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DESIGNING A MICROGRID FOR A REAL GRID TIED PV SYSTEM
تصميم شبكة متناهية الصغر لمحطة فعالة موصولة على الشبكة

A THESIS

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ABSTRACT

The increase demand of power worldwide with high quality and sustainability, and the need of clean energy using renewable resources, had put a lot of challenges in modern power systems. Microgrid has the ability to overcome all these challenges with elimination of load shading. This thesis studies a PV station with a local load using real data collected using different monitoring system, and offer a modified design to convert this part of power system into microgrid, the suggested microgrid is tested and operated using MATLAB simulation tool , assuring power sustainability and acceptable THD , electrical and financial results are reported supporting this design.

الملخص

إن زيادة الطلب على الطاقة في جميع أنحاء العالم بجودة عالية واستدامة ، والحاجة إلى استخدام الطاقة النظيفة باستخدام الموارد المتجددة ، فرضت الكثير من التحديات في أنظمة الطاقة الحديثة. للشبكة متناهية الصغر القدرة على التغلب على كل هذه التحديات مع القضاء على تظليل الحمل. تدرس هذه الأطروحة محطة كهروضوئية ذات حمل محلي مع بيانات حقيقية تم جمعها باستخدام نظام مراقبة ، وتقدم تصميمًا لتحويل هذا الجزء من نظام الطاقة إلى شبكة متناهية الصغر، تم اختبار الشبكة المتناهية الصغر المقترحة وتشغيلها باستخدام أدوات محاكاة مختلفة ، و اظهار نتائج كهربائية ومالية تدعم هذا التصميم.

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DEDICATION

I would like to dedicate my Thesis, first of all to my beloved Father “George”, may his soul rest in peace. He sacrificed so much to let my brothers and me to reach our goals and to have a high degree in our studies. I am sure that he is so proud of me.

To my Mother “Hanna” who had supported me in every step in my life.

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LIST OF ABBREVIATIONS

- AFC: Alkaline Fuel Cell
- CAES: Compressed Air Energy Storage
- CB: Circuit Breaker
- C&I: Commercial and Industrial
- DERs: Distributed Energy Resources
- DG: Distributed Generation
- EMFC: Exchange Membrane Fuel Cell
- ESS: Energy Storage System
- FBES: Flow Batteries Energy Storage
- FC-HES: Fuel cells—Hydrogen energy storage
- FES: Flywheel energy storage
- ICT: Information and Communications Technologies
- IEA: International Energy Agency
- IPCC: Intergovernmental Panel on Climate Change
- JDECO: Jerusalem District Electricity Company
- kWh: Kilo Watt hour
- MCFC: Molten Carbonate Fuel Cell
- NEDO: The New Energy and Industrial Technology Development Organization
- NGS: Natural Gas Storage
- PAFC: Phosphoric Acid Fuel Cell
- PCC: Point of Common Coupling.
- PHS: Pumped Hydro Storage

- PV: Photovoltaic
- SCADA: Supervisory Control and Data Acquisition system
- SMES: Superconducting Magnetic Energy Storage
- SOFC: Solid Oxide Fuel Cell
- TES; Thermal Energy Storage
- THD: Total Harmonic Distortion
- Used: University of California - San Diego
- VPP: Virtual Power Plants
- VSMs: Virtual Synchronous Machines

CHAPTER 1: INTRODUCTION

The world’s electricity delivery system is experiencing a continuous escalating energy demand. In addition, there are growing concerns about the environmental impacts of the electricity generation from fossil fuels. Newer regulations and policies are being enacted to limit the CO2 and other greenhouse gas emissions as per the recommendations of the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA). This is important because fossil fuel electricity generation accounts for around 40% of overall energy related CO2 emissions, or one quarter of total greenhouse gas emissions. For this reason, the penetration of renewable energy sources in the modern electric grid has been rapidly increased and the same trend is expected to continue in the future [1].

One of the renewable energy resources is Photovoltaic (PV), it has two types:

1) A grid-connected photovoltaic power system: It is an electricity generating solar PV system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. On Grid PV systems are comparatively easier to install as they do not require a battery system. It has the advantage of effective utilization of generated power because there are no storage losses involved. A photovoltaic power system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon consumption.

2) Off Grid (stand-alone system): The presence of a functional electricity grid is not always as obvious as it would seem to be, in some cases there are no grid at all, such as Bedouin communities. The need of a reliable electricity supply, invoke using PV system which supply the load locally without using the grid, this leads to use Energy Storage System (ESS) such as batteries.

An issue that modern electric grids must address the infrastructure that needs to accommodate renewable sources. Renewable sources of energy typically exhibit very low marginal costs and hence are most often operated at their maximum available output. Such an operation makes it necessary to treat the renewable as non-dispatchable energy sources in the sense that operators cannot control their output power as the radiation of the sun cannot be controlled. To maintain the reliability, system operators must continuously match the demand for electricity with supply on a second-by-second basis, and this can be very challenging [1].

At higher renewable penetration levels, the available power output may exceed the system load demand. This makes limiting the renewable output inevitable unless there is flexibility available in the electric grid. Such flexibility can be provided by energy storage systems (ESS).

On the other hand, ESS stores the excess energy in the system for later use when other means of supplying power in the grid are unavailable, uneconomical, or when unforeseen additional power is demanded. These issues lead to the development of Microgrid system which is a cluster of interconnected Distributed Generators DGs, loads, and ESS that co-operate with each other to be collectively treated by the grid as a controllable load or generator. The key objectives of a Microgrid are to facilitate the high penetration of DGs without causing power quality problems to the distribution network, and to provide reliable energy delivery to sensitive loads.

The Microgrid can operate in grid-connected or islanded mode of operation. In the grid-connected mode, the Microgrid either draws power from or supplies it to the main grid, depending on the generation and load mix and implemented market policies. However, it should not tightly regulate the voltage at the point of common coupling (PCC). It must be able to separate or island itself from the main grid when an abnormal condition or severe power quality event occurs. During this mode of operation, the primary function of the Microgrid is to satisfy all of its load requirements and contractual obligations with the grid [2-6].

1.1 MOTIVIATION AND IMPORTANCE

PV sector in Palestine is increasing rapidly for example in Jerusalem District Electricity Company (JDECO) the amount of increase in PV energy is 200%, many stations with power greater than 1MW are built, the need of Microgrid systems had much importance for these reasons:

1. Offer a solution for energy sustainability.
2. Microgrids are designed to maintain an organization's mission-critical loads in service when the utility fails.
3. The operation of Microgrids offer distinct advantages to the customers and utilities, i.e. improved energy efficiency, minimization of overall energy consumption, reduced environmental impact, improvement of reliability of supply, network operational benefits such as loss reduction, congestion relief, voltage control, or security of supply and more cost-efficient electricity infrastructure replacement. There is also a philosophical aspect, rooted in the belief that locally controlled systems are more likely to make wise balanced choices, such as between investments in efficiency and supply technologies.

Microgrids can coordinate all these assets and present them to the Megagrid in a manner and at a scale that is consistent with current grid operations, thereby avoiding major new investments that are needed to integrate emerging decentralized resources. Microgrids have been proposed as novel distribution network architecture within the Smart Grids concept, capable to exploit the full benefits from the integration of large numbers of small-scale distributed energy resources into low-voltage electricity distribution systems.

4. A Microgrid not only provides backup for the grid in case of emergencies, but can also be used to cut costs, or connect to a local resource that is too small or unreliable for traditional grid use. A Microgrid allows communities to be more energy independent and in some cases, more environmentally friendly.
5. Provide independency to Palestinian electrical utilities, because PV is the only energy source electrical utilities had access on it.

1.2 OBJECTIVES

JDECO built a PV station in December, 1^{st} using On-grid system. It consists of 13 inverters of 60KW each, with 2360 panel occupied with 10000m2 land, tilt angle of 15. Latitude:32°01'17.83"N, Longitude: 35° 26' 26.23" E. The station is interconnected with 33KV medium voltage line.

The electrical system's cost is covered by "Future of Palestine Institution" and JDECO offered the land, the amount of energy produced every month is deducted from the bills of old city- Jerusalem home consumers as a sustainable support of the inhabitant of the old city.

The main objectives are as follow:

1. Converting established PV station with the interconnected load to Microgrid system, with minimum cost.
2. Assuring sustainability of target load while operating in islanding mode.
3. Assuring low THD of target load while operating in islanding mode.

CHAPTER 2: LITRATURE REVIEW

Two standards concerning Microgrids are established, IEC 61850-7-420 Communications Standard for Distributed Energy Resources and IEEE Std 1547.4™-2011. IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems [7] [8].

Policies in many countries are encouraging the deployment of these new distributed energy resources(DERs)with the objectives of minimizing environmental impact and supply costs and increasing system efficiency, reliability and resilience .This ,together with the fast development of information and communications technologies(ICT),is fostering the study and appearance of more decentralized business models to efficiently manage DERs which range from the MG and virtual power plants(VPP)concepts to the deployment of new distributed services like aggregations of energy resources or electric vehicle fleets. These new business models seek to provide value generators, grid operators, end- users and electricity market [9].

During last decades, a large number of MG related research programs and projects have been established in cooperation between prominent universities and companies all over the world. By now, total installed MG capacity has well passed 4GW throughout the world, with North America leading the world market with a capacity share of 67% [10].

One of the famous practical experience implantations of Microgrid is the University of California - San Diego (UcsD) Microgrid. UcsD has a 42-MW Microgrid with a master controller and optimization system that self-generates 92% of its own annual electricity load and 95% of its heating and cooling load. UcsD now saves more than $800,000 (USD) per month by using the generation on its Microgrid, when compared with the alternative of being a direct-access customer importing energy from the grid. Furthermore, there are ability to supply the loads during grid shading with the aid of battery containers and Microgrid controllers [11].

The New Energy and Industrial Technology Development Organization (NEDO) in Japan had developed many microgrid projects connected with the national grid, to solve the effect of high penetration of renewable resources and to increase power quality [12].

2.1 MICROGRIDS TYPES

Microgrids can be classified into these types bases on many aspects such as number and type of consumers, type of generation, and geographical aspects.

- Campus Environment/Institutional Microgrids: The focus of campus microgrids is aggregating existing on-site generation with multiple loads located in tight geography in which owner easily manage them.

- Community Microgrids: Community Microgrids can serve up to a few thousands of customers. In this type of microgrid, some houses may have some renewable sources that can supply their demand as well as that of their neighbors within the same community. The community microgrid may also have a centralized or several distributed energy storage.

- Remote Off-grid Microgrids: These microgrids never connect to the Grid and instead operate in an island mode at all times because of economic issues or geographical position. Typically, an "off-grid" microgrid is built in areas that are far distant from any transmission and distribution infrastructure and, therefore, have no connection to the utility grid. Studies have demonstrated that operating a remote area or islands' off-grid microgrids, that are dominated by renewable sources, will reduce the levelized cost of electricity production over the life of such microgrid projects. Large remote areas may be supplied by several independent microgrids, each with a different owner (operator).

Although such microgrids are traditionally designed to be energy self-sufficient, intermittent renewable sources and their unexpected and sharp variations can cause unexpected power shortfall or excessive generation in those microgrids. This will immediately cause unacceptable voltage or frequency deviation in the microgrids. To remedy such situations, it is possible to interconnect such microgrids provisionally to a suitable neighboring microgrid to exchange power and improve the voltage and frequency deviations.

- Military Base Microgrids: These microgrids are being actively deployed with focus on both physical and cyber security for military facilities in order to assure reliable power without relying on the Grid.

- Commercial and Industrial (C&I) Microgrids: These types of microgrids are maturing quickly in North America and Asia Pacific; main reasons for the installation of an industrial microgrid are power supply security and its reliability. There are many manufacturing processes in which an interruption of the power supply may cause high revenue losses and long start-up time.

2.2 FIELDS OF STUDY

Due to the importance of microgrid in energy sector, researchers and developers all over the world focus their research in these following fields:

1. Control

Control systems is the main part of microgrid system, it controls the operation of microgrid component based on measurements , and it differ in accordance with the capacity of microgrid and load sharing , dynamic response , grid complexity , many methodologies implemented in this field from Supervisory Control And Data Acquisition system (SCADA) connected to local controller to one control unit for small scale microgrid (nanogrid) [13-17].

2. Effective Energy storage systems

A storage system due to its very fast dynamic response plays an important role in restoring balance between supply and demand , it encountered rapid developments ,there are many types of storage systems which can be used in accordance with the scale of microgrid and operation response such as pumped hydropower storage , compressed air energy storage (CAES) , flywheel , electrochemical batteries (lead-acid , NaS,Liion and Ni-Cd) , flow batteries (vanadium –redox) , superconducting magnetic energy storage , super capacitors , and hydro energy storage (power gas technologies) [18-24].

3. Power conversion

Power conversion systems had encountered rapid development , due to development of semiconductor materials and the cost of these units is decreasing , with increased efficiency, using highly efficient power electronics in generation, transmission/distribution and end-user application .

Together with advanced controls, can pave the way for renewable energy resources .More recently, the concept of virtual synchronous machines (VSMs) has emerged as an effective method for adding virtual inertia to the power system through the control of power electronic converters [25-29].

4. Power quality and integration with the grid:

Power quality problems, such as voltage fluctuation and harmonic, limit high integration of Microgrid . As the interfacing converters normally have much higher control bandwidth compared to distributed synchronous generators, they can also actively regulate the distribution system power quality without using any additional harmonic filtering equipment [30-34].

5. DC microgrid systems:

Compared with traditional AC distribution, DC microgrids are significantly more efficient due to the absence of DC-to-AC or AC-to-DC conversion when implemented using DC-distributed generation (DG). These systems have an end-to-end efficiency of approximately 80% (for DC loads), compared with an efficiency of 60% with AC microgrids [35-36].

6. Economic dispatch:

Given the economic benefit, a MicroGrid is usually installed by group of consumers who control their own electricity production. Since the Utility´s Electric Supply prices includes losses, customer services, congestion, and other costs and taxes; the tariffs are too expensive, so that the self-generation becomes a cheaper alternative and the MG it is an emerging one. The cost-effectiveness of an MG system is a function of its appropriate design and management [37-39]

2.3 ENERGY STORAGE SYSTEMS

Developments in ESS is going on continuously for its importance in modern energy systems, ESS has many types depending on the technology used to store the energy, and it can be classified into these major types:

- Pumped hydro storage (PHS): The main advantage of this technology is that it is readily available. It uses the power of water, a highly concentrated renewable energy source. This technology is currently the most used for high-power applications (a few tens of GWh or 100 of MW). Pumped storage sub transmission stations will be essential for the storage of electrical energy. The principle is generally well known: during periods when demand is low, these stations use electricity to pump the water from the lower reservoir to the upper reservoir. When demand is very high, the water flows out of the upper reservoir and activates the turbines to generate high-value electricity for peak hours.

- Thermal energy storage (TES): TES makes use of the liquid–solid transition of a material at constant temperature. During accumulation, the bulk material will shift from the solid state to liquid and, during retrieval, will transfer back to solid. The heat transfers between the thermal accumulator and the exterior environment are made through a heat-transfer fluid. The energy is stored at a given temperature, the higher the heat the higher the concentration.

- Compressed air energy storage (CAES): A power plant with a standard gas turbine uses nearly two-thirds of the available power to compress the combustion air. It therefore seems possible, by separating the processes in time, to use electrical power during off-peak hours (storage hours) in order to compress the air, and then to produce, during peak hours (retrieval hours), three times the power for the same fuel consumption by expanding the air in a combustion chamber before feeding it into the turbines.

- Energy storage coupled with natural gas storage (NGS): The idea is to couple underground natural gas storage with electricity storage. The pressure difference between high-pressure gas storage (E200 bars) in reservoirs deep underground (1500 m) and gas injected into the conduits with a maximum service pressure of 60–80 bars leads to the consumption of energy for compression, energy that could be released in the form of electricity during decompression.

- Energy storage using flow batteries (FBES): Flow batteries are a two-electrolyte system in which the chemical compounds used for energy storage are in liquid state, in solution with the electrolyte. They overcome the limitations of standard electrochemical accumulators (lead–acid or nickel–cadmium for example) in which the electrochemical reactions create solid compounds that are stored directly on the electrodes on which they form. This is therefore a limited-mass system, which obviously limits the capacity of standard batteries. Various types of electrolyte have been developed using bromine as a central element: with zinc (ZnBr), sodium (NaBr), vanadium (VBr) and, more recently, sodium polysulfide. he electrochemical reaction through a membrane in the cell can be reversed (charge–discharge). By using large reservoirs and coupling a large number of cells, large quantities of energy can be stored and then released by pumping electrolyte into the reservoirs.

- Fuel cells—Hydrogen energy storage (FC– HES): Fuel cells are a means of restoring spent energy to produce hydrogen through water electrolysis. The storage system proposed includes three key components: electrolysis which consumes off-peak electricity to produce hydrogen, the fuel cell which uses that hydrogen and oxygen from air to generate peak-hour electricity, and a hydrogen buffer tank to ensure adequate resources in periods of need. Oxidation-reduction between hydrogen and oxygen is a particularly simple reaction which occurs within a structure (elementary electrochemical cell) made up of two electrodes (anode–cathode) separated by electrolyte, a medium for the transfer of charge as ions .

There are many types of fuel cells, such as: Alkaline Fuel Cell (AFC), Polymer Exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC). The basic differences between these types of batteries are the electrolyte used, their operating temperature, their design, and their field of application. Moreover, each type has specific fuel requirements.

- Chemical storage: Chemical storage is achieved through accumulators. These systems have the double function of storage and release of electricity by alternating the charge–discharge phases. They can transform chemical energy generated by electrochemical reactions into electrical energy and vice versa, without harmful emissions or noise, and require little maintenance. There is a wide range of technologies used in the fabrication of accumulators (lead–acid, nickel–cadmium, nickel–metal hydride, nickel–iron, zinc–air, iron–air, sodium–Sulphur, lithium–ion, lithium–polymer, etc.) Their main inconvenient however is their relatively low durability for large-amplitude cycling (a few 100 to a few 1000 cycles).

