POLITECNICO DI TORINO

Corso di Laurea Magistrale in Ingegneria Elettrica

Tesi di Laurea Magistrale

Impact of decentral photovoltaic power generation and DSM on the local distribution grid stability

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Luglio 2018

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ABSTRACT

The thesis is a model simulation of a microgrid. This model has been created for six dwellings using the software Simulink. These houses have photovoltaic generators, a storage system and a heat pump. Data for consumption and generation in one week from each of the four seasons has been used in the model simulation. Using this simulation, the operation of the batteries of these houses was examined and the power flow in the microgrid analysed. Using this model further simulations have been made with different configurations in order to analyse the different power flow performance and the different power losses in the cables. Using the data from these simulations an economic comparison to determine the best configurations was made. The model and the economic comparisons were carried out using German and Italian standards and regulations.

1 INTRODUCTION

Energy is an important element in the life of the people. Until recent decades it was thought that the primary resource (e.g fossil fuel) was almost “endless”. Now it is seen that this is not the case.

The continued increase of the demand for energy has highlighted the temporal limit of combustible fossil fuels and has led to the need for new ideas for energy saving. Combined with energy saving, new concepts relating to efficiency and environmental pollution have become prominent. Green energy sources are a very important solution compared to fossil fuels, but they must have a greater global diffusion and an important optimization.

An absolute priority is to change the type of production and the traditional management of electric energy with new technologies such that it can resolve the problems of efficient rationalization of resources.

The scope of this thesis is that of analysing an important aspect of the possible and partial solution of these problems using an innovative small scale power distribution method: The Microgrid. This innovative method can be used for a new demand side management (DSM). The analysed area is a small rural area in Germany.

The characteristics of this new technology, the functioning strategies and a comparison with others configuration will be examined. Microgrids are a potentially important technique for optimization of grid efficiency, reduction of energy losses and minimization of environmental impact.

The ability of microgrids to reduce the conflicts of interest of different stakeholders and to optimize energy distribution is highlighted in a global socioeconomic context. The microgrid is not only a different option for increasing the use of green energy and the reliability of supply but it also has economic and environmental advantages.

2 DISTRIBUTED GENERATION

Before moving to a discussion of the microgrid, the current situation and distributed generation will be considered.

The International Energy Agency has said that the world demand of primary energy will increase by 20% by 2020 and 50% in 2035. With this increase of the world demand for primary materials and energy, it is inevitable that a better exploitation of resources and green energy will become important themes in the future.

A large part of the world does not have energy, because not all parts of the world have transmission grids. According to the IEA world energy Outlook (2012) currently there are 1.3 billion people who do not have access to electric energy. This number should decrease to 1 billion people by 2030. Using this data it is necessary to consider new energy policies for the future.

The problems are wide ranging, but we should consider the actual electric system of those parts of the world, where the electric systems are not developed, or for example on a small island where it is hard to build an electric grid to provide energy.

An absolute priority is the change of production methods and the traditional management of the electric energy using new technologies to resolve these problems (also the problems of efficiency and primary resources). This leads to a policy of more installations of small size energy production distributed across the territory. This phenomenon is known as distributed generation DG.

The electric system in recent years has undergone important modifications at structural and management levels.

Distributed generation takes this name in comparison to the classic systems of productions of electric energy, which are based on a few big central plants and a widespread transmission grid. The decentralization across the territory of more small power generation facilities allows the generation of electric energy, and the utilization of storage near the place where it is consumed, so the transmission power losses decrease. These systems can work alone or with an electric grid, depends to the national standards. These installations, of a few kW to a few MW, are changing the classic structure of the electric grid that has large central generation and with unidirectional flow of electric energy, from high level voltage to low level.

The Figure 2-1 Figure 2-2 Figure 2-3 show the distribution of types of generation for Italy, Germany and Europe. It is significant as the thermoelectric and hydro are very high in Italy.

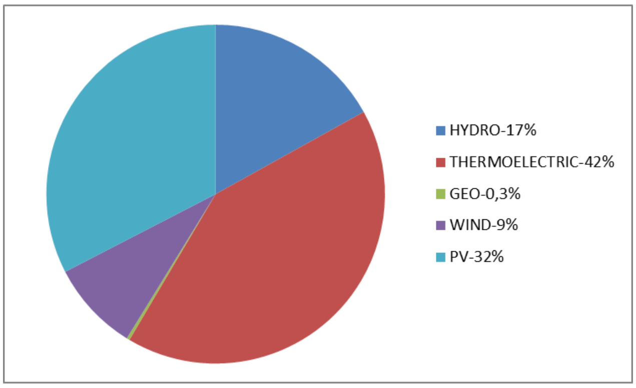

Figure 2-1: Distribution of types of generation for Italy in 2016 (Delibera 222/2018/I/eel ARERA).

The wind production, offshore and onshore, it is dominant in Germany.

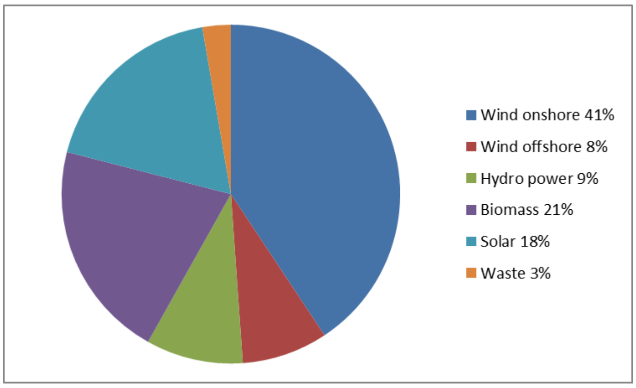

Figure 2-2: Share of energy sources in gross German power production in 2017 (Data:AG Enerziebilanzen)

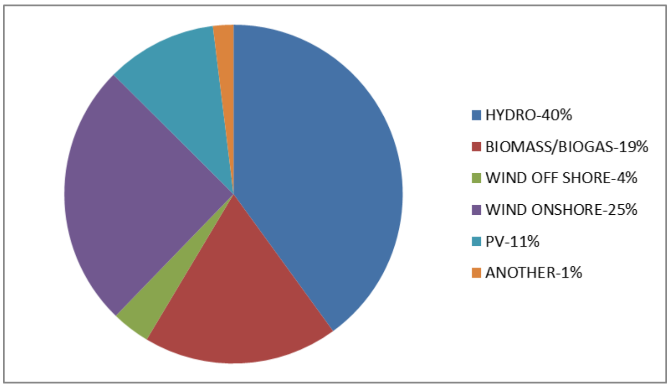

Figure 2-3: Distribution of types of generation for Europe in 2014. (Data: EEA;Eurostat; NREAP reports).

The management of the grid can also be carried out through the coordination of the distributed generation with the objective of a transformation of the grid to the concept of the smart grid.

The diffusion on a large scale of distributed generation has the potential to the lighten up the system of transmission and to partly resolve the growing problems that are experienced by the commercial operators of electric systems, due to increasing loads, new political environments and economic market pressures.

These types of installations give rise to different problems. Under normal operation in the presence of failure they do not have the back-up facilities of a large grid. The units of distributed generation are often connected to the electric grid through an inverter.

The road being taken by countries is to introduce new standards to allow progressive transformation, also at the unit of distributed generation, regulation of the feed-in power, amelioration of drops in voltage and service provision in general.

In particular, regarding the connection of a unit to the distribution grid, the approach used in the past was of the fit and forget type, that is, using criteria which were not constrained in terms of time of power initiation on the grid or obligation in the supply of service to the grid.

Currently, instead, the unit of distributed generation connected to the grid must supply service to the grid conforming to the Italian standards CEI 0-16 ad CEI 0-20 for MV and LV and German standards VDE. If the quality of service for the distributed energy is good the energy agency pays for the service. A unit of distributed production can operate directly in parallel with the grid of principal distribution or inside a microgrid.

3 MICROGRID

A Microgrid is a set of loads and energy sources that work as a single system with the aim of providing electric energy. The microgrids are highly efficient when they are used for energy distribution where an increase of efficiency is a priority, this characteristic is also augmented by the microgrid forming part of an intelligent grid. An increase of economic efficiency and the optimization of the use of the resources are the basic advantages of the use of Microgrids. Indeed, there is a reduction of the transmission cost of energy. The energy is produced and consumed in the same place. The microgrid has advantages for the economy and for the environment. It is often utilized in rural zones, where it is hard to supply energy or in developing countries, where there is a high concentration of renewable sources.

The utilization of Microgrid is usually done in small rural zones or in small industrial areas. The advantages are: improvement of power quality, more reliability, small environmental impact, and economic savings.

3.1 What is a Microgrid

A microgrid is defined as an innovative grid architecture for power distribution. It normally consists of a system of distribution composing units of distributed generation with or without control. The distributed storage and the loads reunite in a point of common coupling along with the electric distribution grid, and the different units of production and consumption. There is also a system of communication operating the microgrid energy manager or power management system. The Figure 3-1 shows as the microgrid is distributed in the world, it is significant the results of Asia and North America.

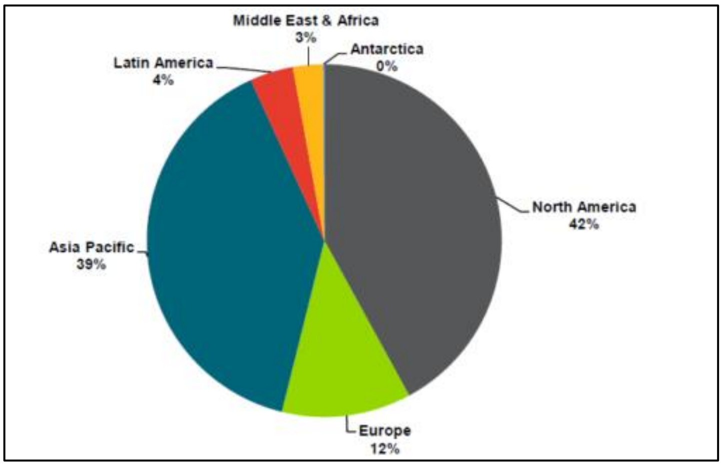

Figure 3-1: Total Microgrid Power Capacity MArket Share by Region (Navigant Reasearch)

Subdivided of total Microgrid power capacity in the world in 2016, where there is installed 4393 MW of microgrid. It is a very important quantity of power. The significant increase in recent years, suggests a continued future increase. In the next Figure 3-2 there is the annual total microgrid market capacity and implementation revenue, world Market for 2015-2024 years.

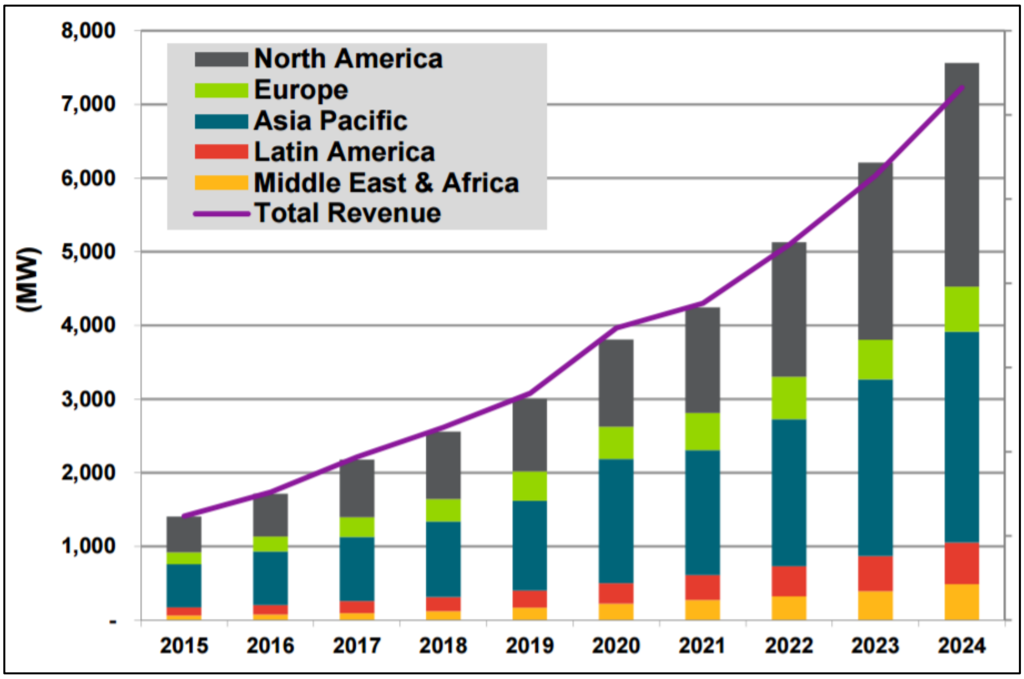

Figure 3-2: Annual Total Microgrid Market Capacity and Implementation Reveneu by Region (Navigant Research)

It is likely that in the future microgrids will increasingly evolve as primary schemes adopted for energy distribution. The installation of different units of distributed generation and of systems of accumulation inside these schemes will render them active. Private users, of residential type and the small, medium and the big firms will be able to produce local green energy, with photovoltaic, wind, and micro hydro and use this energy themselves.

Outside, from the principal electric grid, the microgrid is seen as a controlled entity, with the potential to feed a group of users. It is important to maintain the service quality and to reduce the relative cost.

A microgrid is a system of local distribution on a small scale with generators and loads, that can have two type of operation: autonomous (isolated) or non-autonomous (if it is connected to the principal grid). The concept of microgrid is based on the integration of more than one energy source. A microgrid managed from a central control monitors the demands/offers of energy and it optimizes the utilization of more type of generators and loads.

The fundamental components of a microgrid are:

- The local distributed generation
- The control of the power loads
- The connection to the principal grid
- The system of management of the microgrid
- The system of distributed storage

Microgrids tend to favor local production, when a system of micro generation is not able to fill energy requirements the microgrid can ask for energy from the principal grid.

In reality a single definition does not exist for all types of microgrid. However a microgrid definition according to the US Department of Energy is:

"A group of interconnected loads and distributed energy resources with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or isolation mode"

The important point for a microgrid is its capacity for management of the operation in the two possible states (isolated and within a grid).

Most microgrids will work for more time connected to a grid, except for those built without the connection with the principal electric grid. Communication with the principal grid offers the possibility to maximize the advantages of the microgrid. Often the microgrid can work alone, it works in isolation, but to do this, the system must have distributed storage and a big microgeneration capacity.

The control of the system depends on the type of generation. A very important consideration is the quantity of green energy, because of the constraints imposed on the load or the power quality.

The control scheme for the inverter is an important part of the system, because it must give electric power to the grid but it must give energy for the management of the microgrid at the unit of generation, for example the maintenance of the power factor and the management of the frequency.

3.2 Fundamental Characteristics

A Microgrid is an integrated platform for the supply (micro-generation) and for the controlled utilization of resource (storage and control loads).

In the concept of microgrids there is a strong focus on the local supply of electric energy. The microgrid usually uses the local energy as opposed to the energy of the principal grid. When the systems of micro generation are not able to fill the energy demand, the microgrid demands energy from the principal grid. So the Microgrid must be able to work in isolation or with the principal grid.

In the future the microgrid will work longer connected to grid, if it is not isolated. It is a big advantage to have a direct connection with the grid.

A microgrid can work as an aggregator of small generators, a service supply, and a controller of loads with different interests.

The principal advantage in the concept of microgrids compared to other intelligent solutions is in the capacity to manage different interests, and thus arriving at a decision at a global level and an optimal solution.

The Figure 3-3 shows examples of possible configuration of microgrid. The case that is analyzed, it is similar at Building-Level Microgrid.

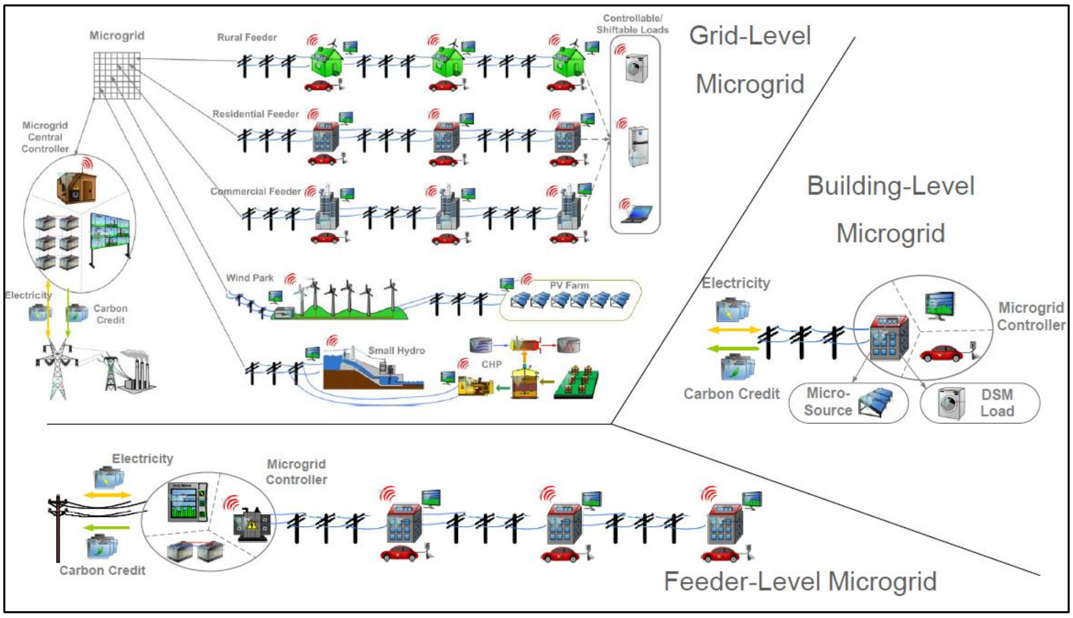

Figure 3-3Examples of a microgrid

The utilization of microgrids is becoming more relevant thanks to not only the control system and other technical aspects, but also thanks to the advantages that they bring in environmental and economic fields.

In addition to the economic benefits that they introduce with integration in medium and large infrastructures, they will have an important impact for the electrification of rural zones in developing countries, benefiting the greater utilization of green energy.

The utilization of microgrids usually occurs in small urban areas and small industrial zones. The advantages are more:

- More reliability, lower environmental impact;
- Economic saving (through the opportunity to reorganize the electric market)
- Improvement of the power quality;
- Availability of a reserve of energy thanks to the system of storage;
- The reduction in the number power failures thanks to the possibility of working in isolation.

This last aspect and the general increase of the quality of the supply can be of benefit in situations where the consumer wants a constant supply, e.g. a data center, infrastructure for security or hospitals.

There are also problematic aspects with this type of grid:

- Low capacity of autoregulation of the system due to the limited extension on the grids and to the low electric inertia
- Difficulties with management of the connection to the electric grid (the functioning in isolation is not desired)
- A continual changing of the demand on the generator and of the system of storage to guarantee the equilibrium of the grid.

The supply grid sees the microgrid as a perfectly controllable single unit, inside however, it consists of a quantity of different sources of energy and users of that energy that are connected to the microgrid through system of inverters (AC/DC and DC/AC).

The systems of generation of photovoltaic energy and wind-farms can be equipped with the possibility of communicating with the microgrid as active generators; they will then be able to carry out the functions of allocation of the load and of giving reactive energy to the grid, depending on the needs through a control protocol. These problems have made essential the utilization of a system of sensors for the measurement of the electrical quantities in all parts of a microgrid.

3.3 Control of Microgrid

A microgrid can be designed for a specific economic, technical target or environment through the real-time control of micro-generation. A microgrid could be considered as an object controlled from the grid, as a unique generator used to complement the load, and supporting the grid. From the point of view of the client, a microgrid gives thermal and electrical energy, but it also increases the local reliability, quality of the energy supply and reduces the cost of energy. For this, there must be an adequate control between the demand and the offer of energy.

