THE REPUBLIC OF TURKEY

BAHCESEHIR UNIVERSITY

THE INTEGRATION OF RENEWABLE ENERGY SOURCES AND STORAGE IN SMART GRID

Master's Thesis

SANDER ADNAN MAHMALJI

ISTANBUL 2020

THE REPUBLIC OF TURKEY

BAHCESEHIR UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
ENERGY SYSTEMS OPERATION AND TECHNOLOGY

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Name of the thesis: The Integration of Renewable Energy Sources and Storage in Smart Grid
Name/Last Name of the Student: Sander MAHMALJI
Date of the Defense of Thesis: 26/06/2020

The thesis has been approved by the Graduate School of Natural and Applied Sciences.

Assoc. Prof. Burak KÜNTAY
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I certify that this thesis meets all the requirements as a thesis for the degree of Master of Science.

This is to certify that we have read this thesis and we find it fully adequate in scope, quality and content, as a thesis for the degree of Master of Science.

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ACKNOWLEDGEMENT

Above all else, I want to thank God for direct me and being by my side until the end of my studies.

To my family who shown me all the materials and spiritual efforts to get a good education since my childhood.

To all my dear professors and the academic stuff at BAHÇEŞEHİR University who constantly supports and motivates me during my master studies.

A special thanks to my thesis advisor Assist. Prof. Dr. Nezihe YILDIRAN for all the helpful information and suggestions which have led up to the improvement of this thesis.

To al Bawaker contracting company in Saudi Arabia, to give the chance to work and study the same time and being flexible with vacation days to travel between Turkey and Saudi Arabia.

ABSTRACT

THE INTEGRATION OF RENEWABLE ENERGY SOURCES AND
STORAGE IN SMART GRID

Sander Mahmalji

Energy Systems Operations and Technology

Thesis supervisor: Assist. Prof. Dr. Nezihe YILDIRAN

Jun 2020, 165 pages

For the transaction from traditional old utility grid system to smart grid many integrations with renewable energy sources and energy storages are required, moreover advance controllers, communication system and power electronics is needed to make the smart grid more reliable and stable.

This research aims to improve the integration for renewables and energy storages with the utility grid and consumers by using power electronics and communication networks, two renewable energy sources are simulated with 1.625 MVA consumer loads, 1.5 MW double feed induction generator wind turbine and 105 kW photovoltaic energy system with a common dc bus for 196 kW tesla lithium batteries bank energy storage system and the peak power for the batteries charging or discharging around 60 kW , depends for the state charge of the batteries, the nominal power for the three phase three level inverter is 120 kW .

The simulation for the system is going to be by MATLAB Simulink for real time, PVSYST for estimating the photovoltaic power production around the year, and EXCEL for estimating the wind turbine yearly power production.

The system works perfectly well in various scenarios and changeable variables at the same time, as the sun irradiation increasing or decreasing and photovoltaic temperature increasing and decreasing with variable power reference for the inverter and variable wind speed for the wind turbine, the total voltage harmonics distortion is equal or less than 3 % , and the alternating current frequency is 50 Hz with a variance of 0.03 Hz, which is good for the stability of the grid.

Keywords: Smart Grid, Renewable Energy, Power Electronics, Solar Energy,

Wind Energy.

ÖZET

AKILLI ŞEBEKEDE YENİLENEBİLİR ENERJİ KAYNAKLARININ VE DEPOLAMANIN ENTEGRASYONU

Sander Mahmalji

Enerji Sistemleri İşletim ve Teknolojisi

Tez Danışmanı: Dr. Öğr. Üyesi Nezihe YILDIRAN

Haziran 2020, 165 sayfa

Geleneksel şebekeden akıllı şebekeye geçiş sırasında yenilenebilir enerji kaynaklarının entegrasyonu, enerji depolama gibi yenilikler gerekli. Dahası akıllı şebekeyi daha güvenilir ve kararlı hale getirebilmek için ileri kontrolörlere, haberleşme sistemlerine ve güç elektroniğine ihtiyaç var.

Bu çalışma güç elektroniği ve haberleşme ağlarını kullanarak yenilenebilir enerji kaynaklarının ve enerji depolamanın şebekeye entegrasyonunu iyileştirmeyi amaçlar. Simülasyonu gerçekleştirilen sistemde 1.625 MVA gücündeki yük, rüzgar sistemi için 1.5 MW çift beslemeli asenkron jeneratör, 105 kW gücünde fotovoltaik enerji sistemi, 120 kW güç değerinde üç fazlı üç seviyeli evirici, 196 kW Tesla lityum aküden oluşan enerji depolama sistemi bulunmaktadır. Akülerden alınabilecek maksimum güç akülerin şarj durumu verisine göre 60 kW değerindedir.

Tez çalışmasında yapılan simulasyonda, gerçek zamanlı analiz için MATLAB Simulink, yıllık fotovoltaik enerji üretiminin hesaplanması için PVSyst ve yıllık rüzgar enerji üretiminin hesaplanması için Excel kullanılmıştır.

Oluşturulan sistem; güneşlenme miktarının artış ve azalışı, panel sıcaklığının artı ve azalışı, rüzgar hızının değişimi gibi çeşitli senaryo ve farklı koşullarda gayet iyi çalışmaktadır. Simülasyon sonuçlarına göre toplam harmonik distorsiyon %3'e eşit ya da küçük, çıkış frekansı 0.03 Hz değişim ile 50 Hz değerlerinde elde edilmiştir. Elde edilen sonuçlar şebeke kararlılığı için başarılı olarak değerlendirilebilir.

Anahtar Kelimeler: Akıllı şebeke, Yenilenebilir enerji, Güç elektroniği, Güneş enerjisi, Rüzgar enerjisi.

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1. INTRODUCTION

Electricity is one of the most important things that has discovered in this world, most of the world completely depends on their working on computers and machines moreover, engineering and technical activities are depending completely on electricity, building materials and welding depend on electricity, as known engineering work needs electricity always, without electricity many horrible scenarios is going to happen, but by hanging on the electricity the demand is increasing rapidly, and most of the energy production comes from fossil fuels, which is going to finish after fifty or seventy years because the reserves for it are limited, the energy production from fossil fuel produces huge green gas that causes climate change and global warming, those effects are increasing rapidly and started to see their effect in the daily routine, as the extreme weather events in summer or winter, where the summer is getting much wormer, on the other hand in winter it is getting much colder, also sea and oceans water level increases 3 millimeters per year on average around the world and that's due the increases of ice melting in the Northern hemisphere pole.

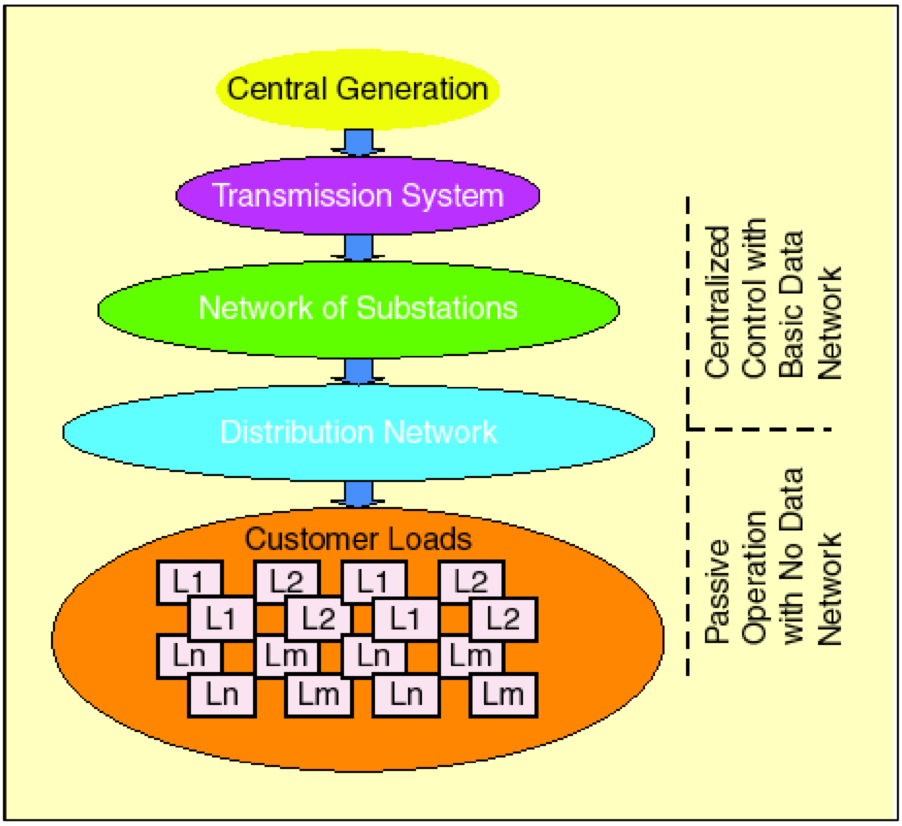
The only way to save the earth and humans civilization for the next generations coming after us is by reducing depending on fossil fuel to limit the climate change and global warming, with starting to integrate the renewable energy and storage system to the grid to balance the demand and increase the efficiency of the total system. But the old grid structure cannot support integrating the renewables energy with it, old grid structure need upgrading to be more intelligent digitalized two way energy network, this could be achieved by integrating information telecommuting power technology with the excessing energy system, the benefit from this smart grid is to improve efficiency, liability and the stability of the electricity supply.

In this research the integration of renewable energy sources and storage in smart grid is examined by connecting a 105.3 kW photovoltaic panels to the boost converter then connect the output power from the boost converter to a DC bus with bi directional converter to charge or discharge the 196 kW tesla lithium batteries bank and control the output power of the inverter, the 120 kW three phase three level inverter is going to generate a synchronized three phase voltage with three phase current in the same phase with the grid, the automatic three phase inverter breaker will protect the grid from any distribution or harm, while the wind turbine consumes power at first to power up the double feed induction generator, then the rotation power coming from the rotor will force the generator to supply electrical power, but this electrical is going to be converted into dc then again into a synchronized three phase alternating current and voltage throw an inverter to supply the power to the grid, while 1.625 MVA consumers are connected to the grid.

2. LITERATURE REVIEW

Most of the world relies on the existed grid which built before 50 years ago, the electricity needs were simple such as few light bulbs and radio. The big power station was centralized and build around the community can easy to control but it is one limited way integration. Traditional grid system, that is shown in Figure 2.1 is inefficient and cannot offer immediate response for today's challenges. System is like a gravity driven water system, the power goes from the top of the hill to downhill to meet the demand for the electricity, and it can be controlled only from the power stations, and any failure across the distribution network cause blackout for the system [1].

Figure 2.1: Traditional old grid system [1]

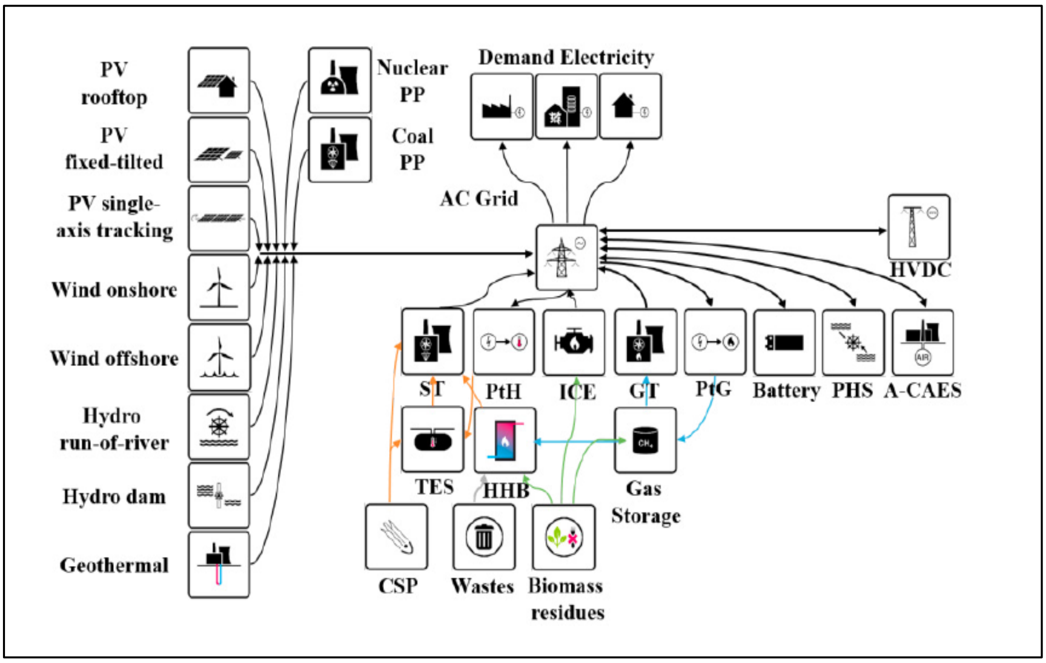


It will be necessary to change the ageing old grid into the smart grid, which is intelligent digitalized two way energy network optimally delivering electricity from source to consumption, this achieved by integrating information telecommuting power technology with the excessing energy system, the benefit from this smart grid is to improve efficiency and liability of the electricity supply. Integration of more renewable energy such as wind and solar energy into the excessing electrical network and supporting the development of electric cars, and for customers to improve the optimization their electrical consumption throw a smart meter, and reduce carbon emission and realizing the full potential of what humanity can offer to use all the resources in the most effective and efficient way.

Aquib Jahangir, 2018 examines DC microgrid with renewable energy such as wind turbine, solar photovoltaic panels and battery bank storage system. The system is controlled by interfaced with dc loads. The battery is connected throw bi-directional converter for charging from the DC grid and discharging from the battery to the DC grid, it is a good idea for beginning to upgrading the old grid into a new modern one, and start depending on renewables energy only for supplying power.

Storage systems for Europe the transition to 100% renewable energy in 2050, by the integration of many renewable sources and energy storage systems as shown in Figure 2.2 is examined (Michael Child, Dmitri Bogdanov, 2018). The study proposes to divide Europe regions into 20 independent energy systems by area, the transmission lines between this areas is going to be with HVDC, the battery storage systems will appear in 2020 in the system and 2030 these batteries will satisfy the shorter term for peak demands moreover, the residential commercial and industrial building should be installed of rooftop PV systems and batteries to be self-generated, and minimize the power consumed from the grid and minimize the cost of their own electricity consumption.

Figure 2.2: Integration of renewable and storage [3]



The comparison between the two-level and three-level inverters efficiency under SVPWM strategy is examined by (Long Zhao, Qunjing Wang, 2014) the authors shows that the efficiency for the two-level inverter between 94-88% and for the three-level inverter between 96-93%.

Three phase inverter grid connected mythology explaining by (Caido Deng, Zhan Shu, 2014) by controlling the PWM for the inverter by combination of current deadbeat controller and PI controller and comparing the output voltage and current with the grid voltage when three phase symmetric load is connected to the system.

The multilevel inverters can reduce power semiconductor losses, voltage transient at motor winding and harmonics losses. Rudolf Mecke, 2015 compares the efficiency of a drive system using a two-level, three-level and five level inverters and showing the five-level inverter have more power efficiency and less harmonics distortion.

Frede Blaabjerg, Yongheng Yang, 2015 specifies that renewable energy nowadays have advance power electronics and controllers to get the maximum productivity from it.

This research focuses on finding a good way to integrate wind turbine and photovoltaic system with the grid without affecting its stability under many various conditions and adding a batteries storage system on common DC bus before inverter and controlling the output power of the inverter to helps with peak demand hours or save the power and used later.

3. PARTS OF THE ENERGY SYSTEM

The main components are going to be used in the system is the energy sources to generate electrical power and power electronics to help to synchronized with the main grid and the transmission lines to deliver the power to the consumer.

3.1 ENERGY SOURCES

The electricity generation from thermal power plants produces a large amount of green gases compare with zero emission renewable energy such as photovoltaic and wind turbine, in turkey the CO_2 producing from thermal power plants is shown in table 3.1 [8].

Table 3.1: Comparison of specific emission factors (kgCo2/MWH)

Fuel type	kgCo2/MWH
Fuel oil	604
Hard coal	844
Lignite	1018
Natural gas	375
Oil (IEA, 2010)	714
Coal (IEA,2010)	1037
Natural gas (IEA, 2010)	350

Renewables energy is the main key for limiting the earth climate and global warming by reducing the green gas emission for electricity generation from thermal power plants, there were many types of research on renewable during the oil crisis in 1970 but after the 1980s the researchers drop off because the fossil fuel markets become stable and cheap, but at the beginning of 21st century, the world get back again to invest in the renewables.

3.1.1 Photovoltaic Energy System

The key element of photovoltaic energy system is solar cells. The development of photovoltaic solar cells can be divided into three main generations of solar panels divided into 7 different types [9]:

Monocrystalline solar panels (first generation):

Is made from monocrystalline and it the purest type, you can easily know it from uniform dark and rounded edges and the newest type are reaching above 20%.

Polycrystalline solar panels (first generation):

Is famous with squares, and its angle is not cut, its color is blue speckled look, they are madding by melting raw silicon which is faster and cheaper in producing but it has a low efficiency around 15%.

Thin film solar panels (second generation):

Are less expansive, these solar panels are created by placing one or more film of silicon, cadmium or copper onto a substrate, this type of solar panels is easiest to produce and more economical, and most advantage of them that they are very flexible.

Amorphous silicon solar cell (second generation):

Are used in a pocket calculator and use a triple layered technology, where is excellent with the thin film variety, which it has a thickness of almost 1 micrometer and have 7% efficiency and the advantage of this solar cell that is low in cost.

Biohybrid solar cell (third generation):

Is still in the research phase, the idea comes from new technology to improve the photosystem 1.

Cadmium (third generation):

Is low cost and has a short payback time almost a year, but solar panels need water for production, the disadvantage of cadmium is that its characteristic is being toxic if ingested or inhaled.

Concentrated PV Cell (third generation):

Generates energy as a photovoltaic system do and they have an efficiency rate up to 41%.

There are three different general structure to use the photovoltaic panel system [10]:

Firstly, on-grid photovoltaic panels:

the most common in houses and businesses, the advantage of this system is no battery needed for it, the extra power produced from the solar system is added to the grid, but with a small disadvantage is when there is no electricity in the grid it cut off the electricity on the whole system.

Secondly, off-grid system:

Is not integrated with the grid and required battery storage, it must design with accuracy to let the system generate enough power and enough battery capacity for the loads needed around the year even in winter when the sunlight is less, the disadvantage is the costly prices for the battery and every ten or five years have to replaced again.

Thirdly, hybrid system:

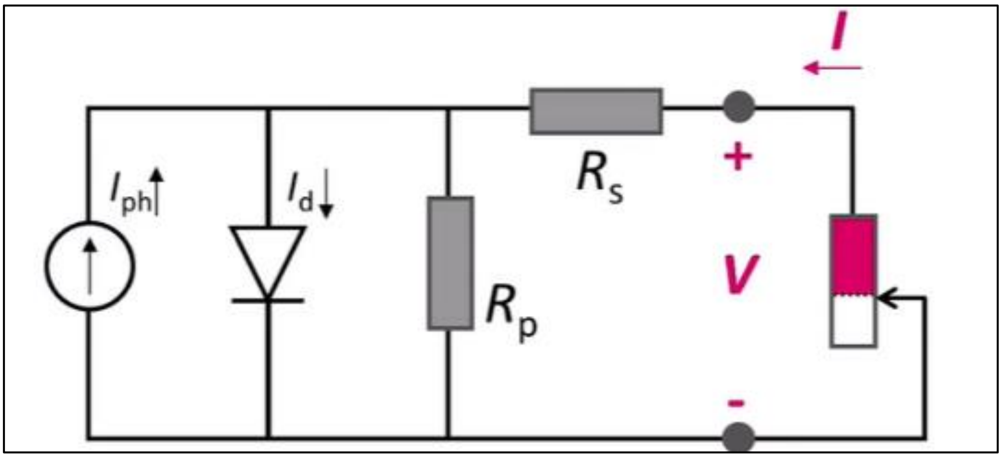
Is combined with the on grid system and the off grid system, it is already integrated with the grid and the battery, this means able to store the electrical energy and use it later at night or when the utility cut off.

Photovoltaic cells are based on gathering two semiconductors with different concentrations, the two materials type N (semiconductor with surplus electrons negative charge) and type P (semiconductor with lack of electrons, called holes, positive charge).

When gathering type N and type P semiconductor, the holes start to travel from P regain to the N region, also the elections start to travel from N regain to the P region through P-N junctions creating diffusion current, the fixed ions near junctions create an electrical field which it is opposite to the direction of the current, where create a drift current, the diffusion current is the same as drift current with make balanced, so the net current is zero.

When the sunlight hit the cell, the solar irritation helps the protons to be absorbed by the electrons, which destroy their bonds and making hole electrons pairs, and the charge being move by the electrical field, and proceed through the P-N junction, so if an extra load connect the potential difference will be between cell terminals will create a current, Figure 3.1 shown the solar single diode cell equivalent circuit [11].

Figure 3.1: Solar single diode cell equivalent circuit [14]



I pv current source for the cell: present the current produced from the cell.

Id-1 diode dark diffusion current: is the solar cell diode which allow some current to pass throw.

Rp shunt resistance is the leakage across P-N junction around the edge

Rs series resistance is the bulk resistance of the metal electrode which contact the resistance between semiconductor and metal

V: the output voltage on the load

The current source equation is given by equation (3.1)

$$I = I0\left(exp(\frac{q(V - I\ x\ Rs\ )}{n\ x\ Kb\ x\ T}) - 1\right) + \frac{V - I\ x\ Rs}{Rp} - Iph \tag{3.1}$$

I_0 : drake saturation current.

n : diode identity factor which is normally one.

q : elemental charge ($1.602176634\times10^{-19}$ C)

K_b : Boltzmann's constant (1.3807 x 10^{-23} j)

T : temperature.

As increasing the R_s from zero to 10 ohms at 0.7 voltage cell when R_p equal to 10,000 ohms the solar cell goes from diode characteristic to almost linear characteristic resulting in decreasing the maximum output power, even V_{oc} and I_{sc} stay the same, it effects the fill factor of the solar cell.

Otherwise R_p is parallel to a load so it should be large as possible, or output power will reduce for the load when R_s equal to zero.

The newest technology for a photovoltaic cell is using double diode model and triple diode model, even more half cute size cell method is used to increase the photovoltaic cells number and decrease the single cell current which leads to lower resistive loses and reduce the shading losing efficiency.

The Voltage of open circuit V_{oc} is the maximum output voltage of the solar panel measured while it is disconnected from the load, also short circuit current I_{sc} is the maximum output current of the solar panel if a short circuit happened in the solar panel, from this two parameters a maximum output voltage V_{mpp} can be determined and maximum output current can be determined while it is connected to the load, also a fill factor can be determined by this relation and as shown in equation (3.2).

$$FF = \frac{Imp\ p\ x\ Vmpp}{Isc\ x\ Voc} \tag{3.2}$$

The output power from the photovoltaic panel changes due to the sun irradiation, shading effect and temperature, a maximum power tracking converter need to extract the maximum power from the photovoltaic panel under the output variation of voltage and current generally it is a boost converter. For grid integration with the photovoltaic system, an inverter connection required between the grid and DC power coming from the maximum power tracking device, therefore the inverter converters the DC power into a three-phase alternating power, to not harm the grid voltage or current waveforms the inverter voltage and current waveforms must be in the same phase with the grid [12].

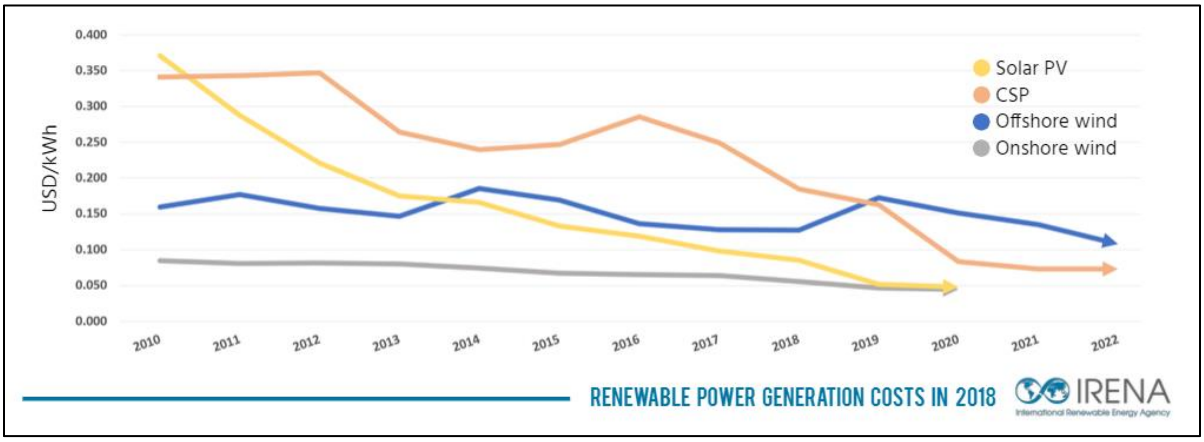
3.1.2 Wind Power

Wind energy is a form of solar energy, one or two percentage of solar energy that hit the earth is converted to wind energy, the wind is generated from the unbalance atmosphere temperature which gets heated by the sun, the terrain of the earth surface, the round cycle of the earth, distribution of water and trees that gives a green cover, the air wind flow or its kinetic energy is observed by modern wind turbines to rotate it is blades and generate electrical power, according to betz's law no turbine can capture more than 59% of the kinetic energy in the wind [13].

In 1980 the first wind farm was built, it was including 20 wind turbines in the USA, New Hampshire, although Denmark started to build offshore wind turbines [14] [15].

From 1995-2000 the wind turbine rotors get bigger and stronger to reach 50 meters diameter, and wind turbines were able to generate electrical power up to 750 kilowatts, almost ten times larger than ten years ago, in 2005 wind energy globally was generating capacity of 59,091 Megawatt, and in 2008 the capacity reaches 120,291 megawatts, in 2013 wind turbines become the third largest electrical source of power in China, that's because on the last decades the wind power generation cost stayed decreasing as showing in Figure 3.2, in 2010 it was almost 0.08 cents for the onshore wind for every kW h, but by the of 2019 it is 0.03 cents for every kW h [16].

Figure 3.2: Cost of wind energy per kW h [16]



The main parts of the commonly used type horizontal three blades wind turbine are shown in Figure 3.3-.

Figure 3.3: Main parts of horizontal wind turbine

Foundation usually is a simple concrete block under the walls or columns, but with wind turbine the foundation is under the wind turbine, to carry the all the wind turbine and prevent the soil erosion during strong wind, because wind turbine normally is more than 80 meters high, when the wind pass throws the blades it forces the blades to rotate for generating power, and turbine housing to tend on the tip that's why the foundations must handle all those effects on it.

Tubular Tower:

Is made up from rolled steel plates welded together with flanges top and bottom to build the parts above each other's and getting narrower to the tip, panted with waterproof paint, on the first rolled steels have two doors, the lower one takes to a high voltage step up transformer or the transformer can be in the nacelle, the other one is the main entrains for the turbine where the control cabinet, series of ladders to a different level plate forms, elevator, and the cables on the wall of the tower, but at some point the cables stop being attached to the wall and hang freely so they can twist as the nacelle rotate to face the wind, as going up the cable's path is going in a hole in the center of each platform.

Nacelle:

Where the torque coming to the rotor converts into electrical power, and main components inside are showing in Figure 3.4:

Shaft is used to move the mechanical energy from the blades to the gearbox and from the gearbox to the generator.

Gearboxes is used to convert the low speed with high torque power coming from the rotor blades to a high speed low torque power then to it a mechanical break connected to a shaft to the generator.

Generator takes the output rotation from the gearbox in making the generator shaft to spin and generate electrical power due to Faraday's law of electromagnetic induction principles.

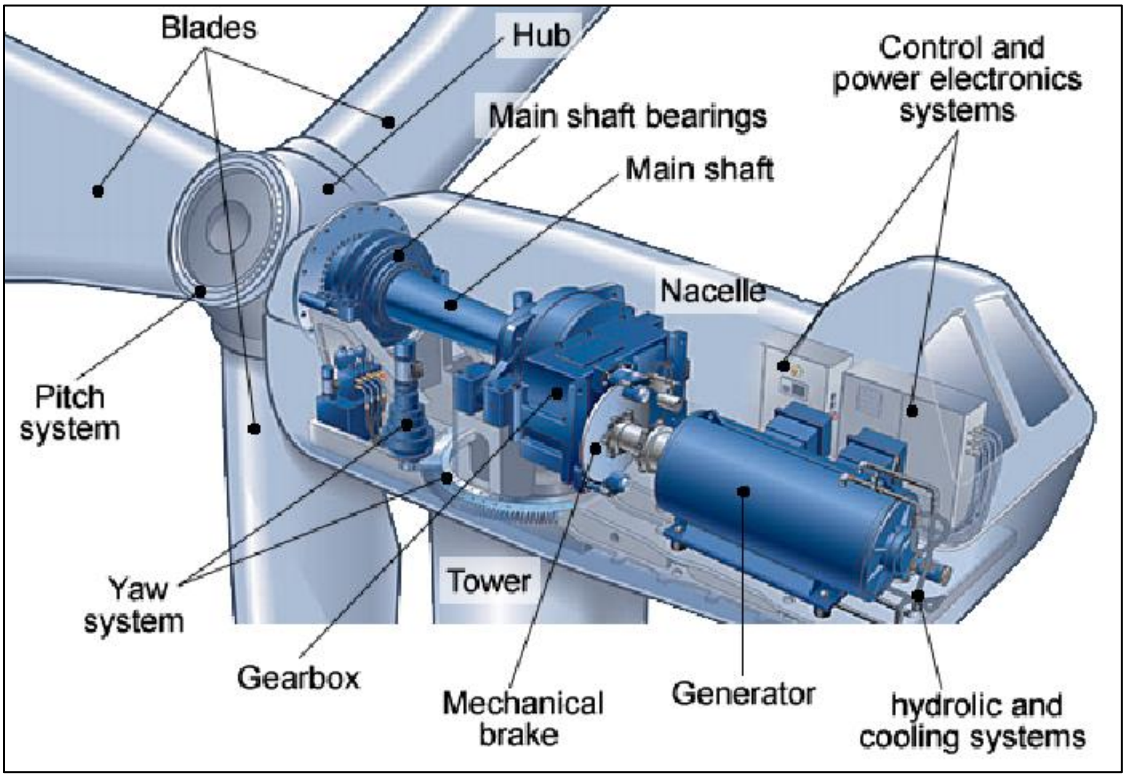
Hydraulic and cooling systems is used to cool the generator while working.

Yaw mechanism: allows the wind turbine to turn the rotor and the nacelle to rotate to face the wind direction.

Anemometers are generally located on the top of the nacelle, this device measures the wind speed and it is directions.

Control and power electronics systems is used for controlling the work magnesium of the wind turbine and controlling the electricity pumping into the grid.

Figure 3.4: Main components of the nacelle



Rotor connects the blades together and converts the mechanical power of the wind to low speed with high torque power and having a pitch controller.

From the datasheet of a wind turbine:

The rated power: the maximum power for the wind turbine

Hub height: the height for a hub from the earth the rotor diameter: the radius is half of this area.

The area swiped: the area swiped from the blade's rotation.

Blades rotational speed: how many times the blades will make a full cycle in one minute.

Pitch angle control: used to control the angle of the blades in a wind turbine.

Cut off speed: when the turbine will turn off because the wind speed is very high.

Cut on speed: minimum wind speeds the wind turbine can work.

For estimating the power of the wind turbine, the wind speed bands must classify into 1 m/s then calculate the air density by the equation (3.3)

(3.3)

$$\rho = \frac{P}{T\ X\ R}$$

ρ: Air density (kg/m^3)

P: Air pressure (pa)

T: Temperature (kelvin)

R: Specific gas constant of air 2.8705

Then the kinetic energy of the air by the equation (3.4)

$$P = \frac{1}{2}\ x\ \rho\ x\ m^2\ x\ V^3 \quad (3.4)$$

P: Kinetic energy

m: Area

ρ: Air density

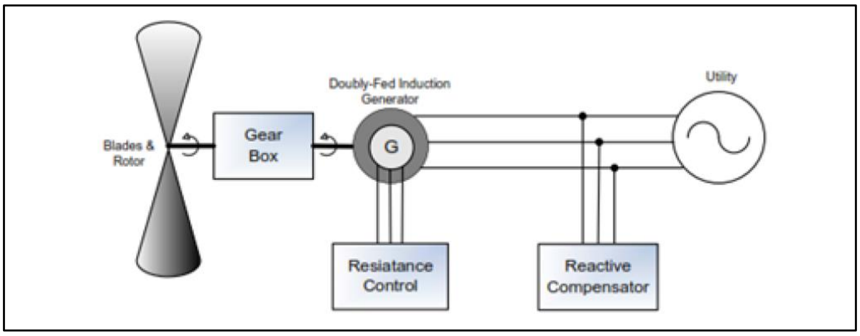
V: Air velocity

Then calculating the probability for the wind speed, then by Weibull distribution estimate the electricity will be generated by the wind turbine.

The wind turbine systems it is divided into three main types [17]:

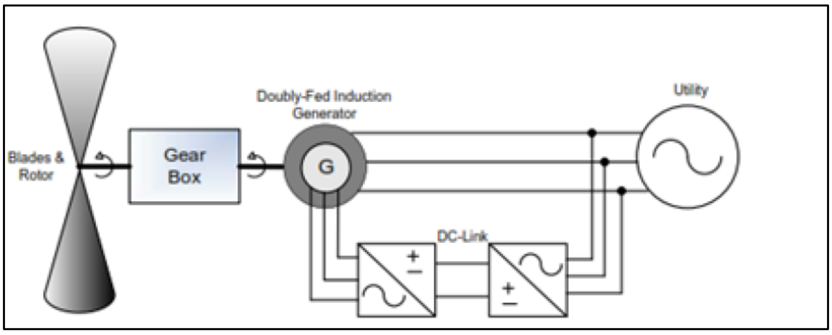
The first wind turbine connected with the utility directly without any power electronics components, this wind turbine must work with constant speed (with a variation of 1%-2%) also the generator required reactive power by adding a capacitor to the machine terminals, after that the generator wound rotor induction adds to the system, and extra resistance adds controlled by power electronics, this type needs a soft starter and reactive power compensator as shown in figure 3.5-.

Figure 3.5: Wind turbine with a resistance controller [17]



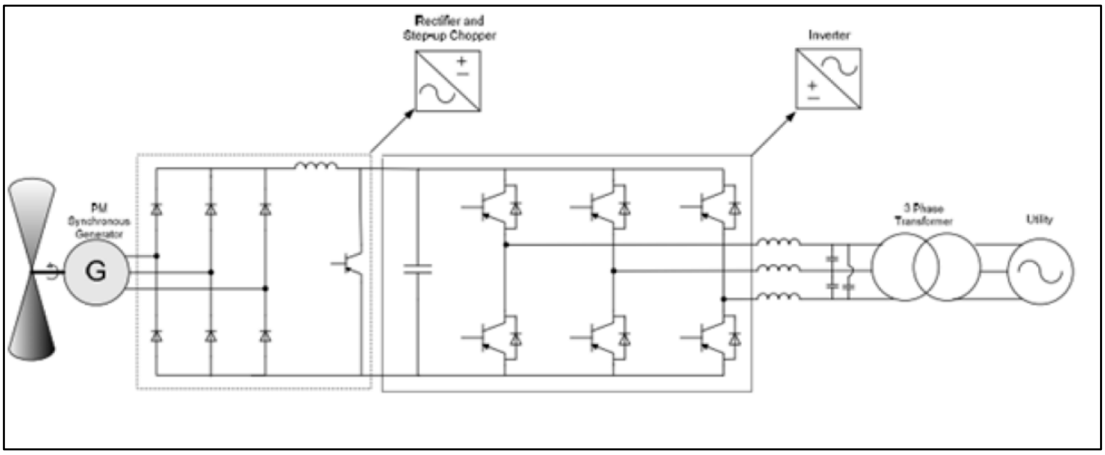
the doubly fed induction generator wind turbine as shown in figure 3.6-, the power generated connected to a rotor with a slips controls the current, this structure allows the wind the turbine to have a various working speed, if the wind turbine generator working on high synchronously electrical power reaching the grid throws the rotate and sector, but when it is not working on synchronously mode the electrical power reaching the grid throw the rotor only, the advantage from this structure to provide reactive power and get more efficiency from the wind power.

Figure 3.6: Double feed induction generator [17]



This design uses full scale power electronics structure use synchronous three phase generator as shown in figure 3.7-, to use the convert the variable input wind speed to a variable voltage with the variable frequency output, then converted to DC throw a rectifier then to an AC throw an inverter, this structure provides the best controllable characteristic for the wind turbine.

Figure 3.7: Wind turbine with power electronics and transformer [17]



3.1.3 Energy Storage

Energy storage is a method for store the extra electrical power from the power source when there is not enough load for or used it later, this method is helpful because too much renewable energy is connecting with the grid, and for updating the old grid to smart grid to helps with the peak demand hours, although some times the renewable energy as a wind turbine or photovoltaic panels are turning off when the electricity demand is very low, to not let this electrical energy goes to west energy storage are very important to balance the grid, also so many devices use to the storage system in a small scale like the phone battery or laptops.

Dc battery is most common energy storage using, this battery uses direct current in two ways for charging and discharging the battery, the first battery invented by the Alessandro Volta in 1800, it was very simple a two plates of copper and zinc separated by wet salty cloth, the voltage for it was 0.76 V, then the evolution of lead acid battery started in 1856 then developed to the battery seen today [18].

Most of Dc batteries is a collection of one or two or more cells together, having chemical reactions between these terminals to produce or absorb electrons, the main three layers for any battery is the anode negative side, the cathode positive side and the third layer is a conductive substance to let the electrons move freely and letting the chemical reaction between the anode and cathode happened, and it called the electrolyte, therefore when the anode and cathode are connected to a circuit the chemical reactions starts between them through the electrolyte forcing the electrons to flow into charging mode or discharging mode [19].

The main four types for the DC batteries are [20]:

Lead acid

The common automobile batteries in which the electrodes are grids of metallic lead containing lead oxides that change in composition during charging and discharging. The electrolyte is diluted sulfuric acid. The new AGM battery technology has made a huge impact on lead-acid batteries, making it one of the best batteries to use in solar electric systems. Industrial-type batteries can last as long as 20 years with moderate care, and even standard deep cycle batteries, such as a car battery, should last 3-5 years.

Intermediate batteries should last 7 to 12 year its advantages are:

i. Low cost.
ii. Reliable. Over 140 years of development.
iii. Robust. Tolerant to abuse.
iv. Tolerant to overcharging.
v. Low internal impedance.
vi. Can deliver very high currents.
vii. Can be left on trickle or float charge for prolonged periods.
viii. Wide range of sizes and capacities available.
ix. The world's most recycled product.

Ni-cd

Nickel Cadmium Batteries 1.2 Volt secondary cells using alkaline chemistry with energy density approximately double that of lead acid batteries. Invented in 1899 however only brought in extent within the early 1960'sThey use nickel hydroxide Ni (OH) 2 for the effective electrode (cathode), cadmium Cd because of the negative electrode (anode) and an alkaline potassium hydroxide KOH electrolyte. Their small size and excessive rate discharge capability made portable equipment and different purchaser packages sensible for the first time. The cells are sealed and utilize a recombinant device to save you electrolyte loss and amplify the useful lifestyles its advantages are:

i. Low internal resistance (less than half the equivalent NiMH cells)
ii. High rate charge and discharge rates possible
iii. Up to 10C discharge rates for short periods typical
iv. Flat discharge characteristic (but falls off rapidly at the end of the cycle)
v. Tolerates deep discharges - can be deep cycled.
vi. Wide temperature range (Up to 70°C)
vii. Typical cycle life is over 500 cycles.

NIFE

Invented over one hundred years in the past by Thomas Edison as a non-polluting and non-consumable alternative to Lead Acid Batteries the usage of no heavy metals. Now synthetic once more worldwide after lead acid battery organizations closed Edison's Plant in 1972, a sourced NiFe at a competitive fee at a bit over double cheap lead acid range and just like Rolls battery expenses. This makes them a very feasible choice for long term off grid solutions. You need 10 cells to make up a 12V financial institution, 20 cells for a 24V financial institution and 40 cells for a 48V bank They have low operation value, low self-discharge, lengthy biking existence and environmental-friendly. They can face up to deep discharge, huge temperature variations, mechanical & electrical abuses and nonetheless show super and reliable performance over a protracted length. The operation existence of solar Ni-Fe batteries is thirty-forty years, the operating temperature variety maybe -forty to 60°C, which is also the longest lifestyles battery for the PV gadget.

Lithium

The fine lithium battery chemistry for solar packages is Lithium Iron Phosphate, shorted to LiFePO4 or LFP batteries. This new technology lasts longer and maybe put throw deeper cycles. They additionally require no preservation or venting, in contrast to lead-acid batteries, lithium batteries cost more up front, but the more efficient approach you could doubtlessly spend less consistent with kilowatt-hour of capacity over the lifespan of the battery, lithium-ion (Li-ion) batteries have several advantages over conventional lead-acid batteries:

i. High energy density, more energy with less weight
ii. High charge currents (shortens the charge period)
iii. High discharge currents
iv. Long battery life (up to six times the battery life of a conventional battery)
v. High efficiency between charging and discharging (very little energy loss due to heat development)
vi. Higher continuous power.
vii. Can handle heavy duty cycle for charging and discharging.

Battery technical design parameters for tesla lithium battery given in Figure 3.8-.

Figure 3.8: Tesla battery datasheet

PERFORMANCE SPECIFICATIONS

AC Voltage (Nominal)	120/240 V
Feed-In Type	Split Phase
Grid Frequency	60 Hz
Total Energy	14 kWh
Usable Energy	13.5 kWh
Real Power, max continuous	5 kW (charge and discharge)
Real Power, peak (10 s, off-grid/backup)	7 kW (charge and discharge)
Apparent Power, max continuous	5.8 kVA (charge and discharge)
Apparent Power, peak (10 s, off-grid/backup)	7.2 kVA (charge and discharge)
Maximum Supply Fault Current	10 kA
Maximum Output Fault Current	32 A
Overcurrent Protection Device	30 A
Imbalance for Split-Phase Loads	100%
Power Factor Output Range	+/– 1.0 adjustable
Power Factor Range (full-rated power)	+/– 0.85
Internal Battery DC Voltage	50 V
Round Trip Efficiency[1,3]	90%
Warranty	10 years

This is the datasheet for the tesla battery one of the most advanced lithium ion on grid battery for the company, it can also charge or discharge a peak power for 10 sec reaching half on its maximum capacity power at 7 kW , and 5kW for a continuous charge or discharging, but it will reduce the lifespan for it this battery has more than 5000 duty cycle and it's life span around 15 years with capacity degeneration to 80% [21], also the company give 10 years warranty on it, also this battery including the inverter and charge controller included but the DC parameters for it are for determining the capacity for it on ampere hour as shown in equation (3.5)

$$Ah = P \backslash V \qquad (3.5)$$

P: the total power of the battery

V: the voltage for the battery

Ah = 14000/50 = 280 Ah

For extending the lifespan for the battery the charging and discharging cycle must be controlled.

There are several ways to charge the battery:

Constant current: where the charging current stay constant and prevent the over current of the initial current charge, for the voltage will depend on the charging current, but normally the voltage is not controlled which could lead into overcharging the battery and temperature rise and affect the lifespan of the battery.

Constant voltage: where the charging voltage stays constant, when the during the initial stage of the charge the current will be high, but when the battery voltage reaches certain value the charge current decrease, it required long charging time and raising the temperature of the battery and affect the lifespan for it.

Constant current – constant voltage: it is combined the constant voltage method with the constant current method, firstly constant current is applying at the initial state of charge until it reaches a certain level then apply the constant voltage method to avoids the overvoltage, and it is the most efficient way for the battery but its charging speed are low [22].

3.2 TRANSMISSION AND DISTRIBUTION

Transmission lines are the way to transfer the electrical power from larger power plant to the distribution line to the consumer, but the smart grid is not relabeled on one source for power generation, it is difficult to the grid and control centers to manage between all the power generations with the consumers especially when renewable energy came to the grid. Smart grid added sensors and software for the transmission and distribution lines, give the utility and control center lives information to understand and react to changes quickly.

Normally the generation plants produce electricity at low voltage because it generates less stress on the armature of the alternator but low voltage transmission create more copper loss and voltage drop and more insulation of the transmission lines, so the voltage should be step up for certain level depends on the quantity of power and the distance need to transmit.

The low voltage level is below 600 voltage for AC system which uses in after the distribution transformers lines or in the generation power plant before stepping the voltage up, the medium voltage level is between 600 V to 69 KV for AC system used for the distribution network in the neighborhood’s.

High voltage 66 KV to 230 KV for AC system used to transmit a bulk quantity of electrical power and reaching to a large consumer, normally use with short transmissions line which has a length less than 60 KM.

Extra high voltage 230 KV to 1,100 KV for AC system used to transmit for longer distance with very high power transmission, generally use with medium transmission line which is between 80 KM and 250 KM.

Ultra high voltage above 1,100 KV this was a game changer to for electricity transmission, therefore is able to transmit five more times than the conventional lines, with over than six times the distance, normally used with long transmission lines which is longer than 250 KM.

New types of transmission lines entering the grid, which is high voltage direct current, this technology preferred for long distance bulk power supply, the longest high voltage direct current transmission lines are Belo Monte-Rio de Janerio, it 2543 km long transmission a 11.2 GW at 800 kV [23].

In Turkey, the low voltage level for the distribution lines are 400 V, although for the medium level transmission lines are 6.3 KV , 10.8 KV , 15.8 KV and 33 KV, and for the high level transmission lines are 66 KV , 154 KV , 380 KV, the electrical grid have a capacity over 90 GW in 2019 transmitting throw its lines, 30% of it comes from renewable energy, hydroelectric generate up to 32,000 MW, wind energy up to 10,000 MW, solar energy up to 3,000 MW and from geothermal power up to 700 MW [24].

3.3 POWER ELECTRONICS

It is an application of semiconductors for the control and conversion of electrical power, these semiconductor switches are diodes, thyristors and power transistor as a MOSFET and IGBT.

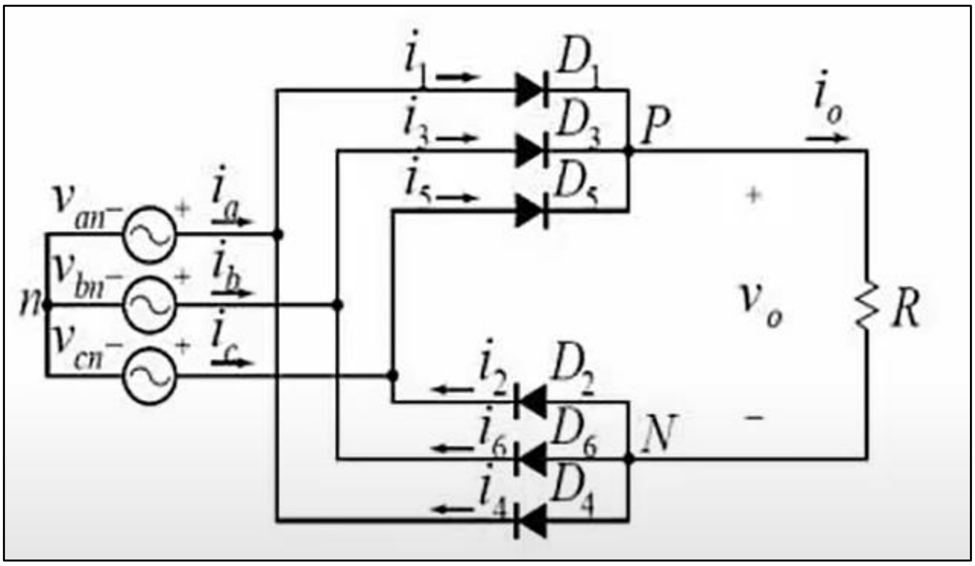
3.3.1 AC-DC

These types of power electronics used to convert the alternating current or voltage source into direct current or voltage, to charge up energy and use it later because ac signal cannot be stored, or to use in direct current loads.

3.3.1.1 Three Phase Diode Rectifier

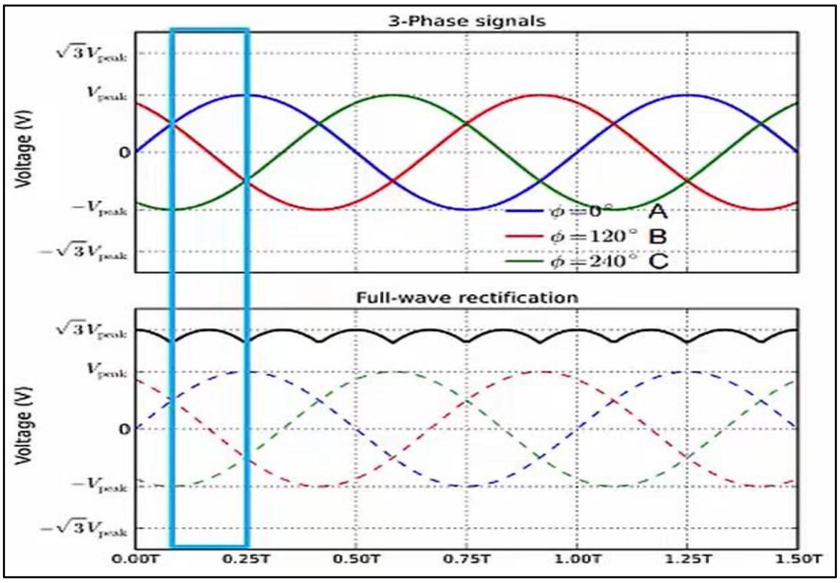
It is the basic form for converting the three phase alternating voltage into direct voltage shown in Figure 3.9-, three phase rectifier containing only six diodes arranging in a way to convert the alternating voltage into tow phase direct voltage, each phase is connected into two diodes points to the load at the same direction.

Figure 3.9: Rectifier circuit



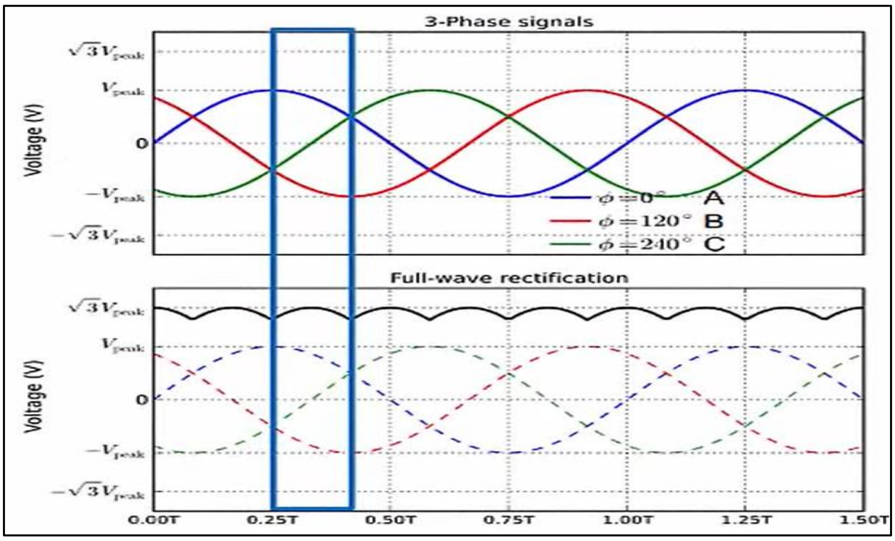
At Figure 3.10 shows alternating voltage from, from 0.0625T to 0.25T the alternating current on phase A at it is the maximum value and some current from phase B, it will pass throw diode number 1, 3 and diode 5 will block the current, then the current will go to the load completing it ways to node N, then it will choose the lowest voltage to complete it way at diode number 2 to phase C [25].

Figure 3.10: Rectifier output voltage from 0.0625 T sec to 0.25 T



At Figure 3.11 shows alternating voltage from, from 0.25T to 0.4375T the alternating current on phase A at it is the maximum value and current from phase C, it will pass throw diode number 1,5 and diode 3 will block the current, then the current will go to the load completing it ways to node N, then it will choose the lowest voltage to complete it way at diode number 6 to phase B, by repeating the same process for all as the positive voltage will from P node and go throw the load to N node then goes to the lowest voltage, the input peak voltage is going to be calculated from RMS value line to neutral Vpeak = $\sqrt{2}\ V_{LN}$, and the output peak voltage is going to be Vdc = $\sqrt{3}\ V_{peak}$, for the output voltage pules is going to repeat itself each $\frac{1}{3}\pi$ of its periodic period.

Figure 3.11: Rectifier output voltage from 0.25 T to 0.4375 T



3.3.2 DC-DC

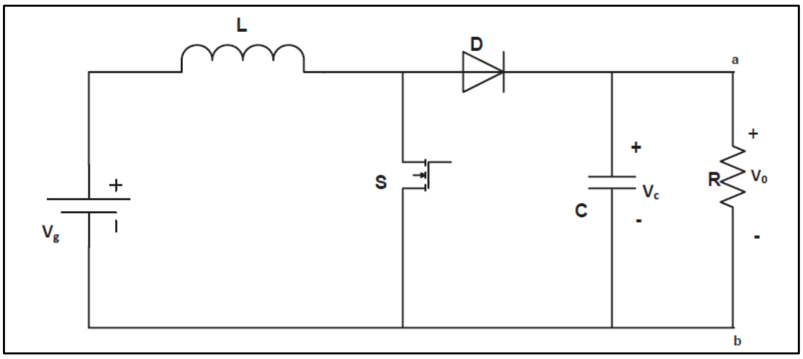
These types of power electronics used to step up or step down the direct current, usually small storage elements are used such as a capacitor and inductance.

3.3.2.1 Boost Converter

Used to step up the voltage and step down the current coming from the source to the load, the beginning for was in the 1960s for the power electronics needed on the aircraft. The DC source can be a solar panel to extract maximum power from it, AC/DC converter, battery, or in the electrical vehicle, the biggest advance boost converter offers a 99% efficiency only 1% is wasted.

It is containing of two semiconductors (IGBT or MOSFET and a diode) with two energy storage elements a capacitor and inductance as showing in Figure 3.12 , the main operation for the converters works on on-off time for the MOSFET or IGBT (T_{on} T_{off}) in a cycle or in the switching frequency f_s , normally use pulse width modulation for controlling T_{on} and T_{off}, it is working on two modes continuous conduction mode when there always an output voltage (the capacitor voltage never goes to zero) and discontinuous conduction mode when the output voltage rises and go back zero again (voltage capacitor goes to zero), it depends on the resonant frequency and the components [26][27].

