University of Southern Queensland
Faculty of Health, Engineering and Sciences

Home Based Solar Power Generation, Storage, and Localised Energy Grids

A dissertation submitted by

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I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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Abstract

The purpose of this dissertation was to undertake a feasibility assessment into the design of a residential energy management and metering device (REMD) which incorporates various operating modes that would replace current retail metering devices. The operating modes that are being implemented under this dissertation are known as sustainability mode, traditional mode and benefit mode. The approach was to undertake the design of each of the operating modes based on aspects of environmental, simplicity and cost incentives which would capture majority of users based on their motivations and ethical stand points on power usage which would hopefully lead to greater market uptake.

After completing the literature review it was discovered that such a device which covered both aspects of energy source management and metering was not readily available and limited research into this area had been undertaken. There is however a lot of research into areas of HEMS which deals with the energy management down stream of electrical switchboard and more broadly MGEMS which looks at energy management on a microgrid level. The intent behind the REMD is that it will fill the void between HEMS and MGEMS offering energy source management and metering as another layer to these two existing technologies. Another aspect of importance from the literature review was the type of controller to be implemented and the original goal was to implement a fuzzy logic controller, but after undertaking the methodology it was discovered that this controller type is not the most practicable as the system parameters are well defined and as such a state-based control approach was implemented.

State transition and flow charts were developed to form the main basis behind each of the three operating modes, and from here these were then used to develop models of each of the operating modes. The models were built in Mathworks MATLAB Simulink with the additional stateflow add-on package, which is specifically developed for the design and implementation of state-based controls. Each operating mode was built iteratively and tested once complete with 24-hour data that was then compared against hand calculated values to determine if the code was operating as intended. Once the code was debugged the controller was given a weeks worth of data with various configurations of PVS and BESS sizes to determine how the controller responds in the various operating modes with different energy source configurations.

After simulating the controller it was determined that the REMD is a feasible device and showed positive signs for each of the operating modes. Varying the PVS and BESS had various effects on how the controller responded but the main takeaway is that larger BESS and PVS systems in conjunction with the REMD will offer the users more benefits in their chosen operating modes. This device will require further development and testing before it can become a viable product but this feasibility assessment has created the foundation for further research.

Acknowledgements

I would like to start by thanking Paul Wen for the topic idea and his guidance and support throughout this dissertation. Without his input on some of the critical stages, especially to discuss control strategies and provide motivation to achieve the design of all three operating modes the dissertation would not be where it is today.

Secondary I would like to thank my friends, family and work colleagues that have all been along this very long journey of mine over the past nine years. Their support and ability to help me when I need it most, even if it is just to mentally unwind has been truly valuable.

Finally, I would like to thank my fiancée Tyler for her understanding and patience whilst I completed this degree. There have been many stressful and late nights, but she has always been the pillar that helps me get through the toughest of days. She has always been my biggest support, motivator and guidance throughout this degree and I really do owe it to her.

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Nomenclature

Abbreviation	Definition
B	BESS discharge (kWh)
$BESS_E$	BESS export (kWh)
B_T	Total BESS discharge over 24 hours (kWh)
c/kWh	Cents per kilowatt-hour
C_{BESS}	BESS export cost ($)
C_d	Total daily cost ($)
$C_{d\ avg}$	Average daily cost ($)
C_{grid}	Retail grid import cost ($)
CO_2	Carbon dioxide
C_{P2P}	P2P import cost ($)
C_{PVS}	PVS export cost ($)
E	Energy (kWh)
E_B	BESS discharge percentage of total load (%)
EF	Emission factor (kg CO_2-e/kWh)
E_G	Retail grid import percentage of total load (%)
E_{P2P}	P2P import percentage of total load (%)
E_S	PVS percentage of total load (%)
G	Retail grid import (kWh)
G_T	Total retail grid import over 24 hours (kWh)
I	Current (A)
kVA	Kilovolt-amps (active power)
kVAr	Kilovolt-amps (reactive power)
kWh	Kilowatt-hour
L	Load (kWh)
L_{G_I}	Total energy imported from retail market to charge BESS (kWh)
L_{P2P_I}	Total energy imported from P2P market to charge BESS (kWh)
L_T	Total load over 24 hours (kWh)
MW	Megawatt
MWh	Megawatt-hour
P	Power (W)
$P2P_I$	P2P import (kWh)
$P2P_{IT}$	Total P2P import over 24 hours (kWh)
PC_{BESS}	BESS export profit cost ($)
PC_d	Daily profit cost ($)
PC_d	Daily profit cost ($)
PC_{PVS}	PVS export profit cost ($)
PC_T	Total profit cost ($)
PVS_E	PVS export (kWh)
S	PVS load offset (kWh)
S_T	Total PVS load offset over 24 hours (kWh)
t_{export}	Export tariff price ($/kWh)
t_{Grid}	Retail grid tariff price ($/kWh)
t_{P2P}	P2P Tariff price ($/kWh)
V	Volts (V)
Y	Emission offset (CO_2-e kg)

Glossary of terms

Abbreviation	Definition
AC	Alternating current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
BESS	Battery energy storage system
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	Current transformers
DC	Direct current
DLT	Distributed Ledger Technology
DNSP	Distributed network service provider
DoD	Depth of discharge
EG	Embedded generation
EMS	Energy management system
EV	Electric vehicle
FiT	Feed in tariff
FLC	Fuzzy logic controller
HEMS	Home energy management system
IES	Imbedded energy system
LV	Low voltage
MGEMS	Microgrid energy management system
MPPT	Maximum power point tracking
MSB	Main switchboard
MSB	Main switchboard
NECF	National Energy Customer Framework
NEM	National Electricity Market
NER	National electricity rules
NTESMO	Northern Territory Electricity System and Market Operator
P2P	Peer-to-peer
PID	Proportional, integral and differential
PV	Photovoltaic
PVS	Photovoltaic system
QECM	Queensland Electrical Construction Manual
QEMM	Queensland Electrical Metering Manual
REBS	Renewable Energy Buyback Scheme
REMD	Residential energy management device
RMS	Root mean square
SM	State machine
SMC	State machine control
SoC	State of charge
ToU	Time of use
VPP	Virtual power plant
VT	Voltage transformers
WEM	Wholesale Electricity Market

Chapter 1 - Introduction

1.1 Introduction

With greater market uptake of residential photovoltaic systems (PVS) and battery energy storage systems (BESS) in conjunction with new emerging localised peer-to-peer (P2P) energy trading markets the current metering and energy management devices need to be overhauled. Connecting to the retail grid requires the user to have a retail meter in accordance with the distribution network service provider (DNSP) requirements. This retail meter provides the functionally of metering energy consumption and depending on the type can also meter the generation export. Typically, a user will sign up with one retailer to buy and sell power and has little to no flexibility with how their energy is managed or sourced. As previously mentioned there is a new emerging energy market which allows energy trading between neighbours in a local area. This new market introduces broader opportunities for cheaper import of energy and increased feed-in-tariffs (FiT) to compete with the retail grid. The P2P energy market can be accessed through current smart-type 4 retail meters, but the missing piece is how these users can manage access to both the P2P energy markets and the retail market. To achieve this an energy management device is required that can strategically choose between the energy markets whilst operating in the best interest of the users.

This is where the following dissertation has been prepared to provide a conceptual design and feasibility assessment into the development of a residential energy management device (REMD). The REMD will aim to present a holistic approach to managing the various energy sources (PVS, BESS, P2P energy market and retail market) and provide the relevant metering for the external energy markets, thus replacing current retail metering. A unique feature to be incorporated into this device is for a user to be able to select an operating profile that manages the energy sources in alignment with their ethical stand points and motivations for energy usage. These operating profiles will be discussed further in this dissertation but provide users the ability for a level of control over their energy choices.

1.2 Idea Origin

The idea for this project was originally proposed by Professor Paul Wen as part of potential project topics for 2023. The basis for the idea came from how domestic solar providers are not optimising solar systems to suit the customer's needs and providing them with the largest system possible for the highest cost. This is good for the provider but not for the customer, as with the current feed-in tariff prices the solar system will not be financially profitable. After discussions with Prof. Wen as part of ENG4110 and ENG4111 the research project has now shifted objectives with less emphasis being placed on the optimisation of PVS and BESS configurations but with more focus placed on the management and strategy control of the energy sources. To encourage users to think more consciously of their energy choices, it was proposed that users should have the ability for aligning the controller to their ethical stand points and motivations for energy usage. This will be achieved through management and strategy control of the four energy sources (PVS, BESS, localised P2P energy market and retail market) with one of the three operating modes. The intent is that the operating modes would dictate slightly different strategy control approaches in line with the users ethical standpoint and motivation towards energy production/consumption.

1.3 Project Objectives & Specific Limitations

The project objective at a high level is to create a conceptual design for a REMD that incorporates both metering and energy management aspects of available energy sources. The REMD will provide a two layered approach to energy management. The first layer is automated energy management via the device and the second layer is user education via a display. One unique aspect of the REMD to be explored in this dissertation is the ability to offer the user the option of selecting different operating modes which are tailored to specific ethical and motivational aspects of energy consumption. Although the operating modes may have similar outcomes the important factor is encouraging users to be more conscious on energy consumption. The following is a summary of the three operating modes:

1. Sustainability mode – Targeted towards users that want to place more emphasis on environmental sustainability. The aim is to reduce grid reliance through optimising internal renewable energy generation, with less emphasis placed on excess generation being exported to the grid.
2. Traditional mode – Targeted towards users that are not actively concerned about their energy choices and want a conventional energy experience. The aim is to give a rounded energy experience without the P2P market that reduces energy bills and grid reliance.
3. Benefit mode – Targeted towards users that want to offset energy bills or possibly receive payments for energy production. The aim is to minimise energy import during peak times and maximise energy export during high FiT times.

The following is a summary of key objectives for this dissertation:

- Design conceptual level strategy controls based on the operating modes.
- Design a conceptual level display that presents the relevant information based on the operating modes.
- Model and simulate the REMD within MathWorks MATLAB Simulink environment.
- Evaluate model outcomes in line with the operating mode aims to determine feasibility of the REMD.

As this dissertation is aimed at conceptual design level only there are limitations to the objectives and these include the following:

- Evaluation of educational benefits and informing users of energy related aspects from the display cannot be assessed, real-world implementation (not practical at this stage) and human studies would be required for this (not practical due to ethical clearance requirements). It is proposed that the display will be evaluated on operational aspects only.
- Modeling will be limited to discrete typical data only and will not operate in a continuous/dynamic modeling environment.
- The finer details of the REMD metering aspects will not be a focal point, as evaluation of the operating modes during modeling is the main objective.

1.4 Justification and Feasibility

The following is a summary of the justification for the dissertation:

- Significance: A holistic energy management and metering device that replaces current retail metering has not been adequately explored with aspects of PVS, BESS, P2P market and retail markets.
- Relevance: This area of research is in line with the degree of electrical/power engineering as energy management and metering is a key aspect within electrical networks.
- Novelty: This research will incorporate the additional aspect of new P2P energy markets along with the ability for the REMD to provide the user various operating modes.

The following is a summary of key feasibility aspects of the dissertation:

- Resources: All required resources, funding, time and data is available for the completion of this dissertation. Refer chapter 3 for details.
- Methodology: The research methods and techniques used in this dissertation are appropriate and achievable. Refer chapter 3 for details.
- Ethical Considerations: As no human/animal subjects are required for this dissertation the ethical considerations have been minimised. Refer to section 1.6 for details.

1.5 Australian Standards and Compliance

It is important that the relevant standards and manuals are consulted and adhered to when undertaking any engineering design. Guidance will be taken from the relevant Australian Standards and other manuals as required during the design and prototyping of the REMD. However, due to the nature of this dissertation being a conceptual design only the finer details of compliance against the relevant Australian Standards and manuals are deemed to be outside the scope.

The following list provides a summary of the relevant Australian Standards for this dissertation (note that this list is not exhaustive):

- AS/NZS 3000 – Wiring Rules
- AS/NZS 3008 – Electrical installations - Selection of cables
- AS/NZS 4509 – Stand-Alone Power Systems
- AS/NZS 5033 – Installation and safety requirements for photovoltaic (PV) arrays
- AS/NZS 5139 – Electrical installations - Safety of battery systems for use with power conversion equipment
- AS/NZS 4777 – Grid connection of energy systems via inverters
- AS 60253 – Electricity metering equipment (AC) - Particular requirements

The other aspect of compliance is tied to the relevant manuals specifically related to the DNSP to which the REMD resides within. For the purposes of this dissertation Energex (division of Energy Queensland) is the nominated DNSP. The following list provides a summary of the relevant Energex standards for this dissertation (note that this list is not exhaustive):

- Queensland Electrical Metering Manual (QEMM)
- Queensland Electrical Connection Manual (QECM)
- STNW1170 - Standard for Small IES Connections
- STNW1174 - Standard for Low Voltage Embedded Generating Connections

1.6 Ethics and Consequential Effects

Before commencing research, researchers (including undergraduate and postgraduate students) who wish to undertake projects involving human participants must obtain approval from the Human Research Ethics Committee. No research can take place without ethics clearance (USQ 2023). As this dissertation does not necessitate the use of human subjects it is deemed that ethics clearance is not required. The data for this dissertation will come from online published sources and any reference to personal effects of the data origin shall not be disclosed. The Engineers Australia Code of Ethics and Guidelines on Professional Conduct will be adhered through the process of this dissertation with attention drawn to the four key areas of demonstrating integrity, practising competently, exercising leadership and promoting sustainability.

The consequential effects of this dissertation are related to the physical REMD itself with aspects of software and hardware, as design choices on these elements will have impacts to cost, reliability, sustainability and overall market uptake. Software choices will need to ensure that the system operates as intended and is not overly complex, and hardware choices will need to consider the design life and ensure cost is kept to a minimum, parts are readily available, and the controller is easily serviceable if parts do fail.

1.7 Considerations for economic, environmental and social impacts

The economic, environmental and social impacts of any research topic need to be addressed to ensure that all factors are considered. Although the following items may not specifically be addressed within this dissertation it is crucial to understand the importance of these aspects for further study on this topic.

<u>Economic considerations</u>

- Choice of materials and component selections
- Complexity of software model and design
- Flexibility/adaptability of the device in various installation configurations
- Compatibility with target purchasing groups

<u>Environmental considerations</u>

- Full life cycle analysis of the device
- Power consumption

<u>Social considerations</u>

- Privacy and security concerns for smart meter energy data transmission
- Reliability and accuracy of the device
- Ability for retrofitting to existing electrical installations
- Efficiency of service and maintenance of product (i.e. software updates, compatibility, etc)

Chapter 2 - Literature Review

In order to undertake this dissertation a literature must be completed to gain an appreciation of previously completed work in this field. The research will ensure that this dissertation is novel and is building on previous knowledge. The following is a summary of the key areas for this dissertation:

- Australian energy market
- Queensland retail energy market
- P2P energy market
- Retail metering
- PVS and BESS configurations
- Energy management systems
- Energy control strategies

2.1 Australian Energy Market

The following research section is intended to provide an overview of the current Australian energy market. The aim is to gain an understating of how the energy market operates, is configured and what organisations are involved.

The Australian electrical energy market consists of an enormous combination of generators (both renewable and non-renewable), transformers, transmission networks, distribution networks, retailers and prosumers/consumers (Figure 1). There is an overarching company called the Australian Energy Market Operator (AEMO) which is responsible for managing the Australian energy market. The AEMO currently operates both within the electrical and gas sectors, but for the purpose of this dissertation only the electrical sector will be analysed.

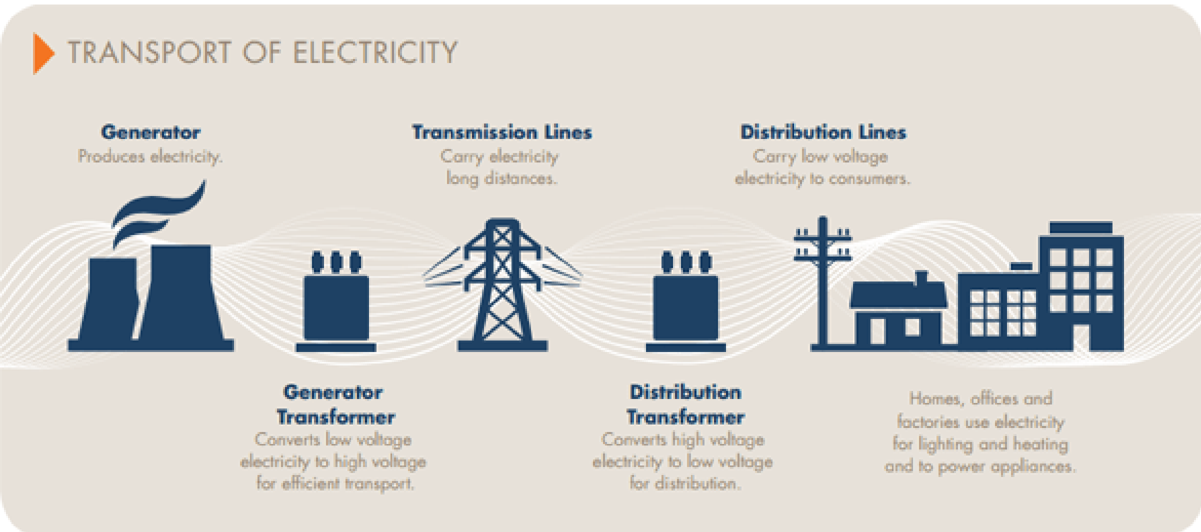


Figure 1: Australian energy market - transport of electricity (AEMO 2022a)

The AEMO manages the three wholesale electrical markets within Australia which are the National Electricity Market (NEM), the Wholesale Electricity Market (WEM) and the Northern Territory (NTESMO) (AEMO 2022b). The NEM operates in five jurisdictional areas of Queensland, New South Wales, The Australian Capital Territory and Victoria, whereas the WEM and NTESMO operate within the one jurisdictional area each of Western Australia and Northern Territory respectively. For the purpose of this dissertation only the NEM will be explored rendering WEM and NTESMO beyond the scope.

There are a set of national electricity rules (NER) which govern the operation of NEM and is supervised by the Australian Energy Market Commission (AEMC). The AEMC is an independent statutory body working for Australia's future productivity and living standards by contributing to a decarbonising, affordable and reliable energy system for consumers (AEMC 2023a). The NER are put in place so that all parties involved understand their rights and responsibilities and to ensure that the cost of purchasing electricity is fair. The main rules are nominally to govern the following elements:

- Operation of the wholesale electricity market – includes the arrangements for commercial exchange of electricity from generation to the energy retailers.
- Economic regulation – tied to the services provided by monopoly transmission and distribution networks (i.e. in Queensland this would include Powerlink for the transmission network and Energy QLD for the distribution network)
- How the AEMO manages power system security (AEMC 2023b)

The way in which the NEM wholesale market operates is via a 5-minute interval spot market that determines how much electricity is required to be produced in order to meet the demand. The 5-minute spot price is then put forward by each generator with only the corresponding generators that come online being paid for their generation amount (usually on a MWh basis). To pay generators the AEMO must recover costs from customers. As most customers don’t participate directly in the NEM, they purchase their electricity through a retailer. Customers pay the retailers a commercial tariff, and retailers manage customers’ energy purchases, including paying AEMO the spot price to avert the risk of system collapse or physical damage to parts of the power system (AEMO 2021).

Transportation of electricity between generators and distribution networks within Queensland consists of a vast array of electrical lines, substations and associated equipment that supports the transmission and distribution. When looking specifically at the transmission (from generator to distribution) There are currently three transmission network service providers operating in Queensland:

- Powerlink Queensland (Government owned corporation)
- ElectraNet Pty Limited
- AusNet Transmission Group Pty Ltd

It is worth noting that majority of the high-voltage transmission network is provided and maintained by Powerlink Queensland (Government 2020).

Moving into the next stage of electricity transportation after transmission is the distribution network, which provides the direct connection to the low voltage consumers. This network also consists of a similar arrangement to that of the transmission network with high voltage and low voltage electrical lines, transformers and associated equipment. Within Queensland the distribution network is provided and maintained by Energy Queensland which has two separate divisions, Energex and Ergon Energy (Figure 2). These two divisions used to operate independently of each other but recently there has been a merge of these two service providers to form Energy Queensland. Energex and Ergon Energy are separated via geographical areas with Energex being responsible for South East Queensland and Ergon Energy being responsible for the remainder of Queensland.

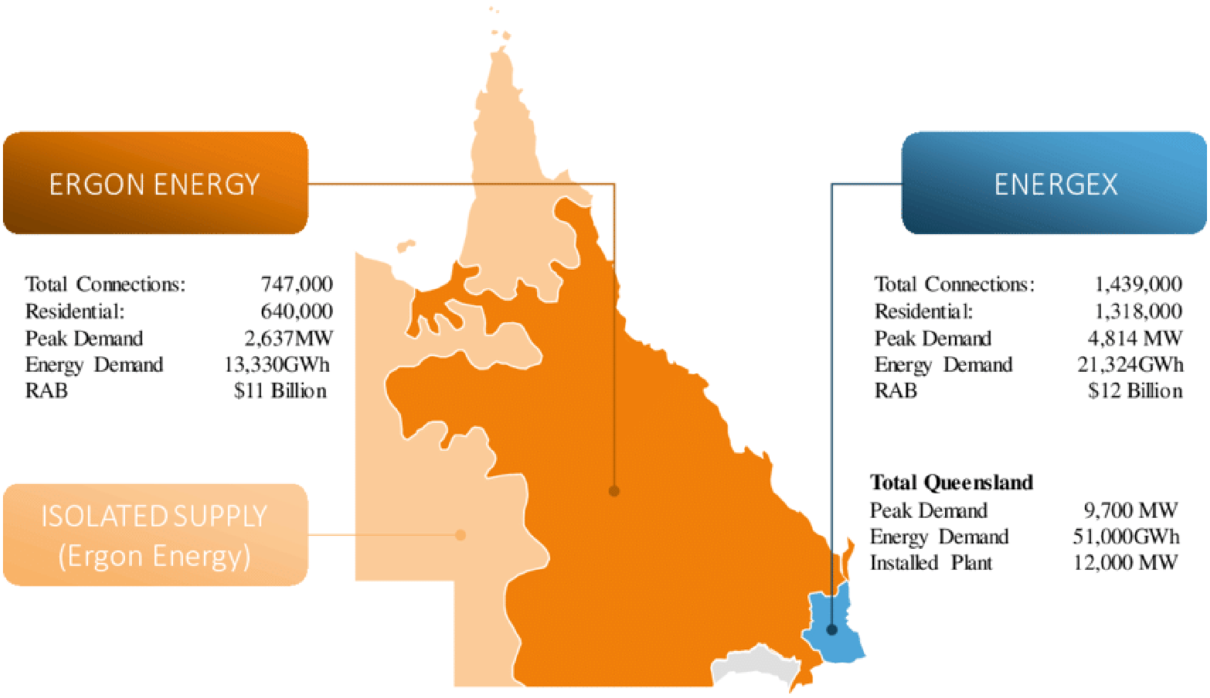


Figure 2: Energex and Ergon DNSP jurisdiction areas (Simshauser 2018)

Key findings for dissertation

Considering the REMD is to be located within the main switchboard (MSB) and is providing the interface to the relevant DNSP region and internal AS/NZS 3000 wiring, the requirements of the relevant DNSP will need to be adhered to. Noting this dissertation is focusing on the DNSP area of Queensland, the specifics related to the requirements for metering and connections of retail customers are covered under the Energy Queensland manuals QEMM and QECM. After reviewing these manuals the key take aways for this dissertation include

- QEMM section 2.1 - General: *Customer's ancillary equipment such as surge diverters, voltmeters, phase failure relays etc. shall be connected on the load side of the revenue metering equipment.*
- QEMM section 2.4 – Customers energy management systems: *A customer requiring an interface with the metering provider's facilities should contact the metering provider.*

Note that as the REMD device is intended to replace current retail metering, section 2.4 in the QEMM is considered not applicable.

2.2 Queensland Retail Energy Market

The following section provides an overview of the current Queensland energy retail market. The purpose of this research is to understand how the retail market operates with reference to energy tariff structures, the role of energy retailers and associated retail energy plans.

Energy retail within Queensland is consistent with the broader NEM jurisdictions in that there are Energy companies (known as retailers) that on-sell power to consumers. For a company or individual to on-sell power they first must be registered by the retail energy governing body, the Australian Energy Regulator (AER), which is responsible for administering retailer authorisations (AER 2023). The electricity retailers operate under the National Energy Customer Framework (NECF), which is a set of national laws, rules and regulations governing the sale and supply of energy to consumers (Government 2022a).

Electricity costs that consumers pay to retailers is based on the relevant DNSP network charges and associated costs of buying the electricity from the generators. Energex network charges that are passed onto retailers cover the cost of building, maintaining and operating the electricity network to safely supply power to homes and businesses. These network charges are represented in the form of tariffs and Energex is responsible for setting these (Energex 2023a). Residential energy consumers were traditionally charged a flat rate for their energy consumption no matter when the usage of energy occurs. One thing that a lot of consumers did to save electricity was to install their electric hot water systems onto economy tariffs such as economy tariff 33 or super economy tariff 31. These particular tariffs would only allow energy usage to occur during off-peak times (outside of 4-8pm) (Energex 2023b). This was achieved through DNSP relay control devices, installed within the energy consumers main switchboard. To help reduce peak demand on the network, DNSPs are implementing cost reflective tariffs that have higher rates during peak periods and lower rates during off-peak periods known as tome of use (ToU) tariffs (Energex 2023a). To access this latest tariff arrangement the energy meter must be a new type 4 smart meter (refer section 2.4 for details) and the energy retailer must have this structure on offer. Table 1 below provides a summary of the latest residential network tariff arrangements provided by Energex.

Tariff type	Network tariff name	Fixed daily charge	Consumption charge	Demand charge	Eligibility
Primary tariff	Residential Flat (NTC8400)	$0.516/day	$0.07437/kWh	N/A	Only for customers with an older style meter – not a 'smart meter'.
Primary tariff	Residential Transitional Demand (NTC3900)	$0.516/day	Flat rate charge $0.03591/kWh	Monthly charge $3.418/kW/month note 1	Must have a smart meter. Where customers are changing from a basic meter to a smart meter due to a meter failure, they must move to this tariff after 12 months.
Primary tariff	Residential Demand (NTC3700)	$0.516/day	Flat rate charge $0.02576/kWh	Monthly charge $7.121/kW/ month note 1	Must have a smart meter.
Primary tariff	Residential Time of Use (ToU) Energy (NTC6900)	$0.516/day	Charges based on when electricity is used: Evening (peak): 4pm to 9pm $0.14450/kWh Overnight (shoulder): 9pm to 9am $0.03670/kWh Day (off-peak): 9am to 4pm $0.03031/kWh	N/A	Must have a smart meter.
Secondary tariff	Economy (NTC9100)	N/A	Flat rate charge $0.04371/kWh	N/A	Must be used in conjunction with one of the above primary tariffs.
Secondary tariff	Super Economy (TNC9000)	N/A	Flat rate charge $0.03371/kWh	N/A	Must be used in conjunction with one of the above primary tariffs.

Notes

1. based on highest half hourly demand between 4pm to 9pm weekdays and weekends

Table 1: Residential network tariff prices (Energex 2023a)

In 2007 the Queensland Government introduced full retail competition for electricity and since this time all consumers connected to the electricity grid have had the right to choose their preferred electricity retailer (Government 2022a). Furthering on from this in July 2016 South East Queensland energy prices were deregulated which meant that the market competition increased and resulted in an abundant number of retailers available. Currently in Queensland there are 30 privately licensed energy retailers (Government 2022a) and to access grid electrical services a consumer must sign up with a single licensed retailer. Each retailer will offer various electrical plans and promotions to suit consumers electrical needs and will nominally factor in elements such as, general usage, supply charges, controlled loads and solar/battery feed in tariffs. Consumers with solar and/or battery storage systems can export the energy that is generated or stored in excess back into the DNSP grid and receive a credit from the retailer for the generated electricity at the going rate. The problem with this arrangement is that the consumer utilising the solar generated electricity is charged the retail electricity price whilst the consumer that generated the electricity receives only the FiT price (Brakels 2020). A summary of some example energy providers and associated energy costs (general usage and not ToU reflective) are listed in Table 2 below (note that this list is not exhaustive):

Charge Type	Energy Retailer			
	AGL Energy (Residential Basics)	Alinta Energy (HomeDeal – Single Rate +CL1 & CL2)	Diamond Energy (Everyday Renewable Saver)	Origin Energy (Go Variable Plan)
General Usage	25.38c/kWh	24.39c/kWh	24.81c/kWh (up to 340 kWh) 32.67c/kWh (after 340kWh)	25.04c/kWh
Daily Supply	123.92c/day	109.53c/day	119.9c/day	114.79c/day
Controlled Loads	20.61c/kWh	18.21c/kWh & 18.46c/kWh	20.59c/kWh	19.38c/kWh
Solar feed-in	5.0c/kWh	8.0c/kWh	5.2c/kWh	5.0c/kWh

Table 2: Nominal retail energy prices

Key findings for dissertation

As the REMD will interface with the retail market there is the requirement that the consumer must be signed with one licensed retailer. Smart metering is required to access the ToU tariff structure which is a consideration for the metering component as it is assumed that this tariff and associated energy plans will provide the most opportunities for successful operation of the REMD.

2.3 P2P Energy Market

A new emerging energy market where excess residential generated energy is sold/purchased by neighbours to neighbours instead of the wholesale electrical grid is known as the peer-to-peer (P2P) energy market. This energy market is currently not readily available within the Australian energy market as it is still in its infancy stages. There has been and currently still is a lot of research and trails being completed to understand if this new market is viable. The following research will provide an overview of current trials and techniques used in the P2P energy trading market sector.

To understand how the P2P energy trading would work within the current Australian energy market, a literature review paper by Soto et al. (2021) provided some key insights. This paper presented an overview approach to how P2P trading works, along with benefits and considerations. The key takeaway from this paper were that conventional energy trading is mainly one-way in that electricity is typically transmitted from large-scale generators to consumers over long distances, while cash flow is the other way around. Whereas with P2P energy trading there are multi-directional trading within a local geographic area (localised energy grid) encouraging localise cash flow. With the proposed P2P market when prosumers have an electrical energy surplus, there are several options for this energy:

1. Stored in a storage device (such as a battery) for later use; or
2. Exported to the electricity grid at the wholesale retailer purchase price; or
3. Exported and sold to other energy consumers at the P2P contract price. (Soto et al. 2021)

A study undertaken by AGL provided more insight into the inner workings of P2P energy market in that trading is most likely to either occur directly between two participants (generator and consumer) who form a short-term contract, or indirectly between two participants who remain anonymous to one another and trade across a secure, auditable marketplace. The transactions between participants would require methods for low-cost authentication, validation, and settlement, while protecting consumer data privacy (AGL 2017). As previously researched in ENG4110 the typical approach for P2P energy market trading is via the well-known Distributed Ledger Technology (DLT) and this is the same case for the AGL trial. The most famous branch of this technology is blockchain. Blockchain can be defined as a distributed and digital transaction technology that allows secure storing of information and execution of smart contracts in P2P networks (Honarmand et al. 2021).

A recent trial (Dr. Jemma Green 2020), funded in part by the Australian Government, ran between December 2018 and January 2020 as part of the RENeW Nexus Project involved using Powerledger's blockchain technology to track the transactions of rooftop solar energy traded between 48 households in Fremantle, Western Australia. The trail proved the validity of using P2P trading within the current energy market and provided many insights to the benefits and future recommendations. During the trial an additional meter was installed in the homes to facilitate real-time solar trading but one of the findings was that the only requirement to facilitate P2P was a smart meter with remote communication capabilities. Although the real-time data was useful the additional costs associated with the meter and installation would not be warranted in large scale retro fits. It was therefore proposed that the standard retailer smart meter would suffice. Another part of this trial called Loco 1, looked at the typical payback time periods for residential batteries (sized between 10kWh and 15kWh) that were coupled with P2P or virtual power plant (VPP) trading. Although VPP is considered outside the scope of this dissertation it was noted that using a battery coupled with VPP, would mean that consumers could purchase locally sourced energy from prosumers with batteries throughout the day, not just when the sun was shining. It also means that batteries could help the grid in dealing with reverse energy flows and provide system services to stabilise the grid. It was also noted that the P2P trading rate was set at the Renewable Energy Buyback Scheme (REBS) feed in tariff (FiT) rate of 7.135 c/kWh + 10%. This particular trading rate differed from a research paper by Azim et al (2020) which presented the ability for seller and buys to set their market buy/sell pricees. It is noted that this dynamic market price arrangment does offer advantages for a more competive P2P market (Azim et al. 2020). That aside, the results from the RENeW Nexus Project showed that over 75% of participants in the trial made an effort to shift their energy usage profile to take advantage of daylight time periods when tradeable energy is most available. This indicates that participation in P2P energy trading did make users more conscious of their energy use behaviours based on incentivised schemes.

Key findings for dissertation

Although P2P energy markets are still new and not readily available, it is an element that could provide beneficial gains for participants and this needs to be explored within the development of the REMD. The REMD will need to consider both the retail market and the P2P energy market in order to achieve the best outcomes for the users of this device. The surplus energy options provided from Soto's research will form the main framework for the controller decision process around how and when to make the best decision about what to do with the surplus energy.

2.4 Retail Metering

In order to be connected to the retail energy market, users must have a retail meter at the point of connection to track the energy consumption/generation. There are three main types of retail energy meters on the market with these being accumulation meters (flat rate meters), interval meters and smart meters (type 4). There has been a large shift in recent years with the emergence of the new smart metering technology and from 1 December 2017 all new retail meters need to be digital smart type 4 meters (Energex 2023c). For the purposes of this research dissertation only smart meters will be investigated due to the other metering types being phased out. Table 3 provides a summary of each of the metering types.

Meter Type	Energy Metering	Display	Nominal Dimensions
Accumulation	Record total energy usage	Analog (cyclometer or dial) or Digital	132mm (W) x 152mm (H) x 51mm (D) (based on AMS (L+G EM500) B1 Meter)
Interval	Record energy usage every 30 mins	Digital	130mm (W) x 125mm (H) x 50mm (D) (based on L&G AMG EM1000 Electronic Meter)
Smart	Record energy usage every 30 mins	Digital	134mm (W) x 214mm (H) x 70mm (D) (based on ECA EDMI Mk7C E1c Meter)

Table 3: Retail metering types summary (Ausgrid 2022)

Modern electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) and finding the product of these to give instantaneous electrical power (watts). This electrical power is then integrated against time to give energy used (joules, kilowatt-hours etc) (Technology n.d). This is given by equation 1. Current retail meters record energy consumption on a 30 minute interval and send this information to the retailers.

$$E = \int_{T1}^{T2} P\, dt \tag{1}$$

E	Energy (kWh)
P	Power (W) = V x I x power factor

The nominal metering configuration in order to achieve the voltage and current measurements is dependent on the peak RMS values of voltage and current. As the retail meter is located within the DNSP LV network the maximum single phase nominal RMS voltage will be 240V and the maximum RMS current cannot exceed the service fuse which is typically limited to 63A in Energex areas. For these reasons the metering of both voltage and current can be achieved via direct metering and separate voltage transformers (VT) and current transformers (CT) are not specifically required as shown in Figure 3.

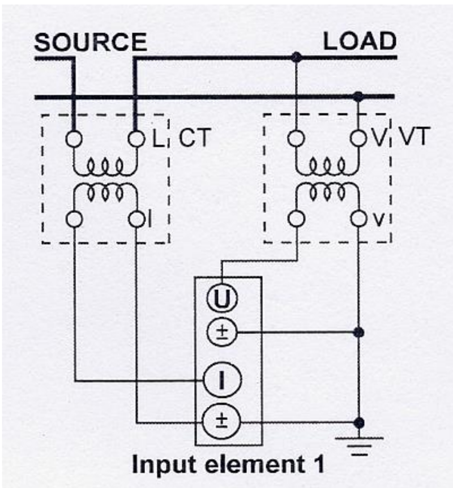


Figure 3: Example of electrical power measurement within energy meter (Yokogawa 2017)

In the residential energy markets consumers are typically only charged for their kWh usage and the other aspects of kVAr and peak demand charges (related to commercial and industrial market sectors) are not applicable. These other charges are not required within the residential energy market due to the low energy consumption of residential homes when compared to large industrial and commercial consumers. Commercial and industrial electric firms consume this in massive amounts, so electricity companies charge them a premium (CoolBlew 2019) in order to reduce negative impacts of grid network stability. It is therefore why it is deemed to not be economically viable to charge residential customers for these additional charges.

Key findings for dissertation

Current metering arrangements and processes will need to be maintained in order to provide retailers and P2P energy market participants the feature of energy consumption/generation. Metering will be maintained as energy consumption (kWh) at 30-minute intervals to align with the current smart meter technologies.

2.5 PVS and BESS configurations

Solar and battery configurations within residential applications vary significantly and are dependent on factors such as the initial cost, installation location (related to weather and available space), the user's objectives and the actual products themselves. The purpose of this research section is to gain an understanding for typical solar and battery storage configurations. Note that the fundamentals and inner workings of these systems is considered outside the research scope of this dissertation.

Currently Queensland has one of the highest rates of household rooftop PVS installations with around 1 in 3 homes using solar and this equates to approximately 700,000 homes and small businesses, producing around 4,300MW of clean energy (Department of Energy and Public Works 2023). Even with a steady rate of rooftop installations, Queensland continues to see a slow uptake of PVS with BESS (Figure 4), accounting for only 12% of the total solar-with-battery installations. (Australian Energy Council 2022b).

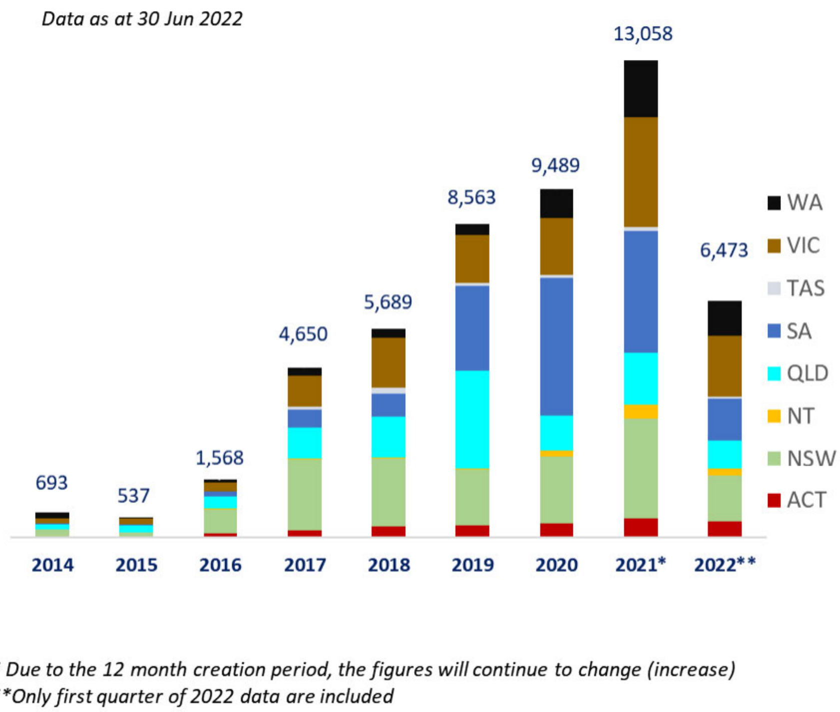


Figure 4: Solar and battery installations per state since 2014 (Australian Energy Council 2022b)

It is important to realise that the financial incentives relating to power bill offsets are a major factor in the uptake of these systems and this was found to be true for 79% of surveyed individuals through a CIRSO study relating to the key uptake for PVS (CSIRO 2019). With the recent phasing out of high profit FiTs to much lower FiTs the economical payback of PVS and BESS systems is much slower than before. The Queensland Governments latest release of the FiTs for 2022–23, showed that the regional FiT was on average 9.3 cents per kilowatt hour (Government 2022b). When comparing this against the Solar Bonus Scheme 44 cent FiT offered prior to 2018 (Government 2018) there has been a reduction of nearly 79%. One of the main reasons for the FiTs falling so low is due to the reduction in wholesale electricity prices caused as a direct result of greater PV penetration within the market (Energy Matters 2023).

When specifically looking at the typical system sizing for Queensland homes, Energex treat solar PV systems, micro-wind turbines, and micro-hydro turbines and batteries as LV embedded generating (EG) units. These LV EG units are treated the same as they are all either DC or AC coupled and to an inverter prior to exporting energy to the grid. Most residential EG units connected to the main grid line fall under a basic connection service with Energex as the rated capacity of the system is less than or equal to 10kVA per phase and with an export limit of up to 5kW per phase (Energex n.d). Energex are investigating a new EG dynamic connection arrangement that will see the ability for customers to export up to 10kW doubling the previous arrangement. At this stage as products progressively gain certification, it is anticipated that customers will be able to register for this dynamic connection on the SEP2 Utility Server in mid-2023 (Energex 2022).

To understand typical PVS and BESS systems the GSES (2022) textbook was used as this provided a good overview of key requirements and aspects into these systems. It was discovered that the typical components in a PVS and BESS setups include:

- PV array
- MPPT (PV converter)
- Inverter
- Battery bank
- Battery charger

It is important to note that the inverter types differ for the discrete PVS and BESS systems. For a PVS a grid connected inverter is required as it is only capable of synching with the grid to export energy. Whereas for a BESS a multi-mode (or hybrid) inverter is required, which allows for management of grid synchronisation for energy import and export (note that import of grid energy is only possible through certain inverters to charge the battery) (GSES 2022). As previously mentioned PVS and BESS systems are either AC or DC coupled. The components are very much the same between the systems, but it is the configuration of these components that differ (Figure 5).

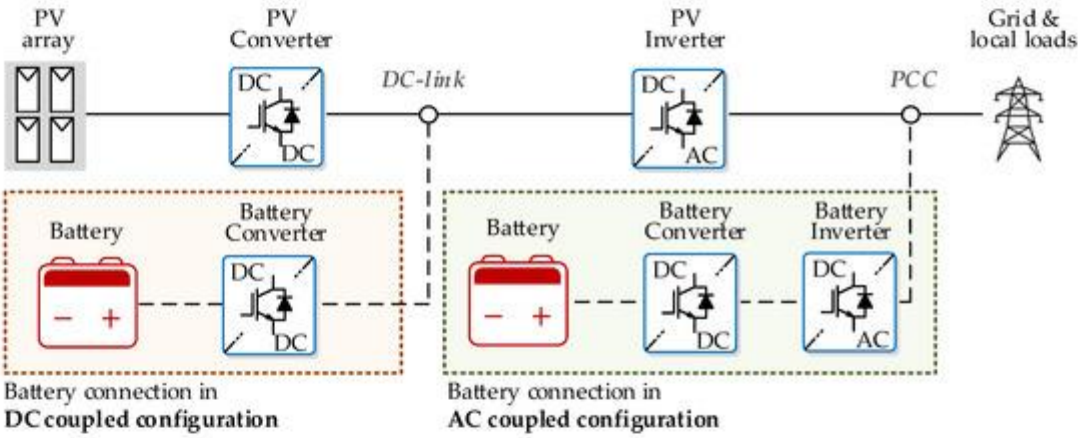


Figure 5: System diagram of AC and DC coupled PVS and BESS (Sandelic et al. 2019)

In regards to AC coupled systems, these are much easier to install especially with retrofits into existing electrical installations but do require the use of more equipment (i.e. two inverters, one for the PVS and the other one for the BESS) with reductions in efficiencies caused by multiple energy conversions (GSES 2022). As previously mentioned, the limiting export factor is determined by the DNSP which is set at 5kW per phase and means that if both the solar and battery systems were exporting the inverters would be limited to 2.5kW each. The other component to consider is when the batteries are AC coupled they can only charge from the AC side of the solar inverter and as such if the solar is producing more than 5kW the inverter limits it to the maximum permissible by the DNSP. This therefore means that the extra generated solar energy is not utilised and is not achieving the maximum yield of the system.

Now looking at a DC coupled system, these are more energy efficient than AC coupled systems due to there being less components and conversions of AC-DC and DC-AC. This arrangement can be more complicated to install and retrofitting into existing electrical installations can become challenging (Marsh 2019). A research paper undertaken by (Sandelic et al. 2019) also provided insight into the reliability of AC and DC coupled systems and found that probability of failure for DC-coupled configurations occurs 7 years later than that for AC-coupled configurations. When comparing against the same case sutdy for the AC coupled system, when excess solar is generated above the inverter output capacity the DC coupled system can absorb this excess energy maximing the yeild.

Finally looking typical system sizing for Australia, data from the Australian Energy Council showed that the typical PVS size was between 6.5kW and 9.5kW (Australian Energy Council 2022a) and data from the Clean Energy Council also showed that typical residential battery storage systems range from 3 to 12 kWh in size (Australian Energy Council 2022a).

Key findings for dissertation

There are various installation configurations and overall system component sizes and such it will be important to ensure that the REMD is designed to operate with various system configurations. For the purposes of modelling a typical PVS and BESS will need to be determined (refer chapter 3), but the size and configuration are not the critical factors here.

