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MATHEMATICAL OPTIMIZATION OF A SOLAR PHOTOVOLTAIC SYSTEM FOR A SINGLE-FAMILY DETACHED HOME

DIPLOMOVÁ PRÁCE
DIPLOMA THESIS

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BRNO 2019

Abstract

This paper presents a mathematical sizing algorithms of a grid-connected photovoltaic-battery system for a residential house. The objective is to minimize the total storage capacity with cost of electricity. The proposed methodology is based on a Linear and Non-linear programming. We have presents results from a existing PV panel FS-4115-3 for the given climatic conditions and the electricity use profile. Measurements for whole household electricity consumption have been obtained over a period of two months. They were all obtained at one hour interval. The algorithm jointly optimizes the sizes of the photovoltaic and the battery systems by adjusting the battery charge and discharge cycles according to the availability of solar resource and a time-of-use tariff structure for electricity. The results show that jointly optimizing the sizing of battery and photovoltaic systems can significantly reduce electricity imports and the cost of electricity for the household.

keywords

Mathematical Optimization, Solar photovoltaic, Battery storage system, Linear programming and Non linear Programming

Bah, Sheikh .O. : *Mathematical optimization of a solar photovoltaic system for a single-family detached home*, Brno University of Technology, Faculty of Mechanical Engineering, 2019. 90 pp. Supervisor: doc. Ing. Pavel Charvát, Ph.D.

I declare that I have worked on this thesis independently under a supervision of doc. Ing. Pavel Charvát, Ph.D. and using the sources listed in the bibliography.

Sheikh Omar Bah

First and foremost, I wish to thank my advisor doc. Ing. Pavel Charvát, Ph.D., for it has been an honor to have worked under his guidance. I appreciate all his contributions in terms of time, ideas, to make my thesis more productive and bring the best out of me.

Second, I would like to express my sincere gratitude to Ing. Františ́ek Janośťák who has always been there for me, helping and advising me during the most difficult times. He went to great lengths so I can achieve my thesis goals. This Master's study would not have been possible without him, for that I am forever grateful.

I would also like to thank my colleagues with whom I spent the best time in Italy and Czech Republic and who have given me the beautiful experience of having friends from all over the world.

Last but not least, I want to give my best appreciation to my brother Salieu Jallow and family for always being there for me.

Sheikh Omar Bah

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1 Introduction

Solar radiation is the most abundant renewable energy source on the Earth.
However, the solar radiation intensity reaching the Earth's surface changes significantly with time as a result is difficult to properly harnessed it. Moreover, as this energy is ready for consumption several loads points varies with time, therefore mathematical optimization is a required tool to help us solve these issues.

In section 4 we have proposed a linear programming and NLP methods using optimization software tool for minimizing the battery capacity and maximizing the scheduling of distributed energy resources with battery storage system in terms of the cost of investment. An optimization-based approach that maximizes daily operational saving for grid connected solar PV customer was presented, have considered the optimization of battery storage by adjusting charge and discharge cycles and jointly optimizing the size of the photovoltaic operation under specific tariff structures according to the availability of solar resource and time-of-use tariff structure for electricity. However, the optimal capacity of such photovoltaic battery varies strongly with the electricity consumption profile of the household, and is also affected by electricity and battery prices.

The optimal benefit of battery energy storage system was computed for summer and winter with the use of meteorological data of Hradec Kralove.

The amount of energy produced by the PV panels is determined by developing a mathematical model of the PV array allowing the determination of the extracted electrical energy as a function of the solar radiation and the ambient air temperature. The parameters of the considered PV panels as provided by the manufacturer are shown in fig. 6. After determining the parameters to complete the PV cell model, the energy provided by the PV module is given. The maximum power provided by the PV array (Pmp) was also given.
Location of installation of the battery is also significant, the battery must be installed in a separate room having sufficient ventilation and moderate temperature to avoid accident due to the formation of hazardous gases. Batteries may be placed over wooden or plastic planks on the floor [5].

1.1 Aim of the thesis

The aim of the thesis is to optimize the size of a photovoltaic array and the capacity of electrical storage in a grid-connected operation of a solar photovoltaic system. A random profile of the electricity use will be generated for each day of the month considering the probability of the use of individual electrical appliances. We will design a PV system with batteries for a grid connected single family house. The size of the batteries needed to provide electricity to the house when the solar power was not available is determined. Also, the system is connected to the grid just in case the reserves of energy are not enough to meet the demand. The optimal solution of the size of the battery storage system is determined to be enough to store and discharge energy to meet the house's need. To optimize the battery size, self-consumption during both winter (January) and summer (June) is key to our optimization in order to maintain the continuity of the distribution of power. The system consists several scenarios of the same load points and energy storage devices that can work effectively when connected to the grid. The simulation is carried out through GAMS.

1.2 Limitations

A random profile of the electricity used was generated for each day of the month considering the probability of the use of individual electrical appliances which might not match the real consumption of a household. We have only simulated the performance of the system in January (winter) and June (summer). In our simulation, the data 1-48 hours correspond to January and 49-97 hours to June. So a 48 hours meteorological data and consumption profile was considered. Finally the revenue of the system is computed without considering the life time of the battery, solar PV and installation equipment cost and also maintenance and operation costs of PV.

2 Theoretical Background

2.1 Energy Use in Households

Energy consumption of households in the year 2017, represented 27% of final energy consumption in the European Union. The highest percentage of energy consumed by households is for heating homes, with a value of 64.1% in the residential sector, water heating representing 14.8%, while lighting and other electrical appliances represents 14.4%, however these energy consumed did not include powering the main heating, cooling or cooking systems, moreover space cooling and other end-uses is exceedingly lower, representing 0.3% and 0.9% respectively [12].

2.2 Self Consumption

Self-consumption is consuming the energy your plants generate. Any energy that your system produces will go first into your home to power any devices that happen to be running-thus you don't have to purchase via the pubic power grid. If your solar system produces more energy than your household can consume at a given moment, the excess solar is automatically sent to the grid, which further minimize the burden on low voltage grids.

In recent years, the prices of solar photovoltaic panels has reduced drastically due to the increment in number of new regulations and other subsidy strategy to promote the installation of panels, moreover this has also resulted in increased worldwide deployment of solar PV [11]. According to [3] the evolution of photovoltaic power installed at the global level expresses a strong growth of the market since the beginning of the decade.

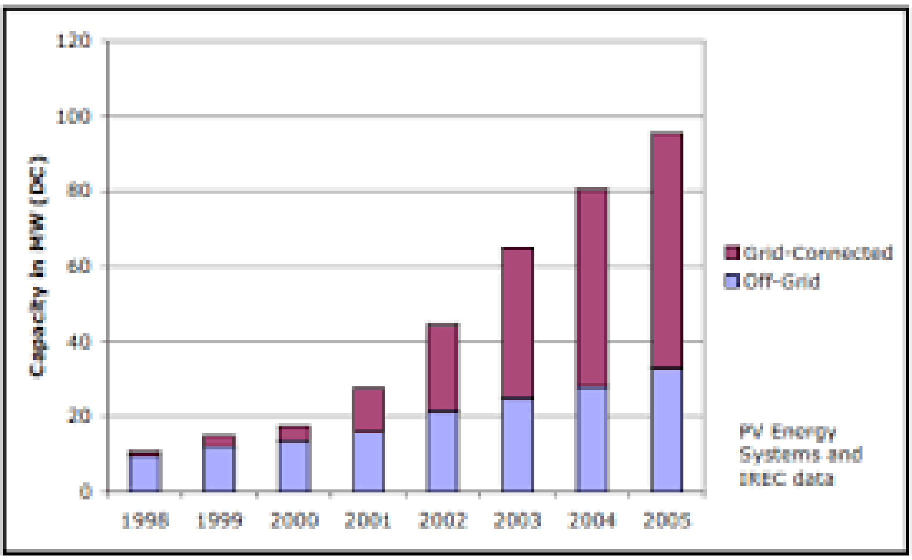

Figure 1: Share of grid-connected and off-grid in the world,1998-2005 [17]

2.3 Operation of Electrical Grid

The electrical grid is responsible for delivering electricity from producers to consumers. Since it has to be transported from the power plant to the consumers over a long distance some power loss is experience due to electrical resistance. Energy loses results in loss of revenue. To reduce this power loss many researchers have suggested various solutions like: increasing high voltage lines, using low transmission wires and raising the level of the voltage.
The electrical grid is divided into three main components associated with different voltage distribution levels: production, transmission, distribution and consumption[9].

- Production

  There are two types of generation in electricity; either by renewable energy such as solar, wind, hydro, wave and biomass or non-renewable energy such as fuel oil, fossil fuels, coal and nuclear energy.

- Transmission and Distribution

  Transmission lines carry high voltages because it reduces the fraction of electricity that is lost in transit. Due to resistance some of it disappear as heat. Power lines are build either underground because they will be less subject to damage from severe weather and other accidents both natural and man-made or overhead power line since they are generally the lowest cost method of transmission of large quantities of electric power.

- Consumption

  The electrical consumers are divided into 4 main categories[9].

  Residential Consumers: It applies to the area of energy for single-family homes and multi-family housing.

  Commercial consumption: It contains property ,corporation, association or agency which is not in a public body that is operated for profit owned by Government facilities, services-providing facilities and equipment, and other public organizations .

  Industrial Consumers: This sector comprises facilities and equipment use in processing, production, or assembling goods. They include agricultural production , manufacturing, construction, other public and private organizations.

  Transport Consumers: Most of the energy consumed by the transportation sector comprises directly burning fossil fuels such as gasoline, diesel, and jet fuel. Nevertheless, some vehicles use electricity from the electric power grid instead.

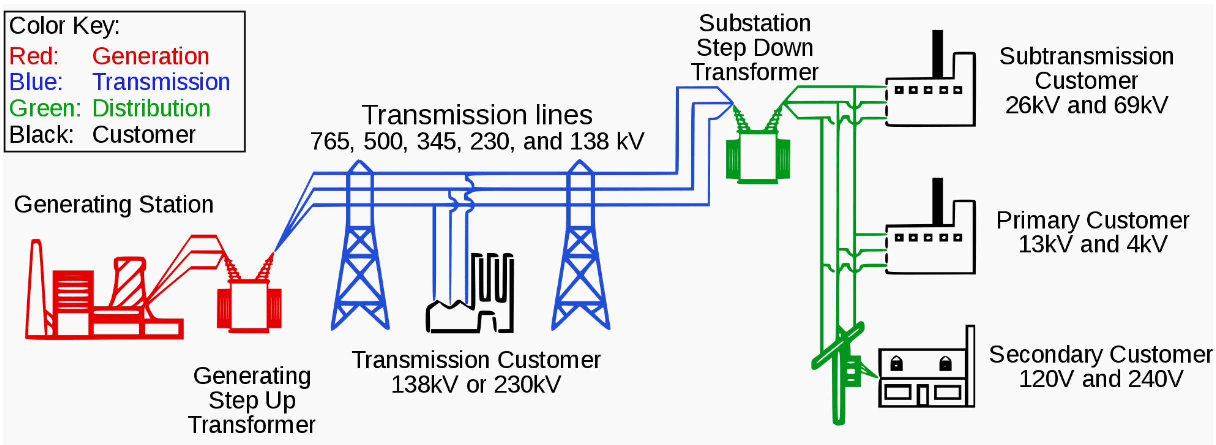

Figure 2: EEP - Electrical Engineering Portal Power System [13]

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2.4 Grid-connected PV-Battery system

Sizing a PV- battery system requires us to know the load demand, load consumption pattern and the amount of energy needed to be supplied to the battery or grid [4].

(For our system, electricity generated from PV is used to supply the demand from loads, store in the battery or sell back to grid. Electricity must be purchased from the electric grid if the PV generation and battery discharge cannot meet the demand. Due to variable electricity prices through the day in EUR tariff peak, electricity can also be purchased from the grid when the price is low, and be sold back to the grid when the price is high.)

2.5 The Smart Grid

As our population increases the contribution to green house gases is also in growing and as these green house gases trap heat and make the planet warmer we will need to find an alternative form of energy resources. There is a growing evidence indicating that there will be challenges with supplying enough fossil energy for continued growth of economics and related energy, especially as the amount of electricity demand is dramatically increasing, a smart grid is that it has a digital technology that allows for two-way communication between the utility and its customers.
Smart grids aim to ensure demand management and control, increased integration of renewable energies, the increase of the units of decentralized production and storage, the deployment of smart meters, smart devices and customer services[9].

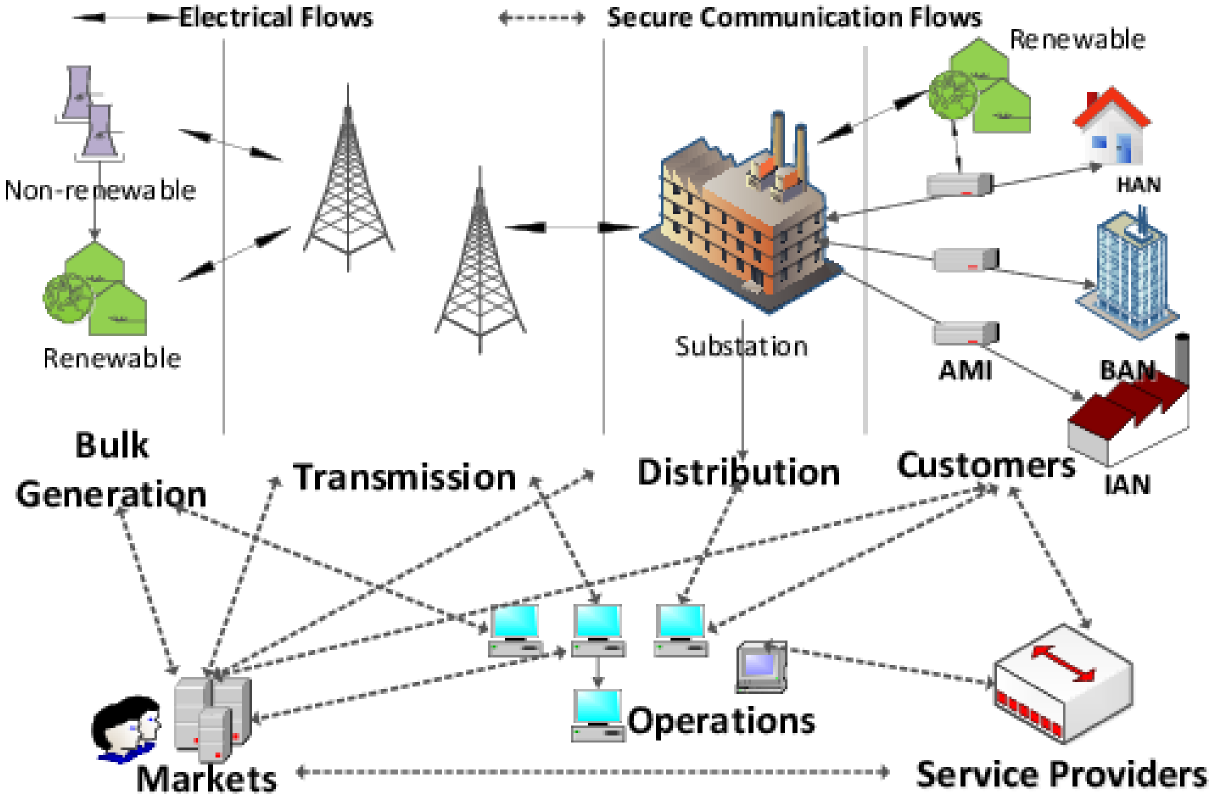

Figure 3: National Institute of Standard and Technology (NIST) Smart Grid Conceptual Model [22]

2.5.1 Renewable Energy Resources

Renewable energy is defined by [11] as "Energy flows which are replenished at the same rate as they are used". During the last years, they are becoming the forward-looking bet to be able to reach a sustainable energetic model. The Sun is the origin of almost all the kind of energies. However, in the atmosphere this energy that comes from the sun becomes a variety of effects and some of them have some importance as an energy resource.

The following numbers shows that renewable-investment is a smart move: its generating capacity saw its largest annual increase ever in 2016, which account for an estimated 62% of net additions to global power generating capacity. Moreover the overall solar energy market alone is expected to expand at the rapid rate of almost 25% per year on average through 2022 to reach $422 billion[16]

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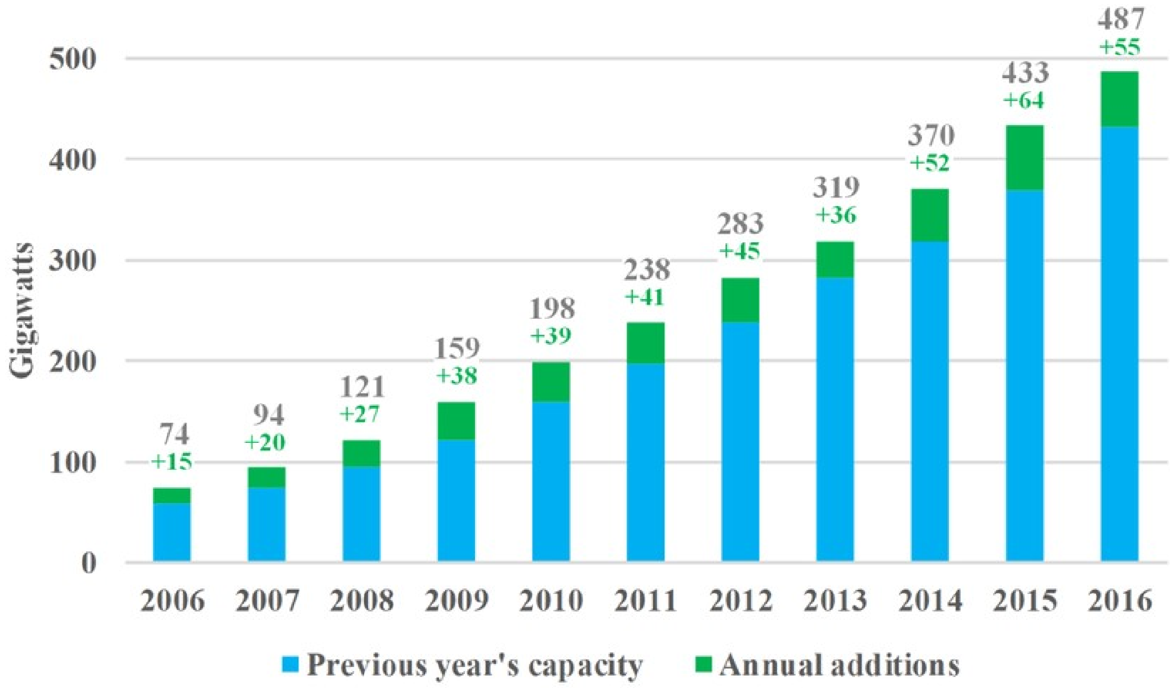

Figure 4: Solar PV global Capacity and Annual Additions, 2006-2016. [14]

2.5.2 Energy Storage System

The energy storage is an important tool since solar,come with their own unique draw backs due to the often meteorological conditions between energy generation and consumption [9]. In order to maintain the efficient flow of power, electricity storage adds flexibility to smart grids in order to meet peak demand. There are many possible techniques for energy storage, found in practically all forms: Mechanical, Chemical, and Thermal energy. Since the storage system have specific technical and economic criteria, then the sizing will be of different types.

