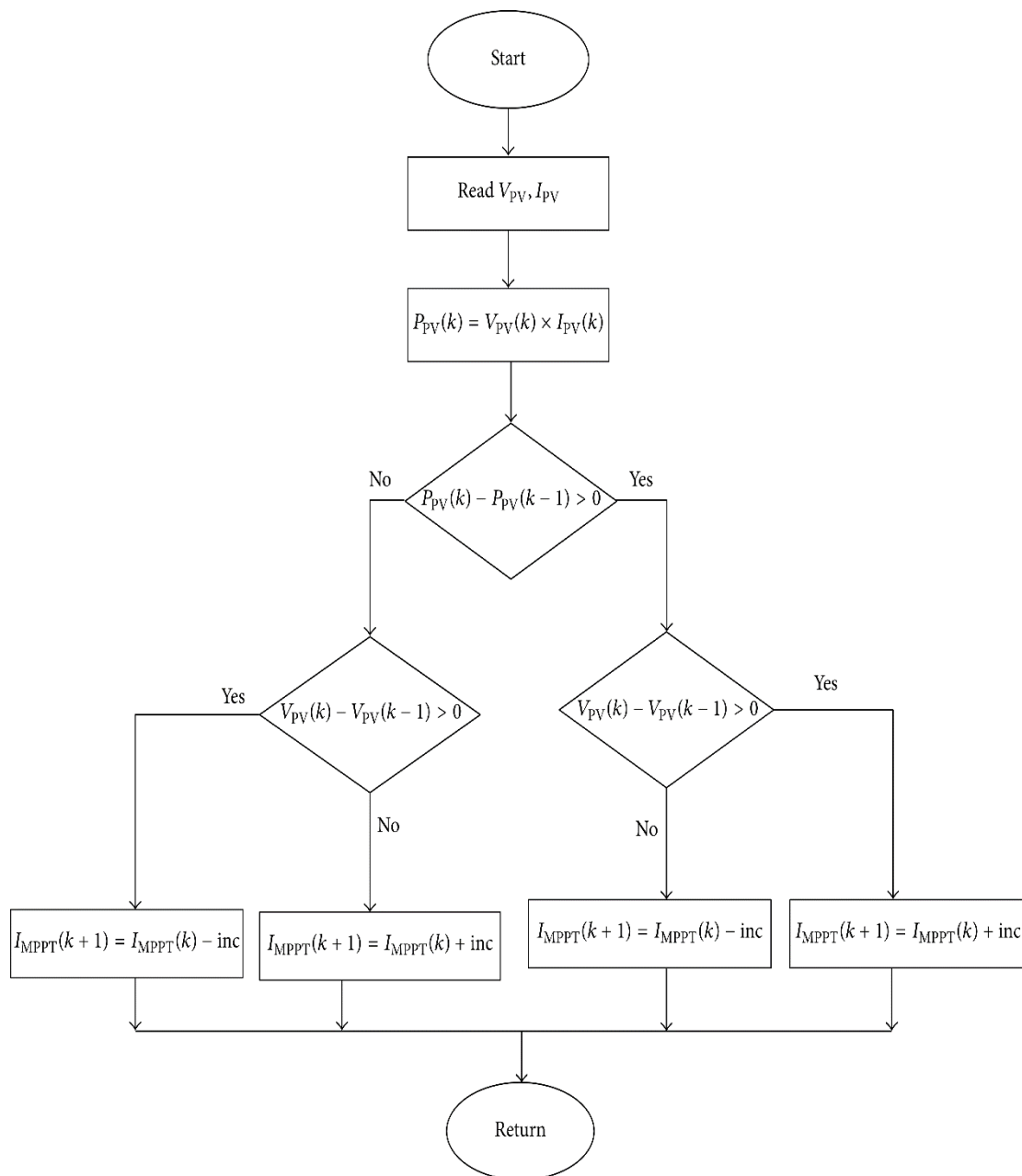


Figure 9: MPPT working algorithm flowchart

3.4 Three Phase Grid Tie Inverter

The output which comes from PV are generally DC. As per requirement of our loads and grid it's important to convert this DC to AC. 3-Phase grid tie inverter converts DC to AC. In this paper IGBT based inverter selected and for switching IGBT used as switching device where PWM generator provide pulse on the IGBT gate and PWM used for making switching interval. For design an inverter first of all it's necessary to select the specification called inverter selection.

3.4.1 Inverter Selection

$$\text{PV Panel Pr} = 250\text{W}$$

$$\text{No. of PV Panels} = 18$$

$$\text{Max. PV Power} = \text{PV Panel P}_R \times \text{No. of PV Panels}$$

$$= 250 \times 18$$

$$= 4500\text{W}$$

$$= 4.5 \text{ KW} < \text{inverter}$$

$$\text{PV Array Vout (series)} = \text{Voc} \times \text{No. PV Panels}$$

$$= 37.6 \times 18$$

$$= 676.8 \text{ V} < \text{inverter}$$

$$\text{PV Array Isc (series)} = 8.70 \text{ A} < \text{inverter}$$

3.4.2 Inverter Specification

According to the specification of PV and the calculation of inverter the specification of the inverter can be define as following table (Table 8) where the input and output data of the inverter was provided.

Table 8: Inverter Specification

Inverter specification	
Input Data	
Max. Input Current	16.0 A
Max. Input Voltage	150 A
Start-up voltage	200 V
Nominal Input Voltage	595 V
Output Data	
AC Nominal Output	4,500 W
Ma. Output Power	4,500 VA
AC Output Current	6.5 A
Frequency	50 HZ

3.5 Working System of grid Tie Inverter

The PV Inverters portray a key role in converting the power delivery from the PV arrays to the AC grid. Inverter is an electronic circuitry that converts from DC to AC for the preferred magnitude and frequency. Inverters can be line commutated or self-commutated inverters. In this work, single-stage inverter is used which has one treating stage – MPPT and grid current control. Inverter bridge is comprised of IGBT switches. Output of the inverter is connected to an LCL filter. LCL filter is used because its superior filtering performance. The control algorithm used is synchronous reference frame theory. To implement the controller, first we need to sense the voltages V_{abc} – line to line voltages. These three voltages (abc) are then transformed to two phase alpha-beta voltages using park's transformation. Using alpha-beta voltages, PLL is implemented. Alpha-beta voltages are then converted to dq voltages using clark's transformation. This is used to sense current for controller implementation. Currents of inverter (I_{abc}) is then transformed to alpha-beta domain using park's transformation and then to dq domain using clark's transformation. I_d (Active current) and I_q (Reactive current) is deducted from the reference current to obtain

the error. Error is fed to PI Controller to find voltages V_d and V_q . To monitor the three load voltages and currents Three-Phase V-I Measurement block is used.

3.6 Flow Chart of Inverter Mechanism

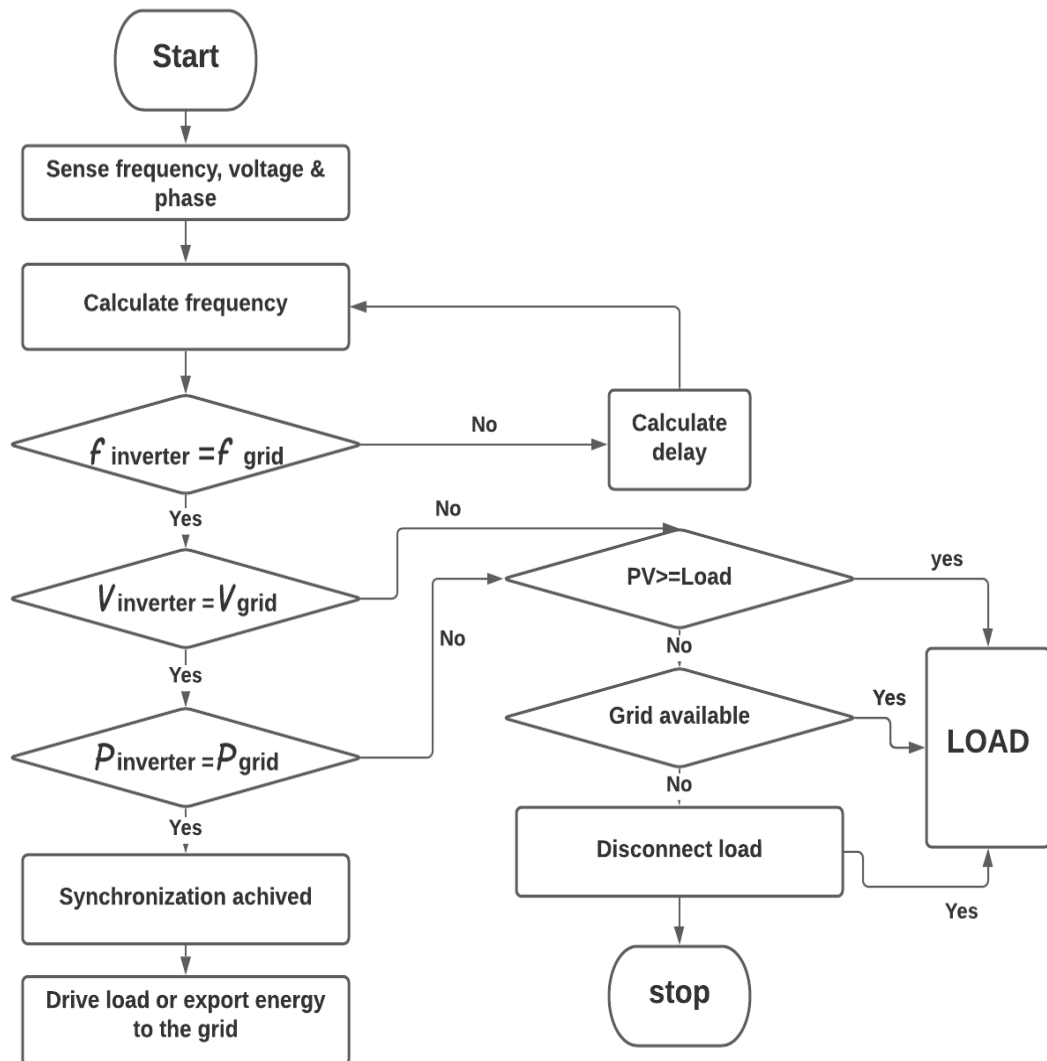


Figure 10: Three Phase grid connected inverter flowchart

The following figure (Figure 10) show the flowchart of a grid tie inverter mechanism where inverter sense frequency, voltage and phase voltage then according to match the frequency

with grid 1st of all calculate frequency. Then match the Voltage and Power for synchronization. Inverter work as a supplier when the demand of the load is less than the PV supply. When PV supply can't fulfil the demand of the load then the necessary power comes from the grid. When PV don't supply any electricity then the demand of the load be fulfil from grid.