Figure 3.12: Boost converter circuit [27]



On T_{on} all the current from source will go throw the semiconductor (inductor) as shown in Figure 3.13, due to the inductor capability it is building a magnetic field around itself and the voltage and the current increase according to equation (3.6)

$$\frac{\Delta Il}{\Delta t} = \frac{Vi}{L} \tag{3.6}$$

ΔIl : Change in inductor current

Vi : The input voltage

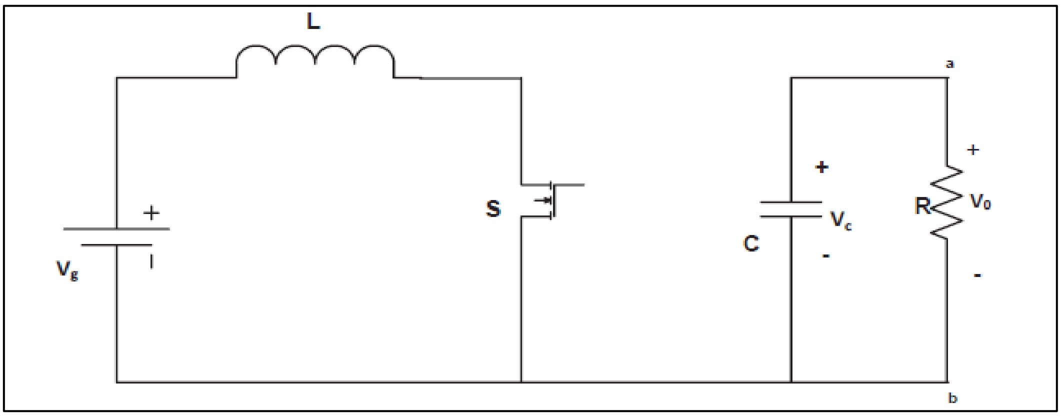
At the end of on state the increase of inductance current according to equation (3.7)

$$\Delta I_{L\ on} = \frac{1}{L}\int_0^{DT} Vi\ dt = \frac{DT}{L}\ Vi \tag{3.7}$$

The capacitor is going to empty its power and the capacitor current output showing equation (3.8) will power up the load during this time, the diode is going to preventing the current from go back to MOSFET direction

$$\mathbf{I_c} = \boldsymbol{C}\frac{\boldsymbol{dVc}}{\boldsymbol{dt}} = \frac{\boldsymbol{Il}}{\boldsymbol{C}} \tag{3.8}$$

Figure 3.13: Boost converter at Ton [27]



When the MOSFET turns off Figure 3.14, the inductor try to maintain the high level of current before, it doesn’t let immediate discharge happened in the current and react as another voltage source on series with the main source and discharge a current equation (3.9).

$$\Delta I_{L\ off} = \int_{DT}^{T} \frac{(Vi-V0)\ dt}{L} = \frac{(Vi-V0)\ (1-D)T}{L} \tag{3.9}$$

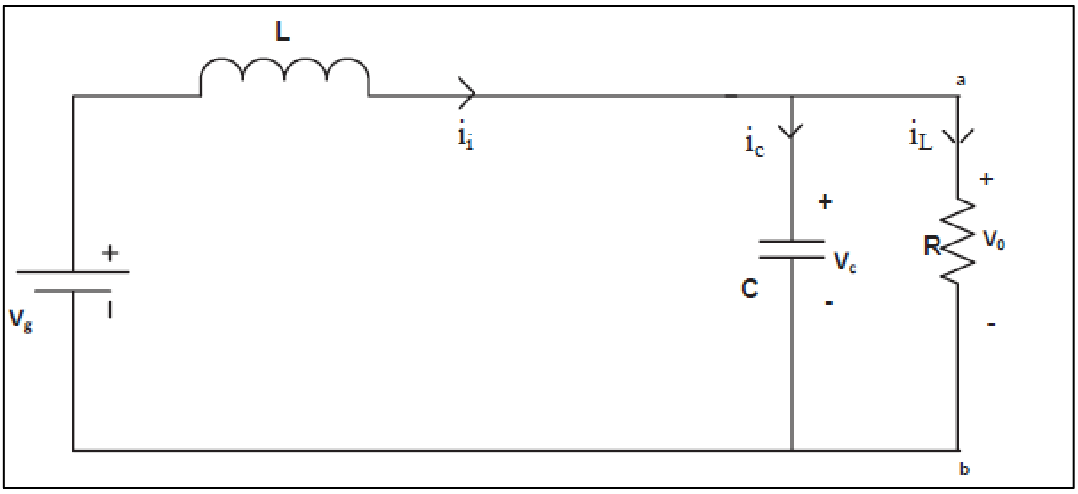
And the energy stored in the inductor is given by equation (3.10).

$$E = \frac{1}{2}\ LI^2 \tag{3.10}$$

Then the output voltage will charge up the capacitor into a higher voltage than before, by the equation (3.11).

$$\frac{\boldsymbol{dV0}}{\boldsymbol{dt}} = \frac{\boldsymbol{Ic}}{\boldsymbol{C}} - \frac{\boldsymbol{V0}}{\boldsymbol{RC}} \tag{3.11}$$

Figure 3.14: Boost converter at Toff [27]



The inductor current must be the same in start and end of the cycle there for

$\Delta I_{L\ on} + \Delta I_{L\ off} = 0$

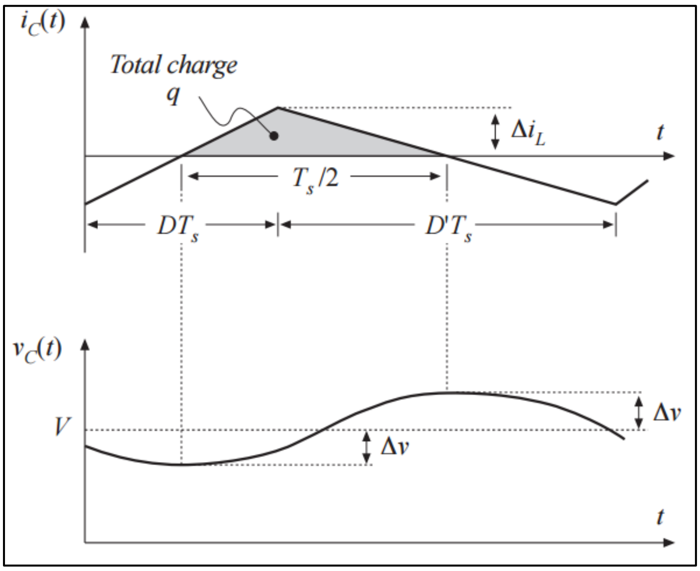
$\Delta I_{L\ on} + \Delta I_{\ Loff} = \frac{DT}{L}\ Vi + \frac{(Vi-V0)\ (1-D)T}{L}$

The relation between the input and output voltage and the duty cycle shown in equation (3.12)

$$\frac{V0}{Vi} = \frac{1}{1-D} \qquad (3.12)$$

By repeating this process many times the output voltage will step up successfully but there will some current ripples and voltage ripples on the load as showing in Figure 3.15

Figure 3.15: Current ripple and voltage ripple



For designing the boost converter must determine basic things:

The input voltage V_{in}

The output voltage $V_{out\ max}$

The input current I_{in}

The output current $I_{out\ max}$

The voltage ripple ΔV_{out}

The current ripple $\Delta I_{L\ out}$

Maximum switch current I_{sw} (largest working current for the semiconductor value can stand)

The frequency for the PWM f_s

For determining the duty cycle (T_{on}/T) D:

$$V_{out} = \frac{Vin}{1-D} \tag{3.13}$$

Then determine the inductance:

$$L = \frac{(Vout-Vin)}{(\Delta ILx\ fs)} \tag{3.14}$$

For the minimum capacitor selection:

$$C_{min} = \frac{(Iout\ x\ D)}{(fs\ x\ \Delta Vout\ )} \tag{3.15}$$

For not letting the boost going into discontinues mode the frequency fs of the PWM must be greater than resonant frequency be determined by:

$$f_0 = \frac{1}{(2\pi\sqrt{L\ x\ C}\ )} \tag{3.16}$$

For the protection of the semiconductor the maximum switch current:

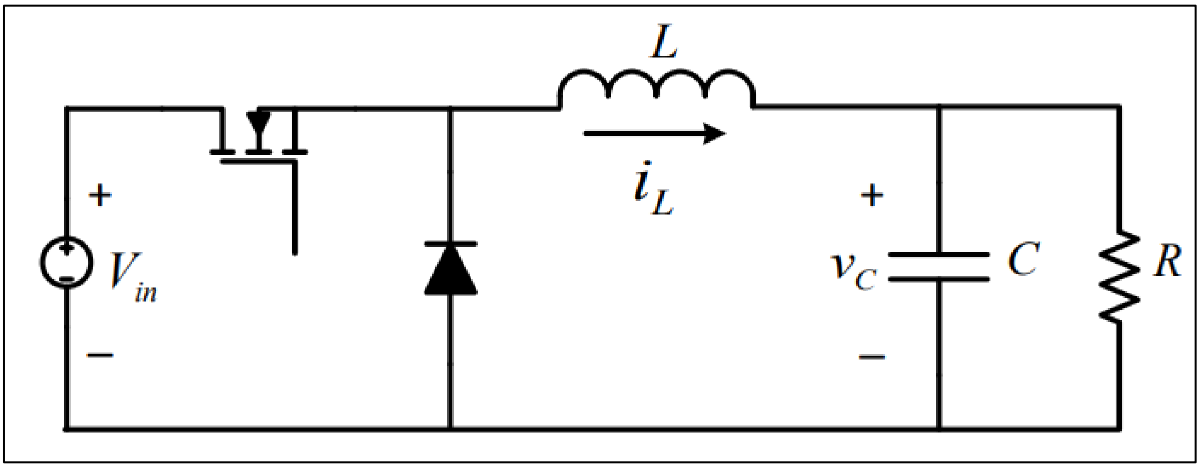
$$I_{sw} = \frac{\Delta IL}{2} + \frac{Iout\ (max)}{1-D} \tag{3.17}$$

3.3.2.2 Buck Converter

Use to step down the voltage and step up the current coming from the source to the load, similar to boost converter but the placed of the inductor and the IGBT or MOSFET are switched works the opposite way it down up the voltage and steps step the current coming from the source to the load. It normally offers more than 90% efficiency it used as a regulator for dc devices such as personal computers or charge regulator or audio amplifiers.

It is containing of two semiconductors (IGBT or MOSFET and a diode) with two energy storage element a capacitor and inductance as shown in Figure 3.16. The main operation for the converters works on on-off time for the MOSFET or IGBT (T_{on} T_{off}) in a cycle or in the switching frequency f_s , normally use pulse width modulation to control the T_{on} and T_{off} [28][29].

Figure 3.16: Buck converter circuit [29]



It works on two modes continuous conduction mode when there always an output voltage (the inductor current never goes zero) and discontinuous conduction mode when the output voltage rises and go back zero again (current inductance goes to zero), it depends on the resonant frequency and the components.

In the continuous mode, the first cycle on the T_{on} when the switch is on as shown in Figure 3.17-, all the current coming from the voltage source will pass throw the IGBT or MOSFET to the inductance and start increasing then it will oppose a voltage across it is terminal by equation (3.18), then to the capacitor, since the voltage of the capacitor can't rise instantly the output voltage is not a full voltage as the source and the current across the inductance store energy is shown by equation (3.19), and this energy stored in inductor give by the equation (3.20) and for the current IL rate changing by equation (3.21)

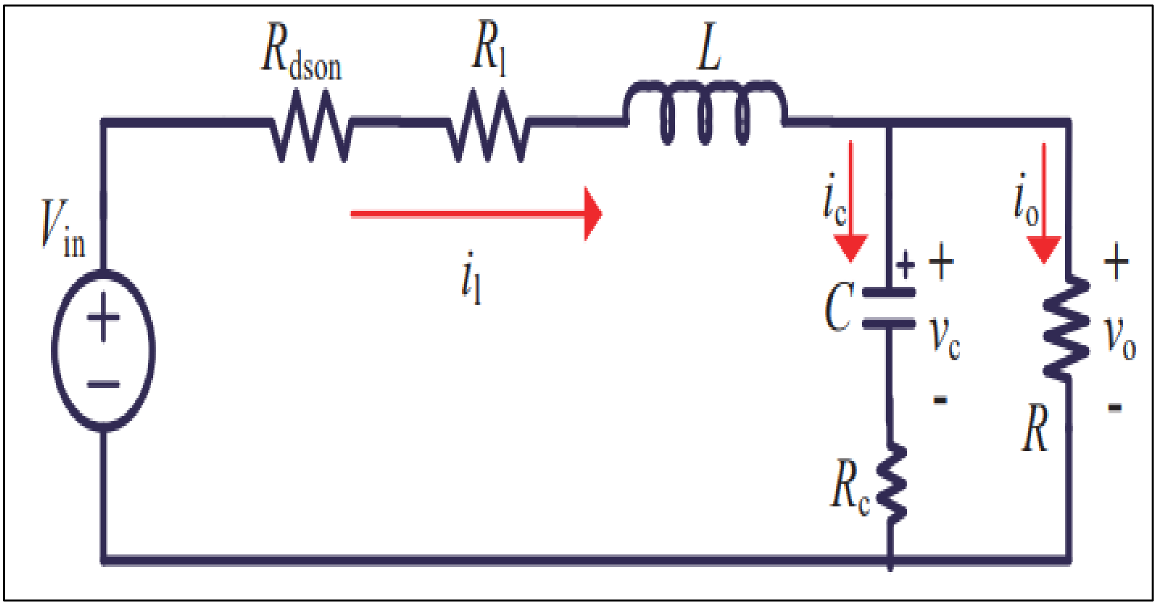
$$V_L = V_i - V0 \quad (3.18)$$

$$\Delta I_{L\ on} = \int_0^{DT} \frac{VL}{L}\, dt \ = \frac{(Vi-V0)}{L} DT \quad (3.19)$$

$$E = \frac{1}{2} LI^2 \quad (3.20)$$

$$VL = L \frac{dIL}{dt} \quad (3.21)$$

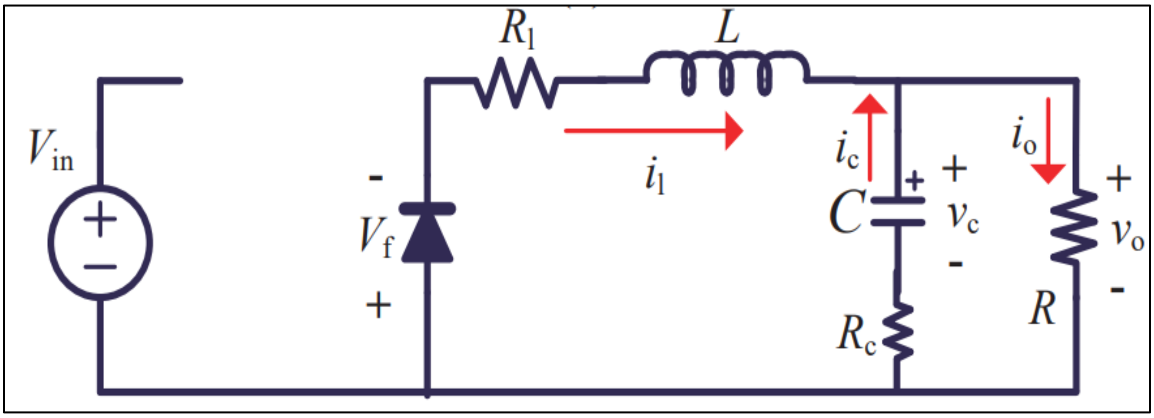
Figure 3.17: Buck converter at Ton [29]



But when T_{off} (the switch is off) as shown in Figure 3.18, the current of the inductor will not go to zero instantly, due to the inductor capability it's building a magnetic field around itself, and it creates a voltage around it, due to this voltage will discharge the current to put extra power as being determined in equation (3.22) for the capacitor and power the load throw the diode, and keep the current flowing to the load.

$$\Delta I_{L\ off} = \int_{DT}^{T} \frac{VL}{L}\, dt \ = -\frac{V0}{L}(1-D)T \quad (3.22)$$

Figure 3.18: Buck converter at Toff [29]



The inductor current must be the same in start and end of the cycle there for

$\Delta I_{L\ on} + \Delta I_{L\ off} = 0$

$\Delta I_{L\ on} + \Delta I_{L\ off} = \frac{(Vi - V0)}{L}\ DT + (-\frac{V0}{L}\ (1-D)T\ )$

(Vi-V0) DT – V0 (1-D) T = 0

The relation between the input and output voltage and the duty cycle shown in equation (3.23)

$$D = \frac{V0}{Vi} \qquad (3.23)$$

For designing the buck converter must determine basic things:

The input voltage V_{in}

The output voltage V_{out}

The input current I_{in}

The output current I_{out}

The voltage ripple ΔV_{out}

The current ripple $\Delta I_{L\ out}$

Maximum switch current I_{sw} (largest working current for the semiconductor value can stand)

The frequency for the PWM f_s

For determining the duty cycle (T_{on}/T) D : $V_{out} = V_{in}$ x D

Then determine the inductance:

$$L = \frac{Vout\ x\ (Vin - Vout\ )}{(\Delta IL\ x\ fs\ x\ Vin)} \qquad (3.24)$$

For the minimum capacitor selection:

$$C_{min} = \frac{\Delta IL}{(8 \; x \; fs \; x \; \Delta Vout)} \tag{3.25}$$

For not letting the boost going into discontinues mode the frequency fs of the PWM must be greater than resonant frequency be determine by

$$f_0 = \frac{1}{(2\pi\sqrt{L \; x \; C})} \tag{3.26}$$

For protection of the semiconductor the maximum switch current

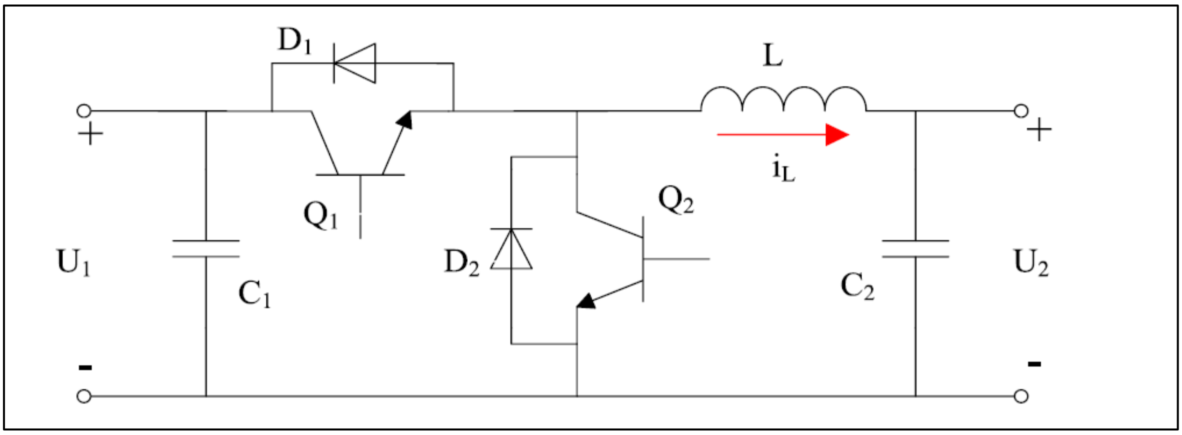
$$I_{sw} = \frac{\Delta IL}{2} + Iout \tag{3.27}$$

3.3.2.3 Bi-Directional Converter

Used to step up the voltage and step down the current or step down the voltage and step up the current, and it can convert the power in both directions, also it can limit the charging and discharging of the battery to protect it from over charge and over discharge. It works as boot converter to step up the voltage and step down the current or as a buck converter to step down the voltage and step up the current when connected to a DC bus and a battery or in electrical vehicle. This bi-directional converter offers efficiency for more than 90% depends on the duty cycle for it and the level of stepping down or stepping up the voltage.

It is containing of two semiconductors (two IGBT or two MOSFET) with a two energy storage elements capacitor and inductance Figure 3.19, from U_1 to U_2 when controlling the Q1, it works as buck converter for stepping down the voltage and stepping up the current, from U2 to U1 when controlling the Q2, it works as boost converter for stepping up the voltage and stepping down the current [30].

Figure 3.19: Bi directional converter circuit [30]



For designing the bi-directional converter must following the buck converter and the boost converter way and choose the bigger value for the inductance, as the boost converter has a bigger inductance value, the inductance can be defined from the boost mode parameters.

3.3.3 DC-AC

It is a DC to AC power conversion, it converts the direct current into alternating current, the concept of multi-level power electronics inverters begins in 1975, the main mechanism comes from the full bridge rectifier with MOSFET or IGBT (known as two level inverter) then developed into three level, five level, seven level, sine level and eleven, inverters topology have been developing due to the large amount of power it had to convert and trying to prevent the harmonic distribution, the main advance for multi-level inverter is to be able to convert higher power from DC renewable energy sources into the synchronize grid with less harmonic distribution compared to two level inverter.

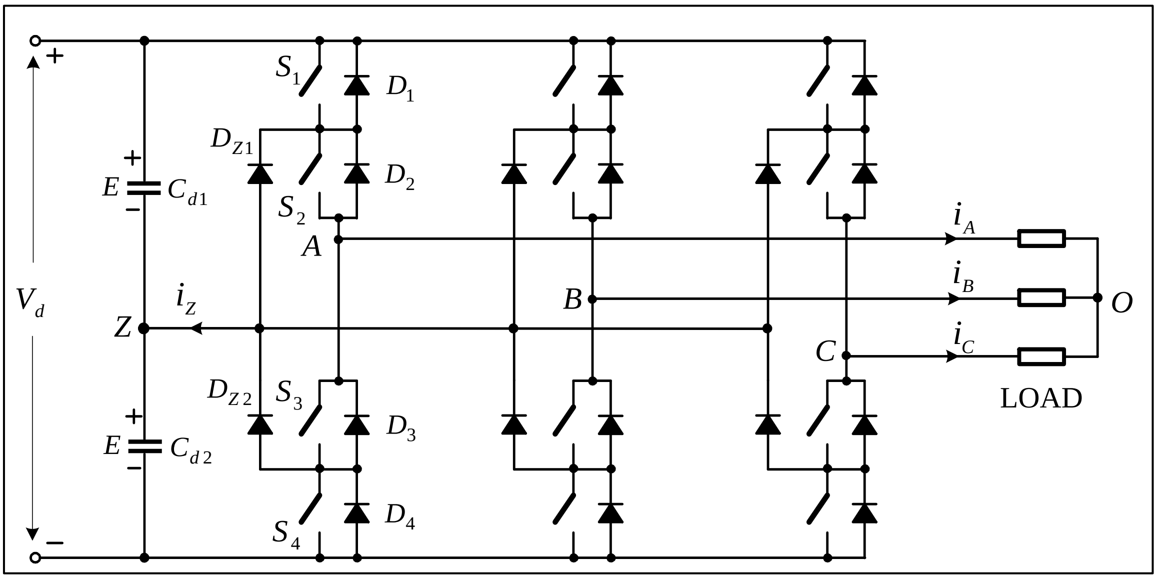
3.3.3.1 Three Phase Three Level Inverter

The three level inverter has many advance over the conventional two level inverter because it is using a higher switching frequency to make the voltage and current harmonics less, also make it more efficient, as it makes the voltage into a different level, the output voltage for it will be similar into sinusoidal wave from without using the passive filters but the filters will be needed [31] [32] [33].

The three multi-level inverter can produce three different voltage reference outputs $\pm$Vdc, $\pm\frac{Vdc}{2}$ and 0.

It is containing of eighteen semiconductors (twelve IGBT or twelve MOSFET and six diodes) as showing in Figure 3.20. The main operation for the inverters works on on-off time for the MOSFET or IGBT (T_{on} T_{off}) in a cycle or in the switching frequency f_s , normally use pulse width modulation to control the T_{on} and T_{off}.

Figure 3.20: Three level three phase inverter [31]



If phase A takes into the conversation have three possibilities for opening and closing the switches, if S1 and S2 are closed and S3 and S4 are open the output voltage will be +Vdc , if S1 and S2 are open and S3 and S4 are closed the output voltage will be -Vdc, if S1 and S4 are open and S2 and S3 are closed and S1 and S4 are open the output voltage will be O the neutral point of the capacitor which is equal to $\pm\frac{Vdc}{2}$, which is S1 and S3 , S2 and S4 are complementary switch pair, as shown in Table 3.2 .

Table 3.2: Three phase switching state

Switching state	Device switching statues (phase A)				Inverter terminal voltage
	S1	S2	S3	S4	
P	on	on	off	Off	+Vdc
O	off	on	on	Off	O
N	off	off	on	On	-Vdc

The vectors for three phase voltage are 120 degree part from each other's, it can directly relate any voltage for the components in each phase and $V_{AO}(t) + V_{BO}(t) + V_{Co}(t) = 0$. According to Clark transformation it could change these three phase reference frames into two reference frame Alpha – Beta.

By equation (3.28)

$$\begin{bmatrix} V\alpha(t) \\ V\beta(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\,0 & cos\,\frac{2\pi}{3} & cos\,\frac{4\pi}{3} \\ sin\,0 & sin\,\frac{2\pi}{3} & sin\,\frac{4\pi}{3} \end{bmatrix} \begin{bmatrix} VAO\ (t) \\ VBO\ (t) \\ VCO\ (t) \end{bmatrix} \quad (3.28)$$

The space vector representation

$V^{\rightarrow} = V\alpha(t) + j\,V\beta(t)$

$$V^{\rightarrow} = \frac{2}{3}\left[VAO(t)e^{j0} + VBO(t)e^{j2\pi/3} + VCO(t)e^{j4\pi/3}\right] \quad (3.29)$$

Where $e^{jx} = cos\,x + j\,sin\,x$

At normal sinusoidal three waveform when phase A at the maximum positive value (P) (upper two switches) switch state phase B and C will be in middle two switches (O)

$$VAO = \frac{1}{3}Vd\ ,\ VBO = -\frac{1}{6}Vd\ ,\ VCO = -\frac{1}{6}Vd \quad (3.30)$$

Substituting (2.3.3) to (2.3.2) into the space vector

$$V^{\rightarrow} = \frac{1}{3}\,Vde^{j0} \quad (3.31)$$

This three level inverter has 27 total switching sates and 19 total space vectors, as shown in Figure 3.21 and explaining in Table 3.3 and 3.4:

Zero vector: V_0 and it has three switching states.

Small vectors: $V_1 – V_6$ it has two switching states per vector.

Medium vectors: $V_7 – V_{12}$ it has one switching stares per vector.

Large vectors: $V_{13} – V_{18}$ it has one switching stares per vector.

Figure 3.21: Space vectors for three phase inverter [43]

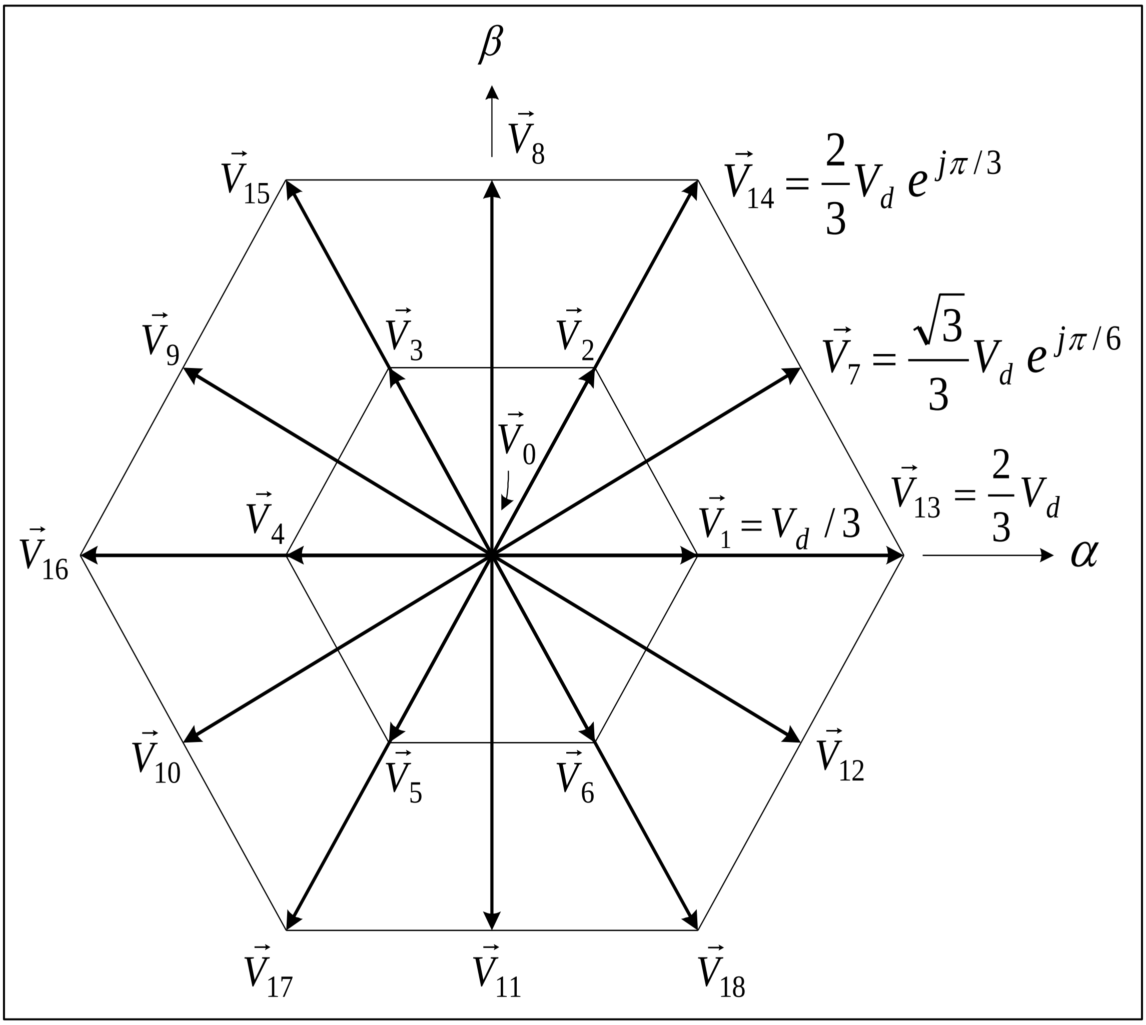


Table 3.3: Small space vectors for three phase inverter

<table>
<tr><td colspan="2">Space vector</td><td colspan="2">Switching state</td><td>Vector classification</td><td>Vector magnitude</td></tr>
<tr><td colspan="2">$V^{\rightarrow}0$</td><td colspan="2">[PPP][OOO][NNN]</td><td rowspan="14">P-type small vector
N-type small vector</td><td rowspan="14">$\frac{1}{3}$</td></tr>
<tr><td rowspan="3">$V^{\rightarrow}1$</td><td rowspan="2">$V^{\rightarrow}1P$</td><td>P-type</td><td>N-type</td></tr>
<tr><td>[POO]</td><td></td></tr>
<tr><td>$V^{\rightarrow}1N$</td><td></td><td>[ONN]</td></tr>
<tr><td rowspan="2">$V^{\rightarrow}2$</td><td>$V^{\rightarrow}2P$</td><td>[PPO]</td><td></td></tr>
<tr><td>$V^{\rightarrow}2N$</td><td></td><td>[OON]</td></tr>
<tr><td rowspan="2">$V^{\rightarrow}3$</td><td>$V^{\rightarrow}3P$</td><td>[OPO]</td><td></td></tr>
<tr><td>$V^{\rightarrow}3N$</td><td></td><td>[NON]</td></tr>
<tr><td rowspan="2">$V^{\rightarrow}4$</td><td>$V^{\rightarrow}4P$</td><td>[OPP]</td><td></td></tr>
<tr><td>$V^{\rightarrow}4N$</td><td></td><td>[NOO]</td></tr>
<tr><td rowspan="2">$V^{\rightarrow}5$</td><td>$V^{\rightarrow}5P$</td><td>[OOP]</td><td></td></tr>
<tr><td>$V^{\rightarrow}5N$</td><td></td><td>[NNO]</td></tr>
<tr><td rowspan="2">$V^{\rightarrow}6$</td><td>$V^{\rightarrow}6P$</td><td>[POP]</td><td></td></tr>
<tr><td>$V^{\rightarrow}6N$</td><td></td><td>[NON]</td></tr>
</table>

Table 3.4: Medium and large space vectors for three phase inverter

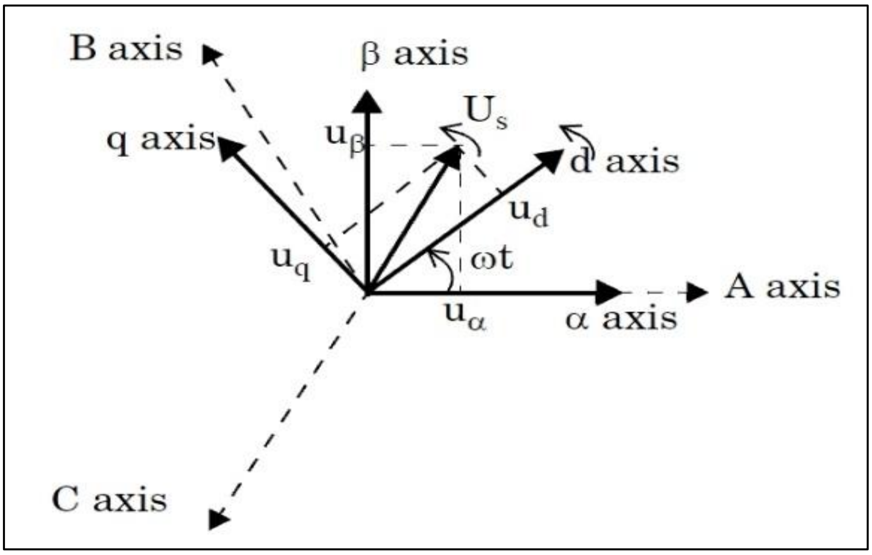
Space vector	Switching state	Vector classification	Vector magnitude
$V^{\rightarrow}7$	[PON]	Medium vector	$\frac{\sqrt{3}}{3}Vd$
$V^{\rightarrow}8$	[OPN]		
$V^{\rightarrow}9$	[NPO]		
$V^{\rightarrow}10$	[NOP]		
$V^{\rightarrow}11$	[ONP]		
$V^{\rightarrow}12$	[PNO]		
$V^{\rightarrow}13$	[PNN]	Large vector	$\frac{2}{3}\,Vd$
$V^{\rightarrow}14$	[PPN]		
$V^{\rightarrow}15$	[NPN]		
$V^{\rightarrow}16$	[NPP]		
$V^{\rightarrow}17$	[NNP]		
$V^{\rightarrow}18$	[PNP]		

This could also present by Park transformation as shown in Figure 3.22, create a rotating d q axis respect with Alpha – Beta axis, the rotation speed wt and $\rho\ is$ the angle between alpha axis and d axis by equation (3.32)

$$\begin{bmatrix} Vd(t) \\ Vq(t) \end{bmatrix} = \begin{bmatrix} \cos\rho & \sin\rho \\ -\sin\rho & \cos\rho \end{bmatrix} \begin{bmatrix} V\alpha(t) \\ V\beta(t) \end{bmatrix} \tag{3.32}$$

So the vector $V^{\rightarrow}$ is always rotate and there for alpha and beta values changes sinusoidal, but as the d q axis rotating with the $V^{\rightarrow}$ vector speed V_d and V_q will be constant.

Figure 3.22: Clark and Park transformation



3.4 CONSUMERS

With changeable energy demand the utility must turn power plant on and off depending on the amount of power needed on that time, and the electricity price depends on the time of use during the day. That's why normally electricity has peak demand, and less efficient power plant must put into work in that time to meet with the higher demand, that's why utility needs the consumer to reduce the peak electricity demand, to reduce their operating cost, drive the electricity way from peak hours and do not let all devices run at the same time and try to make the electricity demand distributed around the day, and that can happen with the smart meter and solar panels on every house to reduce from the electricity demand and to make the consumer participating in the electrical power utility when there is an extra power from his solar panels, although the consumer is going to benefit from this system by reducing the electrical bill by generating some of their own power and reduce the general electrical prices.

Smart meter and smart homes are a two way electrical meters for consuming power from the electrical grid, and generating power to the electrical grid and get paid for it, also can set your electrical devices to work when the electricity is not on peak demand or on cheap time to control your bill and to reduce the peak demand, the researchers working on integrating the electrical vehicles with the smart grid to make it as a storage for electricity, can use later for reducing the peak demand or to generate power to the electrical grid [34] [35].

4. SYSTEM MODEL

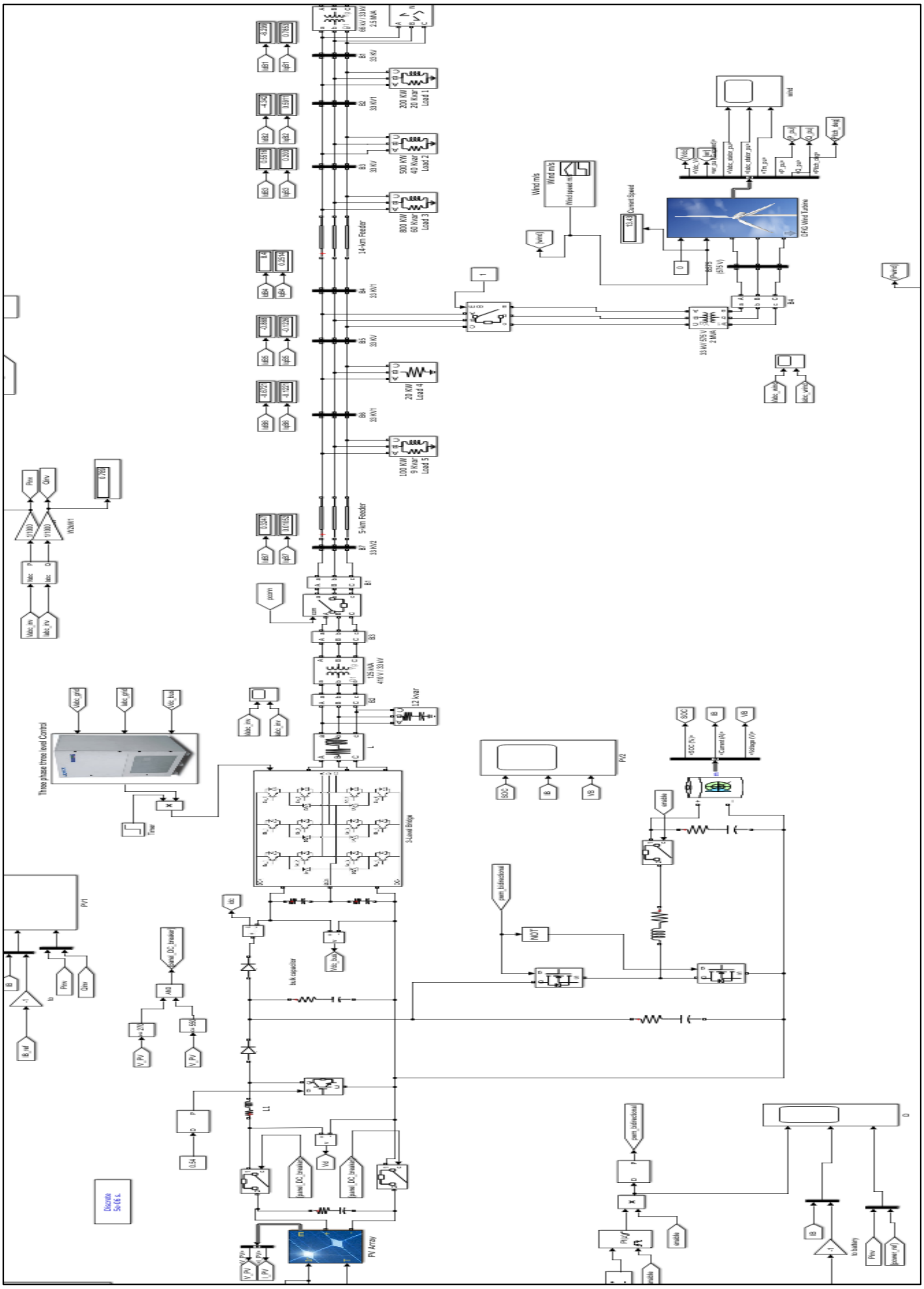
The module is going to be simulated is shown in Figure 4.1-, the power rating for the main parts is shown in Table 4.1-.

The photovoltaic panels are going to generate dc electrical power when there is irradiation from the sun, the maximum power it can produce is 105.3 kW that's when sun irradiation is 1000 and the photovoltaic temperature is 25 degree Celsius, then when the voltage around the solar panels reach a 270 V the DC breaker close to letting the electrical current pass, then it reached to a boost converter the maximum power tracking device to step up the voltage to 670 dc V and extract maximum power from the photovoltaic panels, this voltage is going into the common DC bus between the three phase inverter and the bi directional converter which is connected with the 196 kW tesla lithium battery bank and the three phase three level inverter, depends on the duty cycle of the bi directional converter it can charge up the battery or extract power from the battery bank into the inverter, with solar panels working or without it depends on two method auto and manual as putting the reference output power for the battery and solar together or each energy source alone, the inverter measured the grid voltage and current to produce a three phase electrical synchronous current and voltage to the grid at 400 V line to line voltage, after that the LC filter make the three phase voltage and current more sinusoidal to limit the harmonics effects, the transformer step up the voltage to 33 KV at medium voltage to transmit it to further area, when the inverter voltage be synchronous with the grid and reach 100 V difference and frequency angle less than 15 degree the three phase breaker will close to let the electrical power pass throw it to the grid and the loads throw the transmission lines, for the 1.5 MW double fed induction wind turbine consumes a small power from the grid to its generator then generate unsynchronized voltage and current, this ac power is going to converter into dc power, then again to ac power throw an inverter into a synchronized voltage and current, then into transformer to step up the voltage from 575 V into 33 KV medium voltage to transmit further area, this system have four main loads are going to react with grid and this sources and seven buses measurement puts between them to see how the system reacts all together.

Table 4.1: Power rating for the main parts

Name	Rating power in kW
Photovoltaic panels	105
Three phase Inverter	120
Tesla batteries bank	60
Wind turbine	1550
Consumers	1620

Figure 4.1: System model



5. METHODOLOGY

For the simulation three programs are being used, MATLAB for real time simulation, PVSYST for estimating the daily, monthly, and yearly power production from the photovoltaic system based a case study, and EXCEL for estimating the yearly power production for wind turbine based a case study

5.1 MATLAB REAL TIME SIMULATION

The photovoltaic system shown in Figure 5.1 is going to produce around 105 kW , from SPR-X21-470-COM photovoltaic panel datasheet shown in Figure 5.2 , this photovoltaic panel is chosen to this project as it captures more sunlight and generates more 60% power than conventional solar panels in 25 years, this panel have more 21% efficiency, and it is one of the highest power photovoltaic panels in the market, although it’s company give a warranty for 25 years, and power temperature coefficient is low it means its output power will get effected so much with the hot temperature.

Figure 5.1: Photovoltaic Battery DC system

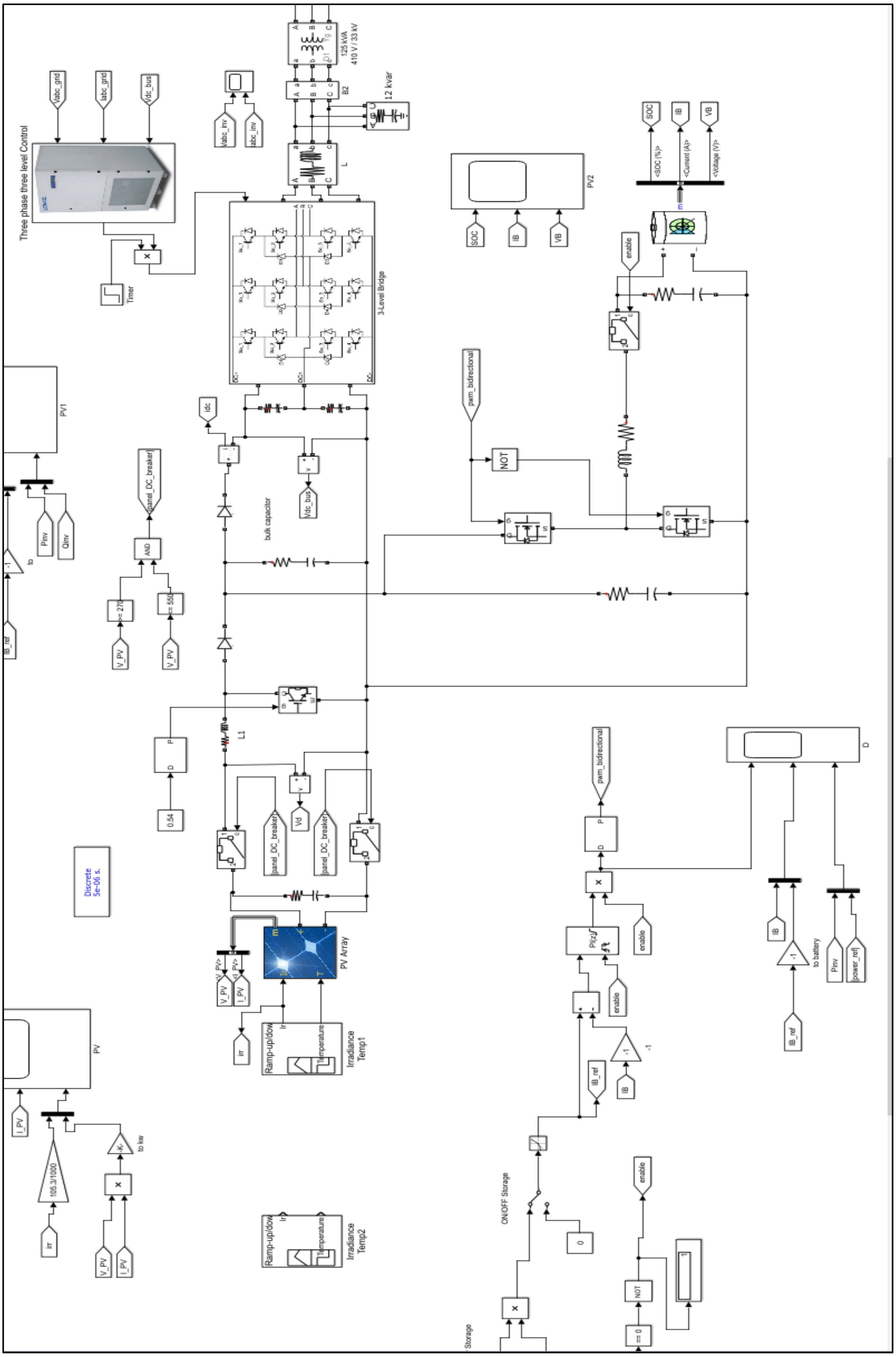


Figure 5.2: SPR-X21-470-COM panel datasheet

Electrical Data			
	SPR-X21-470-COM	SPR-X21-460-COM	SPR-X20-445-COM
Nominal Power (Pnom)[5]	470 W	460 W	445 W
Power Tolerance	+5/−0%	+5/−0%	+5/−0%
Avg. Panel Efficiency[6]	21.7%	21.3%	20.6%
Rated Voltage (Vmpp)	77.6 V	77.3 V	76.5 V
Rated Current (Impp)	6.06 A	5.95 A	5.82 A
Open-Circuit Voltage (Voc)	91.5 V	90.5 V	90.0 V
Short-Circuit Current (Isc)	6.45 A	6.39 A	6.24 A
Max. System Voltage	1000 V UL & 1000 V IEC		
Maximum Series Fuse	15 A		
Power Temp Coef.	−0.29% / ° C		
Voltage Temp Coef.	−223.2 mV / ° C		
Current Temp Coef.	2.9 mA / ° C		

Number of solar panels needed: $\frac{105{,}000 \text{ w}}{470 \text{ w}}$ =223 piece

So 224 pieces are going to be used

The system will have 4 series connected model each of them has a parallel string with 56 panels, their maximum power at 1000 irradiance and 25 Celsius is 105,3 kW according to MATLAB as showing in Figure 5.3 , 5.4 .

In the ideal situation

V_{oc} : 91.5 X 4 = 366 V

V_{mpp} : 77.6 X 4 = 310.4 V

I_{sc} : 6.45 X 56 = 361.2 A

I_{mpp} 6.06 X 56 = 339.36 A

P max = V_{mpp} X I_{mpp} = 105,300 W.

Maximum V_{oc} in -10 Celsius temperature: 366 + (223.2 X10^{-3} X 4 X 35) = 397.24 V

Minimum V_{mpp} at 60 Celsius temperature: 310.4 + (223.2 X 10^{-3} X 4 X $-$ 35) = 279.15 V

Figure 5.3: Solar panel design on MATLAB

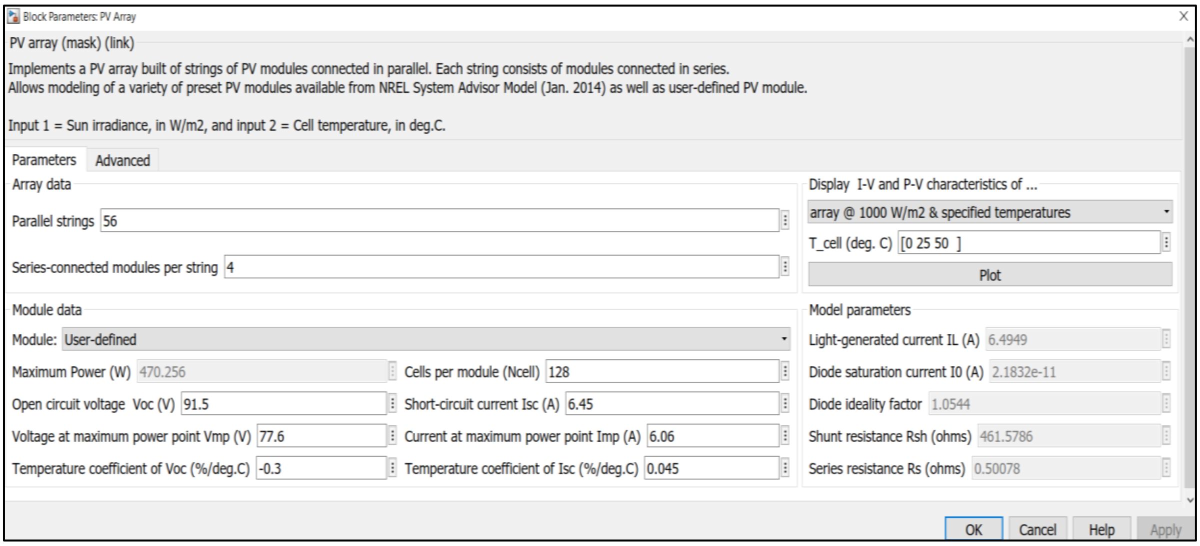
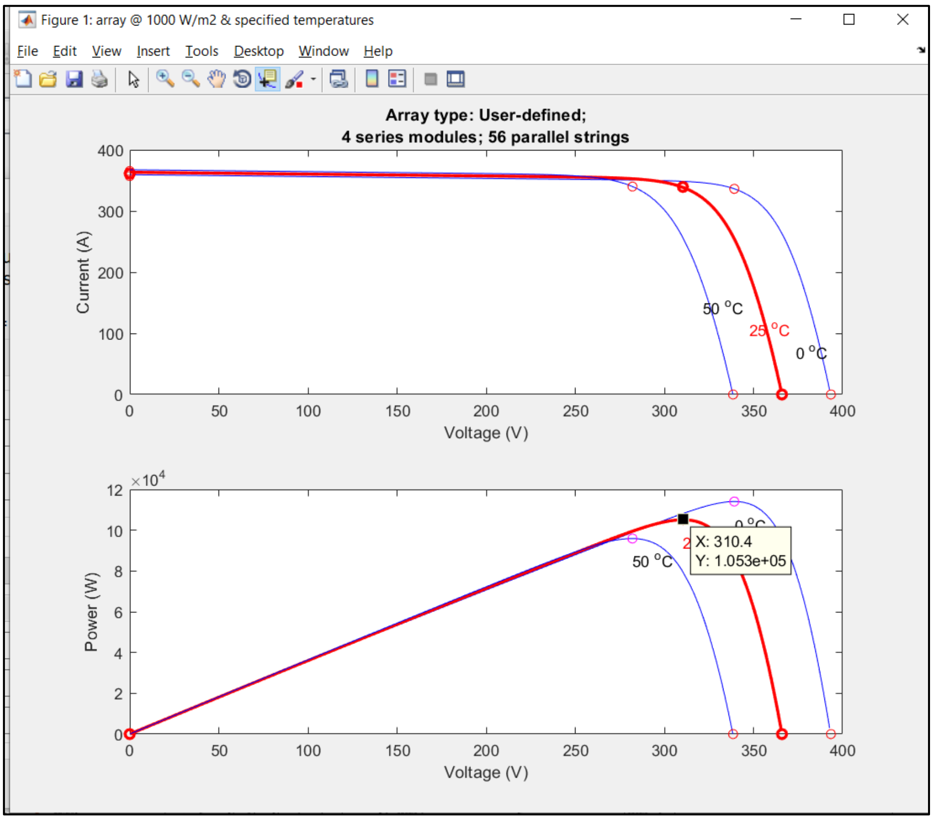


Figure 5.4: Maximum power for solar panels



The capacitor between the solar panel terminals is put to 9 X 10^{-3} F

The DC breaker between the solar panels and the boost converter will close to let the current pass if the voltage larger than 270 V dc and less than 550 V dc similar to a GTP-507 three inverter from Leonics company.

For the minimum DC voltage for the inverter to be able to convert into a 400 AC line to line voltage is

400 x $\frac{2*\text{sqare (2)}}{\text{suqre (3)}}$ = 653 V without any losses

The converter will use switching a frequency at 10,000 Hz

D = 1 - $\frac{310}{673}$ = 0.54 duty cycle

$V_{out} = \frac{310}{1-0.54}$ = 673 V

$I_{out} = \frac{\text{Vin x Iin}}{\text{Vout}} = = \frac{310.4 \text{ x } 361.2}{670} =$ 167.12 A

Current ripple = 5 A

Voltage ripple = 2 V

Then determine the inductance: L = $\frac{(670-310)}{(5 \text{ x } 10000)}$ = 7.2 X 10^{-3} H

For the minimum capacitor: $C_{min} = \frac{(167.12 \text{ X } 0.537)}{(10000 \text{ x } 3)}$ = 4.48 X 10^{-3} F

But this capacitor is going to be bulk capacitor between the boost and bi directional converter and the inverter so must be bigger, it set to be 9 X 10^{-3} F.

The two capacitors on the neutral inverter link are going to be 5.5 X 10^{-3} F to protect the inverter from any sudden drop in the voltage, for controlling the three phase level inverter the voltage and current of the grid must be measured, also of the dc bus voltage before the inverter.

The nominal power is 120 kW similar to a Leonics GTP-507 three phase inverter and the frequency is 50 Hz, the three phase voltage output is 410 V, and the voltage after it has been stepping up from the transformer as shown in figures 5.5 , 5.6 , the transformer leakage impedance and choke impedance are related to lagging the voltage.

