Abstract:

Today's electrical grid was designed in order to meet less total demand, it used to carry power from a few central generators to a large number of users or customers. It supports the operations of electricity generation, transmission, distribution, and control.

But smart grid is a modernized grid that enables bidirectional flow of power and data using two-way communication and control capabilities which leads to a new functionalities and applications. Moreover, it has the ability to connect distribution generators including renewable energy to form a small-scale grid which is called microgrid. Microgrids work even with the main grid in "Grid connected mode", or independent from it in "Island mode".

This project clarifies the concepts of smart grid and its main component microgrid by some experiments have been done practically and modeled by SIMULINK, MATLAB Ra2015, also smart meters are included with their working principals, an explanation of the used software that controls them, and small case study for smart meters to prove their abilities.

The main case study of this project is Beit Sahour village, a power flow and losses analysis were studied by ETAP 16 in order to compare the results with the reality to verify the installed smart meters capabilities, and a small model of SCADA monitoring system was modeled by MATLAB with its own power flow.

In the last section of this project, distribution generators have been discussed with their effects on the connected grid, and a brief study for their types.

الملخص:

صُممت الشبكة الحالية لتزوّد طلب أقل حيث يتم توليد الطاقة من محطات توليد مركزية وتُنقل إلى عدد كبير من المستهلكين وتكون الشبكة الحالية التقليدية مزودة بعملية التوليد، النقل، التوزيع، والتحكم.

ولكن الشبكة الذكية شبكة متقدمة تدعم نقل الطاقة والمعلومات في إتجاهين عن طريق ثنائية الاتصال وقدرات التحكم والتي تقود إلى استخدامات وتطبيقات جديدة.

علاوة على ذلك، الشبكة الذكية لها القدرة على ربط مولدات الطاقة الموزعة من ضمنها (الطاقة المتجددة) لتشكيل شبكة كهربائية مصغرة تسمى المايكروغرد، وتكون لها القدرة على العمل مع الشبكة الأصلية لتكوّن الشبكة المتصلة، أو منفصلة عنها لتكون شبكة قائمة بحد ذاتها.

هذا المشروع يوضح مفاهيم الشبكة الذكية وجزئيتها المايكروغرد من خلال تنفيذ العديد من التجارب العملية ومحاكاتها باستخدام برنامج SIMULINK, MATLAB Ra2015، و يتضمن مبدأ عمل العدادات الذكية و البرنامج التطبيقي المستخدم للتحكم بها عن بعد و يشمل دراسة صغيرة باستخدام كل من العدادات الذكية وبرنامج التحكم وذلك لإثبات قدرات العدادات الذكية وخصائصها.

الدراسة الرئيسية في هذا المشروع تتركز في منطقة بيت ساحور، حيث تم استخدام برنامج ETAP 16 لعمل دراسة على تدفق الطاقة والخسائر المترتبة على خطوط النقل وذلك لمقارنة النتائج العملية بالنظرية و التحقق من قدرات العدادات الذكية في تقليل الخسائر، أيضا محاكاة بسيطة لـ SCADA System منمذجبة باستخدام MATLAB.

في الجزء الأخير من المشروع، تمت مناقشة مولدات الطاقة الموزعة وتأثيرها، فوائد تواجدها على الشبكة ،كما أن هناك دراسة موجزة لأنواعها المختلفة.

الإهــــداء

"كَ فضلِ القمرِ عـلى سائِرِ الكواكبْ"

Dedicated

to

Our Mothers & Fathers

Our Doctors & Teachers

Our Sisters & Brothers

Our Friends

Acknowledgement

First and foremost, thank God

And Our Gratitude To:

Palestine Polytechnic University

Our College: Electrical Engineering Department

Our Supervisor: Dr. Fouad Zaro

JDECo.

Also For:

Eng. Elias Maharmeh

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Abbreviations

DG: Distribution Generators.

PV: Photovoltaic.

JDECo.: Jerusalem District Electricity Company.

IEC: International Electrotechnical Commission.

LV: Low Voltage.

PCC: Point of Common Coupling.

ESS: Energy Storage System.

PE: Power Electronics.

MPPT: Maximum Power Point Tracking.

SCADA: Supervisory Control and Data Acquisition.

EMS: Energy Management System.

AMR: Automatic Meter Reading.

AMI: Advanced Metering Infrastructure.

GPRS: General Packet Radio Service.

PLC: Power Line Carrier.

PMU: Phasor measurement units.

PS: Protection Scheme.

CIM: Common Information Model.

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1.1 Overview:

The main points of project “Smart grid for a new city” will be explained in this chapter, including of the main idea, brief introduction, project motivation, intended objectives, and the time table which defines the required time for each step.

1.2 Introduction:

Due to topology of the traditional grid assets and its weakness in response to failures, same as the slow response to cyber-attack and natural disasters, slow response to power quality issues, and the inability to do self-healing, all of these indicate that the traditional grid is no longer enough to face challenges.

Furthermore, the increasing of demand, technological developments, public awareness about carbon emissions, inability of customer’s participation in marketing and power balancing, all of these issues encourage to reform the traditional grid and get a new one which is called “smart grid”.

Smart grid which is our interest in this project can deal with all the mentioned problems, it uses two-way flow of power and data to create an automated advanced or intelligent energy network. It also integrates with distribution generators including several renewable energy resources with power electronics in order to improve power quality and reliability, also to reduce the public awareness about carbon emissions that generated by the traditional ways of electricity generation. The integration of distribution generators at smart grid distribution system called microgrid.

Microgrids can be viewed as a group of distribution generators, loads, and other parts of a distribution system that can be connected to utility to be grid connected mode, or work as standalone to be island mode.

1.3 Motivation:

Depends on some problems in the legacy electrical system, increasing of the demand at the costumer's side, rapid technological change, generators failures and blackouts, few customer choices, different types of end users, all of these challenges constituted a motive to replace today's grid with the intelligent grid.

1.4 Importance:

Smart grid is needed as a new electrical system in order to improve grid reliability, while dealing with the legacy electrical system with an aging infrastructure, the need for environment preserving, energy conservation, improve operational efficiencies and customer services, and economical benefits for producer/costumer by two-way digital communication of data and power

1.5 Objectives:

1) Practical investigation would be carried out in smart grid lab and JDECo.[1] company lab.

2) Design a module for each experiment using MATLAB SIMULINK.

3) Take a look on smart meters that are used in smart grids and their control software.

4) Design a grid with its components to be a case study on smart meters and analyze results.

5) A brief study on distribution generators, their types, and their effect on smart grid.

[1] Jerusalem District Electricity Company.

1.6 Project diagram:

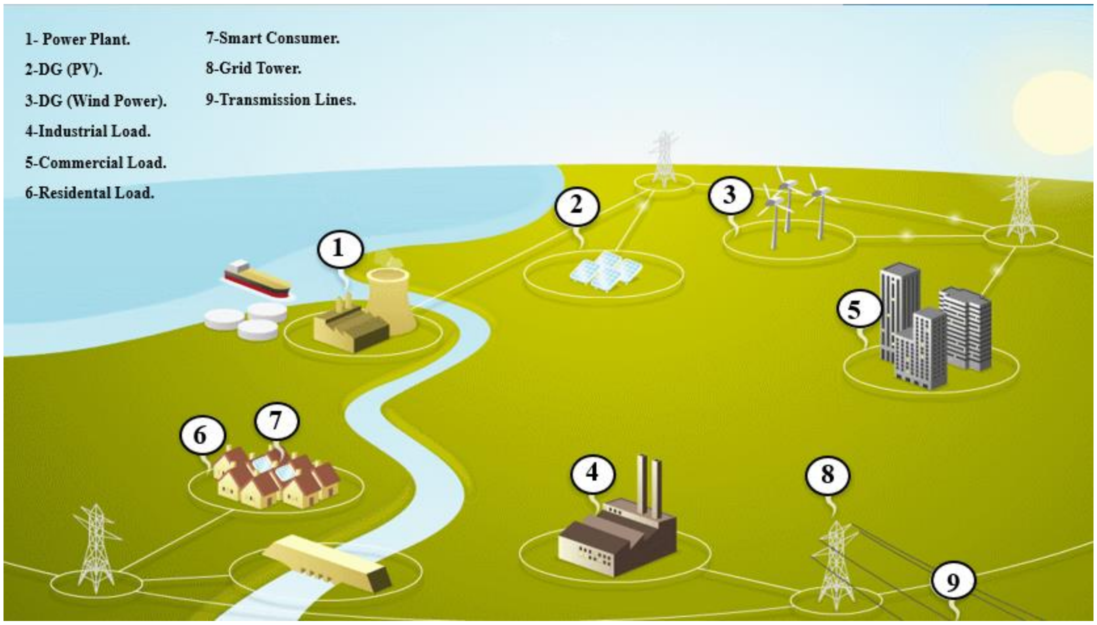

Figure1. 1: Smart grid diagram.

1.7 Time table:

Table1. 1: Time table for the introduction.

(weeks) (task)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choosing the subject																
Selecting references and standards																
literary survey &Selecting software																
Laboratory																
Final report																

Table1.2: Time table for the project.

(weeks) (task)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Review topics and software														
Investigations														
Case study and design														
Study DG locations														
Final report														

1.8 Methodology:

This project will be implemented using ETAP 16, MATLAB SIMULINK, and Meter Data Management Software in conjunction with practical investigations carried out in smart grid lab and JDECo. company lab under supervision to make some different scenarios and experiments.

In chapter 4, which talks about the project implementation, the better standard of smart grid is chosen, and a simulation for the project to get an idea about how things are going in smart grid system.

2

Chapter Two: Smart Grid and Microgrid.

2.1 Overview

2.2 Smart grid

2.3 Integration of distribution generators (DG) with smart grid

2.4 Microgrid

2.5 Power electronics in smart grid

2.6 Smart grid, microgrid connection challenges

2.1 Overview:

This chapter contains a definition of smart grid, microgrid, an outline of benefits, diagrams, and challenges, the difference between smart grid and microgrid was also explained.

2.2 Smart grid:

2.2.1 What is smart grid?

Smart grid is the new grid which will replace the old electrical grid with its old infrastructure, beside that it gives monitoring, analysis, control and communication capabilities to the national power generation and distribution system, and it supports real - time measurement techniques. Furthermore, smart grid is more resistant to failure, more secure, more efficient and delivers power across the system at a lower cost to producers and consumers. However, it is a modernized grid that enables bidirectional flow of energy and data.

2.2.2 Smart grid abilities:

1) Allow using of renewables plug - and – play [2].
2) Optimize quality, efficiency, and reliable supply, by:
   a. Better balancing of supply and demand.
   b. The use of smart meters.
   c. Demand side management

[2] plug and-play in a power system implies that a unit can be placed at any point on the electrical system without reengineering the controls.

3) Provide self - correction, Self-monitoring, and restoration.
   a. Better monitoring achieved by using sensor networks and communications.
4) Many customer choices.

2.2.3 Smart Costumer:

The smart consumers are members of end users in the future smart grid and take an active role in the problem of balancing demand with supply, they are mostly interested in decreasing the electricity bill.
With the consumers providing an active participation in the management of the demand, utilizing the intelligent information and communication technology devices (ICT) has become widespread in domestic environments.

It is easy to envision that in the near future smart homes will be equipped with energy management systems in order to optimize the electricity consumption, to minimize costs and meet supply constraints, while at the same time keeping the desired level of comfort for the users. **[1]**

2.2.4 A brief comparison between today's grid and smart grid:

1) Traditional power grid: **[2]**

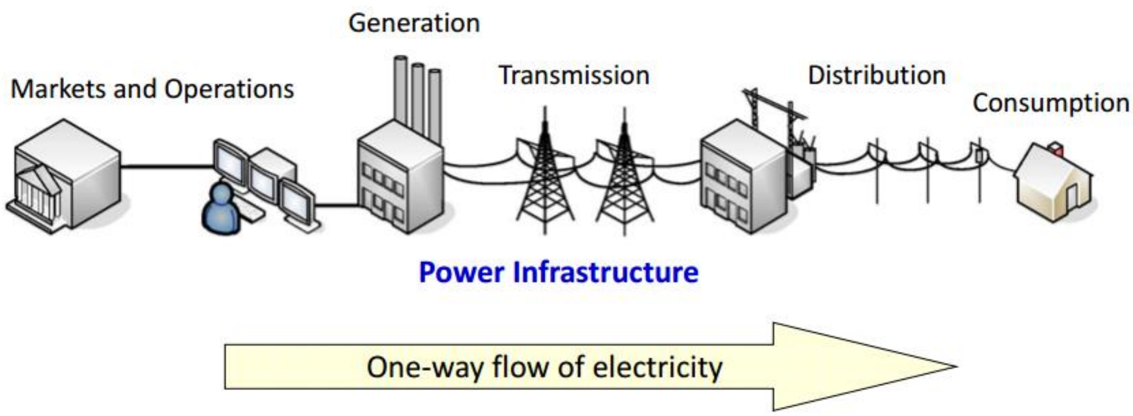

Figure2. 1: Traditional power grid

2) Smart grid: [2]

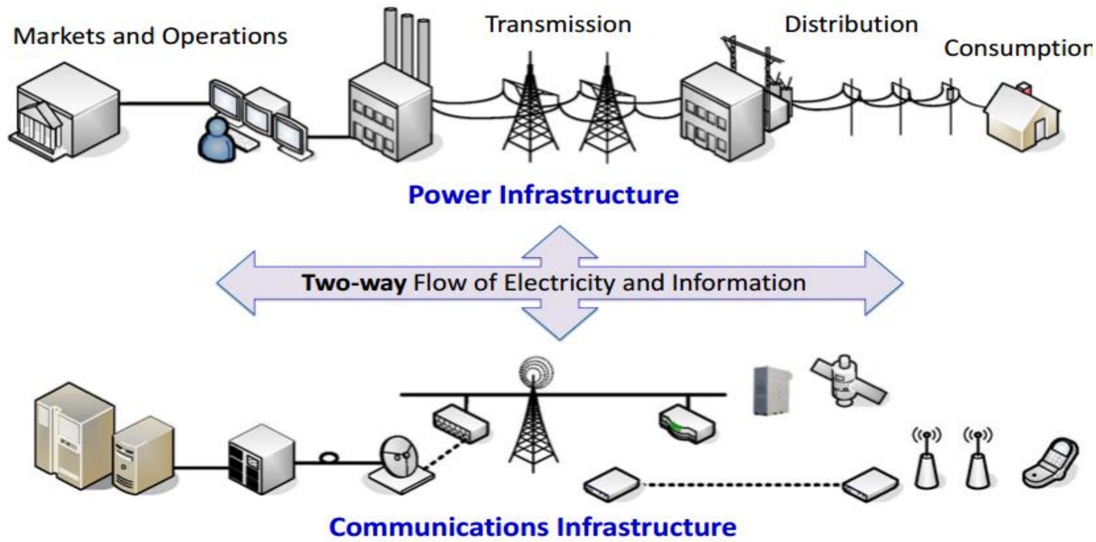

Figure2. 2: Smart grid concept.

The table below shows the differences between today's grid and the smart grid, and consequently it explains the mentioned figures (2.1,2.2).

Table2. 1: A comparison between today's grid and smart grid.

	Today's grid	**Smart grid**
Participation	Customer do not participate	Can be buyer or seller by renewable green
Power Quality	Slow response to power quality issues, focus on outages	Power quality is a priority
(self- healing)	Prevent damage, focus on protecting	Automatically detects and responds to problems.
Resiliency against cyber attack and natural disasters	slow response	Resilient, rapid restoration capabilities

2.2.5 Benefits of smart grid:

There are two main reasons to create smart grid. First, today's grid needs to be upgraded because it is aging, secondly, the benefits of the smart grid are substantial. **[3]**

These benefits result from improvements of:

1) Power reliability and power quality: smart grid provides a reliable power supply with fewer and briefer outages, "cleaner" power, and self- healing power systems, through the use of digital information, and automated control.
2) Safety and cyber security benefits: smart grid continuously monitors itself to detect unsafe or insecure situations that could detract from its high reliability and safe operation. Higher cyber security is built in to all systems and operations including physical plant monitoring, cyber security, and privacy protection of all users and customers.
3) Environmental: smart grid facilitates an improved environment. It helps reduce greenhouse gases, and other pollutants by reducing generation from inefficient energy sources, supports renewable energy sources, and enables the replacement of gasoline-powered vehicles with plug-in electric vehicles.
4) Energy efficiency: smart grid is more efficient, providing reduced total energy use, reduced peak demand, and reduced energy losses.
5) Economics: by keeping downward prices on electricity prices and reducing the amount paid by consumers.

Stakeholder Benefits:

1) Consumers: consumers can balance their energy consumption with the real-time supply of energy and variable pricing.
2) Utilities: utilities can provide more reliable energy, particularly during challenging emergency conditions, while managing their costs more effectively through efficiency and information.
3) Society: society benefits from more reliable power for governmental services, businesses, and consumers sensitive to power outage also renewable energy,

increased efficiencies, and plug in vehicles support will reduce environmental costs, including carbon footprint.

2.2.6 Standards of smart grid:

1) IEC: International Electrotechnical Commission (IEC 61850, 61968/61970).
2) NIST: National Institute of Standards and Technology (NIST Special Publication 1108r3).
3) IEEE: Institute of Electrical and Electronics Engineers (IEEE P2030).
4) ESOs: European Standards Organizations.

2.3 Integration of distribution generators (DG) with smart grid:

DG is power generation built near consumers. It sources include small-scale, environmentally-friendly technologies such as solar energy, wind energy, and biomass installed on to serve a single end user's site. But when reliability and power quality issues are critical, DG most often includes more traditional fossil fuel or gas turbines. **[1]**

DGs connected to utility when the conditions of having:

1) The same frequency rotation with the grid.
2) The same output voltage.
3) The same phase angle with grid.

2.4 Microgrid:

2.4.1 What is microgrid?

The microgrids can be defined as low voltage (LV) network, small, local distribution systems including a cluster of loads with a set of micro sources such as microturbines, fuel cells, photovoltaic (PV) arrays and wind turbines, storage systems, such as batteries. It can be connected to the main grid by Point of Common Coupling (PCC).

The highest priority for microgrids is to keep a reliable power supply to customers, it provides economic benefits, obtains accurate load sharing while ensuring stability, and good regulation of the voltage and frequency. In disasters, current distribution systems can face challenges to provide the required energy supply, by using microgrid in parallel with the grid, the distribution system can recover faster.

Microgrids have the ability to be switched in and out of the system, they can also operate independently from the system for a period of time. Therefore, microgrids can be either in grid-connected mode or islanding mode. Because of their ability to operate in islanding mode, main use of microgrid can be providing power in an emergency to the residential community.

The components of basic microgrid are distributed generator (DG, 10-15 MW), energy storage system (ESS), local loads, power electronic (PE) converters, common coupling point and, intelligent breaker for making microgrid work in grid or standalone modes.

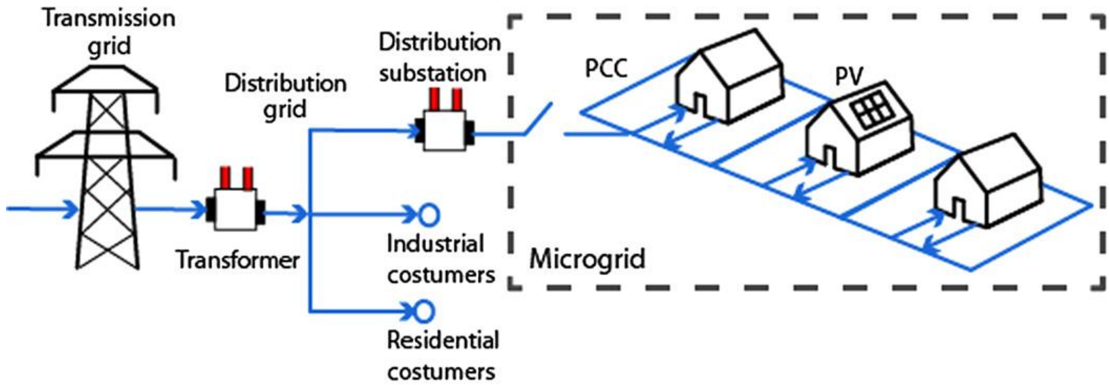

Figure2. 3: Microgrid components

2.4.2 Difference between smart grid and microgrid:

Microgrid plays a key role in the smart grid concept and can operate independently from the larger grid, so it is a piece of the larger grid, which involves nearly all of components of the grid, but these components are smaller sizes.

While smart grid take place at larger utility level such as large transmission and distribution lines.

2.4.3 Reasons and benefits for connecting microgrid to the main grid:

2.4.3.1 **Reasons:**

1) Operations/stability: direct connection of microgrids to a large power grid facilitates stable operation, but only if the power grid acts as a "stiff" [3] source to the microgrid **[4].**
2) Economics: microgrids are typically planned with extra capacity with respect to the local load. This extra power capacity can be injected back into the grid in order to obtain some economic benefit. Furthermore, grid interconnection allows to reduce fuel operational costs by using the grid at night when electricity costs are low.
3) Microgrid could be an additional source acts with the large power grid.

2.4.3.1 **Benefits:**

1) DGs can integrate eco-friendly renewable energy resources.

2) Size and clean energy technology, DGs can be installed in close proximity to end-use consumers.

3) The installation and maintenance costs for generation and transmission facilities can be reduced.

4) Energy losses in transmission and distribution can be reduced and thus the voltage profile in distribution networks can be improved.

5) Improvement of power quality, stability of the power grids and reliability.

[3] A stiff voltage source is defined as one whose internal resistance is less than 1/100 of the load resistance, for the current, internal resistance is more than 100 times the load resistance.

2.4.4 Types of microgrid:

Microgrids can be classified into 3 groups, the classification depends on the way in which the AC and DC buses are connected.

1) AC microgrids: are easily integrated to conventional AC grid because most of loads and grid itself are AC.
   AC microgrids have a common AC bus which is generally connected mixed loads (DC and AC loads), distributed generations, energy storage devices.
   DC sources and energy storage devices are connected to the AC bus via DC/AC inverter, it causes a significantly decrease in efficiency due to the use of power electronics.

2) DC microgrids: the operation principle of DC microgrid is similar to AC microgrid. Compared with AC microgrid, DC microgrid is a good solution to reduce the power conversion losses. It has higher system efficiency, lower cost and system size.

3) Hybrid AC/DC microgrids: is a combination of AC and DC microgrids in same distribution grid, facilitating the direct integration of both AC and DC.

2.4.5 Operation modes of microgrid:

2.4.5.1 Grid mode:

Connected to utility grid, in grid-connected mode, the microgrid operator can take economic decisions, such as to sell or buy energy depending on generation capability, its cost, and the current prices on the energy market.

2.4.5.2 Island mode:

Around the world, a significant number of villages have no access to electricity due to their remoteness. Fortunately, in many of these places, such as in oceanic islands, there are renewable energy sources, especially solar radiation and wind. These energy resources can be used to form isolated microgrids to meet local energy needs.

Island microgrid means that the microgrid continues to operate independently when disconnected from the grid, it is easily islanded by opening the circuit breaker at PCC, in this mode high proportion of renewable based generation, where the major technical challenges are found.

Main challenges of islanded:

1) The power converter control of electrical storage systems.

2) Decentralized control design.

3) Improvement of power quality in grids disturbed by renewable generation.

Energy Storage System:

Standalone operation required some kind of energy storage system (ESS), in practical applications battery banks have been used mainly due to economic reasons. In general, a backup energy source must be used during the lack of the primary renewable energy sources or when the generation system is under maintenance.

Energy storage devices can be classified into three categories as **electrochemical systems** (batteries and flow batteries), **kinetic energy storage systems** (flywheel) and **potential energy storage** (pumped hydro and compresses air storage). **[1]**

1) Batteries: it is the most used energy storage devices; the life cycle and the capacity of the battery depends on its type.

2) Flywheel: it has long life cycle and high-power capacity, 70 -80% efficiency, even though it has a high cost.
3) Pumped hydro and compresses air storage: Compressed Air Energy Storage (CAES), it has capable of providing very large energy storage (above 100 MW with single unit).

2.4.5.3 Sliding mode:

Renewable energy systems are usually equipped with batteries for power balancing, renewable energy systems that are interfaced with the help of batteries to a distribution network have two major disadvantages **[5]**:

1) it makes the entire system costly
2) they also require continuous maintenance/replacement of batteries as they have short-life as compared to other system components.

A control strategy for power balancing for grid connected PV systems is proposed to eliminate the use of batteries or any other expensive energy storage devices. A sliding mode controller is used to control power generated from PV array in a grid connected PV system. The main advantage of the proposed methodology is that back-up energy storage devices are not required for maintaining power balance and constant DC line voltage.

The main objective of power balancing is achieved through buck converter. The buck converter operates in two operating regimes:

1) When PV system output power is sufficient (limited power point): for a given insolation level, if the power requirement is lower than the PV capacity then the system operates under limited power point tracking (MPPT).

2) When PV system output power is insufficient to supply the load demand and the solar PV system is at maximum power point (MPPT).

This control provides reserve capacity to PV system and can be used in situations where there are constraints over the power supplied by the grid.

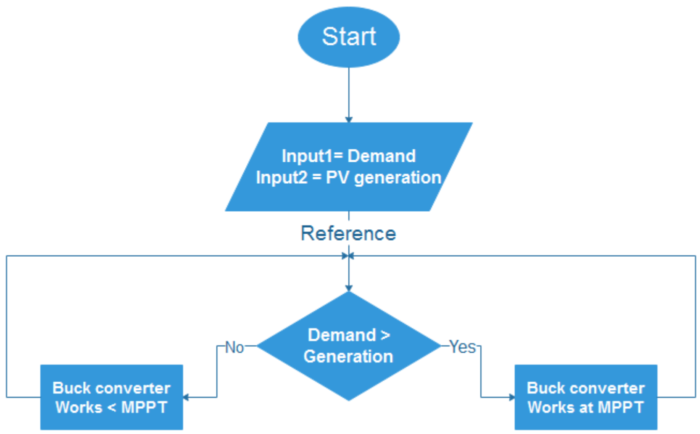

Figure2. 4: Sliding mode algorithm

2.5 Power electronics in smart grid:

Power electronics(PEs) plays as important component of energy control applications for several years, recently it has been assisted with monitoring, communication, real time simulation, charging/discharging control, and demand/supply.

The monitoring and control of power electronics contains protective functions for the DGs and electric power system, also it provides human machine interface, communication interface, and the power management. Moreover, monitoring includes real power, reactive power, and voltage monitoring at PCC are necessary.

1) AC-DC converter: the design of the input converter depends on the specific energy source or storage application. the generation of AC output, often with variable frequencies, such as wind or flywheel storage needs an AC-DC converter.

2) DC-DC converter: it is needed to change the DC voltage level (buck or boost) for the DC output system like PV, fuel cells, or batteries.
3) DC-AC inverter: it is the most generic type, which convert a DC source to grid-compatible AC power.