3.7 Inverter Switching

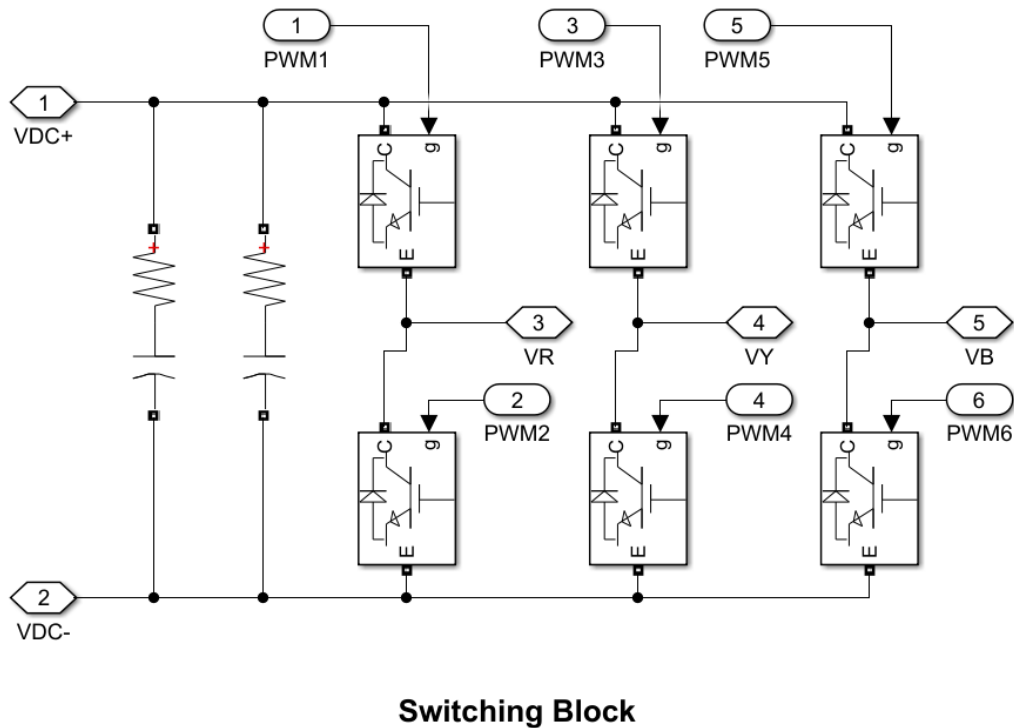


Figure 11: 3-phase IGBT based inverter switching circuit using MATLAB/Simulink

Generally, three phase grid tie Inverter switches with 120°- and 180°- conduction mood and each switch conduct at 60° intervals. The terminals A, B and C are the output terminals of the bridge that are connected to the three-phase delta or star connection of the load. The

operation of a balanced star connected load is explained in the diagram in figure (Figure 11).

3.7.1 180° Degree Conduction Mode

Table 9: 180-degree conduction system of three phase grid tie inverter

Mode	S1	S2	S3	S4	S5	S6
1 st	ON	OFF	OFF	OFF	ON	ON
2 nd	ON	ON	OFF	OFF	OFF	ON
3 rd	ON	ON	ON	OFF	OFF	OFF
4 th	OFF	ON	ON	ON	OFF	OFF
5 th	OFF	OFF	ON	ON	ON	ON
6 th	OFF	OFF	OFF	ON	ON	ON

Each switch's three phase inverter conducts 180° of cycle, with a IGBT pair in each arm, i.e. S1, S4; S3, S6 and S5, S2 are turned on with a time interval of 180°. It means that S1 conduct for 180° and S4 for the next 180° of a cycle. Switch in the upper group S1, S3, S5 conduct at an interval of 120°. It implies that if S1 is fired at $\omega t = 0^\circ$, then S3 must be fired at $\omega t = 120^\circ$ and S5 at $\omega t = 240^\circ$. Same is proved lower group of switches. On the basis of this firing scheme, a table in prepared as shown at the top. In this table, first row show that S1 from upper group conducts for 180°, S4 for the next 180° and then again S1 for 180° and so on. In the second row, S3 from the upper group is shown to start conducting 120° after S1 starts conducting. After S3 conduction for 180°, S6 conducts for the next 180° and again S3 for the next 180° and so on. Further, in the third row, S5 from the upper group start conducting 180° after S3 or 240° after S1. After S5 conduction for 180°, S2 conducts

for the 180°, S5 for the next 180° and so on. In this manner, the pattern of firing the six switch is identified. This table shows that S5, S6, S1 should be gated for step I; S6, S1, S2 for step II; S1, S2, S3 for step III; S2, S3, S4 for step IV and so on. Thus, the sequence of firing the thyristor is S1, S2, S3, S4, S5, S6; S1, S2.... It is seen from the table that in every step of 60° duration, only three switches operate, one from the higher group and two from the lower group, or two from the higher group and one from the lower group.

3.7.2 120° Degree Conduction Mode

Table 10: 120-degree conduction system of grid tie inverter

Mode	S1	S2	S3	S4	S5	S6
1 st	ON	OFF	OFF	OFF	OFF	ON
2 nd	ON	ON	OFF	OFF	OFF	OFF
3 rd	OFF	ON	ON	OFF	OFF	OFF
4 th	OFF	OFF	ON	ON	OFF	OFF
5 th	OFF	OFF	OFF	ON	ON	OFF
6 th	OFF	OFF	OFF	OFF	OFF	ON

The power circuit diagrams of this inverter are the same as that shown. For the 120°-degree mode VSI, each IGBT conducts for 120° of a cycle. Like 180° mode, 120° mode inverter also requires six steps, each of 60° duration for completing one cycle output AC voltage. For this inverter too, a table giving the sequence of firing the six thyristor is prepared as shown in the top. In this table, shown that even conducts for 120° and for the next 60° neither S1 nor S4 conducts. Now S4 is turned on at $\omega t=180^\circ$ is further conducts for 120°, i.e. from $\omega t=180^\circ$ to $\omega t=300^\circ$. This means that for 60° interval from $\omega t=120^\circ$ to $\omega t=180^\circ$, series connected switch S1, S4 do not conduct. At $\omega t=300^\circ$, S4 is turned off, then 60°

interval elapses before S1 is turned on again at $\omega t=360^\circ$. In the second row, S3 is turned on at $\omega t=120^\circ$ as in 180° mode inverter. Now S3 conducts for 120° , then 60° interval elapses during which neither S3 nor S6 conducts. At $\omega t=300^\circ$, S6 is turned on, it conducts for 120° and then 60° interval elapses after which S3 is turned on again. The third row is also completed is similarly. This table show that S6, S1 should be gated for step I ; S1, S2 for step II ; S2 ,S3 for step III and so on. The sequence of firing the six IGBT is the same as for the 180° mode inverter. During each step, only two IGBT conducts for this inverter one from the upper group and one from the lower group; but in 180° mode inverter, three IGBT conduct in each step.

The advantage of the 180° degree conduction as compared to the 120° conduction is the number of switches that remain on at any instant of time. For 180° -degree conduction, it is three switches whereas for 120° conduction, it is only two switches.

The load that can be connected to is also different. 180° conduction mode magnitude of output voltages greater than 120° conduction mode. In this system represents 180° conduction and output of the proposed 180° conduction mode inverter given in figure (Figure 12) and (Figure 13) below.