3.4 Motivations for use of a Microgrid

A microgrid could be installed for several reasons, for example for local reliability, for the decrease of greenhouses gases, for direct economic gain from a generator or for the supply of unused surplus power. Microgrids are not all the same, depending on the country or the situation the differences could be marked. It is necessary to analyze the different constraints to respond to the different problems. Specifically, the units distributed energy resource from a microgrid can belong to different suppliers that have different priorities. For example, the system/network of a company would require the optimization the performance of the grid, reducing the power losses, the voltage variation and other things. But in the case of domestic micro generation, they will wish to obtain the maximum financial gain from the energy supply, and maybe this is in conflict with the electrical distribution company's goals. Other control strategies are necessary for example to decrease environmental problems.This Figure 3-4 summarizes the advantages of microgrids.

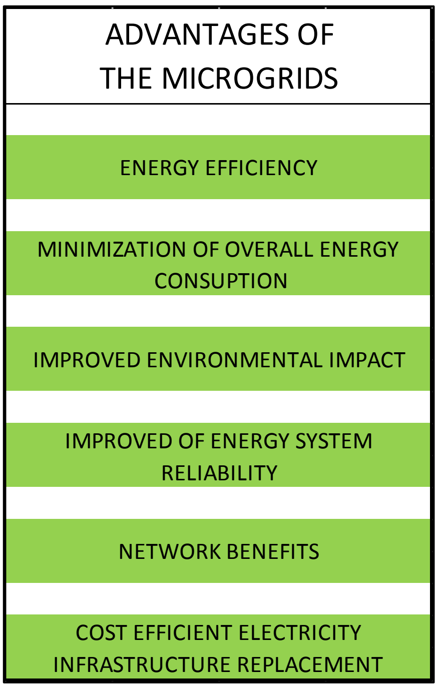

Figure 3-4: The advantages of microgrids

According to the Department of Energy of the USA, 40% of the total energy produced is consumed by buildings in rich countries, of this 40%, 60% is electric energy. Recent studies have shown that 20% to 30% of this energy could be saved, by optimizing the operation and the management of the building without touching the structure. There is a big potential for energy savings through efficient management. The technology of microgrids allows the efficient operation of the different energy sources, optimising the power losses. In the future, the cost of installing this type of micro generation will be decreasing, so microgrids will have the potential to increase, thanks for example to the cost reduction for photovoltaics and storage.

3.5 Benefits of Microgrid

Microgrids brings more benefits to the electric grid: the microgrids can supply power to a set of users improving the quality and the type of supply, so decreasing the cost of energy and the drawing of energy over the cables (power losses). The purchase of energy happens only when the domestic distributed generation or the micro-generation do not supply sufficient energy. Microgrids have an impact on efficiency in the zones where the national distribution grid is limited. The national grids consisting of a set of microgrids allow a real autonomy from the principal grid, giving a very high level of reliability. Another very important advantage is that when an electric failure in the public grid occurs, a microgrid is able to guarantee the power for the users during the period of power failure due to having a high storage capacity. Using a microgrid the continuity of the service increases.

- Also there are advantages for national distribution firms, through new markets for electrical design, development and management.
- The microgrids help to make the regulation of voltage more efficient
- The decentralization of energy production will open up new electric markets

In addition to the benefits of a more widespread use microgrids there is a reduction of losses in the cables, especially in the case of a good balance between production and load demand and attention is paid to the logistic optimization of the distributed sources. In the Figure 3-5, according to the study from Siemens "Technical, Economics and Environmental Benefits of Microgrids Operation", we can see the annual percentage reduction of losses for the low voltage grid at a European level. It is can be seen that with a good distribution of generation there is a reduction of losses in the cables. This is a very important benefit for the distribution system operator.

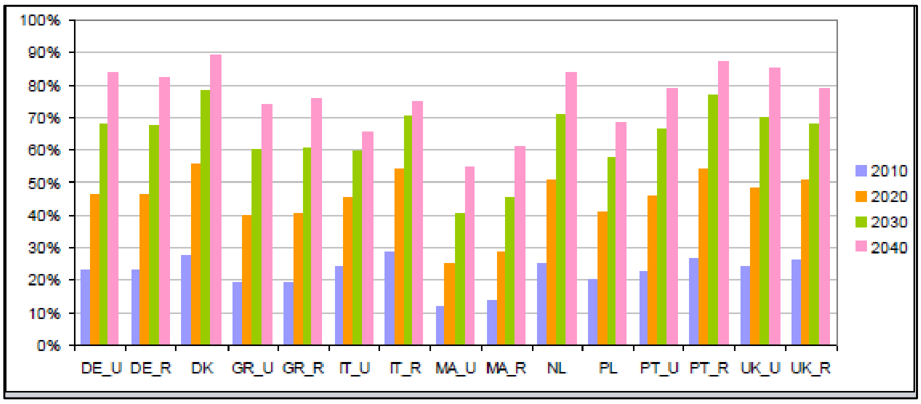

Figure 3-5Ideal Annual Energy Loss Reduction Level under STC

3.6 Connection problem

A microgrid can give electrical or thermal energy. In a grid-connected configuration, the system of public service distribution can provide or absorb every type of gap in generated power from the microgrid to maintain a balance of the power system.

The disconnection of the load or of the generation inside a microgrid can create difficulties where the import/export of power exceeds the severe limits (e.g. voltage, frequency, etc) based on the operative strategy or contractual obligations .

A microgrid can function to promote the different service needs of the clients, an increase in the quality of power and an increase in reliability for the specific loads (e.g. hospitals, datacenters, etc.).

The continual change from grid-connected to isolated functioning is an advantage, but there are problems, because when the microgrid is connected to the principal grid, it imposes a voltage level, when the microgrid works autonomously the microgrid must control the voltage and this is very hard for a small network.

The energy management inside of a microgrid must be effected considering the system of storage and the system of control of the energy flow in the two modes, with and without the connection to the public grid. Microgrid control must be capable of import/export energy from/for the principal grid for the control of active and reactive power flow and for control of the eventual accumulation of energy.

In the grid-connected mode the functioning is fixed from the principal grid, but when the system is disconnected from the principal grid the voltage and frequency must regulated from the generators in the microgrid. If there are only renewable sources and the battery capacity is small, it become hard to regulate the frequency and voltage, because for example in bad weather there is only a small energy production. The standards for operating in isolation are complex and strict, for the supply good power quality.

Microgrid control must continually supervise the state of the national distribution grid and the state of the microgrid (generators, storage system, loads). This information allows the adoption of the best technical solutions for voltage stability and nominal frequency, to avoid overloads and to guarantee the energy and service quality.

3.7 Connection to the public grid

Usually a microgrid connects to the principal grid with a static switch (it is a fast switch). It has the capacity to isolate the microgrid in the case of a fall in voltage, failure, events that decrease the power quality or events that are to listed in the IEEE1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems). The aim is to arrive at an adequate level of security and to provide the protection for the electric system, that prevents an unsolicited isolation for example.

It is possible to effectuate the parallel working with the grid if the parameters of voltage and frequency are:

- The voltage of grid must be between 90% and by 110% of the nominal voltage for at least 30 sec before the parallel working
- The grid frequency must between the 49.9 and 50.1 Hz for at least 30 sec before the parallel working

The energy production must continuously maintain constant power irrespective of the loads:

- The voltage is maintained between 90% and by 110% Un
- The frequency is maintained between 49.9 and 50.1 Hz

Furthermore, they must be able to remain connected to the grid, at the same time changing the power supplied in exceptional conditions of grid functioning.

- The frequency change between 47.5 and 51.5 Hz
- The voltage change between 85% and 110% Un

If the microgrid want participate in the control of the voltage the condition are:

- For values of voltage more than 120% Un for a time of more than 0.2 sec, the distributed generator must disconnect from the grid
- When the median value of the voltage measured over 10 minutes exceeds 110% Un, the distributed generator must disconnected from the grid within 3 sec

3.8 Reliability

One of the principal advantages that the microgrids offer, is the increase in reliability. A grid is more reliable when the service is continued and of good quality.

Sometimes, the national distribution companies, due to a cable failure or maintenance cannot supply energy. It is in this moment that a microgrid is very important, because there is the possibility to continue the supply of energy to the consumers, thanks to an autonomous system. It is known that the microgrids give benefits for the environment, for the electric market and for the grid management, but they also increase the service quality. The first advantages depend on the different functioning strategies of different operators in the energy market, the last advantage depends on the reliability. Underlining the effective impact of the active microgrids on a European scale a large data collection in the Europe project "More MicroGrids" has been carried out. In particular, these data come from the price energy level of the low voltage and medium voltage grids, the structure profiles of load, the losses of power and the structure of the price tariffs of the different European country.

In countries such as Italy and Portugal, where the level of reliability is a little low compared with other countries, they can obtain greater improvements in terms of reliability compared to countries such as Germany and Holland where the level is higher, as the Figure 3-6 shows.

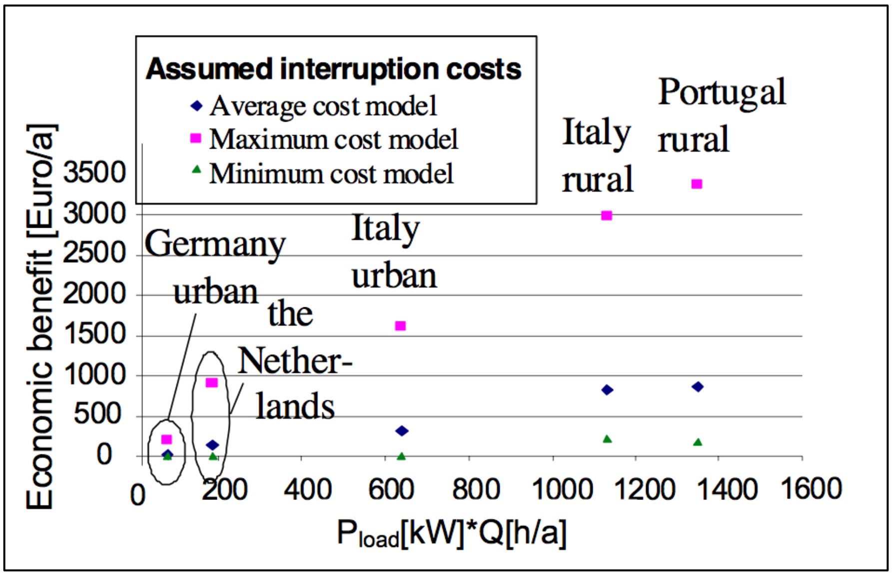

Figure 3-6: Economic Benefits

This Figure compares the maximum economic benefits that the countries can obtain with microgrids as a function of the lowering of the disconnection costs for different Europe countries. With higher disconnection costs, the system reliability could be a further improvement through microgrids. It is possible to say that the high cost of a disconnection justifies the high investment in a microgrid system, to always have a higher reliability . So that the use of microgrids is more advantageous in the countries with a low power quality or to clients with a higher level of interruptions. The voltage and frequency reliability of the microgrid system improves with the increasing level of diffusion of the micro generations, although this can increase the costs.

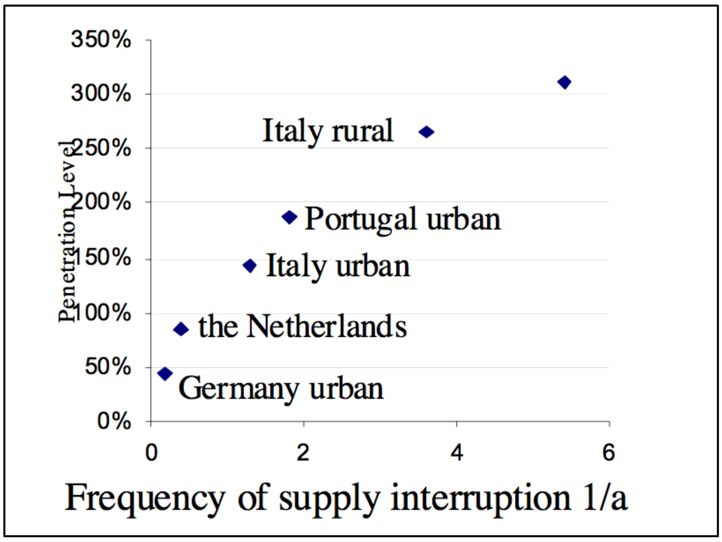

Figure 3-7: System unavalaible with the DG penetration

3.9 Internal configuration of the Microgrid

In a microgrid is possible to have two possible configurations:

- With a DC connection between the sources
- With an AC connection between the sources

In these configurations there are bidirectional inverters for connecting the battery to the AC system. This makes it possible to charge the battery, when there is there is a surplus of renewable energy or there is a surplus in the microgrid system (for example at times of low loads) or when energy is taken from the grid because it is cheap. The battery system is helpful for a function of “peak shaving”, reducing the grid load power peak by using the energy in the storage.

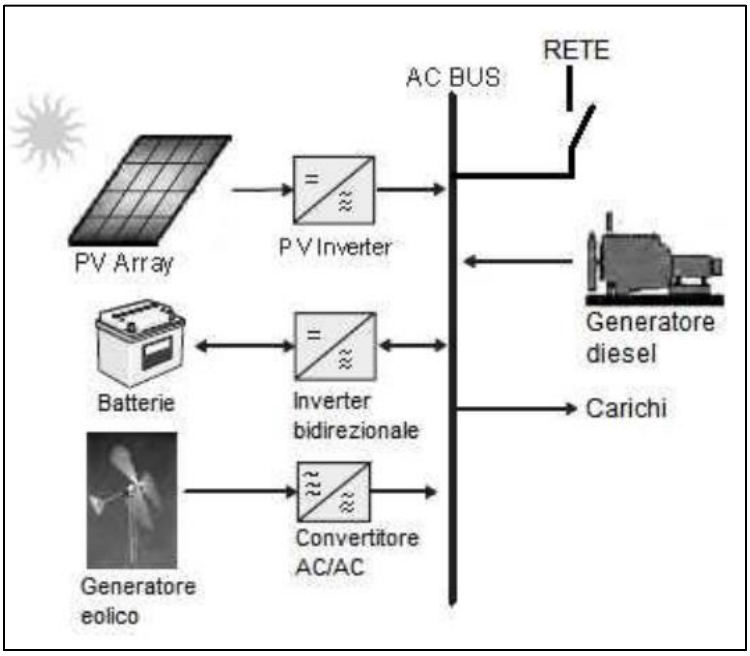

Figure 3-8: AC configuration

With the first (DC) configuration there is only one inverter, with a big power capacity. While in the second configuration there are more inverters, in this case the power capacity for the inverters is lower. An inverter is designed for peak power, but renewable energy sources (Photovoltaic or wind) are more unregulated, so the first solution gives a better exploitation of inverter, because it is often used thanks the continual energy exchanges.

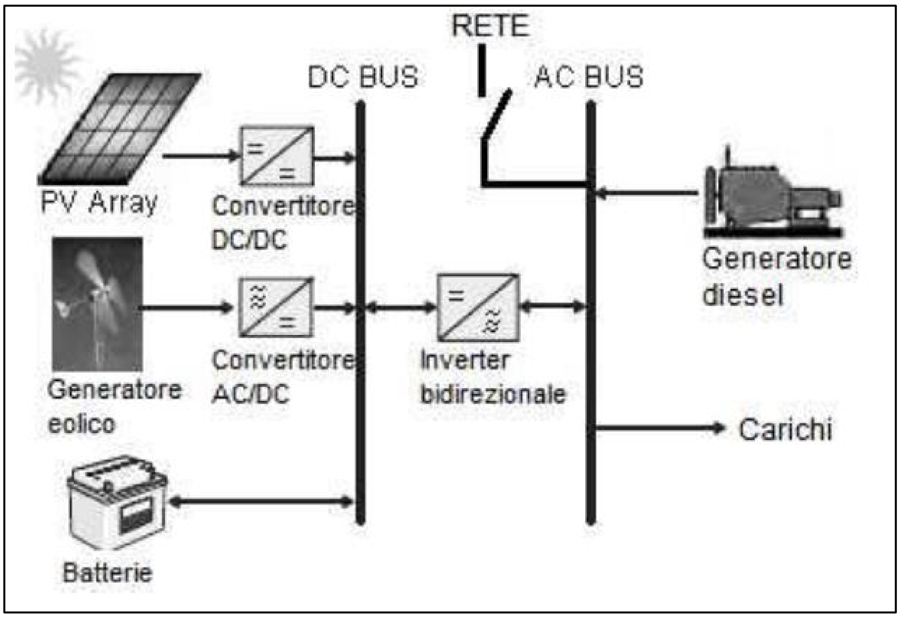

Figure 3-9: DC configuration

3.10 Evolution of the Microgrid

There are a number of complex issues that have determined the evolution of the microgrid. In particular the big advantages that they bring to the evolution of today's supply systems that do not currently allow the opposite energy flows from the generator to user.

The possible configurations of the microgrid with the supply system represented in Figure 3-10 and Figure 3-11.

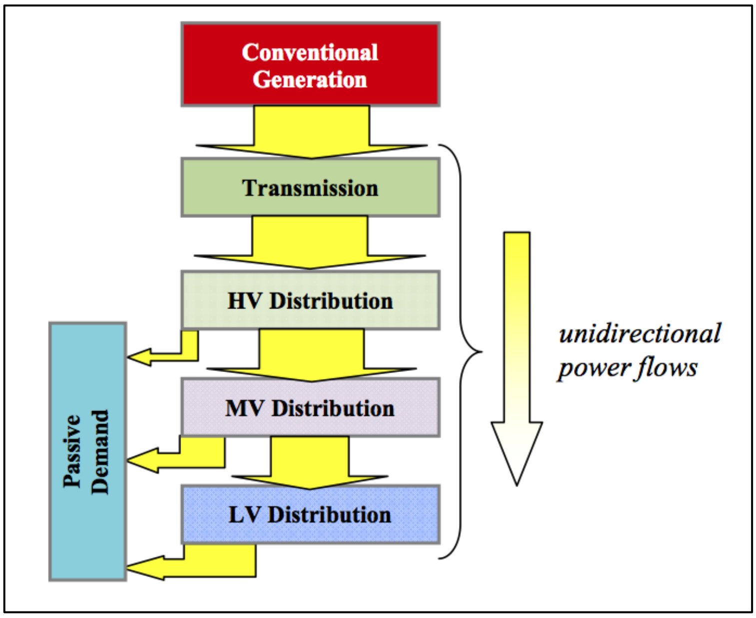

Figure 3-10: Traditional configuration

Comparison of the two figures, shows that the energy flow it is totally different. In particular the second figure highlights a large increase of the energy flow generated at low and medium voltage, using the microgrid integration, while a national distributed generation works at a high voltage transmission level. So it is possible to have energy continuously exchanging between the different transmission levels, but this solution presents some problems. Extensive work is necessary on the protection systems and big technological development is required for this new situation.