2.6 Energy Management Systems

Energy management encompasses energy efficiency and productivity, but also considers the broader elements of energy including procurement, generation, systems and most importantly, strategy (Roberts 2018). Without an EMS, optimisation and strategy control of all available inputs and outputs would not be possible. There are two key areas to an effective EMS with the first being the physical device performing automated management and the second being the educational aspect provided to the user.

2.6.1 EMS Devices

When looking specifically at the EMS devices there has been a lot of research undertaken into this area. The main research and applications noted range from smaller EMS to much larger and broader EMS. The following research has been broken down into the relevant sections of PVS and BESS managers, home energy management systems (HEMS) and microgrid energy management systems (MGEMS).

2.6.1.1 PVS and BESS Energy Management Systems

Energy management systems are only required to be installed when a BESS system is connected. PVS do have controller devices (MPPT) to maximise conversion from solar energy to electrical energy, but they don't specifically require a management system. This is because the PVS only operates when the sun is shining and therefore outside of this time is un-manageable. Only once a BESS is connected can the excess generated energy from the PVS be stored in the batteries (Sage Automation 2018). This is where the EMS is required as it is responsible for determining when the BESS is to be charged/discharged.

There are various third-party devices which can be installed to provide the features of an EMS and range from a simple time scheduled system to much more complex system with aspects of day ahead scheduling, processes for maximum profit gain, etc. An example of a simple energy management system was touched on in section 2.5 with the use of a multi-mode inverter, but this does tend to be very limited with management capabilities. Another example of a more comprehensive PVS and BESS EMS is the Tesla Powerwall which has an internal EMS. The Powerwall allows for the user to select various operating modes for how the battery energy is charged/discharged. The following is a summary of the key operating modes:

- Back-up reserve – provides energy during power outages. The BESS will operate normally to offset loads etc until the back-up reserve limit is reached and will not go below this amount. Only once the grid is lost will the BESS go below the pre-defined level.
- Self-powered – stores excess energy from solar production to be used at night. If batteries are charged excess energy is exported to the grid.
- Time-based control – helps to maximise savings through smart charging and discharging of BESS for users on ToU electrical plans. (Tesla 2023)

2.6.1.2 Home Energy Management Systems

HEMS is a technology platform comprised of both hardware and software that allows the user to monitor energy usage and production and to manually control and/or automate the use of energy within a household (Kitisarn & Martin 2021). HEMS can nominally monitor and management aspects of

- Electricity import/export
- Internal sub-circuit/device control
- PV system
- Battery storage system

HEMS fall under two main categories with grid connected and non-grid connected. Grid connected systems typically do not monitor the grid energy consumption, with the intent being to reduce the grid reliance. Whereas the non-grid connected systems are purely focused on ensuring continuity of supply in the absence of grid connected back-up. For the purposes of this dissertation only grid connected controllers will be explored.

A research paper by Badar & Anvari-Moghaddam (2022) provided a good overview of the details on HEMS within residential settings. HEMS framework shall normally be based on the following process: data collection and monitoring, data processing and analysing, forecasting/estimation (if needed), optimisation and execution. It was noted that majority of HEMS devices reviewed in this paper focus on the load energy control with various scheduling and optimisation strategies to reduce peak demand and consumption. This is typically achieved via separating the loads into controllable and uncontrollable loads. For example, controllable loads consist of air conditioners, washing machines, dishwashers, etc, whereas uncontrollable loads consist of lighting, fridges, ovens, etc. The ability to control these loads creates an element of load shedding that can be applied during times such as high ToU charge periods or when energy sources are not able to cope with the load. Another key component noted in an effective HEMS is the ability to load forecast which can be done for PV systems, loads, energy purchasing, energy selling, energy storage, etc. This element of forecasting allows HEMS the ability to make decisions based on upcoming events resulting in smarter more optimised decisions being made (Badar & Anvari-Moghaddam 2022).

A research paper by A. Derrouazin, M. Aillerie, N. Mekkakia-Maaza and J.-P. Charles provided insight to an application of a HEMS device. This paper looked into the development of a multi input-output fuzzy logic smart controller for grid connected residential applications. This smart controller integrated solar, wind, battery storage and also incorporated an electrolysis system to produce hydrogen suitable for household utilities with the overflow of renewable energy production. The fuzzy logic controller was intended to build on previous logic controllers and avoid the simplistic switching of relays to allow simultaneous routing of energy. The controller operated with a discrete set of rules and was simulated in MATLAB Simulink with the data sets gathered by the researchers. The main outcomes of the simulations proved that energy savings of up to 78% are obtainable with the use of the smart controller (Derrouazin et al. 2017). This research further reinforced the findings in Badar & Anvari-Moghaddam (2022) with regards to the ability for energy saving.

Gaining an appreciation of the current target markets uptake or future uptake for HEMS devices is important to ensure that there is a demand for this product. A Queensland household energy survey was undertaken in 2022 in conjunction with Energy Queensland and Powerlink Queensland. The aim of this survey was to provide an insight into customers reviews and behaviours regarding energy. Some of the key outcomes of this survey specifically related to HEMS showed the following:

- 34% of survey respondents are interested in purchasing a HEMS in the next 3 years.
- Interest in HEMS is higher among those with solar PV (36%) than those without (32%).
- Among the smaller sub-sample of those with solar PV who claimed to have battery storage, 64% declared that they were very or somewhat likely to purchase a battery storage system.
- Respondents with battery storage and/or an EV typically showed higher interest the value of HEMS. (Essential Media 2022)

2.6.1.3 Microgrid Energy Management Systems

When looking at the broader grid EMS level, a research paper by Galvan et al. (2019) provided valuable insight to a proposed MGEMS. This particular system was based on a hybrid control algorithm that combined transactive control and model predictive control for efficient management in a prosumer-centric microgrid. Each home within the MGEMS was provisioned with a HEMS that was responsible for a charge schedule of an electric vehicle and a discharge schedule for PVS and BESS. The overall system was implemented in IEEE 33 bus test system and the overall system was evaluated under different electric vehicle and solar/battery storage scenarios. After simulating the results were as follows:

- Peak load reduction of between 21–30% by shifting surplus PV power from off-peak hours using battery storage.
- load ramp rates reduced between 39–58%
- Power losses reduced between 6.3–6.8%

- Bus voltage improvements between 25–75% for busses that present under voltages.
- Total cost reductions between 29–57% and savings between 52–144%

Inferred from the results that the incentives provided by the pricing mechanisms can encourage customers to not only reduce peak demand but also to install more demand-side energy resources (Galvan et al. 2019). This research paper demonstrated the effectiveness of successful energy control systems especially with regards to the peak load reduction and associated cost savings.

Key findings for dissertation

It was noted that majority of HEMS research has not considered the P2P energy market and this is because the P2P energy market is a relatively new concept. The installation of current HEMS is on the load side of the meter, which offers very little opportunities for the ability to interface directly with both the retail and P2P markets easily. The following areas of EMS have been noted for elements to be incorporated but not specially explored under this dissertation:

- Load scheduling will not be a component explored as a large amount of research has been undertaken in this area. The cost for homes to retrofit smart devices, adjust circuiting and the like is additional costs which may turn people away from such management systems. As such the REMD won't require such drastic changes to electrical installations.
- Load forecasting is a critical feature for an effective EMS but has had a large amount of research undertaken in this area.
- Interfacing of the REMD with broader MGEMS.

2.6.2 EMS Education

The second layer to effective EMS is the prosumer education. It is an important aspect in increasing positive changes to reducing energy consumption and adjusting energy demand profiles, as modest behaviour adjustments can, over time, yield substantial energy savings on their own (Cornago 2021).

Delving further into the article by Cornago (2021) about the behavioural interventions for optimising energy usage showed that habits (relating to subconscious preference for the status quo), personal preferences and social norms shape energy usage routines and behaviours. These behaviours can be hard to break, but through successful use of the following key behavioural levers positive energy improvements can be made:

- Simplification and framing of information to the user – i.e. simplified display or billing data.
- Feedback mechanisms – such as real time data through in-home displays, mobile applications or web portals that are fed with data from smart metering systems.
- Social norms and comparisons - illustrating energy consumption in comparison to that of comparable households in the same area.

- Goal setting, commitment devices and reward schemes. (Cornago 2021)

Looking at an Australian example of educational/behavioural based energy intervention, in 2009 the Queensland Government initiated the ClimateSmart Home Service. This program was designed to secure long-term behaviour change of energy and water usage by focusing on strong customer relations and access to relevant and customised information. After 300,000 homes had been retrofitted with energy monitoring devices with visual displays the results showed that the service had reduced electricity use by an estimated 3.96 kWh/day or 1,445 kWh/year, with total savings estimated at $600 million (Kassirer 2012). This initiative shows that people play an important role in energy consumption as the ClimateSmart Home Service device consisted of nothing more than a visual display aid.

To provide insight to people's motivations a survey undertaken by Petkov et al. (2011) showed that motivation for saving energy came down to two key areas of money and pro-environmental. People motivated by money were obviously interested in how much money they have saved/made, whereas the people interested in with pro-environmental varied between how many kWh or CO_2 was consumed/saved. An influential characteristic for the measurement units was the experience of the user in saving energy. The experienced users were comfortable with kWh whereas those lacking experience sticked mostly to the financial representation and only partly to CO_2. It was also noted that the efficiency scale valuable in providing them a justification for the users performance (Petkov et al. 2011). This research provides valuable insight into the importance of education to prosumers and providing the relevant energy display information in line with their interests.

Key findings for dissertation

The REMD will need to have a display for the relevant information to the user as educational component of EMS is very important. The aspect of keeping the display information simple and relevant especially with reference to differing motives will be a focal point of the display.

2.7 Energy Control Strategies

As discussed in section 2.6 there have been various papers presenting different approaches for EMS, but further research is required into the most appropriate EMS control strategies for the REMD. This is to ensure that the most suitable and efficient energy controller is being implemented. For the purposes of this section the controller types have been narrowed down to fuzzy logic controller (FLC) and state machine control (SMC).

The use of fuzzy logic refers to the decision-based scale with assessing truths of the given information rather than that of the traditional binary logic. To put more simply a two-valued logic (binary) often considers 0 to be false and 1 to be true. Whereas, fuzzy logic deals with truth values between 0 and 1, and these values are considered as intensity (degrees) of truth (Rouse 2022). FLC controllers work by taking a crisp input and using fuzzification techniques to produce a fuzzy variable which is input to the inference section. A set of rules is then used to determine what the corresponding output fuzzy variable will be from the inference section. Form here the output fuzzy variable is input to the defuzzification section which is the inverse of the fuzzification techniques and a crisp output is produced (Figure 6).

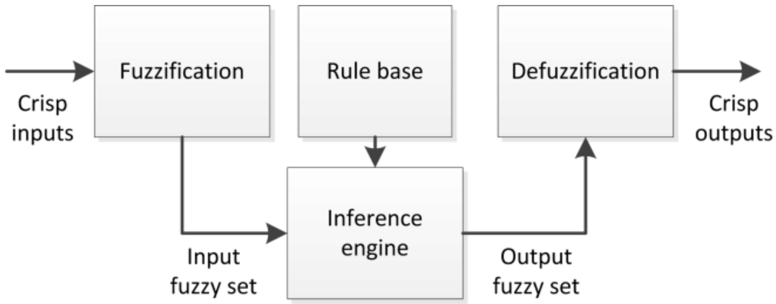


Figure 6: FLC block diagram (Panduru et al. 2014)

Fuzzy logic controllers (FLC) in principle responds in a very similar manner to PID controllers. When developing a controller, a FLC is usually cheaper and easier than PID controller and FLCs are more robust in that they cover a wider operation range (Gouda et al. 2000). Between advanced control strategies, fuzzy logic control is often found in applications where conventional closed loop control does not assure satisfactory results because of non-linearity, asymmetric dynamics, or uncertainties in the controlled processes (Vasičkaninová et al. 2022).

A state machine (SM) also known as a finite state machine is a type of controller which has a finite number of conditions which are known as states. This form of controller reduces the controller to just four components; inputs, outputs, states and state transition rules (UBC 1998). To further extend on this the SM uses the input information to determine the applicable state (associated outputs) based on the transition rules. It is also important to note that the SM can only be in one state at a time and will only change states once a transition rule becomes true. Although this controller type has been around for quite a while it is still very effective and simple at providing decision logic for complex systems. Figure 7 below illustrates the aspects of SM notations and simple state diagram.

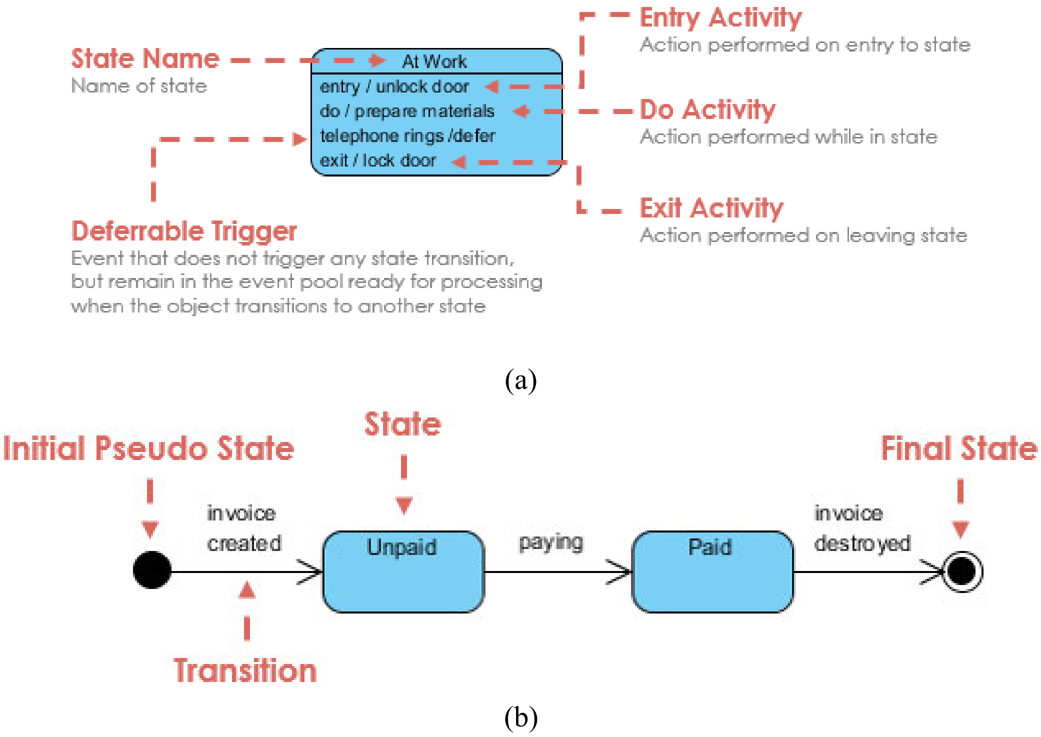


Figure 7: State machine notations and diagram (Visual Paradigm n.d)

<u>Key findings for dissertation</u>

As the model for this dissertation is well understood and defined the implementation of a FLC approach is not practical. It will add additional complexities for a simple model which will have implications for the economic and social considerations described in section 1.7. By implementing a SM it will allow for the REMD to be tested in a more straightforward and logical way which is important at the conceptual design phase to understand the feasibility of this EMS before complex code is written.

Chapter 3 – Methodology

The following is a breakdown of the methodology for this dissertation:

- Conduct background research into the following residential energy components:
  - Australian energy market
  - Queensland retail energy market
  - P2P energy market
  - Retail metering
  - PVS and BESS configurations
  - Energy management systems
  - Energy Control strategies
- Perform visual inspections of residential electrical installations to gain an understating of typical arrangements. This will consist of investigating switchboards, metering, circuits, PV systems and battery storages systems.
- Acquire typical interval load data for the following residential components:
  - PV system export
  - Battery storage system import/export
  - Grid connected power import/export (extending to sub-circuit breakdown)
  - Localised energy grid import/export
- Design a conceptual strategy control for the REMD based on the operating modes.
- Design a conceptual display unit for illustration of relevant information based on the operating modes.
- Model the REMD in MathWorks MATLAB Simulink environment and perform simulations with the gathered data.
- Evaluate and discuss the results from modelling.

As time is of the essence it is intended that there will be specific limitations to allow for completion of this dissertation within the given timeframe. The following is a summary of specific limitations:

- Designing, modelling, simulating and testing the REMD in the all operating profiles may not be possible.
- Simulation of the REMD within a localised energy grid network consisting of other houses has not been explored.
- Simulation of the controller with real-time or detailed load data has not been explored.
- As no human studies are intended as part of this dissertation the educational benefits of the display cannot be assessed.

3.1 Resource Requirements

Without access to the available resources this dissertation would not be possible and Table 4 provides a summary of the required resources to undertake the dissertation.

Resource	Requirement	Availability
Computer	▪ Modelling and simulation ▪ Documenting the dissertation	Yes – Both home and work
Internet	▪ Access to online resources ▪ Complete literature review	Yes – Both home and work
Mathworks MATLAB Simulink and Stateflow	▪ Design, modelling and simulation of REMD	Access provided through USQ student license
Microsoft Office suite	▪ Modelling of data ▪ Documenting the dissertation	Yes – Both home and work
Standards, manuals and specifications	▪ Design of device ▪ Documenting the dissertation	Yes – Access provided through USQ and work subscriptions

Table 4: Summary of required resources and availability

3.2 Data Gathering

Without access to reliable and accurate data the modelling, simulation and testing of the REMD would not be possible. Table 5 provides a summary of the required data resources with subsections 3.2.1 to 3.2.6 providing a detailed breakdown of the specific data types and how this data was accessed.

Data Type	Data Requirement
Typical Residential electrical systems	▪ Site photographs ▪ Metering type ▪ Circuit arrangements ▪ Typical PVS and BESS configuration
Solar	▪ System size ▪ Max continuous export ▪ Typical interval export data for sunny, overcast and rainy-day
Battery	▪ System size ▪ Max continuous export ▪ DoD
Residential load	▪ Typical interval data load profiles
Residential peer to peer energy trading	▪ Residential peer to peer energy trading data model showing when adjacent houses would be buying or selling power
Residential retail energy plan	▪ Simulation of retail energy market plan in model

Table 5: Summary of required data resources

3.2.1 Typical Residential Electrical Systems

To gain an understanding of typical residential electrical systems site visits were conducted at three locations. This component was required to verify and ensure online data sources used for modelling are reflective of current electrical installations. The site visits consisted of visual inspections only and the main areas of interest were the switchboard, metering arrangement, electrical circuit configurations, PVS and BESS. Due to limited access to suitable site locations only one of the sites contained a PV system and none of sites contained a BESS. The following sub-sections provide a summary of each site visit.

3.2.1.1 Site 1

Site location one is an older home (1991 build) in Mooloolah Valley, Sunshine Coast which is a small three-bedroom home. Both a PV system and BESS were not installed at this home.

Figure 8: Site 1 photos: MSB (left) and sub-circuits (right)

Metering Type	Circuits	PVS	BESS	Comments
Accumulation	Hot water unit Stove Power (x2) Lights Air conditioner	No	No	Two meters were present along with a ripple control relay. It was determined that the secondary meter is for the hot water unit which is on a separate tariff (tariff 33).

Table 6: Summary of site 1 electrical system

3.2.1.2 Site 2

Site location two is a newer home (2014 build) in Mountain Creek, Sunshine Coast which is a small three-bedroom home. Both a PV system and BESS were not installed this home.

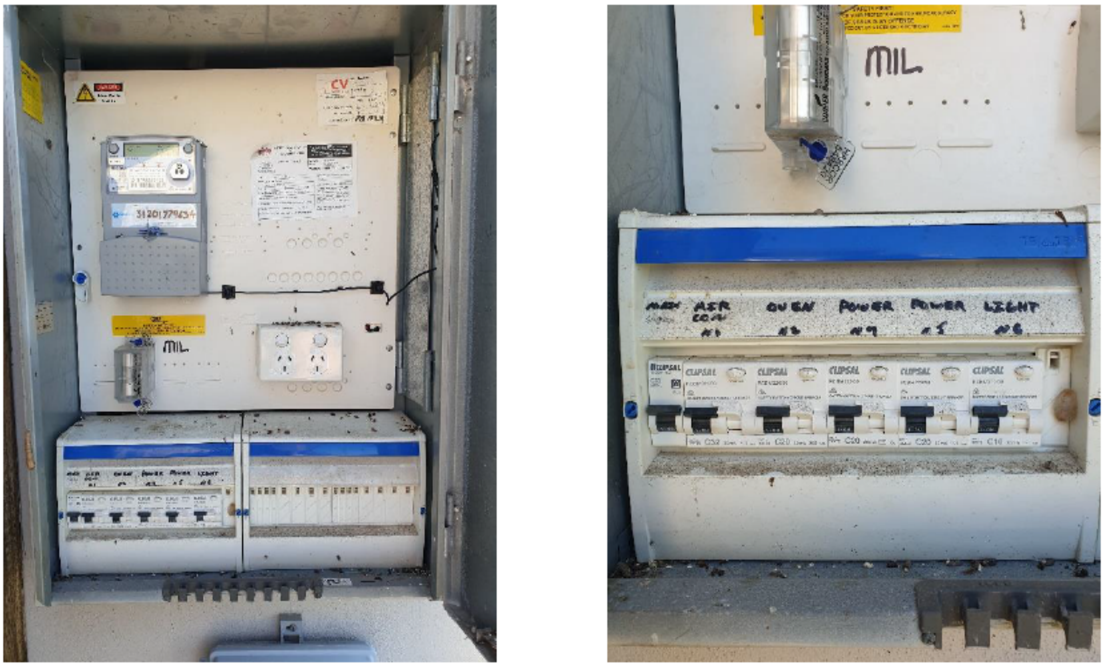


Figure 9: Site 2 photos: MSB (left) and sub-circuits (right)

Metering Type	Circuits	PVS	BESS	Comments
Smart (type 4)	Oven Power (x2) Lights Air conditioner	No	No	Instantaneous gas hot water system and gas stovetops were installed at this house in lieu of electric

Table 7: Summary of site 2 electrical system

3.2.1.3 Site 3

Site location two is an older home (2005 build) located in Mountain Creek, Sunshine Coast which is a larger four-bedroom home. A PV system was installed but no BESS was present.

Figure 10: Site 3 photos: MSB (left) and sub-circuits (right)

Metering Type	Circuits	PVS	BESS	Comments
Smart (type 4)	Hot water unit Pool Solar Stove Power (x3) Lights (x2) Air conditioner	Yes	No	Supply is three-phase Submains connection to distribution board

Table 8: Summary of site 3 electrical system

3.2.2 PVS Data

The PVS interval data has been extracted from website called PV Output (PV Output 2023) where users can record and upload their PV system data. The nominal data for this dissertation has been provided from a location in Brisbane, Queensland as this corresponds to the relevant DNSP jurisdiction area of interest. The exact location and other specifics of the installation have not been included due to ethical considerations. Details pertaining to the system such as PV panels size, type and orientation were not provided but the system size was noted as 6.93kW. For the purposes of conceptual design only modelling of a typical summer sunny, overcast and rainy days will be utilised. This will allow for a more simplified approach to determining how the controller responds and operates under these typical conditions.

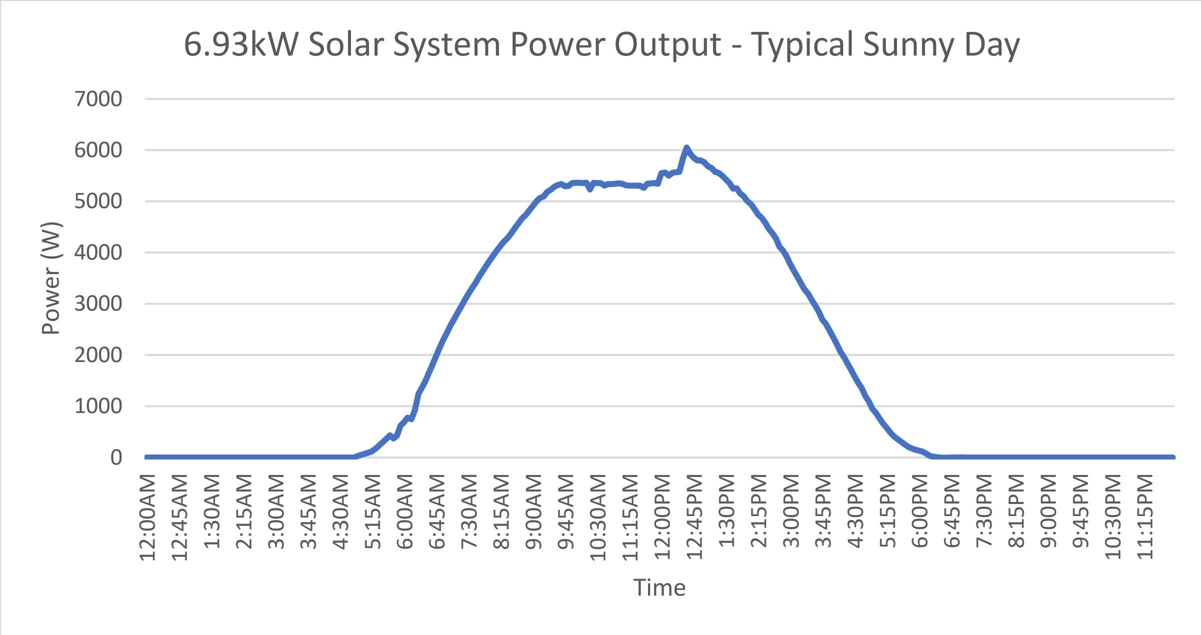


Figure 11: 6.93kW solar system typical sunny day power output

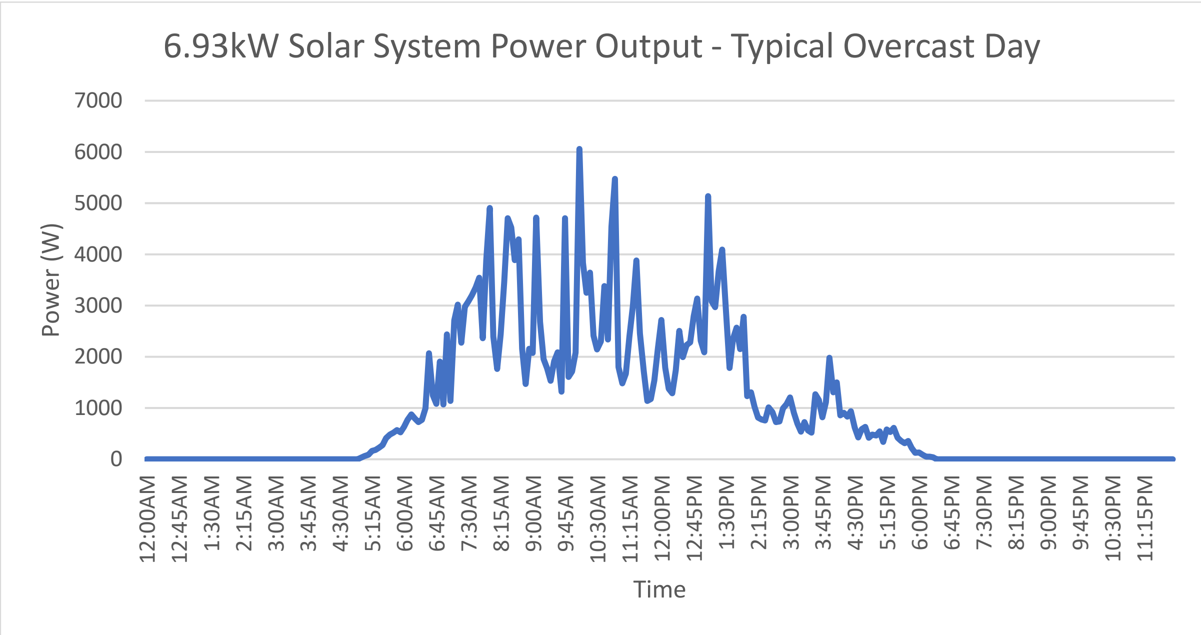


Figure 12: 6.93kW solar system typical overcast day power output

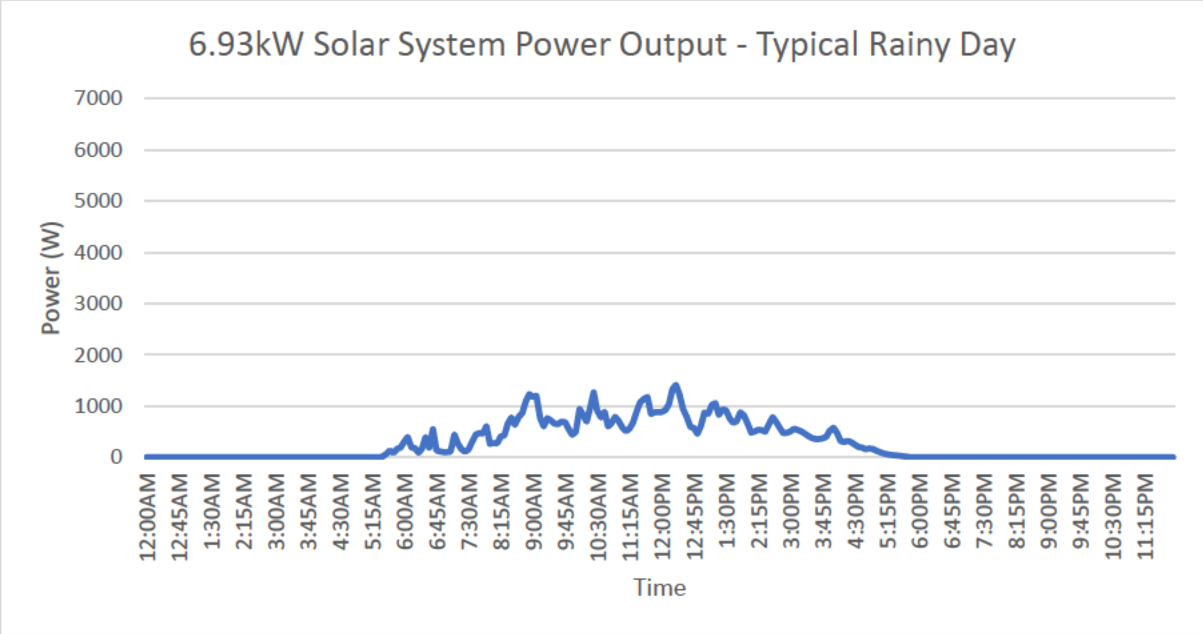


Figure 13: 6.93kW solar system typical rainy day power output

As previously discovered through the literature review the maximum export limit for an inverter within the Energex DNSP region is 5kW per phase. The Sungrow SH5.0RS hybrid single phase inverter has been selected as the reference inverter for modelling. Key parameters of this inverter which will need to be incorporated into the model are shown in table below. Refer to appendix C for detailed datasheet showing all specifications. Note that this reference inverter is a multi-mode inverter allowing for the BESS to charge from the grid if required.

Parameter	Value
Max. continuous output	5 kW
Max. charge power to BESS	6.6 kW
Efficiency	97.7%

Table 9: Reference inverter parameters

3.2.3 BESS Data

The Sungrow SBR0128 lithium iron phosphate battery has been selected as the reference BESS for modelling. This battery has been chosen as it has a high efficiency, very low DoD and a large continuous output. Although the DoD can be as low as 100% it is recommended that the battery not be continuously discharged to this level and as such a nominal figure of 90% has been chosen. It is also worth noting that the limiting export factor is the hybrid inverter (refer section 3.3.2).Key parameters of this battery which will need to be incorporated into the model are shown in table 10. Refer to appendix D for detailed datasheet showing all specifications.

Parameter	Value
Nominal capacity	12.8 kWh
Energy (useable)	11.52 kWh
Max. continuous charge/discharge	6.87 kW note 1
Depth of Discharge (DoD)	90%
Efficiency	90%

Note 1: Maximum continuous charge rate is achievable in the DC coupled configuration. AC coupled configurations would be limited to inverter maximum output of 5kW and BESS charging from the grid will be limited to the multi-mode inverter.

Table 10: Reference battery parameters

3.2.4 Residential Load Data

The residential load data has been extracted from a study undertaken by the CSIRO in 2012/2013 which was undertaken to provide an understanding of typical house energy use (CSIRO n.d). This study consisted of data logging 209 residential households to determine typical loads for air conditioning, ovens, lights and general power. Although the data is 10 years old it is still considered relevant as the homes included within the study were constructed between 2000 and 2010 and would still be a relevant reflection of a typical home today. The data of interest from this study is specifically related to Queensland homes (total of 43 in the study) with an energy star rating of less than 4.5 stars. After completing the site visits in section 3.2.1 it was noted that the typical circuits assessed under this study coincided closely with that witnessed on the three site visits which reinforces the data reliability. For the purposes of a conceptual modelling, simulation and testing, typical seasonal load profiles will provide a good representation in lieu of retail metering interval load data. The following graphs show the relevant Queensland seasonal load profiles for each of the circuits and also the combined total energy load profile.

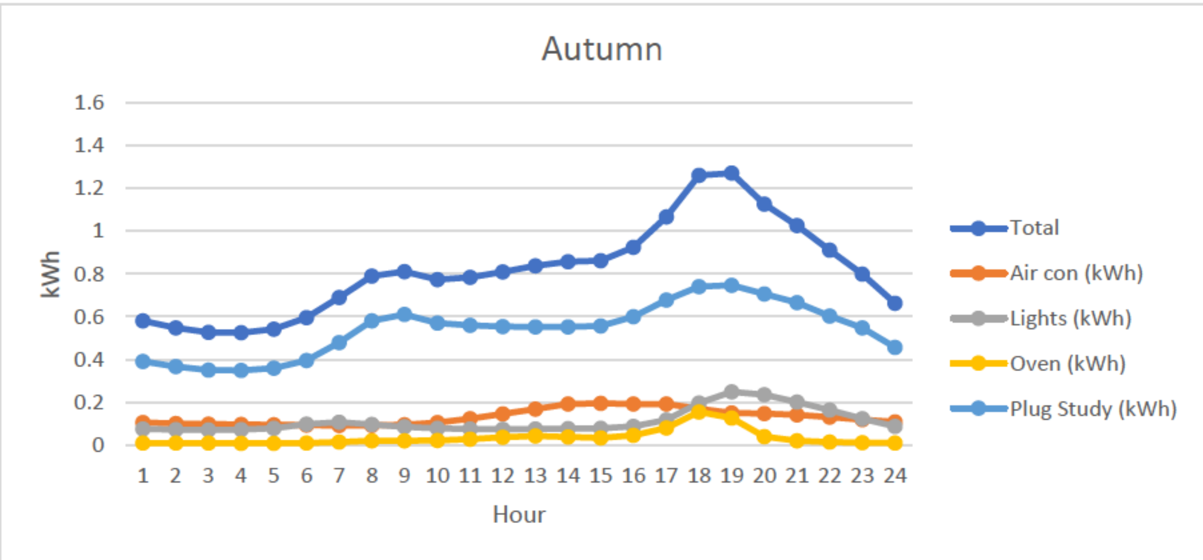


Figure 14: Typical load profile in Autumn

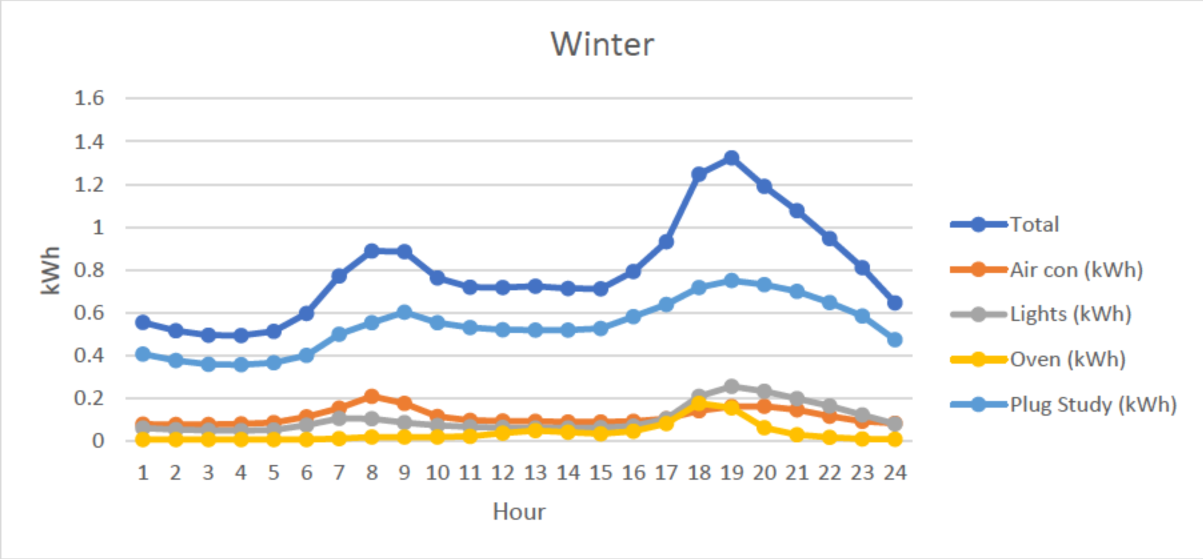


Figure 15: Typical load profile in Winter

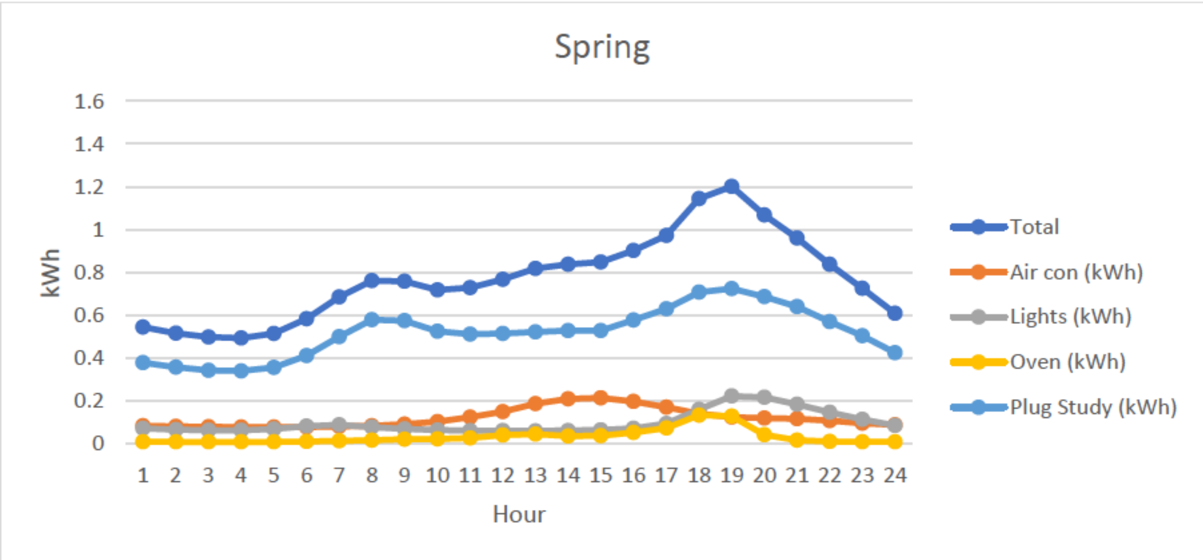


Figure 16: Typical load profile in Spring

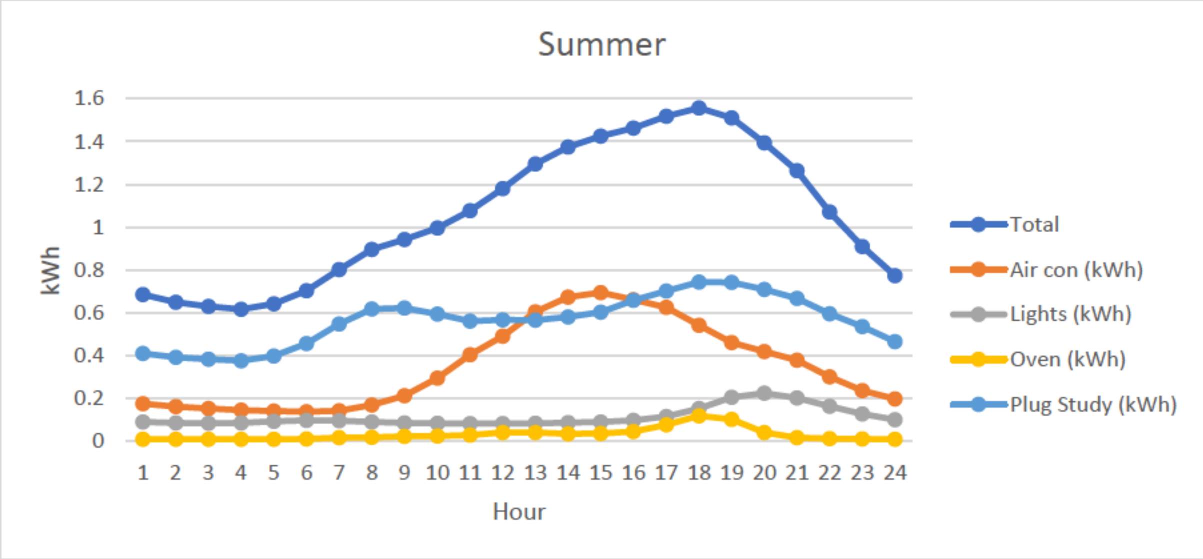


Figure 17: Typical load profile in Summer

3.2.5 P2P Energy Market Data

P2P energy market data is currently not available as this technology is currently not readily accessible to residential energy customers. This data is a critical component to modelling the validity of the REMD so in lieu of having actual data for this component it is proposed that nominal data will have to be created. It is proposed that a simplified P2P energy market model will be simulated via the use of a square wave form. This square waveform will provide the relevant logic (refer below table) to determine if there are prosumers or consumers available in the local P2P energy grid. Noting the price points for P2P markets could be either fixed or dynamic it is nominated that in order to ease simulation, sell and purchase prices of energy on the P2P network will be a nominal flat rate of 15c/kWh.

	Square Waveform Amplitude	
	Export/Import	Nil export/import
P2P energy market logic	1	0

Table 11: P2P energy market logic

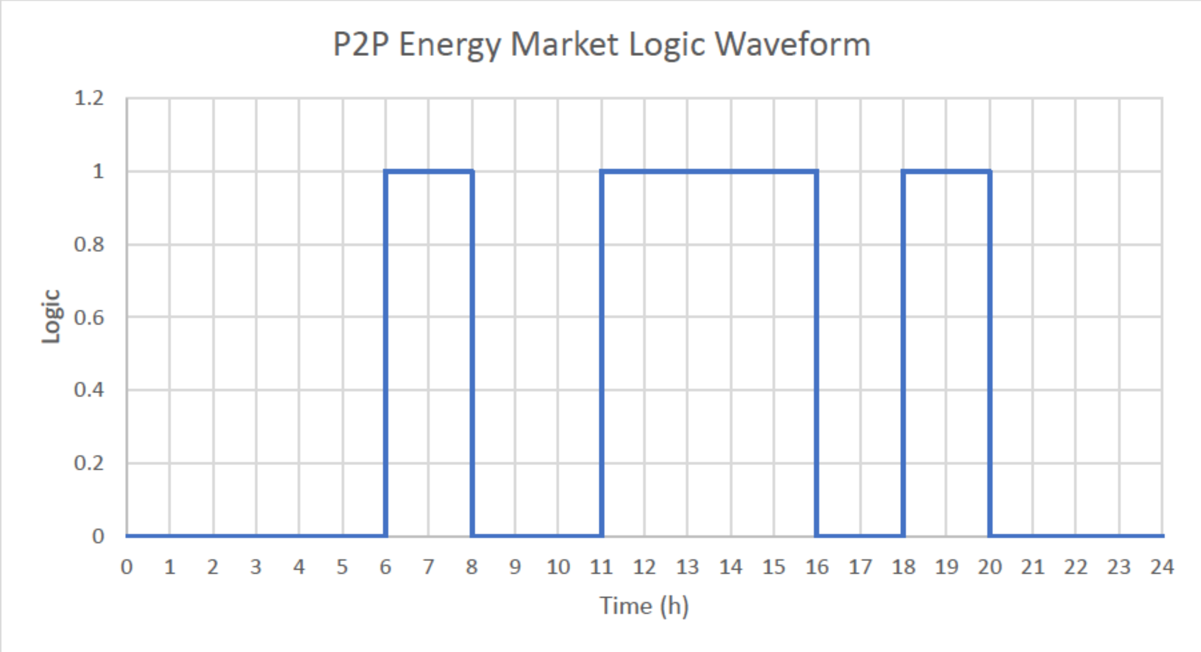


Figure 18: Example P2P energy market logic waveform

3.2.6 Residential Retail Energy Plan Data

Based on the previous research undertaken in chapter 2 with tariff structures and retail metering plans, for the purposes of modelling a typical retail energy plan will be used. Assessing retailer plans and selecting the most suitable plan is considered outside of the scope of this dissertation but the typical plan chosen is reflective of current market conditions for ToU and FiT. Note that controlled loads are considered outside the assessment of this dissertation.

