Towards a Zero Net Energy Community Microgrid

By

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Abstract

Decentralization of the vertically integrated electrical power system can bring economic, reliability and environmental benefits to society. Microgrids are a step towards a more hybrid, less centralized power industry. A key objection from traditional electric utilities to distributed renewable energy is the variation injected to the power grid from variables sources such as the sun. A significant milestone would be to locally manage that variation from renewable sources before it reaches the grid. Furthermore, if a renewable-driven subsystem demands a fixed block of power from the grid, the potential impacts from interconnecting renewable energy are minimized. This thesis focuses on the technical aspects related to realize or come close to zero net energy community microgrids, with the capability to internally managing any variations from rooftop PV systems and demanding a fixed amount of electric energy from the grid.

Resumen

La descentralización de los sistemas de potencia tradicionales puede traer beneficios económicos, ambientales y de confiabilidad a la sociedad. La microredes son un paso hacia industria más hibrida y descentralizada. Una de las objeciones claves de las utilidades eléctricas tradicionales para añadir más recurso de generación renovable distribuida es la variación que inyecta está a la red de fuentes variables como lo es el sol. Un desarrollo significativo sería manejar localmente la variación de las fuentes renovables antes que lleguen a la red eléctrica. Aún más, si los subsistemas de energía renovable demandan un bloque constante de potencia de la red, los impactos de interconectar la energía renovable son minimizados. Esta tesis se enfoca en aspectos técnicos relacionados a microredes comunitarias de energía neta cero, con la capacidad de manejar internamente variaciones de sistemas fotovoltaicos en techos y con una demanda fija de energía eléctrica de la red.

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1. Introduction

1.1 Overview

Throughout the World many countries are moving towards renewable resources, energy conservation and energy efficiency through public policies that promote renewable resources, energy conservation and energy efficiency. An important motivation for this global movement towards energy sustainability is concern about climate change. In 2010 the Legislature of Puerto Rico passed Act 82-2010 also known as “The Law of Public Policy of Energy Diversification through Renewable Sustainable and Alternate Energy in Puerto Rico”. This law promotes renewable energy generation goals projected to the future: 12% of the electric energy of the island has to be generated by renewable resources between the years 2015 and 2019, the goal is set to 15% for 2020 and 20% for 2035. Furthermore, Act 57-2014 was approved in 2014 to maximize the use of renewable energy and promote energy efficiency and conservation. Thus, there are legislative mandates to increase the use of local resources. Puerto Rico is not alone in its quest for an increased renewable energy penetration or energy efficiency and conservation. For Example, Hawaii passed a law that sets the state’s renewable energy goal at 100% by 2045 and Hawaii has an Energy Efficiency Resource Standard that establishes a 4,300 GWh reduction in electricity use by 2030. However, many technical challenges have arisen with high penetration of renewable energy sources. For example, a 1.6 MW system can fluctuate so rapidly that a 50% dropout can be observed in 9 seconds [1]. This type of problems are the reasons for companies to set limits to the operation of variable renewable generation. For example, the Puerto Rico Electric Power Authority (PREPA) requires a 10% per minute ramp rate based on the photovoltaic or wind system capacity for large systems connected at the transmission level [2], although PREPA also tried to apply a similar limit to net-metered systems connected at the sub-transmission level. Due to the growing demand for clean, reliable and economic energy there is an increased interest in microgrids [3]. Microgrids are one of the main driving forces supporting the integration of renewable energy to the power system through distributed generation. Benefits of renewable distributed generators are well discussed in the literature.

This thesis focuses in the concept of a zero or low energy community microgrid. A zero or low net energy community microgrid is one that has enough resources to minimize the impact to the power grid. This type of microgrid has many challenges such as intermittence of renewable resources, peak demand may be not aligned with peak local generation, reduction of the peak and total demand energy to achieve zero or low net energy thru renewable resources, social acceptability due to change in consumption patterns, policy issues related to conservation and efficiency among others. This thesis aims to work in the technical aspects of a zero (low) energy microgrid in order to address some of the challenges of its implementation.

1.2 Topic of Thesis

The topic of the thesis is "Towards a Zero Net Energy Community Microgrid". The work on this thesis aims to find technical solutions to adopt more penetration of renewable energy thru the grid using the concept of a zero (low) net energy community microgrid.

1.3 Objectives and Contributions of the Thesis

The main objective of the thesis is to provide a tool to analyze the performance of a community microgrid, in order to suggest and adapt the best technical approaches.

The specific objectives of this work are the following:

- Study demand response (DR) techniques that can be integrated or developed in a zero (low) energy microgrid.
- Simulate a zero (low) energy microgrid with DR programs and analyze system behavior, feasibility and benefits.
- Classify effectively between critical loads, loads that can be rescheduled and loads that can reduce consumption.
- Vary demand side resources without affecting critical loads.
- Suggest energy policies that can be implemented in Puerto Rico.

1.4 Thesis Outline

The present work is organized as follows: In Chapter 1 is the introduction and the scope of the thesis. Chapter 2 discusses microgrids and an overview of demand response technology and benefits. In Chapter 3 demand response and some energy policies are discussed. Chapter 4 presents a microgrid case study with demand response in the context of Puerto Rico, the description of the simulation and the simulated scenarios; while results are discussed in Chapter 5. Finally, Chapter 6 present the conclusions and future work.

2. Increasing Renewable Energy use with Microgrids and Demand Response

2.1 Introduction

Distributed generation (DG) refers to generation resources connected to the utility grid in the distribution network. Microgrids are a set of loads and distributed generators that can work connected to the utility grid or disconnected to the utility grid. When a microgrid is working disconnected to the utility grid it is said that the microgrid is working in “Island mode”. Microgrids that use renewable resources can bring numerous advantages, not only reliability and the reduction of carbon footprint; but also microgrids can bring operational advantages to the utility grid if they are well coordinated with the grid. For example, utilities do not have to invest to replace overloaded feeders if microgrids are used because they can reduce the current that passes through the feeders through local generators. Most of the work in microgrids is tied to the smart grid philosophy. Smart grid is a concept that describes the next generation of power systems, characterized by the increase use of bidirectional communications and information technology in the generation, delivery and consumption of electrical energy [4]. Some goals of a smart grid are: to provide a more efficient distribution of electricity, provide a quicker restoration of electricity in case of a power outage, reduced operational costs and consumer costs, increase integration of renewable energy and improved security [5].

2.2 Microgrid Classification and Topology

Microgrids can be classified in several ways, by capacity, by type of generation, by types of loads among other criteria. One of the most common ways to classify microgrids it is by its ownership and operational responsibilities [3]. For example, a military microgrid would have a focus in energy reliability and energy security. A community microgrid could have more focus on renewable energy penetration, energy conservation and energy efficiency rather than energy security. A private industrial microgrid will focus on reliability and economics [3]. The main purpose of an electric utility owned microgrid could be to serve special requirements to specials customers such as hospitals that need an uninterruptible energy service. Also, this type of microgrid can be used by the utility to achieve others goals, in addition to the reliability goal mentioned previously. Table 2.1 presents a summary of microgrid classification and some examples of each classification.

Table 2.1 Microgrid Classification and examples

Type	Focus	Example
Military	Reliability, Security	Schofield Barracks, Hawaii
Private Industrial	Economics, Reliability	Toyota “F-Grid”
Community	Sustainability, Renewable energy, Energy Efficiency.	Kythnos Island, Greece
Utility Owned	Special Requirements, Reliability	Østkraft Microgrid in Bornholm

There are different topologies for microgrids; the simplest one is to locate it within a customer premises [6]. In this type of topology, a customer is typically connected to the grid at one point and the interconnection is controlled by the customer. Another topology is multiple customers fed by a distribution network [6]. In this type of connection, the point of connection to the utility grid is usually controlled by the utility. The utility and the group of customers have to come to an agreement of how the point of connection will be controlled by the utility. Another concept well discussed in the literature is a zero-net-energy substation [6]. In this concept the distribution substation connected to the microgrid would have a zero-net energy flow over the course of a year.

2.3 Renewable Driven Microgrids challenges

In Puerto Rico around 70% of the population lives in areas with an excellent solar resource [7]. Hence, rooftop PV systems in Puerto Rico have a greater potential if it is compared with other renewable resources. However, photovoltaic systems have some drawbacks such as the fluctuation of the output power as seen in Figure 2.1 which depends on the weather conditions [8]. These variations and other challenges of PV systems limit the penetration of PV generators in traditionally designed, built, maintained and operated power networks. For example, the maximum penetration of passive PV generators in a European island networks is about 30% [8]. One way to increase the penetration of PV generation is to add energy storage devices. With short term energy storage, long term energy storage and a dedicated control system PV generators transform to an active generator and provide more flexibility for system operators and consumers. This approach is limited by the economic and environmental issues related to energy storage technologies [9]. Another way to increase the penetration of PV generators is by managing the demand of the loads served through demand response strategies. Demand response can be used to match renewable energy production with load profiles [10].

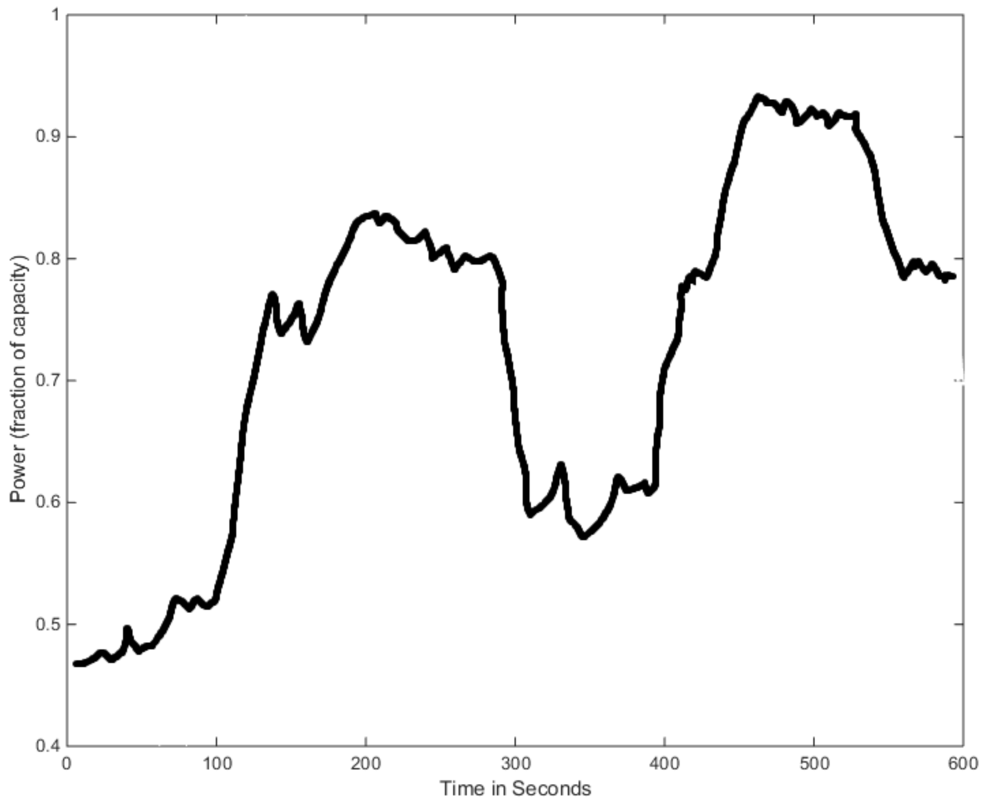

Figure 2.1 Power fluctuation in terms of capacity of the PV array, adapted from [1].

2.4 Demand Response: An Overview

Demand response (DR) techniques are used to balance generation with load, this is done by changing the customer electricity use patterns with incentives. Demand response programs can lower the cost of electricity by deferring generator/transmission capital investment and lowering the peak demand that probably would require the dispatch of a high cost generating unit. Observing Figure 2.2, reducing the demand (D_0 to D_{DR}) using DR programs, one can save an amount of money (P_0-P_{DR}) by not dispatching a high cost on peak generation unit. Also, DR techniques can help the electric utility to maintain reliability by not overloading distribution feeders, transformers and transmission lines. For example, suppose there is an overloaded sub-transmission line during peaks hours, using DR programs as seen in Figure 2.3 one can maintain the power through the sub-transmission line under the maximum line capacity, thus system reliability is not affected through the hours of a day.

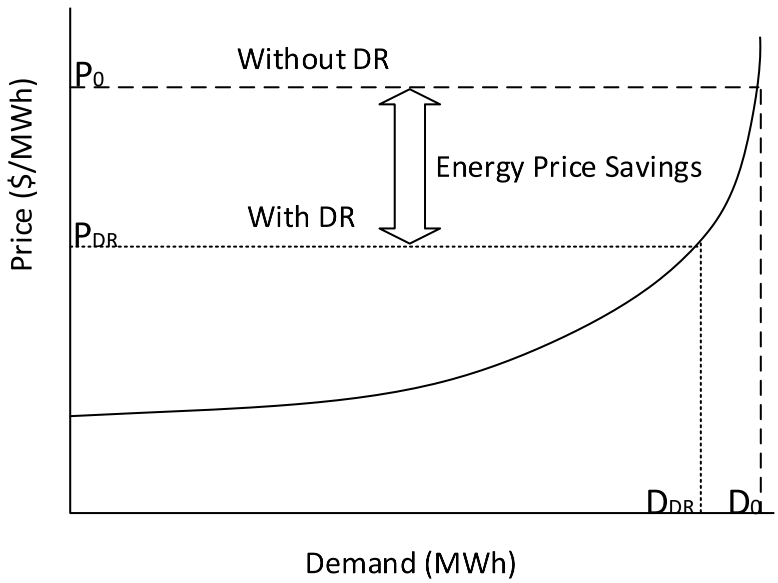

Figure 2.2 Economic Effect of DR. Adapted from [11].

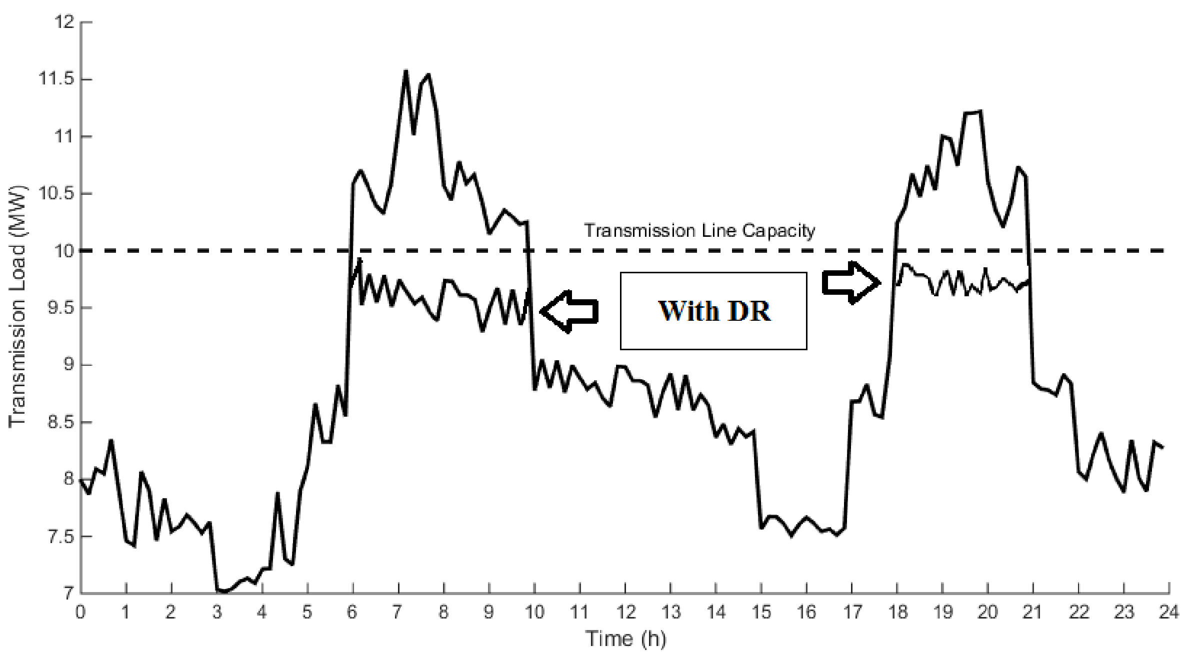

Figure 2.3 Reduction of peak demand with DR. Adapted from [12]

2.5 Demand Response Programs Classification and Architectures

DR Programs can be classified as market-based or reliability-based. Market-based DR programs are triggered by economic signals and reliability-based are usually triggered by emergency conditions [13]. There are several types of demand response programs or products. The most commons are [13]:

- Capacity (Installed Capacity, Unit Commitment)
- Energy (Day-ahead, Real time Balancing)
- Reserve Ancillary Services
    - Regulating Reserve
    - Spinning Reserve/Responsive Reserve
    - Supplemental Reserve/ Non-spinning Reserve
- Reliability Response (Emergency Conditions)

DR products and rules vary among users. For example, the New York ISO (NYISO) has four DR programs: the Emergency Demand Response Program (EDRP), the Installed Capacity-Special Case Resources (ICAP-SCR) program, the Day Ahead Demand Response Program (DADRP) and the Demand Side Ancillary Services Program (DSASP). Other entities could have programs similar to NYISO with the same or different rules or could have other programs.

When it comes to distribution level for residential and small commercial customers a better way to classify DR programs is price based vs incentive based. Incentive based programs are specific contracts between particular end-users and a given actor such as Distributed Network Operator or Distributed System Operator (DNO or DSO) [14]. The end-users are awarded with rebates in their electricity bill due to their participation, in cases that they do not meet the load reduction agreement the users lose the economic benefit and depending on the agreement they may or may not be penalized. In price-based programs DR participation is encouraged by exposing customers to varying electricity prices. Many researchers agree that for residential and small commercial customers, price-based programs are promising and might be better than incentive-based [14-16]. **Table *2.2*** has a comparison between price based and incentives based tariff.

Table 2.2 Incentive based vs Time based

Incentive-based	Price-based
Good for ancillary service.	Great for energy efficiency and managing peak demand.
High cost due to the automation infrastructure if based on demand load control.	Usually requires a smart meter only.
Motivates users to reduce energy consumption.	Motivated users to minimize energy consumption.
Users are necessarily aware of their consumption.	Make users aware of their consumption.
Notable examples: Dynamic Demand; Peak Time Rebate	Notable examples: Time of Use; Real Time Pricing

There are many different incentive-based and price-based residential and small commercial DR programs, the most common products are [17, 18]:

Time-of-use (ToU): This type of program is characterized by low prices when the demand is low and high prices when the demand is high. It is usually divided in two periods on-peak and off-peak periods. This DR option is one of the most commonly used due to the simplicity.

Critical Peak Pricing (CPP): Based on the same principle of ToU, but with the main difference that a warning signal is sent to customers alerting them of a critical peak period. The prices of CPP are considerably high on a critical day compared to a non-critical day.

Peak Time Rebate (PTR): Similar to CPP, but instead of being base on the principle of surcharge for peak consumption, customers receive a rebate in their electricity bill.

Real Time Pricing (RTP): Electricity prices varying through the day typically on an hourly basis, customers respond by changing their consumption to the cheapest hours based on a day-ahead forecast.

Dynamic Demand Response (DDR): Appliances respond automatically to system frequency by switching off when the frequency drops to a specific value.

Inclining Block Rate (IBR): Average electricity consumption is reduced by applying an increasing price level of consumption. The first block should be a lower price compared to the fixed price and after certain threshold a higher price should be set.

There are two common demand response architectures: centralized demand response (CDR) and distributed demand response (DDR). In CDR all requests are delivered from the smart meter devices to the central command and control (CC&C) [19]. All requests are received in the CC&C which then decides when and which requests should be answered [19]. In DDR, the demand response is performed at a distributed command and control unit (DC&C) which is part of the smart meter device [19]. Practically in DDR there is no traffic congestion on a central location but DDR decision are not optimized because DDR do not have an overall knowledge of the system where it operates. In contrast, in CDR there is full knowledge of the system's load characteristics although it has trouble handling all user requests due to its centralized nature [19].

2.5 Renewable Curtailment and how DR can help to reduce.

DR programs can help to reduce renewable curtailment loss by reducing the night peak and by shifting load to the maximum renewable production. For example, in the demand curve on Figure 2.4, one can notice that a lot of renewable curtailment is happening due to the generators that must be on and at least working on minimum power for reliability issues and scheduled due to the night peak. But with the help of demand response one can reduce the night peak and move some load to the valley that occurs during daytime. This results in maximum renewable power output, less generators scheduled and reduced renewable energy curtailment (as seen in Figure 2.5).

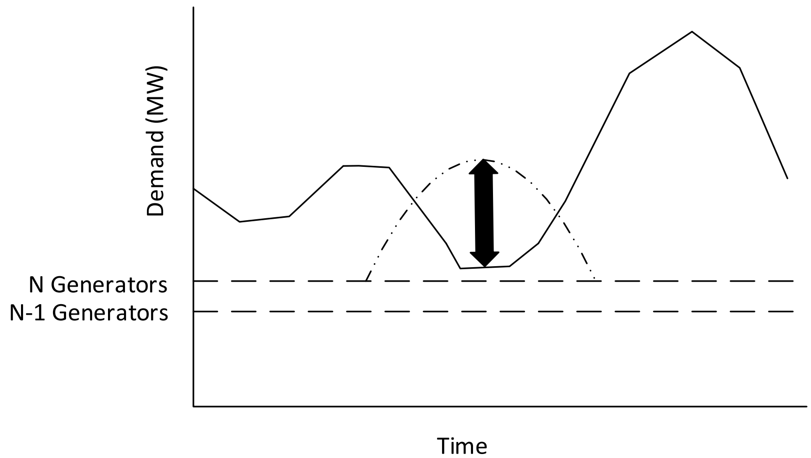

Figure 2.4 Energy Demand, Renewable curtailment without Demand Response. Renewable Curtailment is represented by the two-way arrow.

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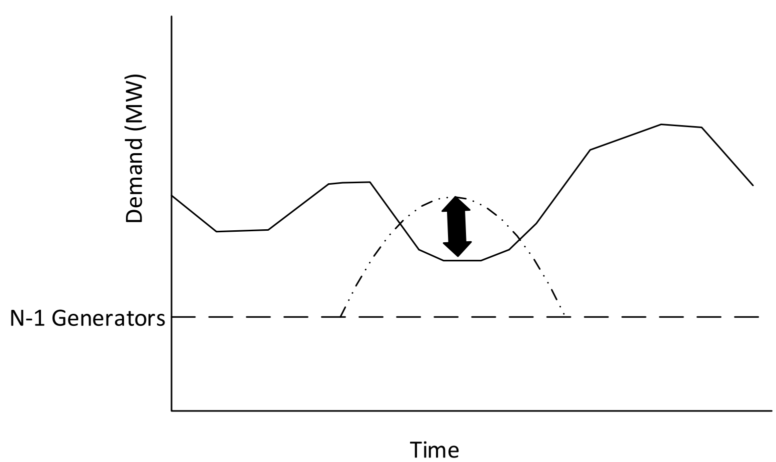

Figure 2.5 Energy Demand, Renewable curtailment without Demand Response. Renewable Curtailment is represented by the two-way arrow.

Renewable energy curtailment is one of the main concerns nowadays in electric power systems. Many methods have been proposed in the literature to reduce curtailment, the most popular is energy storage management. However limited number of energy storage technologies are available that can store large amounts of energy for several hours at a reasonable price and with minimum environmental damage [20-21]. Renewable energy microgrids, operated with DR programs and combined with energy storage management are a good option to decrease renewable energy curtailment and even increase renewable energy use.

3. Demand Response and Energy Policies

3.1 Overview

To move from a vertically integrated power industry to a more hybrid, less centralized power industry a great regulatory environment is needed. The grid will not be only hybrid but also smart. With the smart grid, we can push forward renewable energy goals, energy efficient goals and energy conservation goals. Thanks to the two-way communication capabilities in the smart grid, the introduction of smart appliances and the willingness of people to participate in this energy movement; things like demand response can be implemented to meet those goals.

3.2 Demand Response Policy

The implementation of DR programs is highly dependable of the regulatory policies. One of the most critical and difficult handicaps to overcome by a regulator is the lack of standards. Traditional regulation itself can be a critical barrier for the implementation of DR programs since these are new operating options not known by many regulators [22]. States in the U.S. have created policies and mechanisms that promote the development of DR. In general these policies can be classified in four different categories.

Cost Recovery. In this type of policy electric utilities can recover cost related to DR and energy efficiency [23]. For example, Florida Service Public Commission let utilities charge a conservation cost in the non-fuel charge. In Florida Power & Lighting they define the Energy Conservation Cost Recovery Charge (ECCR) as the cost of programs designed to reduce electric demand and consumption through efficiency measures.

Rate Return. Using rate return, public service commissions allow utilities to add in their next rate case profits for their DR investment.

Loading Orders. Loading orders are essentially government proclamations of their priorities. For example, California's 2003 Energy Action Plan established an energy resource loading order to guide their energy decisions. DR is one of the four preferred resources in their loading order.

Energy Efficiency Portfolio Standards (EEPS). In EEPS, states can set demand reduction mandates. For example, Ohio Alternative Energy Portfolio Standard required electric utilities to implement energy efficiency and peak demand reduction programs that result in a cumulative electricity savings of 22% by the end of 2025. Energy efficiency is emphasized as a demand side change in thirteen states with energy efficiency portfolio standards [24].

3.3 Residential DR: Customer Participation, Behavior and Benefits

To ensure constant participation of customers DR programs must have features that motivate the users to participate in those programs. Participation is usually motivated by economic incentives but also it can also occur due to other factors such as energy security and environmental benefits. To see the impact of voluntary residential peak demand response the authors of [25] investigated the main reasons to participate in voluntary DR programs through a series of surveys. They divided the response factors in three main categories: price, environment and security. They found out that participants were most sensitive to price followed by security and environment. Also, they found that there is no significant difference between price and security as motivation factor. In theory, people may respond to a security signal at peak demand hours in the same way as a price signal [25]. Environmental signals can also contribute to the reduction of the peak demand but not as much as security and price signals. In the price signal area, there is a lot of research on the best method for DR program implementation. The main debate is between price based and incentives based tariff. The main difference between incentive based vs price based is discussed in section 2.5.

One key aspect for customer participation is customer trust in the electric utility [17, 26]. Without customer trust in the utility, key aspects like education are weakened resulting in less interest for the implementation of DR programs. Also, low trust levels raise issues related to customer privacy, for example smart technology suppliers can manage indirectly customer loads and have private information of customer daily behavior, which can result in the emergence of groups against DR development. For example, in California there are many voluntary DR programs that customers can participate, but there has been a strong movement against smart metering with arguments based on health risks due to the use of wireless communication devices, although these arguments have been publicly refuted by the relevant authorities [27]. When DR programs are not available with Demand Load Control (DLC); customers presented “response fatigue”. Response fatigue is when the user tires of continuously checking prices, resulting in a comfort impact that decreases involvement in DR programs [28]. Loss of customer comfort must be minimized to get a successful and large participation in DR programs. Other key aspect to promote customer participation is direct feedback. Direct feedback is defined as immediate transfer of information from the meter or monitoring interface to the user, in contrast, indirect feedback corresponds to the information that has been processed and then sent to the user [18]. One way to understand this is comparing indirect feedback to the electricity bill and direct feedback to an in-home display (IHD). Many studies have shown the success of IHD. Studies have demonstrated that IHD could constitute an incentive to change consumption patterns, other studies have concluded that direct feedback could reach a peak load shedding between 3%-5% [29]. Pilot projects have presented positive results like Hydro One in Ontario, linking IHD with Time-of-use (TOU), this pilot project revealed a reduction of 7.3% with more than half (4.3%) could be attributed to IHD. Many countries have implemented IHD in their SMI, notable examples are U.K. and France. In France SMI can send information to the user's PC or mobile phone and thereby provide analysis, historical records and alert users in some emergency cases like excessive energy consumption [27]. In order to adapt DR programs and SMI, environmental benefits might not be sufficient for end-users to adapt these new concepts and technologies; therefore, monetary benefits have to be significant and sufficient [30].

3.4 Demand Response: Structure

A very important part of DR programs is the structure of the system; how customers will be organized. In the literature, there are various ideas on how this can be done. One of the most discussed is an intermediate body between the market and the user called aggregator [14, 18, 30]. An aggregator is defined as an actor who offers services to aggregate energy production from difference sources and acts towards the grid as one entity including local aggregation of demand and supply [30]. Aggregators can enable DR participation for smaller customers due to their aggregated load, the amount of aggregated load could be sufficient to justify DR program implementation. Aggregators could be a distribution network operator (DNO), a distribution system operator (DSO), the Local Distribution Company (LDC) or even microgrids. With the aggregators, individuals do not lose comfort due to manual operation. Another structure issue is the selection of home and commercial appliances that will be participating in the demand response program and how the appliance will be participating. Table 3.1 has a summary of the most common appliances, how they can contribute (load shedding, load reduction) and their flexibility potential

[25, 31, 32]. Flexibility potential is defined as the potential to increase or decrease power consumption in function of time of the day, combined with how long this power increase or decrease can be sustained.

Table 3.1 Appliances uses for DR, their contribution to DR and their flexibility potential

Appliance	Contribution	Flexibility
Air Conditioner	Load Reduction, Load Shedding	No Data
Heat Pump	Load Reduction, Load Shedding	No Data
Dishwasher	Load Shedding	Low
Clothes Dryer	Load Shedding	Low
Clothes Washer	Load Shedding	Low
Water Heathers	Load Reduction, Load Shedding	High
Electric Vehicles	Load Reduction, Load Shedding	High

The flexibility potential is highly dependable of the place temperature, environment and other factors, the data in Table 3.1 corresponds to a study made in Belgium [32]. Unfortunately, the flexibility potential is highly asymmetric, at any moment of the day maximum power increase surpasses the maximum power decrease. For example, the consumption of all wet appliances in Belgium can increase a maximum of 2 GW at midnight in the weekends for a sustained period of 30 minutes; in contrast, the maximum decrease possible for all wet appliances is 300 MW at 10:00 pm on weekends and can be sustained for 15 minutes [32].

3.5 Demand Response: Business Cases

One of the main questions is: What is the best business structure for implementing residential and small commercial DR programs? One of the key challenges is the high cost of the SMI structure. In many places including Europe the progress on implementing demand response comes in hand with smart metering devices [23]; and as mentioned earlier customers will be less motivated for participating in DR programs if the economic benefits are not sufficient. To stimulate participation, the cost of the smart metering devices has to be covered by the electric utility. The electric utility needs to recover the investment in one way or another. One way to recover the money invested in SMI is with a cost recovery charge in the tariff [33], but this could have a negative effect in the customer bill, making customer less interested in participating in DR programs. Electric utilities could recover their investment in different ways. The most common are avoidance of transmission capacity charges, avoidance of charges between distributed network operators, avoidance or deferral of network reinforcement and carbon tax reduction [14]. Depending on the regulatory environment and market conditions will be the investment recovery potential. Table 3.2 has a brief summary of how these structures could recover the investment. More work has to be done to include externalities such as human and environmental damage and incorporate these externalities in the market to help justify DR programs. Electricity generation accounts for 40% CO_2 emissions from fossil fuel combustion in the United States [34]. Human and environmental damage reduction caused by electricity generation and reduce with DR were calculated for a particular scenario and the estimated savings was around 100,000-300,000 dollars annually in human and environmental damage. Due those findings, the research suggests to implement policies directed toward residential consumers [35]. Other issues can be solved by identifying the best customers that can participate in DR programs. For example, in another study 5% of the homes in the sample represented 40% of the total MW-hours of DR resource, thus the authors suggest that policies and programs should take advantage of this finding and should target those high-energy users to maximize cost-effectiveness [36].

Table 3.2 Business cases and their recovery opportunity.

Business cases	Investment recovery opportunity
Avoid transmission capacity charge.	Avoid capacity penalties, contract lower transmission demand.
Avoid charges between distributed network operators.	Contract less demand from other DNOs; with sufficient demand reduction, DR could replace the interconnection and therefore avoid fixed cost.
Avoid or defer network reinforcement.	Avoid or defer network reinforcement.
Establish a carbon tax.	Reduction of taxes due to lower carbon emissions.

3.6 Net Metering, Net Billing

With the sustained fall in price of PV systems and the increased attention for a sustainable energy more people are interested in installing PV system in their roof or in their community. In the past the idea of a residential customer as an energy seller or producer was not considered, so the need of creating a new energy policy to consider this new energy actor was needed [37]. One effective way of allowing customers to receive compensation for their energy generation is using net metering. Net metering was first introduced in the USA in the 1980s, and now almost all the states have net metering policies [38]. Net metering is an electricity policy which enables customers to operate a distributed generator and be charged for the difference between the utility energy consumption and the injected energy to the utility grid; in the case that were more injected energy surpass the consume utility energy the customer gets paid for the excess [37]. Nowadays this policy has some issues in different parts of the globe, policy makers argue that non-PV system owners are subsidizing PV-system owners, utilities argues that net metering does not account for utility costs such as transmission, distribution, reliability and ancillary services, meaning a lower recovery for the utility investment. A key objection to net metering is that PV systems do not produce electric energy in at night, so to cover the night peak utilities need to have an extra capacity running even during the day in cases that utilities do not have fast-starting generators. This is particularly challenging since during the day the net-metered clients are lowering the utility demand, thus the difference between demand during the day and the night peak increases. There is significant research on the value of solar and how more accurate tariffs can be created. One alternative well discussed is net billing. In net billing, the utility energy consumption is valued separately from the energy injected by the PV system to the grid, the difference between both values is billed to the customers. Typically, electricity injected back into the grid is valued at a price which is lower than the utility rate because only the energy component is paid out [37].

3.7 Community Solar, Solar Microgrids.

Net metering and net billing policies are good but not enough to promote sustainable energy. For people that live in buildings, multifamily households or communities that share the same roof, structure or spaces, cannot benefit form net metering or net billing scheme. The National Renewable Energy Laboratory (NREL) estimate that only 51% of households can install a 1.5-kW PV system in the U.S [39]. Meaning that 49% of household cannot have PV systems due to ownership of the building, access to sufficient roof space or live in a structure with insufficient roof space. An arrangement that is gaining much support among policy makers for expanding solar energy options is called “community solar”. Other types of community solar systems include a single, large system located within the community, and connected directly to the distribution lines that serve the community, and multiple PV systems in the rooftops of the community’s houses but which are considered as an “aggregated” system where benefits and costs are shared among participants. Community solar is a way for citizens to attain the advantages of solar energy through group efforts. Other terms used to describe this or similar strategies are “shared solar” or in

Colorado “solar gardens” (a pioneering state in providing solar access to citizens). A frequently used definition of “community shared solar” is a solar system that provides economic or power benefits to members of a community [40]. A reference properly describes “solar communities” as chameleons that adapt to their environments [41]. That is a very accurate description and reflects the flexibility that should be allowed when establishing solar communities in order to maximize community benefits. The potential of community solar to advance a sustainable energy future resides in the combination of technology, citizen empowerment, social and environmental justice. However, as expected, clashes between PV supporters and the utilities are common. Most of the clashes are policy related. States like California, Connecticut, Massachusetts, Maine, New Hampshire and Vermont have enacted virtual net metering (VNM) laws [42]. VNM works similar to net metering, but the energy credit for the produced energy is based on the size of the customer’s share in the community solar system. This brings the same problems with net metering policies, some costs like transmission, distribution, reliability and ancillary services are not accounted [42]. New alternatives for VNM exist and more will be developed. Notable examples are Solar feed-in tariffs, value of solar tariff and others. These tariffs may not directly match the retail price.

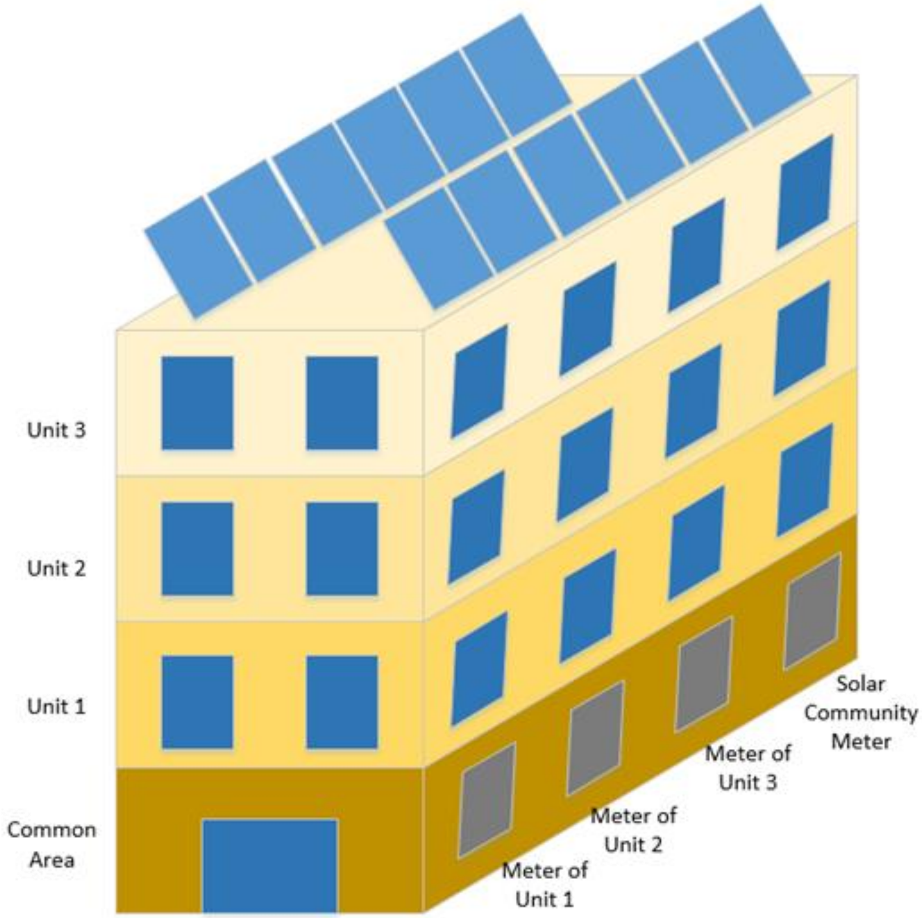

Figure 3.1 VNM in a Solar Building Adapted from [43].