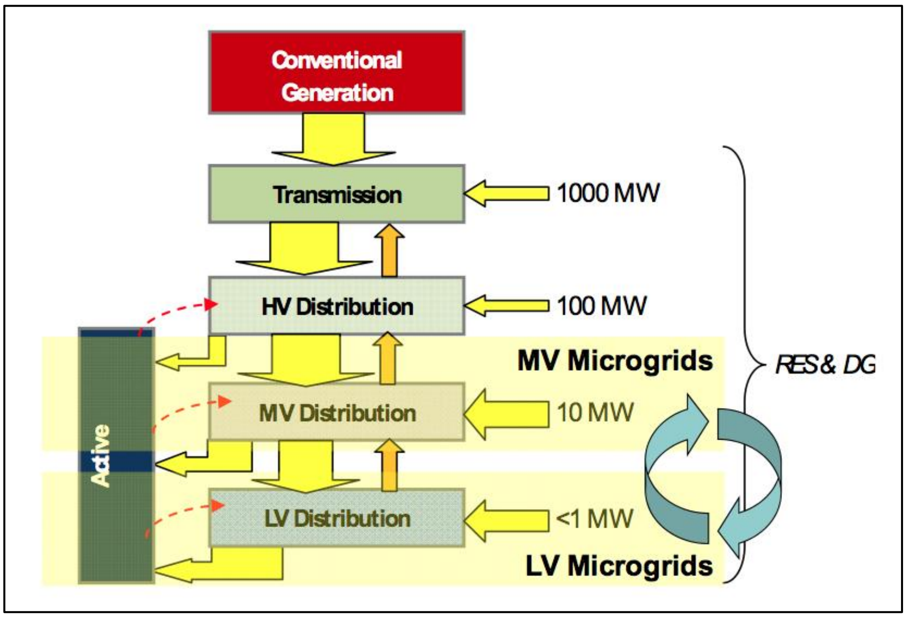

Figure 3-11: New configuration

The cost, the policies of management and the technology have greatly limited the appeal of microgirds. But these three barriers will in the future collapse, this signifies that in the future the micrograds will be an important instrument for the electric network and will be utilized in all parts of the world. The first factor that will in the future decrease will be the cost, this will be a very important goal, because includes reducing the microgeneration and the microgrid costs. Also important is the increased commercial economy, that in a period such as this, with the economic global crisis, is very important.

The decrease in cost will bring an important diffusion of the low voltage microgrids. The electric market will start to consider micro generation as a new producer in the market. The microgrid stakeholders will themselves generate a new characteristic within the collected units of microgeneration where they are potentially able to sell internally to the final users throughout the microgrid, opening a new scenario of market autonomy between the users.

To do this, there is the necessity to drastically change the conditions, the management policy and regulation , so as to allow the possibility of opening a local market in the microgrid.

4 MODELLING

The software used is Simulink developed by MathWorks. It is a graphical program for simulating, modelling and analysing multi domain dynamical systems. It has a primary interface and a set of block libraries and is used in many fields. Simulink is suitable for creating a microgrid model.

The microgrid in this model works in parallel with the public grid and the harmonic effects of the PWM inverters and the problems of switch commutation are not considered. The intention of this model is that of implementing a virtual model of a real situation in a rural zone in Germany and to understand the performance of the microgrid, in terms of the power flow in the lines, the working of the batteries and to understand if are better configurations using an economic comparison.

Considering first of all the scheme of the microgrid: The rural zone consists of about twenty houses six of which have:

- Heat pump
- Domestic load
- Photovoltaic
- Storage

So the devices for each house are considered in the domestic load (e.g the oven, the fridge, the washing machine, etc.).

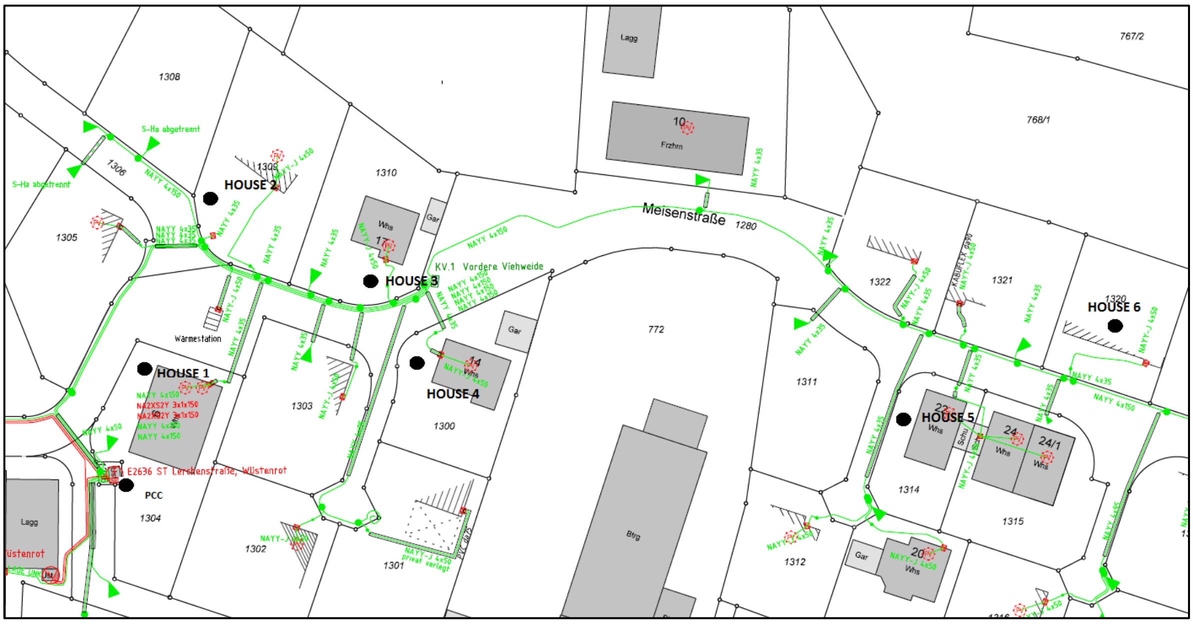

Figure 4-1: Scheme of the rural zone

The Figure 4-1 shows the scheme of the rural zone and as the houses are distributed in this area. PCC is the place where the gird supplies the microgrid.

So considering only these six houses it is possible to analyse them as working together with battery storage. Using this configuration it is possible to make a microgrid model.

The houses are called: HOUSE 1, 2, 3, 4, 5, and 6, in terms of the distance to the point of common coupling.

Table 4-1: Equipment Specifications for the Houses below, shows the specific information for each of the houses.

Table 4-1: Equipment Specifications for the Houses

	HOUSE 1
Heat pump	Alpha Innotec SWC140, 13.9 kW
Battery storage	Liacon 5 kWh
Installed PV power	28.8 kWp
PV manufacturer and model	IBC Polysol 250
Residential useable area	327.12 m²
	HOUSE 2
Heat pump	Viessman Vitocal 300-G BWC 301.B10 / 10,36 kW
Battery storage	Liacon 5 kWh
Installed PV power	5.4 kWp
PV manufacturer and model	SolarWorld Sunmodule Plus SW 270 Mono
Residential useable area	
	HOUSE 3
Heat pump	Viessman Vitocal 300-G BWC 301.B10 / 7,8 kW
Battery storage	Liacon 5 kWh
Installed PV power	7.85 kWp
PV manufacturer and model	48x TSMC CIGS 140 + 14x TSMC CIGS 150 Solarmodules
Residential useable area	193.4 m²
	HOUSE 4
Heat pump	Waterkotte DS 5008 Ai, 6kW
Battery storage	Liacon 5 kWh
Installed PV power	7.85 kWp
PV manufacturer	56x TSMC CIGS 140 Modul

and model	
Residential useable area	131.86 m²
	HOUSE 5
Heat pump	Tecalor TTf10, 9-12 kW
Battery storage	Liacon 5 kWh
Installed PV power	13.6 kWp
PV manufacturer and model	36x TSMC Solar Europe GmbH - TS-150C1; 60x TSMC Solar Europe GmbH - TS-120C1
Residential useable area	162 m²
	HOUSE 6
Heat pump	Waterkotte Modell DS 5023.5Ai, 22.2 kW
Battery storage	Liacon 5 kWh
Installed PV power	13,64 kWp
PV manufacturer and model	Solar Frontier Typ SF155-L
Residential useable area	285.13 m²

The production and consumption of the microgrid system over twelve months has been analysed, taking a random week for each of the seasons.

The model is designed to control the current and the overall voltage is considered to be constant, although the measured voltage is different for each house.

To have a European wide comparison, for the microgrid model, it is necessary to do the same simulation in another country, selecting a zone where the weather it is completely different. In Germany there is a “continental climate”, so Trapani in Sicily where there is a “Mediterranean climate" was chosen for a comparison with the German simulation. Changing the place and climate, also will change the production, consumption, standards, cost and energy price.

4.1 Data input produced by INSEL software

The data input for the photovoltaic production, the heat pump and domestic load consumption come from another software, INSEL. Using specific blocks in the libraries (PV array, battery and heat pump) for these parts of the microgrid, this software provides output data for use in the microgrd system model. The specific parameters considered for the input files for INSEL are:

For the Photovoltaics:

- System size
- Specific type of PV-module
- Tilt angle
- Orientation

For the heat pump load:

- Thermal demand according to building size (scaled up/down according to living area and calculated dynamic data from one building)
- Specific type of heat pump according to characteristic curves
- Buffer storage size
- Cold district heating grid inlet temperature to the heat pump

For the domestic load is not used Insel software but a tool that it supplied the web site loadprofilegenerator.de. Important is to specify:

- All the devices
- Inhabitant behaviur
- Residential useable area
- Location

With this software it is very easy to produce data specific to the location, thanks to this it is possible to rapidly create data for Germany and Italy, enabling a comparison.

INSEL gives the data for a complete year, the weeks considered for the four seasons were:

- Winter: 31 January to 6 February
- Spring: 1 May to 7 May
- Summer: 1 July to 7 July
- Autumn: 15 October to 21 October

4.1.1 Load profile

The selected periods in the seasons, have the following load profiles.

The Figures show the total photovoltaic production for both countries in the four seasons. It is significant to have the two production in the same graphic, so it is possible to have a comparison.

It is possible to see, in Figure 4-2, that the last two days of the week, there is no production in Italy, probably there is no son .

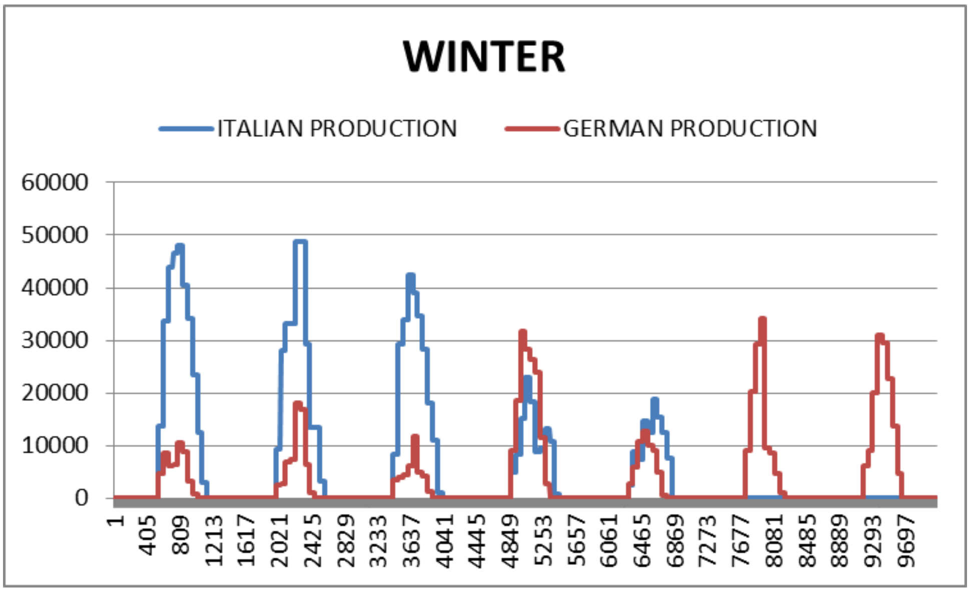

Figure 4-2: total PV production in winter for both countries

The Figure 4-3shows the big different between HOUSE 1 in comparison with the other houses. The winter production is few in comparison the installed kilowatt peak. There is much different between the peak of production in Italian in comparison with the German. Thanks this at a different climate in the two zones.

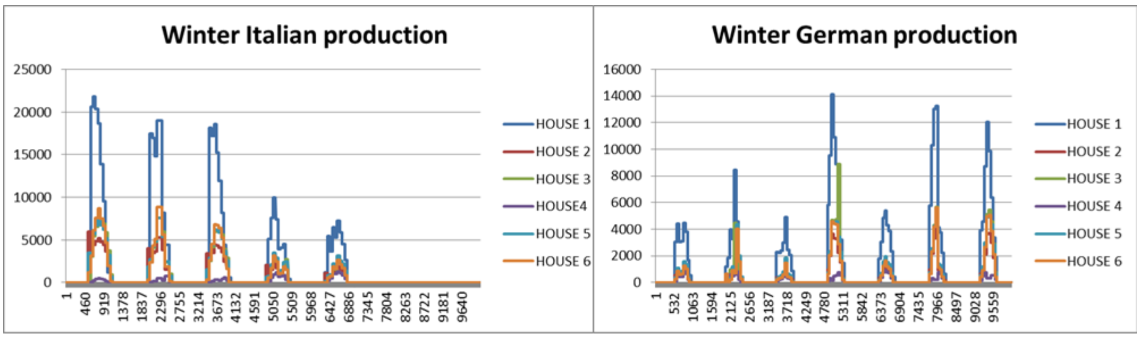

Figure 4-3: winter production for both countries

The Italian production is regular in each day. For the German there are two days with few production. The graphs are shown in the Figure 4-4and Figure 4-5.

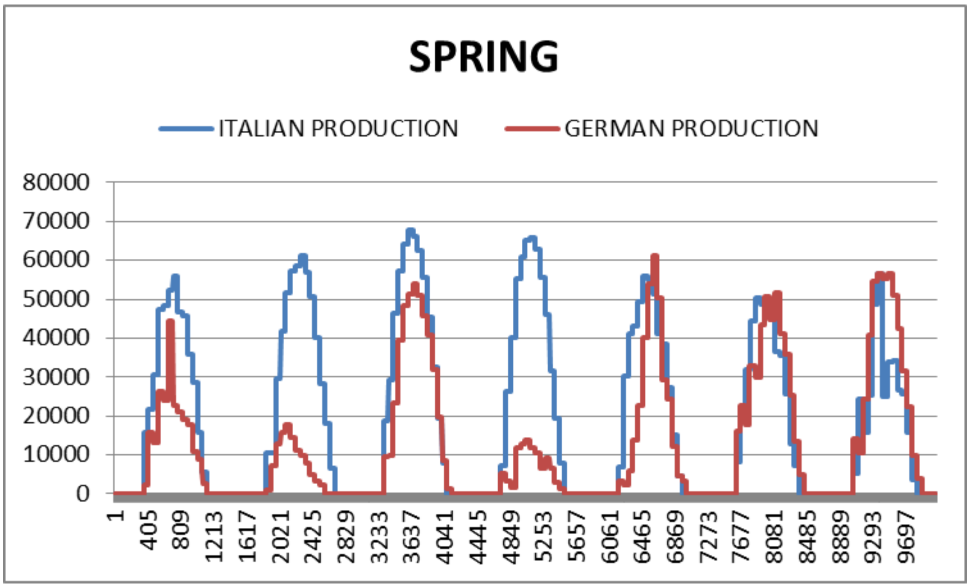

Figure 4-4:total PV production in spring for both countries

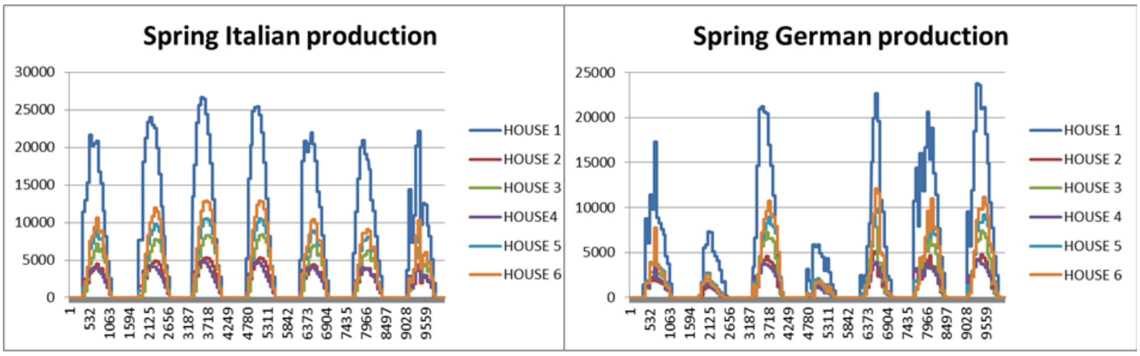

Figure 4-5: spring production for both countries

In Summer in both countries the production is high, and the two graphs are very similar, thanks this at the good weather for the seasons in the two places, even if in the Sicily there is more warm in Germany the hours of son is more. So there is a balance between the two photovoltaic productions. The Figure 4-6 and Figure 4-7 show the results that there are in input in the model.

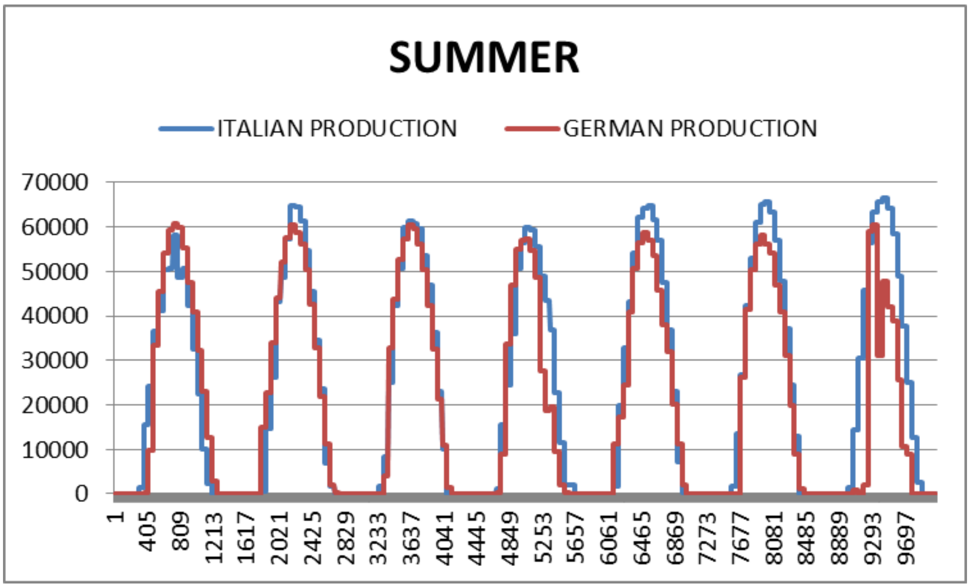

Figure 4-6: total PV production in summer for both countries

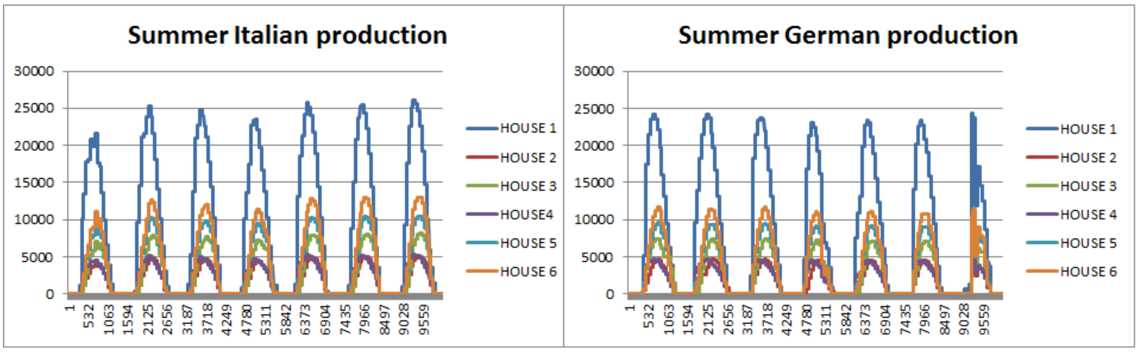

Figure 4-7: PV production for both countries

The results in Autumn are more different between the two countries. If it is taken the historical results for the last years it is possible to see that in autumn , in Germany rained often. So for this the German production is so few. The different climate and the weather favours the Italian production. The Figure 4-8 and Figure 4-9 show the results.