Charge Type		Charge Amount
General Usage (weekdays)	Peak (4pm – 7:59pm)	35.51c/kWh
	Shoulder (7am – 3:59pm) & (8pm – 9:59pm)	23.86c/kWh
	Off-peak (10pm – 6:59am)	22.17c/kWh
General Usage (weekends)	Shoulder (7am – 9:59pm)	23.86c/kWh
	Off-peak (10pm – 6:59am)	22.17c/kWh
Daily Supply		109.53c/day
Solar feed-in		8.0c/kWh

Table 12: Reference energy plan with reflective tariffs

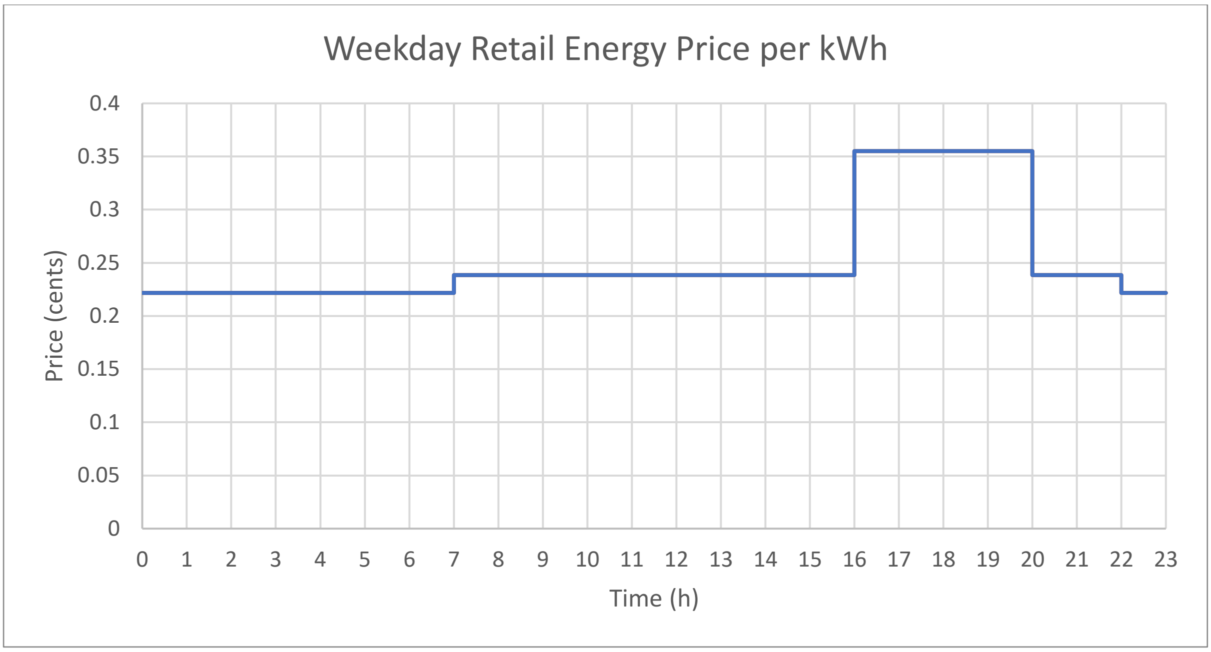


Figure 19: Visual representation of weekday retail energy price per kWh over 24hr period

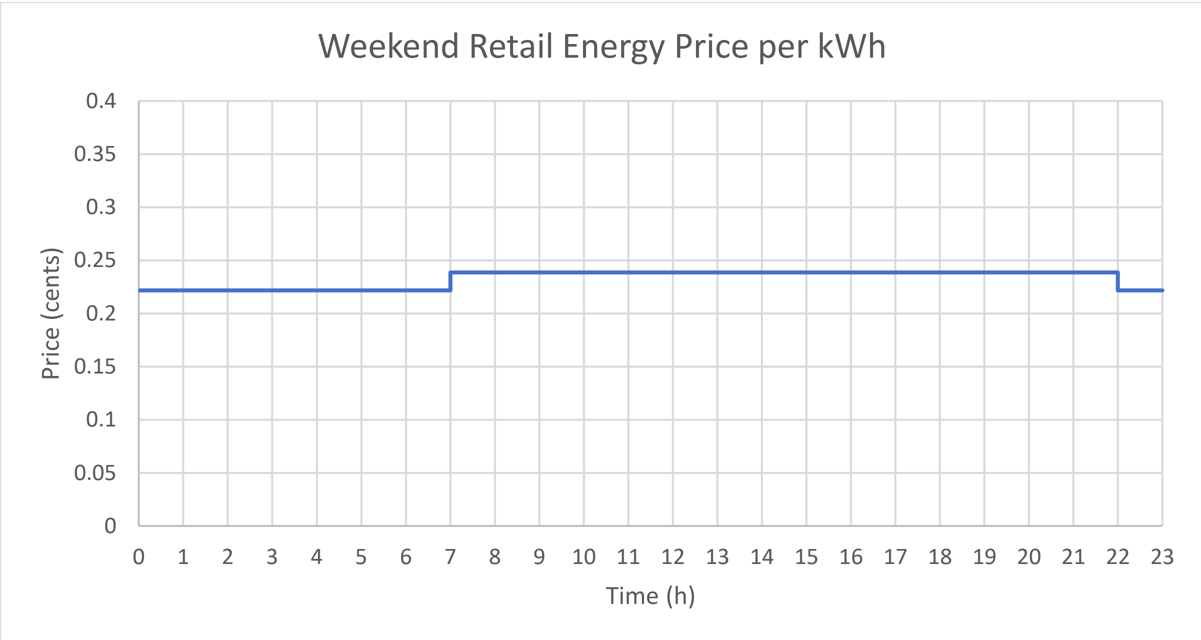


Figure 20: Visual representation of weekend retail energy price per kWh over 24hr period

3.3 REMD Design

The REMD as part of this dissertation is to be designed to conceptual level only as part of a feasibility study. Considerations for system hardware components, sizing, etc have been considered outside the scope of this dissertation. The nominal system for modelling will be achieved via a strategy control state machine as researched in chapter 2 section 2.7 and the approach for designing this system requires an understanding of the inputs, outputs, states and state transition rules (UBC 1998).

3.3.1 Inputs & Outputs

The following table provides a summary of the relevant inputs and outputs of the system with figure 21 providing a schematic representation of the system.

Inputs	Comment
Retail energy network	-
P2P energy grid	-
PVS	-
BESS	DC coupled with PVS
Inverter	-
Operating profile selection	The operating profile buttons will allow the user to select the appropratie operation mode and will be a simple 3 button switch plate
Metering CT's	Used to monitor energy consumption/export
Outputs	Comment
Display	Provides the educational purposes and visual tool for the user to gauge system performance and expected outcomes. Will contain aspects related to the operating profile and individual circuits.
Communication network	Provides the communication to and from the relevant input and outputs of the REMD.
Wireless transmitter	Required for retail and P2P markets for energy data transmission for billing. This specific element of the REMD been considered outside the scope of this dissertation

Table 13: Summary of inputs and outputs of REMD

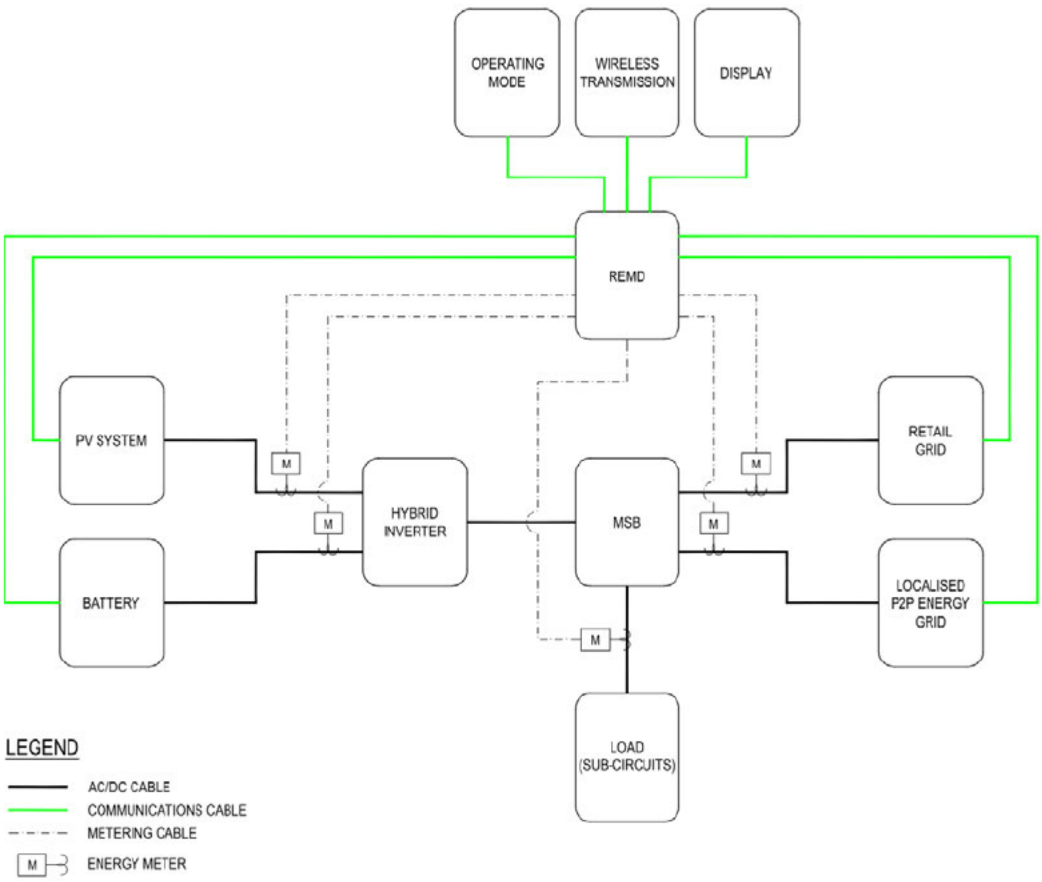


Figure 21: Schematic representation of REMD in a nominal electrical system

3.3.2 States

Each of the operating modes needs to be defined with clear objectives and aims as this will inform the strategy control in the state-based system. Although each operating mode will have a similar energy usage hierarchy there are slight differences with how the excess energy production is handled. The state variables and associated state based flow charts are detailed below.

<u>Operating Mode 1 - Sustainability Mode</u>

Target group: Users that want to place more emphasis on environmental sustainability.

Aim: Reduce grid reliance through optimising internal renewable energy generation, with less emphasis placed on excess generation being exported to the grid.

Energy Strategy:

- PVS → BESS → P2P market → Retail market
- Excess generation from PVS – charge batteries
- BESS – discharge if PVS is not available or not enough for load
- Import of energy – P2P market as preference and if not available import from retail market
- Export of energy to grid – N/A
- Import of energy from grid to charge BESS – N/A

Operating flowchart:

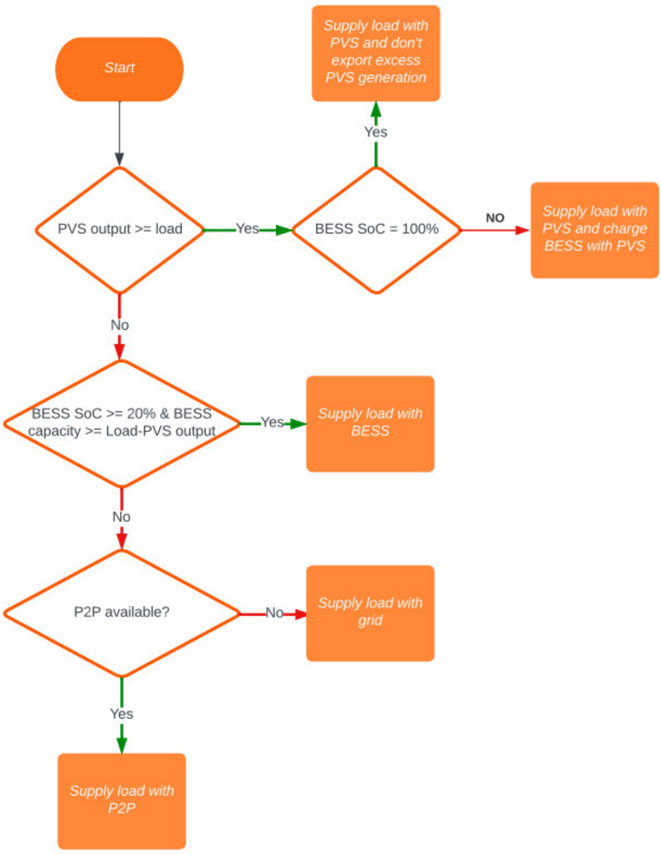


Figure 22: Flowchart for REMD sustainability operation mode

<u>Operating Mode 2 - Traditional Mode</u>

Target group: users that are not actively concerned about their energy choices and want a conventional energy experience.

Aim: The aim is to give a rounded energy experience without the P2P market that reduces energy bills and grid reliance.

Energy Strategy:

- PVS → BESS → Retail market (P2P market not available in this mode)
- Excess generation from PVS – charge BESS first and then export to retail market
- BESS – discharge BESS to offset load with following strategy
    - Peak– export up to the full BESS capacity
    - Off-peak / shoulder – export up to half of BESS capacity
- Import of energy – retail market
- Export of energy to grid – retail market
- Import of energy from grid to charge BESS – retail market during off-peak tariff only

Operating flowchart:

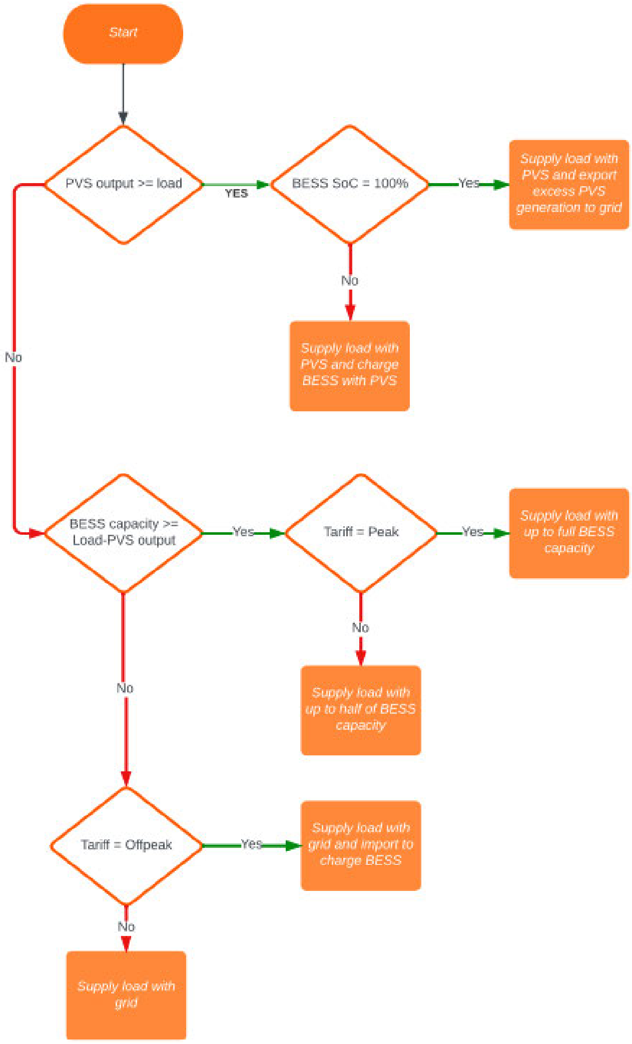


Figure 23: Flowchart for REMD traditional operation mode

<u>Operating Mode 3 - Benefit Mode</u>

Target group: prosumers that want to offset energy bills or possibly receive payments for energy production.

Aim: The aim is to minimise energy import during peak times and maximise energy export during high FiT times.

Energy Strategy:

- PVS → BESS → P2P market → Retail market
- Excess generation from PVS – to occur in the following order
    - BESS SoC = Full – export full excess PVS to retail market or P2P market
    - BESS SoC = high - charge BESS with half of excess PVS and export half of excess PVS to retail market or P2P market
    - BESS SoC < high - charge BESS with full excess PVS
- BESS – discharge BESS to offset load with following strategy
    - Peak / shoulder tariff – export up to the full BESS capacity
    - Off-peak - export up to half of BESS capacity and export a certain proportion of BESS to the retail market or P2P market
- Import of energy – P2P market as preference and if not available import from retail market
- Export of energy to grid – P2P market as preference and if not available export to retail market
- Import of energy from grid to charge BESS - P2P market

Operating flowchart:

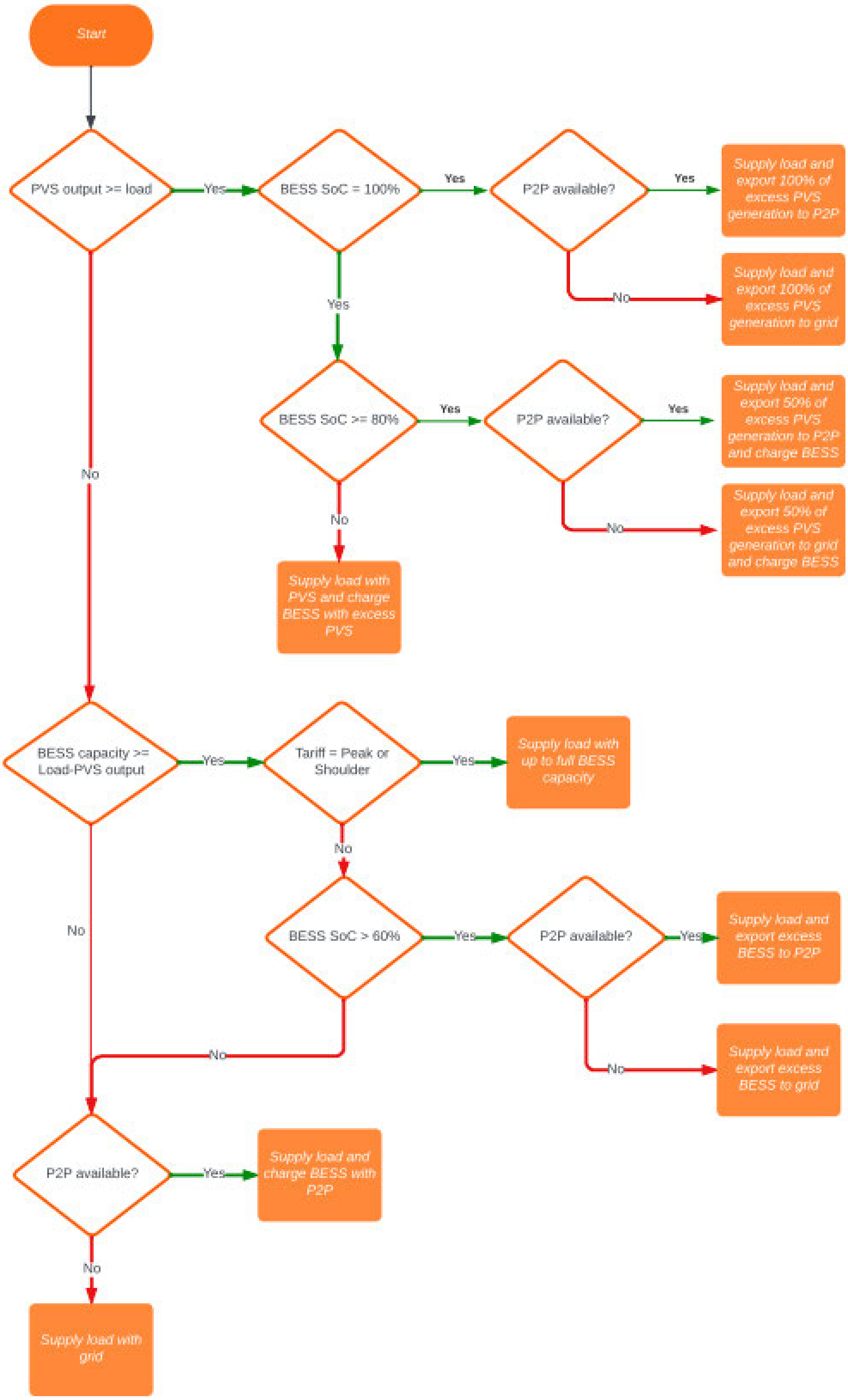


Figure 24: Flowchart for REMD traditional operation mode

3.3.3 Display Design

The other aspect of the REMD is the display which will present the relevant information giving the user a live version of energy consumption, production, etc whilst also providing the ability to switch operating modes. Each display area will have a separate function which are defined in the below table with the overall aim being to provide the educational component and inform user of the relevant information in-line with the operating mode.

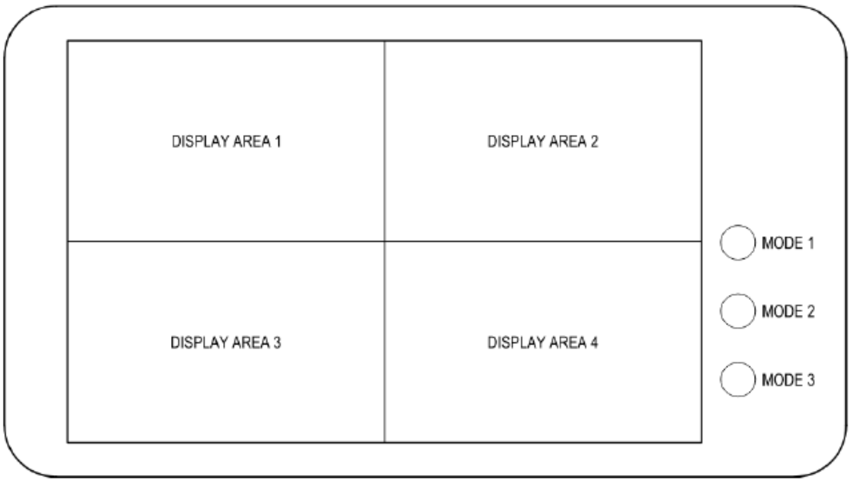


Figure 25: Nominal layout of display unit with demarcation of display areas

Display Area 1	**Display Area 2**
Demand Total daily demand BESS SoC PVS output	Daily cost Average daily cost Sustainability mode – CO_2 offset Traditional mode – N/A Benefit mode – Daily profit and total profit
Display Area 3	**Display Area 4**
Plot of circuits and total energy demand	Breakdown of energy usage across available sources

3.4 Modelling

3.4.1 Software

In order to perform the model design and simulation, Mathworks MATLAB Simulink is the nominated software environment. Simulink is a block diagram environment used to design systems with multidomain models, simulate before moving to hardware, and deploy without writing code (Mathworks n.d). Within the Simulink environment the specific add-on feature stateflow is also being used as it provides a graphical language that includes state transition diagrams, flow charts, state transition tables, and truth tables that are required for the state-based strategy control of the REMD.

Mathworks MATLAB version: R2021a Update 4 (9.10.0.1710957) 64-bit (win64) July 1, 2021

The REMD in general has been modelled utilising the Simulink environment in conjunction with the specific add-on feature stateflow. Each operating mode was configured with a very similar layout within Simulink that consisted of the data components (inputs/outputs), the main stateflow block which is considered as the physical REMD, and finally the REMD display. The following sub-sections delve further into each of the main areas of the model.

3.4.2 Modelling Data Components

3.4.2.1 Input - Clock

Timing was achieved via the Simulink library browser sources "counter limited" block. This block allows a for a counter to count to predefined number at the defined interval and then reset back to zero. For the purposes of this model there were two counters used as follows:

1. 24 hour clock – used to synchronise the model to an hourly interval over a 24 hour day. This was used to determine when each tariff price was applicable and when to import/export energy based on the corresponding tariff pricing and was known as input "count" in the model.
2. Day of the week clock – used to synchronise the model to the corresponding day of the week interval over 7 days. This was used to determine when the weekday and weekend tariff pricing structures were applicable and was known as input "day" in the model.

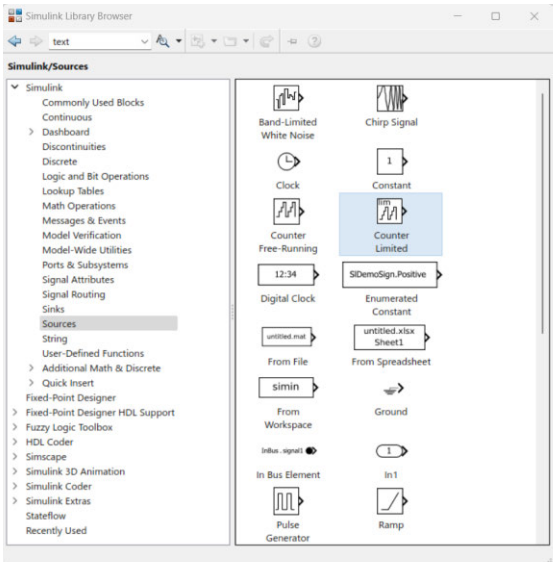


Figure 26: Simulink "counter limited" block

3.4.2.2 Input - Excel Data

Modelling of tabulated data input data components will be achieved via the Simulink library browser sources "from spreadsheet" block (refer figure 27 below). This block reads data from an excel spreadsheet and outputs the data as a signal (i.e. waveform). The following is a list of the excel data components (refer to appendix E for relevant excel data used for the modelling):

- Load interval data
- PVS interval data
- P2P energy market data – logic waveform

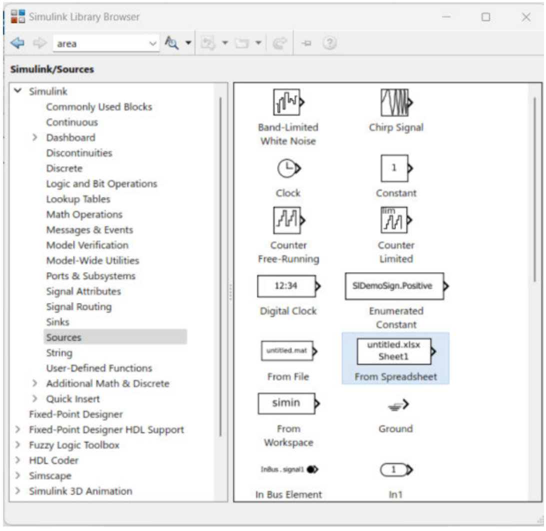


Figure 27: Simulink “from spreadsheet” block

Note that the PVS interval data was also fed through a gain block which allows for the PVS output to be scaled up/down as required to simulate different PVS sizes. Operating with a gain of one will result with the PVS being equivalent to a 6.93kW.

3.4.2.3 Input - Constants

System constants were achieved via the Simulink library browser sources “constant” block. This block allows a for a constant within the model and the following is a list of the constant data components:

- PVS size
- Peak, shoulder and off-peak grid import tariffs price
- Grid export tariff price
- P2P import/export tariff price

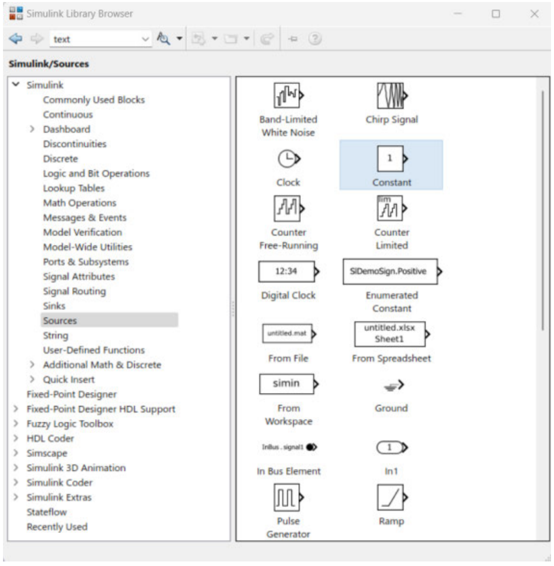


Figure 28: Simulink "constant" block

3.4.2.4 Outputs

System outputs were terminated into Simulink library browser sinks "display" blocks. This block simply displays the output value of the connected port and was used to terminate the output signals to which can be connected to the REMD display.

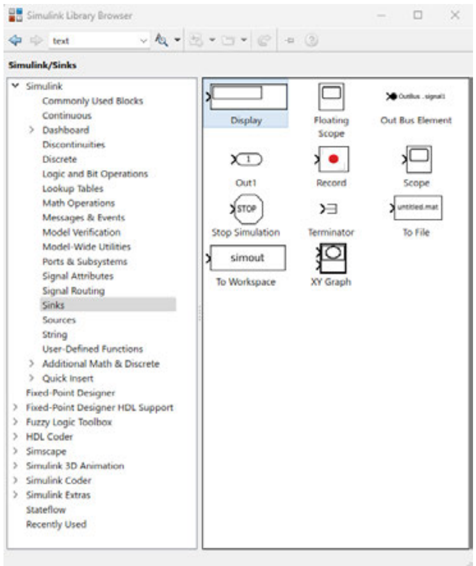


Figure 29: Simulink "display" block

3.4.3 Modelling the REMD

The ideal model for the REMD would be to have an all-in-one design which encompasses the three operating modes in a single stateflow as this would be the intent for the actual design of the product. However, for the purposes of this dissertation each operating mode has been modelled separately as it allows for ease of design, testing/debugging and finally simulation. Each operating mode of the REMD was modelled in an identical framework that consisted of the following sections:

- Tariff state – consistent for all three operating modes
- Battery state – consistent for all three operating modes
- REMD state – specific to the operating mode
- Display state - specific to the operating mode

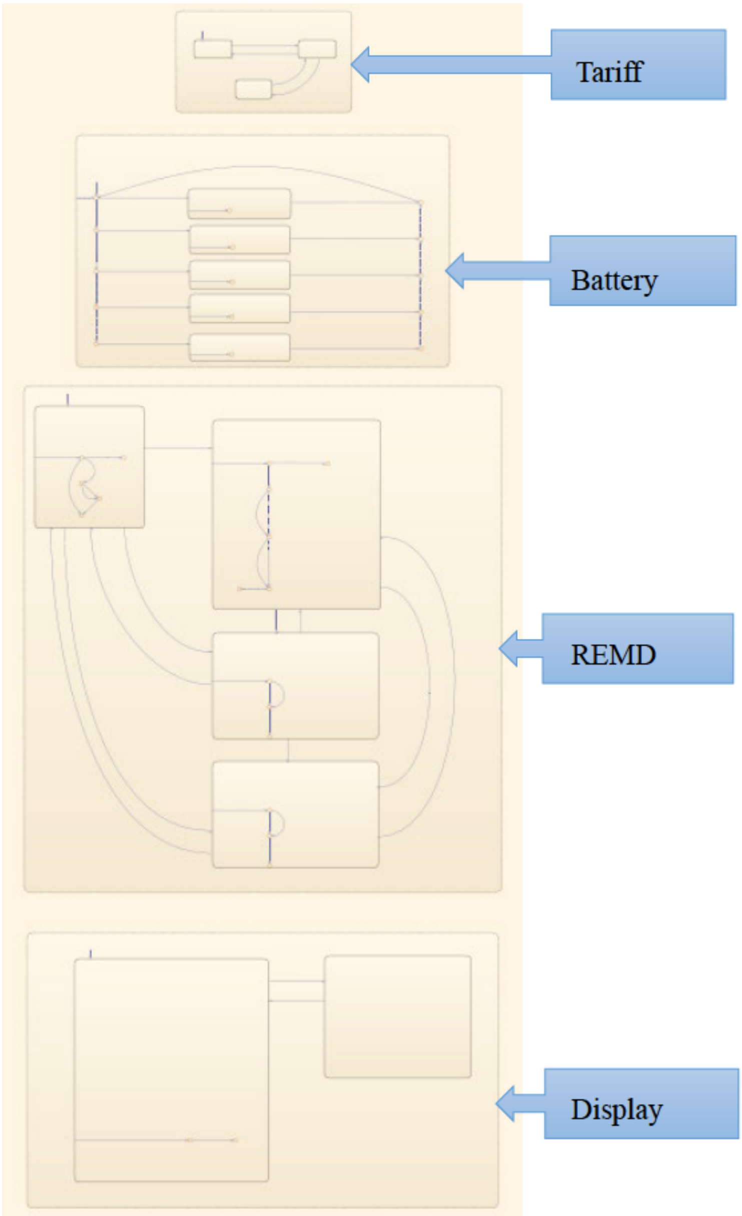


Figure 30: Overall REMD stateflow

Each of the individual stateflows listed above are configured in a parallel arrangement which allows them each to be evaluated at the same time increasing the speed and overall efficiency of the code.

3.4.3.1 Tariff Stateflow

The tariff stateflow (Figure 31) was used to determine which retail tariff pricing was applicable based on the time of day. This allowed for varying tariff pricing to be entered into the constant blocks without the need to change the stateflow code. This stateflow consisted of three operating states which reflected the weekday and weekend tariff structures as shown in section 3.2.6. The state would change dependent on the “count” variable (which functioned as the 24-hour clock) and the “day” variable (which functioned as the day of the week). The return from this stateflow was the corresponding tariff price which was then used in the cost calculations for the import of energy and also for determining when to import/export energy from the grid for the traditional and benefit operating modes.

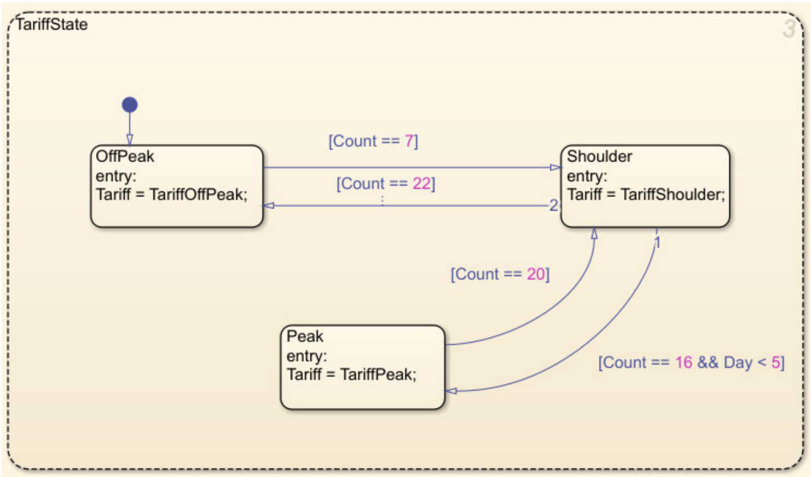


Figure 31: Tariff state stateflow

3.4.3.2 Battery Stateflow

The battery state (Figure 32) was used to determine the battery state of charge (SoC). This particular stateflow allowed for the battery SoC to be known which could be used to determine if there was enough energy capacity to supply the load if operating in battery mode. The SoC was broken down into five levels according to the depth of discharge (DoD) limit for the battery and represented the five possible states for this stateflow. The chosen nominal reference battery in section 3.2.3 has a maximum safe DoD of 90% so the increments between the DoD and 100% were just divided into equal segments. To determine the SoC the charge level of the battery in kWh was compared against the predefined percentage relevant to the SoC state levels.

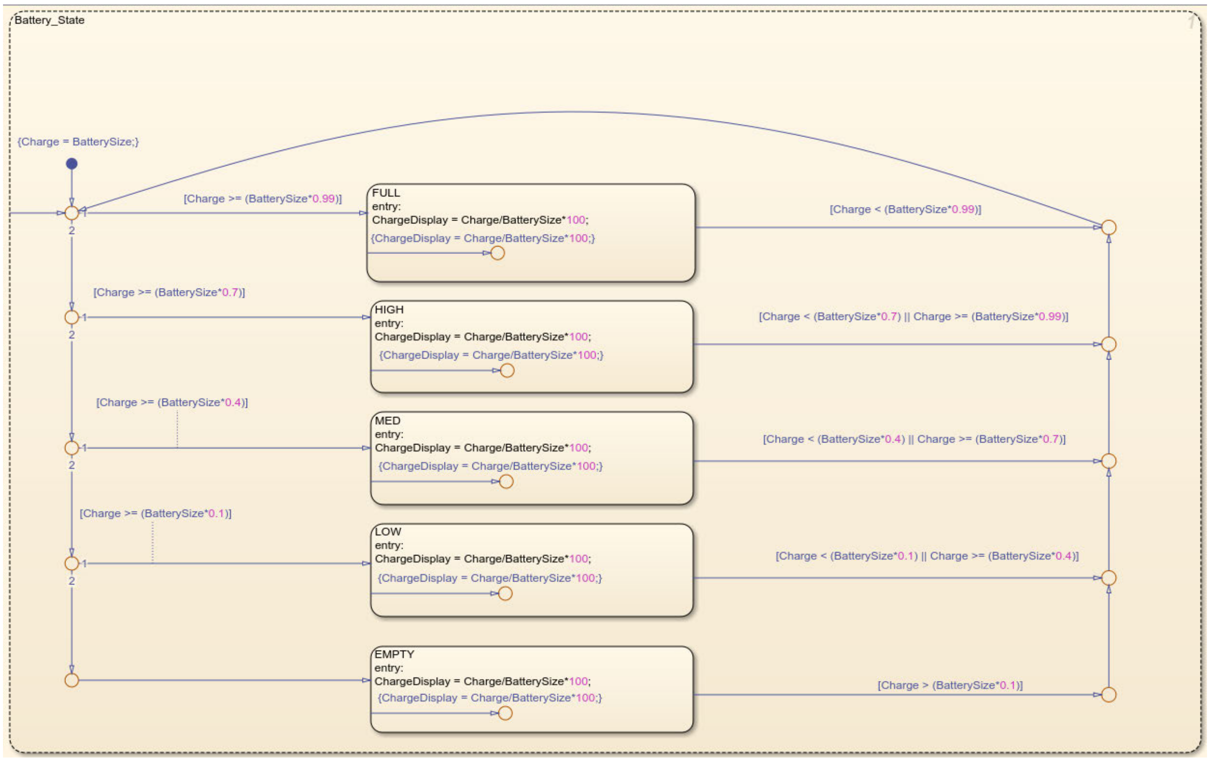


Figure 32: Battery state stateflow

3.4.3.3 <u>REMD Stateflow</u>

The REMD state was used to determine which energy source/s were being used by the home and was configured to suit the each of the specific operating modes of the REMD. Appendices F1-F3 provides a snippet of each of the relevant operating modes configured in the stateflow environment. Each of the operating modes were configured to operate in the manner described in section 3.3.2. The following provides a summary of the relevant key aspects of each operating mode from section 3.3.2 that need further explanation in order to achieve the desired operating profile.

<u>Sustainability Mode</u>

- **Solar state:** the BESS will charge from the PVS and will take as much charge as possible, up to the BESS charge limit of 6.87kWh (as per section 3.2.3), from the excess generated solar.
- **SolarBattery state:** the BESS discharge is set to offset the load minus any available solar, up to the battery discharge limit of 6.87kWh.
- **P2P state and Grid state:** configured as import only and no export of PVS or BESS can occur and the BESS cannot charge from either of these energy sources.

<u>Traditional Mode</u>

- **Solar state:** the BESS is configured to charge from the excess generated solar as per the sustainability mode, however once the BESS is fully charged the excess generated solar is exported to the grid.

- **Solar_Battery state:** configured into two separate states with one operating during peak tariff times and the second operating during shoulder and off-peak tariff times. The shoulder and off-peak tariff Solar_Battery state is also configured to only discharge the BESS down to the SoC of medium (approx. 50%) as this ensures that during the peak period when the load is the greatest there will be some BESS capacity to offset the load.
- **Grid state:** configured so that the BESS can charge from the grid if required. In order to achieve this at a stable rate of charge without heavily drawing from the grid a limit of 10 percent of the battery size of charge is allowed per hour only during off-peak tariffs. This will ensure that the cost for charging from the grid is kept to a minimum. The BESS will not charge from the grid if the tariff is outside of the off-peak hours or if the BESS SoC is full.

Benefit Mode

- **Solar state:** configured to allow multiple scenarios for the PVS and is dependent on the BESS SoC and whether the P2P energy market is available or not. If the BESS SoC is full then the BESS is not charged and the excess generated solar is fully exported to either the P2P energy market or to the retail grid and is determined on the availability of the P2P energy market. If the BESS SoC is high then half of the total excess generated solar is used to charge the BESS with the other half being exported to either the P2P energy market or to the retail grid and is determined on the availability of the P2P energy market. Finally if the BESS SoC is not full or high then the excess energy is not exported and is used to charge the BESS. Note that the charge rate for the BESS is also limited to the maximum charge rate of 6.87kWh (as per section 3.2.3).
- **Solar_Battery State:** configured in much the same way as the traditional operating mode with the two separate states but with one for off-peak tariff and the other for shoulder and peak tariff. During shoulder and peak tariff the BESS is designed to not export any extra BESS energy to the grid and is purely to offset the load and reduce the costs associated with importing energy during these times. During the off-peak tariff the battery will offset the load and also export ten percent of the available energy in the battery to either the P2P energy market or to the retail grid and is determined on the availability of the P2P energy market. The preference is to export to the P2P energy market as this allows for an increased export tariff and increased profit.
- **P2P state:** configured so that the BESS can charge from the P2P energy market if required. In order to achieve this at a stable rate of charge without heavily drawing from the P2P market a limit of 10 percent of the battery size of charge is allowed per hour. The BESS will not charge from the P2P market if the BESS SoC is full.
- **Grid state:** configured as import only as the costs to purchase energy from this retail market is much greater than the P2P market and as such reduces profitability.

3.4.3.4 Display Stateflow

The reference display state (Figure 33) was used to provide the relevant calculations and associated outputs for the display. Each of the displays for the relevant operating modes were configured to align in the manner described in section 3.3.3. The left-hand side (CALC state) was used to complete the relevant calculations required and was completed every hour, whereas the right-hand side (DISPLAY state) was used to complete the final calculations which would then correspond to the relevant display values.

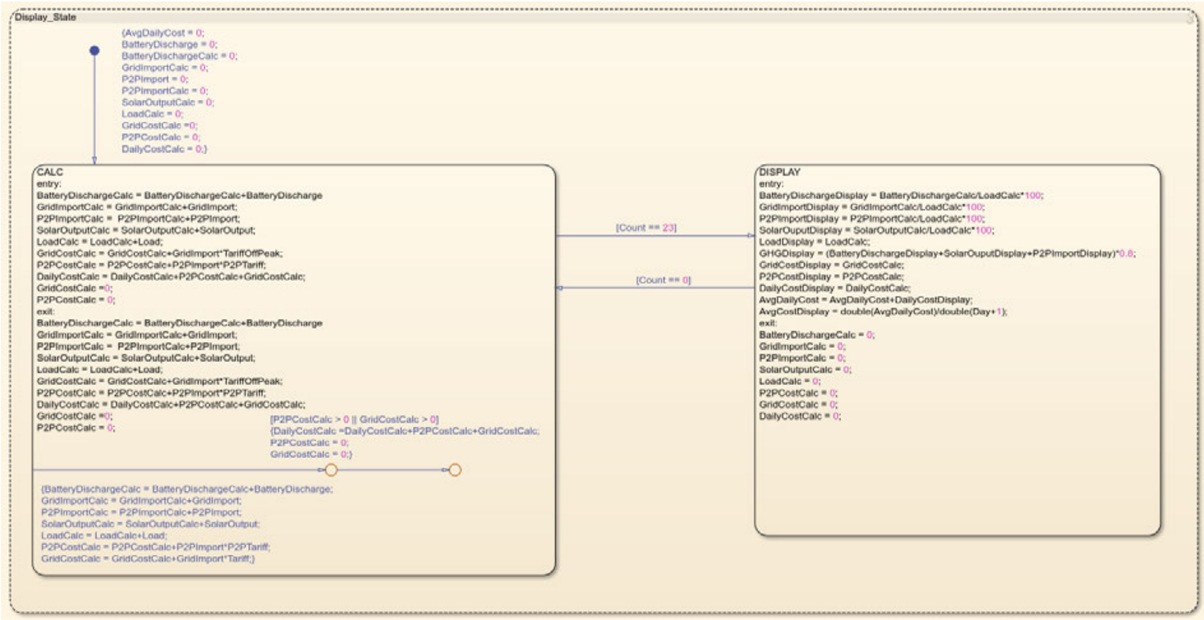


Figure 33: Example Display state stateflow (sustainability operating mode)

The following provides a summary of the relevant calculations required in each of the operating modes to achieve the desired display calculations.