3.8 Zero Net Energy

Another concept that is gaining a lot of support among policy makers is the zero-net energy concept. This concept promotes clean energy and energy conservation through the combination of local renewable energy generation and demand reduction. Most of the research work in the zero-net philosophy focuses on zero net energy building (ZNEB) concept due to the fact that buildings consume over 70% of electricity an about 40% of all U.S. energy consumption [44]. The Department of Energy defines ZNEB as an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy [45]. This same definition can be applied to zero net energy home, zero net energy district, zero net energy campus and zero net energy community. Zero net energy districts (ZNED) expand the idea of ZNEB to a whole distric. Buildings in a ZNED can be more efficient if they cooperate and share resources and energy through the centralization of energy systems [44]. This means that the buildings' collaboration in a ZNED provides an easier way to balance loads, improved reliability and could reduce the overall cost of getting to the zero-net energy goal. The same advantages can be discussed between zero net energy homes (ZNEH) and zero net energy community (ZNEC), like with the ZNED, ZNEC has the advantage of sharing resources and a centralized energy system that provides an easier way to balance loads, to improve the reliability and could reduce the overall cost of reaching zero net energy goal.

4. Community Microgrid Case Study

4.1 Introduction

When simulating a solar community microgrid certain aspects cannot be simulated using a traditional power system software. In traditional power system software users usually enter static power generation values and demand values, thus simplifying behavior that is time variant and not static. In a solar community microgrid, one must take into consideration the variable solar generation, dynamic loads, demand side management and other factors depending what is the purpose of the investigation. The software MATLAB/SIMULINK from Mathworks has a toolbox called Simscape Power Systems^{TM} that provides component libraries and analysis tools for modeling and simulating electrical power systems [46]. The microgrid created in Simulink is based on a template called "Simplified Model of a Small Scale Micro-Grid" available in Mathworks web page [54].

4.2 Microgrid Simulation Description

Using Matlab/Simulink a community microgrid of 200 houses is simulated. The community microgrid is composed of twenty groups of ten houses, each with photovoltaic (PV) systems and energy storage. To simplify the simulation, PV systems and energy storage are simulated as aggregated systems for each group of ten houses (Figure 4.1). PV systems are simulated as current sources that inject power so that one current source model simulates the aggregated system of 10 houses. Energy storage systems are simulated as current sources that can either inject or consume power, again one current source simulate the aggregated system of 10 houses. The state of charge (SOC) of the battery was modeled by adding or subtracting the energy sent or received by the microgrid, and obtaining output decisions from a fuzzy logic controller. The microgrid is grid-connected and the power delivered from the grid to the microgrid should not exceed certain amount and should be as constant as possible, that means with the highest load factor possible. The grid is modeled as an infinite bus, that can always deliver the requested power.

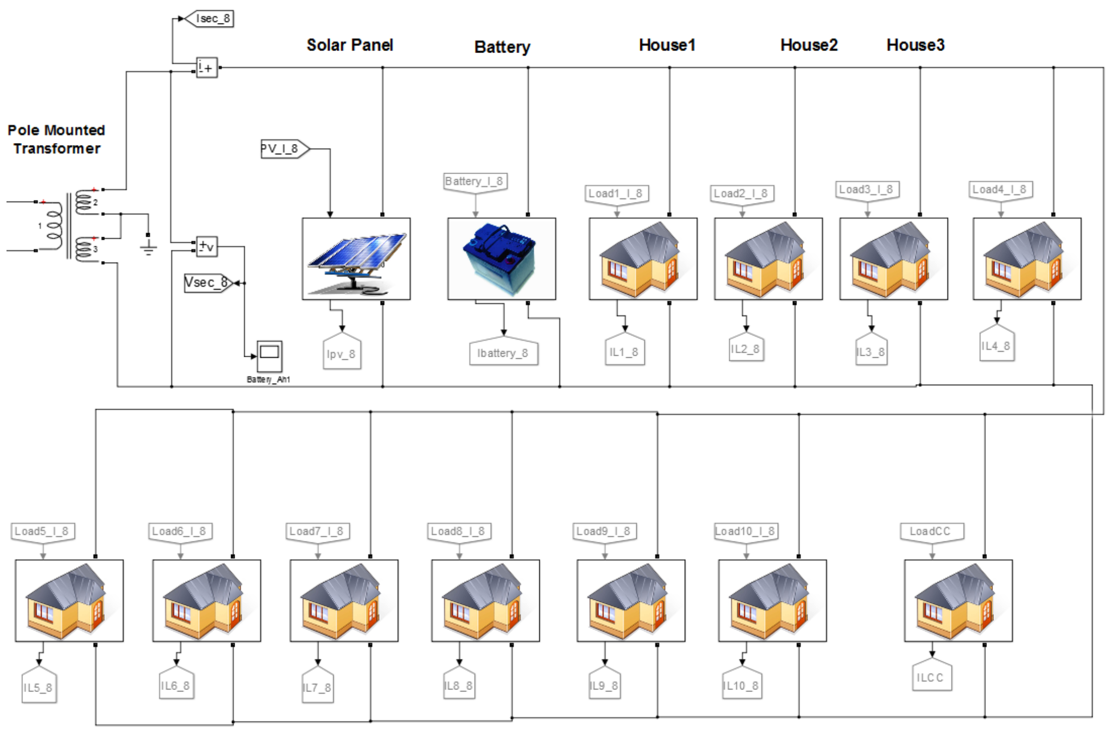

Figure 4.1 One Group of twenty of the microgrid.

4.3 Microgrid Parameters

Some of the data for the simulation was taken from a capstone design project. The data is from a community section composed of 200 houses. The community section is connected to a 4.16 kV distribution substation. The length of the distribution feeders and laterals used in the simulation are estimated values taken from the Capstone project. The topology of the section of the distribution network is in Figure 4.2 and is taken from the same capstone project. The author of this thesis served as graduate mentor for the Capstone project.

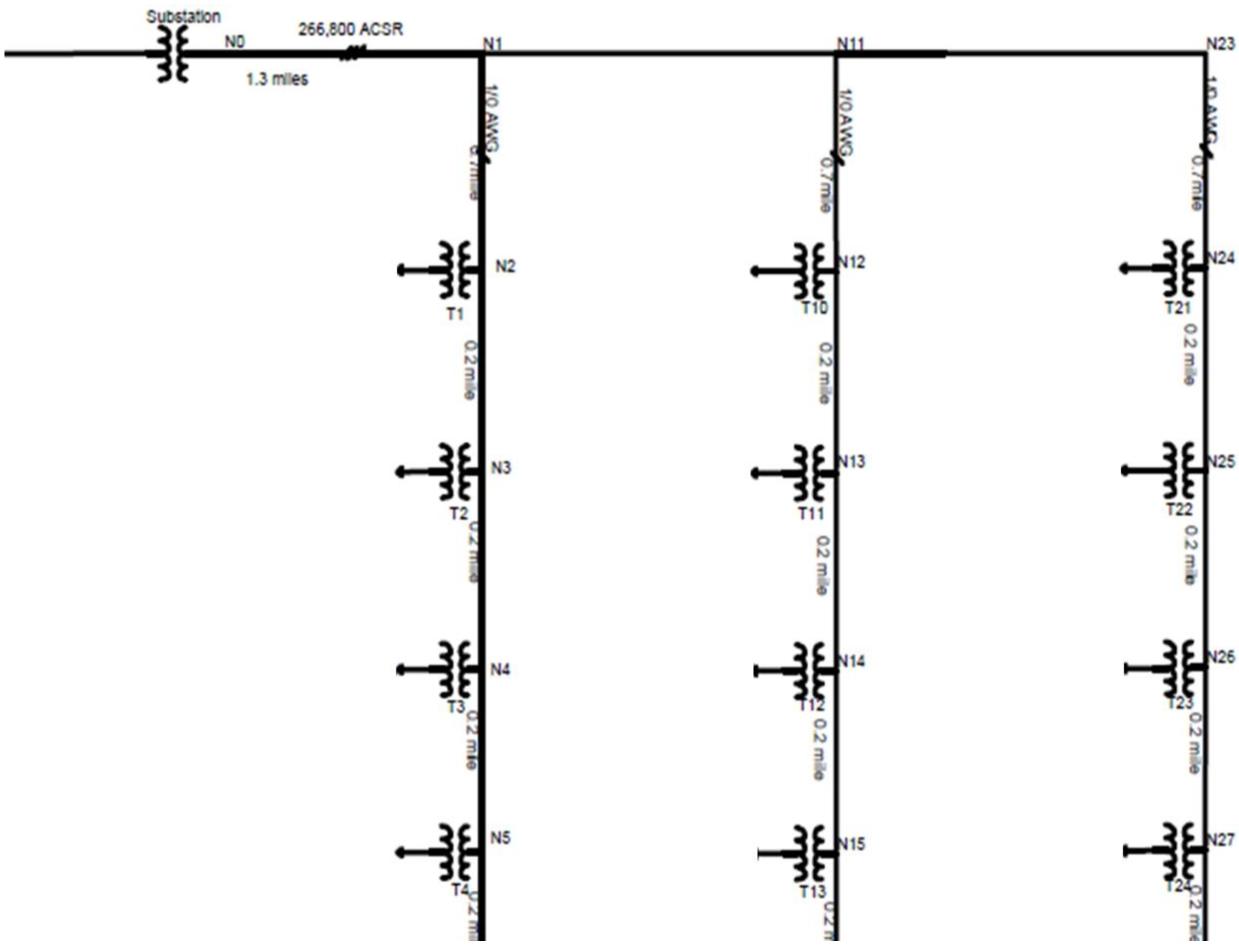

Figure 4.2 Distribution network of a community.

Each group of ten houses is connected to a 75-kVA transformer. The aggregated PV system varies form 10 kW to 20 kW per group (1 kW to 2kW per house), and the aggregated battery storage is 128 kWh per group (12.8 kWh per house). Loads/houses are simulated as components that consume power with one of three demand profiles: one simulating a demand of 834 kWh (50% of the houses), one simulating a demand curve of 918 kWh (25% of the houses) and one simulating a demand of 627 kWh (25% of the houses). The 834 kWh demand curve represents a family of four that is not home during the day. The 918 kWh demand curve represents a family that stays home during the day and has school-age kids that arrive home around 3pm and the 627 kWh demand curve represents a family of two that stays at home. Each group of houses has a different combination of profiles and are not uniformly distributed. Load reduction was achieved depending on the demand profile, and simulates demand response (DR) actions. When load reduction is triggered, demand profiles of 834 kWh and 918 kWh reduce their load 33% or 0.8 kW of their peak, the demand profile of 627 kWh reduces its load 25% or 0.6 kW of the peak.

4.4 Scenarios

Different scenarios were simulated to capture the behavior of a solar community microgrid better. Table 4.1 contains the different scenarios simulated. All scenarios are simulated with a good insolation (sunny day) and a bad insolation (cloudy day).

Table 4.1 Simulation scenarios.

Case #	Secondary Demand Goal per Group	Installed PV Capacity per Group
1	10 kW	10 kW
2	7.5 kW	10 kW
3	7.5 kW	15 kW
4	6.5 kW	15 kW
5	6.5 kW	20 kW
6	No DR, No Energy Storage	10kW
7	No DR, No Energy Storage	15 kW
8	No DR, No Energy Storage	20kW
9	8 – 10 kW	10 kW
10	7 – 8 kW	15 kW
11	6 – 7 kW	20 kW

The results from these scenarios will determine when DR would be a good option to improve the operation of the microgrid. Then similar scenarios with different DR strategies will be simulated and compared with the corresponding non-DR version. Scenarios 1-5 have a specific secondary goal: to maintain as constant as possible the power demanded from the grid. In scenarios

6-8 the microgrid is operated as a solar community; in this scenario energy storage is not present, so without sufficient resources and a balancing mechanism no specific demand from the grid is established. For scenarios 9-11 the demanded power from the grid changes specifically at peak period with the purpose of demanding less energy when the energy price is high and there is enough storage to operate the microgrid without depleting the battery.

Once the simulation ends and all data saved, data are analyzed graphically and numerically. Three main Matlab scripts were created for this task. First there is a community plotter that plots every group of ten houses' power demand and the community total power demand. The second one takes all the data and analyzes load factor, solar energy generation, grid generation, battery storage among other things. The third one calculates the one day microgrid operation using different energy rates.

5. Results and Discussion

5.1 Introduction: Towards a Zero Net Energy Community Microgrid

One key aspect towards a zero-net energy community microgrid is incrementing the renewable distributed generation while reducing the impact to the grid. As previously mentioned in section 2.2 community microgrids are focused on sustainability, renewable energy generation and energy efficiency, hence incrementing renewable generation is one of the main goals of a community microgrid. Nevertheless, only incrementing the renewable generation and not doing anything to reduce the impact to the grid can create problems. The most common solution is to install energy storage to compensate for the rapid fluctuation and cover some load when generation is low or inexistent. However, this approach is limited and without a good resource management plan, it does not address some key utility concerns such as the fact that maximum PV generation is not aligned with maximum consumption, creating renewable curtailment. Also, batteries are the most common energy storage but have some environmental issues. To get to a zero-net energy community microgrid, a good resource plan has to be established. That plan incorporates other resources such as demand respond in order to mitigate the impact to the grid and to reduce the energy storage capacity. In this chapter the results of the simulations will be discussed with emphasis on indicators such as load factor and renewable energy generation that are essential in this type of microgrid.

5.2 Microgrid Operation

Like any other distribution system with renewable distributed generators, microgrids have technical and operational challenges. Power quality, utility requirements, utility restrictions, among other things are the main concerns in a solar community microgrid. This thesis focused on meeting the voltage regulation standards of IEEE 1547 and meeting with PREPA 10% ramp rate for transmission users. The IEEE 1547 establishes that the limits of service voltage for distribution system should follow ANSI C84.1-1995. ANSI C84.1-1995 defines two range voltages: Range A and Range B. Range A is the desirable range of operation and Range B is a more relaxed requirement that electric equipment can operate but not for long periods of time. Thus, when running a system in Range B some corrective measures shall be taken to improve voltage to meet Range A requirements. ANSI C84.1 also defines three voltage classes; low voltage below 1kV; medium voltage between 1 kV and 100 kV, and high voltage that is more than 100 kV. The standard also specifies acceptable operational ranges at two locations on electric power systems: service voltage and utilization voltage. Service voltage is the point where the electrical systems of the supplier and the user are interconnected, utilization voltage is at the line terminals of the utilization equipment; so, for the purpose of this thesis, service voltage recommendations in range A for medium voltage were considered. Table 5.1 has the ANSI C84.1 voltage limits and the simulations lower and higher voltage value obtained in worst case scenarios (highest demand from the grid and lowest demand from the grid). As seen in the Table 5.1 the minimum and maximum voltages encounter in these simulations do not violate ANSI limits, this means that the operation of the microgrid in terms of voltage meets 1547 recommendations.

Table 5.1 ANSI Standard values for medium service voltage and simulation voltages.

	Service	Minimum	Maximum
ANSI limit (Range A)	4160	4050	4370
Simulation	4160	4096	4188

To meet PREPA's 10 % of ramp rate, energy storage was used. In all scenarios where the energy storage was not depleted and DR was not used, the ramp rate was not violated. When using DR and the energy storage was not depleted only in times when DR was executed the ramp rate was violated, and when the energy storage was depleted the ramp rate was violated every time a battery was depleted. This clearly shows the importance of energy storage to mitigate energy variations. However, PREPA's Ten percent ramp rate is required for connections at the transmission level. This ramp rate was used in this thesis as a worst-case scenario, so the results obtained are conservative (including the capacity of battery banks). At the distribution level, another ramp rate should be determined since the impact to the grid is not as severe as a transmission connection. This could decrease the amount of batteries and the microgrid cost. As a future work, various ramp rates can be studied to determine the most suitable for distribution systems.

Another important part of the operation of the microgrid is the logistics behind grid resource operation specifically energy storage management. There are two cases that have to be avoided in order to maintain a high load factor and meet ramp rate requirements; when the battery is fully charged and when the battery is depleted. When the battery is depleted the load will demand everything from the grid causing violations in the contract service agreements and without energy storage a sudden increase in the demanded energy from the grid could not be mitigated, violating the ramp rate requirement. To reduce the chances of this happening, one could slowly reduce the amount of power from the battery or use DR to reduce the power demanded by the loads and match the renewable generation and the SOC of the battery with the loads. This last method was used in the simulation in order to study the DR impact on this type of microgrid. When the battery is full the excess of renewable energy will go to the grid lowering drastically the load factor. Also, when the energy storage is full and there is a sudden reduction in the demanded energy from the grid, a violation could not be avoided. One way to mitigate this is to move some loads to periods when the electric energy production is maximum. Another way is to slowly reduce the rate of charging the battery; this will mitigate any sudden change and ensure the regularity of the electric energy demanded from the grid. This last method was used in the simulations to maximize the renewable energy utilization inside the microgrid.

All these strategies are made to benefit the utilities and the customers. This grid-microgrid arrangement benefits utilities for several reasons:

1. A constant demand from the grid. Benefits are:
    i. Contribution of the microgrid to non-varying fixed costs and operating costs.
    ii. A reduction in demand peaks represents a reduced use of higher cost peak units.
2. Fewer variations would minimize the impact to the grid.
3. More renewable energy can be used since the utility will not see large variations from a microgrid with constant (or almost constant) demand.

As mentioned previously customers also have benefits. The main benefits are:

1. Renewable energy use reduces carbon emissions and environmental impact.
2. Customers change their role form passive to active energy users. The active participation is due to the generation of electric energy and the participation in energy decisions through DR. Customers are now called “prosumers”: producers and consumers.
3. Possible reduction in energy costs. With this arrangement utilities can offer different rates to incentivize desired behaviors.

5.3 Load Factor and the value of constant power demand

Demanding a constant block of energy from the electric utility minimizes the impact of interconnecting renewable sources. This concept tries to overcome two main objections from utilities regarding the penetration of renewable energy: the fluctuation in the power output and the unbalanced energy generation mainly from PV that only produces energy during the day. At the transmission level, where stability of the whole system is at stake and varying power may cause a significant varying operational cost, electric utilities often penalize clients connected if the client violates the load factor agreed in the service contract.

$$Load\ factor = \frac{Average\ Load}{Maximum\ Load\ in\ Given\ Period}$$

As seen in the formula above, a high load factor means that the power usage is relatively constant, in contrast, a low load factor means that there are occasional high demand periods, usually meaning that to serve those demand peaks, capacity is sitting idle during long periods, which increases operation costs. A generation unit in idle mode does not alter the fixed cost of a plant because fixed costs are proportional to the MW capacity of the plant, however fuel consumption and operating cost will vary with the load [47]. If the load factor is 1 the installed capacity is utilized optimally, producing the maximum amount of energy in a period, minimizing the kWh cost on that period. With a lower load factor, the non-varying fixed cost and the lower operating costs are distributed over fewer kWh generated, so as the load factor decreases, the cost per kWh increases [47]. For example, Austin Energy claimed that customers can use the same amount of energy from one month to the next and still cause their average cost of kWh to drop as much as 40% by reducing the peak demand [48]. Also, they state that a 25% load factor in the summer has an average cost per kWh of 13.2 cents, while an 80% load factor would yield an average cost of 7.9 cents per kWh [48]. In Puerto Rico, large industrial customers are required to have a minimum of 0.8 load factor. The tariff LIS only applies to industries connected to 115 kV service with a demand equal or greater than 12,000 kW and less than 25,000 kW.

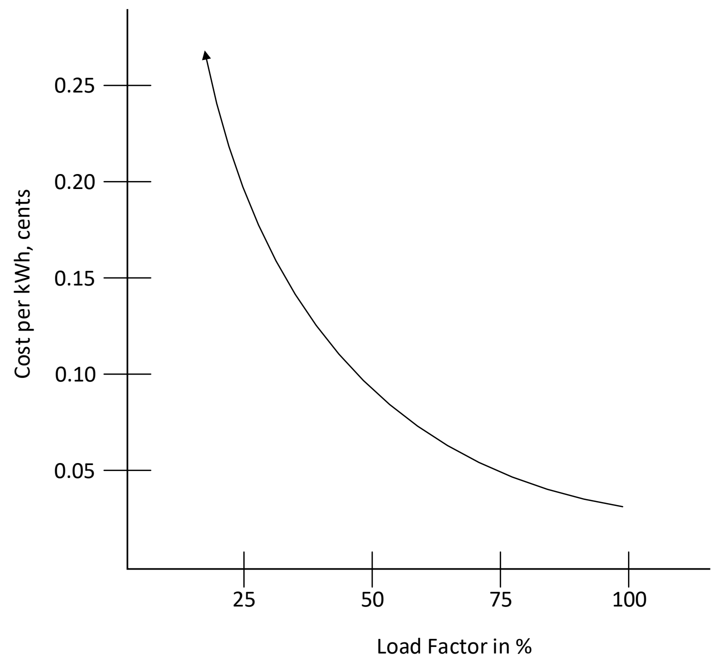

Figure 5.1 Effect of load factor in cost of energy. Adapted from [47].

The principles behind the load factor can be applied at distribution level but in a different manner. Most of distribution customers are residential or small commercial customers. Their individual behavior does not make much difference in the bulk power system, these clients usually do not have many restrictions in the way they use the energy. The behavior of these customers is related to the lifestyle and particularities of residential customers or the operating hours of businesses, having well-defined peaks and valleys and with big differences in consumption between periods of a day. Thus, implementing a load factor requirement can be interpreted as discriminatory for those small commercial loads that do not operate 24 hours or residential clients that are not home during the day but consume much more energy at night. So instead of penalizing a determined load factor, the utility or the distribution system operator (DSO), or microgrid operator, can institute an incentive or program for those customers that reduce their peak, improving overall system load factor. This can be done in different ways such as specific rates offered to clients or direct load control administered by a microgrid operator. The key of this scenario is that the sum of the behavior change can impact positively the system and bring environmental and economic benefits to all participants. In the particular case of a low-energy community microgrid, its objective is to minimize the impact to the grid while supplying the customers with a reliable service. Depending on the agreements with the utility such as the load factor or maximum demand allowed, storage will be sized and the contribution of each participating microgrid customer will be determined. In the end, the economic benefits can be distributed between the utility and the microgrid clients in a similar way that DR programs are compensated by utilities and DSO. The utility can avoid new infrastructure costs or defer infrastructure upgrades and the DSO can reduce the cost of service to their clients by lowering the contracted demand to the utility. Reducing the peaks with DR programs and/or with EMS means that the power demanded from the utility have a higher load factor than before. A constant demand (Load factor =1) in an economic sense would be more beneficial to the utility than to the microgrid because the high cost of storage devices means achieving that load factor will increase costs for the microgrid clients.

Load Factor (LF) in a solar community microgrid is highly dependable in the mix of installed solar generation capacity, storage and demand peaks. Moreover, without a good resource management plan achieving a high load factor could be difficult or costly. Using the simulation scenarios, one can see how different the behavior of a microgrid is depending on the installed capacity and weather conditions. This means that different approaches to mitigate and improve load factor should be executed depending on the conditions and resources. In sunny days, the state of charge (SOC) of the energy storage will be reaching 100%, if this happens, the storage unit will be disconnected and the excess of renewable energy will be injected to the grid, thus reducing the load factor drastically. One approach to mitigate the inevitable load factor reduction is charging the battery at a slower rate and reducing the energy coming from the grid (Figure 5.2). Of course a load factor near 1.00 will be impossible because of the grid reduction by charging slowly the battery but it is better than disconnecting the battery that would send the excess of renewable production to the grid lowering drastically the LF.

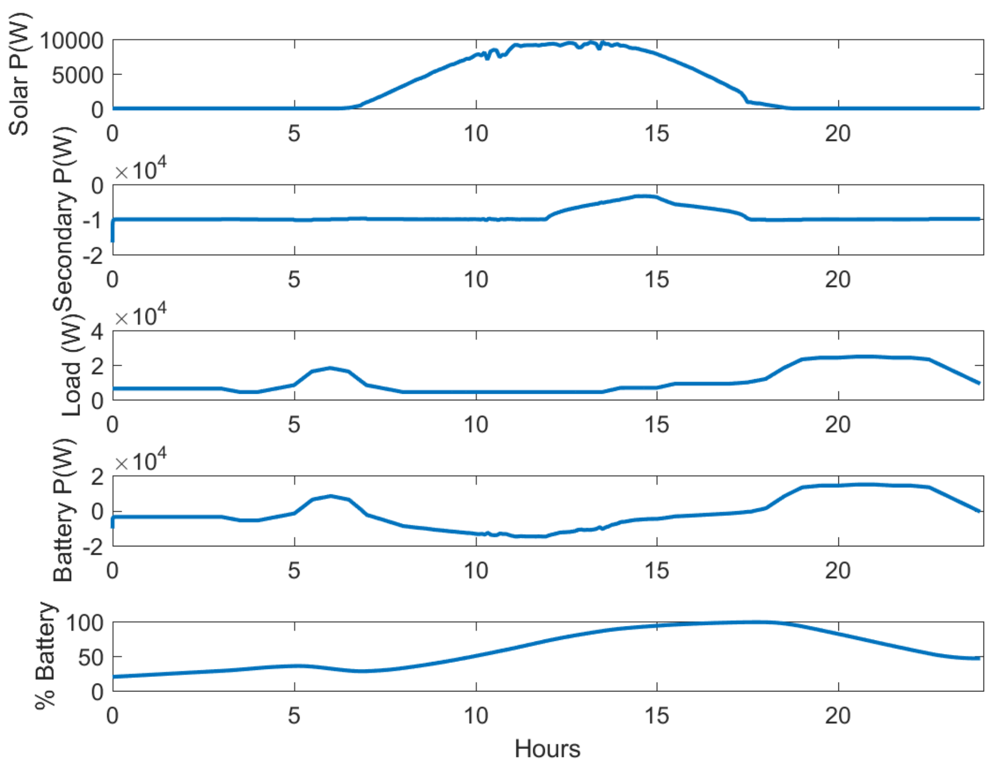

Figure 5.2 Charging the battery slowly to avoid grid disconnection

If the excess of solar generation is so large that slowing the charge rate does not prevent the storage reaching 100%, load shedding must be considered. For example, if a 4kW system per house of solar generation was installed instead of 1kW per house, no matter how slow the battery charging is reduced, the storage will be full at some point or the amount of energy injected to the grid will be so high that a low load factor would occur. In cloudy days, the main problem is under generation, leaving the SOC at a low level to cover the night peak, meaning that if the battery ran out of energy, the microgrid would use more power from the grid than the energy block contracted with the utility. This can be addressed with demand response by matching solar generation with demand. When low solar energy is injected, demand reductions would maintain the energy storage SOC at a desired level. Figure 5.3 compares microgrid operation with DR and without DR, this figure helps to visualize the LF improvement.

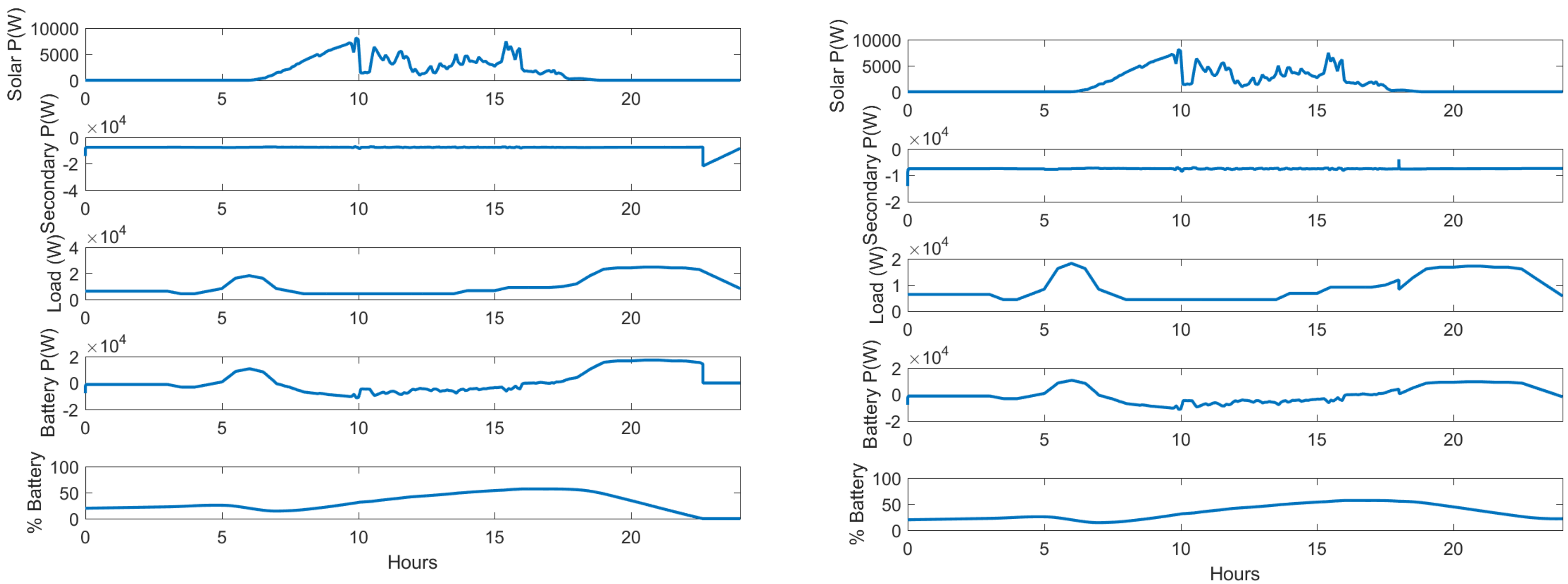

Figure 5.3 Cloudy day operation without (right) and with demand response (left).

5.4 Moving Towards Net-Zero

Moving to net zero energy means more renewable energy generation, which in turns means more challenges. Increasing the number of solar installed capacity, increases the gap between cloudy day generation and solar day generation. Based on the sunny (7.08 kWh per 1kW) and cloudy curves (3.84 kWh per 1 kW), Figure 5.4 displays the solar generation and the generation gap, which increases linearly. The average generation in the selected location is 4.63 kWh per 1 kW.

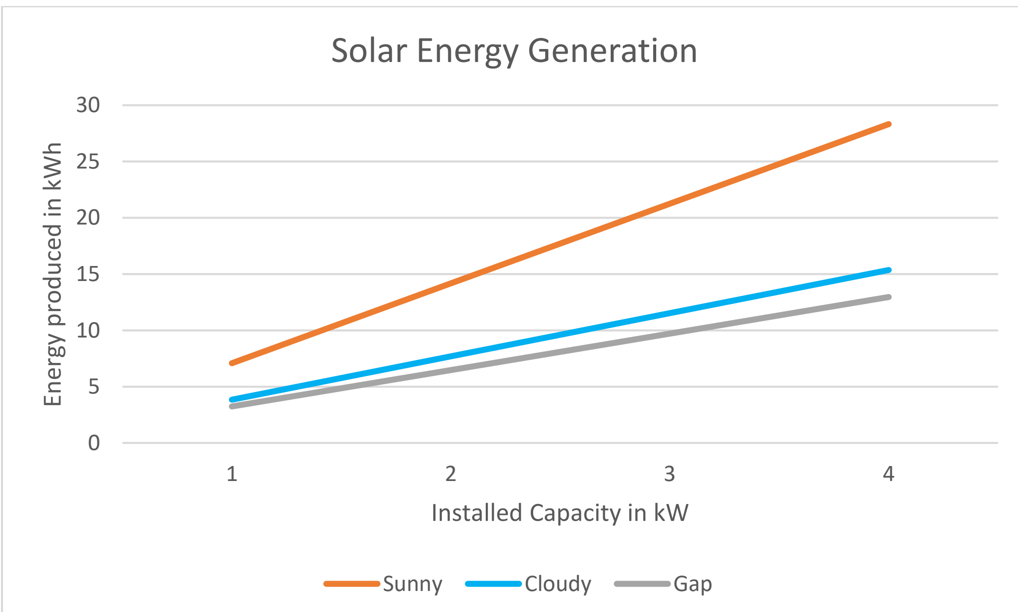

Figure 5.4 Solar energy generation in sunny and cloudy days.

This gap increases the difficulties to operate the microgrid if one plans to reduce the grid consumption while demanding energy with a high load factor. Excess generation in sunny days will be more extreme and shortage of generation will be more severe in cloudy days. Finding the right combination of resources and the right energy management while maintaining good load factor and not increasing the energy storage is a daunting task.

Table 5.2 Load factor and Renewable generation for sunny and cloudy days.

Case #	Secondary Demand Goal per Group	Installed PV Capacity per Group	Sunny | Cloudy Load Factor		Sunny | Cloudy Renewable Generation %	
1	10 kW	10 kW	0.91	0.92	27	14
2	7.5 kW	10 kW	0.86	0.38	27	14
3	7.5 kW	15 kW	0.89	0.67	40	22
4	6.5 kW	15 kW	0.81	0.33	40	22
5	6.5 kW	20 kW	0.77	0.51	53	29
6	No DR, No Energy Storage	10 kW	0.33	0.38	27	14
7	No DR, No Energy Storage	15 kW	0.27	0.35	40	22
8	No DR, No Energy Storage	20 kW	0.21	0.32	53	29

From Table 5.2, one can see that as grid dependence is reduced and renewable generation installed capacity is increased while having the same amount of storage, load factor is affected. However, how much it is affected varies tremendously with weather conditions. In sunny scenarios, load factor is reduced as one is moving toward more renewable generation capacity and/or less grid dependence; toward zero-net. Nevertheless, there are exceptions, take cases 2 and 3, the system has slightly better LF when it has more solar generation installed capacity, which means that scenario 3 is a “sweet spot” to operate the microgrid. Case 3 has a LF similar to case 1 (0.89 vs 0.91) and has more renewable generation installed capacity. In the cloudy scenario, LF is more dependent on the mix, one can see many variations (Figure 5.5) that significantly reduce as one is moving towards zero-net. LF improves as more renewable capacity is installed in the scenarios, demanding the same amount from the grid. When reducing the demanded grid energy, cloudy days are more severely affected than sunny days as the installed renewable capacity increases. The gap increase between sunny days and cloudy days makes microgrid operation more difficult, especially in cloudy days' scenarios. One could demand more energy from the grid in cloudy days and less in sunny days, but the microgrid operation cost will rise, and also instead of moving toward zero-net energy, this solution is moving in the opposite direction. Overall, the microgrid operation maintains a good LF in sunny days and in cloudy days when DR is used. In sunny days, one can easily see a load factor improvement of more than 0.5 in comparison with the scenarios with no DR no energy storage.

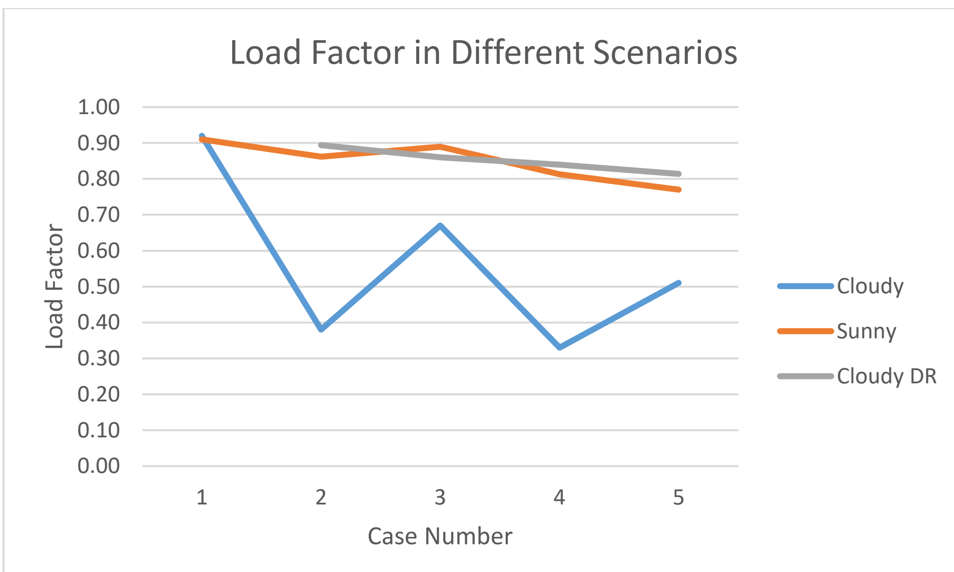

Figure 5.5 Load Factor in different scenarios

Going to net-zero energy is a real challenge as can be seen in Table 5.2, once we move toward net-zero the load factor is reduced no matter the scenario. Scenario #5 is the only scenario in the community microgrid that generated more than half of the electric energy from renewables while the power from the grid is the lowest (PV installation capacity is the highest of all and the

50% more renewable generation is only during a sunny day). Figure 5.6 illustrates the energy analysis of scenario #5 (sunny) vs energy analysis of scenario #1 (sunny); one can notice the huge difference in energy generation for the different sources.

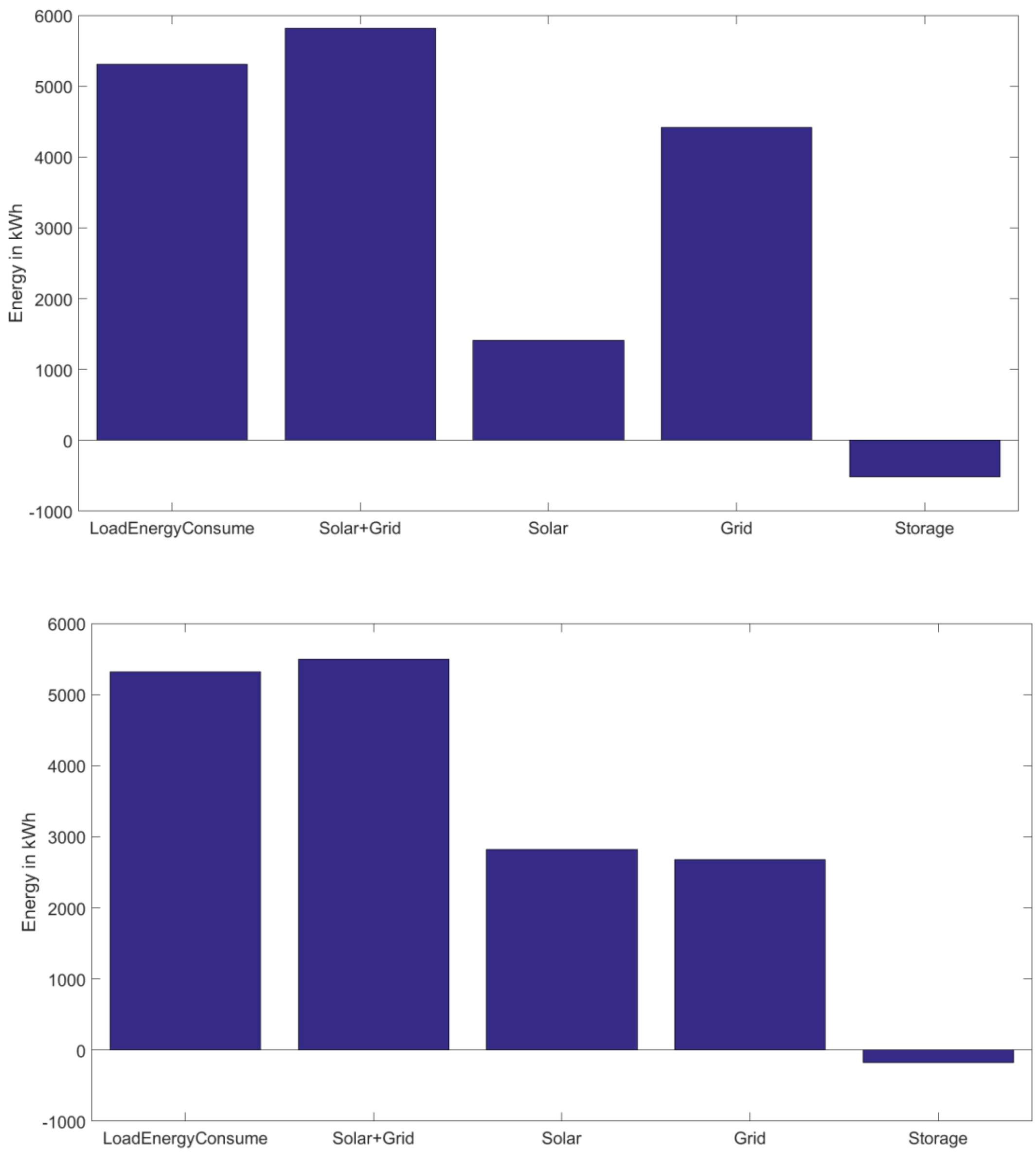

Figure 5.6 Moving toward net-zero.