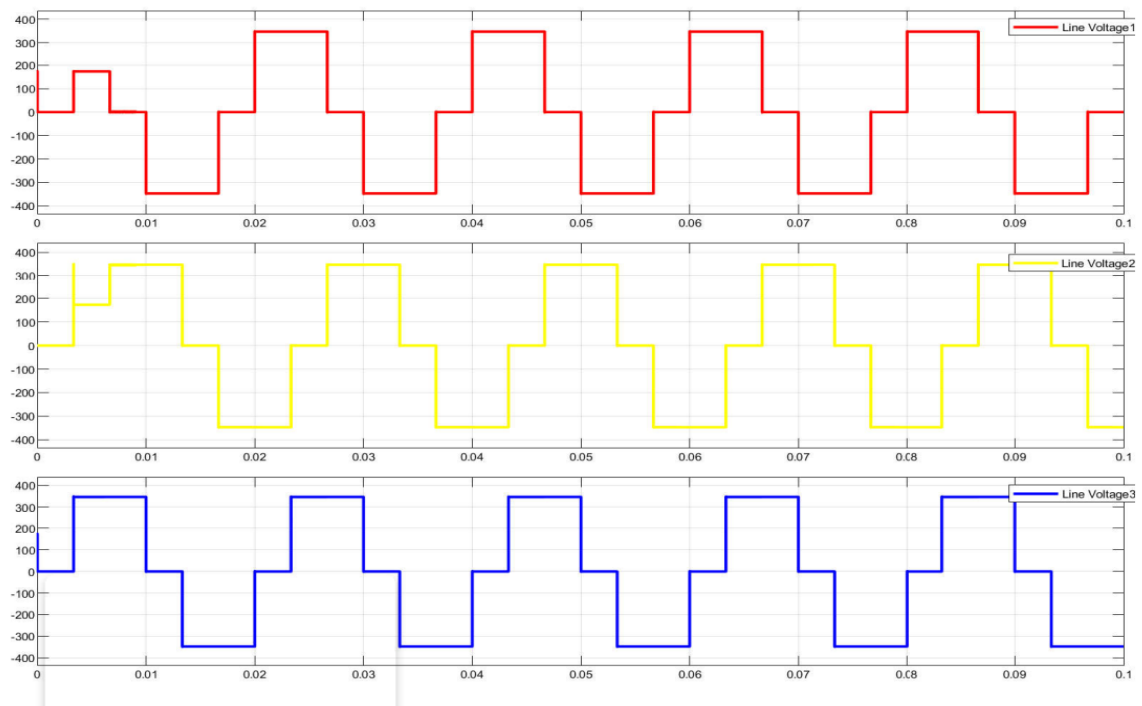


Figure 12: Output Line voltage of inverter switching using MATLAB

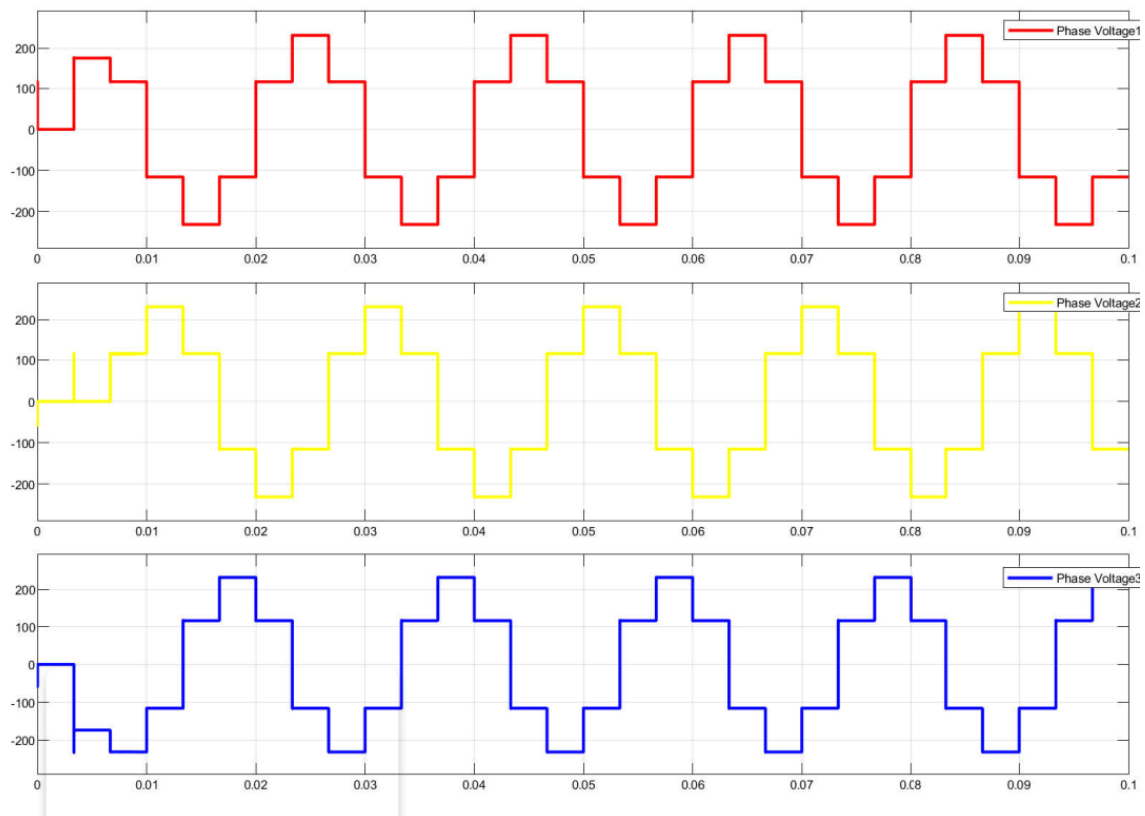


Figure 13: Output Phase voltage of inverter switching system using MATLAB

3.8 Voltage and Current Transformation Blocks

The abc to dq0 conversion needs the value of the angle θ that is determined by a phase locked loop. The scheme of the phase locked loop implemented here is shown in the figure. In applications related to the three phase systems, the PLL based on the synchronous reference frame is normally used. It is used in the conversion of the three-phase voltage vector from the abc reference frame to the dq reference frame using Park's Transformation. The angular position of the dq reference frame is controlled by a feedback loop that regulates the q component to zero. Voltage and current transform unit of a grid tie inverter showed in figure (Figure 14) using MATLAB/ SIMULINK.

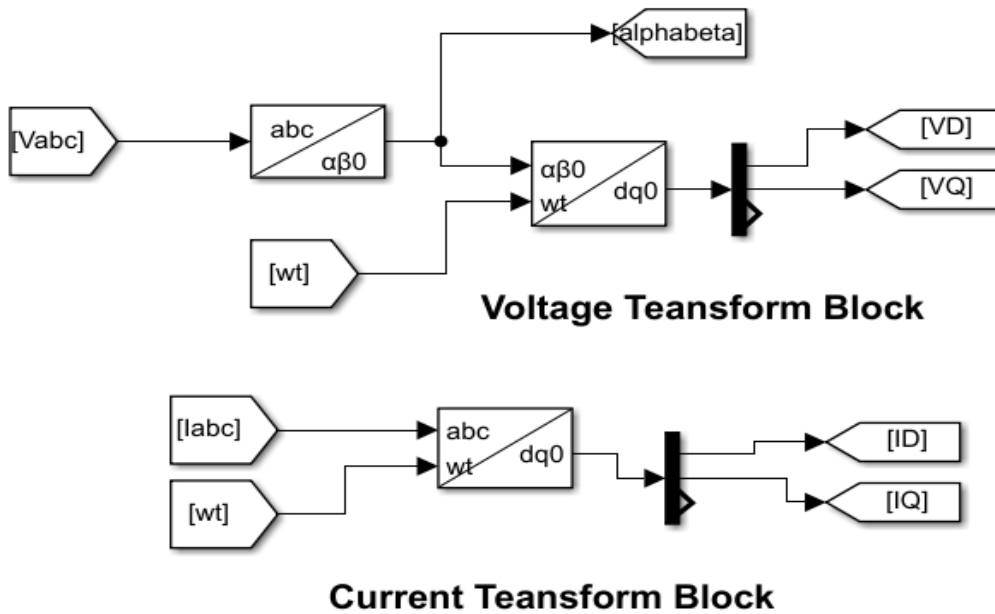


Figure 14: Voltage and Current transform unit of the inverter

3.9 Phase Locked Loop (PLL)

Phase-locked loop (PLL) is a popular method for synchronizing utility network and grid-connected power electronics converter. Phase-locked loop (PLL) is a popular method for synchronizing utility network and grid-connected power electronics converter. The common method to realize PLL on three-phase system is by using synchronous frame PLL. Figure shows the block diagram of synchronous frame PLL. The output of the PI controller is the inverter output frequency that is integrated to obtain inverter phase angle θ . When the difference between grid phase angle and inverter phase angle is reduced to zero PLL becomes active which results in synchronously rotating voltages $V_d = 0$ and V_q gives magnitude of grid voltage. Synchronous frame control also called d-q control uses a reference frame transformation abc to dq which transforms the grid current and voltages into d-q frame. The transformed voltage detects phase and frequency of grid, whereas transformed current controls the grid current. The phase locked loop PLL for a grid tie

inverter showed in figure (Figure 15).

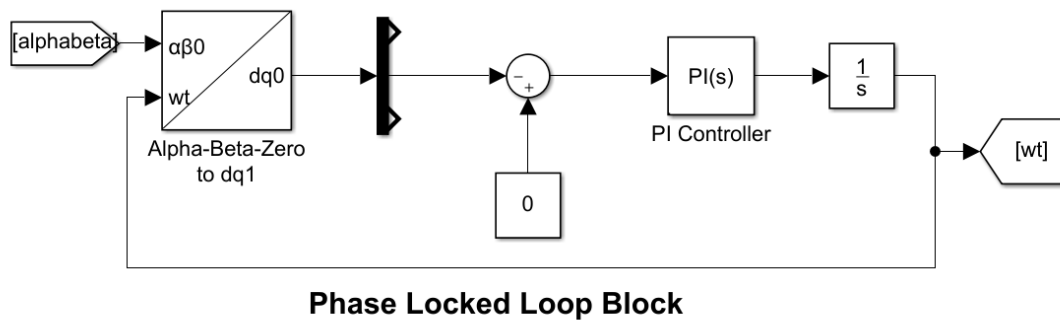


Figure 15: Phase Locked Loop (PLL)

3.10 PWM Generation

A DC input voltage ($V_{DC} = V_S$) is generally constant in magnitude for voltage source inverters that employ PWM switching methods. The job of the inverter is to take a DC input and convert it to an AC output with adjustable amplitude and frequency. Pulse Width Modulation (PWM) can be done in numerous ways (PWM). The modulation schemes used to regulate the inverter are primarily responsible for the efficiency metrics of an inverter, such as switching losses and harmonic reduction. Because the inverter output voltage and frequency may be directly regulated using sine functions, the Sinusoidal Pulse Width Modulation (SPWM) approach was employed to control the inverter in this design.