<u>Sustainability Mode</u>

- BESS discharge calculation – used to summate and record the amount of energy discharged from the BESS over the 24 hour period (calculated every hour) and is given by the following

$$B_T = \sum_{i=1}^{24} B \tag{2}$$

B	BESS discharge (kWh)
B_T	Total BESS discharge over 24 hours (kWh)

- After a 24 hour period equation (2) can be substituted into the following equation to determine the total percentage of energy supplied from the BESS in relation to the total energy demand for that day

$$E_B = \frac{B_T}{L_T} \times 100$$

(3)

E_B	BESS discharge percentage of total load (%)
L_T	Total load over 24 hours (kWh)
B_T	Total BESS discharge over 24 hours (kWh)

- PVS calculation – used to summate and record the amount of energy supplied from the PVS over the 24 hour period (calculated every hour) and is given by the following (note that this calculation is relevant to the solar used to offset the load and not inclusive of the energy used to charge the BESS)

$$S_T = \sum_{i=1}^{24} S$$

(4)

S	PVS load offset (kWh)
S_T	Total PVS load offset over 24 hours (kWh)

- After a 24 hour period equation (4) can be substituted into the following equation to determine the total percentage of energy supplied from the BESS in relation to the total energy demand for that day

$$E_S = \frac{S_T}{L_T} \times 100$$

(5)

E_S	PVS percentage of total load (%)
L_T	Total load over 24 hours (kWh)
S_T	Total PVS load offset over 24 hours (kWh)

- P2P calculation – used to summate and record the amount of energy supplied from the P2P market over the 24 hour period (calculated every hour) and is given by the following

$$P2P_{IT} = \sum_{i=1}^{24} P2P_I$$

(6)

$P2P_I$	P2P import (kWh)
$P2P_{IT}$	Total P2P import over 24 hours (kWh)

- After a 24 hour period equation (6) can be substituted into the following equation to determine the total percentage of energy supplied from the BESS in relation to the total energy demand for that day

$$E_{P2P} = \frac{P2P_{IT}}{L_T} \times 100$$

(7)

E_{P2P}	P2P import percentage of total load (%)
L_T	Total load over 24 hours (kWh)
$P2P_{IT}$	Total P2P import over 24 hours (kWh)

- Grid calculation – used to summate and record the amount of energy supplied from the retail grid over the 24 hour period (calculated every hour) and is given by the following

$$G_T = \sum_{i=1}^{24} G \qquad (8)$$

G	Retail grid import (kWh)
G_T	Total retail grid import over 24 hours (kWh)

- After a 24 hour period equation (8) can be substituted into the following equation to determine the total percentage of energy supplied from the BESS in relation to the total energy demand for that day

$$E_G = \frac{G_T}{L_T} \times 100 \qquad (9)$$

E_G	Retail grid import percentage of total load (%)
L_T	Total load over 24 hours (kWh)
G_T	Total retail grid import over 24 hours (kWh)

- Load calculation – used to summate and record the amount of energy used by the home over the 24 hour period (calculated every hour) and is given by the following

$$L_T = \sum_{i=1}^{24} L \qquad (10)$$

L	Load (kWh)
L_T	Total load over 24 hours (kWh)

- P2P import cost calculation – used to calculate the cost of the P2P energy import based on the tariff price (calculated every hour) and is given by the following

$$C_{P2P} = \mathrm{P2P}_I \times t_{P2P} \qquad (11)$$

C_{P2P}	P2P import cost ($)
$P2P_I$	P2P import (kWh)
t_{P2P}	P2P Tariff price ($/kWh)

- Grid import cost calculation – used to calculate the cost of the retail grid energy import based on the tariff price (calculated every hour) and is given by the following

$$C_{grid} = \mathrm{G} \times t_{Grid}$$

(12)

C_{grid}	Retail grid import cost ($)
G	Retail grid import (kWh)
t_{Grid}	Retail grid tariff price ($/kWh)

- Daily cost calculation – used to summate and record the total cost of the energy import based on equation (11) and (12) over the 24 hour period (calculated every hour) and is given by the following

$$C_d = \sum_{i=1}^{24} C_{grid} + C_{P2P}$$

(13)

C_d	Total daily cost ($)
C_{grid}	Retail grid import cost ($)
C_{P2P}	P2P import cost ($)

- Average daily cost calculation – used to record the running average daily cost of the energy import based on equation (13) and is given by the following

$$C_{d\_avg} = \sum_{i=1}^{x} \frac{C_{d\_avg} + C_d}{x}$$

(14)

C_{d_avg}	Average daily cost ($)
C_d	Total daily cost ($)
x	Total number of days

- Green house gas (GHG) / CO_2 offset calculation – used to calculate the total daily amount (kg) of CO_2 that has been offset by the use of the BESS and PVS instead of the retail grid. In order to calculate this the indirect emission factor for Queensland (0.8 kg CO_2-e/kWh) is required and is a specific value related to the purchased electricity emissions. This figure represents the estimated emissions of CO_2, C_H4 and N_2O expressed together as carbon dioxide equivalent (CO_2-e) (Department of Industry 2021). The following equation from (Department of Industry 2021) has been used and modified to calculate the CO_2 offset by using the total energy used from internal sources in equations (2) and (4) as this relates to the total energy not imported from the grid and isn't contributing to the electricity emissions

$$Y = (B_T + S_T) \times EF$$

(15)

Y	Emission offset (CO_2-e kg)
B_T	Total BESS discharge over 24 hours (kWh)
S_T	Total PVS load offset over 24 hours (kWh)
EF	Emission factor (kg CO_2-e/kWh)

Traditional Mode

- BESS calculation – as per equation (2) and (3)
- PVS calculation – as per equation (4) and (5)
- Grid calculation – as per equation (8) and (9)
- Load calculation – used to summate and record the amount of energy used by the home (including BESS charge imported from the grid) over the 24 hour period (calculated every hour) and is given by the following

$$L_T = \sum_{i=1}^{24} L + L_{G\_I} \tag{16}$$

L	Load (kWh)
L_{G_I}	Total energy imported from retail market to charge BESS (kWh)
L_T	Total load over 24 hours (kWh)

- Grid import cost calculation – as per equation (12)
- PVS export cost calculation – used to calculate the cost of the excess exported PVS energy to the retail grid energy based on the tariff price (calculated every hour) and is given by the following

$$C_{PVS} = \text{PVS}_E \times t_{export} \tag{17}$$

C_{PVS}	PVS export cost ($)
PVS_E	PVS export (kWh)
t_{export}	Export tariff price ($/kWh)

- Daily cost calculation – used to summate and record the total cost of the energy import based on equation (13) and (17) over the 24 hour period (calculated every hour) and is given by the following

$$C_d = \sum_{i=1}^{24} C_{grid} - C_{PVS} \tag{18}$$

C_d	Daily cost ($)
C_{grid}	Retail grid import cost ($)
C_{PVS}	PVS export cost ($)

- Average daily cost calculation – as per equation (14). Note that if the average daily cost calculation value is less than zero the display will show that the cost is zero as export profit is greater than the import cost meaning that no cost is applicable by the retailer for that period of energy usage.

Benefit Mode

- BESS calculation – as per equation (2) and (3)
- PVS calculation – as per equation (4) and (5)
- P2P calculation – as per equation (6) and (7)
- Grid calculation – as per equation (8) and (9)
- Load calculation – used to summate and record the amount of energy used by the home (including BESS charge imported from the P2P energy market) over the 24 hour period (calculated every hour) and is given by the following

$$L_T = \sum_{i=1}^{24} L + L_{P2P\_I} \tag{19}$$

L	Load (kWh)
L_{P2P_I}	Total energy imported from P2P market to charge BESS (kWh)
L_T	Total load over 24 hours (kWh)

- Grid import cost calculation – as per equation (12)
- PVS export cost calculation P2P or Grid – as per equation (17) but with the export tariff being relative to the exported energy market tariff price (ie. Retail market export tariff price or P2P market export tariff price).
- BESS export cost calculation – used to calculate the cost of the exported BESS energy to the retail grid or P2P market based on the tariff price (calculated every hour) and is given by the following

$$C_{BESS} = E_{\mathrm{BESS}} \times t_{export} \tag{20}$$

C_{BESS}	BESS export cost ($)
$BESS_E$	BESS export (kWh)
t_{export}	Export tariff price ($/kWh)

- Daily cost calculation – as per equation (13)
- Average daily cost calculation – as per equation (14)
- Daily profit calculation - used to summate and record the total profit cost of the energy exported based on equation (17) and (20) over the 24 hour period (calculated every hour) and is given by the following

$$PC_d = \sum_{i=1}^{24} PC_{PVS} + PC_{BESS} \tag{21}$$

PC_d	Daily profit cost ($)
PC_{PVS}	PVS export profit cost ($)
PC_{BESS}	BESS export profit cost ($)

- Daily cost display – used to show if the system was profitable or not over the period. If the daily profit calculation is greater than the daily cost calculation, the display will show the result of the following equation

$$PC_d = PC_d - C_d \tag{22}$$

PC_d	Daily profit cost ($)
C_d	Daily cost ($)

Whereas if the daily profit calculation is less than the daily cost calculation, the display will show the result of the following equation

$$C_d = C_d - PC_d \tag{23}$$

C_d	Daily cost ($)
PC_d	Daily profit cost ($)

- Total profit – used to record the summation of the total profit of the energy import based on equations (22) and (23) and is given by the following

$$PC_T = \sum_{i=1}^{\infty} \mathrm{PC}_d - C_d \tag{24}$$

PC_T	Total profit cost ($)
C_d	Daily cost ($)
PC_d	Daily profit cost ($)

3.4.4 Modelling the REMD Display

The REMD display was modelled using standard Simulink dashboard blocks with a combination of display blocks, linear gauge and scope. The blocks were configured to align with the display design requirements detailed in section 3.3.3. Each of the operating modes contained similar dashboards blocks with the following providing the summary

Sustainability Mode

Display area 1

- Demand – display block (configured to display the data hourly)
- Daily demand – display block (configured to display the data daily)
- BESS SoC – linear gauge (configured to display the data hourly for the BESS SoC as a percentage of the total BESS capacity)
- PVS output - display block (configured to display the data hourly)

Display area 2

- Daily cost – display block (configured to display the data daily)
- Average daily cost – display block (configured to display the data daily)
- CO_2 offset – display block (configured to display the data daily)

<u>Display area 3</u>

- Scope block (configured to display the load, BESS and PVS plots hourly)

<u>Display area 4</u>

- Grid usage – display block (configured to display the data daily)
- P2P usage – display block (configured to display the data daily)
- PVS usage – display block (configured to display the data daily)
- BESS usage – display block (configured to display the data daily)

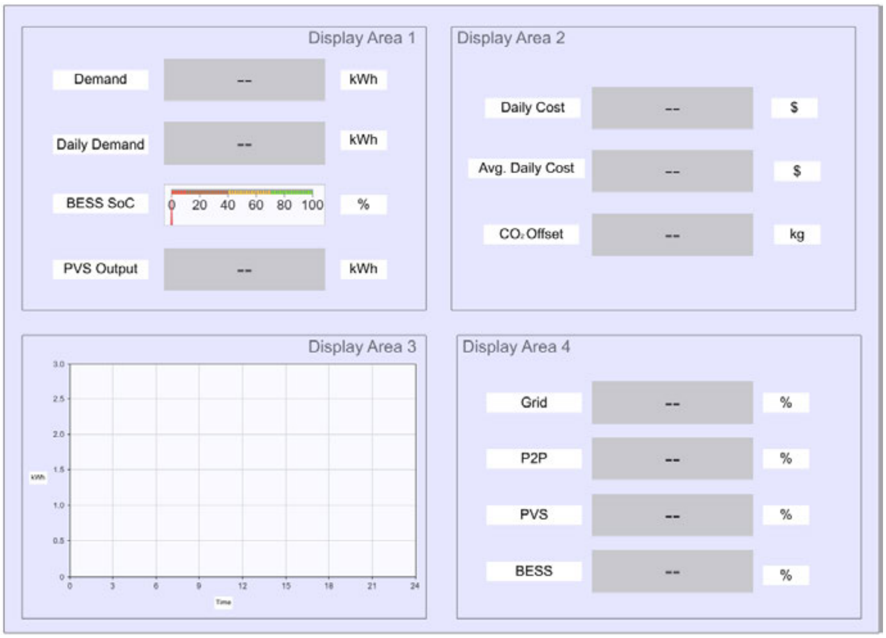


Figure 34: Sustainability mode display modelled in Simulink

<u>Traditional Mode</u>

<u>Display area 1</u>

- As per sustainability mode

<u>Display area 2</u>

- Daily cost – display block (configured to display the data daily)
- Average daily cost – display block (configured to display the data daily)

<u>Display area 3</u>

- As per sustainability mode

<u>Display area 4</u>

- Grid usage – display block (configured to display the data daily)
- PVS usage – display block (configured to display the data daily)

- BESS usage – display block (configured to display the data daily)

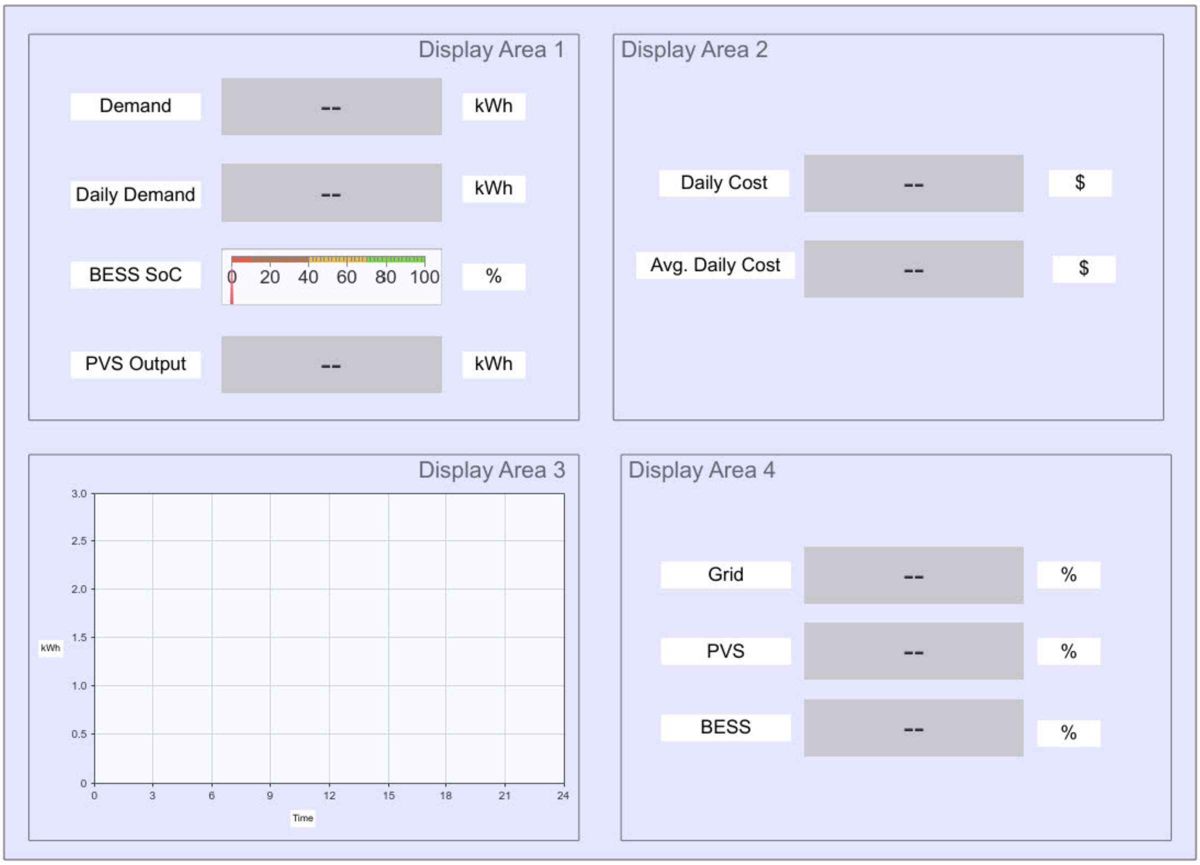


Figure 35: Traditional mode display modelled in Simulink

<u>Benefit Mode</u>

<u>Display area 1</u>

- As per sustainability mode

<u>Display area 2</u>

- Daily cost – display block (configured to display the data daily)
- Daily profit – display block (configured to display the data daily)
- Average daily cost – display block (configured to display the data daily)
- Total profit – display block (configured to display the data daily)

<u>Display area 3</u>

- As per sustainability mode

<u>Display area 4</u>

- As per sustainability mode

Figure 36: Benefit mode display modelled in Simulink

3.4.5 Complete Model Overview

Figure 37 provides a complete model overview of the sustainability mode for the REMD in the Simulink environment. This figure shows the display area at the top of the model and the REMD stateflow below with the relevant inputs on the left-hand side and the relevant outputs on the right-hand side. Note that each operating mode has slightly different Simulink environments (refer appendices G1-G3) with differing inputs/outputs. Each operating mode was modelled in separate files to simplify the testing, debugging and simulation.

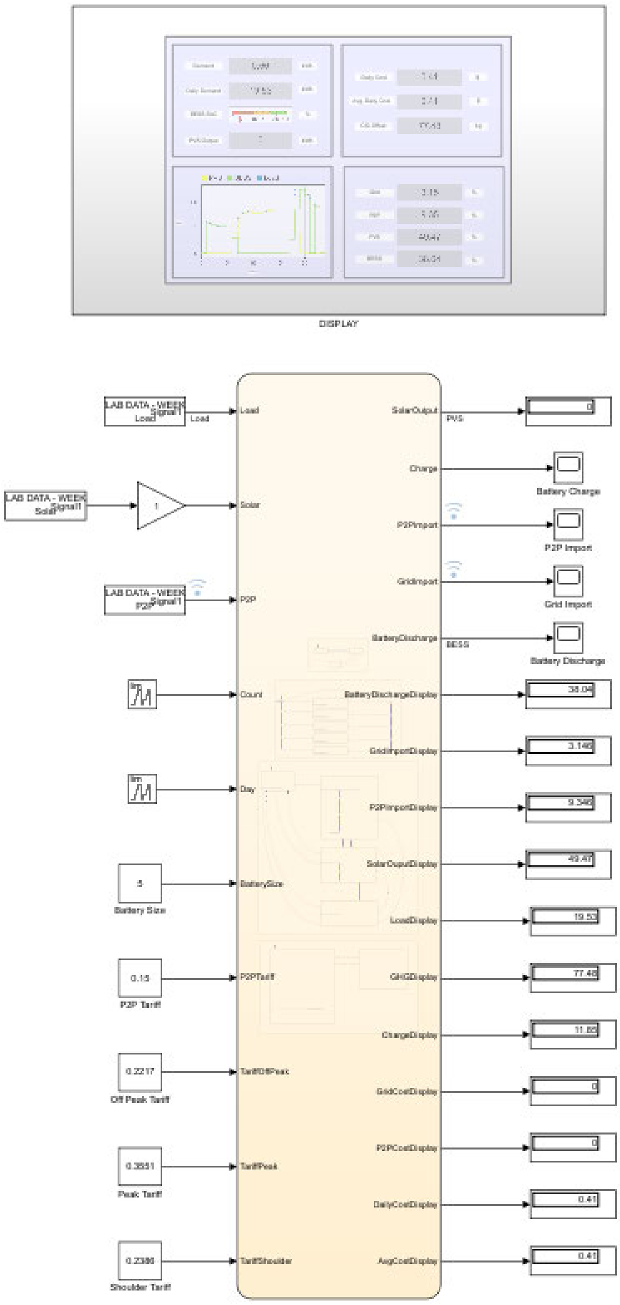


Figure 37: Simulink model overview

3.5 Simulation Methodology

With each of the operating modes of the REMD now modelled in Simulink simulations can now be undertaken to determine how well the REMD operates under various conditions. The simulation approach is to undertake simplified simulations during early testing to verify the code is operating as intended and then increase the data whilst changing variables to gain a better understanding of the REMD response. Each of the operating modes will be simulated separately with the discussion providing the contrasts between them. The following is the modelling approach used and which will be reflected in section 4.

The simulation approach is to be approached in the following manner:

1. Initial testing – used to verify operation of code. Simulation will occur with each of the REMD operating modes over the 24 hour test data. Verification calculations and state logic checks will be undertaken to ensure code is working as intended.
2. Final testing – used to understand how variations in variables (PVS output (ie sunny day, overcast day and rainy day), PVS size and BESS size) affect each of the operating modes. Simulation will occur with each of the REMD operating modes over a weeks worth of finite data and the following variances will be introduced into the models
   - Large PVS and small BESS
   - Large PVS and large BESS
   - Small PVS and large BESS
   - Small PVS and small BESS

3.5.1 Simulation Limitations

Whilst undertaking simulations there have been specific limitations placed on the model which are outlined below

- All input/export data and associated calculations have been limited to hourly data. This data would usually be in fifteen-minute intervals which would align with current industry practice for metering of energy. This limitation has been put in place to reduce the number of calculations thus helping with simulation and proof of concept for the REMD.
- The data used during simulations is finite in nature as no live data was available. All data simulated has been gathered from the relevant sources as described in section 3.2.
- Variations in system parameters related to aspects of PVS size, BESS size, tariff prices, loads, etc have been reduced to what is nominated under section 3.5 in order to reduce the dissertation into a manageable size and testing timeframe.
- Efficiencies of energy conversions from one energy source to another have not been considered in the calculations.

Chapter 4 – Results

4.1 Initial Testing

Initial testing as described in section 3.5 is used to determine that each of the operating modes operate correctly to ensure that the outputs and state logic is in accordance with the design parameters. Any anomalies picked up during initial testing will be rectified and updated in the model which will ensure that the following testing in section 4.2 are accurate. The following table provides a summary of the relevant data used for the initial testing on each of the operating modes with Figure 38 providing the relevant input data for the initial testing.

Data	Value
Load profile	Refer Figure 38
PVS output profile	Refer Figure 38
P2P energy market profile	Refer Figure 38
PVS size	6.93 kWh
BESS size	5 kWh
Grid import tariff price	Peak – $ 0.2217 Shoulder - $ 0.2386 Offpeak - $ 0.3551
P2P import price	$ 0.15
Grid export tariff price	$ 0.08
P2P export price	$ 0.15

Table 14: Initial testing data parameters

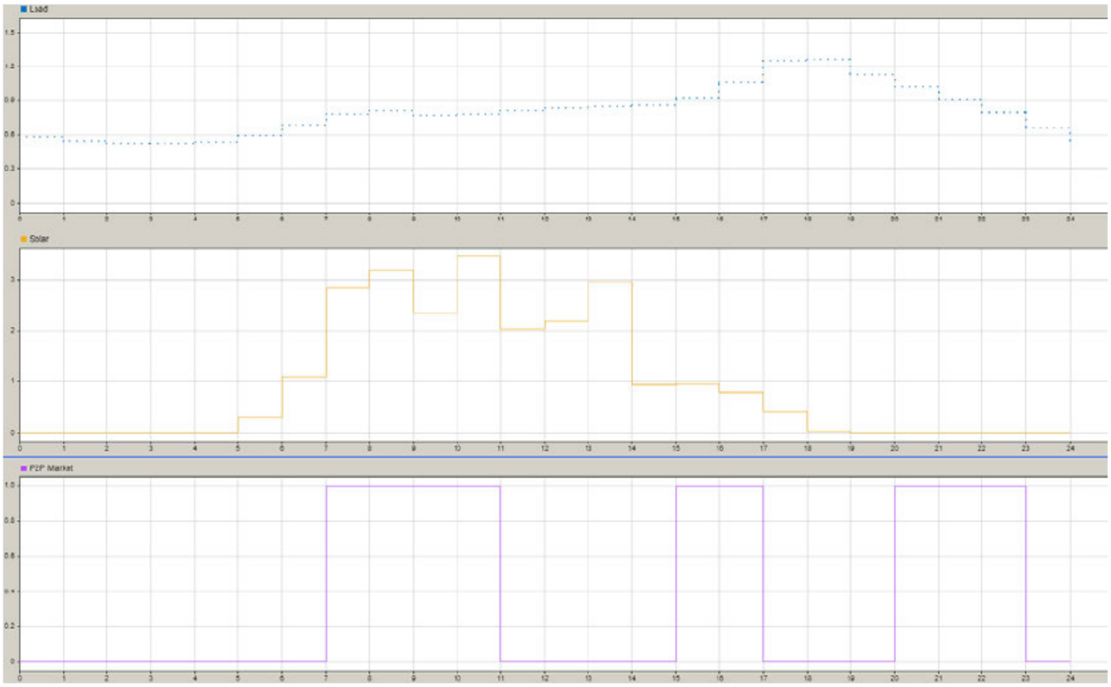


Figure 38: Initial testing data - Load, solar and P2P market

4.1.1 State Sequence Flows

The state sequence flows as shown in appendices H1 to H3 illustrate the relevant states that the REMD was operating in at that given hour during the simulation based on the operating mode. The following tables under each operating mode provide a summary of the state sequence flow with associated commentary for some key aspects for determining what state the REMD would be in.

4.1.1.1 Sustainability Mode

Time	REMD Energy State	Correct Energy State	Comment
0	Grid	Yes	Initial state when REMD is activated
1	SolarBattery	Yes	PVS is not greater than the load and the BESS SoC is enough to support the load. The PVS output does start to increase around hour 5 but isn't enough to warrant a change in operating state.
2	SolarBattery	Yes	
3	SolarBattery	Yes	
4	SolarBattery	Yes	
5	SolarBattery	Yes	
6	Solar	Yes	PVS output is greater than load and can fully support the load with excess power being used to charge battery. With reference to Figure 39 the battery was fully charged over two hours from the PVS.
7	Solar	Yes	
8	Solar	Yes	
9	Solar	Yes	
10	Solar	Yes	
11	Solar	Yes	
12	Solar	Yes	
13	Solar	Yes	
14	Solar	Yes	
15	Solar	Yes	
16	SolarBattery	Yes	PVS output has reduced and the BESS SoC is enough to support the load
17	SolarBattery	Yes	
18	SolarBattery	Yes	
19	SolarBattery	Yes	
20	P2P	Yes	P2P energy market is available and is to be used before the retail market
21	SolarBattery	Yes	Was expecting P2P energy market to still be used here, but as the load has decreased and the BESS SoC is not in empty the load can be offset by the BESS
22	P2P	Yes	The battery charge is not enough to offset the load and is as per hour 20
23	Grid	Yes	P2P energy market is not available and the fallback for energy supply if no other sources are available is the retail market

Table 15: Sustainability mode state sequence flow summary

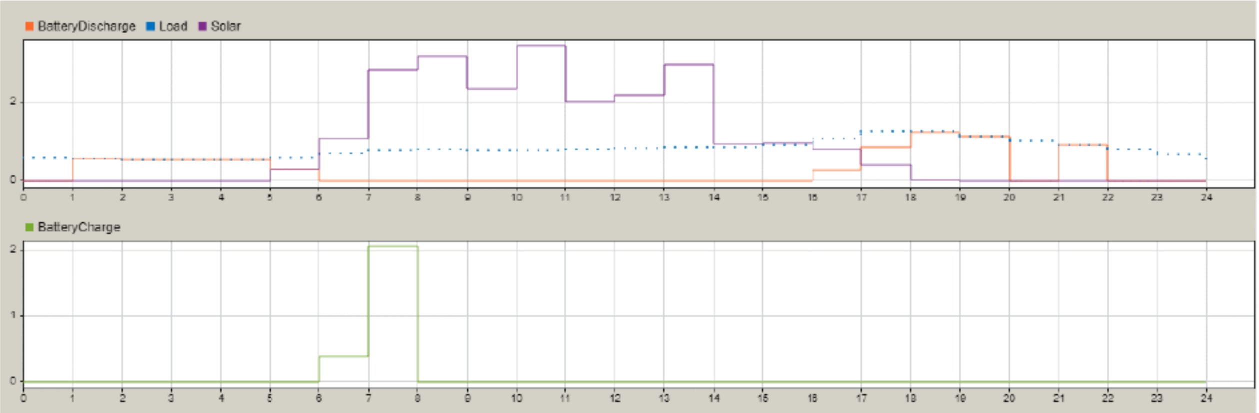


Figure 39: Sustainability mode BESS charging from PVS

4.1.1.2 Traditional Mode

Time	REMD Energy State	Correct Energy State	Comment
0	Grid	Yes	Initial state when REMD is activated
1	SolarBattery (off-peak/shoulder)	Yes	PVS is not greater than the load and the BESS SoC is enough to support the load.
2	SolarBattery (off-peak/shoulder)	Yes	
3	SolarBattery (off-peak/shoulder)	Yes	
4	Grid	Yes	It was expected that this would remain in the SolarBattery_Offpeak_Shoulder state but upon further investigation this change to grid was correct as the BESS SoC dropped into or below the medium state which the SolarBattery (off-peak/shoulder) is only allowed to utilise the high or full SoC states to save BESS energy for the peak tariff time.
5	SolarBattery (off-peak/shoulder)	Yes	It was expected that that the state would remain in Grid, but upon further investigation the BESS was charged enough by the grid that the SoC was greater than medium and thus allowed the SolarBattery (off-peak/shoulder) state to be active.
6	Solar	Yes	PVS output is greater than load and can fully support the load with excess power being used to charge battery. With reference to Figure 40 the battery was fully charged over two hours from the PVS.
7	Solar	Yes	
8	Solar	Yes	
9	Solar	Yes	
10	Solar	Yes	
11	Solar	Yes	
12	Solar	Yes	
13	Solar	Yes	
14	Solar	Yes	
15	Solar	Yes	
16	SolarBattery (off-peak/shoulder)	Yes	PVS output has reduced and the BESS SoC is enough to support the load
17	SolarBattery (peak)	Yes	As the tariff has changed to peak the SolarBattery_Peak state has activated as expected
18	SolarBattery (peak)	Yes	

19	SolarBattery (peak)	Yes	
20	Grid	Yes	It was expected that the state would change to the SolarBattery_Offpeak_Shoulder) state but upon further investigation this change to grid was correct as the BESS SoC was in or below the medium state Figure 41.
21	Grid	Yes	As the battery SoC remained in the medium state the Grid state remained active Figure 41.
22	Grid	Yes	
23	Grid	Yes	

Table 16: Traditional mode state sequence flow summary

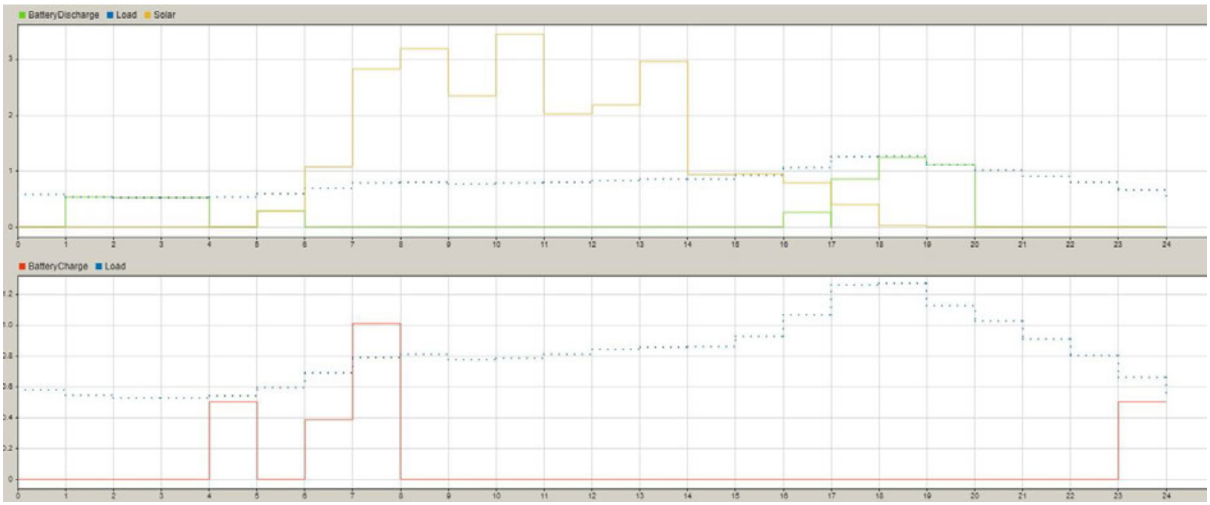


Figure 40: Traditional mode BESS charging from PVS and Grid

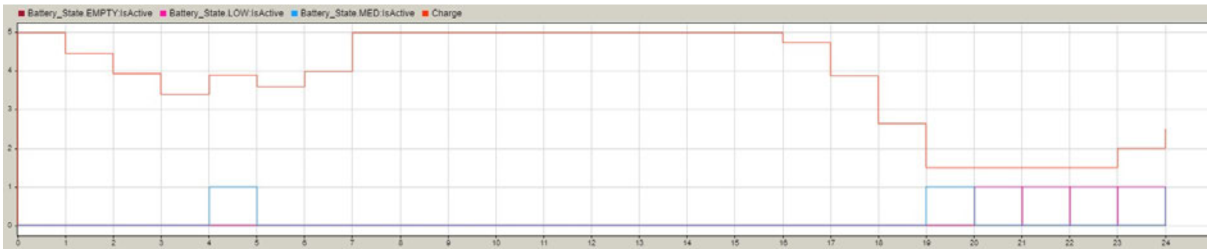


Figure 41: Traditional mode BESS charge SoC medium or below

4.1.1.3 Benefit Mode

Time	REMD Energy State	Correct Energy State	Comment
0	Grid	Yes	Initial state when REMD is activated
1	SolarBattery (off-peak)	Yes	PVS is not greater than the load and the BESS SoC is enough to support the load.
2	SolarBattery (off-peak/shoulder)	Yes	
3	SolarBattery (off-peak)	Yes	
4	SolarBattery (off-peak)	Yes	
5	SolarBattery (off-peak)	Yes	
6	Solar	Yes	PVS output is greater than load and can fully support the load with excess power being used to charge battery. With reference to figure 42 the battery was fully charged over three hours from the PVS. Also once the battery is fully charged the excess energy is exported to the grid or P2P as expected.
7	Solar	Yes	
8	Solar	Yes	
9	Solar	Yes	
10	Solar	Yes	
11	Solar	Yes	
12	Solar	Yes	
13	Solar	Yes	
14	Solar	Yes	
15	Solar	Yes	
16	SolarBattery (peak/shoulder)	Yes	PVS output has reduced and the BESS SoC is enough to support the load
17	SolarBattery (peak/shoulder)	Yes	
18	SolarBattery (peak/shoulder)	Yes	
19	SolarBattery (peak/shoulder)	Yes	
20	P2P	Yes	BESS SoC to low (figure 43) and P2P market available. Note that the battery charged a small amount from the P2P market as expected (figure 42).
21	SolarBattery (peak/shoulder)	Yes	
22	P2P	Yes	BESS SoC too low for SolarBattery_Offpeak state to be active and therefore the P2P market is used as it is available. Note that the battery charged a small amount from the P2P market as expected (Figure 44).
23	Grid	Yes	P2P energy market was not available and the fallback is the grid.

Table 17: Benefit mode state sequence flow summary

Figure 42: Benefit mode BESS charging from PVS and P2P

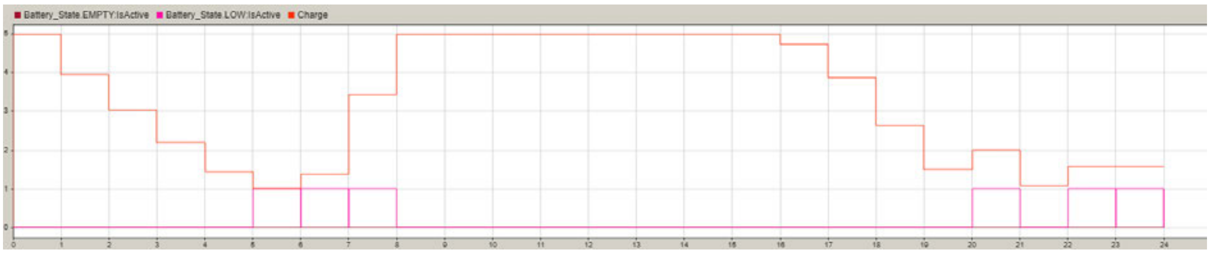


Figure 43: Benefit mode BESS charge SoC medium or below

4.1.2 Energy Usage Breakdown

The energy usage breakdown testing relates to how much each energy source was being used in the given operating modes. The output of this section is used to verify against the display values of display area 4 as described in section 3.4.4.

4.1.2.1 Sustainability Mode

After simulating the code with the initial test data the load was supplied from the available energy sources as shown in Figure 44 and Table 18.

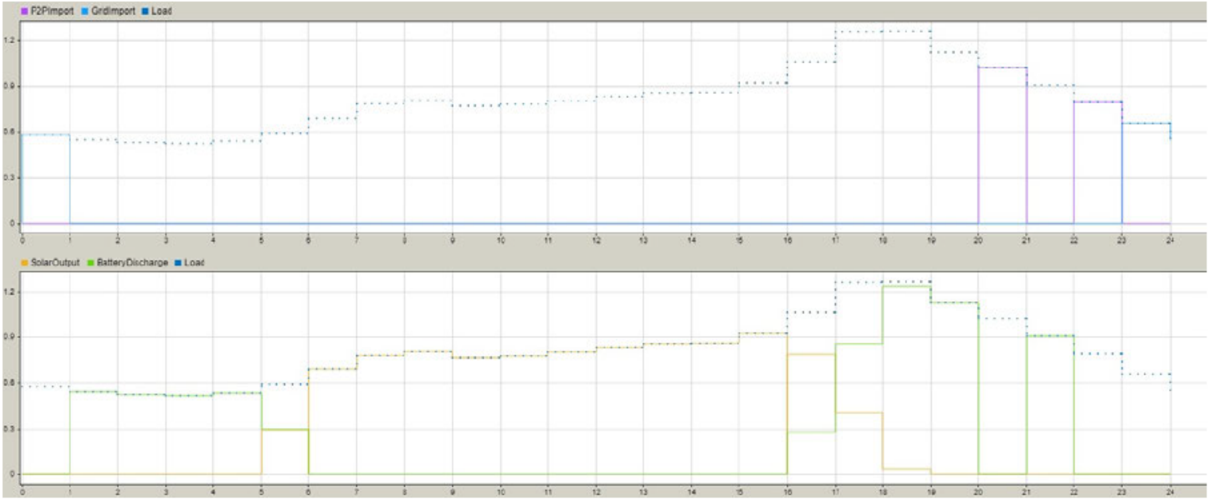


Figure 44: Sustainability mode energy source usage breakdown

Time (hr)	Load (kWh)	Grid Import (kWh)	P2P Import (kWh)	PVS Offset (kWh)	BESS Offset (kWh)
0	0.5809	0.5809	0.0000	0.0000	0.0000
1	0.5474	0.0000	0.0000	0.0000	0.5474
2	0.527	0.0000	0.0000	0.0000	0.5270
3	0.5246	0.0000	0.0000	0.0000	0.5246
4	0.541	0.0000	0.0000	0.0000	0.5410
5	0.5955	0.0000	0.0000	0.2958	0.2997
6	0.6895	0.0000	0.0000	0.6895	0.0000
7	0.7892	0.0000	0.0000	0.7892	0.0000
8	0.8101	0.0000	0.0000	0.8101	0.0000
9	0.773	0.0000	0.0000	0.7730	0.0000
10	0.7843	0.0000	0.0000	0.7843	0.0000
11	0.8092	0.0000	0.0000	0.8092	0.0000
12	0.8383	0.0000	0.0000	0.8383	0.0000
13	0.8572	0.0000	0.0000	0.8572	0.0000
14	0.8622	0.0000	0.0000	0.8622	0.0000
15	0.9237	0.0000	0.0000	0.9237	0.0000
16	1.066	0.0000	0.0000	0.7928	0.2733
17	1.2611	0.0000	0.0000	0.4050	0.8561
18	1.2707	0.0000	0.0000	0.0305	1.2402
19	1.1269	0.0000	0.0000	0.0000	1.1269
20	1.0265	0.0000	1.0265	0.0000	0.0000
21	0.911	0.0000	0.0000	0.0000	0.9110

22	0.7986	0.0000	0.7986	0.0000	0.0000
23	0.6622	0.6622	0.0000	0.0000	0.0000
Energy Total (kWh)	19.58	1.2431	1.8251	9.6608	6.8471

Table 18: Sustainability mode energy breakdown

Utilising the equations (3), (5), (7), (9) and (10) the load breakdown as a percentage of the total load was calculated in excel with the results reflected in Table 19.

	Grid Import	P2P Import	PVS Offset	BESS Offset
Energy source usage	6.35%	9.32%	49.35%	34.98%

Table 19: Sustainability mode energy breakdown as percentage of load

4.1.2.2 Traditional Mode

After simulating the code with the initial test data the load was supplied from the available energy sources as shown in Figure 45 and Table 20.

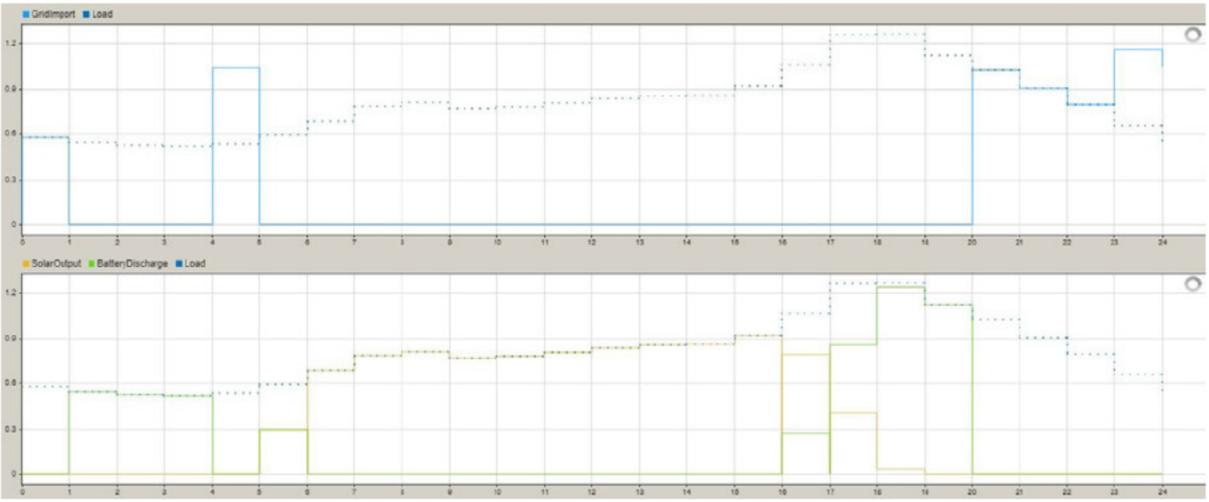


Figure 45: Traditional mode energy source usage breakdown

Time (hr)	Load (kWh)	BESS Charge from Grid (kWh)	Grid Import (kWh)	PVS Offset (kWh)	BESS Offset (kWh)
0	0.5809	0.0000	0.5809	0.0000	0.0000
1	0.5474	0.0000	0.0000	0.0000	0.5474
2	0.527	0.0000	0.0000	0.0000	0.5270

3	0.5246	0.0000	0.0000	0.0000	0.5246
4	0.541	0.5000	1.0410	0.0000	0.0000
5	0.5955	0.0000	0.0000	0.2958	0.2997
6	0.6895	0.0000	0.0000	0.6895	0.0000
7	0.7892	0.0000	0.0000	0.7892	0.0000
8	0.8101	0.0000	0.0000	0.8101	0.0000
9	0.773	0.0000	0.0000	0.7730	0.0000
10	0.7843	0.0000	0.0000	0.7843	0.0000
11	0.8092	0.0000	0.0000	0.8092	0.0000
12	0.8383	0.0000	0.0000	0.8383	0.0000
13	0.8572	0.0000	0.0000	0.8572	0.0000
14	0.8622	0.0000	0.0000	0.8622	0.0000
15	0.9237	0.0000	0.0000	0.9237	0.0000
16	1.066	0.0000	0.0000	0.7928	0.2733
17	1.2611	0.0000	0.0000	0.4050	0.8561
18	1.2707	0.0000	0.0000	0.0305	1.2402
19	1.1269	0.0000	0.0000	0.0000	1.1269
20	1.0265	0.0000	1.0265	0.0000	0.0000
21	0.911	0.0000	0.9110	0.0000	0.0000
22	0.7986	0.0000	0.7986	0.0000	0.0000
23	0.6622	0.5000	1.1622	0.0000	0.0000
Energy Total (kWh)	19.58	1.00	5.5202	9.6608	5.3951

Table 20: Traditional mode energy breakdown

Utilising the equations (3), (5), (9) and (16) the load breakdown as a percentage of the total load was calculated by in excel with the results reflected in Table 21.

	Grid Import Total	PVS Offset	BESS Offset
Energy source usage	26.83%	46.95%	26.22%

Table 21: Traditional mode energy breakdown as percentage of load

4.1.2.3 Benefit Mode

After simulating the code with the initial test data the load was supplied from the available energy sources as shown in Figure 46 and Table 22.