Figure 5.5: Inverter controls with filters

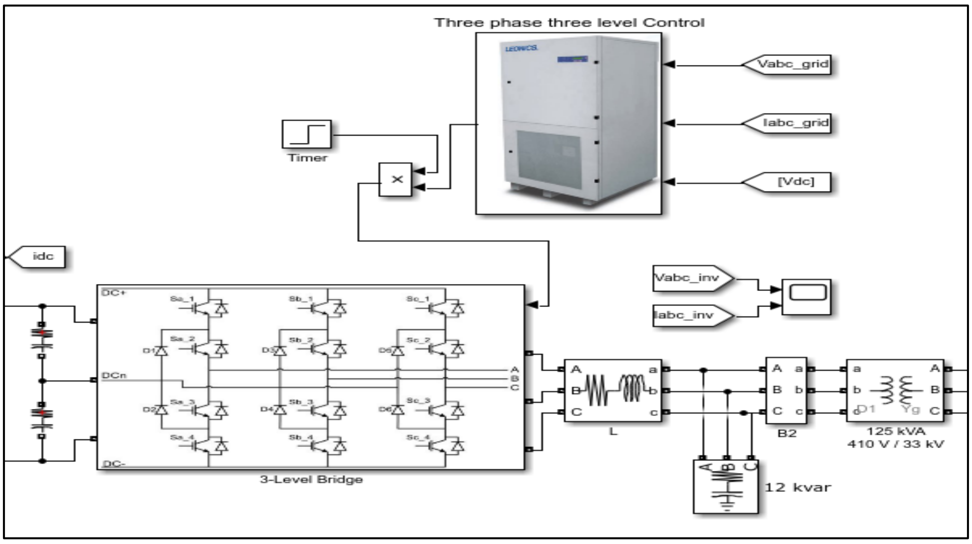
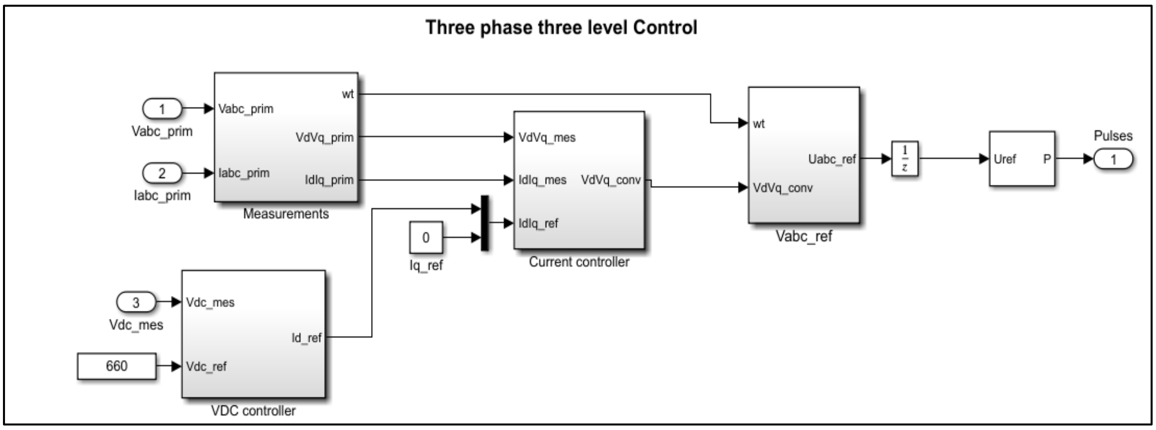
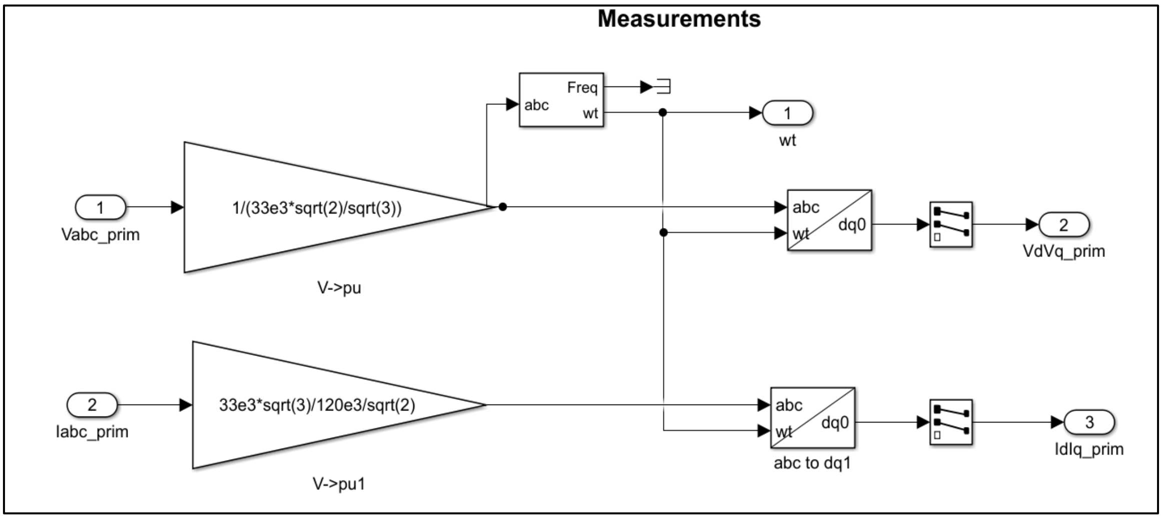


Figure 5.6: Inverter controller block under the mask inside



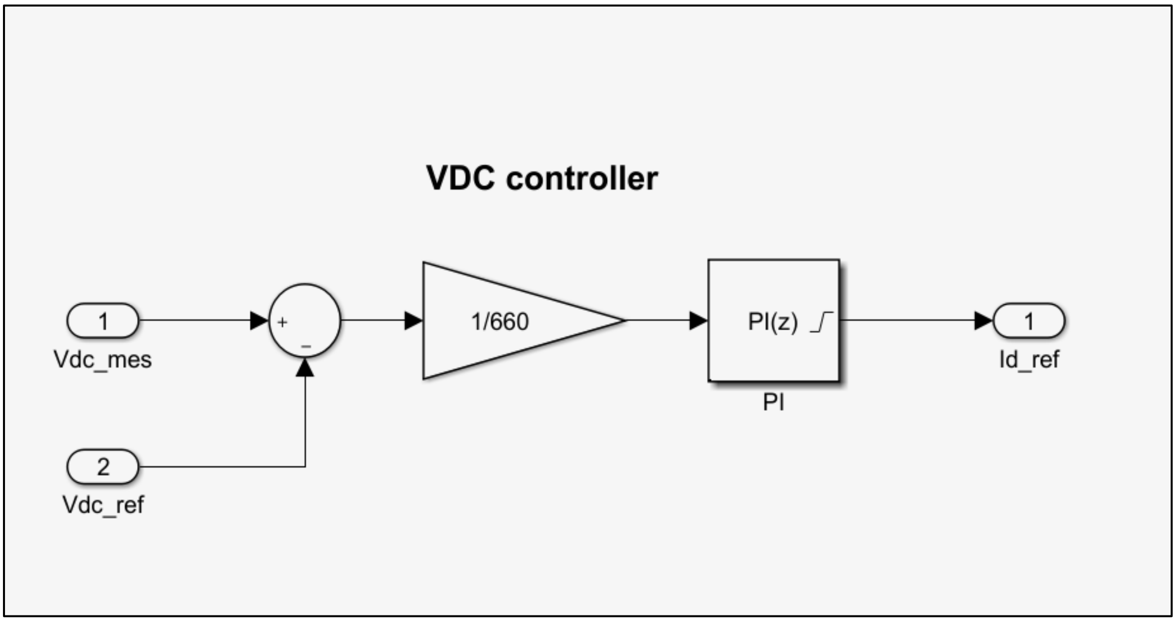
For the measurements block as showing in Figure 5.7-, it measures the three phase voltage and current then convert it into per unit value. Then change the per unit voltage into V_d, V_q throws park transformation, also change the per unit current into I_d, I_q throws park transformation.

Figure 5.7: Measurements block



The VDC regulator as showing in Figure 5.8-, taking two inputs, the first one is the measurement on the DC bus before the inverter, the second one is the nominal DC bus (660 V) voltage, then subtract the DC reference from the measured DC bus, then into divide output into the nominal DC bus, this output is going to be the input for the PI controller which tries to make this value zero, the proportional value is P=7 and the integral is I= 800, the output from the PI controller is the Id reference and for the I_q is zero because the inverter will try produce the three phase power at unity power factor (PF=1), because of I_d positive converter into active power (P positive) and I_q converter in reactive power (Q negative).

Figure 5.8: Vdc controller



For current controller as showing in Figure 5.9-, the (measured I_d, I_q) are going to be subtracted from (Id, Iq reference) then into a PI controller, the proportional value is P=0.3 and the integral is I= 20 for it.

Id positive converter into active power (P positive) and I_q converter in reactive power (Q negative)

The transformer is rated by 125 KV at 50 Hz as showing in Figure 5.10.

The transformer leakage impedance in per unit: R(1) =0.001 R(2)=0.001

L (1) =0.03, L (2) =0.03

Total R for both wending = 0.002 pu

Total L for both wending = 0.06 pu

The choke impedance: R= 2 X 10^{-3} ohm, L= 250 X 10^{-6} H

The Per unit system:

P base = 120,000

V base = 380

Z base = 380*380/120,000 = 1.203 pu

R total = 0.002 + $\frac{2 \text{ X } 10^{-3}}{1.203}$ = 0.003662 pu

L total = 0.06 + $\frac{\frac{250 \text{ X } 10^{-6}}{1.203}}{2 \text{ x pi x } 50}$ = 0.1253 pu

Then

Vd_conv = Vd_mes + Id*R - Iq*L + deriv(Id)*L

Vq_conv = Vq_mes + Id*L + Iq*R + deriv(Iq)*L

Figure 5.9: Current controller

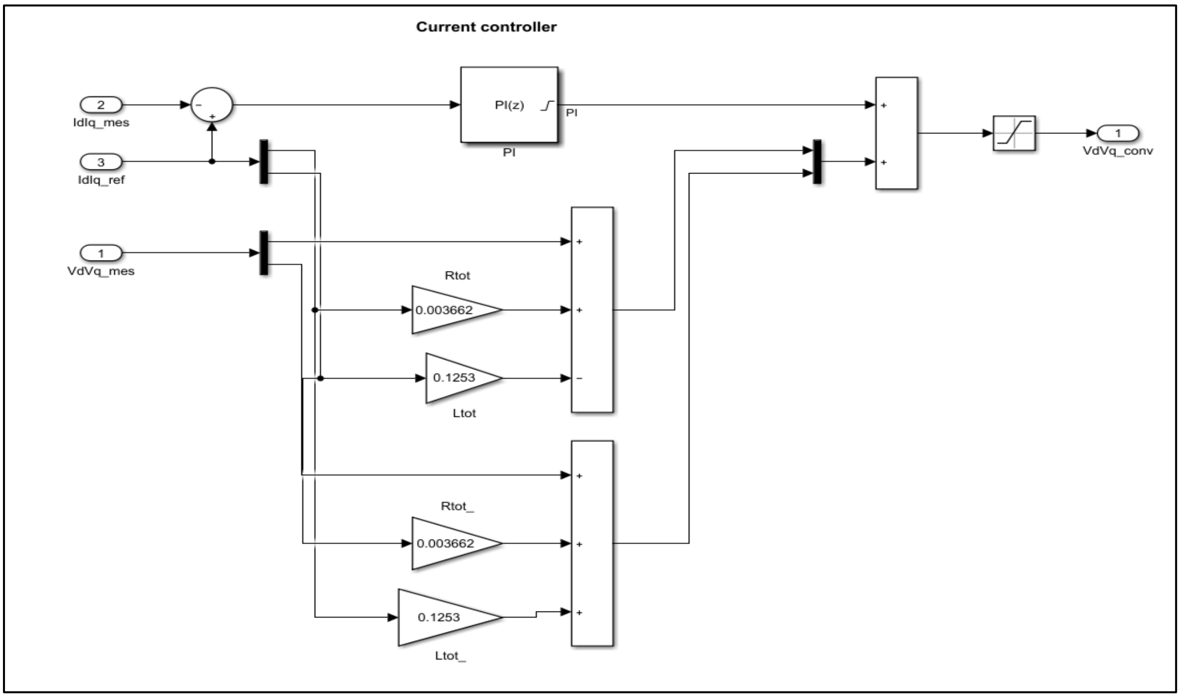
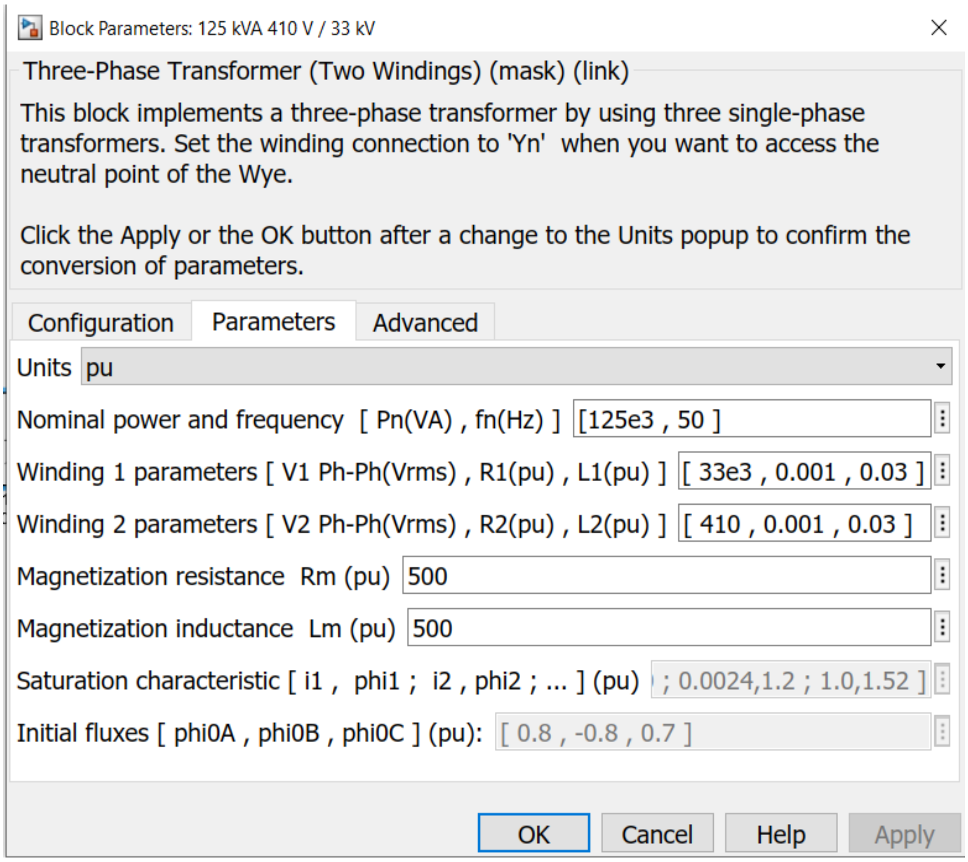


Figure 5.10: Inverter transformer



In Vabc_ref block as shown in Figure 5.11-, the power per unit value for the inverter:

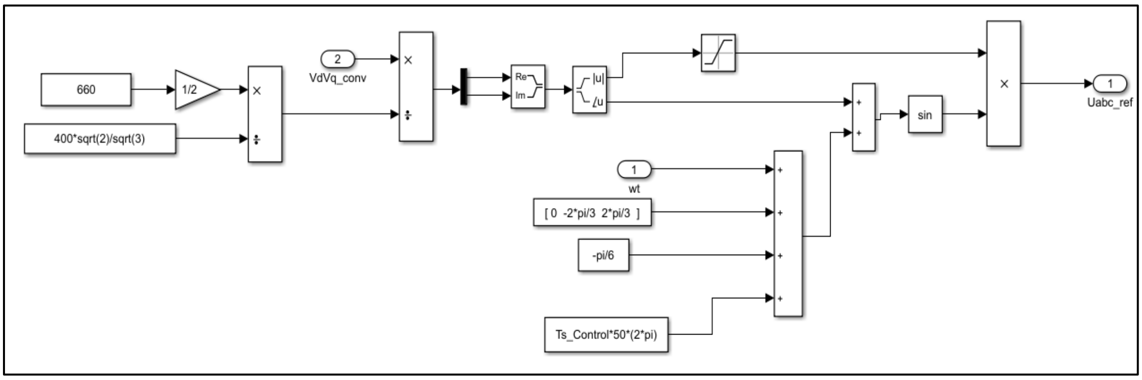
$(660/2) / (400\sqrt{2}) / \sqrt{3} = 1.01$ Pu

And divide the Vd_conv and Vq_conv over it

Vd-con will be the real value and the Vq_conv will be the imaginary value for the system in complex number, then change into two vector parameter the amplitude and angle. This angle will be added to the frequency angle of the measured voltage and parameters for three phase difference [0 -2 X π /3 2 X π /3] and [-pi/6] for the transformer D connection and the delay for the controller [Ts_controll*50*(2* π)].

Then take the sin angle for the sum then multiply it by the amplitude for the (Vd_conv, Vq_conv), then to unit delay by Ts_controller, after that this will be voltage reference for Three phase three level inverter, the final step is doing by the three level PWM generator by generating 12 pules to control the three level bridge.

Figure 5.11: Vabc_ref



For the LC filter normally the capacitor has 10% for the nominal power as a reactive power

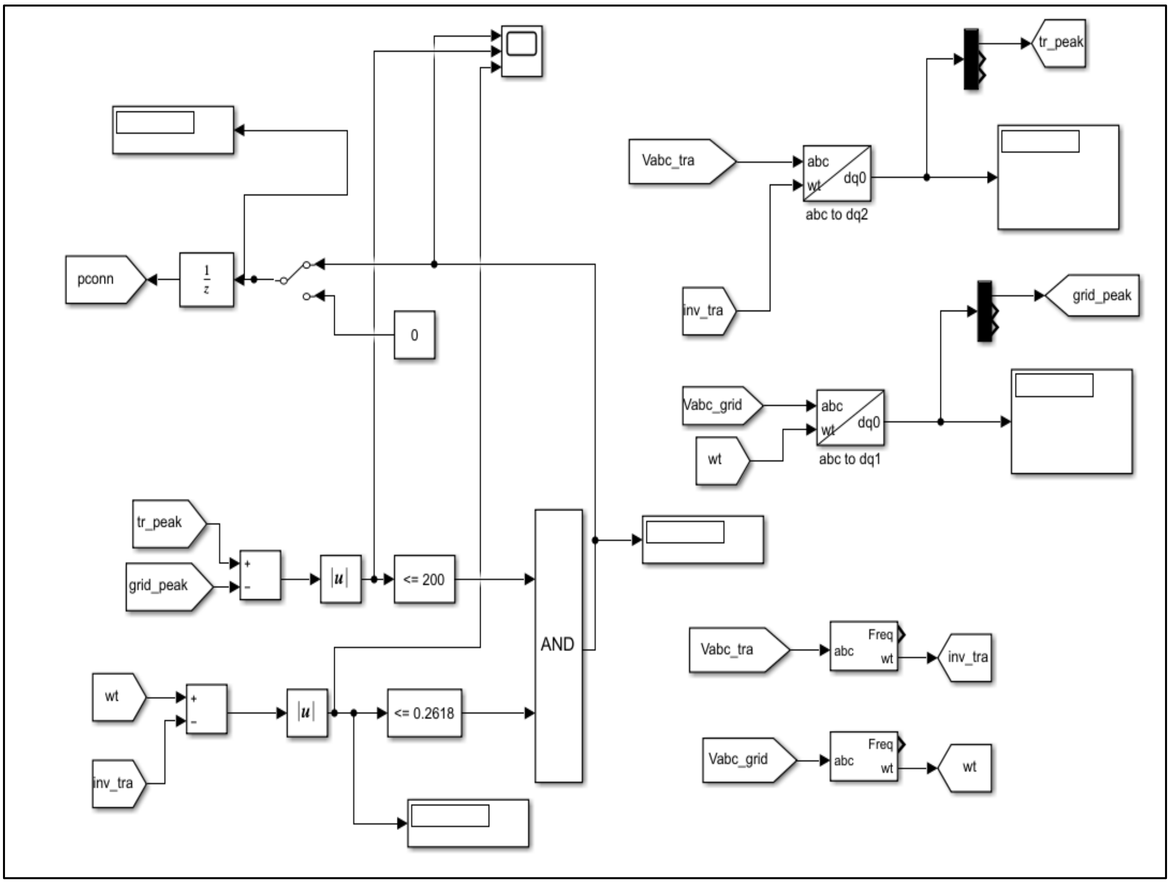
And the inductance value is 0.15 x power base / (2 π 50)

P base = Vbase^2/ P = 1.33 pu

Inductance value = 0.15 x 1.33 / 2 π 50 = 6.36 x 10^{-4} H

The three phase voltage after the transformer will be measured and converted into park transformation parameters $V_{d\ transformer}$ and $V_{q\ transformer}$, also the three phase voltage will be converted into park transformation parameter $V_{d\ grid}$ and $V_{q\ grid}$, and the angular frequency for them will be measured, if the difference between the peak $V_{d\ grid}$ and $V_{d\ transformer}$ is less than 200 V and the difference between the angular frequency for A phase in the transformer and phase A in the grid less than 15 (15*pi/180) degree three phase breaker will automatically close to let the synchronized power pass as showing in Figure 5.12.

Figure 5.12: Three phase breaker controller



On the common Dc bus the bi direction converter is connected with 14 tesla batteries bank, seven battery connected on series and each of them connects with a battery on parallel.

Each battery has 50 internal volts with a maximum current of 75 amperes, and have a power of 14 kW, it has a 14,000 / 50 = 280 Ampere hour, and the total power for them is 14 x 14 = 196 kW

When connecting the batteries on series the voltage is going to be added but the ampere and the ampere hour for it will stay the same, and when connecting the batteries on parallel the voltage will stay the same but the output ampere and the capacity for ampere hour will be added and will react as one big battery as shown in figures 5.13-, 5.14-.

The output voltage for these batteries is: 50 x 7 = 350 V.

The output current for charging or discharging in these batteries is: 75 x 2 = 150 A.

This current can be much larger than this value but 75 amperes to expanding the lifespan of the battery and not make it goes into heavy duty for charging and discharging.

The capacity in ampere hour will be: 280 x 2 = 580 AH

The cutoff voltage 262 V, the fully charged voltage is 407.3 V

The maximum power it will produce almost around = 150 * 400 = 60 kW , if the battery fully charged then worked on fully discharged power it will get empty after three hours and 45 minutes of working in the maximum power, it stops when voltage for the battery reach 262.5 V due to the cut off voltage.

Figure 5.13: Battery parameters

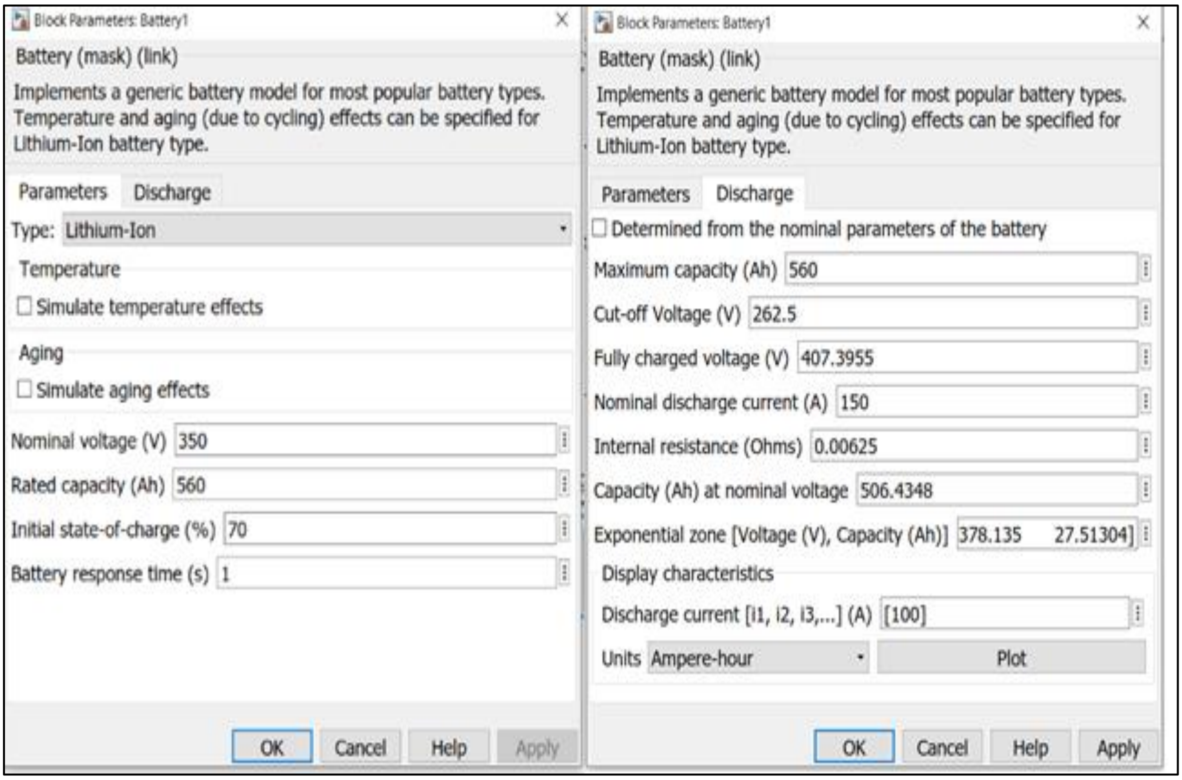
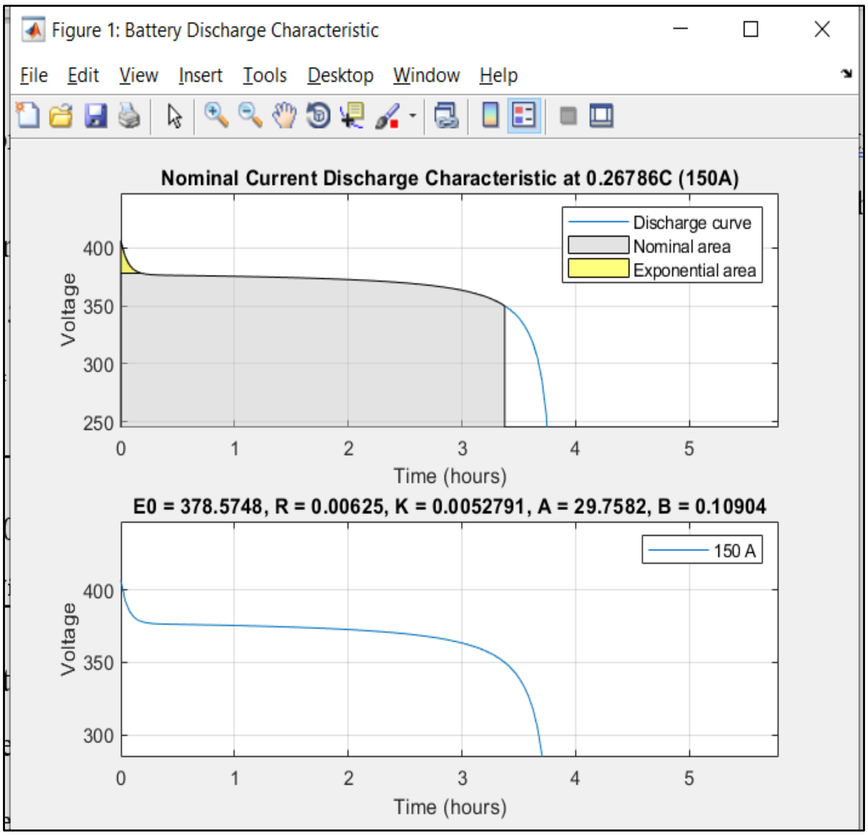


Figure 5.14: Battery discharge



The controlling for charging or discharging are going to be by the bi directional converter, For the designing the parameters must follow the boost converter design method with switching frequency 10,000 Hz

V_{in} = 350 V dc for the battery

V_{out} = 670 V dc

D = 1 - $\frac{350}{670}$ = 0.477 duty cycle, it depends on the state of charge for the battery

I_{In} = 150 A

$I_{out} = \frac{\text{Vin x Iin}}{\text{Vout}} = = \frac{350 \text{ x } 150}{670} =$ 78.3 A

Current ripple = 2 A

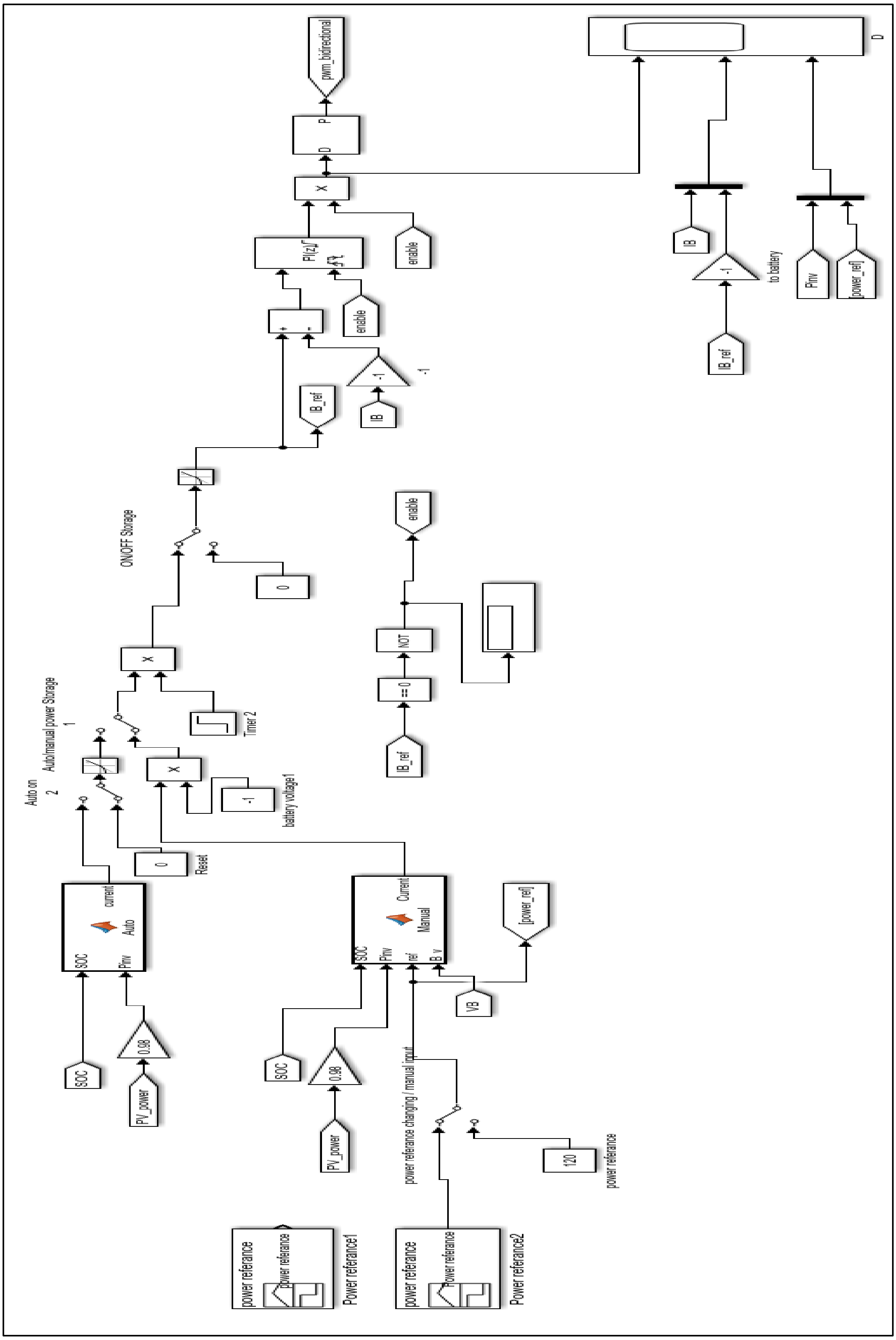
Voltage ripple = 1 V

Then determine the inductance: L = $\frac{(670-350)}{(2 \text{ x } 10000)}$ = 13.5 X 10^{-3} H

For the minimum capacitor: C_{min}= $\frac{(78.3 \text{ X } 0.477)}{(10000 \text{ x } 1)}$ = 3.73 X 10^{-3} F

For controlling the charging and discharging a PI controller is going to generate the duty cycle, as the duty gets larger the discharging current gets larger and bi directional works as a boost converter, taking the power from the battery to the dc bus. on the other side, smaller duty cycle to the bi directional converter works as a buck converter taking the power from the DC bus and charge the battery, also the reference current is zero the two breakers will open as a DC switch, and the current reference changed from zero PI controller will automatically reset into 0.55 duty cycle and charge the duty cycle to meet the current reference, and rate limiter block put before the current reference to protect from sudden changes and a timer put at 0.6 sec to block any current reference before this time as shown in Figure 5.15-.

Figure 5.15: Battery controller



For controlling the charging and discharging two methods created,

The Auto method as the code showing in Figure 5.16:

Reading the state of charge of the battery and the power generating from the solar panels with 98% efficiency.

a) If the output of the photovoltaic panel power more than 70 kW and the state of charge of the battery is less than 20%
   Charge the battery with 30 A
b) If the output of the photovoltaic panel power more than 70 kW and the state of charge of the battery is bigger or equal than 20% and less than 80%
   Charge the battery with 58 A
c) If the output of the photovoltaic panel power more than 70 kW and the state of charge of the battery is bigger or equal than 80% and less than 90%
   Charge the battery with 25 A
d) If the output of the photovoltaic panel power more than 70 kW and the state of charge of the battery is bigger or equal than 90% and less than 95%
   Charge the battery with 10 A
e) If the output of the photovoltaic panel power less than 30 kW and the state of charge of the battery equal or less than 100% and bigger than 20%
   a. discharge the battery with -58
f) Anything else the output is zero

Figure 5.16: Auto mode battery charge code

Editor - Block: lastmodeltry111finallproject1/MATLAB Function2*

test50kellogrid.m | pv.m | MATLAB Function2*

```
function current =  Auto (SOC,Pinv)
if ( SOC<20 && Pinv>70)
    current= 30;
elseif  (SOC<80 && SOC>=20   && Pinv>70 )
    current= 58;
    elseif  (SOC<90 && SOC>=80   && Pinv>70 )
    current= 25;
    elseif  (SOC<95 && SOC>=90 && Pinv>70 )
    current= 10;
    elseif  (SOC<100 && SOC>=95 && Pinv>70 )
    current= 5;
elseif ( SOC<=100 && SOC>=20 && Pinv<30 )
    current= -58;
else current =0;
end
```

Command Window

The Manual method as the code showing in Figure 5.17:

Reading the state of charge of the battery, the power generating from the solar panels with 98% efficiency, the input reference output power for the system (battery and solar panels) and the voltage for the battery.

def variable is the different power between the reference input and the photovoltaic panels power in KW

def= ref-pinv

cu variable to calculate the amount of current should be charging or discharging

cu= def multiply by 1000 to charge to w then divided on the voltage of the battery then divided on 98% efficiency.

a) If the state of charge of the battery is less than 20% and the cu bigger than zero the current equal zero
b) If the state of charge of the battery is bigger than 20% and the cu bigger than zero the discharge current equal cu and if cu bigger than 150 the output is 150
c) If the state of charge of the battery is less than 20% and the cu less than zero the charge current equal cu and if cu less than -30 the output is -30
d) If the state of charge of the battery is bigger or equal to 20% and less or equal to 80 % the cu less than zero the charge current equal cu and if cu less than -150 the output is -150
e) If the state of charge of the battery is bigger than 80% and less or equal to 90 % the cu less than zero the charge current equal cu and if cu less than -30 the output is -30
f) If the state of charge of the battery is bigger than 90% and less or equal to 95 % the cu less than zero the charge current equal cu and if cu less than -10 the output is -10
g) If the state of charge of the battery is bigger than 95% and less or equal to 100 % the cu less than zero the charge current equal cu and if cu less than -5 the output is -5
h) If the state of charge of the battery is bigger or equal to 100% and the cu less than zero the current equal 0

Figure 5.17: Manual mode charge battery code

Editor - Block: finalfinalfinalfinalllllllllll/MATLAB Function1*

pv.m | MATLAB Function1*

```
function Current =  Manual (SOC,Pinv,ref,B_v)
def=ref-Pinv;
cu=(def*1000/B_v)/0.98;
if (SOC<20 && cu>0)
    Current = 0;
elseif(SOC>20 && cu>0)
    Current = cu;
    if Current>150
        Current=150;
    end
elseif (SOC<20 && cu<0)
    Current = cu;
    if Current <-30
        Current=-30;
    end
elseif (SOC>20 && SOC<=80 && cu<0)
    Current=cu;
    if Current<-150
        Current=-150;
    end
    elseif (SOC>80 && SOC<=90 && cu<0)
    Current=cu;
    if Current<-30
        Current=-30;
    end
    elseif (SOC>90 && SOC<=95 && cu<0)
    Current=cu;
    if Current<-10
        Current=-10;
    end
    elseif (SOC>95 && SOC<99 && cu<0)
    Current=cu;
    if Current<-5
        Current=-5;
    end
else (SOC<=100 && cu<0)
    Current=0;
end
```

For the wind turbine is 1.5 mw double feed induction generator wind turbine system with 575 three phase voltage output as shown in Figure 5.18, and for the system under this mask is shown in Figure 5.19 , the power generated connected to a rotor with a slips controls the current, this structure allows the wind the turbine to have a various working speed due to controlling the pitch angle and to the advance power electronics controlled output, where all the three phase output power from the generator is converted into a dc throw a controlled converter then converter again throw the inverter into a synchronized three phase electrical power.

Figure 5.18: Wind turbine mask

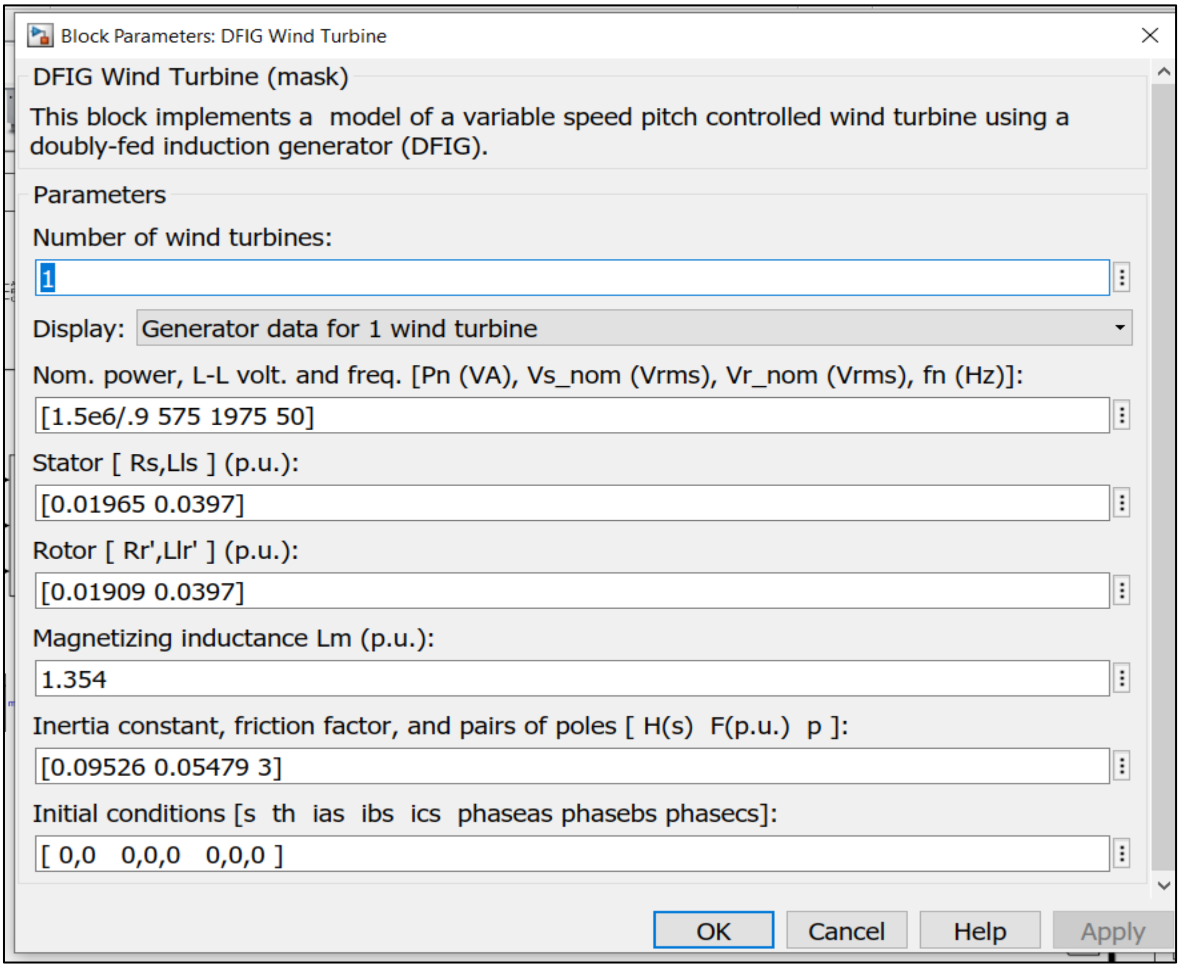
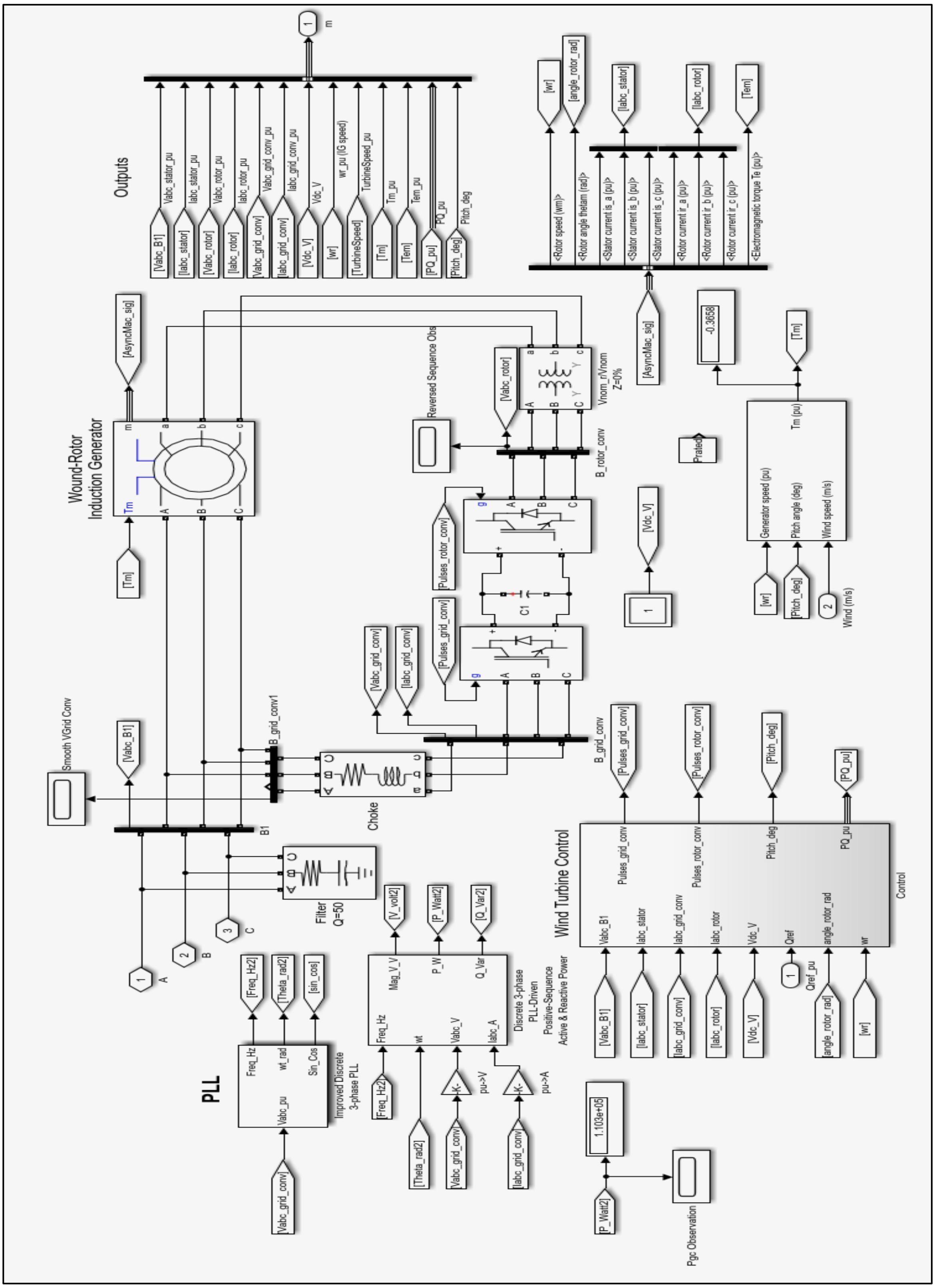


Figure 5.19: 1.5 MW wind turbine under the mask details



The system is going to react with 5 loads as shown in Figure 5.20:

Load 5 = 100 kW 9 kVAr , load 4 = 20 kW , load 3 = 800 kW 60 kVAr , load 2 = 500 kW 40 kVAr , load 1 = 200 kW 20 kVAr.

Seven buses added to the system to measure the power passing throw them,

Bus 1 between the grid and the first load

Bus 2 between the first load and the second load

Bus 3 between the second load and the third load

Bus 4 between the wind turbine power and the third load

Bus 5 between the wind turbine power and the fourth load

Bus 6 between the fourth load and fifth load

Bus 7 the power coming from the inverter

The base voltage for all of them is 33 kV and the base power is 100 kVAr, for measuring the power park transformation is being used as shown in Figure 5.21.

Figure 5.20: Buses system

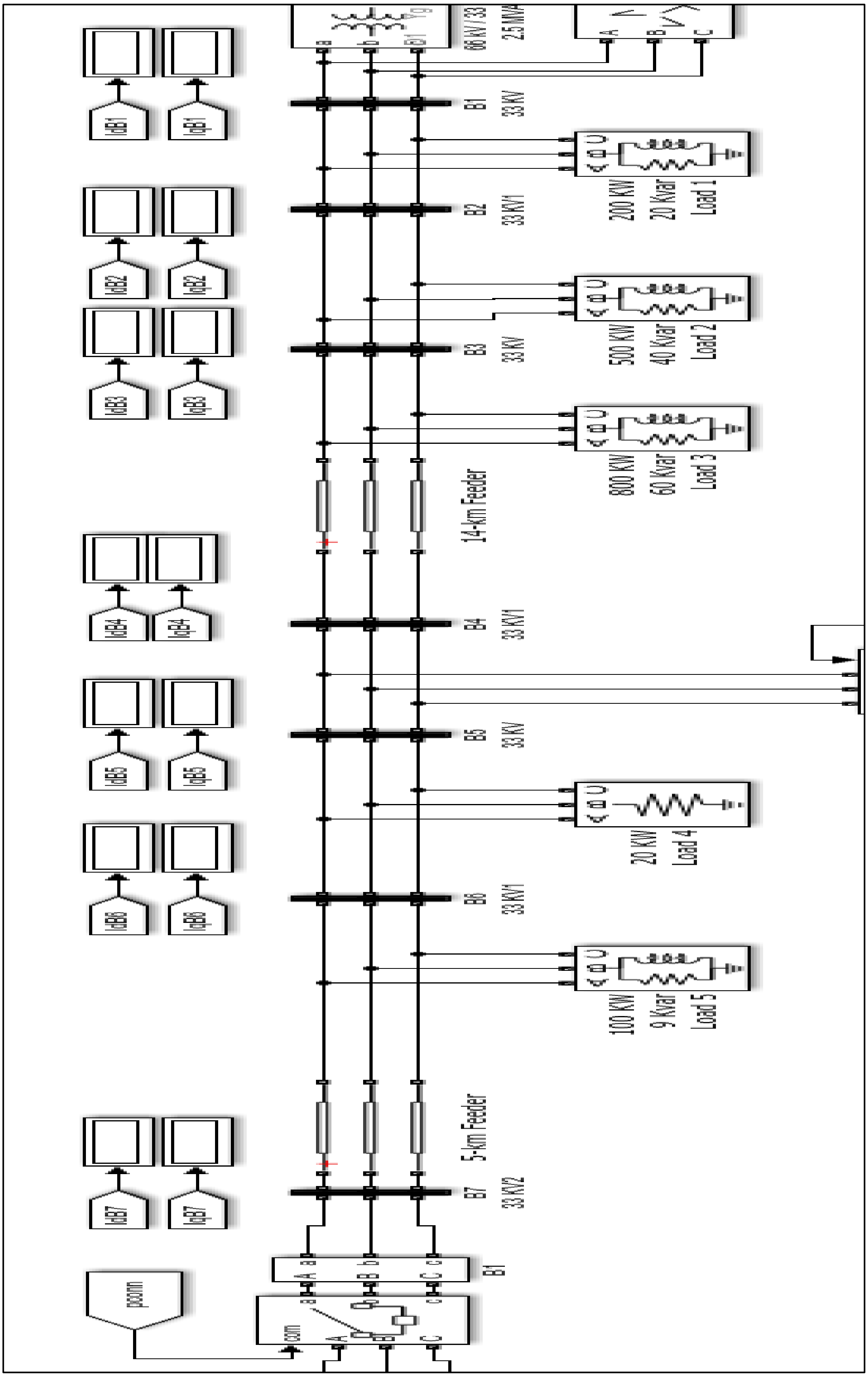
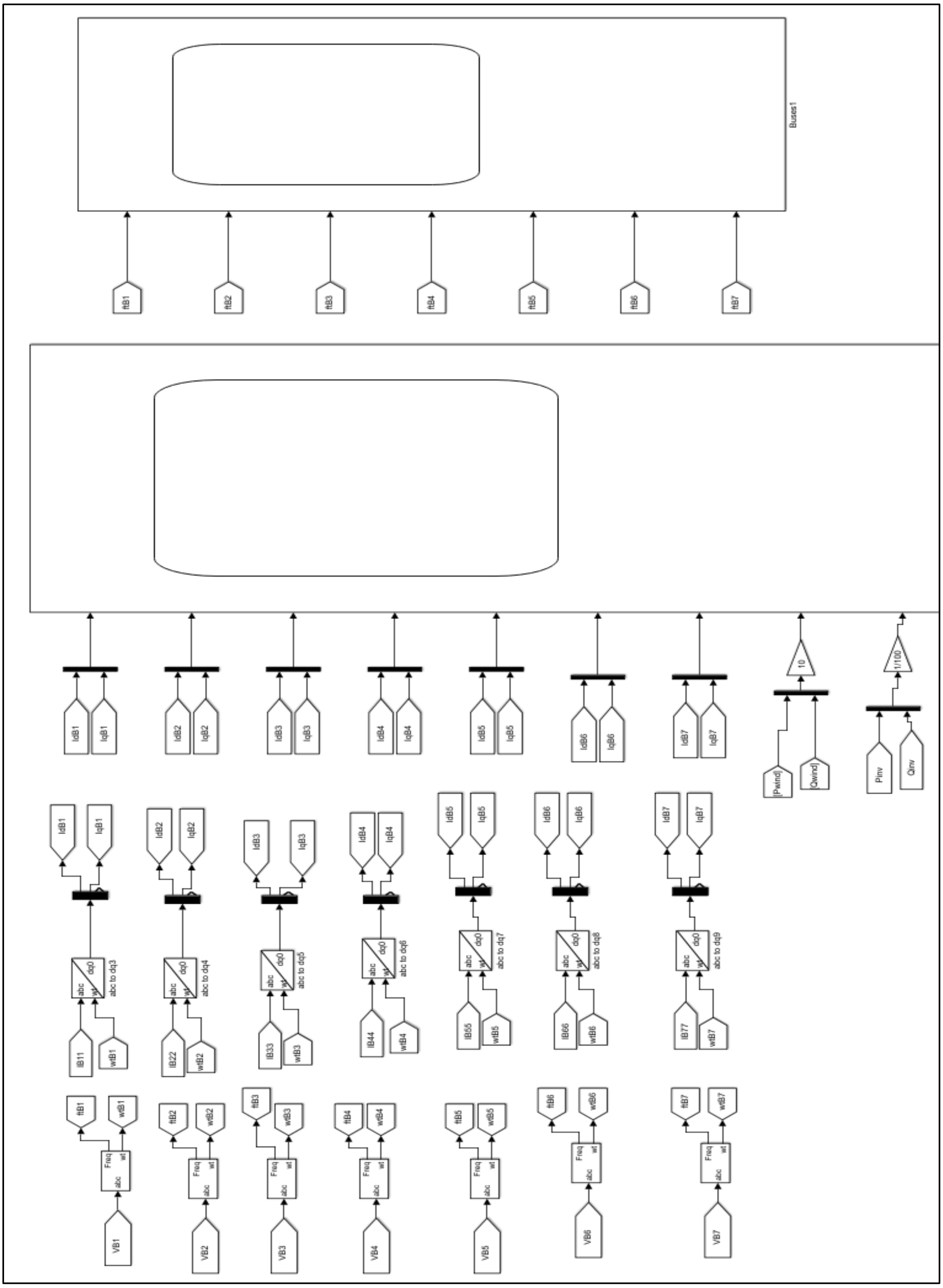


Figure 5.21: Buses measurement



5.2 PHOTOVOLTIC SYSTEM CASE STUDY SIMULATION

For this simulation the same components are going to be used as before but without using the battery storage to calculate the amount of power this system will produce around the year and to calculate the best title angle for the system, it is going to by PVsyst 6.81

The case study will be near the Sabiha airport in Orhanlı_Nasamo area (40°51 N , 29°19 E), where having around 3,500 meter square free area as shown if figures 5.22, 5.23.

Figure 5.22: Geographical area zoomed

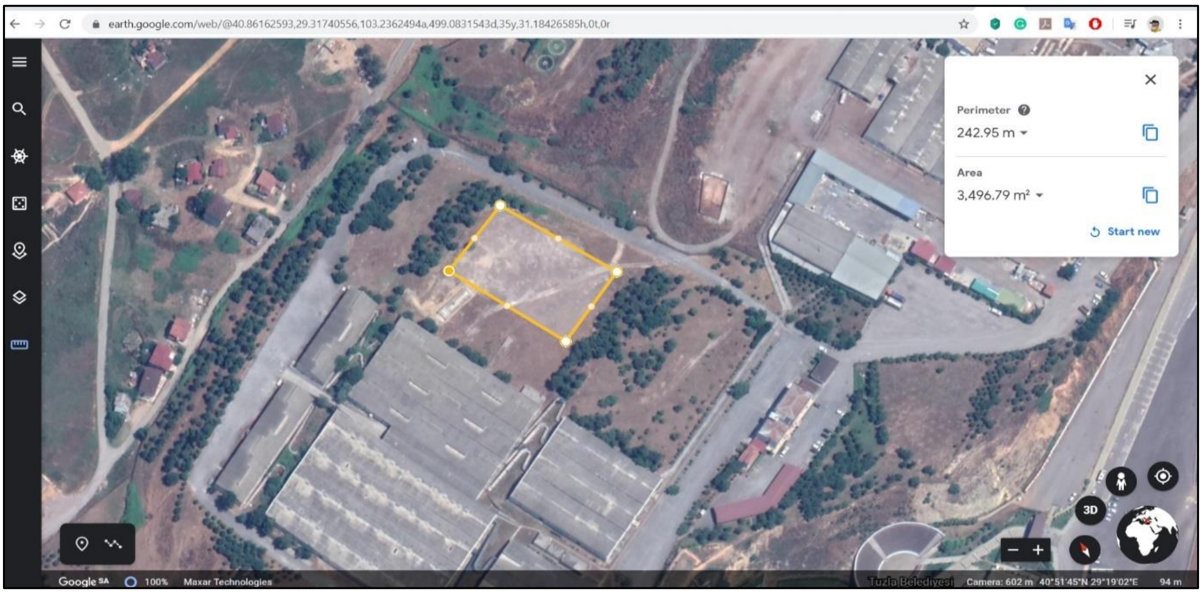
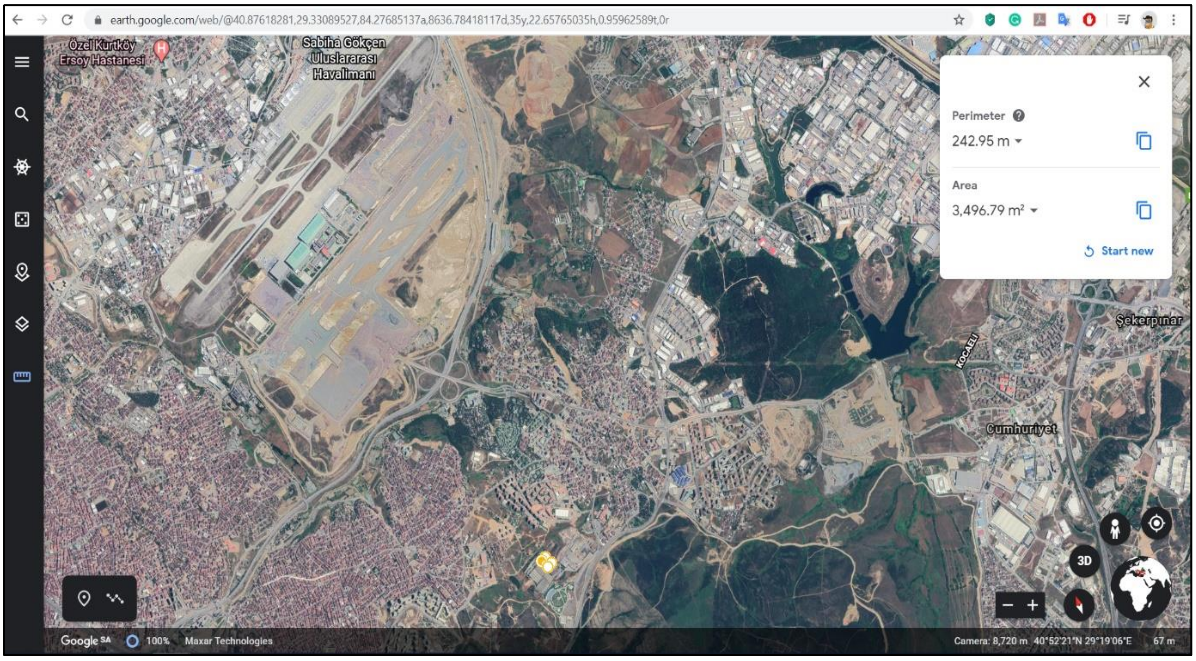
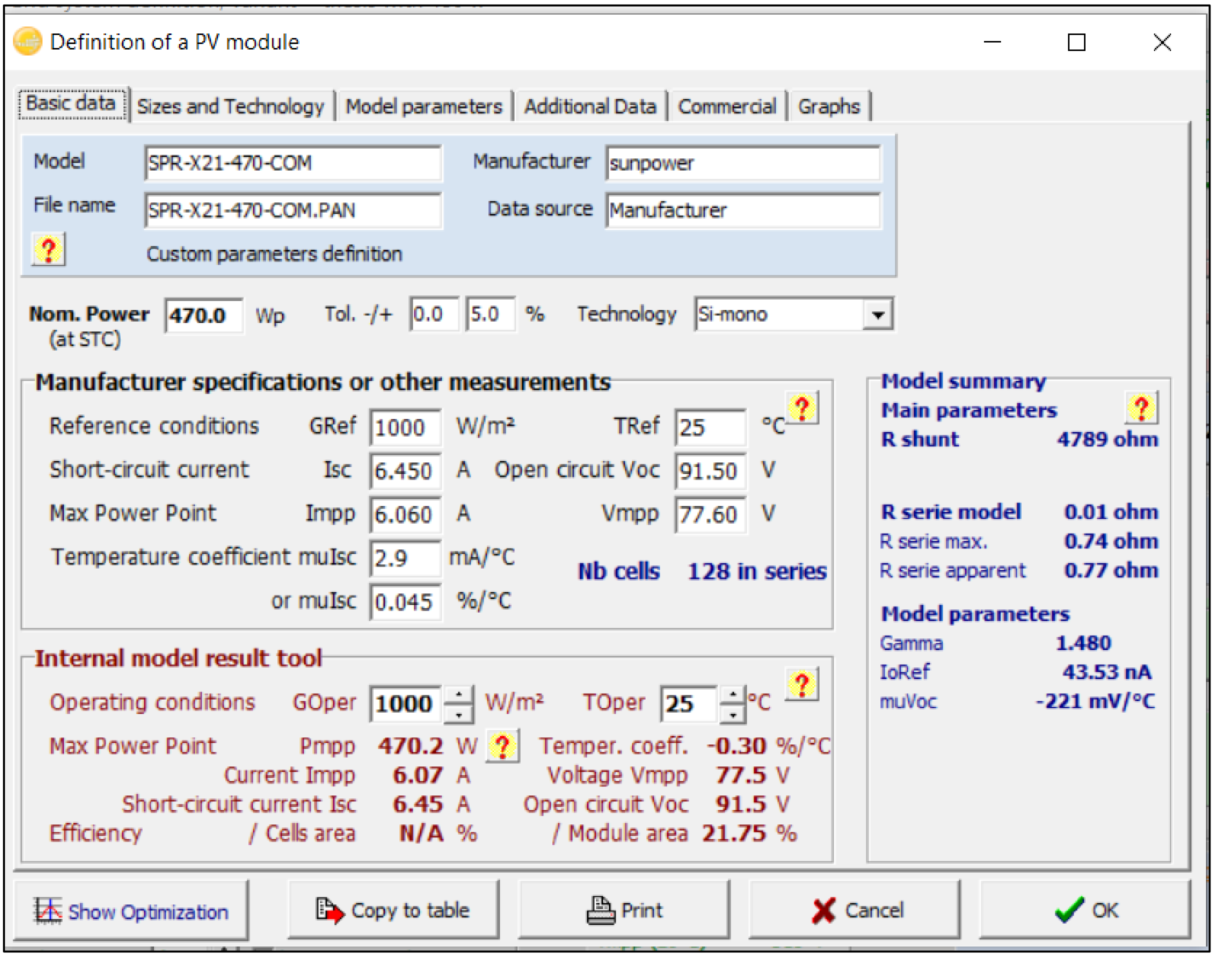


Figure 5.23: Geographical area



This is the solar panel module SPR-X21-470-COM from SunPower Company as shown in Figure 5.24.