The storage system can be divided into two categories, according to their applications: bulk storage, which can output large amounts of power over a long period of time, and distributed storage that can output smaller amounts of energy over shorter periods of time. Some of the storage system includes lead acid batteries, lithium-ion batteries, some types of flow batteries, thermal storage, flywheels, super capacitors, and hydrogen storage [5].

2.6 Modeling of the PV-Battery system component and Energy Flow

2.6.1 PV energy Production Model

Accurate and reliable mathematical models of the various components installed in the PV-Battery backup system are developed in order to establish a robust energy forecasting process.

The sizing of the battery is an optimization problem where the characteristics of the storage, as well as its operation are taken into account. [16].

Following a literature review, numerous researchers have developed several optimization models to solve the battery storage system related to residential house. A simulation of the energy performance of a grid-connected PV system supplying a residential house is considered by [3, 21], the testing results showed that the grid-connected PV system can completely meet the energy needed for a considered house. The integration of renewable energy sources in the building provided positive impact on both the environmental and excess energy demands.

3 Description of the system

The work presented below investigates a photovoltaic system which can vary in size to satisfy the demand of a household. The energy consumed by the house consists of several consuming appliances with different length of operation and power rating. Our system is comprised of a PV array, an inverter and a battery storage system. The appliances considered are either supplied from the PV or grid.
Moreover, we will considered the electric grid to supply electricity only if the PV does not meet the demand of the house. The photovoltaic panels supply the battery storage system, then supply a DC voltage bus through a converter designed to carry out the DC-AC conversion and to ensure the PV generator always operates at its optimum point of operation [3]. Sometimes the PV have surplus energy, in this situation the electricity is send to the grid, the grid can permanently accept the energy produce by the Photovoltaic. The grid is purposely to help meet the demand if the photovoltaic production is not sufficient. For a well-planned PV installation, the power of the inverter must be adapted to the connected PV generator[3].

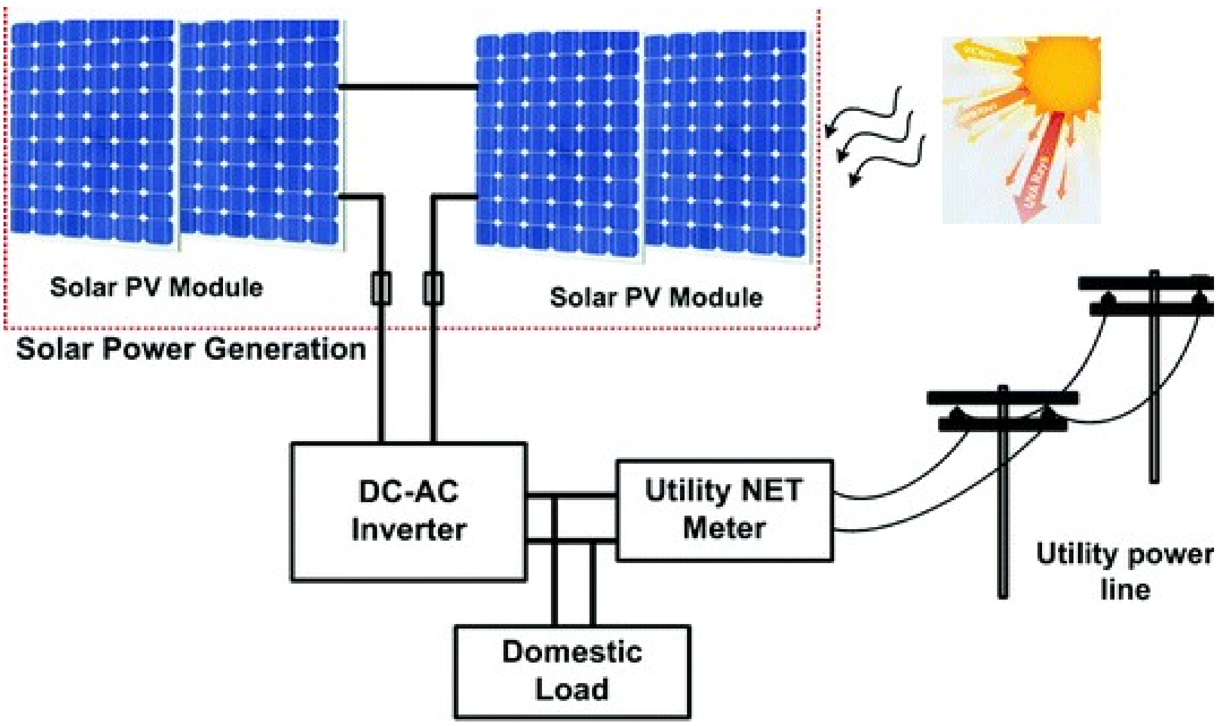

Figure 5: Block diagram of the grid connected photovoltaic system. [15]

MODULE NUMBERS AND RATINGS AT STANDARD TEST CONDITIONS (1000W/m², AM 1.5, 25°C)[5]							
NOMINAL VALUES		FS-4110-3 FS-4110A-3	FS-4112-3 FS-4112A-3	FS-4115-3 FS-4115A-3	FS-4117-3 FS-4117A-3	FS-4120-3 FS-4120A-3	FS-4122-3 FS-4122A-3
Nominal Power[6] (-0/+5W)	P_{MPP} (W)	110.0	112.5	115.0	117.5	120.0	122.5
Voltage at P_{MAX}	V_{MPP} (V)	67.8	68.5	69.3	70.1	70.8	71.5
Current at P_{MAX}	I_{MPP} (A)	1.62	1.64	1.66	1.68	1.70	1.71
Open Circuit Voltage	V_{OC} (V)	86.4	87.0	87.6	88.1	88.7	88.7
Short Circuit Current	I_{SC} (A)	1.82	1.83	1.83	1.83	1.84	1.85
Module Efficiency	%	15.3	15.6	16.0	16.3	16.7	17.0
Maximum System Voltage	V_{SYS} (V)	1500 [7,8]					
Limiting Reverse Current	I_R (A)	4.0					
Maximum Series Fuse	I_{CF} (A)	4.0					
RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m², 20°C air temperature, AM 1.5, 1m/s wind speed)[5]							
Nominal Power	P_{MPP} (W)	83.2	85.1	87.0	89.0	90.8	92.7
Voltage at P_{MAX}	V_{MPP} (V)	63.5	64.5	64.9	65.9	66.3	67.2
Current at P_{MAX}	I_{MPP} (A)	1.31	1.32	1.34	1.35	1.37	1.38
Open Circuit Voltage	V_{OC} (V)	81.6	82.1	82.7	83.2	83.7	83.7
Short Circuit Current	I_{SC} (A)	1.47	1.47	1.48	1.48	1.48	1.49
TEMPERATURE CHARACTERISTICS							
Module Operating Temperature Range	(°C)	-40 to +85					
Temperature Coefficient of P_{MPP}	T_K (P_{MPP})	-0.28%/°C [Temperature Range: 25°C to 75°C]					
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.28%/°C					
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C					

Figure 6: Technical specification of solar PV module (First solar series 4^{TM} PV module)

3.1 Solar Panel

The system studied is for an existing PV panel FS-4115-3 shown in fig. 6.
The optimization model seeks to optimize the battery storage capacity for the real time PV data collected in Hradec Kralove in the Czech republic in an hourly base. The energy consumption profile of the house must be determined in order to help us optimize the maximum battery capacity that can sustain the system. The house is equipped with efficient appliances to offer comfort to the residents [3]. The disparity in solar irradiance and temperature between winter and summer is remarkable. The PV generation at a specific temperature and hour during the entire year are shown in fig. 7. It can be seen that winter days are less sunny in Hradec Kralove than summer days, which influence the proper functioning of the PV systems (decrease in power yield with low irradiance)

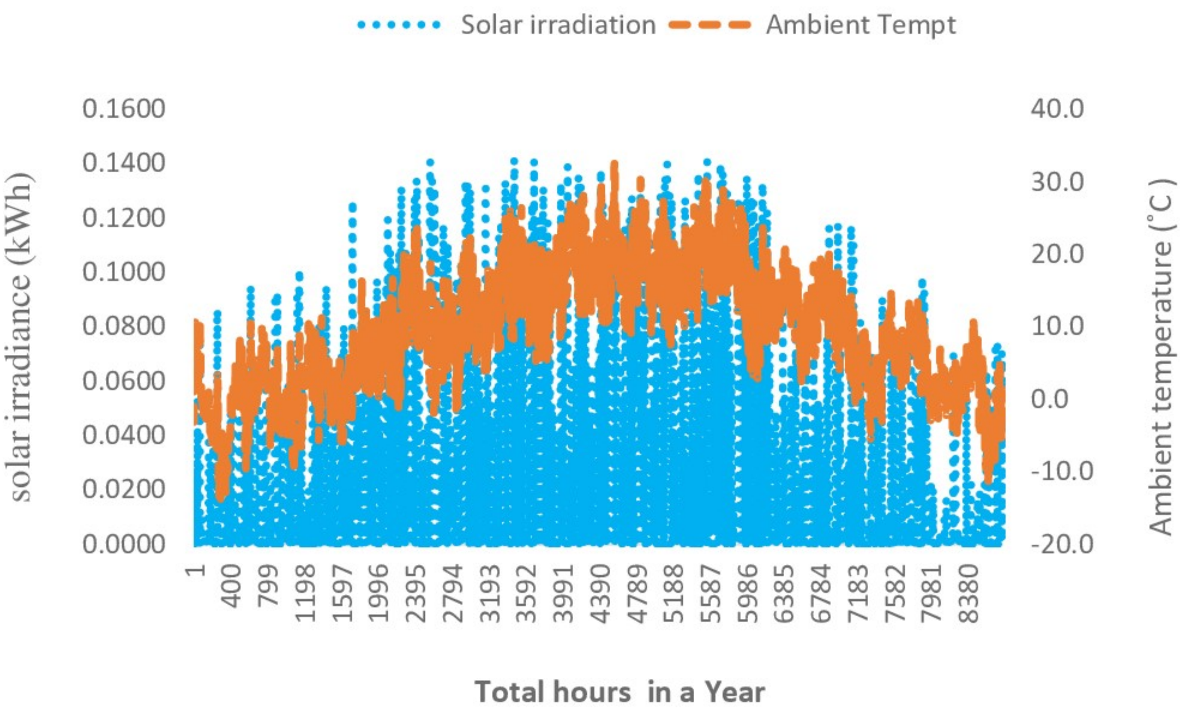

Figure 7: Irradiation and average ambient temperature in Hradec Kralove (First solar series 4^{TM} PV module)

3.2 Electricity load profile

The electricity demand of the house is key to the computation of the PV-Battery backup system. In houses, the consumption of electricity can vary each hour of everyday, weekends and weekdays, and there is significant different between winter and summer days, and also over a few hours due to the types of appliance in use. Consequently, it has a great impact on the sizing of the installation and the resulting cost of the system. The energy consumption profile of each device is determined according to various applied conditions in order to compute total load demand of the house.
This paper, we will consider a data profile at one hour intervals over a period of January and June for two adults with children household type. Moreover, the house space heating, domestic hot water and cooker have been provided by means of gas.

3 Description of the system

Following the description of load profile, the types of loads is discussed:

Timed Appliances:are appliances that can be shifted or interrupted in any of the given time period depending upon their necessity.

Base Load Appliances :are such types of appliances that cannot be shifted or interrupted while performing their operations. Generally, these appliances considered the main load of any household; these appliances are also called non-shift-able or uninterruptible appliances. We consider refrigerators as base load appliances.

We have presented both winter and summer daily energy estimations, based on the power consumed by the equipment given below.

Table 1: List of Home Appliances

Name	**Energy (kWh)**	**Service Time**	**Type of service**
Refrigerator	0.2	24 hours	Based Load
Washing Machine	2	2 hours(4*per month)	Timed
Computer	0.012	4hours	Timed
Lighting(One Lamp)	0.015	5hours	Timed
Television	0.015	4hours	Timed

The figs. 10 to 12 considered show a profile consumption for January. The timing of use of lighting changes depending on the household. It is assumed that the lighting is used for 5 *hours*, laptop is charged for 4 *hours* and the television for 6 *hours*, washing machine for 2 *hours* and the refrigerator for 24 *hours*. The peak of consumption is noticed when the washing machine is used which is assumed to be during weekends. For the television the number of peak hours of use is estimated to be 8 *hours* on a Sunday. We can notice that the PV system continues to generate electricity even in January which is a very cold period in Hradec Kralove. The figures shows that in the considered winter days, the PV electricity which is generated before 10*am* in the morning cannot meet the energy consumption requirement because the solar irradiance was not sufficient, in **scenario I** we will considered a suitable optimization tool to solve such situation. The PV energy begins to increase after 11 *am*, therefore, the power produced from the PV, can effortlessly meet the demand required for the house.

The figs. 13, 15 and 17 shows that in the considered summer days in June, the PV generate more energy due to the high solar irradiance experienced. It is shown in the figures that during the morning the energy that is produced cannot meet the demand which is similar to January. The PV energy begins to increase after 9 *am*, mostly the PV energy produced can meet the need of the house's energy requirement. The extra energy generated in June is stored in our storage system to supply the energy required for the house's energy when there is no sufficient energy from the PV, we will discuss on the mathematical model of our storage system in **scenario I**. However sometimes the energy produced might be more than the capacity of our storage system , especially when the solar irradiance is at its peak level as shown in fig. 13 12-4 *pm*, we will require an alternative mathematical optimization parameters to solve such situations (see scenario II). In both figs. 12 and 15 we can vividly deduce that the electrical characteristics of the photovoltaic panels are related to weather conditions. At the studied site (Hradec Kralove), the evolution of the ambient temperature and solar irradiation during January and June have influence on the production of the PV energy. January is one of the coldest months and June is one of the hottest months of the year in Czech Republic.