- Flywheel energy storage (FES) : Flywheel energy accumulators are comprised of a massive or composite flywheel coupled with a motor generator and special brackets (often magnetic), set inside a housing at very low pressure to reduce self-discharge losses They have a great cycling capacity (a few 10,000 to a few 100,000 cycles) determined by fatigue design.

- Superconducting magnetic energy storage (SMES): Superconducting magnetic energy storage is achieved by inducing DC current into a coil made of superconducting cables of nearly zero resistance, generally made of niobiumtitane (NbTi) filaments that operate at very low temperature. The current increases when charging and decreases during discharge and has to be converted for AC or DC voltage applications.

- Energy storage in supercapacitors: These components have both the characteristics of capacitors and electrochemical batteries, except that there is no chemical reaction, which greatly increases cycling capacity. Energy storage in supercapacitors is done in the form of an electric field between two electrodes. This is the same principle as capacitors except that the insulating material is replaced by electrolyte ionic conductor in which ion movement is made along a conducting electrode with a very large specific surface (carbon percolants grains or polymer conductors) Supercapacitors generally are very durable, that is to say 8–10 years, 95% efficiency, and 5% per day self-discharge, which means that the stored energy must be used quickly. [40].

CHAPTER 3: METHODOLOGY

In JDECO 70% of the load are residential, the load is not stable, it depends on many variables such as temperature, weather, personal habits of using electricity etc. The electrical distribution company must overcome all the energy demands regardless of all these variables.

PV energy is variable; the output power depends on radiation, temperature, dust and other variables. It will not meet the load demand, there will be in certain time more produced power than the load or less produced power than the load, in case the produced power is greater than the load, the rest of the power will be supplied to the grid, in case the load power is greater than PV power the rest will be supplied by the Grid or by using ESS system , in case no PV energy is available and the grid is off, ESS system will supply the target load .

This thesis studies the residential load of a transformer 250KVA, and the PV energy profile, the target load is allocated about 5km from the PV station through medium voltage line as shown in figure 1.

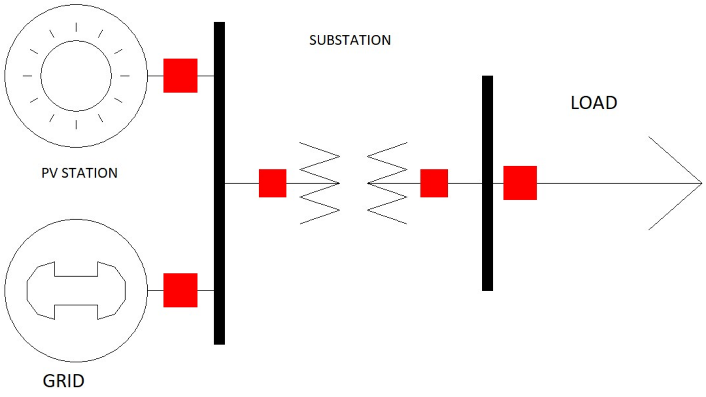


Figure 1: Interconnection between PV station and distribution transformer.

There are no real time data for transformers in Jericho, another transformer data will be used in region called Bet Sahour , because it had a registered load profile data , this region had a climate which match the climate of Jericho with some differences , most of its load is residential , this transformers contains 4 feeders one of them supply more residential load , the amount of this feeder power will be multiplied by 4 to achieve precise data . The data of the PV station is available because the station is monitored using Green power monitoring, with data registered in a server all over the year.

This thesis suggests three different scenarios to modify Dead Sea station from on grid station to microgrid station supplying the target load 24 hours 365 days and optimum scenario will be simulated, in all scenarios the controller will connect and discount circuit breakers managing the operation of PV and ESS and LOAD and GRID as shown in figure 2.

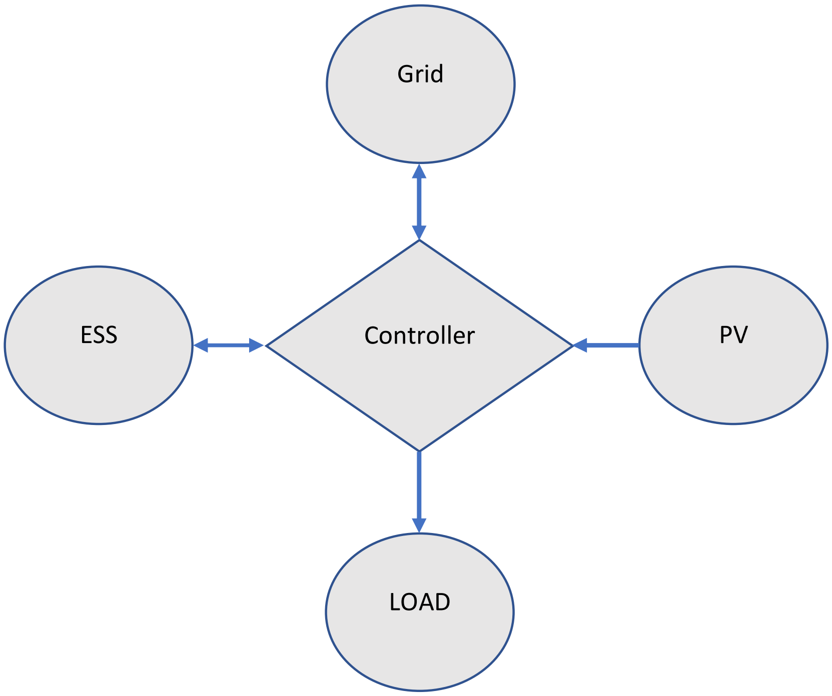


Figure 2: Block Diagram of Microgrid Modified System

Scenario 1: Dividing the existing PV station into two stations , On grid station and OFF grid station with same panels ,by adding ESS working with main controller connected to MV Circuit breakers and adding Off Grid inverters with power of 300KW peak to the existing PV station , and DC circuit breakers connected to the strings , when the power is On the station will work as On grid station , when the power is off the controller will disconnect the MV circuit breakers and DC circuit breakers connected to On grid inverters ,after that will connect the DC circuit breakers connected to Off Grid inverters and the station will work as Off Grid station , the ESS system in this case is the main supply of power , the topology of the system is shown in Figure 3 .

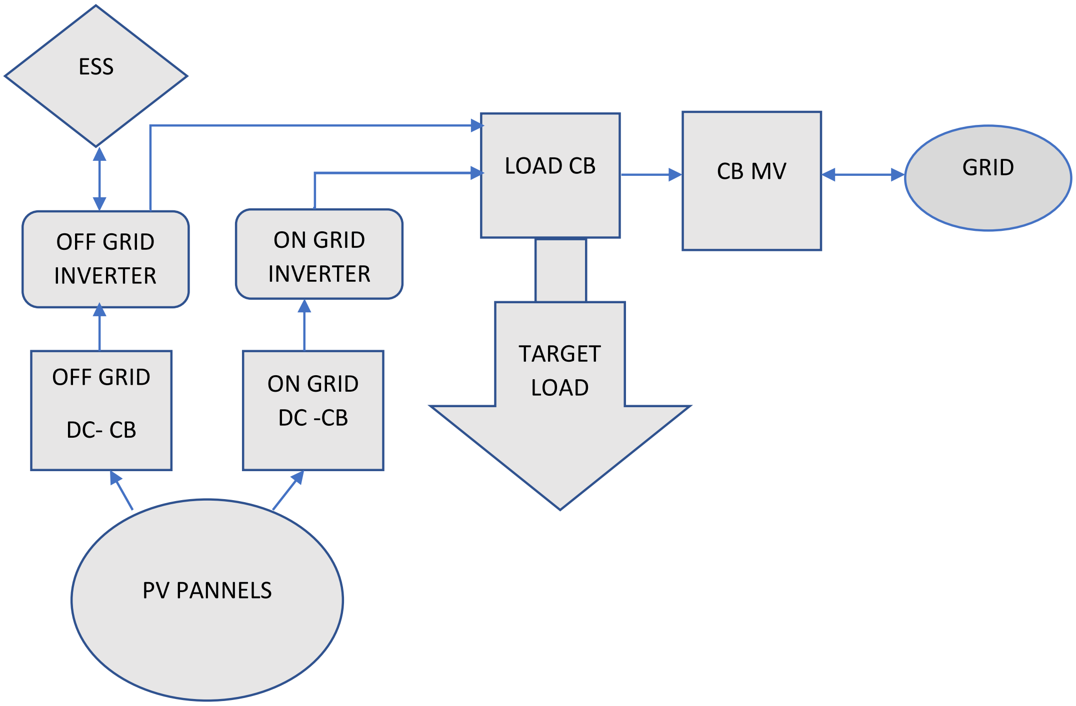


Figure 3: Scenario 1

Scenario 2 :Dividing the existing PV station into two station , On grid station and Microgrid station with same panels by adding ESS working with main controller connected to MV Circuit breakers and adding Microgrid inverters with power of 300KW peak to the existing PV station, and DC circuit breakers connected to the strings , when the power is On the station will work as On grid station , when the power is off the controller will disconnect the MV circuit breakers and DC circuit breakers connected to On grid inverters ,after that will connect the DC circuit breakers connected to Microgrid inverters , ESS will share the supply of power with PV , the topology of the system is shown in figure 4.

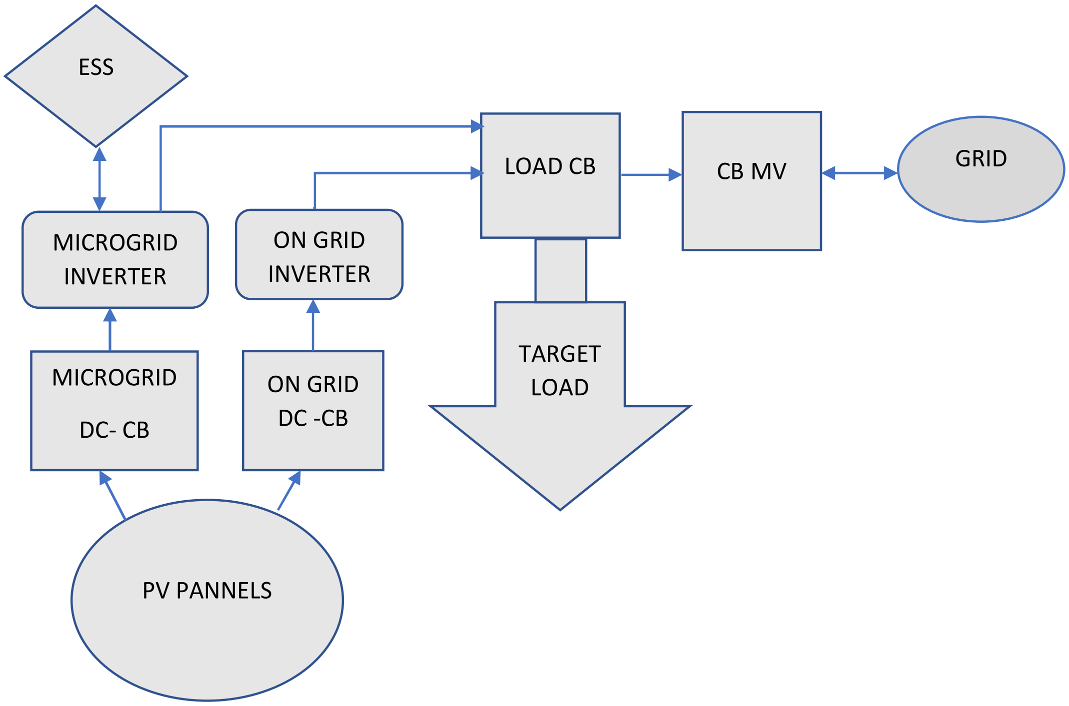


Figure 4: Scenario 2

Scenario 3 : Modifying the existing PV station into two station , On grid station and Microgrid station with same panels, by adding ESS System working with main controller connected to MV Circuit breakers and changing 5 On-Grid inverters to Microgrid inverters , when the power is On the station will work as On grid station , when the grid is off the controller will disconnect the circuit breakers connected to MV circuit breakers and AC circuit breaker connected to the inverters that already exist in the station , the topology of the system is shown in Figure 5.

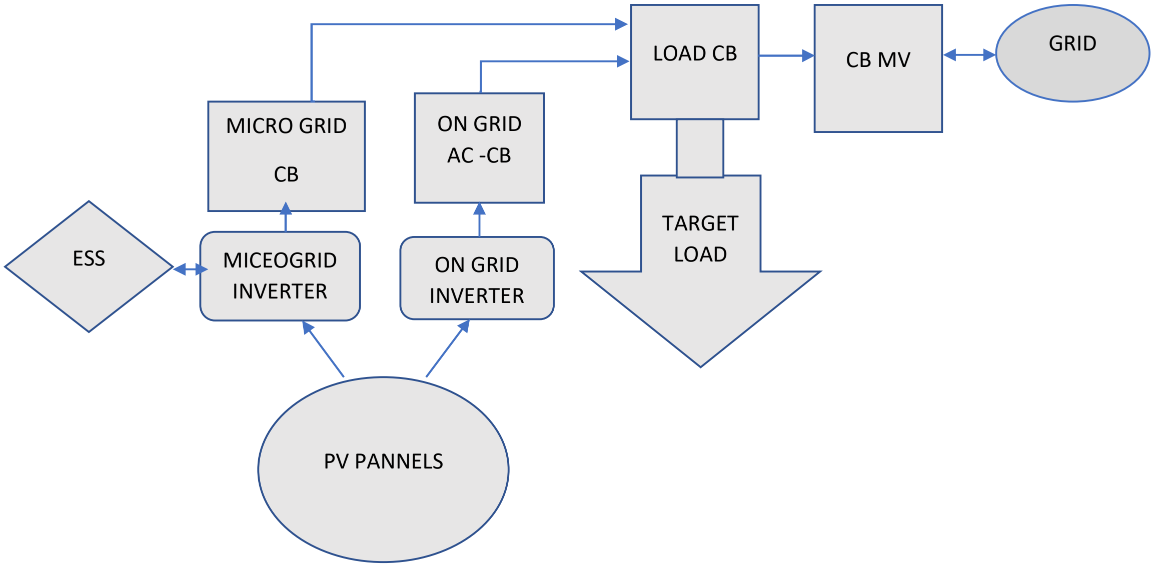


Figure 5:Scenario 3

The storage system had major cost, it not feasible to use ESS power as the load power; instead it is more desirable to supply the load from PV system and the rest from ESS system, thus scenario 1 is not applicable ,furthermore it is not cost efficient to add so many circuit breaker especially the DC circuit breakers , there are no space in the station to add 5 inverters and not cost efficient, thus scenario 2 also is not efficient .

Changing 5 inverters with 300 KW peak, and controlling just ac circuit breakers will achieve the target, thus scenario 3 is the only applicable one, the single line diagrams representing this scenario is shown in appendix A.

This data will be Simulated using different tools, Simulink Matlab Software Tool will be used to model the process of the controller, calculations and logarithms will be tested using Microsoft excel with appropriate logic tools.

3.1 DATA COLLECTION

Data are collected using POWERCOM monitoring system for demand and Greenpower monitor for PV station, these data were not organized on hourly basis, effort were done to reorganize this data on hourly basis for 24 hours, 365 days.

3.2 BATTERY SIZE

The maximum recorded load in this transformer was 200 KW for 1 hour , while the average load is around 100 KW , for microgrid system no need to use all the battery power , in worst case with no sunshine and no grid a 300 KW battery power is efficient and safe , the depth of discharge in worst case is 67% with average load and 34% with maximum load .

3.3 CALCULATIONS

There are 3 variable inputs (Demand and PV power and Grid power) the demand increase or decrease based on time of the day and seasons and feasts and some special events, while PV power change based on weather conditions and the amount of dust over PV panels and temperature and radiation , the Grid is variable also sometimes the Grid is off depending on periodic maintenance of medium voltage stations and lines , and some sudden faults .