2.6 Smart grid, microgrid connection challenges:

Despite many advantages of smart grid and microgrids, there are major challenges to apply smart grid, also with connecting microgrid to distribution grid. These challenges can be classified as **technical challenges**, **regulation challenges**, and **customer participation challenges.**

1) Technical challenges:
    a. Operation: mismatches between generation and loads lead to a severe frequency and voltage control problems, because of the ability in changing from grid-connected mode to islanded mode, the "plug and play" can be a serious problem.
    b. Components and compatibility: microgrid may have many components and they have different characteristic in their generation capacity.
    c. Integration of renewable generation: challenges on maintaining microgrid stability.
    d. Protection: the system must respond to both main grid and microgrid faults.
    e. Communication systems: communication systems refer to the media and to the developing communication protocols.

2) Regulation challenges: the most complained challenge to interconnect microgrids with main grid is the high connectivity costs because of high connection fee policies.

3) Customer participation challenges: challenges that allow or prevent customer to be a smart customer.

3

Chapter Three: Control and Protection.

I Control

3.1 Overview

3.2 Advanced Metering Infrastructure (AMI)

3.3 Phasor measurement units (PMU)

3.4 Microgrid control

3.5 Control at customer’s side

II. Protection

3.6 Overview

3.7 Protection challenges

3.8 Protection strategies

3.9 Summary

I. Control.

3.1 Overview:

Transmission networks have, for many years, been monitored and controlled by Supervisory Control and Data Acquisition (SCADA) networks, in SCADA system, a remote terminal unit (RTU) collects data from devices in a substation, and delivers the data in packets to a central Energy Management System (EMS) [4]. SCADA systems typically moves data wirelessly, it uses microwaves or GPRS (Global packet Radio Server- radio frequency (RF)).

SCADA was integrated with AMR system (Automatic Meter Reading), which is one-way communication network that has been used effectively by utilities in delivering accurate billing data for at least a portion of their customer base, in smart grid SCADA will be connected with AMI meters.

3.2 Advanced Metering Infrastructure (AMI):

Smart metering and infrastructure which is also called advanced metering infrastructure (AMI), provides bidirectional communication for smart grids. It has integration of smart meters, communication system, hardware and software that enables the measurement, storage, analysis, and usage of energy between smart meter and utility or between smart meter and customer.

[4] Energy management system (EMS) is controlling the power flow among the main grid, distribution energy resources, and loads in order to provide stable, reliable, sustainable operation of smart grid, lower cost and reducing dependence on fossil fuels **[1]**.

AMI is the core component of the smart grid technology, it may use an IHD (In-Home Display)[5].

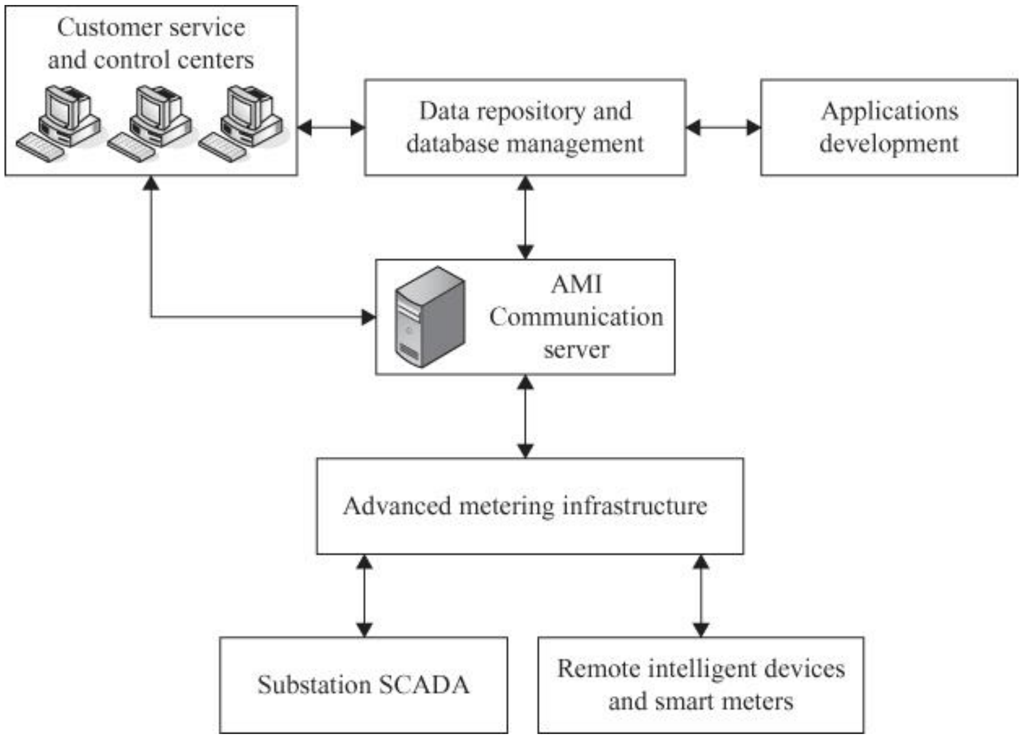

Figure3. 1: AMI Communication.

3.2.1 AMI types:

1) Radio frequency meter: is used to send out a pulse that is read by a meter reader's handheld device, there are 2 types of RF, mesh technology which has a benefit that is a large bandwidth with acceptable latency and point to point technology which has no latency **[7]**.

[5] Is a device that displays information about the consumer/producer's energy consumption/production and will display information such as the current energy consumption, and historical consumption **[6]**.

2) Power line carrier meter: PLC technology usually uses for data communication medium and low voltage power lines, and can be divided into BPLC and NBPLC. **[8]**
    a. Broadband Power Line Communication (BPLC): BPLC uses a standard for high-speed, which has over 100 Mbit per second speed at the physical layer, this standard uses transmission frequencies below 100 MHz
    b. Narrowband Power Line Communication (NBPLC): Uses for low-frequency, which has less than 500 kHz frequency.
3) Cellular meter: provide usage history, service voltage, and power quality information through a built- in cell phone, the utility provider can call to collect the readings.
4) Smart meter: allow the utility provider to remotely monitor and operate their transmission and distribution systems to better manage how energy moves in their grids. Allows two way- communication between provider and meter.

3.2.2 Benefits of AMI:

[7]

1) Improvements of billing accuracy.
2) Easier energy theft detection.
3) Energy Savings.
4) Easier outage management.

3.3 Phasor measurement units (PMU):

Synchronized phasor measurements have become the measurement technique of choice for electric power systems. The phasor measurement units provide synchronized positive sequence voltage and current measurements within a microsecond **[9]**.

This has been made possible by the availability of Global Positioning System (GPS) and the sampled data processing techniques developed for computer applications. In addition to positive sequence voltages and currents these systems also measure local frequency and rate of change of frequency and may be customized to measure harmonics, negative and zero sequence quantities as well as individual phase voltages and currents.

Real time situational awareness and decision support tools are improved by PMU to enhance system's:

1) Reliability.
2) Real time operations applications.
3) Frequency stability monitoring.
4) Power oscillation monitoring.
5) Outage restoration.
6) Wide area controls.

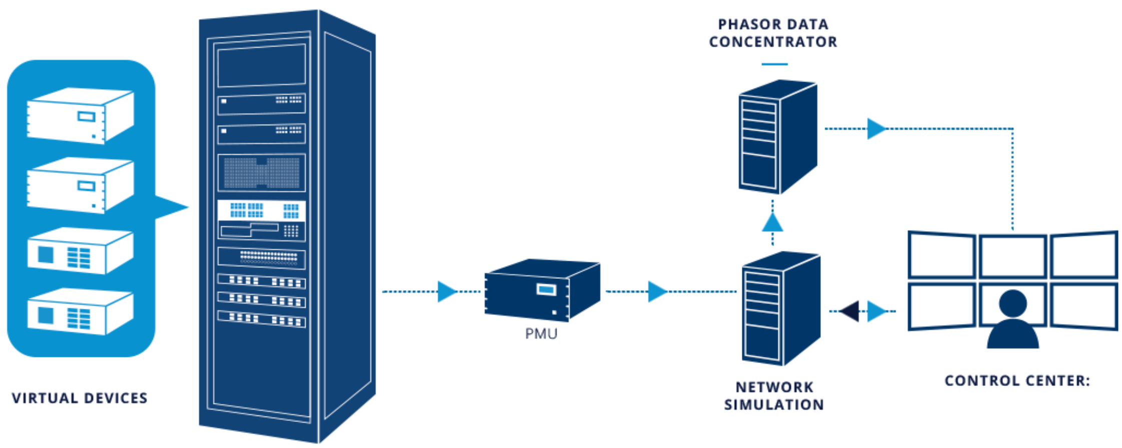

Figure3. 2: PMU with PDC (Phasor Data Concentrator)[6].

[6] PDC: is a software, also it is a part of power plant or substation automation.

3.4 Microgrid control:

3.4.1 Grid connected mode control:

In this mode, the voltage and frequency of the PCC are relatively constant (cannot be controlled). The DGs connect to the microgrid in series and/or parallel and form the microgrid in different configurations, DGs can operate in either the unit power control (UPC) mode or feeder flow control (FFC) mode **[10]**.

1) Unit power control mode: when the microgrid is connected to the main grid, the DG regulates its output to a constant power regardless of the load variation. If the load demand is changed anywhere in the microgrid, the extra power will be compensated by the main grid, the DGs output is regulated to reference power point that must be known.
2) FFC mode used to keep the power flow between the main grid and microgrid unchanged.

3.4.2 Island mode control:

An important issue is to control the power generated to maintain the system energy balance in order to keep the terminal voltage of the battery bank limited to a safe value and consequently maintain its state of charge (SOC) under control, possible methods: **[11]**

1) One is to use physical communication (wiring) between the converters to inform their control systems about the balance of energy in the microgrid and the amount of power that each of them must generate to keep this energy balance under control, it has disadvantage of reducing the system reliability since it is dependent on the operation of a physical communication system.

2) Other solution is to integrate battery banks in microgrids that does not use dumping loads[7] neither wire communication. It considers that all the power converters operate as a voltage source and follows the conventional droop control strategy[8]. When the SOC of the battery bank tends to its maximum value, the system frequency incremented by a specific value, then a reduction in power generated.

3.5 Control at customer's side:

Many utilities are enabling wireless communication systems that allow for customer-owned devices to communicate with the smart meter.

such as:

1) HANs: Home Area Networks.
2) BAN: Building Area Network.
3) IAN: Industrial Area Network.
4) NAN: Neighborhood Area Network
5) FAN: Field Area Network
6) WAN: Wide Area Network, for distribution automation and it is the backbone of the smart grid.

[7] dump load is an electrical device to send electricity to when the batteries are full or the extra power is not required.

[8] is a speed control mode of a prime mover driving a synchronous generator connected to an electrical grid

II. Protection.

3.6 Overview:

Protection of mesh microgrid is a challenging task, some challenges associated with bi-directional power flow, meshed configuration, changing fault current level of DGs and reduced fault current level in an islanded mode **[12]**.

3.7 Protection challenges:

1) The power flow within a microgrid can be bi-directional due to DG connections at different locations or its mesh configuration, this will create new challenges for the protection.
2) Some of the DGs connected to a microgrid are intermittent in nature, so different fault current levels can be experienced in the microgrid depending on the DG connections. As a result, implementation of protection schemes based on fault current level will be further difficult.
3) Once islanding occurs, short circuit levels may drop significantly due to the absence of strong utility grid. Therefore, the protection system which is originally designed for high short circuit current levels will not respond for faults in islanded mode.

3.8 Protection strategies:

The protection scheme (PS) should detect any abnormal condition in the microgrid and it should isolate the smallest possible portion thus allowing rest of the system to continue operation. The PS should also allow the microgrid to operate either in grid connected or islanded modes of operation providing appropriate safety to customers and equipment. In addition to the differential protection elements, overcurrent and under voltage protection elements are incorporated.

3.8.1 Communication in protection:

The current information at the remote end needs to be transferred to the local end. The digital current differential relays sample the line currents and then send them over a communication channel to the other relay, this may introduce a time delay which can be seen as a phase shift between local and remote end current samples, as a result, the relays may calculate a differential current.

To avoid this problem, proper time synchronization of current phasors is required, but the modern digital relays are capable of measuring the time delay and performing the compensation during the calculation.

When a failure in communication link is detected, the relays should automatically switch into their backup protection schemes.

3.8.2 Feeder protection:

Each feeder in the microgrid is protected using two relays which are located at the end of the feeder. In normal operating condition, current entering to a particular feeder should be equal to the current leaving from that feeder. However, this condition will not be satisfied during a fault on the feeder. Therefore, current differential protection is proposed to detect and isolate the feeder faults.

In the proposed current differential PS, each relay has five elements to provide the required protection:

1) Three phase elements for each phase: the phase differential elements are responsible for providing high speed protection for faults which have high currents.

2) Two other elements for negative and zero sequence currents: the negative and zero sequence differential elements provide more sensitive fault protection for lower current unbalanced faults such as high impedance faults in a feeder.

3.8.3 Bus protection:

Buses in the microgrid may have connected to loads, DGs and feeders. Therefore, a high-speed protection is very important for a bus fault to avoid any extensive damage in the microgrid, protection principle is similar to the one explained in differential feeder protection. However, in this case, the relay will issue a trip command to all the circuit breakers connected to the bus during a bus fault.

3.8.4 Distribution generator protection:

Each DG is employed with several protection elements:

1) The under-voltage tripping: is activated below a set voltage level after a defined time period. The defined time allows microgrid relays to isolate a fault and restore the system maintaining as many DG connections as possible.
2) The reverse power flow protection: activates to trip the DG when current flows towards the DG.
3) The over voltage element: responds, when the voltage at point of connection rises above a predefined limit.
4) The synchronism check element: ensures a trouble-free connection to the microgrid when it is being reconnected after any disconnection.

3.9 Summary:

The control and protection of smart grid are important, control was explained at each side even for producer or consumer.

Also, protection of smart grid and microgrid (DGs) with the needed protection relays or others, was clarified.

4

Chapter Four: Project Implementation.

Chapter Four: Project Implementation.

4.1 IEC: International Electrotechnical Commission.

4.2 Experiments and simulation.

4.3 Smart meters and meter data management (MDM).

4.4 Beit Sahour case study.

4.5 Distribution generators.

4.1 IEC: International Electrotechnical Commission:

4.1.1 About IEC:

The IEC is a not-for-profit organization that brings together 166 countries and offers a global platform to nearly 15 000 experts from industry, governments and user-groups. These experts sit together, define and agree on the rules, specifications, measurement methodologies and testing requirements that are needed to do business in the global market. They develop International Standards that cover all aspects of safety, interoperability, efficiency, electromagnetic compatibility and environmental impact. **[13]**

4.1.2 IEC smart grid standards:

The IEC standards are already able to describe many functions that are necessary for smart grid technology. At present, more than 100 IEC Standards have been identified as relevant to the smart grid. The following list shows only some of them: **[14]**

1) IEC 61850: communication networks and systems for power utility automation.
2) IEC 61970: energy management system application program interface including the common information model.
3) IEC 61968: system interfaces for distribution management.
4) IEC 61400-25: communications for monitoring and control of wind power plants.
5) IEC 62325: framework for energy market communication.
6) IEC 62351: standard for the data transfer security.
7) IEC 62056: data exchange for meter reading, tariff and load control.
8) IEC 61508: functional safety of electrical/electronic/programmable electronic safety-related systems.
9) IEC 61131: programmable controllers.
10) IEC 61334: distribution automation using distribution line carrier systems.
11) IEC 61499: distributed control and automation.

4.1.2.1 IEC 61850 – power system communication:

The IEC 61850 standard series consists of several parts, which were originally developed to standardize the substation automation. Since these concepts proved capable not only for protection but for the whole power system automation as well, the standard has been extended and revised accordingly to standardize the communication between power system devices.

Several parts describe the whole procedure of managing energy system automation projects (IEC 61850-4 ed2.0, 2011) and conformance testing (IEC 61850-10 ed2.0, 2012), but the main parts describe the mechanisms of data exchange (IEC 61850-7-1 ed2.0, 2011), provided services (IEC 61850-7-2 ed2.0, 2010), a uniform configuration description (IEC 61850-6 ed2.0, 2009) and also the mapping of the defined communication procedures to existing data exchange transport mechanisms (IEC 61850-8-1 ed2.0, 2011).

4.1.2.2 IEC 61968/61970 and the common information model:

While the IEC 61850 standard is mainly focused on the communication between several single devices in the power system, the IEC 61970 and IEC 61968 standards concentrate on the interfaces in energy management systems. The aim of these standards is to provide a data model to exchange complex data that represents information about many aspects of the power system, ranging from simple topology and asset data to economic aspects. IEC 61968 extends the IEC 61970 to the aspects of the distribution system.

The core of IEC 61970/61968 is the so called common information model (CIM) which mainly is an object-oriented model consisting of many classes, which are associated with each other and represent prototypes for the objects whose information needs to be stored (IEC 61970-301 ed4.0, 2013).

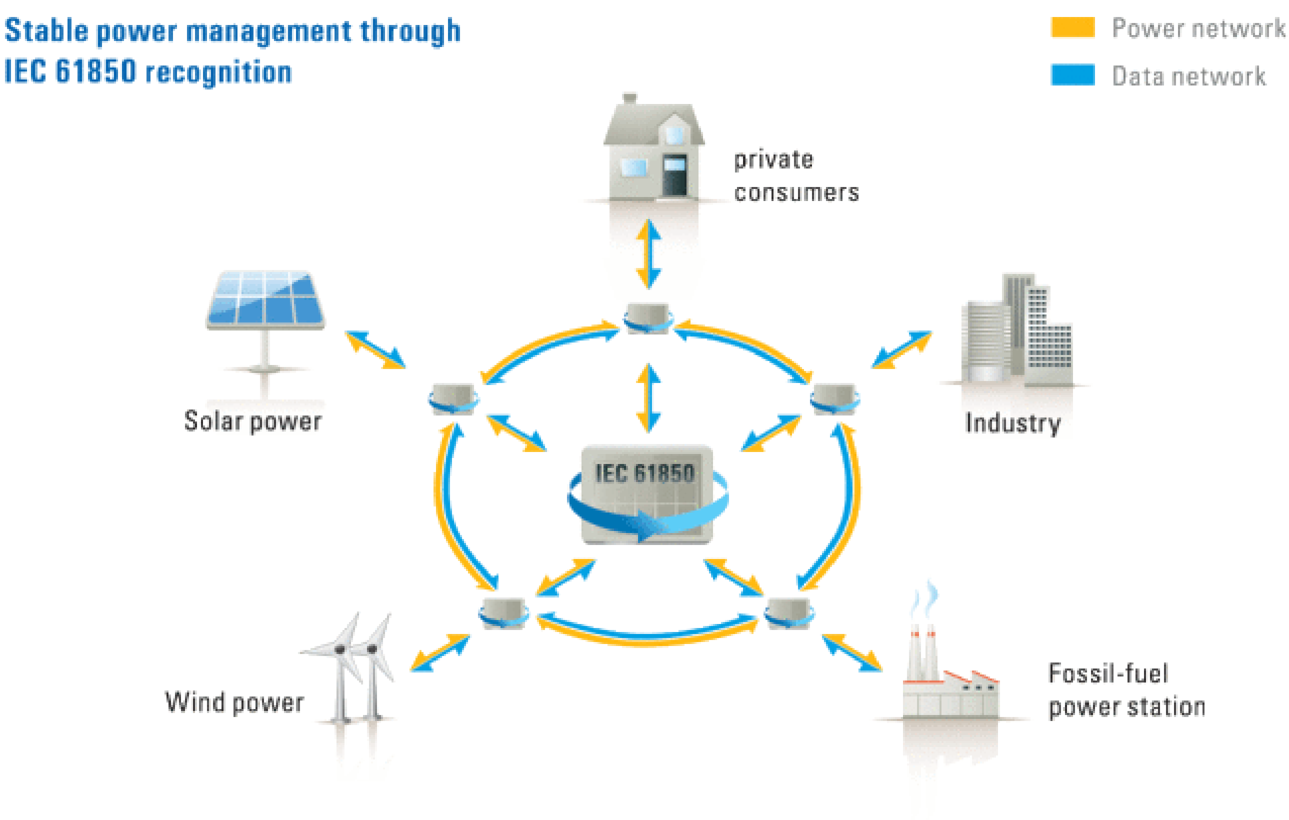

Figure4. 1: IEC smart grid standard example.

4.2 Experiments and simulation:

4.2.1 Overview JDECo (Jerusalem District Electricity Company):

Is a joint electricity company established in its current form in 1956. It distributes and supplies electricity to consumers in and around Jerusalem, Bethlehem, Ramallah and Jericho. The company doesn't have own power stations. It buys over 95% of its electricity from the Israel Electric Corporation (IEC) and the remaining electricity from the Jordanian National Electric Power Company. **[15]**

In the cooperation with JDECo, practical investigations have been done in a successful, interesting, and useful ways, these experiments were to prove the principles of smart grid and its main part microgrid fragmented to grid connected mode and island mode.

Company Location:

JDECo has several administrative offices within its supply regions, the region which concerns to implement the practical part of project of “Smart Grid Design” is located in Jericho city, Palestine.

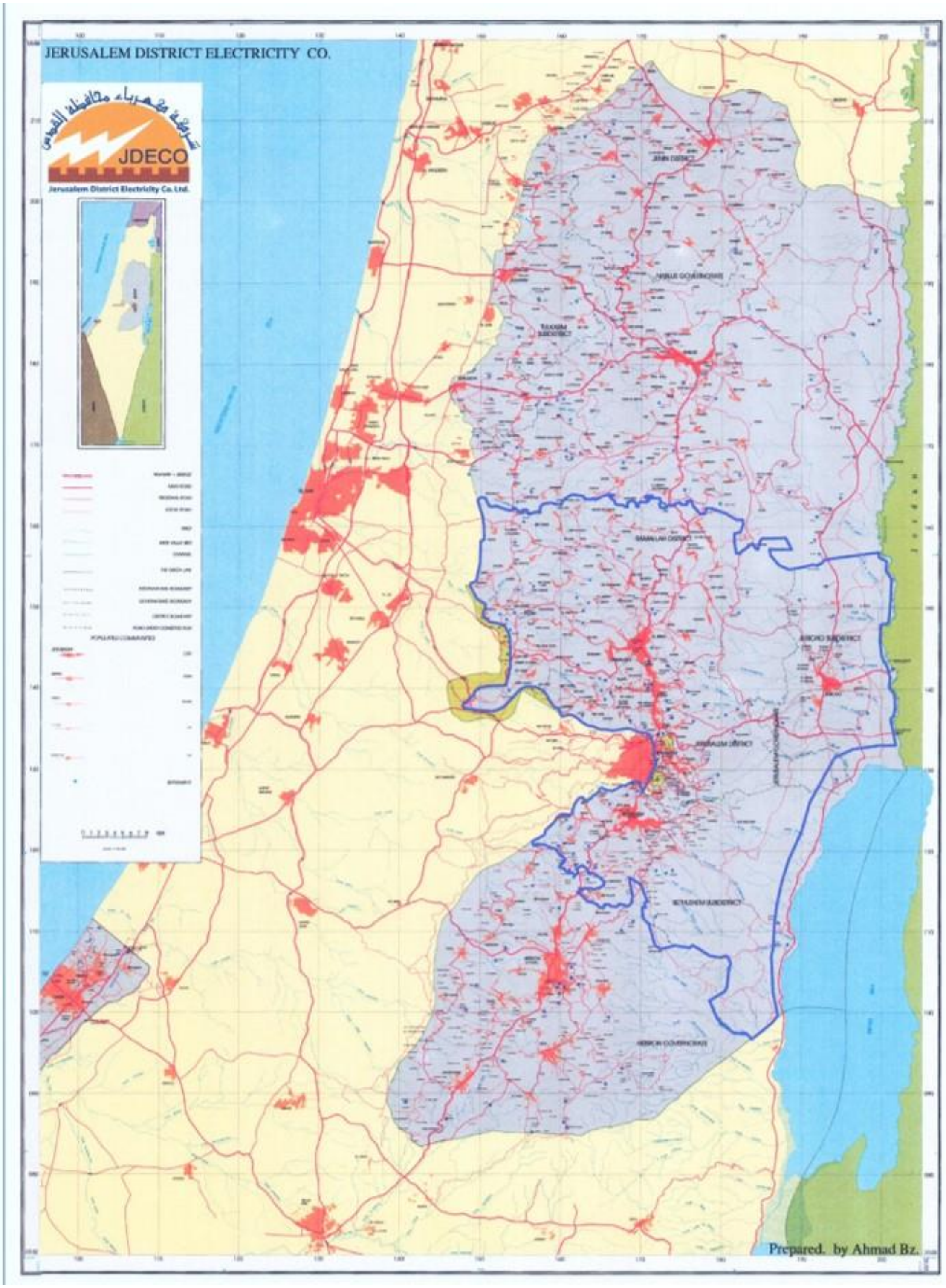

Figure4.2: Company regions in Palestine.

It contains some of modern laboratories that can be used to develop an idea or to implement a project like this one, some of these labs are "smart grid lab, electronics lab, solar system lab" and others, this project needed these labs to be performed, other main components like using of 2250W PV station which is located in training center, Jericho, a hybrid inverter with 3000 VA capacity, 4 series batteries 12V, 20Ah, load and the grid lines.

4.2.1.1 Procedure and components:

To start with this part of the project, an outline will be presented:

i. Modes of microgrid even the connected one or the islanded.

ii. Pictures show the work and results.

iii. Simulation of the used smart network by SIMULINK.

These experiments were completed on the 1st of Nov 2017, when the irradiance and temperature were as follow:

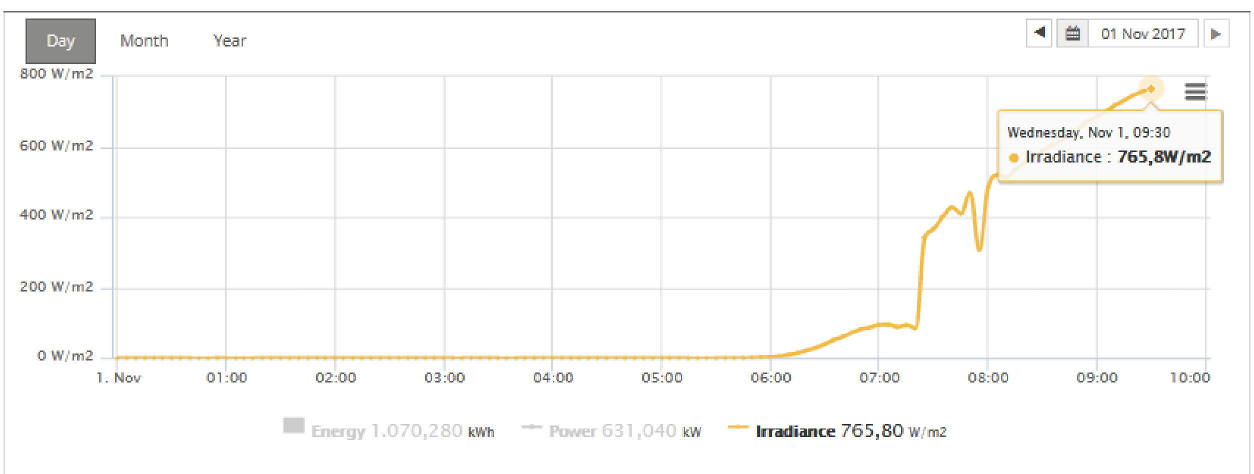

Figure 4.3: Irradiance on the 1st of Nov, 2017, Jericho.