Figure 5.24: SPR-X21-470-COM on PVSYST



For the inverter GTP-507 three will be used from Leonics company, the minimum working voltage power this inverter is 270 V DC, and the maximum working voltage power this inverter can work is 550 V DC as shown in Figure 5.25.

The system overview is PVSYST is shown in Figure 5.26.

Figure 5.25: Inverter GTP-507 three on PVSYST

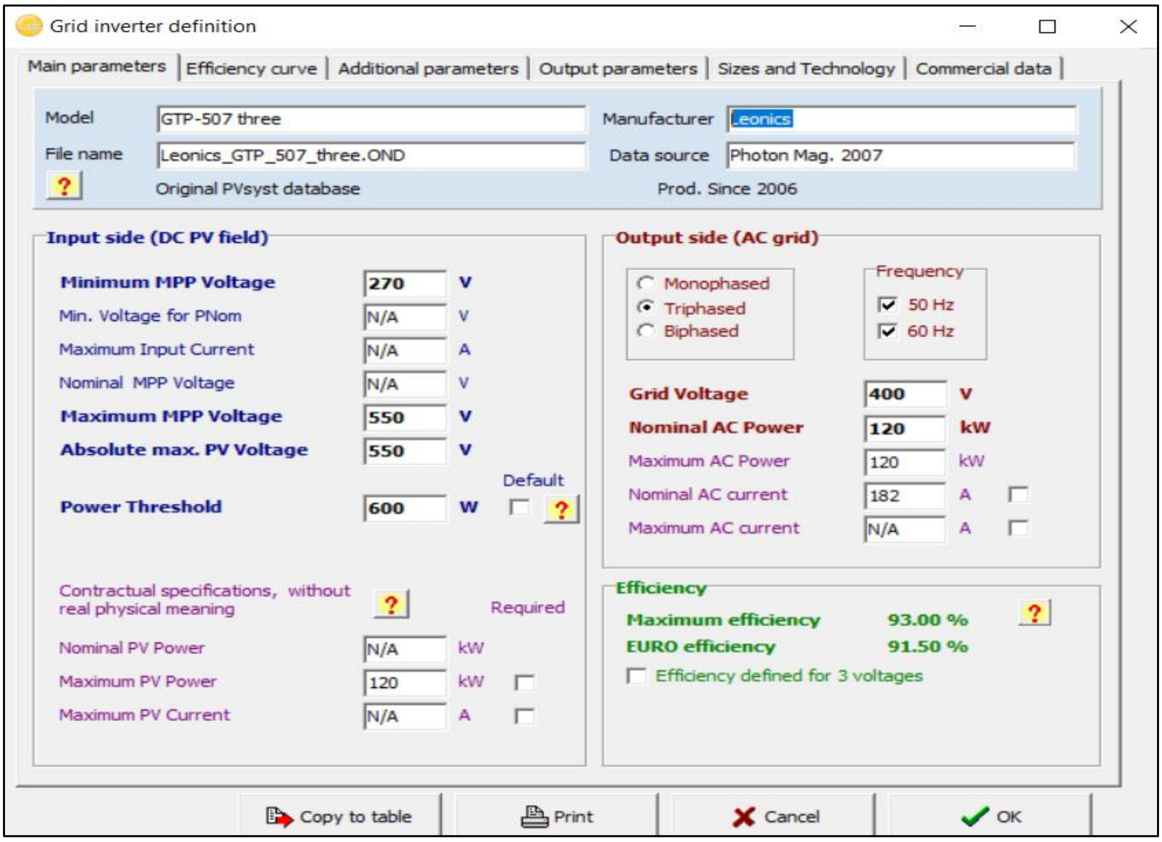
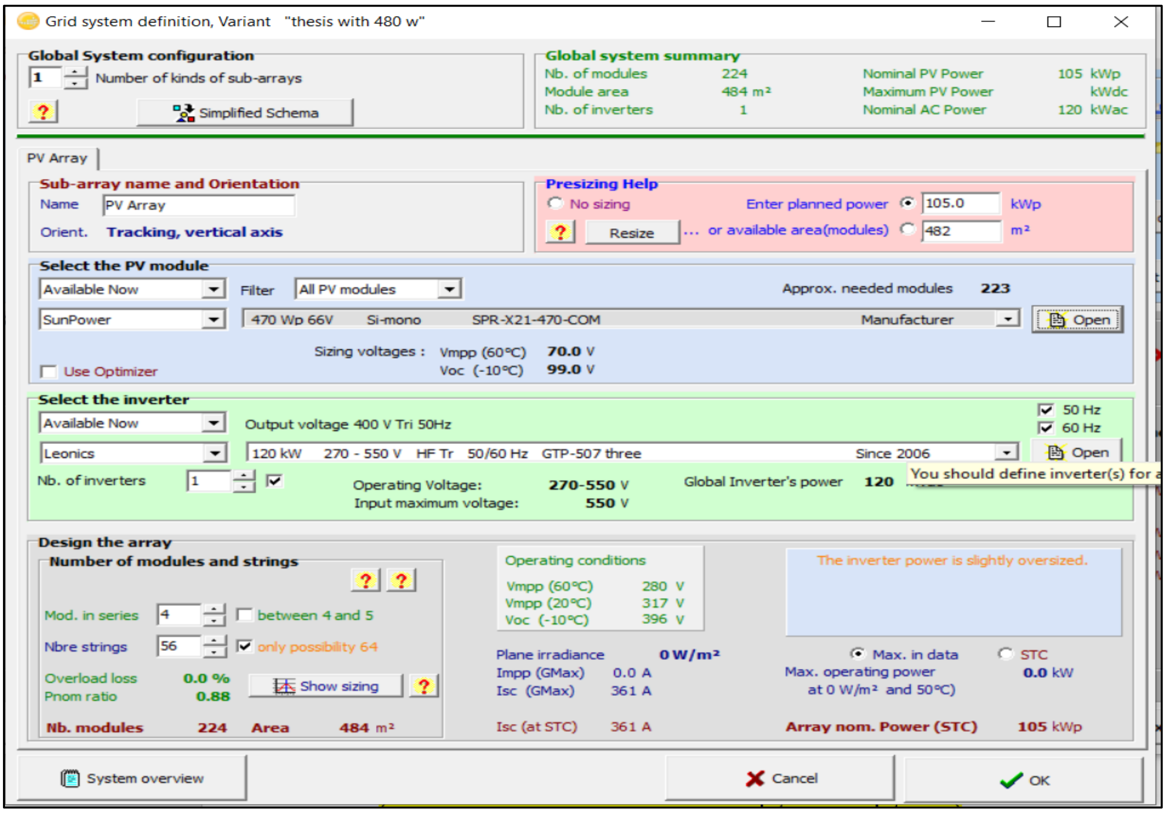
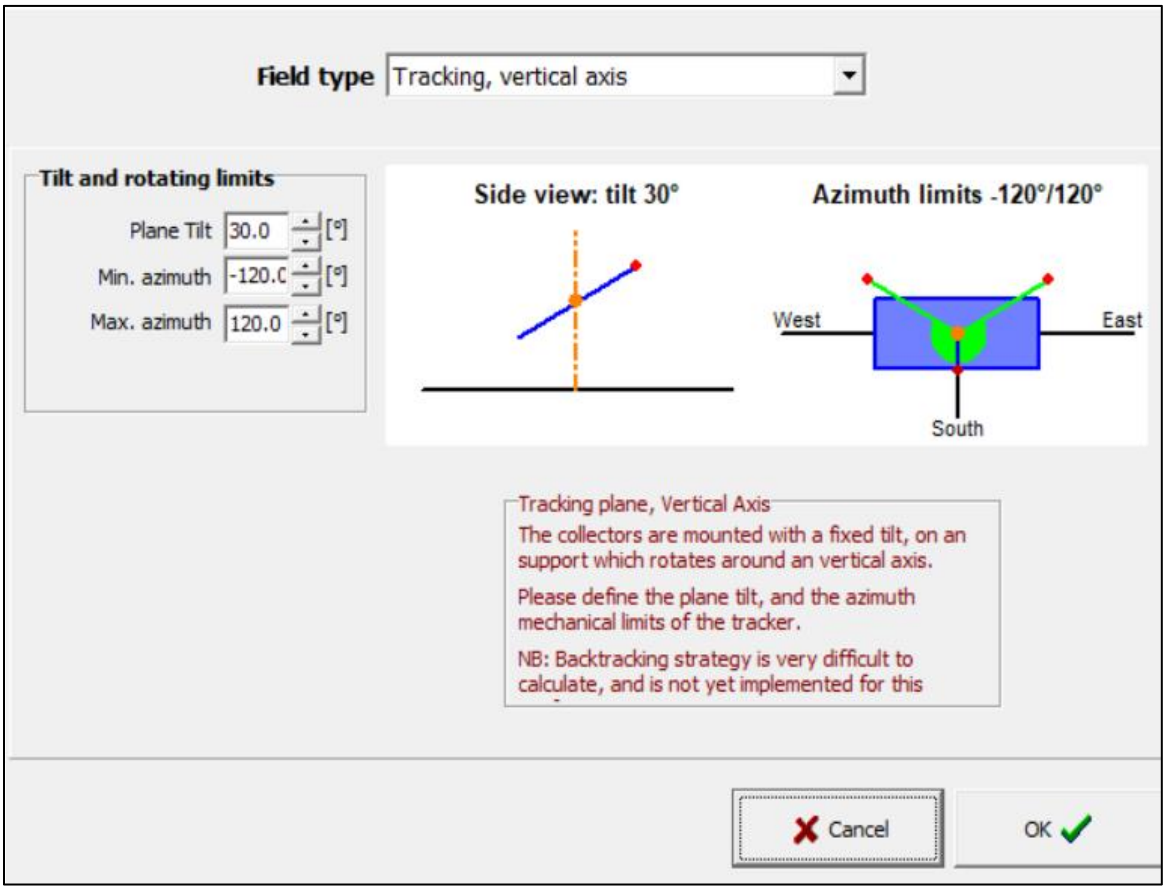


Figure 5.26: System overview on PVSYST



For the taking, the title angle will be constant at 30 degree as it the best angle for summer season when the sun be on it is maximum power there for the yearly power produced will be on its maximum, the tracker will on the vertical axis between -120 azimuth degree and 120 azimuth degree following the sun from the sunrise to sunset as shown in Figure 5.27.

Figure 5.27: Tracking system on PVSYST



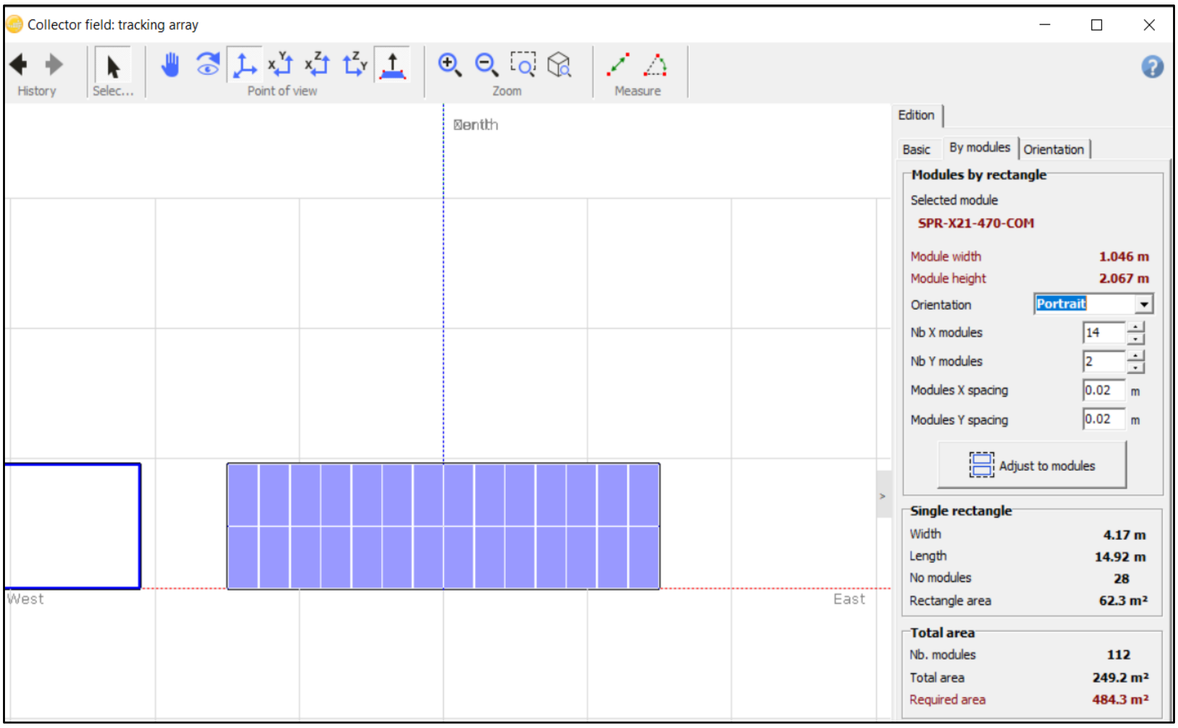
Eight trackers will be on two rows 20 meters space between its centers and 18 meters space in each column, each tracker will hold 28 solar panels, two solar on its y axis and 14 solar on its x axis, with 0.02 meter gab different between them, the tracker will be 4.17 meter width and 14.92 meter length as shown in Figure 5.28.

The system will need eight tracking holder difference between them 20 meter and 18 meters the minimum length needed: 18+18+18 + 15 = 68.9 meter (for both side)

The width needed: 20 + 5 = 25 meter

The minimum area needed: 25 x 68.9 = 1725 meter square

Figure 5.28: PV array tracking



For the shading effect will be very low, on early morning when the sun rising and, on the sunset, that time the sun will be on its minimum power as shown in Figure 5.29 .

Figure 5.29: Shading analysis

Status

Displaying generated tables — Recompute

Plane orientation

Tracking, vertical axis

Shading factor table (linear), for the beam component, Orient. #1

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10°	0.000	0.026	0.004	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.004	0.026	0.000
2°	0.309	0.186	0.244	0.341	0.442	0.442	0.341	0.271	0.267	0.345	0.267	0.271	0.341	0.442	0.442	0.341	0.244	0.186	0.309

Shading factor for diffuse: 0.011 and for albedo: 0.297

5.3 WIND TURBINE CASE STUDY SIMULATION

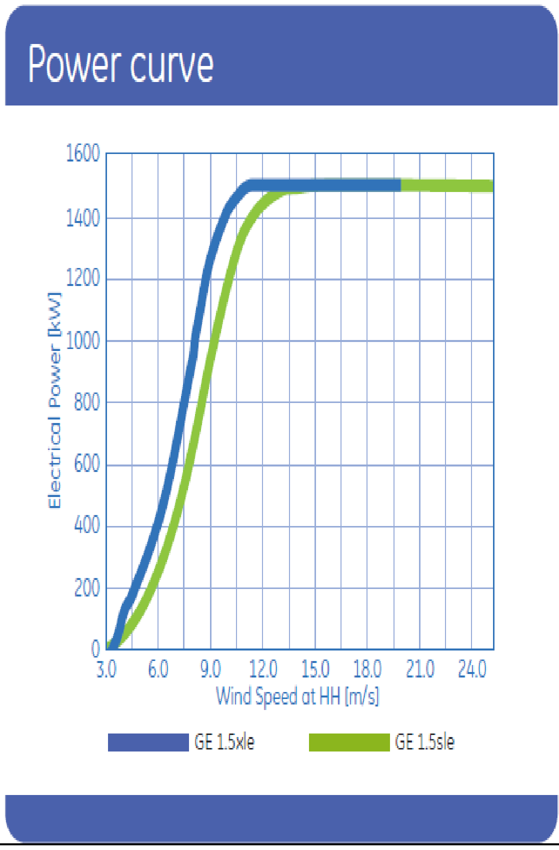
I have a 52704 data in excel sheet for one year in the date and time, wind velocity, wind direction, air temperature, atmospheric pressure for every 10 minutes in around Sabiha Gokcen area (I could only access this data).

GE 1.5xle from GE Energy Company is picked for the case study and, the datasheet is shown in Figure 5.30

Figure 5.30: GE 1.5xle from GE Energy Company

Technical data

		1.5sle	1.5xle
Operating Data			
Rated Capacity:		1,500 kW	1,500 kW
Temperature Range: (with Cold Weather Extreme Package)	Operation:	-30°C - +40°C	-30°C - +40°C
	Survival:	-40°C - +50°C	-40°C - +50°C
Cut-in Wind Speed:		3.5 m/s	3.5 m/s
Cut-out Wind Speed (10 min avg.):		25 m/s	20 m/s
Rated Wind Speed:		14 m/s	11.5 m/s
Wind Class – IEC:		IIa (V_{e50} = 55 m/s V_{ave} = 8.5 m/s)	IIIb (V_{e50} = 52.5 m/s V_{ave} = 8.0 m/s)
Electrical Interface			
Frequency		50/60 Hz	50/60 Hz
Voltage		690V	690V
Rotor			
Rotor Diameter:		77 m	82.5 m
Swept Area:		4657 m²	5346 m²
Tower			
Hub Heights:		65/80 m	80 m
Power Control		Active Blade Pitch Control	Active Blade Pitch Control



From the datasheet of this turbine:

The rated power: 1,500 kW

Hub height: 65 / 80 meters high the rotor diameter: 77 meters, the radius: 38.5 meters.

The area swiped by the 4657 m^2

Pitch angle control and the yaw system are active.

Cut off speed: 25 m/s

Cut on speed: 3.5 m/s (minimum wind speeds the wind turbine can work.

The relation between the wind speed and wind turbine power is shown in table 5.1.

Table 5.1: GE 1.5xle Wind turbine output power

Wind m/s	Power (kW)
1	0
2	0
3	0
4	50
5	160
6	270
7	400
8	710
9	890
10	1,150
11	1,376
12	1,450
13	1,473
14	1,500
15	1,500
16	1,500
17	1,500
18	1,500
19	1,500
20	1,500
21	1,500
22	1,500
23	1,500
24	1,500
25	1,500

From the table can determine the maximum power coefficient at 8 , 9 m/s , means the wind turbine get the maximum efficiency from the wind power at that point as shown in table 5.3-.

Classifying the wind speed bands to be a natural number with 1 m/s band using IF state of excel as shown in Figure 5.31 and classifying the wind data into 16 direction using IF state on excel as shown in Figure 5.32-.

Then the air density

$$\rho = \frac{P}{T\ X\ R}$$

Then kinetic energy of the air passes throws the winds turbine blades per one meter square area

$$P = \frac{1}{2}\ x\ \rho\ x\ m^2\ x\ V^3$$

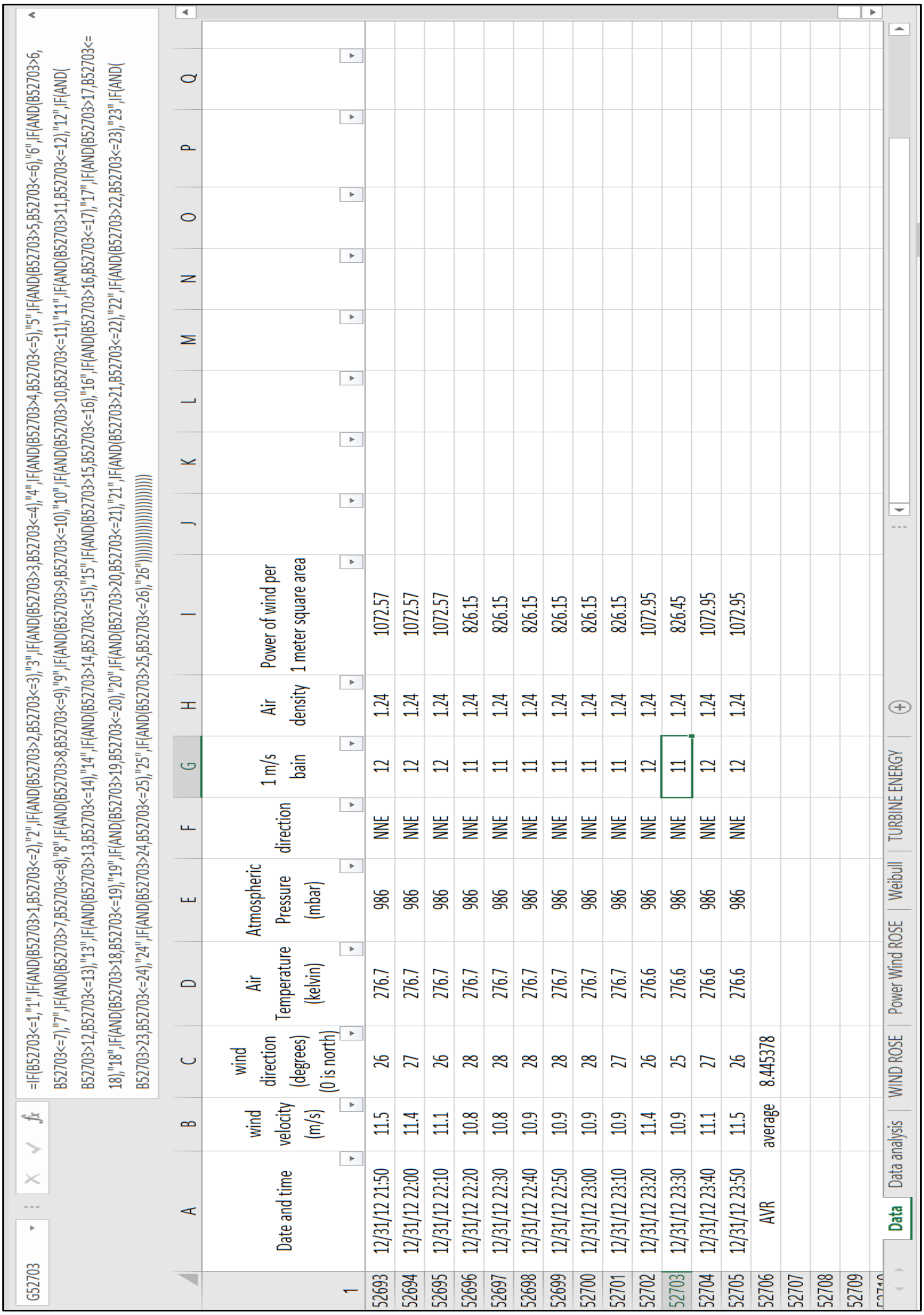
Then classified the data into the 1 meter band wind velocity and 16 wind direction and the probability for it as shown in Figure 5.33-.

From the probability of the direction can get the wind direction rose as shown in Figure 5.34-.

Then to see from which direction comes the strong wind, should classified the amount of power with the direction of the wind and the probability for it and get the power roses of the wind as shown in Figure 5.35-.

To determining wind turbine electricity generation around the year should use Weibull distribution, after calculating the hours in a year for the wind speed from Weibull distribution as shown in Figure 5.36-.

Figure 5.31: Classifying wind speed

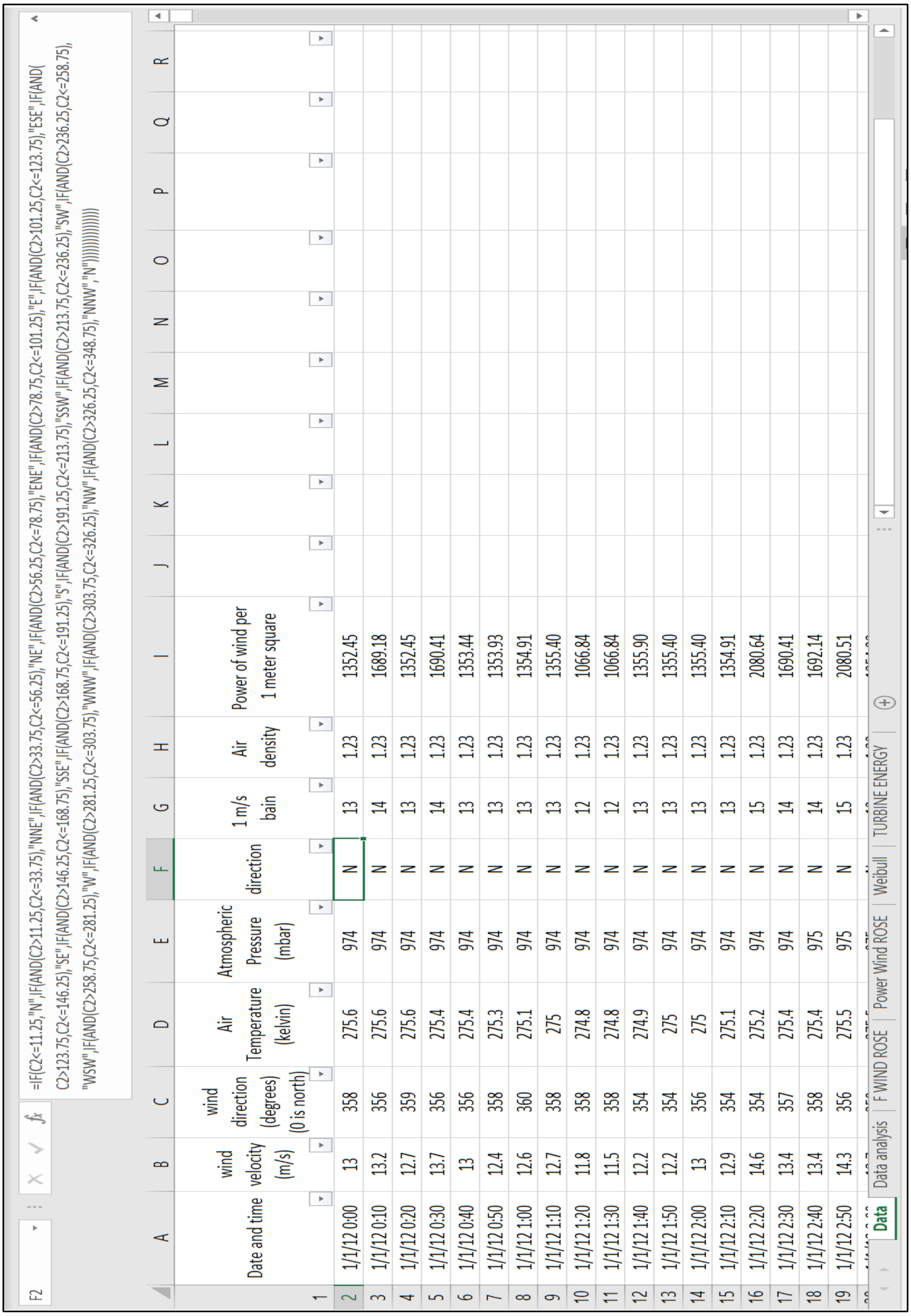


G52703

=IF(B52703<=1,"1",IF(AND(B52703>1,B52703<=2),"2",IF(AND(B52703>2,B52703<=3),"3",IF(AND(B52703>3,B52703<=4),"4",IF(AND(B52703>4,B52703<=5),"5",IF(AND(B52703>5,B52703<=6),"6",IF(AND(B52703>6,B52703<=7),"7",IF(AND(B52703>7,B52703<=8),"8",IF(AND(B52703>8,B52703<=9),"9",IF(AND(B52703>9,B52703<=10),"10",IF(AND(B52703>10,B52703<=11),"11",IF(AND(B52703>11,B52703<=12),"12",IF(AND(B52703>12,B52703<=13),"13",IF(AND(B52703>13,B52703<=14),"14",IF(AND(B52703>14,B52703<=15),"15",IF(AND(B52703>15,B52703<=16),"16",IF(AND(B52703>16,B52703<=17),"17",IF(AND(B52703>17,B52703<=18),"18",IF(AND(B52703>18,B52703<=19),"19",IF(AND(B52703>19,B52703<=20),"20",IF(AND(B52703>20,B52703<=21),"21",IF(AND(B52703>21,B52703<=22),"22",IF(AND(B52703>22,B52703<=23),"23",IF(AND(B52703>23,B52703<=24),"24",IF(AND(B52703>24,B52703<=25),"25",IF(AND(B52703>25,B52703<=26),"26"))))))))))))))))))))))))))

	A	B	C	D	E	F	G	H	I
1	Date and time	wind velocity (m/s)	wind direction (degrees) (0 is north)	Air Temperature (kelvin)	Atmospheric Pressure (mbar)	direction	1 m/s bain	Air density	Power of wind per 1 meter square area
52693	12/31/12 21:50	11.5	26	276.7	986	NNE	12	1.24	1072.57
52694	12/31/12 22:00	11.4	27	276.7	986	NNE	12	1.24	1072.57
52695	12/31/12 22:10	11.1	26	276.7	986	NNE	12	1.24	1072.57
52696	12/31/12 22:20	10.8	28	276.7	986	NNE	11	1.24	826.15
52697	12/31/12 22:30	10.8	28	276.7	986	NNE	11	1.24	826.15
52698	12/31/12 22:40	10.9	28	276.7	986	NNE	11	1.24	826.15
52699	12/31/12 22:50	10.9	28	276.7	986	NNE	11	1.24	826.15
52700	12/31/12 23:00	10.9	28	276.7	986	NNE	11	1.24	826.15
52701	12/31/12 23:10	10.9	27	276.7	986	NNE	11	1.24	826.15
52702	12/31/12 23:20	11.4	26	276.6	986	NNE	12	1.24	1072.95
52703	12/31/12 23:30	10.9	25	276.6	986	NNE	11	1.24	826.45
52704	12/31/12 23:40	11.1	27	276.6	986	NNE	12	1.24	1072.95
52705	12/31/12 23:50	11.5	26	276.6	986	NNE	12	1.24	1072.95
52706	AVR	average	8.445378						

Figure 5.32: Classifying wind directions



F2

=IF(C2<=11.25,"N",IF(AND(C2>11.25,C2<=33.75),"NNE",IF(AND(C2>33.75,C2<=56.25),"NE",IF(AND(C2>56.25,C2<=78.75),"ENE",IF(AND(C2>78.75,C2<=101.25),"E",IF(AND(C2>101.25,C2<=123.75),"ESE",IF(AND(C2>123.75,C2<=146.25),"SE",IF(AND(C2>146.25,C2<=168.75),"SSE",IF(AND(C2>168.75,C2<=191.25),"S",IF(AND(C2>191.25,C2<=213.75),"SSW",IF(AND(C2>213.75,C2<=236.25),"SW",IF(AND(C2>236.25,C2<=258.75),"WSW",IF(AND(C2>258.75,C2<=281.25),"W",IF(AND(C2>281.25,C2<=303.75),"WNW",IF(AND(C2>303.75,C2<=326.25),"NW",IF(AND(C2>326.25,C2<=348.75),"NNW","N"))))))))))))))))

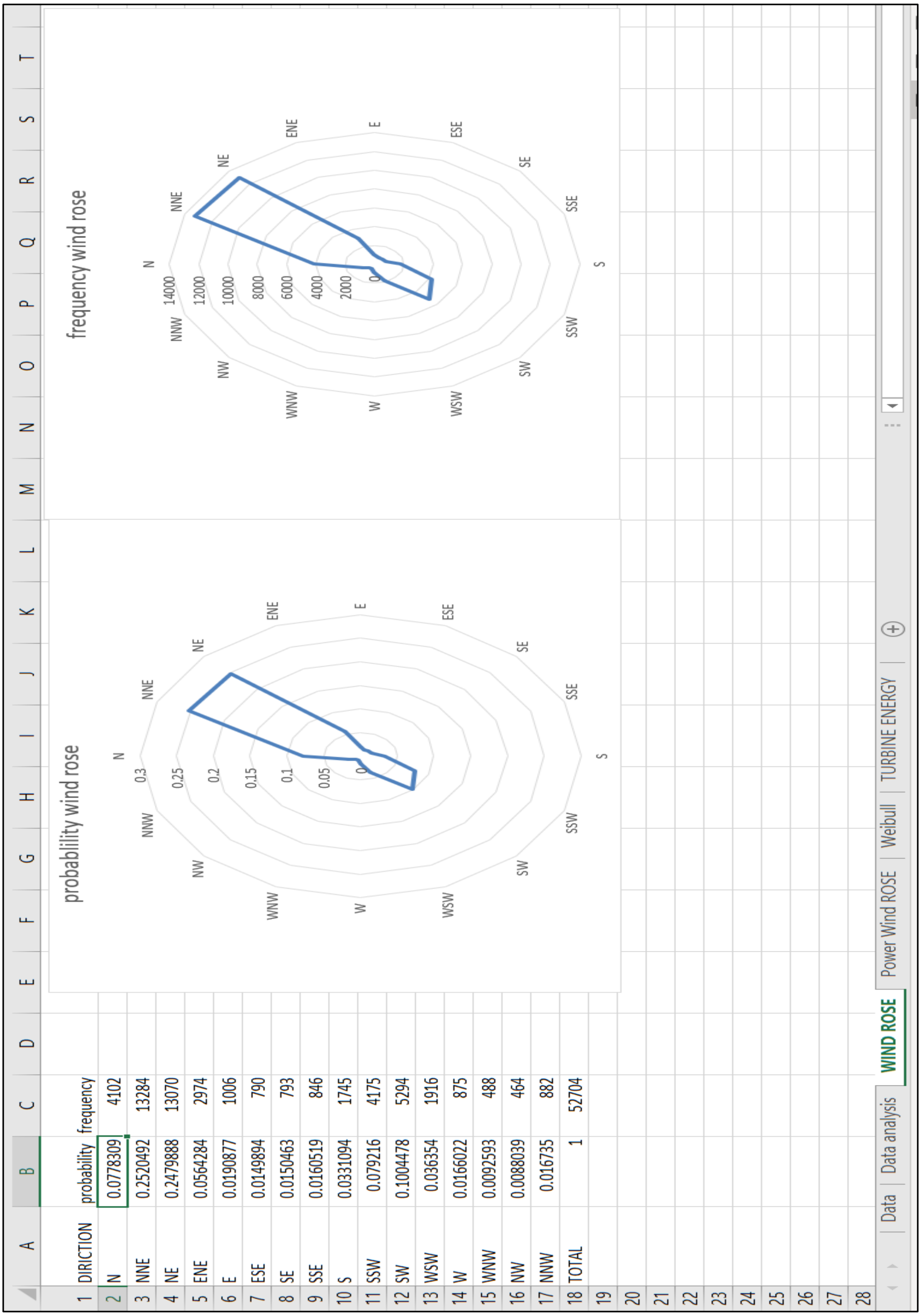
	A	B	C	D	E	F	G	H	I
1	Date and time	wind velocity (m/s)	wind direction (degrees) (0 is north)	Air Temperature (kelvin)	Atmospheric Pressure (mbar)	direction	1 m/s bain	Air density	Power of wind per 1 meter square
2	1/1/12 0:00	13	358	275.6	974	N	13	1.23	1352.45
3	1/1/12 0:10	13.2	356	275.6	974	N	14	1.23	1689.18
4	1/1/12 0:20	12.7	359	275.6	974	N	13	1.23	1352.45
5	1/1/12 0:30	13.7	356	275.4	974	N	14	1.23	1690.41
6	1/1/12 0:40	13	356	275.4	974	N	13	1.23	1353.44
7	1/1/12 0:50	12.4	358	275.3	974	N	13	1.23	1353.93
8	1/1/12 1:00	12.6	360	275.1	974	N	13	1.23	1354.91
9	1/1/12 1:10	12.7	358	275	974	N	13	1.23	1355.40
10	1/1/12 1:20	11.8	358	274.8	974	N	12	1.23	1066.84
11	1/1/12 1:30	11.5	358	274.8	974	N	12	1.23	1066.84
12	1/1/12 1:40	12.2	354	274.9	974	N	13	1.23	1355.90
13	1/1/12 1:50	12.2	354	275	974	N	13	1.23	1355.40
14	1/1/12 2:00	13	356	275	974	N	13	1.23	1355.40
15	1/1/12 2:10	12.9	354	275.1	974	N	13	1.23	1354.91
16	1/1/12 2:20	14.6	354	275.2	974	N	15	1.23	2080.64
17	1/1/12 2:30	13.4	357	275.4	974	N	14	1.23	1690.41
18	1/1/12 2:40	13.4	358	275.4	975	N	14	1.23	1692.14
19	1/1/12 2:50	14.3	356	275.5	975	N	15	1.23	2080.51

Data | Data analysis | F WIND ROSE | Power Wind ROSE | Weibull | TURBINE ENERGY

Figure 5.33: Wind direction and speed probability

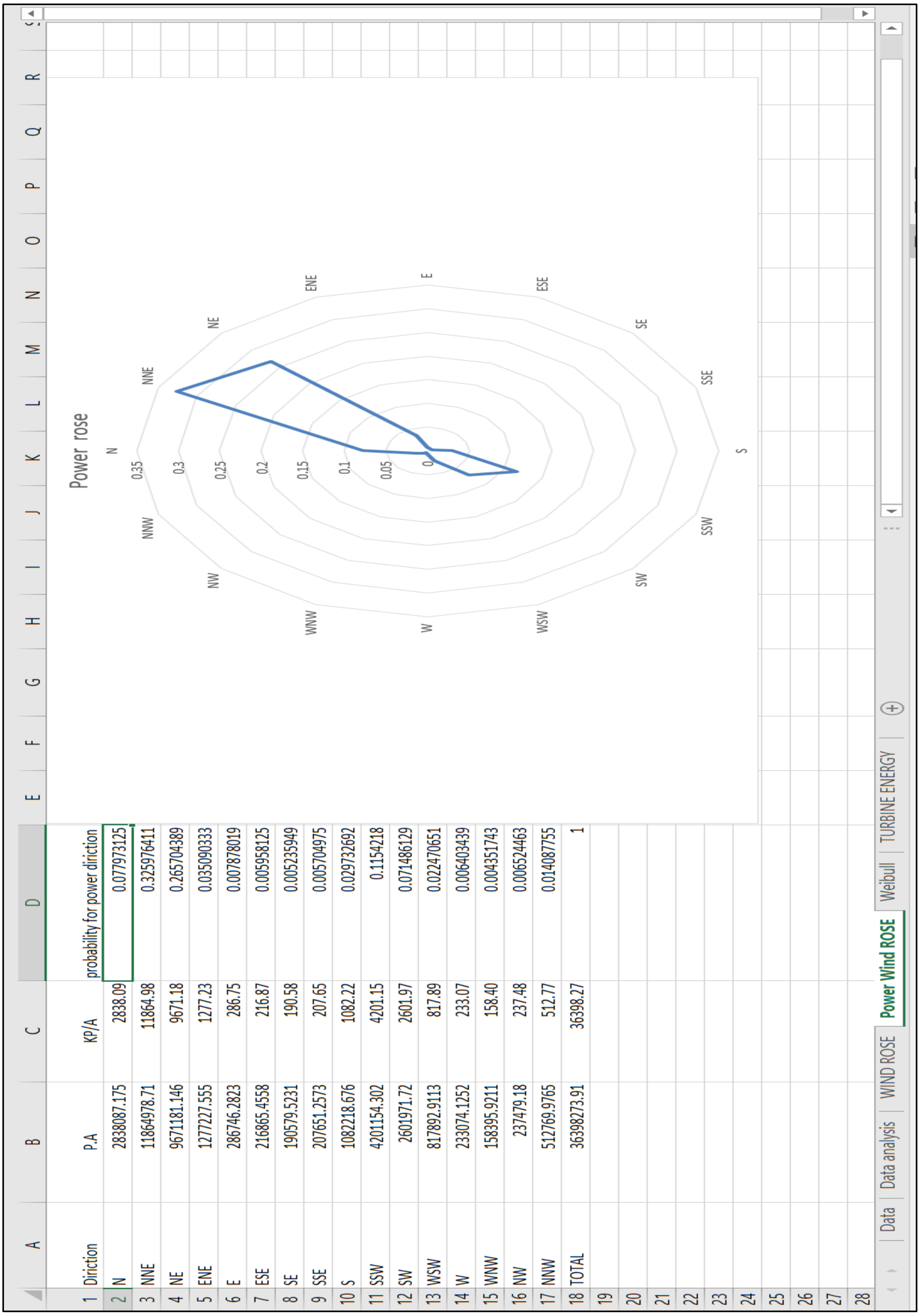
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL	probability for 1 m band	wind speed
1	15	7	22	11	15	9	14	17	13	30	6	17	15	16	17	7	231	0.004382969	231
2	72	102	113	84	51	42	78	68	83	93	77	89	37	28	30	34	1081	0.020510777	2162
3	123	205	206	191	124	131	326	282	146	222	230	194	160	61	40	39	2680	0.05085003	8040
4	185	295	319	262	275	165	213	232	201	269	519	312	228	120	91	57	3743	0.071019277	14972
5	348	537	504	293	202	174	52	81	226	438	546	198	125	87	58	79	3948	0.074908925	19740
6	340	1056	740	288	114	92	29	37	173	460	617	185	98	53	46	77	4405	0.083579994	26430
7	396	1147	1101	378	82	55	14	24	124	336	736	203	56	19	44	82	4797	0.09101776	33579
8	393	1219	1103	373	44	29	10	17	130	341	599	126	46	35	30	96	4591	0.087109138	36728
9	439	1349	1346	284	28	27	10	16	132	327	492	122	27	18	24	96	4737	0.089879326	42633
10	435	1439	1597	249	10	13	4	15	87	207	311	106	19	7	6	97	4602	0.087317851	46020
11	341	1431	1901	202	9	4	0	8	72	170	291	102	12	4	10	69	4626	0.087773224	50886
12	246	1244	1657	202	3	6	1	6	81	181	310	62	8	6	15	42	4070	0.07722374	48840
13	218	1060	1134	60	1	2	2	7	31	154	172	56	5	2	9	43	2956	0.056086825	38428
14	222	594	668	28	2	3	3	2	42	133	127	61	2	3	1	23	1914	0.036316029	26796
15	165	454	328	26	11	10	6	3	56	95	81	32	9	7	10	11	1304	0.024741955	19560
16	79	349	175	18	7	8	8	6	45	117	81	15	9	7	6	4	934	0.017721615	14944
17	40	252	75	6	6	7	1	4	45	131	43	17	4	6	10	7	654	0.012408925	11118
18	20	218	46	2	3	3	6	5	23	167	19	5	5	5	6	10	543	0.010302823	9774
19	14	160	17	2	6	5	3	5	16	119	13	3	6	1	4	4	378	0.007172131	7182
20	6	109	6	3	2	2	5	7	9	99	14	5	2	1	1	1	272	0.005160899	5440
21	3	47	5	4	4	1	5	4	5	40	9	3	1	0	2	0	133	0.002523528	2793
22	1	5	2	5	3	1	2	0	3	27	1	1	0	1	3	1	56	0.001062538	1232
23	1	2	5	0	3	1	0	0	2	16	0	1	1	0	1	1	34	0.000645112	782
24	0	3	0	3	1	0	1	0	0	2	0	1	0	1	0	1	13	0.000246661	312
25	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3.79478E-05	50
TOTAL	4102	13284	13070	2974	1006	790	793	846	1745	4175	5294	1916	875	488	464	882	52704	1.00	8.89236315
Direction probability	0.077831	0.252049	0.247989	0.056428	0.019088	0.014989	0.015046	0.016052	0.033109	0.079216	0.100448	0.036354	0.016602	0.009259	0.008804	0.016735	1		
	average wind speed= 8.89 m/s																		

Figure 5.34: Wind rose



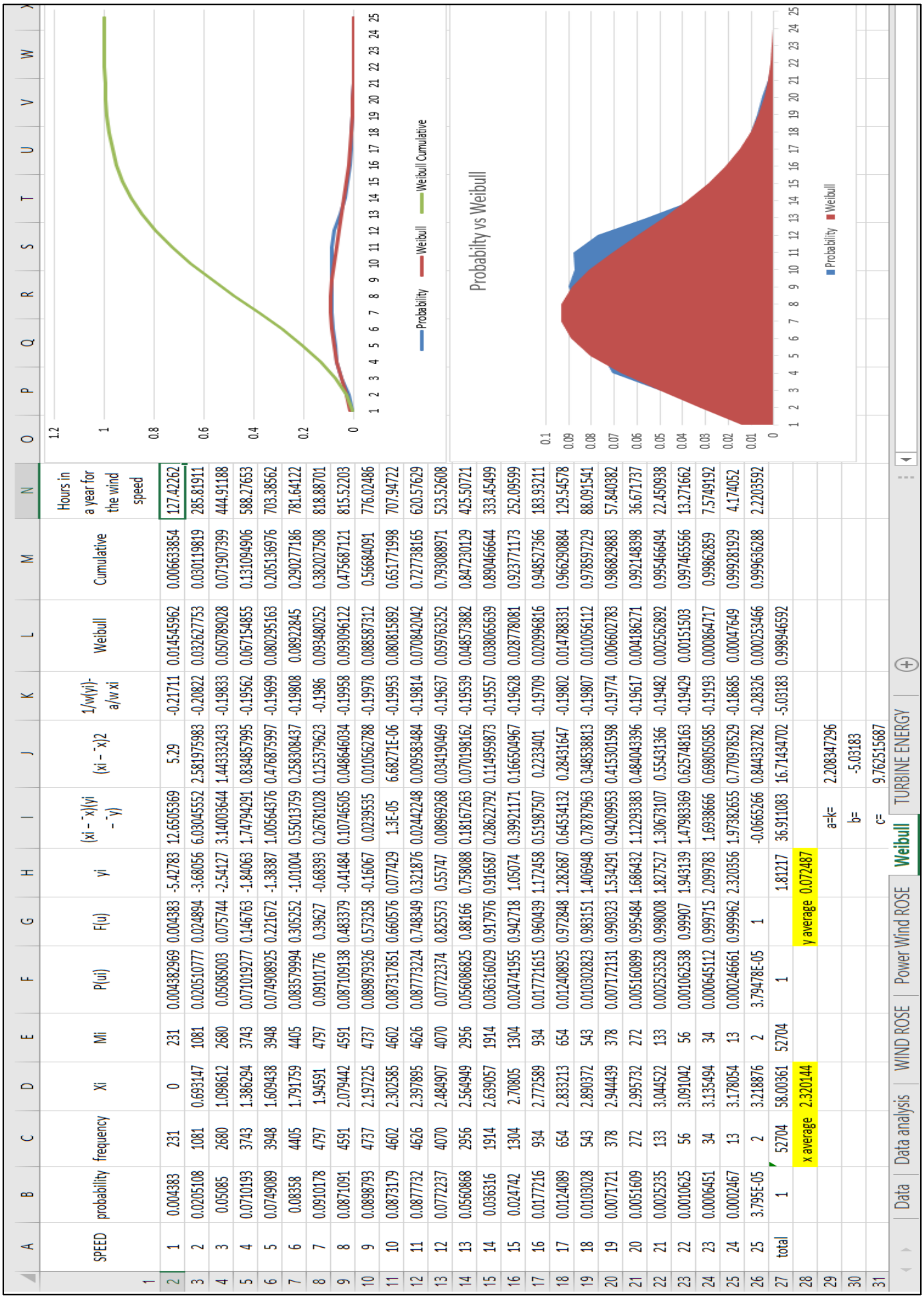
DIRICTION	probability	frequency
N	0.0778309	4102
NNE	0.2520492	13284
NE	0.2479888	13070
ENE	0.0564284	2974
E	0.0190877	1006
ESE	0.0149894	790
SE	0.0150463	793
SSE	0.0160519	846
S	0.0331094	1745
SSW	0.079216	4175
SW	0.1004478	5294
WSW	0.036354	1916
W	0.0166022	875
WNW	0.0092593	488
NW	0.0088039	464
NNW	0.016735	882
TOTAL	1	52704

Figure 5.35: Power wind rose



Diriction	P.A	KP/A	probability for power diriction
N	2838087.175	2838.09	0.077973125
NNE	11864978.71	11864.98	0.325976411
NE	9671181.146	9671.18	0.265704389
ENE	1277227.555	1277.23	0.035090333
E	286746.2823	286.75	0.007878019
ESE	216865.4558	216.87	0.005958125
SE	190579.5231	190.58	0.005235949
SSE	207651.2573	207.65	0.005704975
S	1082218.676	1082.22	0.029732692
SSW	4201154.302	4201.15	0.1154218
SW	2601971.72	2601.97	0.071486129
WSW	817892.9113	817.89	0.022470651
W	233074.1252	233.07	0.006403439
WNW	158395.9211	158.40	0.004351743
NW	237479.18	237.48	0.006524463
NNW	512769.9765	512.77	0.014087755
TOTAL	36398273.91	36398.27	1

Figure 5.36: Weibull distribution



SPEED	probability	frequency	Xi	Mi	P(ui)	F(u)	yi	(xi - ¯x)(yi - ¯y)	(xi - ¯x)2	1/w(yi)-a/w xi	Weibull	Cumulative	Hours in a year for the wind speed
1	0.004383	231	0	231	0.004382969	0.004383	-5.42783	12.6505369	5.29	-0.21711	0.014545962	0.006633854	127.42262
2	0.0205108	1081	0.693147	1081	0.020510777	0.024894	-3.68056	6.03045552	2.581975983	-0.20822	0.032627753	0.030119819	285.81911
3	0.05085	2680	1.098612	2680	0.05085003	0.075744	-2.54127	3.14003644	1.443332433	-0.19833	0.050789028	0.071907399	444.91188
4	0.0710193	3743	1.386294	3743	0.071019277	0.146763	-1.84063	1.74794291	0.834857995	-0.19562	0.067154855	0.131094906	588.27653
5	0.0749089	3948	1.609438	3948	0.074908925	0.221672	-1.38387	1.00564376	0.476875997	-0.19699	0.080295163	0.205136976	703.38562
6	0.08358	4405	1.791759	4405	0.083579994	0.305252	-1.01004	0.55013759	0.258308437	-0.19808	0.08922845	0.290277186	781.64122
7	0.0910178	4797	1.94591	4797	0.09101776	0.39627	-0.68393	0.26781028	0.125379623	-0.1986	0.093480252	0.382027508	818.88701
8	0.0871091	4591	2.079442	4591	0.087109138	0.483379	-0.41484	0.10746505	0.048646034	-0.19958	0.093096122	0.475687121	815.52203
9	0.0898793	4737	2.197225	4737	0.089879326	0.573258	-0.16067	0.0239535	0.010562788	-0.19978	0.088587312	0.56684091	776.02486
10	0.0873179	4602	2.302585	4602	0.087317851	0.660576	0.077429	1.3E-05	6.68271E-06	-0.19953	0.080815892	0.651771998	707.94722
11	0.0877732	4626	2.397895	4626	0.087773224	0.748349	0.321876	0.02442248	0.009583484	-0.19814	0.070842042	0.727738165	620.57629
12	0.0772237	4070	2.484907	4070	0.07722374	0.825573	0.55747	0.08969268	0.034190469	-0.19637	0.059763252	0.793088971	523.52608
13	0.0560868	2956	2.564949	2956	0.056086825	0.88166	0.758088	0.18167263	0.070198162	-0.19539	0.048573882	0.847230129	425.50721
14	0.036316	1914	2.639057	1914	0.036316029	0.917976	0.916587	0.28622792	0.114959873	-0.19557	0.038065639	0.890466644	333.45499
15	0.024742	1304	2.70805	1304	0.024741955	0.942718	1.05074	0.39921171	0.166504967	-0.19628	0.028778081	0.923771173	252.09599
16	0.0177216	934	2.772589	934	0.017721615	0.960439	1.172458	0.51987507	0.2233401	-0.19709	0.020996816	0.948527366	183.93211
17	0.0124089	654	2.833213	654	0.012408925	0.972848	1.282687	0.64534132	0.28431647	-0.19802	0.014788331	0.966290884	129.54578
18	0.0103028	543	2.890372	543	0.010302823	0.983151	1.406948	0.78787963	0.348538813	-0.19807	0.010056112	0.978597229	88.091541
19	0.0071721	378	2.944439	378	0.007172131	0.990323	1.534291	0.94209953	0.415301598	-0.19774	0.006602783	0.986829883	57.840382
20	0.0051609	272	2.995732	272	0.005160899	0.995484	1.686432	1.12293383	0.484043396	-0.19617	0.004186271	0.992148398	36.671737
21	0.0025235	133	3.044522	133	0.002523528	0.998008	1.827527	1.30673107	0.55431366	-0.19482	0.002562892	0.995466494	22.450938
22	0.0010625	56	3.091042	56	0.001062538	0.99907	1.943139	1.47983369	0.625748163	-0.19429	0.00151503	0.997465566	13.271662
23	0.0006451	34	3.135494	34	0.000645112	0.999715	2.099783	1.6938666	0.698050585	-0.19193	0.000864717	0.99862859	7.5749192
24	0.0002467	13	3.178054	13	0.000246661	0.999962	2.320356	1.97382655	0.770978529	-0.18685	0.00047649	0.999281929	4.174052
25	3.795E-05	2	3.218876	2	3.79478E-05	1		-0.0665266	0.844332782	-0.28326	0.000253466	0.999636288	2.2203592
total	1	52704	58.00361	52704	1		1.81217	36.911083	16.71434702	-5.03183	0.998946592		
		x average	2.320144			y average	0.072487						
								a=k=	2.208347296				
								b=	-5.03183				
								c=	9.762515687				

6. RESULTS AND DISCUSSION

For the MATLAB simulation it is divided into three parts when the battery power control is off, battery power control put to 120 kW, and battery power control put to variable values. Also the report from PVSYST for the case study, and wind turbine case study result.