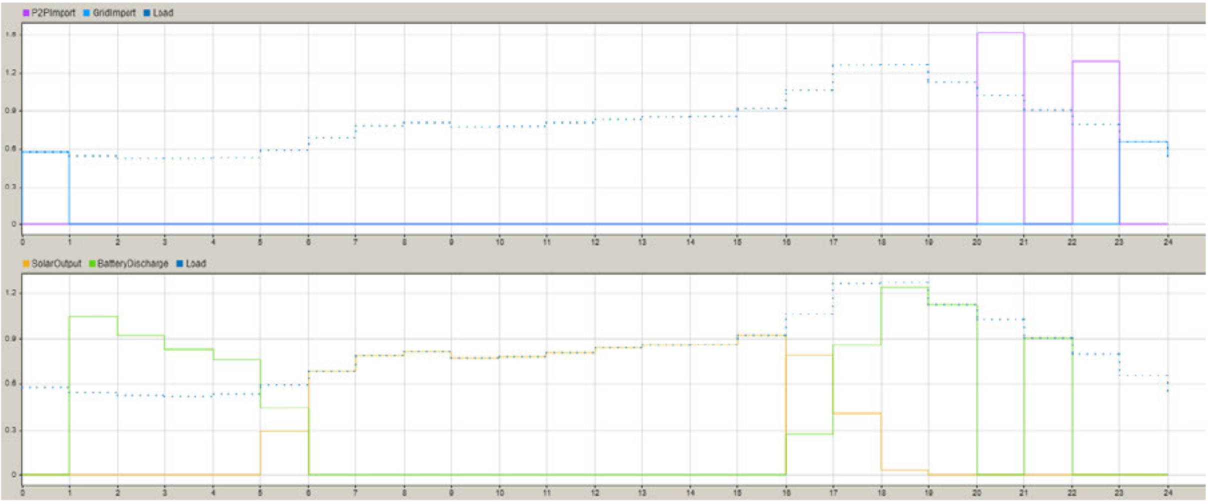


Figure 46: Benefit mode energy source usage breakdown

Time (hr)	Load (kWh)	Grid Import (kWh)	BESS Charge from P2P (kWh)	P2P Import (kWh)	PVS Offset (kWh)	BESS Offset (kWh)
0	0.5809	0.5809	0.0000	0.0000	0.0000	0.0000
1	0.5474	0.0000	0.0000	0.0000	0.0000	0.5474
2	0.5270	0.0000	0.0000	0.0000	0.0000	0.5270
3	0.5246	0.0000	0.0000	0.0000	0.0000	0.5246
4	0.5410	0.0000	0.0000	0.0000	0.0000	0.5410
5	0.5955	0.0000	0.0000	0.0000	0.2958	0.2997
6	0.6895	0.0000	0.0000	0.0000	0.6895	0.0000
7	0.7892	0.0000	0.0000	0.0000	0.7892	0.0000
8	0.8101	0.0000	0.0000	0.0000	0.8101	0.0000
9	0.7730	0.0000	0.0000	0.0000	0.7730	0.0000
10	0.7843	0.0000	0.0000	0.0000	0.7843	0.0000
11	0.8092	0.0000	0.0000	0.0000	0.8092	0.0000
12	0.8383	0.0000	0.0000	0.0000	0.8383	0.0000
13	0.8572	0.0000	0.0000	0.0000	0.8572	0.0000
14	0.8622	0.0000	0.0000	0.0000	0.8622	0.0000
15	0.9237	0.0000	0.0000	0.0000	0.9237	0.0000
16	1.0660	0.0000	0.0000	0.0000	0.7928	0.2733
17	1.2611	0.0000	0.0000	0.0000	0.4050	0.8561
18	1.2707	0.0000	0.0000	0.0000	0.0305	1.2402
19	1.1269	0.0000	0.0000	0.0000	0.0000	1.1269
20	1.0265	0.0000	0.5000	1.5265	0.0000	0.0000
21	0.9110	0.0000	0.0000	0.0000	0.0000	0.9110

22	0.7986	0.0000	0.5000	1.2986	0.0000	0.0000
23	0.6622	0.6622	0.0000	0.0000	0.0000	0.0000
Energy Total (kWh)	19.58	1.2431	1.0000	2.8251	9.6608	6.8471

Table 22: Benefit mode energy breakdown

Utilising the equations (3), (5), (7), (9) and (19) the load breakdown as a percentage of the total load was calculated in excel with the results reflected in Table 23.

	Grid Import Total	P2P Import Total	PVS Offset	BESS Offset
Energy source usage	6.04%	13.73%	46.95%	33.28%

Table 23: Benefit mode energy breakdown as percentage of load

4.1.3 Energy Cost

The energy cost testing relates to how much cost was incurred from importing energy from the retail market or P2P market. The output of this section is used to verify against the display values of display area 3. Note that the daily average cost will reflect the same value as the daily cost price as the REMD is only running for one day during the initial testing.

4.1.3.1 Sustainability Mode

The below table is a tabulated form of Figure 44 with equations (11) and (12) being used to calculate the relevant import costs.

Time (hr)	Grid Import (kWh)	Grid Tariff	Grid Cost	P2P Import (kWh)	P2P Tariff	P2P Cost
0	0.5809	$ 0.22	$ 0.13	0.0000	$ 0.15	$ -
1	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
2	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
3	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
4	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
5	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
6	0.0000	$ 0.22	$ -	0.0000	$ 0.15	$ -
7	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
8	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
9	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -

10	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
11	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
12	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
13	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
14	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
15	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
16	0.0000	$ 0.36	$ -	0.0000	$ 0.15	$ -
17	0.0000	$ 0.36	$ -	0.0000	$ 0.15	$ -
18	0.0000	$ 0.36	$ -	0.0000	$ 0.15	$ -
19	0.0000	$ 0.36	$ -	0.0000	$ 0.15	$ -
20	0.0000	$ 0.24	$ -	1.0265	$ 0.15	$ 0.15
21	0.0000	$ 0.24	$ -	0.0000	$ 0.15	$ -
22	0.0000	$ 0.22	$ -	0.7986	$ 0.15	$ 0.12
23	0.6622	$ 0.22	$ 0.15	0.0000	$ 0.15	$ -
	Grid total import cost		$ 0.28	P2P total import cost		$ 0.27

Table 24: Sustainability mode energy import cost

4.1.3.2 Traditional Mode

The below table is a tabulated form of Figure 45 with equations (12) and (17) being used to calculate the relevant import/export costs.

Time (hr)	Grid Import (Load & BESS charge) (kWh)	Grid Tariff	Grid Cost	PVS Export (kWh)	Grid Export Tariff	PVS Export Cost
0	0.5809	$ 0.22	$ 0.13	0.0000	$ 0.08	$ -
1	0.0000	$ 0.22	$ -	0.0000	$ 0.08	$ -
2	0.0000	$ 0.22	$ -	0.0000	$ 0.08	$ -
3	0.0000	$ 0.22	$ -	0.0000	$ 0.08	$ -
4	1.0410	$ 0.22	$ 0.23	0.0000	$ 0.08	$ -
5	0.0000	$ 0.22	$ -	0.0000	$ 0.08	$ -
6	0.0000	$ 0.22	$ -	0.0000	$ 0.08	$ -
7	0.0000	$ 0.24	$ -	0.0000	$ 0.08	$ -
8	0.0000	$ 0.24	$ -	2.3701	$ 0.08	$ 0.19
9	0.0000	$ 0.24	$ -	1.5670	$ 0.08	$ 0.13
10	0.0000	$ 0.24	$ -	2.6703	$ 0.08	$ 0.21
11	0.0000	$ 0.24	$ -	1.2238	$ 0.08	$ 0.10
12	0.0000	$ 0.24	$ -	1.3424	$ 0.08	$ 0.11
13	0.0000	$ 0.24	$ -	2.1133	$ 0.08	$ 0.17
14	0.0000	$ 0.24	$ -	0.0855	$ 0.08	$ 0.01
15	0.0000	$ 0.24	$ -	0.0340	$ 0.08	$ 0.00

16	0.0000	$ 0.36	$ -	0.0000	$ 0.08	$ -
17	0.0000	$ 0.36	$ -	0.0000	$ 0.08	$ -
18	0.0000	$ 0.36	$ -	0.0000	$ 0.08	$ -
19	0.0000	$ 0.36	$ -	0.0000	$ 0.08	$ -
20	1.0265	$ 0.24	$ 0.24	0.0000	$ 0.08	$ -
21	0.9110	$ 0.24	$ 0.22	0.0000	$ 0.08	$ -
22	0.7986	$ 0.22	$ 0.18	0.0000	$ 0.08	$ -
23	1.1622	$ 0.22	$ 0.26	0.0000	$ 0.08	$ -
	Grid total import cost		$ 1.26	PVS total export cost		$ 0.91

Table 25: Traditional mode energy import and export cost

4.1.3.3 Benefit Mode

The below tables are a tabulated form of Figure 46 with equations (11), (12), (17) and (20) being used to calculate the relevant import/export costs.

Time (hr)	Grid Import (kWh)	Grid Tariff	Grid Cost	P2P Import (Load & BESS charge) (kWh)	P2P Tariff	P2P Cost
0	0.58	$ 0.22	$ 0.13	0.00	$ 0.15	$ -
1	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
2	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
3	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
4	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
5	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
6	0.00	$ 0.22	$ -	0.00	$ 0.15	$ -
7	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
8	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
9	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
10	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
11	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
12	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
13	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
14	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
15	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
16	0.00	$ 0.36	$ -	0.00	$ 0.15	$ -
17	0.00	$ 0.36	$ -	0.00	$ 0.15	$ -
18	0.00	$ 0.36	$ -	0.00	$ 0.15	$ -
19	0.00	$ 0.36	$ -	0.00	$ 0.15	$ -
20	0.00	$ 0.24	$ -	1.53	$ 0.15	$ 0.23
21	0.00	$ 0.24	$ -	0.00	$ 0.15	$ -
22	0.00	$ 0.22	$ -	1.30	$ 0.15	$ 0.19
23	0.66	$ 0.22	$ 0.15	0.00	$ 0.15	$ -
	Grid total import cost		$ 0.28	P2P total import cost		$ 0.42

Table 26: Benefit mode energy import cost

Time (hr)	PVS Export to Grid (kWh)	Grid Export Tariff	PVS Export Cost Grid	PVS Export to P2P (kWh)	P2P Export Tariff	PVS Export Cost P2P
0	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
1	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
2	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
3	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
4	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
5	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
6	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
7	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
8	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
9	0.00	$ 0.08	$ -	1.57	$ 0.15	$ 0.24
10	0.00	$ 0.08	$ -	2.67	$ 0.15	$ 0.40
11	1.22	$ 0.08	$ 0.10	0.00	$ 0.15	$ -
12	1.34	$ 0.08	$ 0.11	0.00	$ 0.15	$ -
13	2.11	$ 0.08	$ 0.17	0.00	$ 0.15	$ -
14	0.09	$ 0.08	$ 0.01	0.00	$ 0.15	$ -
15	0.00	$ 0.08	$ -	0.03	$ 0.15	$ 0.01
16	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
17	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
18	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
19	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
20	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
21	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
22	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
23	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
	PVS total export cost Grid		$ 0.38	PVS total export cost P2P		$ 0.64

Table 27: Benefit mode PVS energy export

Time (hr)	BESS Export to Grid (kWh)	Grid Export Tariff	BESS Export Cost Grid	BESS Export to P2P (kWh)	P2P Export Tariff	BESS Export Cost P2P
0	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
1	0.50	$ 0.08	$ 0.04	0.00	$ 0.15	$ -
2	0.40	$ 0.08	$ 0.03	0.00	$ 0.15	$ -
3	0.30	$ 0.08	$ 0.02	0.00	$ 0.15	$ -
4	0.22	$ 0.08	$ 0.02	0.00	$ 0.15	$ -
5	0.14	$ 0.08	$ 0.01	0.00	$ 0.15	$ -
6	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
7	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
8	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
9	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
10	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
11	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
12	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
13	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
14	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
15	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
16	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
17	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
18	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
19	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
20	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
21	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
22	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
23	0.00	$ 0.08	$ -	0.00	$ 0.15	$ -
	BESS total export cost Grid		$ 0.13	BESS total export cost P2P		$ -

Table 28: Benefit mode BESS energy export

4.1.4 Display

The display testing is the final piece of the initial testing and is verifying that the hand calculations from the previous sections align with the simulation calculated values and that the display operated as intended. The following sections provide the relevant display designs for the operating modes.

4.1.4.1 Sustainability Mode

Figure 47: Sustainability mode display – initial testing

4.1.4.2 Traditional Mode

Figure 48: Traditional mode display – initial testing

4.1.4.3 Benefit Mode

Figure 49: Benefit mode display – initial testing

4.2 Final Testing

Final testing as described in section 3.5 is used to determine how the REMD operating modes respond to variances in system parameters. Figure 50 illustrates the relevant load and P2P market profile used for all final testing. Note that the BESS size and PVS size will be adjusted and defined for each of the following tests.

Data	Value
Load profile	Refer Figure 50
PVS output profile	(scale 1) - Refer Figure 50
P2P energy market profile	Refer Figure 50
Grid import tariff price	Peak – $ 0.2217 Shoulder - $ 0.2386 Off-peak - $ 0.3551
P2P import price	$ 0.15
Grid export tariff price	$ 0.08
P2P export price	$ 0.15

Table 29: Initial testing data parameters

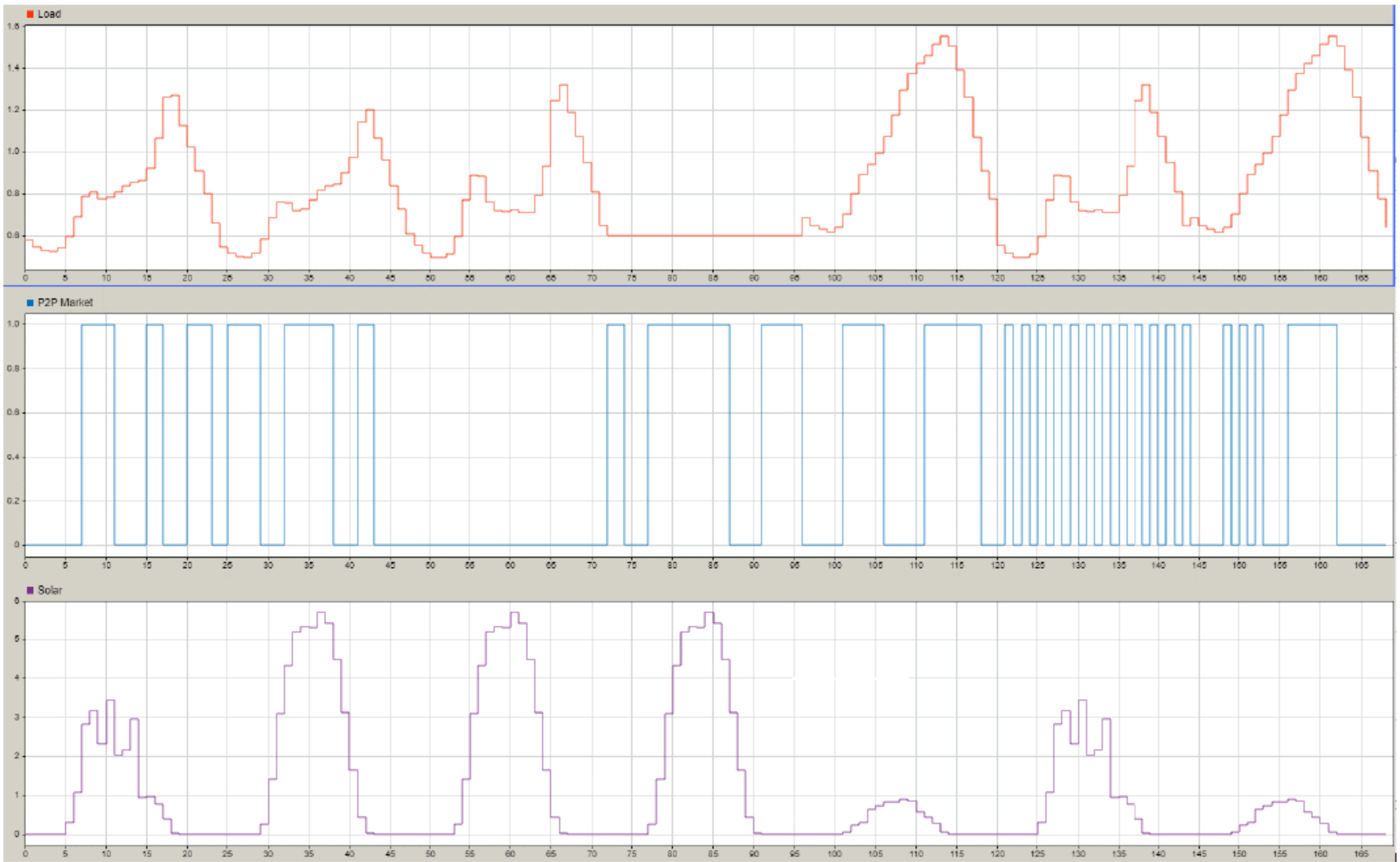


Figure 50: Final testing data – Load, P2P market and PVS output

A couple of things to note about Figure 50 include:

- The load in this data set reflects various load profiles relevant to the typical summer, winter, autumn and spring days as reflected in section 3.2.4.

- The load on the fourth day reflects base load only (ie. no one is home to use energy and just the typical appliances are running like fridge, hot water unit, etc).
- P2P energy market availability is just arbitrary
- The P2P energy market on the third day reflects a full day with no P2P market available.
- PVS output data is based on a typical system as described in section 3.2.2 and 3.4.2 with the following weather days
  - Day 1: Overcast
  - Day 2: Sunny
  - Day 3: Sunny
  - Day 4: Sunny
  - Day 5: Raining
  - Day 1: Overcast
  - Day 7: Raining

4.2.1 Small PVS & Small BESS

The following results are from the simulation of a small PVS and small BESS as described in Table 30. Refer to appendix I for the relevant plot outputs for each of the operating modes.

Data	Value
BESS size	5 kWh
PVS output scale	1 (6.93 kW)

Table 30: Final testing - small PVS and small BESS data parameters

4.2.1.1 Sustainability Mode

Small PVS (6.93kW) & Small BESS (5kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	34.98	6.35	9.32	49.35
2	21.12	16.39	10.92	51.56
3	25.88	24.94	0.00	49.18
4	25.92	12.48	10.62	50.98
5	2.70	25.99	44.79	26.52
6	23.18	18.13	10.29	48.40
7	0.00	45.75	27.73	26.52
Week Average	19.11	21.43	16.24	43.22

Table 31: Final testing small PVS and small BESS – Sustainability mode energy source usage

Small PVS (6.93kW) & Small BESS (5kWh) - Costs		
Day	Cost ($)	Average cost ($)
1	0.55	0.55
2	1.00	0.78
3	1.08	0.88
4	0.63	0.82
5	3.22	1.30
6	1.09	1.26
7	3.75	1.62
Week Total	11.32	

Table 32: Final testing small PVS and small BESS – Sustainability mode costs

4.2.1.2 Traditional Mode

Small PVS (6.93kW) & Small BESS (5kWh) - Energy Source Usage			
Day	Battery Usage (%)	Grid Usage (%)	Solar Usage (%)
1	26.22	26.83	46.95
2	22.45	32.12	45.43
3	22.16	35.36	42.48
4	13.00	44.81	42.19
5	14.55	61.31	24.14
6	14.25	42.97	42.78
7	8.41	67.87	23.72
Week Average	17.29	44.47	38.24

Table 33: Final testing small PVS and small BESS – Traditional mode energy source usage

Small PVS (6.93kW) & Small BESS (5kWh) - PVS & BESS Export/Import		
	BESS Import Grid (kWh)	Solar Export Grid (kWh)
Week Total	17.50	125.54

Table 34: Final testing small PVS and small BESS – Traditional mode PVS & BESS Export/Import

Small PVS (6.93kW) & Small BESS (5kWh) - Costs			
Day	Cost ($)	Export Profit ($)	Average cost ($)
1	1.26	0.91	1.26
2	1.51	2.66	1.38
3	1.74	2.69	1.50
4	1.74	2.81	1.56
5	4.45	0.00	2.14
6	1.20	0.96	1.98
7	3.97	0.00	2.27
Week Total	15.86	10.04	

Table 35: Final testing small PVS and small BESS – Traditional mode costs

4.2.1.3 Benefit Mode

Small PVS (6.93kW) & Small BESS (5kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	33.28	6.04	13.73	46.95
2	28.48	15.96	5.35	50.21
3	22.97	27.86	0.00	49.18
4	19.10	10.96	25.18	44.76
5	18.23	17.22	41.64	22.91
6	19.85	12.26	25.11	42.78
7	11.19	37.93	27.17	23.72
Week Average	21.87	18.32	19.74	40.07

Table 36: Final testing small PVS and small BESS – Benefit mode energy source usage

Small PVS (6.93kW) & Small BESS (5kWh) - PVS & BESS Export/Import					
	BESS Import P2P (kWh)	Solar Export Grid (kWh)	Solar Export P2P (kWh)	BESS Export Grid (kWh)	BESS Export P2P (kWh)
Week Total	13.00	47.99	61.63	2.21	0.42

Table 37: Final testing small PVS and small BESS – Benefit mode PVS & BESS Export/Import

Small PVS (6.93kW) & Small BESS (5kWh) - Costs				
Day	Cost ($)	Export Profit ($)	Average cost ($)	Total Profit ($)
1	0.70	1.15	0.70	0.45
2	0.84	4.06	0.77	3.67
3	1.19	2.38	0.91	4.86
4	1.02	5.02	0.94	8.86
5	2.99	0.04	1.35	5.90
6	1.41	0.67	1.36	5.15
7	3.64	0.02	1.68	1.53
Weekly Total	11.79	13.32		

Table 38: Final testing small PVS and small BESS – Benefit mode costs

4.2.2 Large PVS & Small BESS

The following results are from the simulation of a large PVS and small BESS as described in Table 39. Refer to appendix J for the relevant plot outputs for each of the operating modes.

Data	Value
BESS size	5 kWh
PVS output scale	2 (13.86 kW)

Table 39: Final testing - large PVS and small BESS data parameters

4.2.2.1 Sustainability Mode

Large PVS (13.86kW) & Small BESS (5kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	33.82	2.97	8.73	54.48
2	23.13	10.40	10.91	55.57
3	20.80	26.13	0.00	53.07
4	28.70	8.33	8.74	54.23
5	14.00	16.63	27.02	42.35
6	20.88	12.47	13.69	52.97
7	12.62	36.72	8.31	42.35
Week Average	21.99	16.23	11.06	50.72

Table 40: Final testing large PVS and small BESS – Sustainability mode energy source usage

Large PVS (13.86kW) & Small BESS (5kWh) - Costs		
Day	Cost ($)	Average cost ($)
1	0.39	0.39
2	0.74	0.56
3	1.13	0.75
4	0.45	0.68
5	1.98	0.94
6	0.93	0.94
7	2.47	1.16
Week Total	8.09	

Table 41: Final testing large PVS and small BESS – Sustainability mode costs

4.2.2.2 Traditional Mode

Large PVS (13.86kW) & Small BESS (5kWh) - Energy Source Usage			
Day	Battery Usage (%)	Grid Usage (%)	Solar Usage (%)
1	26.33	21.84	51.83
2	18.37	33.81	47.82
3	20.68	32.41	46.91
4	13.40	41.71	44.88
5	19.60	41.85	38.55
6	10.21	42.97	46.82
7	14.33	47.11	38.55
Week Average	17.56	37.39	45.05

Table 42: Final testing large PVS and small BESS – Traditional mode energy source usage

Large PVS (13.86kW) & Small BESS (5kWh) - PVS & BESS Export/Import		
	BESS Import Grid (kWh)	Solar Export Grid (kWh)
Week Total	17.00	212.05

Table 43: Final testing large PVS and small BESS – Traditional mode PVS & BESS Export/Import

Large PVS (13.86kW) & Small BESS (5kWh) - Costs			
Day	Cost ($)	Export Profit ($)	Average cost ($)
1	1.01	2.65	1.01
2	1.63	3.79	1.32
3	1.56	3.79	1.40
4	1.62	3.84	1.45
5	3.01	0.11	1.77
6	2.11	2.69	1.82
7	3.02	0.11	1.99
Week Total	13.96	16.98	

Table 44: Final testing large PVS and small BESS – Traditional mode costs

4.2.2.3 Benefit Mode

Large PVS (13.86kW) & Small BESS (5kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	32.84	2.82	12.51	51.83
2	27.31	9.65	10.33	52.72
3	20.51	26.42	0.00	53.07
4	33.54	0.00	17.35	49.12
5	18.37	14.87	28.89	37.87
6	25.18	4.99	21.89	47.93
7	13.48	38.28	7.49	40.75
Week Average	24.46	13.86	14.06	47.61

Table 45: Final testing large PVS and small BESS – Benefit mode energy source usage

Large PVS (13.86kW) & Small BESS (5kWh) - PVS & BESS Export/Import					
	BESS Import P2P (kWh)	Solar Export Grid (kWh)	Solar Export P2P (kWh)	BESS Export Grid (kWh)	BESS Export P2P (kWh)
Week Total	9.50	91.38	94.23	2.61	0.74

Table 46: Final testing large PVS and small BESS – Benefit mode PVS & BESS Export/Import

Large PVS (13.86kW) & Small BESS (5kWh) - Costs				
Day	Cost ($)	Export Profit ($)	Average cost ($)	Total Profit ($)
1	0.51	3.46	0.51	2.95
2	0.72	5.55	0.62	7.78
3	1.13	3.39	0.79	10.04
4	0.41	5.95	0.69	15.58
5	2.16	0.04	0.99	13.46
6	0.92	3.28	0.98	15.82
7	2.62	0.08	1.21	13.27
Weekly Total	8.49	21.76		

Table 47: Final testing large PVS and small BESS – Benefit mode costs

4.2.3 Small PVS & Large BESS

The following results are from the simulation of a small PVS and large BESS as described in Table 30. Refer to appendix K for the relevant plot outputs for each of the operating modes.

Data	Value
BESS size	12.8 kWh
PVS output scale	1 (6.93 kW)

Table 48: Final testing - small PVS and large BESS data parameters

4.2.3.1 Sustainability Mode

Small PVS (6.93kW) & Large BESS (12.8kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	47.68	2.97	0.00	49.35
2	48.44	0.00	0.00	51.56
3	50.82	0.00	0.00	49.18
4	49.02	0.00	0.00	50.98
5	28.01	9.99	35.47	26.52
6	39.41	5.29	6.89	48.40
7	17.49	33.03	22.96	26.52
Week Average	40.13	7.33	9.33	43.22

Table 49: Final testing small PVS and large BESS – Sustainability mode energy source usage

Small PVS (6.93kW) & Large BESS (12.8kWh) - Costs		
Day	Cost ($)	Average cost ($)
1	0.13	0.13
2	0.00	0.06
3	0.00	0.04
4	0.00	0.03
5	1.94	0.41
6	0.42	0.42
7	2.85	0.76
Week Total	5.34	

Table 50: Final testing small PVS and large BESS – Sustainability mode costs

4.2.3.2 Traditional Mode

Small PVS (6.93kW) & Large BESS (12.8kWh) - Energy Source Usage			
Day	Battery Usage (%)	Grid Usage (%)	Solar Usage (%)
1	33.38	20.29	46.32
2	26.75	30.55	42.70
3	31.37	25.28	43.35
4	36.14	20.57	43.28
5	31.61	46.32	22.07
6	21.06	42.72	36.22
7	15.44	62.49	22.07
Week Average	27.97	35.46	36.57

Table 51: Final testing small PVS and large BESS – Traditional mode energy source usage

Small PVS (6.93kW) & Large BESS (12.8kWh) - PVS & BESS Export/Import		
	BESS Import Grid (kWh)	Solar Export Grid (kWh)
Week Total	26.88	119.78

Table 52: Final testing small PVS and large BESS – Traditional mode PVS & BESS Export/Import

Small PVS (6.93kW) & Large BESS (12.8kWh) - Costs			
Day	Cost ($)	Export Profit ($)	Average cost ($)
1	0.95	0.91	0.95
2	1.53	2.66	1.24
3	1.23	2.42	1.24
4	0.77	2.81	1.12
5	3.40	0.00	1.58
6	2.42	0.78	1.72
7	4.43	0.00	2.11
Week Total	14.74	9.58	

Table 53: Final testing small PVS and large BESS – Traditional mode costs

4.2.3.3 Benefit Mode

Small PVS (6.93kW) & Large BESS (12.8kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	47.68	2.97	0.00	49.35
2	46.74	1.69	0.00	51.56
3	50.82	0.00	0.00	49.18
4	42.92	0.00	10.26	46.82
5	29.04	7.18	43.42	20.36
6	31.10	4.59	24.03	40.27
7	22.85	26.21	28.88	22.07
Week Average	38.74	6.09	15.23	39.94

Table 54: Final testing small PVS and large BESS – Benefit mode energy source usage

Small PVS (6.93kW) & Large BESS (12.8kWh) - PVS & BESS Export/Import					
	BESS Import P2P (kWh)	Solar Export Grid (kWh)	Solar Export P2P (kWh)	BESS Export Grid (kWh)	BESS Export P2P (kWh)
Week Total	17.92	35.90	38.88	14.45	4.38

Table 55: Final testing small PVS and large BESS – Benefit mode PVS & BESS Export/Import

Small PVS (6.93kW) & Large BESS (12.8kWh) - Costs				
Day	Cost ($)	Export Profit ($)	Average cost ($)	Total Profit ($)
1	0.13	0.95	0.13	0.82
2	0.07	2.91	0.10	3.66
3	0.00	1.92	0.07	5.58
4	0.24	3.75	0.11	9.08
5	2.72	0.27	0.63	6.63
6	1.06	0.57	0.70	6.15
7	3.16	0.15	1.05	3.15
Weekly Total	7.37	10.52		

Table 56: Final testing small PVS and large BESS – Benefit mode costs

4.2.4 Large PVS & Large BESS

The following results are from the simulation of a large PVS and large BESS as described in Table 57. Refer to appendix L for the relevant plot outputs for each of the operating modes.

Data	Value
BESS size	12.8 kWh
PVS output scale	2 (13.86 kW)

Table 57: Final testing - large PVS and large BESS data parameters

4.2.4.1 Sustainability Mode

Large PVS (13.86kW) & Large BESS (12.8kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	42.55	2.97	0.00	54.48
2	44.43	0.00	0.00	55.57
3	46.93	0.00	0.00	53.07
4	45.77	0.00	0.00	54.23
5	41.81	6.63	9.21	42.35
6	33.51	8.21	5.31	52.97
7	30.36	27.28	0.00	42.35
Week Average	40.77	6.44	2.07	50.72

Table 58: Final testing large PVS and large BESS – Sustainability mode energy source usage

Large PVS (13.86kW) & Large BESS (12.8kWh) - Costs		
Day	Cost ($)	Average cost ($)
1	0.13	0.13
2	0.00	0.06
3	0.00	0.04
4	0.00	0.03
5	0.74	0.17
6	0.50	0.23
7	1.64	0.43
Week Total	3.00	

Table 59: Final testing large PVS and large BESS – Sustainability mode costs

4.2.4.2 Traditional Mode

Large PVS (13.86kW) & Large BESS (12.8kWh) - Energy Source Usage			
Day	Battery Usage (%)	Grid Usage (%)	Solar Usage (%)
1	32.94	15.93	51.14
2	28.32	25.66	46.02
3	27.94	25.28	46.78
4	38.20	11.99	49.81
5	36.22	26.99	36.78
6	17.57	42.79	39.64
7	22.18	41.03	36.78
Week Average	29.05	27.10	43.85

Table 60: Final testing large PVS and large BESS – Traditional mode energy source usage

Large PVS (13.86kW) & Large BESS (12.8kWh) - PVS & BESS Export/Import		
	BESS Import Grid (kWh)	Solar Export Grid (kWh)
Week Total	23.04	184.76

Table 61: Final testing large PVS and large BESS – Traditional mode PVS & BESS Export/Import

Large PVS (13.86kW) & Large BESS (12.8kWh) - Costs			
Day	Cost ($)	Export Profit ($)	Average cost ($)
1	0.74	2.26	0.74
2	1.27	3.39	1.00
3	1.23	3.39	1.08
4	0.42	3.44	0.91
5	1.77	0.00	1.08
6	2.43	2.31	1.31
7	2.75	0.00	1.51
Week Total	10.59	14.79	

Table 62: Final testing large PVS and large BESS – Traditional mode costs

4.2.4.3 Benefit Mode

Large PVS (13.86kW) & Large BESS (12.8kWh) - Energy Source Usage				
Day	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
1	42.55	2.97	0.00	54.48
2	44.43	0.00	0.00	55.57
3	46.93	0.00	0.00	53.07
4	41.66	0.00	8.53	49.81
5	33.81	5.76	23.64	36.78
6	27.86	6.83	21.23	44.08
7	26.32	22.55	12.66	38.47
Week Average	37.65	5.44	9.44	47.46

Table 63: Final testing large PVS and large BESS – Benefit mode energy source usage

Large PVS (13.86kW) & Large BESS (12.8kWh) - PVS & BESS Export/Import					
	BESS Import P2P (kWh)	Solar Export Grid (kWh)	Solar Export P2P (kWh)	BESS Export Grid (kWh)	BESS Export P2P (kWh)
Week Total	11.52	79.05	76.99	14.89	4.35

Table 64: Final testing large PVS and large BESS – Benefit mode PVS & BESS Export/Import

Large PVS (13.86kW) & Large BESS (12.8kWh) - Costs				
Day	Cost ($)	Export Profit ($)	Average cost ($)	Total Profit ($)
1	0.13	3.15	0.13	3.02
2	0.00	5.06	0.06	8.08
3	0.00	3.23	0.04	11.31
4	0.20	6.10	0.08	17.21
5	1.41	0.28	0.35	16.08
6	1.07	1.80	0.47	16.80
7	1.99	0.10	0.69	14.91
Weekly Total	4.81	19.72		

Table 65: Final testing large PVS and large BESS – Benefit mode costs

Chapter 5 – Discussion

5.1 REMD Design

As previously described in detail the REMD consists of three operating modes that are aimed at specific target audiences. The intent was that each of the operating modes would operate with a different set of rules and energy sources to best align with the ethics and motivational aspects for the individual related to energy usage.

Sustainability mode placed a lot more emphasis on using internal energy sources (PVS and BESS) as priority. The BESS didn't have any time scheduled or load offset limits and the excess energy from PVS generation or excess BESS capacity could not be exported to the either the retail market or the P2P market. This was configured this way as the main premise behind this operating mode was to ensure the home was using all of the available internal energy sources. It was hoped that these two features would create a load shift or greater consciousness with regards to how much of the BESS was being used outside of PVS hours, but no live installation trials or human trials are proposed under this dissertation so this aspect could not be confirmed. This operating mode also had access to all four energy sources (PVS, BESS, retail market and P2P market) but with the P2P market being preference over the retail market. This was configured this way as the P2P market would most likely consist of renewable energy source exports from neighbouring houses which would align with the operating modes objects of aligning with sustainable energy sources.

Originally the intent for traditional mode was to operate in a way that the total import/export ratio was as close to one as possible. The intent behind this was to essentially create a net zero impact to the grid by not being a large energy importer or exporter. The problem discovered before modelling was it is not a feasible energy management strategy as it would mean that the PVS and BESS would be in a constant cycle of discharging and charging in order to try and maintain the net zero arrangement. This would create a non-optimised operating profile for the BESS and there are better benefits to trying to offset the load (import from the grid) during peak hours with the use of the BESS and then charging the battery during non-peak hours if the battery gets below a certain percentage. Now the traditional operating mode was configured to provide an energy experience very similar to what the current users would be experiencing, but with additional layers for more optimised energy import and export. This operating mode would be more targeted at the users that don't want the confusion or hassle of complex energy control and metering systems (i.e. older people or people not concerned about their energy usage), and is why the P2P market was not being accessed in this operating mode. The BESS under this operating mode had a timed scheduled and load offset limit which were tied to the tariffs of peak and off-peak/shoulder. During the peak tariff the BESS would export up to the full capacity and during the off-peak/shoulder tariffs the BESS would export up to half of the total capacity. This tariff time scheduled approach has a good effect of reducing the load during peak hours and increases the load during non-peak hours. This has a similar desired effect to evening out the import/export times more evenly across a 24hr period which is much the same as the intended nil import/export approach that was originally proposed.

Benefit mode was intended to provide users with an energy management system that aimed to reduce the total import but maximise the export of energy to increase system profits. The REMD would prioritise energy export to the P2P market over the retail market as the export tariff on the P2P market is much better than the retail market. One aspect that was explored early during the design for this operating mode was a BESS charging profile from the P2P market or the retail market that would only allow import and export of energy during low energy demand. The problem with this approach was that the REMD would have to know what is considered a low energy demand for the house and then also make decisions on whether to import or export the BESS energy. As the peak demand usually occurs during the evening when the PVS has minimal to no export the BESS would be offsetting majority of the load and would be depleted quite quickly. Not long after this evening demand peak (which also occurs during the peak tariff time) the tariff structure would transition into shoulder and the off-peak which would than allow the BESS to import or export, but as previously mentioned the battery would be somewhat depleted after the evening peak demand and would always want to import energy. The problem here is that the BESS would charge all night (increasing import energy costs) and the excess generated PVS energy during the next day would not go to charging the battery but exporting to the grid. To combat this issue and improve the import/export to the grid a system similar to the traditional operating mode was implemented with time schedule and load offset limits for the BESS. This meant that during peak/shoulder tariffs the BESS could load offset up to the full capacity and during the off-peak tariff the load offset and export limit was set to half of the total BESS capacity. The BESS could also only charge from the P2P market if the BESS was fully depleted and was set at a constant charge rate of 10% of the BESS total capacity. It was envisaged that with the PVS and BESS export configurations and the BESS import configuration that the system would provide an increased profit over the other operating modes.

Overall each of the operating modes were configured with what was believed to be the most suitable energy management strategies based on the objectives of the operating modes. Each of these modes appeared to work as intended but as no other energy management strategies were actually modelled it is hard to determine if the chosen strategies are the most optimal. Further investigation and comparison of other energy management strategies would have provided clarity if any tweaks are required.

5.2 MATLAB Simulink Stateflow Model

The original intent for this dissertation was to build the REMD device as a fuzzy logic controller as this type of energy management system at the time was believed to provide a workable solution. Upon further research into fuzzy logic controllers as part of the literature review under section 2.7 and discussions with the project supervisor it was discovered that this approach was not suitable. Fuzzy logic controllers are suited to systems where the system is unknown or not well defined, but for this REMD the system is very well defined and hence why the state-based control approach is preferred in these situations.

To undertake the modelling and simulation MATLAB Simulink with the additional add-on feature of stateflow was utilised. This stateflow add-on allowed for the REMD to be configured with a state-based control approach that allowed for the knowledge gained through the USQ course ELE2303 (embedded systems and design) to be implemented into the stateflow model. It was discovered through the designing of the model that the original plan for separate states for each of the energy source combinations/configurations would be impractical and very complicated to implement and would detract from the benefits of using state-based control. The limitation of a state-based controller is that the controller can only operate in one state at a time and means that some of the flexibility of the model is limited and various scenarios do need to be captured very accurately. The implemented strategy for the models was to have each major operating mode (PVS, BESS, retail market and P2P market) as a state with sub-states dependent on system variables such as PVS output, tariffs, BESS SoC, etc. This approach worked well and did provide a much simpler modelling experience but did add some complexities to the state transition criteria.

During the initial construction of the models the approach was to build discrete states in isolation and then join them together once the previous state was working correctly. This approach allowed for a streamlined approach to debugging as only one state needed to be focused on at a time. For each of the operating modes the build process was very similar with the following order

- Code tariff states
- Code BESS SoC states
- Code REMD main controller states
- Code Display states
- Build display

Throughout the modelling process there were lots of debugging and tweaks required to ensure the correct operation and this was undertaken by comparing the REMD state choices and associated outputs with predefined state expectations and hand calculations for the associated outputs (refer section 41 for a detailed breakdown of the initial testing procedures/results). Although the initial testing was computing correctly with the initial 24 hour data provided, it was discovered that there were still underlying errors once the simulation was provided with a weeks worth of data. These errors came from simple and very minor code errors which the initial data didn't capture and that is because the variance of load, energy import/export, BESS size and PVS size were only included in the final testing.

5.3 Results - Initial Testing

The initial testing was completed for each of the operating modes and associated models to test the functionality and also to debug the system. The initial testing in general was successful and found some minor errors that required rectification, but overall the initial testing was positive. The following provides a summary of the results for each of the operating modes.

5.3.1 Sustainability Mode

The state sequence flow for this operating mode worked as intended. One anomaly that was noted with the code was when the controller state was compared against predefined expectations as at the 21 hour mark the REMD state went from the P2P market to the BESS. This ended up being correct as it was thought originally that the state would have remained in the P2P market as the BESS could not support the load. Upon further investigation it was discovered that the load had dropped enough at the 21 hour mark to allow the BESS to fully offset the load before being fully depleted.

With reference to figure 39 the BESS charged fully over two hours from the excess PVS generation which is good, but the excess generated energy is purely wasted as the load is much less than the PVS generated energy. This means that the user would see benefits with a larger battery that could absorb the excess generated PVS energy or shifting some of the peak load during the evening to hours when the PVS is generating the most.

When looking specifically at the energy source usage breakdown the traditional mode can be used as a baseline to understand if the sustainability mode offers improvements for greater PVS and BESS usage and reduced retail market and P2P market import. From table 66 it is clear that the sustainability mode does increase internal energy source usage by approximately 2.4% greater PVS usage and 8.76% greater BESS usage, whilst also decreasing the total energy import by approximately 11.16%.

Energy Source Usage – Sustainability & Traditional Comparison			
	Grid or P2P Import	PVS Offset	BESS Offset
Sustainability Mode	15.67%	49.35%	34.98%
Traditional Mode	26.83%	46.95%	26.22%

Table 66: Energy source usage – sustainability and traditional mode operating comparison

The cost calculation comparison showed an interesting result that was not apparent on face value until further investigation was completed. Even though sustainability mode had less energy import when compared to the traditional mode the cost calculations showed otherwise with sustainability mode total import costs being $0.55 and traditional mode total import costs being $0.35. The reason for the traditional mode import costs being less than sustainability mode is due to the fact that the traditional mode can export the excess generated PVS energy to the retail market and receive a feedback cost. As shown in table 67 this feedback cost for the day was $0.91 which when deducted from the energy import cost of $1.26 results in the daily total import of $0.35.

Cost Calculation – Sustainability & Traditional Comparison		
	Energy Import Cost	Energy Export Cost
Sustainability Mode	$ 0.55	N/A
Traditional Mode	$ 1.26	$ 0.91

Table 67: Cost calculation – sustainability and traditional operating mode comparison

The REMD display also worked as intended and all values/plots shown were correct against all of the calculated values and no adjustments were required.

5.3.2 Traditional Mode

The state sequence flow for this operating mode worked as intended but there were some anomalies that were noted with some states that weren't expected initially, but the commentary under section 4.1.1.2 provides a summary of the anomalies and the associated investigation to prove the state was actually correct.

With reference to figure 40 the BESS charged from both the retail market and the excess PVS generation. Similar to the sustainability operating mode the PVS was able to fully charge the BESS over a 2 hour period, but there was also two instances where the BESS was charged from the retail market at hour 4 and 22 respectively. The BESS charging from the retail market aligned with the off-peak tariff timeframes which was intended to reduce total retail import energy costs.

When the BESS charged from the retail market at hour 4 mark it was able to charge enough that the SoC was no longer less than medium and was able to export a little bit of the BESS energy to offset the load. Running some cost calculations on this 4-5 hour timeframe it actually worked out more expensive to charge the battery and discharge to offset some of the load then it was to just simply import the required energy from the retail market (refer table 68). Further refinement could be made here to ensure that energy import costs are not inherently higher for the user in cases like this. Another aspect that could be implemented to combat this issue is day ahead forecasting as if the weather is sunny and the BESS will receive a full charge then the import of energy in the morning should be avoided, whereas if the weather is overcast then the BESS should charge during the non-peak tariff hours.

	Energy Import Cost
BESS charge	$ 0.252
No BESS charge	$ 0.296

Table 68: Energy import cost comparison for morning BESS charge from grid versus no charge from grid

It was also noted that the traditional mode was unable to utilise the last bit of the BESS at the 21 hour mark as shown in figure 41 and this was due to the timeframe discharge limit for the BESS during off-peak/shoulder tariff times and as the BESS was less than medium SoC the BESS was not allowed to export to offset the load.

The associated cost calculations and the REMD display also worked as intended and all values/plots shown were correct against all of the calculated values and no adjustments were required.

5.3.3 Benefit Mode

The state sequence flow for this operating mode did not work as intended through the initial testing as there was a state transition issue where the SolarBattery_Peak_Shoulder would not end once the peak and shoulder tariffs were not active. This state would only break once the BESS was fully depleted and would then transition to the retail or P2P market. It was discovered that there was a transition condition missing between the SolarBattery_Peak_Shoulder and SolarBattery_Offpeak states relating to the off-peak tariff times. This was subsequently rectified and the state sequence flow worked as intended. There were some anomalies that were noted with the states that weren't expected initially but the commentary under section 4.1.1.3 provides a summary of the anomalies and the associated investigation to prove the state was actually correct.

With reference to figure 42 the BESS charged fully over three hours from the excess PVS generation which is one hour longer than the sustainability and traditional modes. This was due to the export parameters defined for the PVS in conjunction with the SoC of the BESS. As the SoC of the BESS increases into the high range the half of the excess PVS is exported to the retail or P2P market and the other half is used to charge the BESS which has resulted in an additional one hour required to charge the BESS. The use of the P2P market to charge the BESS at hour 20 was advantageous as this allowed for the next hour of load to be offset.