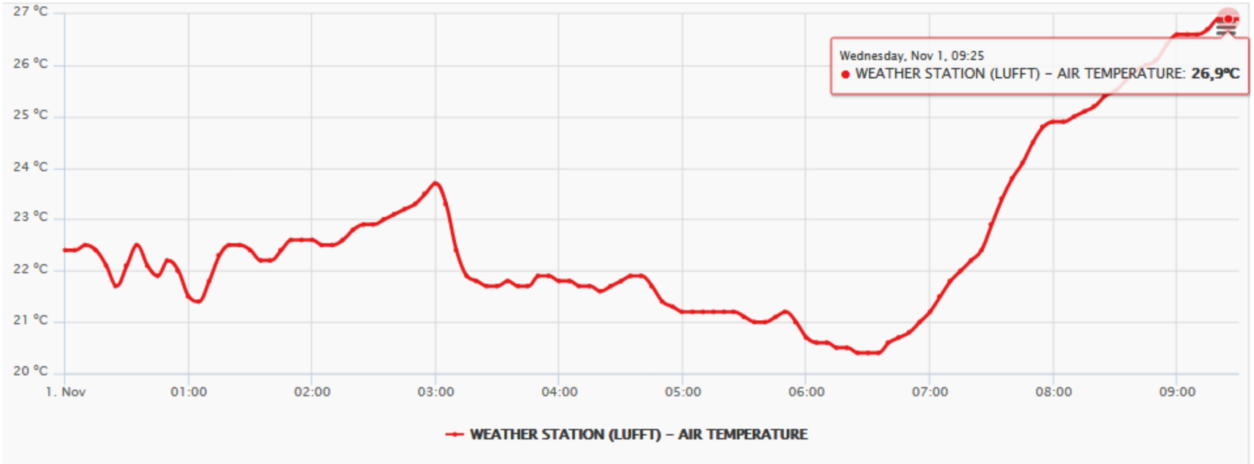

Figure 4.4: Air temperature on the 1st of Nov, 2017, Jericho.

4.2.1.2 The used components:

1) 2250W PV station.
2) Hybrid inverter with 3000 VA
3) 4 series batteries 12V, 20Ah, and 1KW.
4) The grid lines.
5) Oscilloscope and measurements.
6) Pure resistive 750 W load.

Figure4.5: Used components.

4.2.1.3 Practical scenarios:

The 2250W PV station is configured as 3 series PV modules, they are connected in parallel with other 2 strings each has 3 series modules as shown:

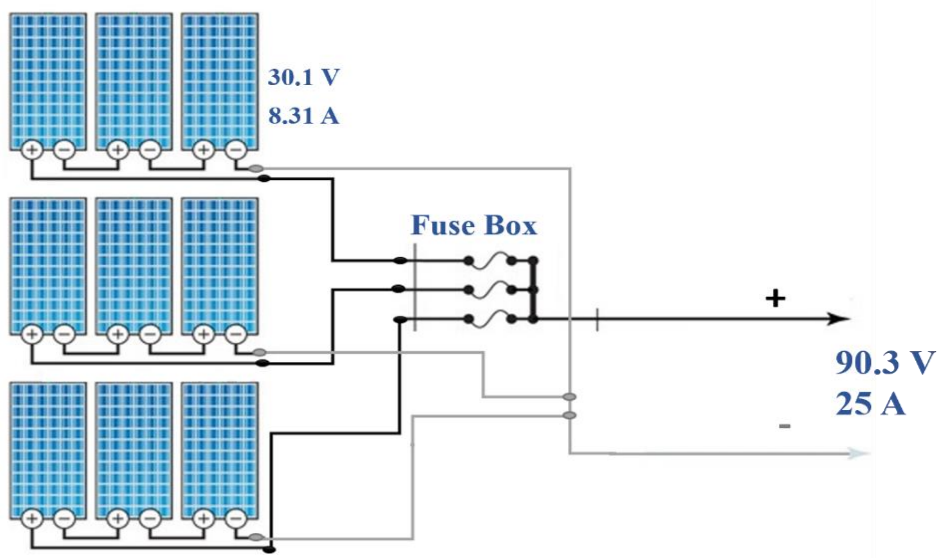

Figure 4.6: 2250 W PV station configuration.

The following nameplate will show the maximum currents and voltages of used PV cell:

Table4.1: Parameters and nameplate of used PV.

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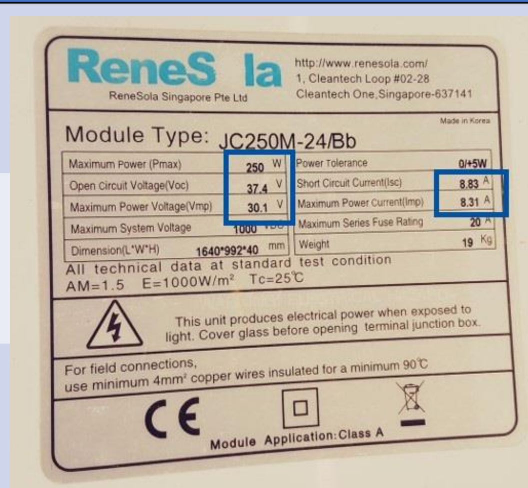
Parameter	Value	Nameplate
Power	250 W	
Vmax	30.1 V	
Imax	8.31 A	

Load is supplied from three sides:

i. Grid lines.
ii. PV 2250 W PV station.
iii. 1 KW batteries are for internal controller and emergency at nights.

Since it is a single-phase load with the pure resistive 750 W, 240 V should be supplied and approximately 3.125 A is consumed; these results were obtained even in the practical work or the simulation, the following image shows the diagram of the connection:

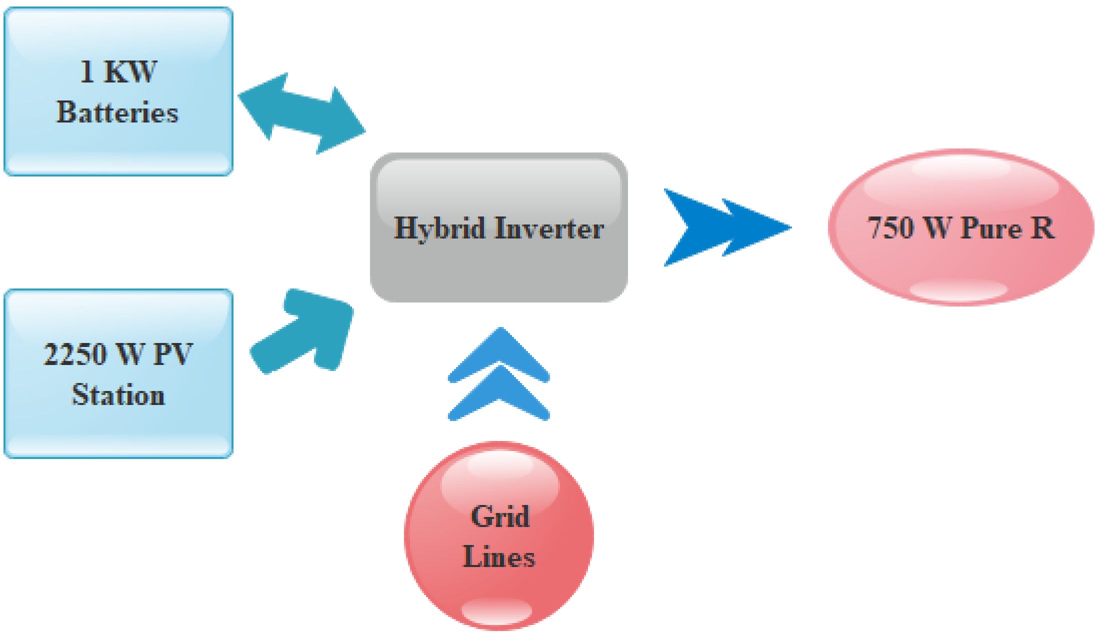


Figure4.7: Diagram of the connection.

In the normal cases or in the on-grid inverters, PV, batteries, and grid are cooperate and sharing the supplying operation of the connected loads; In smart grid concept, the inverter should be able to act like the one in grid connected mode, also, to be able to switch between grid, PV, and batteries as needed which is the island mode.

The used hybrid inverter operates like this, when both PV and grid are connected, the supplier is one of them, and the other is for charging batteries, but there is no sharing or bidirectionality between grid and PV station; 2250 W PV station plus 1 KW from batteries are able to cover 750 watts of the load, but not at nights when batteries are discharged, or when the clouds blocks the cells during discharging.

Hybrid inverter converts its connection between them in order to supply the load with the needed power. The practical experiments are shown below, the output signal of the load is displayed using oscilloscope, measured by voltmeter, and clamp meter.

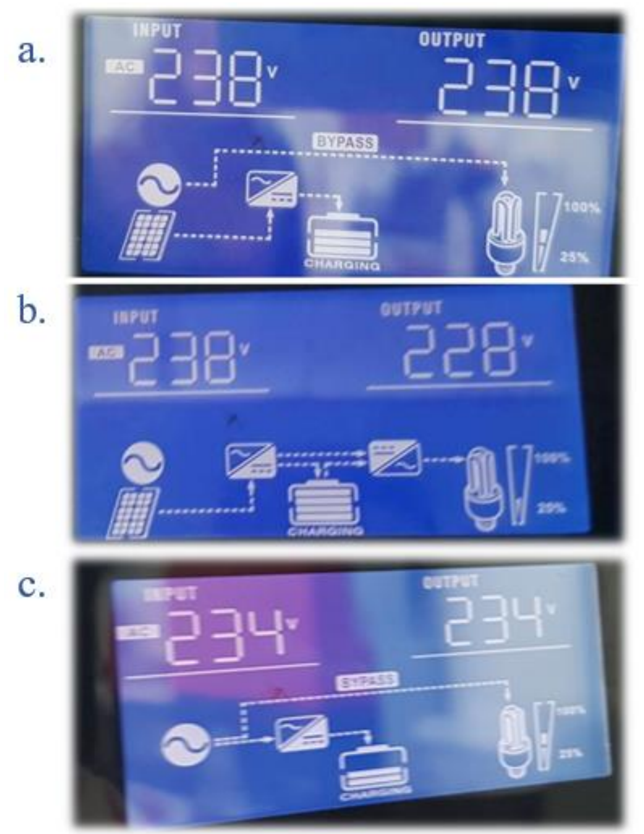


Figure4.8: (a): The provider is grid, PV is on. (b): The provider is PV. (c) The provider is grid, PV is off.

Explanation:

a. The previous figure shows the display of the hybrid inverter in different cases, part (a) /case 1, when the grid is connected, PV also connected but has the priority to charge the batteries, and grid only is supplying the load.
b. Part (b) / case 2 shows the case when the grid is disconnected and the supplier is the PV, even for the load or to continue charging of batteries.

c. Part (c) / case 3 shows an emergency case, batteries are discharged, PV is blocked and unable to supply the load, but the grid is connected, so the switching operation in the inverter will connect the grid to supply the load and charging the batteries.

4.2.1.4 Results:

Case 1: When grid is the main supplier for 750W load, it gives 240V rms, and 3.04 A are shown below:

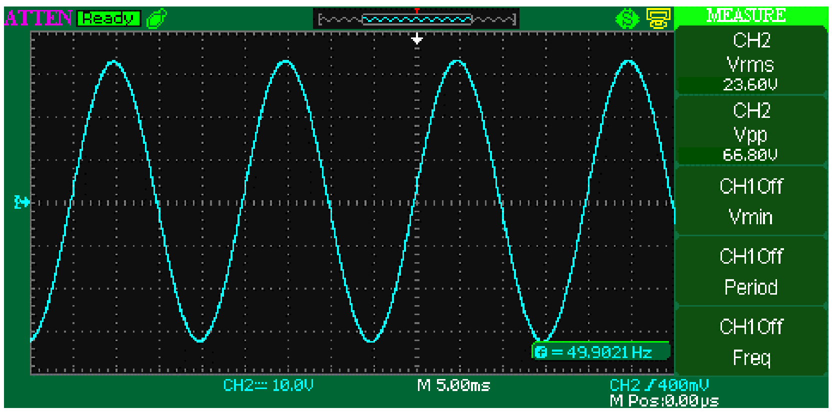


Figure4.9: Oscilloscope for grid voltage wave doubled 10 times.

Figure 4.10: Load voltage and current at grid connected.

Case 2: When the PV and batteries are the main suppliers and the grid is disconnected:

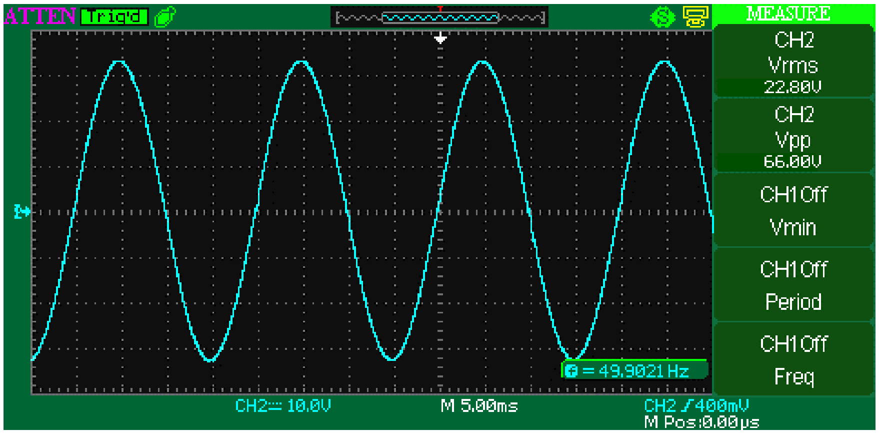


Figure4.11: Oscilloscope for PV and battery voltage wave doubled 10 times.

Figure4.12: Load voltage and current of PV and battery

case3: Show the same waveform for the voltage such as part (a) / case 1, and different values of measured voltage and current as shown:

Figure4.13: Load voltage and current of grid and battery.

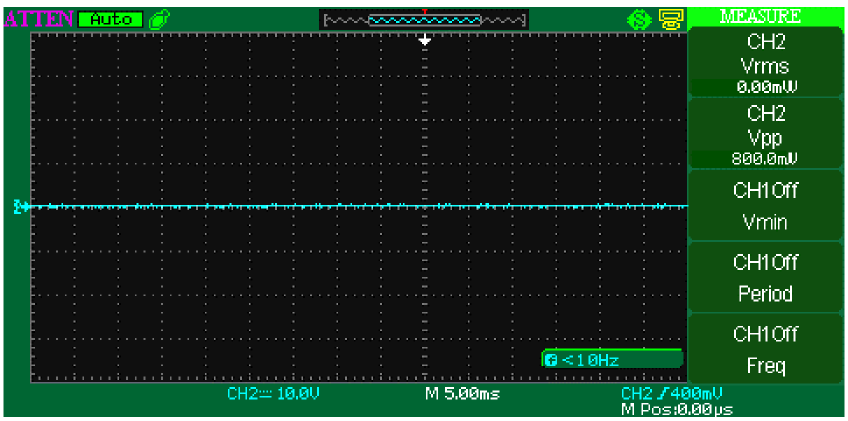


Figure4.14: Oscilloscope voltage wave for no supplier.

Results collection tables:

Table4.2: JDECo. scenarios results.

Measured / Case	Voltage rms	Current rms
Both are connected	**240 V**	**3.04 A**
Only PV	**228 V**	**2.97 A**
Only grid	**234 V**	**2.91 A**

4.2.1.5 JDECo. experiments simulation:

This simulation is done by SIMULINK with the same configuration of the real case in order to prove it.

At first, irradiance and temperature of the 1st of Nov 2017 should be as same as the reality, so use signal builder to create them and for sure Microsoft Excel tables.

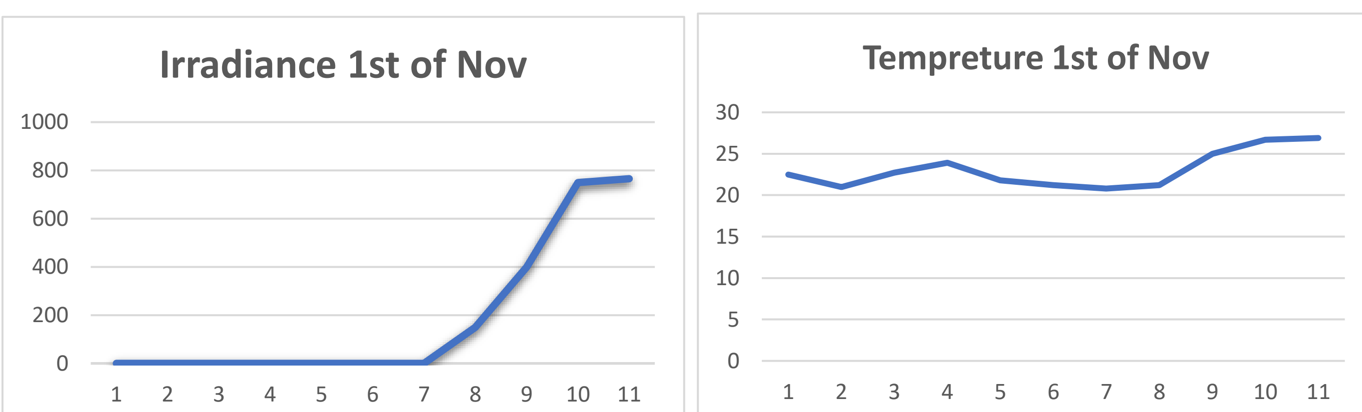


Figure4.15: Irradiance and temp. using Excel.

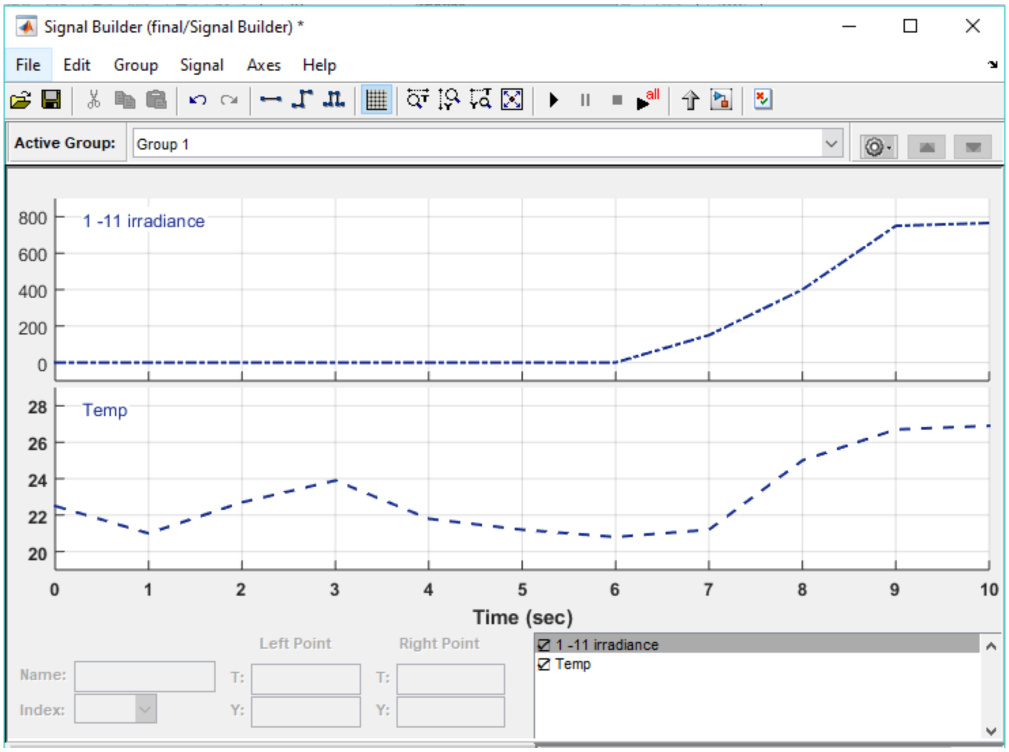


Figure4.16: Irradiance and temp. using SIMULINK.

These signals would be the input of the selected PV which should be as same as the real PV type and configuration, which is shown in the previous mention of table (4.1), SIMULINK is shown in the following figure.

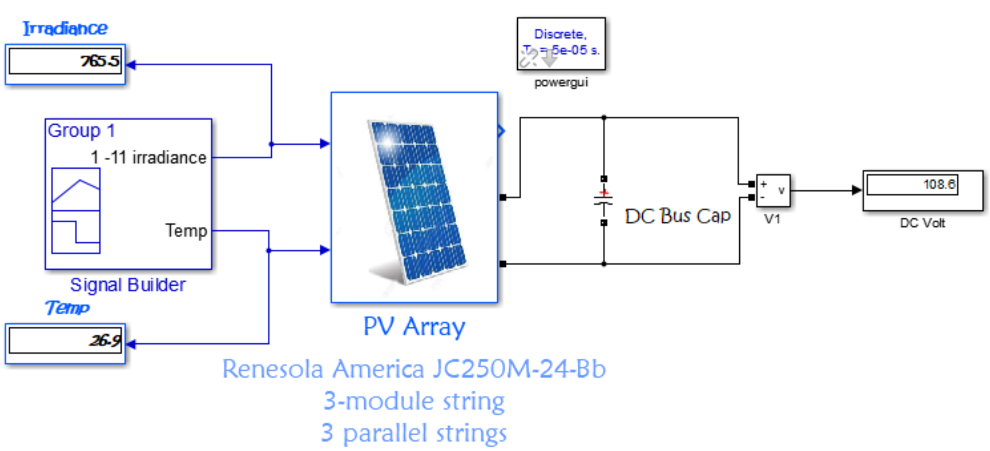


Figure4.17: PV system using SIMULINK.

The capacitor is DC Bus Capacitor, it used to stabilize voltage on DC side, and it can be calculated as shown in Appendix A, part1.

The second input of the inverter is the batteries, they are 4 connected in series, each is 12 V, and 20Ah.

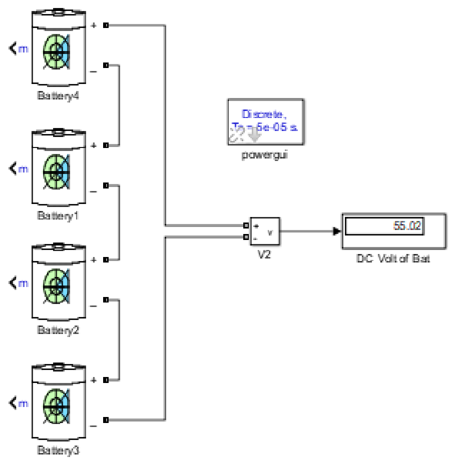


Figure 4.18: Batteries using SIMULINK.

Then the grid configuration, grid is connected to the load one time, and disconnected another time using a single-phase circuit breaker, the SIMULINK of grid with the load is shown in the following figure, and the internal components are included in Appendix A.

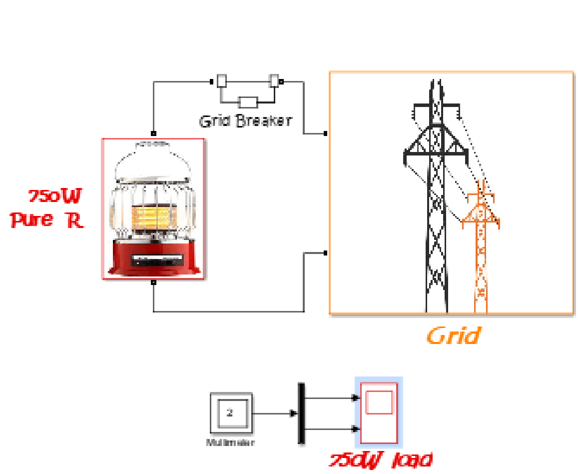


Figure 4.19: Grid connected to load using SIMULINK.

The output voltage of batteries should be boosted up to be as same as PV output voltage, then both should be boosted up in order to achieve the desired output voltage from inverter which is 240 Vrms, the following figure shows the connection circuit; components, and calculations are included in Appendix A.

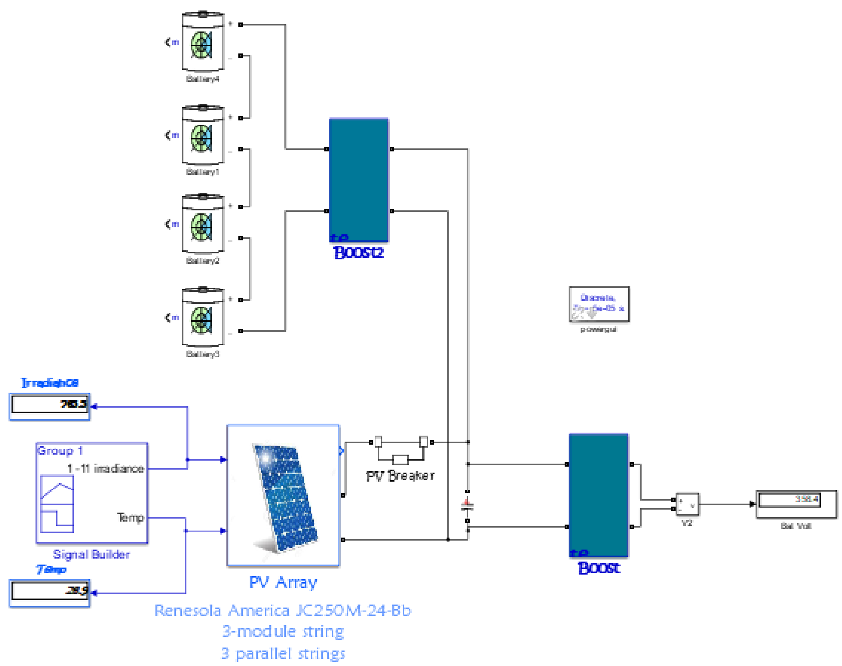


Figure4.20: boosts of PV and batteries using SIMULINK.

Since the load is a pure R load, power factor should be 1, peak voltage is ($\sqrt{2}$ * 240 = 340 V), current needed to get 750 W is (I = $\frac{V}{R}$ = $\frac{750\ W}{250\ \Omega}$ = 3 A rms.), I peak = ($\sqrt{2}$ * 3 = 4.3 A).