6.1 BATTERY CONTROLLER OFF

When the sun irradiation hit the solar panels, it is going to generate dc power, when the output voltage reaches 270 V the dc breaker will close to let the power go to the boost converter, to extract the maximum power from it (the maximum power is 105.3 kW) without changing in the duty cycle of the boost, the input sun irradiation will be a 1000 W/m^2 then at 1 sec start to decrease until reaching its minimum irradiation 300 at 1.5 sec, then rise again at 2 sec until reaching 1000 W/m^2 at 2.5 sec, the solar panels temperature is going to be 25 Celsius as shown in Figure 6.1-, but increase at 3 sec to reaching 50 Celsius at 3.5 sec then decrease again at 4 sec to reach 25 Celsius again, for the relation maximum power from the solar panels and the boost converter extracting power from the panels a boost scope is shown in Figure 6.2-.

Figure 6.1: Irradiation and temperature input

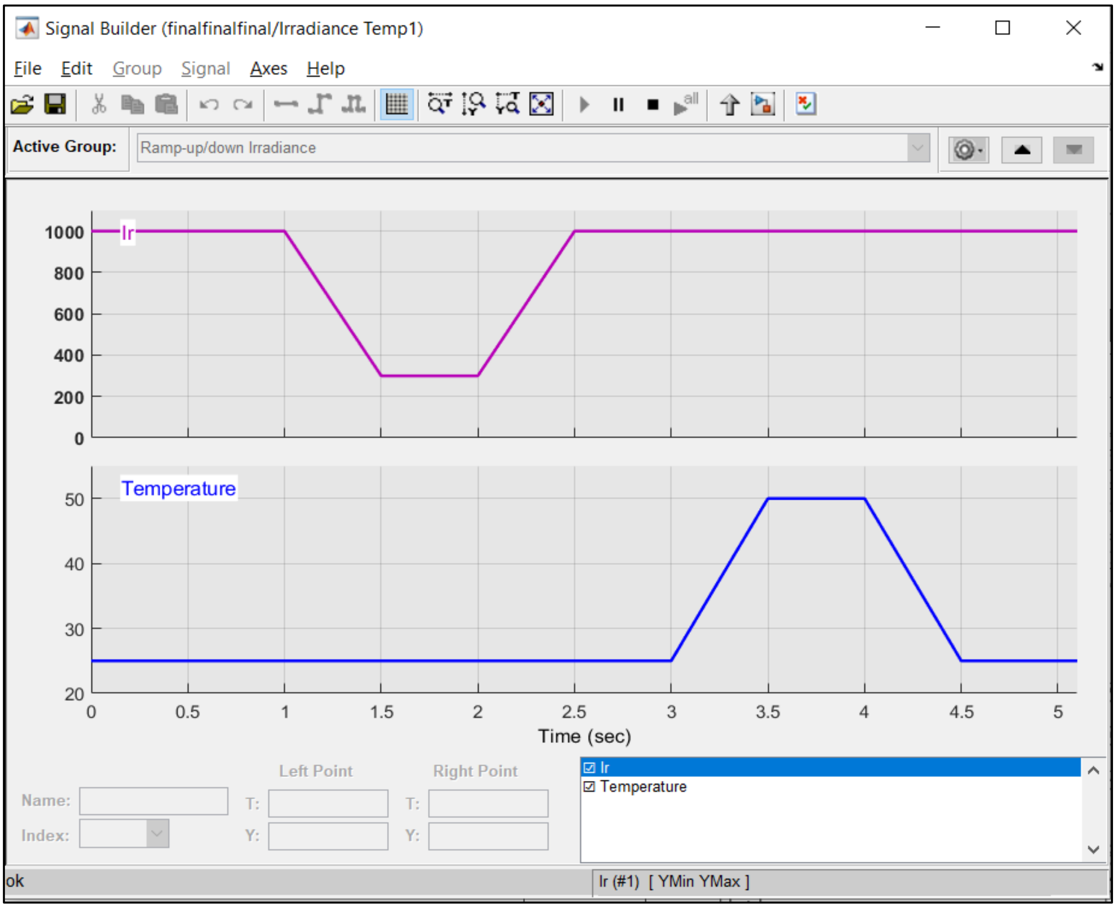
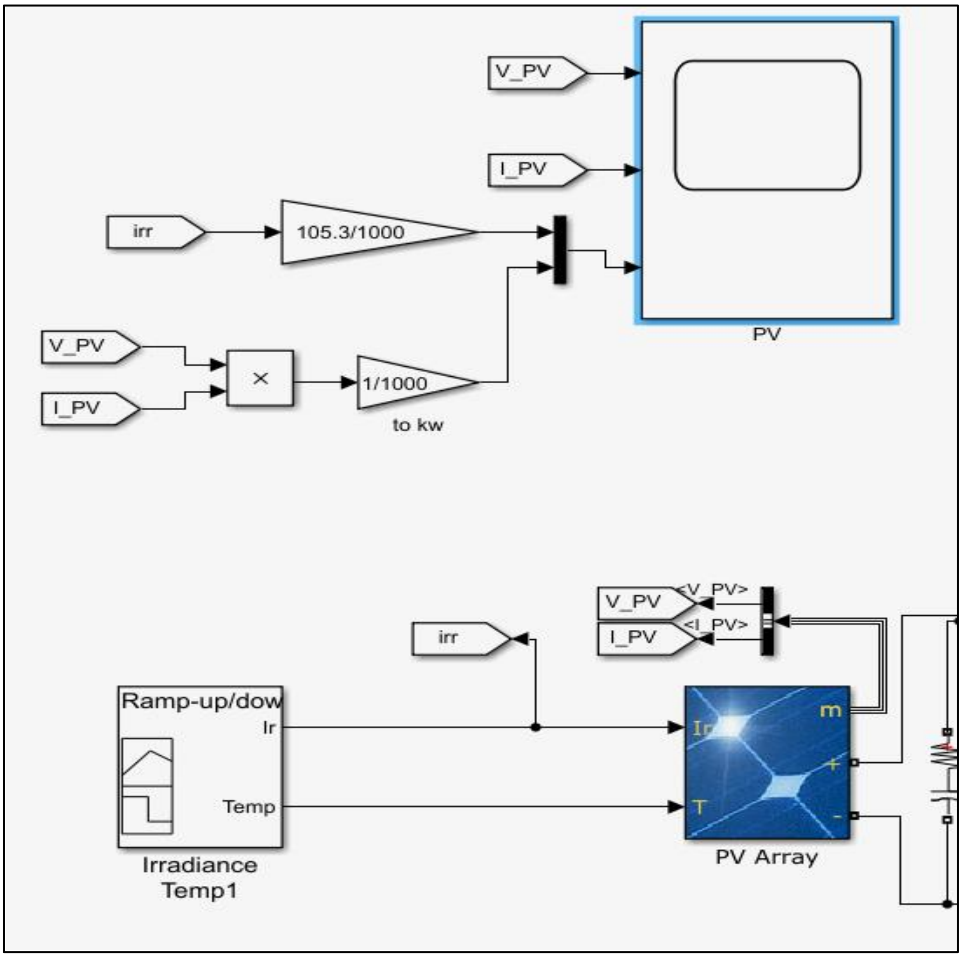
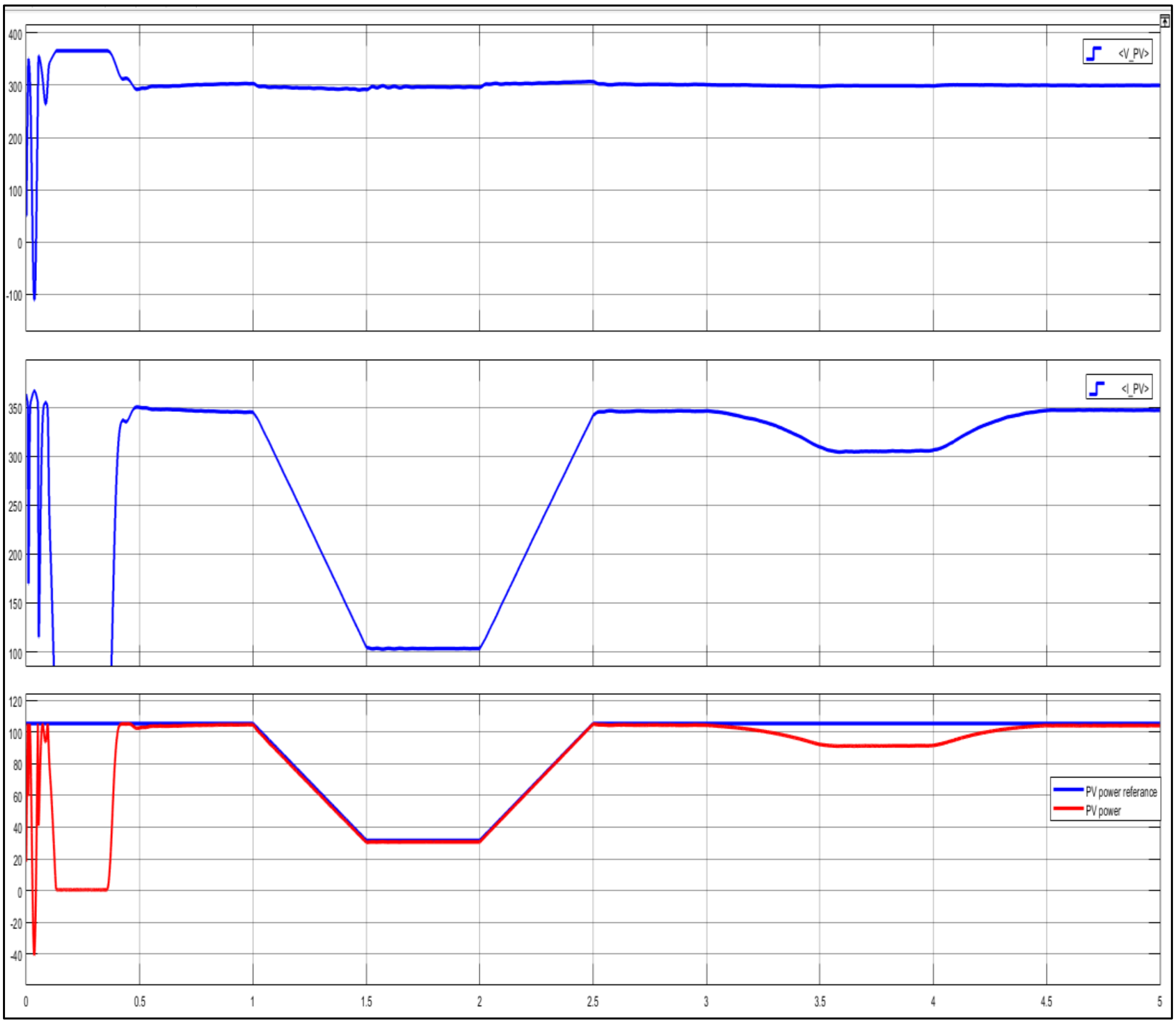


Figure 6.2: Boost scope



At the beginning of the simulation big amount of power been absorbed from the solar to charge up the capacitors inside the system as shown in Figure 6.3-. Then when the synchronization is done and the three phase breaker is closed, the amount of power absorbing from the solar panels reach its maximum at 104 kW which almost 98.7% efficiency from the maximum power at 105.3, then follow the irradiation graph in the decreasing mode, the power produce from the solar panels at 300 irradiation is 31.6 kW and power from the boost is 31.6 kW, therefor the efficiency at lowest point is 96.8% from 1.5 sec until 2 sec, then increasing in stable mode at 2 sec until it reach 1000 irradiation at 2.5 sec, at 3 sec the temperature increases until it reach 50 Celsius at 3.5 sec and become stable there at 3.5 sec, decreasing the output power by changing it into 91.4 kW then when the temperature starts decrees at 4 sec until it reach 25 at 4.5 sec, then system become stable again producing its maximum power.

Figure 6.3: Boost scope when the battery controller is off



The inverter pulse start working at 0.03sec, the automatic inverter-grid three phase breaker will only close when the peak voltage difference between them is less or equal to 200V and the difference between the frequency angle of the grid voltage and the frequency angle transformer voltage of is less or equal to 15 degree (15*pi/180) as shown in Figure 6.4-, the three breaker start to close and open at 0.31 sec as shown in Figure 6.5-, but when the voltage and current are fully synchronized at 0.58 sec It will stay closed.

Figure 6.4: Automatic breaker controller

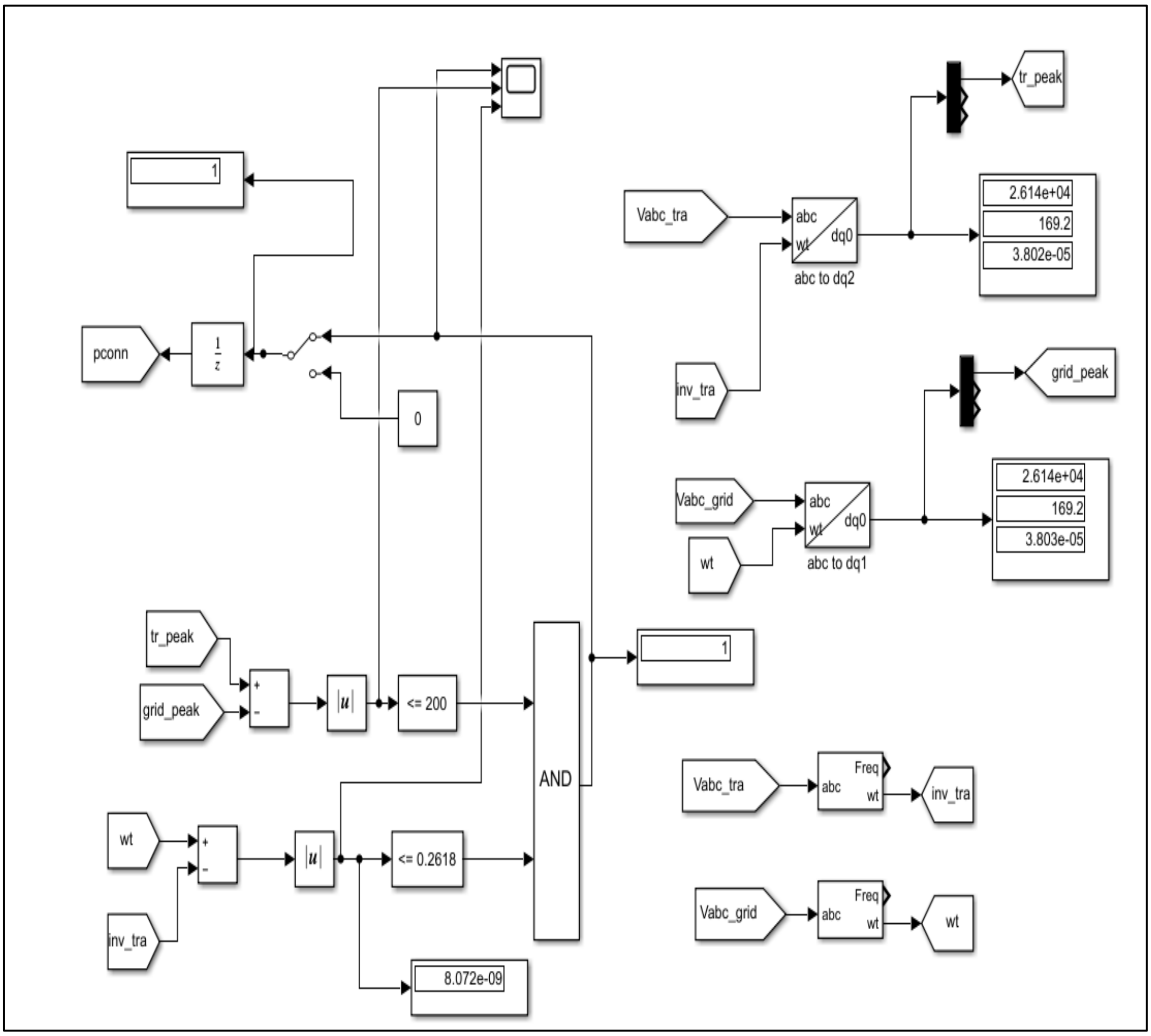
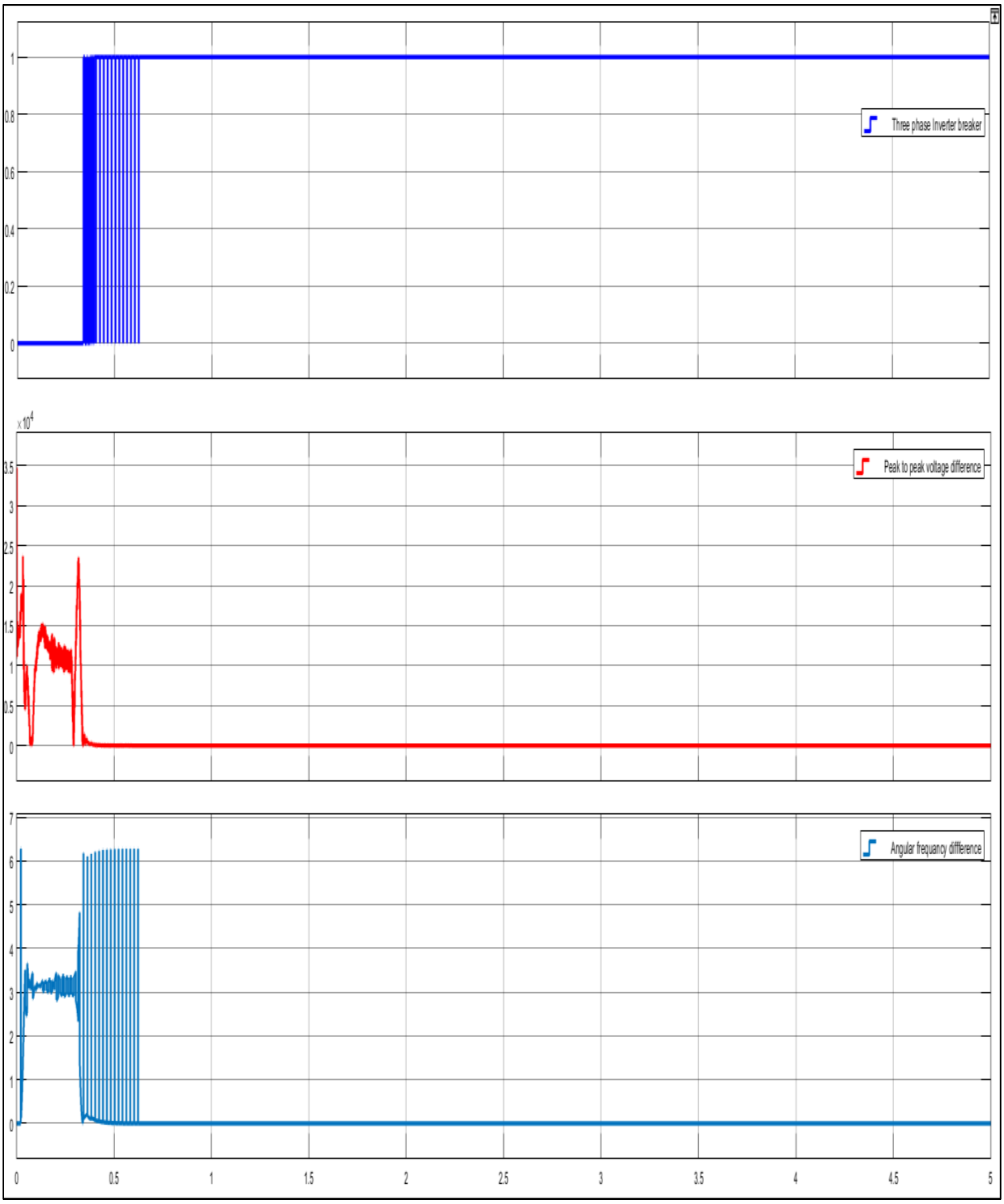
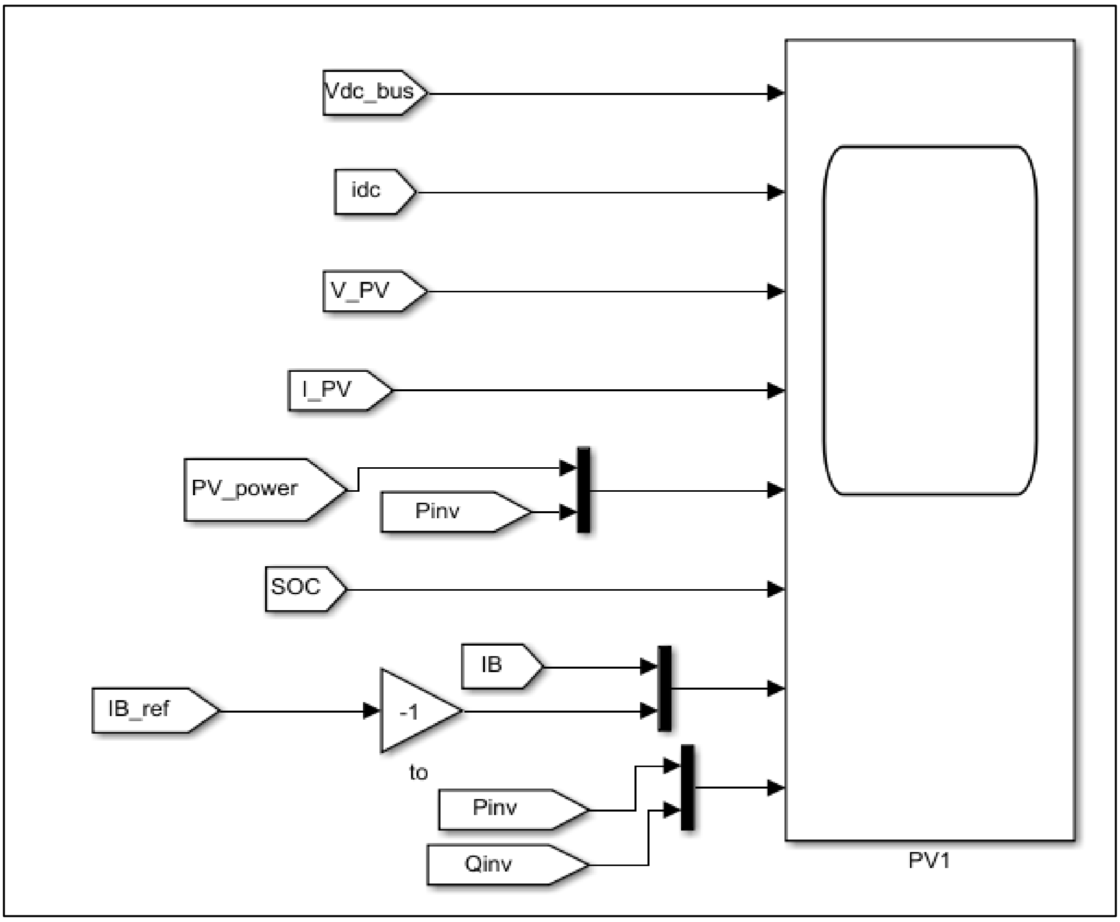


Figure 6.5: three phase auto breaker scope when the battery controller is off



for this scope the DC bus voltage and current, and the voltage and current for the panel and the power for it, the state of charge for the battery with the current reference and the current from the battery, and the active and reactive power for the three phase inverter all will be measured at shown in Figure 6.6-.

Figure 6.6: Inverter scope



The inverter scope measurement is shown in Figure 6.7 , DC bus voltage it rises from 0 until 950 V collecting power from the solar panels but after the inverter start working is will decrease until 620 V, then when the synchronize happened it rise reaching it nominal voltage at 660 V.

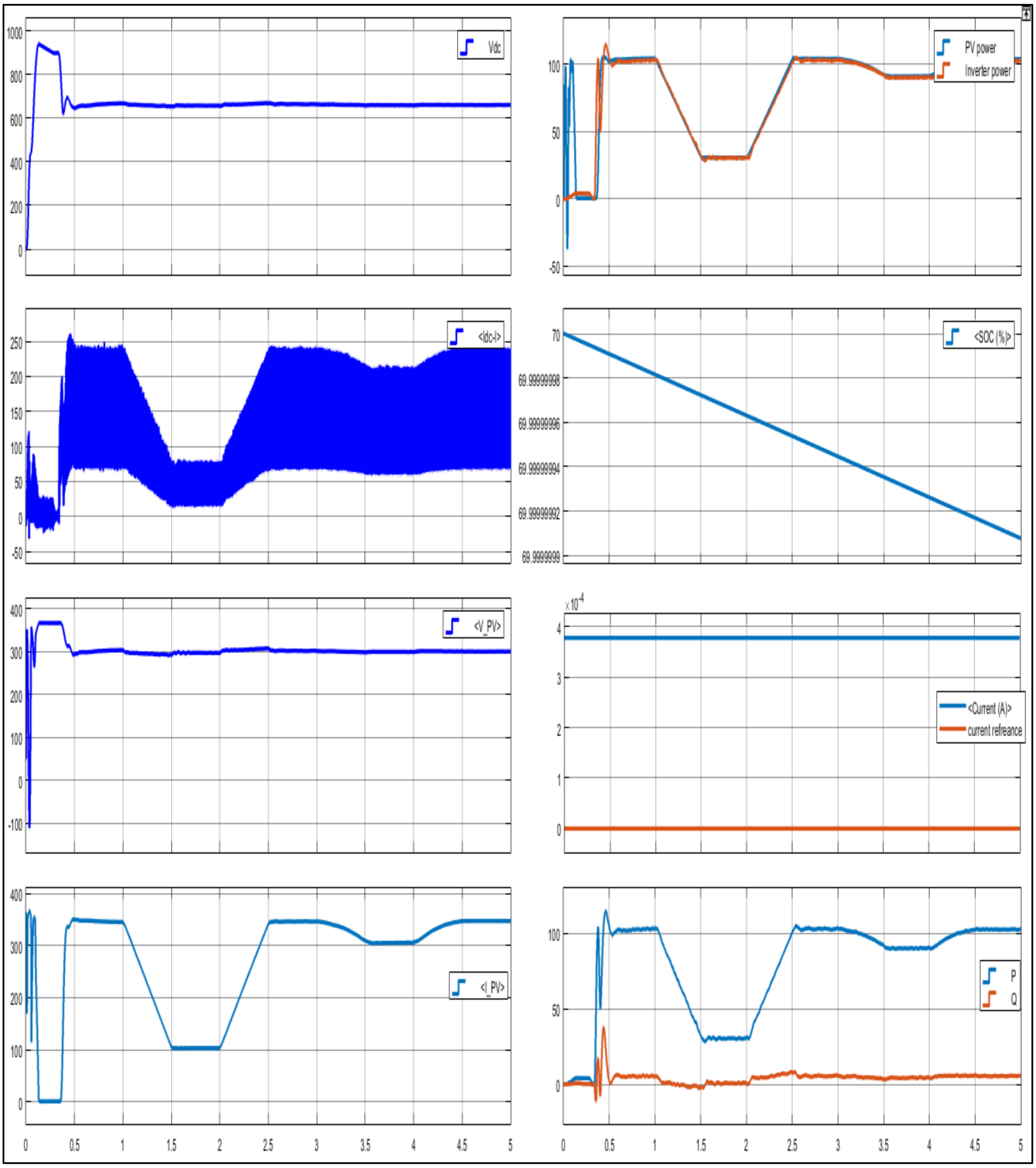
For the DC bus current it raises at the beginning then drops until the synchronization happened, then goes with proportional with the power absorbing of the panels, it is showing as thick line due to semiconductor opening and closing.

For inverter active power at the 0.03 it increasing slowly as it absorb some power from the solar panels and build a medium voltage throw the transformer around the transmission lines, then when the synchronizing started to happened at 0.31 sec and the three phase breaker close the active power rise rapidly, producing around 102 kW , therefore the efficiency of boost inverter system around 98% , then the output power will follow the irradiation at stable mood, in decreasing case or increasing case, when the irradiation at 300 the power absorbing from the solar panels is 30.6 kW and the inverter power around 30 kW , therefor the efficiency at the lowest power point for boost inverter system is almost 98%, then the photovoltaic panels temperature increase at 3 sec the inverter output power will decrease until reaching 90 kW at 3.5 sec then stay stable until 4 sec but when the photovoltaic panels temperature decrease the inverter output increases until reaching 103 kW at 4.5 sec.

For battery it is turn of for charging or discharging.

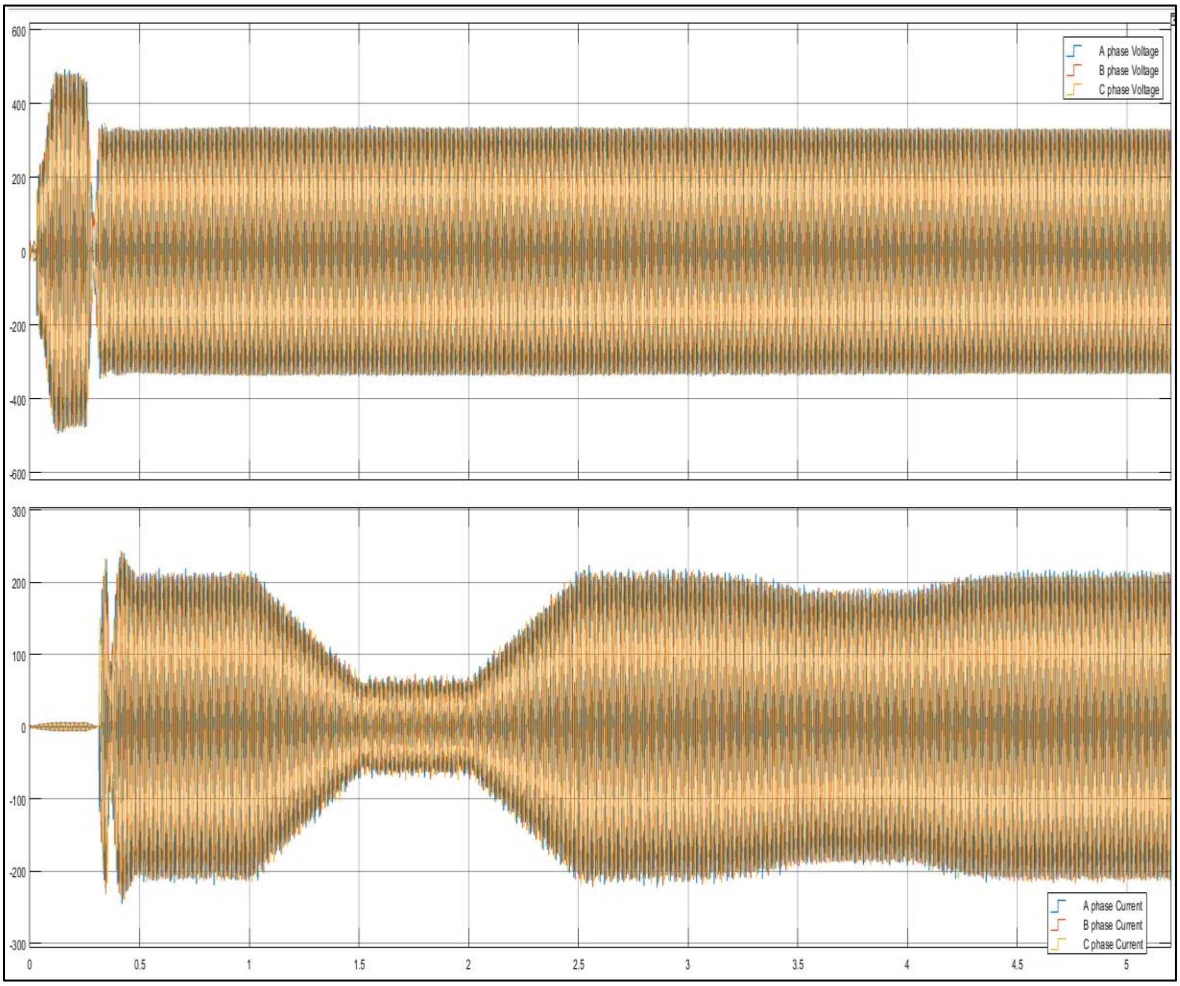
When the breaker closes a huge reactive power will be generated then it became stable to generate around 5.5 kVA.

Figure 6.7: Inverter scope when the battery controller is off



For the output inverter waveform for voltage and current measurement is shown in Figure 6.8, the inverter generates three phase peak voltage value is 330 V phase to ground measurement and it is equal to 233 V_{rms} single phase and 403 V_{rms} on the phase to phase.

Figure 6.8: Inverter wavefrom when the battery controller is off



The inverter wavefrom from 0.6 sec until 1 sec is shown in Figure 6.9 the total harmoics distortion of voltage that at time is 1.13% as shown in Figure 6.10 and the total harmoics distortion of current is 2.44% as shown in Figure 6.11-.

Figure 6.9: Inverter output waveform when the battery controller is off

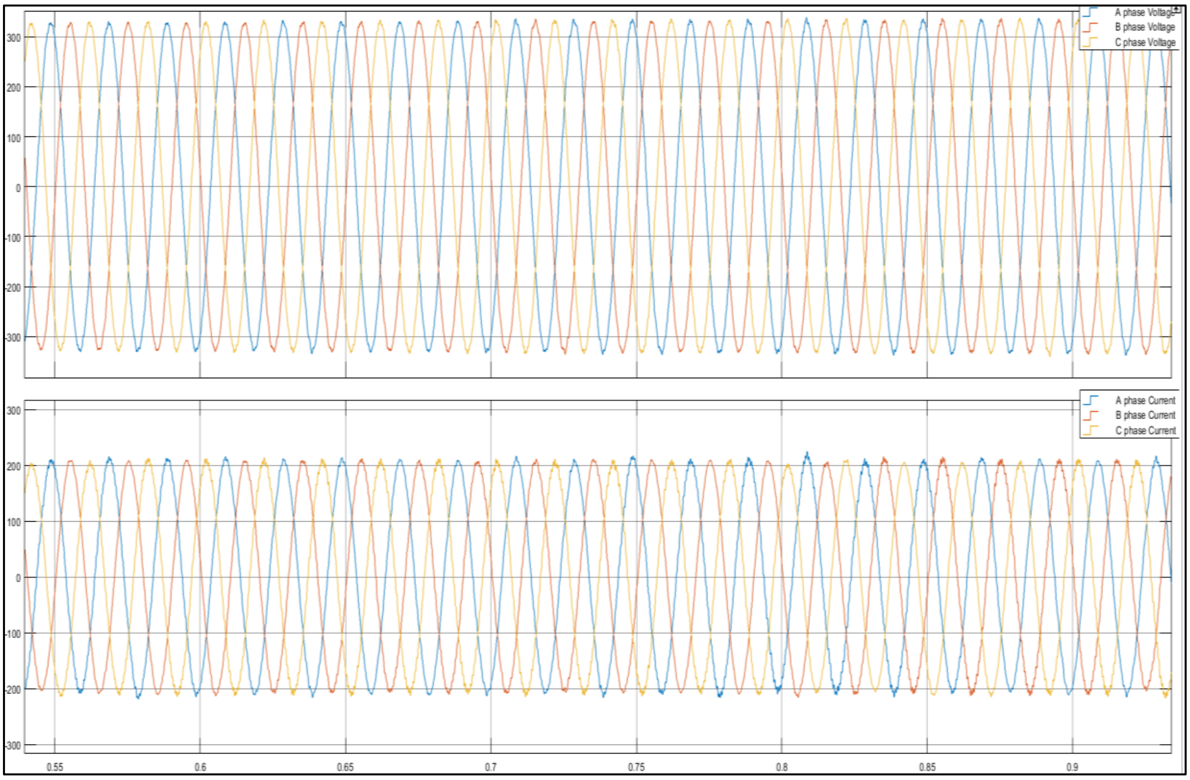


Figure 6.10: THD for inverter voltage when the battery controller is off

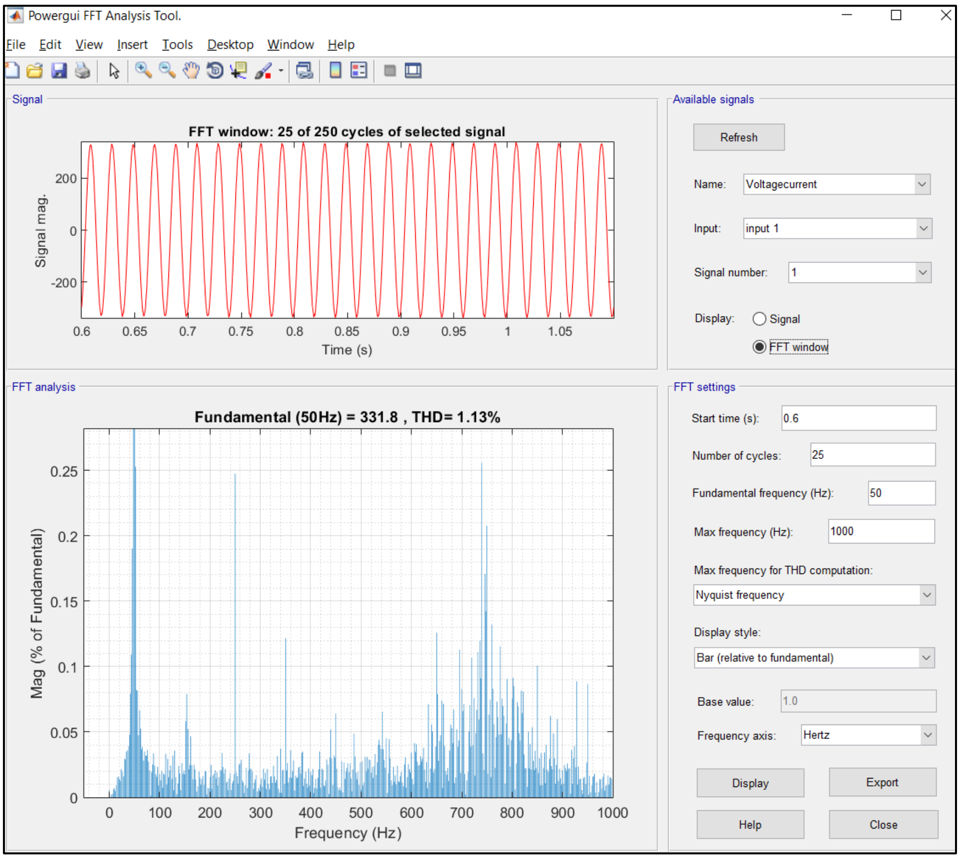
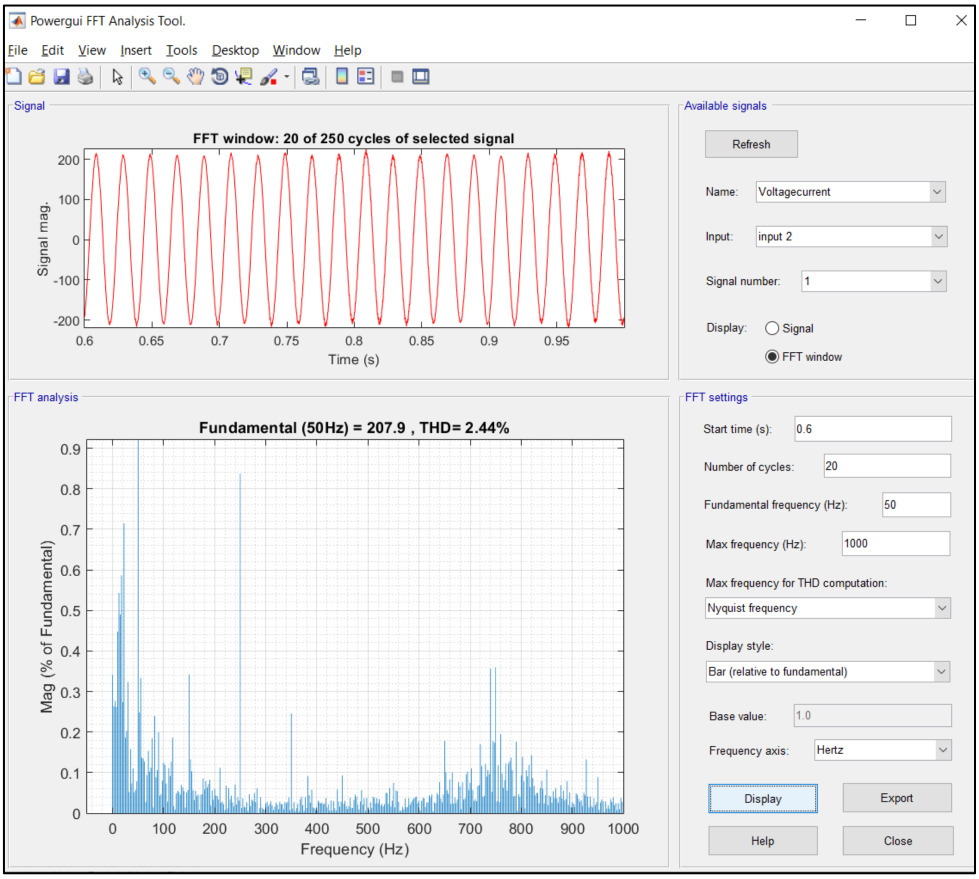


Figure 6.11: THD for inverter current when the battery controller is off



The inverter waveform from 1.6 sec until 2 sec is shown in Figure 6.12 the total harmonics distortion of voltage at that time is 1.12% as shown in Figure 6.13 and the total harmonics distortion of current is 5.94% as shown in Figure 6.14-.

Figure 6.12: Inverter waveform output from 1.6 sec to 2 sec when the battery controller is off

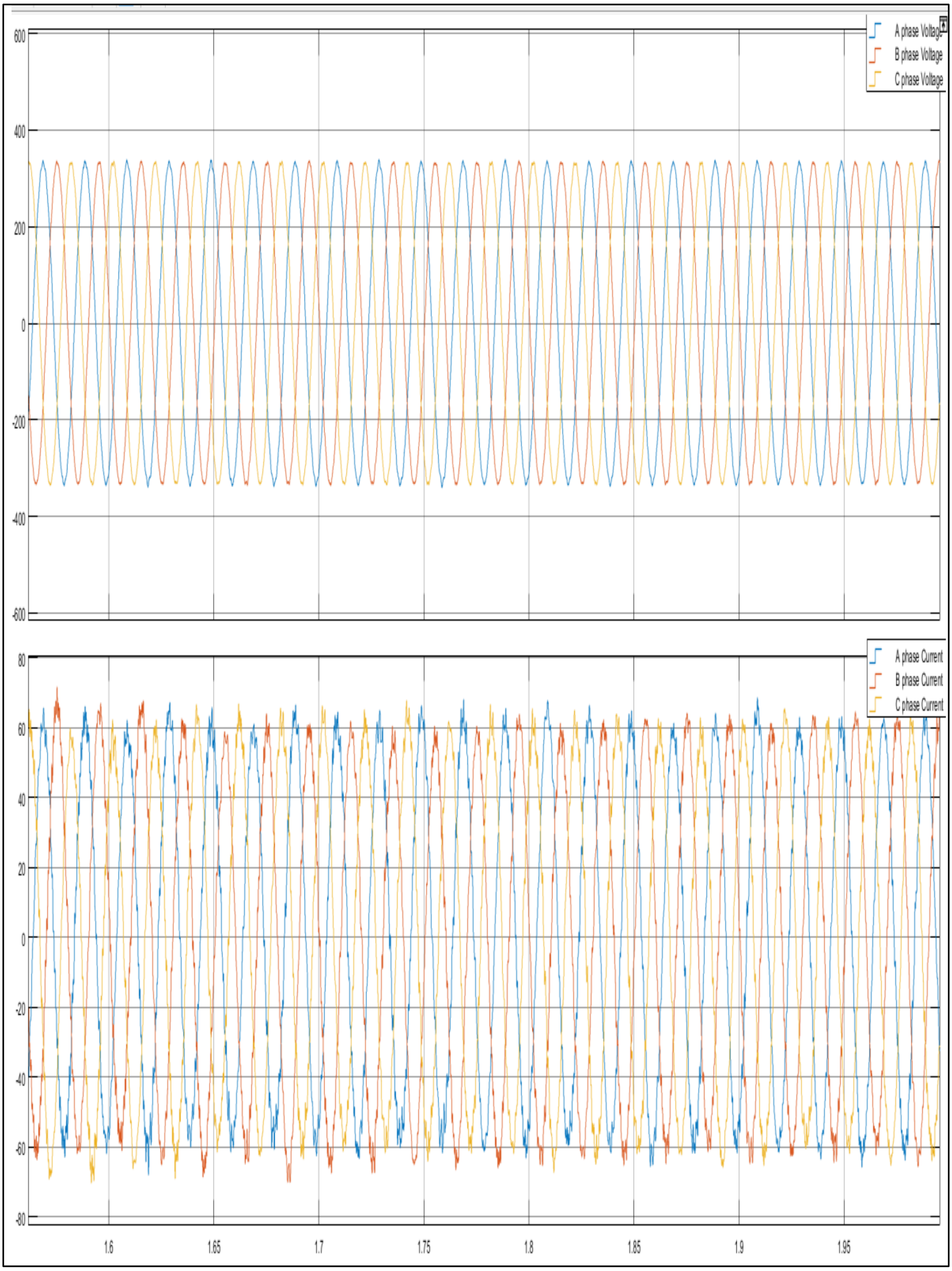


Figure 6.13: THD for inverter current from 1.6 sec to 2 sec when the battery controller is off

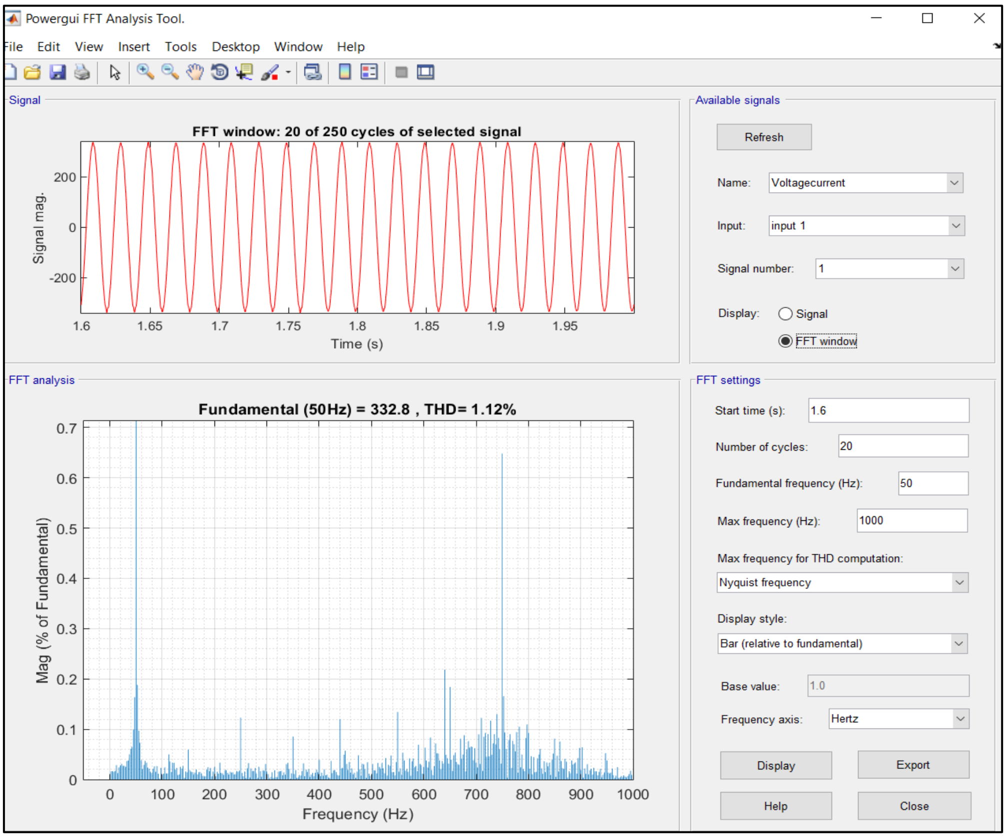
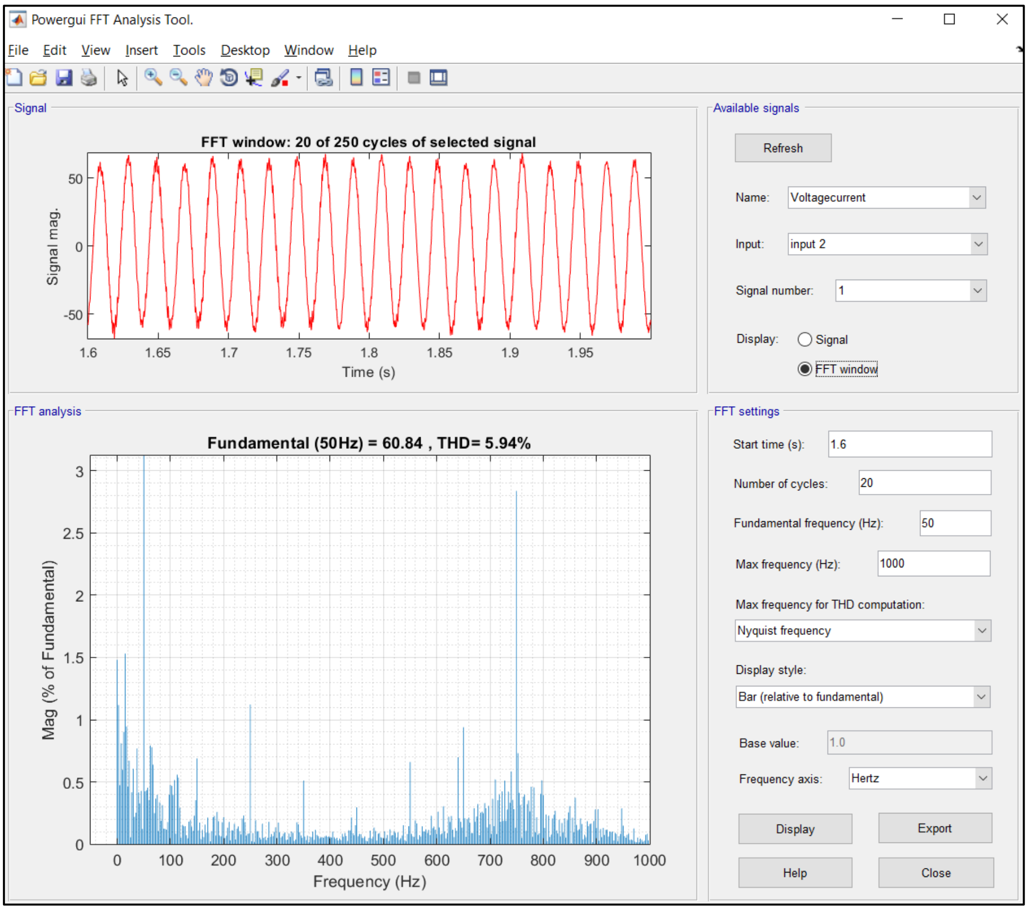


Figure 6.14: THD inverter current from 1.6 sec to 2 sec when the battery con troller is off



For the wind turbine measurement is shown in Figure 6.15 , at the first 1.6 sec the wind turbine is absorbing 200 kW from the grid the power up its generator, then it start pumping the power to the grid as its components start working and the wind speed is above the cut on speed, with time it start increasing due the wind velocity increases, at 20 sec when wind speed reached it nominal value the maximum output power 1.55 MW and stay stable, for the pitch angle it puts as 25 degree as default to wind protection then the wind speed increases the pitch angle decrease, after on high wind speed it start increasing to protect the wind turbine from high wind speed, for voltage and current waveform is shown in Figure 6.16 the voltage peak value is 480 which is equal to 585 V_{rms} phase to phase.

For the inverter output waveform for voltage and current measurement is shown in Figure 6.16-, the inverter generates a three phase peak voltage value at 330 V phase to ground measurement and it is equal to 233 V_{rms} single phase and 403 V on the three phase.

For the total harmonic distortion on the wind turbine voltage is 2.3% at 21 sec for 37 cycles as shown in Figure 6.17-, and the total harmonic distortion on the wind turbine current is 1.39% at 21 sec for 3 cycles as shown in Figure 6.18-.