There are 4 calculated outputs which are as follow:

1. Calculating the amount of energy bought from IEC
    - If Demand + Bat charge > PV power and the Grid is ON, the amount of electricity bought = demand -PV + Bat charge (This statement give priority to charge the batteries from PV).
    - If Demand < PV power and the Grid is ON, the amount of electricity bought = ZERO

- If Demand < PV power OR Demand > PV power and the Grid is OFF, the amount of electricity bought = ZERO

2. Calculating the amount of energy sold to consumers

    - If Demand > PV power and the Grid is ON, the amount of electricity sold = ZERO
    - If Demand+ Bat charge < PV power and the Grid is ON, the amount of electricity sold = PV -demand – Bat charge (This statement give priority to charge the batteries from PV).
    - If Demand < PV power OR Demand > PV power and the Grid is OFF, the amount of electricity sold= ZERO

3. Battery discharging

    - If the Grid is Off and PV < Demand, the amount of discharged power = demand -PV
    - If the Grid is Off and PV > Demand, the amount of discharged power = Zero
    - If the Grid is ON and PV > Demand, PV < Demand, the amount of discharged power = Zero

4. Battery charging

    If battery is discharged and the Grid is ON, Battery charging = Battery discharging

The logic statement chart is shown in figure 6

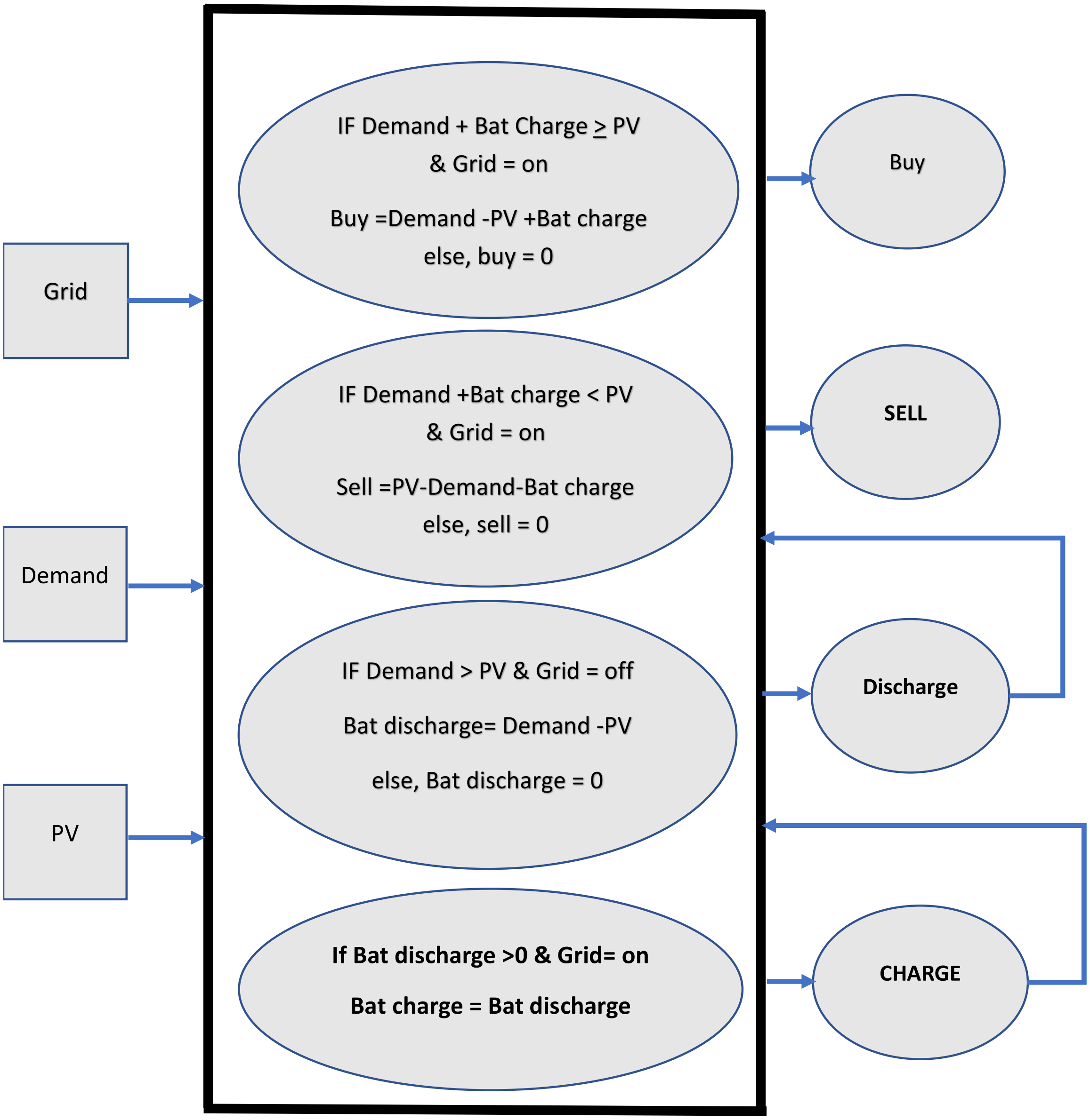


Figure 6: Logic statement chart

3.4 EXAMPLES

Example1: If the Demand equal 50KW and PV energy equal 100KW and the grid is On,

- Energy sold =50 kWh
- Energy bought = ZERO
- Battery discharged = ZERO
- Battery charged = ZERO

Example 2: If the Demand equal 50KW and PV energy equal 100KW and the grid is Off

- Energy sold =ZERO
- Energy bought = ZERO
- Battery discharged = ZERO
- Battery charged = ZERO

The load is supplied by PV energy

Example 3: If the Demand equal 50KW and PV energy equal 40KW and the grid is Off

- Energy sold =ZERO
- Energy bought = ZERO
- Battery discharged = 10KWH
- Battery charged = ZERO

The load is supplied by PV energy and batteries

CHAPTER 4: SIMULATION AND RESULTS

Two different tools are used to simulate the system and to analyze the data, technically and economically, as described in this chapter.

4.1 SIMULINK

The main block diagram of the model is shown in figure 7 , the PV system is divided into two systems PV microgrid system connected to CBmicro (circuit breaker microgrid) and PV On Grid system connected to CBOG (circuit breaker on grid) , CB1 (circuit breaker 1) is used to island the target load from the grid .

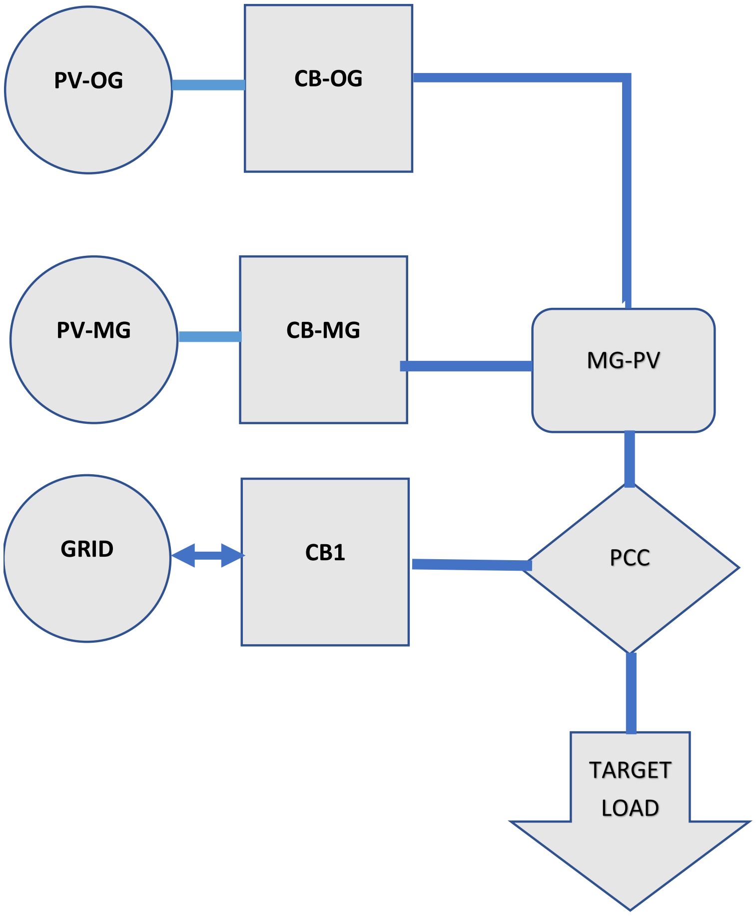


Figure 7 : Main block diagram

This microgrid has two modes of operation, depending upon the measurement of RMS current and THD, the added controller has input from measurement unit and based on this measurement the controller will operate as shown in the flowchart in figure 8.

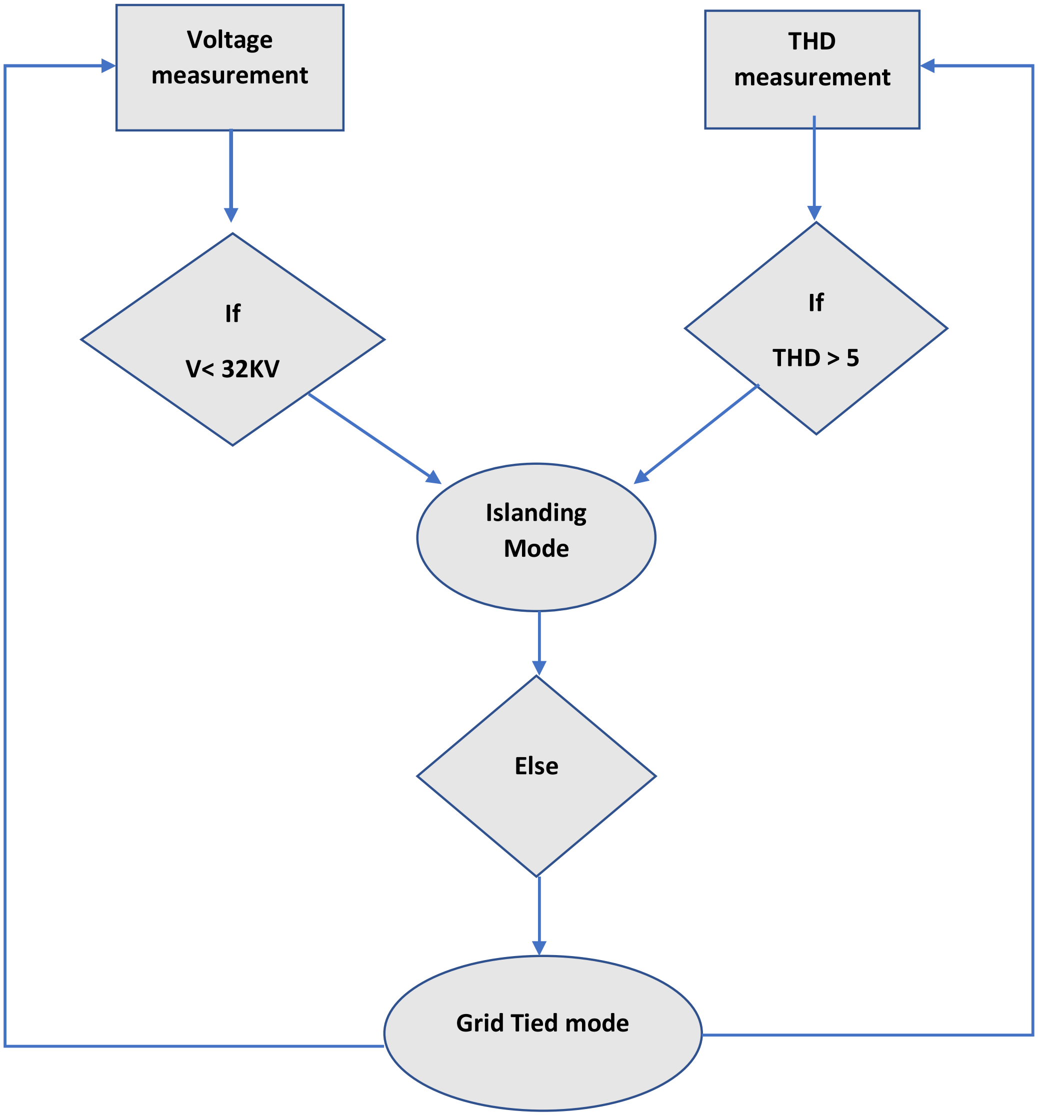


Figure 8 : Controller operation flow chart

The modes of operation are described as follow:

1- Grid tied mode:

In this mode, the controller is just monitoring the grid and THD of the target load, all the circuit breakers are On.

2- Islanding mode:

The microgrid will go to islanding mode when the grid is off or when THD reach 5%.

2.1- Islanding mode, Grid off

In this mode if the grid is off, the controller will open CB1 and CBOG thus supplying the target load using the microgrid, the voltage of the grid shown in figure 9 at 10 second range of simulation , the target load voltage before improving the system is shown in figure 10, after improving the system the target load is shown in figure 11 .

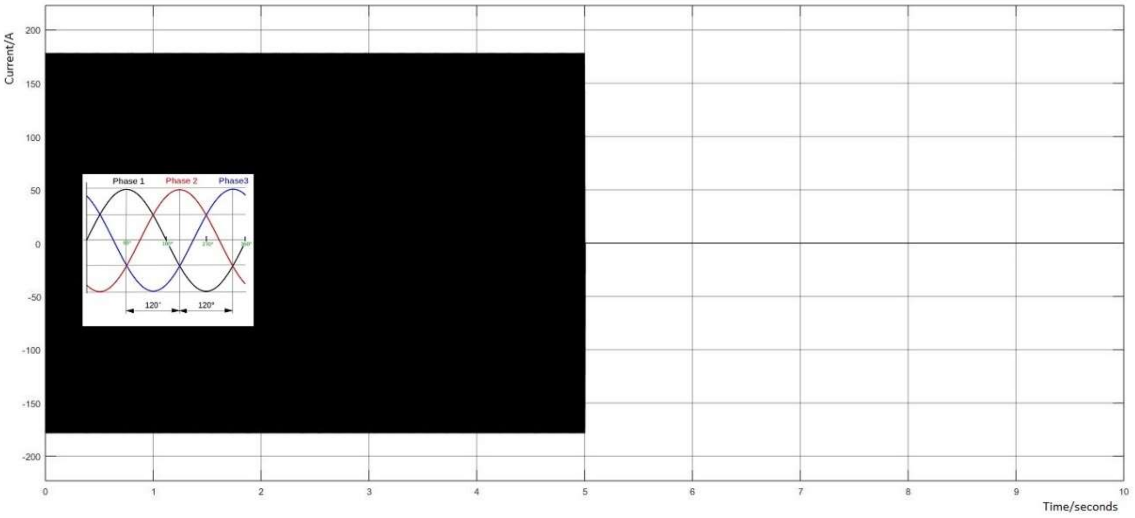


Figure 9: GRID

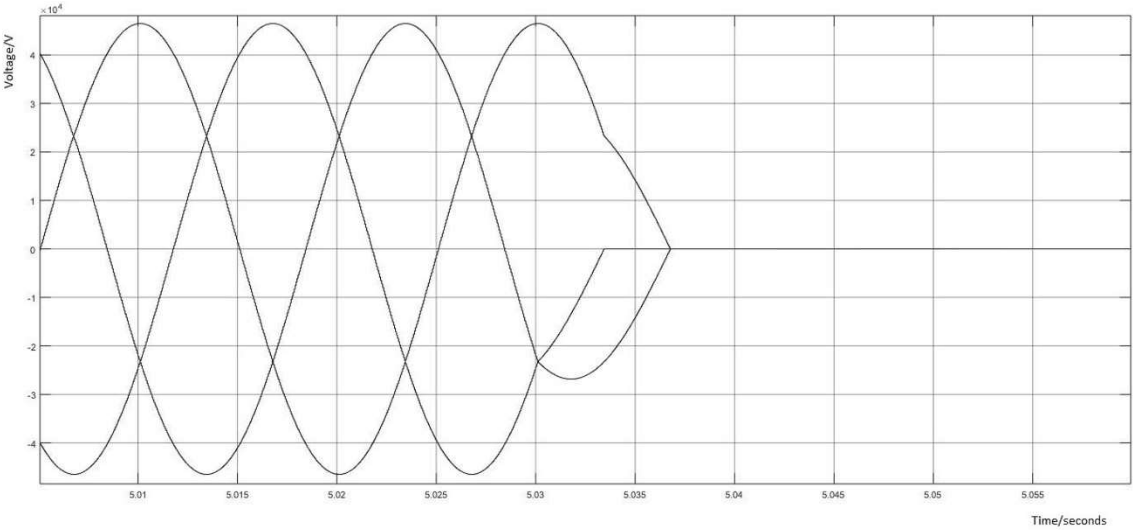


Figure 10: Load voltage without microgrid operation

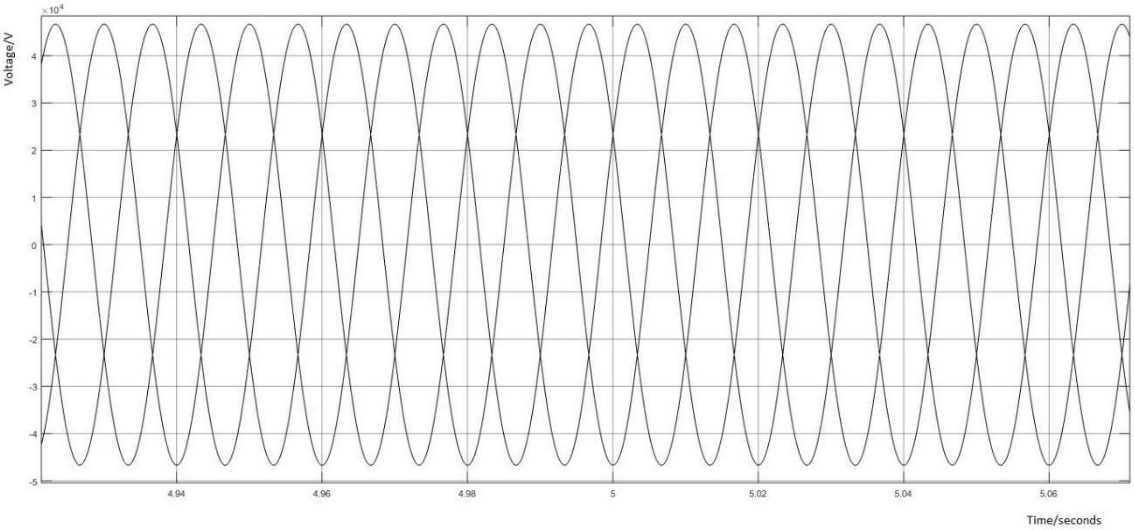


Figure 11: Load voltage with microgrid operation

As shown in figure 9 the grid is off after 5 seconds, without operating the system, the load also will be off as shown in figure 10, operating microgrid system will keep supplying the load with energy as shown in figure 11.

2.2- Islanding mode improving THD

In this mode if the THD is above 5% the controller will open CB1 and CBOG thus supplying the target load using microgrid system, the THD of the grid is shown in figure12, and the THD of the load is shown in figure 13.