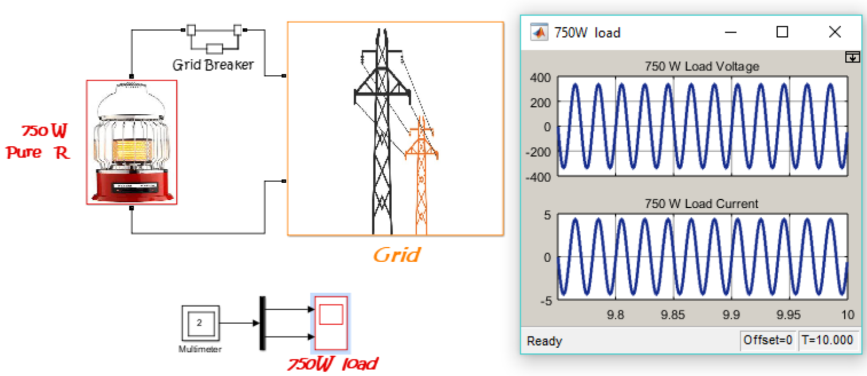


Figure4.21: load voltage and current using SIMULINK.

Inverter and its filter are designed to get 240 Vrms or 340 V peak; inverter designed using 4 switches (IGBT) with switching frequency chosen of 25 KHZ, and the filter is a combination between inductors, capacitor, and a resistor (RLC) filter.

The internal design and calculations of both are attached in Appendix A.

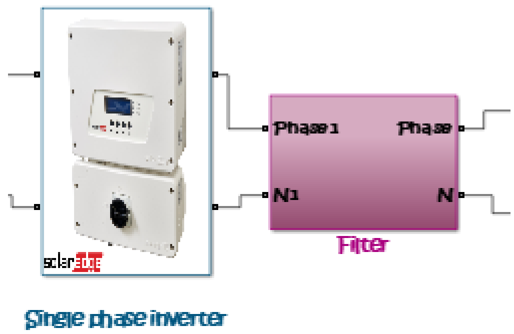


Figure4.22: Inverter and filter using SIMULINK.

There is an (1:1) isolation transformer used in the design in order to isolate the inverter out of the grid.

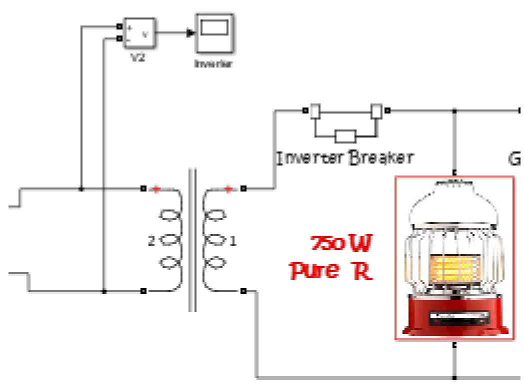


Figure4.23: Isolation transformer in SIMULINK design.

The full MATLAB / SIMULINK design:

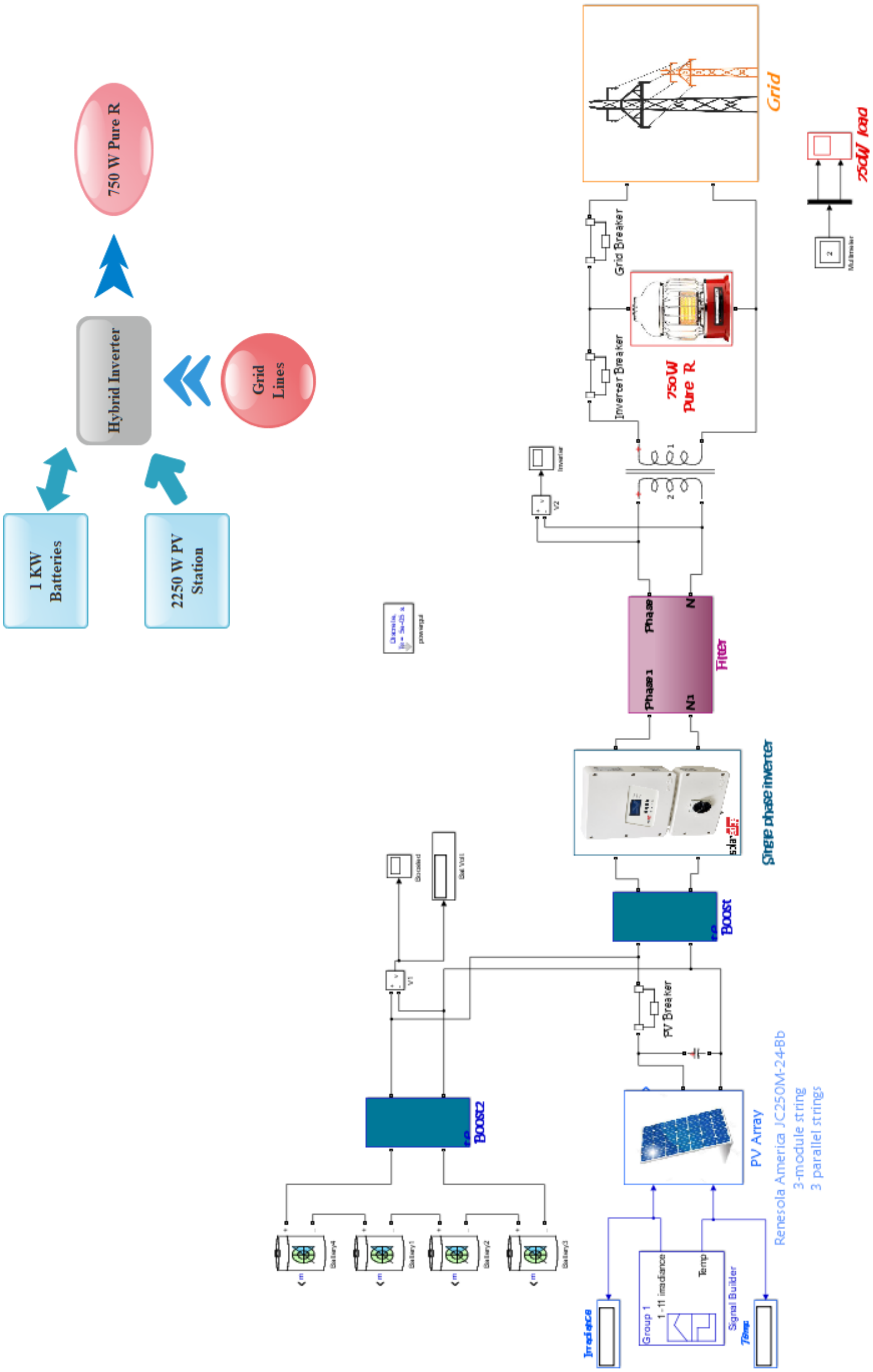


Figure4.24: Full design, SIMULINK.

4.2.1.6 Scenarios by SIMULINK:

These scenarios are as same as the practical ones:

1) When both are connected.
2) When PV station is only connected.
3) When PV is not connected, grid is supplying the load and suppose to charge the batteries.

Case 1: both are connected:

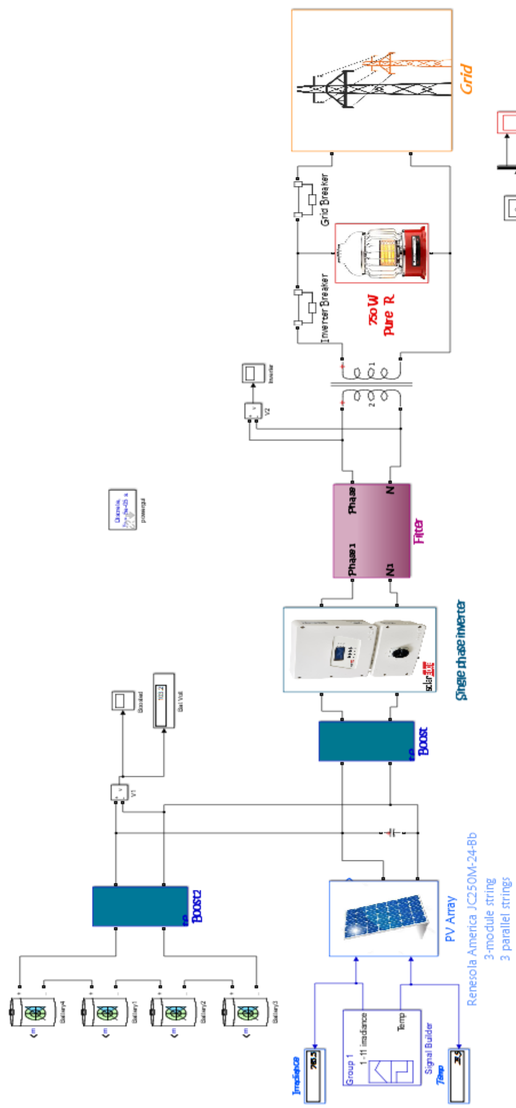


Figure4.25: Case1, PV and grid are connected SIMULINK.

Load voltage and current (peak):

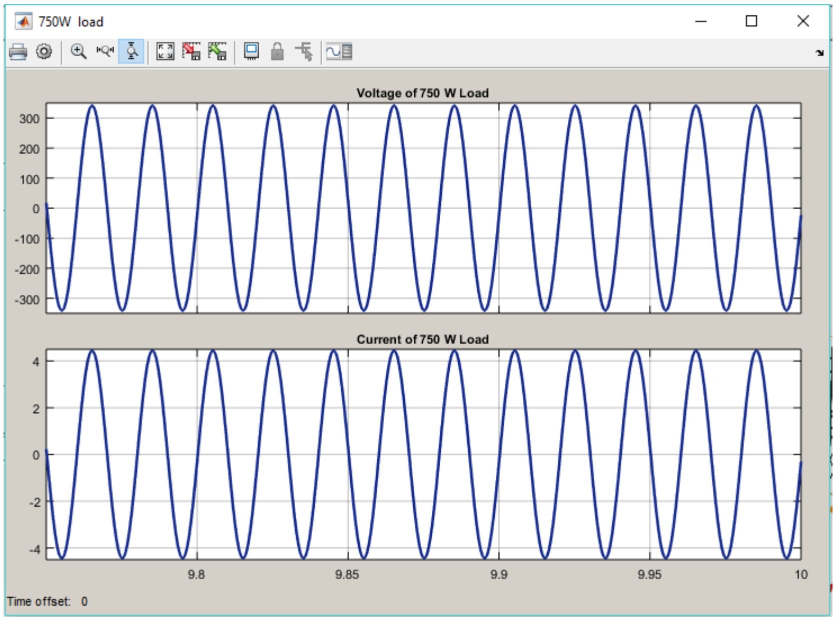


Figure4.26: Load voltage and current for case 1, SIMULINK.

Case 2:

This case will be implemented by opening the circuit breaker at the grid lined, and let the PV station be the main provider for the load.

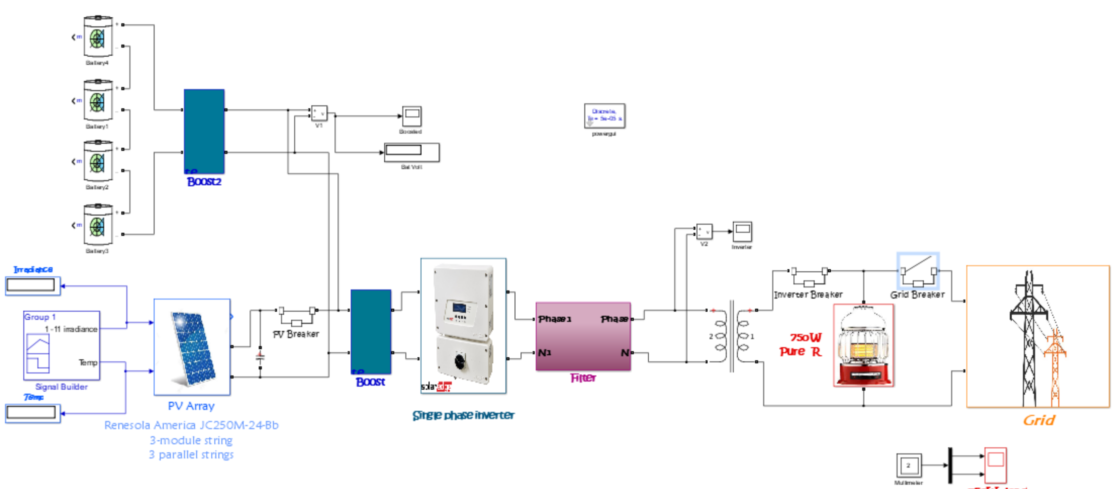


Figure4.27: Case 2, PV and batteries are connected, SIMULINK.

Load voltage and current (peak):

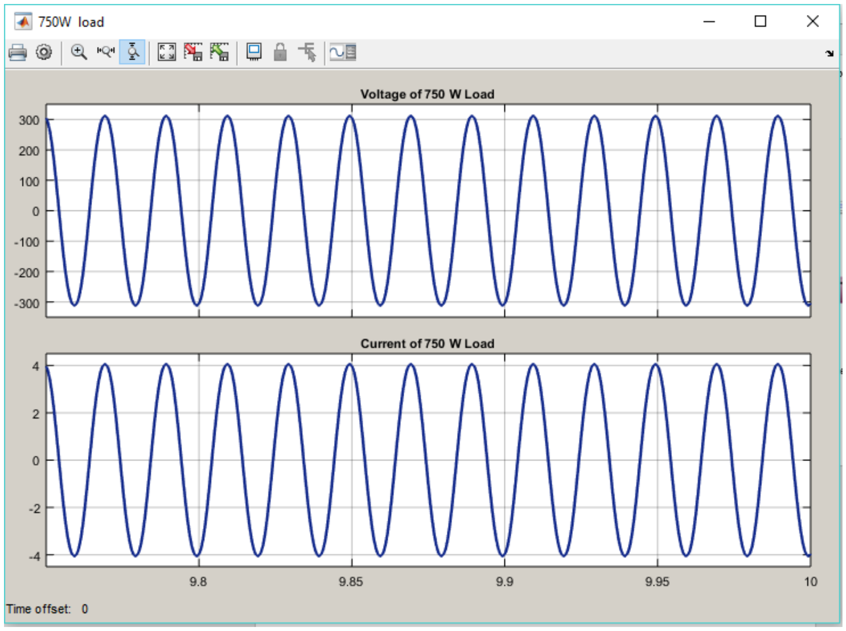


Figure4.28: Load voltage and current for case2, SIMULINK.

Case 3:

By opening the circuit breaker at the PV side only, the circuit will be:

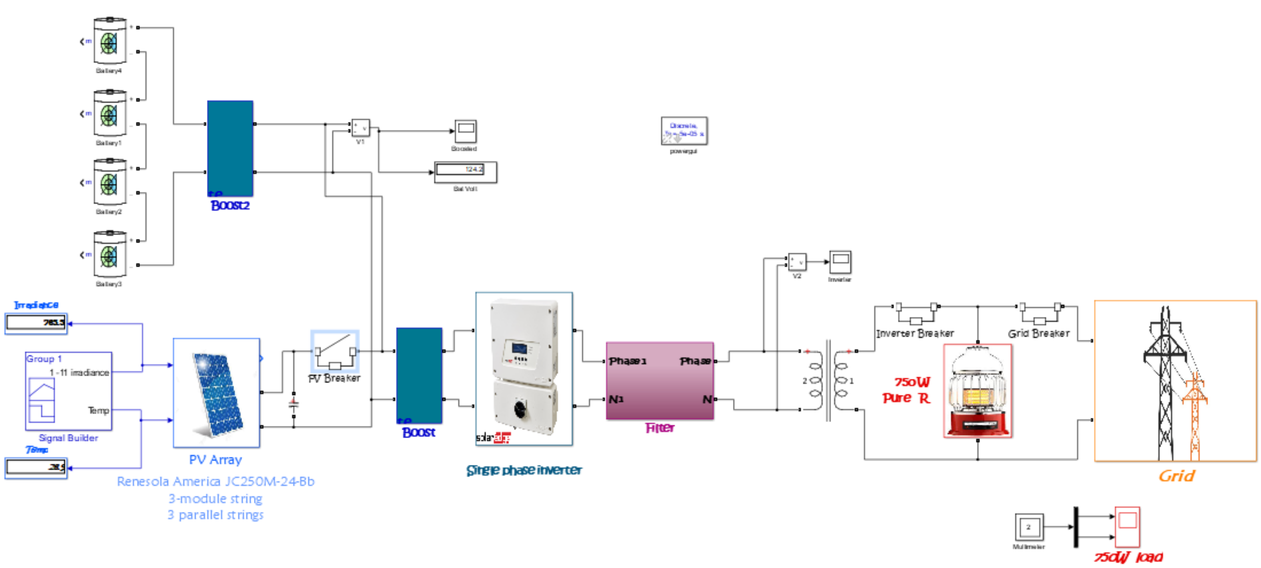


Figure4.29: Case 3, only PV is disconnected, SIMULINK.

Load voltage and current (peak):

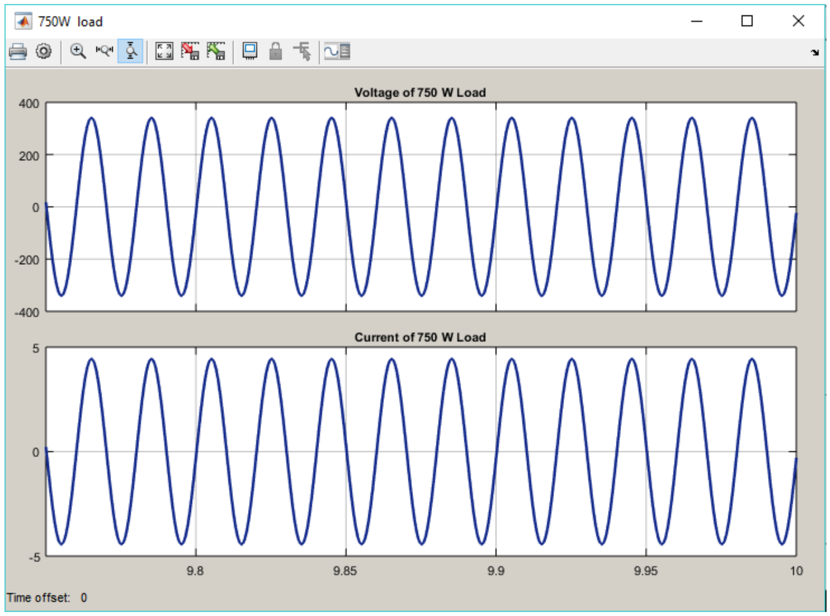


Figure4.30: Load voltage and current for case3, SIMULINK.

Try for grid and PV are disconnected, if the batteries are charged, they will support the load with the needed power, as shown:

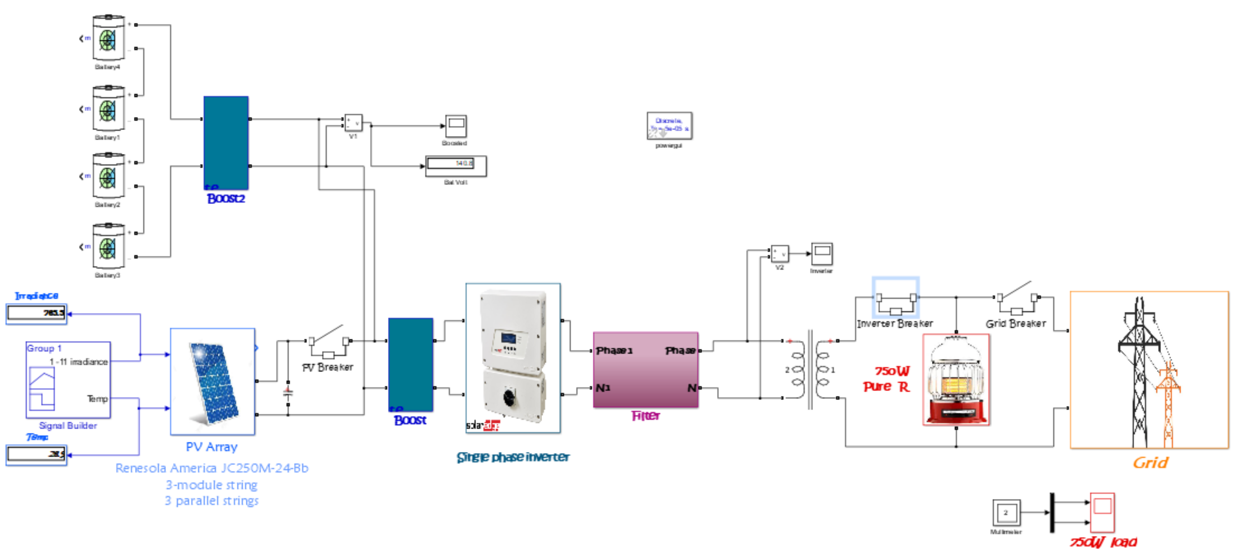


Figure4.31: Only batteries are connected, SIMULINK.

Load voltage and current (peak):

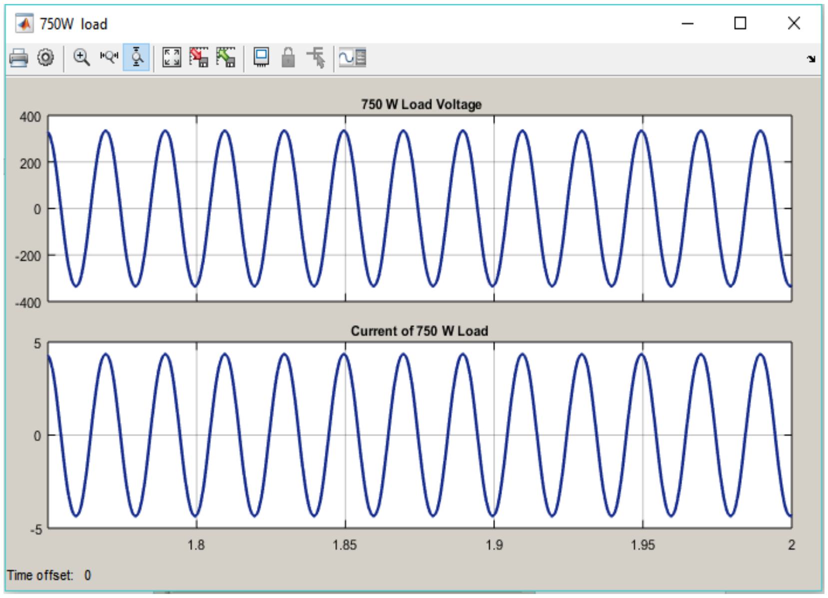


Figure4.32: Load voltage and current of batteries, SIMULINK.

Gathering results:

The table below shows the voltage and current in rms, for each case:

Table 4.3: Implementation results of cases.

Measured / Case	Voltage rms	Current rms
Case 1	240 V	3.18 A
Case 2	219.2 V	2.8 A
Case 3	240 V	3.1 A
Batteries Only	219 V	2.8 A

Power flow by ETAP 16:

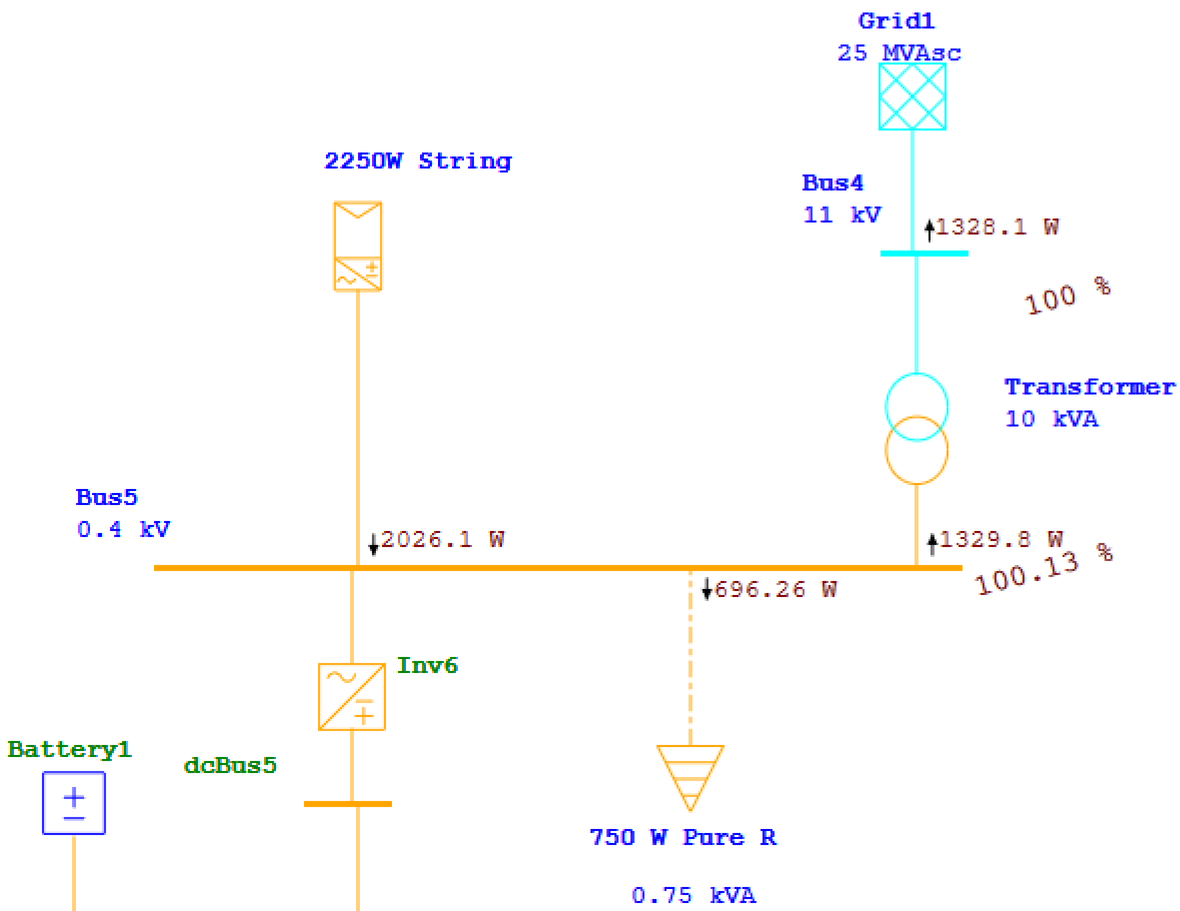


Figure4.33: JDECo. experiments power flow, ETAP16.

4.2.2 University smart grid lab experiments and simulation:

4.2.2.1 Overview:

University smart grid lab is equipped with educational modules from "DE LORENZO" group, these modules are designed to confirm concepts of smart grid.

The modular laboratory for the study simulates the generation of energy from three different sources (thermal, hydroelectric, wind farm), its transmission and distribution by means of high voltage lines simulation models and its utilization, including small photovoltaic solar energy plants for domestic use.

Figure4.34: DE LORENZO smart grid lab.

4.2.2.2 Practical experiments:

Smart grid lab was supposed to achieve a high degree of clarity of the concept and behavior of smart grid and its components, controllers, also microgrid modes specially island mode which is the most important mode for now due to the very high loading and the problems of the legacy network.

Some of these targets have not been achieved because of the unexpected limitations of the lab modules, PV is very small to provide a load, induction generator cannot be islanded to provide a load during the isolation of the network, and the wind turbine was not ready to work yet.