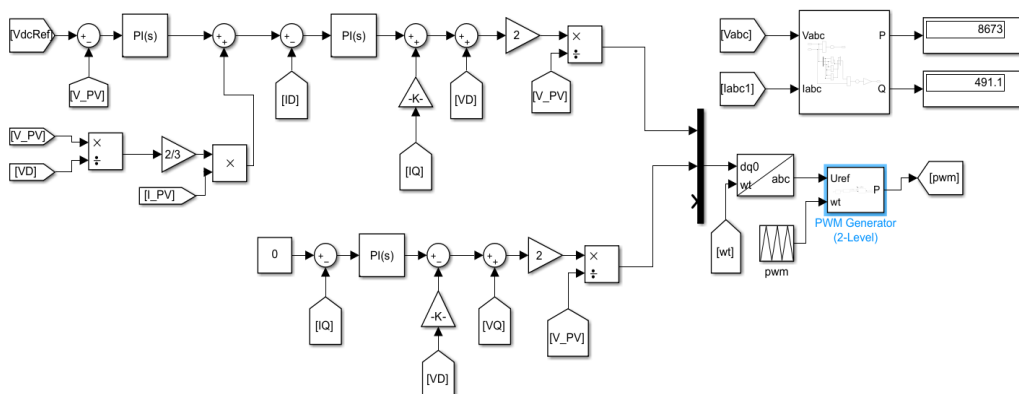


Figure 16: PWM generation of three phase grid tie inverter

3.11 Filter Design

To reduce the switching frequency harmonics produced by grid-connected inverters, an LCL filter is frequently installed between the inverter and the grid. When compared to the L filter, the LCL filter is superior. However, because of the unwanted resonance induced by zero impedance at certain frequencies, an LCL filter can cause stability issues. The added resistor causes power loss and reduces the LCL filter's attenuation capacity. For design LCL filter circuit in figure (Figure 17) some calculation needed step by step followed below:

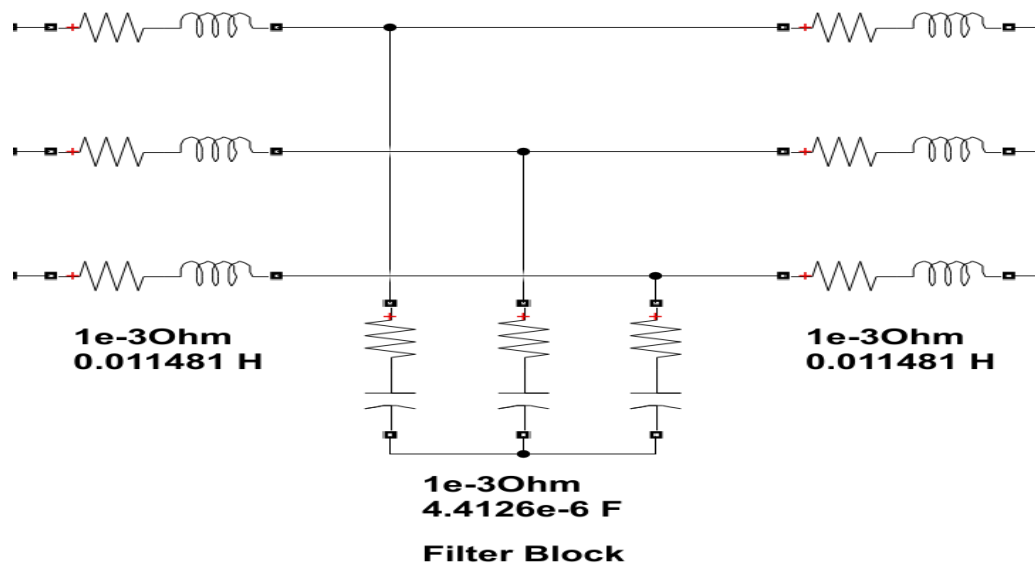


Figure 17: LCL filter design for grid tie inverter

3.11.1 Capacitor Sizing

A capacitor is designed based on the reactive power absorbed at the rated condition.

Reactive power (Q) is absorbed by the capacitor limited to 5% of rated power (S) condition.

$$\text{Reactive Power } Q = \frac{v^2}{(2 * \pi * f * c)}$$

$$V_{dc} = 400\text{v}$$

$$V_{grid} = 230\text{v}, 50\text{hz}$$

$$\frac{v^2}{(2 * \pi * f * c)} = 5\% \text{ of } S$$

$$P_o = 2\text{kVA}$$

$$P_s = 10\text{Khz}$$

$$I_{ripple} = 20\%$$

$$\text{Value of Capacitor } c = \frac{0.05 * S}{v^2 * \pi * f}$$

$$c = \frac{0.05 * 2000}{230^2 * 2\pi * 50}$$

$$= 6.01\mu\text{f}$$

3.11.2 Inductor

Value of inverter side inductor. (L1) is Selected based on the max permissible current ripple.

The current ripple should be limited to 20% of the rated current condition 1.

$$\text{Inverter Side Inductor } L1 = \frac{V_{dc}}{4 * f_{sw} * \Delta I_{ppmax}}$$

$$L1 = \frac{400}{4 * 10000 * 8.69 * 1.414 * 0.2}$$

$$= 4.06\text{mH}$$

The total inductance (L1+L2) is selected based on the maximum voltage drop across the inductor.

Max drop is limited to 10% of rated voltage condition 2.

$$V_{L1+L2} = I * X_{L1+L2} = I * 2\pi * f * (L_1 + L_2) = I * 2\pi f * (L_1 + L_2)$$

$$= 10\% \text{ of } V$$

$$L_1 + L_2 = \frac{10\% \text{ of } V}{\left(\frac{s}{v}\right) * 2\pi f}$$

$$L_1 + L_2 = \frac{0.1 * v^2}{s * 2 * \pi * f}$$

$$= \frac{0.1 * 230^2}{2000 * 2 * \pi * 50}$$

$$= 8.41 \text{ mH}$$

$$i = \frac{\text{power}}{\text{voltage}} = \frac{s}{v}$$

Switching frequency = **10KHz**

Resonant frequency = Switching frequency /10

Therefore, $f_{rs} = 10\text{KHz}/10 = 1000\text{Hz}$

value of Capacitance C = 6.01 μ f

value of Inductance L= 8.41 mH

The filter or LCL filter is usually placed between the inverter and the grid to attenuate the switching frequency harmonics produced by the grid-connected inverter.

Chapter4 CIRCUIT SIMULATION ON MATLAB/ SIMULINK

Here, figure (Figure 18) MATLAB/SIMULINK is used to simulate the full circuit modeling process. The load AC voltage is used as the reference signal for the PWM pulse generator, which is also used as the requisite phase for generating sine waves. To obtain the AC output waveform, the acquired pulses are fed into a three-phase bridge inverter. The three-phase AC source receives this output waveform. Scope blocks are connected so that the output waveforms can be measured and viewed. The full system modeled in MATLAB/Simulink is represented by the figure (Figure 18). A PV array feeds an inverter, which feeds the utility grid (AC Voltage) through an LCL filter. The PI controller is used to control the inverter. When we run the simulation, we notice that as the irradiance level changes, the output current of the inverter changes as well. Since the PV industry has developed, so has its impact on the AC grid system, which is also expanding.

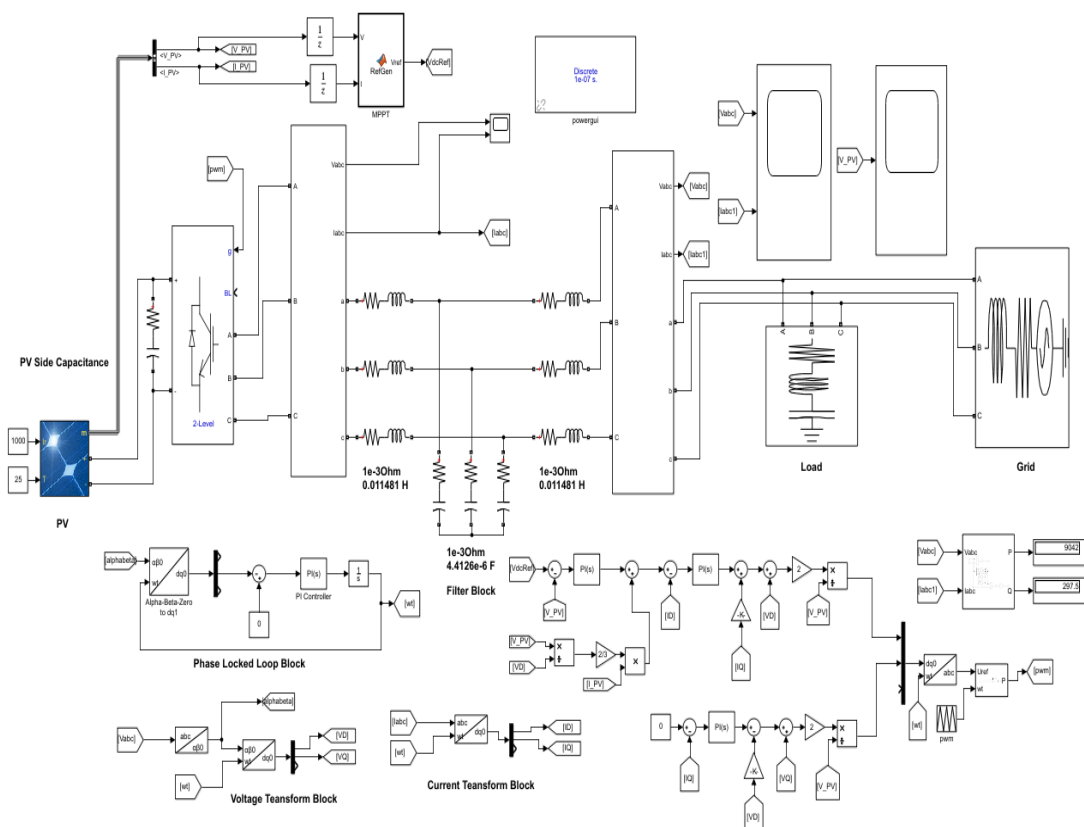


Fig: Inverter Circuit Diagram

Figure 18: Three phase grid tie inverter circuit diagram using MATLAB/ Simulink

4.1 MATLAB Simulation Results

4.1.1 PV Output Voltage Curve

Figure (Figure 19) shows the output waveform of PV voltage curve. The output measured by using a scope with PV output side when MPPT tracking maximum point of voltage. Output measured by changing the value of irradiance. Here, the simulation result of the output of PV simulated by using MATLAB/ SIMULINK according to the figure (Figure 18). In MATLAB/ SIMULINK the value of irradiance settled as 1000, 750, 500 & 350 and the temperature is fixed at 25 degree Celsius which showed in figure (Figure 8). The simulation result shows that the value of PV output voltage being an average stable position when MPPT works properly & the output value is 565V.