5.5 Demand Response Role in a Community Microgrid

Energy storage helps and brings flexibility to renewable resources, but if energy storage is the only resource to solve renewable generation problems a large storage capacity would be needed, resulting in expensive solutions and environmental issues related to disposal. The cheapest source of flexibility and the most environmentally friendly resource is customer demand itself [49]. Combining energy storage with demand response can lower the cost of the microgrid reducing the energy storage capacity needed and reducing the demand from the grid as much as possible. Also, demand response programs can help in emergency conditions when system stability is jeopardized. In a solar community microgrid demand response can also help maintain the microgrid operating in a strategic way that helps the microgrid meet electric utility restrictions. For example, demand response can help to ensure the microgrid does not exceed the maximum contracted demand, in addition DR can help to maintain a high load factor meeting utility restrictions and avoiding penalties. From the point of view of the utility microgrids can act as a demand aggregator. As discussed in section 2.5 there are different kinds of DR programs. The most common ones are TOU, RTP, CPP and IBR; all these programs are price-based programs. IBR contributes to reduce the overall monthly energy demand, but not necessarily when most needed, at the peaks. TOU, RTP and CPP are design to reduce demand when energy prices are high, typically in the peaks. Various pilot programs have seen a peak demand reduction of 3% to 6% in TOU tariff, and 13% to 20% in CPP [50]. CPP with enabling technologies achieved a peak demand reduction as high as 51% in the California's Advanced Demand Response System Program [50]. Enabling technologies are crucial to demand response programs because they free customers form manual response to price changes. In incentive based programs, typically the load is controlled directly by the utility (DLC); this creates some privacy concerns. However, DLC programs can achieve an average peak load reduction of 0.8 kW and 1.5 kW per residential customer [50].

There are essentially two perspectives of demand side management in a solar community microgrid. The first perspective is managing the energy demand coming from the grid taking into consideration microgrid resources and the second perspective is managing the internal demand. In solar community microgrid managing the demand from the grid could bring economic benefits. The microgrid operator could decide based on the status of the microgrid resources, the best strategy to operate the microgrid in a reliable and economic way. For example, during a good insolation day and seeing that the batteries are full or near full, the microgrid operator can demand less energy from the grid in times when the energy prices are high. Taking as an example the ToU for its simplicity, scenarios 9-11 simulated a change in demand in the peak, in other words when energy prices are higher (see Table 5.2). This can be done in a more robust way to CPP and RTP. In scenario 9 the microgrid is demanding 10 kW of power per group of 10 houses from the grid off peak, when reaching the night peak the microgrid reduces its demand to 8 kW per group, the same happens in scenario 10 and 11 but with their respective boundaries. In contrast to a sunny day, in the cloudy day scenarios no demand reduction is made since not enough energy is produced for a complete charge of the battery, so the load factor and renewable generation of cloudy days in Table 5.3 correspond to a non-demand grid reduction scenario. This demand side management strategy can help to tackle the big energy gap problem that exists between sunny days and cloudy days. From the perspective of the microgrid user is only a demand side management strategy, microgrid users did not respond to price change, the microgrid operator did, so in the utility perspective his client (the microgrid as a whole) responds to a price change in the peak demanding less energy, so from utility perspective the microgrid is a demand respond user. This same line of thought can be implemented in CPP, RTP and others. For example, in RTP, the microgrid operator can reduce or increase the demanded energy from the grid in an hourly basis taking into consideration the microgrid resources, utility requirements, utility services contracted and SOC of the storage system. Running these scenarios, load factor and renewable generation was checked, and in spite of the change in demand at peak from the grid, load factor values where high (see Table 5.3) almost the same on the scenarios when the demanded energy was not scheduled to change at the peak demand period.

Table 5.3 Load Factor and Renewable generation for ToU scenarios.

Case #	Secondary Demand Goal per Group	Installed PV Capacity per Group	Sunny | Cloudy Load Factor		Sunny | Cloudy Renewable Generation %	
9	8 – 10 kW	10 kW	0.85	0.92	27	14
10	7 – 8 kW	15 kW	0.85	0.85	40	22
11	6 – 7 kW	20 kW	0.76	0.75	53	29

To analyze how grid energy cost is reduced by this type of strategy, rate prices from Florida Power & Light Company were used [51]. In General Service tariff GS-1 the energy base charge is 5.439¢ per kWh and in General Service Time of Use tariff GST-1 the base energy charge in On-Peak period is 10.038¢ per kWh and the base energy charge in Off-Peak period is 3.441¢ per kWh, other charges are not included in this analysis. For the purpose of these scenarios the peak period is from 6:00 pm to 12:00 am. Table 5.4 are energy cost from the grid in a sunny day; they present a comparison between running the microgrid with the original setup (no demand reduction at peak), running the microgrid with the grid demand reduction but with a traditional non-motivational rate, and running the microgrid reducing grid demand and with a ToU rate.

Observing scenario #9 one can notice that the difference in price from the original setup to ToU rate is $66.37, this is only for one-day operation, if the microgrid had 10-20 days a month of similar insolation the price energy savings could be from $ 663.7 to $ 1327.4 a month. Appendix A includes the procedure used to determine these costs.

Table 5.4 Grid Energy Cost from different tariff.

Case #	Original Setup (No DR, Traditional Tariff)	Traditional Tariff (With DR)	ToU Tariff (With DR)	Change in Demand per group
9	$257.05	$204.95	$190.68	2000 W
10	$204.95	$178.90	$166.45	1000 W
11	$180.98	$154.33	$143.33	1000 W

It is critical for this type of rate and other price-varying rate to minimize consumption when the energy prices are higher. Observing Figure 5.7 one can see that the on-peak energy cost is similar to the off peak energy cost; this figure emphasizes the importance of reducing grid demand when energy prices are high. For only 6 hours the demand was reduced 2000 W per group and the energy cost on-peak was $93.11, for the rest 18 hours the energy cost of off- peak was $97.57 and the demand was not reduced, a difference of only $4.46 reflects the impact of this type of rate, even with a demand reduction from the grid and an on-peak operation of 1/3 of the time off-peak operation, the on-peak period was almost the same as the off peak period.

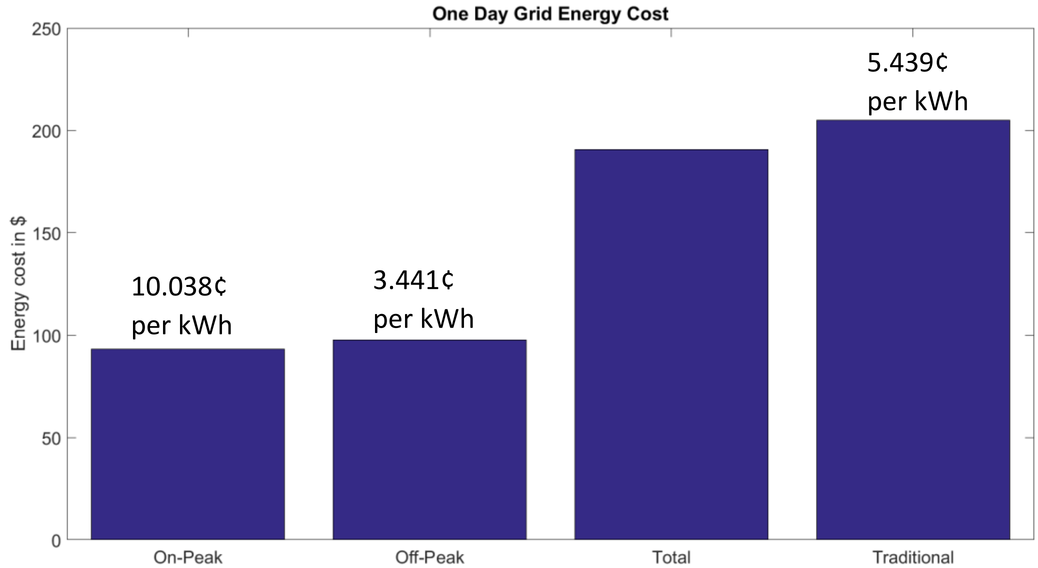

Figure 5.7 One day grid energy cost.

Bringing back the gap difference in energy generation between a sunny and cloudy day, in a sunny day it is very effective to reduce the demand in the peak because of the excess of energy. Observing Figure 5.8 one can notice that besides a demand reduction at peak the energy storage ended with more energy stored than in the initial value at hour 0:00. An acceptable microgrid operation requires a high load factor, meeting the utility's requirements and services contracted. In cloudy days the battery will be drained and utility requirements and contracted service conditions will be violated. As mentioned previously non-demand reductions were made in cloudy day to maintain a high load factor and meet utility requirements and contracted service conditions. In these scenarios, the microgrid reduced the demanded energy form the grid taking into consideration solar insolation and SOC of the battery. Adding internal demand response could bring more flexibility in the operation of this strategy especially in days with less insolation. A good alternative could be a reduction of grid demand and at the same time a reduction in the residential load.

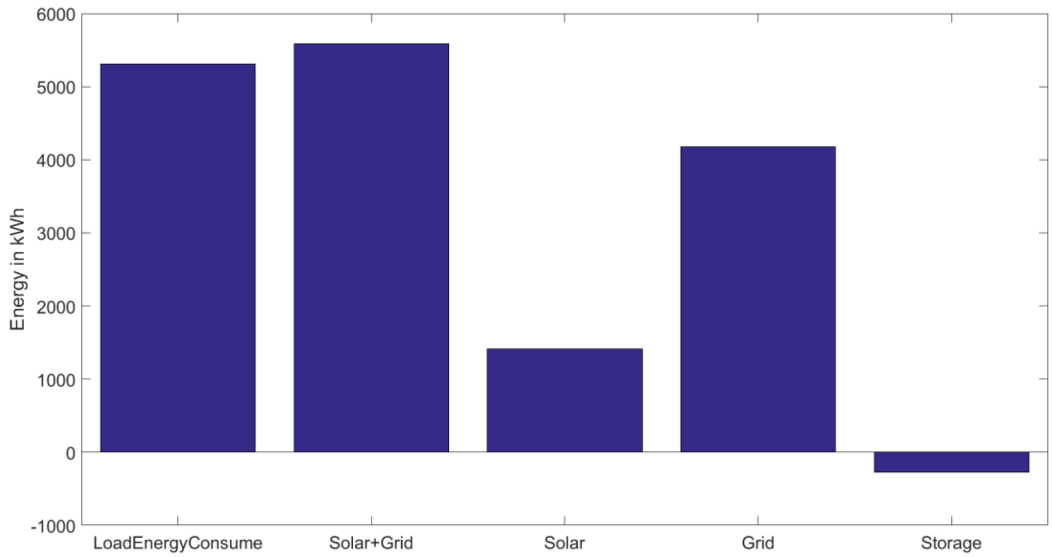

Figure 5.8 Energy Produced and Consumed from different resources.

Managing the residential demand is more challenging than managing the microgrid resources such as the energy storage, but managing the residential demand could bring more flexibility. The main challenge is customer acceptance, which depends on economics and customer comfort. As discussed in section 3.3 customers are more sensitive to price signals and the motivation to participate is usually economic but can also be environmental. Thus, to guarantee a constant participation an economic benefit need to be present; the environmental benefit may not be enough. Also, customer discomfort has to be minimized in order to guarantee a constant participation, issues like customer fatigue and house discomfort have to be avoided. The use of a smart infrastructure can include DLC or other enabling technologies such as smart appliances. With DLC the microgrid operator has full control of the appliances and can manage them in an optimal way, but this brings privacy and fairness concerns. Furthermore, constant communication of the appliance status could make the operation costly due to the large number of appliances in a microgrid communicating with the centralized control unit. A better way could be one where privacy concerns are minimal or nonexistent and decisions are made in a decentralized manner. For example, enabling technologies such as smart appliances that work only when energy prices are below a user-set value. For example, a full clothes washer is left ready in the morning and when grid prices are below the desired value and/or the renewable generation output is at its peak the smart clothes washer operates. With DLC load discrimination assessment has to be made to identify which energy users and appliances in the microgrid have to always be on, which could be turned off, which could be rescheduled. In contrast, with enabling technologies such as smart appliances users decice directly what loads are essential and how they will be managed, and they want can make setting changes directly.

The scenarios where demand response was executed appear in Table 5.5**Error! Reference source not found.**, these scenarios were chosen due to the low load factor present. In terms of the simulation the load reduction was made through a DLC method for ease of simulation. The focus in the research is how load reduction can help the operation of the microgrid. Demand response programs such as CPP, RTP and ToU are difficult to simulate at residential level due to human factors, there is little research on how humans interact or would interact with smart appliances, what is or will be their preferences. These issues vary among different social class, different countries or geographical areas, but the principle of load reduction apply in all DR programs. As mentioned earlier the main difference in terms of load reduction between programs is the time window of the reduction and the amount reduced. In these scenarios, the maximum load reduction is 0.8 kW per house and that is in the two profile with the highest demand, taking into consideration that DLC can achieve an average peak load reduction of 0.8 kW and 1.5 kW per residential customer [50]. Five houses of the microgrid did not reduced their load, these houses represent critical loads such as houses with persons needing medical equipment 24 hours. In all cases the LF was improved and was above 0.80, that is above the requirement of PREPA for transmission users.

Table 5.5 Load Factor and Renewable generation for cloudy days and cloudy days with DR.

Case #	Secondary Demand Goal per Group	Installed PV Capacity per Group	Cloudy | Cloudy DR Load Factor		Cloudy | Cloudy DR Renewable Generation %	
2	7.5 kW	10 kW	0.38	0.89	14	17
3	7.5 kW	15 kW	0.67	0.86	22	25
4	6.5 kW	15 kW	0.33	0.84	22	25
5	6.5 kW	20 kW	0.51	0.81	29	34

Traditional distribution rates like general service and ToU do not take into consideration LF. Commercial users have a demand charge that promotes the use of energy efficient equipment that reduces the overall demand including the peak to energy costs. This approach does not guarantee a constant demand or a high load factor demand especially if the user has renewable generation. If the user reduces the energy bill by lowering the peak demand with energy efficient equipment, the utility may continue to see a valley or a power injection to the grid from the user when the PV is generating, and a peak at night, resulting in a low LF that affects utility economics. The operation of this type of microgrid that has a high load factor needs to be compensated in some way. This special rate for microgrids could automatically reward the customer for having a high load factor and also penalize if a minimum is not met. For example; if the utility requires a 0.7 LF for community microgrids and the microgrid operates at 0.85, instead of the standard price of energy, the microgrid would pay less per kWh. Choosing the minimum LF in the rate is a difficult task; historic data of similar load behavior have to be analyzed to see what is a typical LF for a similar load. Data could be acquired from solar communities and other loads with demand in a similar range of the microgrid. Solar communities could be viewed as an early stage of a community microgrid. A solar community does not have enough resources to minimize grid impact such as ramp problems and LF problems, hence using solar community as a benchmark for LF can be justified. In the long run some solar communities could invest in storage to become community microgrid to take advantage of this special rates at and the same time help increase renewable production by reducing electric utilities concerns.

5.6 Solar Community Microgrids in Puerto Rico

Solar community microgrids operation are very dependable on the location. The location will determine how variable and how much electric energy the solar systems would produce. One study found that temperate climatic regions show less PV variability than subtropical regions [52]. In the previous study, no comparison was made with tropical regions but other study concludes that "the shading effect caused by passing clouds in tropical regions, especially in Singapore, is one of the most significant factors influencing the power output of a PV system, thus, users in tropical areas need to take the shading effect due to passing clouds into consideration when evaluating energy production, or sizing the batteries for energy storage in a household PV system." [53]. Puerto Rico is a tropical region so the shading effect due to passing clouds needs to be considered when a solar community microgrid is developed to have the best PV and energy storage combination. This variability not only affects the energy production but also affects the ramp rate requirement. Nowadays distribution users do not have ramp rate (RR) requirement in PR. However, as more renewable energy is used a requirement could be established for distribution users to mitigate PV variations. The main question is what is a fair ramp rate for a solar community microgrid or large PV distributed generators? Some probabilistic studies are needed. In [52] the probability of exceeding different ramp rates was calculated for different places. They found huge differences between the sites, the probability to exceed a 10% RR in one location in Sydney (temperate region) was 11.12% vs 22.55% in Brisbane (humid subtropical region), for 30% of RR the probability for Sydney was reduced to 2.66 % vs 11.62 % for Brisbane (note that the probability of 10% RR violation in Sydney is similar as the probability of 30% RR in Brisbane) . Observing the probability in different locations in Puerto Rico for different RR (10%, 20%, 30%) could be beneficial to determine a fair ramp rate for solar community microgrids. Knowing that PR is a tropical region with a lot of solar variability an initial guess is that 10% is unfair (huge probability, more investment for the microgrid) and not needed in a distribution system where PV systems have less impact to the grid than a transmission level connection. Tropical environments typically have warm to hot temperature, so A/C is commonly seen in a household and is one of the largest loads. In a sunny day A/C units have to work harder to maintain the desired room temperature as compared to cloudy days, but in sunny days more solar energy is generated. The microgrid operator could take advantage on this fact and manage the A/C units in a way that customer discomfort is minimized and microgrid operation, specifically the SOC of the battery, remains within desirable values in cloudy days where PV generation is minimal and A/C units consume less energy. In terms of LF, PREPA requires that transmission users have a 0.8 LF or higher under LIS tariff, but again transmission users have a greater impact to the grid than distribution users and large industries can operate their plants 24/7. There is no study that recommends LF for distribution users, since distribution users mostly residential and small commercial users have a defined energy consumption schedule. Solar community microgrids with energy storage bring more flexibility than traditional distribution users, so they can help the utility reduce the disproportional consumption of energy between periods of the day. Using the simulations of this thesis to choose a recommended LF value for a solar community microgrid, one can determine that a 0.80 LF is feasible, but it will require a large energy storage capacity (12.8 kWh per house per day in these simulations). For less energy storage and/or more renewable generation, more flexibility should come from the grid (allow a lower LF such as 0.7).

Another influential factor in a solar community microgrids development is energy policy. A lot of aspects of the microgrid are highly influenced by energy policy; demand response programs, renewable energy generation goals, energy efficiency goals, loading orders among others. The right combination of policies can easily stimulate the construction of solar community microgrids. In PR there is a renewable energy generation goal, but not for energy efficiency (only for government). An energy efficiency goal can help the introduction of DR programs. Also like in California, PR can make a loading order that put DR as one of the preferred resources. The Energy Commission and the state energy office should guide the future of the electric industry sector by promoting DR programs, microgrids and smart technologies to ensure renewable energy use is maximized in PR. In terms of rate design in section 5.5 there are some comments of how the rate design could be. Virtual net metering and traditional rates are obsolete and do not reflect the benefits of having a load that mitigates grid impacts. With the introduction of smart technologies in the future in PR some new opportunities will appear like demand aggregator services, paving the way to community microgrids. As more households install solar panels, Puerto Rico should start seriously establishing as a goal to turn as many communities as possible into solar communities. And eventually, community microgrids to increase energy security and resiliency. Figure 5.9 summarizes a process towards community microgrids.

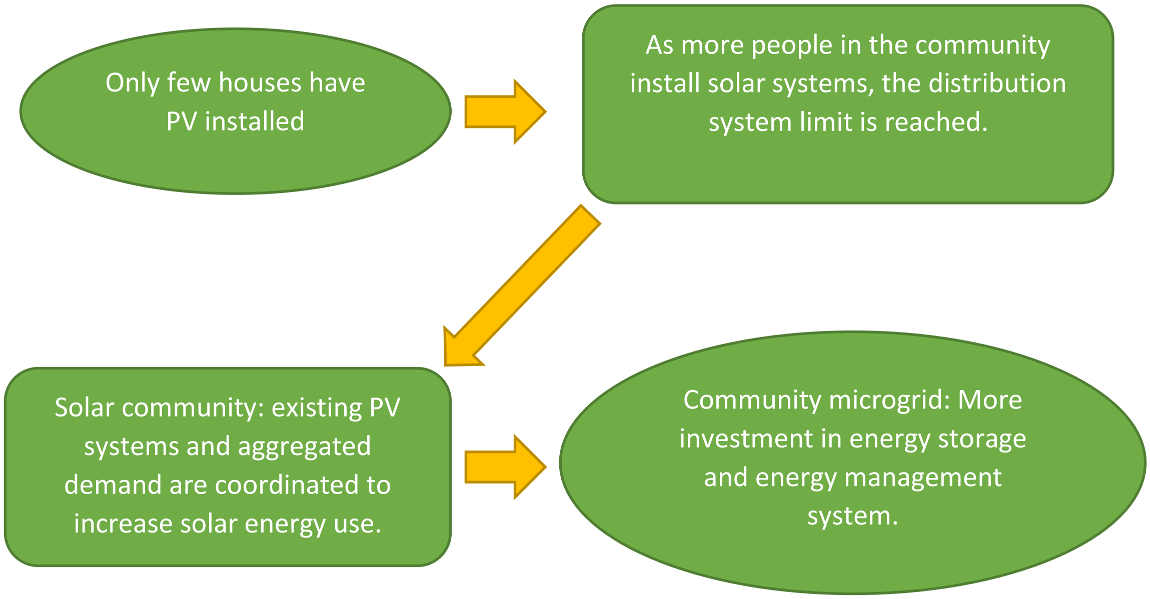

Figure 5.9 Moving towards community microgrid.

Currently there are some trends worldwide that are paving the way for this type of microgrid to occur.

- Reduction of battery prices and solar panels.
    - Storage costs have already fallen 70% since 2011, and BNEF (Bloomberg New Energy Finance) predicts they will fall another 15% in 2017[49].
- Renewable and Energy Efficient Goals
    - Most states and countries are setting goals for their renewable production and are setting goals for reducing their consumption.
        - Example: Hawaii renewable energy goal is 100% by 2045 and Hawaii establishes a 4,300 GWh goal by 2030.
- A higher concern of climate change.
- The rise of the Electric Vehicle and plug-in hybrid: this new load can be scheduled to consume energy (charge the battery) when energy prices are low specifically in valleys to help maintain a good load factor with sunny days' excess.

6. Conclusions and Future Work

6.1 Conclusion

Solar community microgrids can contribute to the generation and penetration of renewable energy in Puerto Rico and other parts of the world for several reasons. First this type of system minimizes the impact of renewable energy by limiting renewable energy fluctuations. In addition, this type of microgrid reduces the renewable energy curtailment by managing efficiently the microgrid resources and the energy from the grid. Also, this community microgrid can work as a demand aggregator that can facilitated by managing the residential loads and small commercial loads through the implementation of DR programs. Using DR programs in the community microgrid not only brings environmental benefits, also the implementation of DR programs in the microgrid can help the electric utility in emergency conditions. Microgrid customers as well as electric utilities will benefit from renewable energy generation; renewable energy generation would help utilities to meet legislative mandates while allowing microgrid customers to use local, clean energy. Also, microgrid customer could benefit with a reduction in energy prices, and would be more empowered by being active users in energy transactions decisions.

When increasing PV installation capacity, the gap of production between sunny and cloudy days' increases, creating a more challenging way to operate the microgrid when moving towards net zero. Moving toward net zero needs flexibility, this flexibility can come from installing more energy storage or from the electric utility supply. Electric utilities need to be a facilitator in this process making rates and technical requirements that are flexible and fair. A reasonable ramp rate needs to be determined for distribution systems, especially in tropical climates such as Puerto Rico's. Load factor would be a huge concern, if the utility requires the same LF in distribution that is in transmission, a huge amount energy storage would be needed as seen is this thesis. Reducing the LF requirement could reduce the amount of energy storage needed. One of the main challenges that exist to develop this type of microgrid is the lack of standardization in DR programs. There many different programs, each one of them with its own rules. DR programs appropriate for Puerto Rico's realities need to be developed. Also, traditional regulation itself could be a barrier if regulators do not facilitate these new options. Moving toward net zero community microgrids is a challenge that needs be tackled in two main aspects: economically and regulatory.

6.2 Future Work

This thesis focuses in the technical aspects of moving towards a net zero community microgrid. This type of microgrid was analyzed through simulations; in order to have a better selection of energy resources to find different operational points and move through net-zero methods. The optimal use of energy resources is left as future work, as well as a more detailed consideration of load factor and ramp rates for distribution systems to address the gap when operating the microgrid in a sunny day vs a cloudy day. It is very important that the future optimization work provides some type of graphical interface that illustrates the operation of the microgrid during a day, week or month. This will provide a tool for better understanding of the operation of a microgrid operation and options that a community could have. Future research should also include other resources, such as micro-hydro or wind than can contribute when solar generation is not possible. Also, to provide a more realistic simulation a more robust battery model needs to be used. Interaction between microgrids of this type could be analyzed, and how a distribution market could be used to sell services and energy between community microgrids.

Finally, an in-depth regulatory study of demand response options and microgrid rates is needed to have a more complete picture of the possibilities and challenges of community microgrids.

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Appendix A: Energy Cost Calculations

$$Original\ Setup\ Cost\ (No\ DR) = (Total\ Grid\ Energy\ Consume) \times (Cost\ of\ the\ Energy\ in\ kWh)$$

$$= 4.7252 * 10^3 \times 0.0544 = 257.05$$

$$Traditional\ Tariff\ (With\ DR) = (Total\ Grid\ Energy\ Consume) \times (Cost\ of\ the\ Energy\ in\ kWh)$$

$$= 3.767 * 10^3 \times 0.0544 = 204.95$$

$$ToU\ Tariff\ (With\ DR)$$

$$= (Total\ Grid\ Energy\ Consume\ on\ peak) \times (Cost\ of\ the\ Energy\ on\ peak\ in\ kWh)$$

$$+\ (Total\ Grid\ Energy\ Consume\ off\ peak) \times (Cost\ of\ the\ Energy\ off\ peak\ in\ kWh)$$

$$= 931.06 \times 0.10 +\ 2.8365 * 10^3 \times 0.344 = 190.68$$

Appendix B: Puerto Rico Time of Use Future Scenario.

Having the on-peak and the off-peak values of the PR ToU tariff. The only code lines that need to be changed are line 30 and line 31. For example, suppose that the on-peak value is 5 cents per kWh and the off peak value is 15 cents per kWh the code line will change to the following.

OnpeakCost=-.15*onpeakener;

OffpeakCost=-.05*offpeakener;

Appendix C: Matlab Code

Script 1: Start_Simulation.m

```
%Script para empezar la simulación Version 7.
% Author: Isaac L. Jordán Forty
% Last Edit:   February 2017
clear;
load('loadandsolar3'); %Carga los datos de carga y datos solares de facto
load('RLC_parameters.mat'); %Carga los parametros de las lineas de
distribucion
load('Initial_power_SImulation') %Datos necesarios para iniciar simulacion
caso=10000; %Aqui se escoge cuanto va estar supliendo el segundario
caso1=caso;
IV_DR1=IV/1.15; %Primera etapa de DR 15% Carga de 627 kWh
IV_DR2=IV/1.35; %Segunda etapa de DR 35% Carga de 627 kWh
OOH_PDR1=OOH_P/1.25; %Primera etapa de DR 25% Carga de 834kWh
OOH_PDR2=OOH_P/1.50; %Segunda etapa de DR 50% Carga de 834kWh
IH_PDR1=IH_P/1.25; %Primera etapa de DR 25% Carga de 918kWh
IH_PDR2=IH_P/1.50; %Segunda etapa de DR 50% Carga de 918kWh
SPD_1min=SPD_1min*2; %Sol de facto de matlab cambiar con otras curvas solares
DL=10; %Delay 1
DLI=10; %Delay 2
INI=(Pinit-caso)/240; %Valor iniciar que empiezan las baterias.
caso=10000-caso;
bat=267*2; %Capacidad de la batería
```

Script 2: Community_Plots.m

```
%Script para graficar todos los datos de la microred comunitaria.
% Author: Isaac L. Jordán Forty
% Last Edit:   February 2017

ScopeSPS0=ScopeSPS;
for j=0:1:19;
ref=num2str(j);
Scopenum=strcat('ScopeSPS',ref);
Scopenum1=strcat(Scopenum,'.time');
Scopenum2=strcat(Scopenum,'.signals(1).values');
Scopenum3=strcat(Scopenum,'.signals(2).values');
Scopenum4=strcat(Scopenum,'.signals(3).values');
Scopenum5=strcat(Scopenum,'.signals(4).values');
Scopenum6=strcat(Scopenum,'.signals(5).values');
figure(j+1);
subplot(5,1,1);
plot(eval(Scopenum1)/(3600),eval(Scopenum2),'LineWidth',2);
xlim([0 24])
%ylim([0 1e4])
ylabel('Solar P(W)');
set(gca,'FontSize',12)
subplot(5,1,2);
%xlabel('Hours')
```

```
%figure(2)
plot(eval(Scopenum1)/(3600),eval(Scopenum3),'LineWidth',2);
xlim([0 24])
%ylim([-2e4 0e4])
ylabel('Secondary P(W)');
set(gca,'FontSize',12)
subplot(5,1,3);
%xlabel('Hours')
%figure(3)
plot(eval(Scopenum1)/(3600),eval(Scopenum4),'LineWidth',2);
xlim([0 24])
%ylim([0e4 3e4])
ylabel('Load (W)');
set(gca,'FontSize',12)
subplot(5,1,4);
%xlabel('Hours')
%figure(4)
plot(eval(Scopenum1)/(3600),eval(Scopenum5),'LineWidth',2);
xlim([0 24])
%ylim([-2e4 2e4])
ylabel('Battery P(W)');
set(gca,'FontSize',12)
subplot(5,1,5);
%xlabel('Hours')
%figure(5)
plot(eval(Scopenum1)/(3600),eval(Scopenum6),'LineWidth',2);
xlim([0 24])
%ylim([0 100])
xlabel('Hours')
ylabel('% Battery')
set(gca,'FontSize',12)
saveas(figure(j+1),Scopenum,'png')
end
figure(21)
plot(ComunityTotal.time/(3600),ComunityTotal.signals(1).values,'LineWidth',2)
xlim([0 24])
%ylim([1e5 5e5])
xlabel('Hours')
ylabel('Community Aggregated Load (W)')
set(gca,'FontSize',12)
saveas(figure(21),'Community Total','png')
close all
```

Script 3: Community_Energy_Analysis.m

```
%Script para graficar todos los datos de la microred comunitaria.
% Author: Isaac L. Jordán Forty
% Last Edit:   February 2017

ScopeSPS0=ScopeSPS;
for j=0:1:19;
ref=num2str(j);
Scopenum=strcat('ScopeSPS',ref);
```

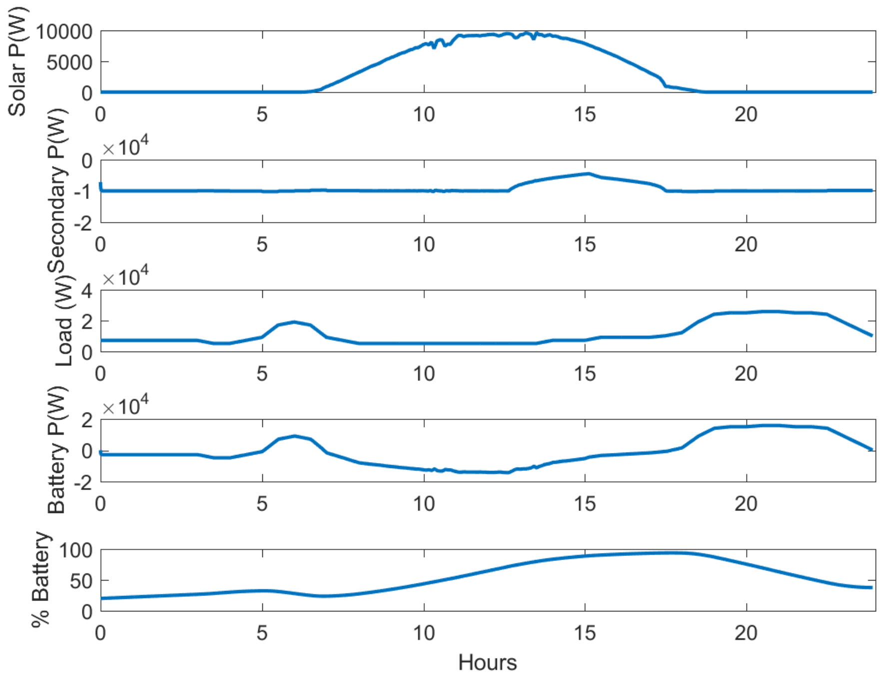
```
Scopenum1=strcat(Scopenum,'.time');
Scopenum2=strcat(Scopenum,'.signals(1).values');
Scopenum3=strcat(Scopenum,'.signals(2).values');
Scopenum4=strcat(Scopenum,'.signals(3).values');
Scopenum5=strcat(Scopenum,'.signals(4).values');
Scopenum6=strcat(Scopenum,'.signals(5).values');
figure(j+1);
subplot(5,1,1);
plot(eval(Scopenum1)/(3600),eval(Scopenum2),'LineWidth',2);
xlim([0 24])
%ylim([0 1e4])
ylabel('Solar P(W)');
set(gca,'FontSize',12)
subplot(5,1,2);
%xlabel('Hours')
%figure(2)
plot(eval(Scopenum1)/(3600),eval(Scopenum3),'LineWidth',2);
xlim([0 24])
%ylim([-2e4 0e4])
ylabel('Secondary P(W)');
set(gca,'FontSize',12)
subplot(5,1,3);
%xlabel('Hours')
%figure(3)
plot(eval(Scopenum1)/(3600),eval(Scopenum4),'LineWidth',2);
xlim([0 24])
%ylim([0e4 3e4])
ylabel('Load (W)');
set(gca,'FontSize',12)
subplot(5,1,4);
%xlabel('Hours')
%figure(4)
plot(eval(Scopenum1)/(3600),eval(Scopenum5),'LineWidth',2);
xlim([0 24])
%ylim([-2e4 2e4])
ylabel('Battery P(W)');
set(gca,'FontSize',12)
subplot(5,1,5);
%xlabel('Hours')
%figure(5)
plot(eval(Scopenum1)/(3600),eval(Scopenum6),'LineWidth',2);
xlim([0 24])
%ylim([0 100])
xlabel('Hours')
ylabel('% Battery')
set(gca,'FontSize',12)
saveas(figure(j+1),Scopenum,'png')
end
figure(21)
plot(ComunityTotal.time/(3600),ComunityTotal.signals(1).values,'LineWidth',2)
xlim([0 24])
%ylim([1e5 5e5])
xlabel('Hours')
ylabel('Community Aggregated Load (W)')
set(gca,'FontSize',12)
saveas(figure(21),'Community Total','png')
close all
```

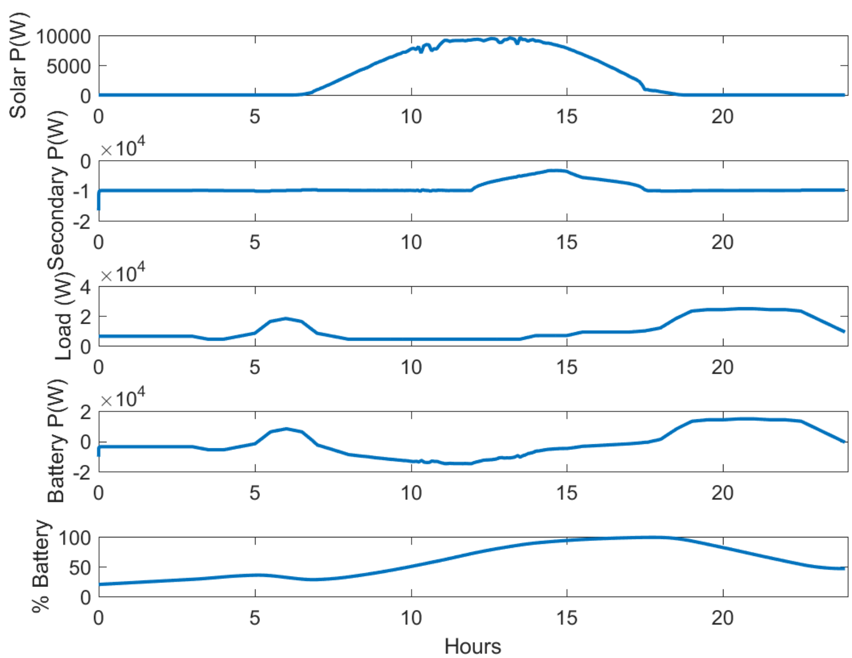
Script 4: Grid_Cost.m

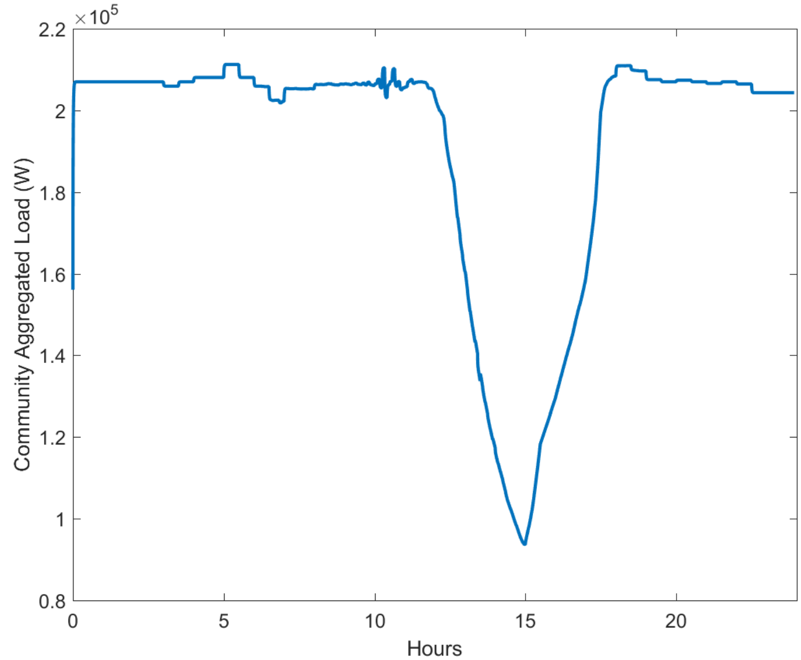
```
%Script Analisis de TOU.
% Author: Isaac L. Jordán Forty
% Last Edit:   February 2017
SecondaryEnergyTOU = 0;
ScopeSPS0=ScopeSPS;
TOU=18*60*60;
onpeakener=0;
offpeakener=0;
for j=0:1:19;
ref=num2str(j);
Scopenum=strcat('ScopeSPS',ref);
Scopenum1=strcat(Scopenum,'.time'); %Tiempo
Scopenum3=strcat(Scopenum,'.signals(2).values'); %Power Secondary
stop=length(eval(Scopenum1));
for i=1:1:stop-1
      dtime(i)=ScopeSPS.time(i+1)-ScopeSPS.time(i); % ime Step are the
same????
end
dtime(stop)=10;
Ind=eval(Scopenum1)<TOU;
Tempsec=eval(Scopenum3);
for h=1:1:stop
    if Ind(h) == 0
        onpeakener=onpeakener + dtime(i)'.*Tempsec(i)/(3600*1000);
    end
    if Ind(h) ==1
        offpeakener=offpeakener + dtime(i)'.*Tempsec(i)/(3600*1000); %cambiar
1 y0
    end
end

OnpeakCost=-.10*onpeakener;
OffpeakCost=-.0344*offpeakener;
TotalCost=OnpeakCost+OffpeakCost;
TraditionalCost=-.0544*(onpeakener+offpeakener);

bar([OnpeakCost OffpeakCost TotalCost TraditionalCost])
ax = gca;
title('One Day Grid Energy Cost');
ax.XTick = [1 2 3 4];
ax.XTickLabels = {'On-Peak','Off-Peak','Total','Traditional'};
ax.XTickLabelRotation = 0;
ylabel('Energy cost in $');
set(gca,'FontSize',20)
%e
end
display(TotalCost);
display (TraditionalCost);
```