Despite the limitations, the objective was accomplished with some results from running of:

1) Three phase grid lines.
2) Three phase induction generator with 1.5 KW.
3) PV module of 90W and single-phase inverter of 360W.
4) Three phase load of approximately 300 W.
5) Personal computer to simulate the module and SCADA software.
6) Relays and protection components of the lab module.

Pictures of the module, components, and the practical work are following.

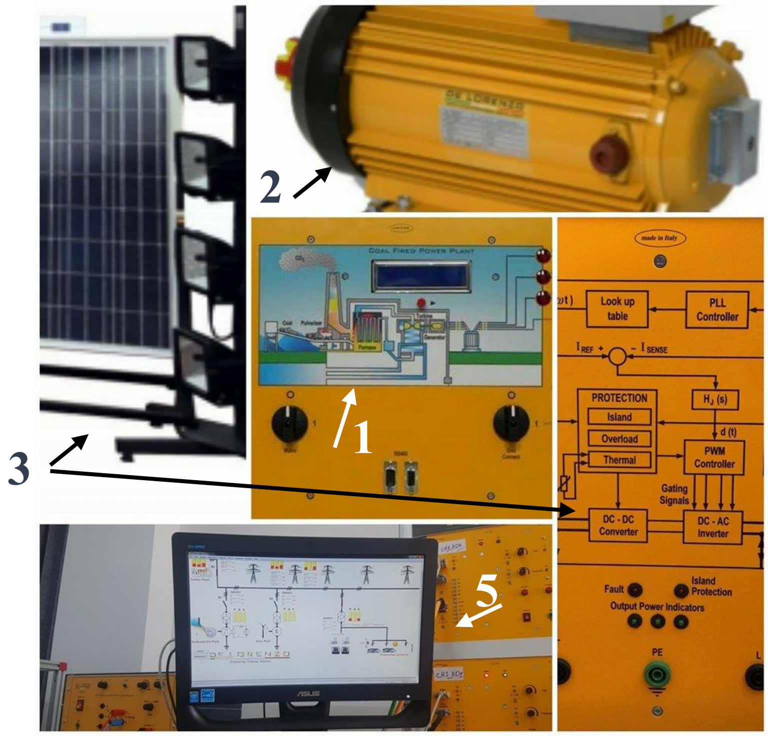


Figure4.35: Basic components used in smart grid lab.

Figure4.36: Practical investigations, smart grid lab

Panel components:

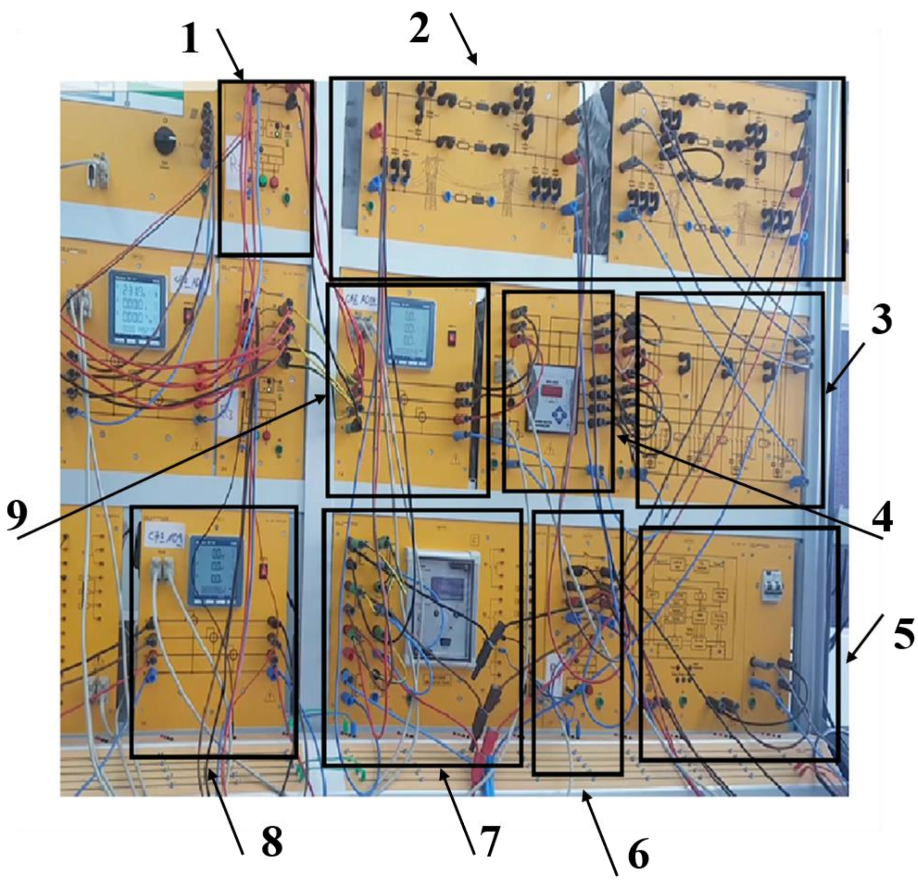


Figure4.37: Panel components in smart grid lab.

1) Main grid connecter.
2) Transmission lines.
3) Capacitors for power factor correction.
4) Power factor controller.
5) Inverter.
6) Load.
7) Protection relay.
8) Induction generator relay.
9) Main power meter.

The 300 W load was supported from 2 sides, despite the PV module was connected, it gave only 11 W, and they did nothing.

The 2 sides are the grid and induction generator, even the generator can give 1500 W, it was controlled to give only 117 W which were injected to the grid, and the network was entering with 172 W.

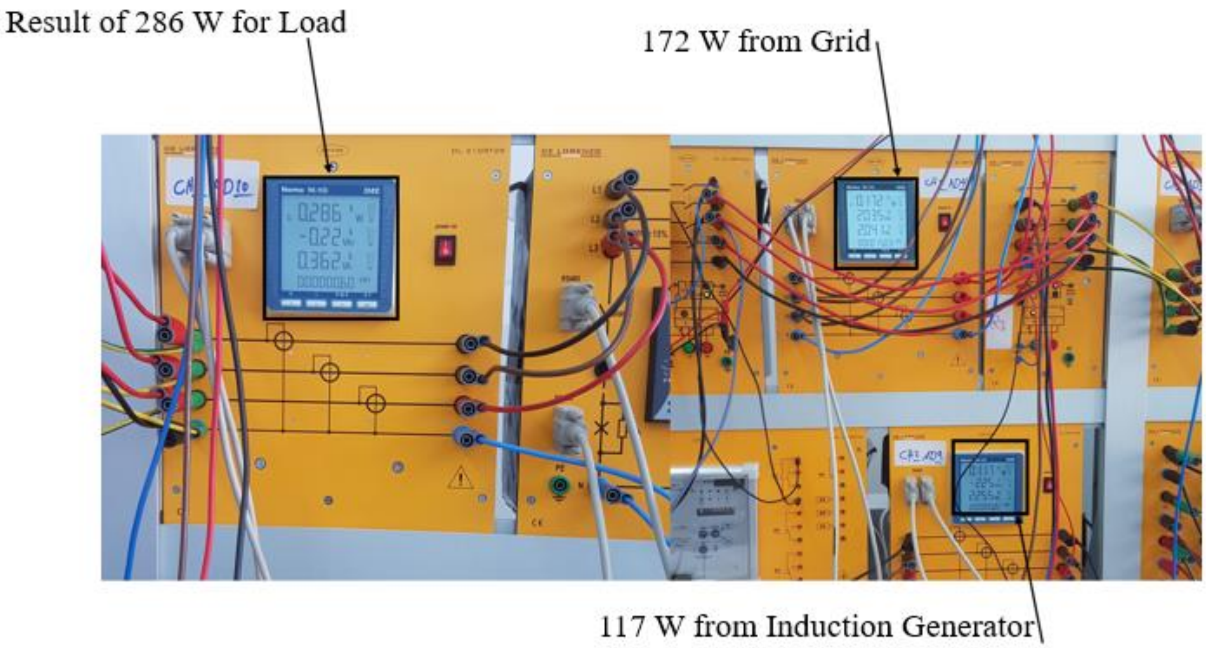


Figure4.38: Results of power flow.

4.2.2.3 University lab simulation:

The module is built using “SIMULINK, MATLAB, Ra2015”.

Just like the previous module in JDECo. experiments, but in this section, it is three phase loads with 300 W, three phase induction generators with 1.5 KW, one PV string of 90 W, 360 W inverter, and three phase grids.

Full design is appearing in the following figure, to look inside, see Appendix A part 2.

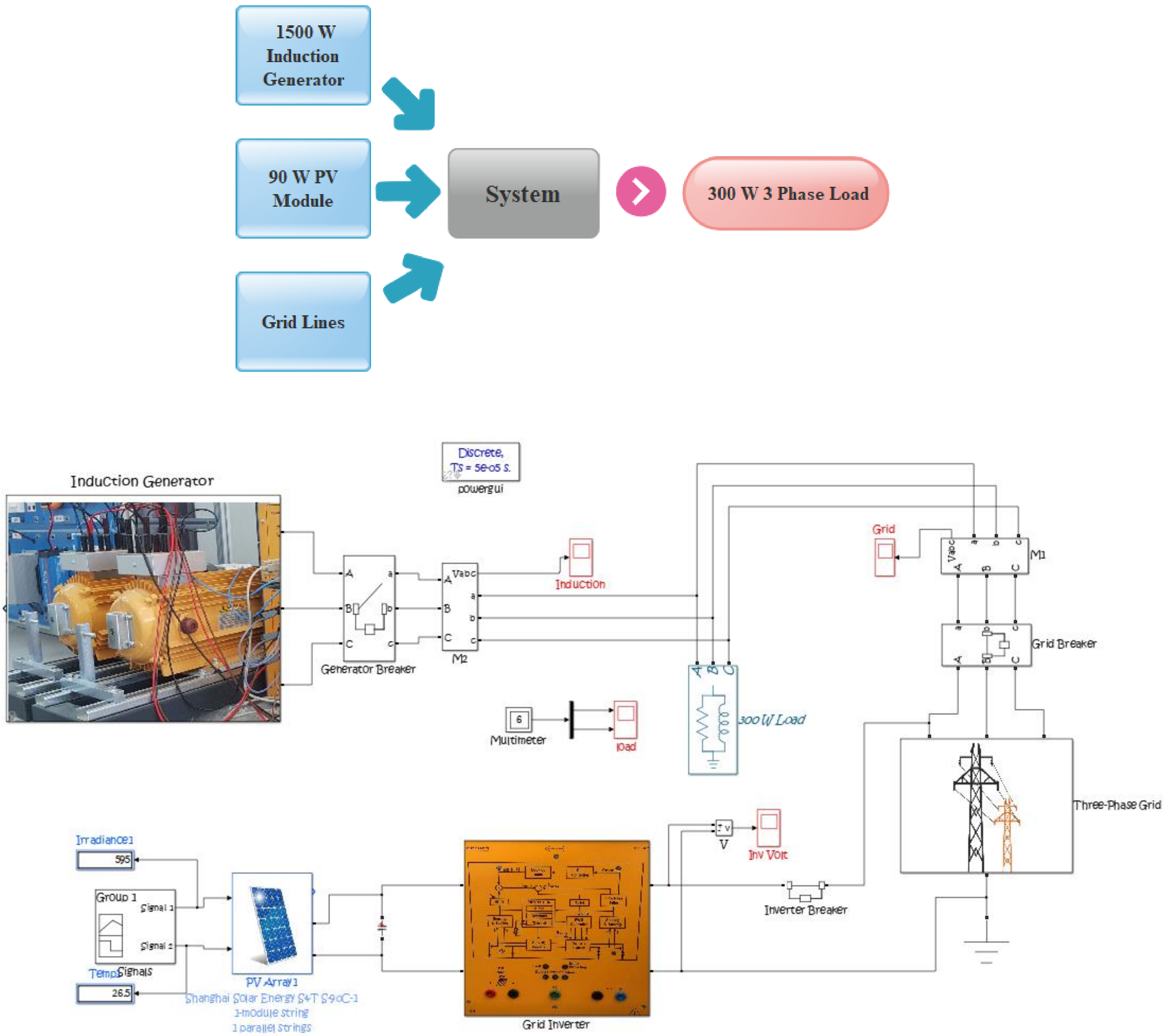


Figure4.39: Full MATLAB/SIMULINK design and block diagram for the smart lab.

4.2.2.4 Simulation results:

1) The three sources are connected to supply 300 W load.

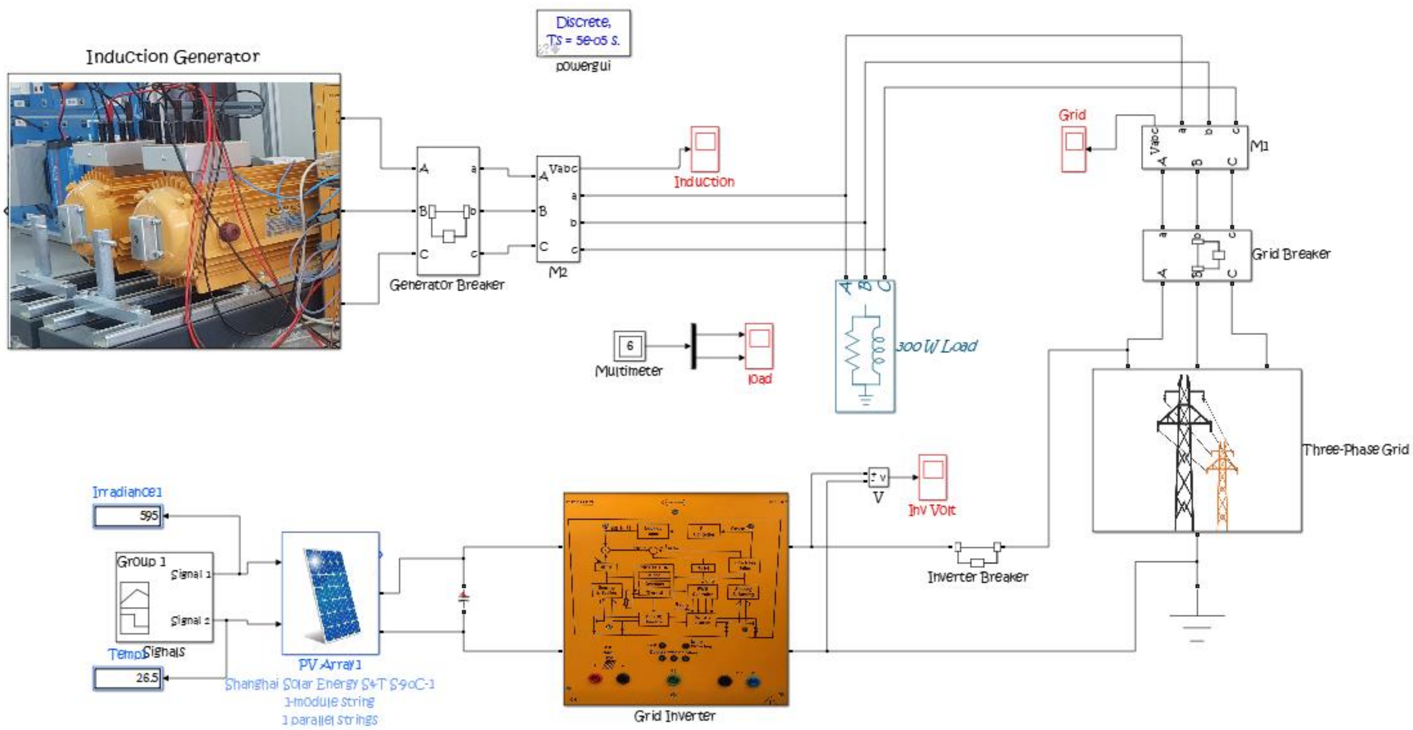


Figure4.40: Three sources are connected to supply 300 W load.

For this case and because of the connection of PV string to a single line which is line 1, the voltage and current of this line may be a little bit higher or less than the other 2 lines.

The following figure is showing the voltages and currents of the 3-phase load.

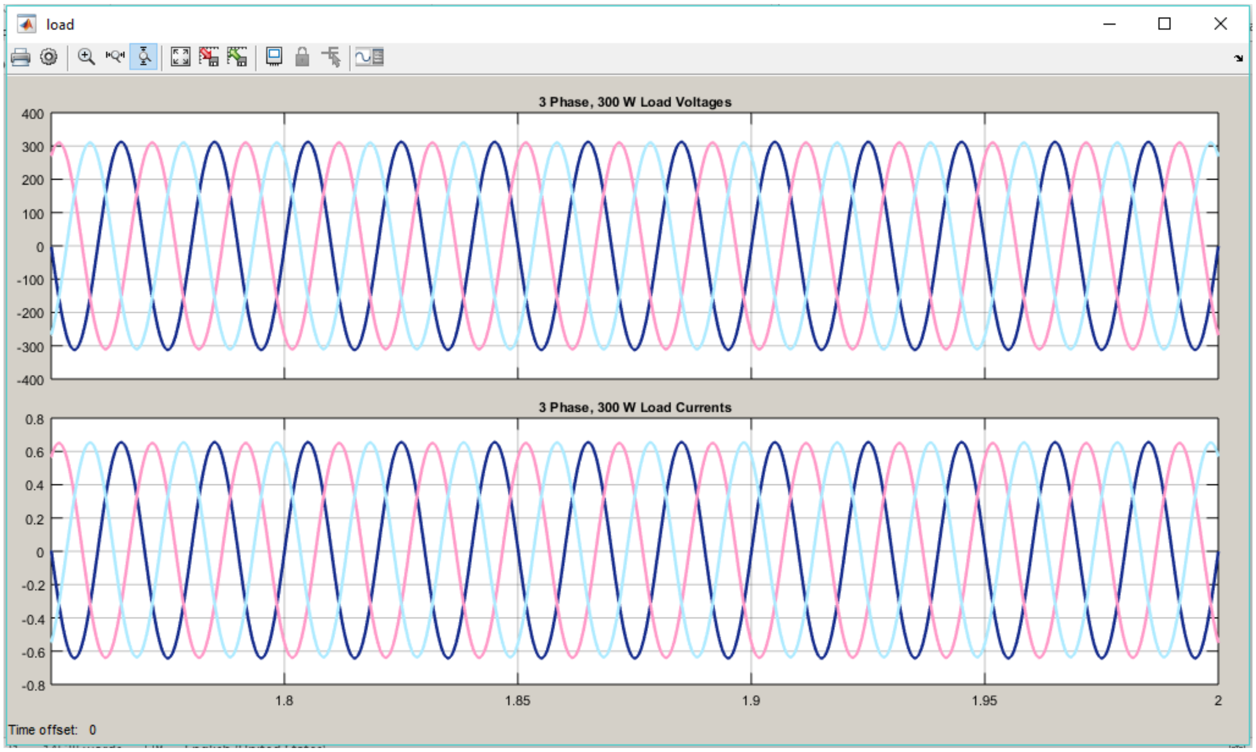


Figure4.41: Voltages and currents for 300 W load when 3 sources are connected.

2) When grid is disconnected from the load, by the way, PV will be disconnected too.

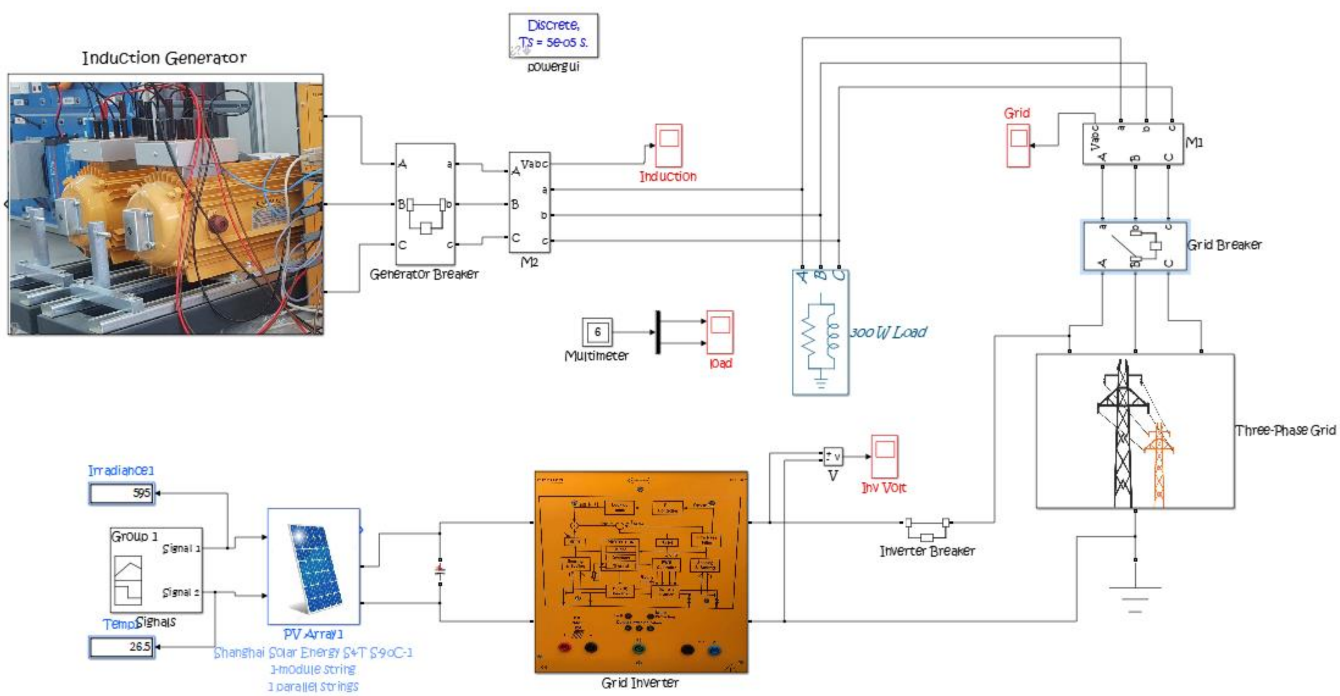


Figure4.42: Induction generator is the only supplier for the 300 W load.

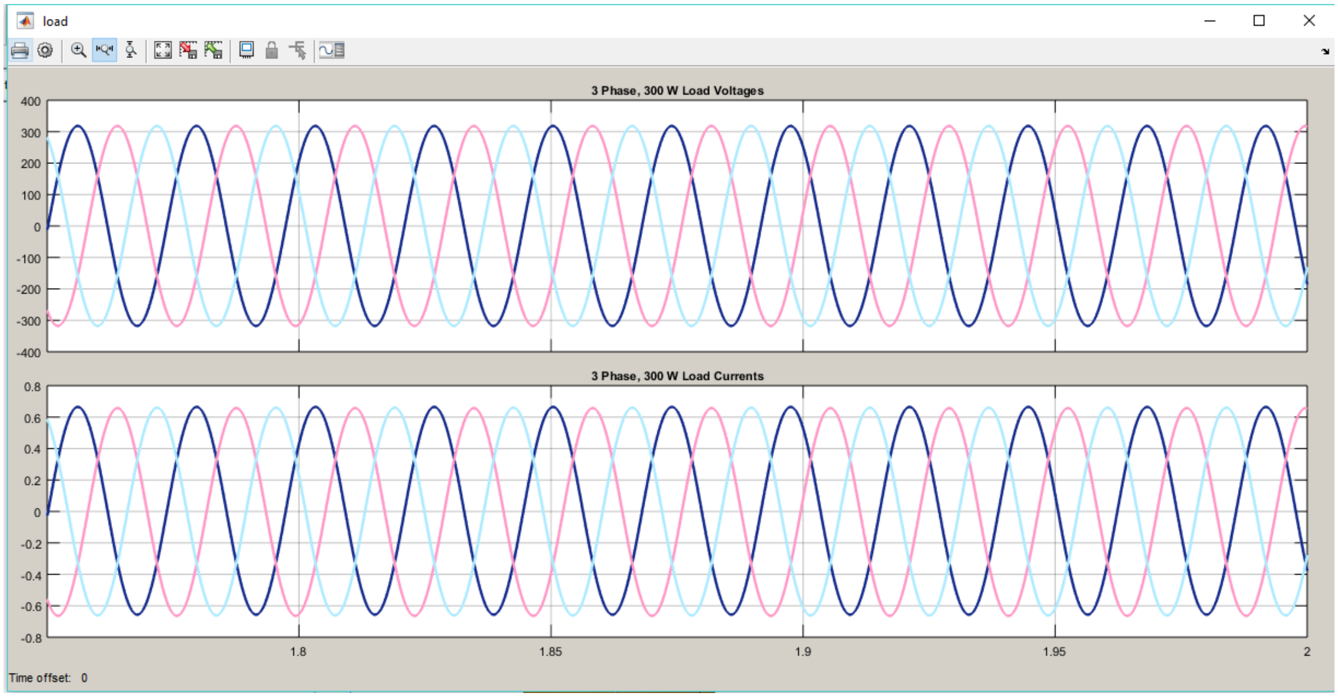


Figure4.43: Voltages and currents for 300 W load when induction generator suppling alone.

3) If the PV string is removed, and the grid with induction generator are connected:

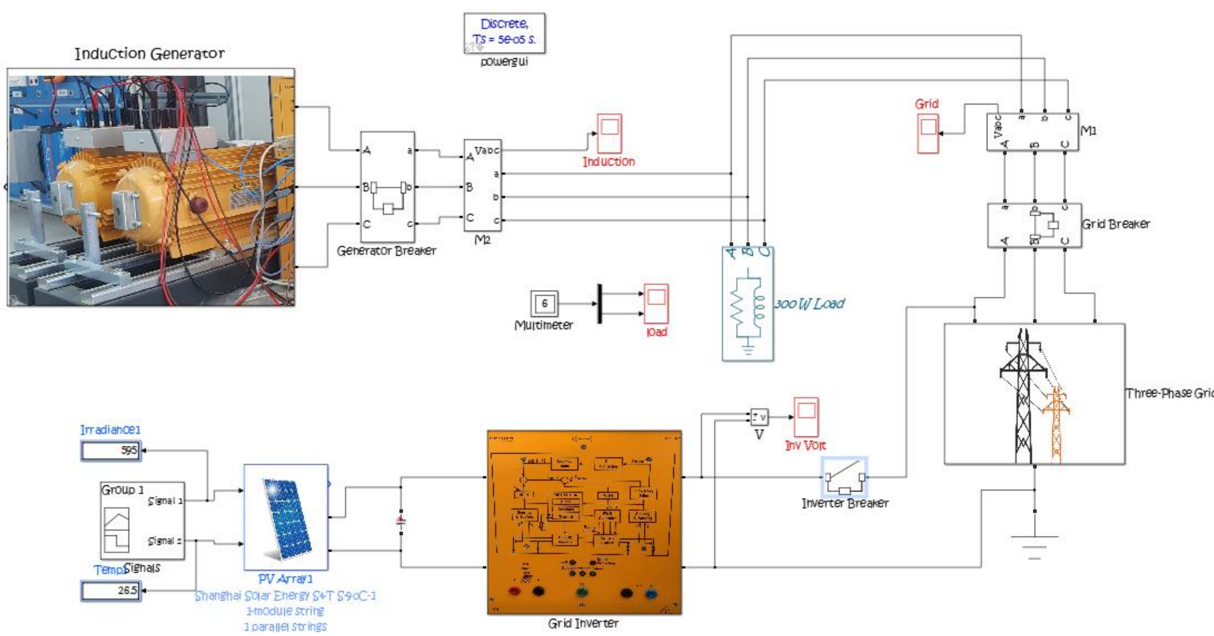


Figure4.44: Removing of PV from supply.