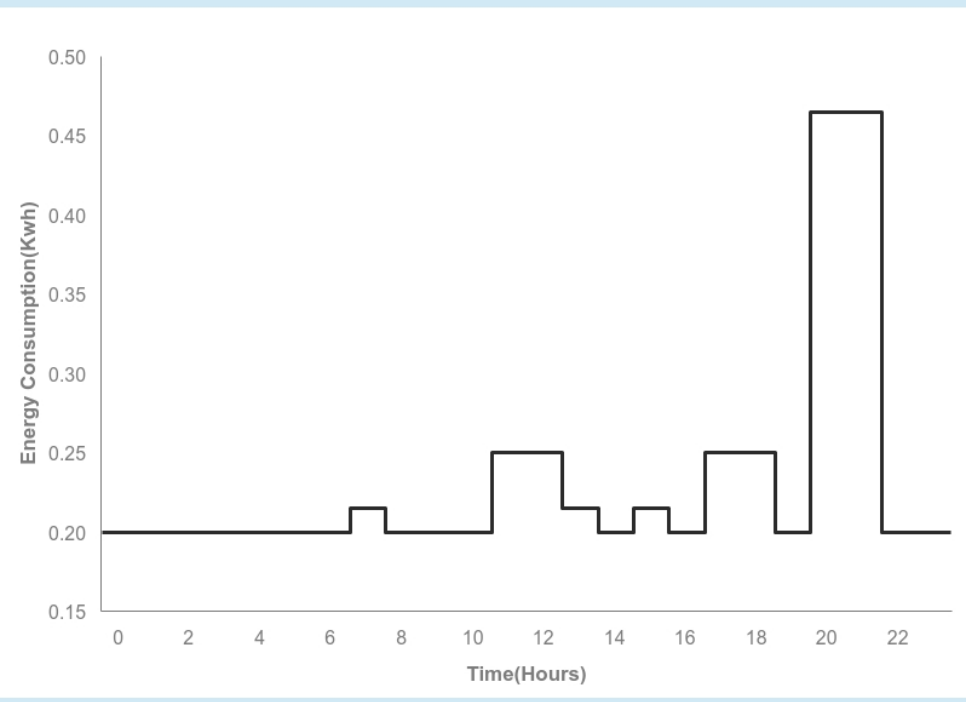

Figure 8: Daily Energy Consumption Profile of the Residential building

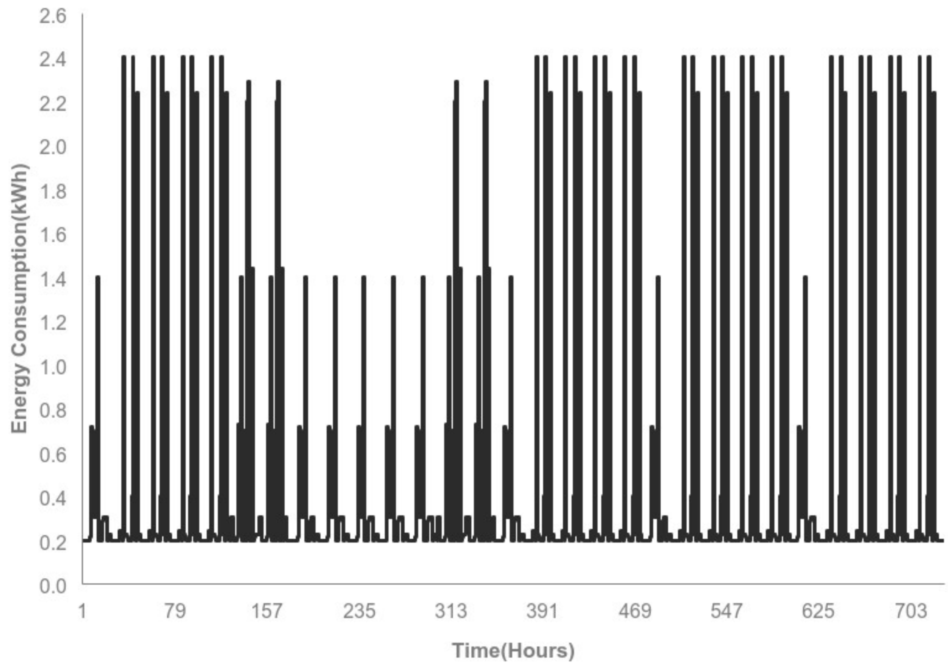

Figure 9: Monthly Energy Consumption Profile of the Residential House

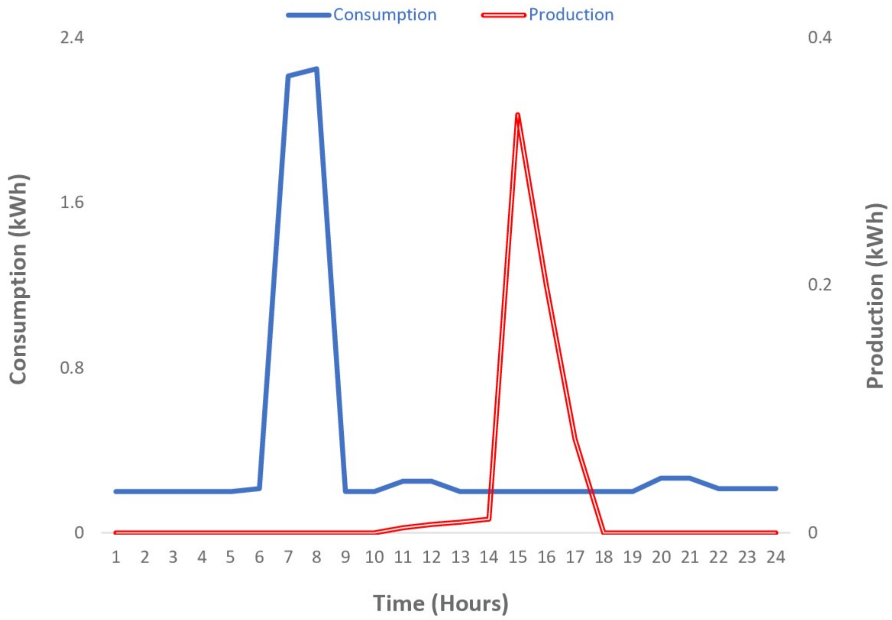

Figure 10: Daily Energy consumption in January (4^{TM} PV module)

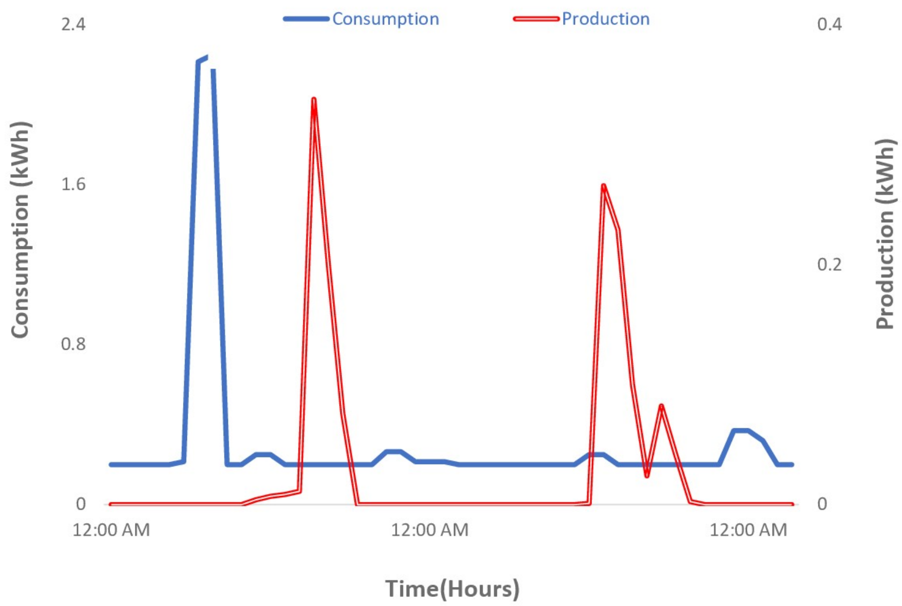

Figure 11: Energy consumption for 48 hours in January (4^{TM} PV module)

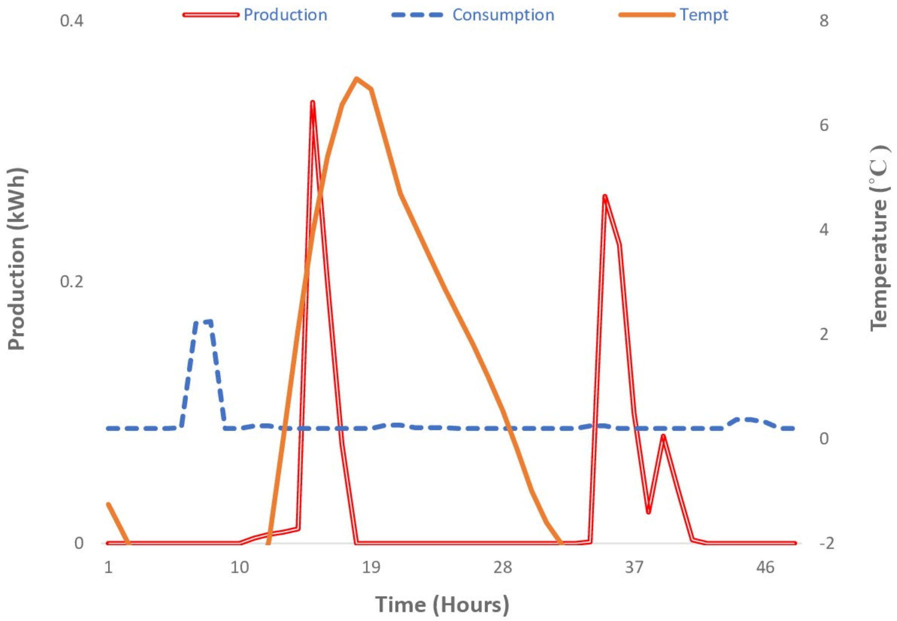

Figure 12: Energy consumption for 48 hours in January with corresponding temperature

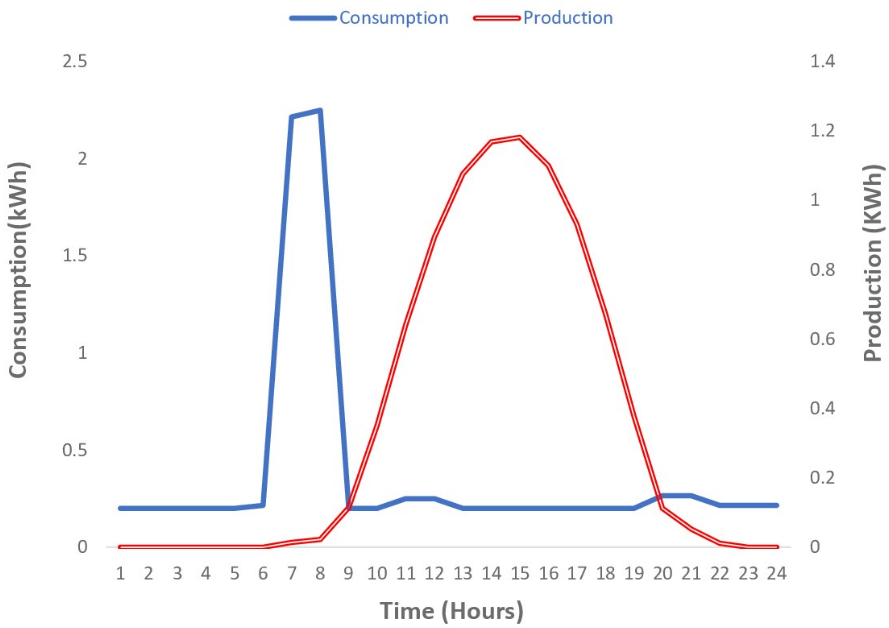

Figure 13: Daily Energy consumption in June (4^{TM} PV module)

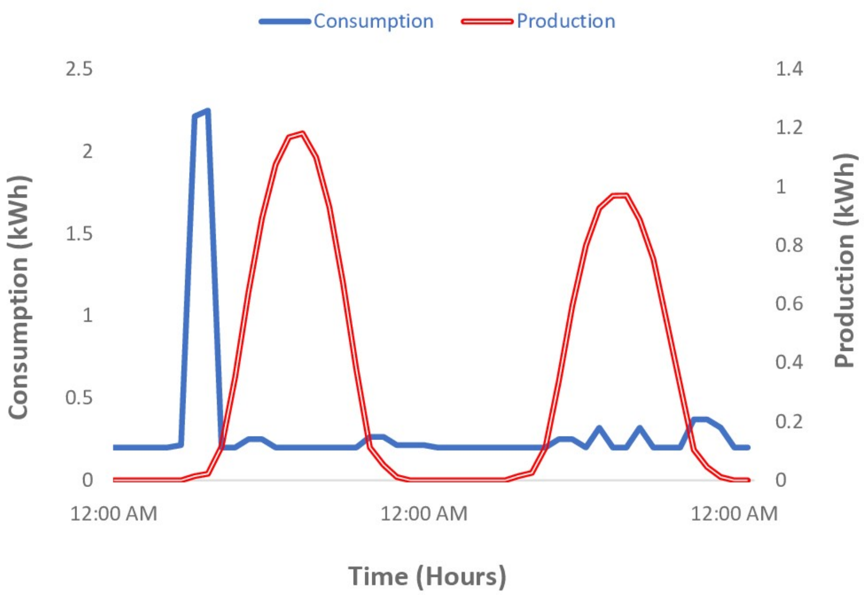

Figure 14: Energy consumption for 48 hours in June (4^{TM} PV module)

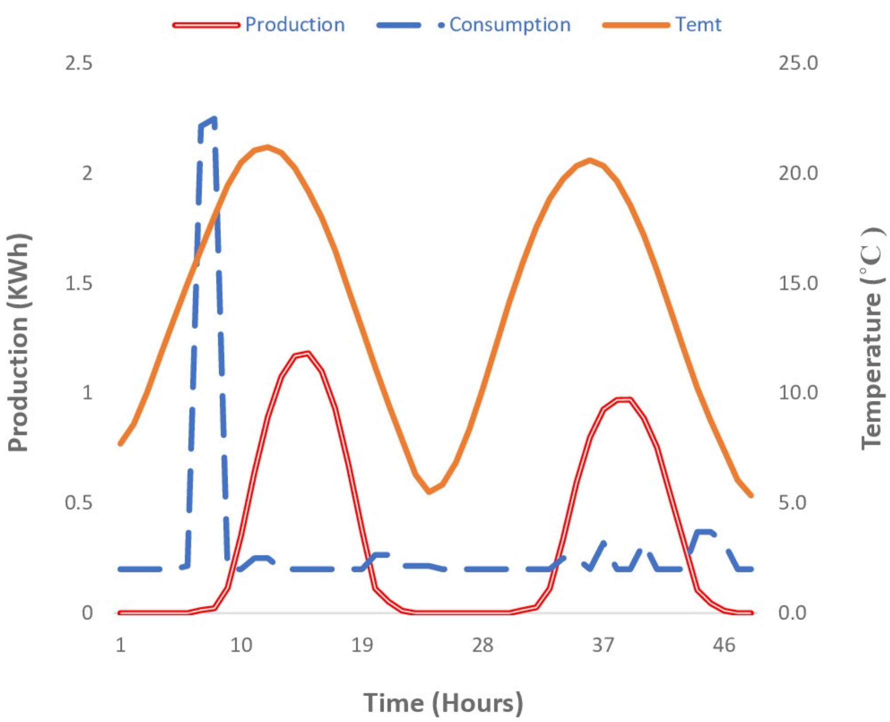

Figure 15: Energy consumption for 48 hours in June with corresponding temperature

4 Optimization of the Battery-PV system

Since the generation of solar power is irregular, energy storage is necessary as a backup supply to fulfill energy-demand, especially at night and cloudy days [7]. In this section we will use General Algebraic modeling system (GAMS) to determine our battery capacity from our demand profile with the corresponding PV hourly generation. For the battery selection procedure using a better battery type also play a significant role with the sizing of the system, you want to make sure the battery is not very expensive, has high efficiency, low rate of discharge and low internal resistance. The task is to optimize the maximum capacity of the battery type reducing significant cost.

In sizing the battery the designers must understand two important aspect of the battery which are: state of charge (SOC) and the state of discharge (SOD). State of charge is the amount of energy stored in the battery and state of discharge shows the battery's discharge percentage. These are important because a battery's maximum depth of discharge (DOD) can affect the battery's life cycle, since the battery's total life cycle will increased if it's charge is maintained in high state [7].

Batteries of PV system are subjected to frequent charging and discharging process. Lead acid battery with deep discharge is commonly used for PV application. Gel type Lead acid batteries are used for remote area where maintenance free operation is required. The batteries for PV applications are designed to meet the following characteristics: low cost, high energy efficiency, long life time, low maintenance, robust construction, good reliability, loss of self discharge and wide operating temperature system [5].

The optimization model is formulated as LP problem and solved in GAMS. The system is tailored for complex, large-scale modeling applications and allows the user to build large maintainable models that can be adapted to new situations.

Mathematical Formulation

1) *paramters*:*inputs*/*outputs* The optimization model requires some inputs in order to provide optimal outputs. These include prices of electricity, the battery storage system and the solar PV generation. The outputs include the battery storage capacity, solar capacity, electricity imported from grid, electricity exported to grid and the plant total revenues.
The LP model has the following input and outputs:

2) *Inputs*

- $E_{price}p_{grid}{}^{-}(i)$: Price of electricity from grid
- $E_{price}p_{grid}{}^{+}(i)$: Price of electricity from PV
- $E_{sola}(i)$: Energy produced by the solar PV
- $ba.LO$: Lower bound of battery
- $ba.UP$: Upper bound of battery
- $d(i)$: Hourly energy demand

3) *Outputs*

- $maxBAT$: Maximum Battery capacity (kWh)
- $k_{dis}(i)$: Energy discharged from the battery
- k_{ch} : Energy supply by the PV to the battery
- $p_{grid}{}^{-}(i)$:Energy imported from grid to satisfy demand
- $p_{grid}{}^{+}(i)$: Energy exported to the grid
- $p_{investBAT}$: Cost of battery (kWh)
- $P_{investsolarpan}$: Investment on solar (kWh)
- $Cost$:Revenue made

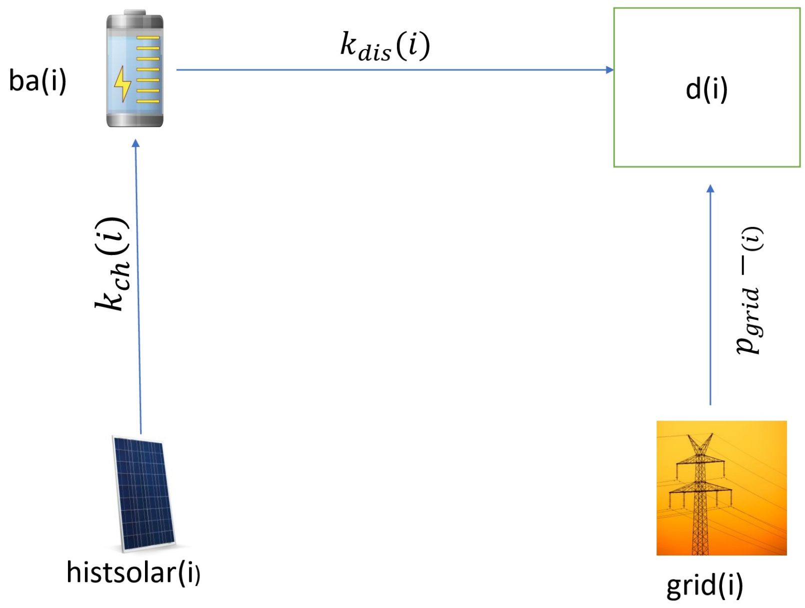

Figure 16: Scenario I (4^{TM} PV module)

4.1 Scenario I

We will demonstrate a complete operation optimization problem of this system by considering a household that is connected to both a photovoltaic system and a grid.