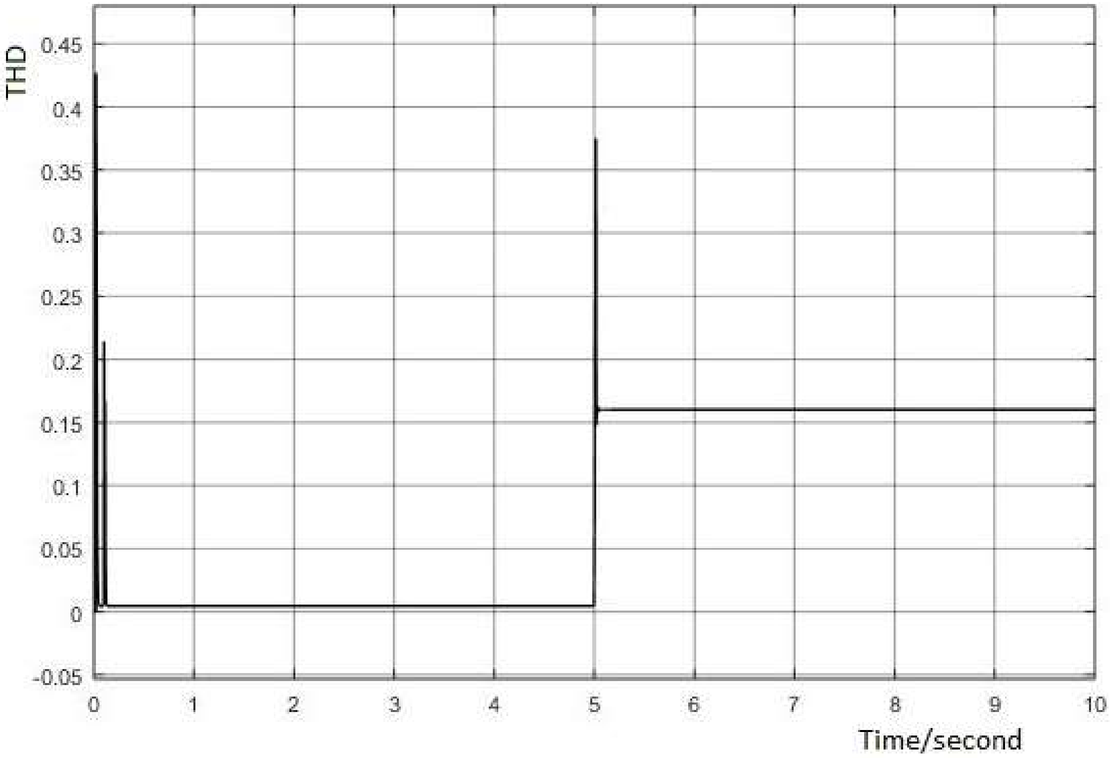


Figure 12: THD of the Grid

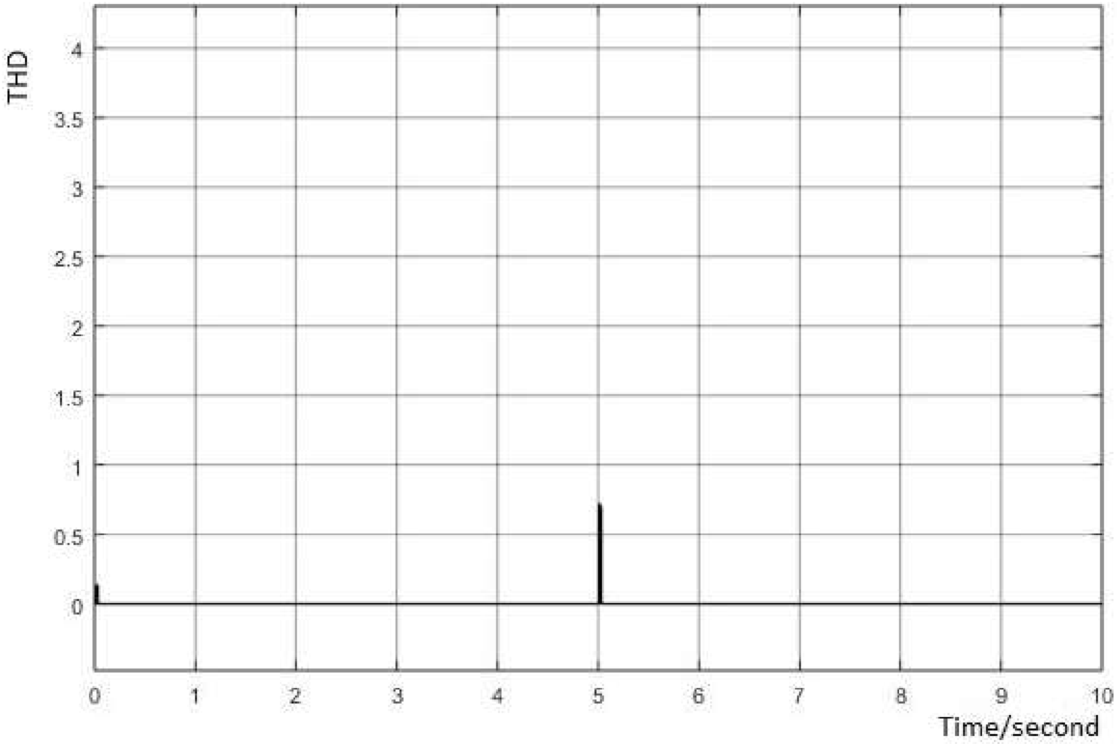


Figure 13: THD of the target load

Usualy the THD is variable and depends on other loads connected to the Grid , figure 12 shows at 5 seconds some undesriable loads enter the grid , discounting the grid and operating in isalnding mode will be good solution to improve the THD as shown in figure 13 .

4.2 LOAD PROFILE ANALYSIS

Records from PV station every hour is stored using green power monitor for 365 days, and hourly data of the demand load are stored using Powercom program for 365 days .

The controller is programed with an algorithm, to supply the load 24 hours a day with no cut off with maximum benefit of PV station had been tested for 365 day and 24-hour operation

Appendix B show a sample day in every month containing the demand and PV production and the status of the grid, based on the input data, the amount of energy bought and sold and battery discharging and charging is calculated.

.

4.3 ECONOMIC DISPATCH

After running the system, the total amount of energy bought and sold, using microgrid operation for every month is shown in table 1 and figure 14.

Table 1: Energy bought and sold

Month	Buy(kWh)	Sell(kWh)
January	34054.33	43501.37
February	27368.39	52368.83
March	19941.39	80507.75
April	19525.17	83608.28
May	25399.2	78835.44
June	22289.54	87069.45
July	29441.7	78609.01
August	30392.19	73829.28
September	27417.15	66863.53
October	20582.49	69487.92
November	22739.96	55498.96
December	40416.35	37829.01
Sum	319567.9	808008.8

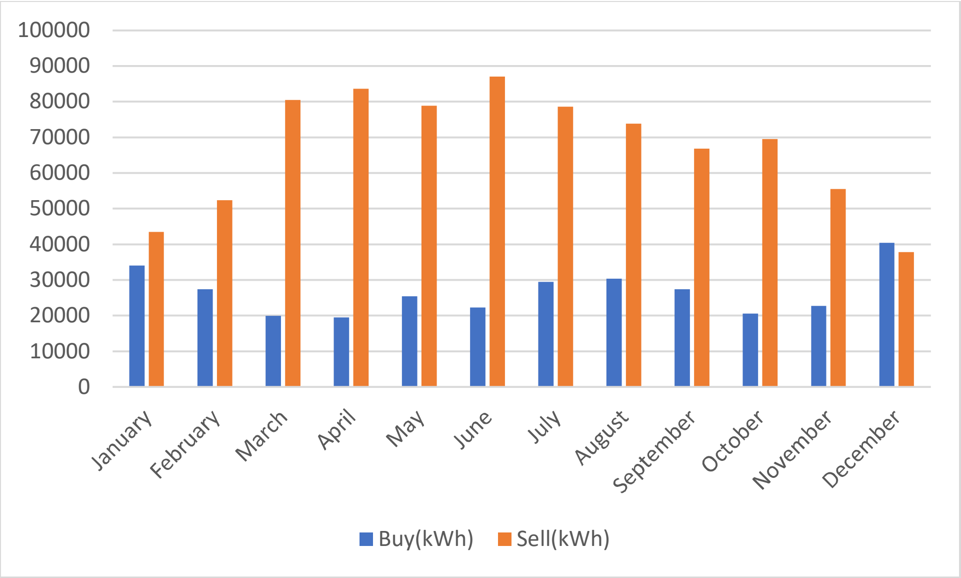


Figure 14 : Energy bought and sold in 2018

Microgrid system supply the target load 365 days 24 hours, and the excess energy is sold to the grid , which increases the revenue , the expenses depends on the amount of energy bought from IEC , the buying tariff from IEC in 2018 is 0.371 NIS , and the selling tariff is 0.5448 , table 2 and figure 15 shows the expenses vs revenue monthly , they are calculated using these equations .

Expenses = amount of energy bought * buying tariff

Revenue = (amount of energy sold to the grid + demand) * selling tariff

Table 2 : Expenses vs revenue

Month	Expenses (NIS)	Revenue (NIS)
January	12673.48243	52561.96078
February	10153.67269	53317.41314
March	7398.25569	66538.467
April	7243.83807	67770.22166
May	9423.1032	72568.58035
June	8269.41934	74066.7858
July	10922.8707	79041.65969
August	11275.50249	75887.19686
September	10171.76265	66332.63066
October	7636.10379	58839.44602
November	8436.52516	50824.69709
December	14994.46585	53752.69745
Sum	118599.0021	771501.7565

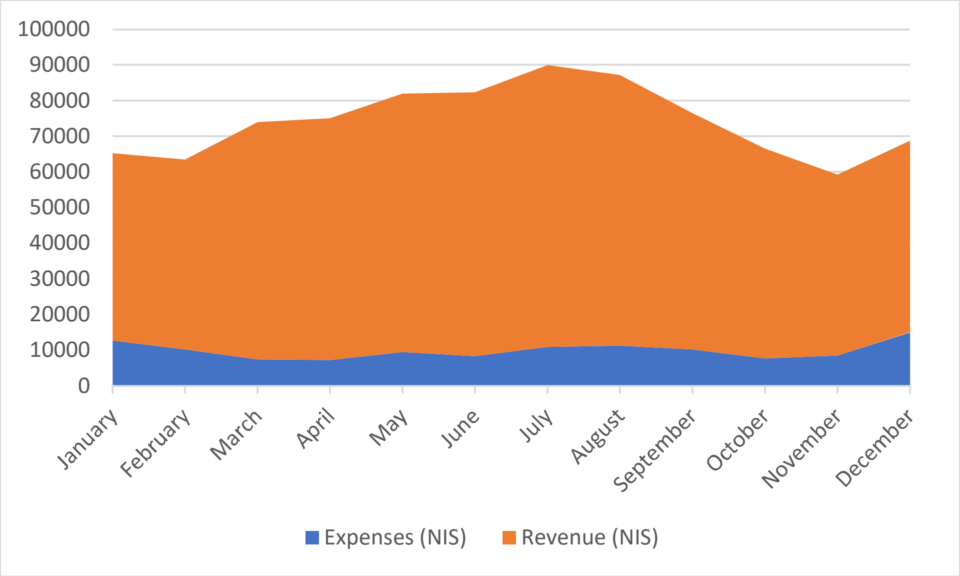


Figure 15: Expenses vs revenue

The monthly profit with microgrid implementation equals revenue minus expenses minus battery usage factor which is 6562NIS/month based on practical experience, profit without microgrid implementation equals demand multiplied by the difference between selling and buying tariff ,if the grid is on.

Table 3 and figure 16 shows the profit comparison between microgrid operation and supplying the load without using microgrid.

Table 3 : Monthly Profit comparison

Month	Profit with micro (NIS)	Profit without micro (NIS)
January	33326.48	9093.84
February	36601.74	7779.15
March	52578.21	7154.23
April	53964.38	7004.42
May	56583.48	9363.51
June	59235.37	8394.82
July	61556.79	11438.20
August	58049.69	11263.00
September	49598.87	9451.80
October	44641.34	6608.78
November	35826.17	6487.81
December	32196.23	10460.05
Sum	574158.75	104499.61

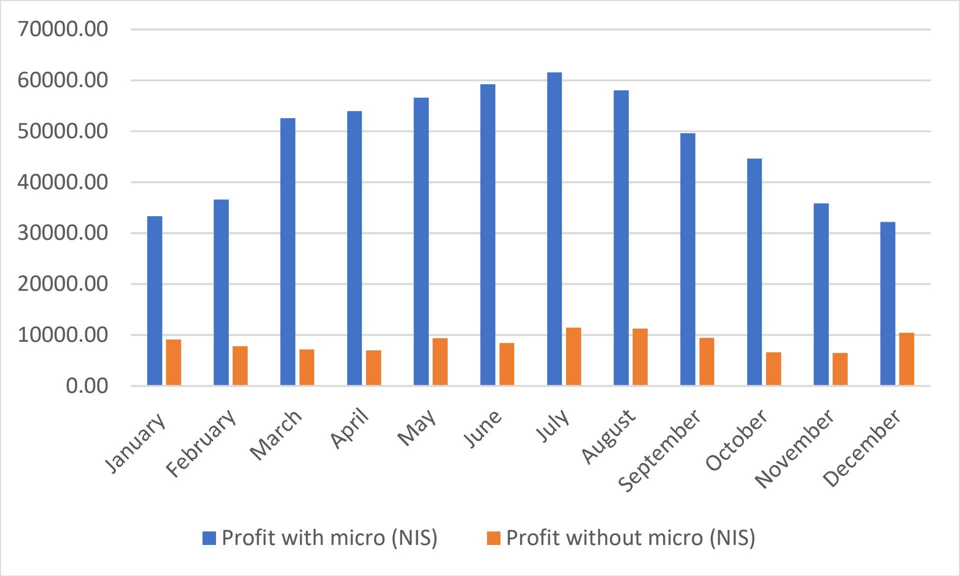


Figure 16: Profit comparison

The cost of the station contains the fixed cost and running cost and modification cost, it is shown in table 4.

Table 4 : Total cost

Item	Cost US $
Old station	700,000
Inverters	45,000
Controller and accessories	20,000
Running cost for 5 years	35,000
Sum	800,000

With a degradation factor the profit will be minimized for every year, table 5 shows the profit for 5 years with degradation factor of 1%.

Table 5 : Five years economic dispatch

	Profit (NIS)	Profit (USD)
1	574,159	164,045
2	568,417	162,405
3	562,733	160,781
4	557,106	159,173
5	551,535	157,581
	2,813,949	803,985

Based on the above data, the payback period is within 5 years with overall station cost of 800,000 USD and degradation factor of 1%.

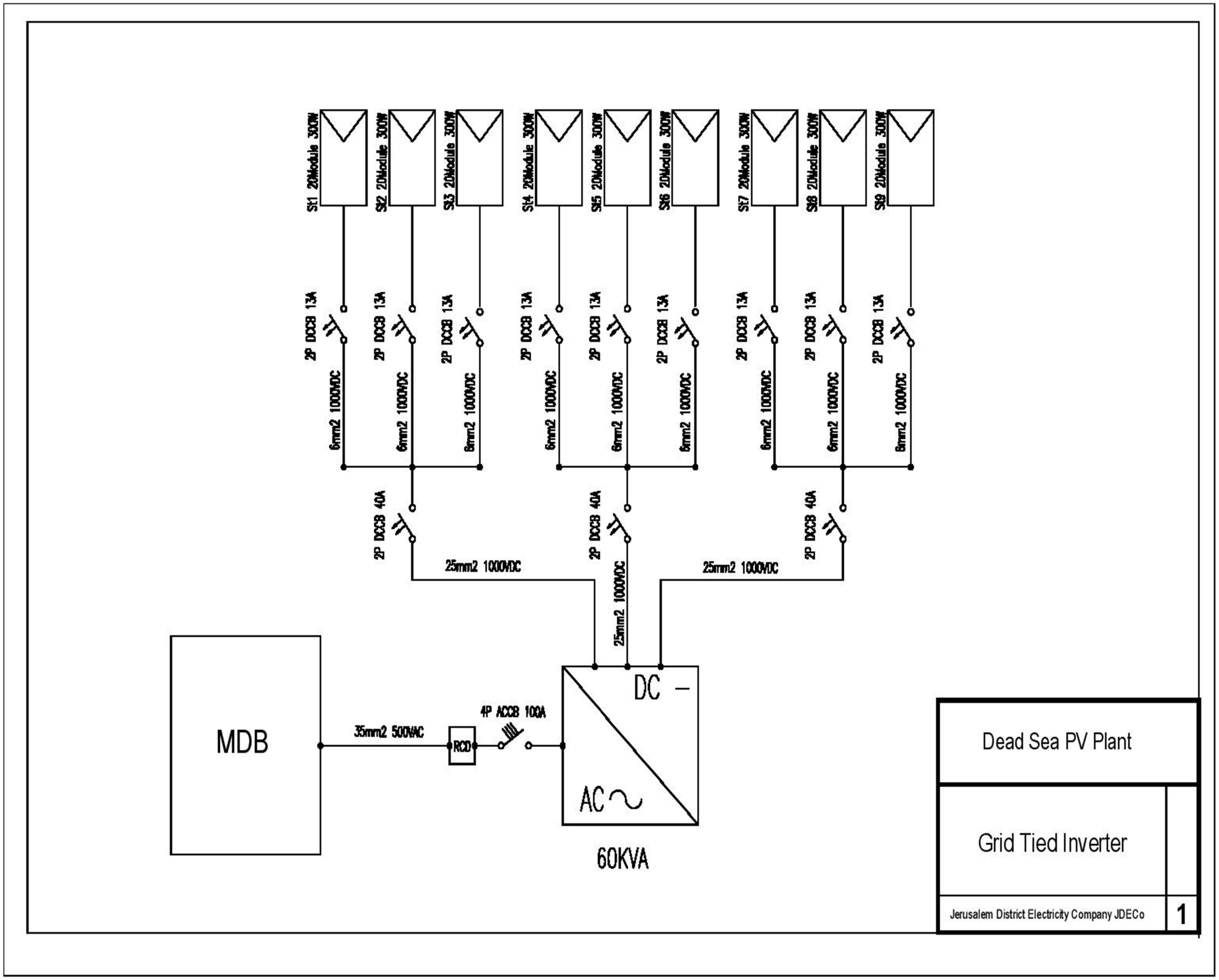
CHAPTER 5: CONCLUSION AND FUTURE WORK

The increase use of renewable energy resources worldwide and the need for sustainable clean source of energy leads to the development of Microgrid, Microgrid system is one of the leading topics in energy, many studies and practical implementations are done in this field.