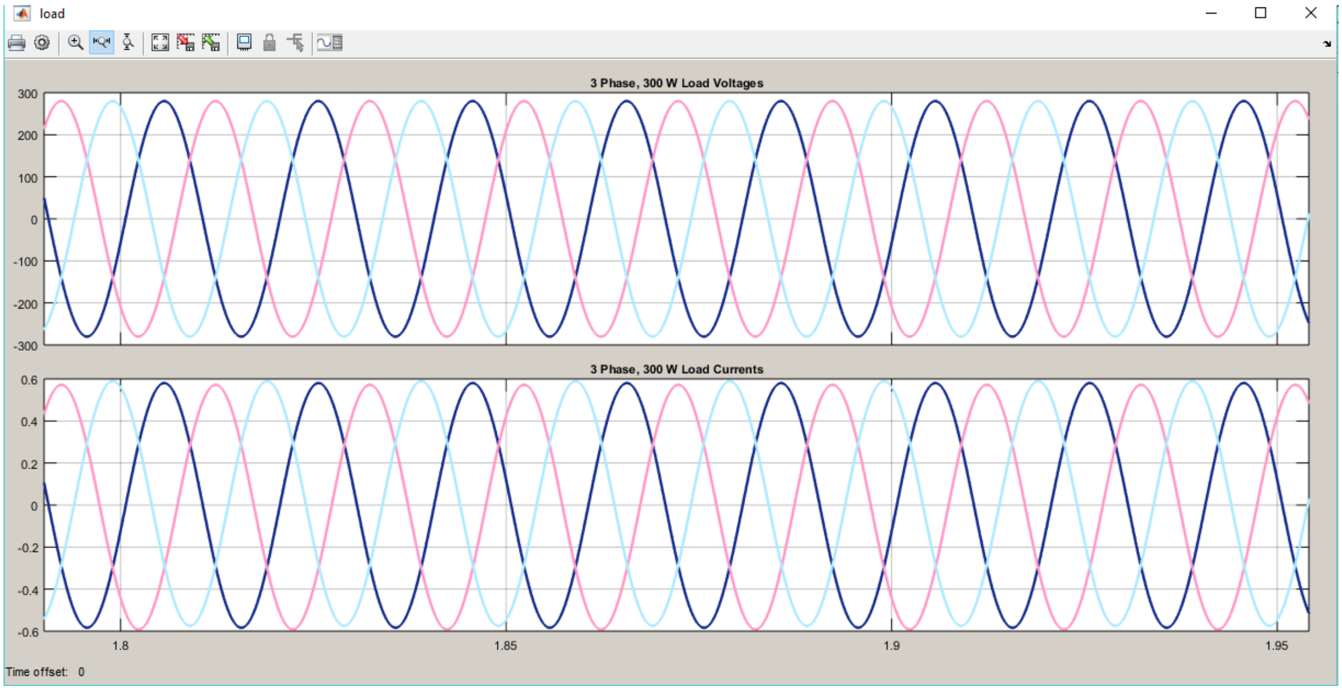


Figure4.45: Voltages and currents for 300 W load when PV is removed.

4) Grid is only the supplier for the load.

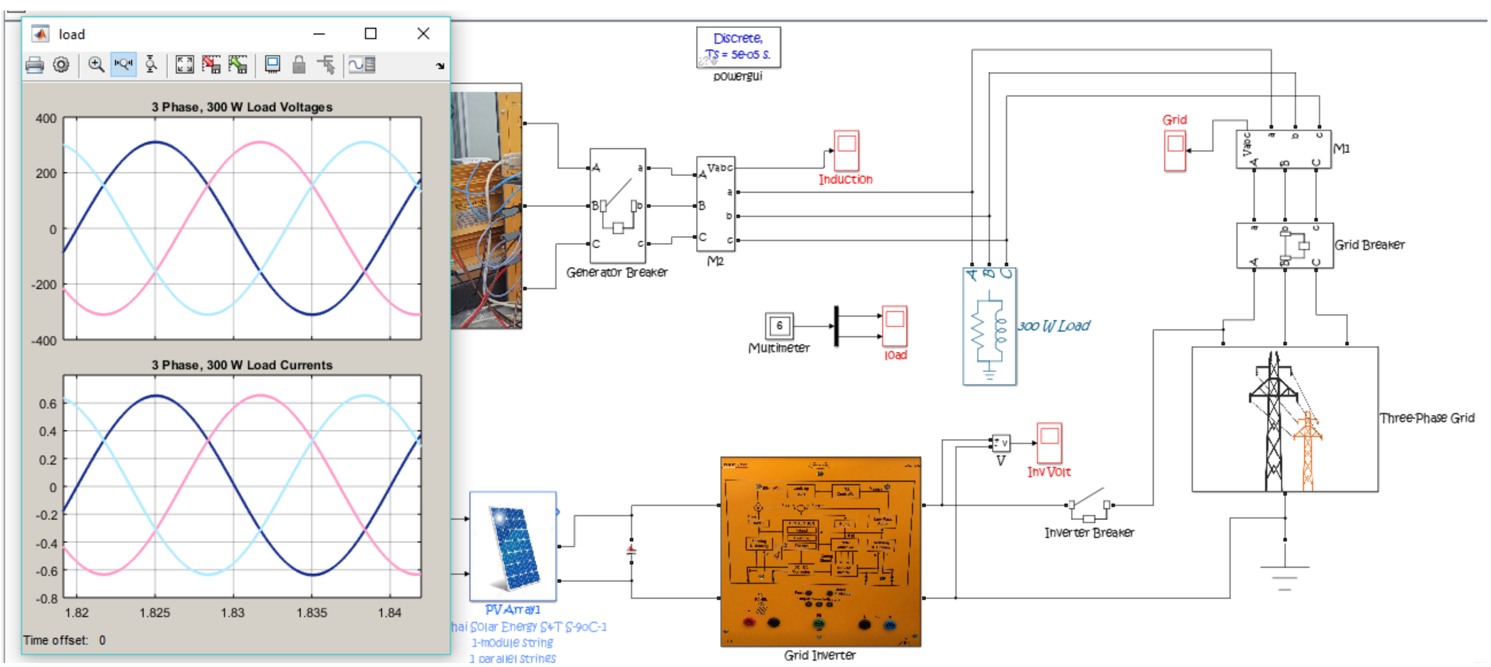


Figure4.46: Voltages, currents and network when grid is connected only.

Power flow using ETAP 16:

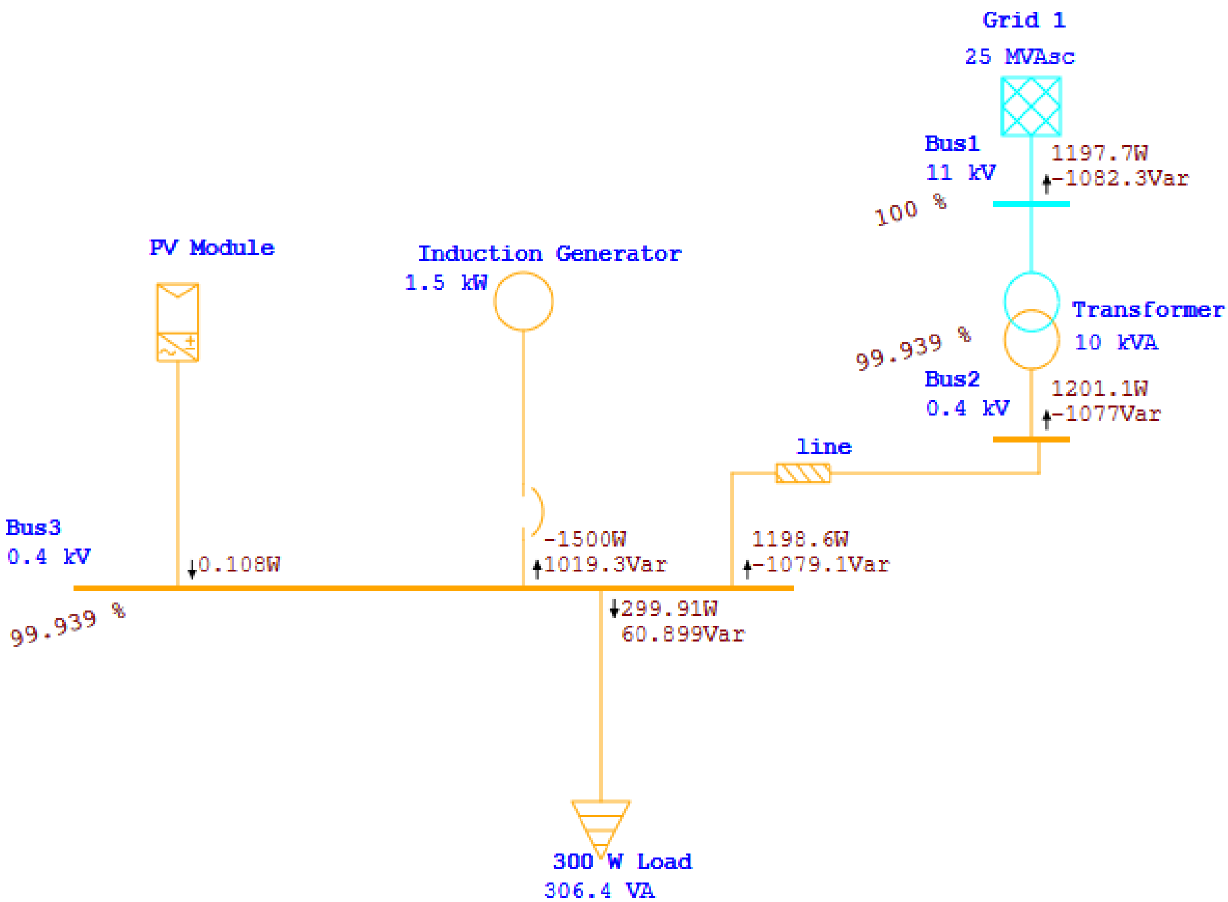


Figure4.47: Smart grid lab experiments power flow, ETAP16.

4.3 Smart meters and Meter Data Management (MDM):

4.3.1 PowerCom company profile:

PowerCom is a leading provider of smart grid "end to end" solutions for electricity, water, and gas utilities; developing, manufacturing, and marketing a complete AMI of innovative products including smart meters, communications infrastructure, demand response and smart home appliances, as well as **Meter Data Management software,** utilizing all available open protocol communication such as RF, GPRS, and Ethernet**. [16] [17]**

4.3.1.1 Smart meters:

Single and three phase smart electricity meter are shown below in the figure:

Figure4.48: Smart meters single and three phases.

The PCR421(single phase), PCR423 (three phase) meter is a powerful smart electricity meter built for residential applications. The meter combines advanced metering technology, and internal relay unit, integrated in a single housing, the meter supports energy, power, voltage, current, frequency, power factor, and other load profile measurements.

The integrated solution allows PowerCom to offer a real time AMI solution with two-way communication. It enables reading, controlling and interfacing other sensors or meters

The meter supports renewable energy sources (PV and Wind), also meter is approved according to **IEC62052, MID (**Measuring Instruments Directive**), SABS (**South African Bureau of Standards**), STS (**Standard Transfer Specification**) and ISO (**International Organization for Standardization).

The PCR421, PCR423 series comprise the following meter types:

1) Credit meter: credit meter registers energy consumption against time-of-use and multi-tariffs, it offers local and remote load control functionality.
2) Prepayment meter: prepayment meter, a credit amount is entered into the meter, and the remaining credit register is decremented as power is consumed, if the credit expires, the meter switches off automatically.

Features:

1) Fully featured IEC standard, certified **IEC** for active energy**, MID, SABS** and **STS** approved.
2) Measure and reverse active energy, RMS voltage, RMS current and power factor.
3) Measures demand response every 15 minutes or at any settable time.
4) Two step tariffs can be activated over a designated time (upon time or consumption).
5) Load disconnection when configurable power thresholds are exceeded.
6) Automatic, periodic register meter reading: interval, hour, daily and monthly freeze
7) Hardware and software security protection.
8) Multi communication flexibility which includes RS485, optical port, PLC (default) with GPRS or LAN (optional).
9) Remote firmware upgrade through communication.
10) Unit life expectancy of at least 20 years

Data concentrator unit (DCU):

The PCCG340 is a concentrator (Computing unit) that has the ability to communicate with various sensors and calculate real values as temperature, pressure, etc. It collects data and sends it to the management system.

Also, can send commands to the sensors as well as sends tamper alerts to the management system. This unit stores all sensor readings in a flash memory.

Features:

1) Provides information on GPRS signal quality back to the control center.
2) The following communication interfaces are supported:
   a. Upload: GPRS (max 85.6kbps), LAN, RS485, RS232 and IR.
   b. Compliant with international standards DLT645.
   c. Data rates from 2,400bps (bits per second).
3) The Concentrator works on power and battery.
4) In case of power failure, it stores the data in the non-volatile memory, to be uploaded to the management system.
5) Performs automatic time synchronization to all sensors.
6) Includes digital input and outputs to read or activate external devices.
7) Collects and stores 30 days of data from a maximum of 2000 sensor daily.
8) Stores last 12 months of data.

4.3.1.2 Dynamic power line communications:

PLC lines are mentioned in section 3.2.1, PLC also achieves real two-way communication with the highest reliability in the industry, and can be integrated into the smart meters.

1) The technology allows meters to communicate with a concentrator at a distance up to 2 Km over electricity wires (Aluminum/Copper) within 2-3 seconds with greater than 95% success.
2) PLC Concentrator communicates with up to 10,000 meters.
3) The system is plug & play, simply plug in the meter.

Figure4.49: Connection of DCU, smart meter, and management unit.

4.3.1.3 Meter Data Management:

It is a software that used to achieve remote monitoring, control, loss reduction and billing capabilities to manage, analyze, alert, report and respond to real-time events in the grid. this purpose is achieved by enhancing smart metering solution features between the smart meters, smart home devices and the MDM software.

Software abilities:

1) Energy theft reduction:
    a. Energy balancing.
    b. Consumption analysis.
    c. Real-Time alarms of meter fraud.
2) Demand response:
    a. Under frequency.
    b. Load control.
    c. Meter critical limits.
    d. Phase balancing.
3) Prepayment.
4) Customer Engagement:
    a. Online bills.
    b. Messaging to In Home Displays.
    c. SMS/Email customer alerts.
5) Remote meter control.
6) Secure.

4.3.1.4 Software manual:

The main screen, which has the following sections:

1) Top information bar:

a. Date and time.

b. User name log in.

c. Refresh.

d. Log out button.

2) VeriSign: located below the top info bar. The VeriSign icon indicates web security, data transmission.

3) Main menu: located on the green strip across the top of the screen. This menu enables access to the main PowerCom functions.

4) Fast access buttons: located immediately below the main menu. These buttons enable fast access to the most frequently used PowerCom MDM functions, derived from the main menu.

5) Tree: located in the left pane. The tree is to manage areas, DCUs and individual meters.

6) View pane: located in the center of the screen. This area is for working with tabs and settings for areas, DCUs and individual meters selected in the tree.

7) Search: located above the tree. It allows the user to search for a specific component (area / DCU / meter…) in the tree.

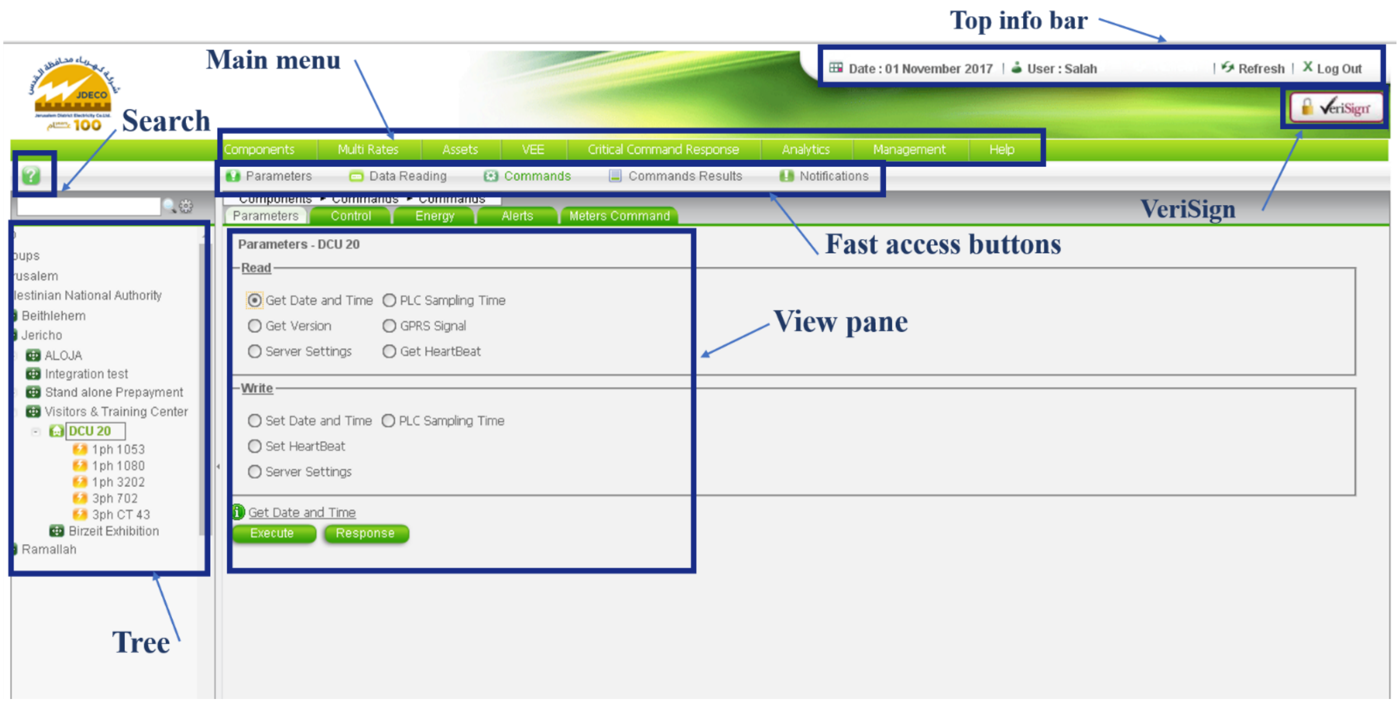


Figure4.50: MDM software main screen.

The tree and its components are the basis of the PowerCom MDM system. By selecting a specific component, the component information will be displayed in the view pane.

The tree consists of different type of components represented by different icons such:

1) Area (region): an area is a top-level grouping that includes all associated DCUs and meters. Areas are functional divisions, and can extend beyond a single geographical location, can be added or deleted as needed.
2) Electricity data concentrator unit (DCU): can be created, replaced, or deleted.
3) Electricity meter: can be created, updated, replaced, or deleted.

Icons of each component of tree can be seen in the previous figure also are shown in the table below:

Table4.4: Icons of each component of tree.

Component	Icon
Area	
DCU	
Smart Meter	

To set up the connection, GPRS communication details of the server should be prepared, also for DCU and meters; The same details should be in the area top level, this will affect all GPRS device below the area.

Figure4.51: Connection set up of meters and DCU.

Once the DCUs and meters have been defined in the system for a designated area, you must verify that PowerCom can communicate with the physical DCU and meter units. DCU connectivity is verified by sending a short series of commands to the DCU. meter connectivity is similarly verified by sending several commands to each meter. Once DCU and meter connectivity are verified, the PowerCom smart grid system is ready for operation.

Meter energy data:

PowerCom MDM collects the meter energy data reading from the meter to the server. The real-time data is displaying on tables and graphs where it is obtained from meter energy commands.

The data readings screen includes three tabs:

1) Reading: display meter data readings, it reads the following options:

   a. Daily: display meter data for one day by selecting the required date.
   b. Weekly: display meter data for one week by selecting the required week.
   c. Monthly: display meter data for one month by selecting the required month.
   d. Range: display meter data for range of dates by selecting the required dates.

2) Consumption: display meter consumption.
3) Graph: display meter consumption on graph.

The system also provides several options of devices commands:

1) DCU commands: one command at a time.
2) DCU meters command: multi commands from same subject to all DCU meters, the commands will be send by matching it to meter parameters and type.

Energy losses:

PowerCom enables comparison of the total electricity supplied via a transformer, and the actual electricity drawn by the meters associated with that transformer. If there is a difference between the power drawn and the power used, it indicates there is a problem, such as foul up, electricity theft or a disconnected meter.

Electricity supply and actual demand is verified by assigning a master meters to a transformer. They measure and compare transformer and meter network energy requirements, and identify any energy losses. The energy loss is calculating daily and alerts will open once a day.

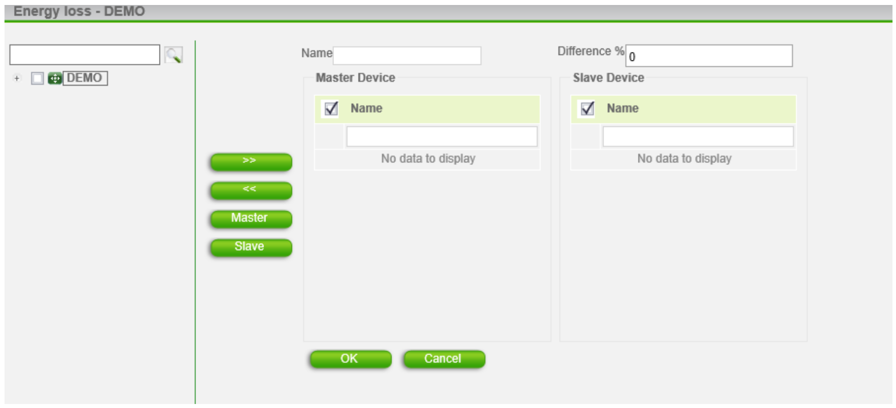


Figure4.52: Energy loss by MDM.

Load limitation:

It gives the option for the meters to limit the power, voltage and frequency, it also has the option to disconnect in the threshold.

DST or Day Light Saving:

Practice of advancing clocks during summer months by one hour. PowerCom meters perform an automatic clock change by settings of DST of the meter.

Load profile:

For selected meters the system can collect up to 24 channels of load profile. The system collection time can be defined to 15, 30, or 60 minutes intervals, as shown below.

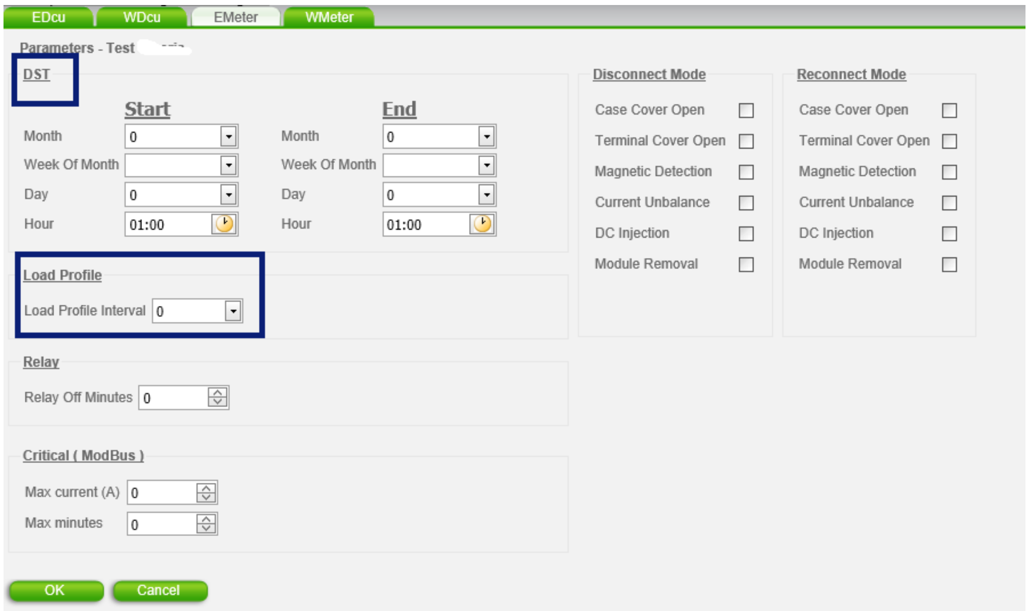


Figure4.53: DST and load profile in MDM software.

Installation history:

The history gives information about all installations made by installers with PowerCom.

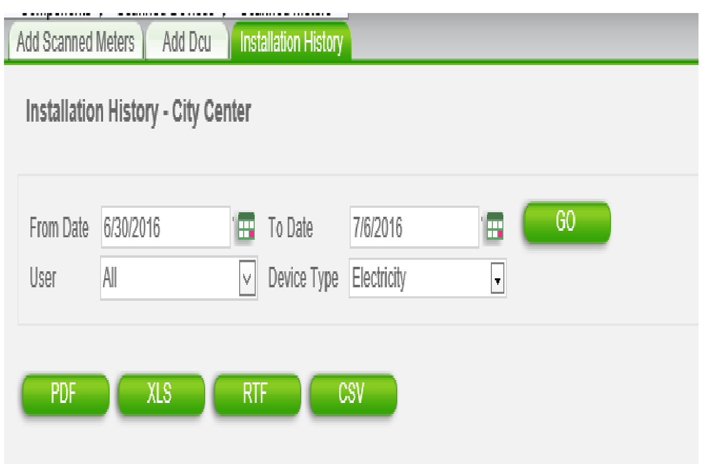


Figure4.54: Installation history of PowerCom.

Time of use:

TOU rates based on cost of electricity during particular time period during the day.

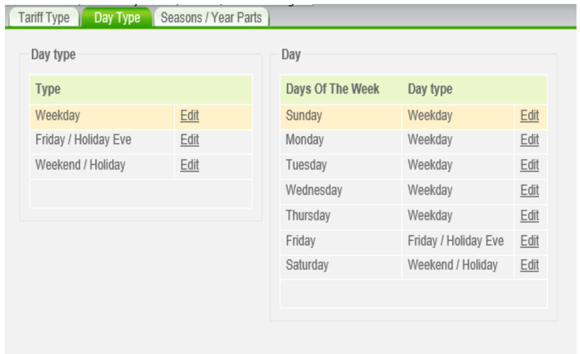


Figure4.55: Time of use by PowerCom.

Reports:

Reports can be produce on the PowerCom application. There are two different reports:

1) Build-in reports with filtering adapter to each report type.
2) Reports generator that give the user all tools to build and design reports.