4.1.1 Constraint

The optimization model is indexed by the sets (i, j) , where i is hours data and j is the corresponding solar irradiance The constraint presented in eq. (4.1) restrict the maximum battery capacity of our battery.

$$maxBAT \leq ba(i) \tag{4.1}$$

We assume the energy produced by the solar PV must be supply to battery first before it's ready for consumption. We denote our battery discharge and charging respectively as:

$k_{ch}(i)\ and\ k_{dis}(i)$

When optimizing our battery capacity, we will assume the lower bound of battery is already determined. Let $ba.LO$ be the lower bound constraints and $ba.UP$ must also be determined with the same value (upper bound).

4.1.2 Constraint

We add more constraints to compute the maximum capacity $maxBAT$ of the battery and the import of electricity ${p_{grid}}^{-}(i)$ from grid to satisfy the demand when the battery discharge is not sufficient.

$$d(i) = k_{dis}(i) + {p_{grid}}^{-}(i) \tag{4.2}$$

The energy remaining in the battery at time i is the amount of energy remaining in the battery at (i-1) plus the charging from the PV to the battery storage and minus the energy discharged. Moreover we have also considered the energy of the battery in the beginning before charging and discharging. The storage equation did not take into account the self discharge rate and efficiency of the battery storage.

$$ba(i+1) = ba(i) + k_{ch}(i) - k_{dis}(i) \tag{4.3}$$

Positive bound constraints

Another constraints that is important is the positive value constraints.

$$\begin{aligned} k_{dis}(i) &\geq 0 \\ k_{ch}(i) &\geq 0 \end{aligned} \tag{4.4}$$

Scenario I is solved using Linear Programming (LP), the main objective is to find the smallest battery size possible to meet the demand.

4.2 Scenario II

We will demonstrate a complete operation optimization problem of this system in two case studies. Study case I and II differentiated by the electricity tariff structure.

4.2.1 Objective function

Scenario I is modified to include the investment and income cost. We want to import the minimum amount of electricity from grid with the minimum amount of price available. The new objective function with tariff of electricity is shown below

$$objectfunction = \sum_i \Big({p_{grid}}^{+}(i) \cdot E_{price}{p_{grid}}^{+}(i) - {p_{grid}}^{-}(i) \cdot E_{price}{p_{grid}}^{-}(i) \Big) - p_{investBAT} \cdot maxBAT \tag{4.5}$$

The objective function computes the net revenue from the import of electricity and exporting of electricity.

4.2.2 Case Study I

This case study is a conditioned when the buying price of electricity from the grid has a constant rate (fixed-electricity tariffs).

$$\begin{aligned} ba(i+1) =& ba(i) + k_{ch}(i) - k_{dis}(i) + {p_{grid}}^{-}(i) \\ d(i) =& k_{dis}(i) + {p_{grid}}^{-}(i) \\ maxBAT \leq & \, ba(i) \\ ba.LO & \\ ba.UP & \end{aligned} \tag{4.6}$$

Positive bound constraints

Another constraints that is important is the positive value constraints.

$$\begin{aligned} k_{dis}(i) \geq 0 \\ k_{ch}(i) \geq 0 \\ {p_{grid}}^{+}(i) \geq 0 \end{aligned} \tag{4.7}$$

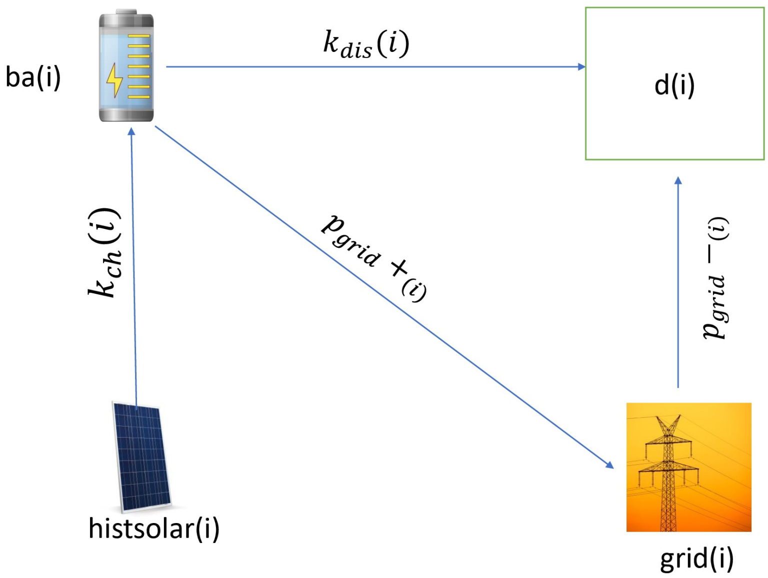

Figure 17: Scenario II, Case Study I

When storing and discharging energy at the same time, energy is lost in the process because there is an efficiency sacrifice related to storing and discharging energy. Since the model objective function is to maximize the revenue, it is more optimal to supply this energy rather than storing and discharging it.

4.2.3 Case Study II

This second case study is modified to include price variability (time-varying electricity tariffs), when the energy storage system is at low price times, then it is kept on hold until the high price time occurs. At that time, the energy stored in battery storage system is sell to the grid.

4.2.4 Case Study III

We will supply energy to the grid only when the battery storage system reaches its maximum capacity. The model constraints presented in equation eq. (4.8) is modified to include maximum battery to be reached before selling electricity to the grid.

$$
\begin{aligned}
ba(i+1) =& ba(i) + k_{ch}(i) - k_{dis}(i) + p_{grid}{}^{-}(i) \\
d(i) =& k_{dis}(i) + p_{grid}{}^{-}(i) \\
maxBAT \leq & \; ba(i) \\
& ba.LO \\
& ba.UP \\
p_{grid}{}^{-}(i) \cdot & \; p_{grid}{}^{minus}(i) = 0 \\
ba(i) + k_{ch}(i) - k_{dis}(i) - p_{grid}{}^{-}(i) - maxBAT =& -p_{grid}{}^{minus}(i)
\end{aligned}
\tag{4.8}
$$

The simulation results from the optimization is shown in table 6 in appendix. Case study (III) is solve using NLP while case (I), (II) is solve using LP, the main objective is to find the total daily energy imported from the grid (Grid-purchases), which arises when the PV array gives less power.

4.3 Scenario III

Objective Function

The objective function in eq. (4.6) is modified in order to find the most optimum configuration to supply a specific demand with the lowest investment possible, it is inevitable to perform investment analysis before actual installation, to determine whether the investment is acceptable or not. In this objective function, the cost of energy from grid (time-varying tariff) , battery cost, solar cost and electricity imported to the grid is choose to combine for our possible system configuration. The installation cost is calculated by using the following equation:

$$
\begin{aligned}
objectfunction =& \sum_i \left(p_{grid}{}^{+}(i) \cdot E_{price} p_{grid}{}^{+}(i) - p_{grid}{}^{-}(i) \cdot E_{price} p_{grid}{}^{-}(i) \right) \\
& - p_{investBAT} \cdot maxBAT - p_{investsolarpan}
\end{aligned}
\tag{4.9}
$$

4.3.1 Model Constraints

The model constraints in eq. (4.9) is also modified to include the number of solar panels and its cost.

$$\begin{aligned}
ba(i+1) =& ba(i) + k_{ch}(i) - k_{dis}(i) + p_{grid}{}^{-}(i) \\
d(i) =& k_{dis}(i) + p_{grid}{}^{-}(i) \\
maxBAT \leq & \; ba(i) \\
& ba.LO \\
& ba.UP \\
p_{grid}{}^{-}(i) \cdot & \; p_{grid}{}^{minus}(i) = 0 \\
ba(i) + k_{ch}(i) - k_{dis}(i) - & \; p_{grid}{}^{-}(i) - maxBAT = -p_{grid}{}^{minus}(i) \\
P_{investsolarpan} =& \Gamma \cdot invest_{solar} \\
solar_{pa}(i) =& \Gamma \cdot k_{dis(i)}
\end{aligned} \tag{4.10}$$

Γ represents the number of solar panel and $invest_{solar}$ is the investment price on solar. With $P_{investsolarpan}$ is the investment made on solar .

4.3.2 Economic Analysis

Life cycle based simulation.
The economic assessment is considered for our system. Consequently, we didn't considered the replacement cost of the batteries as needed for the life time of the solar photovoltaic. The economic analysis takes into considering how long is going to take to pay back the cost of investment of our system considering if some energy were imported and exported to the grid with time varying tariff. These variables and parameters are defined below:

Objective Function

$$\begin{aligned}
Cost =& revenue_{invest} - revenue_{income} \\
Years_{return} =& \frac{revenue_{invest}}{revenueincome}
\end{aligned} \tag{4.11}$$

4.3.3 Model Constraints

The constraints in eq. (4.11) is modified, to include both the revenue investment and revenue income.

$$
\begin{aligned}
ba(i+1) =& ba(i) + k_{ch}(i) - k_{dis}(i) + p_{grid}{}^{-}(i) \\
d(i) =& k_{dis}(i) + p_{grid}{}^{-}(i) \\
maxBAT \leq & \, ba(i) \\
& ba.LO \\
& ba.UP \\
& p_{grid}{}^{-}(i) \cdot p_{grid}{}^{minus}(i) = 0 \\
ba(i) + k_{ch}(i) - & k_{dis}(i) - p_{grid}{}^{-}(i) - maxBAT = -p_{grid}{}^{minus}(i) \\
P_{investsolarpan} =& \Gamma \cdot invest_{solar} \\
solar_{pa}(i) =& \Gamma \cdot k_{dis(i)} \\
revenue_{income} =& \sum_{i} \left(p_{grid}{}^{+}(i) \cdot E_{price} p_{grid}{}^{+}(i) - p_{grid}{}^{-}(i) \cdot E_{price} p_{grid}{}^{-}(i) \right) \\
revenue_{invest} =& p_{investBAT} \cdot maxBAT + p_{investsolarpan}
\end{aligned}
\tag{4.12}
$$

The optimization is solved using NLP, the main objective is to find out, how long is going to take to pay back the cost of our investment.

5 Results and Analysis

The simulation of the developed optimization model with both fixed and time-varying electricity tariff shows an interesting perspective of the management of battery energy flows which could be deployed for existing PV systems, tables 4 and 5(see in appendix) provide insights of a building with PV systems on how they maximize revenue streams by deploying battery storage. It also shows how to optimize system operation in periods of high and low electricity tariffs. The analysis procedure of all scenarios can be used by PV – battery designers to carry out which models to developed, for example, the battery storage capacity that will maximize revenue streams for an existing residential house. PV generation systems under time-varying and fixed electricity tariffs. The results of the three scenarios are presented below.

5.1 Scenario I

We can observe the maximum storage capacity with charging and discharging rate in table 3 and appendix A.1, and we can see that the PV system continues generating electricity on winter days but not as much as on a summer days, for example at 11-13 hours the power that was produced was not sufficient to meet the house's energy consumption requirement because the sun's irradiance was not sufficient, during these periods therefore the house's energy consumption is utterly purchased from grid as observed in fig. 19. During summer we can observed a shift, the power that is produced from the sun can effortlessly meet the need of the house's energy requirement. Hence, the scenario reduces the capacity of the storage while meeting the service requirement. The results shows that our storage system was not able to meet the demand and the remaining energy was imported from the grid to satisfy the demand. When the demand is equal to the generated energy we can observe the storage system discharge all the energy to meet the house's demand.

The result of the model is shown in fig. 18 maxBAT , the optimal solution provides the lowest size possible.

```
----     214 VARIABLE maxBAT.L               =          8.649
```

Figure 18: Maximum Battery Capacity

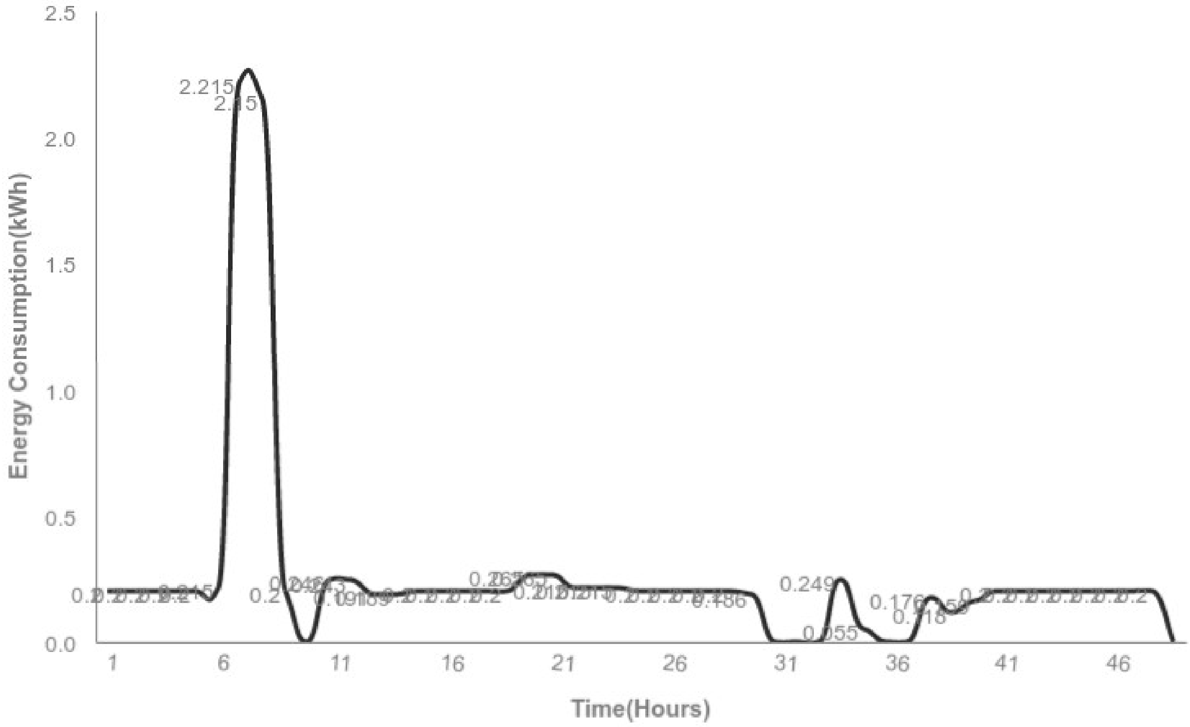

Figure 19: Grid Electricity Import During Winter

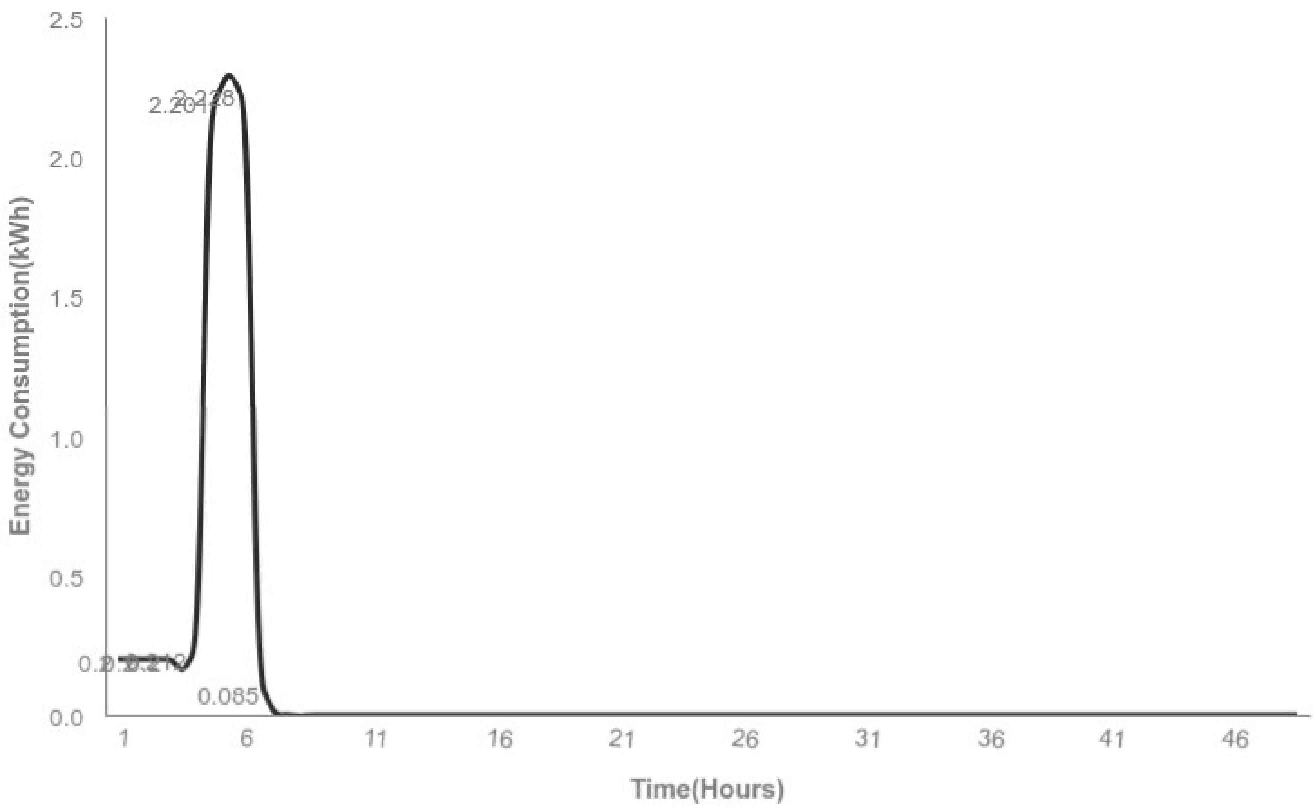

Figure 20: Grid Electricity Import During Summer

5.2 Scenario II

5.2.1 Fixed electricity tariffs

Case Study I

In this scenario the demand is satisfied while minimizing the storage system. For our case study I we will consider a fixed price to purchase electricity from grid. Our optimization objective is to find the minimum storage capacity while minimizing cost. We will present both winter and summer daily energy production see table 7 in appendix. The different results are: the solar production, battery charging, battery discharging, consumption, grid purchase and its corresponding price(fixed-price), electricity sold and its corresponding price(time-varying electricity tariffs). Therefore in this scenario when the PV produced enough power for the house's consumption it can sell the remaining energy when the price is at its peak or store for future consumption when the price is low. We can observe in winter as shown in fig. 21 at 11 hours our solar generates a power of 0.0041 € kWh consequently the price of selling electricity is 0.1299 kWh and the purchasing price is 0.1230 kWh, the energy that was generated by the solar was sold to the grid. At 12 Hours the PV array produced an energy of 0.0068 kWh and it could not encounter the energy consumption 0.2500 kWh required by the house, and the selling price to the grid was 0.1047 kWh which was less than the purchase price, therefore our system imported 0.1230 kWh from grid to satisfy the consumption. At 15, 16, and 35 hours the same observation was made. During the winter most of the electricity for consumption is purchased from the grid as shown in fig. 25. In summer, at 55 hours the same scenario was observed as in 12 hours during winter; the system supplied the household's energy and import the rest of the electricity from the grid to meet the demand. At 59 hours the initial storage was 0.3 kWh an d the power produced by the PV was 0.7928 kWh and it was sufficient to meet the house's consumption of 0.2500 kWh, the battery discharge 0.2500 kWh and store the energy that is at most sufficient to meet the maximum storage capacity of 0.300 kWh for future consumption and sold the rest to the grid. The peak of production was noticed in the hours of 61, 62 and 63 (corresponding to 13, 14, and 15 hours in fig. 22)