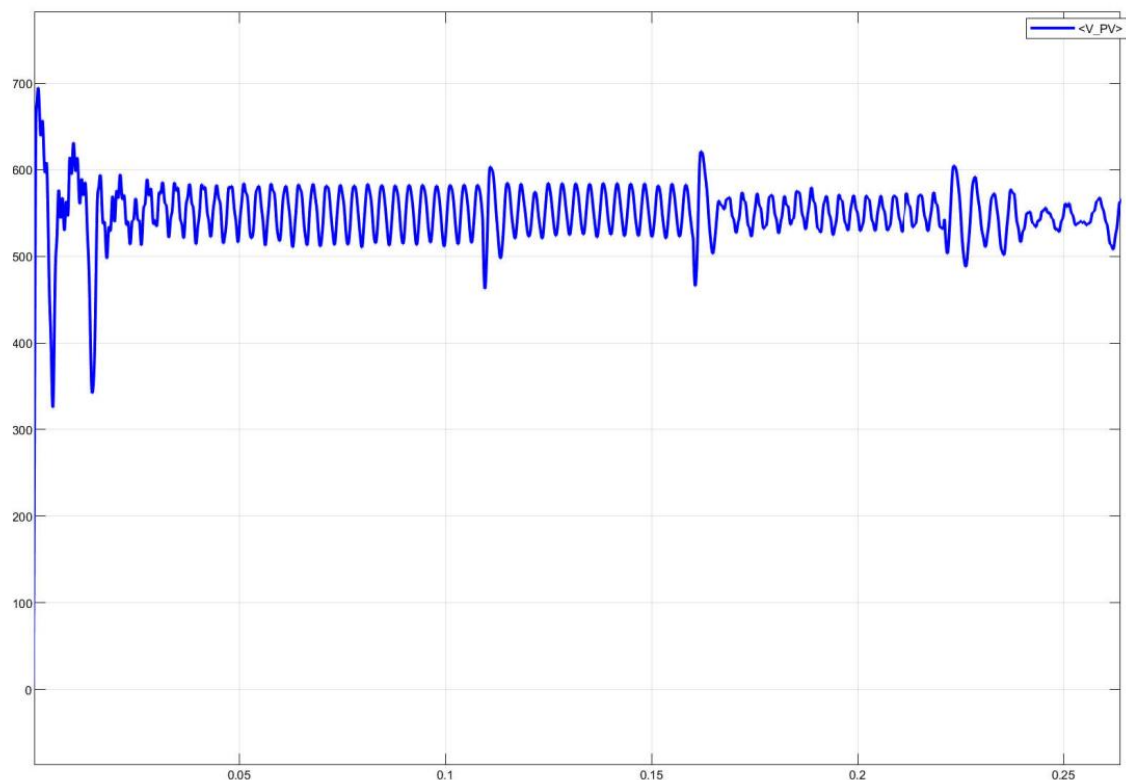


Figure 19: PV output voltage curve

4.1.2 Inverter Output V-I Curve

The output of the inverter measured by using two different scopes in figure (Figure 18). Figure (Figure 20) shows the output waveform of the invert. Waveform shows the starting condition of the inverter when the output have some distortion or have some harmonic in sine wave. LCL filter used to reduce this harmonic. The design of the filter showed in figure (Figure 17). According to the simulation it takes more than 0.08 second to reduce the harmonic distortion from the output of the inverter. The output value of the inverter is about 10 A when irradiance is 1000. Output voltage and frequency will be same as grid but the value of the current will be change according to the power of PV harnessing from sun.

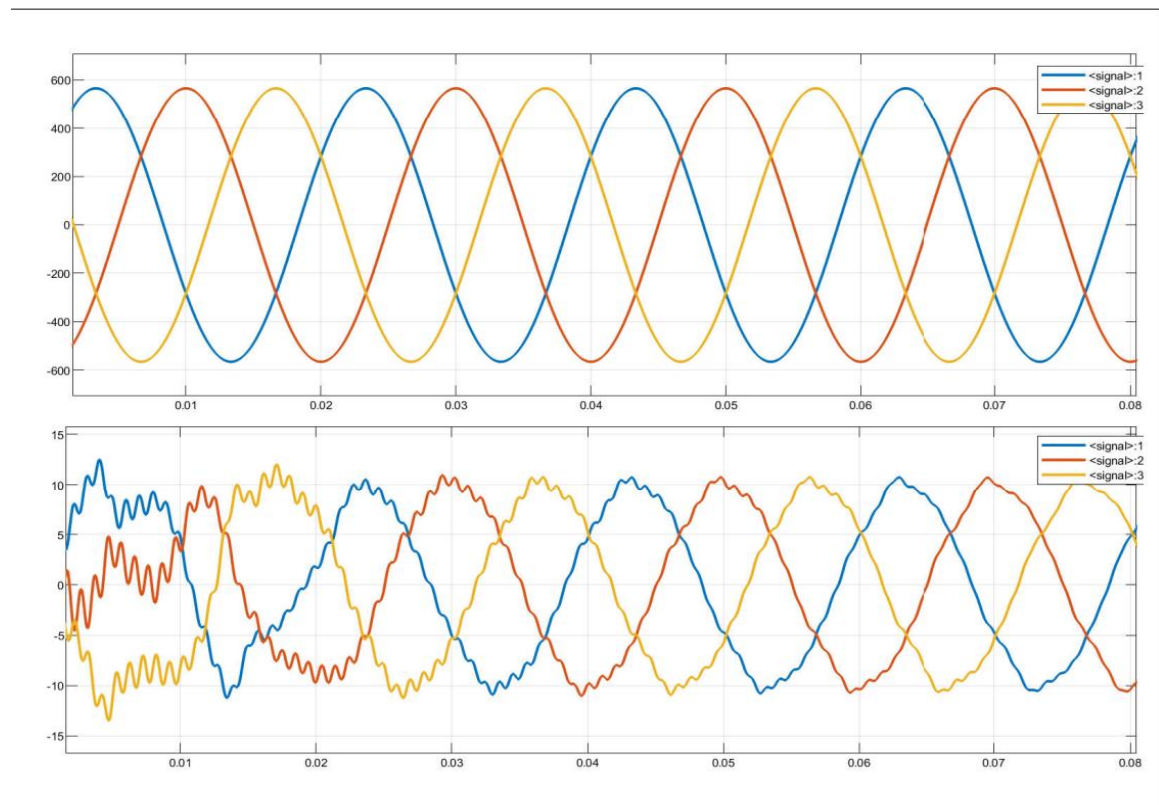


Figure 20: Inverter output V-I curve

4.1.3 Inverter Output V-I Curve in Different Irradiance

We know the value of DC power be change according to the sun power. Here, figure (Figure 21) represents the output waveform of the inverter in different irradiance which shows in figure (Figure 11) and figure (Figure 8). By changing the value of irradiance the output value of Voltage being same by changing the value of Current to match the value of Voltage, Frequency with grid.