Appendix D: Simulations

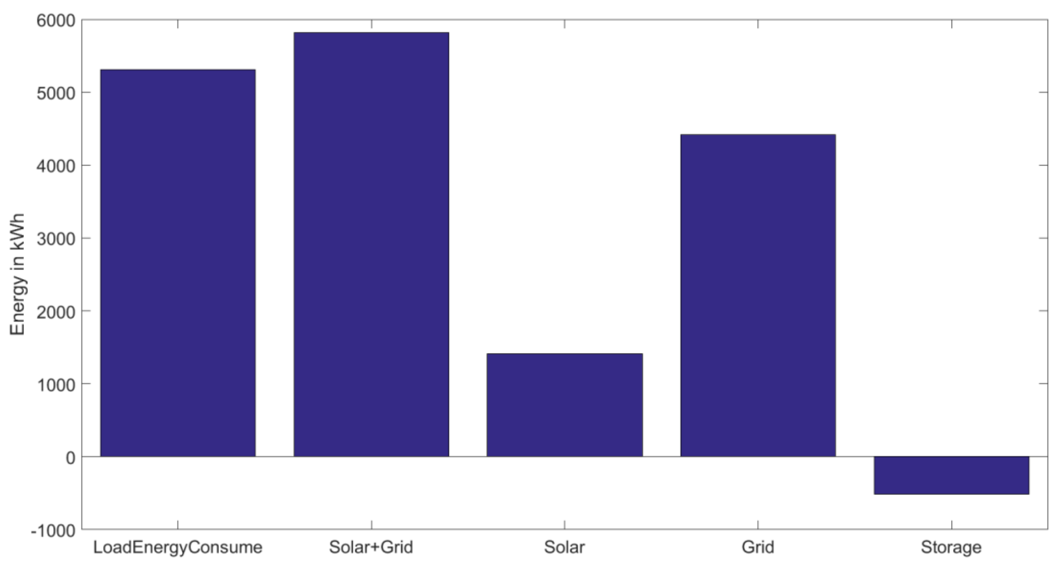
Case 1 Sunny





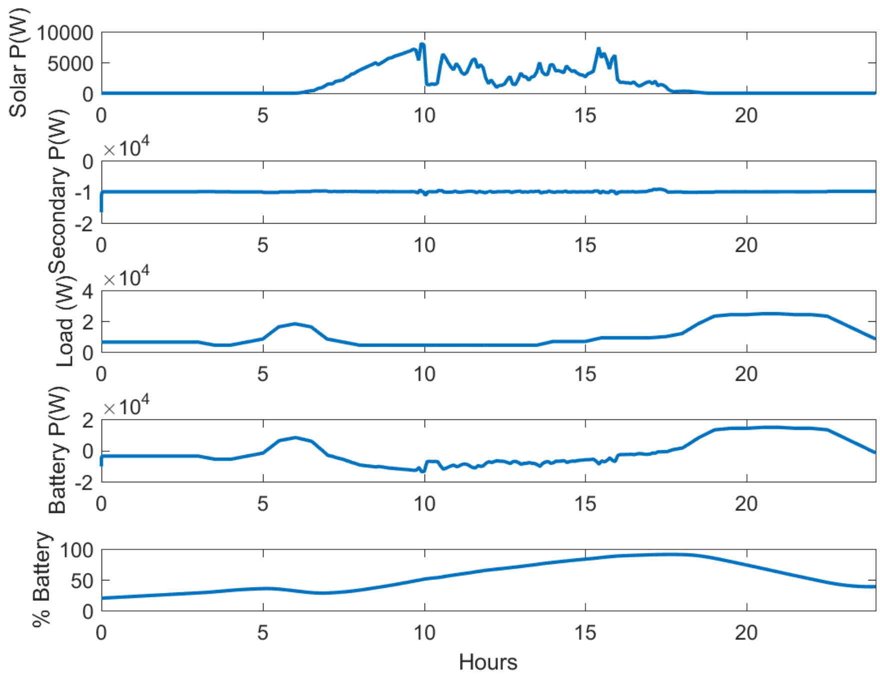


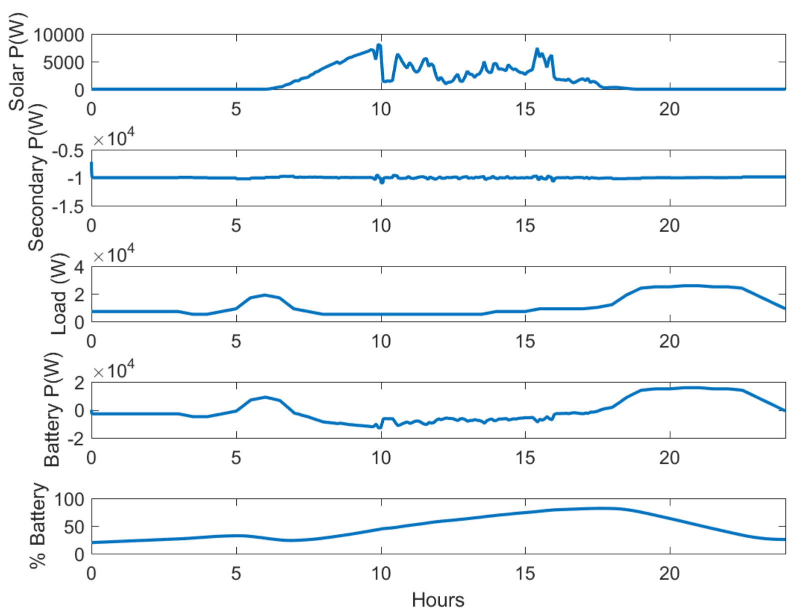
2.2
2
1.8
1.6
1.4
1.2
1
0.8
$\times 10^5$
Community Aggregated Load (W)
0
5
10
15
20
Hours

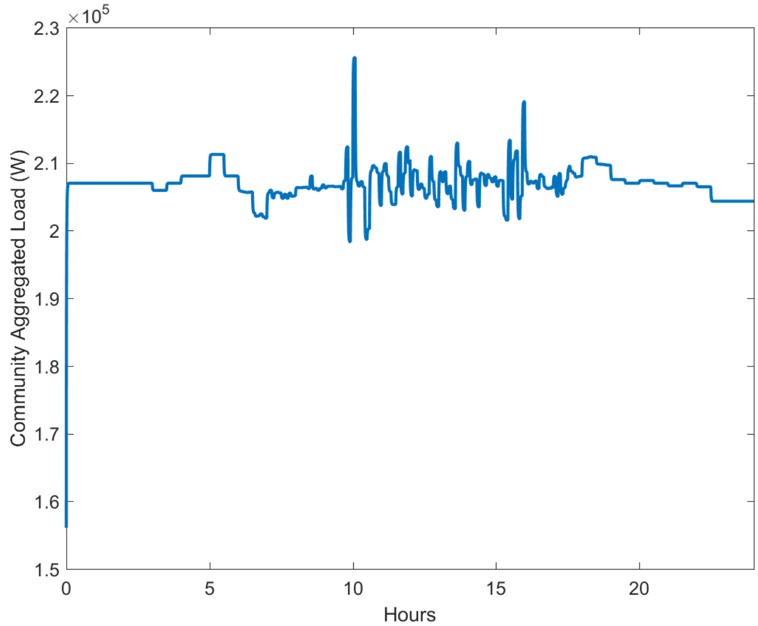


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

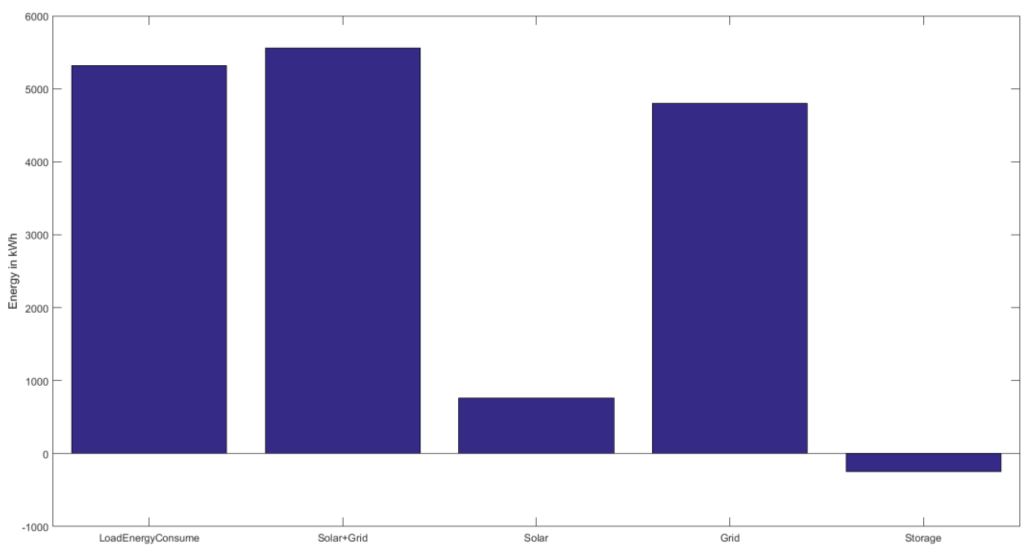
Case 1 Cloudy





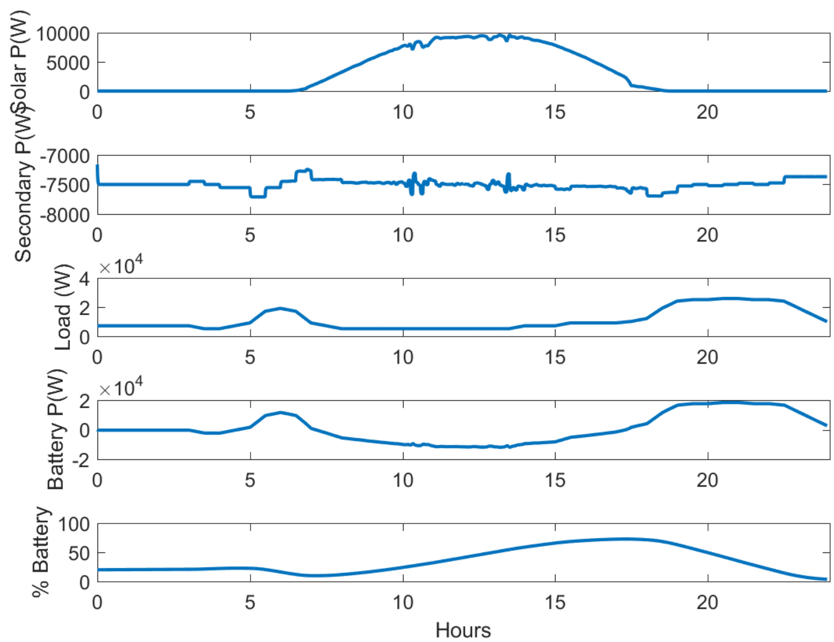


×10^5
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
Community Aggregated Load (W)
0
5
10
15
20
Hours

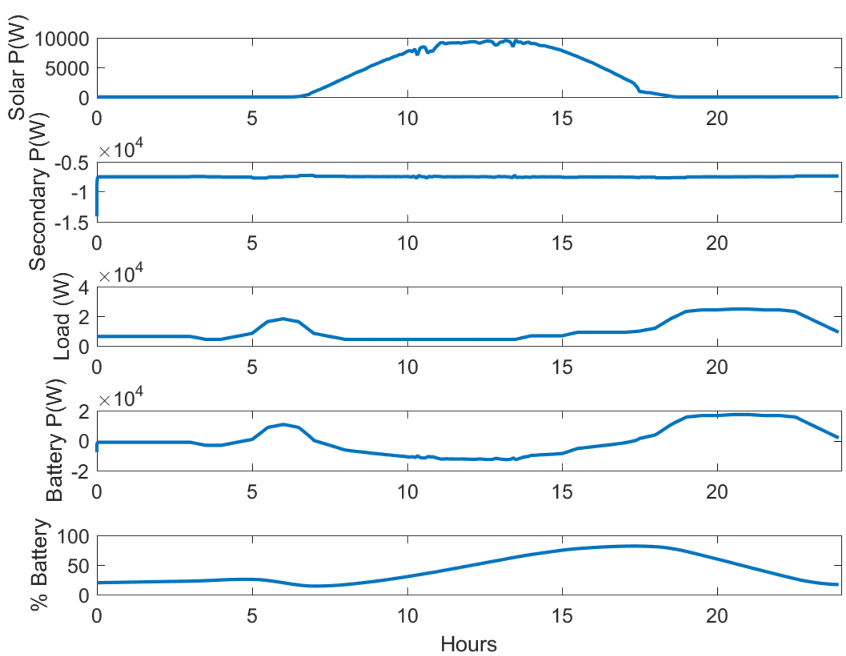


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

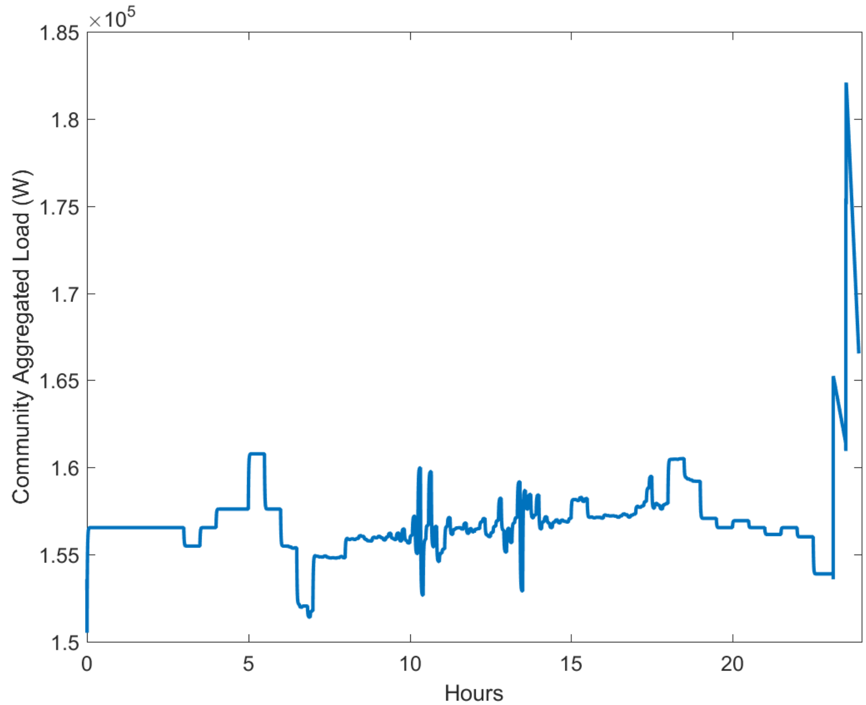
Case 2 Sunny



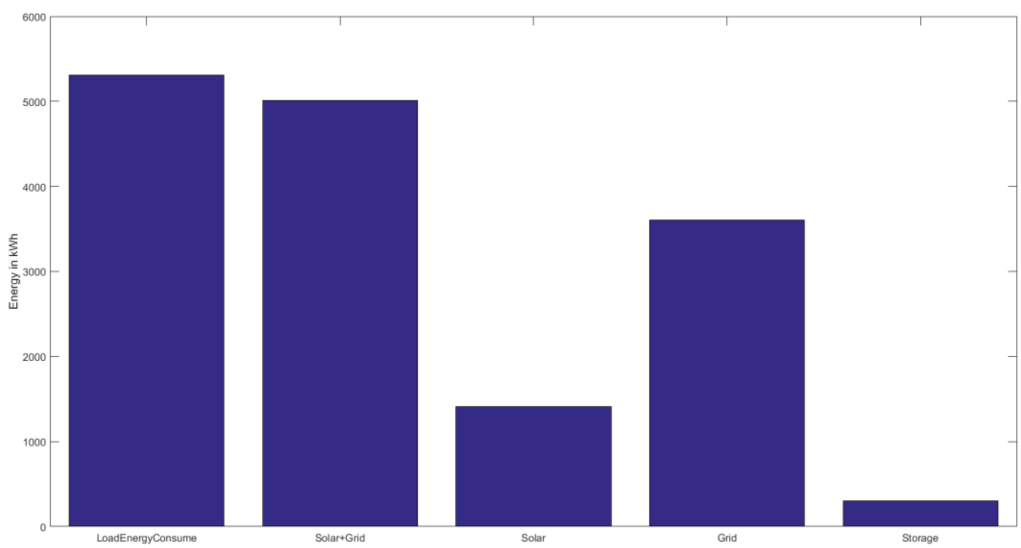
Solar P(W)
Secondary P(W)
Load (W)
Battery P(W)
% Battery
Hours



Solar P(W)
Secondary P(W)
Load (W)
Battery P(W)
% Battery
Hours

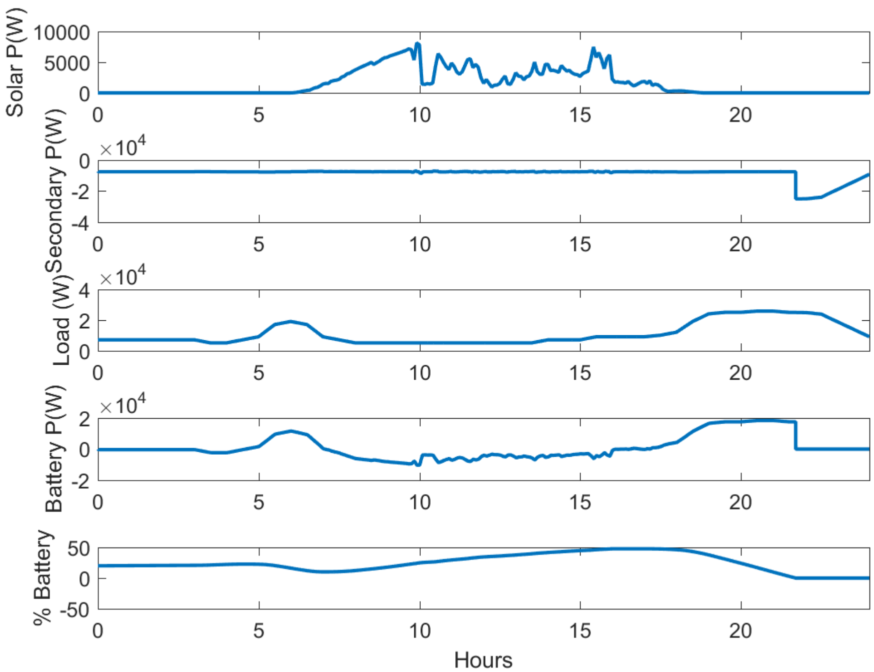


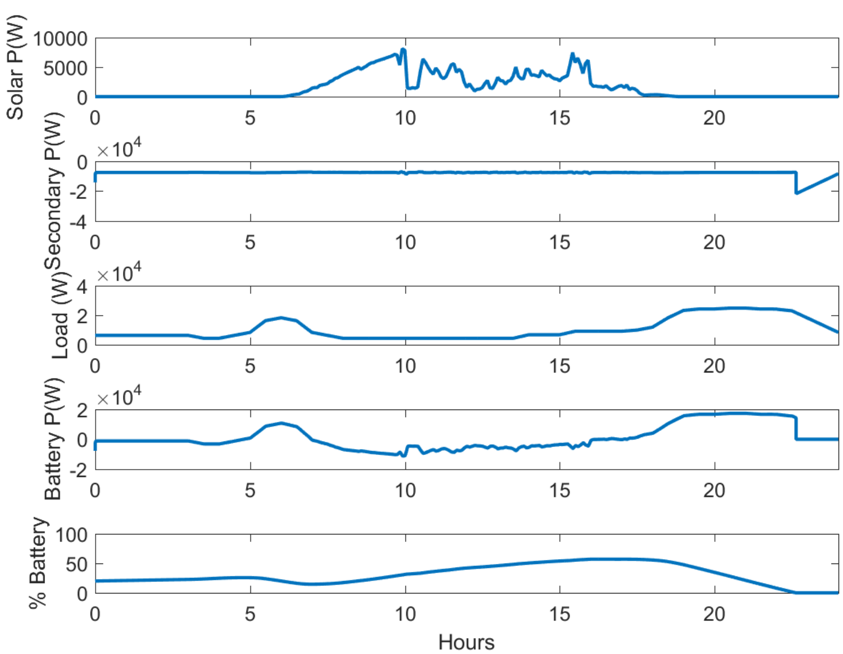
$\times 10^5$
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
Community Aggregated Load (W)
0
5
10
15
20
Hours

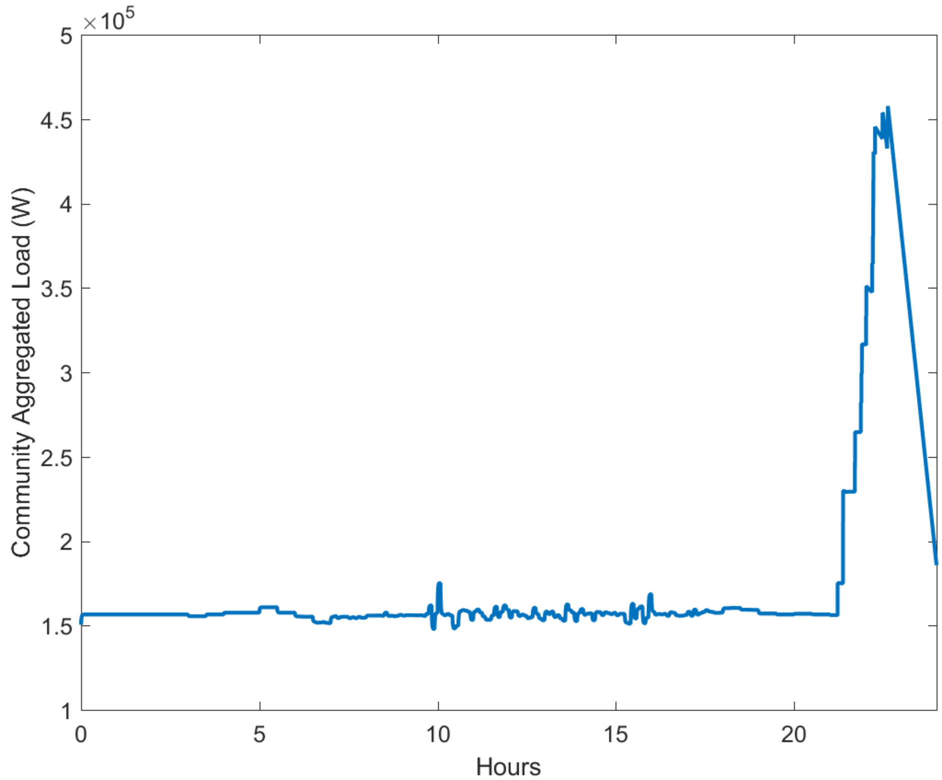


6000
5000
4000
3000
2000
1000
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

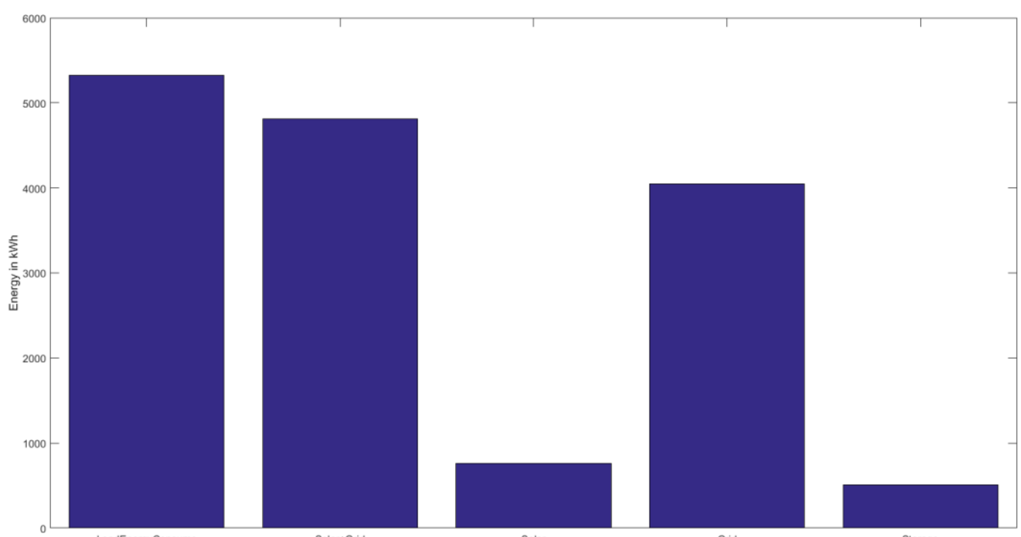
Case 2 Cloudy





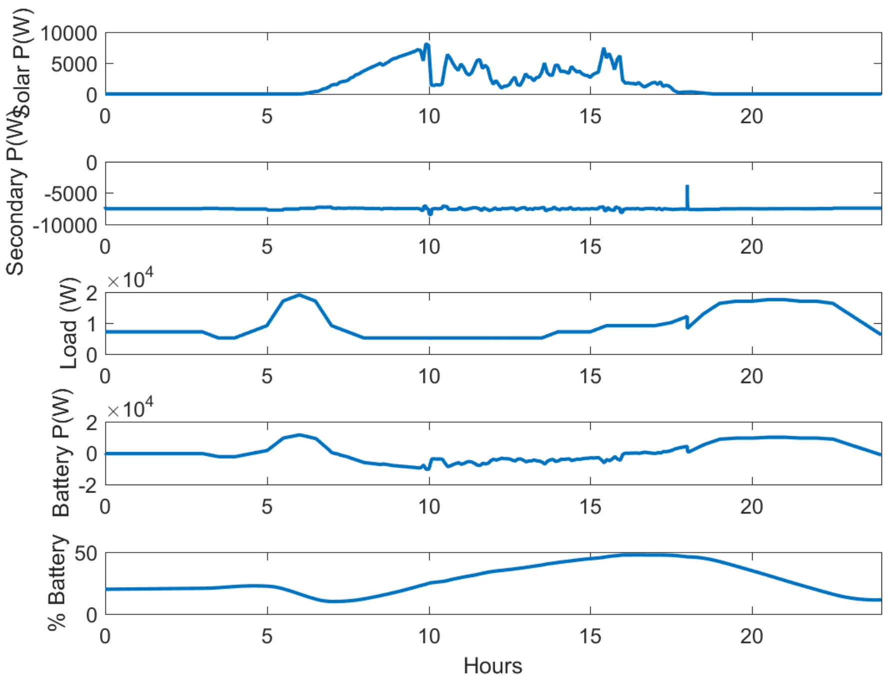


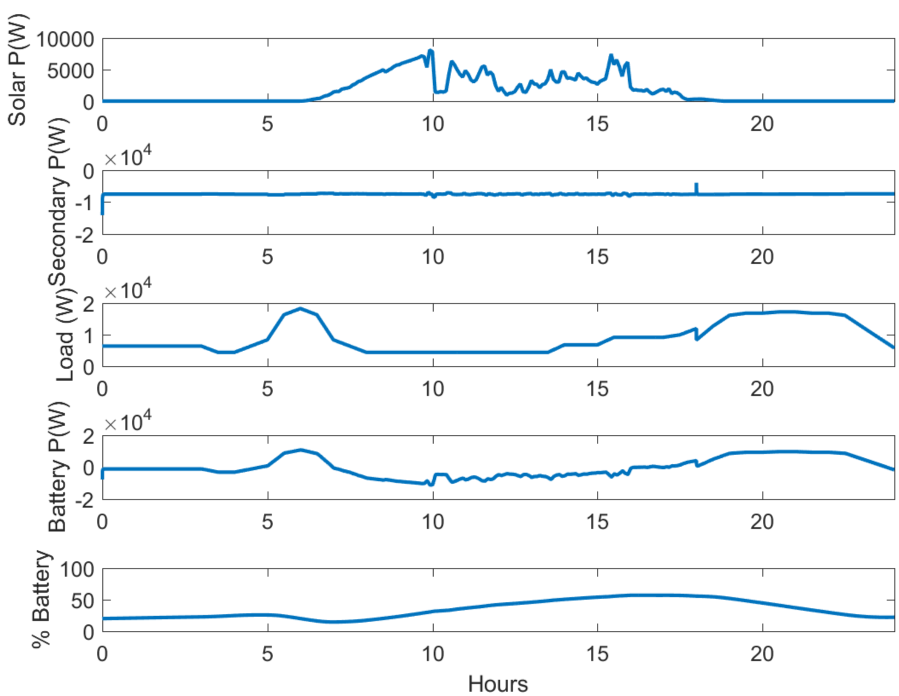
×10^5
5
4.5
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20
Community Aggregated Load (W)
Hours

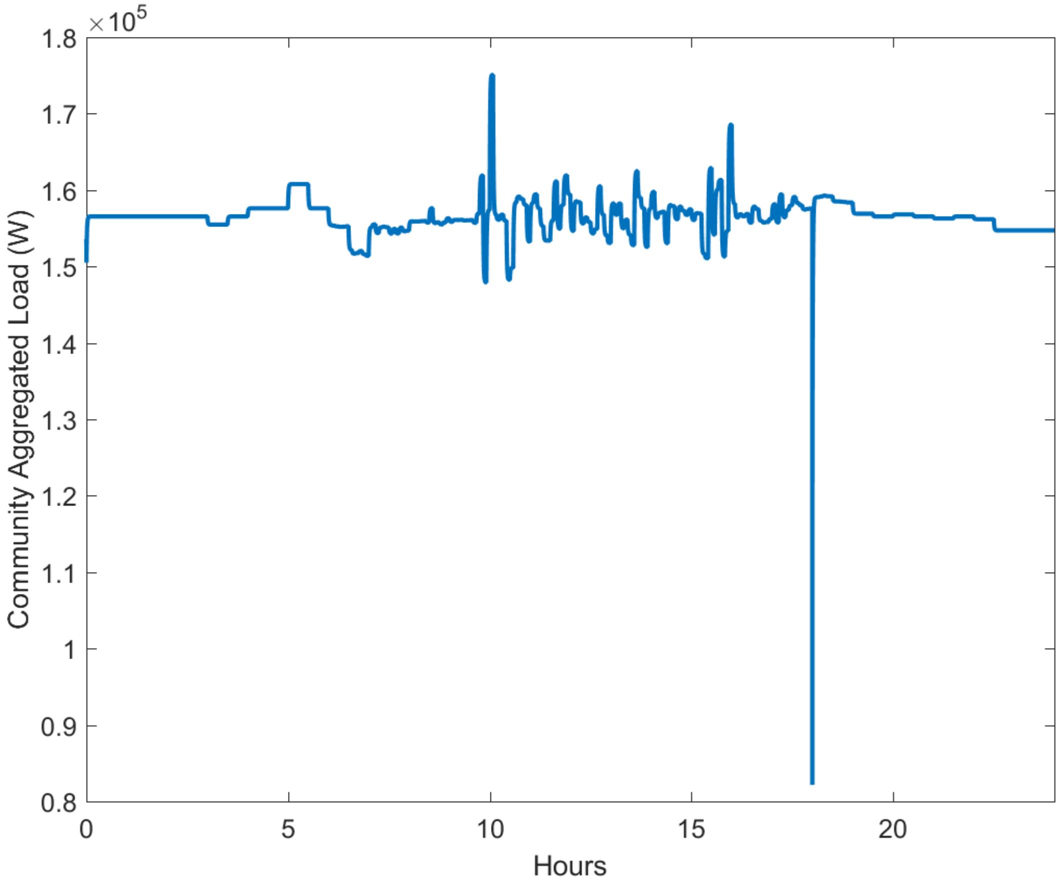


6000
5000
4000
3000
2000
1000
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

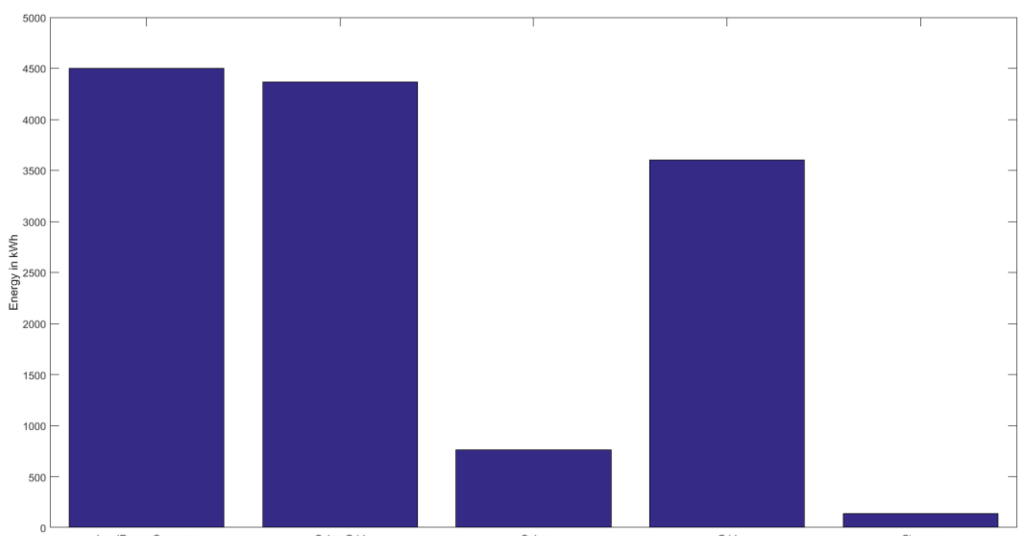
Case 2 Cloudy DR





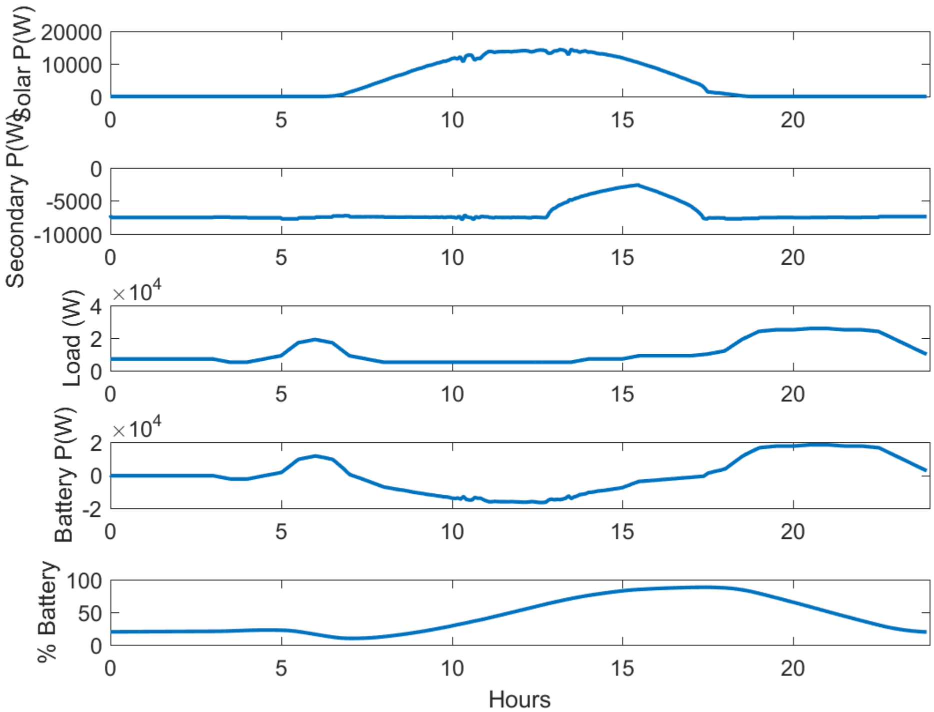


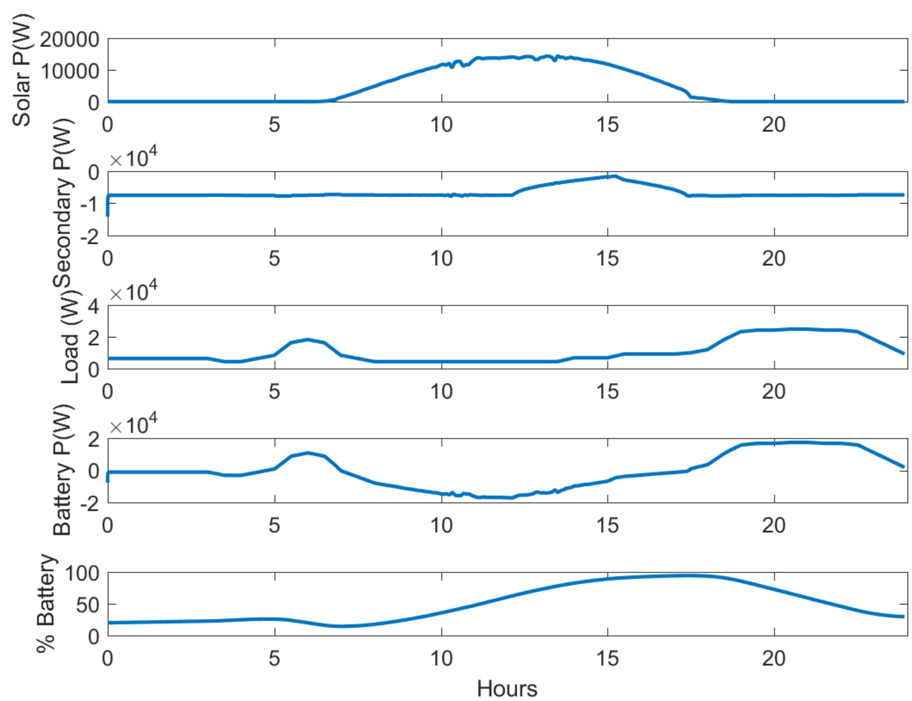
$\times 10^5$
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
Community Aggregated Load (W)
0
5
10
15
20
Hours