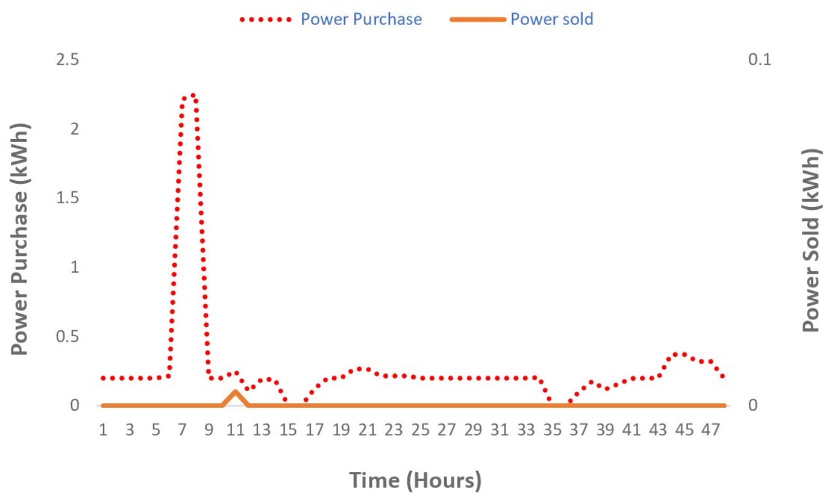

Figure 21: case study I with fixed electricity tariffs in Winter

Figure 22: case study I with fixed electricity tariffs in Summer

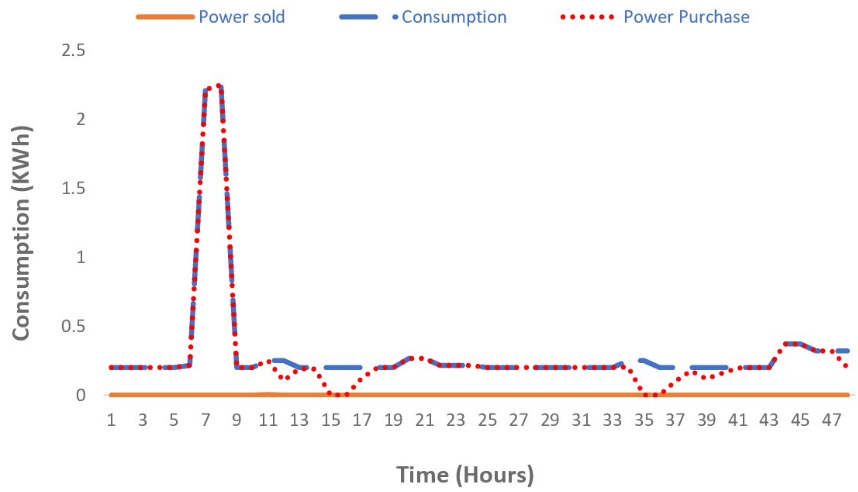

Figure 23: case study I with fixed electricity tariffs in Winter with average ambient temperature

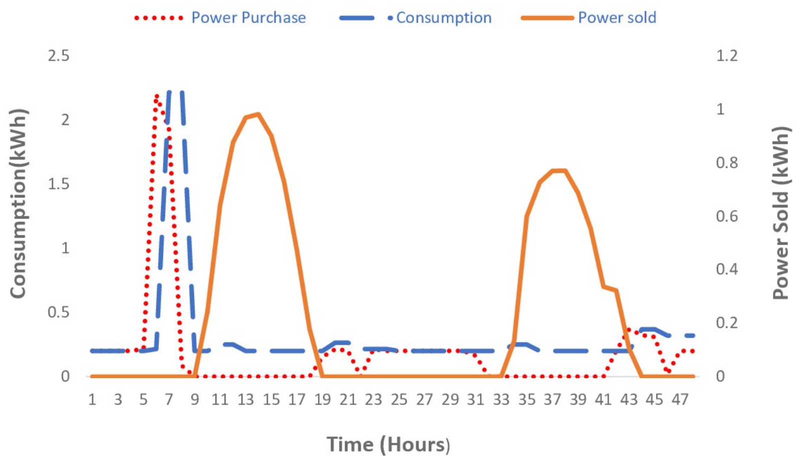

Figure 24: case study I with fixed electricity tariffs in Summer with average ambient temperature

Case Study II

For this case study we will considered the day-ahead data of electricity prices from grid (see table 5 in appendix) and selling price to the grid. For example at 11 hours the selling price of electricity was 0.1229 €/kWh which is a very low price compare to the grid price of 0.1776 €/kWh and for our system to satisfy the demand it imported everything from the grid to meet the house's consumption and store the rest of the energy for future use. We can observe that only 0.00041 kWh was produced from the solar PV which was not sufficient to meet a consumption of 0.2500 kWh During the summer the price of selling electricity to the grid was at its lowest, but peak price is achieved at 60 and 63 hours (corresponding to 12 hours illustrated fig. 28 time-varying electricity tariffs) and we can observe the system sold most of the electricity at that peak hours when the average price was 0.8763-0.9008 €/ kWh At 57 hours the storage was 0.00 kWh and the solar production was 0.3520 kWh while the consumption was at 0.200 kWh the system sold 0.152 kWh instead of storing during peak price of €/ 0.1085 kWh. As observed when the energy storage system is at low price times, then it is kept on hold until the high price time occurs. At that time, the energy stored in battery storage system is released. After discharging the energy when the prices reach the maximum, it again restores energy when the price drops in order to discharge it at higher price. The system revenues increases by optimally scheduling the charging and discharging of the energy storage system, the discharging of BESS at higher priced hours, enables the house to sell energy when it is expensive.

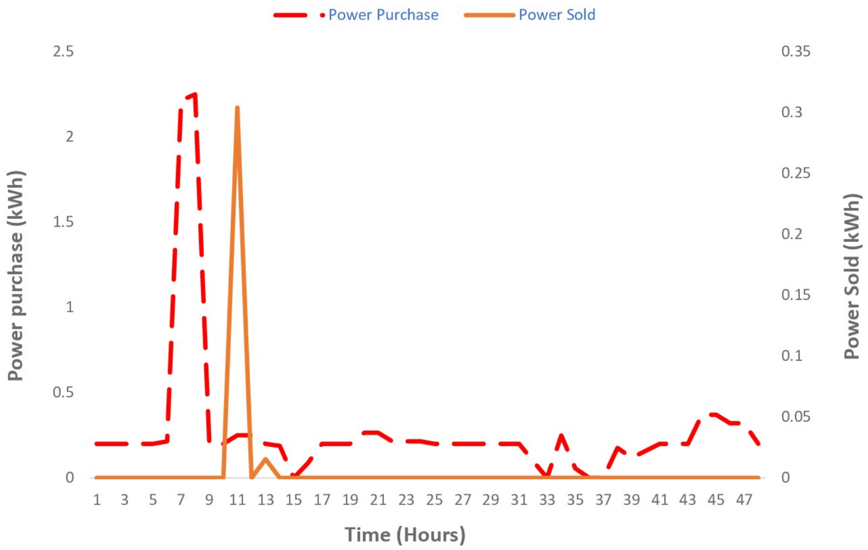

Figure 25: case study II with time-varying electricity tariffs in Winter

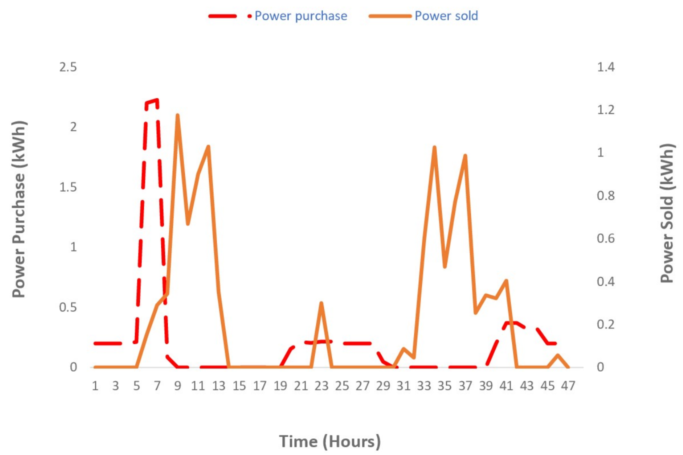

Figure 26: case study II with time-varying electricity tariffs in Summer

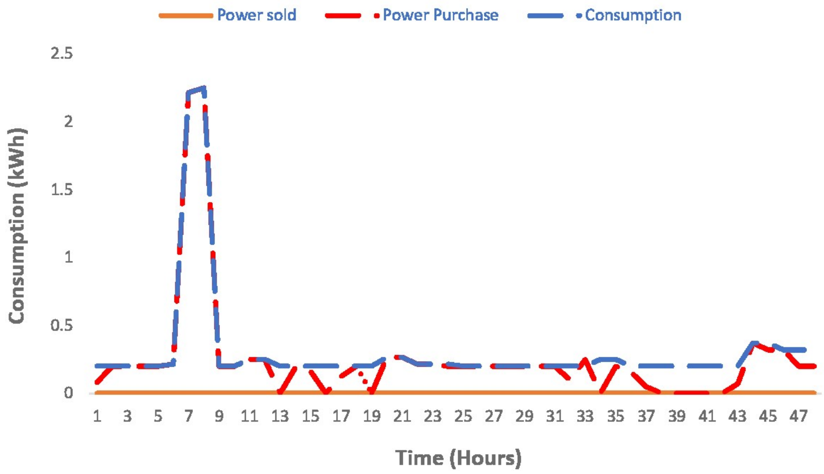

Figure 27: case study II with time-varying electricity tariffs with average ambient temperature in Winter

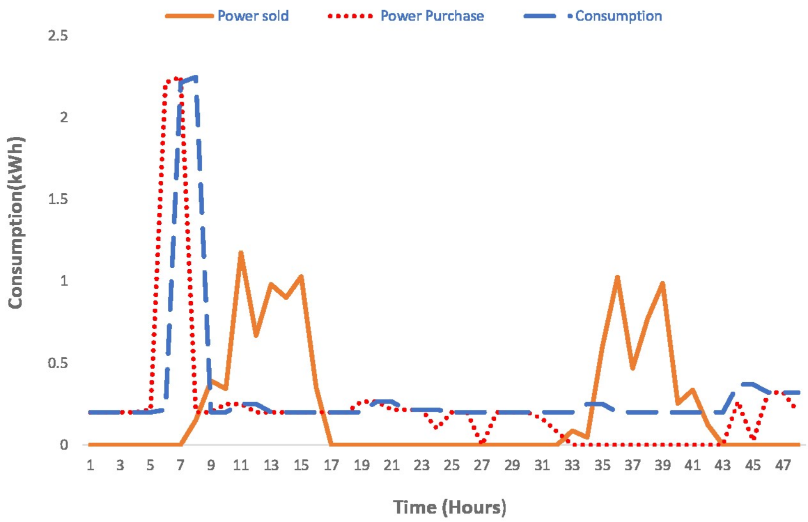

Figure 28: case study II with time-varying electricity tariffs with average ambient temperature in summer

5.2.2 Case Study III

Considering Maximum Battery Capacity

In this case we will only sell electricity to the grid when our BESS is at its maximum capacity and hence cannot store any surplus energy. Moreover this scenario reduces the amount of energy imported from grid while minimizing the size of the battery. In some countries energy is not sold to the grid which have cost implications to the system. With that establishment our system will only supply electricity to the grid when our demand has been satisfied and our battery has reach its maximum capacity. The power-purchase is the energy imported from the grid and power-sold denoted the monthly energy exported to the grid.As illustrated in Fig.30 in addition we have calculated the net energetic gain by subtraction of the electricity exported to the grid from the electricity imported from the grid. For example at 11 hours during winter the solar produced an energy of 0.0041 kWh and the demand was 0.2500 kWh, since the power produced was not sufficient to meet the demand the system imported the electricity from the grid similar to case study II above, however at 57 hours the storage was 0.00 kWh and the solar production was 0.3520 kWh while the consumption was at 0.200 kWh the system store the energy for future consumption instead of selling as in case study II. However at hours of 58 the solar produced a power of 0.6408 kWh, it supplied the house with 0.25 kWh and stores 0.3 kWh and the extra energy of 0.1687 kWh is sold to the grid as shown in fig. 30

Figure 29: case study III with time-varying electricity tariffs in Winter

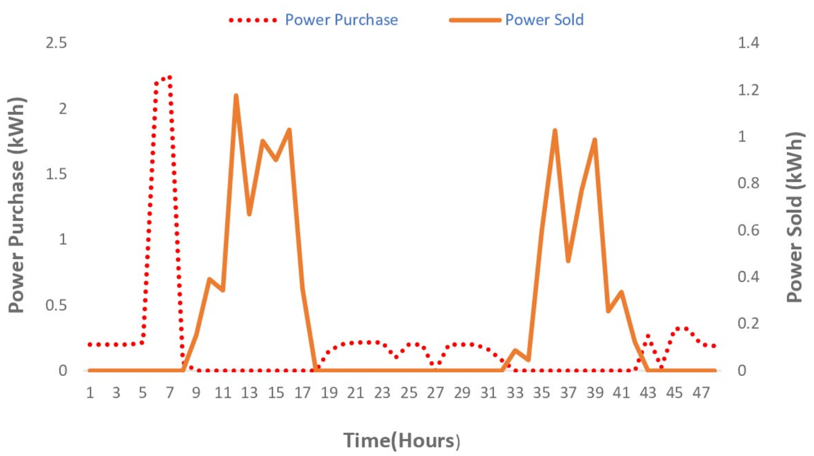

Figure 30: case study III with time-varying electricity tariffs in Summer

5.3 Scenario III

Given that we have minimized the amount of electricity that can be imported from the grid and the maximum battery capacity that will meet our demand, given the minimized number of solar panels for a specified PV area, the investment return is minimized. From our objective solution the investment return was calculated as shown in fig. 31.

Considering we have not take into details the duration of the desired time of the solar panel and battery life times, the results is shown in fig. 31, the investment return for our optimization is negative which means that our system is not cost effective for two months because the present value of the investment return didn't considered the cases we ignored as given in the equation above.

```
245 VARIABLE z_invest.L          =       687.000
    VARIABLE z_income.L          =         7.687
    VARIABLE z.L                 =       679.313
    VARIABLE maxBAT.L            =         0.300
```

Figure 31: Objective Function

The number of years =

$$NY = \frac{revenue_{invest}}{revenue_{income}} = 89.37 years \tag{5.1}$$

5.3.1 Objective function summary

Table 2: Results of Scenario I, II, III and Economic Analysis

Scenarios	Case Study	Battery Capacity (kWh)	Revenue income €
Scenario I	Case I	10.1591	—
Scenario I	Case II	8.6493	
Scenario II	Case I	0.300	-122.898
Scenario II	Case II	0.300	-123.232
Scenario II	Case III	0.300	-123.275
Scenario III	–	0.300	-690.27
Economic Analysis	–	0.300	-679.313

The price of PV considered was 63 €$/kWh$, and the price of battery storage at 400 €$/kWh$, the fixed-electricity tariff price considered is 0.123 €$/kWh$ from grid, and with time-varying price interval of 0.07-0.13 €$/kWh$ from PV, and time-varying price interval of 0.15-0.25 €$/kWh$ from grid.