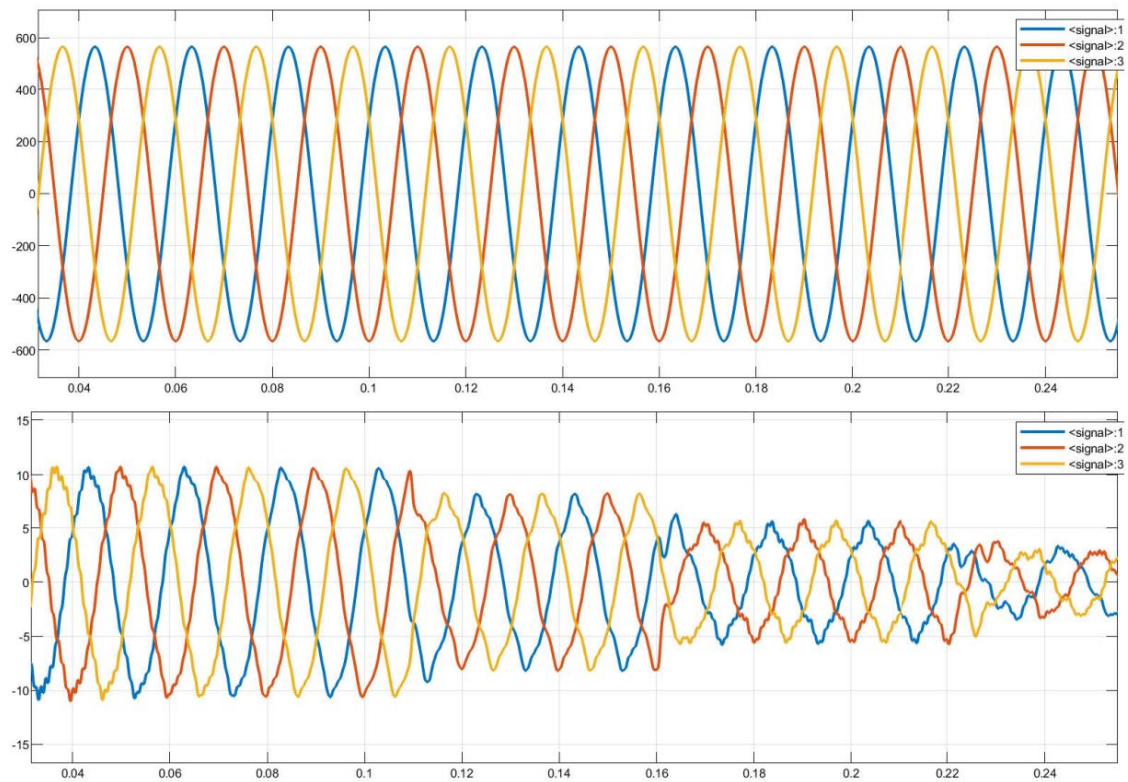


Figure 21: Output of the inverter in different irradiance

Chapter5 BI-DIRECTIONAL ENERGY METER

Net metering is a billing mechanism which credits solar energy system owners for the electricity they inject to the grid. Utility customers can generate their own electricity cleanly and efficiently with net metering. Customers can produce more electricity than they consume during the day. Net metering allows them to export that power to the grid and thereby reduce their future electricity bills. The bidirectional meter records how much electricity is delivered to your facility. And on the “sunny side,” if the solar panel system is in full swing and producing more energy than the operation can use, the meter records how much electricity is received by the utility. A third reading on the meter displays the difference between the amount delivered and received, or net energy used. (Hence net metering.) The traditional net meter will only give the net power of the system, a negative value of power specifies that the power is injected to the utility in this case the consumer gains money since power is injected into the utility. A positive value of power indicates that the power is taken from the utility to meet the extra load requirements, in this case the consumer has to pay extra money to the utility to gain extra power.

5.1 Flowchart of Bi-Directional Energy Meter.

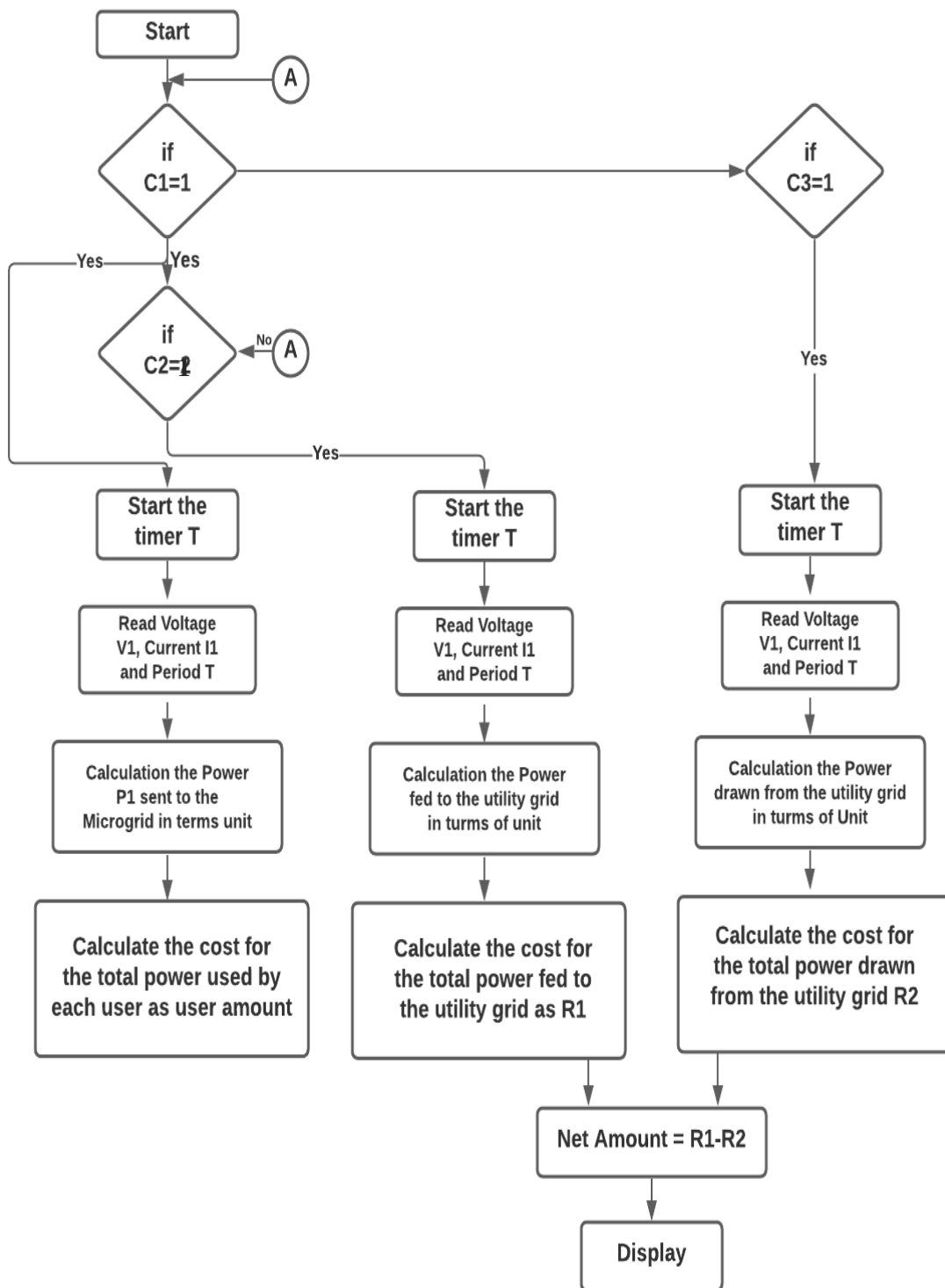


Figure 22: Flowchart of bi-directional energy meter

Figure C1 shows a simple flow of the entire net metering system. Control signals C2, C3, and C4 are pre-defined control signals for the net metering control unit algorithm. The control signal C1 indicates if the power available from the PV system is sufficient to meet the residential load when the system is first turned on. If the generated PV energy exceeds the load requirement, the control signal C2 is toggled high, and the uniform surplus energy model is used to calculate the remaining energy. Similarly, a high control Signal C3 indicates that there is enough utility power to meet the home load's PV energy shortfall. In the event that the utility grid is unable to meet the power differential, the local battery storage system is set up to make up the difference in PV energy. Finally, the cost of drawn and fed energy to and from the utility is determined in order to estimate the Registered owner's monthly payment. R1 is the amount received when excess PV array power is fed into the utility grid. When power is pulled from the utility grid, R2 is the amount obtained. Net-Amount is the difference between these two.

5.2 Control signal C1 is high

Here the control signal C1 is made high, the power generated from the PV array is fed to the Microgrid and current and voltage values are sensed and given to the control unit.

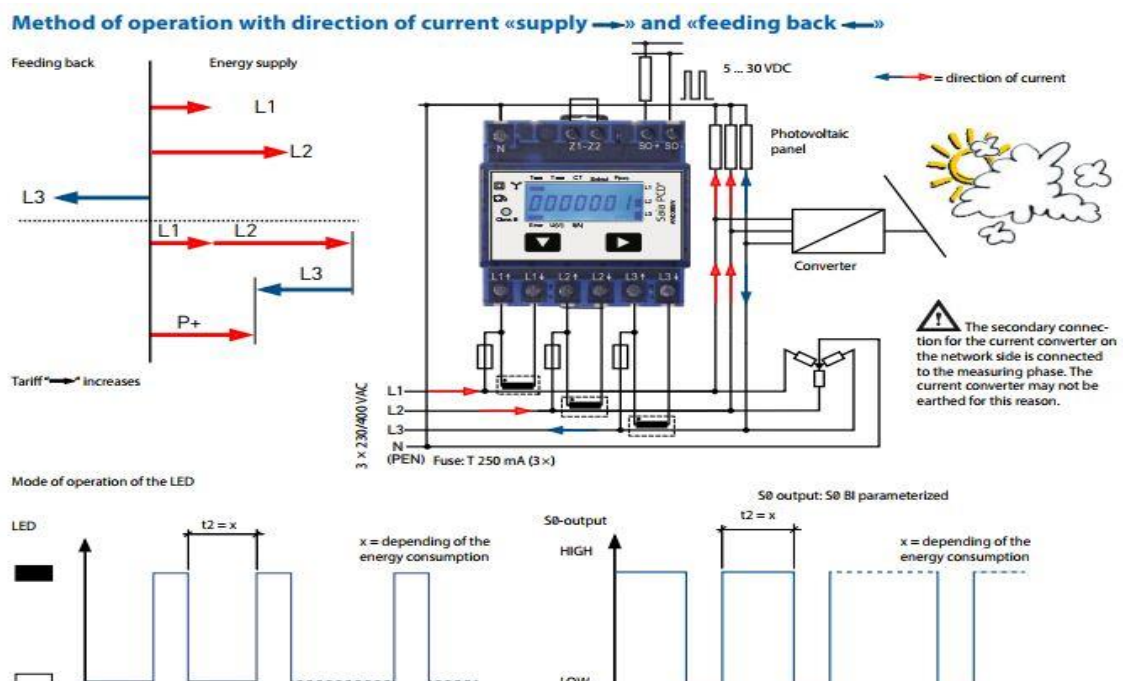


Figure 23: Condition when PV producing electricity but not send to grid

Figure (Figure 23) shows when PV getting some sun power in cloudy day or not in sun peak hour. The energy which generated from PV isn't enough to fulfill the demand of the load then the extra necessary energy come from the grid to fulfill the demand of the load and the Net energy be imported or be calculate as imported energy.