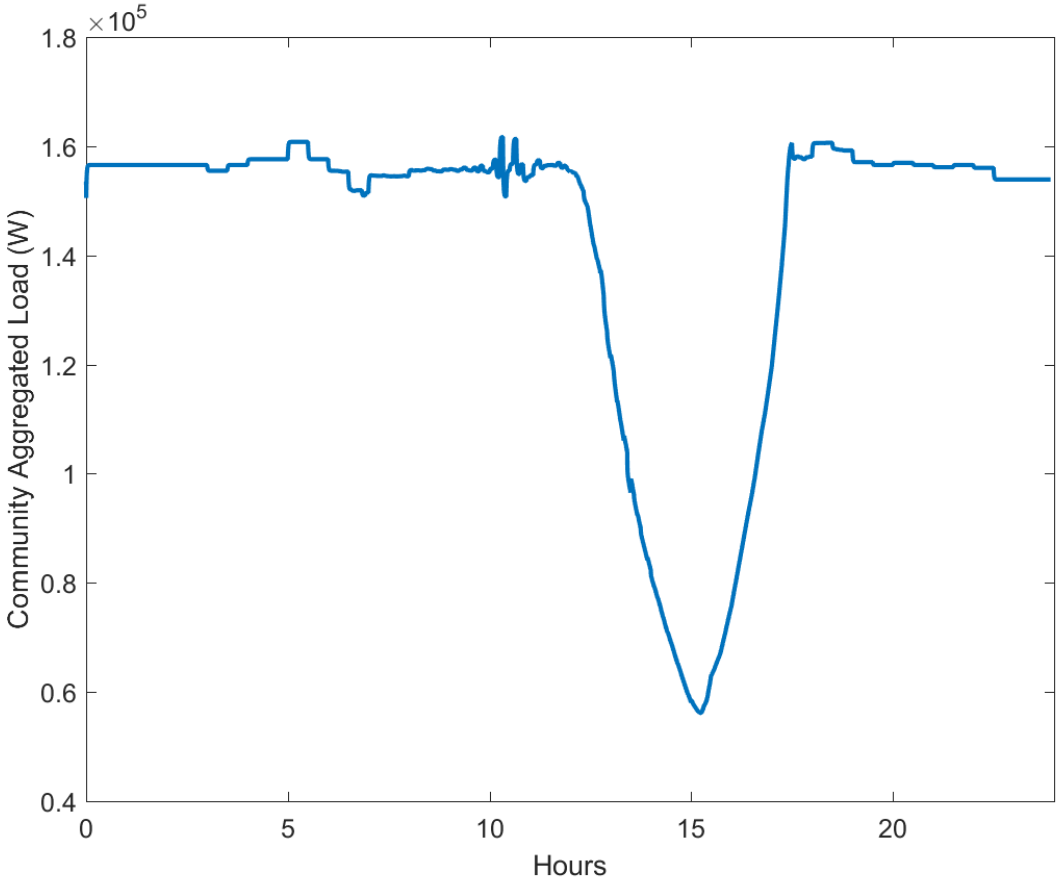


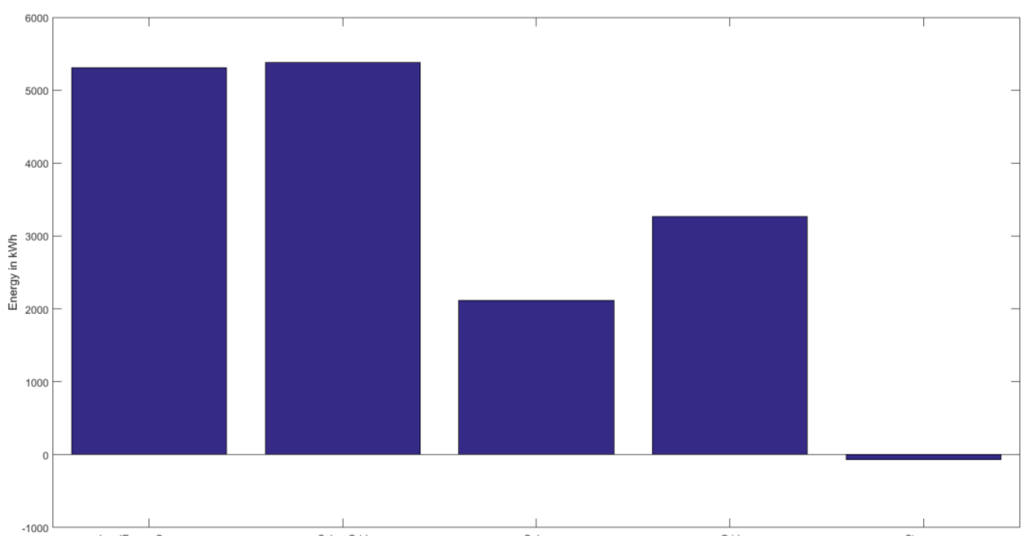
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

Case 3 Sunny

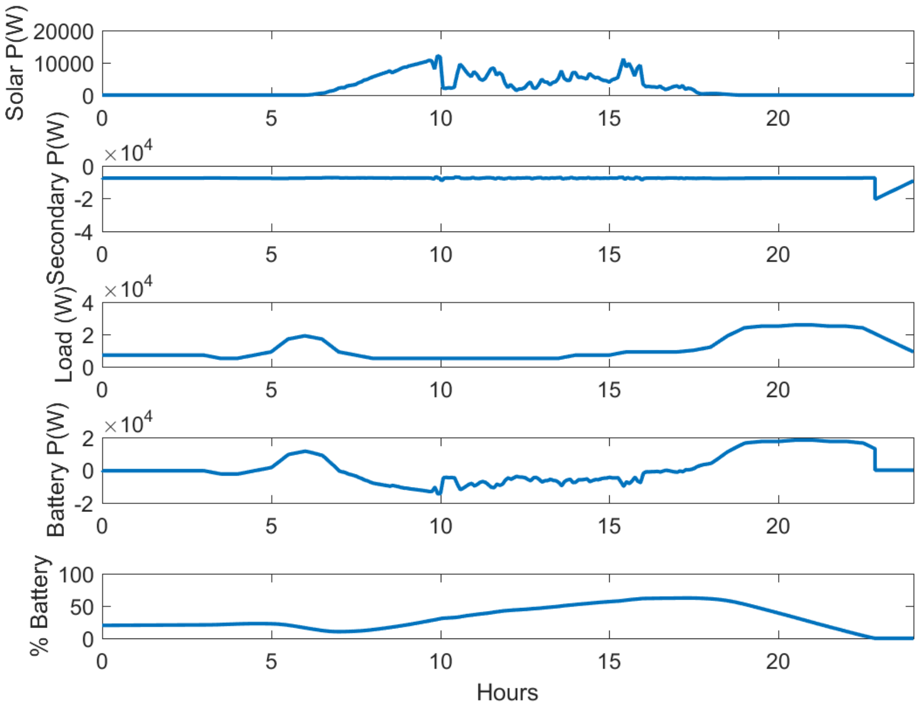

Solar P(W)
20000
10000
0
Secondary P(W)
0
-5000
-10000
Load (W)
$\times 10^4$
4
2
0
Battery P(W)
$\times 10^4$
2
0
-2
% Battery
100
50
0
0
5
10
15
20
Hours

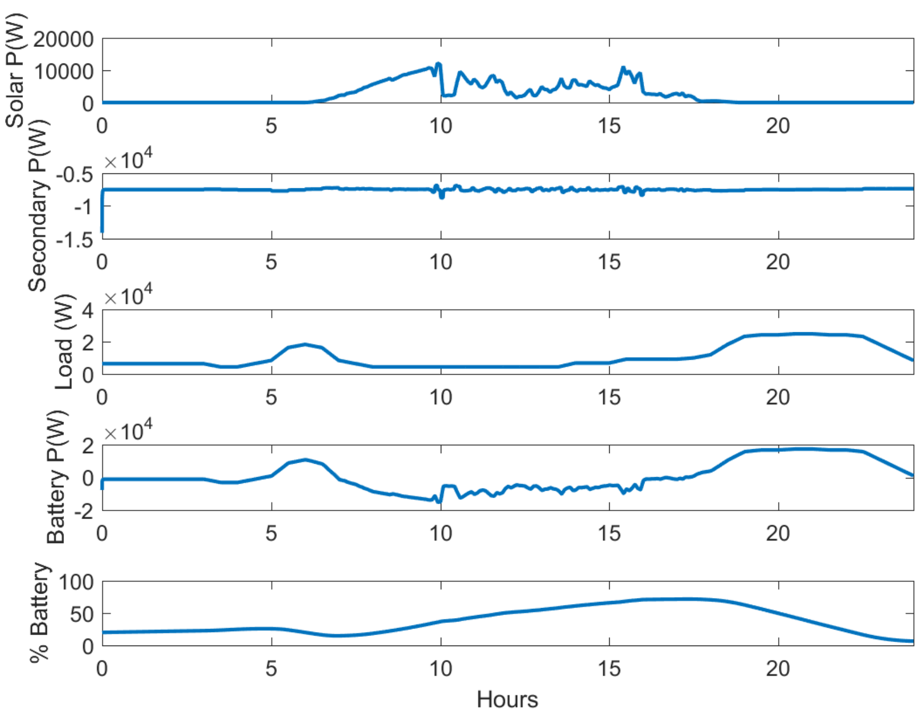

Solar P(W)
20000
10000
0
Secondary P(W)
$\times 10^4$
0
-1
-2
Load (W)
$\times 10^4$
4
2
0
Battery P(W)
$\times 10^4$
2
0
-2
% Battery
100
50
0
0
5
10
15
20
Hours

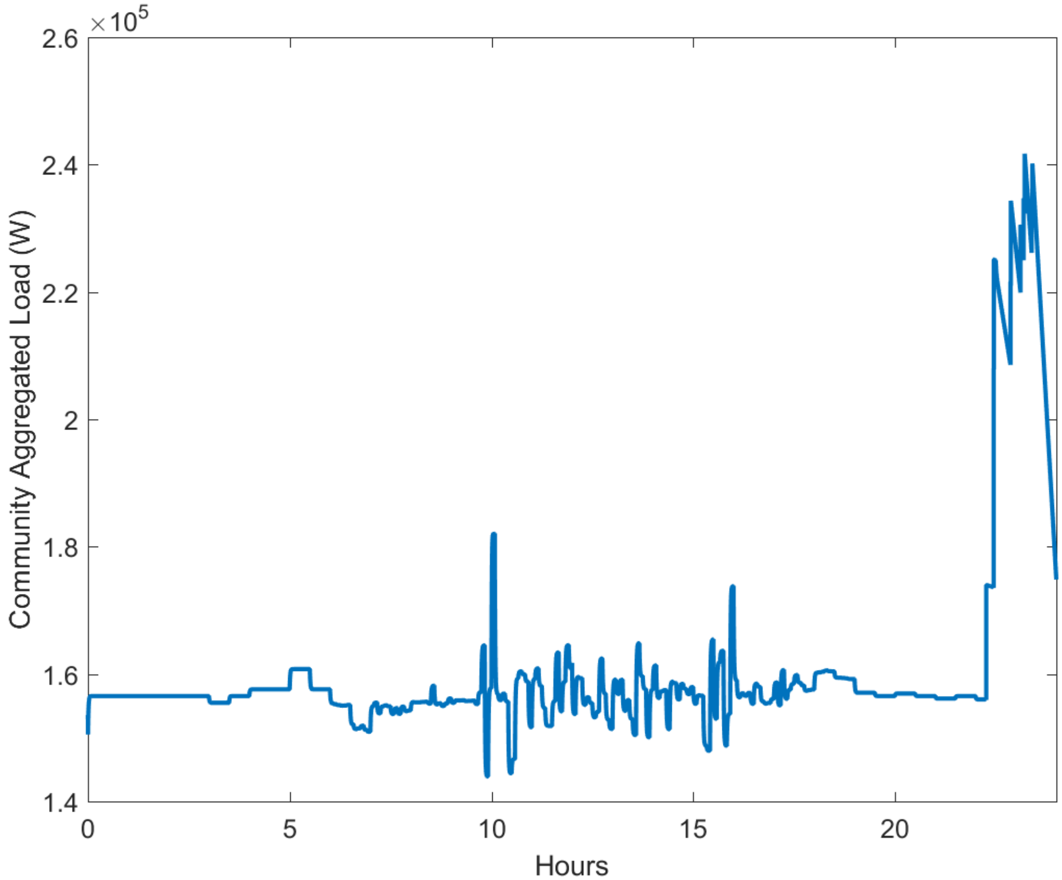

×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0
5
10
15
20
Hours
Community Aggregated Load (W)

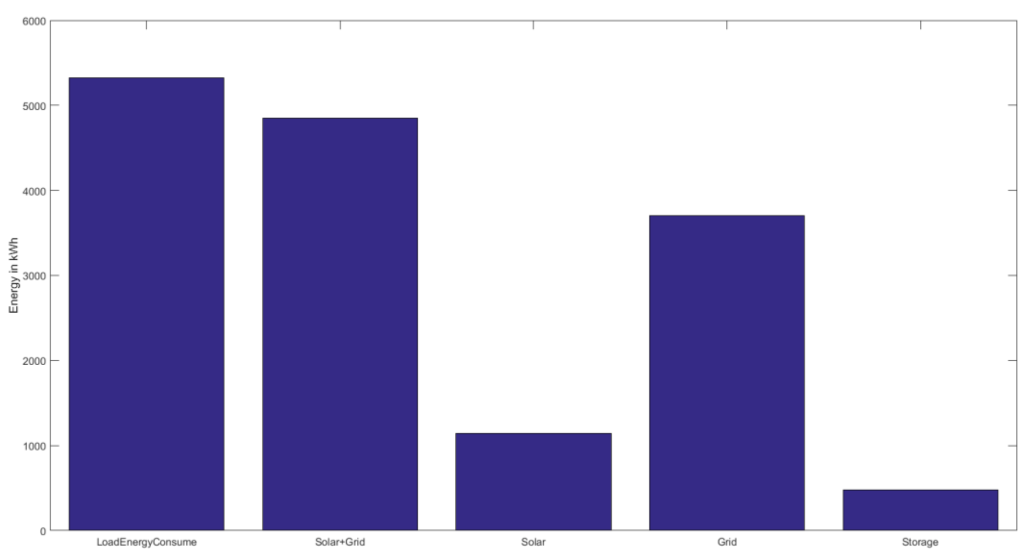

6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

Case 3 Cloudy

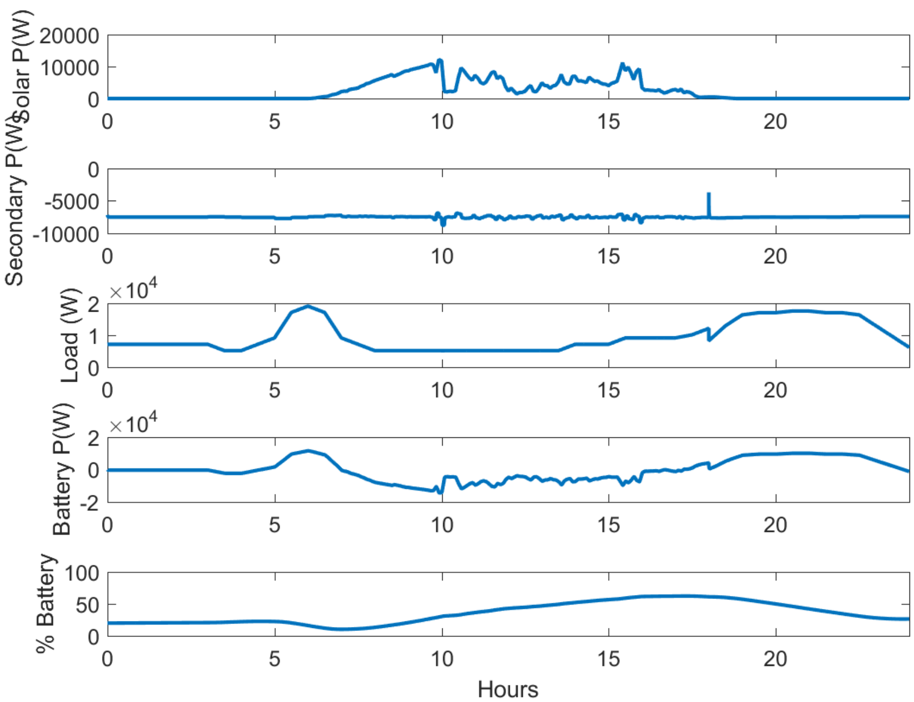


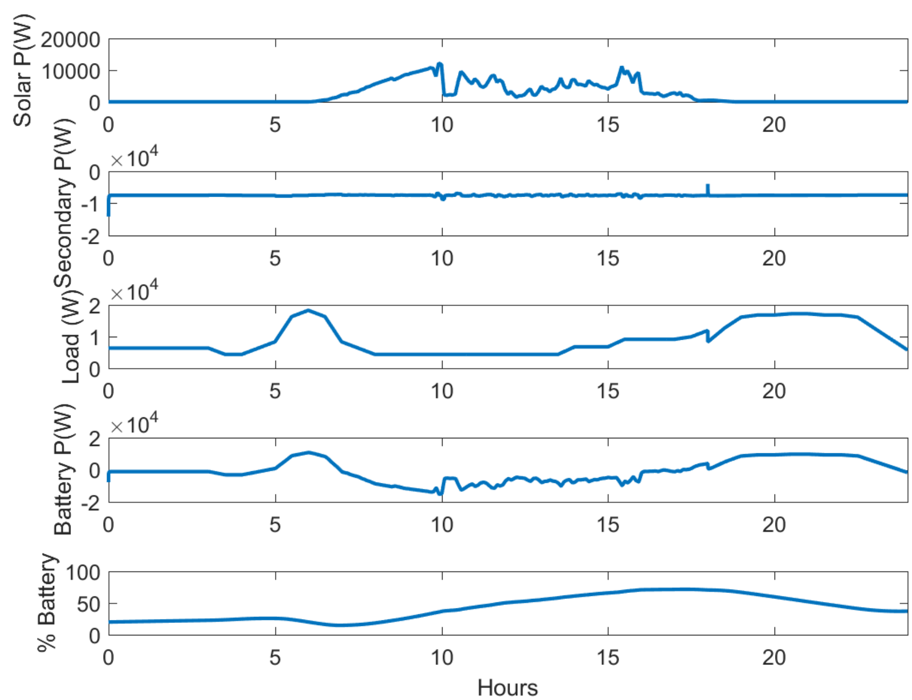



×10^5
2.6
2.4
2.2
2
1.8
1.6
1.4
Community Aggregated Load (W)
0
5
10
15
20
Hours

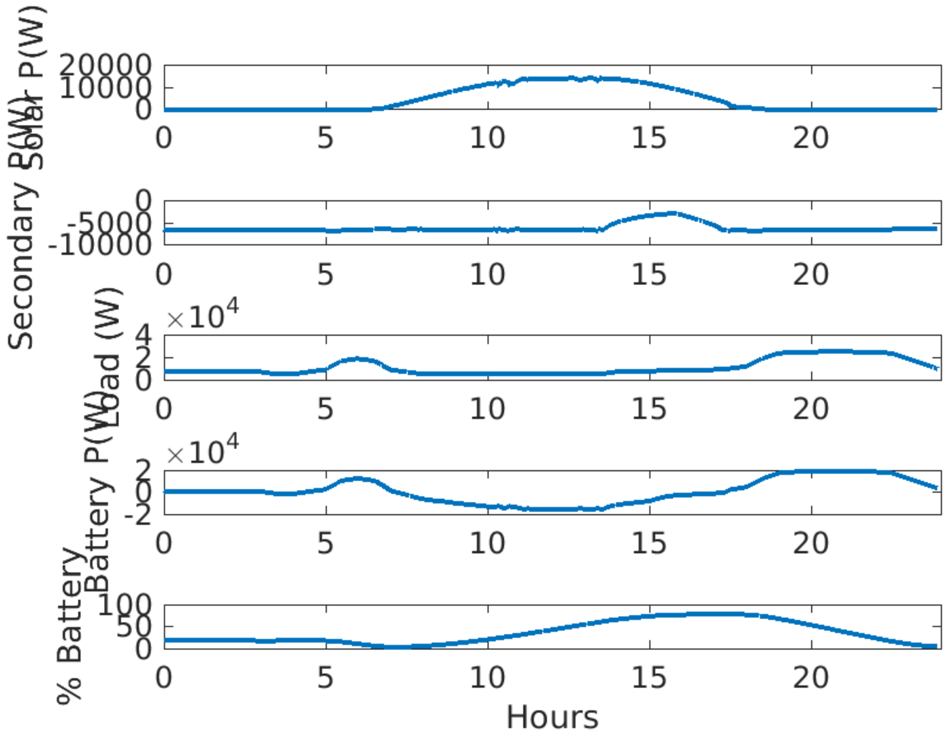

6000
5000
4000
3000
2000
1000
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

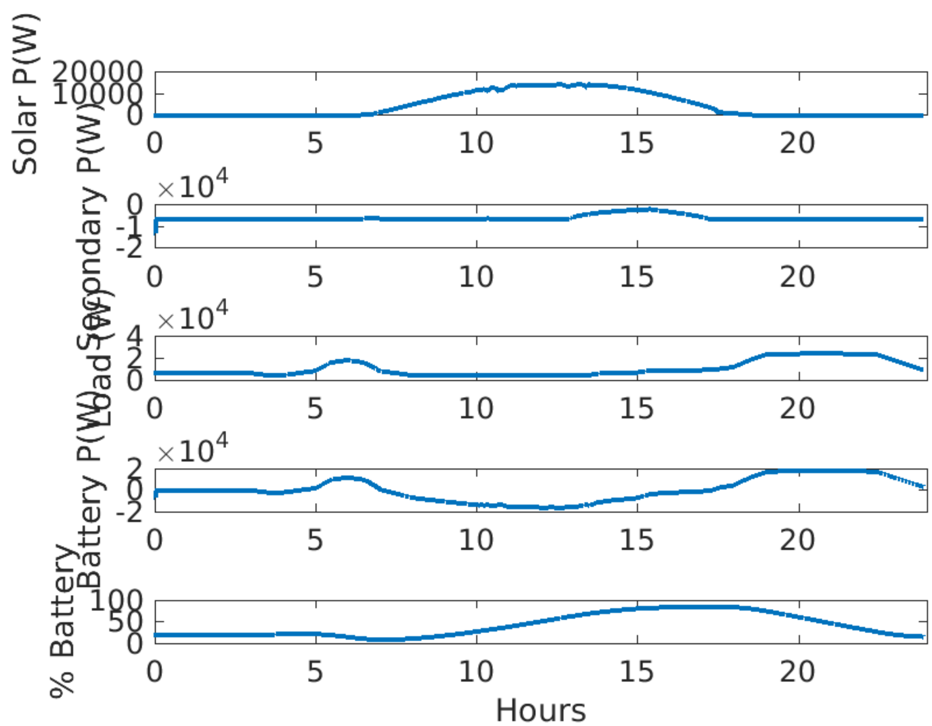
Case 3 Cloudy DR

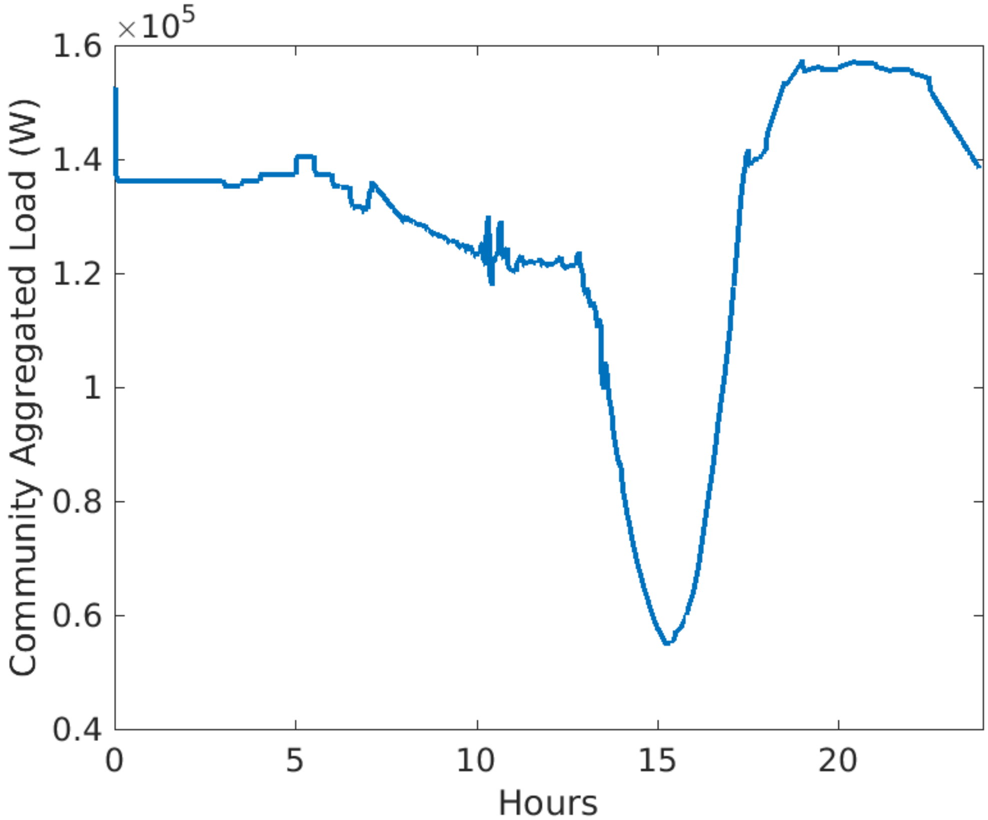


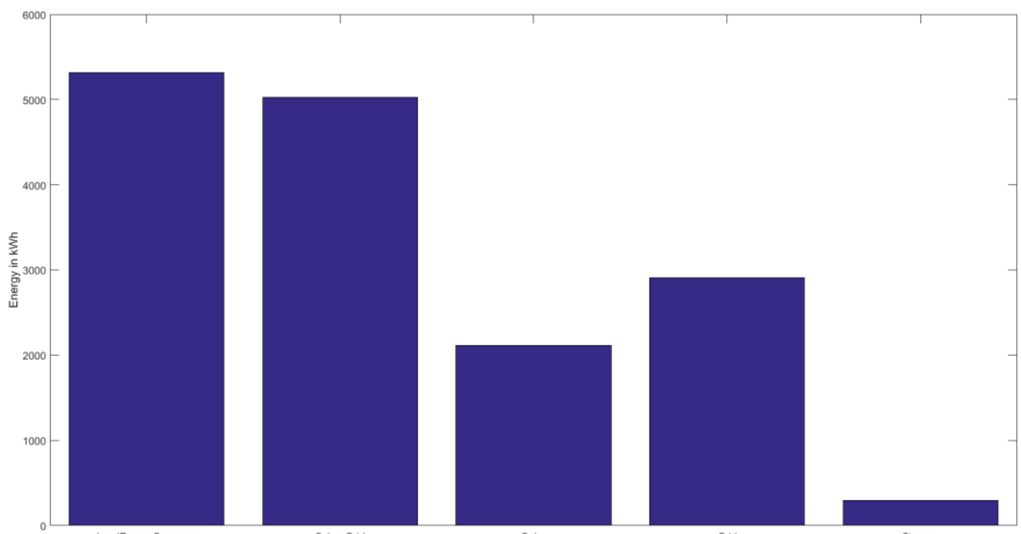


Case 4 Sunny

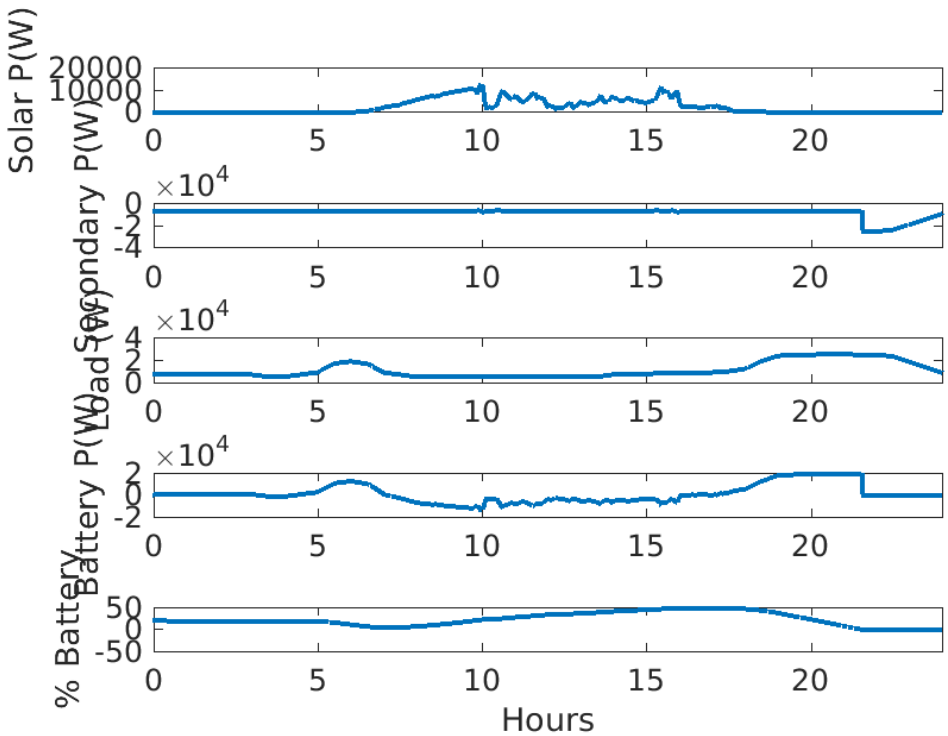

Solar P(W)
Secondary P(W)
Load (W)
Battery P(W)
% Battery
Hours

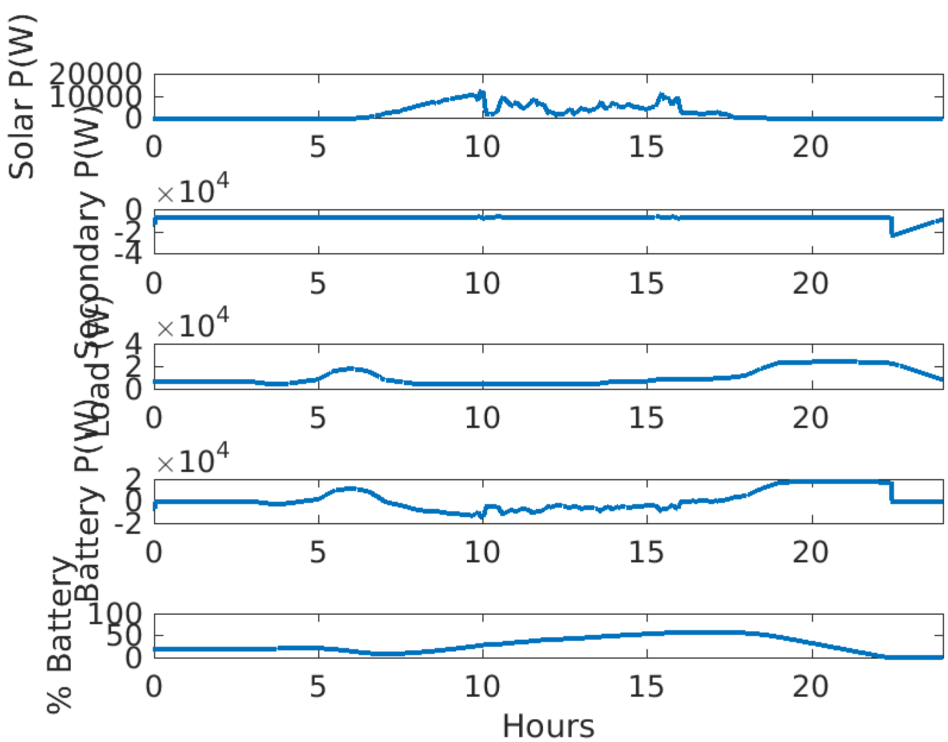

Solar P(W)
Secondary P(W)
Load (W)
Battery P(W)
% Battery
Hours

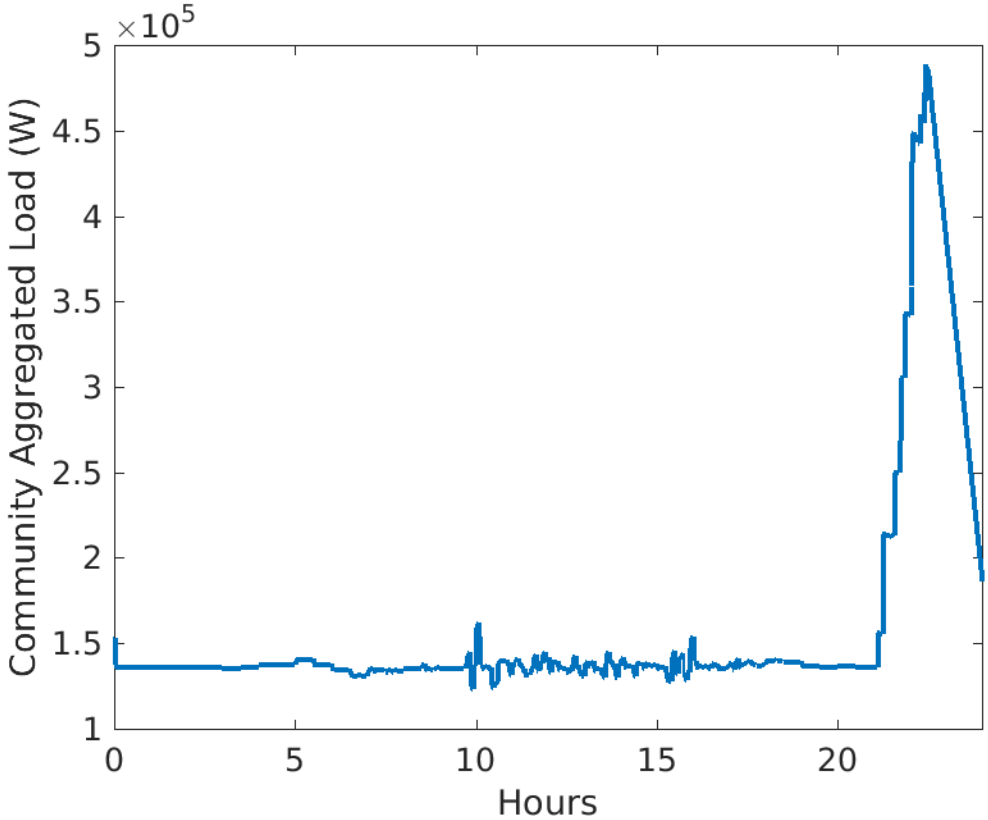

×10^5
1.6
1.4
1.2
1
0.8
0.6
0.4
Community Aggregated Load (W)
0
5
10
15
20
Hours


6000
5000
4000
3000
2000
1000
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