The number of solar panels=

```
39 PARAMETER numberofsolar          =          9.000
```

Figure 32: Objective Function

6 Conclusion

In this paper, an optimization model was developed to optimize the size of the storage capacity and solar PV for an existing PV generation system. For the system, the optimization model was simulated for January and June with real hourly PV generation profiles. The impact of the unit cost of storage (price/kWh) on the adoption of the battery storage system for a new PV system was also investigated in the GAMS optimization platform. The conclusions are:

(1) In the case of the PV system with grid, reveals that the grid-connected PV system can completely meet the energy needed for the considered house, with a smaller storage size, where we can still utilize the grid as a storage of electricity during night time when solar energy is off.

(2) However, with a time varying tariff structure the consumption of electricity is purchased from the grid when the electricity tariffs are low and discharge at high electricity tariff periods. Also, it was found that the battery prefers to charge when the PV generation is at its maximum

(3) The sensitivity analysis for evaluating the impact of battery storage capacity on objective function shows that both time varying tariff structure and fixed-electricity tariff structure have the same battery capacity.

(4)The results of simulation of electrical performances are very effective and efficient. The daily energy balance on a summer day shows that the photovoltaic system produced more than the energy required for the house. Regarding the excess energy, it was exported to the grid. However, it was found that for a winter day, photovoltaic production is not sufficient to meet all of the demand. Nevertheless, in order to compensate the needed energy, this later is purchased from the grid.

(5)The integration of renewable energy sources in buildings provides positive impact on both the environment and excess energy demands. In addition to the advantages of this system, it has neither electrochemical storage nor preventive maintenance.

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Nomenclature

A_b	Based Load (kWh)
A_s	Shift-able loads (kWh)
AC	Alternating current
ba	Battery charging stage
$ba.LO$	Lower bound of battery
$ba.UP$	The battery upper bound
d	Hourly energy demand
DOD	Depth of discharge
e_b	Total consumed electricity (kWh)
DSM	Demand side-management
E_{price}	The price of electricity (€/ kWh)
$k_{dis}(i)$	Battery discharging rate
$k_{ch}(i)$	Battery charging rate
LP	Linear Programming
$maxBAT$	Maximum battery capacity
NLP	Non-Linear Programming
NY	Number of years to recover investment
$p^-_{grid}(i)$	Energy imported from grid to satisfy demand
$p^+_{grid}(i)$	Energy exported to grid
$p_{investBAT}$	Price invested on battery (€/ kWh)
PV	Photovoltaic
$p_{investsolarpanel}$	Investment on solar panels (€/ kWh)
SOC	State of charge

SOD	State of discharge
λ_b	Power rating of appliances (kWh)
Γ	Number of solar panels (kWh)

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Appendices

A

Scenario I

A.1 Grid-Connected

A
SCENARIO I

Table 3: Case study (Grid-Connected)

i	maxBAT	charging	solar	Discharging	demand	grid
1	8.6493	0.3000	0.0000	0.0000	0.2000	0.2000
2	8.6493	0.3000	0.0000	0.0000	0.2000	0.2000
3	8.6493	0.3000	0.0000	0.0000	0.2000	0.2000
4	8.6493	0.3000	0.0000	0.0000	0.2000	0.2000
5	8.6493	0.3000	0.0000	0.0000	0.2000	0.2000
6	8.6493	0.3000	0.0000	0.0000	0.2150	0.2150
7	8.6493	0.3000	0.0000	0.0000	2.2150	2.2150
8	8.6493	0.3000	0.0000	0.1000	2.2500	2.1500
9	8.6493	0.2000	0.0000	0.0000	0.2000	0.2000
10	8.6493	0.2000	0.0000	0.2000	0.2000	0.0000
11	8.6493	0.0000	0.0041	0.0041	0.2500	0.2459
12	8.6493	0.0000	0.0068	0.0068	0.2500	0.2432
13	8.6493	0.0000	0.0085	0.0085	0.2000	0.1915
14	8.6493	0.0000	0.0112	0.0112	0.2000	0.1888
15	8.6493	0.0000	0.3379	0.0000	0.2000	0.2000
16	8.6493	0.3379	0.2004	0.0000	0.2000	0.2000
17	8.6493	0.5383	0.0759	0.0000	0.2000	0.2000
18	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
19	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
20	8.6493	0.6142	0.0000	0.0000	0.2650	0.2650
21	8.6493	0.6142	0.0000	0.0000	0.2650	0.2650
22	8.6493	0.6142	0.0000	0.0000	0.2150	0.2150
23	8.6493	0.6142	0.0000	0.0000	0.2150	0.2150
24	8.6493	0.6142	0.0000	0.0000	0.2150	0.2150
25	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
26	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
27	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
28	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000
29	8.6493	0.6142	0.0000	0.0000	0.2000	0.2000

30	8.6493	0.6142	0.0000	0.0142	0.2000	0.1858
31	8.6493	0.6000	0.0000	0.2000	0.2000	0.0000
32	8.6493	0.4000	0.0000	0.2000	0.2000	0.0000
33	8.6493	0.2000	0.0000	0.2000	0.2000	0.0000
34	8.6493	0.0000	0.0011	0.0011	0.2500	0.2489
35	8.6493	0.0000	0.2658	0.1948	0.2500	0.0552
36	8.6493	0.0710	0.2288	0.2000	0.2000	0.0000
37	8.6493	0.0998	0.1002	0.2000	0.2000	0.0000
38	8.6493	0.0000	0.0240	0.0240	0.2000	0.1760
39	8.6493	0.0000	0.0821	0.0821	0.2000	0.1179
40	8.6493	0.0000	0.0414	0.0414	0.2000	0.1586
41	8.6493	0.0000	0.0026	0.0000	0.2000	0.2000
42	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
43	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
44	8.6493	0.0026	0.0000	0.0000	0.3700	0.3700
45	8.6493	0.0026	0.0000	0.0000	0.3700	0.3700
46	8.6493	0.0026	0.0000	0.0000	0.3200	0.3200
47	8.6493	0.0026	0.0000	0.0000	0.3200	0.3200
48	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
49	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
50	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
51	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
52	8.6493	0.0026	0.0000	0.0000	0.2000	0.2000
53	8.6493	0.0026	0.0000	0.0026	0.2150	0.2124
54	8.6493	0.0000	0.0141	0.0141	2.2150	2.2009
55	8.6493	0.0000	0.0221	0.0221	2.2500	2.2279
56	8.6493	0.0000	0.1148	0.1148	0.2000	0.0852
57	8.6493	0.0000	0.3520	0.2000	0.2000	0.0000
58	8.6493	0.1520	0.6408	0.2500	0.2500	0.0000
59	8.6493	0.5428	0.8936	0.2500	0.2500	0.0000

60	8.6493	1.1864	1.0763	0.2000	0.2000	0.0000
61	8.6493	2.0627	1.1691	0.2000	0.2000	0.0000
62	8.6493	3.0318	1.1820	0.2000	0.2000	0.0000
63	8.6493	4.0138	1.1008	0.2000	0.2000	0.0000
64	8.6493	4.9146	0.9302	0.2000	0.2000	0.0000
65	8.6493	5.6449	0.6728	0.2000	0.2000	0.0000
66	8.6493	6.1177	0.3780	0.2000	0.2000	0.0000
67	8.6493	6.2957	0.1118	0.2650	0.2650	0.0000
68	8.6493	6.1424	0.0522	0.2650	0.2650	0.0000
69	8.6493	5.9297	0.0116	0.2150	0.2150	0.0000
70	8.6493	5.7262	0.0000	0.2150	0.2150	0.0000
71	8.6493	5.5112	0.0000	0.2150	0.2150	0.0000
72	8.6493	5.2962	0.0000	0.2000	0.2000	0.0000
73	8.6493	5.0962	0.0000	0.2000	0.2000	0.0000
74	8.6493	4.8962	0.0000	0.2000	0.2000	0.0000
75	8.6493	4.6962	0.0000	0.2000	0.2000	0.0000
76	8.6493	4.4962	0.0000	0.2000	0.2000	0.0000
77	8.6493	4.2962	0.0000	0.2000	0.2000	0.0000
78	8.6493	4.0962	0.0140	0.2000	0.2000	0.0000
79	8.6493	3.9102	0.0257	0.2000	0.2000	0.0000
80	8.6493	3.7359	0.1120	0.2000	0.2000	0.0000
81	8.6493	3.6479	0.3368	0.2500	0.2500	0.0000
82	8.6493	3.7347	0.5956	0.2500	0.2500	0.0000
83	8.6493	4.0803	0.8002	0.2000	0.2000	0.0000
84	8.6493	4.6805	0.9271	0.2000	0.2000	0.0000
85	8.6493	5.4077	0.9695	0.2000	0.2000	0.0000
86	8.6493	6.1772	0.9710	0.2000	0.2000	0.0000
87	8.6493	6.9482	0.8877	0.2000	0.2000	0.0000
88	8.6493	7.6358	0.7545	0.2000	0.2000	0.0000
89	8.6493	8.1903	0.5363	0.2000	0.2000	0.0000

B

Scenario II

B.1 Fixed- Electricity Tariff

B
SCENARIO II

Table 4: Case study I (Fixed-Electricity Tariff)

i	maxBAT	Cinv	Charging	solar	Disch	demand	grid_imp	byin_price	grid_exp	selling_Price
1	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0803
2	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1206
3	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1030
4	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0881
5	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0875
6	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.0834
7	0.3000	100.00	0.3000	0.0000	0.0000	2.2150	2.2150	0.1230	0.0000	0.0910
8	0.3000	100.00	0.3000	0.0000	0.0000	2.2500	2.2500	0.1230	0.0000	0.1214
9	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0740
10	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1000
11	0.3000	100.00	0.3000	0.0041	0.0000	0.2500	0.2500	0.1230	0.0041	0.1299
12	0.3000	100.00	0.3000	0.0068	0.1447	0.2500	0.1053	0.1230	0.0000	0.1047
13	0.3000	100.00	0.1621	0.0085	0.0085	0.2000	0.1915	0.1230	0.0000	0.1295
14	0.3000	100.00	0.1621	0.0112	0.0116	0.2000	0.1884	0.1230	0.0000	0.1157
15	0.3000	100.00	0.1617	0.3379	0.2000	0.2000	0.0000	0.1230	0.0000	0.0778
16	0.3000	100.00	0.2996	0.2004	0.2000	0.2000	0.0000	0.1230	0.0000	0.1084
17	0.3000	100.00	0.3000	0.0759	0.0759	0.2000	0.1241	0.1230	0.0000	0.0796
18	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0850
19	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1101
20	0.3000	100.00	0.3000	0.0000	0.0000	0.2650	0.2650	0.1230	0.0000	0.0961
21	0.3000	100.00	0.3000	0.0000	0.0000	0.2650	0.2650	0.1230	0.0000	0.0916
22	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.0911
23	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.0779
24	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.0790
25	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1053
26	0.3000	100.00	0.3000	0.0000	0.0003	0.2000	0.1997	0.1230	0.0000	0.1199
27	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0838
28	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1099

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SCENARIO II

29	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1166
30	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0882
31	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0766
32	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1001
33	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0796
34	0.3000	100.00	0.2997	0.0011	0.0457	0.2500	0.2043	0.1230	0.0000	0.1223
35	0.3000	100.00	0.2552	0.2658	0.2500	0.2500	0.0000	0.1230	0.0000	0.0859
36	0.3000	100.00	0.2710	0.2288	0.1998	0.2000	0.0002	0.1230	0.0000	0.0871
37	0.3000	100.00	0.3000	0.1002	0.1002	0.2000	0.0998	0.1230	0.0000	0.1056
38	0.3000	100.00	0.3000	0.0240	0.0240	0.2000	0.1760	0.1230	0.0000	0.1134
39	0.3000	100.00	0.3000	0.0821	0.0821	0.2000	0.1179	0.1230	0.0000	0.1077
40	0.3000	100.00	0.3000	0.0414	0.0414	0.2000	0.1586	0.1230	0.0000	0.0978
41	0.3000	100.00	0.3000	0.0026	0.0026	0.2000	0.1974	0.1230	0.0000	0.0948
42	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0771
43	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0889
44	0.3000	100.00	0.3000	0.0000	0.0000	0.3700	0.3700	0.1230	0.0000	0.0728
45	0.3000	100.00	0.3000	0.0000	0.0000	0.3700	0.3700	0.1230	0.0000	0.0903
46	0.3000	100.00	0.3000	0.0000	0.0000	0.3200	0.3200	0.1230	0.0000	0.0809
47	0.3000	100.00	0.3000	0.0000	0.0000	0.3200	0.3200	0.1230	0.0000	0.1087
48	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1036
49	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1162
50	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0879
51	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1097
52	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1153
53	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.1076
54	0.3000	100.00	0.3000	0.0141	0.0141	2.2150	2.2009	0.1230	0.0000	0.0870
55	0.3000	100.00	0.3000	0.0221	0.3221	2.2500	1.9279	0.1230	0.0000	0.0752
56	0.3000	100.00	0.0001	0.1148	0.1148	0.2000	0.0852	0.1230	0.0000	0.0762
57	0.3000	100.00	0.0000	0.3520	0.2000	0.2000	0.0000	0.1230	0.0000	0.1085

B
SCENARIO II

29	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1166
30	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0882
31	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0766
32	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1001
33	0.3000	100.00	0.2997	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0796
34	0.3000	100.00	0.2997	0.0011	0.0457	0.2500	0.2043	0.1230	0.0000	0.1223
35	0.3000	100.00	0.2552	0.2658	0.2500	0.2500	0.0000	0.1230	0.0000	0.0859
36	0.3000	100.00	0.2710	0.2288	0.1998	0.2000	0.0002	0.1230	0.0000	0.0871
37	0.3000	100.00	0.3000	0.1002	0.1002	0.2000	0.0998	0.1230	0.0000	0.1056
38	0.3000	100.00	0.3000	0.0240	0.0240	0.2000	0.1760	0.1230	0.0000	0.1134
39	0.3000	100.00	0.3000	0.0821	0.0821	0.2000	0.1179	0.1230	0.0000	0.1077
40	0.3000	100.00	0.3000	0.0414	0.0414	0.2000	0.1586	0.1230	0.0000	0.0978
41	0.3000	100.00	0.3000	0.0026	0.0026	0.2000	0.1974	0.1230	0.0000	0.0948
42	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0771
43	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0889
44	0.3000	100.00	0.3000	0.0000	0.0000	0.3700	0.3700	0.1230	0.0000	0.0728
45	0.3000	100.00	0.3000	0.0000	0.0000	0.3700	0.3700	0.1230	0.0000	0.0903
46	0.3000	100.00	0.3000	0.0000	0.0000	0.3200	0.3200	0.1230	0.0000	0.0809
47	0.3000	100.00	0.3000	0.0000	0.0000	0.3200	0.3200	0.1230	0.0000	0.1087
48	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1036
49	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1162
50	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0879
51	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1097
52	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1153
53	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.1076
54	0.3000	100.00	0.3000	0.0141	0.0141	2.2150	2.2009	0.1230	0.0000	0.0870
55	0.3000	100.00	0.3000	0.0221	0.3221	2.2500	1.9279	0.1230	0.0000	0.0752
56	0.3000	100.00	0.0001	0.1148	0.1148	0.2000	0.0852	0.1230	0.0000	0.0762
57	0.3000	100.00	0.0000	0.3520	0.2000	0.2000	0.0000	0.1230	0.0000	0.1085

B

SCENARIO II

58	0.3000	100.00	0.1520	0.6408	0.2500	0.2500	0.0000	0.1230	0.2428	0.1027
59	0.3000	100.00	0.3000	0.8936	0.2500	0.2500	0.0000	0.1230	0.6436	0.0719
60	0.3000	100.00	0.3000	1.0763	0.2000	0.2000	0.0000	0.1230	0.8763	0.1175
61	0.3000	100.00	0.3000	1.1691	0.2000	0.2000	0.0000	0.1230	0.9691	0.0744
62	0.3000	100.00	0.3000	1.1820	0.2000	0.2000	0.0000	0.1230	0.9820	0.0805
63	0.3000	100.00	0.3000	1.1008	0.2000	0.2000	0.0000	0.1230	0.9008	0.1015
64	0.3000	100.00	0.3000	0.9302	0.2000	0.2000	0.0000	0.1230	0.7302	0.1150
65	0.3000	100.00	0.3000	0.6728	0.2000	0.2000	0.0000	0.1230	0.4728	0.0807
66	0.3000	100.00	0.3000	0.3780	0.2000	0.2000	0.0000	0.1230	0.1780	0.0720
67	0.3000	100.00	0.3000	0.1118	0.1118	0.2650	0.1532	0.1230	0.0000	0.1051
68	0.3000	100.00	0.3000	0.0522	0.0522	0.2650	0.2128	0.1230	0.0000	0.1073
69	0.3000	100.00	0.3000	0.0116	0.0116	0.2150	0.2034	0.1230	0.0000	0.0934
70	0.3000	100.00	0.3000	0.0000	0.2150	0.2150	0.0000	0.1230	0.0000	0.0915
71	0.3000	100.00	0.0850	0.0000	0.0000	0.2150	0.2150	0.1230	0.0000	0.0846
72	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0848
73	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0778
74	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1260
75	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0928
76	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.1170
77	0.3000	100.00	0.0850	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0880
78	0.3000	100.00	0.0850	0.0140	0.0000	0.2000	0.2000	0.1230	0.0000	0.0775
79	0.3000	100.00	0.0990	0.0257	0.0377	0.2000	0.1623	0.1230	0.0000	0.1149
80	0.3000	100.00	0.0869	0.1120	0.1990	0.2000	0.0010	0.1230	0.0000	0.0742
81	0.3000	100.00	0.0000	0.3368	0.2500	0.2500	0.0000	0.1230	0.0000	0.0821
82	0.3000	100.00	0.0868	0.5956	0.2500	0.2500	0.0000	0.1230	0.1324	0.0703
83	0.3000	100.00	0.3000	0.8002	0.2000	0.2000	0.0000	0.1230	0.6002	0.0862
84	0.3000	100.00	0.3000	0.9271	0.2000	0.2000	0.0000	0.1230	0.7271	0.1000
85	0.3000	100.00	0.3000	0.9695	0.2000	0.2000	0.0000	0.1230	0.7695	0.0791
86	0.3000	100.00	0.3000	0.9710	0.2000	0.2000	0.0000	0.1230	0.7710	0.0805