5.3 Control Signal C2 is high

As soon as the control signal C1 is high, if the power generated from the PV array is more than the demand then that extra generated power is sent to the Utility grid the current and voltage values

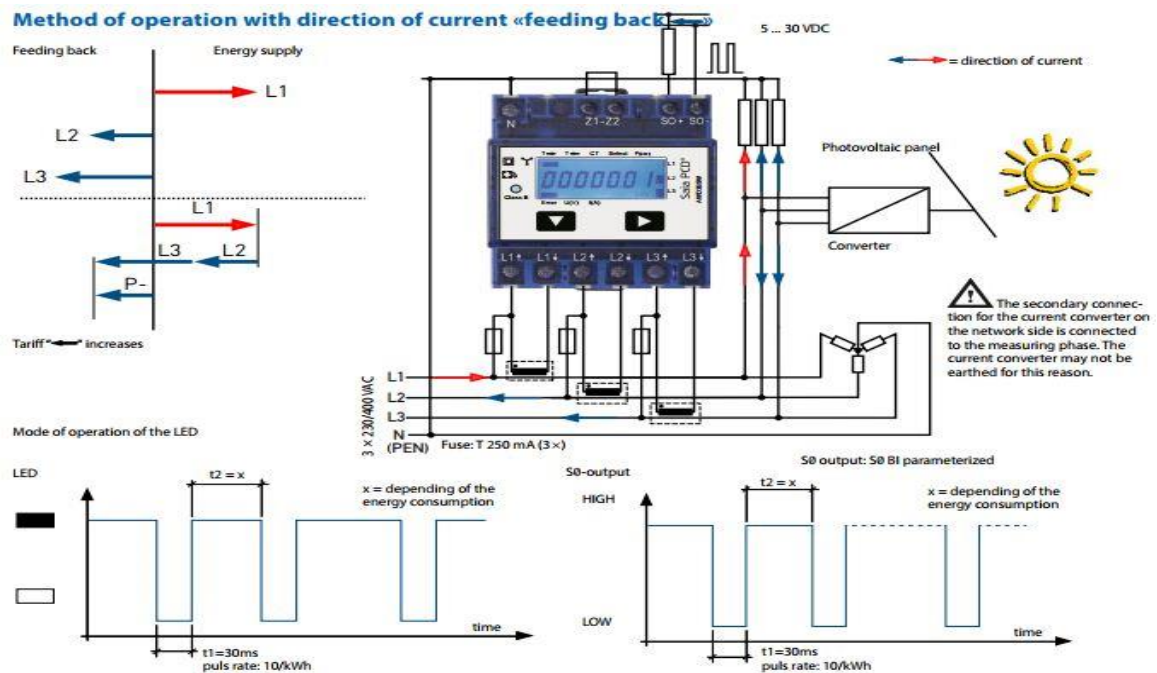


Figure 24: Condition when PV producing electricity more than the demand of the load

Figure (Figure 24) shows when PV getting enough sun power in sunny day or sun peak hour. The energy which generated from PV is enough to fulfill the demand of the load then the excess energy supply to the grid and the Net energy be export or be calculate as export energy.

5.4 Control Signal C3 Is High

When there is no power generation from the PV array or less than the demand, then control signal C3 in FPGA will go high and power is drawn from the utility grid. Here in the same way current and voltage values are sensed and are sent to the control unit

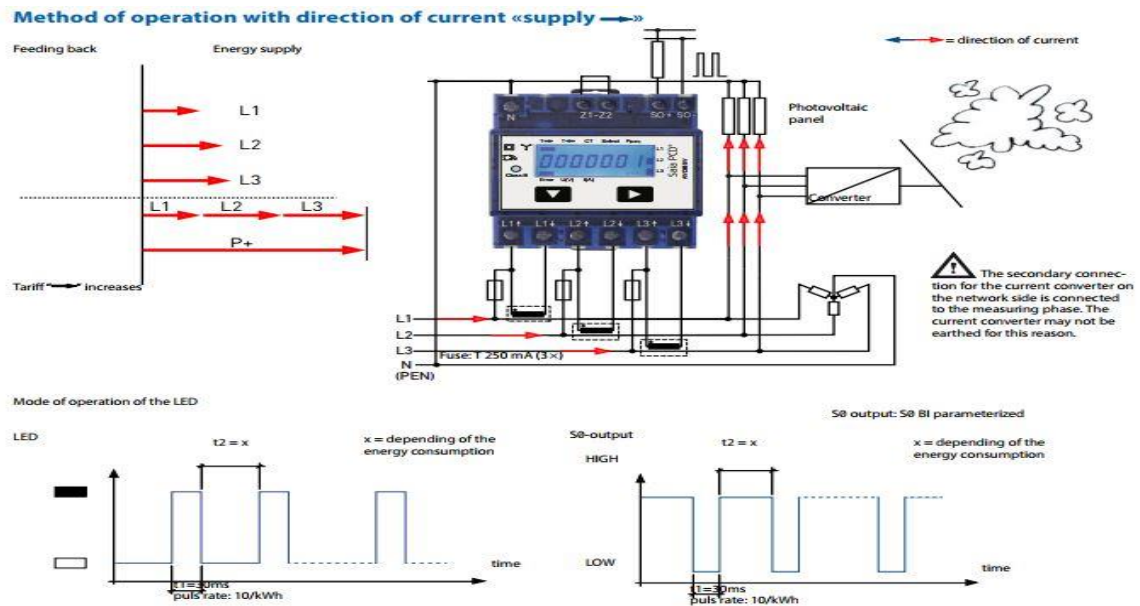


Figure 25: Condition when PV's producing electricity can't fulfil the demand of the load

Figure (Figure 25) shows when PV are not getting sun power in night time. The energy isn't generating from PV. Then grid supply energy to the load to fulfill the demand of the load, then the excess energy supply to the load and the Net energy be imported or be calculate as import energy.

5.5 Bi-Directional Energy Meter Circuit Simulation Using Proteus

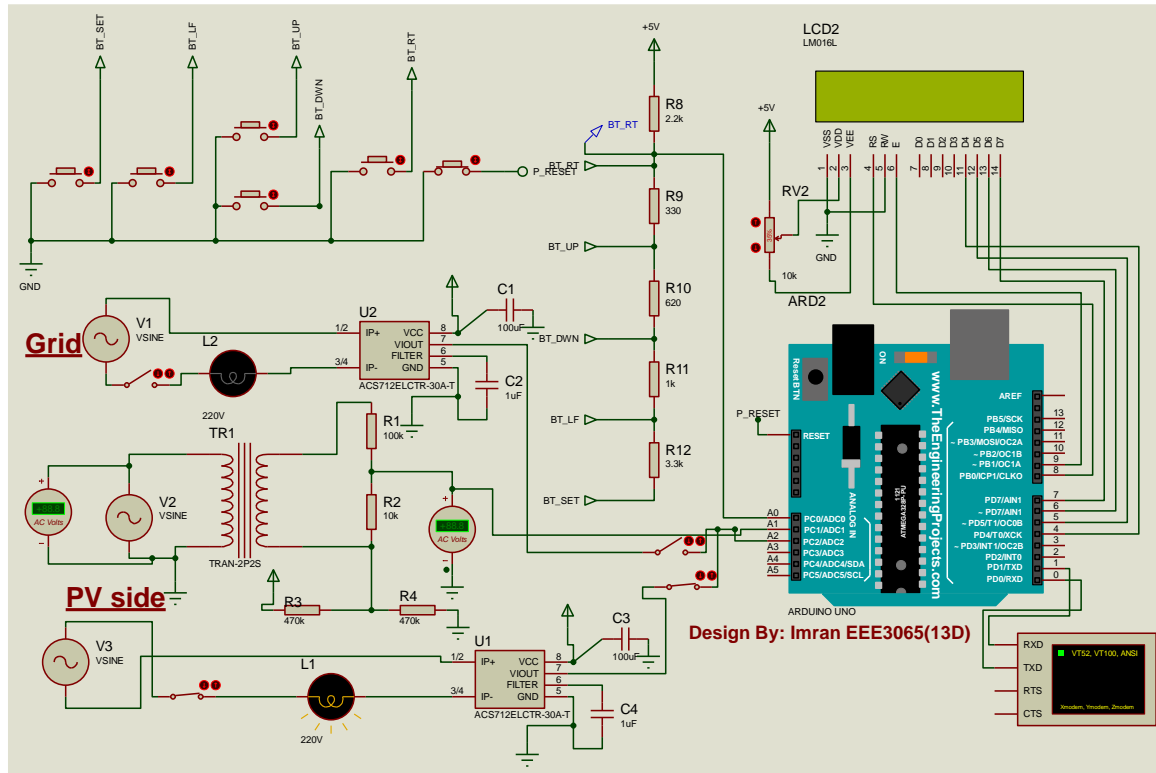


Figure 26: Circuit diagram of Bi-Directional energy meter for each phase using PROTEUS

Figure (Error! Reference source not found.) shows the circuit diagram of a bi-directional energy meter using proteus software. Energy meter designed for measure each phase only. This energy meter can measure in both directions. Power source considered from one source for design and simulation purpose only. Potential transformer TRANS2427 used to step down the voltage and bridge rectifier transfer the ac voltage as dc voltage. Arduino convert this dc value as provided ac value and display it using 16*2 LCD. CT or current transformer ACS712 measure the amount of current flowing through the line. 2 CT used to measure two side current value. 1st CT considered as the flowing electricity from PV to the grid and 2nd CT considered as the flowing electricity from grid to the load. Arduino measure CT 1s value as Export energy and CT 2s as Imported energy. Arduino calculate Net Energy from Export and Import Energy which described in figure (Figure 22). Keypad shield used to move one page to another page.