When looking specifically at the energy source usage breakdown the traditional mode can be used as a baseline to understand if the benefit mode offers improvements for greater export of internal energy sources and reduced retail market and P2P market import. From table 69 benefit mode does increase internal BESS energy source usage by approximately 7.06%, has the same PVS usage, whilst also decreasing the total energy import by approximately 7.06%.

Energy Source Usage – Benefit & Traditional Comparison			
	Grid or P2P Import	PVS Offset	BESS Offset
Benefit Mode	19.77%	46.95%	33.28%
Traditional Mode	26.83%	46.95%	26.22%

Table 69: Energy source usage – benefit and traditional operating mode comparison

The cost calculation comparison showed (table 70) that the benefit mode does operate more profitable than the traditional mode. Traditional mode had a net cost of $0.35 and net profit of $0, whereas benefit mode had a net cost of $0 and net profit of $0.45. This increased profit is due to the benefit mode being able to export to the P2P market and receive better FiT rates and also the export of the BESS and excess PVS is optimised to maximise the export amount.

Cost Calculation –Benefit & Traditional Comparison		
	Energy Import Cost	Energy Export Cost
Benefit Mode	$ 0.7	$ 1.15
Traditional Mode	$ 1.26	$ 0.91

Table 70: Cost calculation – benefit and traditional operating mode comparison

The REMD display also worked as intended and all values/plots shown were correct against all of the calculated values and no adjustments were required.

5.4 Results - Final Testing

After completing the initial testing the final testing was used to simulate the operating modes over a larger time period of seven days. This is used to determine how the REMD operating modes respond with variations in system size components. Across the seven days variances of load, solar irradiance and P2P market availability were all introduced and considered as constants as this input data was the same for all operating modes under all of the final testing simulations. The main variables changed in the final testing was the scaling factor for the PVS (used to simulate small and large systems) and also the size of the BESS (used to simulate small and large systems).

During the preliminary testing and associated outputs it was noted that the breakdown of energy source usage was not fully adding up to 100% across all of the available energy sources (dependant on the operating mode). It was discovered that in each of the operating modes there were minor errors within the code that impacted the final breakdown results. These particular errors were not apparent in the initial testing as that data was only for 24 hours and as such when the controlled variances of load, solar irradiance and P2P market availability were adjusted the calculations undertaken by the controller were slightly wrong. These issues were rectified after meticulously going through and debugging the associated code and the following is a summary of the identified issues:

- Sustainability mode – the display state was missing the battery discharge calc for the entry and exit conditions for the calculations state and was leading to on certain days not adding to 100%. This was only occurring on certain days and was dependant if the battery was discharging during the first and last display calculations.
- Traditional mode – the solar output value during the grid state and during off-peak tariff was not included and the associated display calculations were not adding to 100%. This was only occurring on certain days and was dependant if the battery was discharging during the first and last display calculations.
- Benefit Mode – the calculations would sometimes equal 100% and not other times, but upon further investigation it was discovered that one of the lines of codes in the entry condition to the display state calc state was wrong.

5.4.1 Impacts of different PVS and BESS Sizes on Energy Source Usage

The below tables provide a summary of the difference between the weekly averages for the energy source usage across differing PVS and BESS configurations. Comparing against the weekly averages for the energy source usage across the operating modes will provide an insight to how the operating modes best responds to an increase in the PVS, BESS or a combination of both. The following can be noted from the results

- Increasing the PVS size has marginal improvements to the system performance
- Increasing the BESS size has significant improvements to the system performance
- Increasing both the PVS and BESS is only marginally better than the BESS size increase alone

The reason why the PVS size increase didn't have as large of an impact as the BESS size increase is due to the PVS export being limited to 5kW total by the inverter. The BESS is also critical at reducing the load during peak demand times which usually occurs outside of the available PVS export and thus has the greater reduction for energy import from the retail or P2P market.

Energy Source Usage – Sustainability Mode – Differing PVS & BESS Sizes				
	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
Small PVS & Small BESS	-	-	-	-
Large PVS & Small BESS	2.88 %	-5.2 %	-5.18 %	7.5 %
Small PVS & Large BESS	21.0 %	-14.1 %	-6.91 %	0%
Large PVS & Large BESS	21.7 %	-15.0 %	-6.80 %	7.5 %

Table 71: Differing PVS and BESS sizes on energy source usage – sustainability mode – compared against small PVS & BESS configuration

Energy Source Usage – Traditional Mode – Differing PVS & BESS Sizes			
	Battery Usage (%)	Grid Usage (%)	Solar Usage (%)
Small PVS & Small BESS	-	-	-
Large PVS & Small BESS	0.27%	-7.1%	6.81%
Small PVS & Large BESS	10.7%	-9%	-1.67%
Large PVS & Large BESS	11.8%	-17.37	-5.61%

Table 72: Differing PVS and BESS sizes on energy source usage – traditional mode – compared against small PVS & BESS configuration

Energy Source Usage – Benefit Mode – Differing PVS & BESS Sizes				
	Battery Usage (%)	Grid Usage (%)	P2P Usage (%)	Solar Usage (%)
Small PVS & Small BESS	-	-	-	-
Large PVS & Small BESS	2.59%	-4.46%	-5.68%	7.54%
Small PVS & Large BESS	16.9%	-12.2%	-4.51%	-0.1%
Large PVS & Large BESS	15.8%	-8.88%	-10.3%	7.39%

Table 73: Differing PVS and BESS sizes on energy source usage – benefit mode – compared against both small PVS & BESS configuration

5.4.2 Impacts of different PVS and BESS Sizes on Energy Import/Export

The below tables provide a summary of the difference between the weekly totals for PVS and BESS import/export across differing PVS and BESS configurations. Comparing against the weekly totals for PVS and BESS import/export across the operating modes will provide an insight into how the operating modes respond to the amount of imported/exported energy. Note that the sustainability mode cannot import energy to charge the BESS or export energy to the retail market or P2P market. The following can be noted from the results

- Increasing the PVS size increases PVS output, reduces BESS import and the BESS export remains similar
- Increasing the BESS size decreases PVS output, increases BESS import and the BESS export increases

- Increasing both the PVS and BESS increases the PVS output, reduces the BESS import and increase BESS export

PVS & BESS Export/Import - Traditional Mode – Differing PVS & BESS Sizes		
	BESS Import Grid (kWh)	Solar Export Grid (kWh)
Small PVS & Small BESS	17.00	212.05
Large PVS & Small BESS	-0.5 kWh	86.52 kWh
Small PVS & Large BESS	9.38 kWh	-5.75 kWh
Large PVS & Large BESS	5.4 kWh	59.22 kWh

Table 74: Differing PVS and BESS sizes on export/import – traditional mode – compared against small PVS & BESS configuration

PVS & BESS Export/Import - Benefit Mode – Differing PVS & BESS Sizes					
	BESS Import P2P (kWh)	Solar Export Grid (kWh)	Solar Export P2P (kWh)	BESS Export Grid (kWh)	BESS Export P2P (kWh)
Small PVS & Small BESS	-	-	-	-	-
Large PVS & Small BESS	-3.5 kWh	43.4 kWh	32.6 kWh	0.39 kWh	0.32 kWh
Small PVS & Large BESS	4.92 kWh	-12.1 kWh	-22.8 kWh	12.2 kWh	3.95 kWh
Large PVS & Large BESS	-1.48 kWh	31.1 kWh	15.4 kWh	12.7 kWh	3.93 kWh

Table 75: Differing PVS and BESS sizes on export/import – benefit mode – compared against small PVS & BESS configuration

5.4.3 Impacts of different PVS and BESS Sizes on Energy Costs

The below tables provide a summary of the difference between the weekly totals for energy costs across differing PVS and BESS configurations. Comparing against the weekly total costs across the operating modes will provide an insight into how each of the operating modes import and export energy resulting in differing energy costs. The following can be noted from the results

- Increasing the PVS or BESS size in sustainability mode results in reduced import costs
- Increasing the PVS or BESS size in traditional mode results in reduced import costs and increased export profits
- Increasing the PVS or PVS and BESS size in benefit mode results in reduced import costs and increased export profits. Only increasing the BESS size results in reduced import costs and reduced export costs, however overall the system would still be in profit but just not as much as other PVS and BESS size configurations. This reduction in exports costs is a result of the excess PVS energy being used to charge the BESS.

Energy Costs - Sustainability Mode – Differing PVS & BESS Sizes	
	Import Costs
Small PVS & Small BESS	-
Large PVS & Small BESS	$ -2.94
Small PVS & Large BESS	$ -5.69
Large PVS & Large BESS	$ - 8.03

Table 76: Differing PVS and BESS sizes on energy costs – sustainability mode – compared against small PVS & BESS configuration

Energy Costs - Traditional Mode – Differing PVS & BESS Sizes		
	Import Costs	Export Profit
Small PVS & Small BESS	-	-
Large PVS & Small BESS	$ -1.90	$ 3.92
Small PVS & Large BESS	$ -1.12	$ 0.46
Large PVS & Large BESS	$ -5.27	$ 4.75

Table 77: Differing PVS and BESS sizes on energy costs – traditional mode – compared against small PVS & BESS configuration

Energy Costs – Benefit Mode – Differing PVS & BESS Sizes		
	Import Costs	Export Profit
Small PVS & Small BESS	-	-
Large PVS & Small BESS	$ -3.3	$ 8.44
Small PVS & Large BESS	$ -4.42	$ -2.8
Large PVS & Large BESS	$ -6.98	$ 6.40

Table 78: Differing PVS and BESS sizes on energy costs – benefit mode – compared against small PVS & BESS configuration

Chapter 6 – Conclusions

6.1 Conclusion

The original intent for this dissertation was to undertake a feasibility study into the development of a central metering and energy management device. After working through the literature reviews and identifying the market gap it was discovered that a device of this nature is currently lacking and further research and development is required. As such the REMD was designed to also have the additional operating modes to encourage market uptake by allowing the end users to align their energy management in line with their respective standpoints on ethical and motivational aspects of energy usage. The operating modes allowed for the two layered approach of energy control related to automated (controller based) and educational (consumer based) aspects which both play important roles in energy management.

The REMD operating modes were refined and associated preliminary state control strategies were developed. These control strategies were then implemented and modelled in MATLAB Simulink Stateflow to allow the controller to be simulated within a controlled virtual environment. Nominal load, BESS, PVS, tariffs, etc were configured in the model which represented typical installations within the current residential market sector. The design and modelling of the matching display for the REMD was also simulated within the same model which would present the relevant system data parameters to the end user based on the controllers operating mode.

Early results from the model simulation showed that the controller operated in line with the predefined operating modes and showed signs of better energy management matching to the requirements outlined in section 3.3. The 24 hour data simulation demonstrated the codes functionality and the associated bugs identified were rectified and allowed for the next phase of testing to occur which was weekly data. This weekly data allowed for variances in the PVS and BESS sizes to be modelled and provided insight to how the controller would respond to various system sizes/configurations. The results from this weekly data tests showed that the controller is able to manage systems with non-optimised configurations or sizes, but for the end user to receive the most benefit they need to ensure that there system is suited to the intended operating mode and energy usage profile.

Overall the conceptual design of the REMD showed that this is a feasible device that could potentially replace current metering in residential installations and incorporate various energy sources that would be managed in various operating modes. Further research and development into this device is required before it can become commercially available but the outcomes of this dissertation demonstrate its ability to effectively manage the available energy sources.

6.2 Evaluation of Aims and Objectives

When specifically evaluating the aims and objectives of this dissertation it is important to note that the purpose of this dissertation has been to provide a conceptual design and feasibility assessment into the development of a residential energy management device (REMD). The feasibility assessment has been completed and the following evaluations can be made:

Criteria	Comment	Evaluation
Aim	The REMD aim is to present a holistic approach to managing the various energy sources (PVS, BESS, P2P energy market and retail market) whilst providing the relevant metering for the external energy markets, thus replacing current retail metering.	All energy sources nominated were incorporated along with functionality of both metering and energy source management/control into one device.
Objectives	Design conceptual level strategy controls based on the operating modes	Control strategies and associated flow charts were developed and aligned with the original intent.
	Design a conceptual level display that presents the relevant information based on the operating modes.	A display meeting all of the relevant criteria was developed.
	Model and simulate the REMD within MathWorks MATLAB Simulink environment.	Each operating mode was modelled and simulated in the Simulink Stateflow add-on.
	Evaluate model outcomes in line with the operating mode aims to determine feasibility of the REMD	After simulations were completed the REMD was assessed and discussed within the results and discussion section and demonstrated that this device is feasible.

6.3 Future Work

The project objectives and specific limits were described in section 1.3 and over the course of this dissertation it was noted that there are a multitude of future work areas which could be explored further as part of other research. Some possible future scope items that would build on this dissertation include the following:

- Adding other energy sources for the REMD to manage such as EV batteries, small wind turbines, generators, etc. This inclusion would allow for broader uptake with users with different energy sources. The intent would be that the REMD can manage any combination of the energy sources available.
- Incorporation of day ahead weather predictions which would allow the REMD to determine how much solar energy would be available. This element can provide the REMD with the

availability to charge the BESS from the grid at night if there is low solar energy the next day and the BESS doesn't have enough capacity for the load.

- Developing and simulating other state flows based on the operating modes to determine the best performing state flows and system configurations for each operating mode. The state flows in this dissertation were designed with what is believed to be the best configuration for the operating mode, however until other state flows are tested this cannot be confirmed.
- Increasing variations into system parameters to determine the REMD response. Variations in system parameters related to aspects of PVS size, BESS size, tariff prices, loads, etc have been reduced to what is nominated under section 3.5 in order to reduce the dissertation into a manageable size and testing timeframe.
- Testing the operation of the REMD with different electrical configurations in the model. This dissertation focused on a DC coupled BESS and it would be interesting to see the implications for an AC coupled BESS.
- Development of the wireless transmitter to transmit the relevant information to the retail market or P2P market. This element would allow for the automatic energy bill generation without the need for meter readers and the intent would be that this wireless transmitter is very similar to that of the current smart meters.
- Evaluation of educational benefits to users of energy related aspects could be assessed through real-world implementation with human studies undertaken.
- Development of a prototype REMD device for incorporation into a trial electrical system. This would provide greater insight into the operation, practicality and benefits of such a device.

6.4 Reflection

After completing the journey of this dissertation from the original concept idea by Paul Wen to where the dissertation currently ends after refinements in the aims and objects has been an overall good experience. The information gathered, researched and applied has helped to gain further understanding in the area of energy control and metering whilst also learning how to develop much more complex MATLAB Simulink models than previously undertaken. At the start of this dissertation there was little experience in Simulink, let alone the stateflow add-on and by the end of the modelling and results the competence in both aspects of the program was exponential. Time management was also another important aspect which could have been better implemented as there were times when the dissertation would stall due to lack of motivation and then very rapidly ramp up as certain submissions were due. The whole experience has been worthwhile and allowed a much deeper understanding into a focal area of interest. This device although only currently being in its feasibility and concept phase is something that may become a product in the near future and will be interesting to see how it is implemented.

References

AEMC 2023a, *About Us*, viewed 24 March 2023, <https://www.aemc.gov.au/about-us>.

AEMC 2023b, *National Electricity Rules*, viewed 24 March 2023, <https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules>.

AEMO 2021, 'Fact Sheet - The National Electricity Market ', viewed 20 March 2023,<https://aemo.com.au/-/media/files/electricity/nem/national-electricity-market-fact-sheet.pdf>.

AEMO 2022a, *About the National Electricity Market (NEM)*, AEMO, viewed 05 October, <https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/about-the-national-electricity-market-nem>.

AEMO 2022b, *Energy markets and systems*, viewed 20 March 2023, <https://aemo.com.au/learn/energy-markets-and-systems>.

AER 2023, *Public register of authorised retailers & authorisation applications*, Australian Government, viewed 24 March 2023, <https://www.aer.gov.au/retail-markets/authorisations/public-register-of-authorised-retailers-authorisation-applications?f%5B0%5D=field_accc_aer_sector%3A4&f%5B1%5D=field_accc_aer_region%3A17&f%5B2%5D=field_accc_aer_region%3A16&f%5B3%5D=field_accc_aer_status%3A7>.

AGL 2017, 'Peer-to-Peer Distributed Ledger Technology Assessment ', https://arena.gov.au/assets/2017/10/Final-Report-MHC-AGL-IBM-P2P-DLT.pdf>.

Ausgrid 2022, *Types of meters*, Ausgrid, viewed 01 April 2023, <https://www.ausgrid.com.au/Your-energy-use/Meters/Type-of-meters>.

Australian Energy Council 2022a, 'Solar Report January 2022', https://www.energycouncil.com.au/media/5wkkaxts/australian-energy-council-solar-report_-jan-2022.pdf>.

Australian Energy Council 2022b, 'Solar Report Quarter 2, 2022', https://www.energycouncil.com.au/media/43xlsldg/australian-energy-council-solar-report_q2-2022.pdf>.

Azim, MI, Tushar, W & Saha, TK 2020, 'Regulated P2P Energy Trading: A Typical Australian Distribution Network Case Study', pp. 1-5, viewed 2020,<.

Badar, AQH & Anvari-Moghaddam, A 2022, 'Smart home energy management system - a review', *Advances in building energy research*, vol. 16, no. 1, pp. 118-43.

Brakels, R 2020, *Why Your Solar Feed-In Tariff Is Lower Than Your Electricity Usage Tariff*, Solar Quotes Blog, viewed 05 October, <https://www.solarquotes.com.au/blog/solar-electricity-bill-breakdown/>.

CoolBlew 2019, *What is KVAR?*, https://coolblew.com/blog/what-is-kvar/>.

Cornago, E 2021, 'The Potential of Behavioural Interventions for Optimising Energy Use at Home', https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home>.

CSIRO 2019, 'Adoption of solar power – why or why not?'.

CSIRO n.d, *Typical House Energy Use*, viewed 04 May 2023, <https://ahd.csiro.au/other-data/typical-house-energy-use/>.

Department of Energy and Public Works 2023, *Queensland's renewable energy target*, Queensland Government - Department of Energy and Public Works, https://www.epw.qld.gov.au/about/initiatives/renewable-energy-targets>.

Department of Industry, S, Energy, and Resources, 2021, *Australian National Greenhouse Accounts*, https://www.dcceew.gov.au/sites/default/files/documents/national-greenhouse-accounts-factors-2021.pdf>.

Derrouazin, A, Aillerie, M, Mekkakia-Maaza, N & Charles, JP 2017, 'Multi input-output fuzzy logic smart controller for a residential hybrid solar-wind-storage energy system', *Energy Conversion and Management*, vol. 148, pp. 238-50.

Dr. Jemma Green, PPNaNF 2020, 'RENeW Nexus Project Report', https://assets.website-files.com/5fc9b61246966c23f17d2601/607e724f8dfb1a2d5928bbc0_renew-nexus-project-report.pdf>.

Energex 2022, *Dynamic Connections for Small Inverter Energy System (IES) Connections < 30 kVA IES Systems* Energex, viewed 03 April 2023, <https://www.energex.com.au/__data/assets/pdf_file/0006/1014963/Dynamic-Connections-Under-30-Fact-Sheet.pdf>.

Energex 2023a, *Residential electricity tariffs*, Energex, https://www.energex.com.au/home/our-services/pricing-And-tariffs/residential-tariffs-and-prices>.

Energex 2023b, *Hot Water*, Energex, viewed 01 April 2023, <https://www.energex.com.au/home/control-your-energy/save-money-And-electricity/hot-water>.

Energex 2023c, *Power of Choice for customers*, Energex, viewed 01 April 2023, <https://www.energex.com.au/home/our-services/meters/power-of-choice-for-customers>.

Energex n.d, *Solar & LV generation under 30kVA*, Energex, viewed 03 April 2023, <https://www.energex.com.au/home/our-services/connections/residential-and-commercial-connections/solar-and-lv-generation-connections/solar-and-lv-generation-under-30kva#:~:text=a%20rated%20capacity%20of%20less,up%20to%205kW%20per%20phase>.

Energy Matters 2023, *Feed in Tariffs Keep Getting Lower. Is Solar Still Worth it in 2023?*, Energy Matters, https://www.energymatters.com.au/renewable-news/feed-in-tariffs-keep-getting-lower-is-solar-still-worth-it-in-2023/>.

Essential Media 2022, 'Queensland Household Energy Survey 2022', https://www.powerlink.com.au/sites/default/files/2022-08/2022%20Queensland%20Household%20Energy%20Survey%20Report.pdf>.

Galvan, E, Mandal, P, Chakraborty, S & Senjyu, T 2019, 'Efficient Energy-Management System Using A Hybrid Transactive-Model Predictive Control Mechanism for Prosumer-Centric Networked Microgrids', *Sustainability*, vol. 11, no. 19, p. 5436.

Gouda, MM, Danaher, S & Underwood, CP 2000, 'Fuzzy Logic Control Versus Conventional PID Control for Controlling Indoor Temperature of a Building Space', *IFAC Proceedings Volumes*, vol. 33, no. 24, pp. 249-54.

Government, Q 2018, *Solar Bonus Scheme 44c feed-in tariff*, Queensland Government viewed 27 September, <https://www.qld.gov.au/housing/buying-owning-home/energy-water-home/solar/feed-in-tariffs/solar-bonus-scheme-44c#:~:text=To%20maintain%20eligibility%20for%20the,solar%20power%20system%20is%20installed>.

Government, Q 2020, *Electricity transmission*, Queensland Government - Business Queensland, https://www.business.qld.gov.au/industries/mining-energy-water/energy/electricity/queensland/transmission#:~:text=There%20are%20currently%203%20transmission,Ltd%2C%20trading%20as%20AusNet%20Services.>.

Government, Q 2022a, *Retail electricity providers*, Business Queensland, viewed 02 April 2023, <https://www.business.qld.gov.au/industries/mining-energy-water/energy/electricity/queensland/retail>.

Government, Q 2022b, *Solar feed-in tariff for regional Queensland*, Queensland Government, viewed 27 September, <https://www.qld.gov.au/housing/buying-owning-home/energy-water-home/solar/feed-in-tariffs/feed-in-tariff-regional-queensland>.

GSES 2022, 'Battery Storage Systems for Grid-Connected PV Systems - Second Edition', in Global Sustainable Energy Solutions, vol. 2, ch Chapter 4 - Power Conversion Equipment, pp. 70-1.

Honarmand, ME, Hosseinnezhad, V, Hayes, B & Siano, P 2021, 'Local energy trading in future distribution systems', *Energies*, vol. 14, no. 11, p. 3110.

Kassirer, J 2012, 'ClimateSmart Home Service, Queensland, Australia', https://toolsofchange.com/en/case-studies/detail/637>.

Kitisarn, R & Martin, J 2021, *Beginners Guide to Energy Efficiency - Chapter 9 Home Energy Management Systems*, CarbonTrack, https://carbontrack.com.au/guides/energy-efficiency-guide/home-energy-management-systems/#:~:text=Definition%20of%20HEMS&text=A%20home%20energy%20management%20system,of%20energy%20within%20a%20household.>.

Marsh, J 2019, *AC vs. DC solar battery coupling: what you need to know*, Energy Sage, https://news.energysage.com/ac-vs-dc-solar-battery-coupling-what-you-need-to-know/>.

Mathworks n.d, *Simulink*, Mathworks, https://au.mathworks.com/products/simulink.html>.

Panduru, K, Riordan, D & Walsh, J 2014, *Fuzzy Logic Based Intelligent Energy Monitoring and Control for Renewable Energy*, vol. 2014.

Petkov, P, Köbler, F, Foth, M & Krcmar, H 2011, *Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media*.

PV Output 2023, https://pvoutput.org/intraday.jsp?id=77847&sid=69030&dt=20221130>.

Roberts, Q 2018, 'Untapped Power The Need for Strategic Energy Management', https://www.efficientsee.com.au/files/untapped-power-white-paper.pdf>.

Rouse, M 2022, *Fuzzy Logic*, Techopedia, https://www.techopedia.com/definition/1809/fuzzy-logic>.

Sage Automation 2018, *4 limitations of industrial solar systems – and how to overcome them*, Sage Automation, https://www.sageautomation.com/blog/4-limitations-of-industrial-solar-pv-systems-and-how-to-overcome-them>.

Sandelic, M, Sangwongwanich, A & Blaabjerg, F 2019, 'Reliability Evaluation of PV Systems with Integrated Battery Energy Storage Systems: DC-Coupled and AC-Coupled Configurations', *Electronics*, vol. 8, no. 9.

Simshauser, P 2018, *Price discrimination and the modes of failure in deregulated retail electricity markets*.

Soto, EA, Bosman, LB, Wollega, E & Leon-Salas, WD 2021, 'Peer-to-peer energy trading: A review of the literature', *Applied Energy*, vol. 283, p. 116268.

Technology, EIo n.d, *Fundamentals of Smart Metering - kWh and kVArh*, viewed 14 April 2023, <https://www.eit.edu.au/resources/fundamentals-of-smart-metering-kwh-and-kvarh-meters/#:~:text=Modern%20electricity%20meters%20operate%20by,%2C%20kilowatt%2Dhours%20etc).>.

Tesla 2023, *Powerwall Modes*, https://www.tesla.com/en_au/support/energy/powerwall/mobile-app/powerwall-modes#advanced-setting>.

UBC 1998, 'State Machines', https://people.ece.ubc.ca/edc/380.jan98/lectures/lec4.pdf>.

USQ 2023, *Human ethics*, University of Southern Queensland, https://www.unisq.edu.au/current-students/academic/higher-degree-by-research-students/conducting-research/human-ethics>.

Vasičkaninová, A, Bakošová, M & Mészáros, A 2022, 'Cascade fuzzy control of a tubular chemical reactor', in L Montastruc & S Negny (eds), *Computer Aided Chemical Engineering*, Elsevier, vol. 51, pp. 1021-6.

Visual Paradigm n.d, *What is State Machine Diagram*, https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/>.

Yokogawa 2017, *How to Measure Electrical Power*, Yokogawa https://www.yokogawa.com/au/library/resources/media-publications/how-to-measure-electrical-power/>.

Appendices

Appendix A: Project Specification

ENG4111/4112 Research Project

Project Specification

For: Billy Dauth

Title: Home based solar power generation, storage, and localised energy grids

Major: Power Engineering

Supervisors: Paul Wen

Enrollment: ENG4111 – EXT S1, 2023

ENG4112 – EXT S2, 2023

Project Aim: To research and develop a conceptual design for a centralised energy controller aimed at residential homes incorporating solar power generation, storage, and localised energy grids. The controller will have 3 operating profiles allowing the user to make choices related to their ethical and financial stand points on power usage. The benefits for each user will be different, but the overall outcome is the same as it requires that there is a decrease in energy consumption and hopefully a change in the home energy usage profile.

Programme: Version 1, 8th March 2023

1. Conduct initial background research on the current status of solar power generation, battery storage and localised energy grids and also research current energy controllers.
2. Review existing residential installations to gauge typical configurations of electrical installations relating to components of switchboards, circuits, solar systems, battery storages systems.
3. Undertake data acquisition of typical exports/imports of energy relating to solar systems, battery storage systems, grid connected power and localised energy grids. This will consist of utility interval data and other online data sources.
4. Conceptualise a suitable flowchart diagram for one operating profile of the controller. This will form part of the main code and algorithm design.
5. Assess hardware requirements for necessary capability and concept costs.
6. Select hardware and a suitable software development environment.
7. Model the controller and associated inputs/outputs in proposed simulation software.
8. Simulate controller.
9. Refine flowcharts and algorithms based on the simulation.
10. Simulate the final controller version in operation.
11. Process and evaluate experimental data.

If time and resource permit:

12. Complete steps 4-10 for the other operating profiles.
13. Simulate the controller in operation within a localised energy grid format. The above simulation will be for just one home in isolation and not intended to be connected into a grid with other homes, creating the complete localised energy grid format.

Project Plan

Phase	Timeline (2023 weeks)																																		
	Semester 1																	Semester Break			Semester 2														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Phase 1 - Project Initiation & Preparation																																			
1A - Project endorsement	■																																		
1B - Project planning & specification	■	■																																	
Phase 2 - Research Phase																																			
2A - Literature review			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
2B - Controller interface requirements			■	■	■	■	■																												
2C - Controller algorithms				■	■	■	■																												
2D - Residential house visual inspections				■	■	■																													
Phase 3 - Data Acquisition																																			
3A - Interval load data							■	■	■	■	■	■	■	■																					
3B - Solar & battery systems							■	■	■																										
3C - Residential power circuit breakdown							■	■	■																										
Phase 4 - System Design																																			
4A - Component flow chart design												■	■	■	■																				
4B - Overall system flow chart design														■	■	■	■																		
4C - Hardware & interface design												■	■	■	■	■																			
Phase 5 - System Modelling & Analysis																																			
5A - Model each component																■	■	■	■	■	■														
5B - Simulate system																			■	■	■	■	■	■	■	■	■								
5C - Refine flowcharts and system																										■	■	■							
5D - Simulate final system																												■	■	■					
Phase 6 - Dissertation																																			
6A - Prepare draft			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
6B - Present project during ENG4903																															■				
6C - Finalise & submit																																■	■	■	■

Appendix B: Risk Assessment

			Consequence				
		Safety	No injuries. Minor delays	First Aid required. Small spill gas release easily contained within work area	Medical treatment required. Large/spill gas release contained on campus	Medical attention and hospitalisation required, permanent severe health effects	One or more deaths. Toxic substance, genetically modified organism escapes or biosafety critical incidents
			Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Likelihood	1 in 2	**Almost Certain**	High	High	High	Extreme	Extreme
	1 in 100	**Likely**	Medium	Medium	High	High	Extreme
	1 in 1,000	**Possible**	Low	Medium	Medium	High	High
	1 in 10,000	**Unlikely**	Very Low	Low	Medium	Medium	Medium
	1 in 1,000,000	**Rare**	Very Low	Very Low	Low	Low	Medium

2089	RISK DESCRIPTION	TREND	CURRENT	RESIDUAL
	ENG4111/ENG4112 - Home based solar power generation, storage, and localised energy grids – Billy Dauth		Medium	Low

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
Billy Dauth	06/03/2023		

THIS IS A RESTRICTED RISK ASSESSMENT
This risk assessment is for my dissertation and only applicable to myself and anyone involved

RISK FACTOR(S)	EXISTING CONTROL(S)	CURRENT	PROPOSED CONTROL(S)	TREATMENT OWNER	DUE DATE	RESIDUAL
Physical ergonomics - Strains on the musculoskeletal system	Control: Following ergonomic principles and guidelines, ensuring work station and equipment is fit for purpose Control: Taking regular breaks and stretching	Low	No Control:			Low
Visual Strain - Eye strain related to glare from both artificial and natural sources, improper computer screen settings	Control: Ensuring proper lighting is provided over the work space and all glare sources are minimised	Low	Taking regular breaks from screen based activities			Very Low

Stress - mental health degradation	Control: Taking regular breaks and personal time to unwind from the task at hand	Medium	Ensure that the work is planned and evenly spread throughout the year. Don't leave tasks to the last minute		15/03/2023	Low
Slips, trips and falls - injury (sprains, factures or bruises) related to falling over an object during site visits	Control: Ensure that the work environment is clear of obstructions, is left in a tidy manner and objects are not left on the floor	Medium	Tape down any electrical cords on the floor			Low
Electrical safety related to the computer area - Electrical shock or electrocution from power sources within the work area	Control: Australian rated power equipment to be used that is in good working condition, reducing the number of power boards, ensuring that all electrical equipment plugged into an outlet that is protected via an RCD	Low	No Control:			Low
Electrical safety related to visual inspections of typical domestic installations Electrical shock, electrocution or ark flash from switchboards or exposed cabling when performing visual inspections	Control: Visual assessment will not be invasive in nature and the electrical escutcheons will remain in place. If escutcheons need to be removed then this will be undertaken by a licensed electrician.	Medium	PPE will be worn at all times during the inspection including, gloves, glasses and hard hat. Ensuring that the inspection area is free from obstructions or trip hazards			Low
Vehicle incident - travel to and from site	Control: Ensure current and valid Australian license is held. Avoid driving fatigued and follow all road roads.	Low	No Control:			Low

Appendix C: Reference Inverter

SH3.0/3.6/4.0/5.0/6.0RS

Residential Hybrid Single Phase Inverter

NEW

FLEXIBLE APPLICATION

- 80~460 V wide battery voltage range
- Ideal for both retrofitting and new installations
- Built-in smart PID recovery function

ENERGY INDEPENDENCE

- Seamless transition to backup mode, for protection against power outages
- Fast Charging or discharging, enabling higher self-consumption results
- Built-in EMS with advanced customization

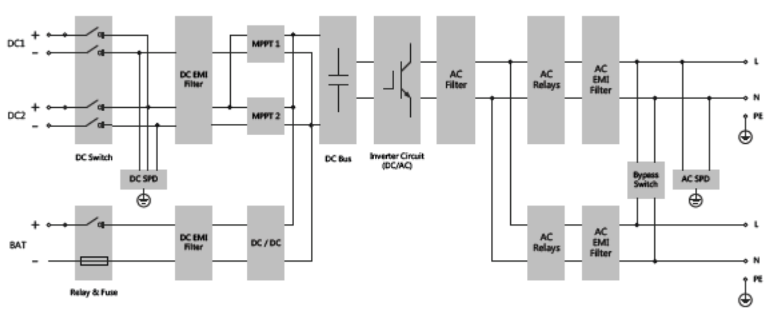
USER FRIENDLY SETUP

- Plug and play installation
- iSolarCloud monitoring available on App and Web
- Lightweight and compact, optimized for heat-dissipation

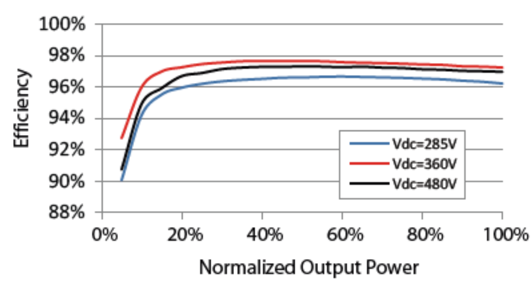
SMART MANAGEMENT

- Real time data (10 seconds refresh sample)
- 24/7 live monitoring both online and with integrated display
- Online IV curve scan and diagnosis

CIRCUIT DIAGRAM



EFFICIENCY CURVE



Type designation	SH3.0RS	SH3.6RS	SH4.0RS	SH5.0RS	SH6.0RS
Input (DC)					
Recommended max. PV input power	10000 Wp	10700 Wp	11000 Wp	12000 Wp	13000 Wp
Max. PV input voltage	600 V				
Min. operating PV voltage / Start-up input voltage	40 V / 50 V				
Rated PV input voltage	360 V				
MPP voltage range	40V – 560 V				
No. of independent MPP inputs	2				
Default No. of PV strings per MPPT	1				
Max. PV input current	32 A (16 A/16 A)				
Max. DC short-circuit current	40 A (20 A/20 A)				
Input / Output (AC)					
Max. AC input power from grid	10000 VA	10700 VA	11000 VA	12000 VA	13000 VA
Rated AC output power	3000 W	3680 W	4000 W	5000 W*	6000 W
Max. AC output power	3000 VA	3680 VA	4000 VA	5000 VA*	6000 VA
Rated AC output current (at 230 V)	13.1 A	16 A	17.4 A	21.8 A**	26.1 A
Max. AC output current	13.7 A	16 A	18.2 A	22.8 A**	27.3 A
Rated AC voltage	220 / 230 / 240 V				
AC voltage range	154 V – 276 V				
Rated grid frequency / Grid frequency range	50 Hz / 45 – 55 Hz 60 Hz / 55 – 65 Hz				
Harmonic (THD)	<3 % (of rated power)				
Power factor at rated power / Adjustable power factor	>0.99 at default value at rated power (adj. 0.8 overexcited/leading to 0.8 underexcited/lagging)				
Feed-in phases / connection phases	1 / 1				
Efficiency					
Max. efficiency / European efficiency	97.4 % / 97.0 %	97.5 % / 97.1 %	97.6 % / 97.2 %	97.7 % / 97.3 %	97.7 % / 97.3 %
Protection & Function					
Grid monitoring	Yes				
DC reverse polarity protection	Yes				
AC short circuit protection	Yes				
Leakage current protection	Yes				
Surge Protection	DC Type II /AC Type II				
DC switch(solar)	Yes				
DC fuse(battery)	Yes				
PID recovery function	Yes				
Battery input reverse polarity protection	Yes				
Battery Data					
Battery type	Li-ion battery				
Battery voltage	80 V – 460 V				
Max charge / discharge current	30 A / 30 A				
Max charge / discharge power	6600 W				
General Data					
Dimensions (W * H * D)	490 * 340 * 170 mm				
Weight	18.5 kg				
Mounting method	Wall-mounting bracket				
Topology (Solar / Battery)	Transformerless / Transformerless				
Degree of protection	IP65				
Operating ambient temperature range	-25 ℃ to 60 ℃				
Allowable relative humidity range	0 % – 100 %				
Cooling method	Natural convection				
Max. operating altitude	4000 m				
Display	LED digital display & LED indicator				
Communication	RS485 / Ethernet / WLAN / CAN				
DI / DO	DI * 4 / DO * 1 / DRM				
DC connection type	MC4 (PV) / Sunclix (Battery)				
AC connection type	Plug and Play				
Grid compliance	IEC/EN 62109-1, IEC/EN 62109-2, IEC/EN 61000-3-11, IEC/EN 61000-3-12, EN 62477-1, AS/NZS 4777.2, EN 50549-1, CEI 0-21, G98 / G99				
Backup Data (on grid mode)					
Rated output power for backup load	6000 W				
Rated output current for backup load	27.3 A				
Backup Data (off-grid mode)					
Rated voltage	220 V / 230 V / 240 V (±2 %)				
Frequency range	50 Hz / 60 Hz (±0.2 %)				
Total output THDv for linear load	< 2 %				
Switch time to emergency mode	< 10 ms				
Rated output power	3000 W / 3000 VA	3680 W / 3680 VA	4000 W / 4000 VA	5000 W / 5000 VA	6000 W / 6000 VA
Peak output power	8400 VA, 10s				

* AS4777.2 4999W, 4999VA ** AS 4777.2 :Rated and Max. AC current is 21.7A

Appendix D: Reference Battery

SBR096/128/160/192/224/256

High Voltage LFP Battery

NEW

HIGH-PERFORMANCE

- Up to 30A continuous charging and discharging current with high efficiency
- Up to 100% usable energy

SAFETY

- Lithium iron phosphate Battery
- Multi-stages protection design and extensive safety certification

FLEXIBILITY

- Extendable during lifetime
- Support 3-8 modules per unit, max. 4 units in parallel, 9–100 kWh capacity range

EASY INSTALLATION

- Compact and light, single person installation
- Plug and play, no cables needed between battery modules

Type designation	SBR096	SBR128	SBR160	SBR192	SBR224	SBR256
Technical properties	3 modules	4 modules	5 modules	6 modules	7 modules	8 modules
System Data						
Battery Type	LiFePO4 Prismatic Cell					
Battery Module	3.2 kWh, 33 kg					
Nominal Capacity	9.6 kWh	12.8 kWh	16 kWh	19.2 kWh	22.4 kWh	25.6 kWh
Energy (usable) [1]	9.6 kWh	12.8 kWh	16 kWh	19.2 kWh	22.4 kWh	25.6 kWh
Nominal voltage	192 V	256 V	320 V	384 V	448 V	512 V
Operating voltage	150 – 219 V	200 – 292 V	250 – 365 V	300 – 438 V	350 – 511 V	400 – 584 V
Rated DC power	5.76 kW	7.68 kW	9.6 kW	11.52 kW	13.44 kW	15.36 kW
Max. charge / discharge power	6.57 kW	8.76 kW	10.95 kW	13.14 kW	15.33 kW	17.52 kW
Max. charging / discharging current: continuous	30 A					
Max. charging / discharging current:	42 A					
Depth of Discharge	Max.100 % DOD (settable)					
Short circuit current	3500 A					
Display	SOC indicator, status indicator					
Communication interface	CAN					
Protection						
Over / under voltage protection	Yes					
Over current protection	Yes					
Over / under temperature protection	Yes					
DC breaker	Yes					
General Data						
Dimensions (W*H*D)	625*545*330 mm	625*675*330 mm	625*805*330 mm	625*935*330 mm	625*1065*330 mm	625*1195*330 mm
Weight	114 kg	147 kg	180 kg	213 kg	246 kg	279 kg
Installation Location	Indoor / Outdoor					
Mounting method	Floor stand					
Operating ambient temperature range	Charge: 0 to 50 ℃ Discharge: -30 to 50 ℃					
Degree of protection	IP55					
Allowable relative humidity range	0 % to 95 % no condensing					
Max. operating altitude	Max. 2000 m					
Cooling method	Natural convection					
Certificates	CE, CEC, IEC 62619, IEC 62040, UN38.3, VDE 2510-50					
Warranty [2]	10 Years					

1: Test conditions: 25 ℃, 100 % depth of discharge (DOD), 0.2C charge&discharge
2: Refer to battery warranty letter for conditional application

Appendix E: Input Data for Model

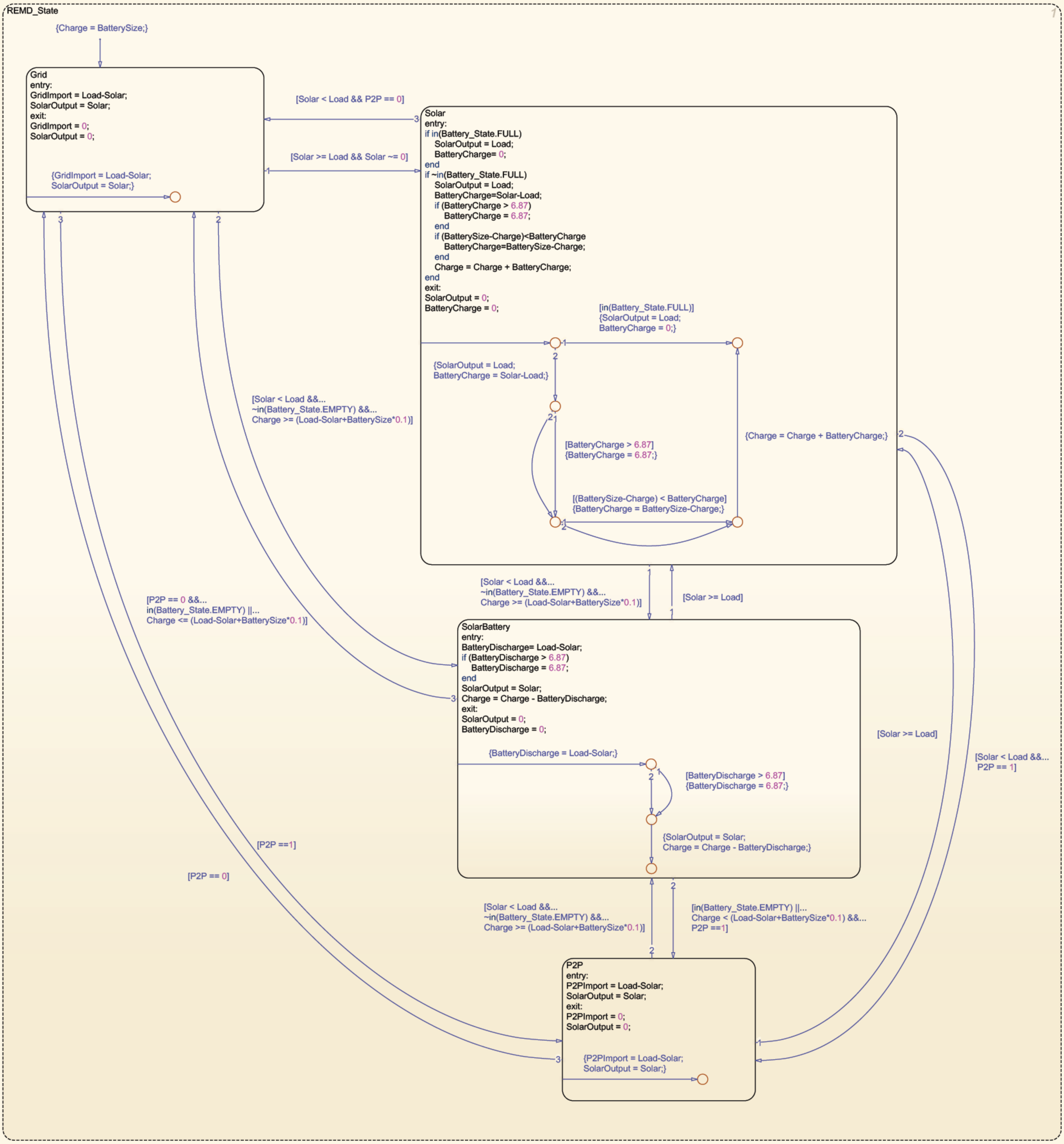
Hour	Load (kWh)	Solar (kWh)	P2P market availability
0	0.5809	0	0
1	0.5474	0	0
2	0.527	0	0
3	0.5246	0	0
4	0.541	0	0
5	0.5955	0.295833333	0
6	0.6895	1.077	0
7	0.7892	2.8335	1
8	0.8101	3.180166667	1
9	0.773	2.34	1
10	0.7843	3.454583333	1
11	0.8092	2.033	0
12	0.8383	2.180666667	0
13	0.8572	2.9705	0
14	0.8622	0.94775	0
15	0.9237	0.957666667	1
16	1.066	0.79275	1
17	1.2611	0.405	0
18	1.2707	0.0305	0
19	1.1269	0	0
20	1.0265	0	1
21	0.911	0	1
22	0.7986	0	1
23	0.6622	0	0
24	0.5459	0	0
25	0.5162	0	1
26	0.4986	0	1
27	0.4942	0	1
28	0.515	0.002333333	1
29	0.5844	0.270916667	0
30	0.686	1.43	0
31	0.7617	3.116083333	0
32	0.7588	4.345083333	1
33	0.7184	5.196666667	1
34	0.7289	5.34075	1
35	0.7688	5.324833333	1
36	0.8188	5.715916667	1
37	0.8383	5.440916667	1
38	0.8482	4.501666667	0
39	0.9019	3.125833333	0
40	0.9735	1.649583333	0