JDECO had built PV stations in Jericho, to implement a Microgrid system using this station and sustainable important load with optimum cost, a model is built and tested based on real data, the results assure power security and low THD with reasonable payback period.

Nowadays for commercial and residential PV energy system , net metering is used and it had a payback period of 3 or 4 years , but it had its limit of 30% of the grid load , which will be reached within 3 or 4 years in some areas in Palestine , microgrid system offer an optimum solution for this obstacle , modifying one of the net metering consumers within JDECO to microgrid system with financial and technical study is proposed for future work.

APPENDIX A: SINGLE LINE DAGRAMS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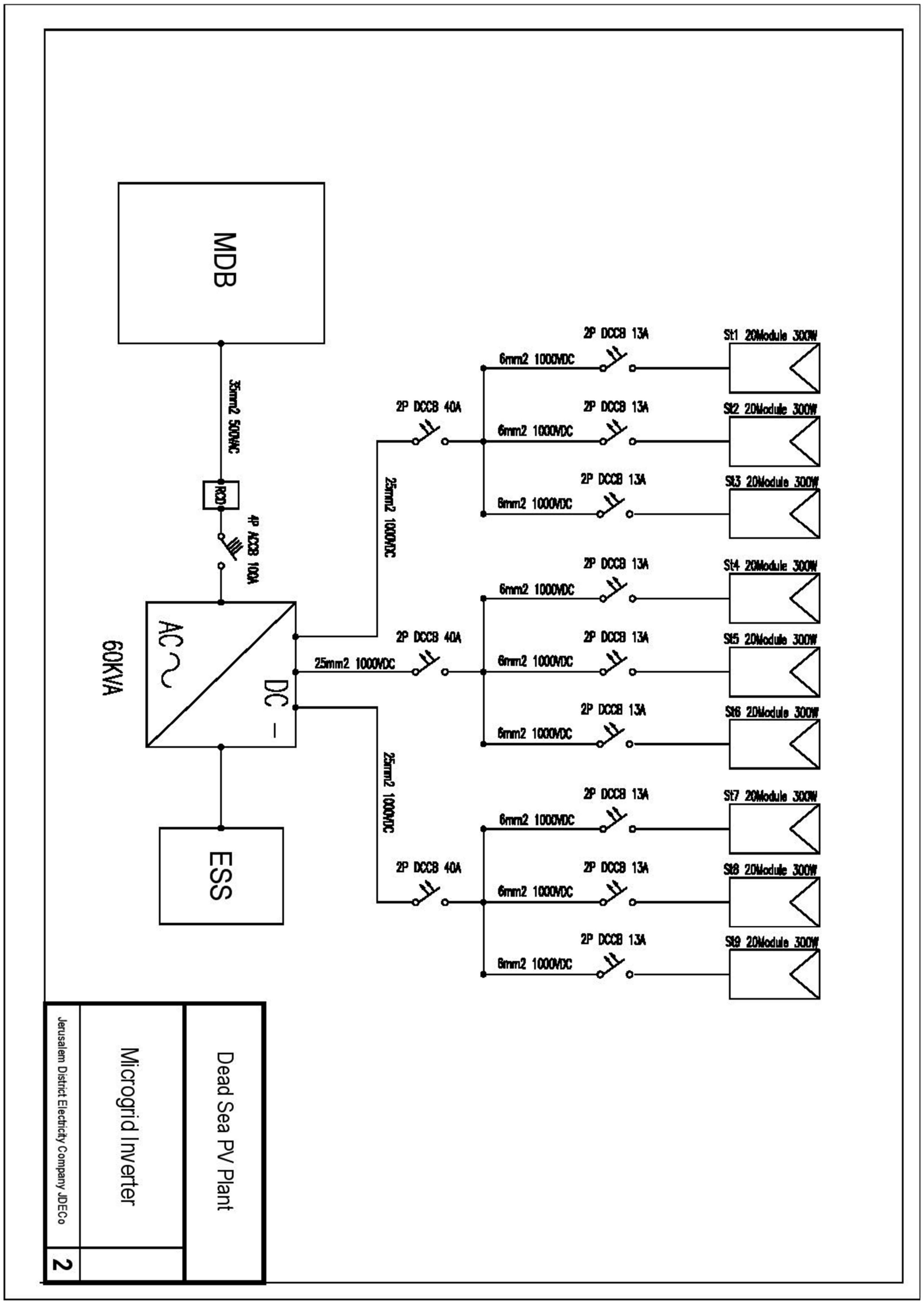
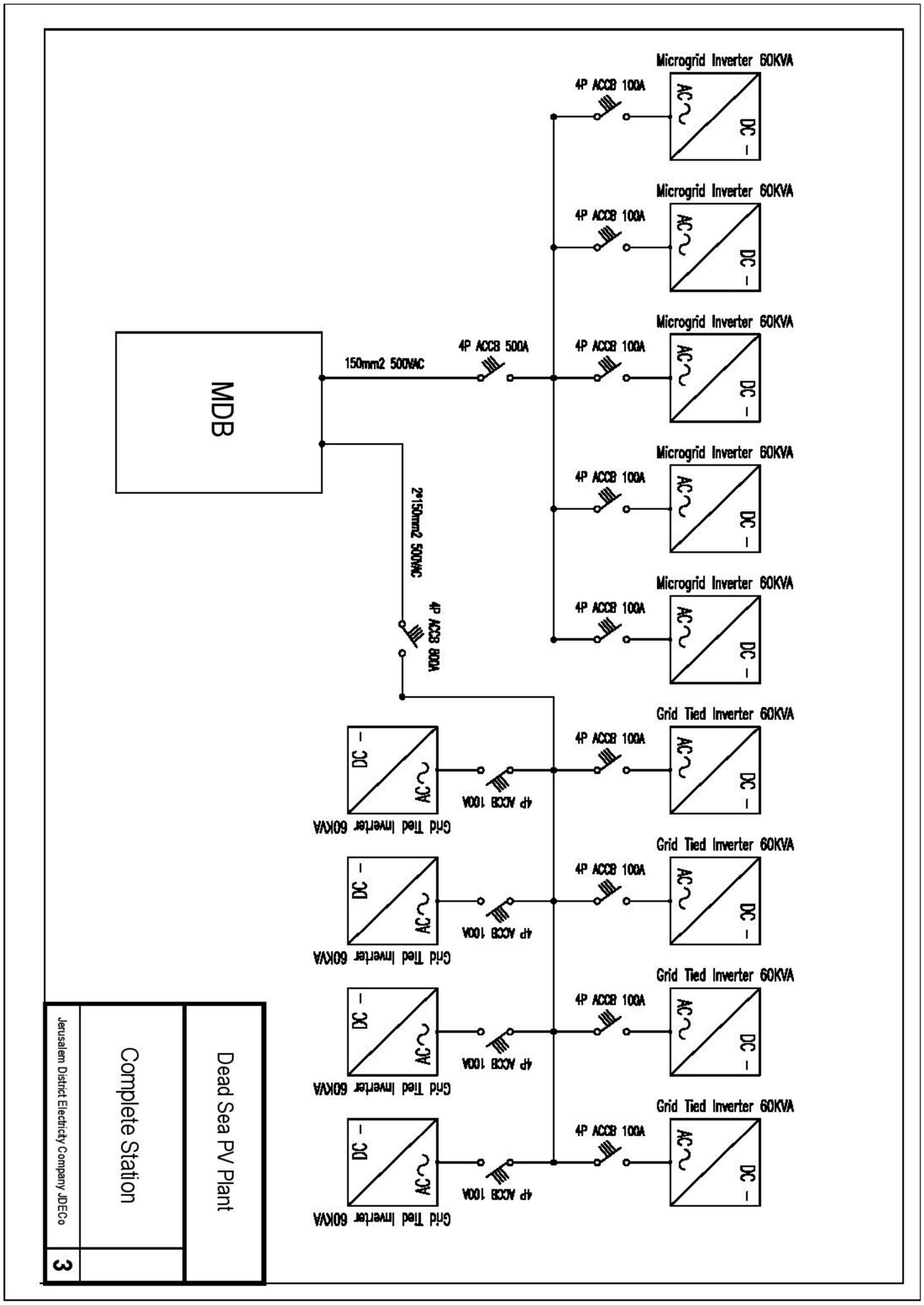
St2 20Module 300W
St3 20Module 300W
St4 20Module 300W
St5 20Module 300W
St6 20Module 300W
St7 20Module 300W
St8 20Module 300W
St9 20Module 300W
2P DCCB 13A
6mm2 1000VDC
2P DCCB 40A
25mm2 1000VDC
DC –
AC ~
60KVA
4P ACCB 100A
RCD
35mm2 500VAC
MDB
Dead Sea PV Plant
Grid Tied Inverter
Jerusalem District Electricity Company JDECo
1


MDB
35mm2 500VAC
RCD
4P ACCB 100A
60KVA
AC ~
DC –
ESS
25mm2 1000VDC
25mm2 1000VDC
25mm2 1000VDC
2P DCCB 40A
2P DCCB 40A
2P DCCB 40A
6mm2 1000VDC
2P DCCB 13A
St1 20Module 300W
St2 20Module 300W
St3 20Module 300W
St4 20Module 300W
St5 20Module 300W
St6 20Module 300W
St7 20Module 300W
St8 20Module 300W
St9 20Module 300W
Dead Sea PV Plant
Microgrid Inverter
Jerusalem District Electricity Company JDECo
2


MDB
150mm2 500VAC
4P ACCB 500A
2*150mm2 500VAC
4P ACCB 800A
Microgrid Inverter 60KVA
Microgrid Inverter 60KVA
Microgrid Inverter 60KVA
Microgrid Inverter 60KVA
Microgrid Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
Grid Tied Inverter 60KVA
4P ACCB 100A
AC
DC
Dead Sea PV Plant
Complete Station
Jerusalem District Electricity Company JDECo
3

APPENDIX B: LOAD PROFILE IN SAMPLE DAY EVERY MONTH

Table B6: Load profile analysis in 31 January

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	95.2	0	on	95.2	0	0	0
1:00	60.4	0	on	60.4	0	0	0
2:00	48	0	on	48	0	0	0
3:00	41.6	0	on	41.6	0	0	0
4:00	41.2	0	on	41.2	0	0	0
5:00	39.2	0	on	39.2	0	0	0
6:00	67.2	0	on	67.2	0	0	0
7:00	81.2	6	on	75.2	0	0	0
8:00	74.8	60	on	14.8	0	0	0
9:00	53.6	236.57	on	0	182.97	0	0
10:00	68.8	349.34	on	0	280.54	0	0
11:00	73.6	434.34	on	0	360.74	0	0
12:00	66.4	466.16	on	0	399.76	0	0
13:00	78.4	452.7	on	0	374.3	0	0
14:00	87.6	394.22	on	0	306.62	0	0
15:00	74	299.88	on	0	225.88	0	0
16:00	99.2	163.63	on	0	64.43	0	0
17:00	133.2	32.04	on	101.16	0	0	0
18:00	167.2	0.23	on	166.97	0	0	0
19:00	177.2	0	on	177.2	0	0	0
20:00	161.2	0	on	161.2	0	0	0
21:00	132.8	0	on	132.8	0	0	0
22:00	186	0	on	186	0	0	0
23:00	142.8	0	on	142.8	0	0	0

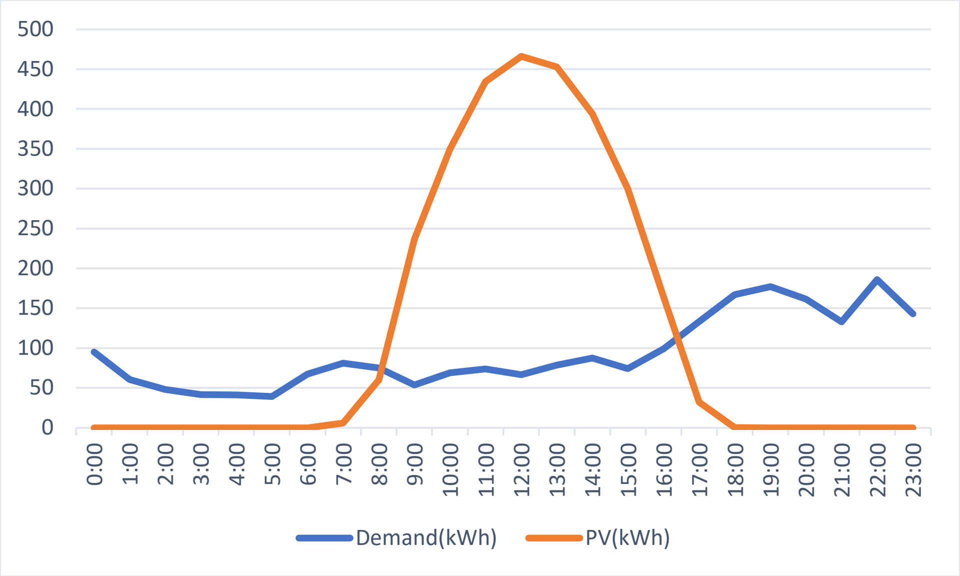


Figure B1: Demand and PV production in 31 january

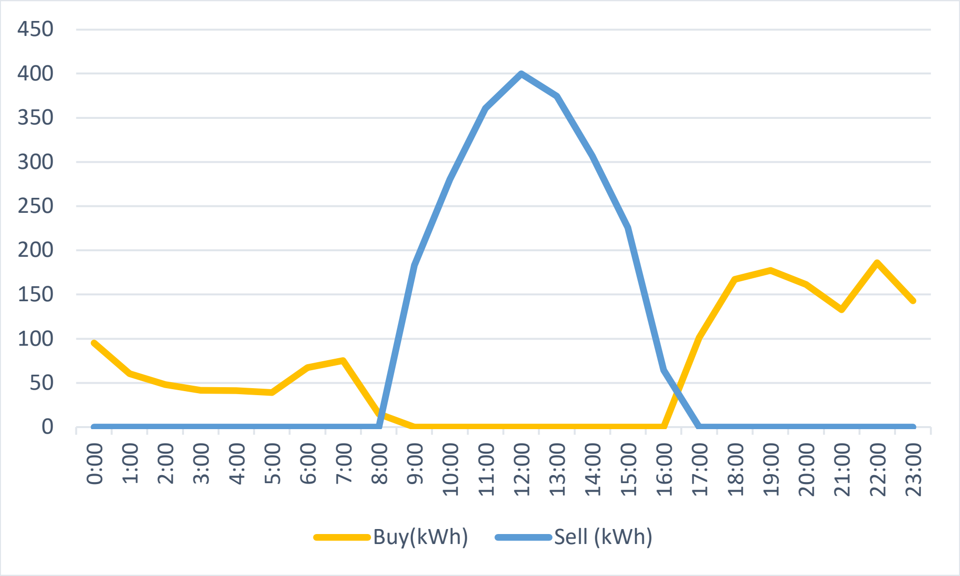


Figure B2: Energy Bought and sold in 31-Jan

Table B7: Load profile analysis in 2 February

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	120	0	on	120	0	0	0
1:00	101.6	0	on	101.6	0	0	0
2:00	80	0	on	80	0	0	0
3:00	78.4	0	on	78.4	0	0	0
4:00	70.4	0	on	70.4	0	0	0
5:00	50	0	on	50	0	0	0
6:00	35.2	0	on	35.2	0	0	0
7:00	38.4	4.38	on	34.02	0	0	0
8:00	80	80.37	on	0	0.37	0	0
9:00	72.8	232.57	on	0	159.77	0	0
10:00	68	368.58	on	0	300.58	0	0
11:00	71.6	484.44	on	0	412.84	0	0
12:00	69.6	493.06	on	0	423.46	0	0
13:00	61.6	495.49	on	0	433.89	0	0
14:00	55.6	443.84	on	0	388.24	0	0
15:00	55.2	340.35	off	0	0	0	0
16:00	66.4	201.45	on	0	135.05	0	0
17:00	80.8	40.51	on	40.29	0	0	0
18:00	122.8	0.43	on	122.37	0	0	0
19:00	113.6	0	on	113.6	0	0	0
20:00	147.2	0	on	147.2	0	0	0
21:00	165.2	0	on	165.2	0	0	0
22:00	166.4	0	on	166.4	0	0	0
23:00	100.8	0	on	100.8	0	0	0