Figure 6.15: Wind turbine scope

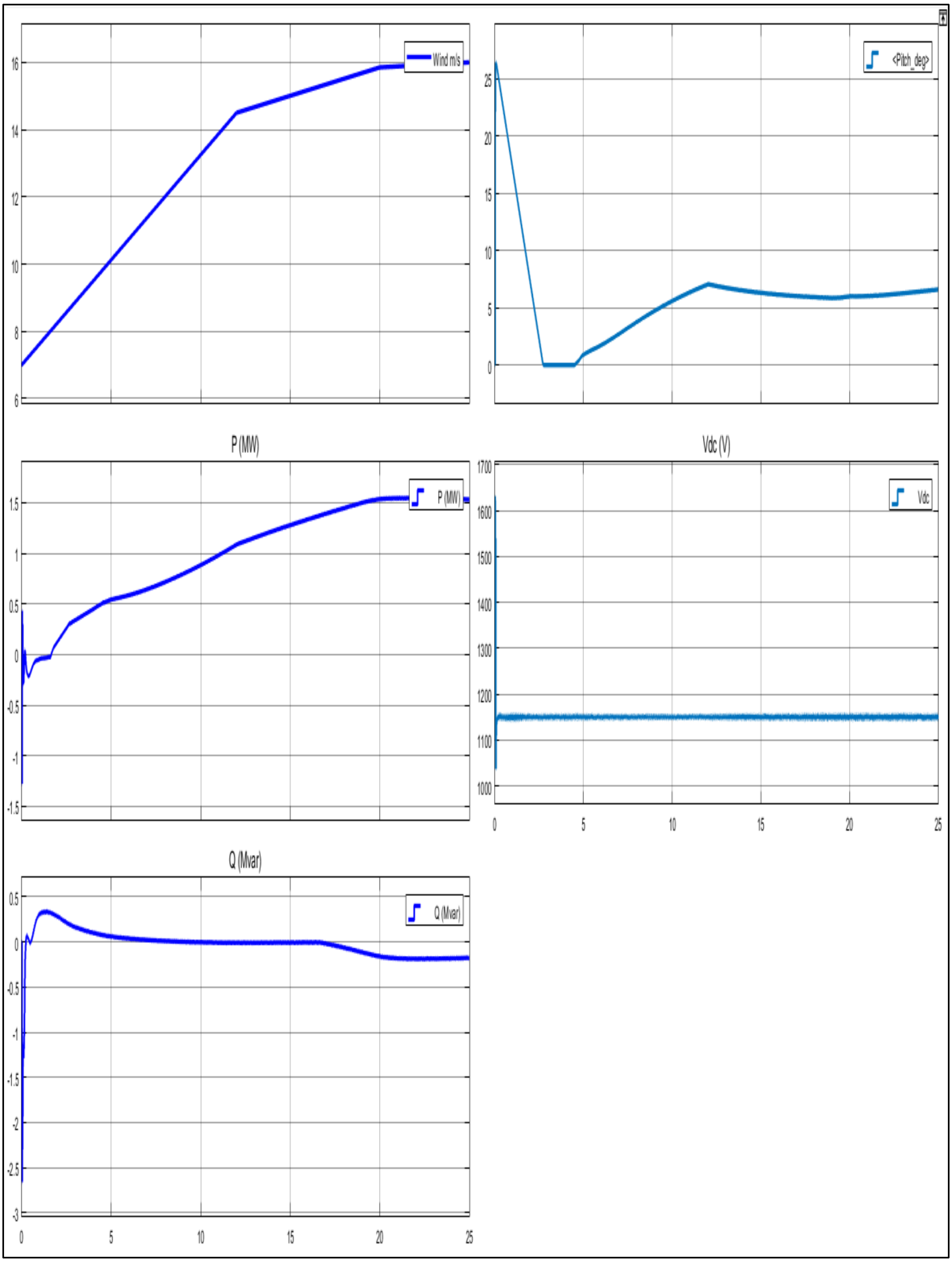


Figure 6.16: Wind turbine output waveform

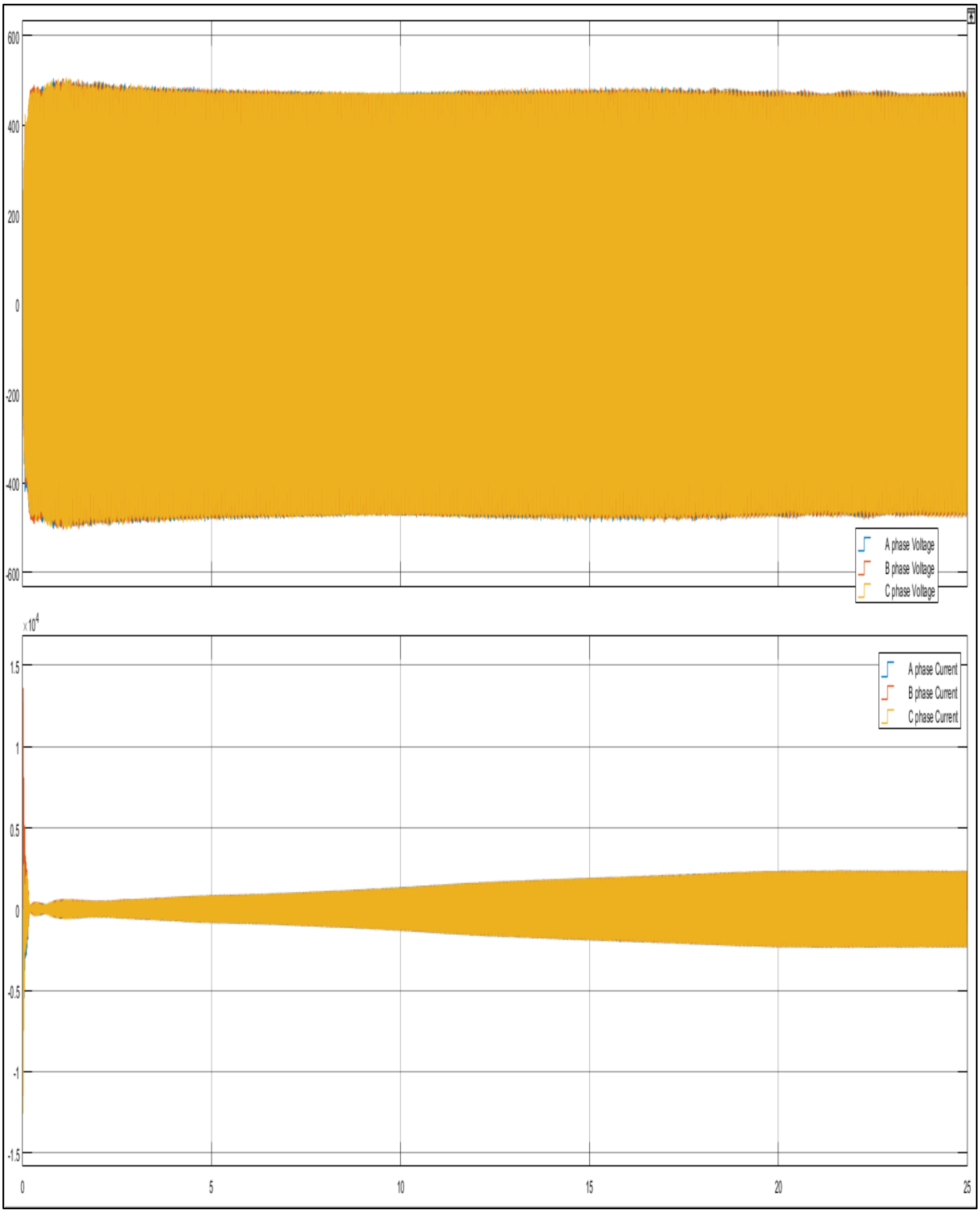


Figure 6.17: THD for wind turbine voltage

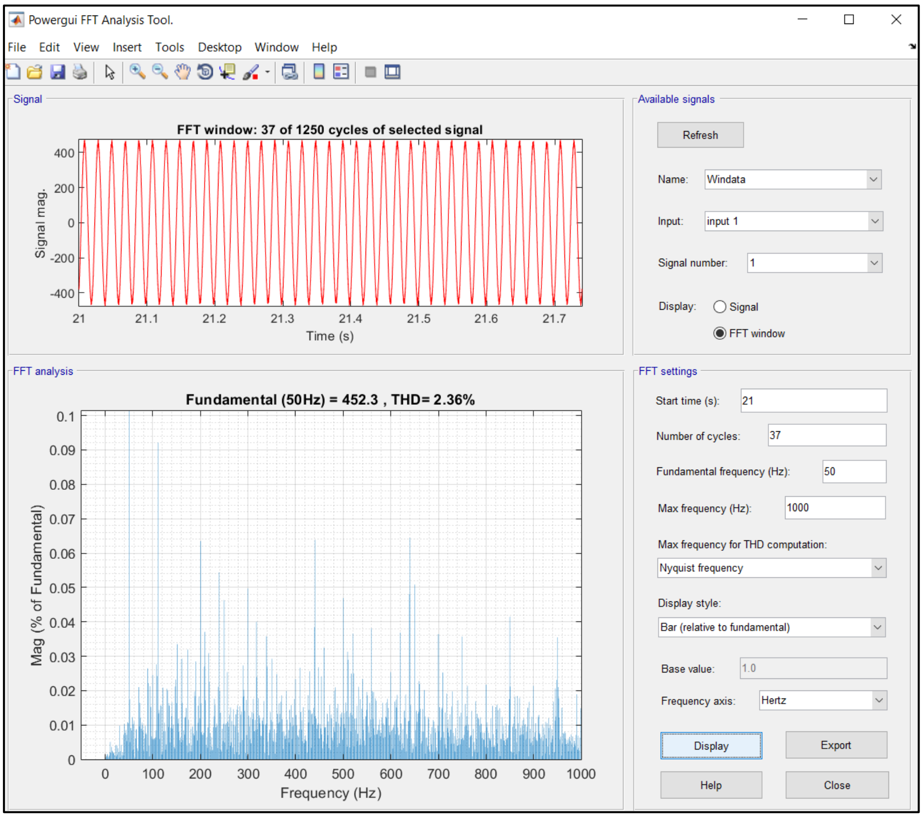
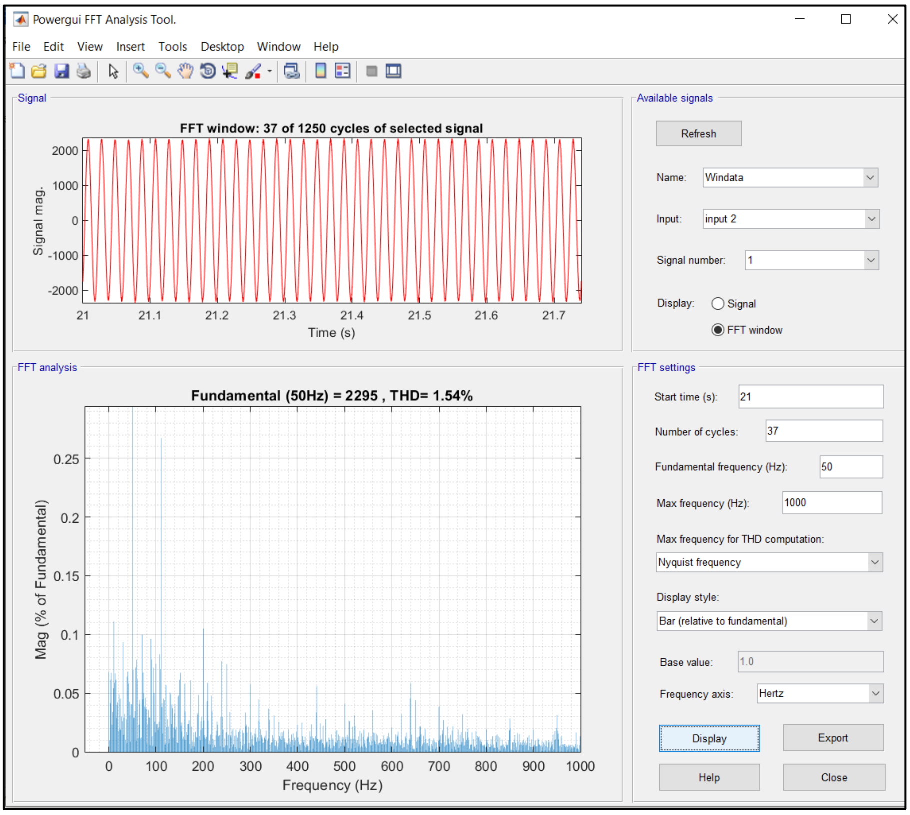


Figure 6.18: THD for wind current



To see how the system will reacts with the different loads the buses measurement is shown in Figure 6.19 and the measurement starts at 0.2 sec, at the beginning of the simulation they system absorb huge amount of power to balance with the loads throw buses and the total amount of power being absorbed is shown in bus 1, which is almost 1600 kW and 300 kVAr , and bus 2 takes 1400 kW 270 kVAr , bus 3 takes 940 kW and the loads 4 and 5 will get the power for the grid, but at 0.5 sec when the inverter start working at 100 kW it will give power up the completely load 5 and give some power to load 4 but not power it up completely, but when the sun irradiation start decreasing at 1 sec to 1.5 sec at stable there it cannot power up the load 5 completely, it will start taking power from the grid as the wind turbine didn't stabilized yet, but when the sun irradiation increase at 2 sec until 2.5 sec at 100 kW , the power at bus 6 was negative it will slow goes to zero then above zero to 0.03 kW extra power given to load 4, and can see this effect of all the buses, but the temperature on photovoltaic panels increase to 50 Celsius at 3 sec can see the effect on buses 5, 6, 7 only, the rest of the loads will not get effected so much because at that time, and after the temperature goes back to 25 at 4.5 sec the 5, 6, 7 buses become stable and load 4 get 18 kW from the wind turbine, as the power generating from the wind turbine increased to 1550 kW at 20 sec the extra power will be pumping into the grid around 30 kW , and the frequency is 50 Hz in all the buses as showing in Figure 6.20-.

Figure 6.19: Buses power scope when the battery controller is off

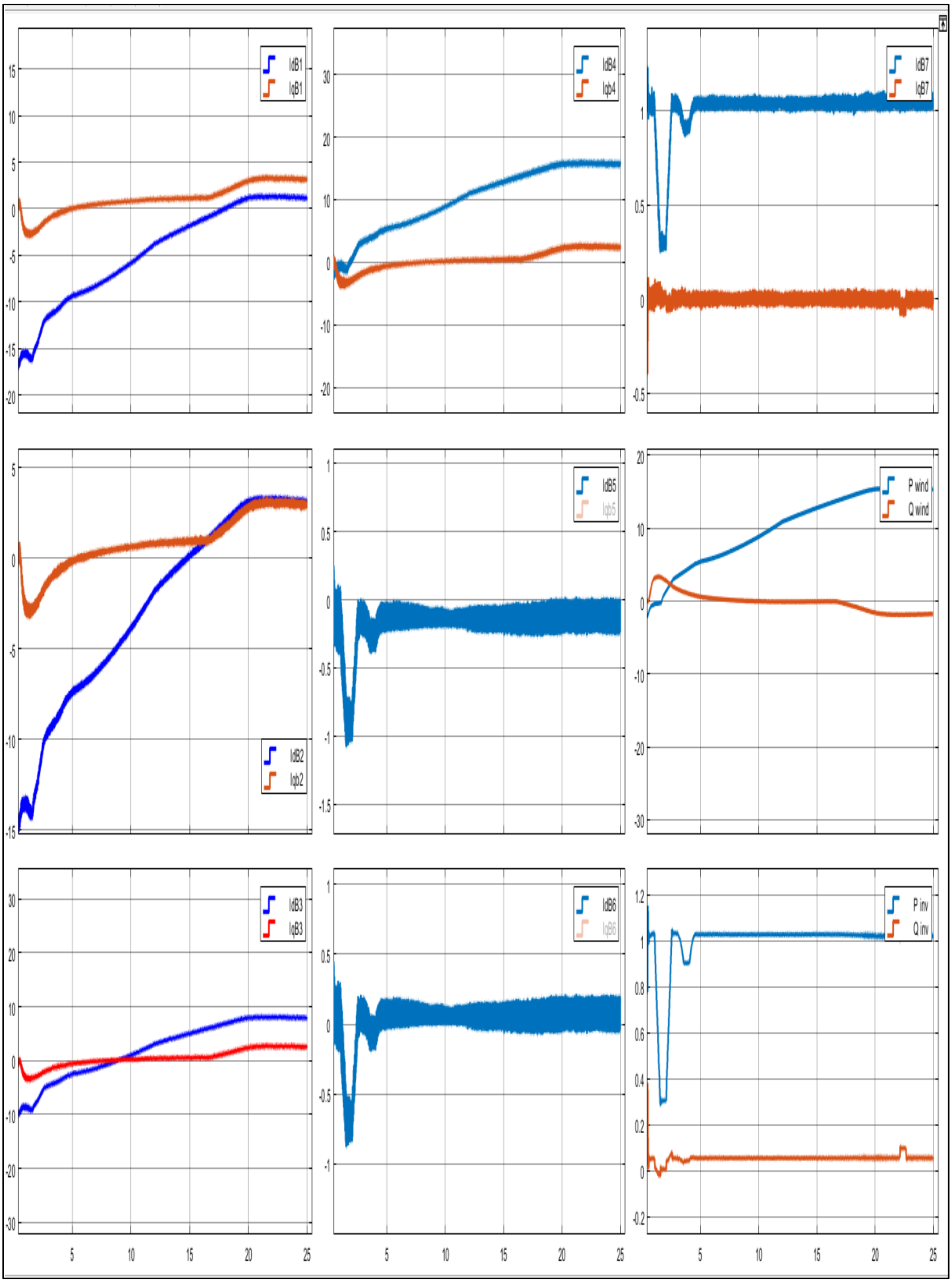
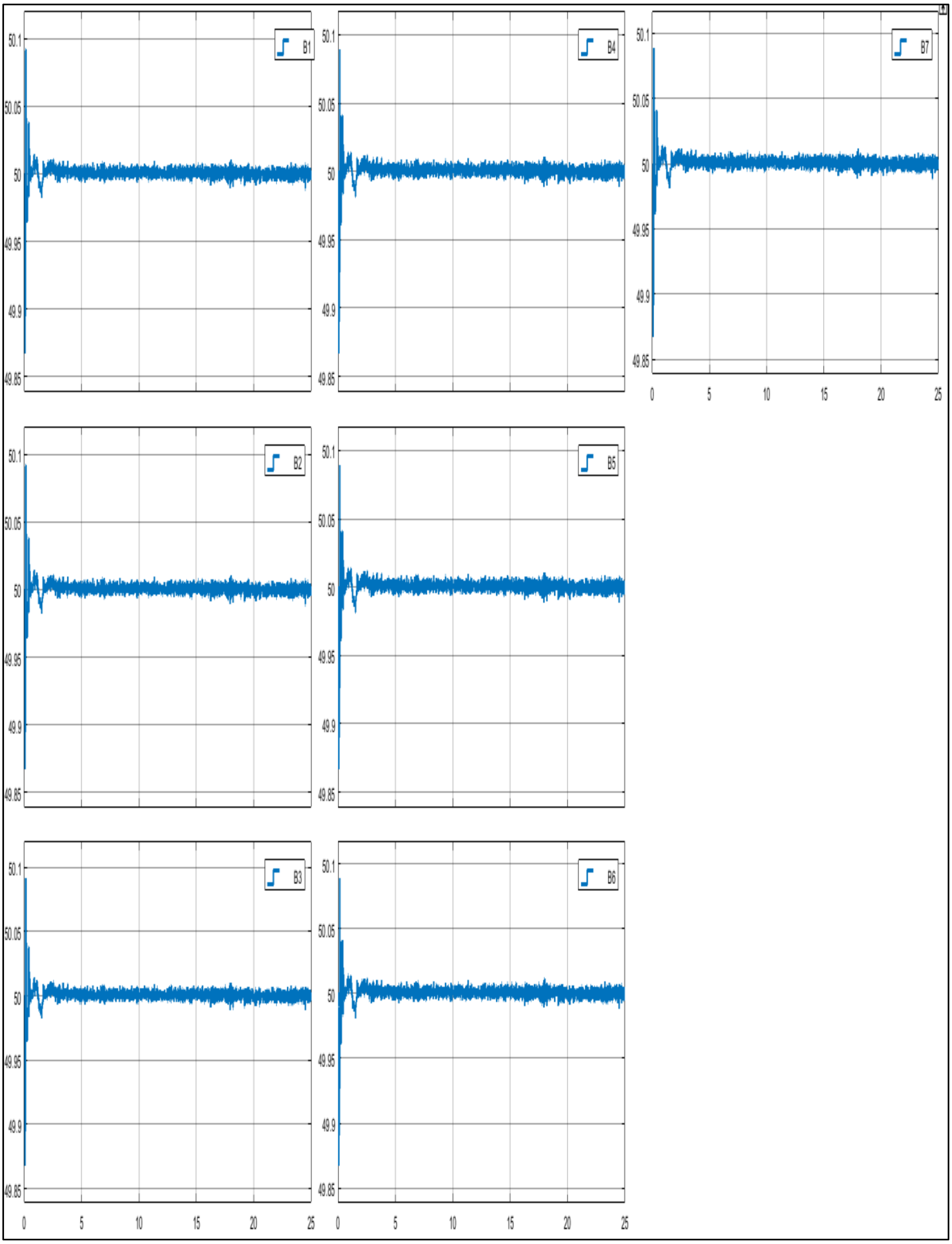


Figure 6.20: Buses frequancy scope when the battery controller is off



6.2 BATTERY CONTROLLED POWER REFERENCE AT 120 KW

Then doing the simulation again with manual battery controller puts to 120 kW and the initial state of charge for the battery is on 70%, the boost converter is stable and following the irradiation power reference the same as before when the battery was off as shown in Figure 6.21-, and for the inverter scope as shown in Figure 6.22-, it is the same as before until 0.6 sec when the timer for the battery controller start working at 120 kW the reference battery discharge goes to 46 A and stable there until 1 sec, at 1 sec the sun irradiation start to decrease and the current reference increase until reaching it limits at 150 A and stop there, then the output power from the inverter decrease less than 120 kW until 80 kW because the batteries working at it is full potential power and cannot follow the missing power until 120 kW , then at 2 sec the sun irradiation increase at but the current reference not change immediately at 2.25 sec the current reference start decreasing from 150 A until reaching the reference discharge current at 46 A and stabilized there until 3 sec, then when the temperature incases the PV output power will decrease and discharge current reference increase until 85 A it become stable at 3.5 sec to 4 sec and the inverter output stays at 120 kW , then when the temperature decrease reaching 25 Celsius the current discharge reference decrease until reaching 46 A then stabilize at that time.

Figure 6.21: boost scope when the battery controller power reference 120 kW

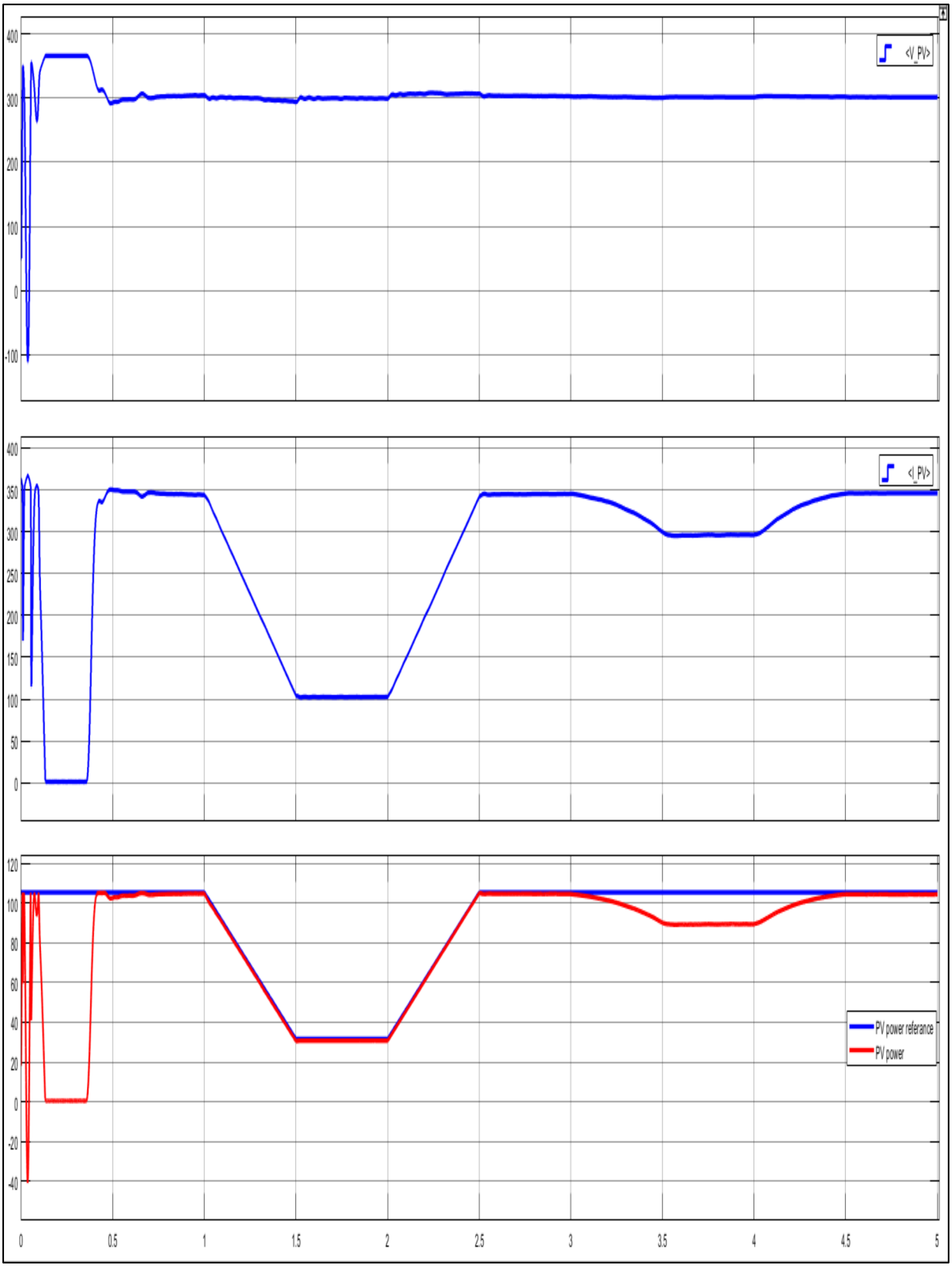
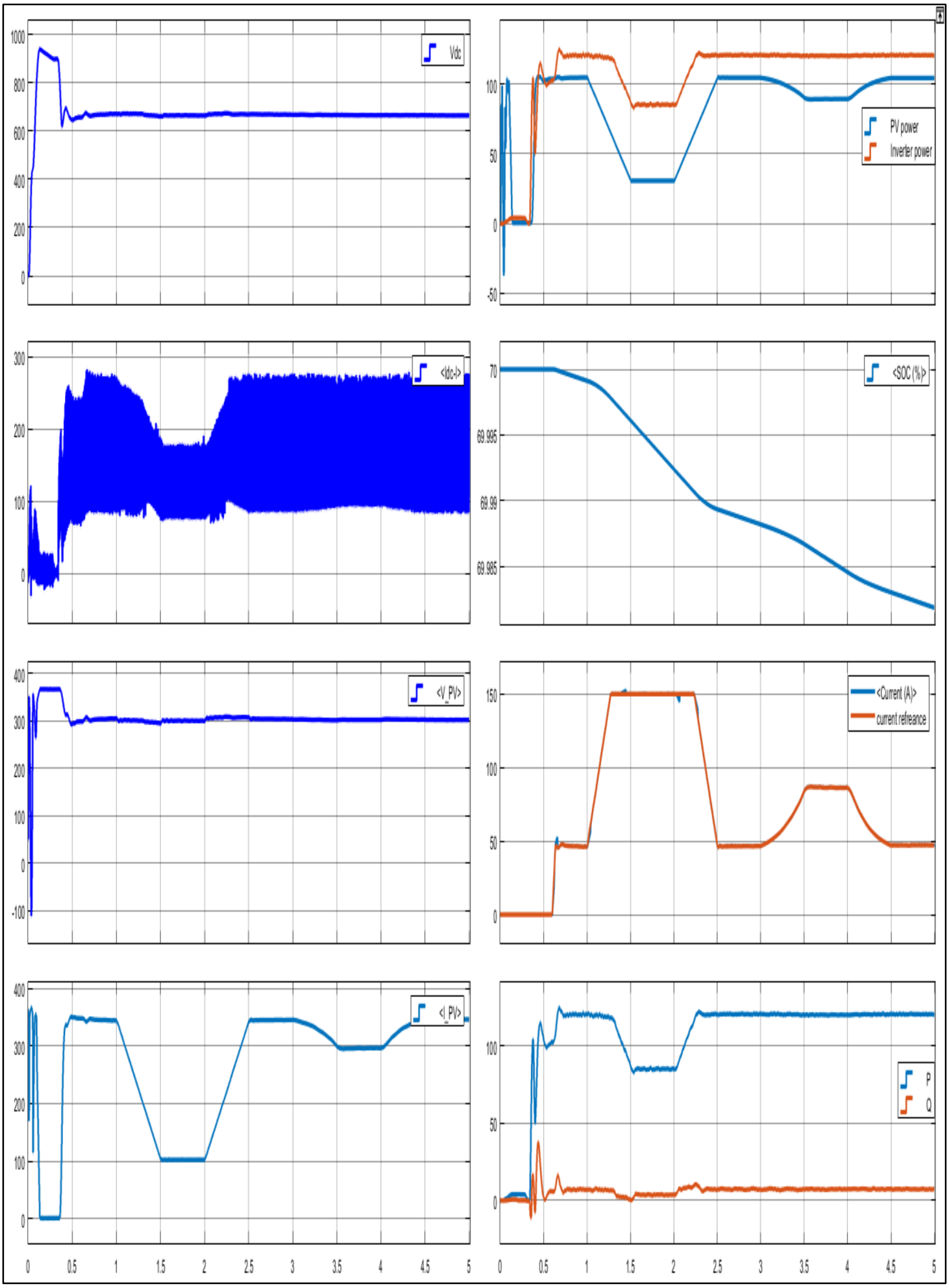


Figure 6.22: Inverter scope when the battery controller power reference 120 kW

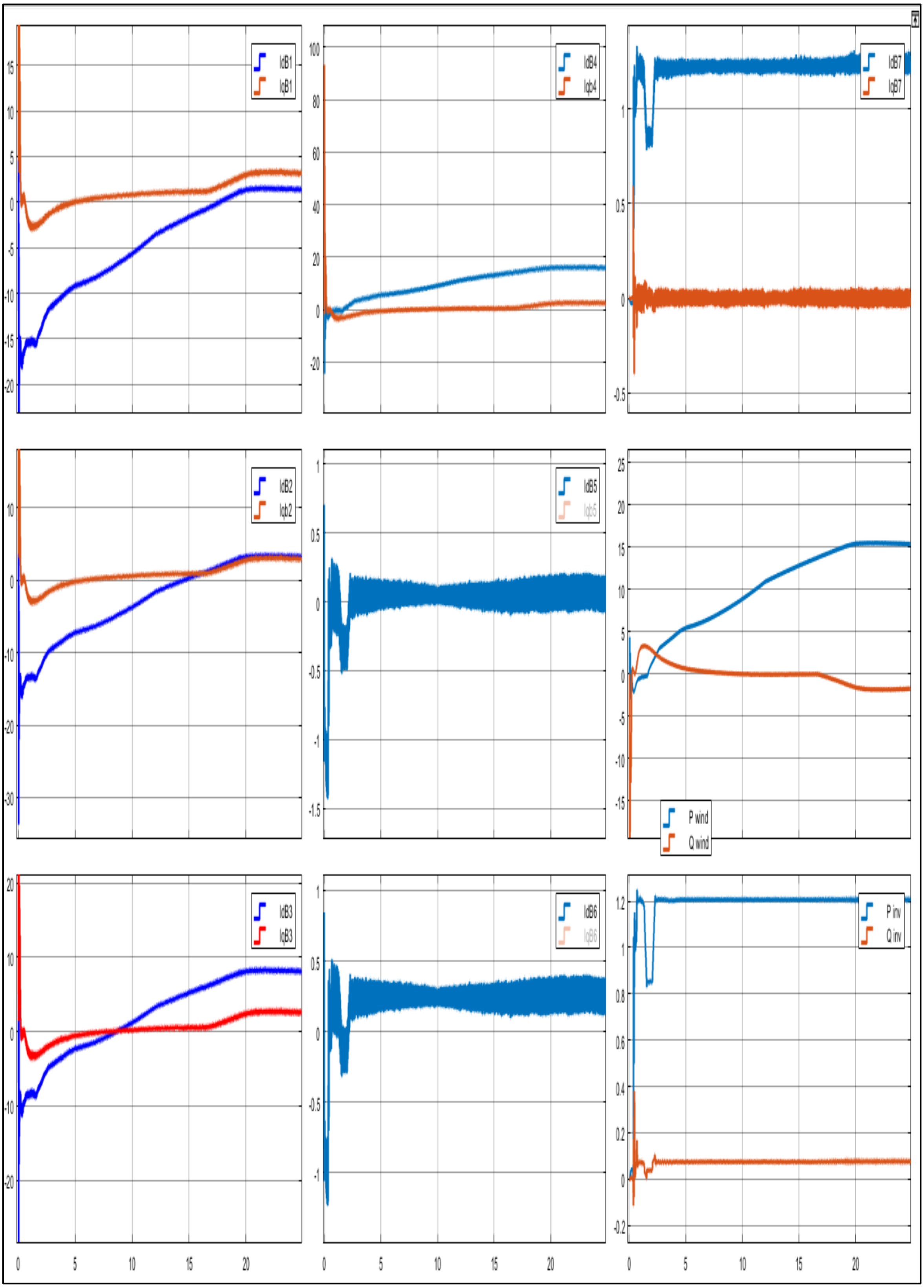


For the wind turbine works the same as before as shown in Figure 6.15-.

For the buses scope result is shown in Figure 6.23-, the inverter output stay stable at 120 kW at 0.6 sec until 1.3 sec the output power start decreasing until reaching to 80 kW at 1.5 sec and stabilized until 2 sec, then go back again to 120 kW at 2.25 sec and the output will not get effected with increasing the temperature of the photovoltaic panels, the inverter will power up load 5 and 4 from 0.6 sec until then when the inverter output drops, load 4 and small amount of power from load 5 will get 40 kW from the grid for 0.75 sec then when the irradiation increase the inverter output increase to 120 kW and stabilized there and power up load 4and 5.

20 kW is not a big amount of power due to the big loads the system will continue almost the same as before, but the wind turbine is not going to power load 4, and the but the for powering full load 3 is 8.5 sec instated of 9 sec, and for the power pumping into the grid at 20 sec is around 70 kW.

Figure 6.23: Buses scope when the battery controller power reference 120 kW



6.3 BATTERY CONTROLLED POWER REFERENCE CHANGING

Then doing the simulation again with the initial state of charge for the battery is on 70%, and the manual battery controller reference changing as shown in Figure 6.24 , in the first 6 sec the power reference is 60 kW then increase to 120 kW from 6 sec to 8 sec, then become stable at 120 kW until 17 sec, at 18 sec drops again to reach 70 kW at 20 sec then rise again to reach 110 kW at 23 sec, for the solar irradiation and temperature and wind speed stays the same as before, a duty cycle scope put to measure the duty cycle and the reference power with the actual power and reference current with actual current as shown in Figure 6.25-.

As showing in Figure 6.26-, the boost is working perfectly the same as before, also the wind turbine mechanism stays the same because there is no changing in the wind speed.

The battery scope shown in Figure 6.27-, shows how the state of charge is changing with charging and discharging, also for the voltage when it is charging the voltage increase and when it discharges the voltage decrease.

At Figure 6.28 shows the duty cycle scope, the actual power is following the reference power and the actual current if following the reference current, for the duty cycle it a small changes only it decrease to work more in boost converter putting more power to the dc bus and increases to work more in buck converter and charge the battery

At Figure 6.29 shows the inverter scope, for the power coming from the photovoltaic panels and the inverter output power shows whenever the power reference is in the range of the battery power it charge to discharge the output will be the same as the reference power.

Figure 6.24: output power reference

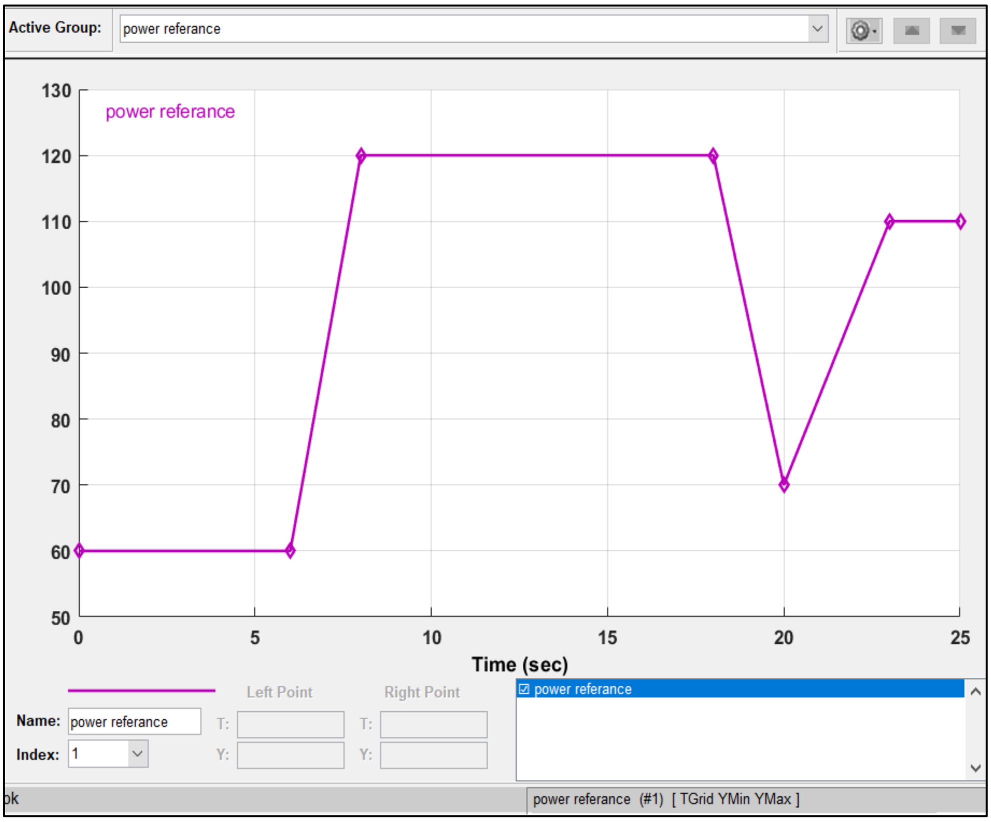


Figure 6.25: Duty cycle scope

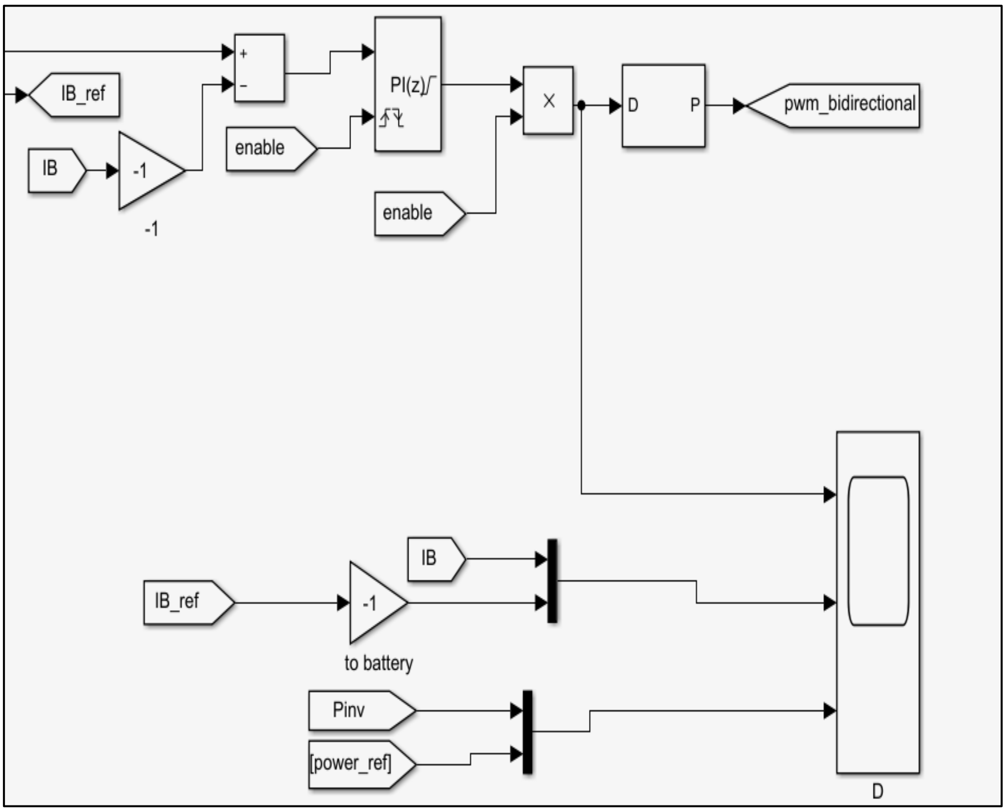


Figure 6.26: Boost scope when the battery controller power reference changing

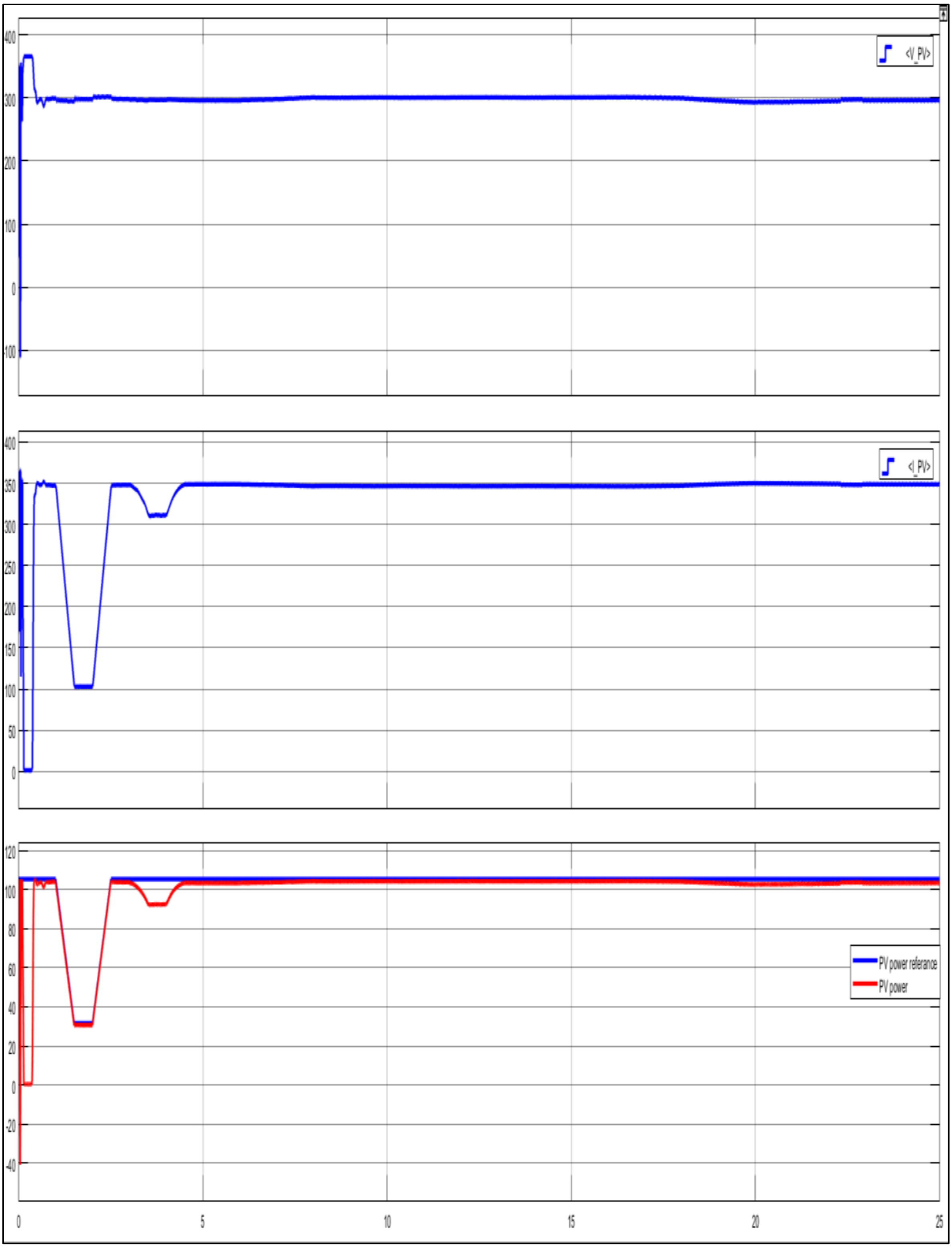


Figure 6.27: Battery scope when the battery controller power reference changing

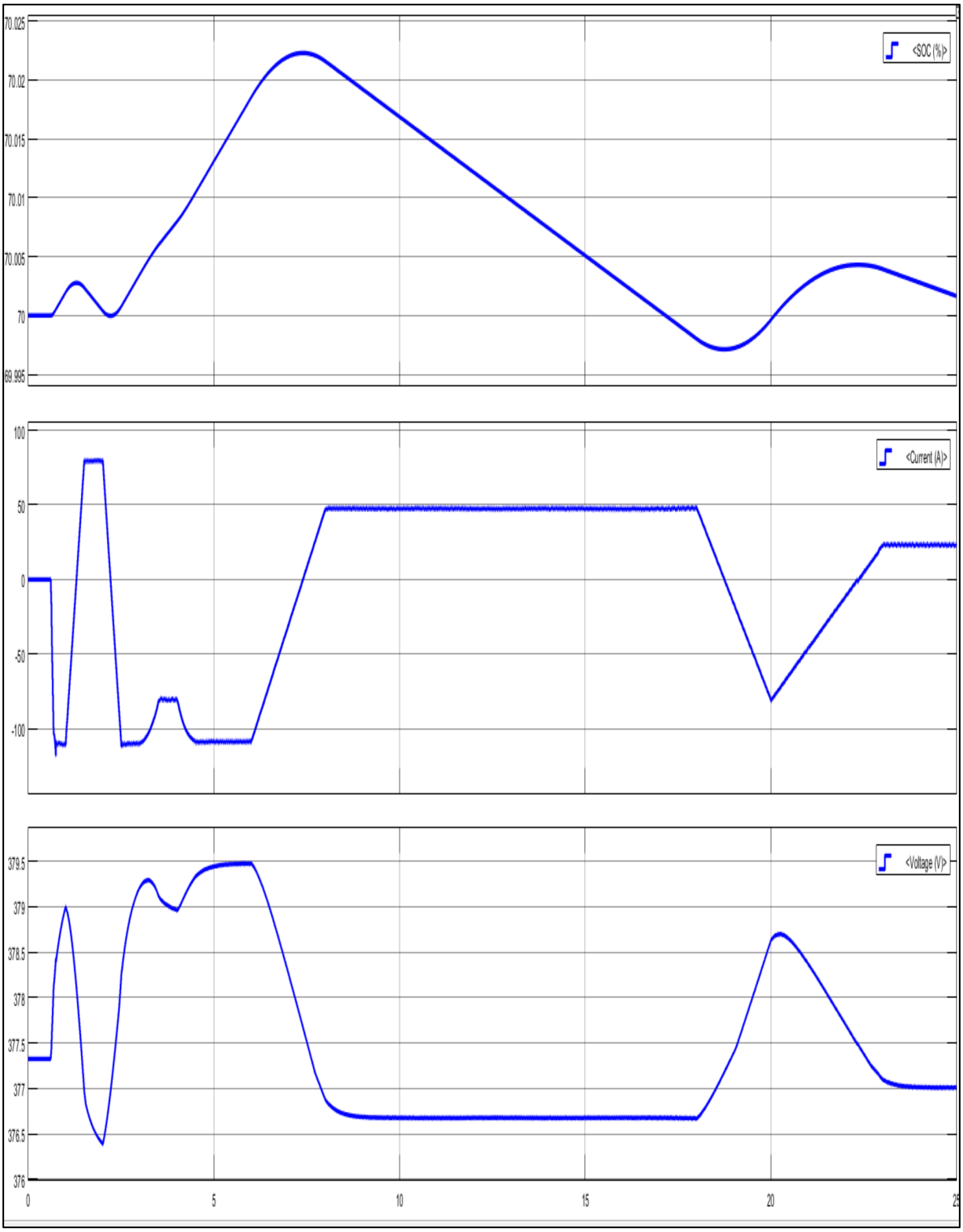


Figure 6.28: Duty cycle, reference current and power reference scope when the battery controller power reference changing

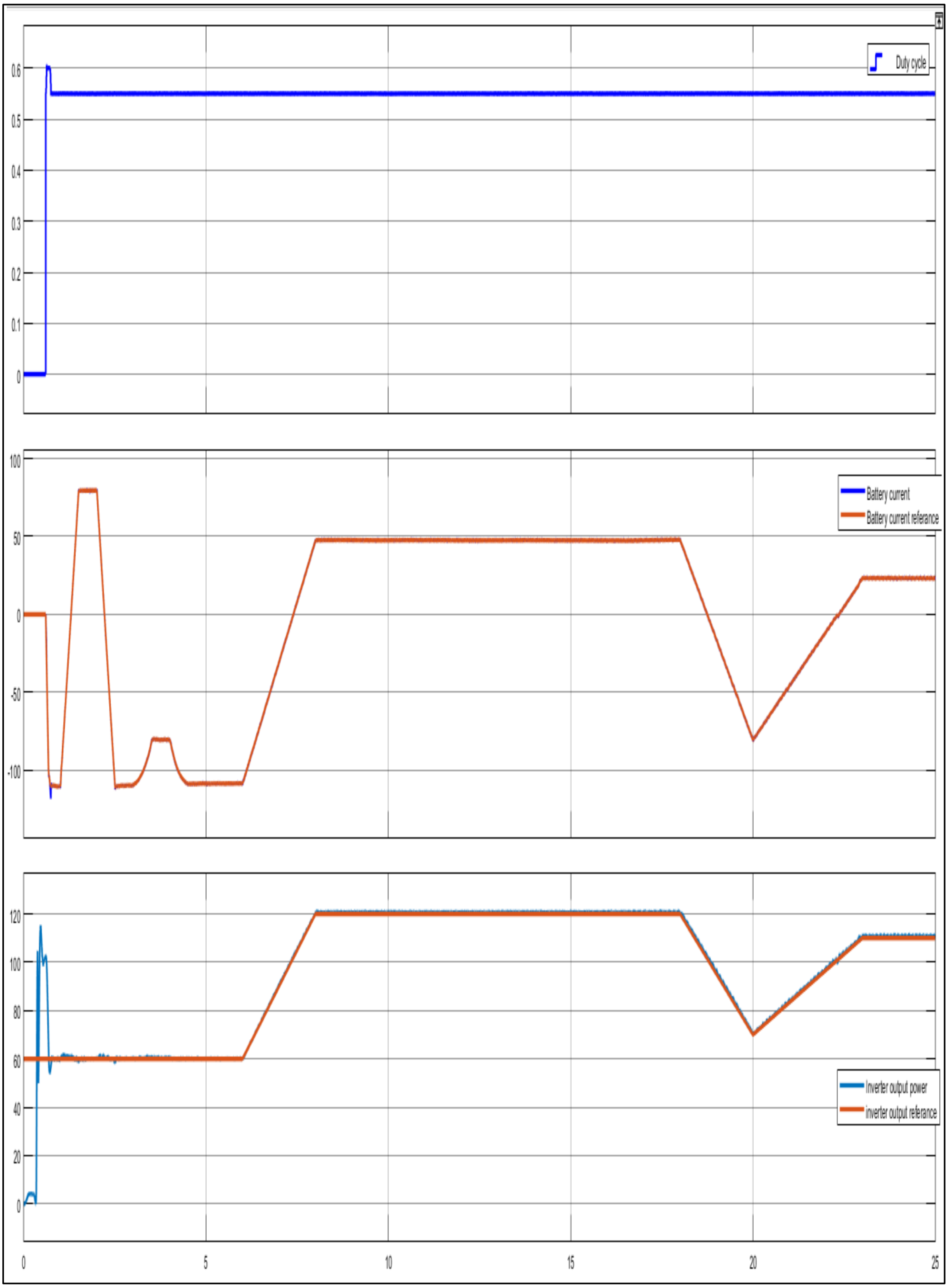
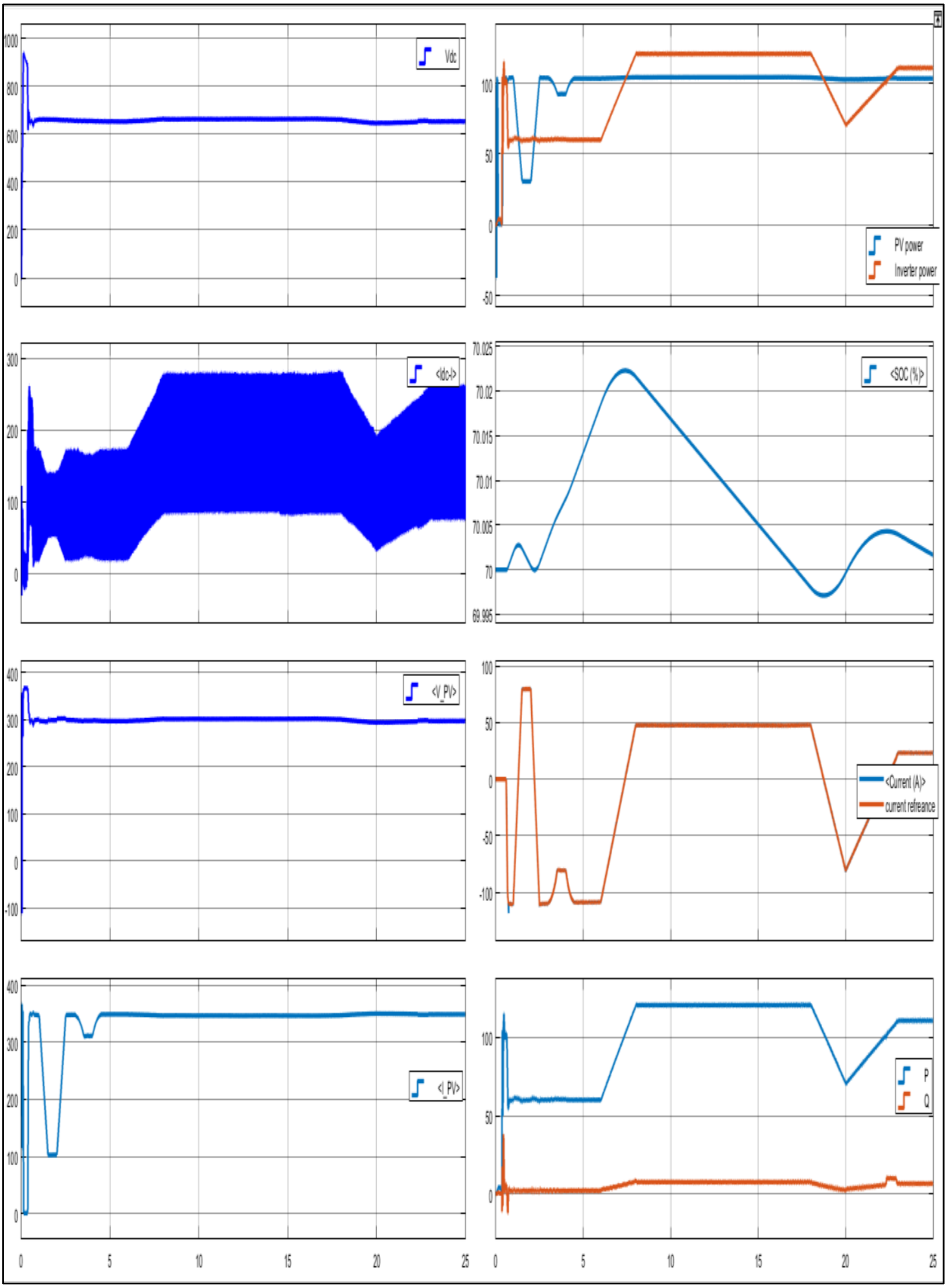


Figure 6.29: Inverter scope when the battery controller power reference changing



For the output inverter waveform for voltage and current measurement is shown in Figure 6.30 , the inverter generates a three phase peak voltage value at 330 V phase to ground measurement and it is equal to 233 V_{rms} single phase.

The inverter wavefrom from 6 sec until 6.5 sec is shown in Figure 6.31-, the total voltage harmoics distortion at that time is 1.16% during the current incraseing as shown in Figure 6.32.

The inverter wavefrom from 19 sec until 21 sec is shown in Figure 6.33 the total voltage harmoics distortion at that time is 1% during the current decraseing and incraseing as shown in Figure 3.34-.