41	1.1453	0.436	1
42	1.2017	0.0315	1
43	1.0691	0	0
44	0.9603	0	0
45	0.8388	0	0
46	0.7262	0	0
47	0.6099	0	0
48	0.555	0	0
49	0.5166	0	0
50	0.4948	0	0
51	0.494	0	0
52	0.513	0.002333333	0
53	0.5974	0.270916667	0
54	0.7716	1.43	0
55	0.8888	3.116083333	0
56	0.8861	4.345083333	0
57	0.7632	5.196666667	0
58	0.7191	5.34075	0
59	0.7172	5.324833333	0
60	0.7234	5.715916667	0
61	0.7133	5.440916667	0
62	0.7126	4.501666667	0
63	0.7925	3.125833333	0
64	0.9313	1.649583333	0
65	1.2473	0.436	0
66	1.3232	0.0315	0
67	1.1909	0	0
68	1.0775	0	0
69	0.9474	0	0
70	0.8104	0	0
71	0.6469	0	0
72	0.6	0	1
73	0.6	0	1
74	0.6	0	0
75	0.6	0	0
76	0.6	0.002333333	0
77	0.6	0.270916667	1
78	0.6	1.43	1
79	0.6	3.116083333	1
80	0.6	4.345083333	1
81	0.6	5.196666667	1
82	0.6	5.34075	1
83	0.6	5.324833333	1
84	0.6	5.715916667	1

85	0.6	5.440916667	1
86	0.6	4.501666667	1
87	0.6	3.125833333	0
88	0.6	1.649583333	0
89	0.6	0.436	0
90	0.6	0.0315	0
91	0.6	0	1
92	0.6	0	1
93	0.6	0	1
94	0.6	0	1
95	0.6	0	1
96	0.6846	0	0
97	0.6487	0	0
98	0.6291	0	0
99	0.6164	0	0
100	0.6412	0	0
101	0.7036	0.054666667	1
102	0.8022	0.233833333	1
103	0.8954	0.302166667	1
104	0.942	0.642	1
105	0.9956	0.742416667	1
106	1.0768	0.81975	0
107	1.1797	0.8265	0
108	1.2946	0.898083333	0
109	1.3749	0.859666667	0
110	1.4245	0.572583333	0
111	1.4626	0.447	1
112	1.518	0.285083333	1
113	1.5567	0.044833333	1
114	1.5101	0	1
115	1.3931	0	1
116	1.2643	0	1
117	1.0713	0	1
118	0.9094	0	0
119	0.7735	0	0
120	0.555	0	0
121	0.5166	0	1
122	0.4948	0	0
123	0.494	0	1
124	0.513	0	0
125	0.5974	0.295833333	1
126	0.7716	1.077	0
127	0.8888	2.8335	1
128	0.8861	3.180166667	0

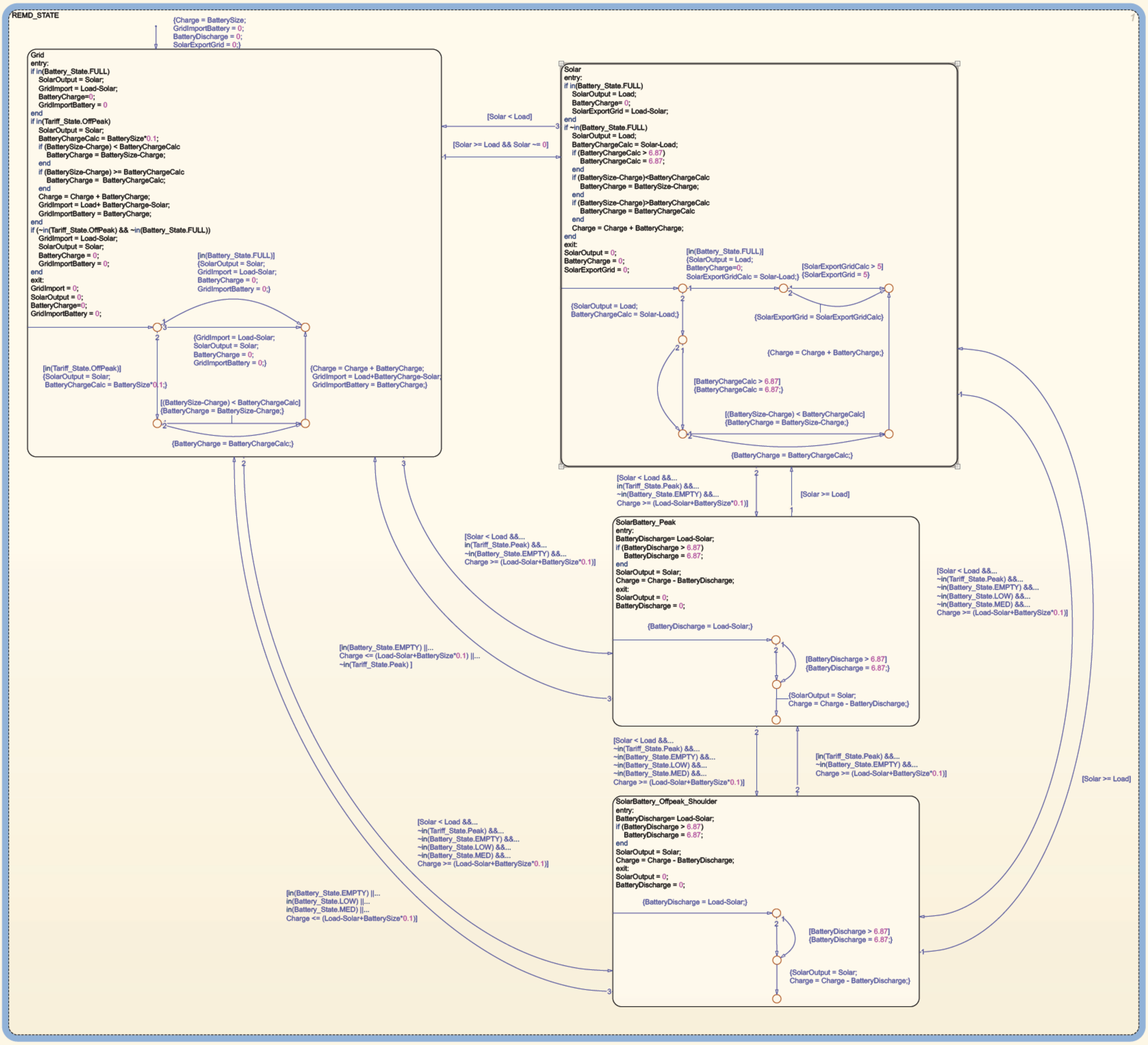
129	0.7632	2.34	1
130	0.7191	3.454583333	0
131	0.7172	2.033	1
132	0.7234	2.180666667	0
133	0.7133	2.9705	1
134	0.7126	0.94775	0
135	0.7925	0.957666667	1
136	0.9313	0.79275	0
137	1.2473	0.405	1
138	1.3232	0.0305	0
139	1.1909	0	1
140	1.0775	0	0
141	0.9474	0	1
142	0.8104	0	0
143	0.6469	0	1
144	0.6846	0	0
145	0.6487	0	0
146	0.6291	0	0
147	0.6164	0	0
148	0.6412	0	1
149	0.7036	0.054666667	0
150	0.8022	0.233833333	1
151	0.8954	0.302166667	0
152	0.942	0.642	1
153	0.9956	0.742416667	0
154	1.0768	0.81975	0
155	1.1797	0.8265	0
156	1.2946	0.898083333	1
157	1.3749	0.859666667	1
158	1.4245	0.572583333	1
159	1.4626	0.447	1
160	1.518	0.285083333	1
161	1.5567	0.044833333	1
162	1.5101	0	0
163	1.3931	0	0
164	1.2643	0	0
165	1.0713	0	0
166	0.9094	0	0
167	0.7735	0	0

Appendix F1: Sustainability Mode Stateflow REMD

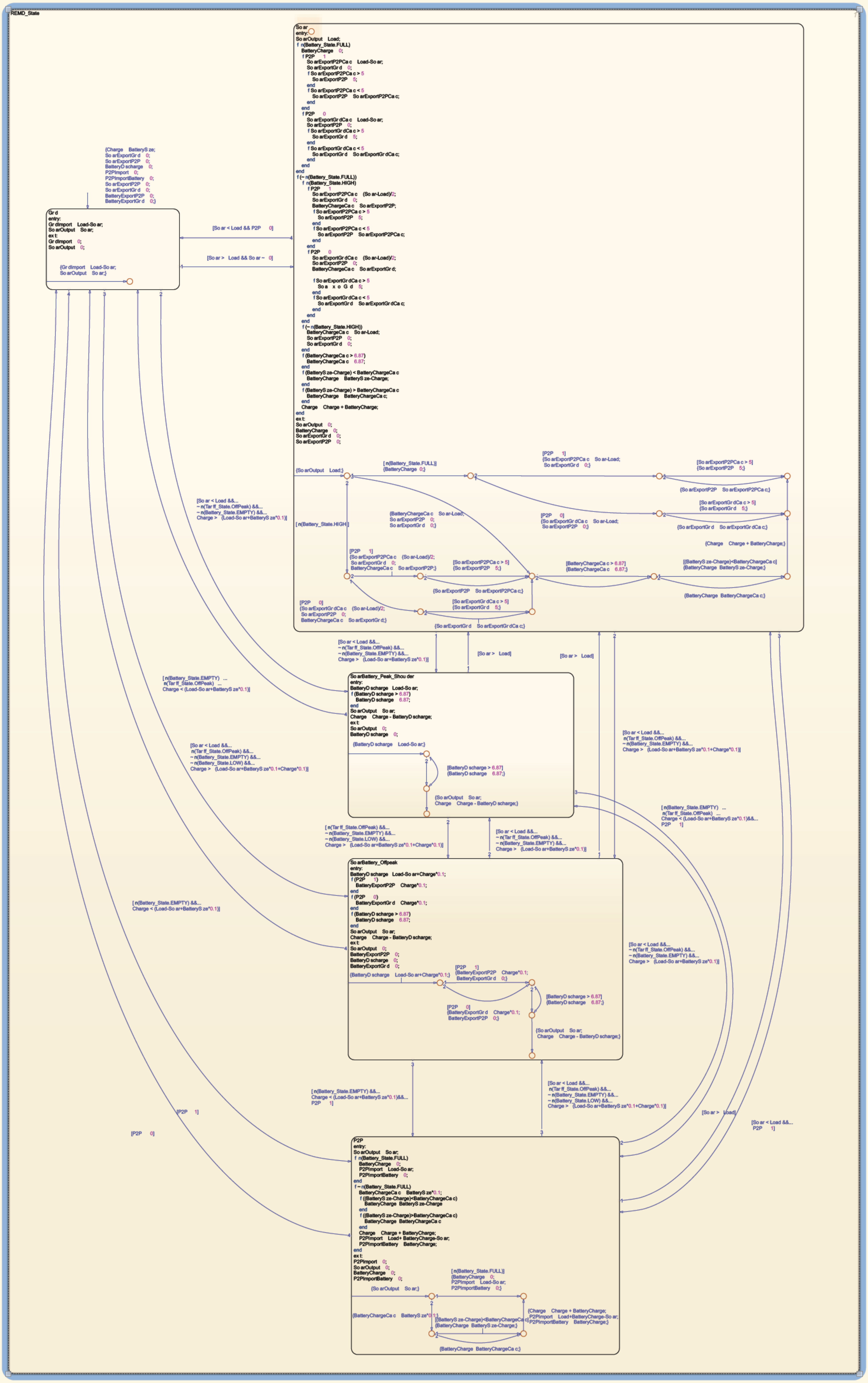


REMD_State
{Charge = BatterySize;}
Grid
entry:
GridImport = Load-Solar;
SolarOutput = Solar;
exit:
GridImport = 0;
SolarOutput = 0;
{GridImport = Load-Solar;
SolarOutput = Solar;}
[Solar < Load && P2P == 0]
[Solar >= Load && Solar ~= 0]
Solar
entry:
if in(Battery_State.FULL)
SolarOutput = Load;
BatteryCharge= 0;
end
if ~in(Battery_State.FULL)
SolarOutput = Load;
BatteryCharge=Solar-Load;
if (BatteryCharge > 6.87)
BatteryCharge = 6.87;
end
if (BatterySize-Charge)<BatteryCharge
BatteryCharge=BatterySize-Charge;
end
Charge = Charge + BatteryCharge;
end
exit:
SolarOutput = 0;
BatteryCharge = 0;
[in(Battery_State.FULL)]
{SolarOutput = Load;
BatteryCharge = 0;}
{SolarOutput = Load;
BatteryCharge = Solar-Load;}
[BatteryCharge > 6.87]
{BatteryCharge = 6.87;}
[(BatterySize-Charge) < BatteryCharge]
{BatteryCharge = BatterySize-Charge;}
{Charge = Charge + BatteryCharge;}
[Solar < Load &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[Solar < Load &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[Solar >= Load]
[P2P == 0 &&...
in(Battery_State.EMPTY) ||...
Charge <= (Load-Solar+BatterySize*0.1)]
SolarBattery
entry:
BatteryDischarge= Load-Solar;
if (BatteryDischarge > 6.87)
BatteryDischarge = 6.87;
end
SolarOutput = Solar;
Charge = Charge - BatteryDischarge;
exit:
SolarOutput = 0;
BatteryDischarge = 0;
{BatteryDischarge = Load-Solar;}
[BatteryDischarge > 6.87]
{BatteryDischarge = 6.87;}
{SolarOutput = Solar;
Charge = Charge - BatteryDischarge;}
[Solar >= Load]
[Solar < Load &&...
P2P == 1]
[P2P ==1]
[P2P == 0]
[Solar < Load &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[in(Battery_State.EMPTY) ||...
Charge < (Load-Solar+BatterySize*0.1) &&...
P2P ==1]
P2P
entry:
P2PImport = Load-Solar;
SolarOutput = Solar;
exit:
P2PImport = 0;
SolarOutput = 0;
{P2PImport = Load-Solar;
SolarOutput = Solar;}

Appendix F2: Traditional Mode Stateflow REMD


REMD_STATE
{Charge = BatterySize;
GridImportBattery = 0;
BatteryDischarge = 0;
SolarExportGrid = 0;}
Grid
entry:
if in(Battery_State.FULL)
SolarOutput = Solar;
GridImport = Load-Solar;
BatteryCharge=0;
GridImportBattery = 0
end
if in(Tariff_State.OffPeak)
SolarOutput = Solar;
BatteryChargeCalc = BatterySize*0.1;
if (BatterySize-Charge) < BatteryChargeCalc
BatteryCharge = BatterySize-Charge;
end
if (BatterySize-Charge) >= BatteryChargeCalc
BatteryCharge = BatteryChargeCalc;
end
Charge = Charge + BatteryCharge;
GridImport = Load+ BatteryCharge-Solar;
GridImportBattery = BatteryCharge;
end
if (~in(Tariff_State.OffPeak) && ~in(Battery_State.FULL))
GridImport = Load-Solar;
SolarOutput = Solar;
BatteryCharge = 0;
GridImportBattery = 0;
end
exit:
GridImport = 0;
SolarOutput = 0;
BatteryCharge=0;
GridImportBattery = 0;
Solar
entry:
if in(Battery_State.FULL)
SolarOutput = Load;
BatteryCharge= 0;
SolarExportGrid = Load-Solar;
end
if ~in(Battery_State.FULL)
SolarOutput = Load;
BatteryChargeCalc = Solar-Load;
if (BatteryChargeCalc > 6.87)
BatteryChargeCalc = 6.87;
end
if (BatterySize-Charge)<BatteryChargeCalc
BatteryCharge = BatterySize-Charge;
end
if (BatterySize-Charge)>BatteryChargeCalc
BatteryCharge = BatteryChargeCalc
end
Charge = Charge + BatteryCharge;
end
exit:
SolarOutput = 0;
BatteryCharge = 0;
SolarExportGrid = 0;
[Solar < Load]
[Solar >= Load && Solar ~= 0]
[in(Battery_State.FULL)]
{SolarOutput = Solar;
GridImport = Load-Solar;
BatteryCharge = 0;
GridImportBattery = 0;}
{GridImport = Load-Solar;
SolarOutput = Solar;
BatteryCharge = 0;
GridImportBattery = 0;}
[in(Tariff_State.OffPeak)]
{SolarOutput = Solar;
BatteryChargeCalc = BatterySize*0.1;}
{Charge = Charge + BatteryCharge;
GridImport = Load+BatteryCharge-Solar;
GridImportBattery = BatteryCharge;}
[(BatterySize-Charge) < BatteryChargeCalc]
{BatteryCharge = BatterySize-Charge;}
{BatteryCharge = BatteryChargeCalc;}
[in(Battery_State.FULL)]
{SolarOutput = Load;
BatteryCharge=0;
SolarExportGridCalc = Solar-Load;}
[SolarExportGridCalc > 5]
{SolarExportGrid = 5}
{SolarOutput = Load;
BatteryChargeCalc = Solar-Load;}
{SolarExportGrid = SolarExportGridCalc}
{Charge = Charge + BatteryCharge;}
[BatteryChargeCalc > 6.87]
{BatteryChargeCalc = 6.87;}
[(BatterySize-Charge) < BatteryChargeCalc]
{BatteryCharge = BatterySize-Charge;}
{BatteryCharge = BatteryChargeCalc;}
[Solar < Load &&...
in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[Solar >= Load]
SolarBattery_Peak
entry:
BatteryDischarge= Load-Solar;
if (BatteryDischarge > 6.87)
BatteryDischarge = 6.87;
end
SolarOutput = Solar;
Charge = Charge - BatteryDischarge;
exit:
SolarOutput = 0;
BatteryDischarge = 0;
{BatteryDischarge = Load-Solar;}
[BatteryDischarge > 6.87]
{BatteryDischarge = 6.87;}
{SolarOutput = Solar;
Charge = Charge - BatteryDischarge;}
[Solar < Load &&...
in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[in(Battery_State.EMPTY) ||...
Charge <= (Load-Solar+BatterySize*0.1) ||...
~in(Tariff_State.Peak)]
[Solar < Load &&...
~in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
~in(Battery_State.LOW) &&...
~in(Battery_State.MED) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[Solar < Load &&...
~in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
~in(Battery_State.LOW) &&...
~in(Battery_State.MED) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[Solar >= Load]
SolarBattery_Offpeak_Shoulder
entry:
BatteryDischarge= Load-Solar;
if (BatteryDischarge > 6.87)
BatteryDischarge = 6.87;
end
SolarOutput = Solar;
Charge = Charge - BatteryDischarge;
exit:
SolarOutput = 0;
BatteryDischarge = 0;
{BatteryDischarge = Load-Solar;}
[BatteryDischarge > 6.87]
{BatteryDischarge = 6.87;}
{SolarOutput = Solar;
Charge = Charge - BatteryDischarge;}
[Solar < Load &&...
~in(Tariff_State.Peak) &&...
~in(Battery_State.EMPTY) &&...
~in(Battery_State.LOW) &&...
~in(Battery_State.MED) &&...
Charge >= (Load-Solar+BatterySize*0.1)]
[in(Battery_State.EMPTY) ||...
in(Battery_State.LOW) ||...
in(Battery_State.MED) ||...
Charge <= (Load-Solar+BatterySize*0.1)]

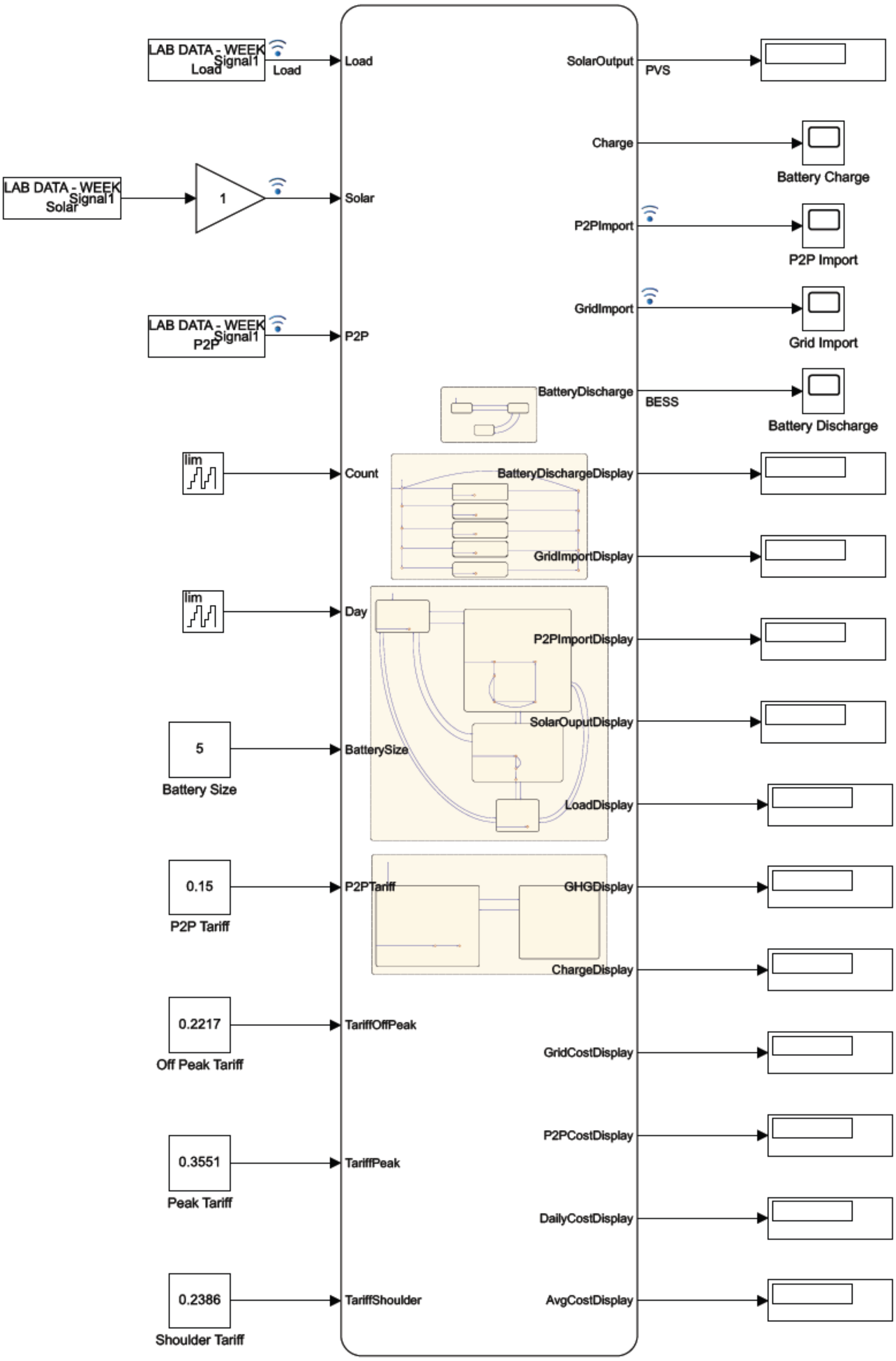
Appendix F3: Benefit Mode Stateflow REMD



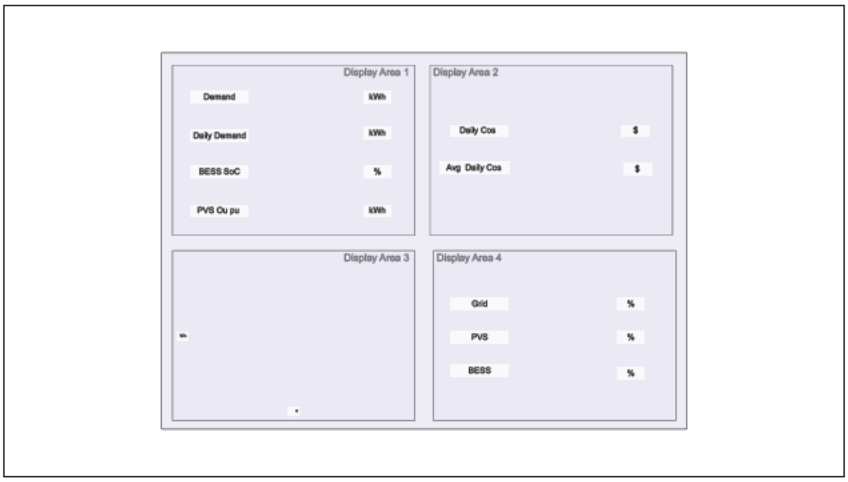
Appendix G1: Sustainability Mode Simulink Model

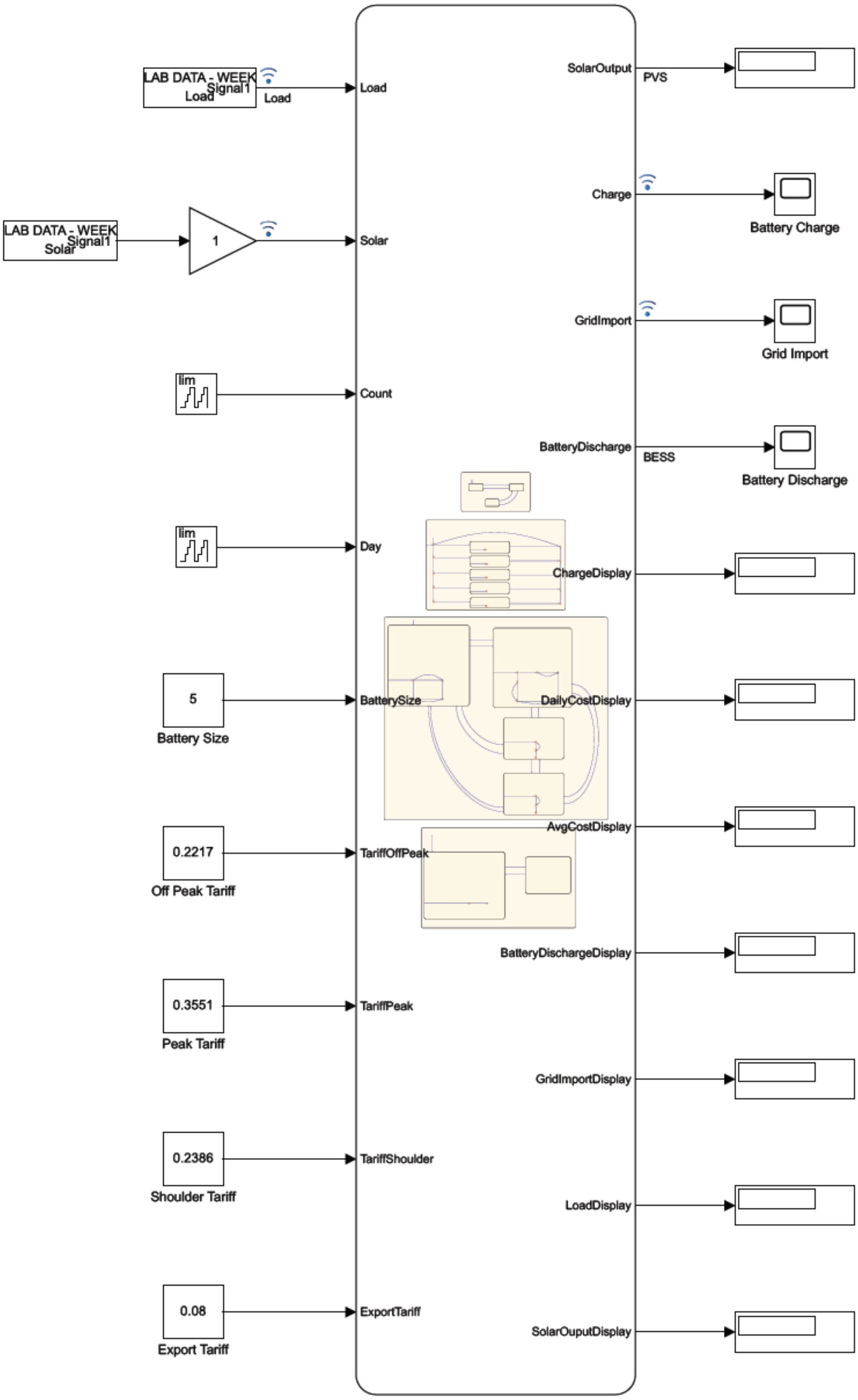

D sp ay Area 1
Demand
kWh
Daily Demand
kWh
BESS SoC
%
PVS Output
kWh
D sp ay Area 2
Daily Cost
$
Avg Daily Cost
$
CO₂ Offset
kg
D sp ay Area 3
D sp ay Area 4
Grid
%
P2P
%
PVS
%
BESS
%

DISPLAY


LAB DATA - WEEK
Signal1
Load
Load
LAB DATA - WEEK
Signal1
Solar
1
Solar
LAB DATA - WEEK
Signal1
P2P
P2P
lim
Count
lim
Day
5
Battery Size
BatterySize
0.15
P2P Tariff
P2PTariff
0.2217
Off Peak Tariff
TariffOffPeak
0.3551
Peak Tariff
TariffPeak
0.2386
Shoulder Tariff
TariffShoulder
SolarOutput
PVS
Charge
Battery Charge
P2PImport
P2P Import
GridImport
Grid Import
BatteryDischarge
BESS
Battery Discharge
BatteryDischargeDisplay
GridImportDisplay
P2PImportDisplay
SolarOuputDisplay
LoadDisplay
GHGDisplay
ChargeDisplay
GridCostDisplay
P2PCostDisplay
DailyCostDisplay
AvgCostDisplay

Appendix G2: Traditional Mode Simulink Model

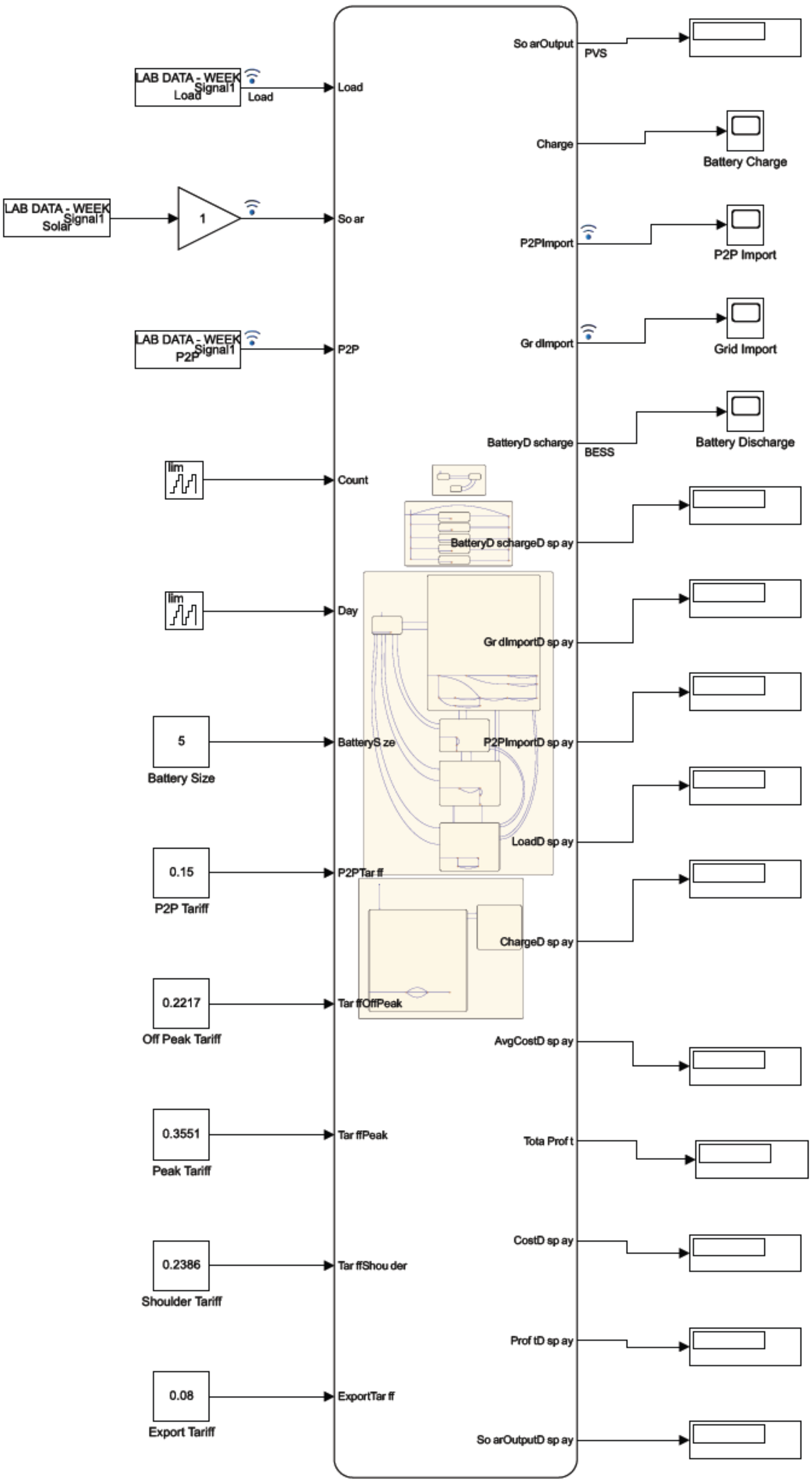

Display Area 1
Demand
kWh
Daily Demand
kWh
BESS SoC
%
PVS Ou pu
kWh
Display Area 2
Daily Cos
$
Avg Daily Cos
$
Display Area 3
Display Area 4
Grid
%
PVS
%
BESS
%
DISPLAY


LAB DATA - WEEK
Load
Signal1
Load
LAB DATA - WEEK
Solar
Signal1
1
lim
lim
5
Battery Size
0.2217
Off Peak Tariff
0.3551
Peak Tariff
0.2386
Shoulder Tariff
0.08
Export Tariff
Load
Solar
Count
Day
BatterySize
TariffOffPeak
TariffPeak
TariffShoulder
ExportTariff
SolarOutput
PVS
Charge
Battery Charge
GridImport
Grid Import
BatteryDischarge
BESS
Battery Discharge
ChargeDisplay
DailyCostDisplay
AvgCostDisplay
BatteryDischargeDisplay
GridImportDisplay
LoadDisplay
SolarOuputDisplay

Appendix G3: Benefit Mode Simulink Model


Display Area 1
Demand
kWh
Daily Demand
kWh
BESS SoC
%
PVS Output
kWh
Display Area 2
Daily Cost
$
Daily Pro it
$
Avg. Daily Cost
$
otal Pro it
$
Display Area 3
Display Area 4
Grid
%
P2P
%
PVS
%
BESS
%

DISPLAY


LAB DATA - WEEK Load
Signal1
Load
LAB DATA - WEEK Solar
Signal1
1
LAB DATA - WEEK P2P
Signal1
5
Battery Size
0.15
P2P Tariff
0.2217
Off Peak Tariff
0.3551
Peak Tariff
0.2386
Shoulder Tariff
0.08
Export Tariff
Load
So ar
P2P
Count
Day
BatteryS ze
P2PTar ff
Tar ffOffPeak
Tar ffPeak
Tar ffShou der
ExportTar ff
So arOutput
PVS
Charge
P2PImport
Gr dImport
BatteryD scharge
BESS
BatteryD schargeD sp ay
Gr dImportD sp ay
P2PImportD sp ay
LoadD sp ay
ChargeD sp ay
AvgCostD sp ay
Tota Prof t
CostD sp ay
Prof tD sp ay
So arOutputD sp ay
Battery Charge
P2P Import
Grid Import
Battery Discharge

Appendix H1: Sustainability Mode Sequence Flow

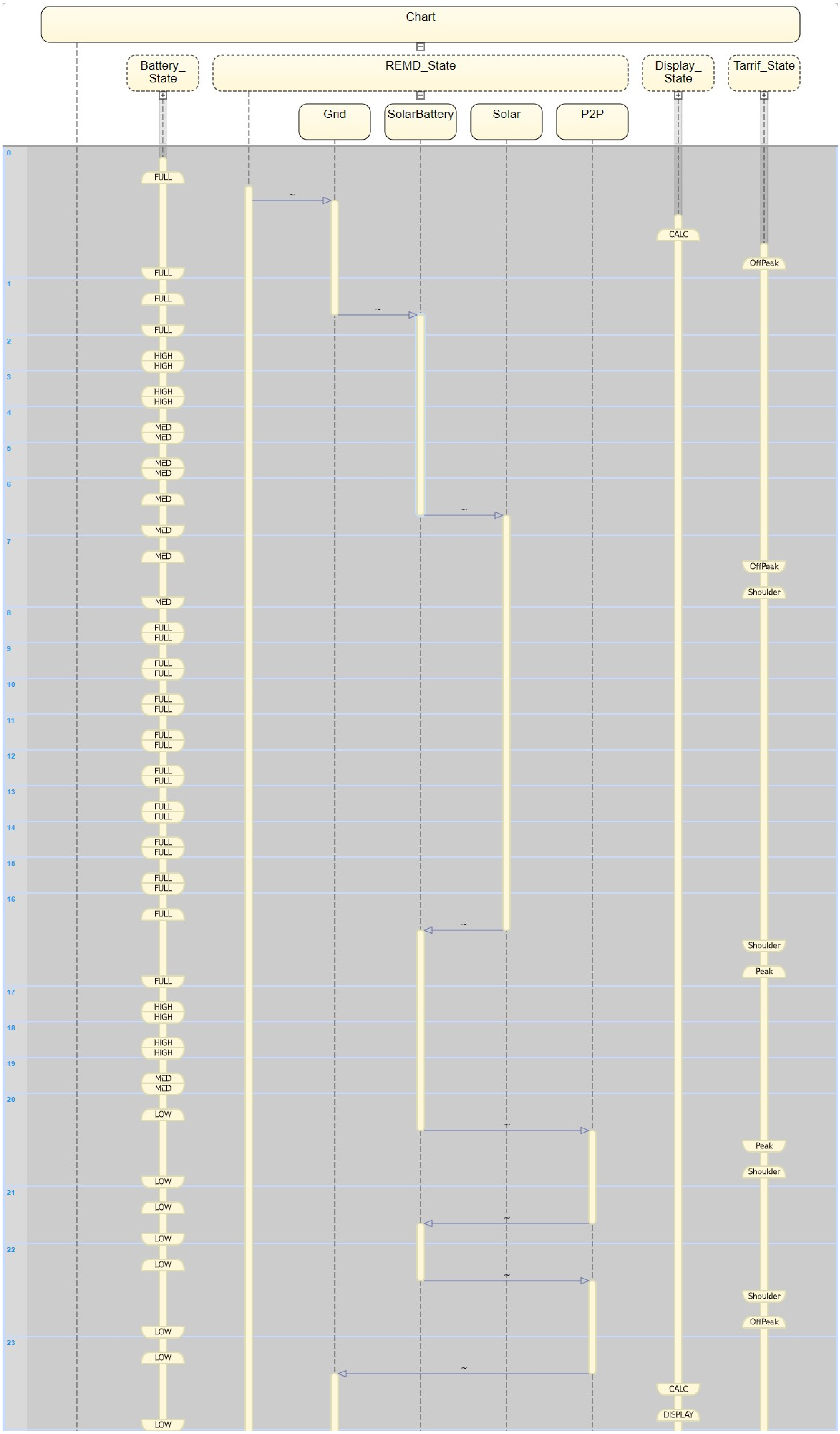


Chart
Battery_State
REMD_State
Display_State
Tarrif_State
Grid
SolarBattery
Solar
P2P
FULL
HIGH
MED
LOW
CALC
DISPLAY
OffPeak
Shoulder
Peak
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Appendix H2: Traditional Mode Sequence Flow

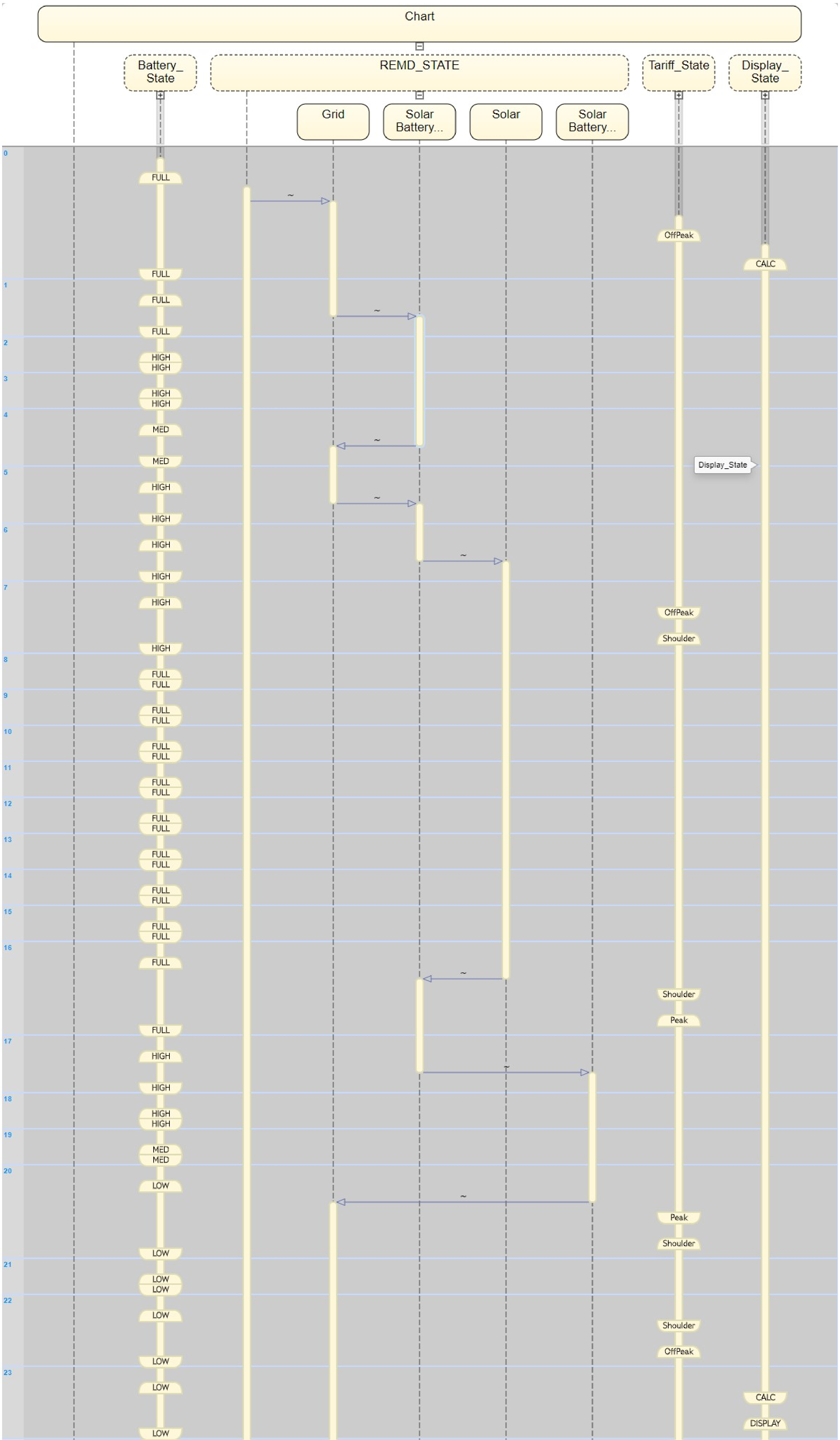


Chart
Battery_ State
REMD_STATE
Tariff_State
Display_ State
Grid
Solar Battery...
Solar
Solar Battery...
FULL
HIGH
MED
LOW
OffPeak
Shoulder
Peak
CALC
DISPLAY
Display_State
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Appendix H3: Benefit Mode Sequence Flow