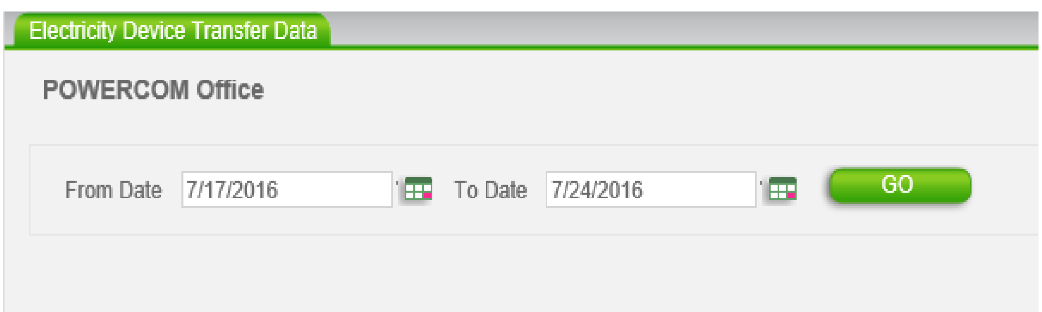


Figure4.56: Reports in PowerCom, built in reports or generated reports.

4.3.2 Smart meters and meter data management (MDM), case study:

This case study will present the same scenarios that mentioned before, but with a smart meter connected on the load side, in JDECo. that means two of their labs will be merged using a long cable to create the desired connection, they're smart grid lab and solar system lab.

Figure4.57: Connecting of two labs to study the scenarios by PowerCom components.

These scenarios, as explained before, are:

1) When both are connected, the operation will be as explained is before, PV is to charge the batteries, and grid is supplying the pure resistive 750 W load.
2) When PV station is only connected.
3) When PV is not connected, grid is supplying the load and charging the batteries.

After determining which meter should be used to be connected to the load, the ID number of it (1 Ph 3202) should be known to know which DCU is the smart meter connected to, then both should be selected by the MDM in order to set the relay of the meter on, send commands and receive data.

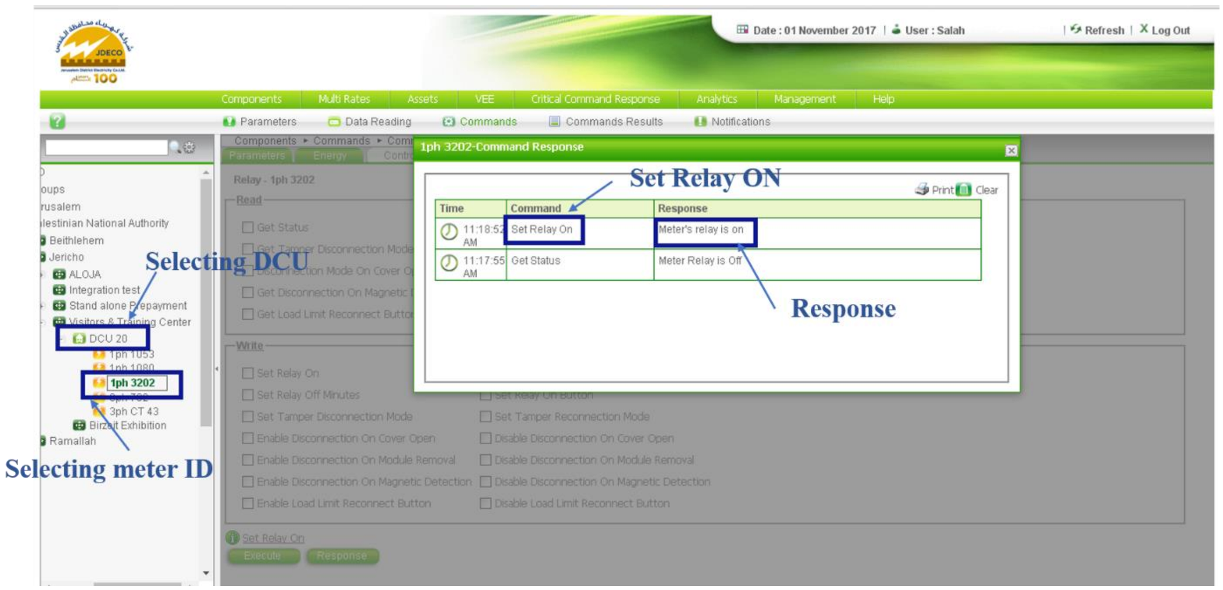


Figure4.58: DCU, smart meter, set relay on, response.

To start with the firs case, multi commands should be sent to the smart meter, in order to read the load profile of the connected load.

Figure4.59: Sending commands to smart meter.

Then, a message should appear on the view pane to approve that the commands are successfully verified.

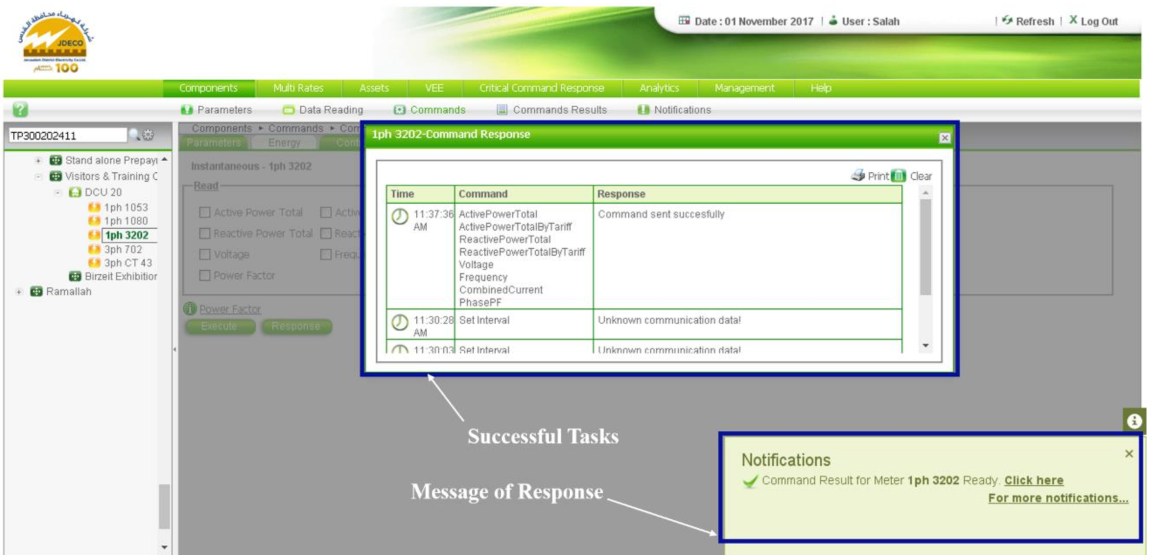


Figure4.60: Successful tasks and message of response.

These steps are repeated in every case to get the load profile for the pure resistive load.

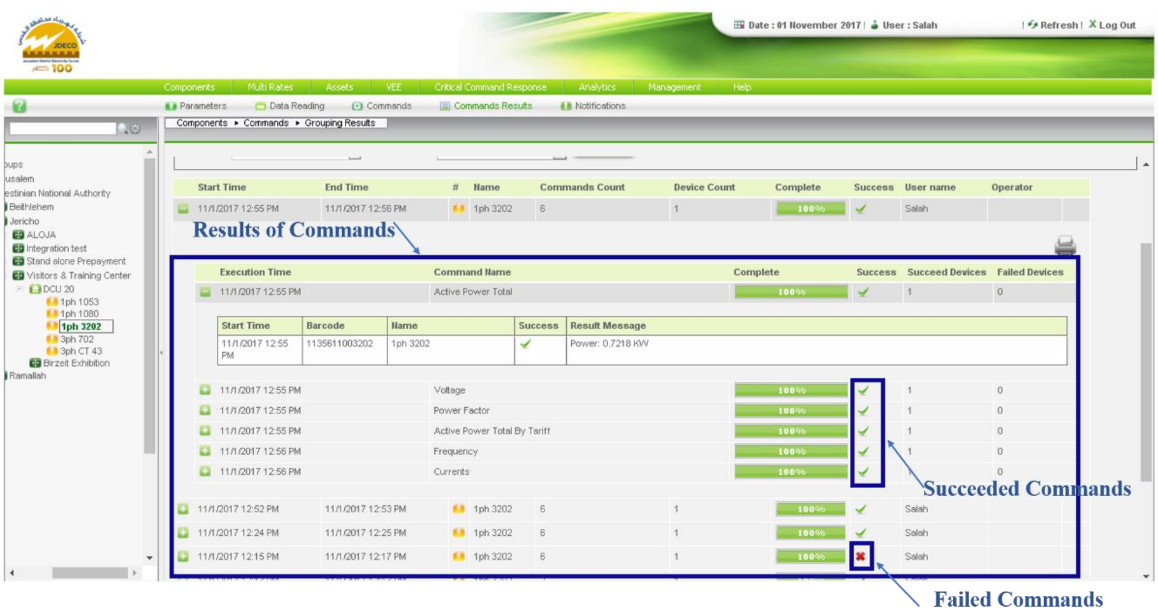


Figure4.61: Command results screen, succeeded commands and failed ones.

From this screen, load profile that consists of (power, voltage, power factor, frequency, and current) only, because there is no reactive power for the pure resistive load, or power by tariff since it is an educational smart meter.

1) Case 1, when both are connected, but the PV is charging the batteries and the grid is supplying the load, results for the load are:

Power

Start Time	Barcode	Name	Success	Result Message
11/1/2017 12:55 PM	1135611003202	1ph 3202	✓	Power: 0.7218 KW

Voltage

Start Time	Barcode	Name	Success	Result Message
11/1/2017 12:55 PM	1135611003202	1ph 3202	✓	232.2

Power factor

Start Time	Barcode	Name	Success	Result Message
11/1/2017 12:55 PM	1135611003202	1ph 3202	✓	0.999

Frequency

Start Time	Barcode	Name	Success	Result Message
11/1/2017 12:56 PM	1135611003202	1ph 3202	✓	Frequency: 49.92

Current

Start Time	Barcode	Name	Success	Result Message
11/1/2017 12:56 PM	1135611003202	1ph 3202	✓	Neutral Current: 3.128 Phase Current: 3.111

Figure4.62: Results of case 1, both are connected.

2) Results of case 2 are appeared on the following figure, PV station is only connected and grid is disconnected.

Power

Start Time	Barcode	Name	Success	Result Message
11/1/2017 11:38 AM	1135611003202	1ph 3202	✓	Total: 0.6787

Voltage

Start Time	Barcode	Name	Success	Result Message
11/1/2017 11:38 AM	1135611003202	1ph 3202	✓	225.5

Power factor

Start Time	Barcode	Name	Success	Result Message
11/1/2017 11:39 AM	1135611003202	1ph 3202	✓	0.999

Frequency

Start Time	Barcode	Name	Success	Result Message
11/1/2017 11:38 AM	1135611003202	1ph 3202	✓	Frequency: 49.96

Current

Start Time	Barcode	Name	Success	Result Message
11/1/2017 11:39 AM	1135611003202	1ph 3202	✓	Neutral Current: 3.03 Phase Current: 3.015

Figure4.63: Results of case 2, PV is connected only.

3) Results of case 3 will be as same as results of case 1, since the supplier in case one is the grid only.

4) When PV and grid are connected but there is no load:

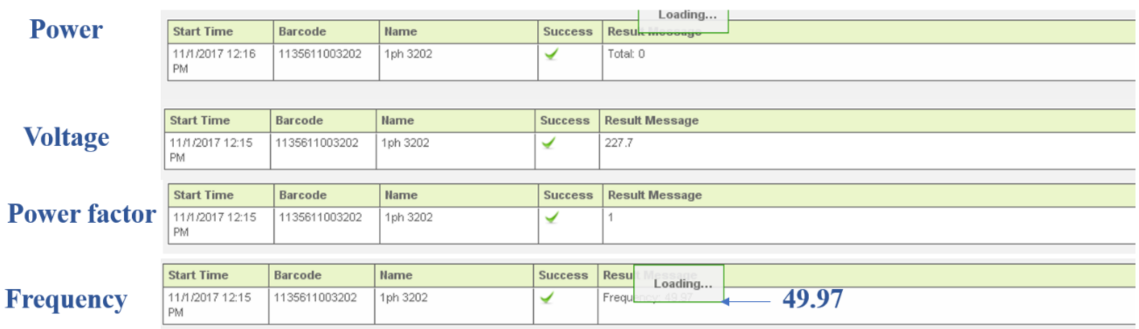


Figure4.64: No load case when both PV and grid are connected.

4.4 Beit Sahour case study:

4.4.1 Overview:

Beit Sahour is a Palestinian town east of Bethlehem under the administration of the Palestinian National Authority, in this section, a small neighborhood will be studied in order to prove the abilities and features of smart meters, the focus will be on losses on branches and loads compared with reality.

4.4.2 Analysis:

The small neighborhood has a distribution transformer rated of 160 KVA, and a PV station of 30 KW, located near the transformer and supplies a load of almost 7 KW, the remaining energy is injected to the electricity pool due to agreement between the consumer and JDECo. The transformer usually loaded by 60 KW plus 21 KW from PV station as maximum loading, losses on transformer and branches at this load is almost (1630 W) which is 2.7% of the transformer load, simulation shows that the load on transformer is 56.869 KW plus 27 KW from PV station which differs from the real production, and the losses are 1.589 KW.

4.4.2.1 Highlights:

1) Transformer: this transformer was installed and named by JDECo. since Beit Sahour is an area that provided by them, its name is (TR 3002-13).

Figure4.65: TR 3002 -13.

2) PV station: consumer who has this station has a load in **average** of 7 KW, and 17 KW generation, so the bidirectional power measured by the smart meter is the power that is about 10 KW surplus. But the maximum generation of this station as mentioned before is 21 KW. The station contains PV cells connected in series and parallel to give in the ideal situation 30 KW.

   Nameplate is attached in Appendix B.

3) Feeders: three feeders are connected to the transformer, one is the main from the electrical grid, and the other two feeders are CR3, and CR6 is for the same consumer that has PV station, and CR3 is for other consumers, a load profile was generated by smart meters in 2-5 days with time interval of 0:30 hrs. is attached in Appendix B,

results of the transformer loading and PV generation are calculated by MATLAB, included in the following figure:

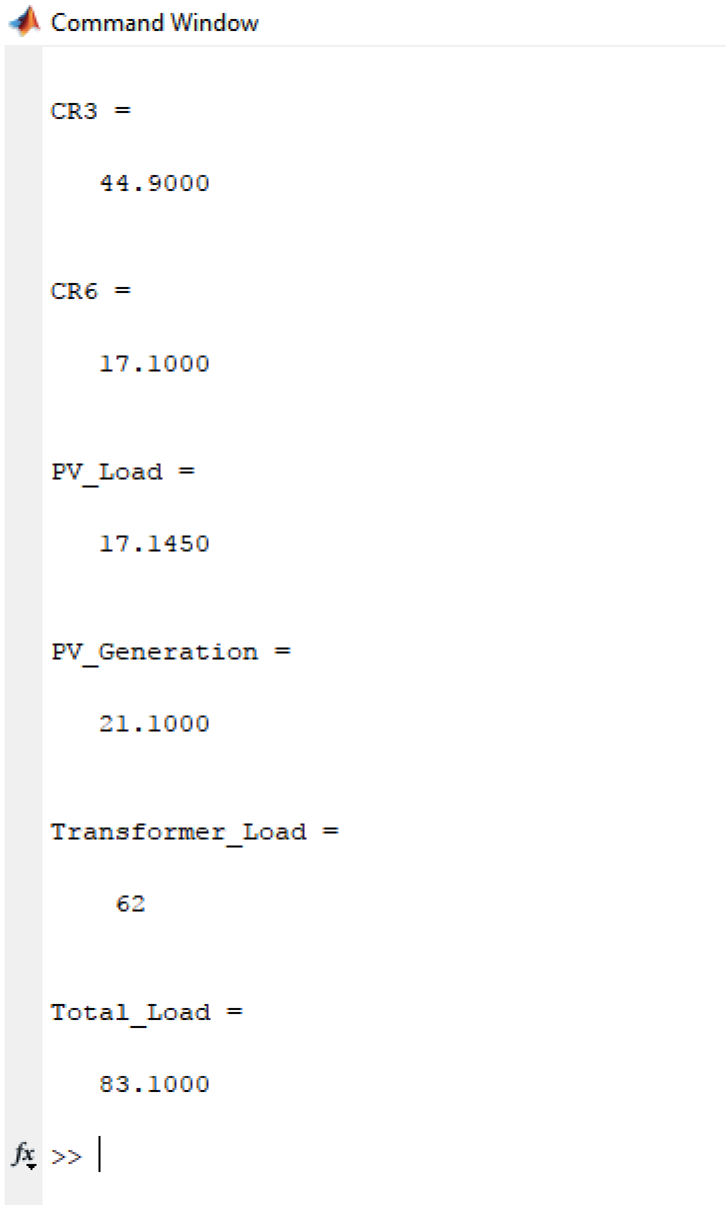


Figure4.66: Maximum load and generation of feeders, MATLAB.

4.4.2.2 ETAP 16 results:

Site and power flow of the chosen case are included in Appendix B, power flow shows that the transformer is loaded by 56.869 KW and the generation from PV station is 27.1 KW, the loads are at their maximum or rated values, sum of generation will be 84 KW which is close to the reality maximum loading. Power flow table is attached below, and power flow network is attached in Appendix B.

Table4.5: Power flow results by ETAP16.

Load ID	Rating/Limit	Rated kV	CASE STUDY- SMART METERS, KW
302-13-CX1	11.53 kVA	0.24	9.812
302-13-CX5	7.33 kVA	0.24	6.132
302-13-CX7	2.54 kVA	0.24	1.75
L302-13-CX3	3.25 kVA	0.24	2.613
Load1	3.15 kVA	0.24	2.653
PV Station Load(TP)	7.4 kVA	0.4	6.877
SP300201373	2.21 kVA	0.24	1.75
SP300201628	2.1 kVA	0.24	1.77
SP300201646	1.09 kVA	0.24	0.88
SP300202400	5.24 kVA	0.24	4.392
SP300202565	2.1 kVA	0.24	1.767
SP300203816	2.1 kVA	0.24	1.813
SP300204166	1.05 kVA	0.24	0.88
TP300201626	23.05 kVA	0.4	20.592
TP300202213	15.72 kVA	0.4	13.921
TP300203962	4.19 kVA	0.4	3.786
TP300204268	1.05 kVA	0.4	0.952

The reality losses are the losses of transformer and branches or cables between poles, it is in sum equals to 1630 W which is considered as (1630/ 60 KW) * 100 = 2.71 %.

ETAP 16 simulation, gives losses in total (1.589 KW/56.869KW =2.7%):

Table4.6: ETAP 16 losses.

Branch \ Losses	Losses in KW
Main Transformer	0.225
Under_G2	0.027
Under_G3	0.077
Under_G1	0.001
Over Head 1	0.403
Under_G4	0.019
Over Head 2	0.310
Bundel_3	0.021
Bundel_4	0.008
Bundel_5	0.008
Under_G8	0.005
Under_G9	0.013
Under_G7	0.001
Under_G18	0.001
Bundel_2	0.001
Under_G5	0.001
Bundel_6	0.108
Under_G10	0.001
Under_G11	0.003
Under_G12	0.001
Bundel_7	0.022
Bundel_8	0.084
Under_G13	0.053
Over Head 3	0.048
Under_G14	0.001
Over Head 4	0.061
Under_G15	0.061
Under_G16	0.025
Bundel_9	0
Under_G17	0
Sum	**1.589**

A scaled power flow which is made to let the transformer run at full capacity, and losses are included in appendix B, also company simulation results are included in Appendix B.

4.4.2.3 Monitoring system:

SCADA system and as mentioned before, is the system that used to monitor and control electrical grids and remote units, a simple model of SCADA system has been built using SIMULINK MATLAB, Ra2015 with a power flow. Monitoring system was built and connected at some bus of the used case study buses in order to measure the voltage, current, power, power factor, apparent power, percentage over voltage and voltage drop if exist, THDv, THDi, and symmetrical components.

The same case study and its power flow are following:

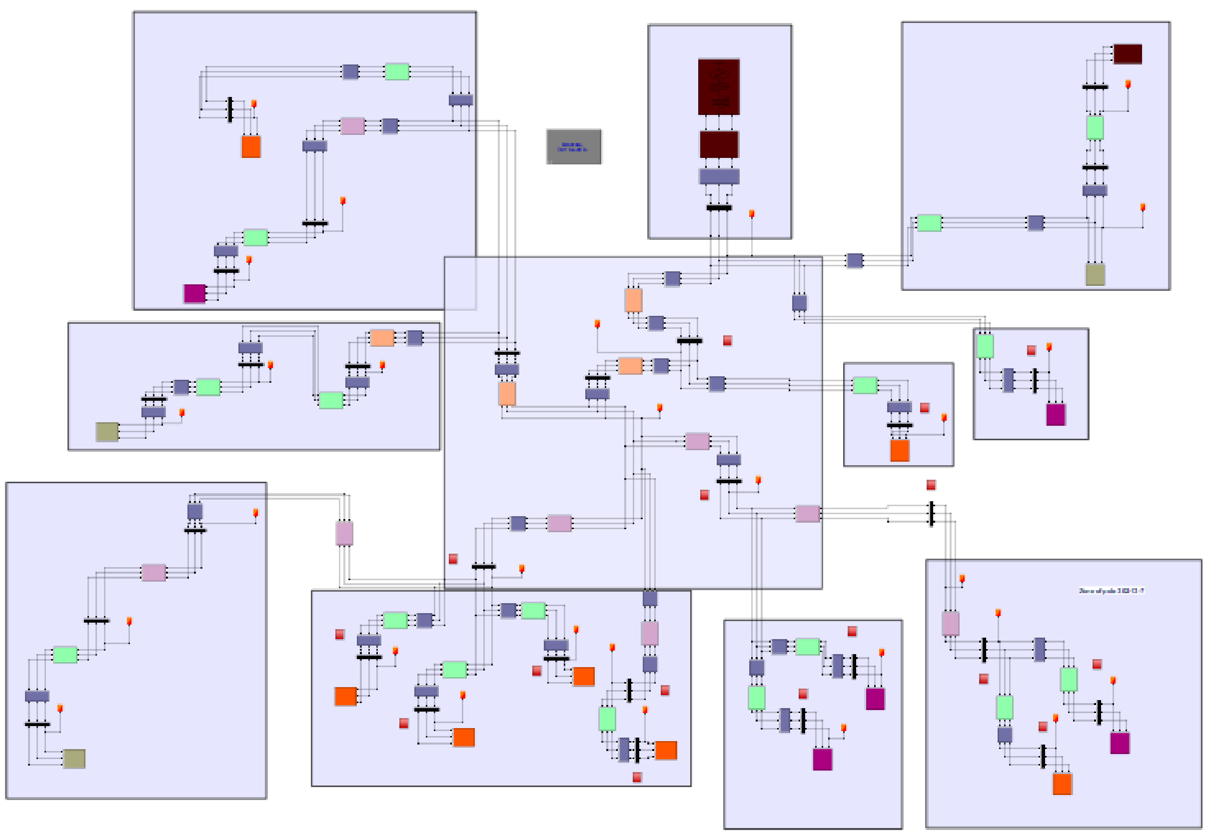


Figure4.67: Case study electrical design by SIMULINK.

In this design, the grid is divided into 11 zones as the figure shows, the main components are attached in Appendix B, monitoring system will be explained later in this section.

Zoom to one zone, let it be the zone of pole 302-13-7:

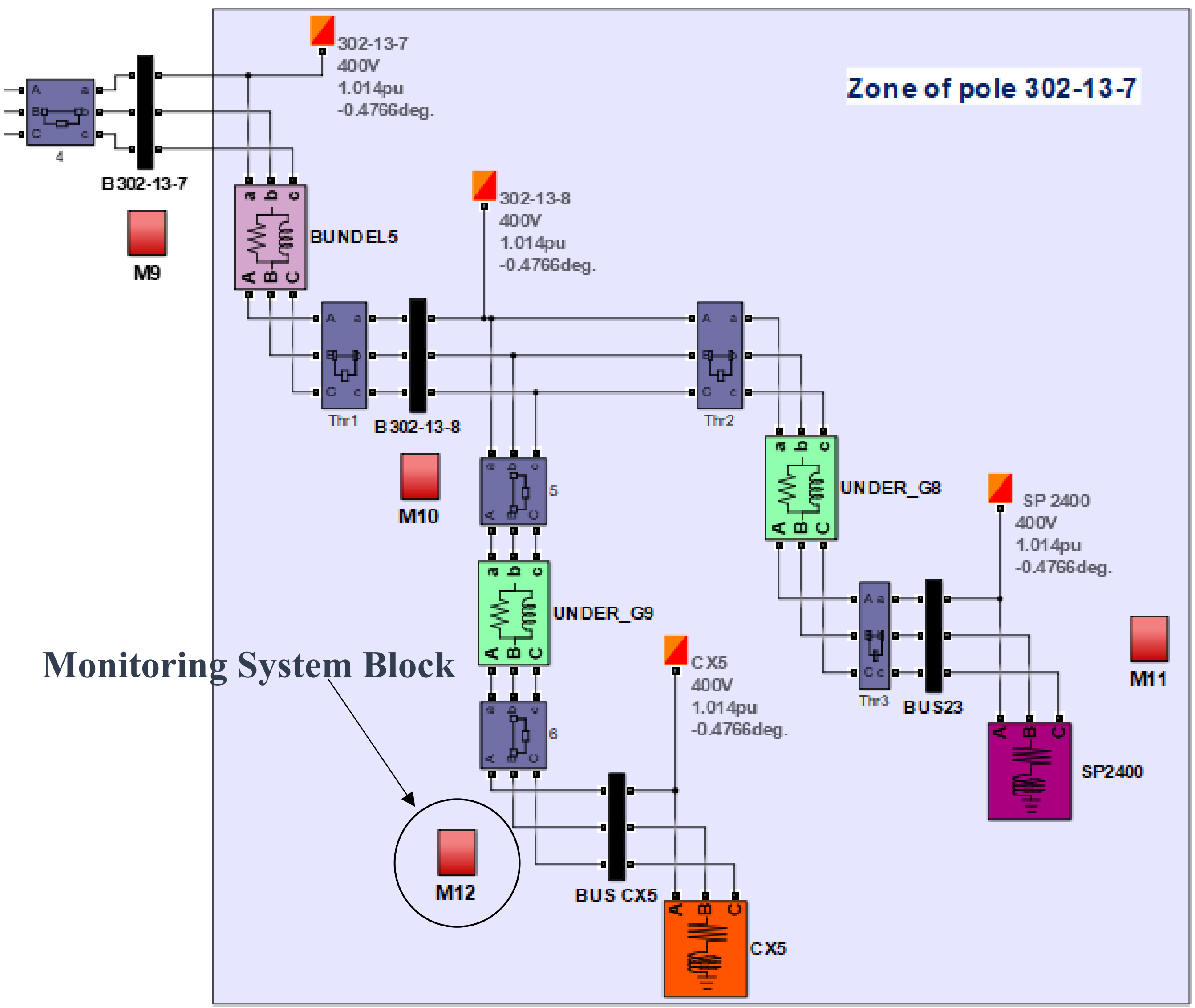
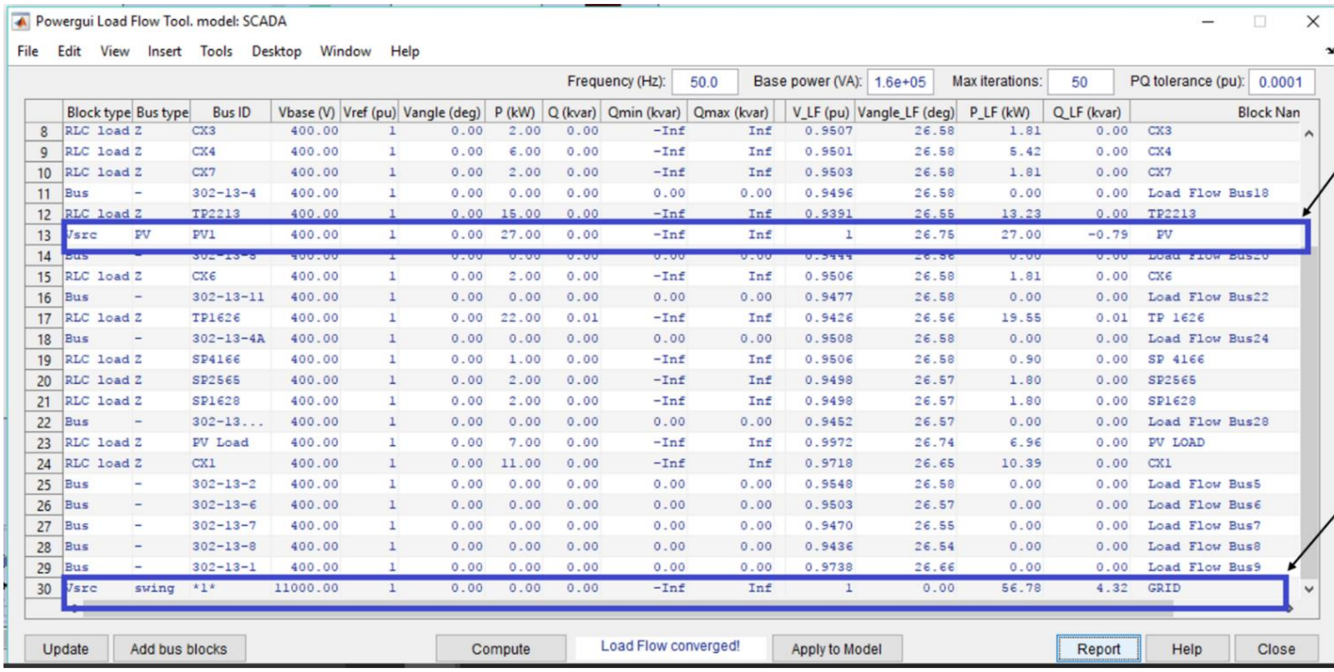


Figure4.68: Zone of pole 203-13-7 in SIMULINK.