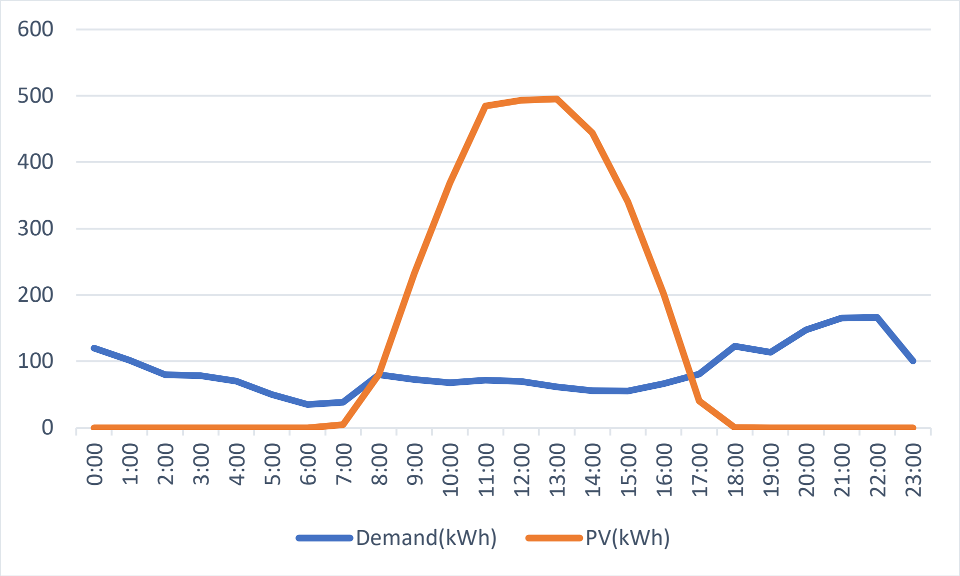


Figure B3: Demand and PV production in 2 february

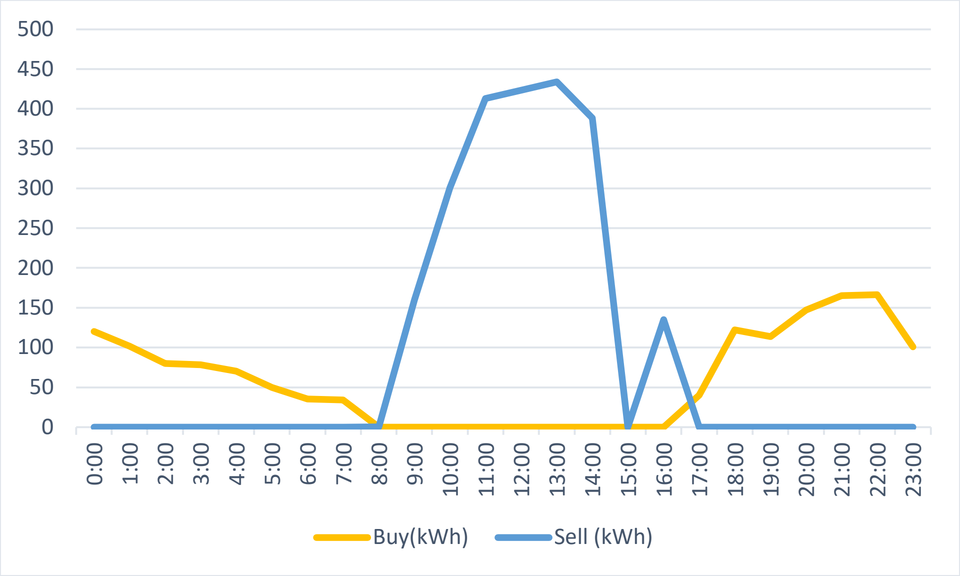


Figure B417: Energy Bought and sold in 2 february

Table B8: Load profile analysis in 8 march

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	44.4	0	on	44.4	0	0	0
1:00	28	0	on	28	0	0	0
2:00	24.8	0	on	24.8	0	0	0
3:00	24.4	0	on	24.4	0	0	0
4:00	24	0	on	24	0	0	0
5:00	24	0	on	24	0	0	0
6:00	26.8	0	on	26.8	0	0	0
7:00	35.2	37.98	on	0	2.78	0	0
8:00	59.2	173.83	on	0	114.63	0	0
9:00	56	285.29	on	0	229.29	0	0
10:00	67.2	364.13	on	0	296.93	0	0
11:00	77.2	442.67	on	0	365.47	0	0
12:00	93.6	423.44	on	0	329.84	0	0
13:00	78.8	302.65	on	0	223.85	0	0
14:00	83.6	420.87	on	0	337.27	0	0
15:00	77.2	380.58	on	0	303.38	0	0
16:00	62.4	181.03	on	0	118.63	0	0
17:00	42.8	60.12	on	0	17.32	0	0
18:00	69.6	6.53	off	0	0	63.07	0
19:00	74.4	0	on	137.47	0	0	63.07
20:00	71.6	0	on	71.6	0	0	0
21:00	69.6	0	on	69.6	0	0	0
22:00	60.4	0	on	60.4	0	0	0
23:00	60.8	0	on	60.8	0	0	0

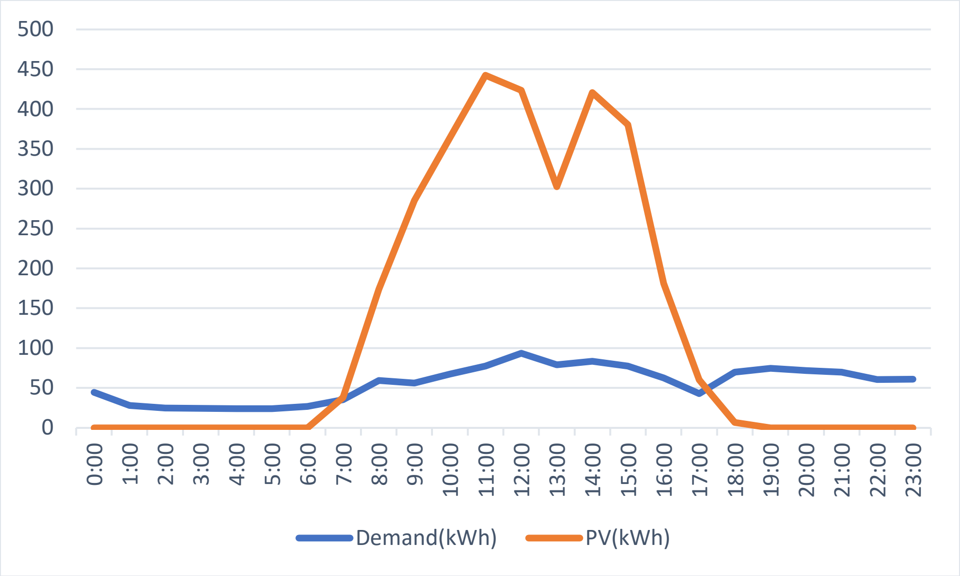


Figure B5: Demand and PV production in 8 march

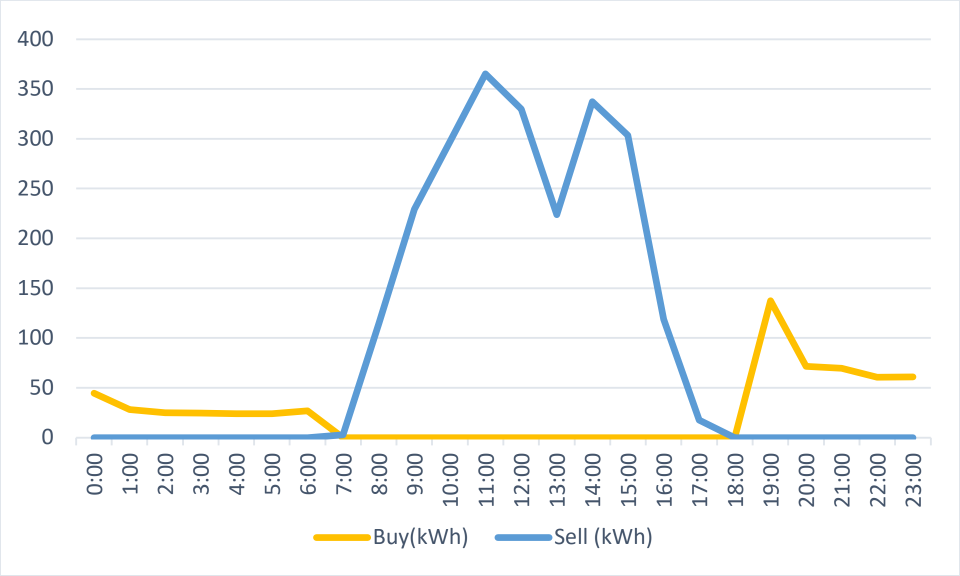


Figure B6: Energy Bought and sold in 8 march

Table B4: Load profile analysis in 8 April

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	59.2	0	on	59.2	0	0	0
1:00	45.6	0	on	45.6	0	0	0
2:00	39.6	0	on	39.6	0	0	0
3:00	38.4	0	on	38.4	0	0	0
4:00	33.2	0	on	33.2	0	0	0
5:00	30.4	0	on	30.4	0	0	0
6:00	30	0	on	30	0	0	0
7:00	32.4	12.74	on	19.66	0	0	0
8:00	46.4	82.7	on	0	36.3	0	0
9:00	42.4	193.78	on	0	151.38	0	0
10:00	64	309.79	on	0	245.79	0	0
11:00	85.6	389.1	on	0	303.5	0	0
12:00	73.6	439.32	on	0	365.72	0	0
13:00	47.6	475.41	on	0	427.81	0	0
14:00	47.2	463.16	on	0	415.96	0	0
15:00	41.6	414.78	on	0	373.18	0	0
16:00	45.6	339.67	on	0	294.07	0	0
17:00	43.6	212.77	on	0	169.17	0	0
18:00	44	105.71	on	0	61.71	0	0
19:00	46.8	17.24	on	29.56	0	0	0
20:00	63.6	0	on	63.6	0	0	0
21:00	61.6	0	on	61.6	0	0	0
22:00	66.4	0	on	66.4	0	0	0
23:00	70.4	0	on	70.4	0	0	0

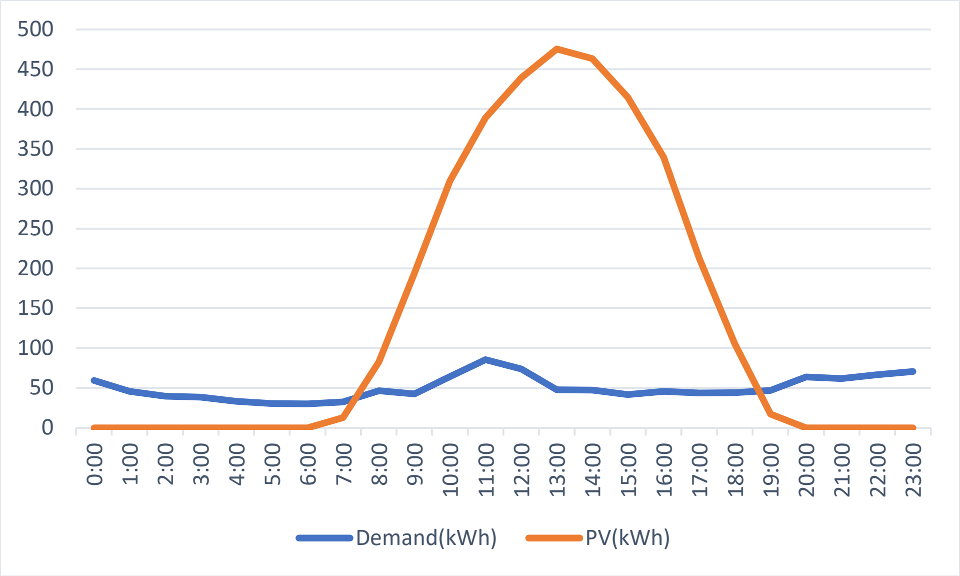


Figure B7: Demand and PV production in 8 april

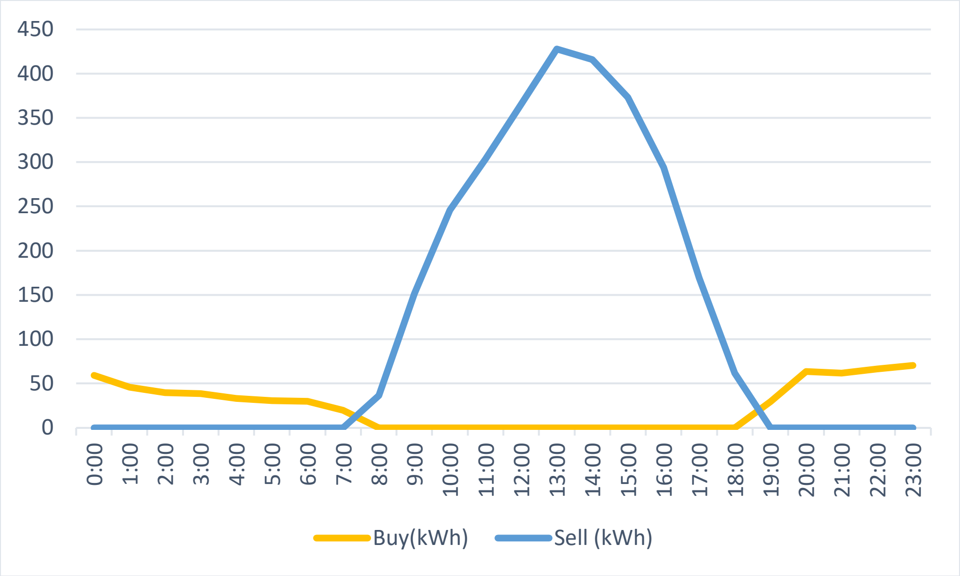


Figure B8: Energy Bought and sold in 8 april

Table B5: Load profile analysis in 14 may

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	49.2	0	on	49.2	0	0	0
1:00	39.2	0	on	39.2	0	0	0
2:00	38.4	0	on	38.4	0	0	0
3:00	33.2	0	on	33.2	0	0	0
4:00	32	0	on	32	0	0	0
5:00	31.2	0	on	31.2	0	0	0
6:00	36	0	on	36	0	0	0
7:00	31.6	36.23	off	0	0	0	0
8:00	41.6	142.8	on	0	101.2	0	0
9:00	51.2	276.36	on	0	225.16	0	0
10:00	65.2	379.07	on	0	313.87	0	0
11:00	74	432.45	on	0	358.45	0	0
12:00	83.6	511.12	on	0	427.52	0	0
13:00	65.2	528.7	on	0	463.5	0	0
14:00	65.2	519.45	on	0	454.25	0	0
15:00	79.2	467.8	on	0	388.6	0	0
16:00	87.2	382.4	on	0	295.2	0	0
17:00	59.2	202.04	on	0	142.84	0	0
18:00	62.8	117.63	on	0	54.83	0	0
19:00	61.2	42.03	on	19.17	0	0	0
20:00	61.2	1.66	on	59.54	0	0	0
21:00	76.4	0	on	76.4	0	0	0
22:00	78	0	on	78	0	0	0
23:00	61.6	0	on	61.6	0	0	0

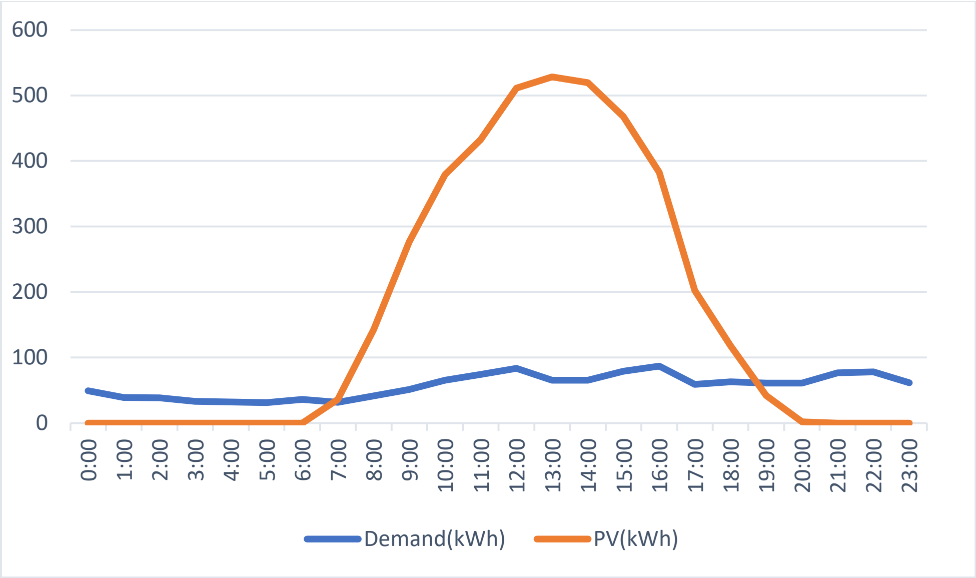


Figure B9: Demand and PV production in 14 may

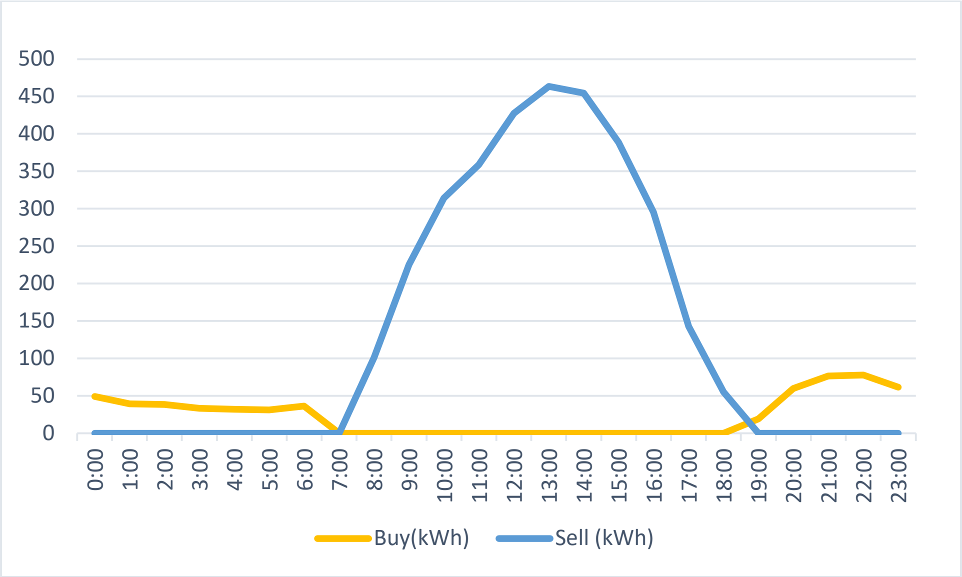


Figure B10: Energy Bought and sold in 14 may

Table B9: Load profile analysis in 12 June

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	71.2	0	on	71.2	0	0	0
1:00	69.2	0	on	69.2	0	0	0
2:00	58.4	0	on	58.4	0	0	0
3:00	63.2	0	on	63.2	0	0	0
4:00	58.8	0	on	58.8	0	0	0
5:00	53.2	0	on	53.2	0	0	0
6:00	51.2	0	on	51.2	0	0	0
7:00	50.4	34.44	on	15.96	0	0	0
8:00	49.2	131.38	on	0	82.18	0	0
9:00	69.2	254.4	on	0	185.2	0	0
10:00	61.6	373.17	on	0	311.57	0	0
11:00	60	450.63	on	0	390.63	0	0
12:00	56.4	413.92	on	0	357.52	0	0
13:00	54.4	423.08	on	0	368.68	0	0
14:00	72.8	103.81	on	0	31.01	0	0
15:00	68	339.55	on	0	271.55	0	0
16:00	61.2	344.19	on	0	282.99	0	0
17:00	64.4	280.2	on	0	215.8	0	0
18:00	77.2	149.4	on	0	72.2	0	0
19:00	68.4	42.76	on	25.64	0	0	0
20:00	62	3.9	on	58.1	0	0	0
21:00	72.4	0	on	72.4	0	0	0
22:00	71.6	0	on	71.6	0	0	0
23:00	72	0	on	72	0	0	0