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87	0.3000	100.00	0.3000	0.8877	0.2000	0.2000	0.0000	0.1230	0.6877	0.0898
88	0.3000	100.00	0.3000	0.7545	0.2000	0.2000	0.0000	0.1230	0.5545	0.0890
89	0.3000	100.00	0.3000	0.5363	0.2000	0.2000	0.0000	0.1230	0.3363	0.0893
90	0.3000	100.00	0.3000	0.3226	0.0000	0.2000	0.2000	0.1230	0.3226	0.1278
91	0.3000	100.00	0.3000	0.1044	0.0000	0.3700	0.3700	0.1230	0.1044	0.1296
92	0.3000	100.00	0.3000	0.0457	0.0457	0.3700	0.3243	0.1230	0.0000	0.0922
93	0.3000	100.00	0.3000	0.0114	0.0114	0.3200	0.3086	0.1230	0.0000	0.0924
94	0.3000	100.00	0.3000	0.0000	0.2999	0.3200	0.0201	0.1230	0.0000	0.1163
95	0.3000	100.00	0.0001	0.0000	0.0000	0.2000	0.2000	0.1230	0.0000	0.0938
96	0.3000	100.00	0.0001	0.0000	0.0001	0.2000	0.1999	0.1230	0.0000	0.1248
97	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.0000	0.1230	0.0000	0.0772

B.2 Time-varying electricity tariffs

Table 5: Case study II (Time-varying electricity tariff)

i	maxBAT	Invest	Charge	Solar	Disch	Demand	Grid_Impo	Bying_Price	Grid_Exp	Sold_Price
1	0.3000	100.0000	0.3000	0.0000	0.1194	0.2000	0.0806	0.2235	0.0000	0.0803
2	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.1555	0.0000	0.1206
3	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.2076	0.0000	0.1030
4	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.1551	0.0000	0.0881
5	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.1506	0.0000	0.0875
6	0.3000	100.0000	0.1806	0.0000	0.0000	0.2150	0.2150	0.1901	0.0000	0.0834
7	0.3000	100.0000	0.1806	0.0000	0.0000	2.2150	2.2150	0.2020	0.0000	0.0910
8	0.3000	100.0000	0.1806	0.0000	0.0000	2.2500	2.2500	0.2129	0.0000	0.1214
9	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.1726	0.0000	0.0740
10	0.3000	100.0000	0.1806	0.0000	0.0000	0.2000	0.2000	0.1896	0.0000	0.1000
11	0.3000	100.0000	0.1806	0.0041	0.0000	0.2500	0.2500	0.1776	0.0000	0.1299
12	0.3000	100.0000	0.1847	0.0068	0.0000	0.2500	0.2500	0.1652	0.0000	0.1047
13	0.3000	100.0000	0.1915	0.0085	0.2000	0.2000	0.0000	0.2436	0.0000	0.1295
14	0.3000	100.0000	0.0000	0.0112	0.0112	0.2000	0.1888	0.1923	0.0000	0.1157
15	0.3000	100.0000	0.0000	0.3379	0.0383	0.2000	0.1617	0.1635	0.0000	0.0778
16	0.3000	100.0000	0.2996	0.2004	0.2000	0.2000	0.0000	0.1886	0.0000	0.1084
17	0.3000	100.0000	0.3000	0.0759	0.0759	0.2000	0.1241	0.1875	0.0000	0.0796
18	0.3000	100.0000	0.3000	0.0000	0.0000	0.2000	0.2000	0.1768	0.0000	0.0850
19	0.3000	100.0000	0.3000	0.0000	0.2000	0.2000	0.0000	0.2448	0.0000	0.1101
20	0.3000	100.0000	0.1000	0.0000	0.0000	0.2650	0.2650	0.1689	0.0000	0.0961
21	0.3000	100.0000	0.1000	0.0000	0.0000	0.2650	0.2650	0.1798	0.0000	0.0916
22	0.3000	100.0000	0.1000	0.0000	0.0000	0.2150	0.2150	0.1575	0.0000	0.0911
23	0.3000	100.0000	0.1000	0.0000	0.0000	0.2150	0.2150	0.1901	0.0000	0.0779
24	0.3000	100.0000	0.1000	0.0000	0.0000	0.2150	0.2150	0.1602	0.0000	0.0790
25	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.1884	0.0000	0.1053
26	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.1824	0.0000	0.1199
27	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.1692	0.0000	0.0838
28	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.1612	0.0000	0.1099
29	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.2097	0.0000	0.1166
30	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.2011	0.0000	0.0882
31	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.1545	0.0000	0.0766
32	0.3000	100.0000	0.1000	0.0000	0.0000	0.2000	0.2000	0.2283	0.0000	0.1001
33	0.3000	100.0000	0.1000	0.0000	0.1000	0.2000	0.1000	0.2446	0.0000	0.0796
34	0.3000	100.0000	0.0000	0.0011	0.0011	0.2500	0.2489	0.2096	0.0000	0.1223
35	0.3000	100.0000	0.0000	0.2658	0.2500	0.2500	0.0000	0.2107	0.0000	0.0859
36	0.3000	100.0000	0.0158	0.2288	0.0000	0.2000	0.2000	0.1863	0.0000	0.0871
37	0.3000	100.0000	0.2446	0.1002	0.0448	0.2000	0.1552	0.2094	0.0000	0.1056
38	0.3000	100.0000	0.3000	0.0240	0.1501	0.2000	0.0499	0.2180	0.0000	0.1134
39	0.3000	100.0000	0.1739	0.0821	0.0000	0.2000	0.2000	0.2007	0.0000	0.1077
40	0.3000	100.0000	0.2560	0.0414	0.0000	0.2000	0.2000	0.1659	0.0000	0.0978
41	0.3000	100.0000	0.2974	0.0026	0.0000	0.2000	0.2000	0.2157	0.0000	0.0948
42	0.3000	100.0000	0.3000	0.0000	0.0000	0.2000	0.2000	0.2024	0.0000	0.0771
43	0.3000	100.0000	0.3000	0.0000	0.0000	0.2000	0.2000	0.1624	0.0000	0.0889
44	0.3000	100.0000	0.3000	0.0000	0.3000	0.3700	0.0700	0.2487	0.0000	0.0728
45	0.3000	100.0000	0.0000	0.0000	0.0000	0.3700	0.3700	0.1728	0.0000	0.0903
46	0.3000	100.0000	0.0000	0.0000	0.0000	0.3200	0.3200	0.2176	0.0000	0.0809
47	0.3000	100.0000	0.0000	0.0000	0.0000	0.3200	0.3200	0.2277	0.0000	0.1087
48	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.2432	0.0000	0.1036
49	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.1701	0.0000	0.1162
50	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.1797	0.0000	0.0879
51	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.1697	0.0000	0.1097
52	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.1746	0.0000	0.1153
53	0.3000	100.0000	0.0000	0.0000	0.0000	0.2150	0.2150	0.2146	0.0000	0.1076

54	0.3000	100.0000	0.0000	0.0141	0.0141	2.2150	2.2009	0.2235	0.0000	0.0870
55	0.3000	100.0000	0.0000	0.0221	0.0000	2.2500	2.2500	0.1585	0.0000	0.0752
56	0.3000	100.0000	0.0221	0.1148	0.1369	0.2000	0.0631	0.1650	0.0000	0.0762
57	0.3000	100.0000	0.0000	0.3520	0.2000	0.2000	0.0000	0.1934	0.1520	0.1085
58	0.3000	100.0000	0.0000	0.6408	0.2500	0.2500	0.0000	0.1687	0.3908	0.1027
59	0.3000	100.0000	0.0000	0.8936	0.2500	0.2500	0.0000	0.2193	0.3436	0.0719
60	0.3000	100.0000	0.3000	1.0763	0.2000	0.2000	0.0000	0.2263	1.1763	0.1175
61	0.3000	100.0000	0.0000	1.1691	0.2000	0.2000	0.0000	0.1655	0.6691	0.0744
62	0.3000	100.0000	0.3000	1.1820	0.2000	0.2000	0.0000	0.1889	0.9820	0.0805
63	0.3000	100.0000	0.3000	1.1008	0.2000	0.2000	0.0000	0.2195	0.9008	0.1015
64	0.3000	100.0000	0.3000	0.9302	0.2000	0.2000	0.0000	0.2346	1.0302	0.1150
65	0.3000	100.0000	0.0000	0.6728	0.2000	0.2000	0.0000	0.2113	0.3508	0.0807
66	0.3000	100.0000	0.1220	0.3780	0.2000	0.2000	0.0000	0.2476	0.0000	0.0720
67	0.3000	100.0000	0.3000	0.1118	0.1118	0.2650	0.1532	0.1527	0.0000	0.1051
68	0.3000	100.0000	0.3000	0.0522	0.0638	0.2650	0.2012	0.1687	0.0000	0.1073
69	0.3000	100.0000	0.2884	0.0116	0.0000	0.2150	0.2150	0.1587	0.0000	0.0934
70	0.3000	100.0000	0.3000	0.0000	0.0000	0.2150	0.2150	0.2040	0.0000	0.0915
71	0.3000	100.0000	0.3000	0.0000	0.0000	0.2150	0.2150	0.1627	0.0000	0.0846
72	0.3000	100.0000	0.3000	0.0000	0.1000	0.2000	0.1000	0.2234	0.0000	0.0848
73	0.3000	100.0000	0.2000	0.0000	0.0000	0.2000	0.2000	0.1613	0.0000	0.0778
74	0.3000	100.0000	0.2000	0.0000	0.0000	0.2000	0.2000	0.1988	0.0000	0.1260
75	0.3000	100.0000	0.2000	0.0000	0.2000	0.2000	0.0000	0.2296	0.0000	0.0928
76	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.1992	0.0000	0.1170
77	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.2034	0.0000	0.0880
78	0.3000	100.0000	0.0000	0.0140	0.0000	0.2000	0.2000	0.1511	0.0000	0.0775
79	0.3000	100.0000	0.0140	0.0257	0.0396	0.2000	0.1604	0.2044	0.0000	0.1149
80	0.3000	100.0000	0.0000	0.1120	0.1120	0.2000	0.0880	0.1951	0.0000	0.0742
81	0.3000	100.0000	0.0000	0.3368	0.2500	0.2500	0.0000	0.2475	0.0868	0.0821
82	0.3000	100.0000	0.0000	0.5956	0.2500	0.2500	0.0000	0.1684	0.0456	0.0703
83	0.3000	100.0000	0.3000	0.8002	0.2000	0.2000	0.0000	0.1664	0.6002	0.0862
84	0.3000	100.0000	0.3000	0.9271	0.2000	0.2000	0.0000	0.1525	1.0271	0.1000
85	0.3000	100.0000	0.0000	0.9695	0.2000	0.2000	0.0000	0.1678	0.4695	0.0791
86	0.3000	100.0000	0.3000	0.9710	0.2000	0.2000	0.0000	0.1561	0.7710	0.0805
87	0.3000	100.0000	0.3000	0.8877	0.2000	0.2000	0.0000	0.1517	0.9877	0.0898
88	0.3000	100.0000	0.0000	0.7545	0.2000	0.2000	0.0000	0.2336	0.2545	0.0890
89	0.3000	100.0000	0.3000	0.5363	0.2000	0.2000	0.0000	0.2102	0.3363	0.0893
90	0.3000	100.0000	0.3000	0.3226	0.2000	0.2000	0.0000	0.1527	0.1226	0.1278
91	0.3000	100.0000	0.3000	0.1044	0.1044	0.3700	0.2656	0.1696	0.0000	0.1296
92	0.3000	100.0000	0.3000	0.0457	0.3457	0.3700	0.0243	0.2451	0.0000	0.0922
93	0.3000	100.0000	0.0000	0.0114	0.0000	0.3200	0.3200	0.1836	0.0000	0.0924
94	0.3000	100.0000	0.0114	0.0000	0.0000	0.3200	0.3200	0.2094	0.0000	0.1163
95	0.3000	100.0000	0.0114	0.0000	0.0000	0.2000	0.2000	0.1759	0.0000	0.0938
96	0.3000	100.0000	0.0114	0.0000	0.0114	0.2000	0.1886	0.2141	0.0000	0.1248
97	0.3000	100.0000	0.0000	0.0000	0.0000	0.2000	0.0000	0.1655	0.0000	0.0772

B.3 Considering Maximum Battery

Time-varying electricity tariffs

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Table 6: Case study III (Time-varying Electricity tariff)

i	maxBAT	Cinv	Charg	solar	Disch	demand	grid_imp	buying	grid_exp	selling
1	0.3000	100.00	0.3000	0.0000	0.1194	0.2000	0.0806	0.2235	0.0000	0.0803
2	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.1555	0.0000	0.1206
3	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.2076	0.0000	0.1030
4	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.1551	0.0000	0.0881
5	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.1506	0.0000	0.0875
6	0.3000	100.00	0.1806	0.0000	0.0000	0.2150	0.2150	0.1901	0.0000	0.0834
7	0.3000	100.00	0.1806	0.0000	0.0000	2.2150	2.2150	0.2020	0.0000	0.0910
8	0.3000	100.00	0.1806	0.0000	0.0000	2.2500	2.2500	0.2129	0.0000	0.1214
9	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.1726	0.0000	0.0740
10	0.3000	100.00	0.1806	0.0000	0.0000	0.2000	0.2000	0.1896	0.0000	0.1000
11	0.3000	100.00	0.1806	0.0041	0.0000	0.2500	0.2500	0.1776	0.0000	0.1299
12	0.3000	100.00	0.1847	0.0068	0.0000	0.2500	0.2500	0.1652	0.0000	0.1047
13	0.3000	100.00	0.1915	0.0085	0.2000	0.2000	0.0000	0.2436	0.0000	0.1295
14	0.3000	100.00	0.0000	0.0112	0.0112	0.2000	0.1888	0.1923	0.0000	0.1157
15	0.3000	100.00	0.0000	0.3379	0.0383	0.2000	0.1617	0.1635	0.0000	0.0778
16	0.3000	100.00	0.2996	0.2004	0.2000	0.2000	0.0000	0.1886	0.0000	0.1084
17	0.3000	100.00	0.3000	0.0759	0.0759	0.2000	0.1241	0.1875	0.0000	0.0796
18	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1768	0.0000	0.0850
19	0.3000	100.00	0.3000	0.0000	0.2000	0.2000	0.0000	0.2448	0.0000	0.1101
20	0.3000	100.00	0.1000	0.0000	0.0000	0.2650	0.2650	0.1689	0.0000	0.0961
21	0.3000	100.00	0.1000	0.0000	0.0000	0.2650	0.2650	0.1798	0.0000	0.0916
22	0.3000	100.00	0.1000	0.0000	0.0000	0.2150	0.2150	0.1575	0.0000	0.0911
23	0.3000	100.00	0.1000	0.0000	0.0000	0.2150	0.2150	0.1901	0.0000	0.0779
24	0.3000	100.00	0.1000	0.0000	0.0000	0.2150	0.2150	0.1602	0.0000	0.0790
25	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.1884	0.0000	0.1053
26	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.1824	0.0000	0.1199
27	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.1692	0.0000	0.0838
28	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.1612	0.0000	0.1099

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29	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.2097	0.0000	0.1166
30	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.2011	0.0000	0.0882
31	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.1545	0.0000	0.0766
32	0.3000	100.00	0.1000	0.0000	0.0000	0.2000	0.2000	0.2283	0.0000	0.1001
33	0.3000	100.00	0.1000	0.0000	0.1000	0.2000	0.1000	0.2446	0.0000	0.0796
34	0.3000	100.00	0.0000	0.0011	0.0011	0.2500	0.2489	0.2096	0.0000	0.1223
35	0.3000	100.00	0.0000	0.2658	0.2500	0.2500	0.0000	0.2107	0.0000	0.0859
36	0.3000	100.00	0.0158	0.2288	0.0000	0.2000	0.2000	0.1863	0.0000	0.0871
37	0.3000	100.00	0.2446	0.1002	0.0448	0.2000	0.1552	0.2094	0.0000	0.1056
38	0.3000	100.00	0.3000	0.0240	0.1501	0.2000	0.0499	0.2180	0.0000	0.1134
39	0.3000	100.00	0.1739	0.0821	0.0000	0.2000	0.2000	0.2007	0.0000	0.1077
40	0.3000	100.00	0.2560	0.0414	0.0000	0.2000	0.2000	0.1659	0.0000	0.0978
41	0.3000	100.00	0.2974	0.0026	0.0000	0.2000	0.2000	0.2157	0.0000	0.0948
42	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.2024	0.0000	0.0771
43	0.3000	100.00	0.3000	0.0000	0.0000	0.2000	0.2000	0.1624	0.0000	0.0889
44	0.3000	100.00	0.3000	0.0000	0.3000	0.3700	0.0700	0.2487	0.0000	0.0728
45	0.3000	100.00	0.0000	0.0000	0.0000	0.3700	0.3700	0.1728	0.0000	0.0903
46	0.3000	100.00	0.0000	0.0000	0.0000	0.3200	0.3200	0.2176	0.0000	0.0809
47	0.3000	100.00	0.0000	0.0000	0.0000	0.3200	0.3200	0.2277	0.0000	0.1087
48	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.2432	0.0000	0.1036
49	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.1701	0.0000	0.1162
50	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.1797	0.0000	0.0879
51	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.1697	0.0000	0.1097
52	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.1746	0.0000	0.1153
53	0.3000	100.00	0.0000	0.0000	0.0000	0.2150	0.2150	0.2146	0.0000	0.1076
54	0.3000	100.00	0.0000	0.0141	0.0141	2.2150	2.2009	0.2235	0.0000	0.0870
55	0.3000	100.00	0.0000	0.0221	0.0000	2.2500	2.2500	0.1585	0.0000	0.0752
56	0.3000	100.00	0.0221	0.1148	0.1369	0.2000	0.0631	0.1650	0.0000	0.0762
57	0.3000	100.00	0.0000	0.3520	0.2000	0.2000	0.0000	0.1934	0.0000	0.1085