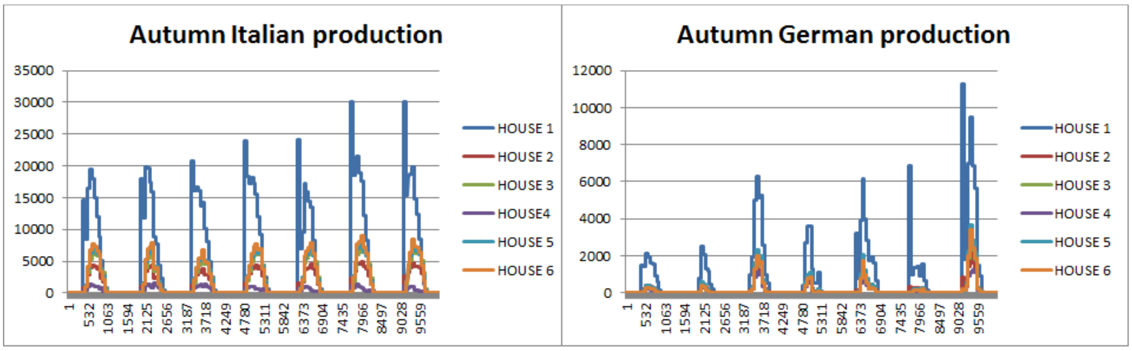

Figure 4-8: PV production for both countries

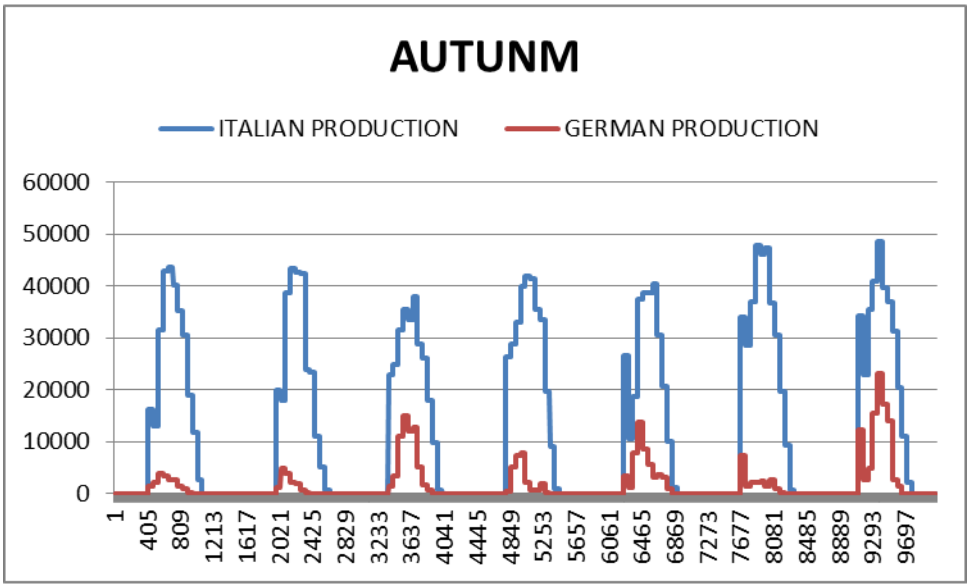

Figure 4-9: total PV production in summer for both countries

The graphs show the working of the different devices in the houses in different seasons. It is assumed that in both countries the heat pump works for 20 min and then pauses. The domestic load has two peaks, one in the morning and one in the evening. It is the classic domestic load profile. To compare the different load curve between the two countries, the graphs for HOUSE 1 for each seasons are shown in the Figure 4-10, Figure 4-11, Figure 4-12 and Figure 4-13.

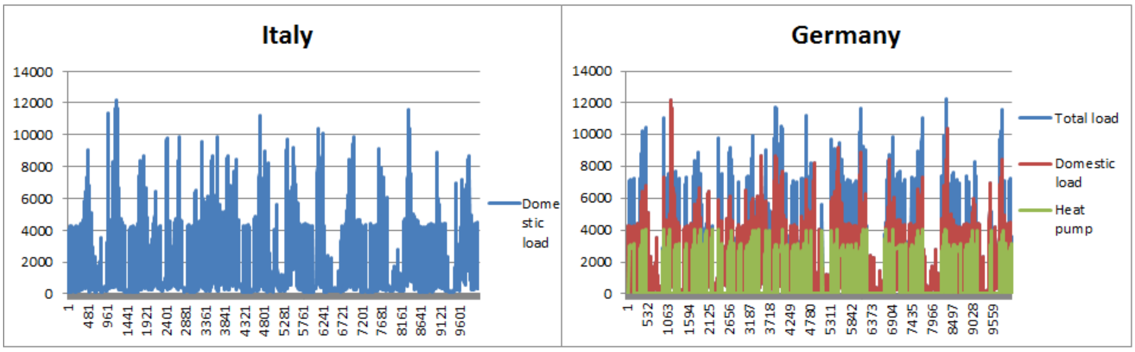

Figure 4-10: Winter home load for both countries

In Italy there is only one energy meter, so in input there is only one load, this is the summ between the domestic load and heat pump. For German it it neccesary to specificat the two loads.

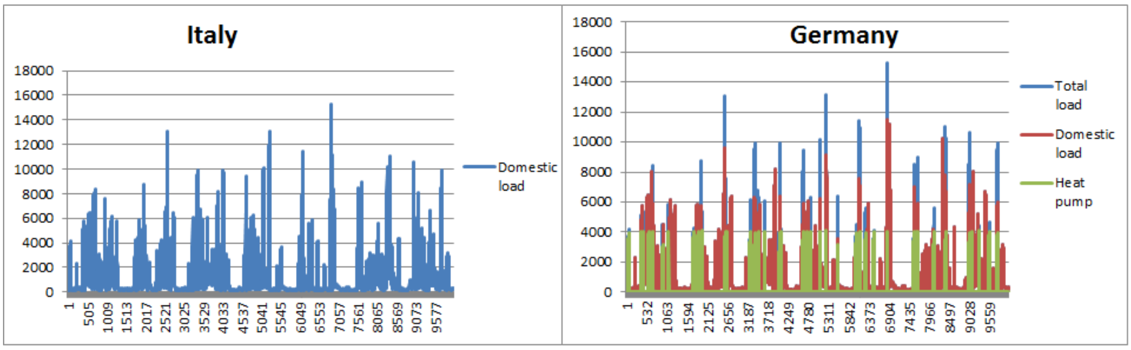

Figure 4-11: Spring home load for both countries

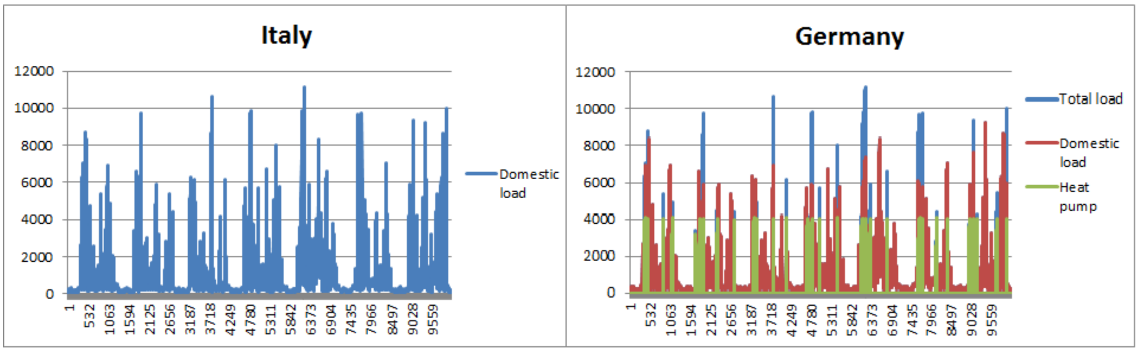

Figure 4-12:Summer home load for both countries

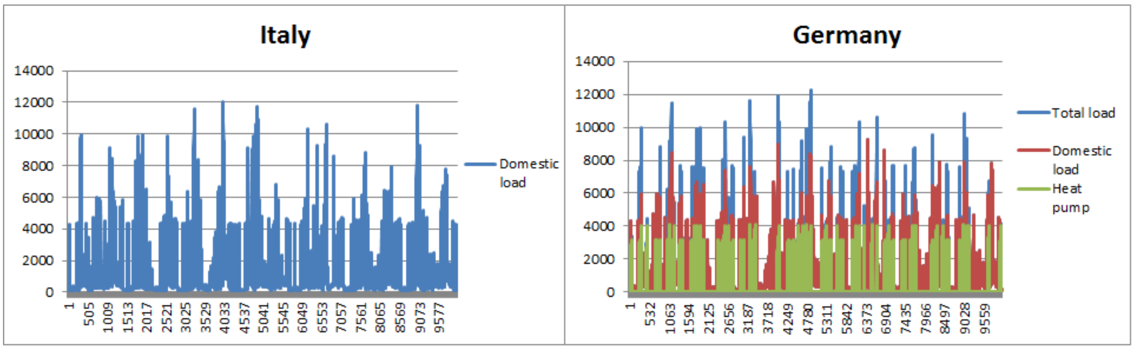

Figure 4-13:Autumn home load for both countries

4.2 Model blocks

The microgrid model is composed of different blocks. The principal blocks are:

- House
- Battery controller
- Scenario

- Line design
- Grid connection
- Data output

4.2.1 House

The first block is the “House Block” which for the German model is composed of four sub-blocks:

- The domestic load
- The heat pump
- The battery
- The solar panel

Instead for the Italian model there are only three sub-blocks, there is no heat pump block. The house load is the sum of domestic load and heat pump , this because in Germany there is a separate counter for the heat pump but in Italy there is none, so for Italy it is not important to divide the two powers. In the Figure 4-14 the house block for the German model is shown.

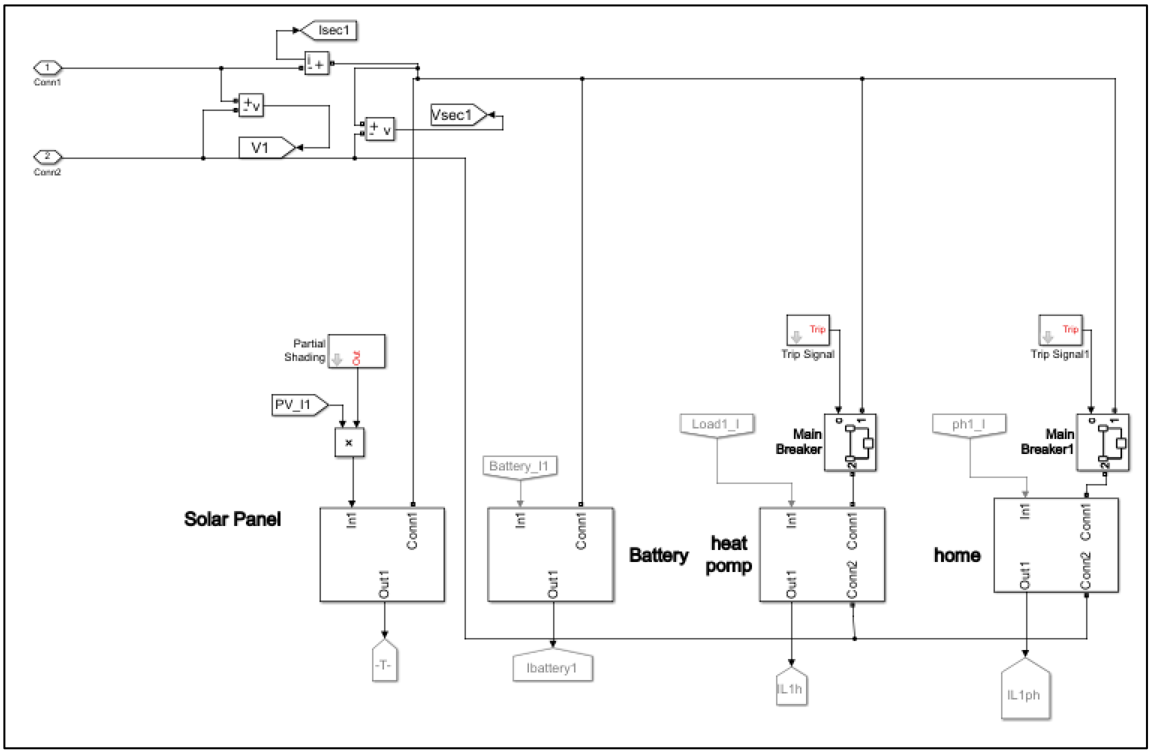

Figure 4-14: House block

The first pass for creating the house system is to create the block for the domestic load (Figure 4-15). It is a Subsystem, which inside is composed of other blocks that simulate the domestic load structure.

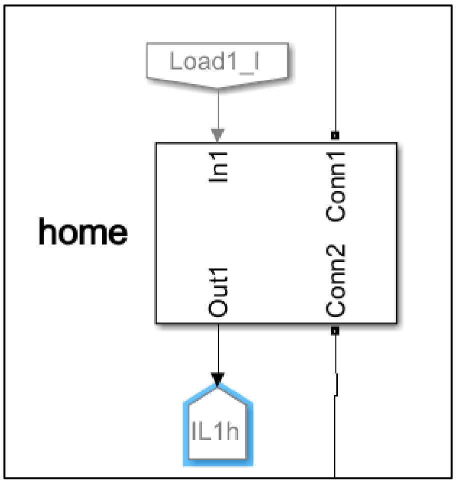

Figure 4-15: domestic sub-block

The input power consumption of the domestic devices is considered without the contribution from the photovoltaics, battery or grid. As said previously, the model is designed with current control. Using a controlled current source it is possible to simulate the domestic load. In1 represents the information input, that the Simulink block converts into an equivalent current source. The controlled current source is also a generator current and it is driven by the input signal of the block. As shown in Figure 4-16, in parallel to the current generator there is a protection snubber.

The initialized current generator parameters are:

- AC Source type
- Initial phase 30 deg
- Initial frequency 50 Hz

"Meas cur2" is a block for the current measurements, in this case this is a complex measurement, because along with these currents the active and reactive power for the domestic load are calculated. "Coon 1" is the input for the feed and "Conn 2" is the output feed. The resistance of the connection cable is also taken into consideration.

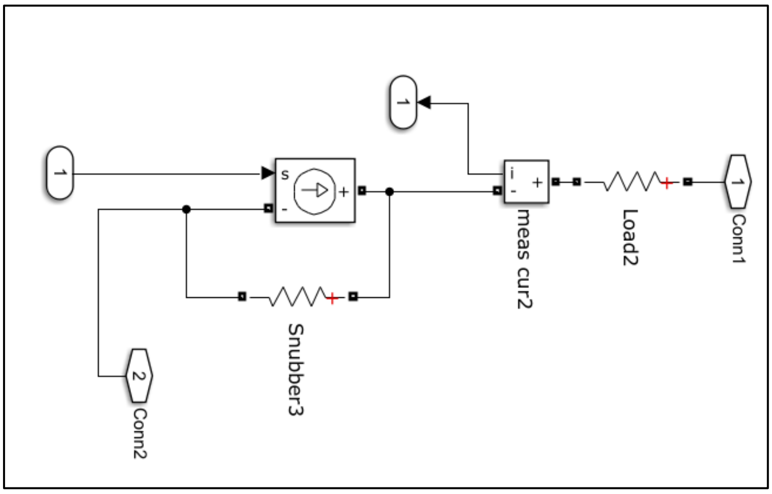

Figure 4-16: scheme of the domestic load

The sub-system for the heat pump, solar panel and battery have the same components as the sub-system for domestic load.

4.2.2 Scenario

The information input signal for the house sub-blocks comes from the "Scenario block" which analyses the power input of the different sources and converts the power to a current, using the algebraic block. Figure 4-17 shows the block's scheme.

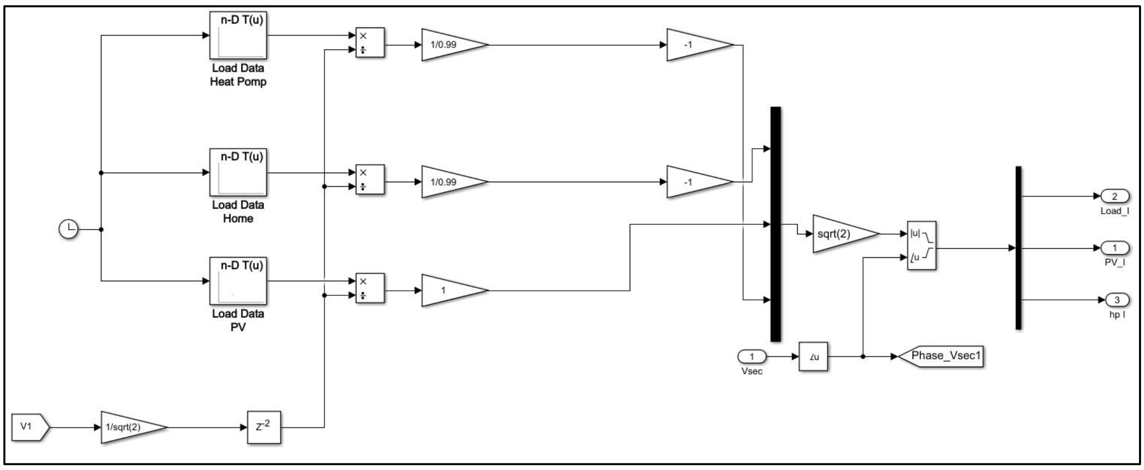

Figure 4-17: scenario scheme

The block "load data" takes the data developed previously using INSEL of: domestic load, heat pump and photovoltaics. In addition to this it is necessary to put the breakpoints specification, *viz* the time sampling for the data input. The current for the "House Block" sub-systems is obtained taking the voltage measured near the house. This current is the input signal. It is necessary to convert the average current to a peak current, because the model controls the peak current, thus obtaining the maximum power of the microgrid blocks.

There is an error loop because the input measured voltage, v1, is a value measured in output. To overcome this problem, as shown in Figure 4-18, a delay is added for the voltage error.

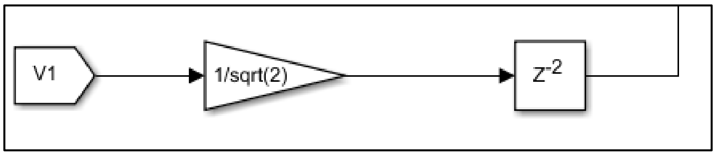

Figure 4-18: solution of the error loop

4.2.3 Battery controller

The battery controller is an important part of the model. It is composed of many blocks, as seen in Figure 4-19. This battery controller sub- block supplies the current battery, the state of charge and the capacity of the battery.

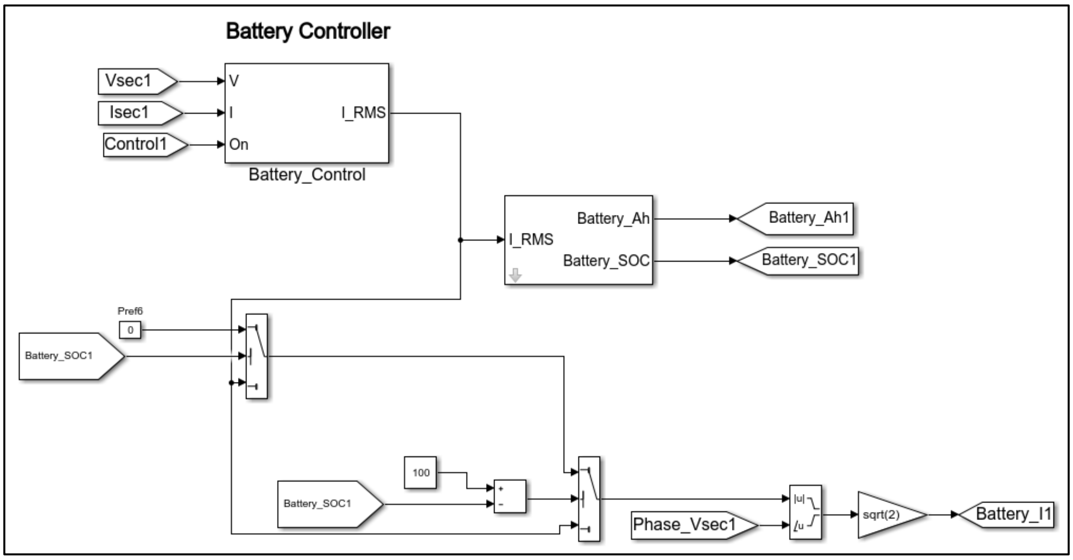

Figure 4-19: scheme of the battery control

For the input there are three pieces of data: the voltage and current measured near the house and “Control1”. This last parameter gives a signal to the battery when it must work and when not.