Power flow results are:


Powergui Load Flow Tool. model: SCADA

File Edit View Insert Tools Desktop Window Help

Frequency (Hz): 50.0 Base power (VA): 1.6e+05 Max iterations: 50 PQ tolerance (pu): 0.0001

	Block type	Bus type	Bus ID	Vbase (V)	Vref (pu)	Vangle (deg)	P (kW)	Q (kvar)	Qmin (kvar)	Qmax (kvar)	V_LF (pu)	Vangle_LF (deg)	P_LF (kW)	Q_LF (kvar)	Block Nan
8	RLC load	Z	CX3	400.00	1	0.00	2.00	0.00	-Inf	Inf	0.9507	26.58	1.81	0.00	CX3
9	RLC load	Z	CX4	400.00	1	0.00	6.00	0.00	-Inf	Inf	0.9501	26.58	5.42	0.00	CX4
10	RLC load	Z	CX7	400.00	1	0.00	2.00	0.00	-Inf	Inf	0.9503	26.58	1.81	0.00	CX7
11	Bus	-	302-13-4	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9496	26.58	0.00	0.00	Load Flow Bus18
12	RLC load	Z	TP2213	400.00	1	0.00	15.00	0.00	-Inf	Inf	0.9391	26.55	13.23	0.00	TP2213
13	Vsrc	PV	PV1	400.00	1	0.00	27.00	0.00	-Inf	Inf	1	26.75	27.00	-0.79	PV
14	Bus	-	[illegible]	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9444	[illegible]	0.00	0.00	Load Flow Bus20
15	RLC load	Z	CX6	400.00	1	0.00	2.00	0.00	-Inf	Inf	0.9506	26.58	1.81	0.00	CX6
16	Bus	-	302-13-11	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9477	26.58	0.00	0.00	Load Flow Bus22
17	RLC load	Z	TP1626	400.00	1	0.00	22.00	0.01	-Inf	Inf	0.9426	26.56	19.55	0.01	TP 1626
18	Bus	-	302-13-4A	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9508	26.58	0.00	0.00	Load Flow Bus24
19	RLC load	Z	SP4166	400.00	1	0.00	1.00	0.00	-Inf	Inf	0.9506	26.58	0.90	0.00	SP 4166
20	RLC load	Z	SP2565	400.00	1	0.00	2.00	0.00	-Inf	Inf	0.9498	26.57	1.80	0.00	SP2565
21	RLC load	Z	SP1628	400.00	1	0.00	2.00	0.00	-Inf	Inf	0.9498	26.57	1.80	0.00	SP1628
22	Bus	-	302-13...	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9452	26.57	0.00	0.00	Load Flow Bus28
23	RLC load	Z	PV Load	400.00	1	0.00	7.00	0.00	-Inf	Inf	0.9972	26.74	6.96	0.00	PV LOAD
24	RLC load	Z	CX1	400.00	1	0.00	11.00	0.00	-Inf	Inf	0.9718	26.65	10.39	0.00	CX1
25	Bus	-	302-13-2	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9548	26.58	0.00	0.00	Load Flow Bus5
26	Bus	-	302-13-6	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9503	26.57	0.00	0.00	Load Flow Bus6
27	Bus	-	302-13-7	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9470	26.55	0.00	0.00	Load Flow Bus7
28	Bus	-	302-13-8	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9436	26.54	0.00	0.00	Load Flow Bus8
29	Bus	-	302-13-1	400.00	1	0.00	0.00	0.00	0.00	0.00	0.9738	26.66	0.00	0.00	Load Flow Bus9
30	Vsrc	swing	*1*	11000.00	1	0.00	0.00	0.00	-Inf	Inf	1	0.00	56.78	4.32	GRID

Update · Add bus blocks · Compute · Load Flow converged! · Apply to Model · Report · Help · Close

Figure4.69: Power flow results in SIMULINK.

Monitoring block:

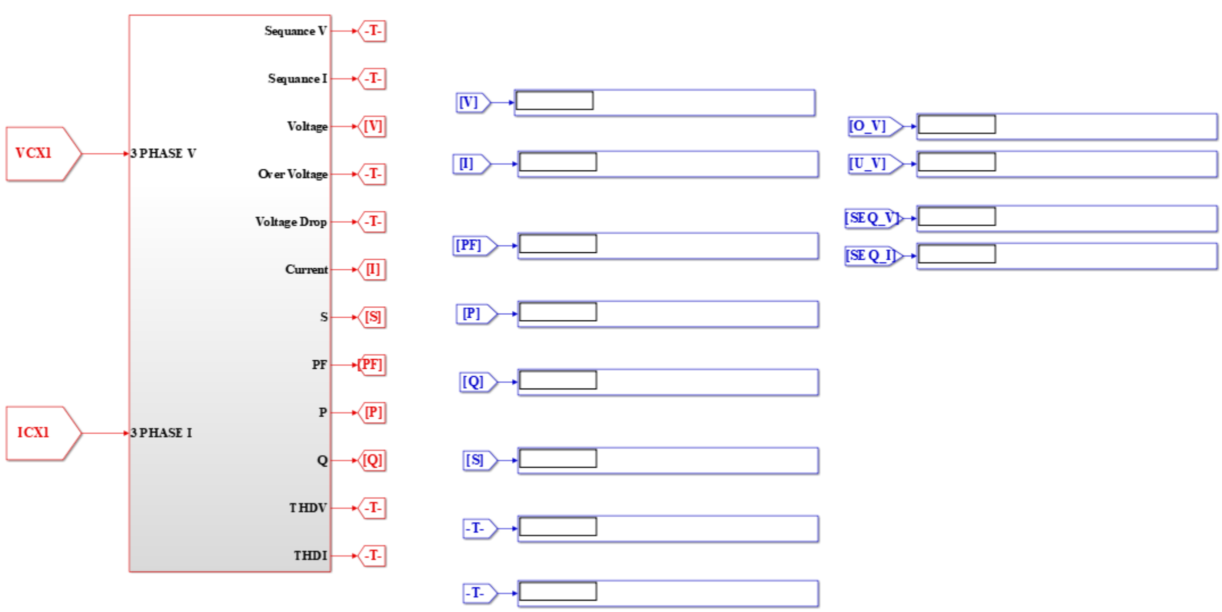


Figure4.70: Monitoring block in SIMULINK.

To look inside the monitoring block, see Appendix B.

Testing of one pole using monitoring block:

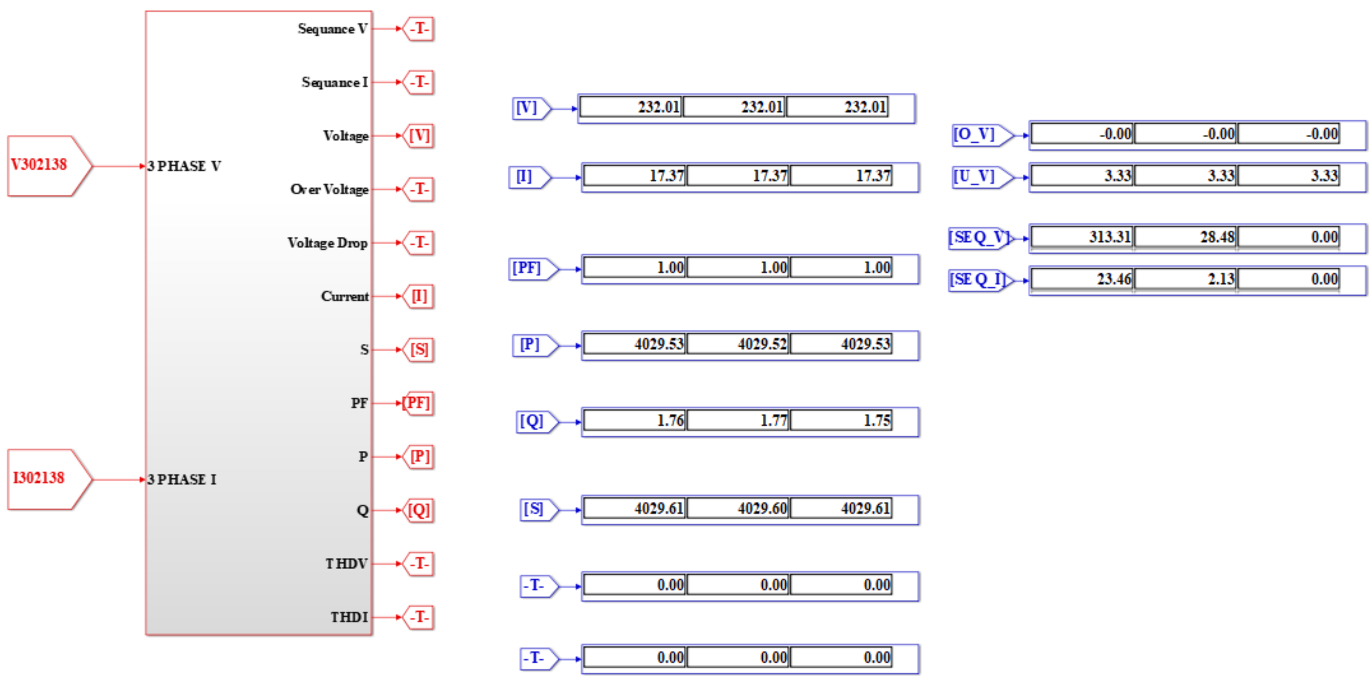


Figure4.71: Testing of monitoring block in SIMULINK.

4.5 Distribution generators:

4.5.1 Overview:

The key goal of smart grid is to promote active customer participation and decision making as well as to create the operation environment in which both utilities and electricity users influence each other. In smart grids, users can influence utilities by adding distributed generation sources such as photovoltaic (PV) modules or energy storage at the point of use, and reacting pricing signals.

DG are related with the use of small generating units installed at strategic points of the electric power system or locations of load centers. The equipment ranges in size from less than a kilowatt (kW) to tens of megawatts (MW). DG can be used to supply the consumer's local demand, or integrated into the grid supplying energy to the remainder of the electric power system **[18].** DG can be interconnected at substation, distribution feeder or customer load levels.

Distributed generation can support weak grids, adding grid voltage and improving power quality. Having generation close to load can reduce transmission losses and infrastructure costs and can support the operation of local islands of electricity to reduce impacts of wide scale black-outs. **[19]**

4.5.2 DG technology:

DG technologies can run on as:

1) Non- Renewable energy resources.

2) Renewable energy resources.

4.5.2.1 Combined Heat and Power (CHP):

Combined heat and power (CHP) includes **[19]**:

1) Reciprocating engines: also often known as a piston engine, used to convert pressure into a rotating motion, it has low cost and can achieve fuel efficiencies more than 40% , while nearly half of the capacity is for standby use.
2) Gas turbine: are widely used in power industry. They are helpful when the required temperature steam is higher than reciprocating engines. it can be noisy but it has a high efficiency.

These types of CHP are the most significant type of the embedded generation in distribution systems. It produces electrical power and useful heat. While the generating heat are usually used for industrial processes. Also, it is a well-established way for increasing overall energy efficiency.

4.5.2.2 Microturbines:

These units can use a wide range of fuels such as natural gas, hydrogen, propane and diesel to produce electricity, they can be used for base load power, stand-by power, peak shaving and cogeneration applications and well-suited for small commercial buildings.

The capacity of microturbines range from 25 kW to 500 kW and have an electrical efficiency of about 15%.

4.5.2.3 Fuel Cells:

Fuel cells can convert chemical energy to electricity without combustion. Fuel cell technologies were initially developed for space applications, and then the transportation sector found it to be a promising technology. Since this technology has good efficiency, compact size, and very low noise.

The output current of a fuel cells is dc and hence can be used directly for dc applications. For ac applications, it needs power electronics controllers to convert the output power to ac form. Fuel cells can operate in various modes such as grid independent operating mode, and grid connected operating mode.

4.5.2.4 Renewable Energy (RE):

Salient features of Renewable Energy sources that impact their integration into power grids are their size of generation capacity as compared to other sources of power generation on a system, their geographical location with respect to network topology, and their variability of output which critically depends on time and climatic conditions.

The growing installations of renewable energy resources require a coordinated effort from the planning stage all the way down to the electronic devices used for power generation, distribution, storage and consumption, types of most common RE are:

1) Photovoltaic System (PV): PV generates power in a manner that is fundamentally different than the way power has been generated in the past, and requires a power electronics interface to convert the native format of the generation so it becomes grid-

compatible. The intermittency of PV power stems from the diurnal and seasonal cycles of the sun and is deterministic. Its variability due to the fact that the instantaneous power generation depends on the level of solar radiation. Its variability due to the fact that the instantaneous power generation depends on the level of incident solar radiation. it is best for small commercial applications or household.

2) Wind System: wind turbine can be defined as the tool that changes the energy of the kinetic from the wind, which is sometimes known as the wind energy, into automatic power throughout procedures named the wind power, types of the generators used in wind turbines are shown below **[20]**:

Table4.7: Generators used in wind turbines.

Type \ Definitions		Definition
Asynchronous Generator	Squirrel Cage Induction Generator	fixed speed concept, directly connected to the wind through a transformer, soft starter is used for smooth grid connection, does not support any speed control.
	Wound rotor induction generator (WRIG)	variable speed concept, Wound Rotor Induction Generator is directly connected to the grid, soft starter used here for reduce inrush current, poor control of active and reactive power.

Synchronous Generator	Wound Rotor Generator	it's configuration neither require soft starter nor a reactive power comparator, partial scale frequency converter used in the system will perform reactive power compensation as well as smooth grid connection, disadvantage is that in the case of grid fault it require additional protection.
	Permanent Magnet	connected to the grid via full scale frequency converter, frequency converter helps to control both the active and reactive power delivered by the generator to grid.

4.5.3 DG benefits:

1) Impact on electricity price.
2) Utilization of wasted energy sources and fuel flexibility.
3) Reliable power.
4) Power quality: installation of DG can regulate the voltage at some buses. In areas where maintaining the voltage within the specified standards is difficult, DG may be able to improve the quality of power. Also, most DG systems are capable of providing reactive power support at distribution system level.

i. Voltage profile:

At the distribution system, the voltage must be within specified limits. When the DG are connected to the distribution system the flow of the power is change then voltage profile is change. DG along a distribution feeder may lead to a voltage rise at some points because of high impedance of the conductors and because these generators are often operated close to the upper voltage limit. This voltage rise can be reduced by:

1) Limiting the size of DG plant: the voltage rise level depend on the generation level compared to load level.
2) Reinforcing the network (using larger conductors with a lower impedance).
3) Installing shunt reactor banks to draw additional reactive power from the network.
4) Operating the generator at a leading power factor (exporting VAR from the network), which will reduce overall power flow and hence reduce voltage drop.

A brief study of the effects of importing Q or exporting it to grid is designed by ETAP16 and shown below, when the generator is importing (consuming) Q VARS from grid, the voltage drops and losses are higher than the case when it is producing VARS.

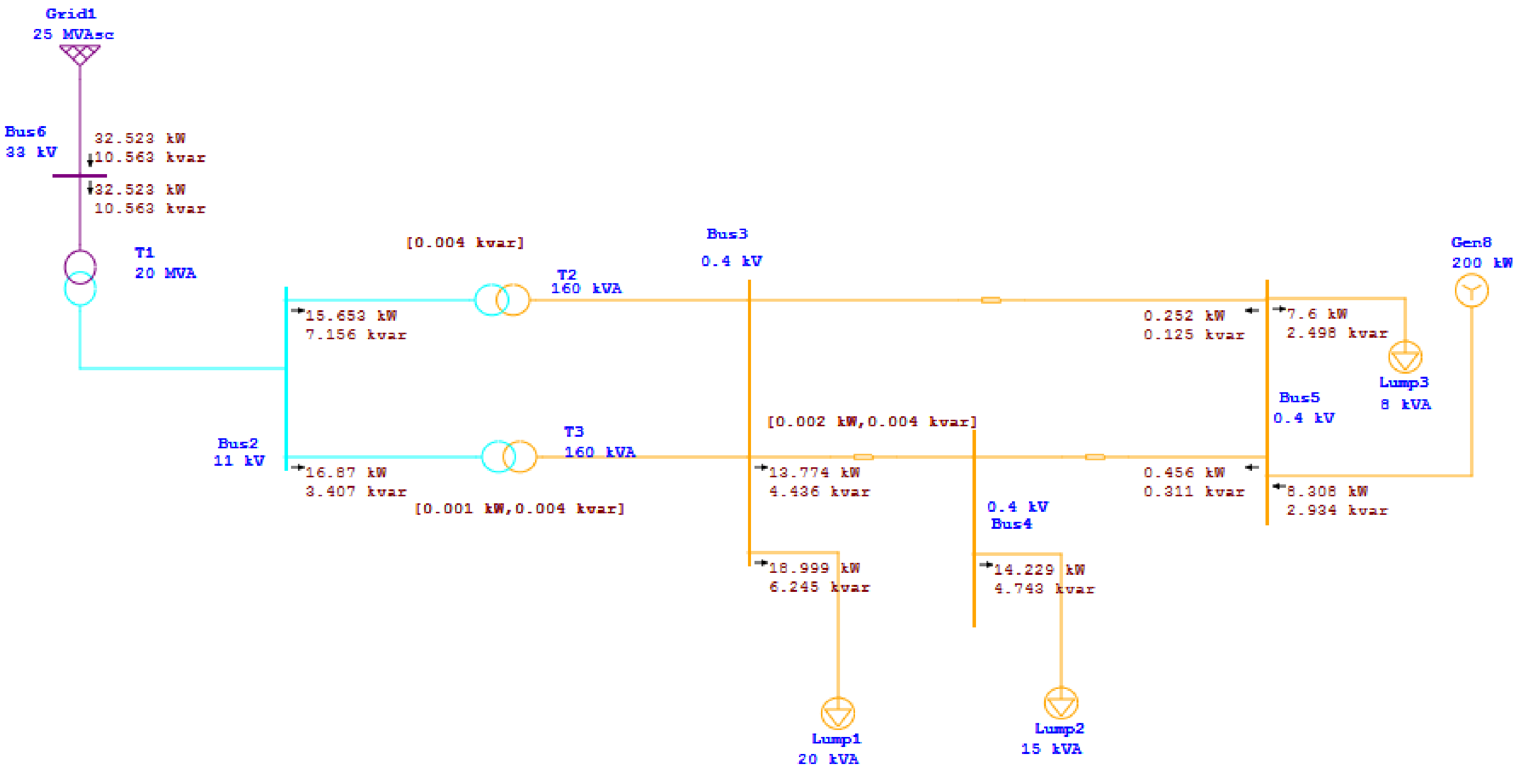


Figure4.72: Power flow and losses in case of producing Q (VARS).

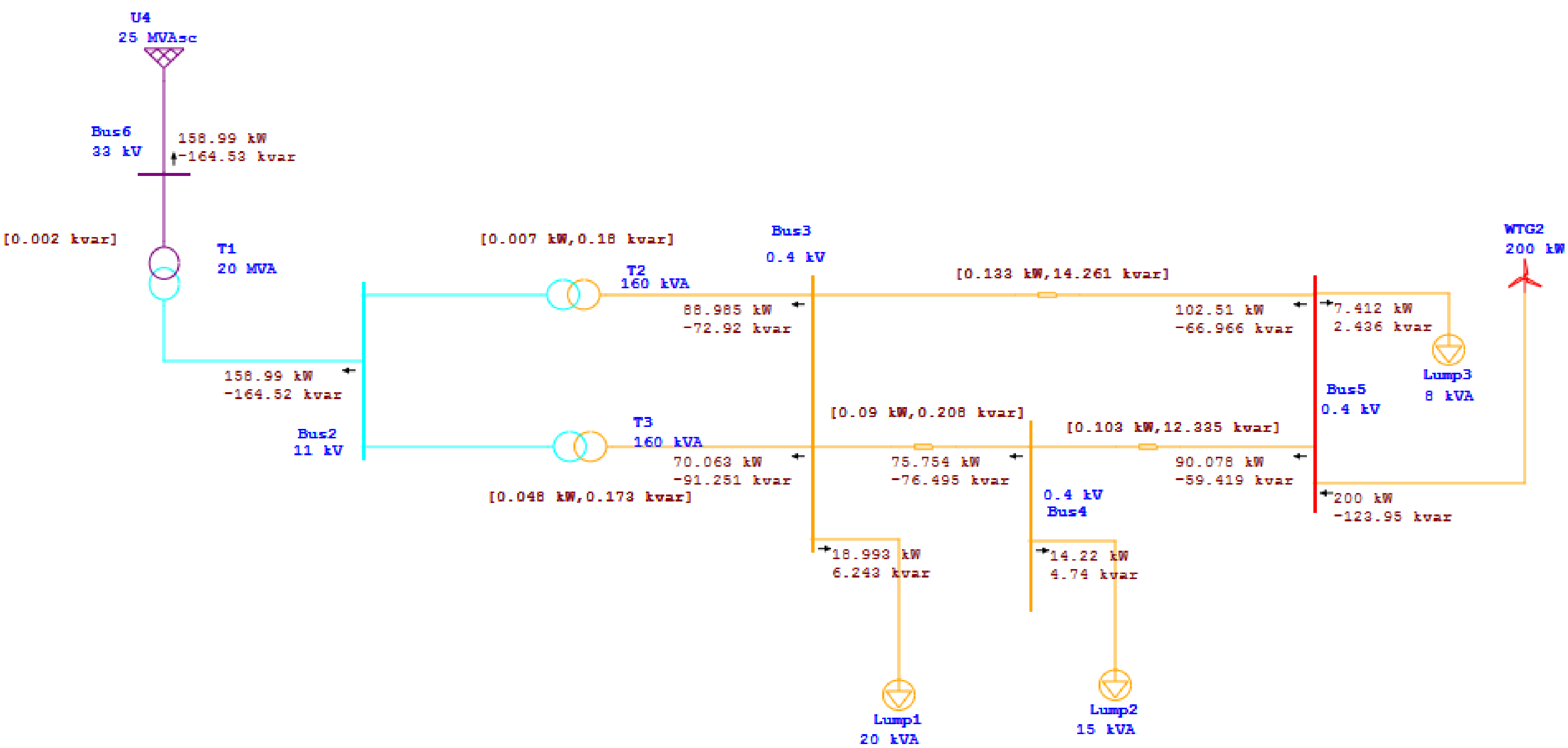


Figure4.73: Power flow and losses in case of consuming Q (VARS).

5

Chapter Five: Conclusion.

Chapter Five: Conclusion.

5.1 Conclusion:

It is obvious that, smart grid is a really substantial grid that has great benefits even for environment, power quality and reliability, and for stakeholders (producers, consumers, society), these benefits and smart grid concepts are explained using SIMULINK, MATLAB Ra2015.

Smart grid does not mean to build a new grid instead of the legacy one, it is just a development process to get more advanced grid in terms of the usage of communication technologies, and bidirectional flow of data and power, that was proved by the simulation results in ETAP16, compared with the results taken from smart meters that installed in a chosen case study which lies under supporting of Jerusalem District Electricity Company, these results were taken from the company simulation program. They show that smart meters and their features are better than the existing meters to reduce branches losses, thefts and to improve grid's efficiency.

SCADA system monitors grids, and controls them remotely, a simple model is created by MATLAB to monitor the chosen case study.

5.2 Recommendations:

For JDECo.:

1) To develop smart grid lab to be a modernized lab that contains microgrid with its control strategies, microgenerators, and equipments that allow bidirectional flow of power and data, in short, not limited to smart meters.

For Electrical Engineering Department in Palestine Polytechnic University:

1) To look in smart grid lab's limitations, that are:
   ii. Wind turbine is not ready to work.
   iii. Induction generator cannot be islanded.
   iv. PV system is not able to support loads in the system, also cannot be islanded.
2) Introducing a smart grid lab course for student who are interesting in.

For future work:

1) For students who are interesting in smart grid concept and design, they can start from PIC lab and exploit it to design a smart meter, this project will be in the cooperation with Eng. Mohammed Al-qaisi, and Southern Electricity Company in Dura.
2) Another project idea can be a complement for this project, which is distribution generators, the idea will be specialized in distribution generators allocations.
3) Microgrid controllers can be a powerful project idea.

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