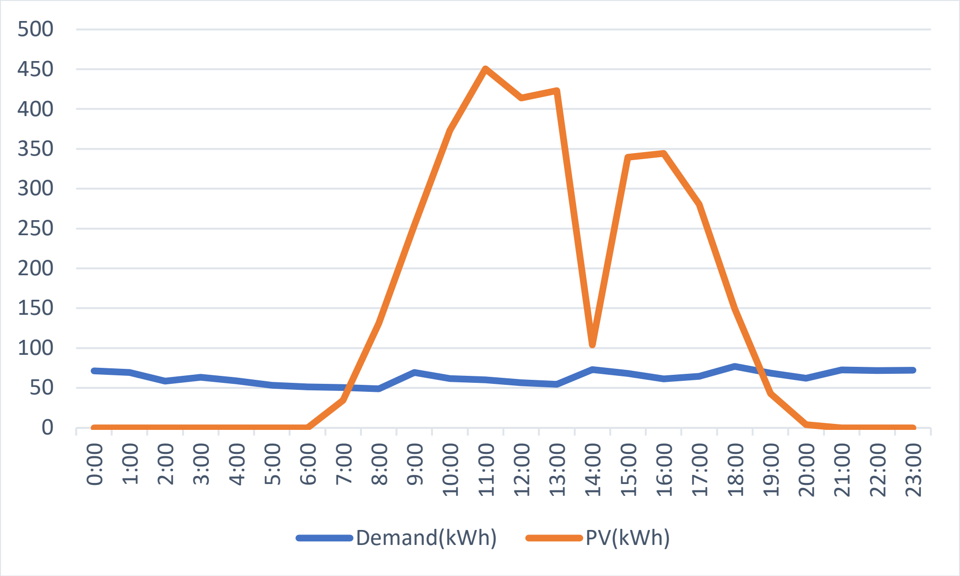


Figure 18: Demand and PV production in 12 june

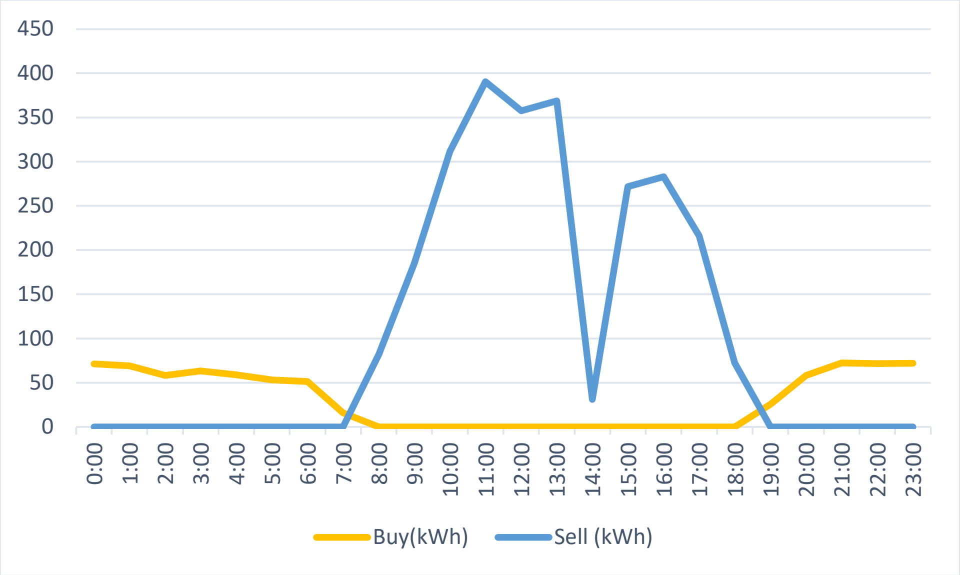


Figure B12: Energy Bought and sold in 12 june

Table B7: Load profile analysis in 22 July

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	66	0	on	66	0	0	0
1:00	73.6	0	on	73.6	0	0	0
2:00	69.2	0	on	69.2	0	0	0
3:00	56.8	0	on	56.8	0	0	0
4:00	58.4	0	on	58.4	0	0	0
5:00	56.4	0	on	56.4	0	0	0
6:00	53.6	0	on	53.6	0	0	0
7:00	50	22.93	on	27.07	0	0	0
8:00	52	100.34	on	0	48.34	0	0
9:00	63.6	217.45	on	0	153.85	0	0
10:00	99.2	330.25	on	0	231.05	0	0
11:00	104.8	413.78	on	0	308.98	0	0
12:00	78	465.81	on	0	387.81	0	0
13:00	72.4	480.53	on	0	408.13	0	0
14:00	86	467.08	on	0	381.08	0	0
15:00	124.8	425.59	on	0	300.79	0	0
16:00	150	350.55	on	0	200.55	0	0
17:00	145.2	253.05	on	0	107.85	0	0
18:00	108	141.43	on	0	33.43	0	0
19:00	109.2	41.19	on	68.01	0	0	0
20:00	83.6	3.51	off	0	0	80.09	0
21:00	63.2	0	on	143.29	0	0	80.09
22:00	66.4	0	on	66.4	0	0	0
23:00	82.8	0	on	82.8	0	0	0

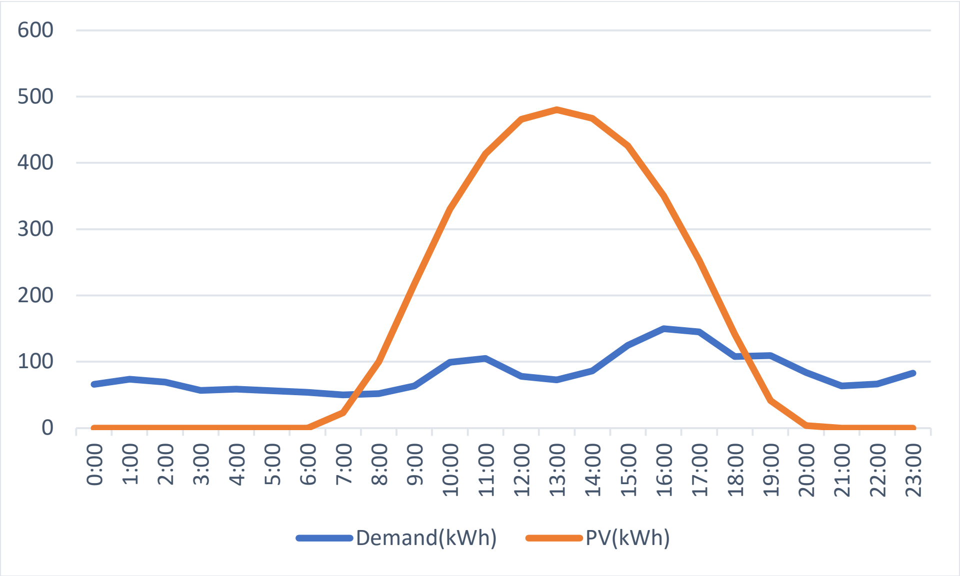


Figure 19: Demand and PV production in 22 july

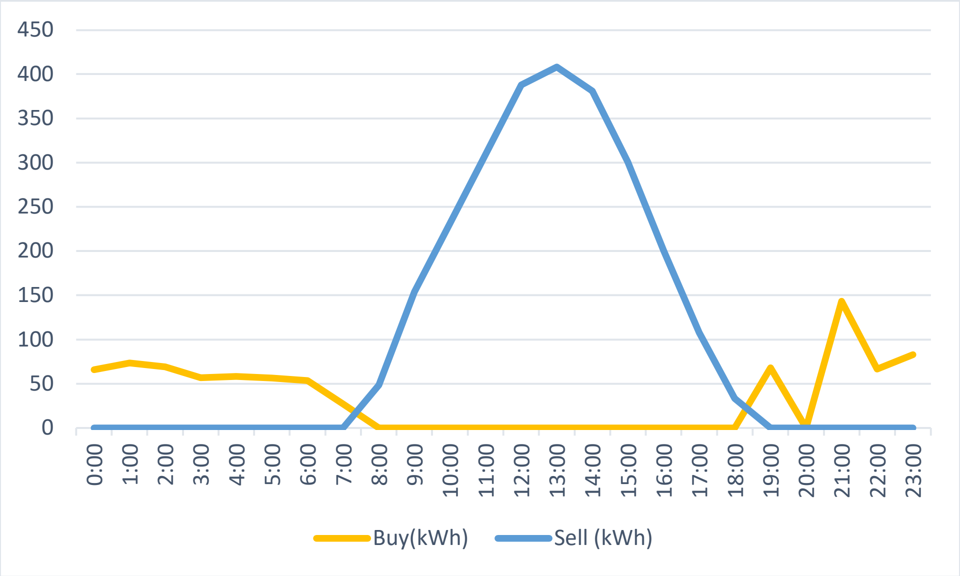


Figure B14: Energy Bought and sold in 22 july

Table B8: Load profile analysis in 8 August

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	93.6	0	on	93.6	0	0	0
1:00	99.6	0	on	99.6	0	0	0
2:00	81.6	0	on	81.6	0	0	0
3:00	77.6	0	on	77.6	0	0	0
4:00	68	0	on	68	0	0	0
5:00	65.6	0	on	65.6	0	0	0
6:00	66	0	on	66	0	0	0
7:00	67.2	17.82	on	49.38	0	0	0
8:00	79.2	95.63	on	0	16.43	0	0
9:00	83.2	215.36	on	0	132.16	0	0
10:00	92.8	324.1	on	0	231.3	0	0
11:00	89.6	400.11	on	0	310.51	0	0
12:00	88.8	461.21	on	0	372.41	0	0
13:00	91.6	484.01	on	0	392.41	0	0
14:00	114.4	480.34	on	0	365.94	0	0
15:00	109.6	430.04	on	0	320.44	0	0
16:00	132.4	342.89	on	0	210.49	0	0
17:00	150.4	242.15	on	0	91.75	0	0
18:00	146.8	125.83	off	0	0	20.97	0
19:00	107.2	32.25	on	95.92	0	0	20.97
20:00	74.4	1.43	on	72.97	0	0	0
21:00	65.6	0	on	65.6	0	0	0
22:00	81.6	0	on	81.6	0	0	0
23:00	82	0	on	82	0	0	0

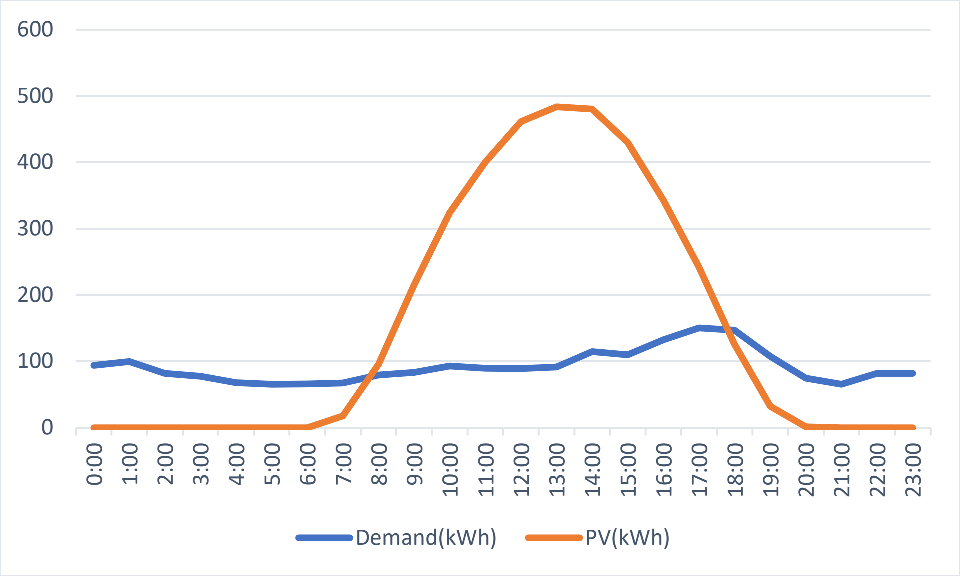


Figure 20: Demand and PV production in 8 august

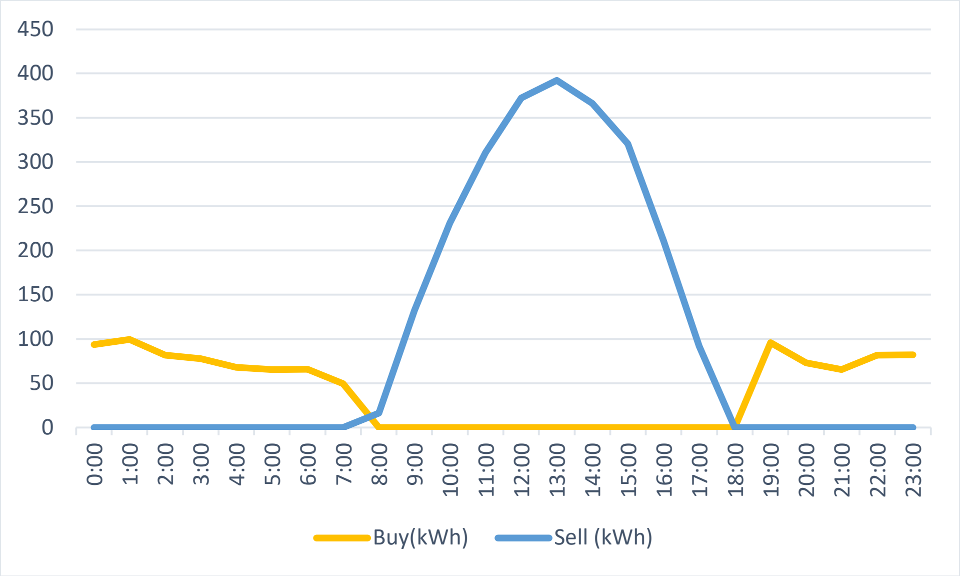


Figure B16: Energy Bought and sold in 8 august

Table B9: Load profile analysis in 15 September

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	62.8	0	on	62.8	0	0	0
1:00	72.4	0	on	72.4	0	0	0
2:00	67.2	0	on	67.2	0	0	0
3:00	61.2	0	on	61.2	0	0	0
4:00	54.4	0	on	54.4	0	0	0
5:00	54.4	0	on	54.4	0	0	0
6:00	54.4	0	on	54.4	0	0	0
7:00	57.6	7.83	on	49.77	0	0	0
8:00	61.6	84.27	on	0	22.67	0	0
9:00	70.4	208.43	on	0	138.03	0	0
10:00	62.4	327.08	on	0	264.68	0	0
11:00	62.4	409.67	on	0	347.27	0	0
12:00	74.8	456.23	on	0	381.43	0	0
13:00	91.6	468.12	on	0	376.52	0	0
14:00	89.2	443.17	on	0	353.97	0	0
15:00	107.2	389.07	on	0	281.87	0	0
16:00	130.8	299.68	on	0	168.88	0	0
17:00	120.8	182.08	on	0	61.28	0	0
18:00	76.8	68.9	on	7.9	0	0	0
19:00	89.6	5.95	on	83.65	0	0	0
20:00	78.4	0	on	78.4	0	0	0
21:00	86.4	0	on	86.4	0	0	0
22:00	73.2	0	on	73.2	0	0	0
23:00	74.4	0	on	74.4	0	0	0