B
SCENARIO II

58	0.3000	100.00	0.1520	0.6408	0.2500	0.2500	0.0000	0.1687	0.2428	0.1027
59	0.3000	100.00	0.3000	0.8936	0.2500	0.2500	0.0000	0.2193	0.6436	0.0719
60	0.3000	100.00	0.3000	1.0763	0.2000	0.2000	0.0000	0.2263	0.8763	0.1175
61	0.3000	100.00	0.3000	1.1691	0.2000	0.2000	0.0000	0.1655	0.9691	0.0744
62	0.3000	100.00	0.3000	1.1820	0.2000	0.2000	0.0000	0.1889	0.9820	0.0805
63	0.3000	100.00	0.3000	1.1008	0.2000	0.2000	0.0000	0.2195	0.9008	0.1015
64	0.3000	100.00	0.3000	0.9302	0.2000	0.2000	0.0000	0.2346	0.7302	0.1150
65	0.3000	100.00	0.3000	0.6728	0.2000	0.2000	0.0000	0.2113	0.4728	0.0807
66	0.3000	100.00	0.3000	0.3780	0.2000	0.2000	0.0000	0.2476	0.1780	0.0720
67	0.3000	100.00	0.3000	0.1118	0.1118	0.2650	0.1532	0.1527	0.0000	0.1051
68	0.3000	100.00	0.3000	0.0522	0.0638	0.2650	0.2012	0.1687	0.0000	0.1073
69	0.3000	100.00	0.2884	0.0116	0.0000	0.2150	0.2150	0.1587	0.0000	0.0934
70	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.2040	0.0000	0.0915
71	0.3000	100.00	0.3000	0.0000	0.0000	0.2150	0.2150	0.1627	0.0000	0.0846
72	0.3000	100.00	0.3000	0.0000	0.1000	0.2000	0.1000	0.2234	0.0000	0.0848
73	0.3000	100.00	0.2000	0.0000	0.0000	0.2000	0.2000	0.1613	0.0000	0.0778
74	0.3000	100.00	0.2000	0.0000	0.0000	0.2000	0.2000	0.1988	0.0000	0.1260
75	0.3000	100.00	0.2000	0.0000	0.2000	0.2000	0.0000	0.2296	0.0000	0.0928
76	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.1992	0.0000	0.1170
77	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.2000	0.2034	0.0000	0.0880
78	0.3000	100.00	0.0000	0.0140	0.0000	0.2000	0.2000	0.1511	0.0000	0.0775
79	0.3000	100.00	0.0140	0.0257	0.0396	0.2000	0.1604	0.2044	0.0000	0.1149
80	0.3000	100.00	0.0000	0.1120	0.1120	0.2000	0.0880	0.1951	0.0000	0.0742
81	0.3000	100.00	0.0000	0.3368	0.2500	0.2500	0.0000	0.2475	0.0000	0.0821
82	0.3000	100.00	0.0868	0.5956	0.2500	0.2500	0.0000	0.1684	0.1324	0.0703
83	0.3000	100.00	0.3000	0.8002	0.2000	0.2000	0.0000	0.1664	0.6002	0.0862
84	0.3000	100.00	0.3000	0.9271	0.2000	0.2000	0.0000	0.1525	0.7271	0.1000
85	0.3000	100.00	0.3000	0.9695	0.2000	0.2000	0.0000	0.1678	0.7695	0.0791
86	0.3000	100.00	0.3000	0.9710	0.2000	0.2000	0.0000	0.1561	0.7710	0.0805

B
SCENARIO II

87	0.3000	100.00	0.3000	0.8877	0.2000	0.2000	0.0000	0.1517	0.6877	0.0898
88	0.3000	100.00	0.3000	0.7545	0.2000	0.2000	0.0000	0.2336	0.5545	0.0890
89	0.3000	100.00	0.3000	0.5363	0.2000	0.2000	0.0000	0.2102	0.3363	0.0893
90	0.3000	100.00	0.3000	0.3226	0.2000	0.2000	0.0000	0.1527	0.1226	0.1278
91	0.3000	100.00	0.3000	0.1044	0.1044	0.3700	0.2656	0.1696	0.0000	0.1296
92	0.3000	100.00	0.3000	0.0457	0.3457	0.3700	0.0243	0.2451	0.0000	0.0922
93	0.3000	100.00	0.0000	0.0114	0.0000	0.3200	0.3200	0.1836	0.0000	0.0924
94	0.3000	100.00	0.0114	0.0000	0.0000	0.3200	0.3200	0.2094	0.0000	0.1163
95	0.3000	100.00	0.0114	0.0000	0.0000	0.2000	0.2000	0.1759	0.0000	0.0938
96	0.3000	100.00	0.0114	0.0000	0.0114	0.2000	0.1886	0.2141	0.0000	0.1248
97	0.3000	100.00	0.0000	0.0000	0.0000	0.2000	0.0000	0.1655	0.0000	0.0772

C Scenario III

C.1 Time-varying electricity tariffs

Table 7: Considering battery capacity before exporting electricity to grid

i	z	maxBAT	cinv	ba	histsol	k	demand	gridp	cb	gridm	cs	#solar
1	-690.27	0.300	400.00	0.300	0.000	0.119	0.200	0.081	0.224	0.000	0.080	9.0
2	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.156	0.000	0.121	9.0
3	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.208	0.000	0.103	9.0
4	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.155	0.000	0.088	9.0
5	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.151	0.000	0.088	9.0
6	-690.27	0.300	400.00	0.181	0.000	0.000	0.215	0.215	0.190	0.000	0.083	9.0
7	-690.27	0.300	400.00	0.181	0.000	0.000	2.215	2.215	0.202	0.000	0.091	9.0
8	-690.27	0.300	400.00	0.181	0.000	0.000	2.250	2.250	0.213	0.000	0.121	9.0
9	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.173	0.000	0.074	9.0
10	-690.27	0.300	400.00	0.181	0.000	0.000	0.200	0.200	0.190	0.000	0.100	9.0
11	-690.27	0.300	400.00	0.181	0.004	0.000	0.250	0.250	0.178	0.000	0.130	9.0
12	-690.27	0.300	400.00	0.185	0.007	0.000	0.250	0.250	0.165	0.000	0.105	9.0
13	-690.27	0.300	400.00	0.192	0.009	0.200	0.200	0.000	0.244	0.000	0.129	9.0
14	-690.27	0.300	400.00	0.000	0.011	0.011	0.200	0.189	0.192	0.000	0.116	9.0
15	-690.27	0.300	400.00	0.000	0.338	0.038	0.200	0.162	0.163	0.000	0.078	9.0
16	-690.27	0.300	400.00	0.300	0.200	0.200	0.200	0.000	0.189	0.000	0.108	9.0
17	-690.27	0.300	400.00	0.300	0.076	0.076	0.200	0.124	0.187	0.000	0.080	9.0
18	-690.27	0.300	400.00	0.300	0.000	0.000	0.200	0.200	0.177	0.000	0.085	9.0
19	-690.27	0.300	400.00	0.300	0.000	0.200	0.200	0.000	0.245	0.000	0.110	9.0
20	-690.27	0.300	400.00	0.100	0.000	0.000	0.265	0.265	0.169	0.000	0.096	9.0
21	-690.27	0.300	400.00	0.100	0.000	0.000	0.265	0.265	0.180	0.000	0.092	9.0
22	-690.27	0.300	400.00	0.100	0.000	0.000	0.215	0.215	0.157	0.000	0.091	9.0
23	-690.27	0.300	400.00	0.100	0.000	0.000	0.215	0.215	0.190	0.000	0.078	9.0
24	-690.27	0.300	400.00	0.100	0.000	0.000	0.215	0.215	0.160	0.000	0.079	9.0
25	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.188	0.000	0.105	9.0
26	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.182	0.000	0.120	9.0
27	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.169	0.000	0.084	9.0
28	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.161	0.000	0.110	9.0

C SCENARIO III

29	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.210	0.000	0.117	9.0
30	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.201	0.000	0.088	9.0
31	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.155	0.000	0.077	9.0
32	-690.27	0.300	400.00	0.100	0.000	0.000	0.200	0.200	0.228	0.000	0.100	9.0
33	-690.27	0.300	400.00	0.100	0.000	0.100	0.200	0.100	0.245	0.000	0.080	9.0
34	-690.27	0.300	400.00	0.000	0.001	0.001	0.250	0.249	0.210	0.000	0.122	9.0
35	-690.27	0.300	400.00	0.000	0.266	0.250	0.250	0.000	0.211	0.000	0.086	9.0
36	-690.27	0.300	400.00	0.016	0.229	0.000	0.200	0.200	0.186	0.000	0.087	9.0
37	-690.27	0.300	400.00	0.245	0.100	0.045	0.200	0.155	0.209	0.000	0.106	9.0
38	-690.27	0.300	400.00	0.300	0.024	0.150	0.200	0.050	0.218	0.000	0.113	9.0
39	-690.27	0.300	400.00	0.174	0.082	0.000	0.200	0.200	0.201	0.000	0.108	9.0
40	-690.27	0.300	400.00	0.256	0.041	0.000	0.200	0.200	0.166	0.000	0.098	9.0
41	-690.27	0.300	400.00	0.297	0.003	0.000	0.200	0.200	0.216	0.000	0.095	9.0
42	-690.27	0.300	400.00	0.300	0.000	0.000	0.200	0.200	0.202	0.000	0.077	9.0
43	-690.27	0.300	400.00	0.300	0.000	0.000	0.200	0.200	0.162	0.000	0.089	9.0
44	-690.27	0.300	400.00	0.300	0.000	0.300	0.370	0.070	0.249	0.000	0.073	9.0
45	-690.27	0.300	400.00	0.000	0.000	0.000	0.370	0.370	0.173	0.000	0.090	9.0
46	-690.27	0.300	400.00	0.000	0.000	0.000	0.320	0.320	0.218	0.000	0.081	9.0
47	-690.27	0.300	400.00	0.000	0.000	0.000	0.320	0.320	0.228	0.000	0.109	9.0
48	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.243	0.000	0.104	9.0
49	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.170	0.000	0.116	9.0
50	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.180	0.000	0.088	9.0
51	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.170	0.000	0.110	9.0
52	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.175	0.000	0.115	9.0
53	-690.27	0.300	400.00	0.000	0.000	0.000	0.215	0.215	0.215	0.000	0.108	9.0
54	-690.27	0.300	400.00	0.000	0.014	0.014	2.215	2.201	0.223	0.000	0.087	9.0
55	-690.27	0.300	400.00	0.000	0.022	0.000	2.250	2.250	0.159	0.000	0.075	9.0
56	-690.27	0.300	400.00	0.022	0.115	0.137	0.200	0.063	0.165	0.000	0.076	9.0
57	-690.27	0.300	400.00	0.000	0.352	0.200	0.200	0.000	0.193	0.000	0.108	9.0

C SCENARIO III

58	-690.27	0.300	400.00	0.152	0.641	0.250	0.250	0.000	0.169	0.243	0.103	9.0
59	-690.27	0.300	400.00	0.300	0.894	0.250	0.250	0.000	0.219	0.644	0.072	9.0
60	-690.27	0.300	400.00	0.300	1.076	0.200	0.200	0.000	0.226	0.876	0.118	9.0
61	-690.27	0.300	400.00	0.300	1.169	0.200	0.200	0.000	0.165	0.969	0.074	9.0
62	-690.27	0.300	400.00	0.300	1.182	0.200	0.200	0.000	0.189	0.982	0.081	9.0
63	-690.27	0.300	400.00	0.300	1.101	0.200	0.200	0.000	0.220	0.901	0.102	9.0
64	-690.27	0.300	400.00	0.300	0.930	0.200	0.200	0.000	0.235	0.730	0.115	9.0
65	-690.27	0.300	400.00	0.300	0.673	0.200	0.200	0.000	0.211	0.473	0.081	9.0
66	-690.27	0.300	400.00	0.300	0.378	0.200	0.200	0.000	0.248	0.178	0.072	9.0
67	-690.27	0.300	400.00	0.300	0.112	0.112	0.265	0.153	0.153	0.000	0.105	9.0
68	-690.27	0.300	400.00	0.300	0.052	0.064	0.265	0.201	0.169	0.000	0.107	9.0
69	-690.27	0.300	400.00	0.288	0.012	0.000	0.215	0.215	0.159	0.000	0.093	9.0
70	-690.27	0.300	400.00	0.300	0.000	0.000	0.215	0.215	0.204	0.000	0.092	9.0
71	-690.27	0.300	400.00	0.300	0.000	0.000	0.215	0.215	0.163	0.000	0.085	9.0
72	-690.27	0.300	400.00	0.300	0.000	0.100	0.200	0.100	0.223	0.000	0.085	9.0
73	-690.27	0.300	400.00	0.200	0.000	0.000	0.200	0.200	0.161	0.000	0.078	9.0
74	-690.27	0.300	400.00	0.200	0.000	0.000	0.200	0.200	0.199	0.000	0.126	9.0
75	-690.27	0.300	400.00	0.200	0.000	0.200	0.200	0.000	0.230	0.000	0.093	9.0
76	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.199	0.000	0.117	9.0
77	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.200	0.203	0.000	0.088	9.0
78	-690.27	0.300	400.00	0.000	0.014	0.000	0.200	0.200	0.151	0.000	0.078	9.0
79	-690.27	0.300	400.00	0.014	0.026	0.040	0.200	0.160	0.204	0.000	0.115	9.0
80	-690.27	0.300	400.00	0.000	0.112	0.112	0.200	0.088	0.195	0.000	0.074	9.0
81	-690.27	0.300	400.00	0.000	0.337	0.250	0.250	0.000	0.248	0.000	0.082	9.0
82	-690.27	0.300	400.00	0.087	0.596	0.250	0.250	0.000	0.168	0.132	0.070	9.0
83	-690.27	0.300	400.00	0.300	0.800	0.200	0.200	0.000	0.166	0.600	0.086	9.0
84	-690.27	0.300	400.00	0.300	0.927	0.200	0.200	0.000	0.152	0.727	0.100	9.0
85	-690.27	0.300	400.00	0.300	0.969	0.200	0.200	0.000	0.168	0.769	0.079	9.0
86	-690.27	0.300	400.00	0.300	0.971	0.200	0.200	0.000	0.156	0.771	0.080	9.0

87	-690.27	0.300	400.00	0.300	0.888	0.200	0.200	0.000	0.152	0.688	0.090	9.0
88	-690.27	0.300	400.00	0.300	0.754	0.200	0.200	0.000	0.234	0.554	0.089	9.0
89	-690.27	0.300	400.00	0.300	0.536	0.200	0.200	0.000	0.210	0.336	0.089	9.0
90	-690.27	0.300	400.00	0.300	0.323	0.200	0.200	0.000	0.153	0.123	0.128	9.0
91	-690.27	0.300	400.00	0.300	0.104	0.104	0.370	0.266	0.170	0.000	0.130	9.0
92	-690.27	0.300	400.00	0.300	0.046	0.346	0.370	0.024	0.245	0.000	0.092	9.0
93	-690.27	0.300	400.00	0.000	0.011	0.000	0.320	0.320	0.184	0.000	0.092	9.0
94	-690.27	0.300	400.00	0.011	0.000	0.000	0.320	0.320	0.209	0.000	0.116	9.0
95	-690.27	0.300	400.00	0.011	0.000	0.000	0.200	0.200	0.176	0.000	0.094	9.0
96	-690.27	0.300	400.00	0.011	0.000	0.011	0.200	0.189	0.214	0.000	0.125	9.0
97	-690.27	0.300	400.00	0.000	0.000	0.000	0.200	0.000	0.166	0.000	0.077	9.0

D SCENARIO I GAMS CODE

D.1 CASE STUDY

```
variable maxBAT; positive variable k_dis(i), ba(i),grid(i);
equations demandconstr(i1), timeconstr(i), maxBATconstr(i),
storageConstr(i);
demandconstr(i1).. demand(i1) =E= k_dis(i1) + grid(i1);
timeconstr(i)$(ORD(i) LT CARD(i))..
ba(i+1) =E= ba(i)+k_ch(i)-k_dis(i);
storageConstr(i)..ba(i+1)*k_dis(i)=E=0;
maxBATconstr(i).. maxBAT =G= ba(i);
model battery / all /; ba.LO("1")=0.3;ba.UP("1")=0.3;
grid.L(i)=0;k.L(i)=0;
solve battery minimizing maxBAT using LP;
display i, , ba.L, k_dis.L, grid.L,maxBAT.L;
histsolar, demand
file out / "output.txt" /; put out;
put " i  ", " maxBAT ", "   charging "," solar", "   Discharging ",
" demand ", " grid "/;
loop(i, put i.TL:6, maxBAT.L:15:4, ba.L(i):15:4, histsolar(i):15:4,
k_dis.L(i):15:4, demand(i):15:4, grid.L(i):17:4 /;);
```