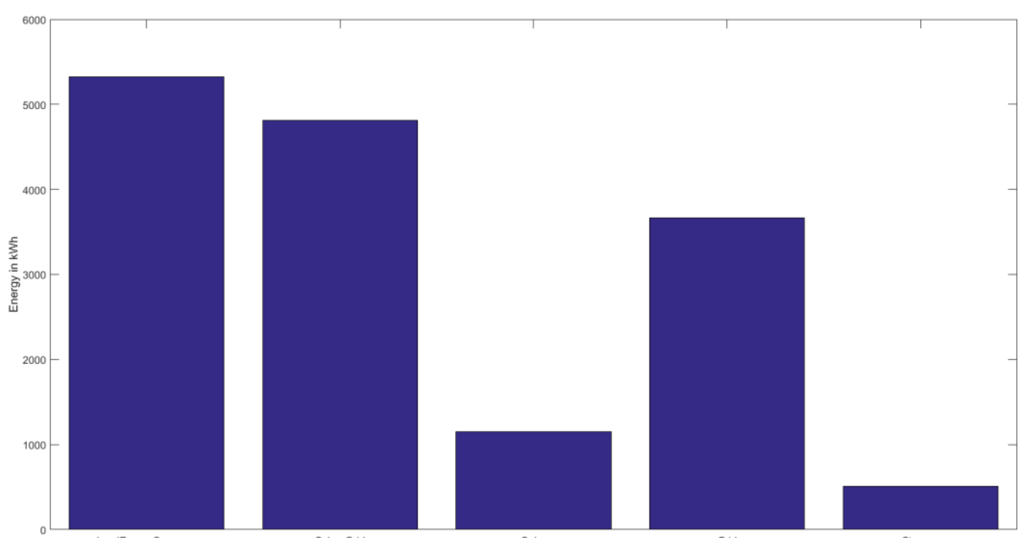
Case 4 Cloudy





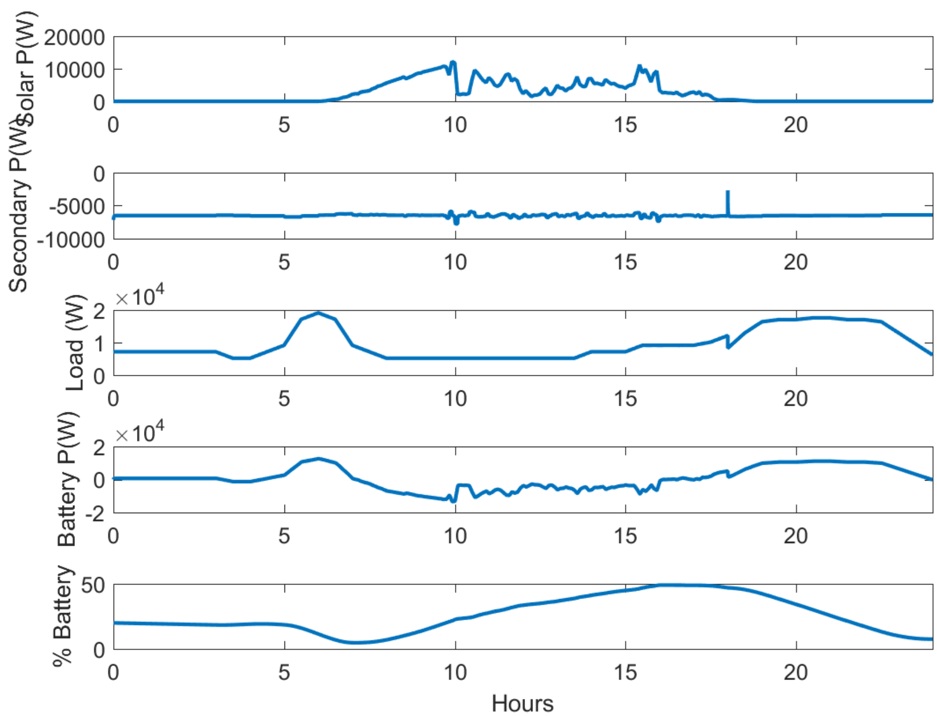


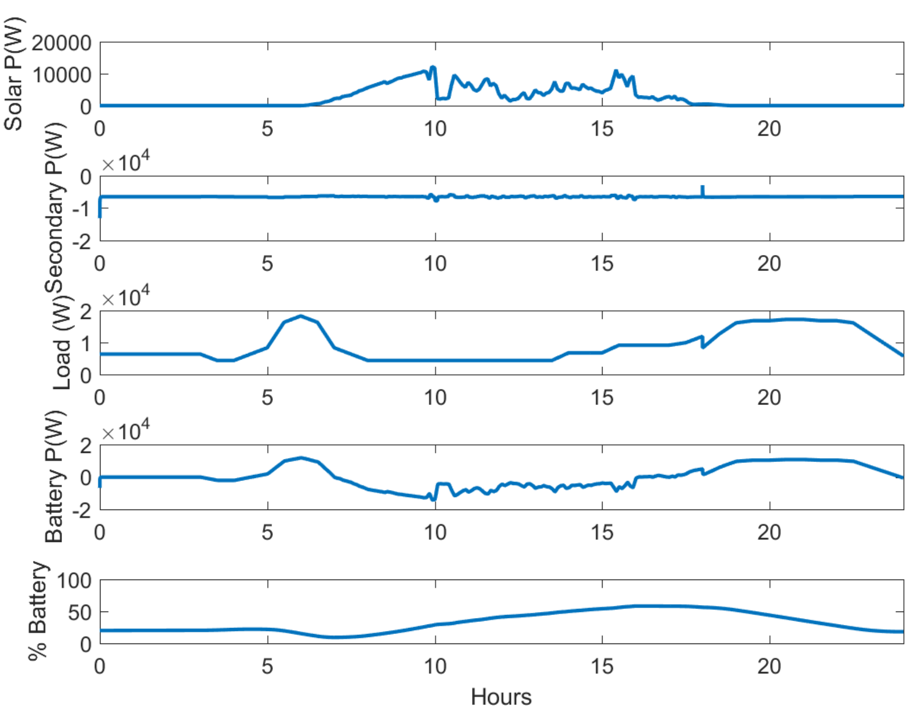
$\times 10^5$
Community Aggregated Load (W)
Hours

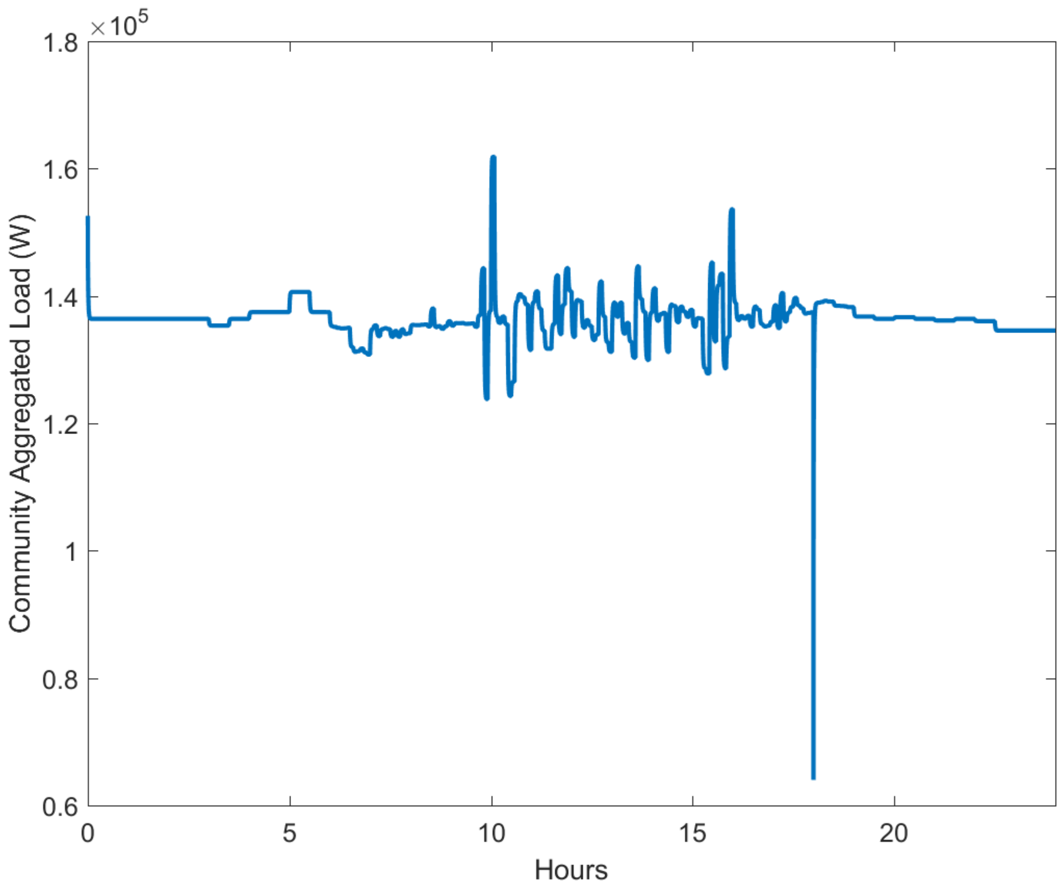


Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

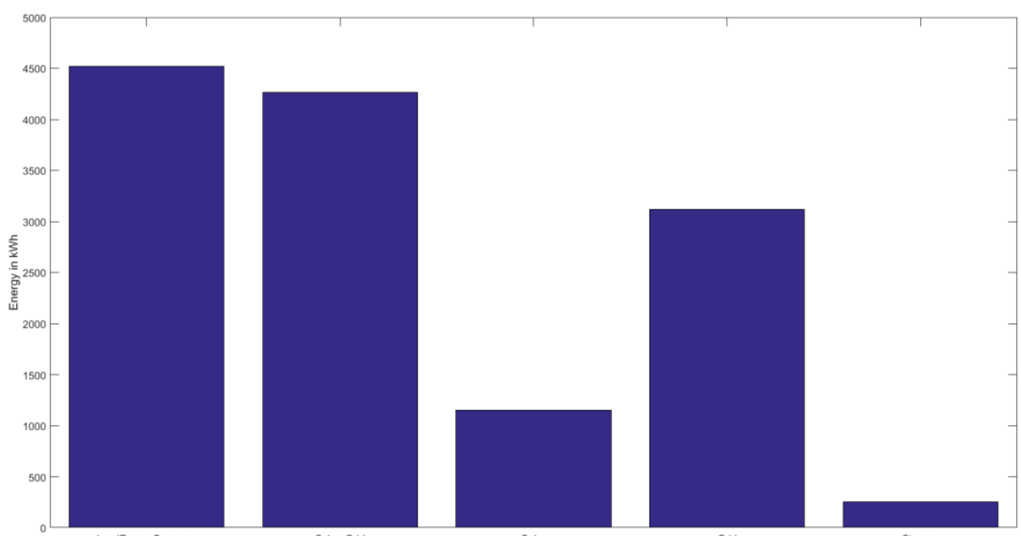
Case 4 Cloudy DR





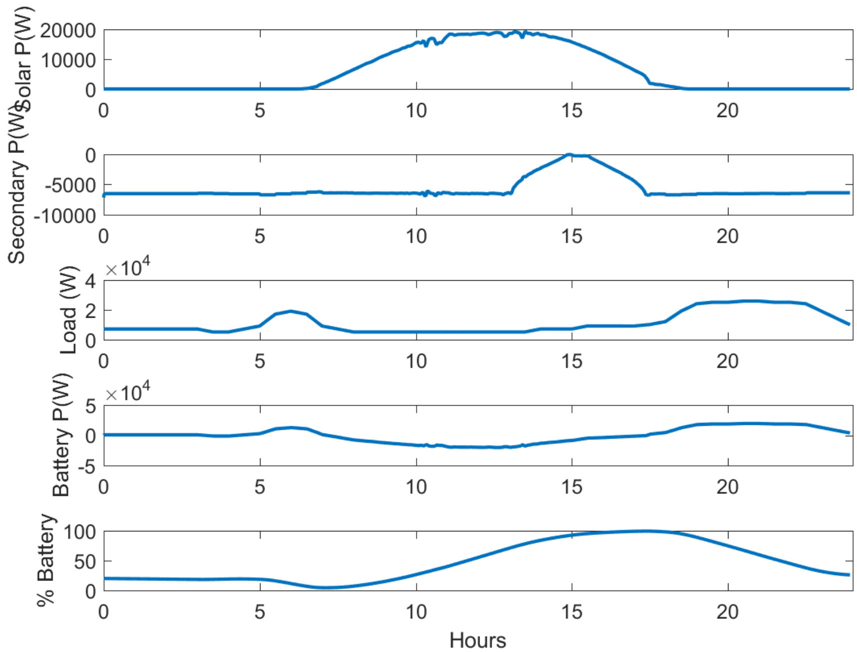


×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
Community Aggregated Load (W)
0
5
10
15
20
Hours

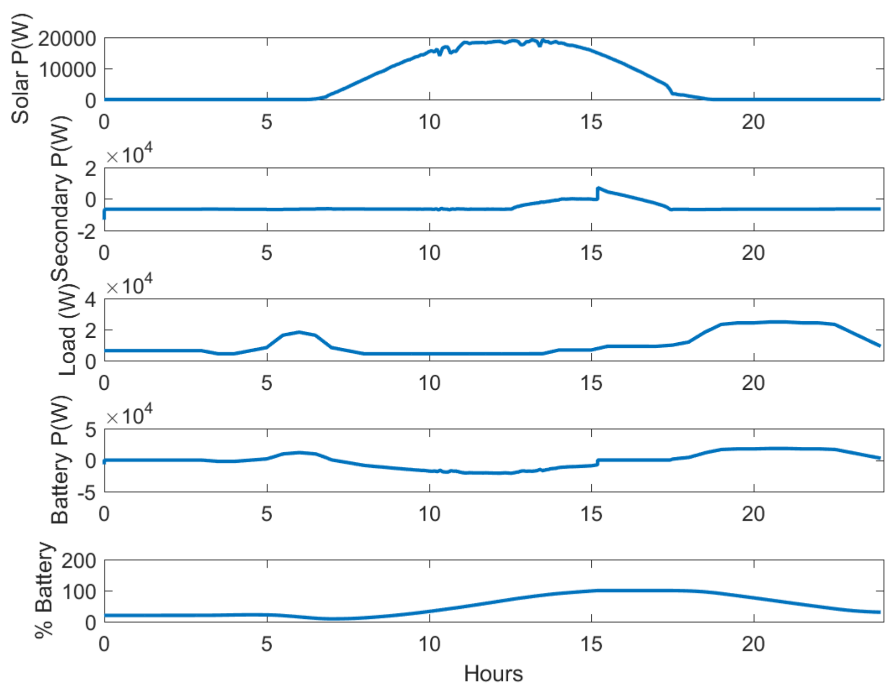


5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

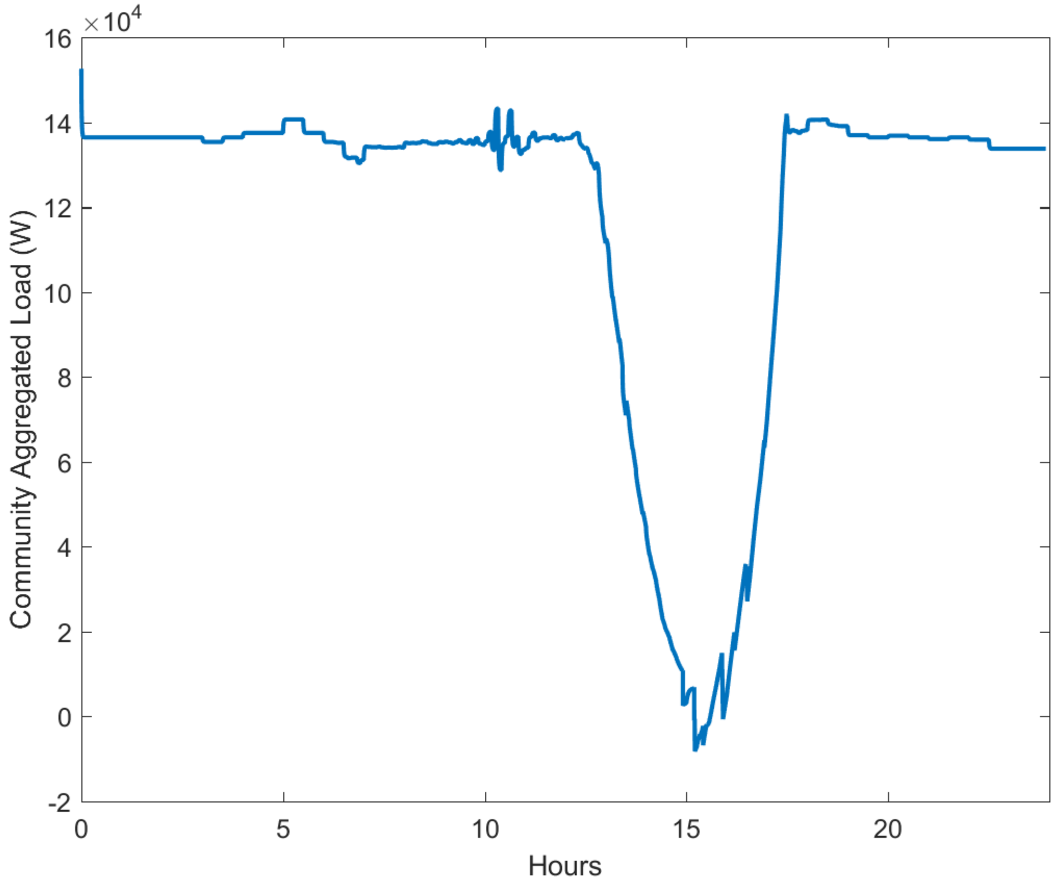
Case 5 Sunny

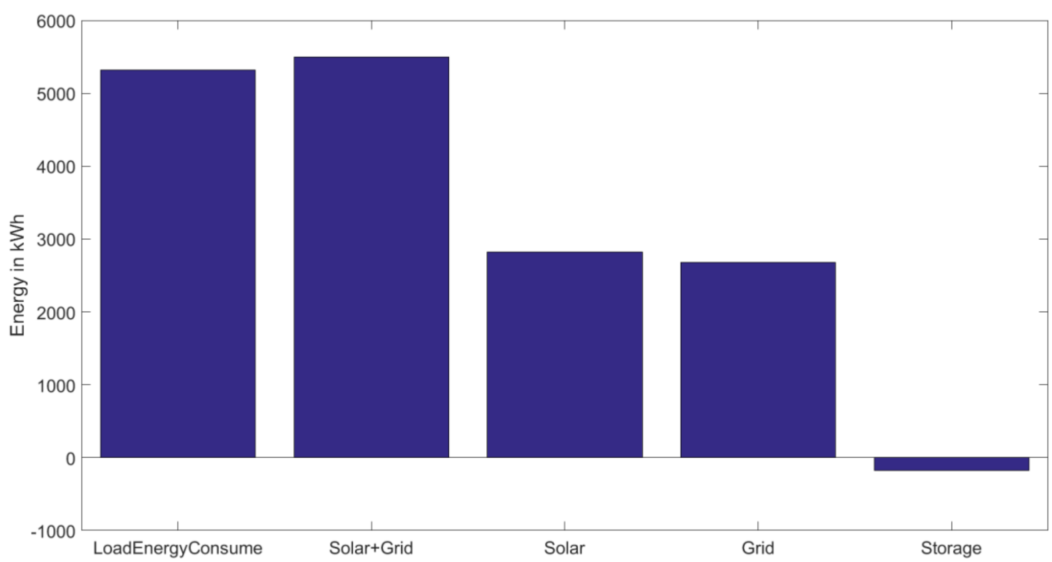


Solar P(W)
20000
10000
0
0
5
10
15
20
Secondary P(W)
0
-5000
-10000
$\times 10^4$
Load (W)
4
2
0
Battery P(W)
5
-5
% Battery
100
50
Hours

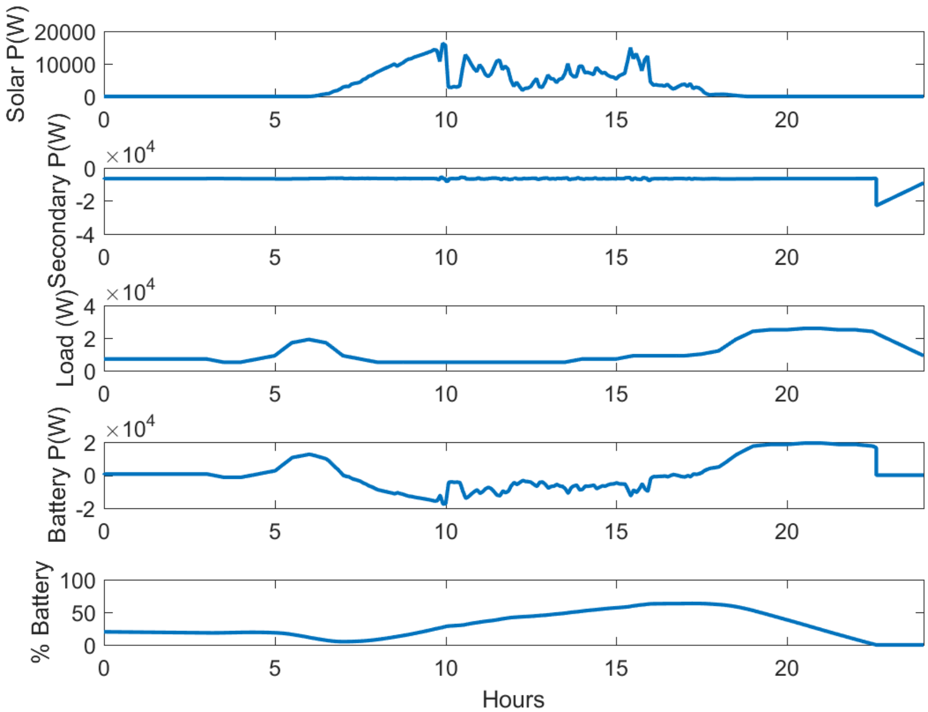


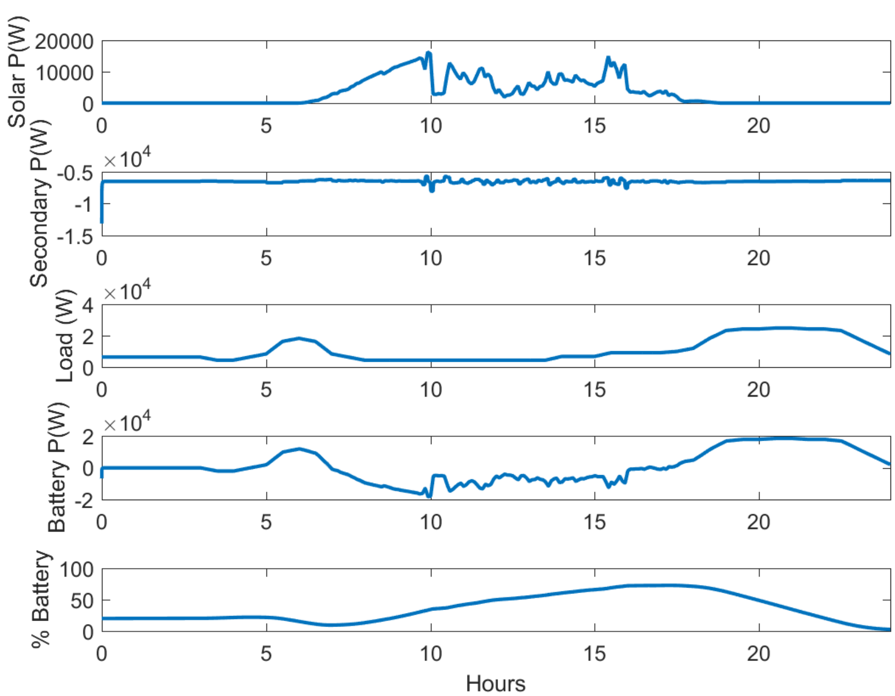
Solar P(W)
20000
10000
0
0
5
10
15
20
$\times 10^4$
Secondary P(W)
2
0
-2
Load (W)
4
Battery P(W)
5
-5
% Battery
200
100
Hours

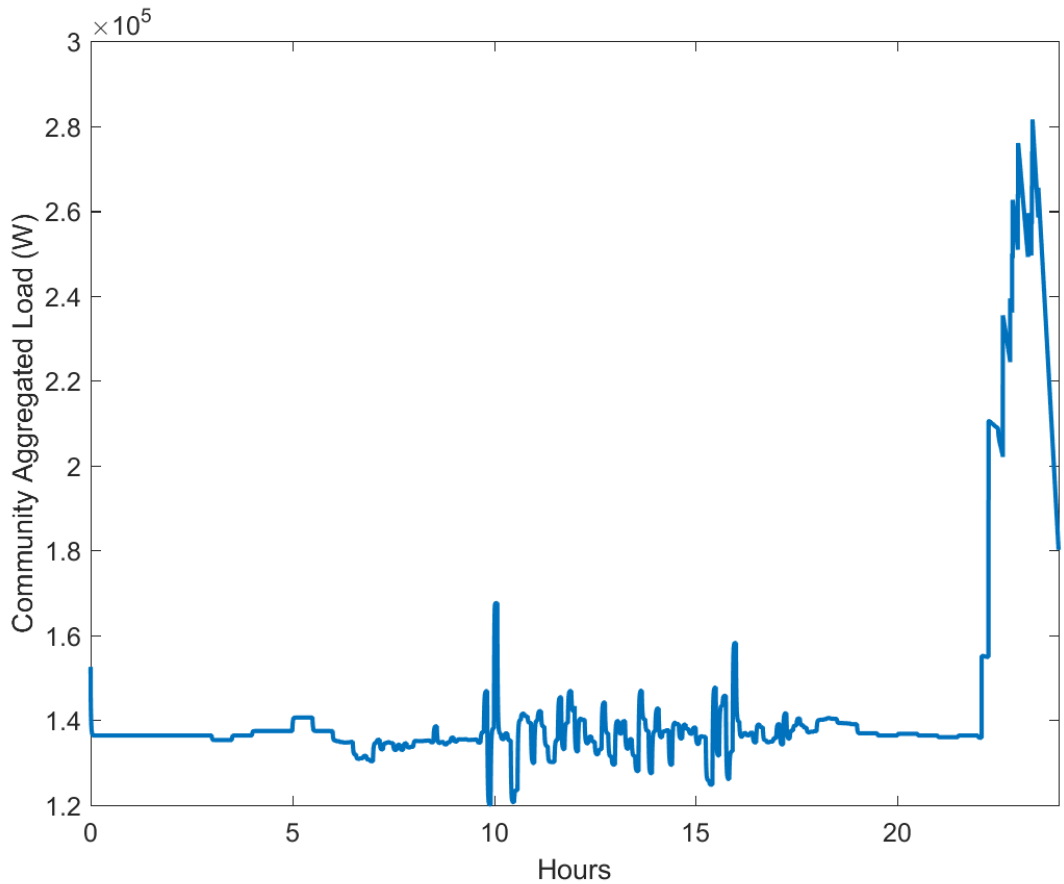

×10^4
16
14
12
10
8
6
4
2
0
-2
0
5
10
15
20
Community Aggregated Load (W)
Hours


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

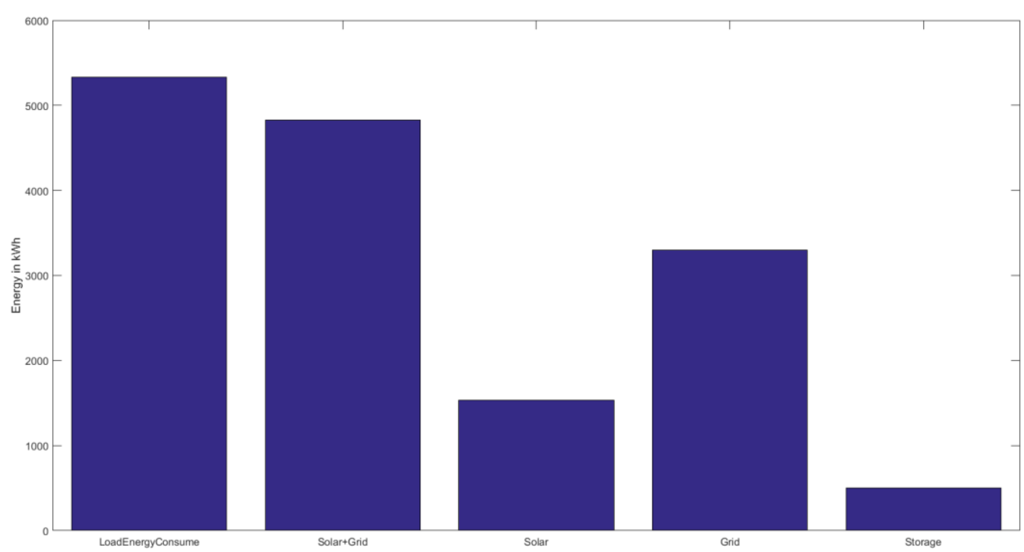
Case 5 Cloudy





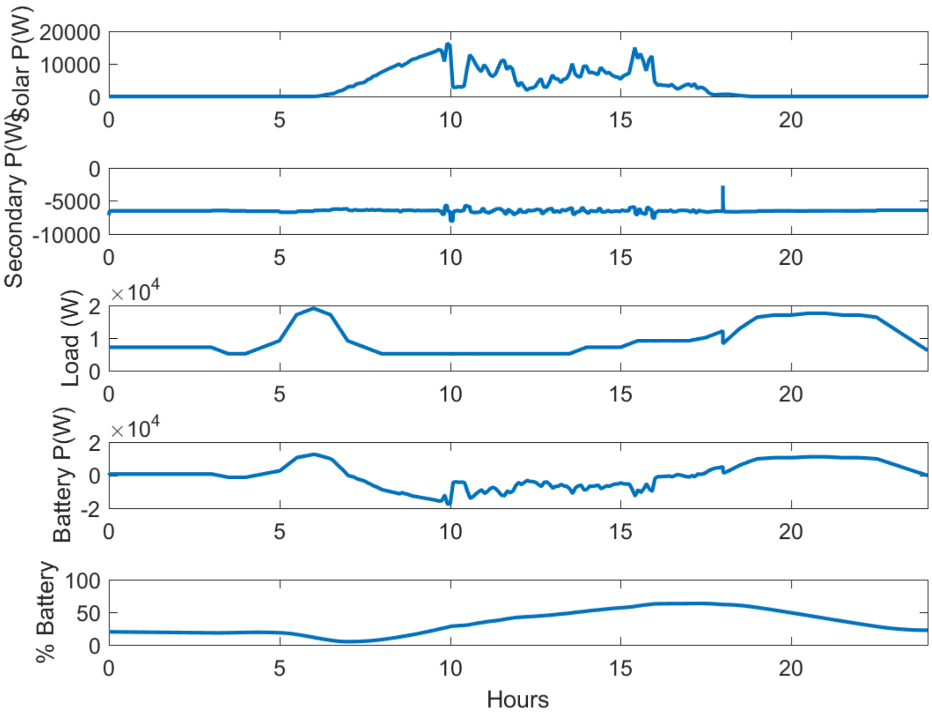


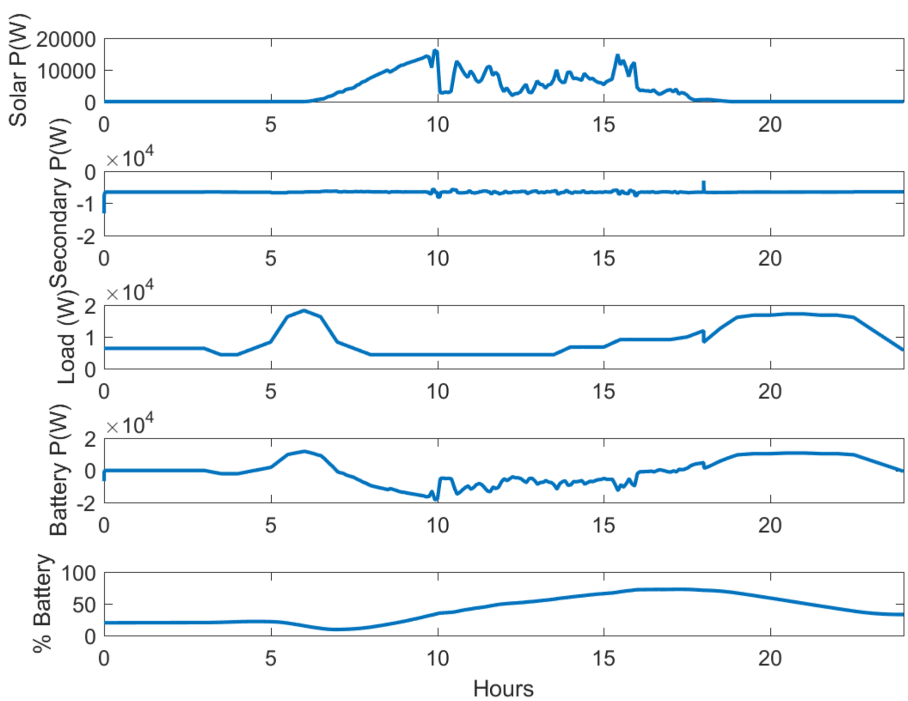
$\times 10^5$
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
Community Aggregated Load (W)
0
5
10
15
20
Hours

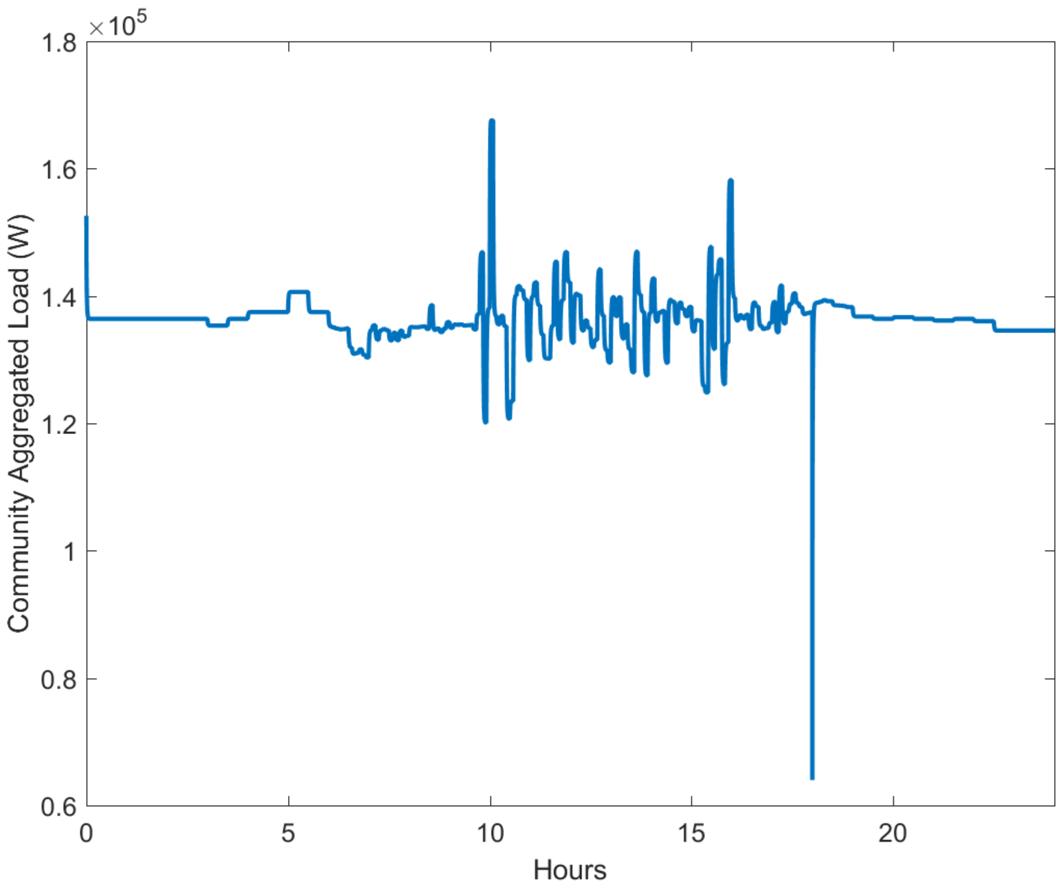


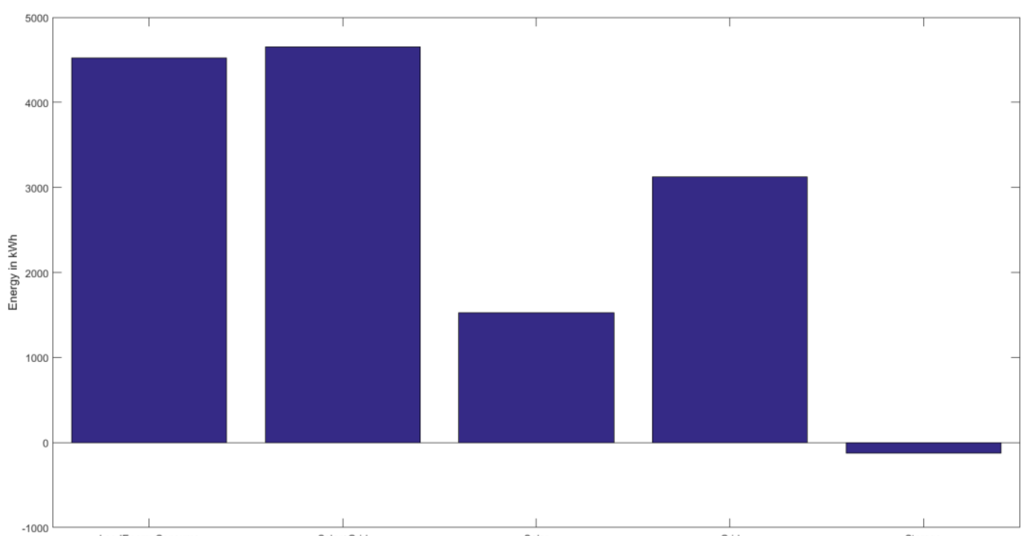
6000
5000
4000
3000
2000
1000
0
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