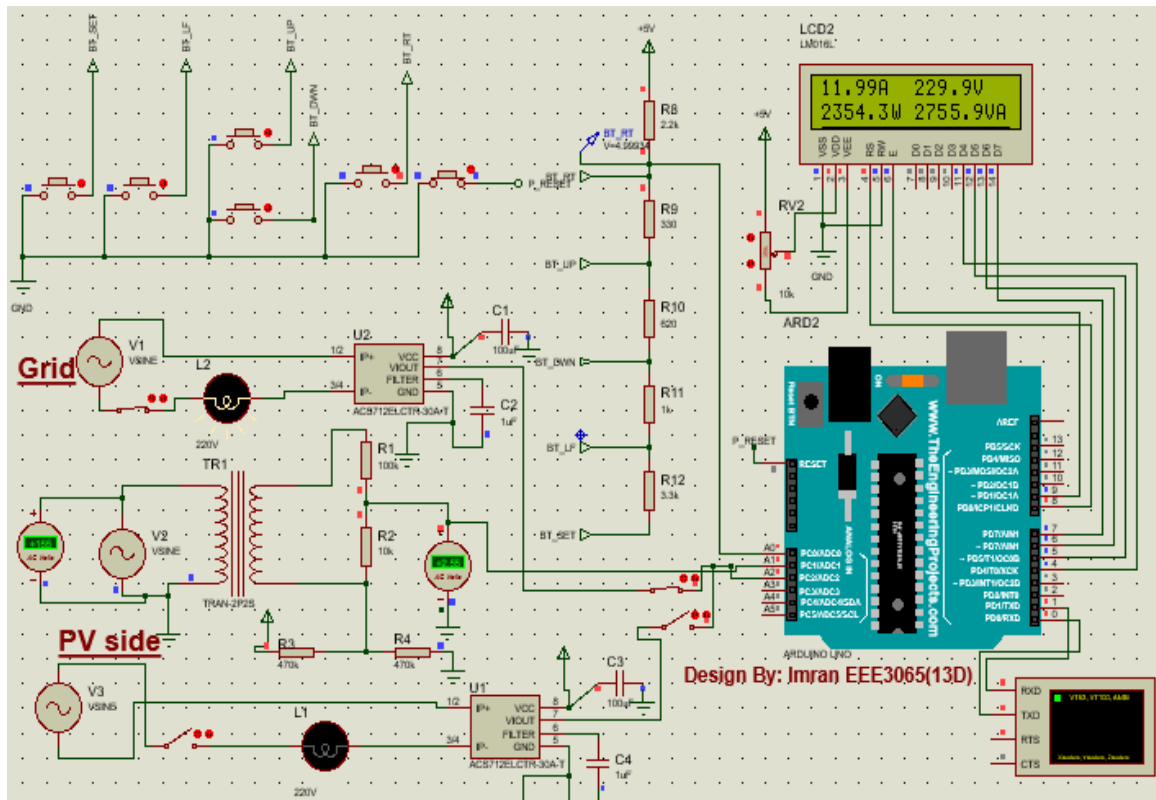


Figure 27: Bi-Directional energy meter measuring Current, Voltage & Power

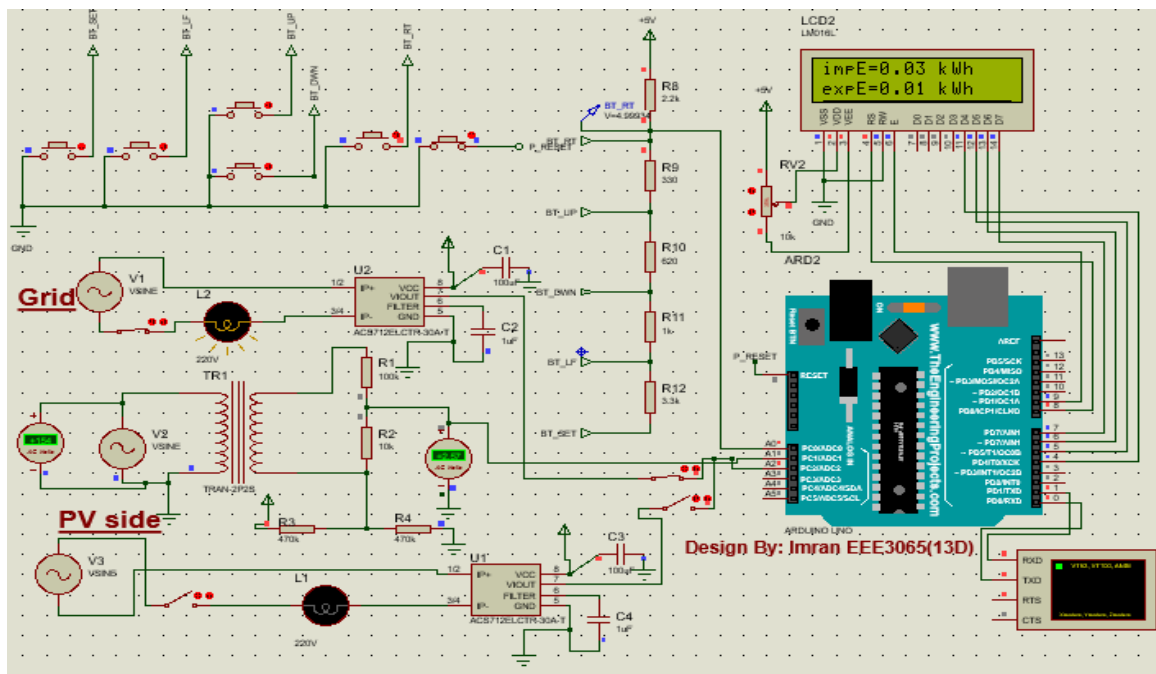


Figure 28: Bi-Directional energy meter measuring Import and Export Energy

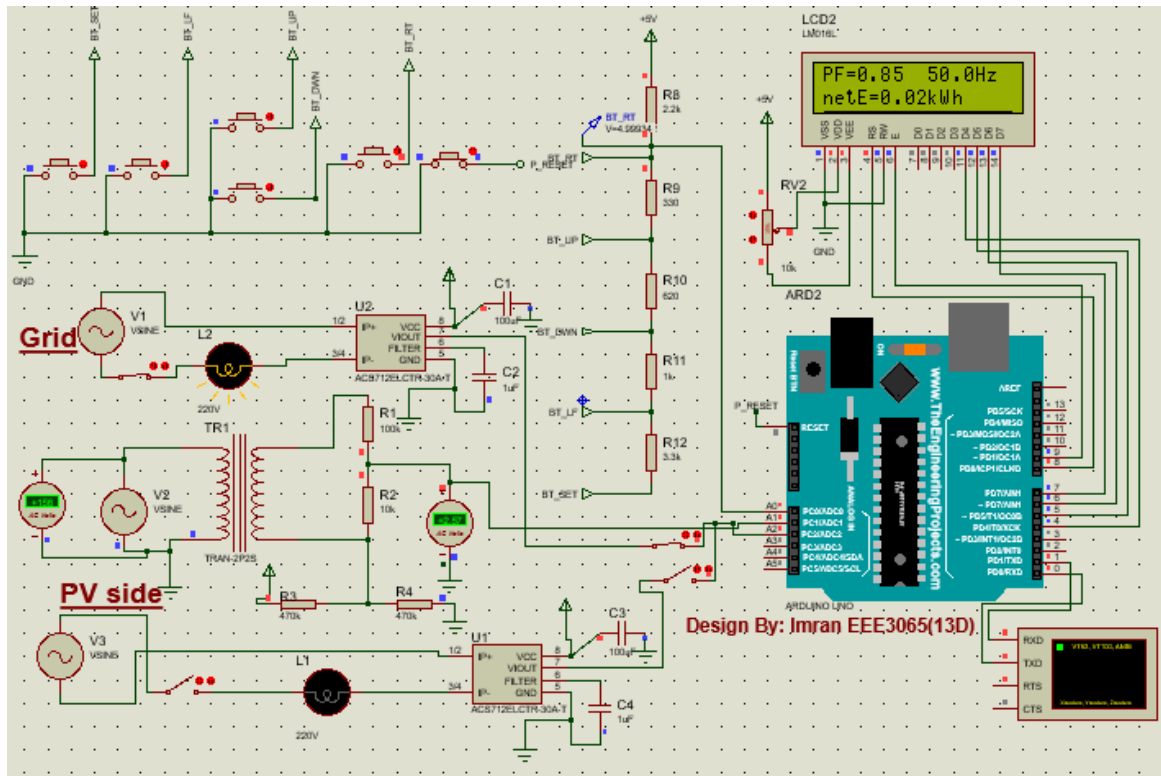


Figure 29: Bi-Directional energy meter measuring Power factor, Frequency and Net value

Figure (Figure 26) shows the complete circuit diagram of a bi-directional energy meter called Net-Meter. 1st source considered as the power which comes from grid and 2nd source considered as the power which comes from PV side. According to the figure (Figure 20) output of the inverter or PV side showed in figure (Figure 27) where the Current, Voltage and Power measure by Arduino. Figure (Figure 28) shows Arduino measuring the value of total Import and Exported energy and calculate it according to figure (Figure 22). Finally, systems Power Factor, Frequency & Net Energy be calculate which showed in figure (Figure 29).

Chapter6 FUTURE SCOPES

The government of Bangladesh has already decided to equip all Govt. Building and all public and private industries to set rooftop solar system including Net-Metering system. To reduce carbon pollution and to save the earth from greenhouse effect and also to save money it's would be a best money-saving choice, and it prompts people to switch to a solar PV system according to Net-Metering system.

Chapter7 CONCLUSION

Solar power, or electricity generated by the sun, is a visually appealing solution to reduce our reliance on electricity generated by burning fossil fuels. As the power produced by solar energy using PV systems is difficult and costly to store, this net metering provides opportunity to supply the excess power produced to grid and when solar power is not sufficient or unavailable, power can be drawn from grid, thus creating an opportunity of two-way supply and making solar energy more reliable. By using this system customer be profited financially and the demand of electricity will be covered by producing their own generated electricity.

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