The first sub-block “battery_control” receives as input the three signals and outputs an average current. As is shown in the scheme in Figure 4-20, the work of this sub-block is to analyse the power of the “House block”, if there is surplus of energy, there is a signal to charge the battery, if instead there is deficit of energy a signal is given to discharge the battery. Then there is another appropriate control that indicates state of the battery.

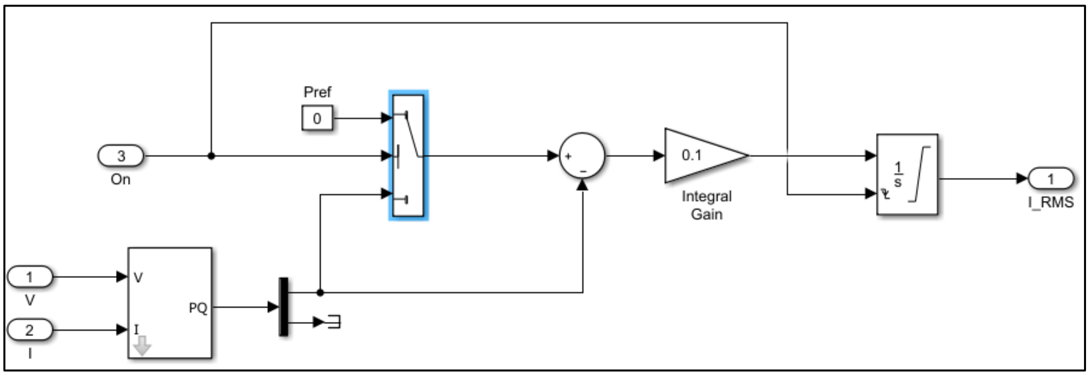

Figure 4-20: battery control

In Figure 4-21 the characteristic of the batteries installed in the houses is shown. The batteries are Black Diamond 5000. The battery block is constructed using the supplied parameters. Most relevant is the parameter for “calendrical Lifespan”, which is highly helpful for an economic comparison.

Black Diamond Series

System Data			
Battery system	Black Diamond 3000	Black Diamond 4000	Black Diamond 5000
Capacity	3 kWh	4 kWh	5 kWh
Maximum output current	60 A	80 A	100 A
Modules	9 (upgradable)	12 (upgradable)	15
Charge-/Discharge Rate	Up to 1 C	Up to 1 C	Up to 1 C
DOD	100%	100%	100%
System Voltage	48 V	48 V	48 V
Efficiency (system level)	> 95%	> 95%	> 95%
Calendrical Lifespan (years)	Up to 20	Up to 20	Up to 20
Interfaces	TCP/IP client protocol (LAN); CAN-Bus		
Display	Touch screen GUI for parametric and statistic visualization		

Figure 4-21: characteristic of the battery

Next to the "Battery_Control" there is a block that calculates the SOC and the Ah of the battery.

The SOC , is calculated starting with the average current. The function that is used to calculate the SOC is:

$$BATTERY\_SOC\% = 100(1 - \int_{AH*3600} \frac{I_{AVG}}{AH * 3600})$$

Where AH is the maximum capacity of the battery and 3600 the number of seconds in one hour.

As is seen in Figure 4-22, for the state of Ah there is no control but for the SOC there are two. The first is that if the SOC is greater than 0%, the battery can be charged and discharged, if it is less than 0% it can only be discharged. These conditions are important, when calculating the SOC, such that the integrator block remains in the feed limits. The second control state is if the SOC is full (100%), it can be only discharge, but if it is not full, it can charge and discharge the battery. The last part of the figure is for the calculation of the SOC, only applying the function as reported previously, and the calculation of the capacity of the battery.

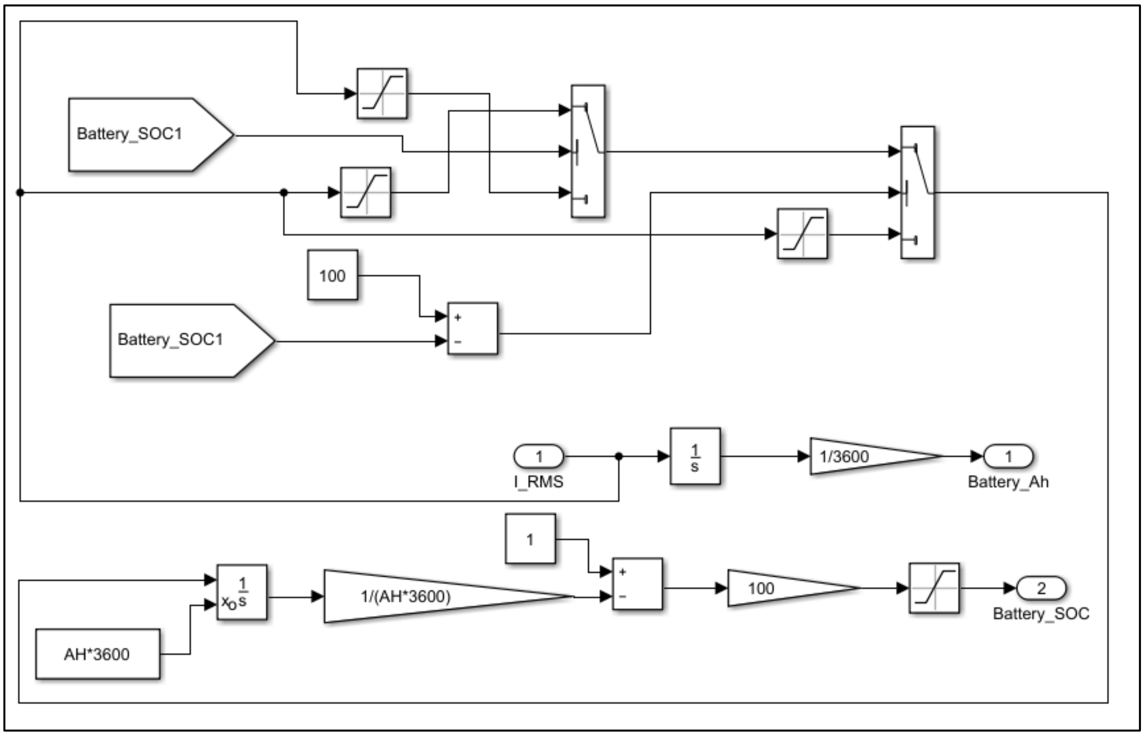

Figure 4-22: SOC and Ah scheme

There are two possible outputs from “Battery_Control”, one of which has just been explained. The other is the calculation of the peak current of the battery, that is used as a signal input in the sub-block battery in “House Block”. The scheme is shown in Figure 4-23. Here there are the same two state controls as were used before for the SOC.

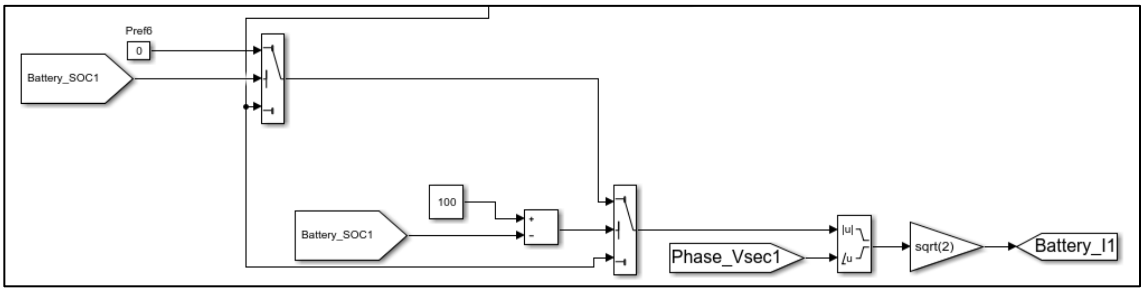

Figure 4-23:battery control

4.2.4 Grid connection

The grid connection is formed with: a generator, a line (P.I.)and a transformer. Connecting these three parts together it is possible to simulate the performance of a grid. A three phase source block is used for the generator. The power is oversize for reasons of convenience, so the cable used is a three phase PI section line.

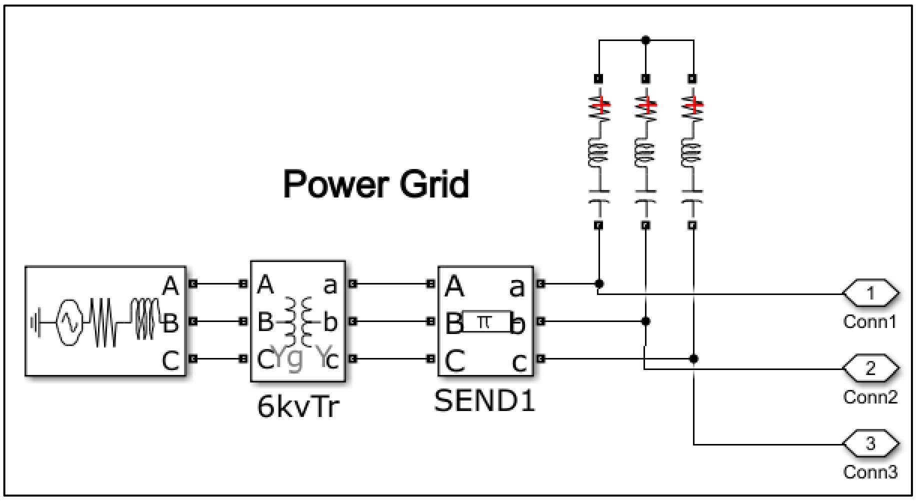

Figure 4-24: Grid connection

The components in Figure 4-24 are put in a subsystem that is shown in Figure 4-25 with the name of “Electric Grid”. This last block is connected with the PCC block. It is formed with a transformer, whose power is oversized, because if in the future the microgrid model is expanded, it will not be necessary to change the transformer.

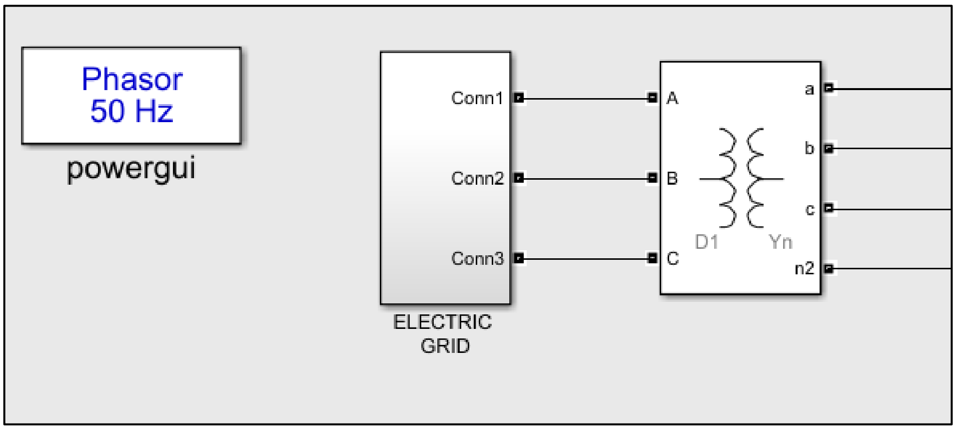

Figure 4-25: Electric grid

4.2.5 Line design

For the design of the microgrid distribution lines, it is necessary to consider the two different standards for the two countries. Italy has the CEI 0-21, for low voltage design, Germany has the VDE 0100 standard. The model uses parameters for a real rural distribution system used in Germany.

The lines from the point of PCC are:

- Line A: from PCC to House 1/House 2
- Line C: from House 1/House 2 to House 3/House 4
- Line B: from House 3/House 4 to House 5
- Line D: from House 5 to House 6

For every line there is the same set of conditions. There are buried cables. In line A there are two cables in contact, and in line B three cables in contact and lines C and B have only one cable.

For the house power is considered as the sum of the maximum domestic power expected for every house with the maximum heat pump power. The results are high, because the houses are large and the contribution of the photovoltaic generators and battery are not considered. The power quantities are:

- House 1: 19,41 kVA
- House 2: 17,66 kVA
- House 3: 15,25 kVA
- House 4: 16,25 kVA
- House 5: 17,94 kVA
- House 6: 19,71 kVA

For the scheme, the distribution cable is a NAYY 4x150 in PVC.

4.2.5.1 For the Italian model

Using the standard CEI 0-21, the lines are satisfactorily designed. In Italy the maximum percentage voltage drop is 4%. It is necessity to design the line respecting this limit.

Using a voltage of 400 V and the house power, the currents Ib [A] are is calculated. It is necessary to assess the correction coefficients according to the temperature, the depth of the cable, the number of cables there are altogether and the soil resistivity. For this design the following coefficients were used:

- K1=1,1 for an environmental temperature of 10°C for each line
- K2 depends on the line:
    - K2 line A=0,85 there are 2 cables
    - K2 line B=0.75 there are 3 cables
    - K2 line C and D= 1 there is 1 cable
- K3=1 for a depth of cable of 0,8 m
- K4=1 for a soil resistivity of 1,5

Multiplying the current Ib by these coefficients gives currents Io'. Comparing these currents with the limit current of the cable Io, it is possible to say if the first condition Io'<Io is respected.

Table 4-2: results Italian cable design

Line	from	to	distance	type	S	V	Ib	k1	k2	k3	k4	Io'	Io
A	PCC	Home 1/Home 2	63	Three phase	106240	400	153,3	1,1	0,9	1	1	164	272
B	Home 1/Home 2	Home 3/Home 4	30	Three phase	69165,6	400	99,83	1,1	0,8	1	1	121	272
C	Home 3/Home 4	Home 5	120	Three phase	37658,6	400	94,15	1,1	1	1	1	85,6	272
D	Home 5	Home 6	30	Three phase	19715,5	400	49,29	1,1	1	1	1	44,8	272

Calculating the percentage voltage drop for each line, it is possible to verify the 4%. condition has not been exceeded. The results are presented in Table 4-3.

Table 4-3: percentage voltage

	% voltage drop
A	0,727
B	0,225
C	0,850
D	0,111
TOT.	1,914

The total sum is 1.914 % < 4 %, and thus the condition is respected. It is correct to have a margin, because in this 4% there must be also be an allowance for the voltage drop in the domestic cables.

With respect to these conditions, the parameters of the line (resistance [Ohms] and inductance[H])can be calculated. The results are shown in Table 4-4.

Table 4-4: results resistance and inductance

Line	from	to	distance	R	X
A	PCC	Home 1/Home 2	63	0,009891	0,00469
B	Home 1/Home 2	Home 3/Home 4	30	0,00471	0,00224
C	Home 3/Home 4	Home 5	120	0,01884	0,00894
D	Home 5	Home 6	30	0,00471	0,00224

4.2.5.2 *For the German model*

In this case the VDE 0100 standards are used. The design uses the same functions as the Italian model but a condition and coefficients are changed. In Germany the maximum percentage voltage drop is 5%. For this design these corrected coefficients were used:

- K1=1,05 for environmental temperature of 10°C for every line
- K2=1 for every lines
- K3=1 for a cable depth of 0,7 m
- K4=1 for a soil resistivity of 1

Using these coefficients it is possible to calculate the maximum current drawn in the cables Io'. Comparing this current with the maximum capacity of the cable Io, it can be seen if the condition Io'<Io is respected.

Table 4-5: results of the German cable design

Line	from	to	distance	type	S	V	Ib	k1	k2	k3	k4	Io'	Io
A	PCC	Home 1/Home 2	63	Three phase	106240	400	153,3	1,05	1	1	1	146	246
B	Home 1/Home 2	Home 3/Home 4	30	Three phase	69165,6	400	99,83	1,05	1	1	1	95,1	246
C	Home 3/Home 4	Home 5	120	Three phase	37658,6	400	94,15	1,05	1	1	1	89,7	246
D	Home 5	Home 6	30	Three phase	19715,5	400	49,29	1,05	1	1	1	46,9	246

There is the last condition to be controlled. In this case the sum of percentage voltages drop must be lower than 5 %.

Table 4-6: percentage voltage

	% voltage drop
A	0,922
B	0,286
C	1,078
D	0,141
TOT.	2,428

As before the conditions are corrected, so it is possible to calculate the parameters of the lines. It is reported in the Table 4-7.

Table 4-7: results of the resistance and inductance

Line	from	to	distance	R	X
A	PCC	Home 1/Home 2	63	0,012978	0,00506
B	Home 1/Home 2	Home 3/Home 4	30	0,00618	0,00241
C	Home 3/Home 4	Home 5	120	0,02472	0,00965
D	Home 5	Home 6	30	0,00618	0,00241

4.2.6 Data output

In the sub-block there are the data output of my model. Second the countries have different electric meters. For example in Germany there is a meter for the heat pump.

For every house there is this list of outputs:

- Photovoltaic Power
- Total Load Power
- Domestic Power
- Heat Pump Power
- Battery Power
- Hour
- SOC

Additionally there is the output for the "Grid", so for every house there is a measurement of offer and demand of energy to and from the grid. There is also the total energy that the microgrid system asks from public grid. So it is possible to calculate the power losses in the cable. In the model for Trapani there are only electric meters for the sum of all loads in the house.

4.3 FINAL MODEL

The difference in the two models are in the design of cables and in the scopes, because the standards in the two countries are not the same, despite the specifications arising from European standards. Thanks to these models it is possible to make many simulations, changing the environmental, electrical and other conditions.

The final microgrid model is shown in Figure 4-26.

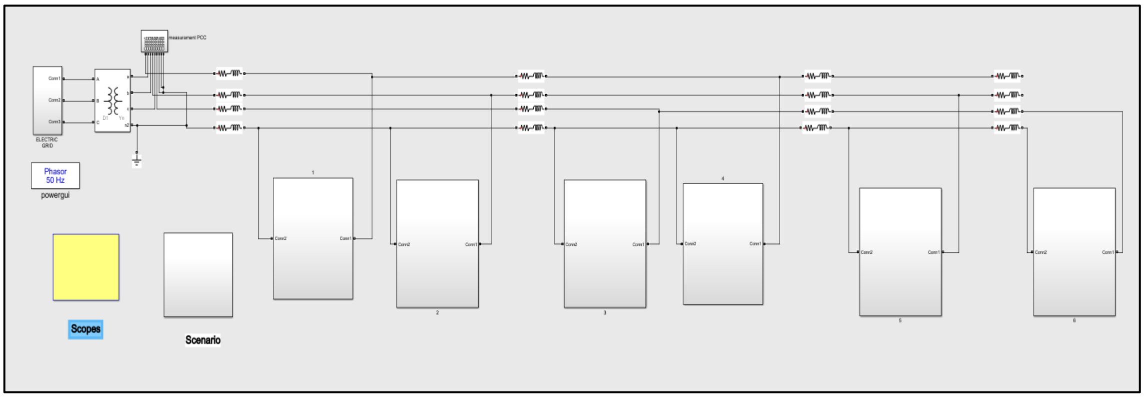

Figure 4-26:final model

5 SIMULATION USING SIMULINK

5.1 Introduction

In this chapter simulations will be carried out for the microgrid model with different configurations. The following measurements of the input data for each house will be carried out to verify if the results of the model are correct:

- Photovoltaic generation
- Domestic load
- Heat pomp load

These virtual measurements are taken near the houses, as if they were from power meters. If they are same the model is working in the right way. Satisfying these conditions, it is possible to start the simulations.