Figure 6.30: Inverter scope when the battery controller power reference changing

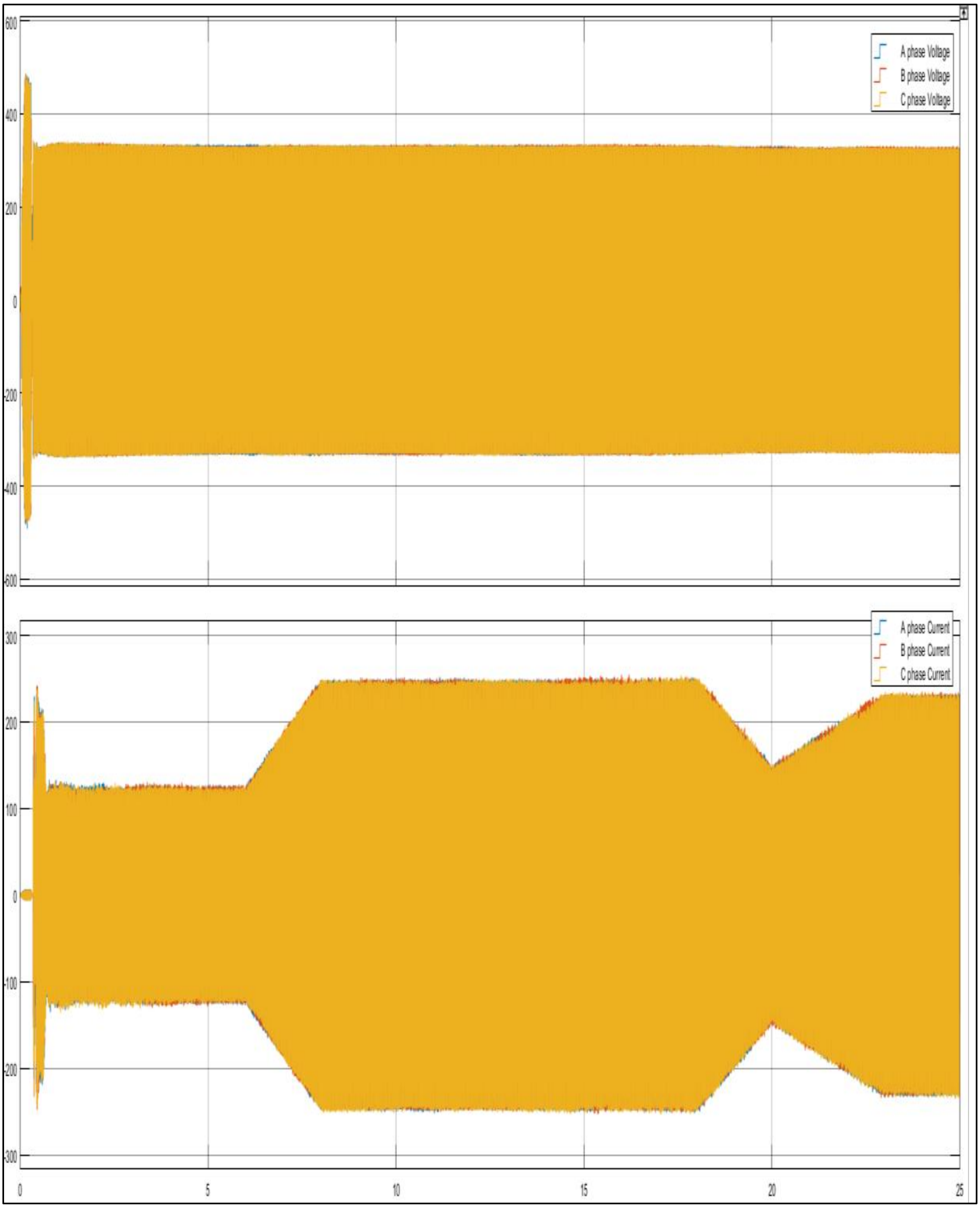


Figure 6.31: Inverter scope when the battery controller power reference changing

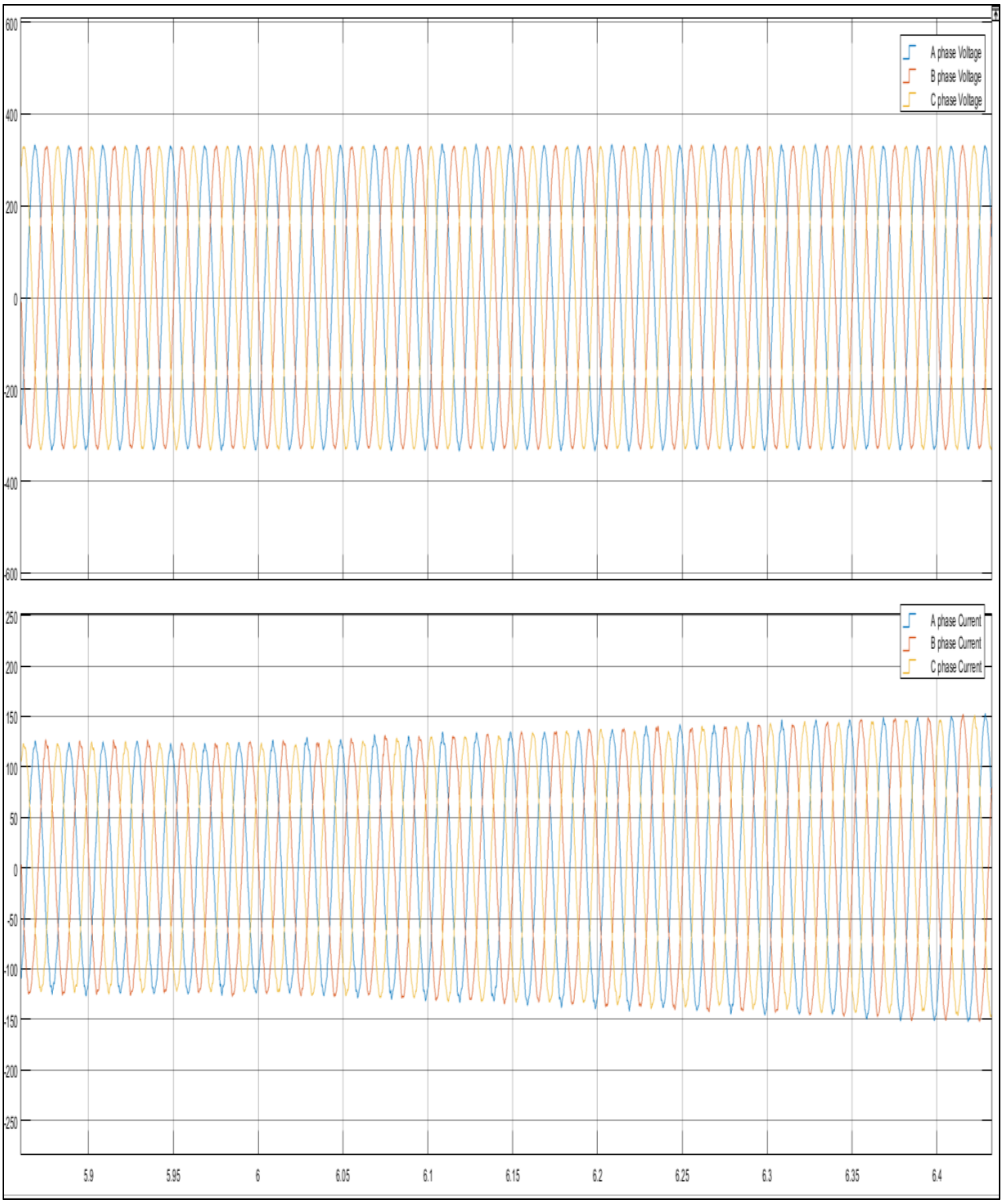


Figure 6.32: THD for voltage waveform when the battery controller power reference changing

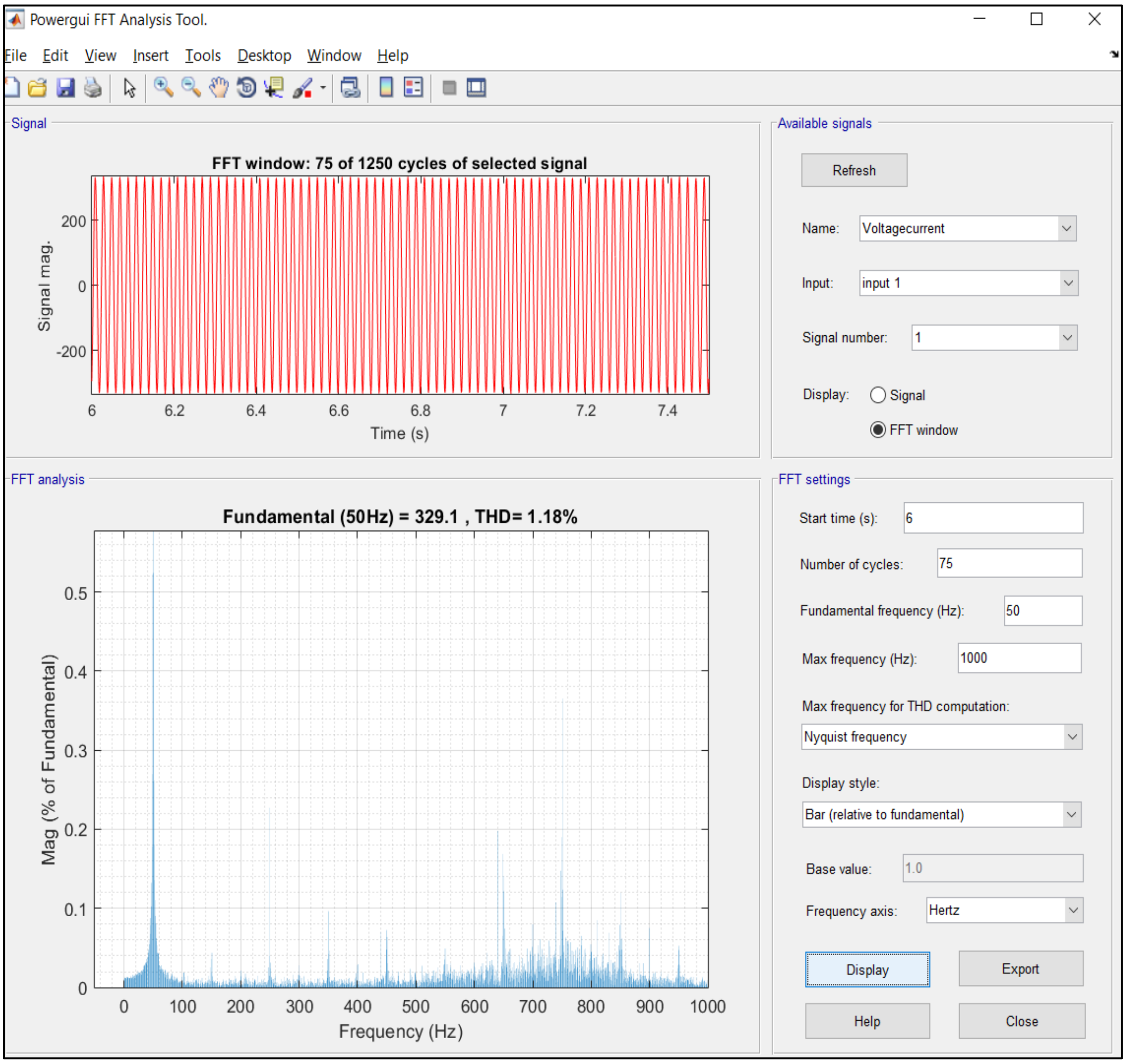


Figure 6.33: Inverter scope when the battery controller power reference changing from 19.6 sec to 20.4 (lowest power point)

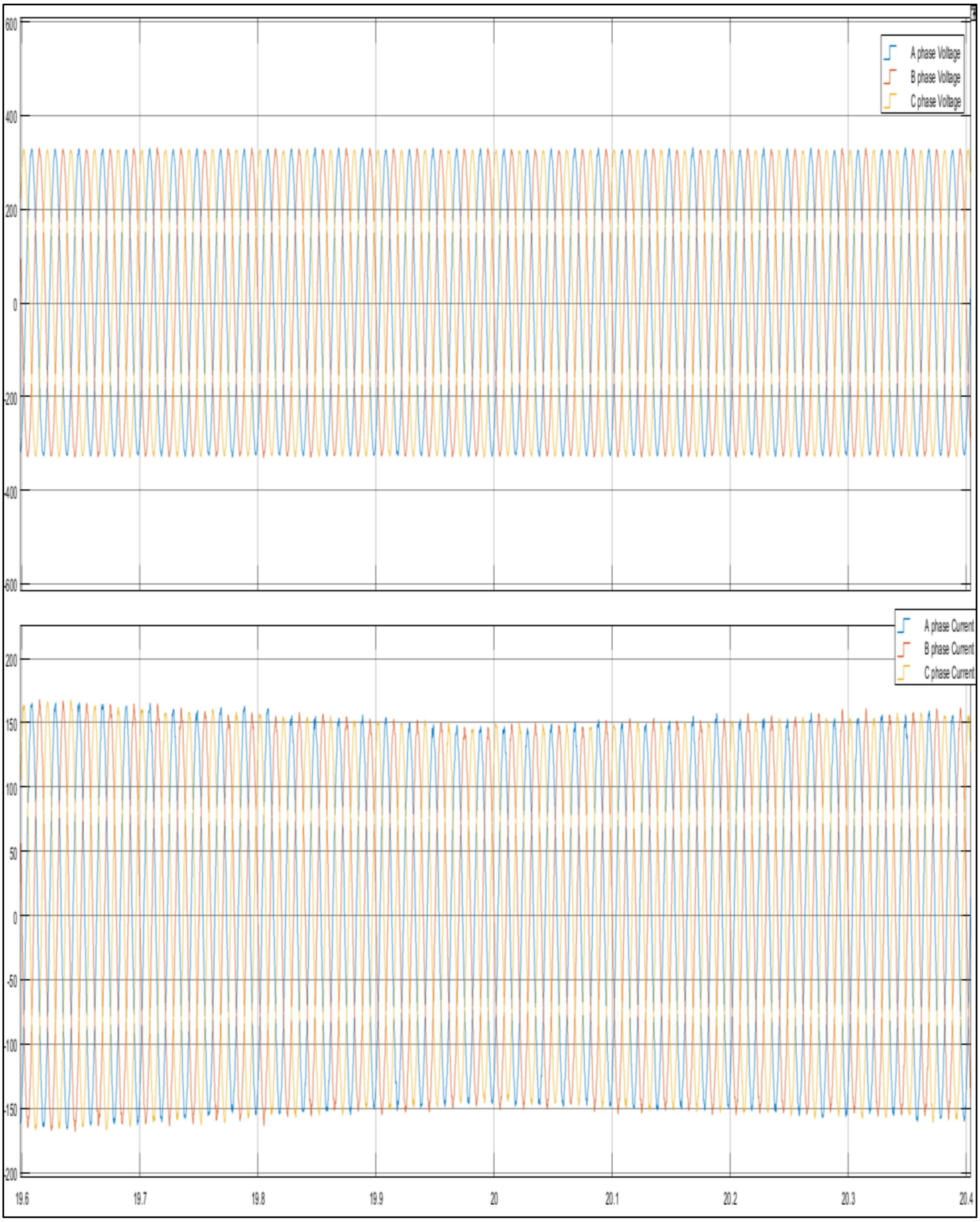
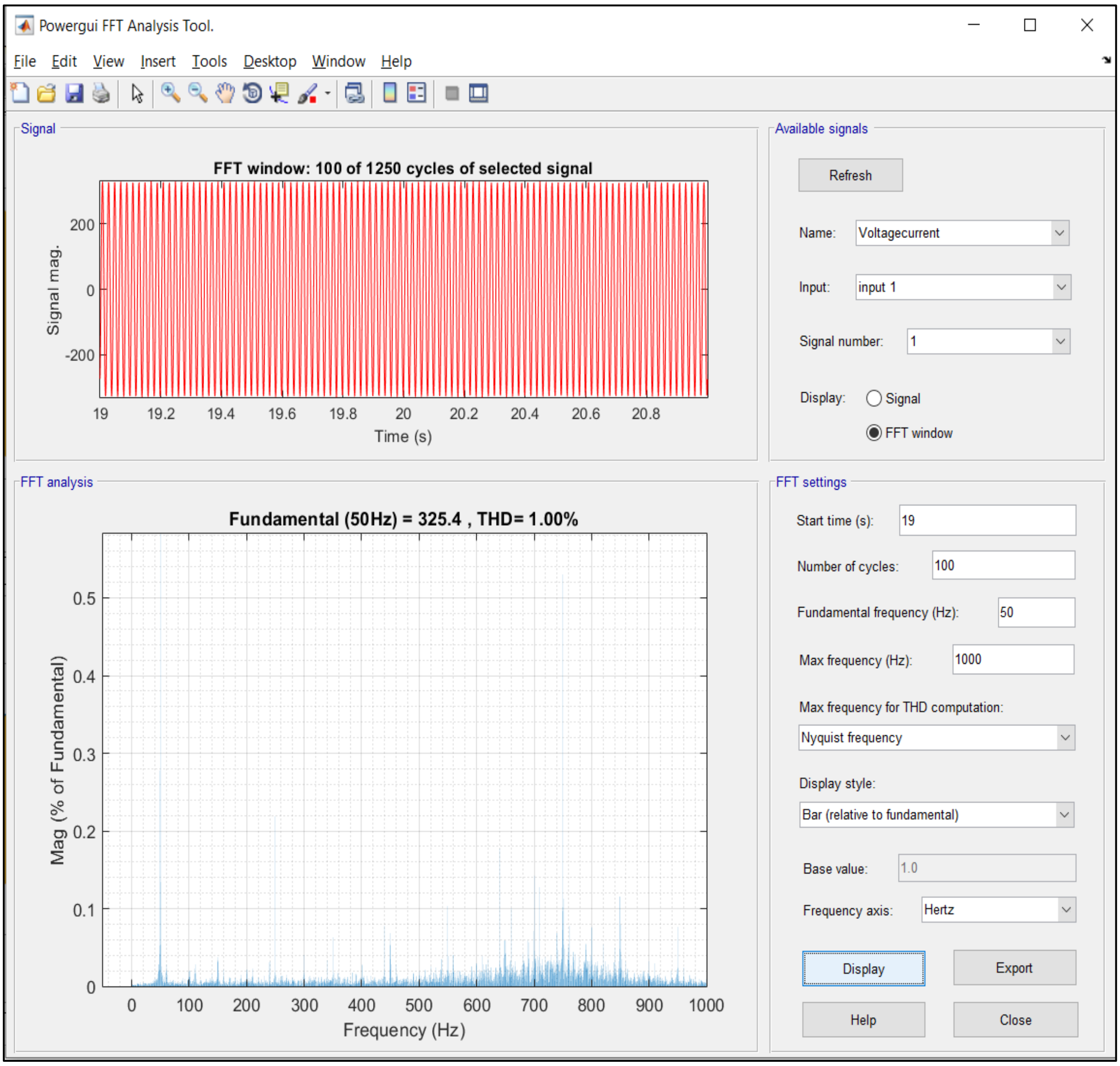
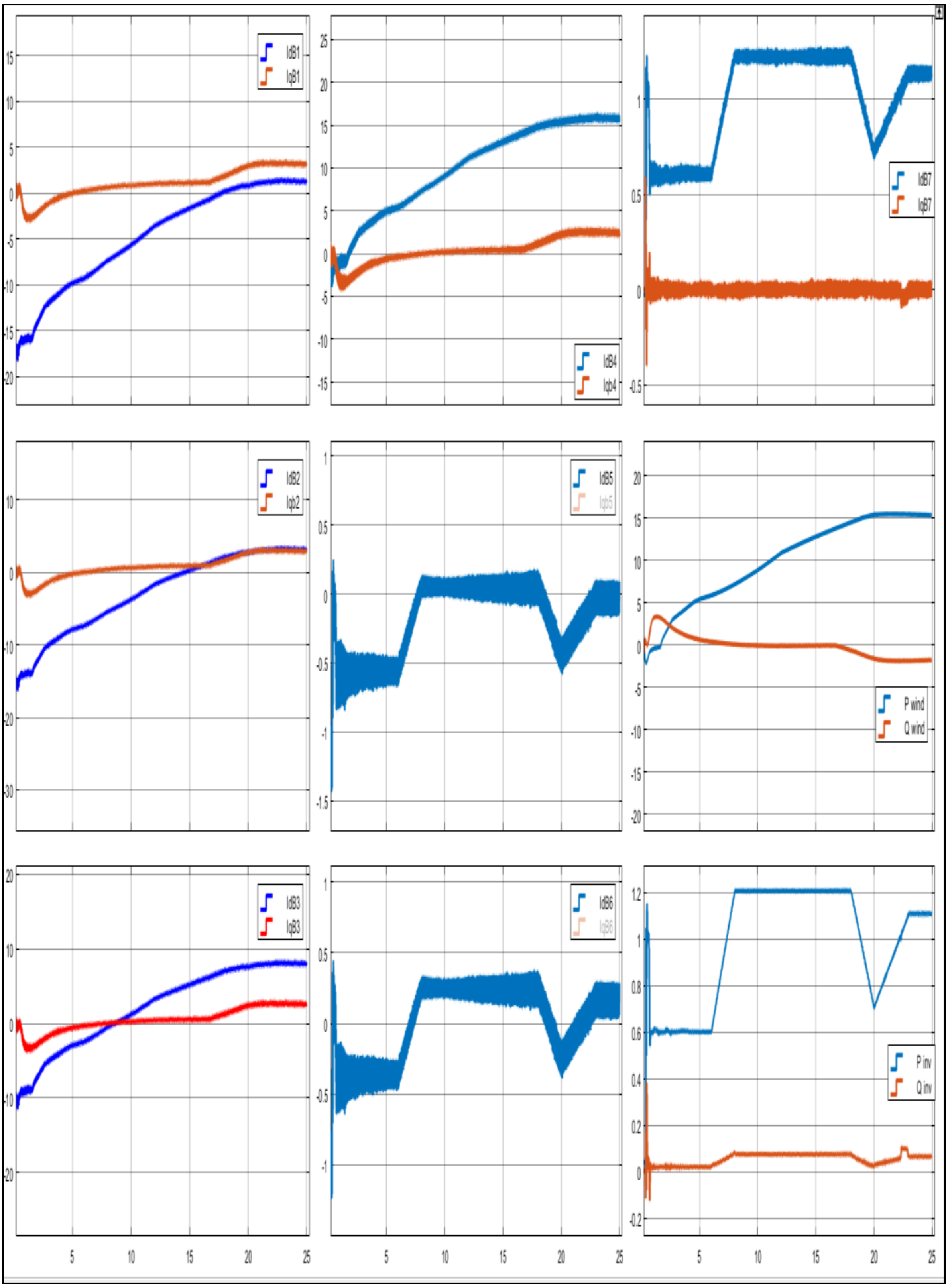


Figure 6.34: THD for voltage waveform when the battery controller power reference changing from 19.6 sec to 20.4 (lowest power point)



At Figure 6.35 shows the buses scope, bus 7 shows the photovoltaic power pumping into the grid and it is changing as the reference, the first 6 sec reference is 60 kW so the load 5 is going to take 40 kW extra from the wind turbine and load 4 is going to get the power from the wind turbine, after that power reference increase to 120 kW , the inverter is going to power up load 4 and 5, then when power reference decrease load 4 and 5 will get the power from the wind turbine.

Figure 6.35: Buses scopes when the battery controller power reference changing



6.4 BATTERY ONLY CONTROLLED POWER REFERANCE CHANGING

For this simulation, the initial state of charge for the battery is 100% and the sun irradiation starts with 1000 W/m^2 then decrease to 0 at 0.7 sec as shown in Figure 6.36-, just to make the inverter working and synchronized. The power reference is 50 kW at the first second then decrease 10 kW each half second to reach 10 kW at 2.5 sec then increase 10 kW each 0.25 sec to reach 80 kW at 4 second then start decrease at 4.25 seconds to reach 30 kW at 4.75 sec then stabilized as shown in Figure 6.37-.

Figure 6.36: Irradiation input decreasing to zero and temperature input

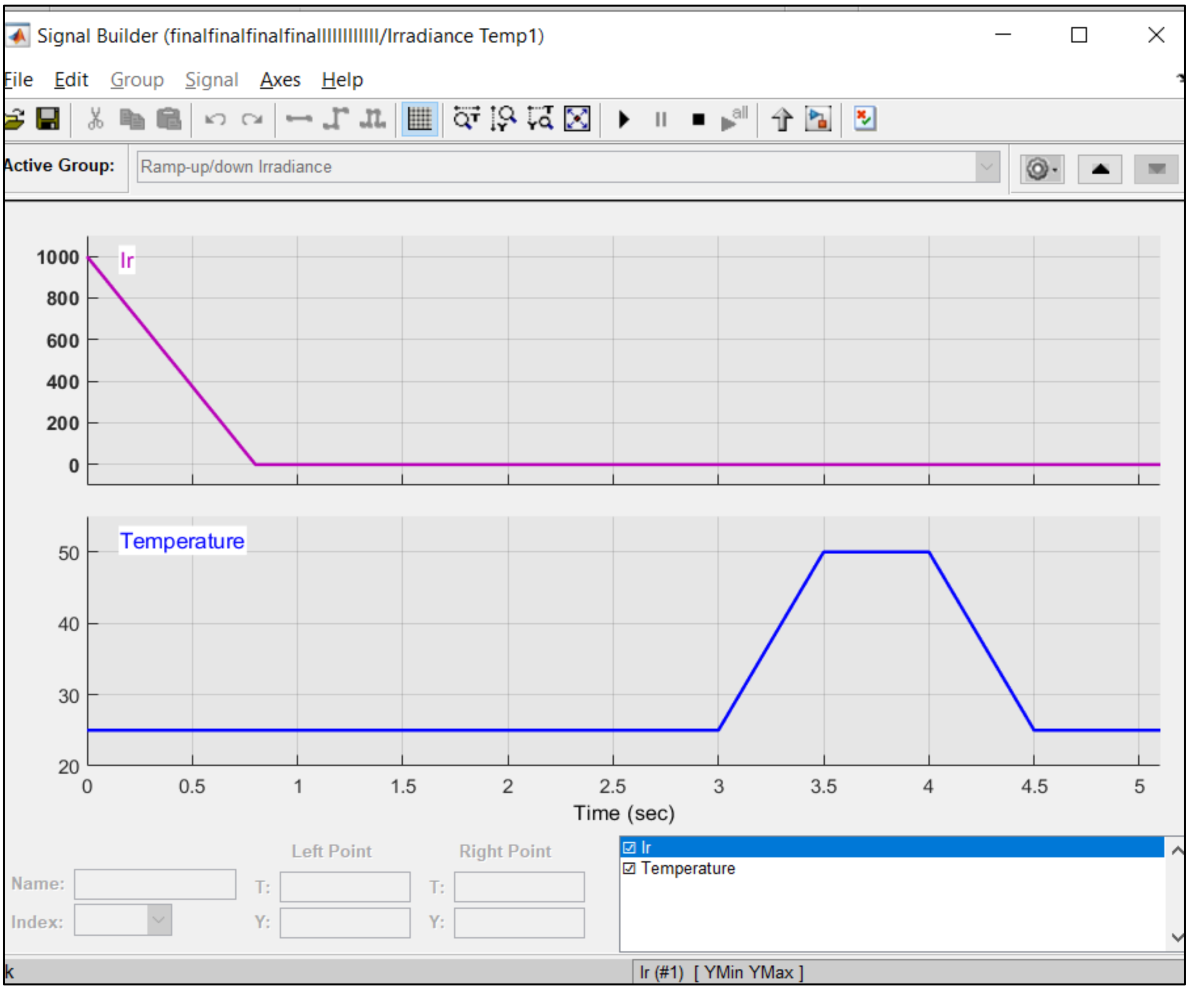


Figure 6.37: Sudden changes in output power reference

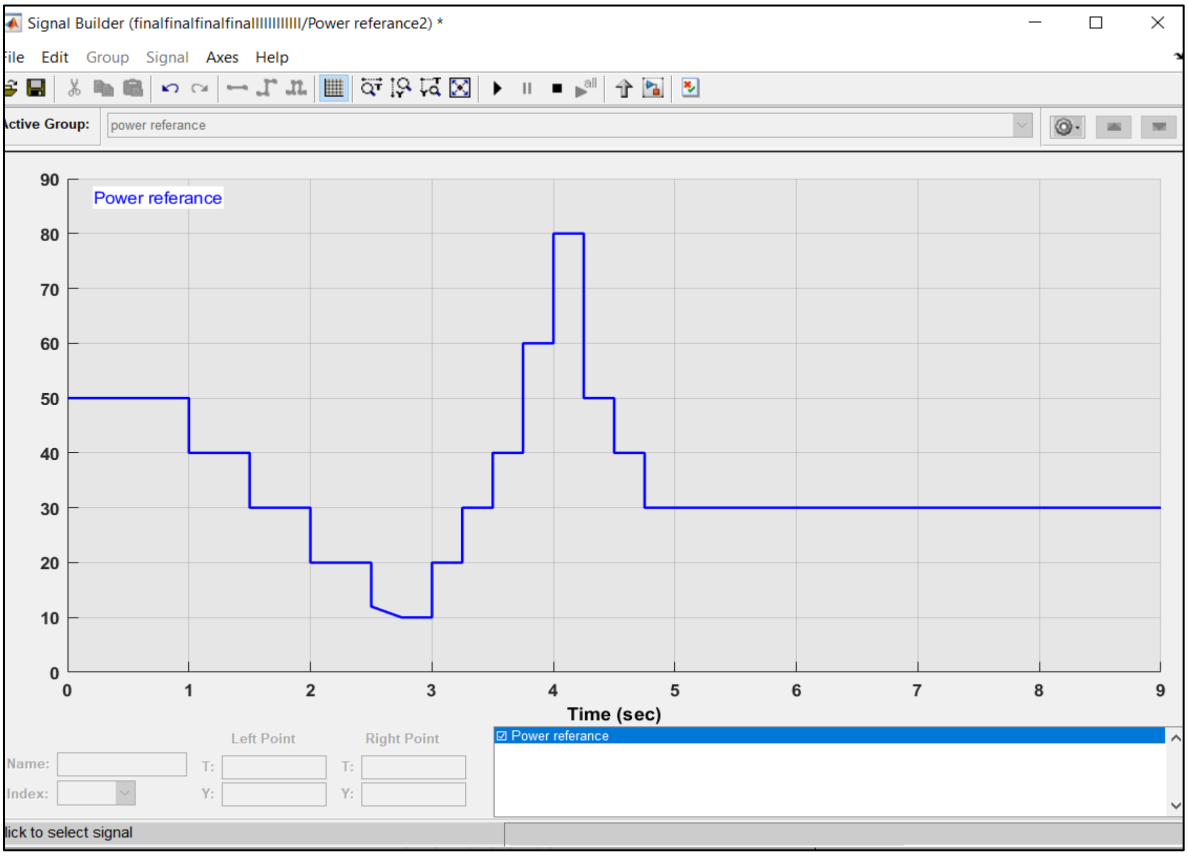


Figure 6.38 shows the battery scope and can see the voltage of the battery decrease with increase the discharge current.

Figure 6.39 shows the duty cycle, reference current and power reference scope, when a sudden increase or decrease in the discharge current, the duty cycle for the bi directional converter have a sudden decrease to increase also but after it stabilized when the discharge current be almost the same as the reference, this sudden change create a small peak value for the current, also the power of the inverter follow the power reference in sudden changes, the discharge current will not increase than 150 A even the maximum power for the batteries is 60 kW even when the power reference reach above than 60 it stabilized at 60 kW , with a small peak value, the current ripple for the converter is 0.4 A as shown in Figure 6.40-.

In Figure 6.41 shows the inverter scope at beginning the inverter will power up for the photovoltaic panels then at 0.6 sec when the battery start working it will pump power to the inverter to follow the power reference and at 1 sec the photovoltaic current reach 0.

Figure 6.38: Battery scope when sudden changes in power reference

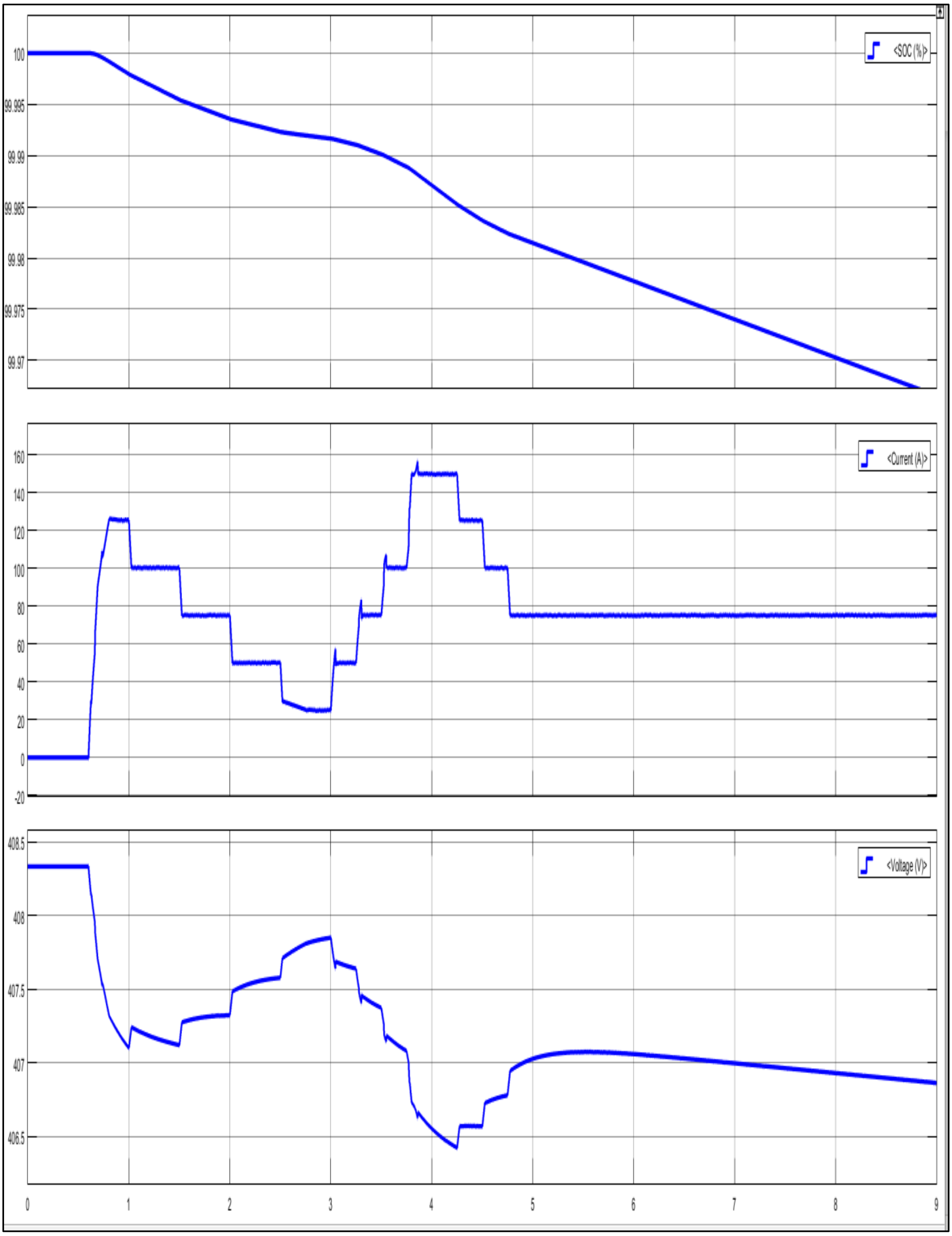


Figure 6.39: Duty cycle, reference current and power reference scope when sudden changes in power reference

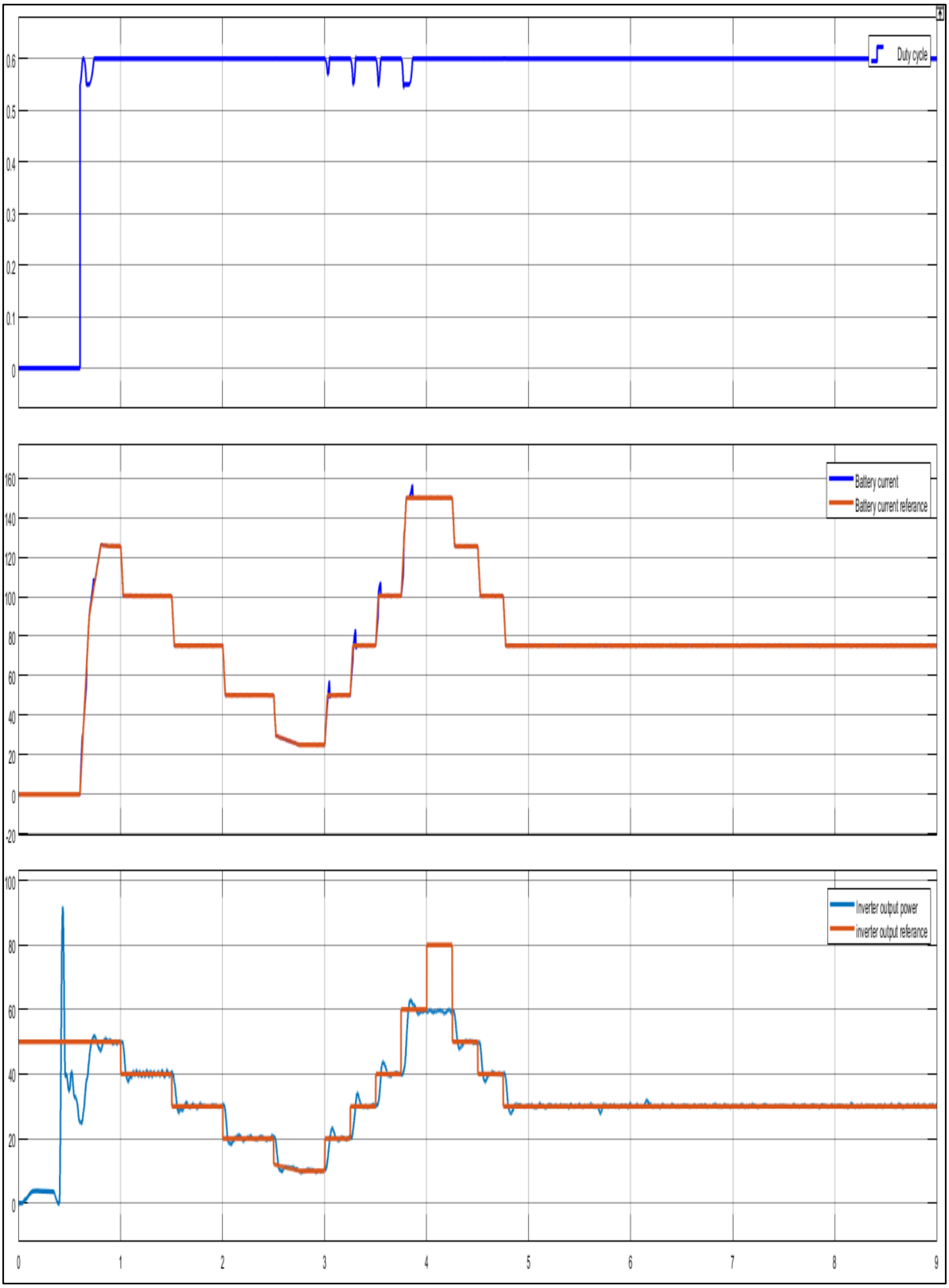


Figure 6.40: Duty cycle, reference current and power reference scope when sudden changes in power reference (current ripple)

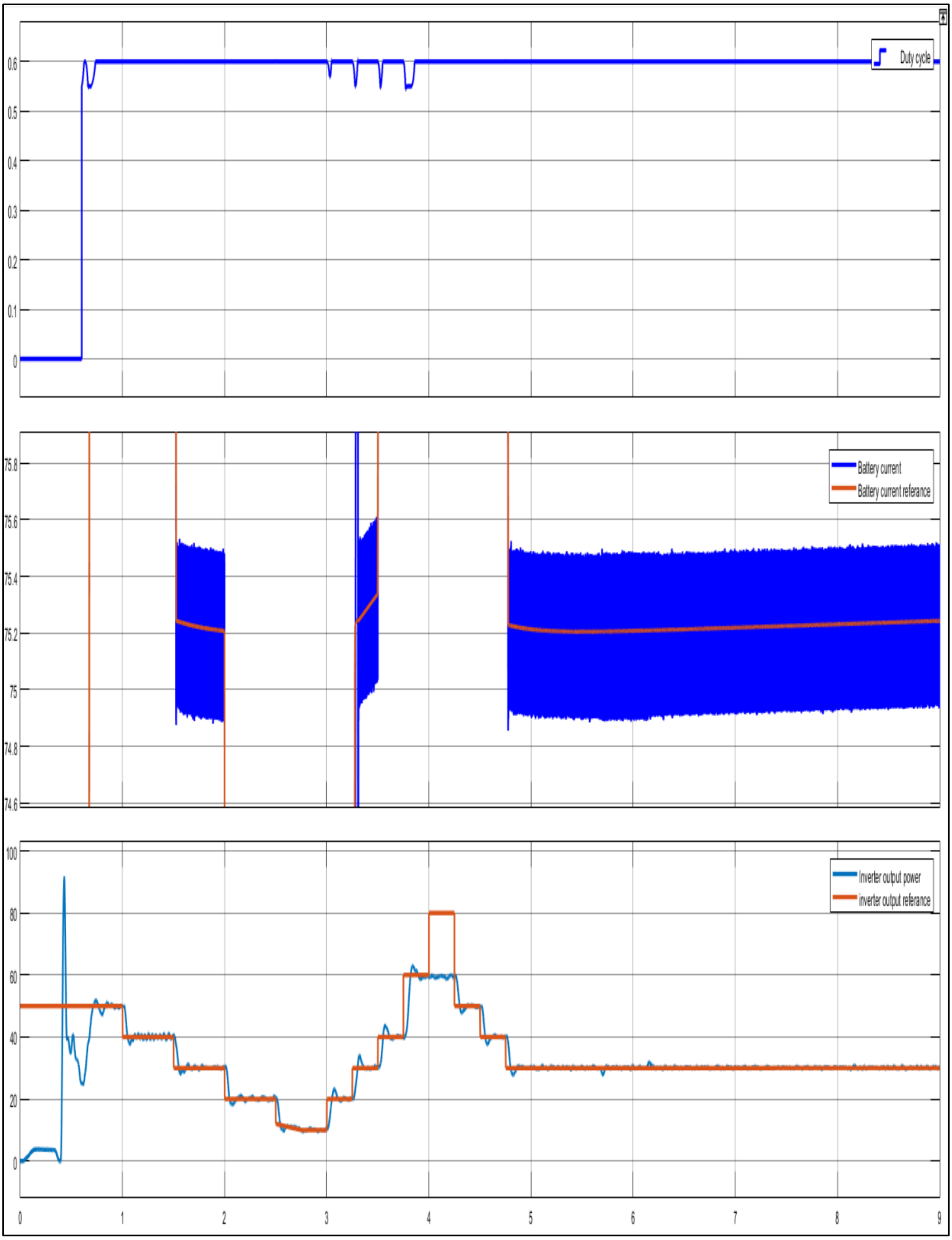
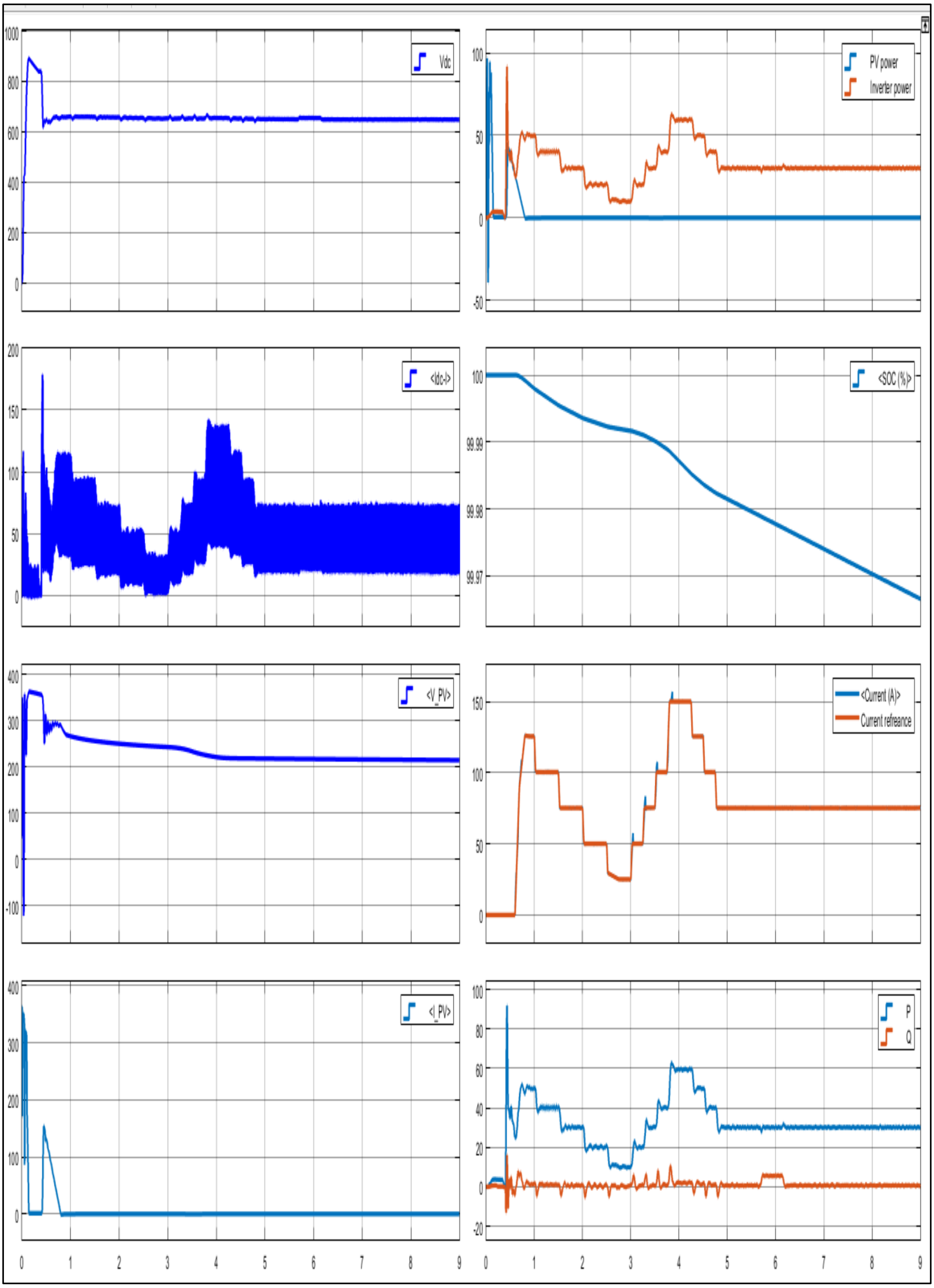


Figure 6.41: Inverter scope when sudden changes in power reference



In Figure 6.42 shows the inverter voltage and current output waveforms, at 10 kW power reference period the waveforms are shown in Figure 6.43-.

The total harmonics distortion of the voltage wave form from 2 sec to 6 sec is 1.46% as show in Figure 6.44-. The total harmonics distortion of current waveform from 5 sec to 5.25 sec in 4.84% as shown in Figure 6.45-.

Figure 6.46 shows the buses scope how the system reacts all together and wind turbine power reacts the same as before.

Figure 6.47 shows the frequency of each buses which is around 50 Hz.

Figure 6.42: Inverter output waveforms when sudden changes in power reference

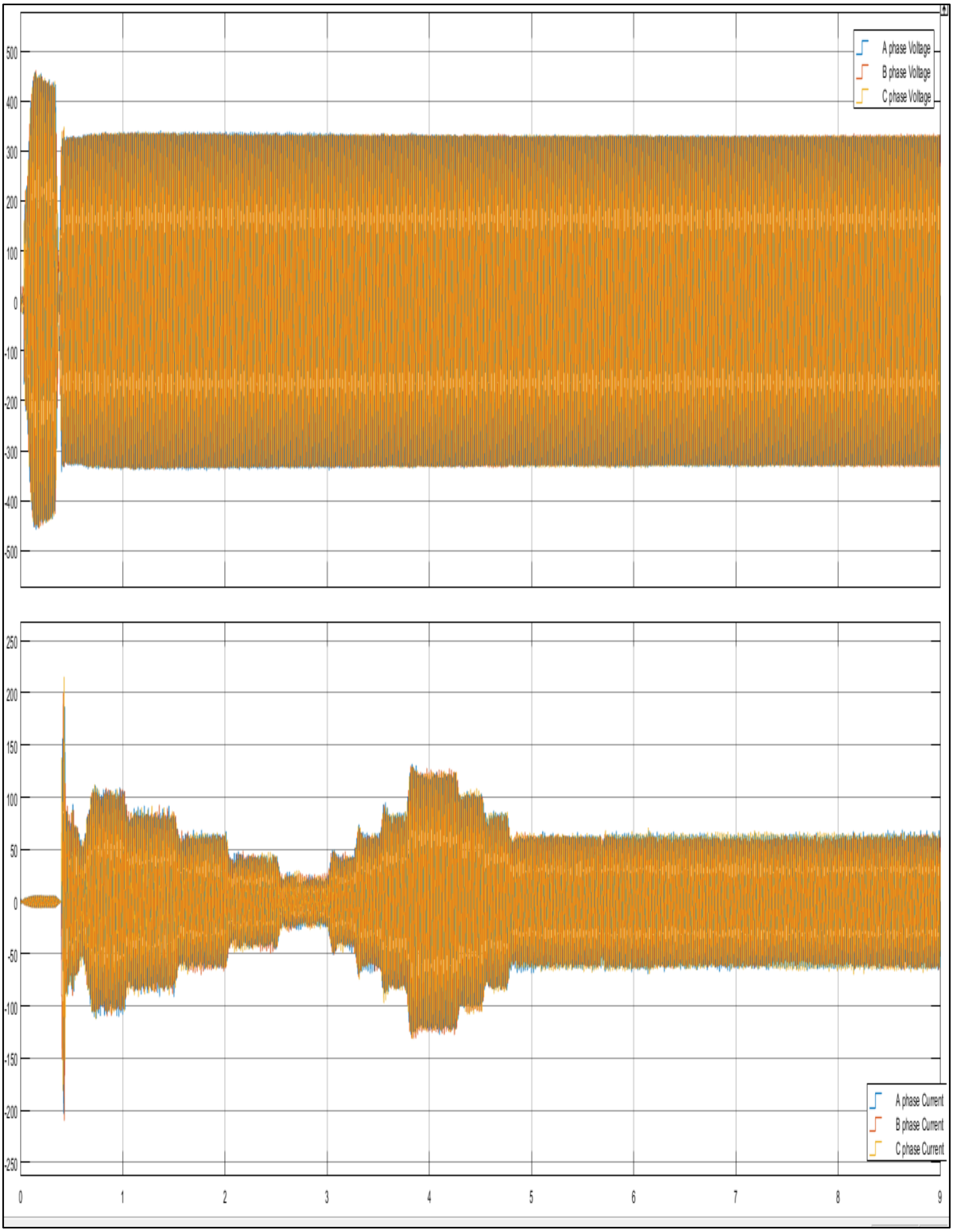


Figure 6.43: Inverter output waveforms when sudden changes in power reference (lowest power reference point)

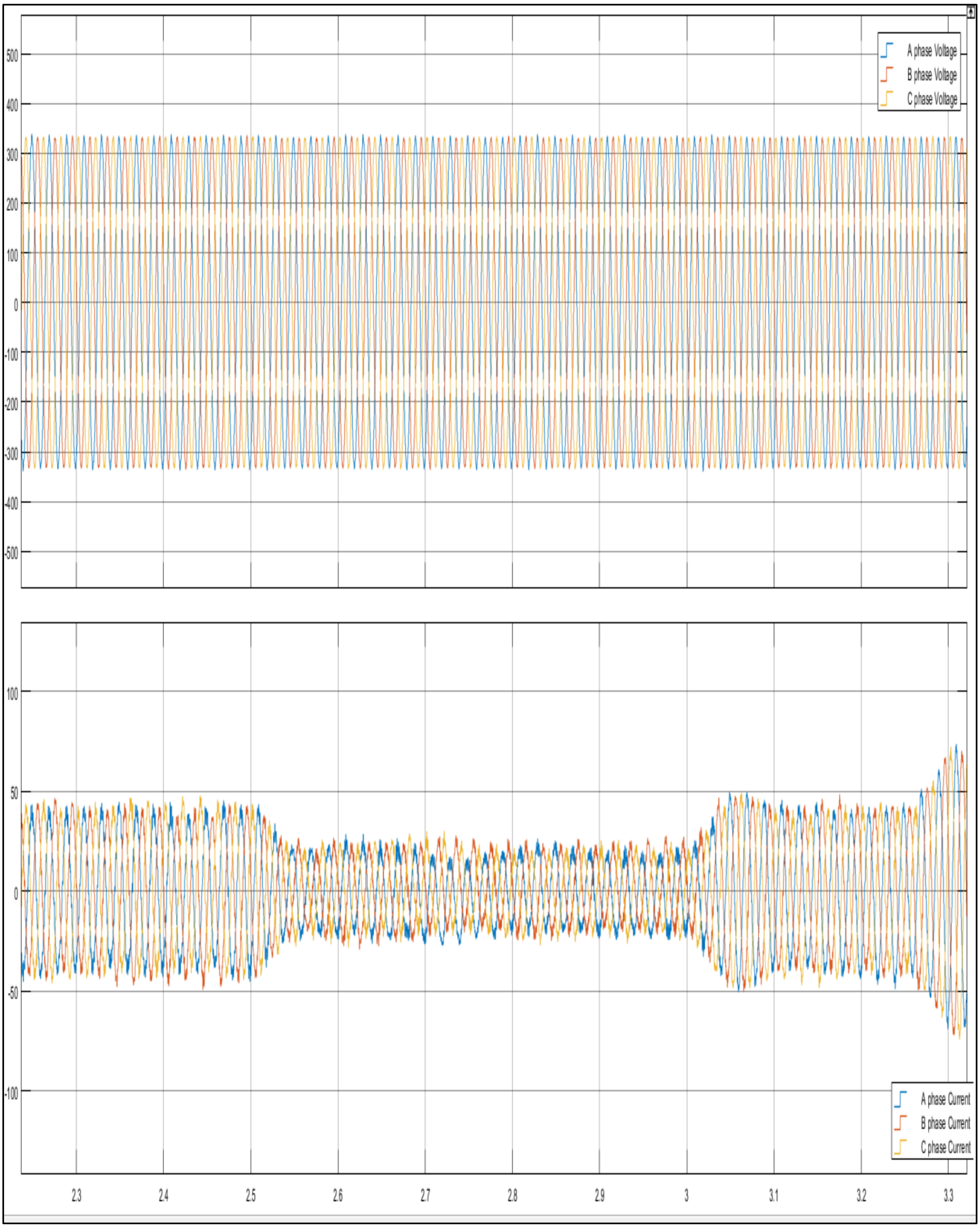


Figure 6.44: THD for inverter voltage when sudden changes in power reference (lowest power reference point)

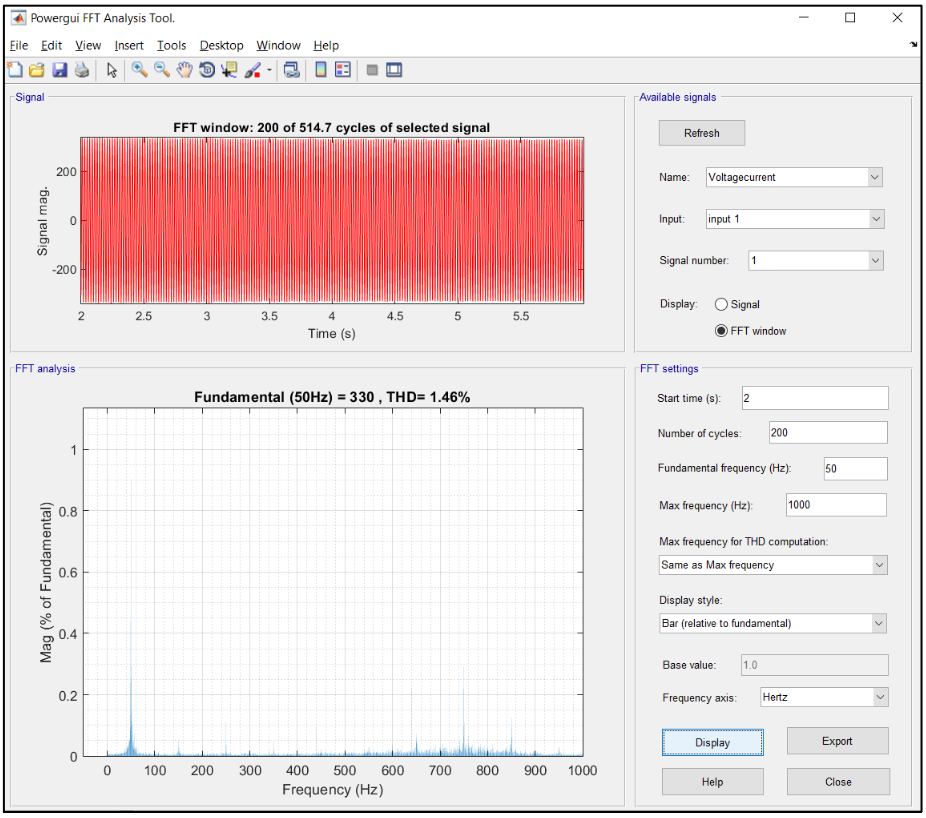


Figure 6.45: THD for Inverter current when sudden changes in power refer ence (lowest power reference point)

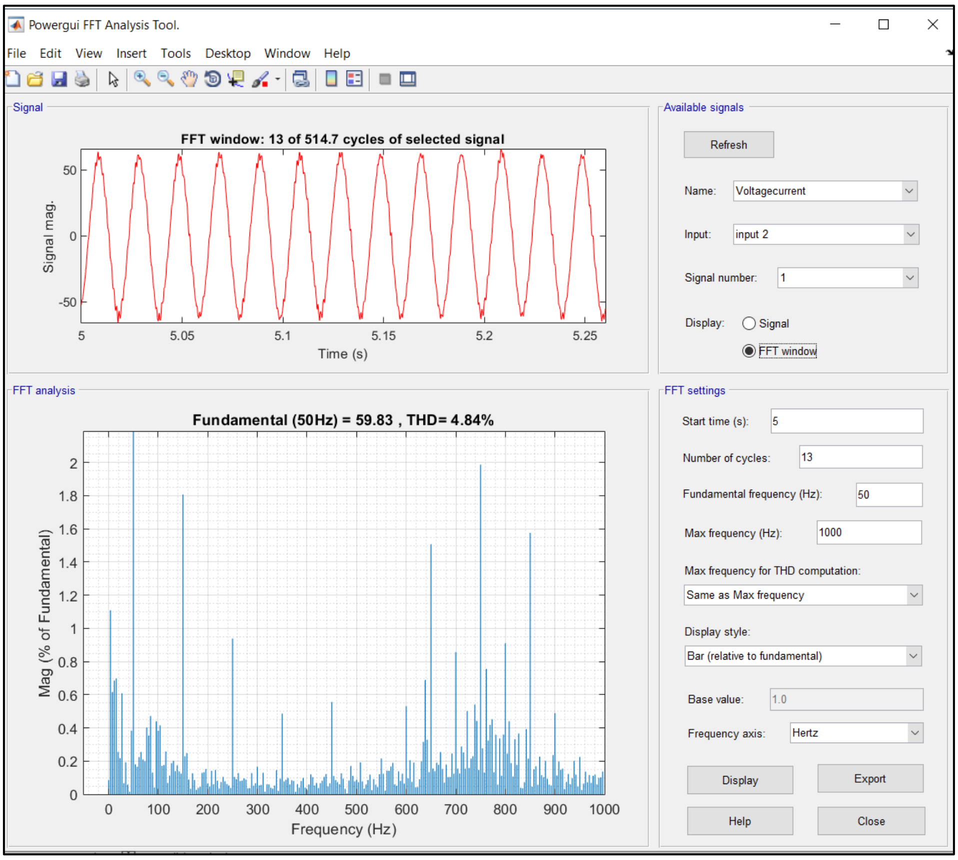


Figure 6.46: Buses power scope when sudden changes in power reference

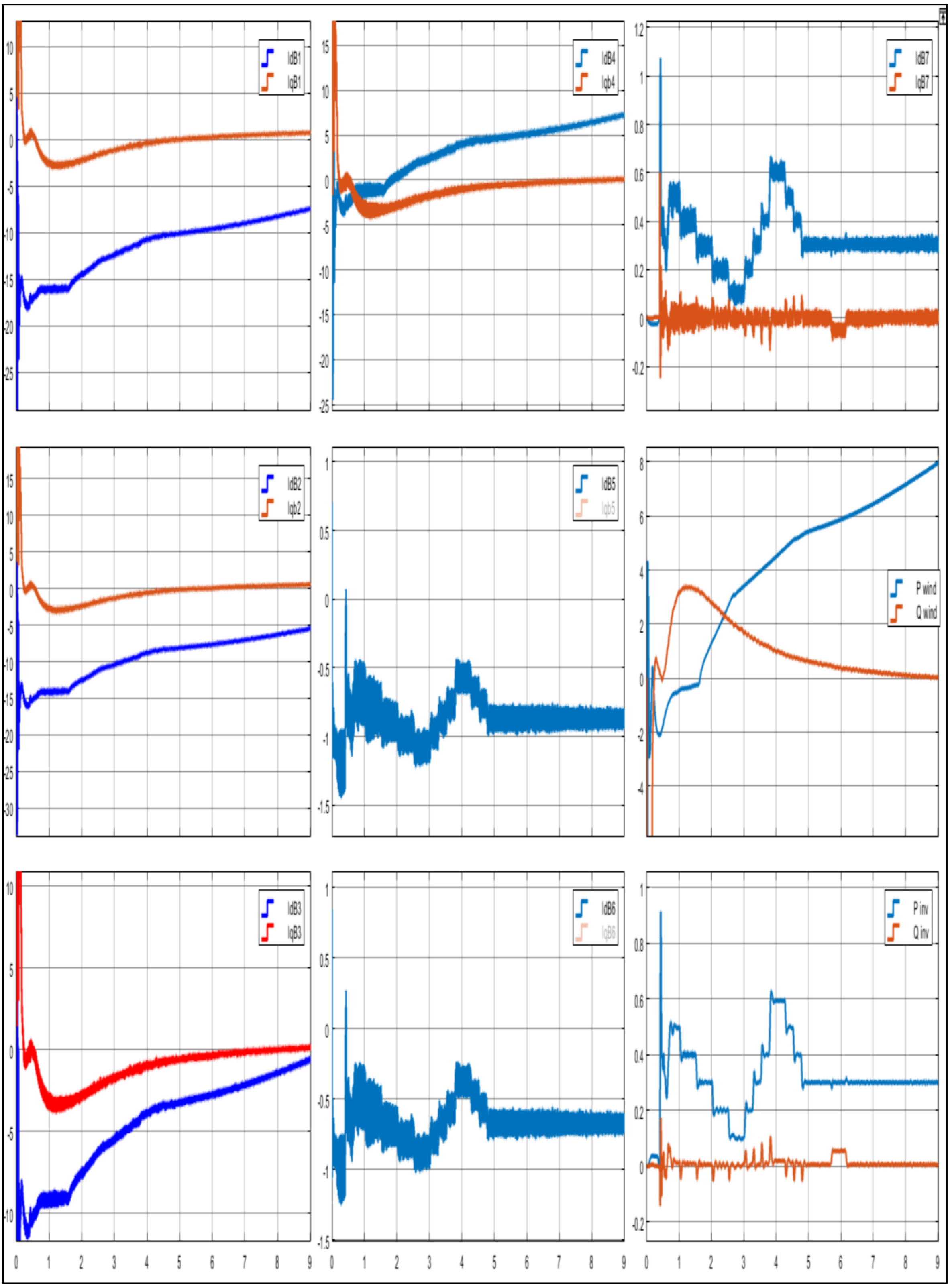
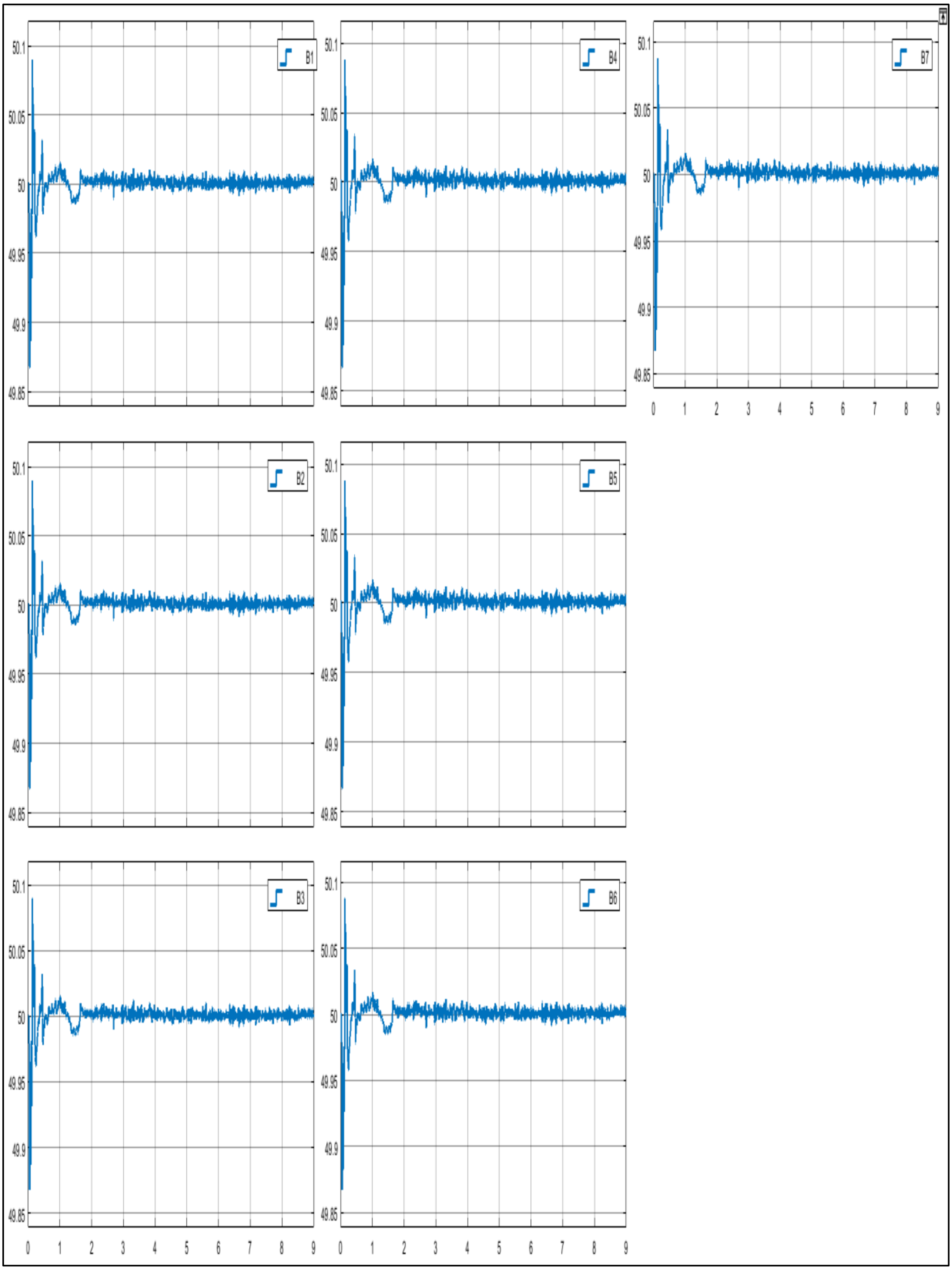


Figure 6.47: Buses frequency scope when sudden changes in power reference



For this simulation it is the same as before but the sun irradiation temperature is set to zero and the timer for battery controller is 0.02 sec.