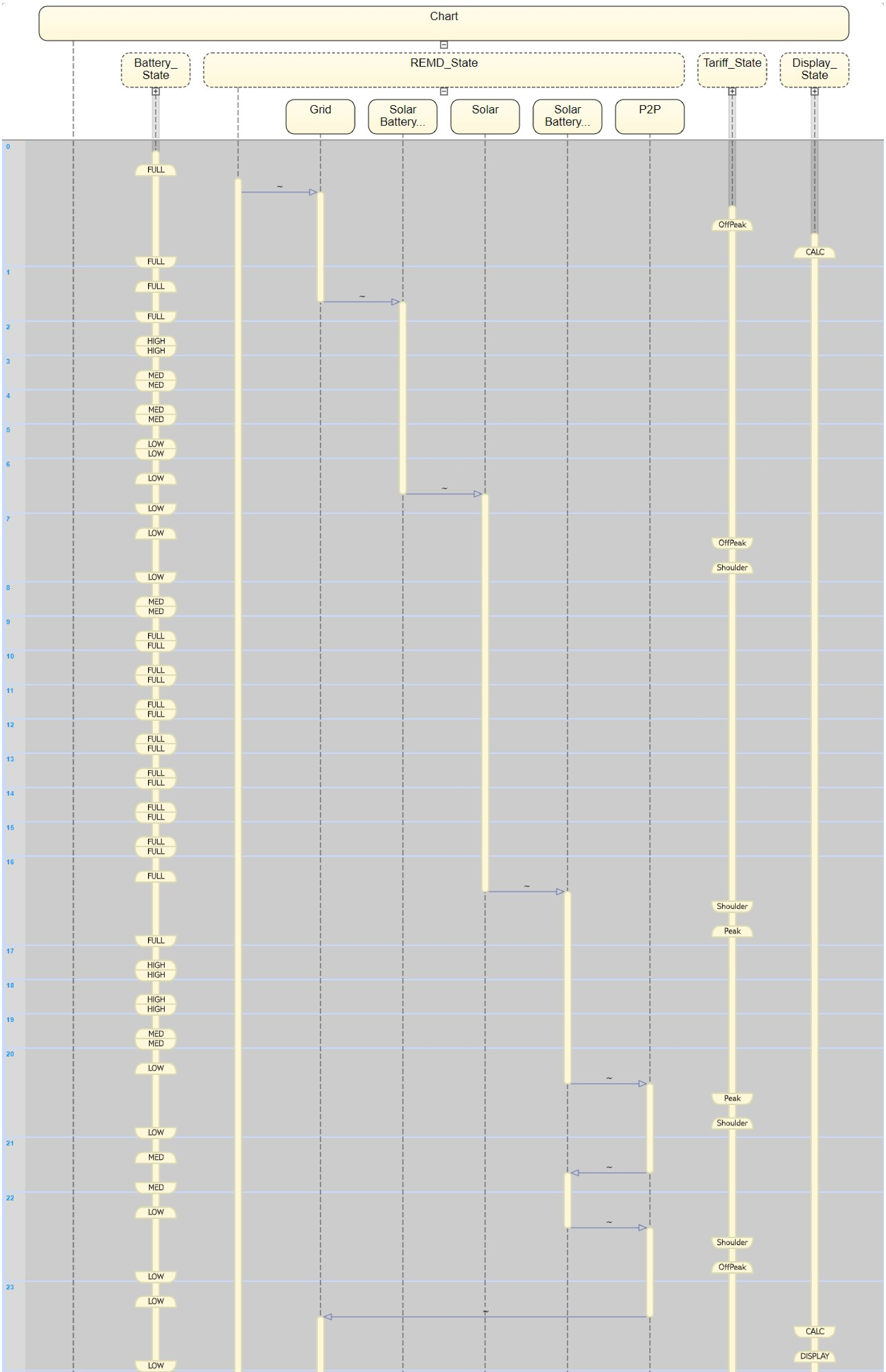
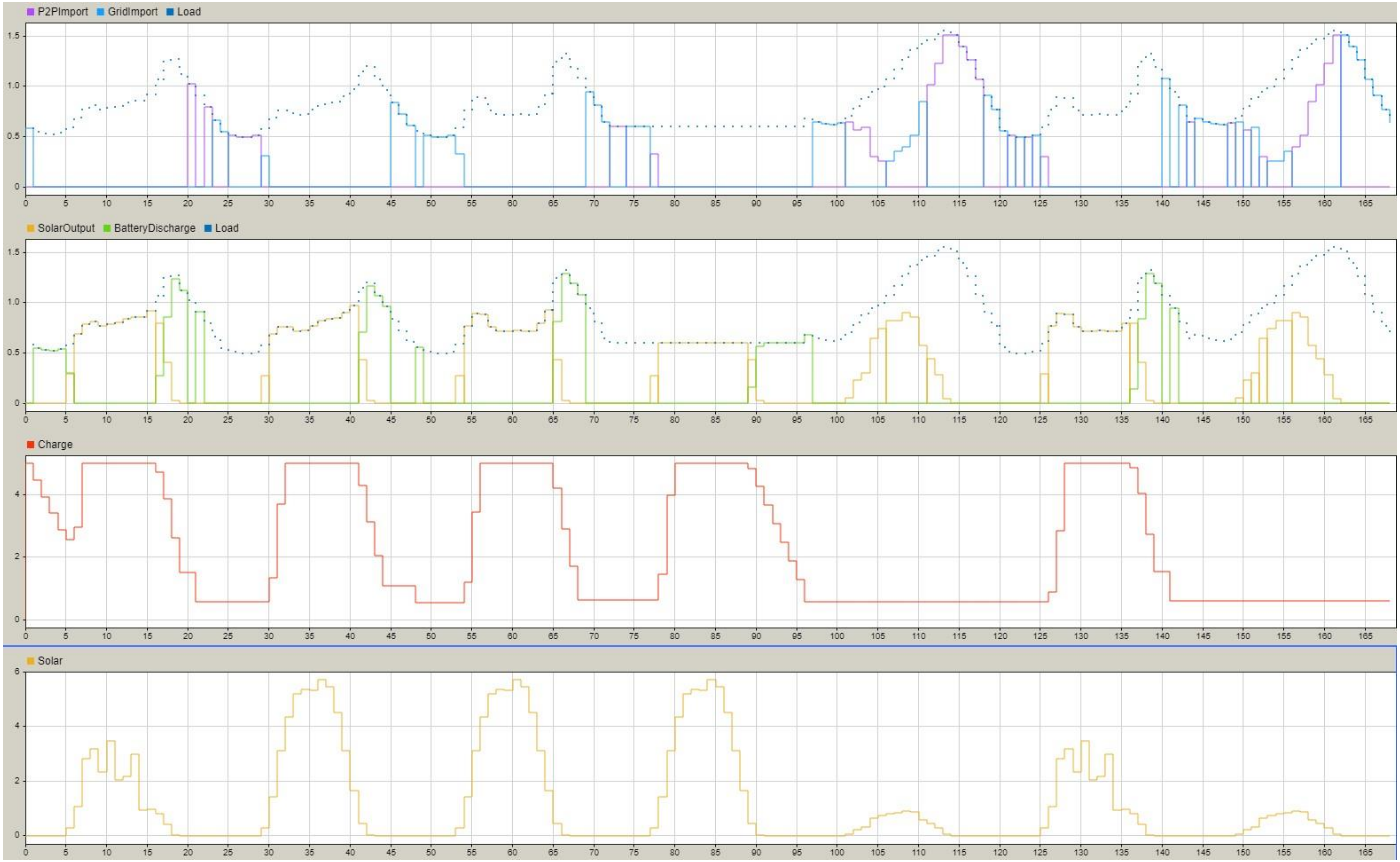


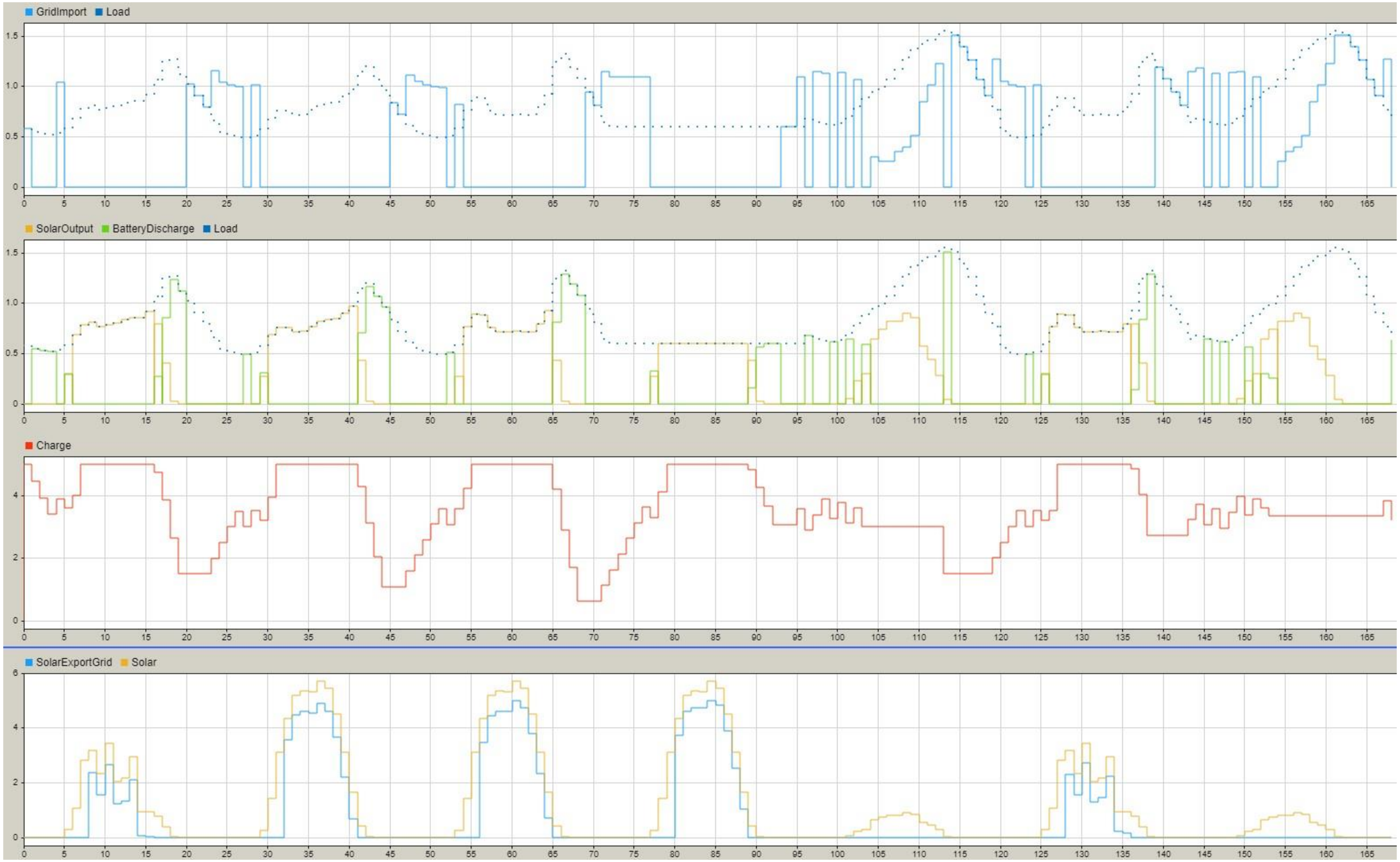
Chart
Battery_ State
REMD_State
Tariff_State
Display_ State
Grid
Solar Battery...
Solar
Solar Battery...
P2P
FULL
HIGH
MED
LOW
OffPeak
Shoulder
Peak
CALC
DISPLAY

Appendix I: Small PVS & Small BESS Model Outputs

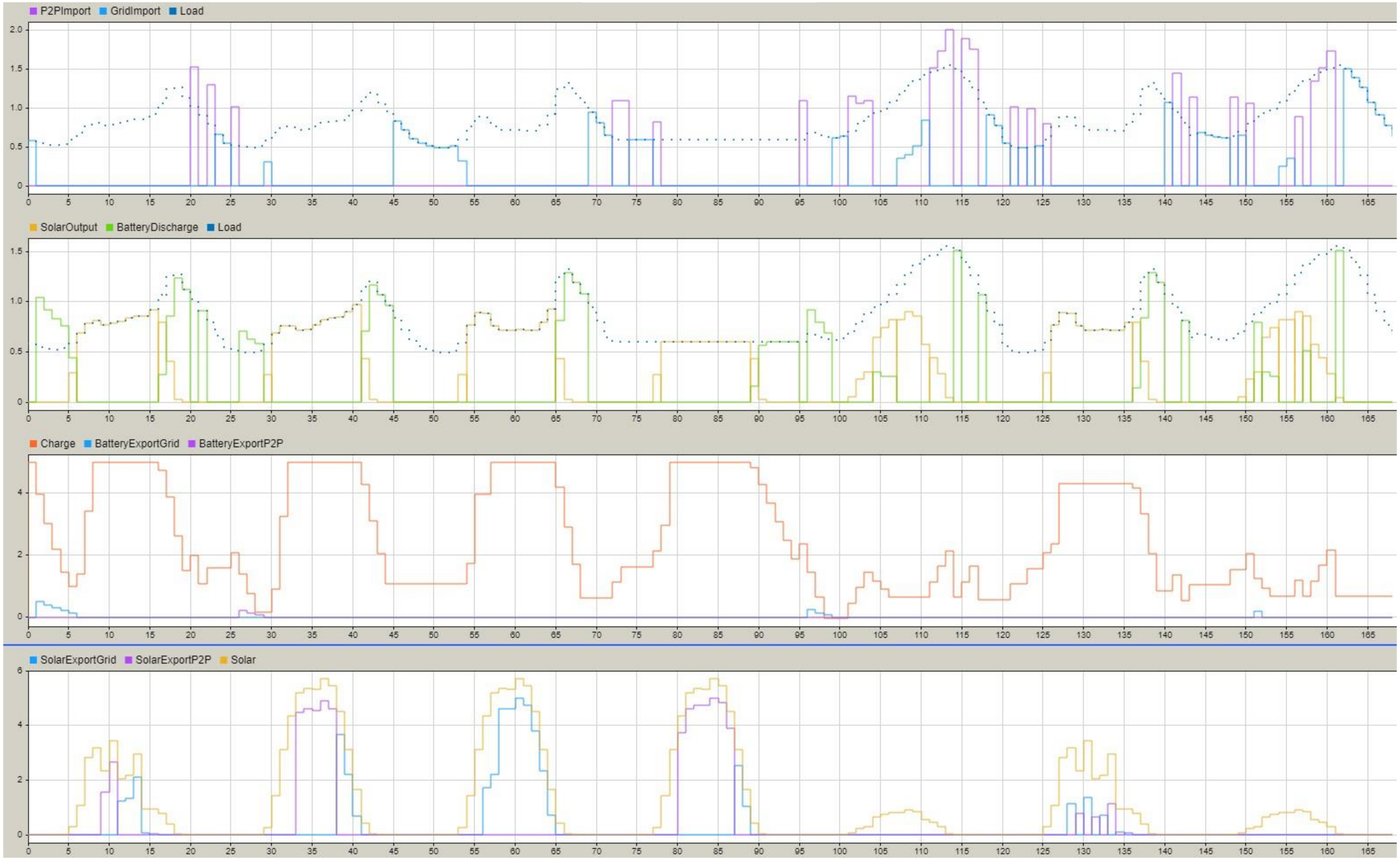
Sustainability Mode



Traditional Mode

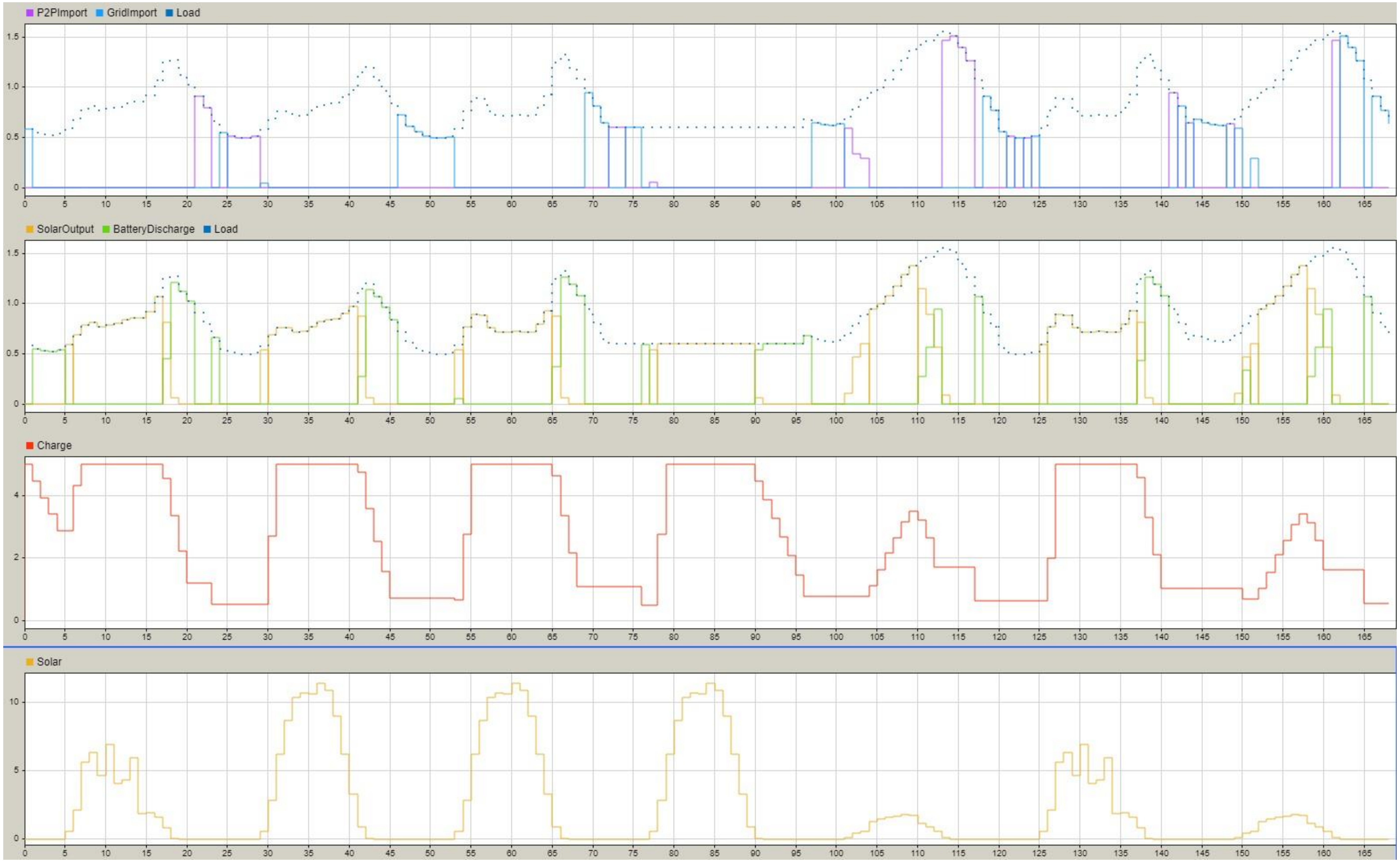


Benefit Mode

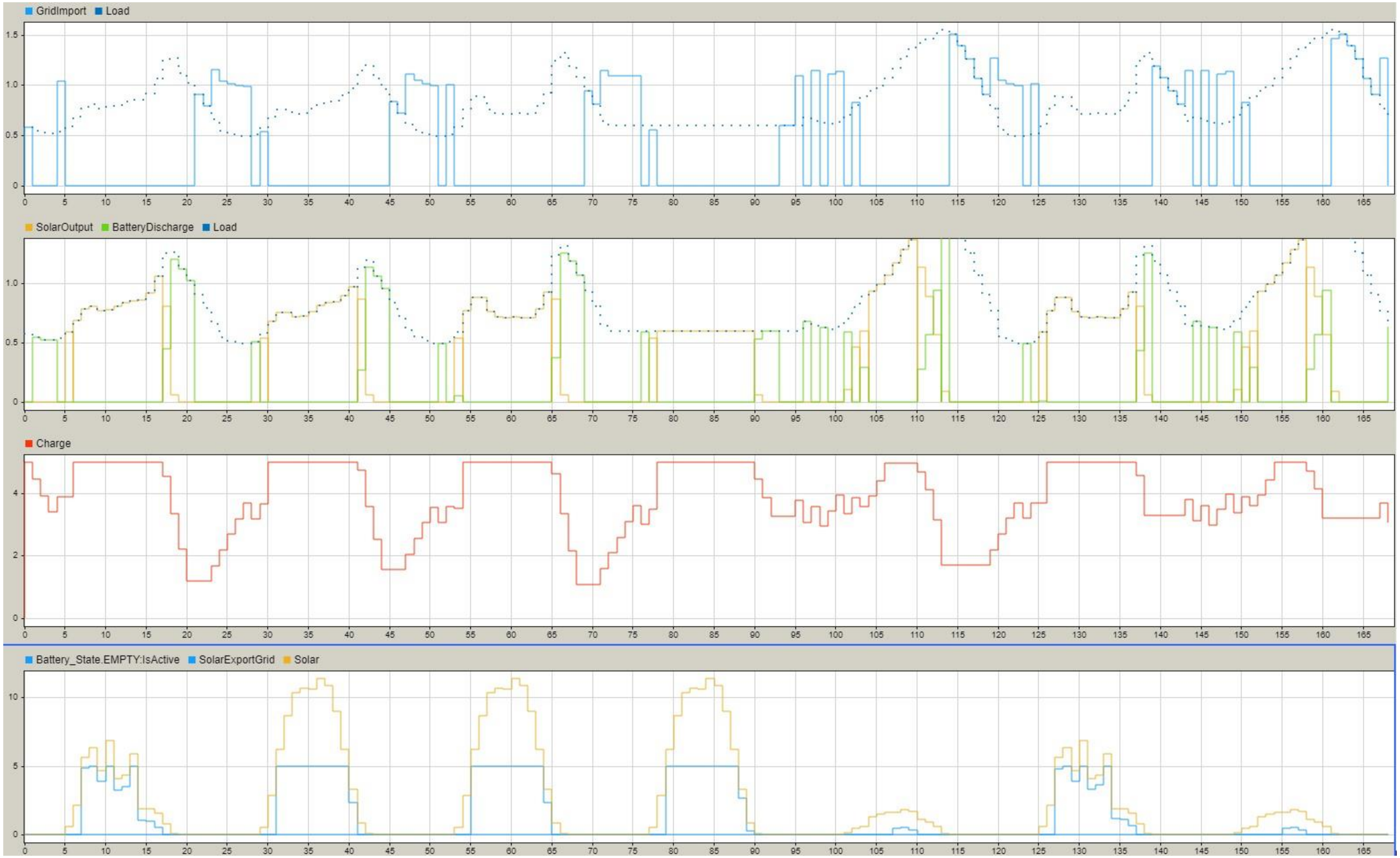


Appendix J: Large PVS & Small BESS Model Outputs

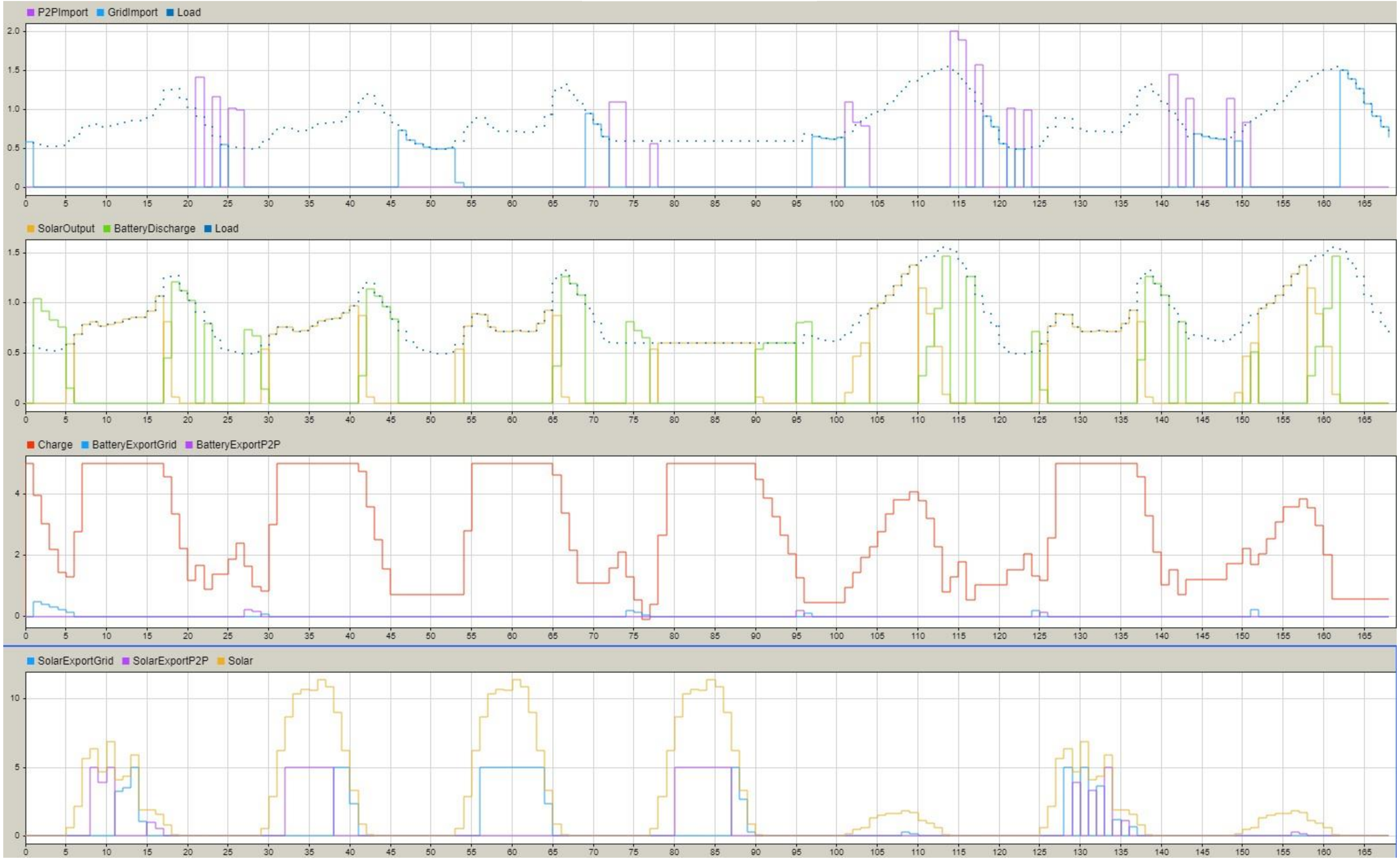
Sustainability Mode



Traditional Mode

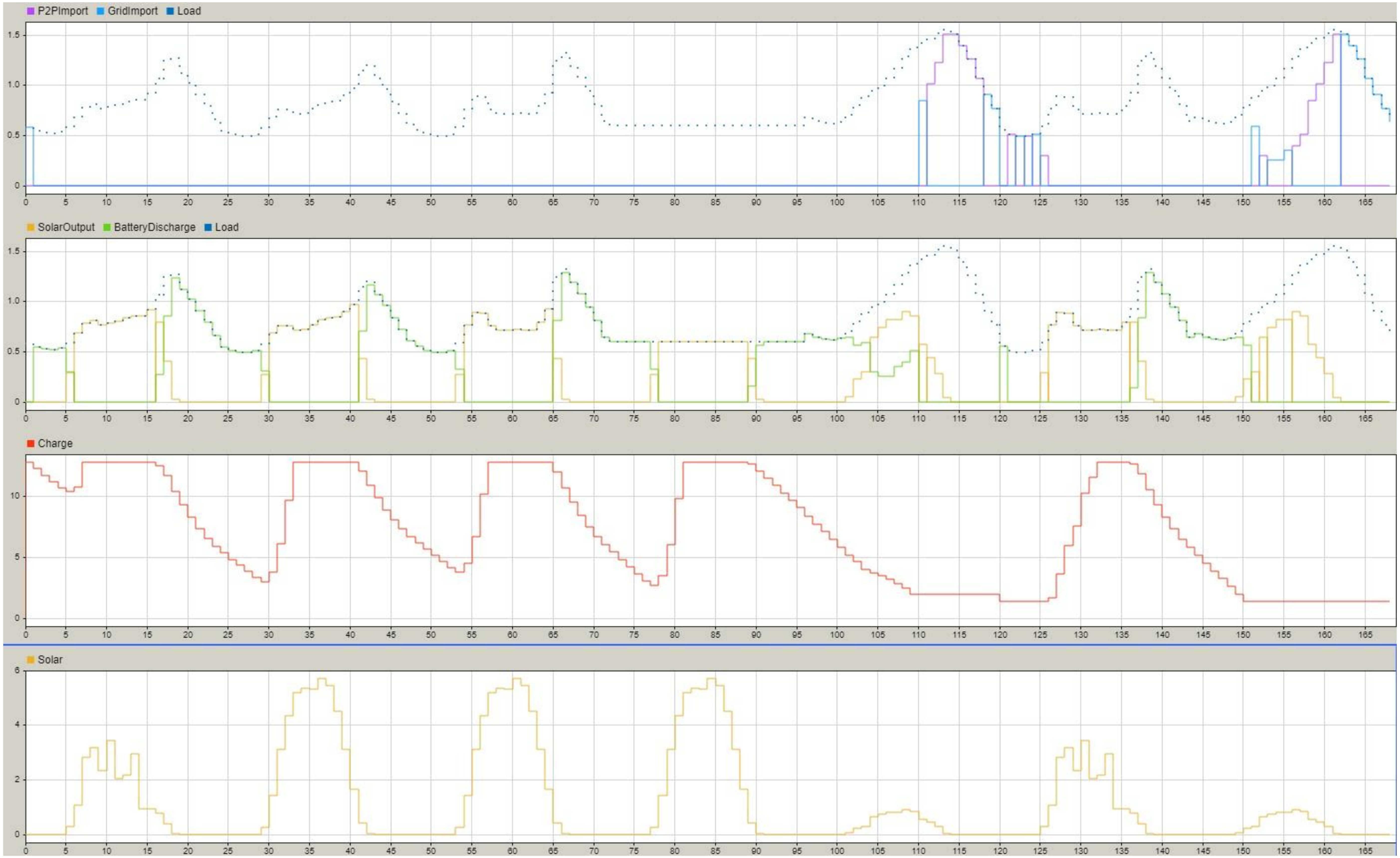


Benefit Mode

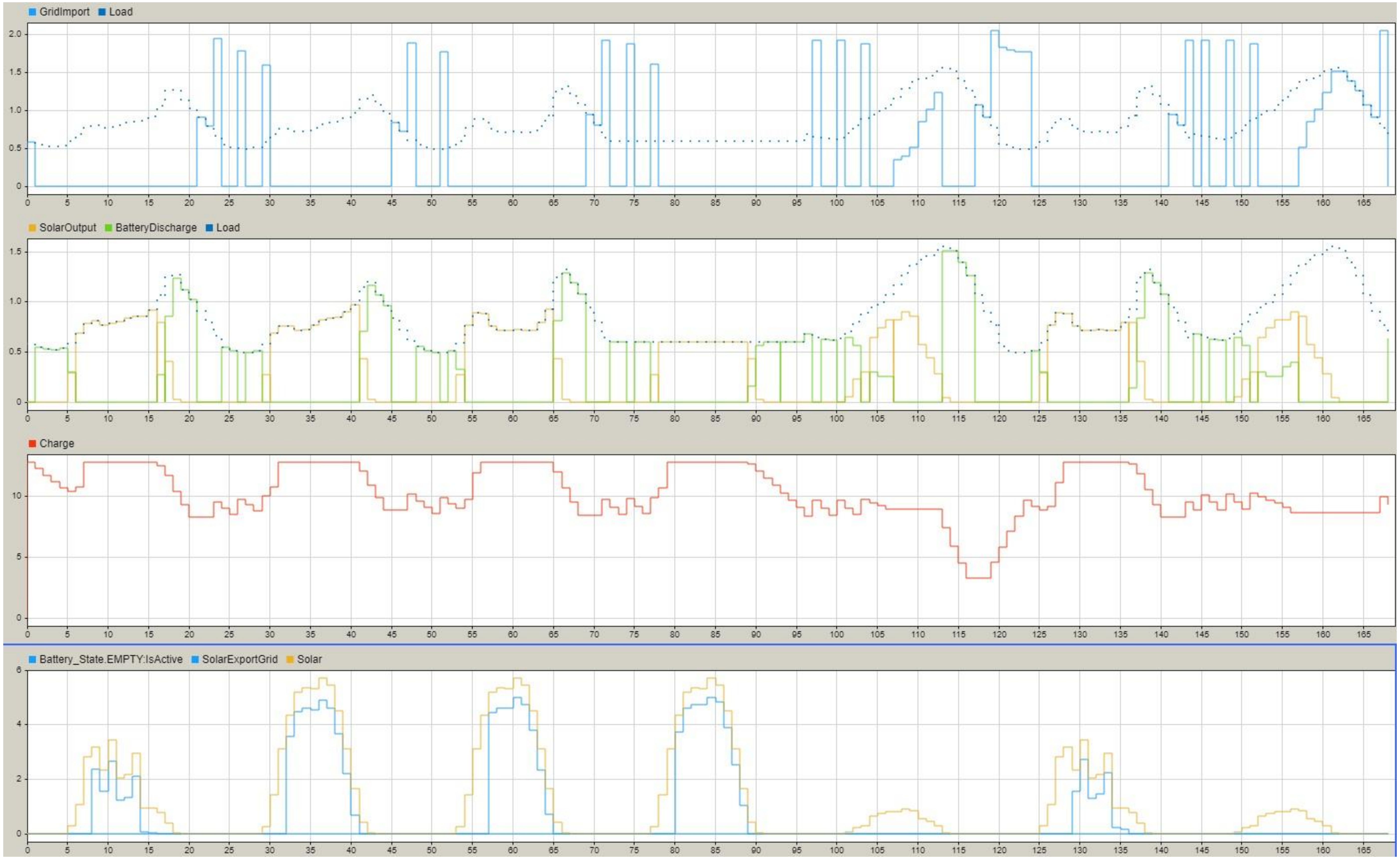


Appendix K: Small PVS & Large BESS Model Outputs

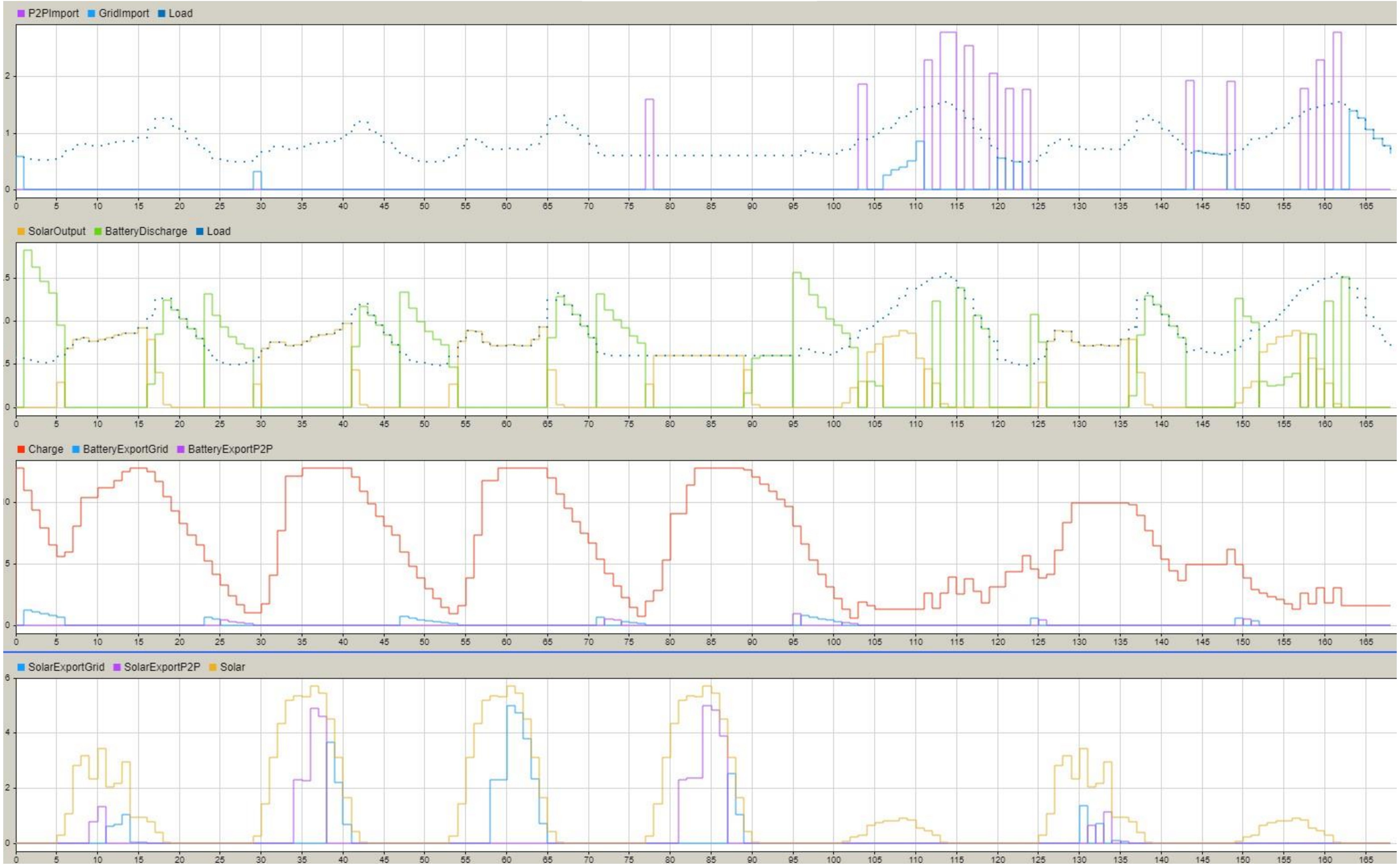
Sustainability Mode



Traditional Mode

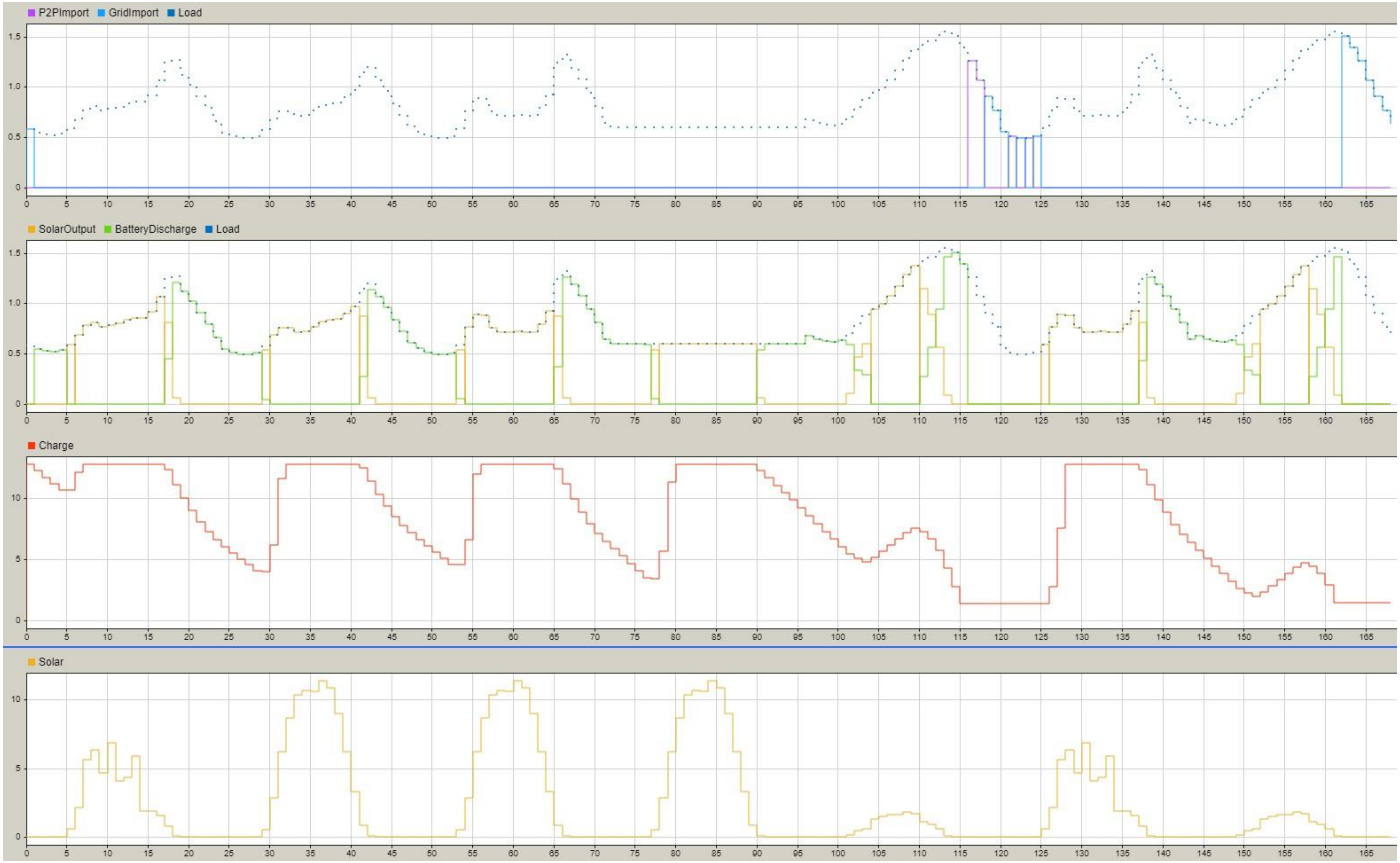


Benefit Mode

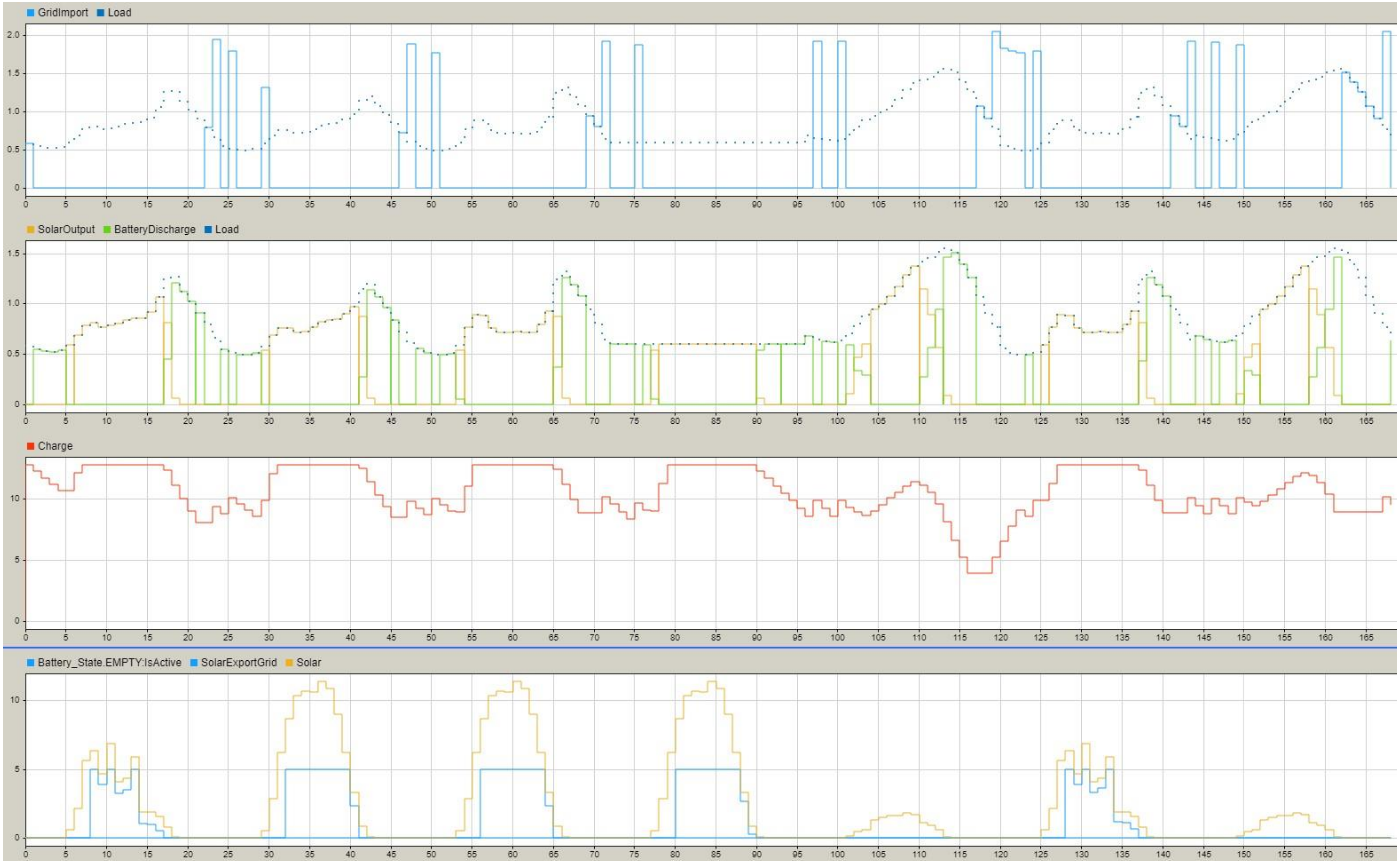


Appendix L: Large PVS & Large BESS Model Outputs

Sustainability Mode



Traditional Mode



Benefit Mode