Four simulations will be made for both models:

- Real configuration (battery and photovoltaics)
- Without the battery
- Without the battery and photovoltaics
- Security

The first simulation is to see how the real microgrid system works, by examining the power flow in the lines; the times when the batteries are functioning and the exchange of energy with the grid. The second is to make a comparison with the first simulation, but with no batteries, so the power flow in the lines is greater and it is possible to see which are the advantages to having a battery (power losses, management of the cables, etc). The third simulation is for an economic comparison. This is the case where the cost of buying energy is maximum. The last is to understand if it is possible for the system to work in isolation or to be autonomous without the grid.

As it said in previous chapters, it is a simulation time of one week has been adopted for all cases. These simulations will measure:

- The power in the PCC
- The power near the homes
- The SOC of the battery
- All loads
- The photovoltaic power generation
- The power battery

the power measured in the PCC is called: GRID and the power measured near the houses is called: GRID 1, GRID 2, GRID 3, GRID 4, GRID 5 and GRID 6.

In the next paragraph the results of the simulations are shown as graphics.

5.2 Simulation for German model

Starting with the German simulations, the model is run for the following configurations:

5.2.1 Real

With this configuration there is nothing to change in the microgrid model. The results of the simulations are shown in the figures. Divided into the four seasons.

5.2.1.1 Winter

The Figure show the photovoltaic production for German model, it is necessary to compare this figure with the Figure 4-4:total PV production in spring for both countries. It is possible to see that the results are the same.

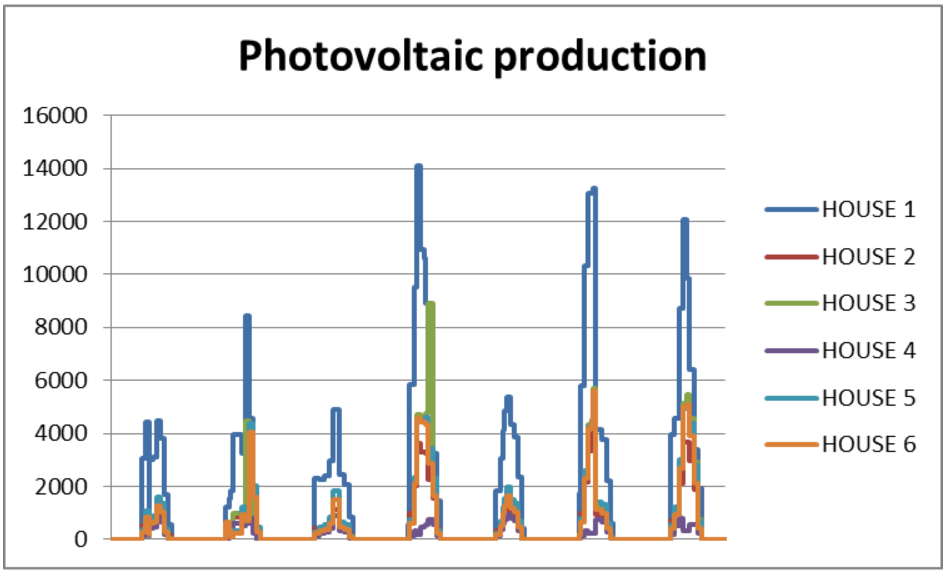

Figure 5-1: output PV production Germany

Also here it is necessary to do a comparison between the graph "Loads" with the **Figure** 4-10**:** Winter home load for both countries . It is possible to see that the results are the same and the model give the same results that there are in input, this is important, the model work correctly. The power battery is shown in the Figure 5-2, it is interest when the battery charge and discharge, then are shown the SOC for all houses.

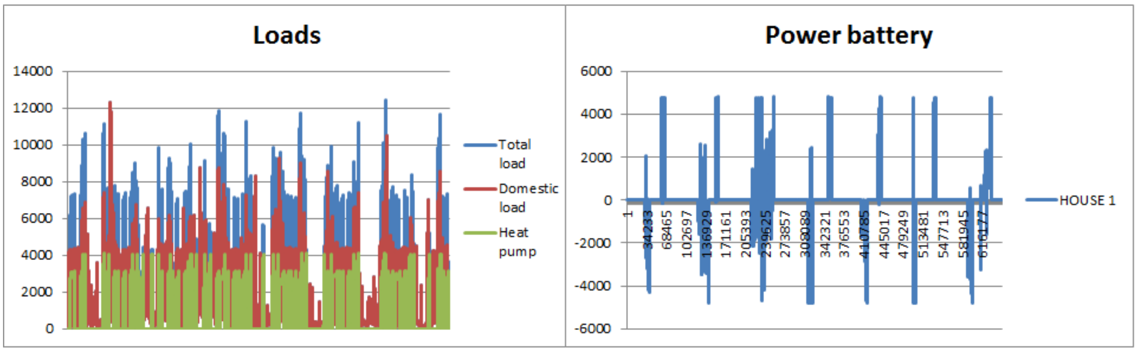

Figure 5-2: HOUSE 1 measurements meters

The energy exchanged with the grid are shown in the Figure 5-3 and Figure 5-4. It is significant, which is the received and supplied quantity energy.

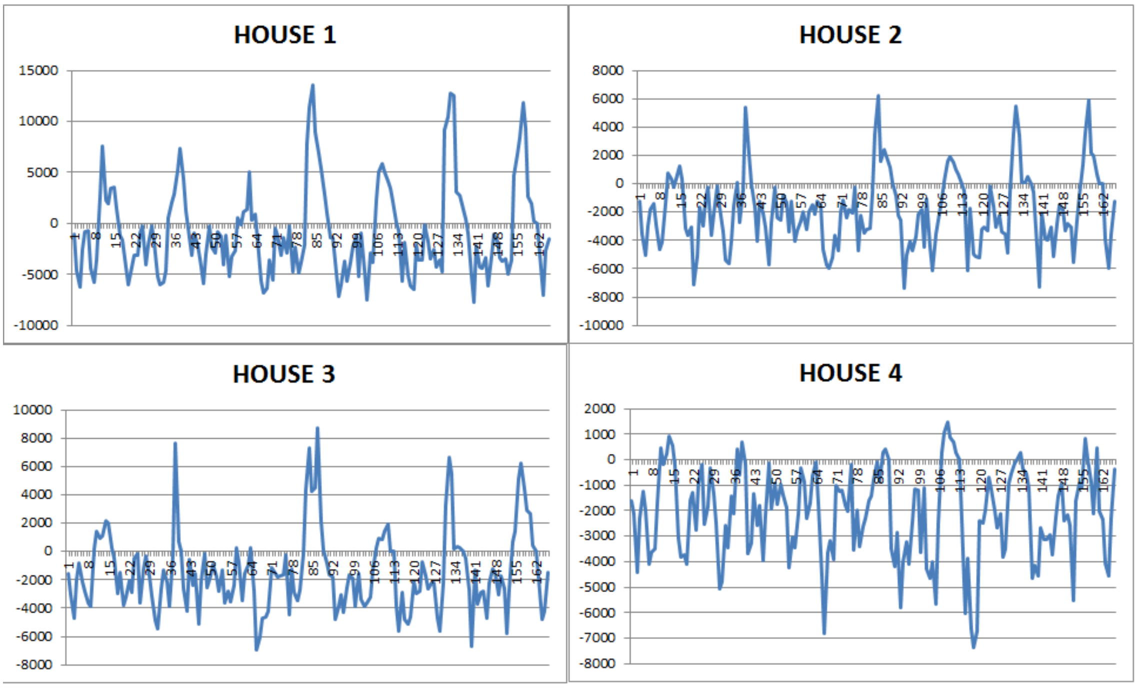

Figure 5-3: Energy exchanged with the grid

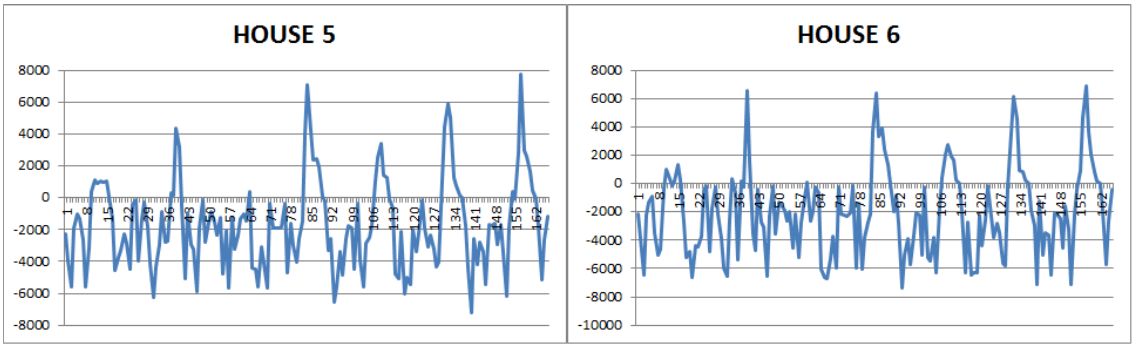

Figure 5-4: Energy exchanged with the grid

The graphs "PCC" show the energy exchanged in PCC, the positive values are the energy that the grid to supply and the negative values are the energy to receive.

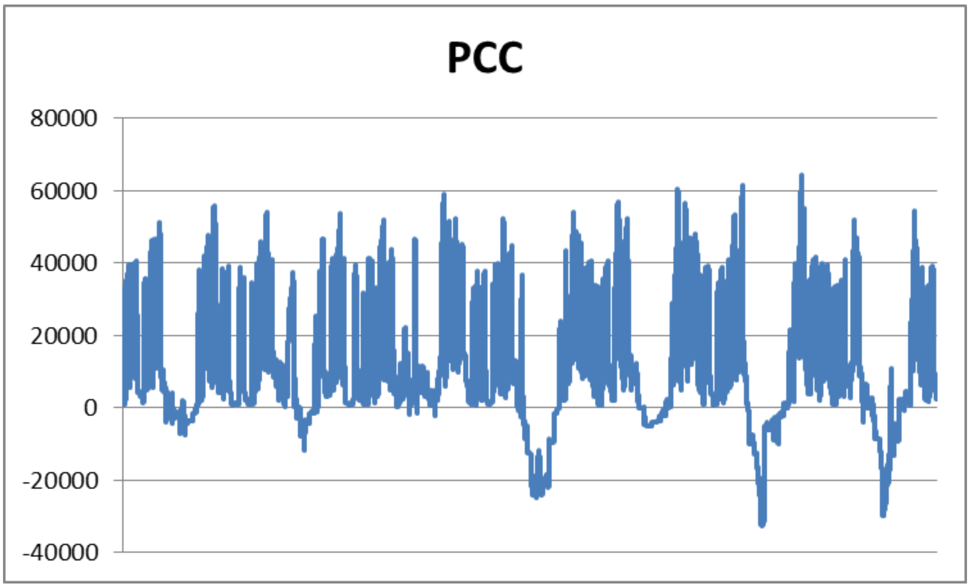

Figure 5-5: energy exchanged in PCC

The Figure 5-6 shows the SOC trends for each house, the third day the battery for each house do not charge, this because there is a few photovoltaic production. The SOC of HOUSE 4 is few for the all week. It is hard to have a microgrid operation in winter, because the loads are high and the photovoltaic production is few. The battery do not supplies the loads in the night.

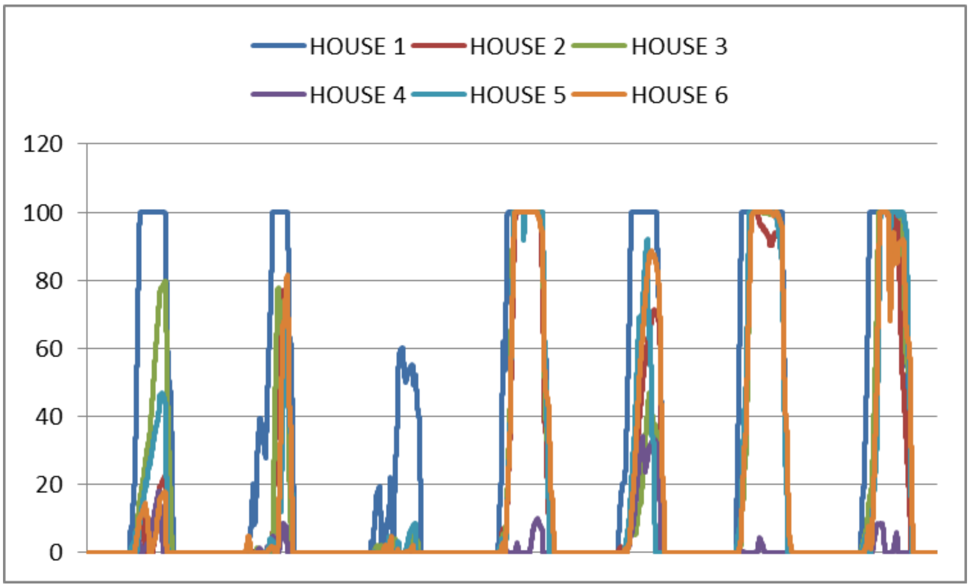

Figure 5-6: SOC for each house

5.2.1.2 Spring

Said above the simulation supplied correct results, are shown the other results of the seasons.

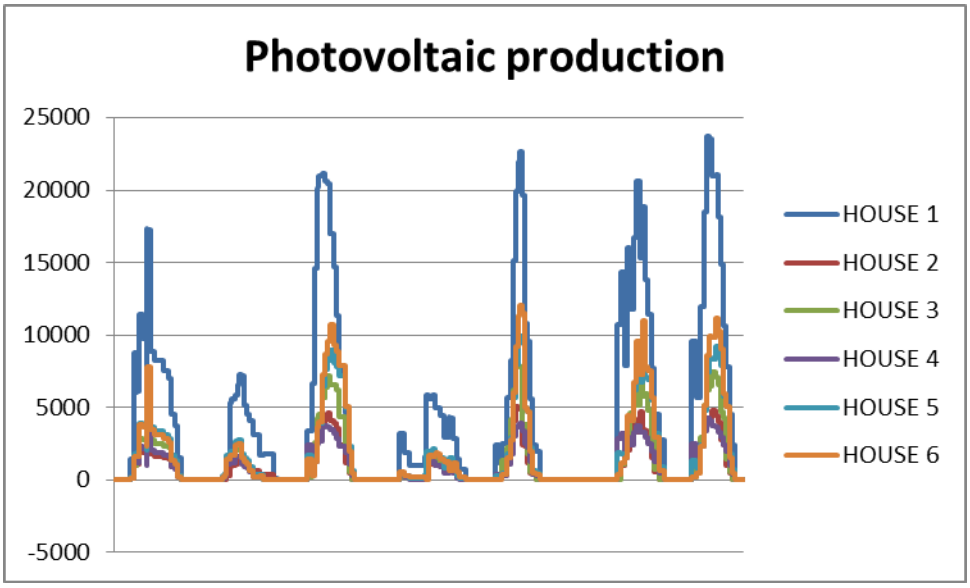

Figure 5-7: PV production

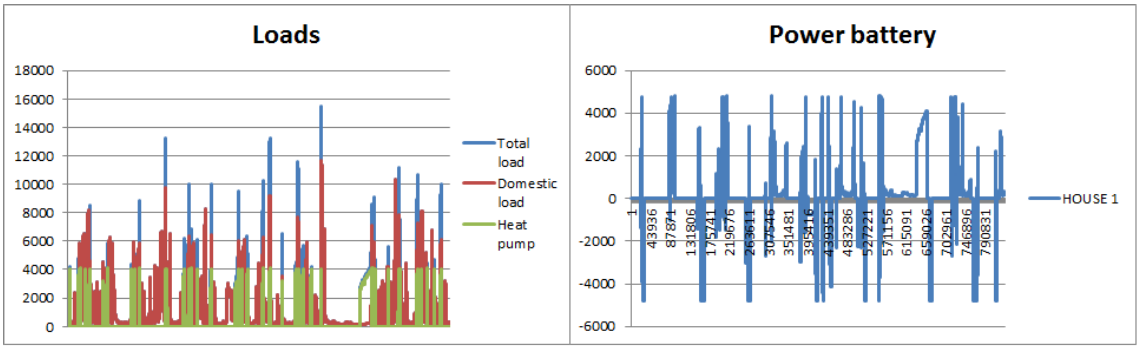

Figure 5-8: measurement meters

The Figure 5-9 show the energy exchanged with the grid, in comparison with winter, in spring the asked energy is very few. It is thinkable an autonomous work in this case. Just only to have a battery with more capacity, or reduce the loads in the night.

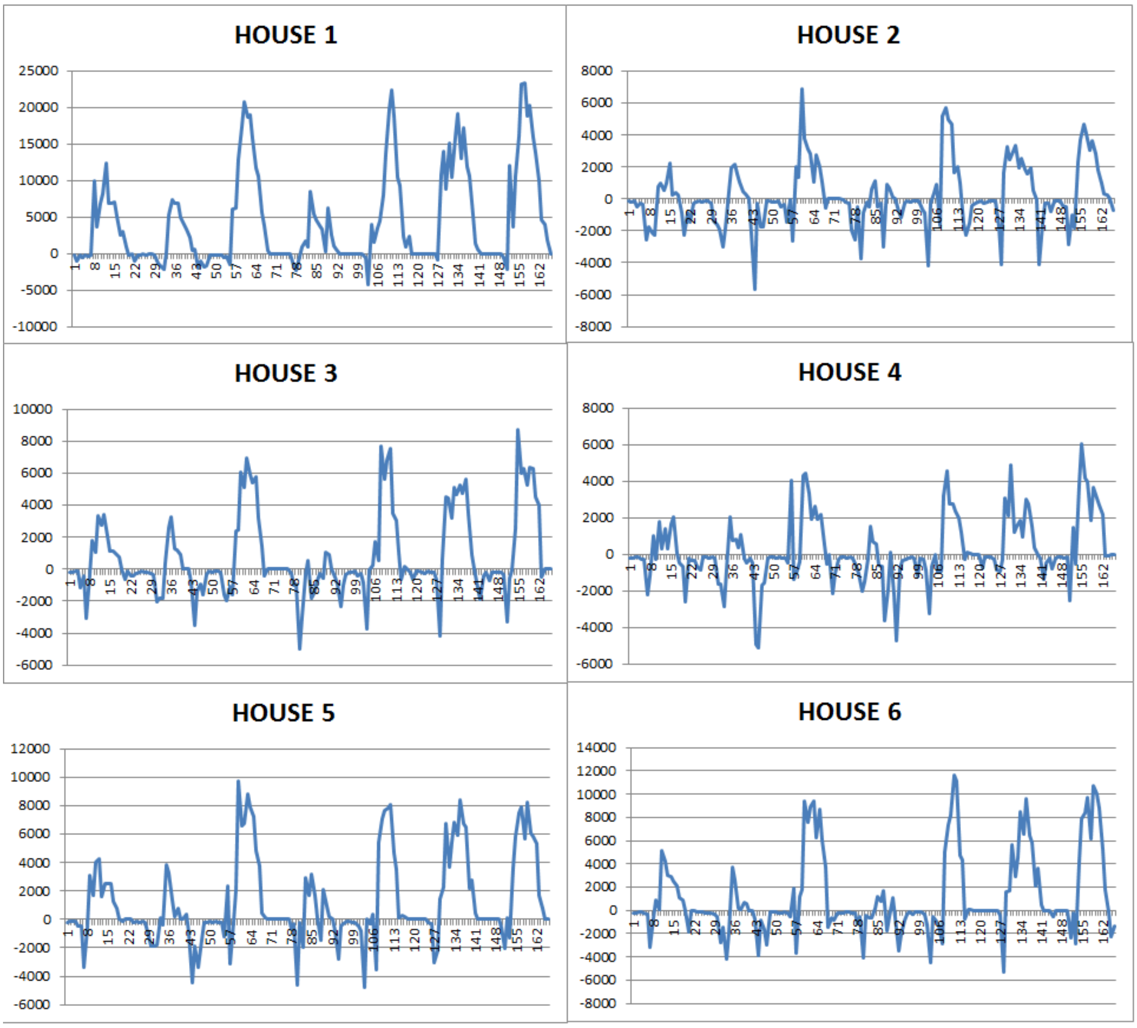

Figure 5-9: Energy exchanged with the grid

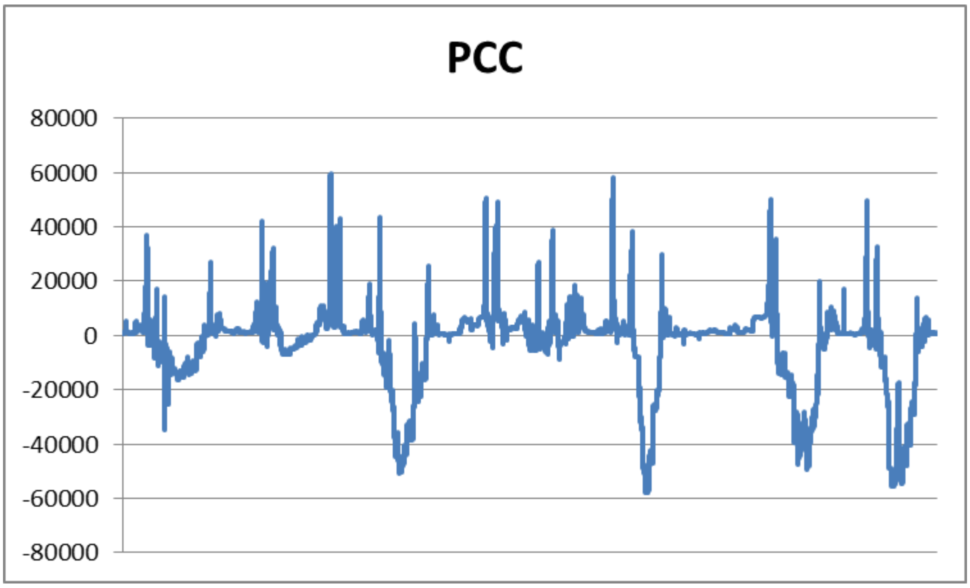

Figure 5-10:energy exchanged in PCC

The Figure 5-11 show the SOC of the batteries, in comparison with the winter, it is significant to see as the battery discharge in the night and there are houses that in the night do not discharge completely the battery, in the last days of the week.