Case 5 Cloudy DR

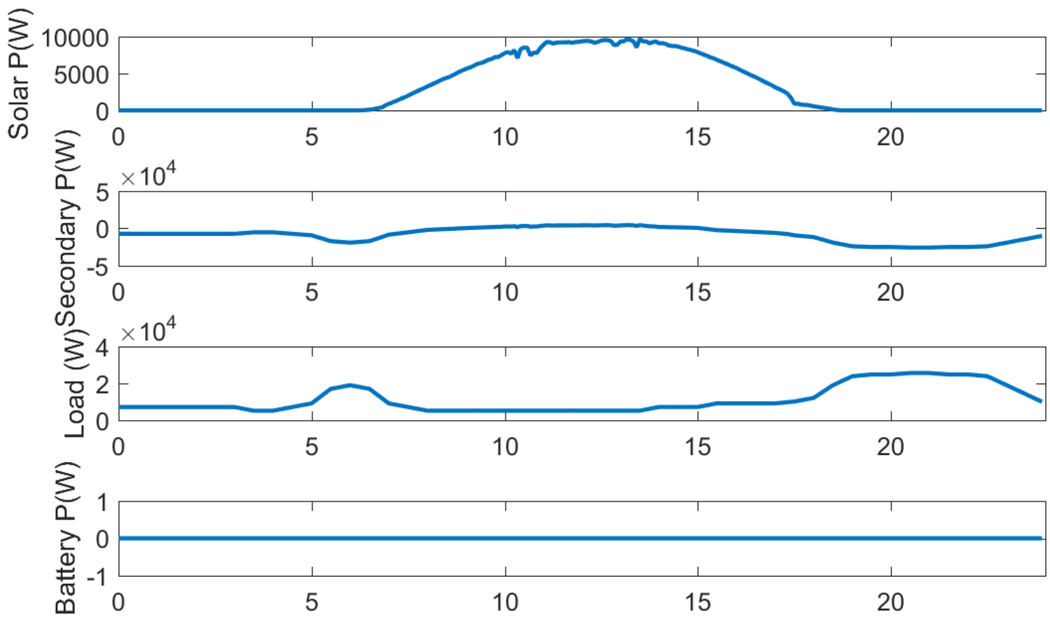


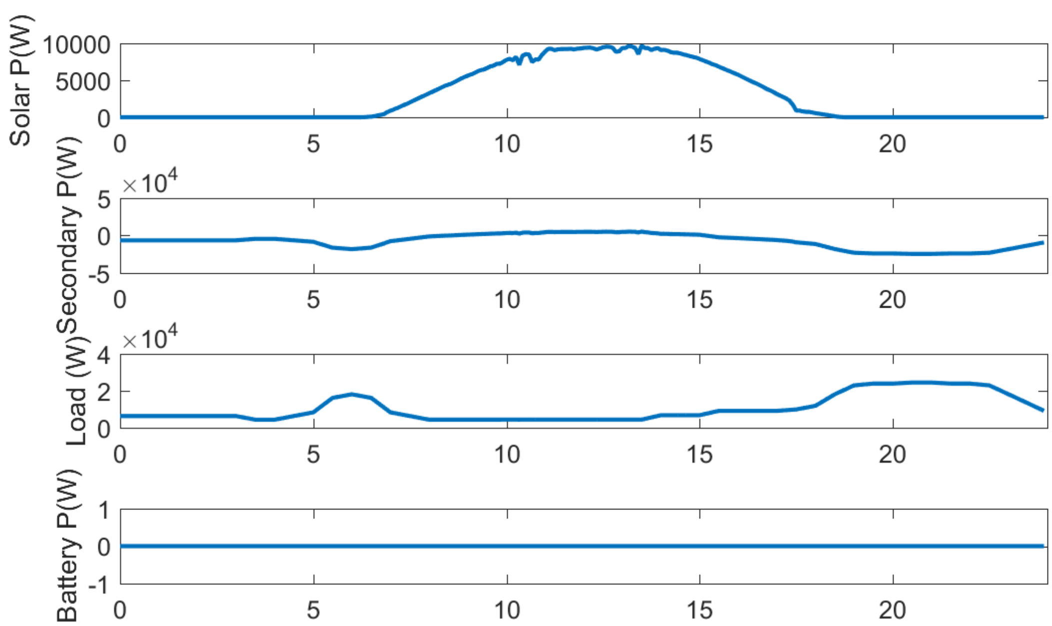


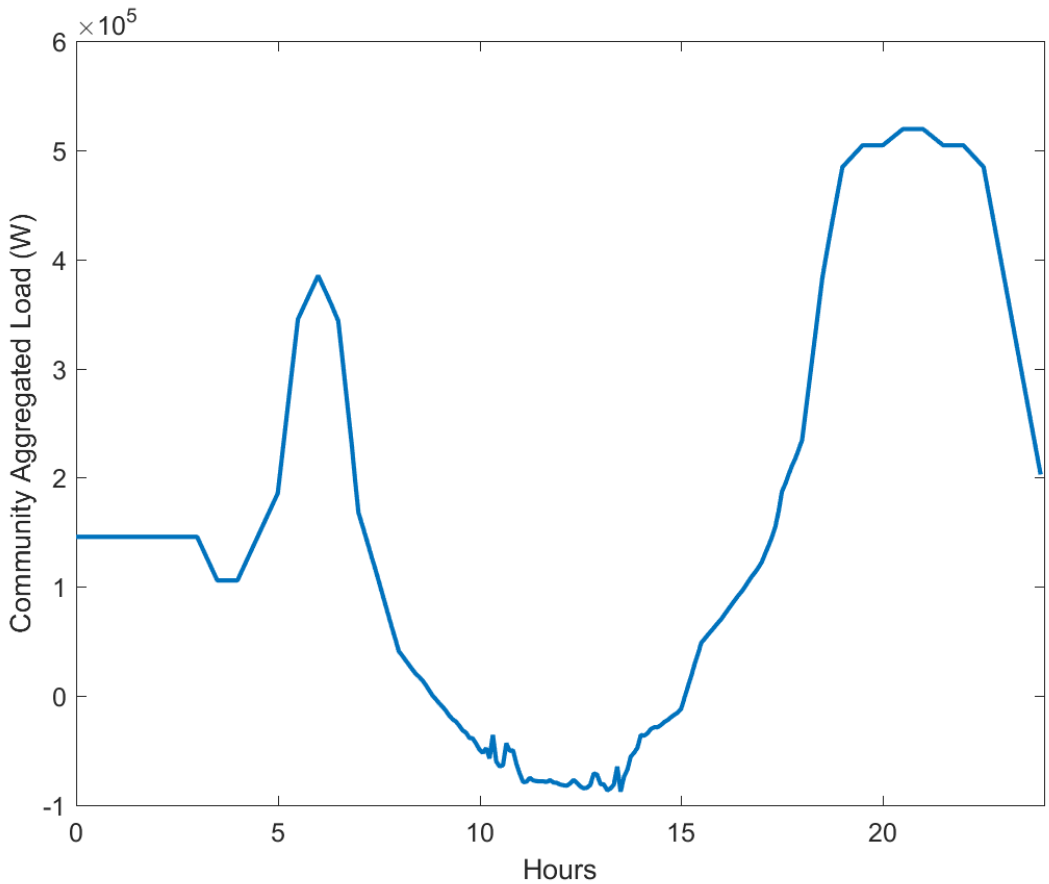

×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
Community Aggregated Load (W)
0
5
10
15
20
Hours


5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

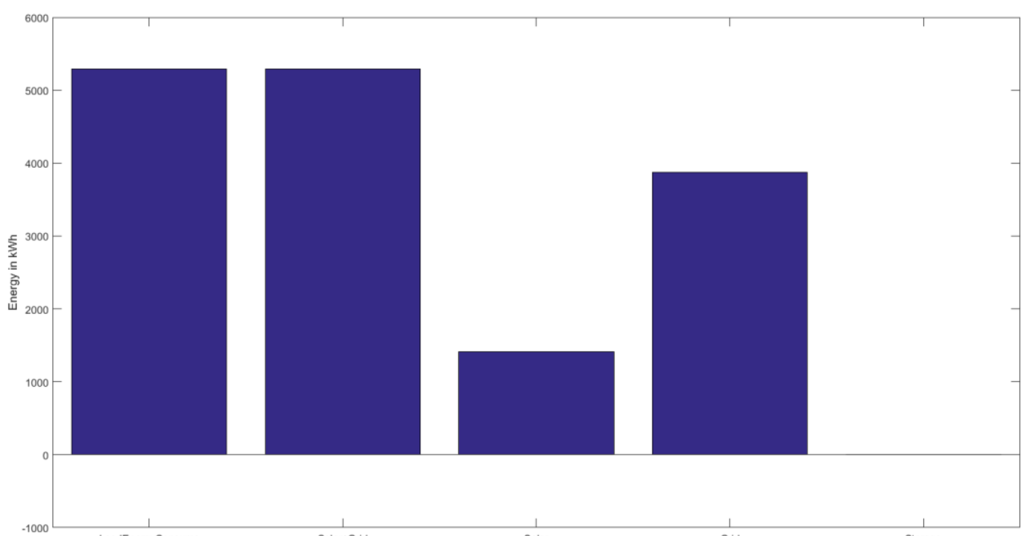
Case 6 Sunny


Solar P(W)
10000
5000
0
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1
0
5
10
15
20


Solar P(W)
10000
5000
0
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1
0
5
10
15
20

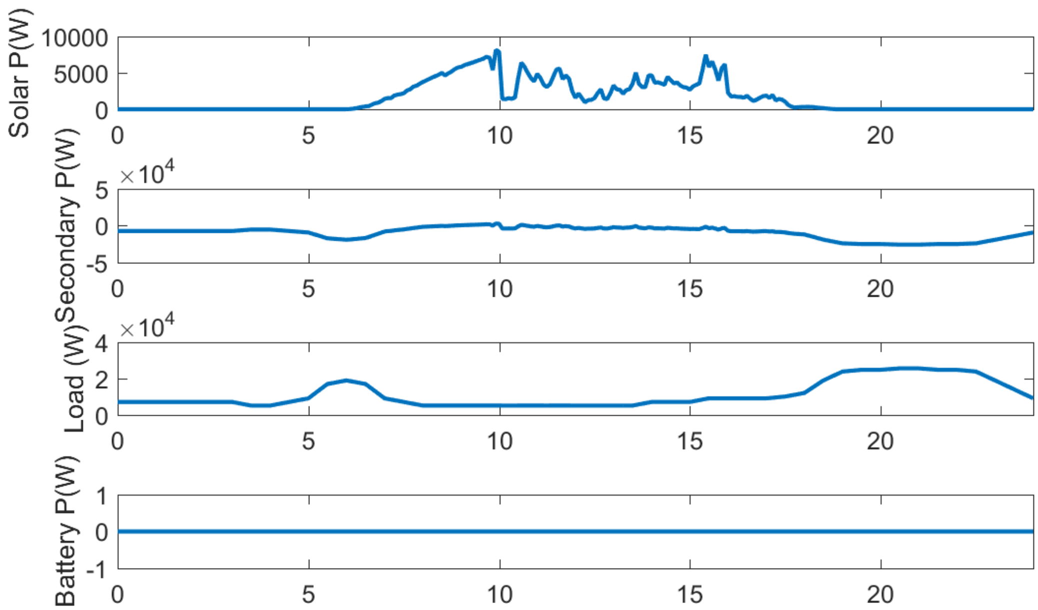


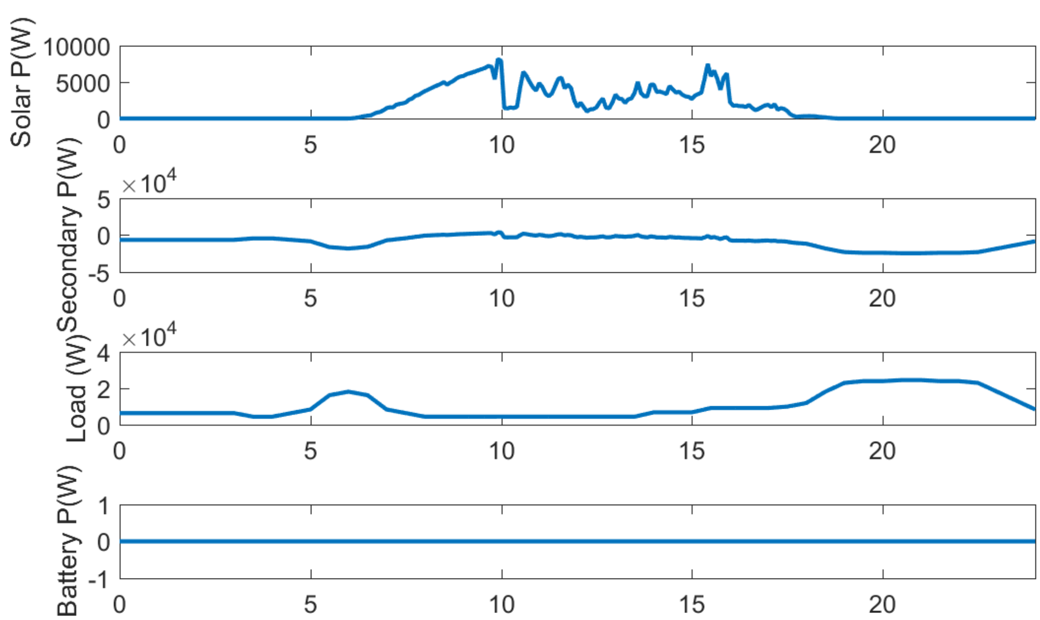
×10^5
6
5
4
3
2
1
0
-1
Community Aggregated Load (W)
0
5
10
15
20
Hours

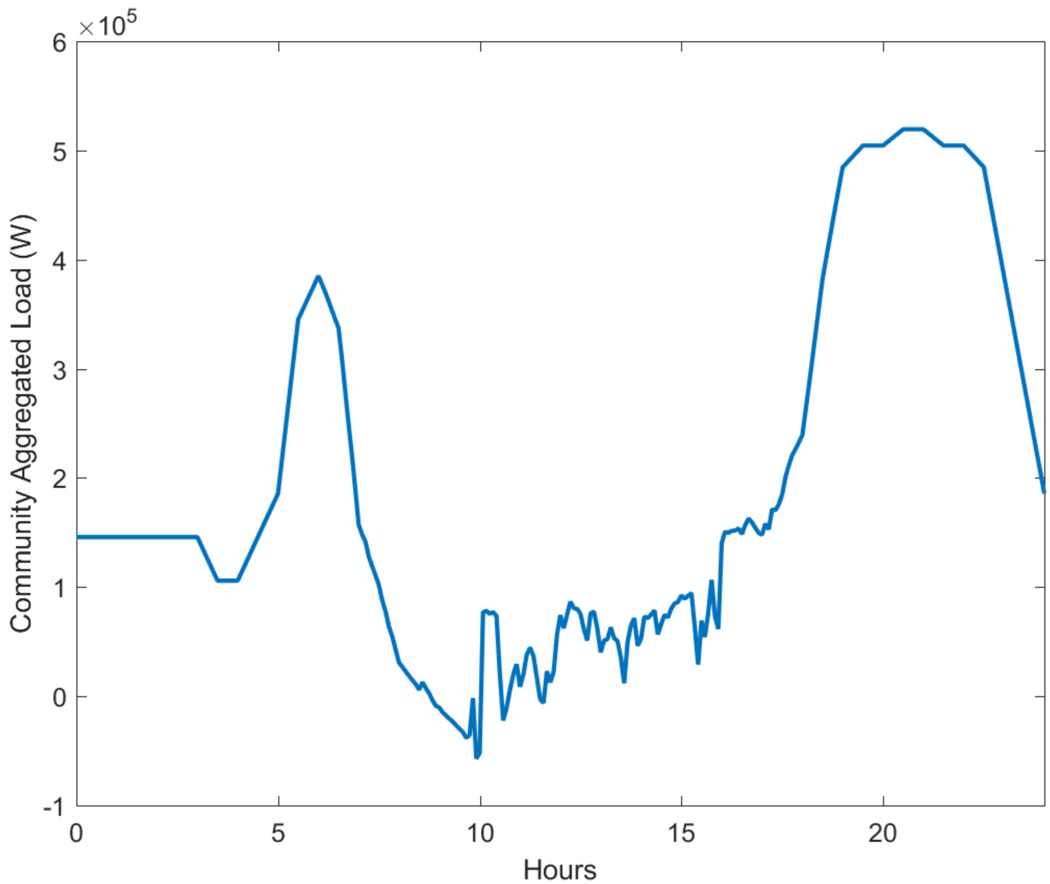


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

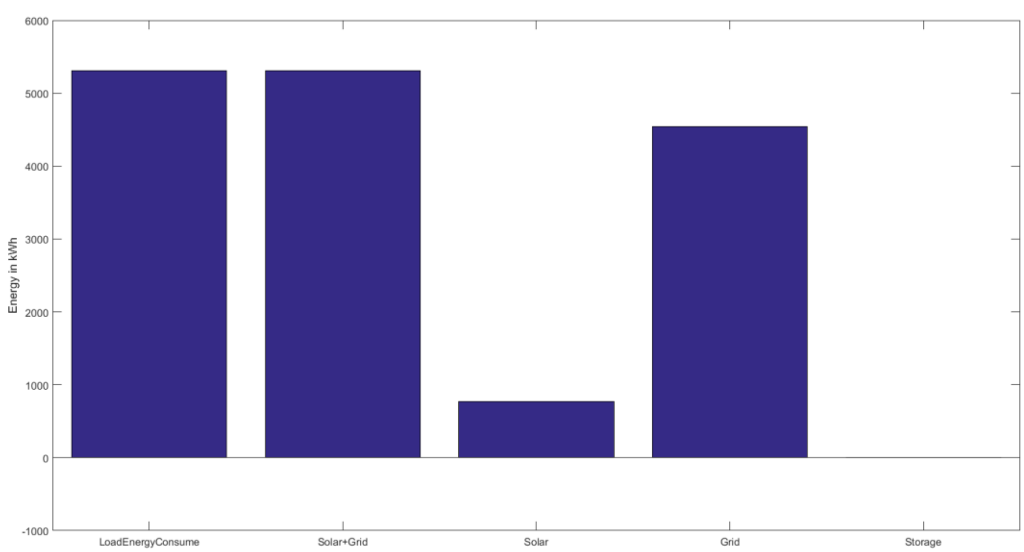
Case 6 Cloudy





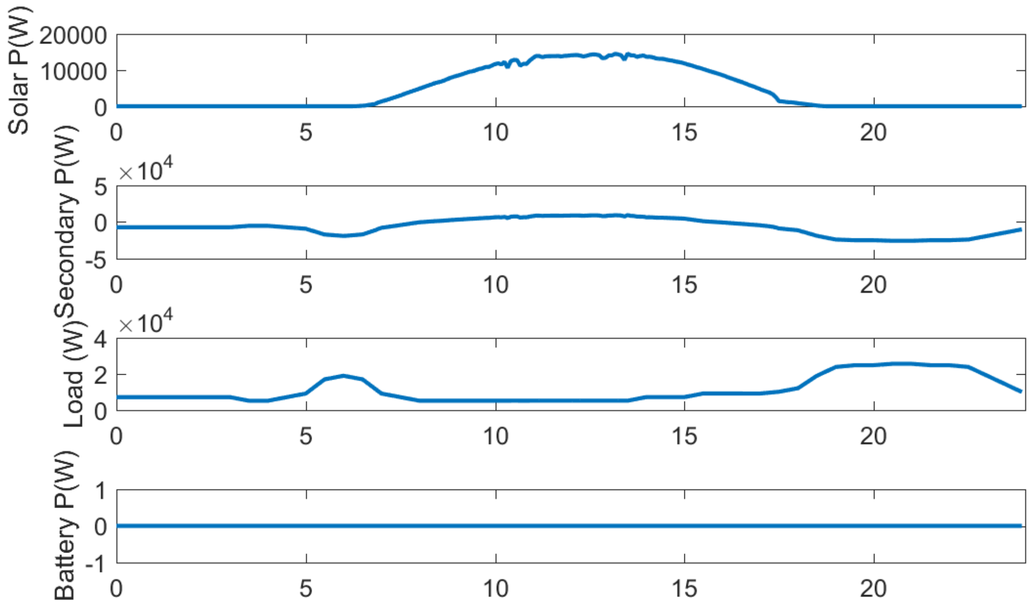


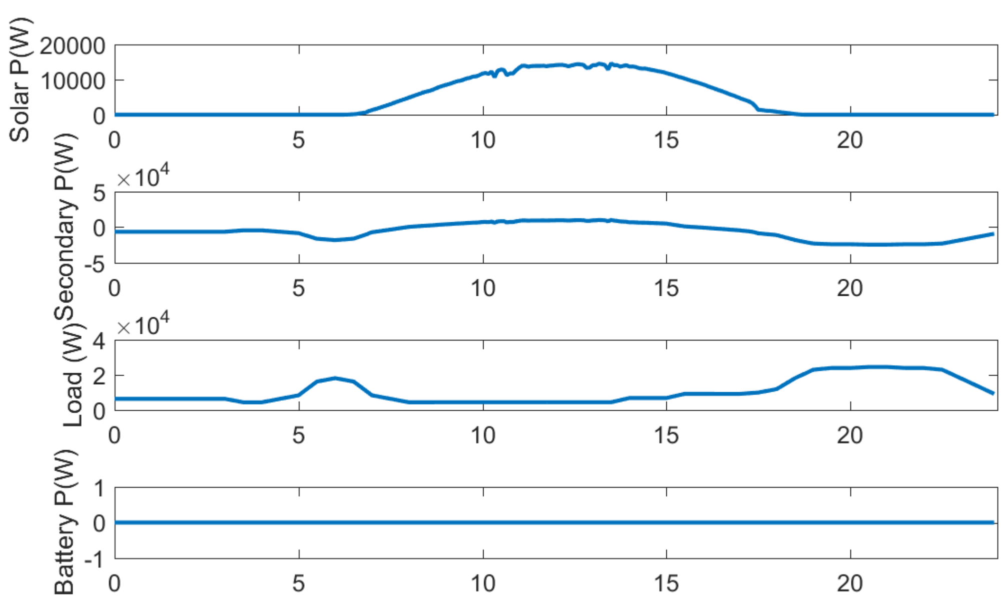
×10^5
6
5
4
3
2
1
0
-1
Community Aggregated Load (W)
0
5
10
15
20
Hours

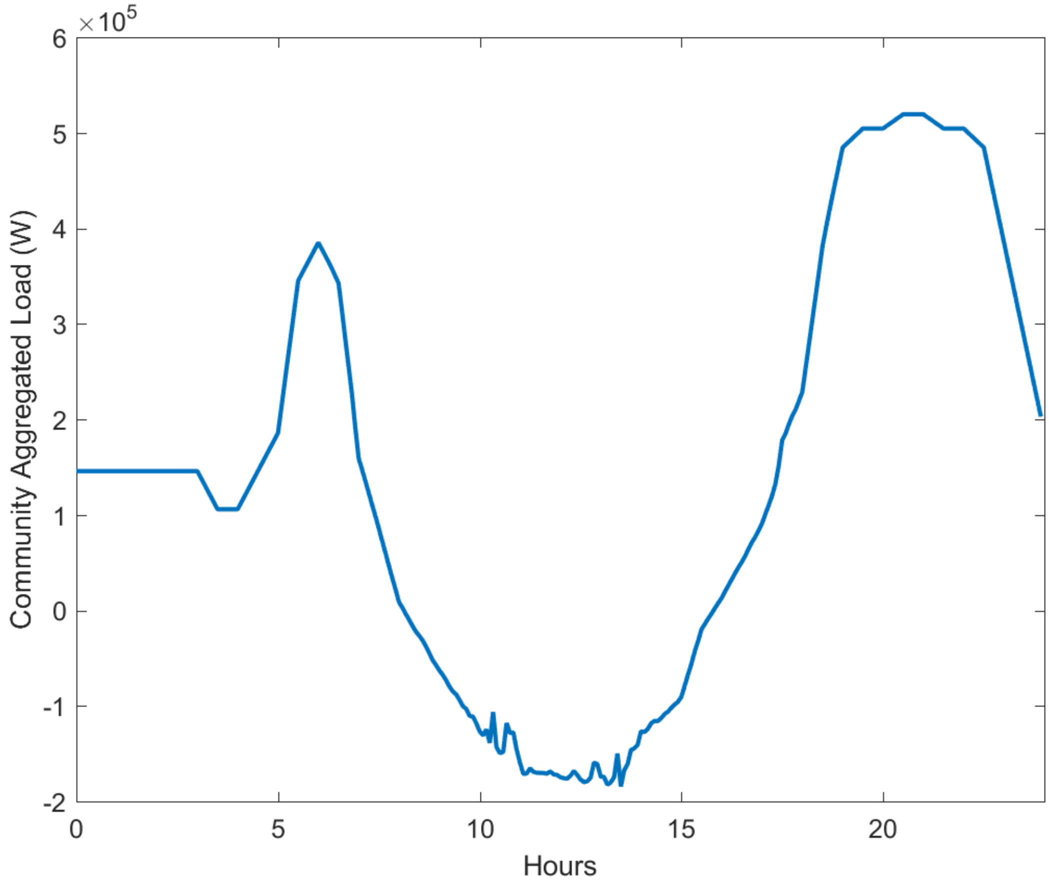


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

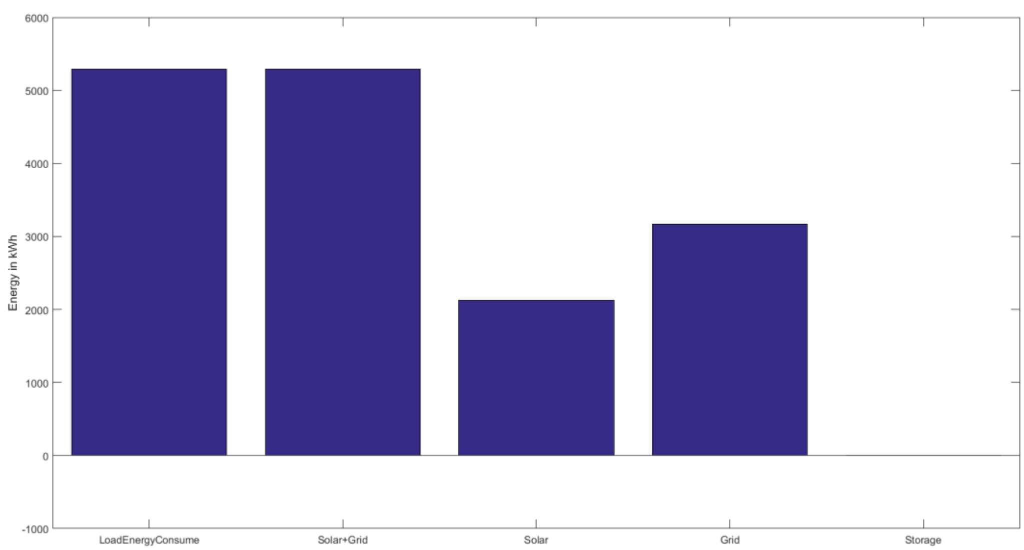
Case 7 Sunny


Solar P(W)
20000
10000
0
0
5
10
15
20
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1


Solar P(W)
20000
10000
0
0
5
10
15
20
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1

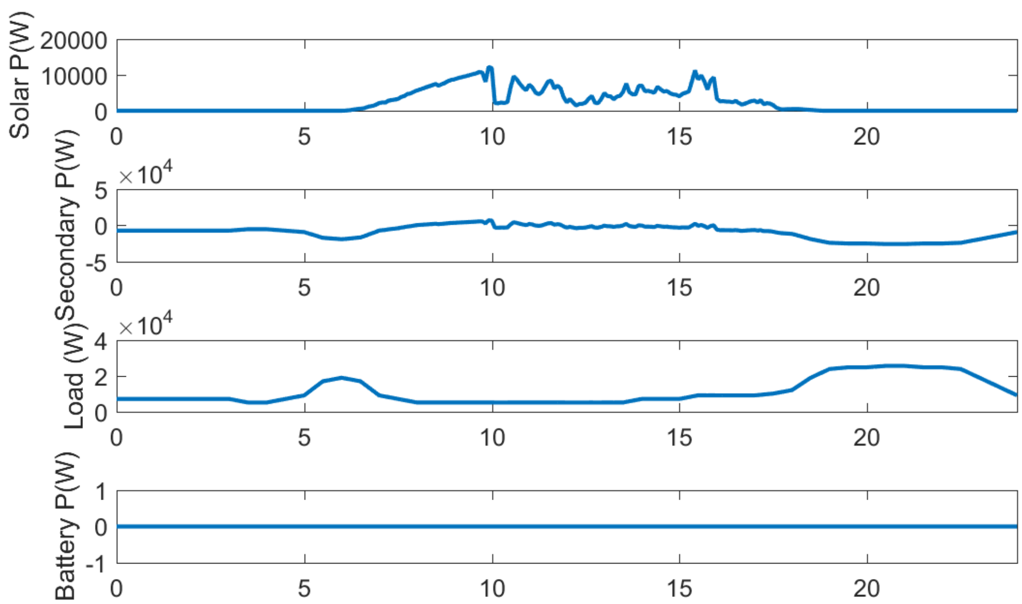


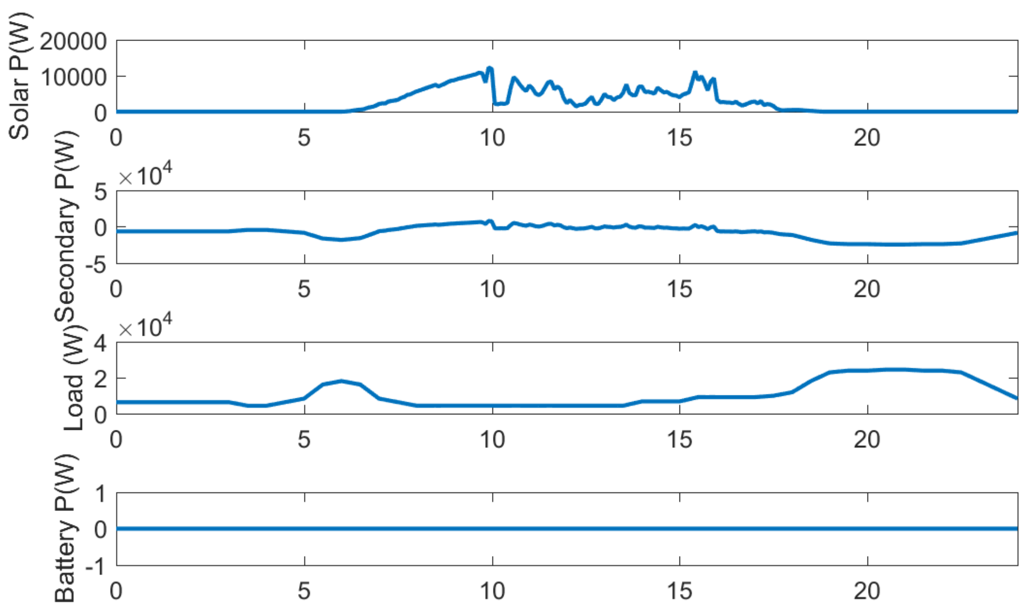
×10^5
6
5
4
3
2
1
0
-1
-2
0
5
10
15
20
Community Aggregated Load (W)
Hours

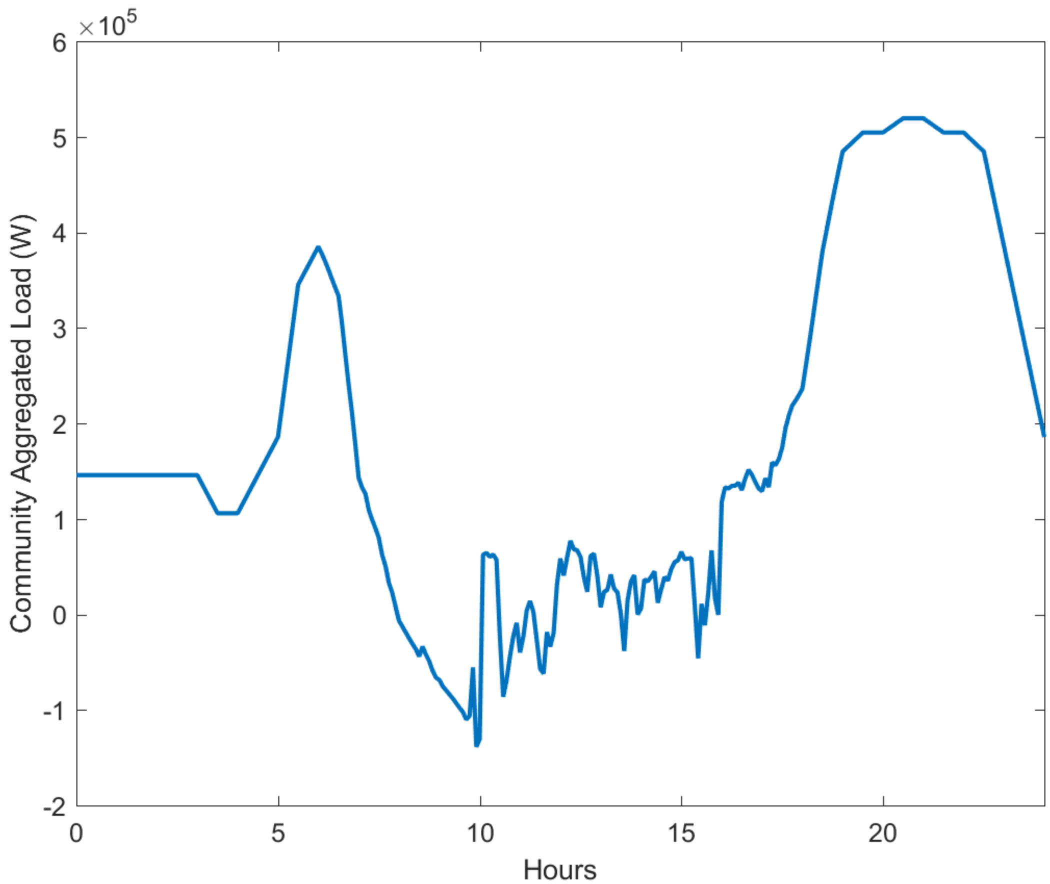


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

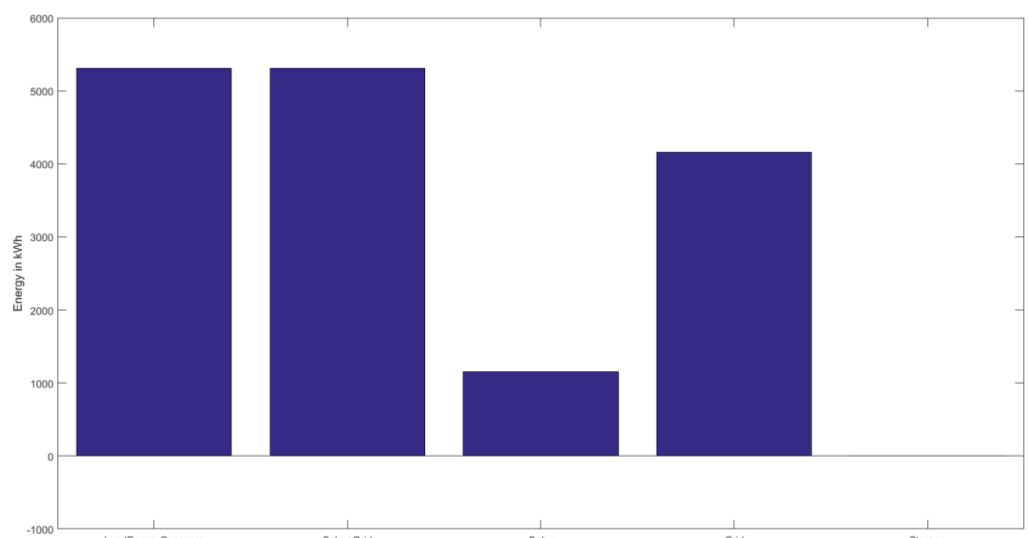
Case 7 Cloudy





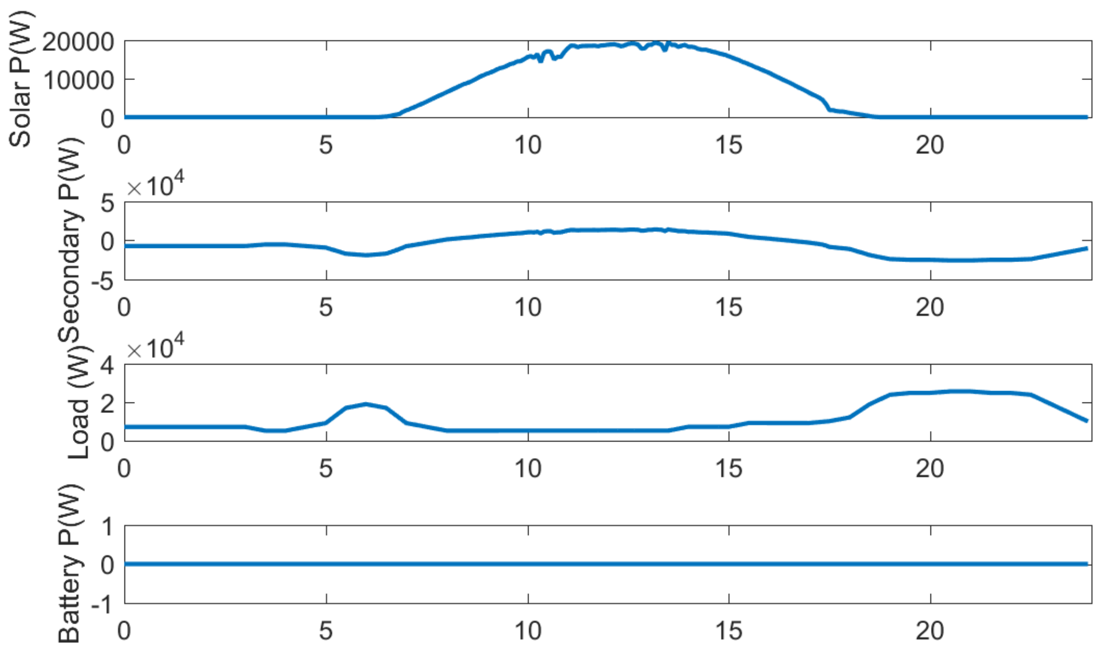


×10^5
6
5
4
3
2
1
0
-1
-2
Community Aggregated Load (W)
0
5
10
15
20
Hours

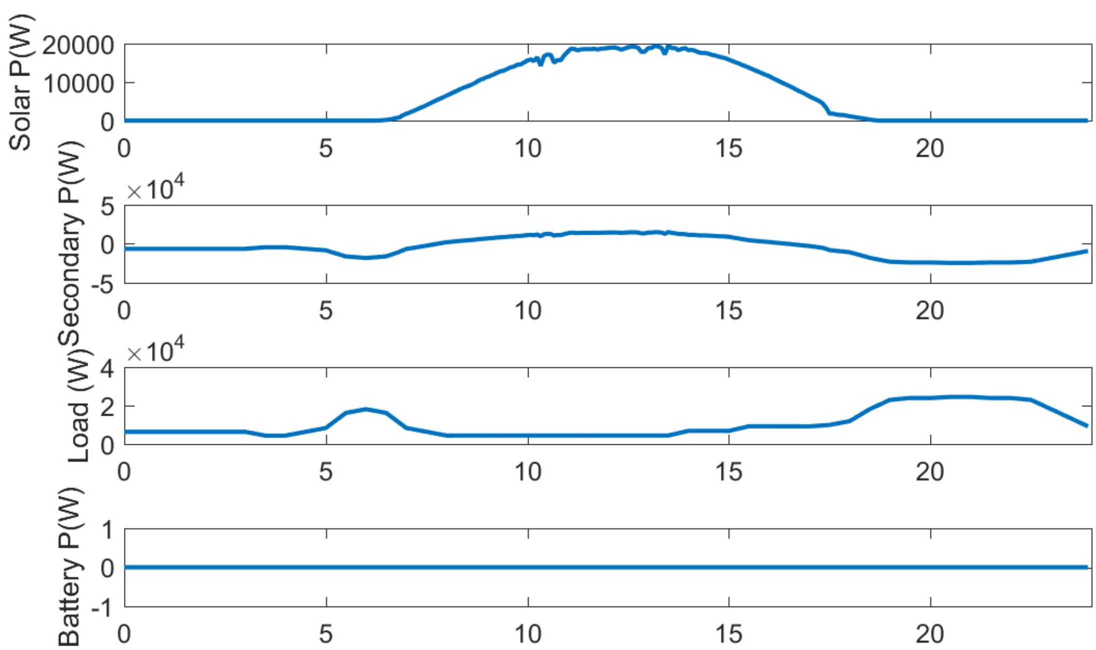


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

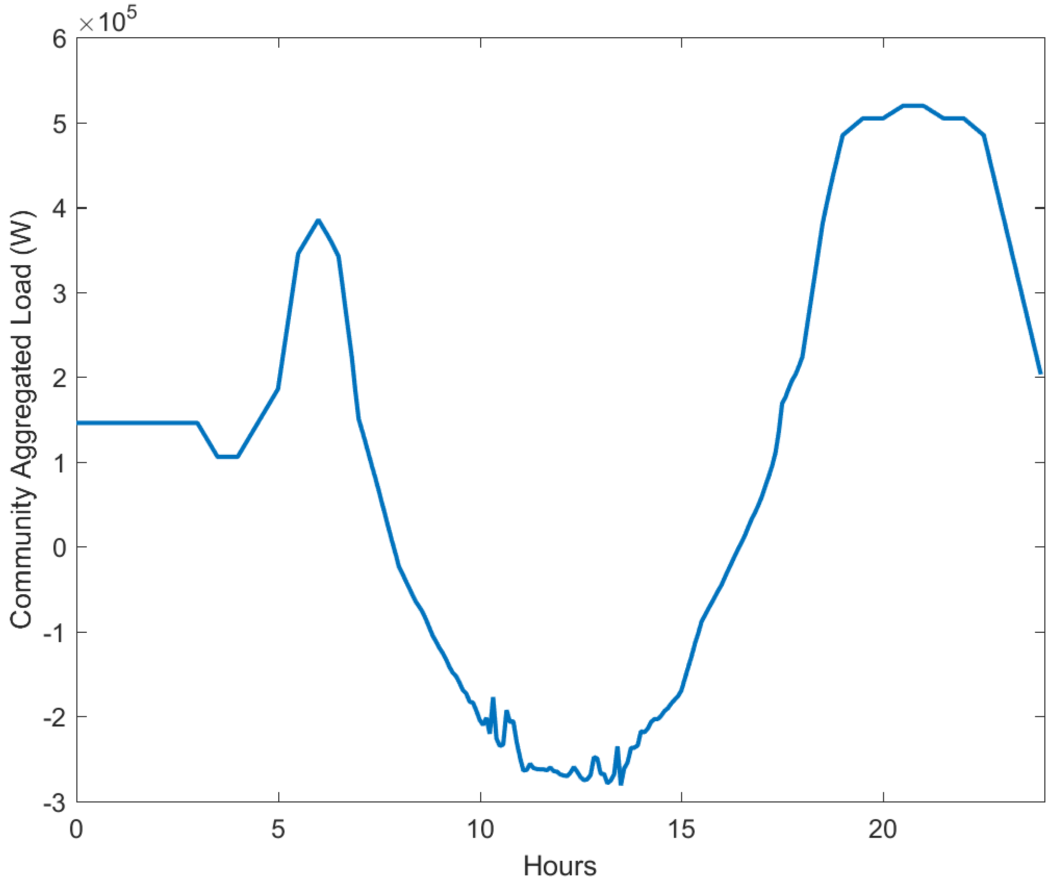
Case 8 Sunny



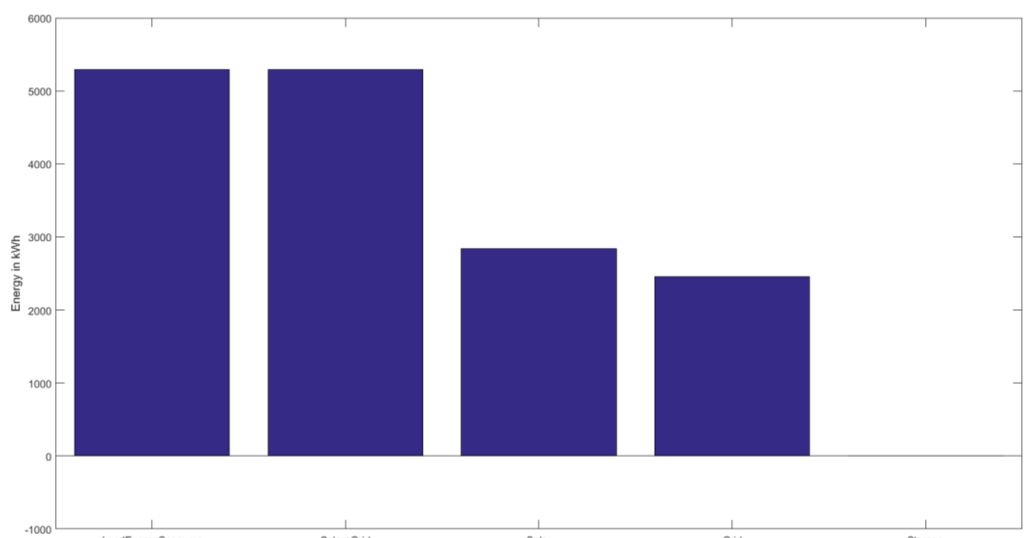
Solar P(W)
20000
10000
0
0
5
10
15
20
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1