At 0.02 sec a huge amount of current will discharge for the batteries, as the PI controller take the maximum value and the minimum value , the batteries will be in discharge mode and charge mode periodically depends on the duty cycle but when the automatic three phase inverter close as the synchronized started at 0.25 sec a huge amount of power stored in the capacitors will discharge creating a peak inverter output around 180 kW then it is stabilized at 0.5 second as shown in Figures 6.48-, 6.49-, 6.50-, respectively.

The inverter's voltage and current output waveforms are shown in Figure 6.51-, and the total harmonics distortion of the voltage waveform from 0.25 sec until 0.8 sec is 3.03% as shown in Figure 6.52-.

Figure 6.53 shows the buses scope and how the system reacts with each other's, this peak power value at the beginning of the synchronization have a negative effect of the system.

Figure 6.48: Duty cycle, reference current and power reference scope when sudden changes in power reference without PV

Figure 6.49: Three phase automatic breaker scope when sudden changes in power reference without PV

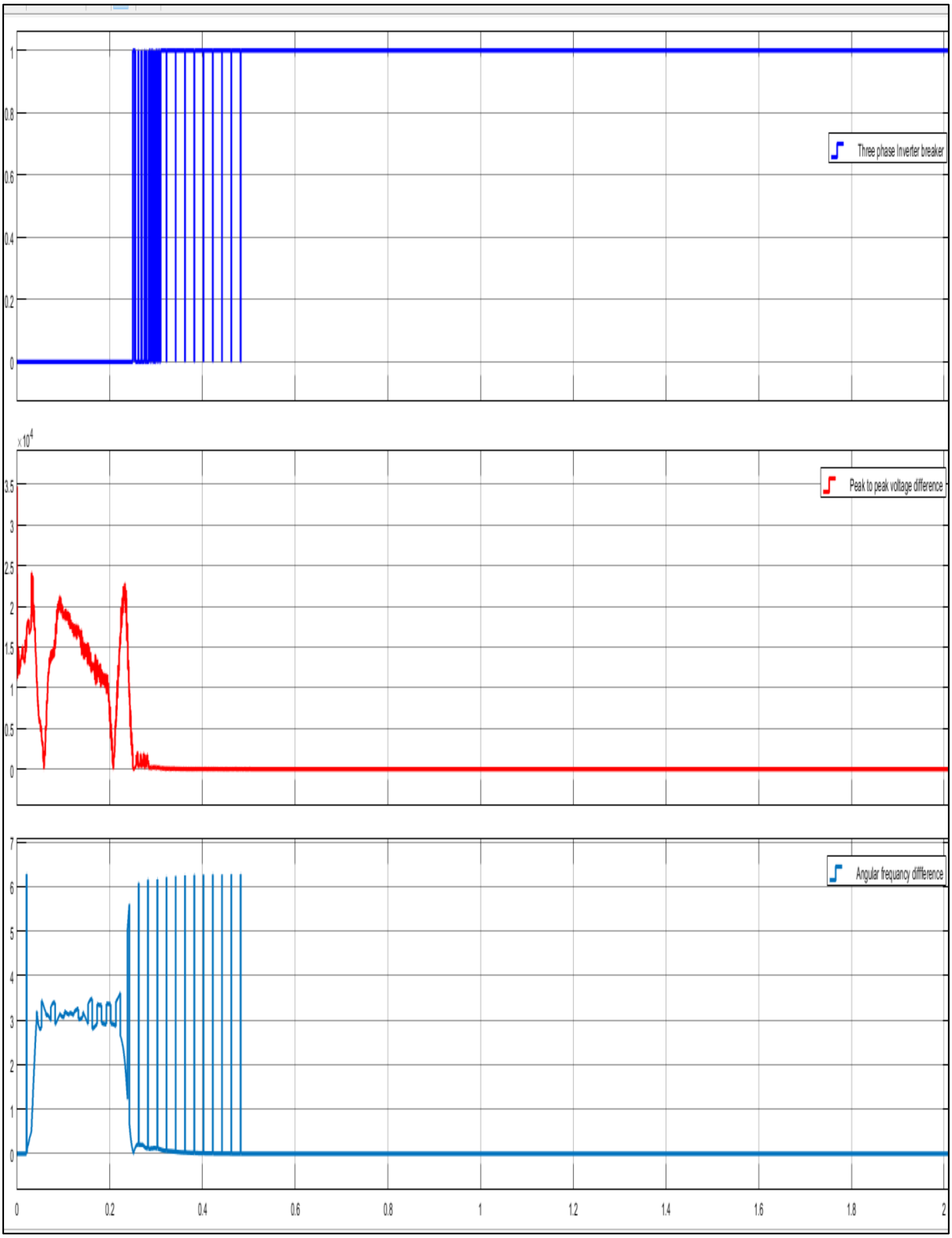


Figure 6.50: Inverter scope when sudden changes in power reference without PV

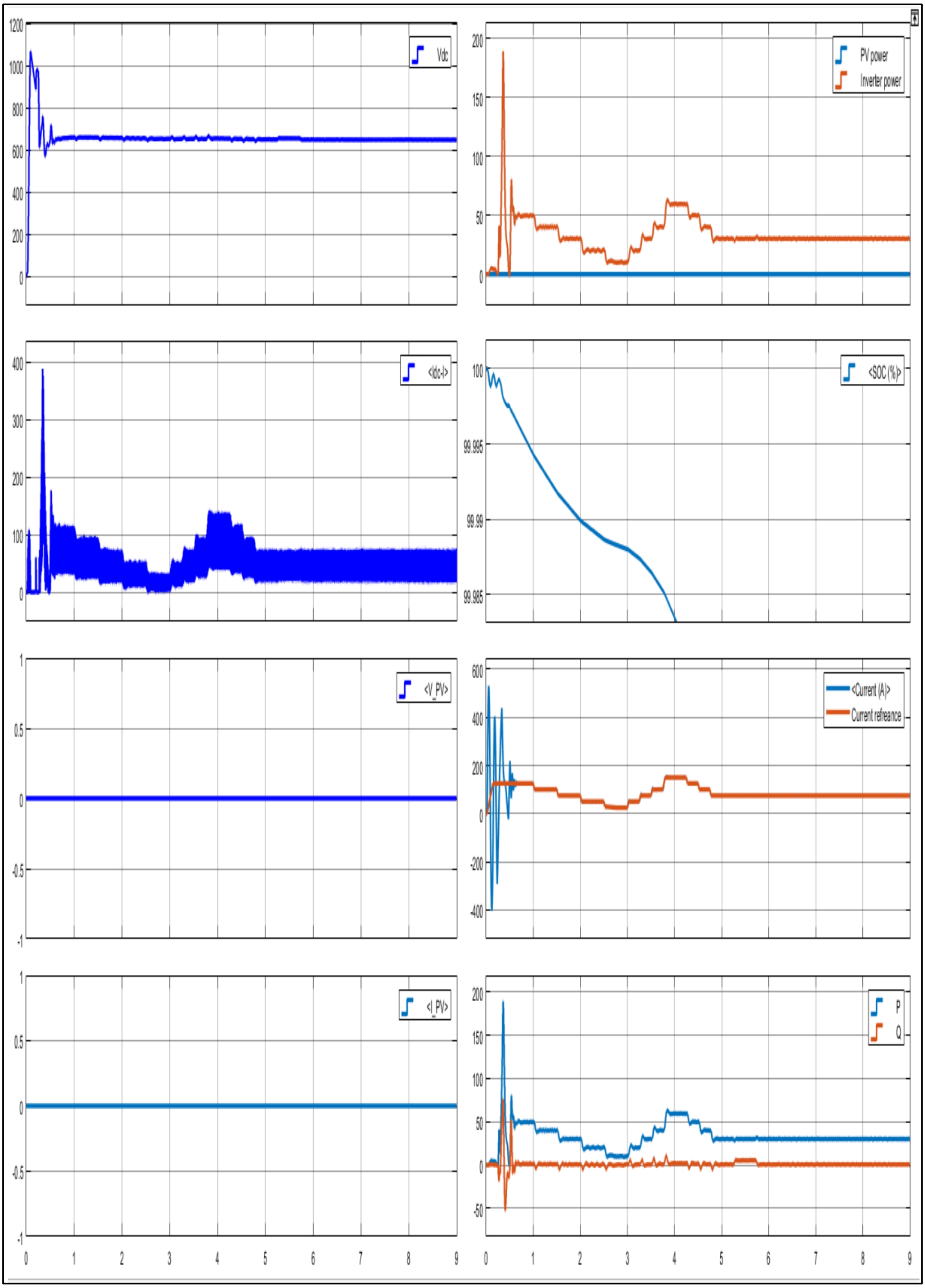


Figure 6.51: Inverter output waveform when sudden changes in power reference without PV

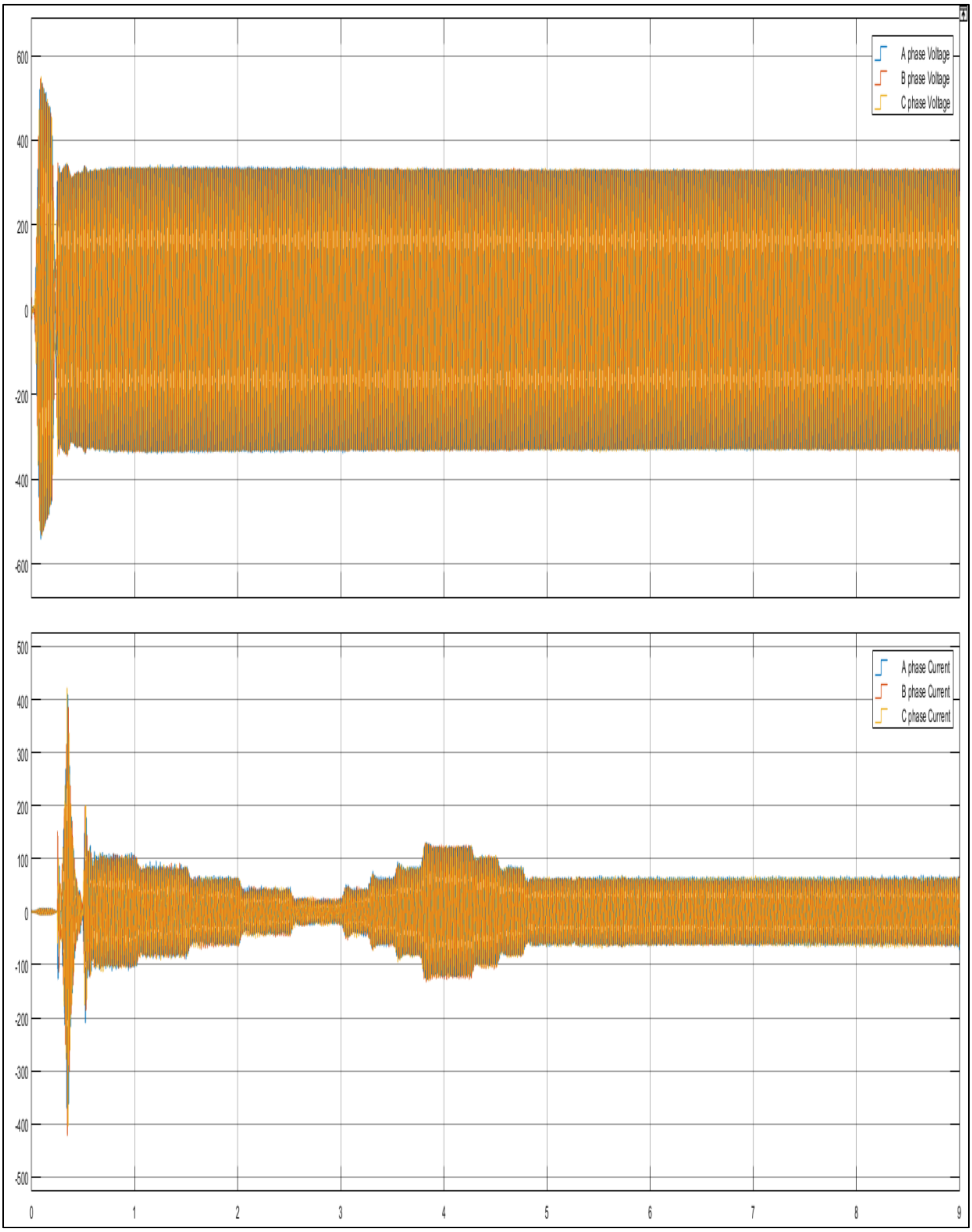


Figure 6.52: THD for inverter voltage when sudden changes in power reference without PV

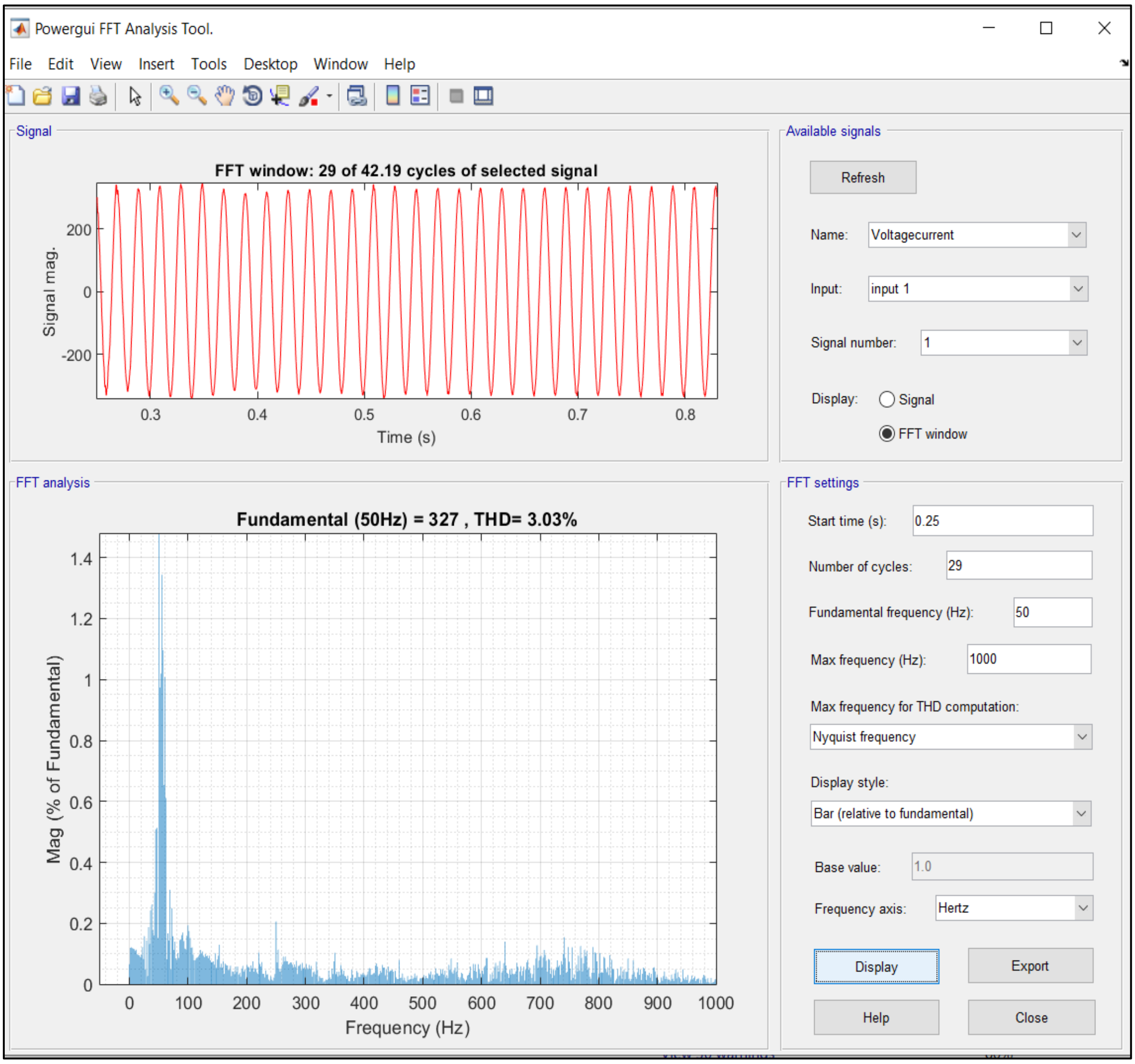
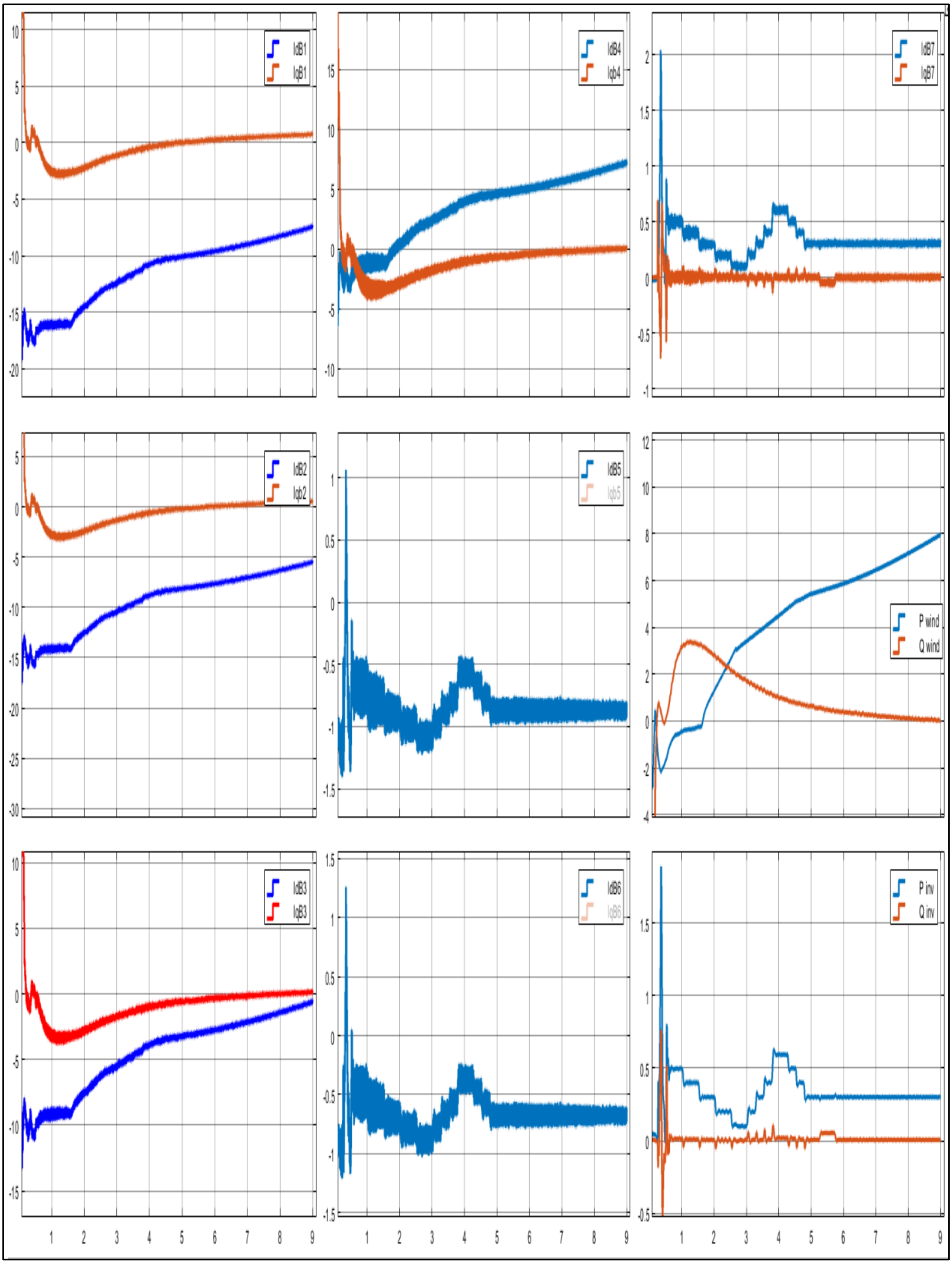


Figure 6.53: Buses power scope when sudden changes in power reference without PV



6.5 PHOTOVOLTIC CASE STUDY

The output of PVSYST analysis is given in this section. Simulation parameters, near shading definition, main results, special graphs, and loss diagram outputs are given, respectively.

Figure 6.54 shows the place for the case study is in Orhanli Turkey, With 40.78 N latitude, 29.34 E longitude and the altitude is 99 m above the sea surface, and 8 tacking system works on vertical axis only, each tracking with14.9 meter length and 4.17 meter width, with the title angle is 30 degree from maximizing the power on summer.

SPR-X21-470-COM solar panels will be used, 4 series modules with 56 string in parallel total of 224 solar panels generating 105 kW.

At 50 Celsius temperature V_{mpp} is 285 V and I_{mpp} is 340 A generating 96.9 kW, this system needs 484 meter square at least, but with 8 tracking holder it needs 1722.5 minimum space area, and GTP-507 three inverter from Lenoics Company is being used.

The losses for the wiring are 1.5%, the module and string losses are 1.1% and for the incidence effect is 0.05, the total losses are 2.65% for this system

Figure 6.55 shows the drawing of the system and each square have 25 meters square, almost 70 squares needed, the total area needed is 1750 meter square ,the shading effect is very limited with the sun path, only at the early morning when the sunrise, or sunset.

Figure 6.56 shows the total energy produce is 155 MWH/year, and the monthly power produce and it is losses, as normal the maximum power produced are be in July (20.19 MWH) and June (19.46 MWH) due to long sunny hours and higher sun irradiation but with the highest loses, also the minimum power produce are in January (5.9 MWH) and December (5.91MWH), the output power is reduced by almost a quarter from July to January.

Figure 6.57 shows the daily power injected into the grid and the system output distribution.

Figure 6.58 shows the system supply 188.3 MWH yearly but due to the losses of the solar panels it is drops into 168.9 MWH, also due the losses of the inverter it drops into 155 MWH.

Figure 6.54: Simulation parameters

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Grid-Connected System: Simulation parameters

Project : 100 KW solar panels

Geographical Site	**Orhanlı**		Country	**Turkey**
Situation	Latitude	40.87° N	Longitude	29.34° E
Time defined as	Legal Time	Time zone UT+3	Altitude	99 m
	Albedo	0.20		
Meteo data:	**Orhanlı**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : thesis

Simulation date 11/05/20 23h52

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	30°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	8	Identical arrays	
	Tracker Spacing	18.0 m	Collector width	14.9 m
			Ground cov. Ratio (GCR)	82.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	Si-mono	Model	**SPR-X21-470-COM**		
Custom parameters definition		Manufacturer	sunpower		
Number of PV modules		In series	4 modules	In parallel	56 strings
Total number of PV modules		Nb. modules	224	Unit Nom. Power	470 Wp
Array global power		Nominal (STC)	**105 kWp**	At operating cond.	97.0 kWp (50°C)
Array operating characteristics (50°C)		U mpp	285 V	I mpp	340 A
Total area		Module area	**484 m²**		
Inverter		Model	**GTP-507 three**		
Original PVsyst database		Manufacturer	Leonics		
Characteristics		Operating Voltage	270-550 V	Unit Nom. Power	120 kWac
Inverter pack		Nb. of inverters	1 units	Total Power	120 kWac
				Pnom ratio	0.88

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	14 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-1.3 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Figure 6.55: Near shading definition

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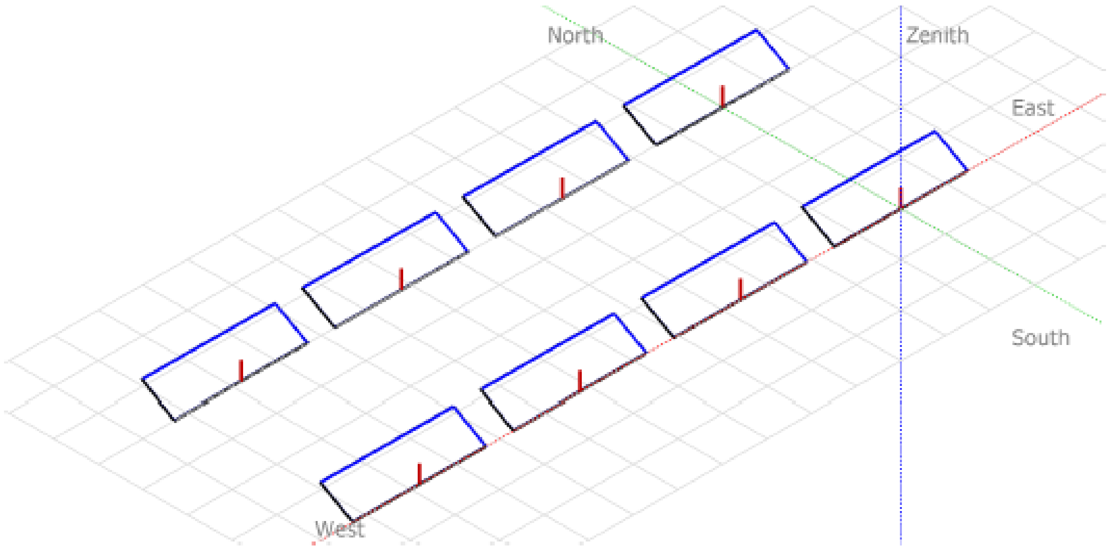
Grid-Connected System: Near shading definition

Project : 100 KW solar panels

Simulation variant : thesis

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	30°
PV modules	Model	SPR-X21-470-COM	Pnom	470 Wp
PV Array	Nb. of modules	224	Pnom total	**105 kWp**
Inverter	Model	GTP-507 three	Pnom	120 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

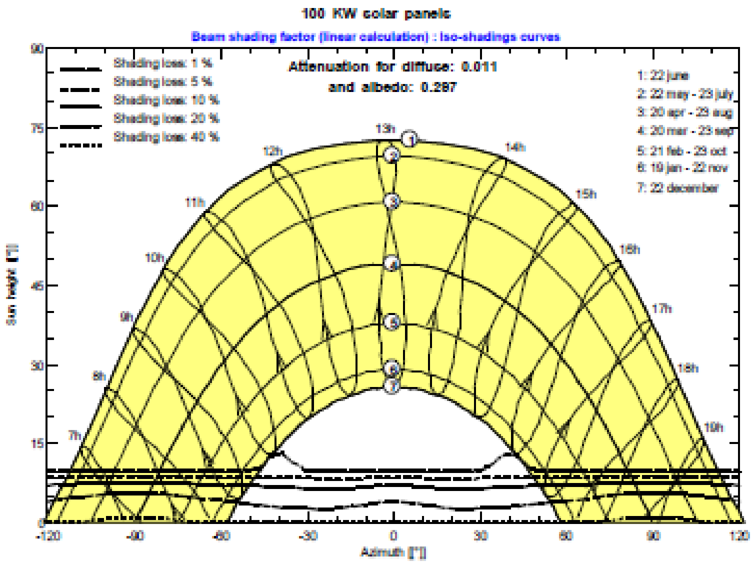


Figure 6.56: Main results

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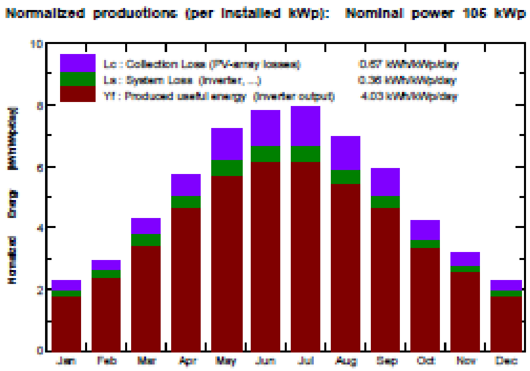
Grid-Connected System: Main results

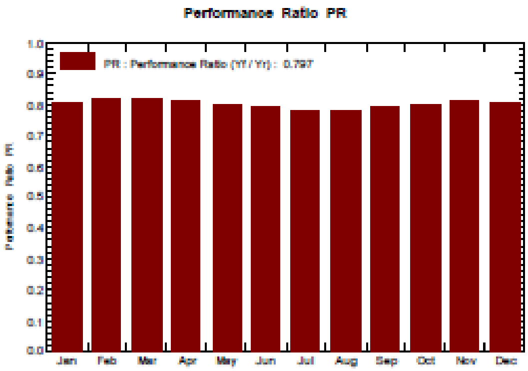
Project : 100 KW solar panels

Simulation variant : thesis

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	30°
PV modules	Model	SPR-X21-470-COM	Pnom	470 Wp
PV Array	Nb. of modules	224	Pnom total	**105 kWp**
Inverter	Model	GTP-507 three	Pnom	120 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**155.0 MWh/year**	Specific prod.	1472 kWh/kWp/year
	Performance Ratio PR	79.65 %		





thesis

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	46.2	30.28	6.23	69.6	67.1	6.55	5.90	0.805
February	58.5	34.83	6.49	82.9	80.3	7.85	7.12	0.816
March	98.1	53.61	9.33	132.5	128.6	12.43	11.36	0.815
April	133.8	74.11	12.70	171.9	166.9	16.00	14.71	0.812
May	174.1	87.53	18.18	222.5	215.8	20.34	18.74	0.800
June	185.9	85.97	22.67	234.1	227.8	21.11	19.46	0.790
July	192.3	84.36	25.77	245.6	239.1	21.89	20.19	0.781
August	167.7	79.94	25.64	215.5	209.7	19.20	17.70	0.780
September	127.7	58.64	21.06	177.5	172.5	16.06	14.77	0.791
October	87.8	44.60	16.98	130.4	126.6	11.96	10.96	0.799
November	58.3	29.81	11.83	95.8	92.9	8.93	8.15	0.808
December	44.0	28.17	8.13	69.8	67.3	6.53	5.91	0.804
Year	1374.6	691.86	15.47	1848.1	1794.6	168.85	154.98	0.797

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Figure 6.57: Special graphs

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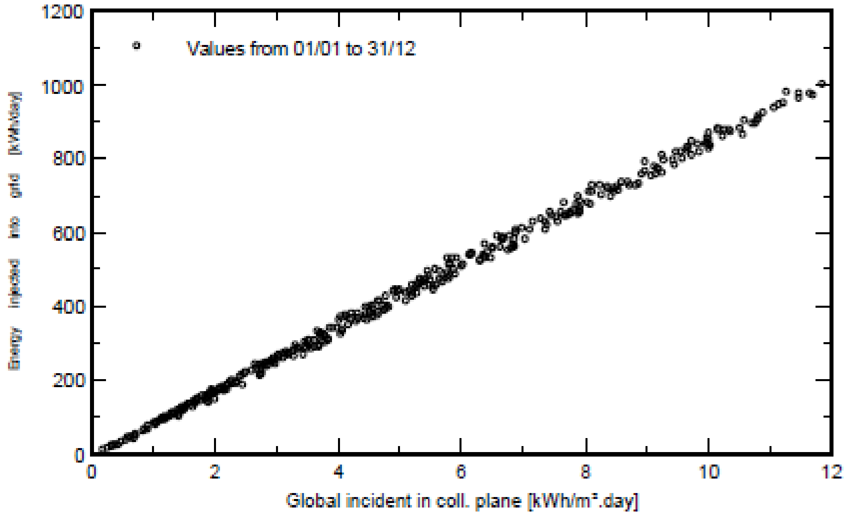
Grid-Connected System: Special graphs

Project : 100 KW solar panels

Simulation variant : thesis

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	30°
PV modules	Model	SPR-X21-470-COM	Pnom	470 Wp
PV Array	Nb. of modules	224	Pnom total	**105 kWp**
Inverter	Model	GTP-507 three	Pnom	120 kW ac
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution

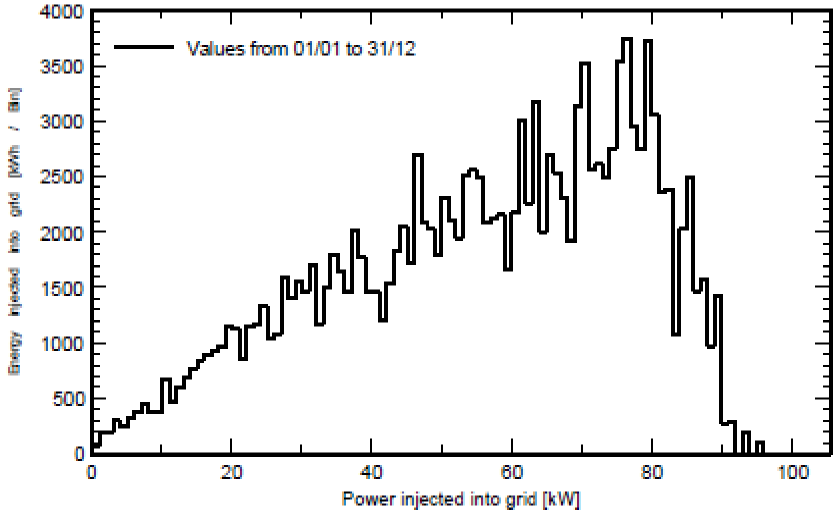


Figure 6.58: Loss diagram

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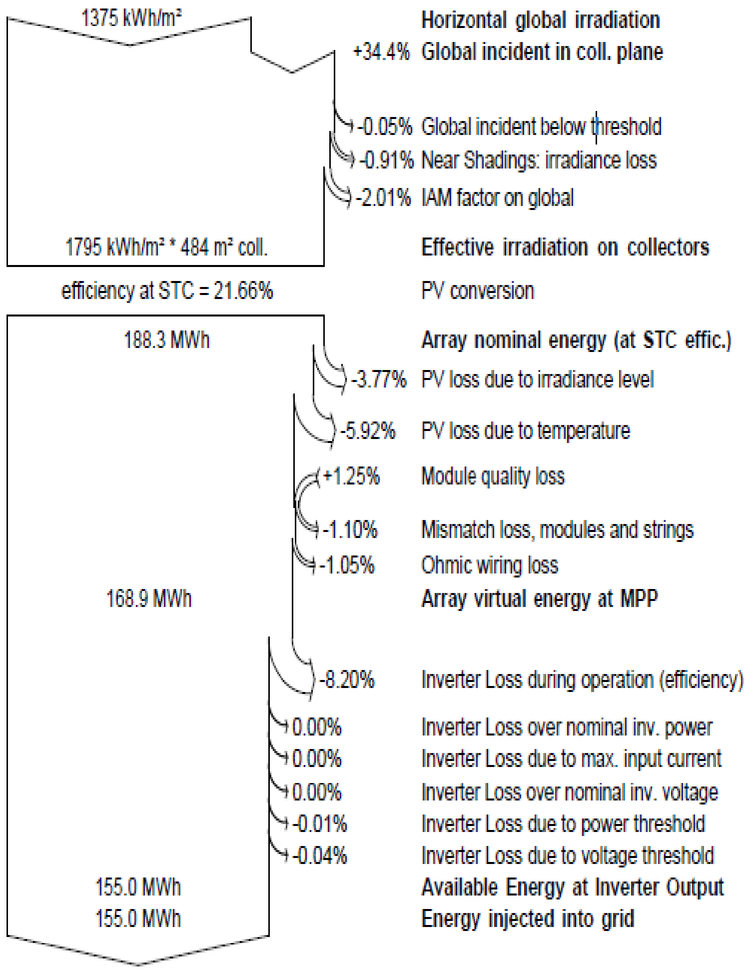
Grid-Connected System: Loss diagram

Project : **100 KW solar panels**

Simulation variant : **thesis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	30°
PV modules	Model	SPR-X21-470-COM	Pnom	470 Wp
PV Array	Nb. of modules	224	Pnom total	**105 kWp**
Inverter	Model	GTP-507 three	Pnom	120 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

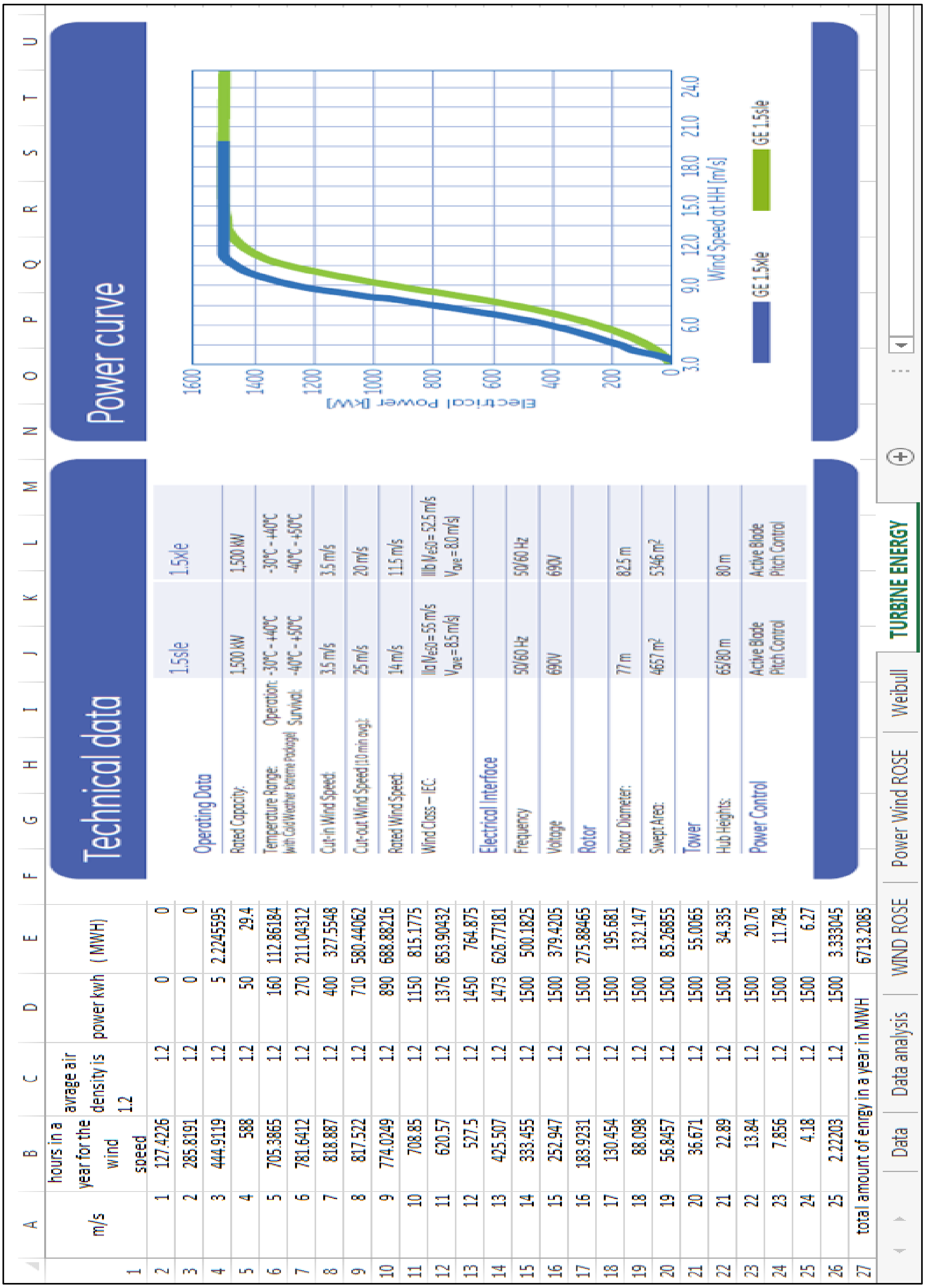


6.6 WIND TURBINE CASE STUDY

The power from each wind seed band is being calculated the add all of them to estimate the power is being produced from this wind turbine as shown in Figure 6.59-.

This turbine will generate around 6,713 MWH in a year

Figure 6.59: Wind turbine output power



m/s	hours in a year for the wind speed	avrage air density is 1.2	power kwh	(MWH)
1	127.4226	1.2	0	0
2	285.8191	1.2	0	0
3	444.9119	1.2	5	2.2245595
4	588	1.2	50	29.4
5	705.3865	1.2	160	112.86184
6	781.6412	1.2	270	211.04312
7	818.887	1.2	400	327.5548
8	817.522	1.2	710	580.44062
9	774.0249	1.2	890	688.88216
10	708.85	1.2	1150	815.1775
11	620.57	1.2	1376	853.90432
12	527.5	1.2	1450	764.875
13	425.507	1.2	1473	626.77181
14	333.455	1.2	1500	500.1825
15	252.947	1.2	1500	379.4205
16	183.9231	1.2	1500	275.88465
17	130.454	1.2	1500	195.681
18	88.098	1.2	1500	132.147
19	56.8457	1.2	1500	85.26855
20	36.671	1.2	1500	55.0065
21	22.89	1.2	1500	34.335
22	13.84	1.2	1500	20.76
23	7.856	1.2	1500	11.784
24	4.18	1.2	1500	6.27
25	2.22203	1.2	1500	3.333045
total amount of enrgy in a year in MWH				6713.2085

Technical data

	1.5sle	1.5xle
Operating Data		
Rated Capacity:	1,500 kW	1,500 kW
Temperature Range: (with Cold Weather Extreme Package) Operation:	-30°C - +40°C	-30°C - +40°C
Survival:	-40°C - +50°C	-40°C - +50°C
Cut-in Wind Speed:	3.5 m/s	3.5 m/s
Cut-out Wind Speed (10 min avg):	25 m/s	20 m/s
Rated Wind Speed:	14 m/s	11.5 m/s
Wind Class – IEC:	IIa (V_{e50} = 55 m/s V_{ave} = 8.5 m/s)	IIIb (V_{e50} = 52.5 m/s V_{ave} = 8.0 m/s)
Electrical Interface		
Frequency	50/60 Hz	50/60 Hz
Voltage	690V	690V
Rotor		
Rotor Diameter:	77 m	82.5 m
Swept Area:	4657 m²	5346 m²
Tower		
Hub Heights:	65/80 m	80 m
Power Control	Active Blade Pitch Control	Active Blade Pitch Control

7. CONCLUSIONS

In this thesis, the integration of renewable energy sources and storage in smart grid is examined with 105.3 kW photovoltaic energy generation, 1550 kW wind energy generation, and 196 kW battery energy storage. Photovoltaic energy system consists of boost converter to extract the maximum power from panels and bi-directional converter to supply the battery banks. Wind energy system has double feed induction generator to convert the mechanical energy to the electrical energy. 196 kW Tesla lithium batteries are used as energy storage system. Entire sources are connected via 120 kW three level inverter to be able to obtain parallel operation with grid. The system is going to react with 1.625 MVA load divided into 5 loads (load 1 : 200 kW 20 kVAr-, load 2 : 500 kW 40 kVAr-, load 3 : 800 kW 60 kVAr-, load 4 : 20 kW 0 kVAr-, load 4 : 100 kW 9 kVAr-.)

Initially, all the consumers consume the power from the grid. When the inverter works at its maximum power of 120 kW and the double feed induction generator of wind turbine works at its maximum power of 1.55 MW, all the consumers are supplied with renewable energy, also extra 50 kW of power is pumped into the grid utility.

As been shown in the results and discussion chapter, the system is stable and works perfectly well in many different scenarios and changeable variables at the same time, as the sun irradiation and shading effect, photovoltaic temperature, inverter output reference power sharply changing and wind speed for the wind turbine, it is a good and reliable methodology for the integration between the renewables, energy storage, the consumers and the grid. The total voltage harmonics distortion is equal or less than 3% for all the different scenarios and the alternating voltage frequency is 50 Hz all the time with a variance of 0.03 Hz, which is good for the stability of the grid, even more this system work as a two way power flow with the grid utility.

The first scenario: Only the photovoltaic panels and wind turbine works as sources for the system where the battery controller is turned off, the changeable variables are the sun irradiation, shading effect, photovoltaic temperature and wind speed for the wind turbine. At that case, the boost converter followed the maximum power point tracking for the output power from the photovoltaic panels, the synchronization for the inverter work and the automatic three phase breaker close, the total harmonics distortion of the voltage waveform less than 1.13% voltage, and for the wind turbine output power increase proportional with the wind speed, the total harmonics distortion of the voltage waveform 2.36% voltage. For the power flow at the beginning all the consumers consume power from the grid but when the sources work at their maximum power all the consumers consume power from the renewable sources and the extra power will be pumped into the grid and the frequency is stable at 50 Hz.

The second scenario: the photovoltaic panels, wind turbine, battery banks work as sources for the system and the battery controller output power reference sets to 120 kW, the changeable variables are the sun irradiation, shading effect, photovoltaic temperature and wind speed for the wind turbine. At that case, the boost converter followed the maximum power point tracking for the output power from the photovoltaic panels, the synchronization for the inverter work and the automatic three phase breaker close, but the output power not stable at 120 kW due to its limited discharge current at 150 A, and for the wind turbine output power increase proportional with the wind speed. For the power flow at the beginning all the consumers consume power from the grid but when the sources work at their maximum power all the consumers consume power from the renewable sources and the extra power will be pumped into the grid and the frequency is stable at 50 Hz.

The third scenario: the photovoltaic panels, wind turbine, battery banks work as sources for the system and the battery controller output power reference is changing, the changeable variables are the sun irradiation, shading effect, photovoltaic temperature, the power reference and wind speed for the wind turbine. At that case, the boost converter followed the maximum power point tracking for the output power from the photovoltaic panels, the synchronization for the inverter work and the automatic three phase breaker close, the output power followed the power reference as the charging mode and the discharging mode of battery banks within it limited current, the total harmonics distortion of the voltage waveform between the decreasing output power and increasing output power is 1.0% voltage and for the wind turbine output power increase proportional with the wind speed. For the power flow at the beginning all the consumers consume power from the grid but when the sources work at their maximum power all the consumers consume power from the renewable sources and the extra power will be pumped into the grid and the frequency is stable at 50 Hz.

The fourth scenario: wind turbine and battery banks work as sources for the system and the battery controller output power reference is changing, the changeable variables are sudden changes in power reference and wind speed for the wind turbine. At that case, the synchronization for the inverter work and the automatic three phase breaker close, the output power followed the power reference when it within its limited discharge mode at 150 A, but there is an initial peak current battery banks can be damaged also a huge amount of power pump into the grid then drops down, the total harmonic distortion of voltage is equal to 3% which is not causing any harm for the grid stability and for the wind turbine output power increase proportional with the wind speed, however the grid frequency is stable at 50 Hz.

In the presented case study, the photovoltaic system will supply 155 MWH and Wind system will supply 6,713 MWH, so the total amount of electricity is going to be produced is 6,868 MWH.

If this amount of power is going to be produced from the thermal power plant as shown in table 3.1, the extra amount of carbon dioxide in this planet is going to be 2,574 Ton for the natural gas thermal power plant or 7,119 Ton for the coal (IEA, 2010) thermal power plant, by installing this system a huge amount of carbon dioxide can be prevented yearly to save this planet for the next generation and limit global warming and climate change.

In the economic point of view, the investment in the renewable energy produce profits for more than 25 years, at the first five or seven years it will pay itself back then the rest of 25 years it will be a conformed profit, the profit is going to larger than the normal photovoltaic panels farm due to the energy storage mechanism to save the energy then used later on the peak demands hours when the electricity market price is high.

Even more, the integration of renewable energy sources and battery energy storage system have opportunity for many new jobs such as, designing the project, manufacturing, the field workers, and the maintenance workers.

Briefly, the integration of renewable energy sources in the grid infrastructure is beneficial in terms of economic, environmental, and social.

This system needs some improvement for the battery controller methodology when the inverter starts working with the battery banks only because of initial peak current battery banks can be damaged also it is not good for the grid when a huge amount of power pump into the grid then drops down. However, the total harmonic distortion of voltage is equal to 3% which is not causing any harm for the grid stability, this can be avoided but not letting the inverter turn off completely by make the batteries bank works on a low amount of power before the sunset while the photovoltaic panels produce a low amount of power.

This research is similar to (Aquib Jahangir, Autonomous Battery Storage Energy System Control of PV-Wind Based DC Microgrid) research but additionally three phase three level inverter is used and DC power coming from the wind. As further study, it is good to mix this presented research with Aquib Jahangir research by adding a microgrid with a DC power source coming from the double feed induction generator wind turbine and increase the photovoltaic panels power and energy storage capacity.

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