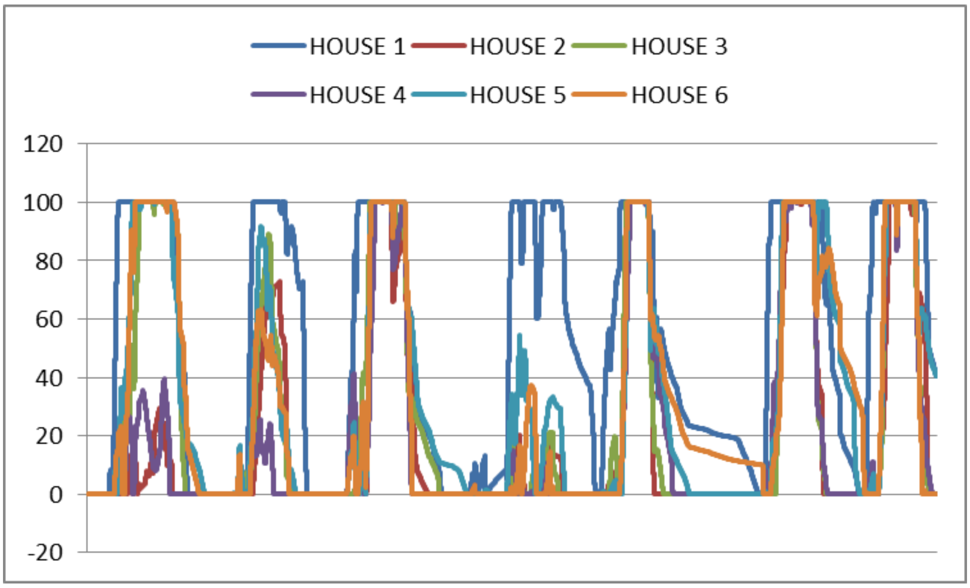

Figure 5-11: SOC of houses

5.2.1.3 Summer

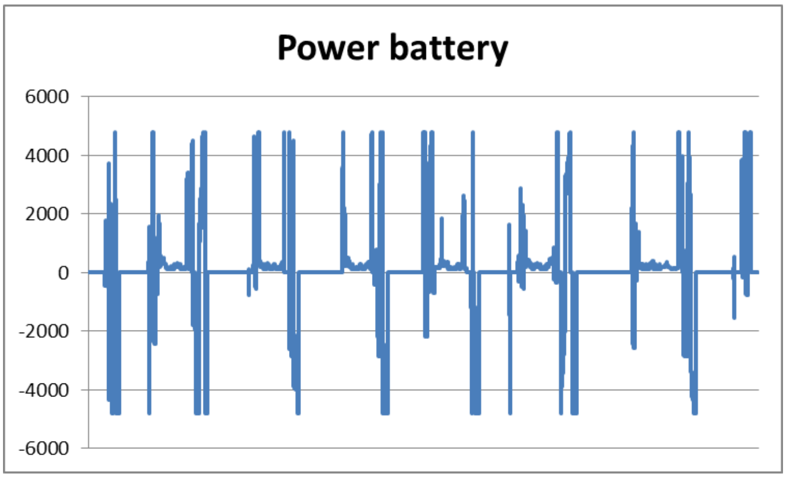

Figure 5-12:Power battery HOUSE 1

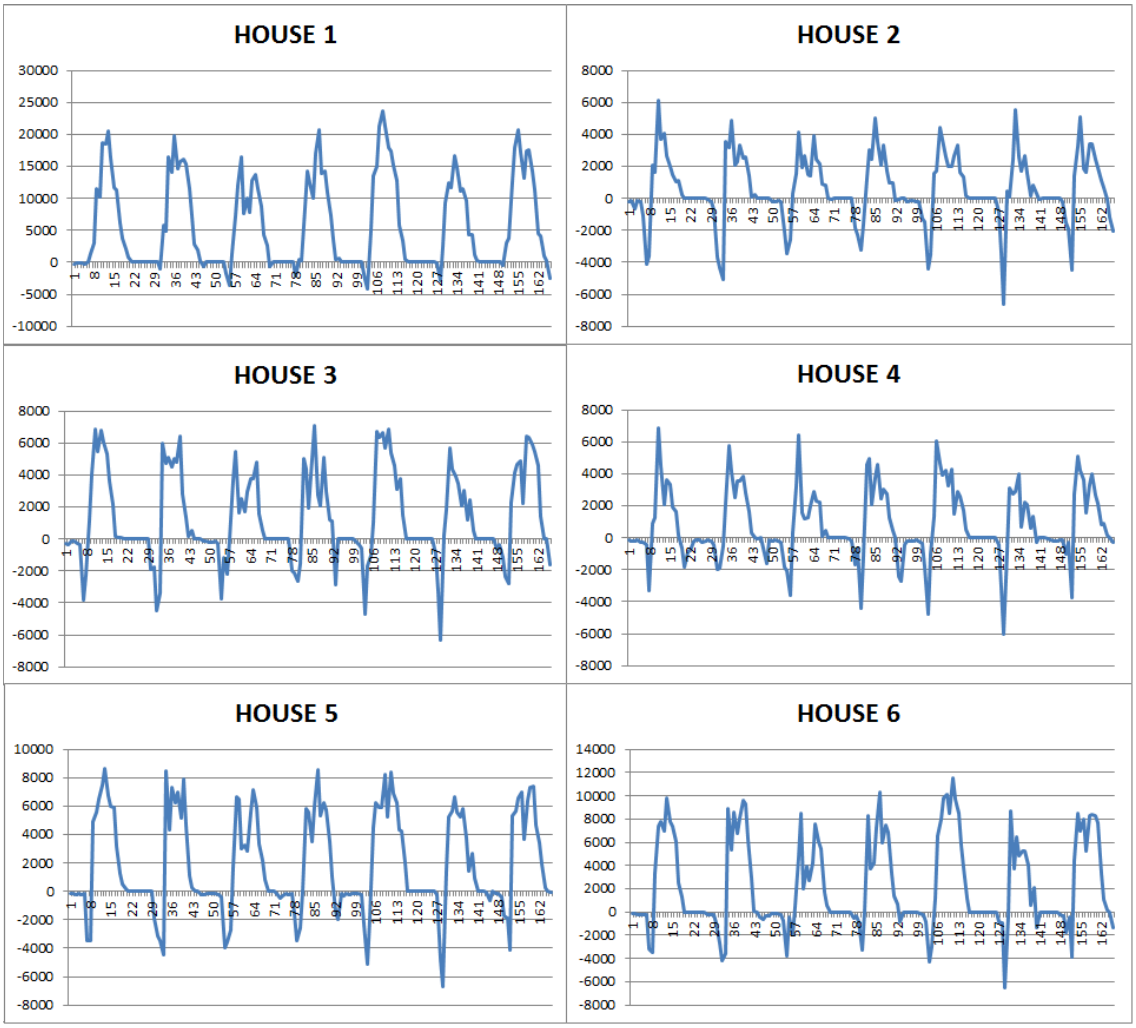

Figure 5-13: Energy exchanged with the grid

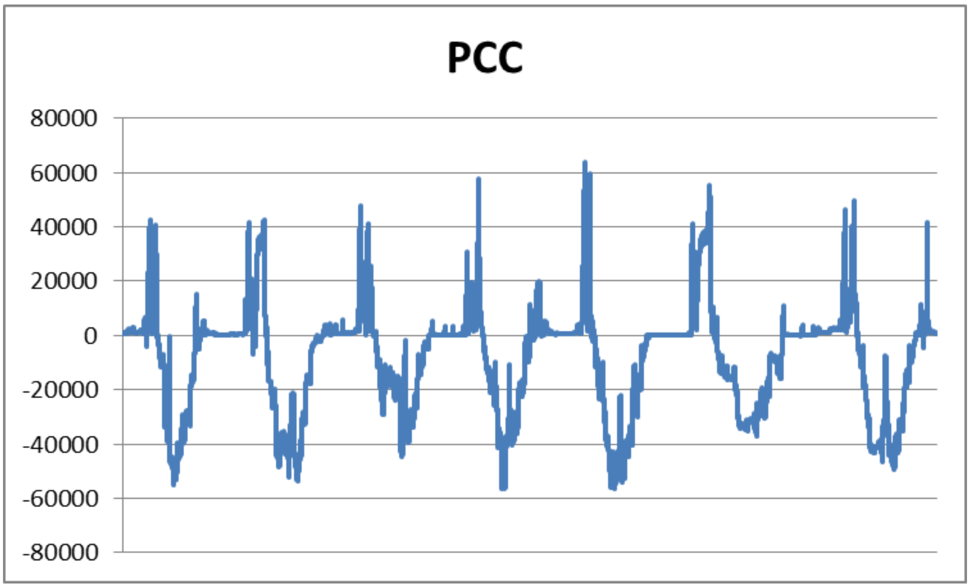

Figure 5-14:Energy exchanged in PCC

The Figure 5-15 show the SOC of the batteries in summer, it is possible to see that the battery do not discharge completely in the day. The energy did not use, this is worse. It is necessary a system that take and use this energy. In summer there is the possibility to be autonomous from the grid.

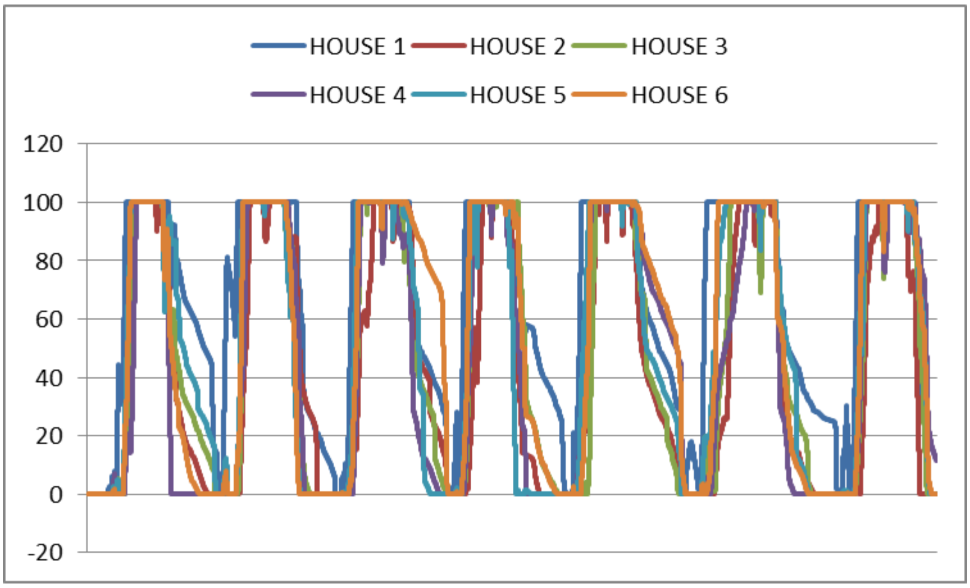

Figure 5-15: SOC of batteries

5.2.1.4 Autumn

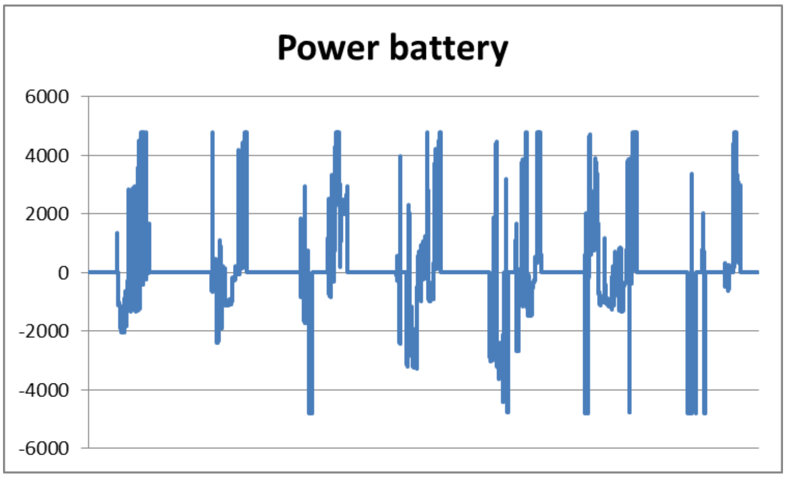

Figure 5-16:Power battery HOUSE 1

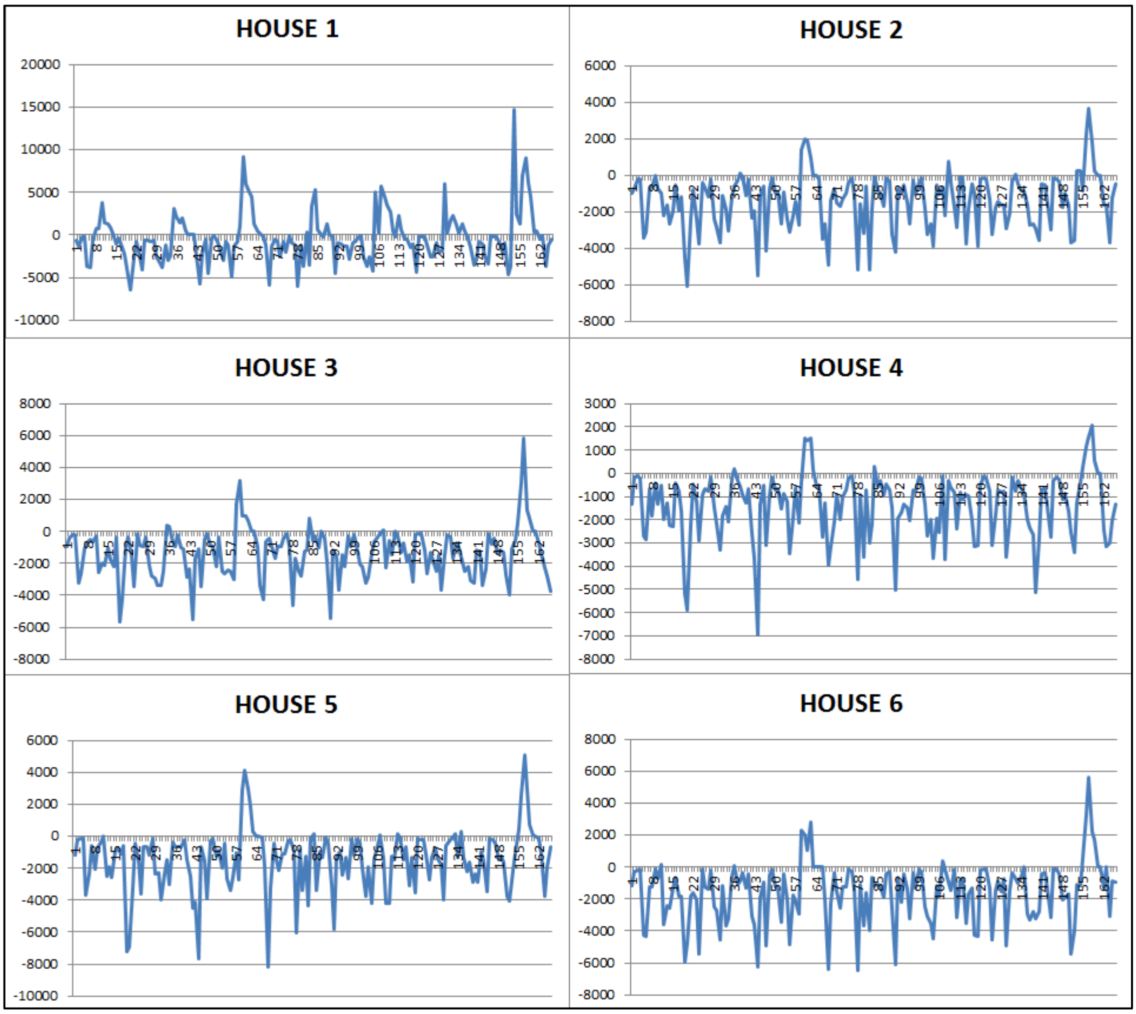

Figure 5-17: energy exchanged with the grid

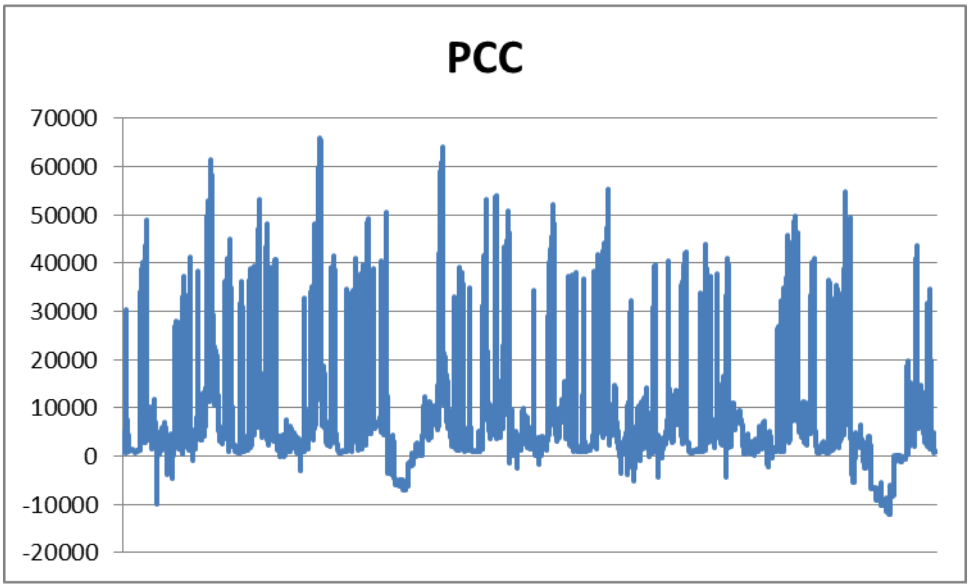

Figure 5-18:energy exchanged PCC

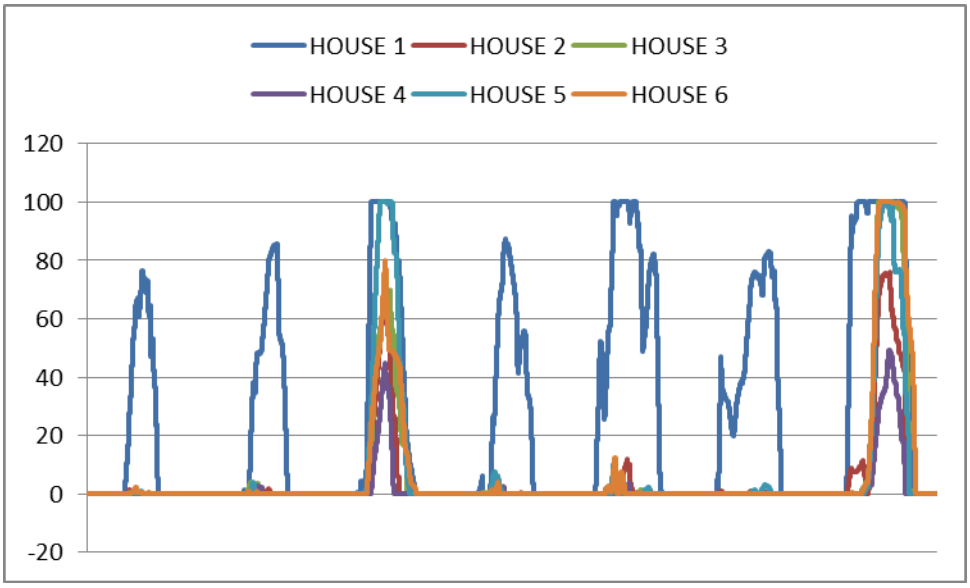

Figure 5-19: SOC of batteries

5.2.2 Without the battery

Changing a part of the model in Figure 5-20, it is possible to have a simulation without the battery. Only the graphics with the power measured near the PCC and near the houses are shown, because the photovoltaic generation and the loads are the same as before.