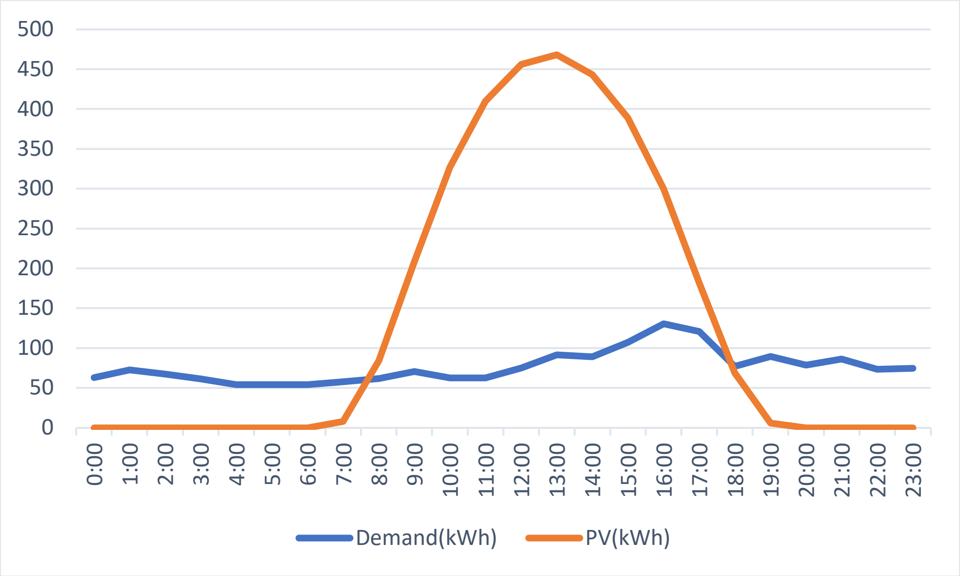


Figure 21: Demand and PV production in 15 september

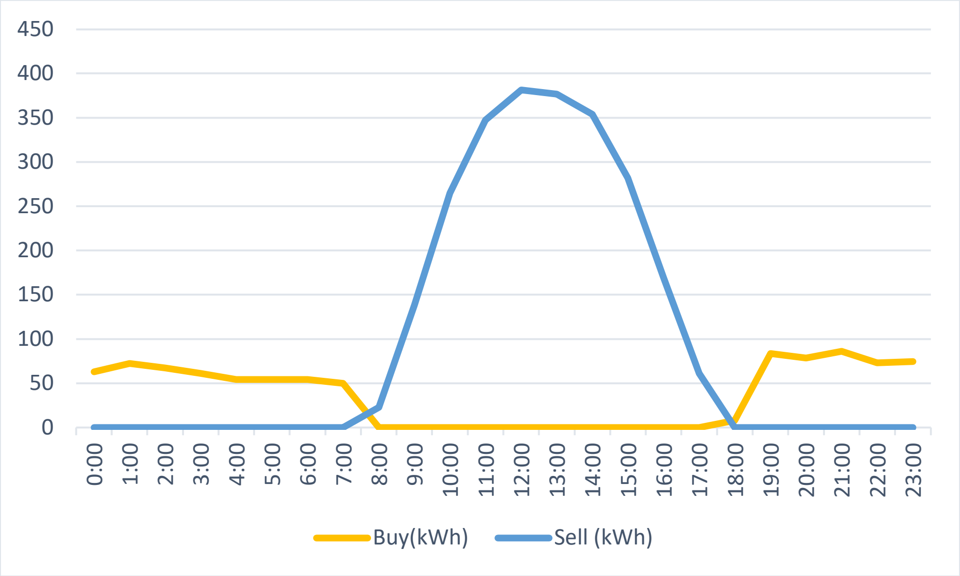


Figure 22: Energy Bought and sold in 15 september

Table 10: Load profile analysis in 10 October

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	69.2	0	on	69.2	0	0	0
1:00	66.8	0	on	66.8	0	0	0
2:00	62.8	0	on	62.8	0	0	0
3:00	56	0	on	56	0	0	0
4:00	57.6	0	on	57.6	0	0	0
5:00	48	0	on	48	0	0	0
6:00	45.6	0	on	45.6	0	0	0
7:00	41.2	3.12	on	38.08	0	0	0
8:00	55.6	64.55	off	0	0	0	0
9:00	50.4	190.77	on	0	140.37	0	0
10:00	63.2	305.87	on	0	242.67	0	0
11:00	57.2	399.87	on	0	342.67	0	0
12:00	59.2	443.9	on	0	384.7	0	0
13:00	61.6	455.91	on	0	394.31	0	0
14:00	76	424.77	on	0	348.77	0	0
15:00	95.2	360.69	on	0	265.49	0	0
16:00	96.8	241.01	on	0	144.21	0	0
17:00	102.4	148.61	on	0	46.21	0	0
18:00	107.2	38.89	on	68.31	0	0	0
19:00	85.6	0.74	on	84.86	0	0	0
20:00	95.6	0	on	95.6	0	0	0
21:00	93.6	0	on	93.6	0	0	0
22:00	66	0	on	66	0	0	0
23:00	75.2	0	on	75.2	0	0	0

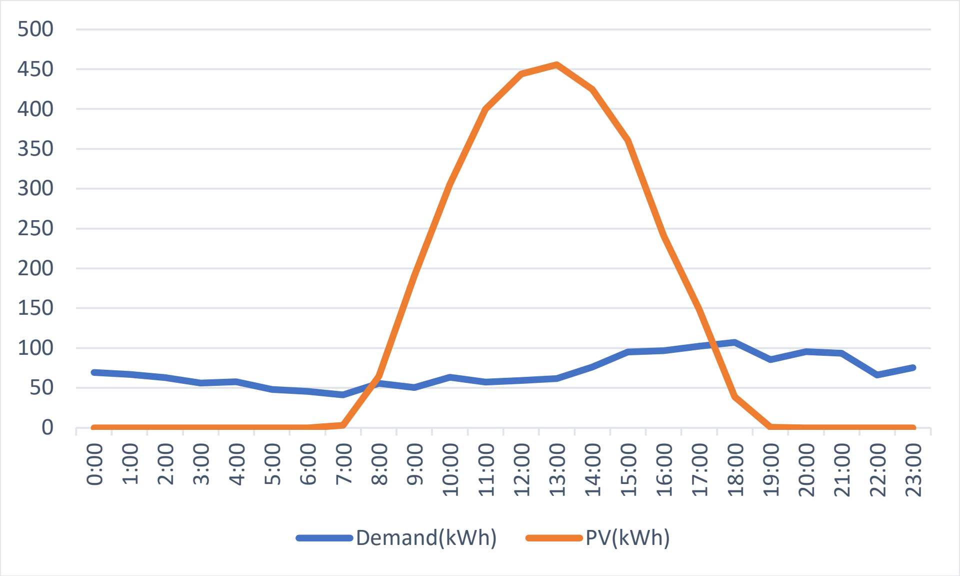


Figure B19: Demand and PV production in 10 october

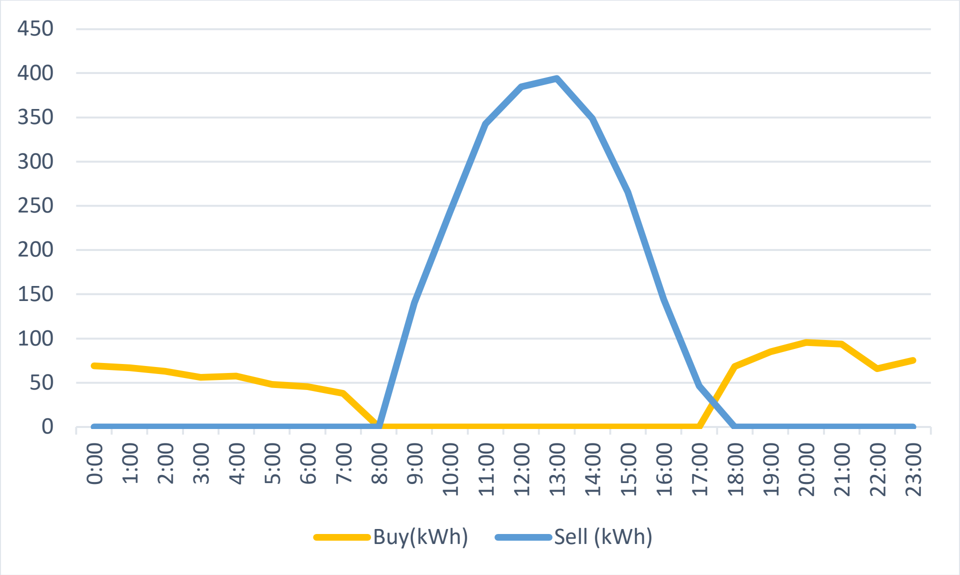


Figure B20: Energy Bought and sold in 10 october

Table 11: Load profile analysis in 18 November

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	46.8	0	on	46.8	0	0	0
1:00	52.4	0	on	52.4	0	0	0
2:00	52.4	0	on	52.4	0	0	0
3:00	36.8	0	on	36.8	0	0	0
4:00	34	0	on	34	0	0	0
5:00	28.4	0	on	28.4	0	0	0
6:00	34	0	on	34	0	0	0
7:00	30.8	25.75	on	5.05	0	0	0
8:00	41.6	167.33	on	0	125.73	0	0
9:00	35.6	322.9	on	0	287.3	0	0
10:00	35.2	423.17	on	0	387.97	0	0
11:00	34	482.06	on	0	448.06	0	0
12:00	32.8	483.92	on	0	451.12	0	0
13:00	34.4	443.32	on	0	408.92	0	0
14:00	34.4	373.27	on	0	338.87	0	0
15:00	38	266.46	on	0	228.46	0	0
16:00	60.8	86.49	on	0	25.69	0	0
17:00	72.4	5.04	on	67.36	0	0	0
18:00	61.6	0	on	61.6	0	0	0
19:00	60.4	0	on	60.4	0	0	0
20:00	57.6	0	on	57.6	0	0	0
21:00	56	0	on	56	0	0	0
22:00	55.2	0	on	55.2	0	0	0
23:00	45.2	0	on	45.2	0	0	0

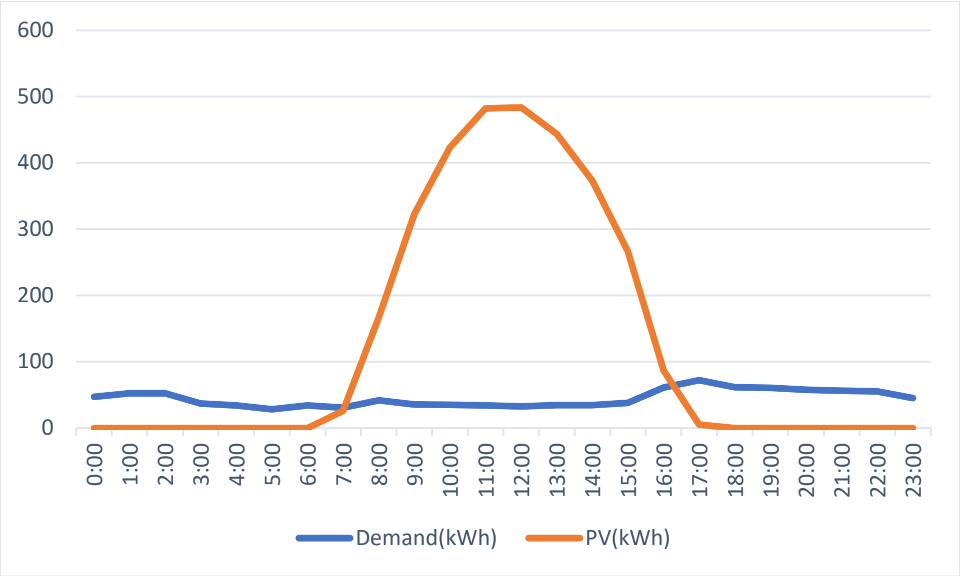


Figure B21: Demand and PV production in 18 november

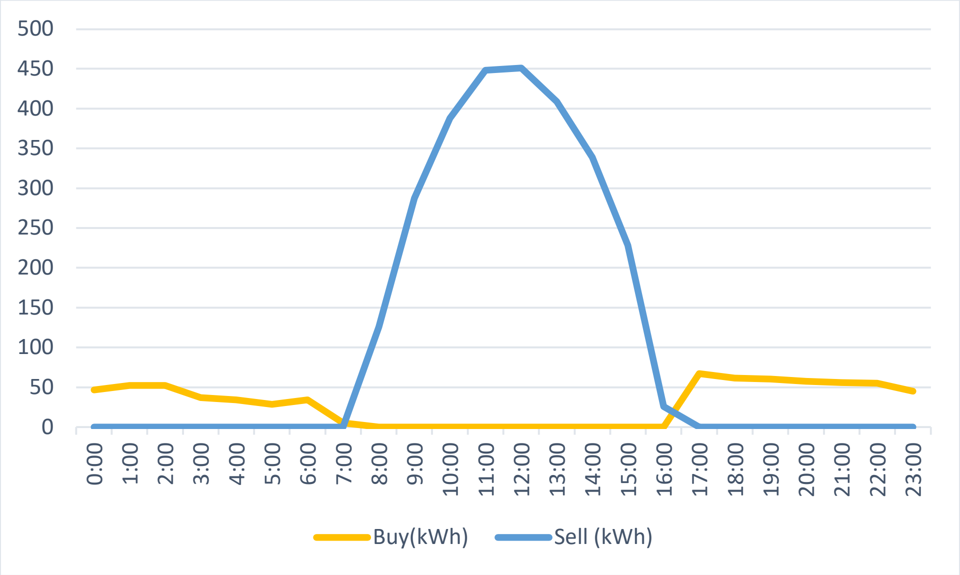


Figure B22: Energy Bought and sold in 18 november

Table B12 12: Load profile analysis in 20 December

Date	Demand (kWh)	PV (kWh)	Grid	Buy (kWh)	Sell (kWh)	Battery discharge	Battery charge
0:00	72.4	0	on	72.4	0	0	0
1:00	34.4	0	on	34.4	0	0	0
2:00	33.6	0	on	33.6	0	0	0
3:00	32.4	0	on	32.4	0	0	0
4:00	30	0	on	30	0	0	0
5:00	43.2	0	on	43.2	0	0	0
6:00	60.8	0	on	60.8	0	0	0
7:00	74.4	0.28	on	74.12	0	0	0
8:00	77.6	30.44	on	47.16	0	0	0
9:00	106.8	58.71	on	48.09	0	0	0
10:00	84.8	173.3	on	0	88.5	0	0
11:00	92.8	153.01	on	0	60.21	0	0
12:00	114.8	137.84	on	0	23.04	0	0
13:00	114.4	69.88	on	44.52	0	0	0
14:00	121.6	81.67	on	39.93	0	0	0
15:00	123.2	175.01	on	0	51.81	0	0
16:00	156.8	59.78	on	97.02	0	0	0
17:00	163.6	0.46	on	163.14	0	0	0
18:00	130	0	on	130	0	0	0
19:00	136.8	0	on	136.8	0	0	0
20:00	161.6	0	on	161.6	0	0	0
21:00	154	0	on	154	0	0	0
22:00	114.8	0	on	114.8	0	0	0
23:00	136	0	on	136	0	0	0

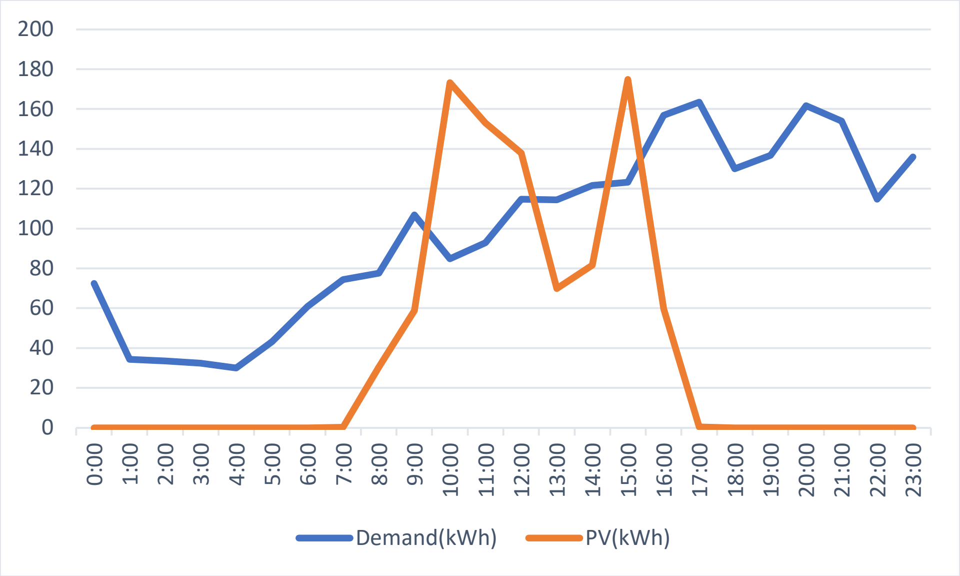


Figure B23: Demand and PV production in 20 december

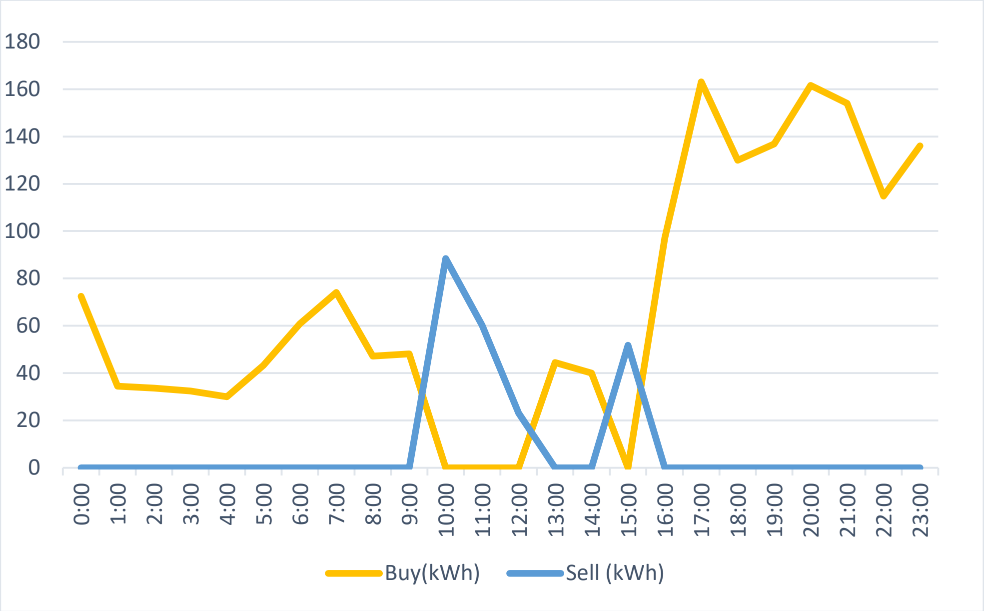


Figure B24: Energy Bought and sold in 20 december

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