Solar P(W)
20000
10000
0
0
5
10
15
20
Secondary P(W)
×10^4
5
0
-5
Load (W)
×10^4
4
2
0
Battery P(W)
1
0
-1

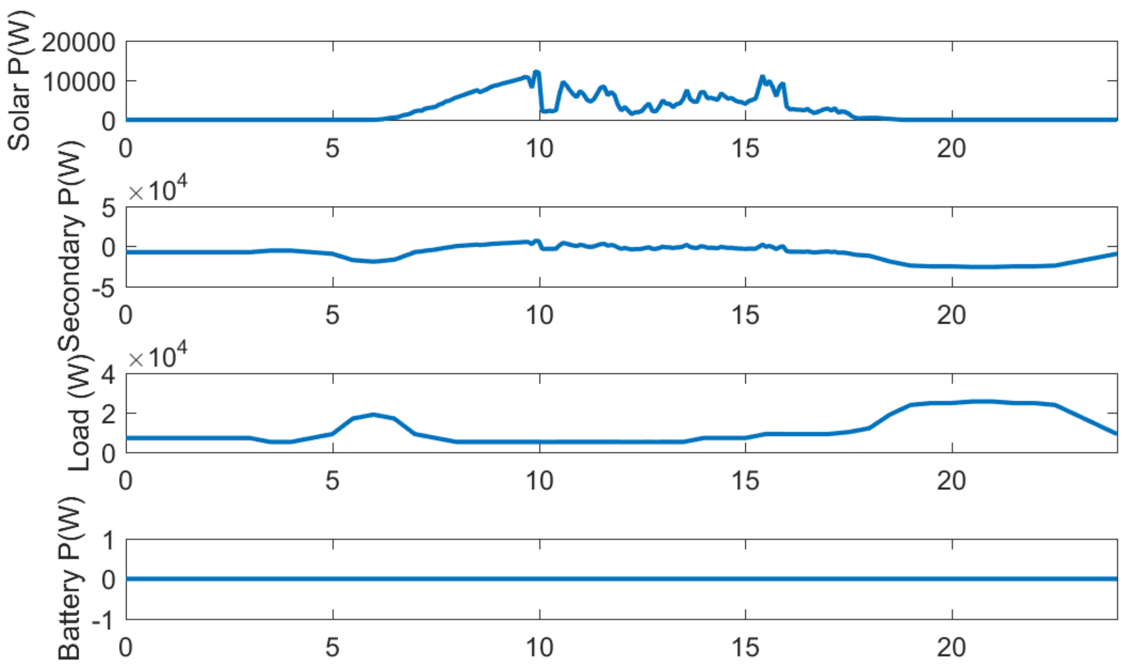


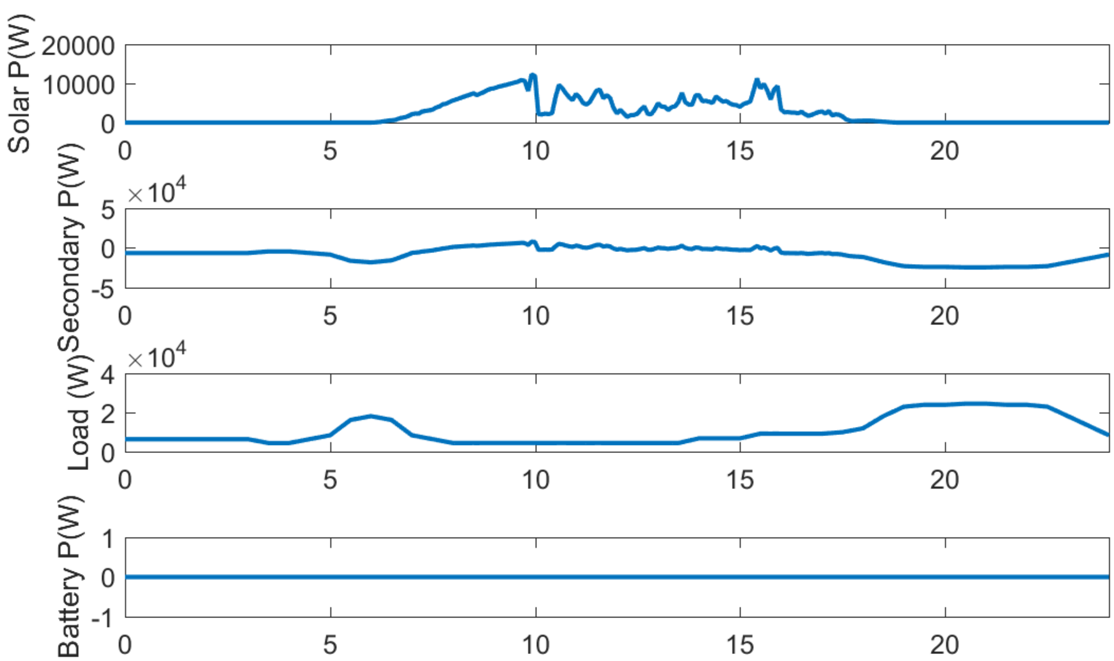
$\times 10^5$
6
5
4
3
2
1
0
-1
-2
-3
Community Aggregated Load (W)
0
5
10
15
20
Hours

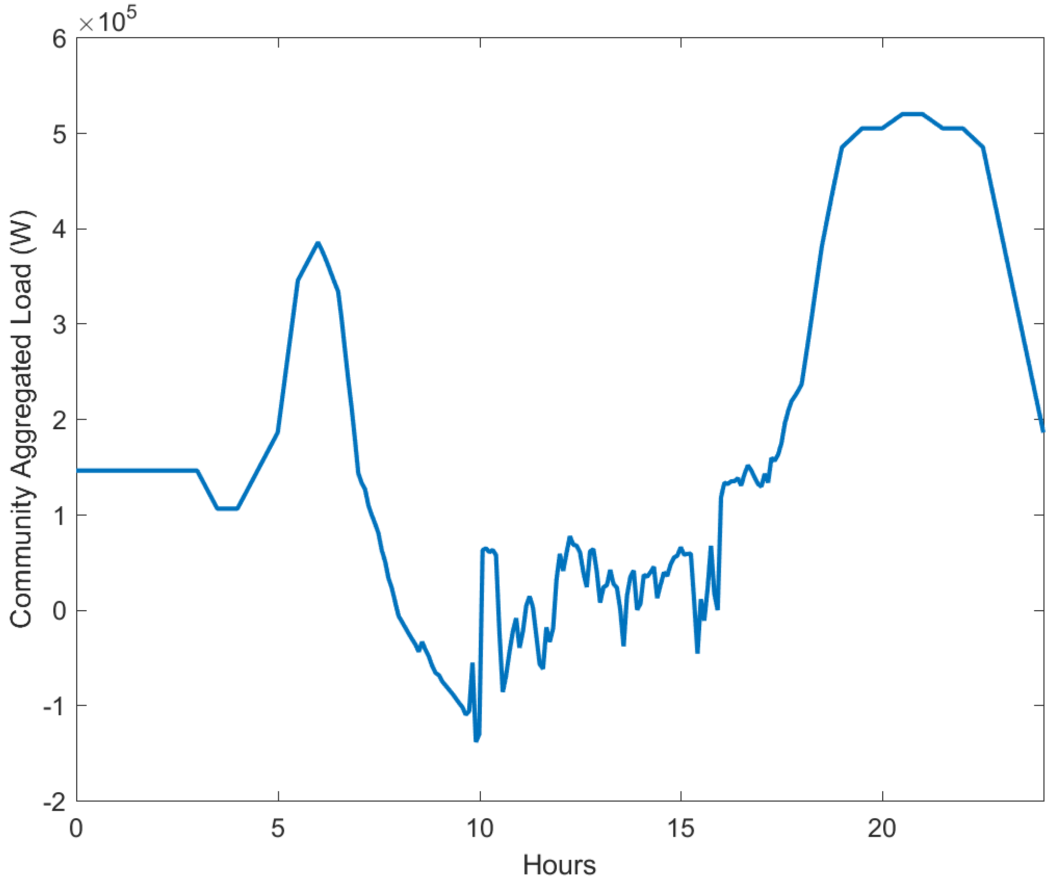


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

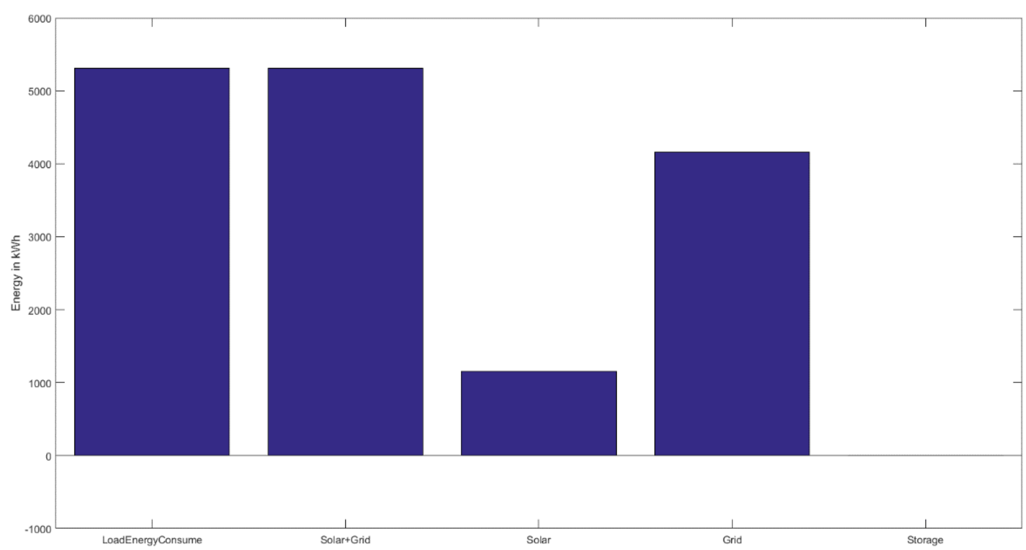
Case 8 Cloudy





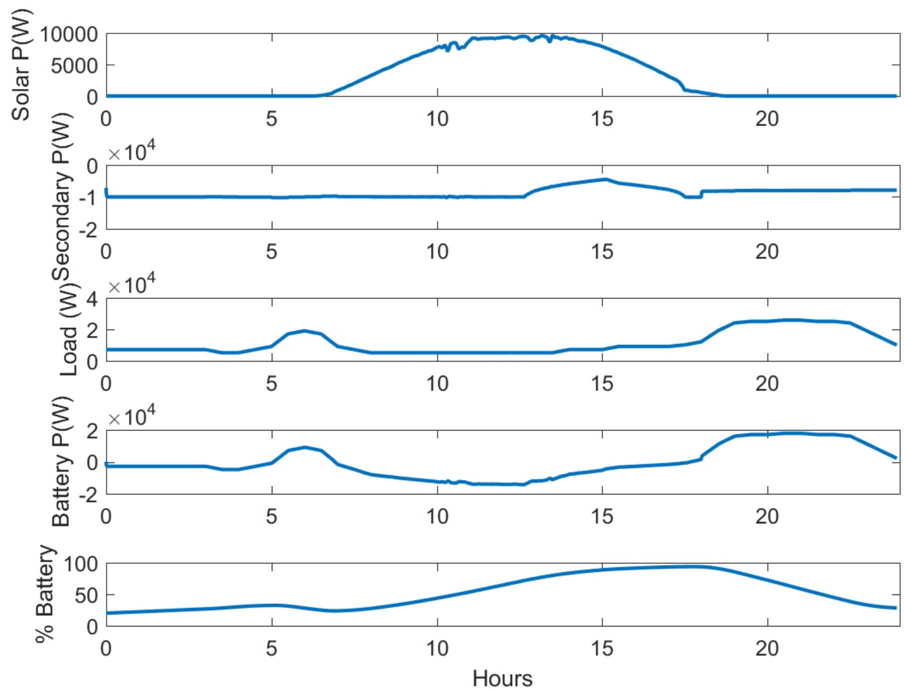


×10^5
6
5
4
3
2
1
0
-1
-2
0
5
10
15
20
Community Aggregated Load (W)
Hours

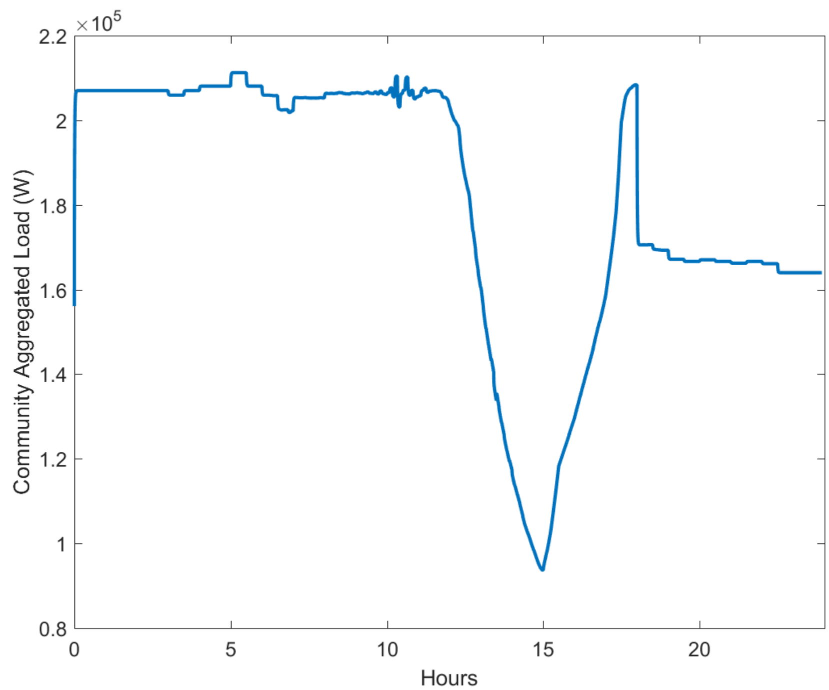


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

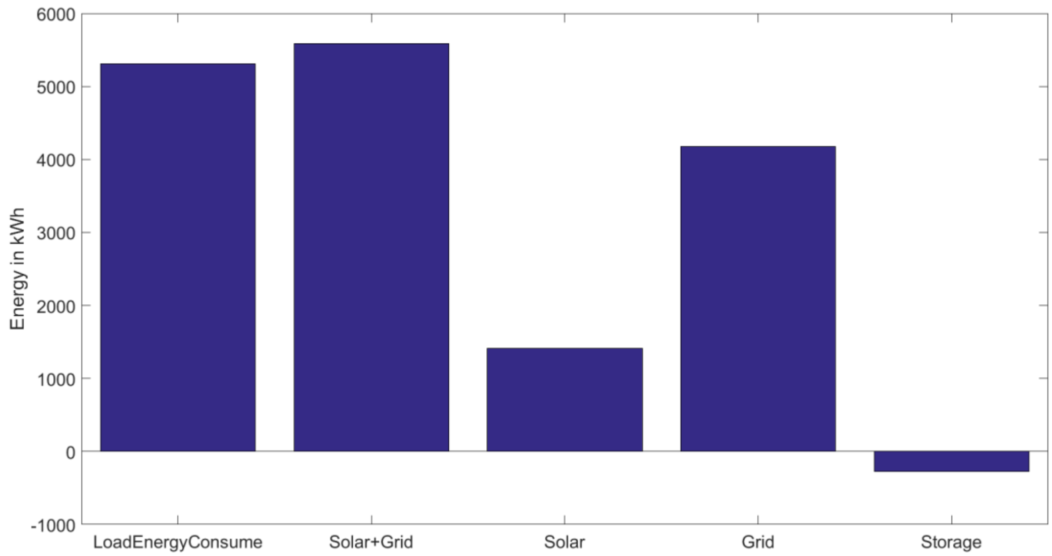
Case 9



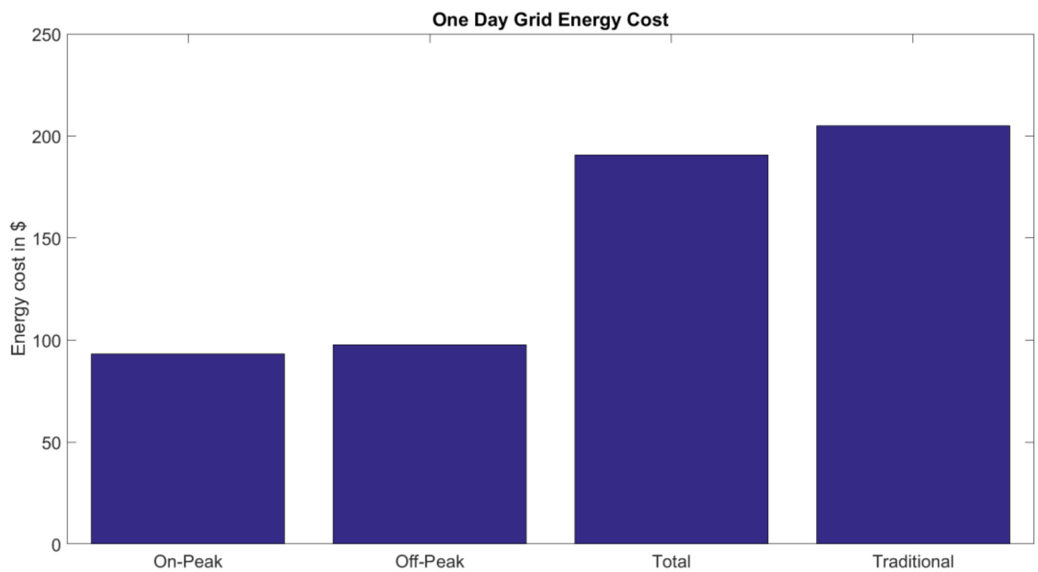
Solar P(W)
10000
5000
0
Secondary P(W)
×10^4
0
-1
-2
Load (W)
×10^4
4
2
0
Battery P(W)
×10^4
2
0
-2
% Battery
100
50
0
0
5
10
15
20
Hours



×10^5
2.2
2
1.8
1.6
1.4
1.2
1
0.8
Community Aggregated Load (W)
0
5
10
15
20
Hours

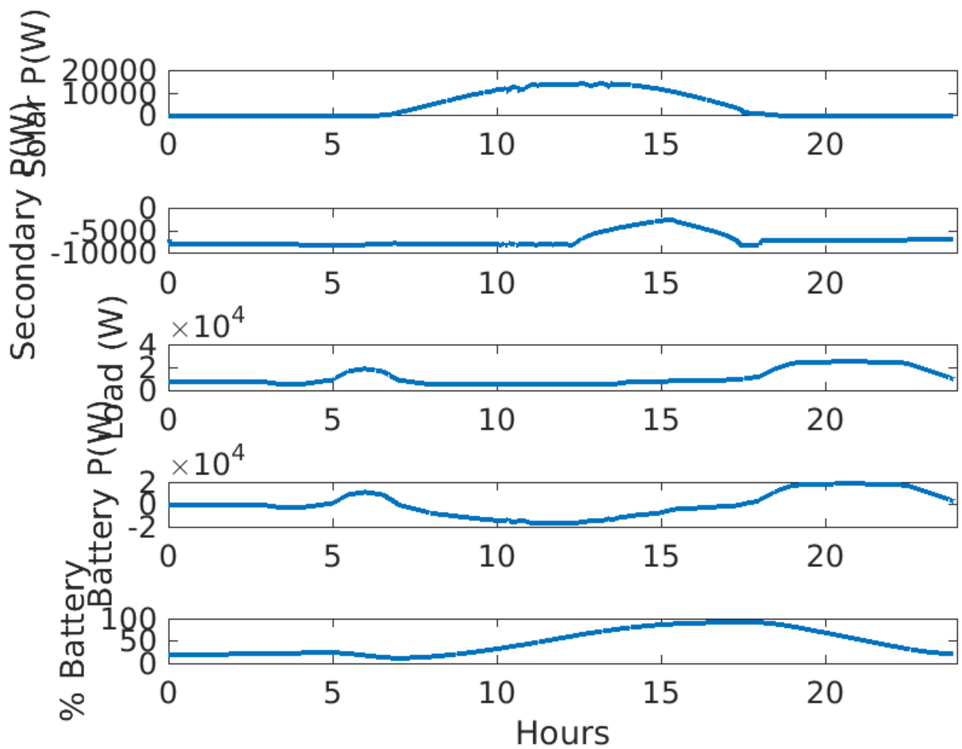


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage

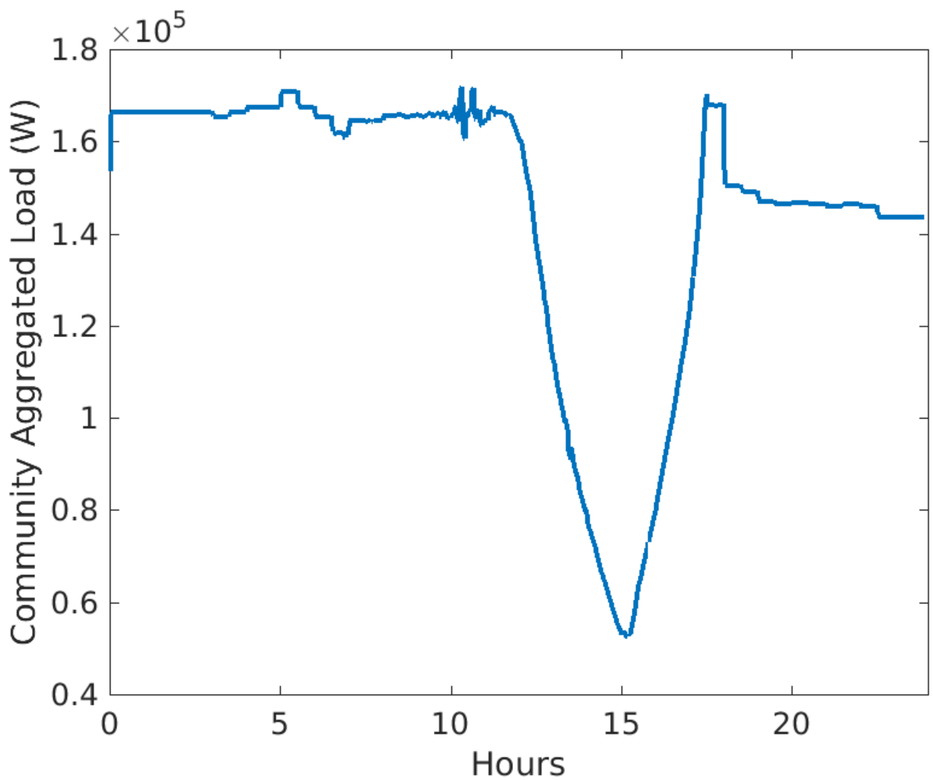


One Day Grid Energy Cost
250
200
150
100
50
0
Energy cost in $
On-Peak
Off-Peak
Total
Traditional

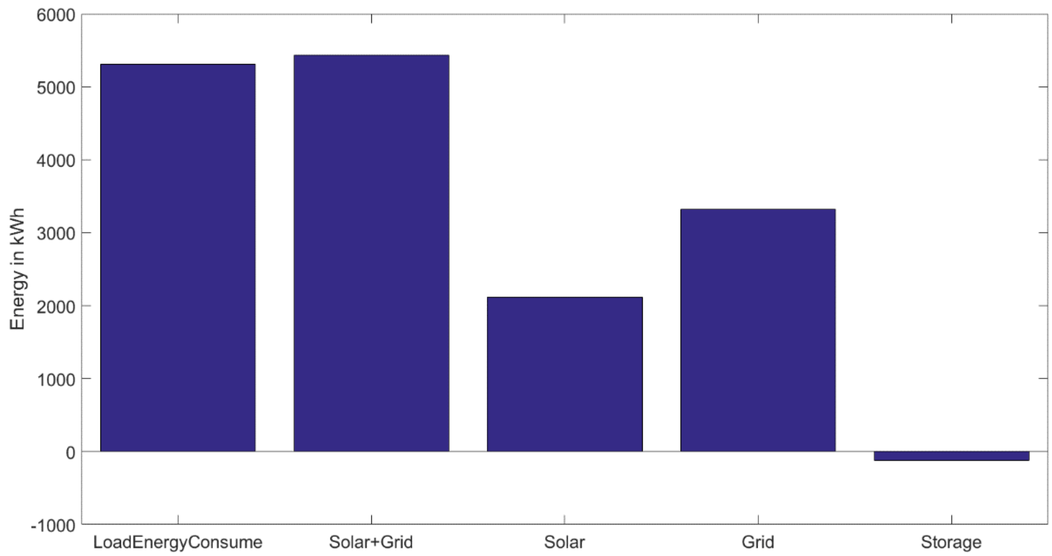
Case 10

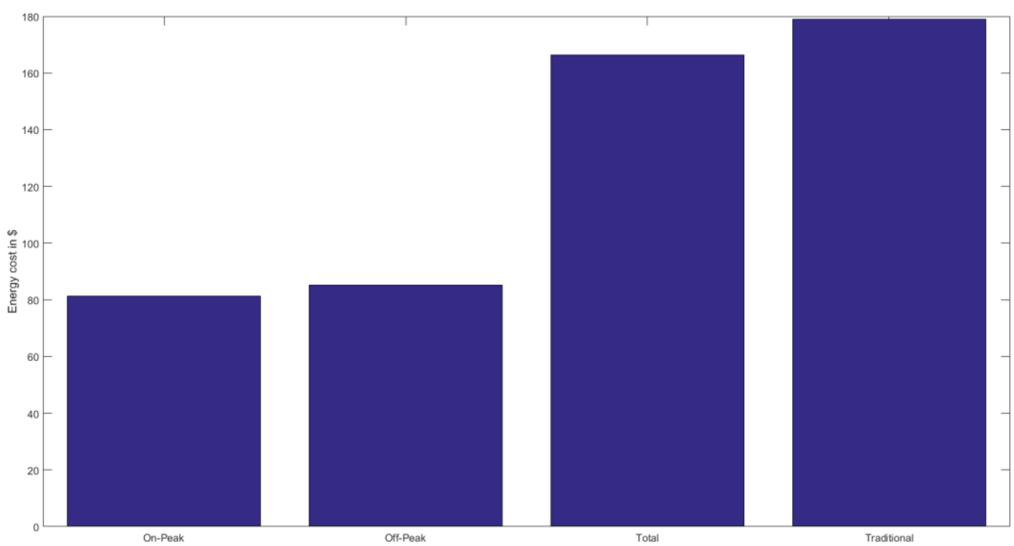


Solar P(W)
20000
10000
0
Secondary P(W)
0
-5000
-10000
Load (W)
×10^4
4
2
0
Battery P(W)
×10^4
2
0
-2
% Battery
100
50
0
0
5
10
15
20
Hours

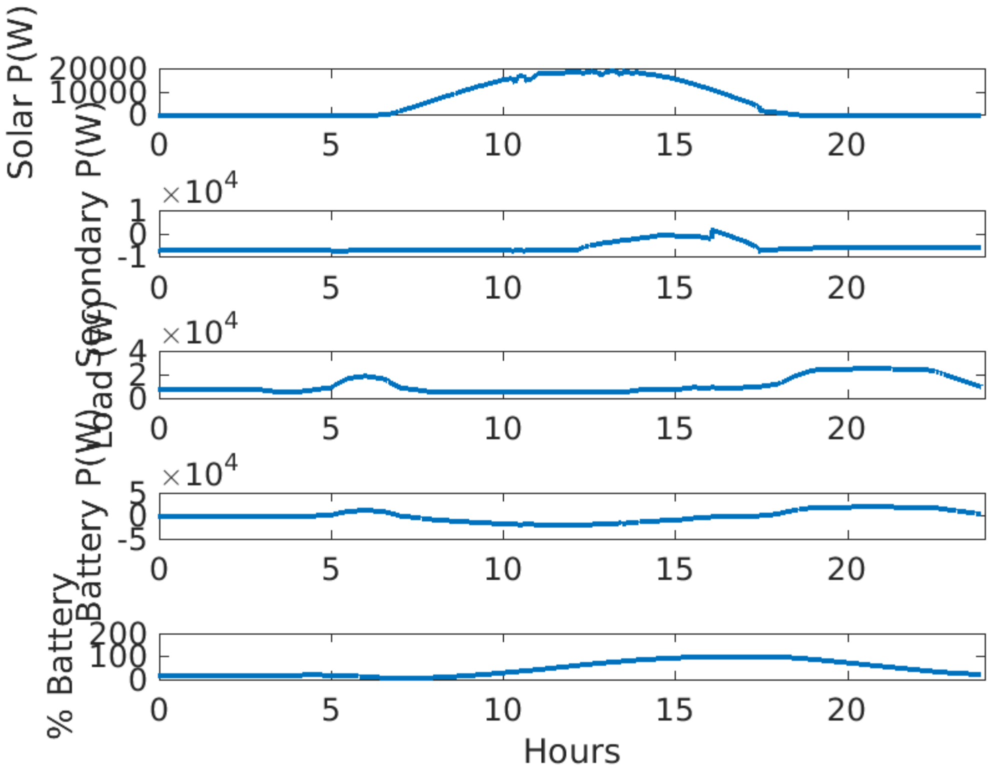


×10^5
Community Aggregated Load (W)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0
5
10
15
20
Hours

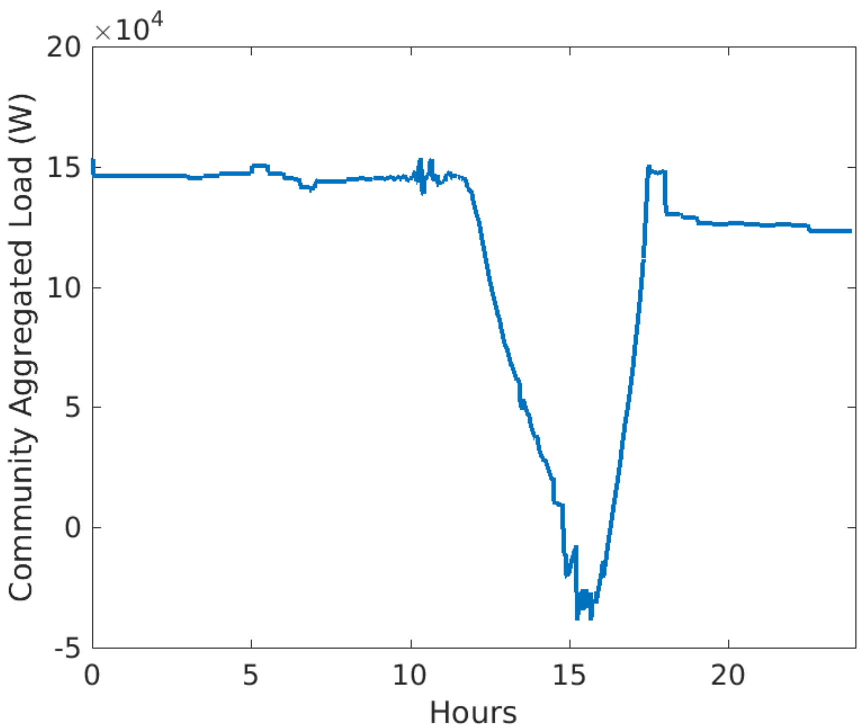

6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage


180
160
140
120
100
80
60
40
20
0
Energy cost in $
On-Peak
Off-Peak
Total
Traditional

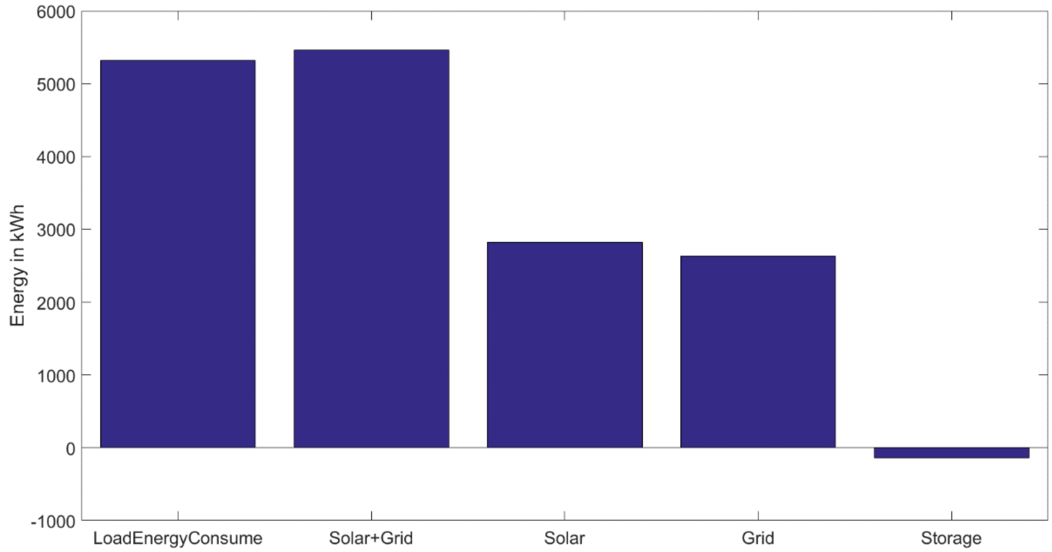
Case 11

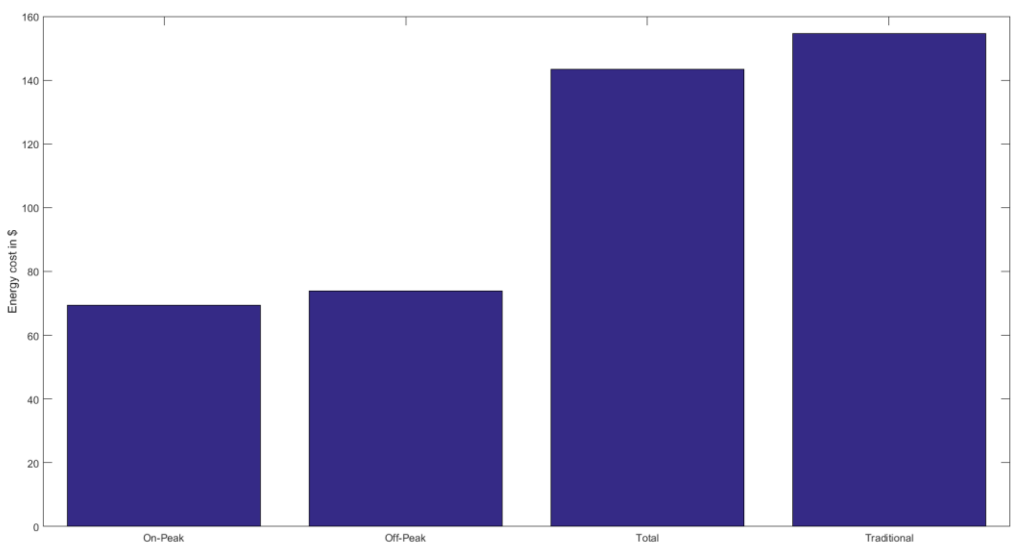


Solar P(W)
20000
10000
0
Secondary P(W)
×10^4
1
0
-1
Load (W)
×10^4
4
2
0
Battery P(W)
×10^4
5
0
-5
% Battery
200
100
0
0
5
10
15
20
Hours



×10^4
Community Aggregated Load (W)
20
15
10
5
0
-5
0
5
10
15
20
Hours


6000
5000
4000
3000
2000
1000
0
-1000
Energy in kWh
LoadEnergyConsume
Solar+Grid
Solar
Grid
Storage


160
140
120
100
80
60
40
20
0
Energy cost in $
On-Peak
Off-Peak
Total
Traditional