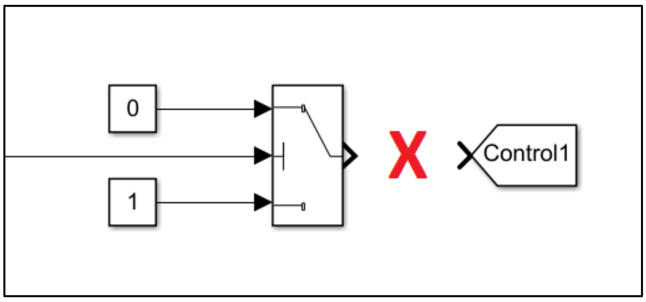

Figure 5-20: part to change

5.2.2.1 Winter

Without the battery in the night , it is necessary to receive the energy.

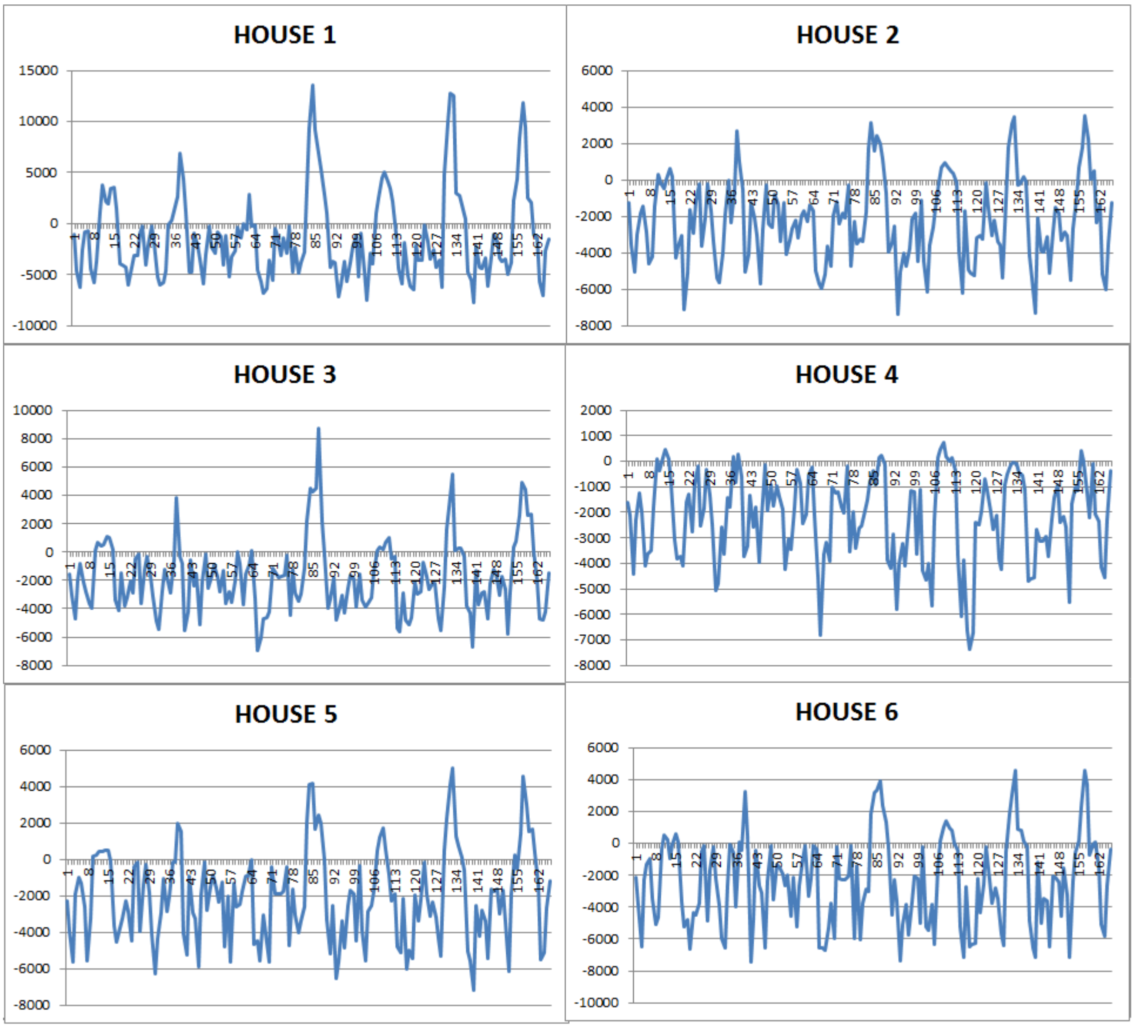

Figure 5-21: Energy exchanged with the grid

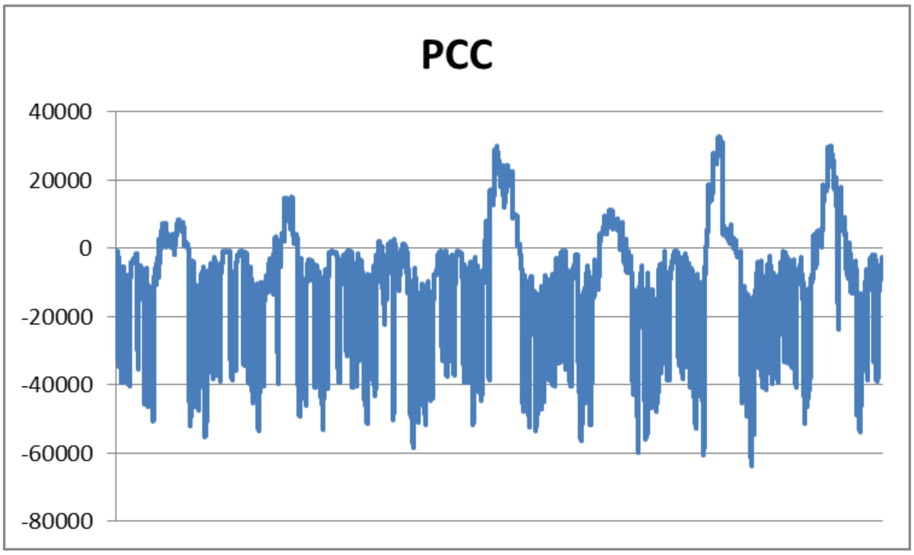

Figure 5-22: Energy exchanged in PCC

5.2.2.2 Spring

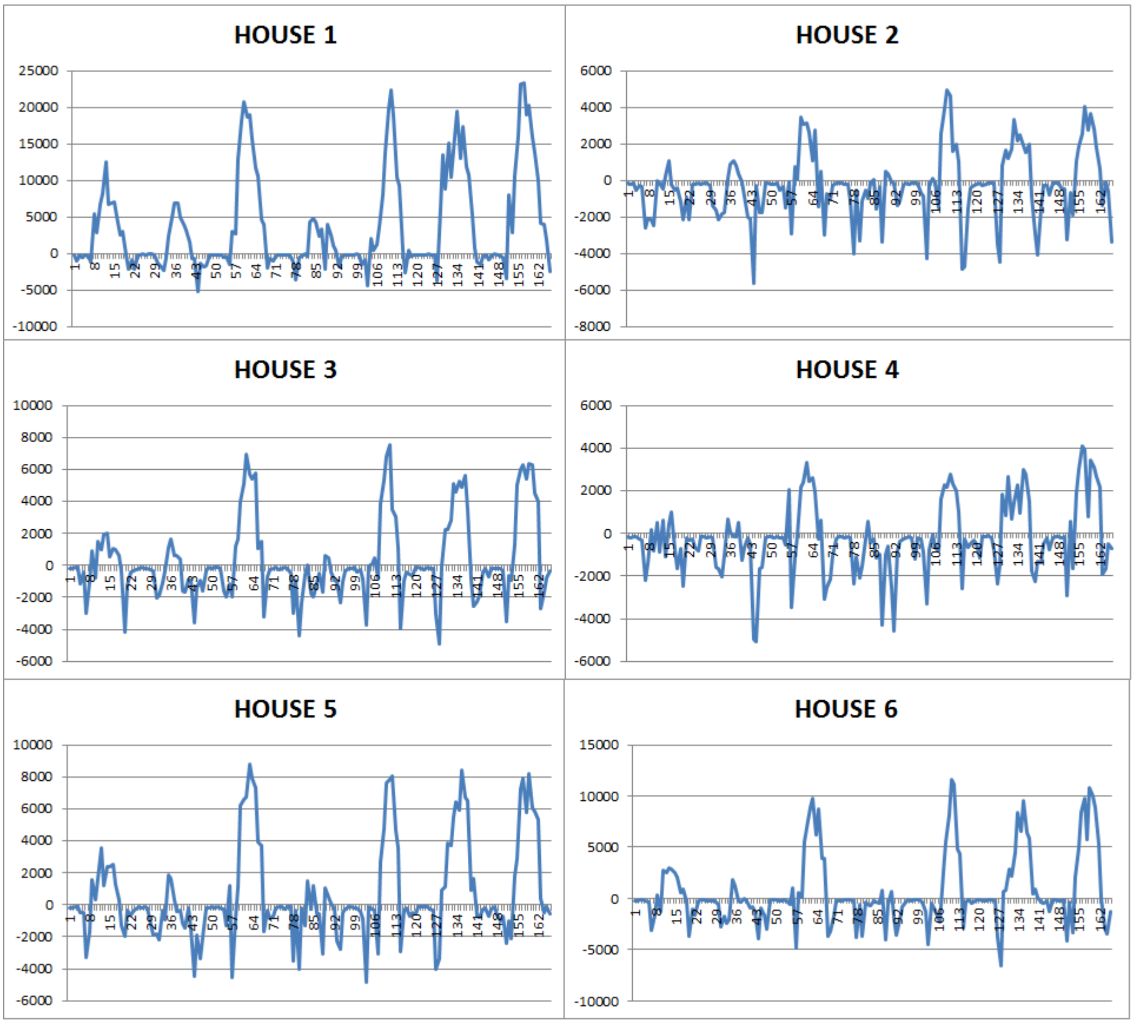

Figure 5-23: Energy exchanged with the grid

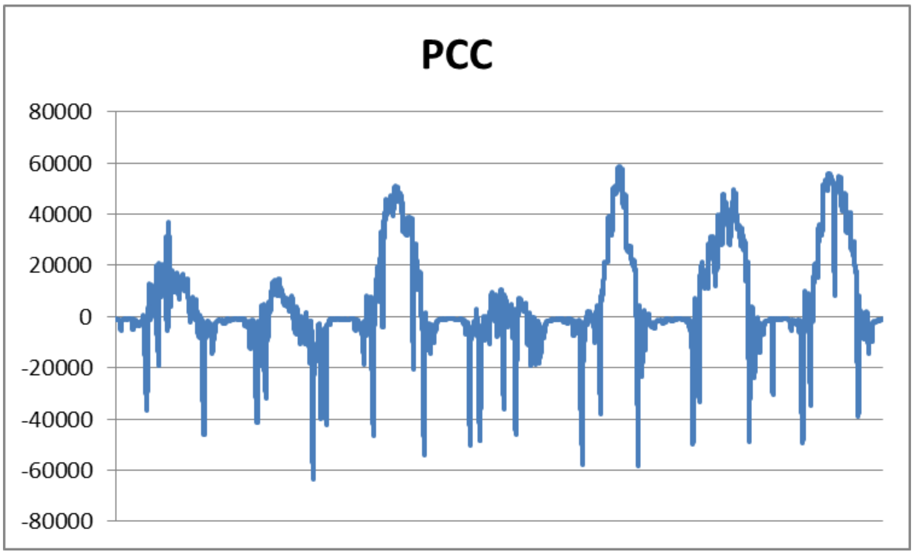

Figure 5-24: Energy exchanged in PCC

5.2.2.3 Summer

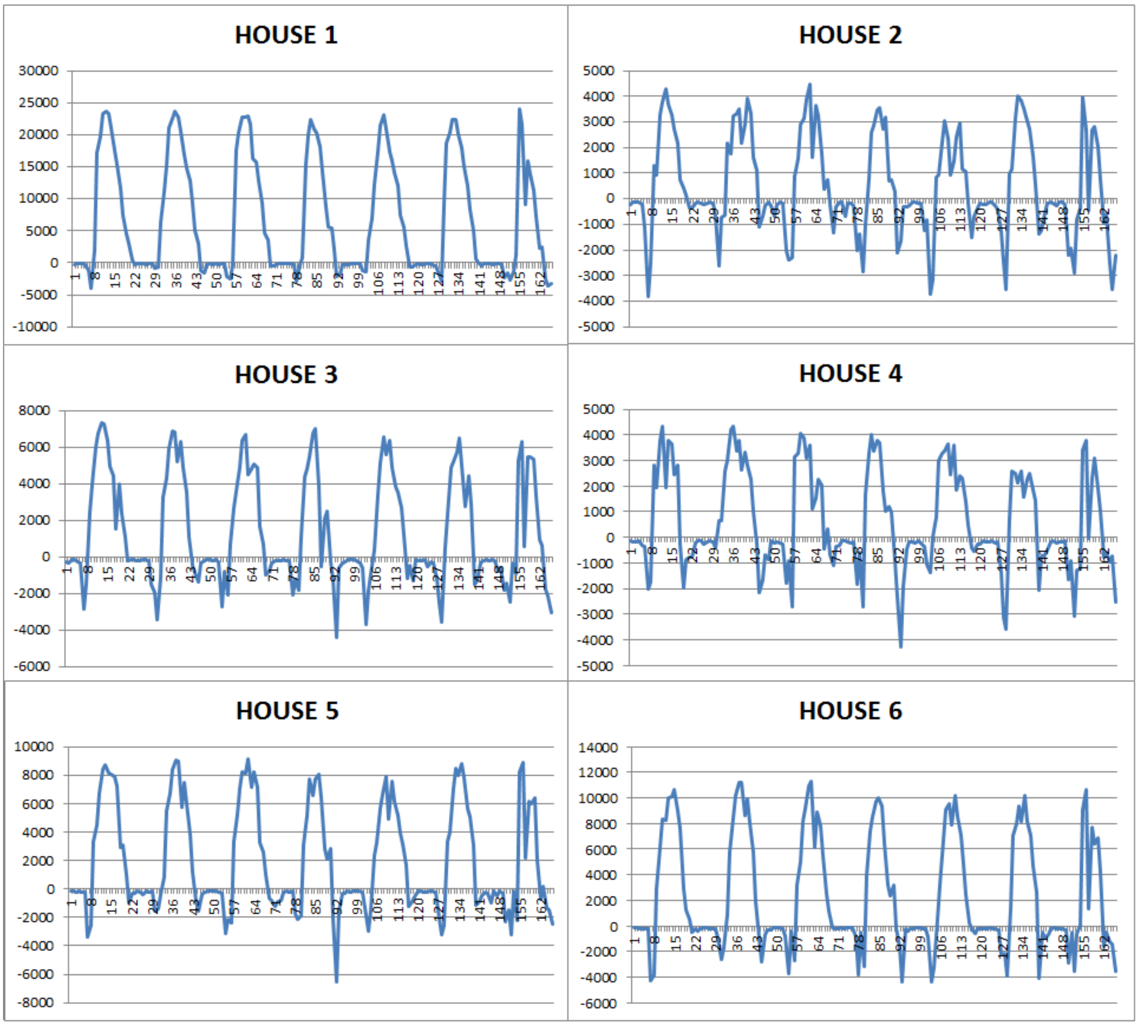

Figure 5-25: Energy exchanged with the grid

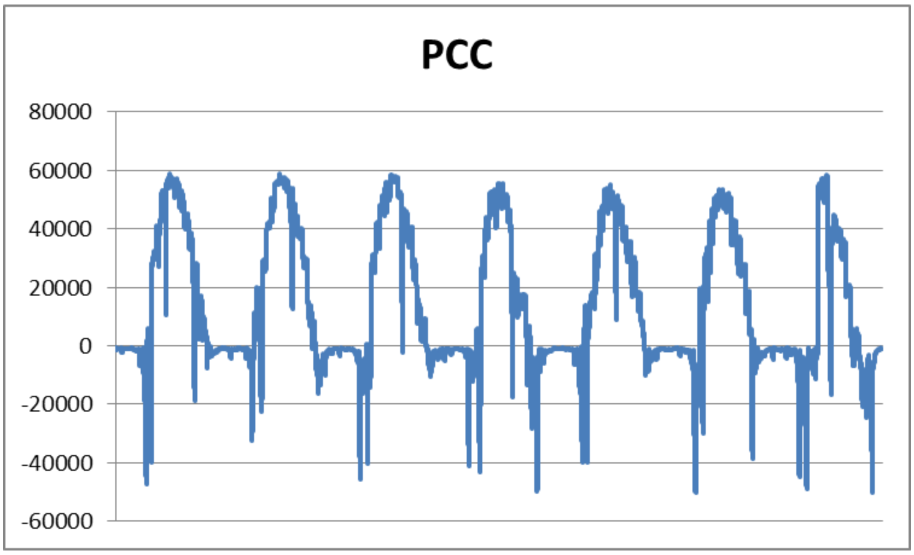

Figure 5-26: Energy exchanged in PCC

5.2.2.4 Autumn

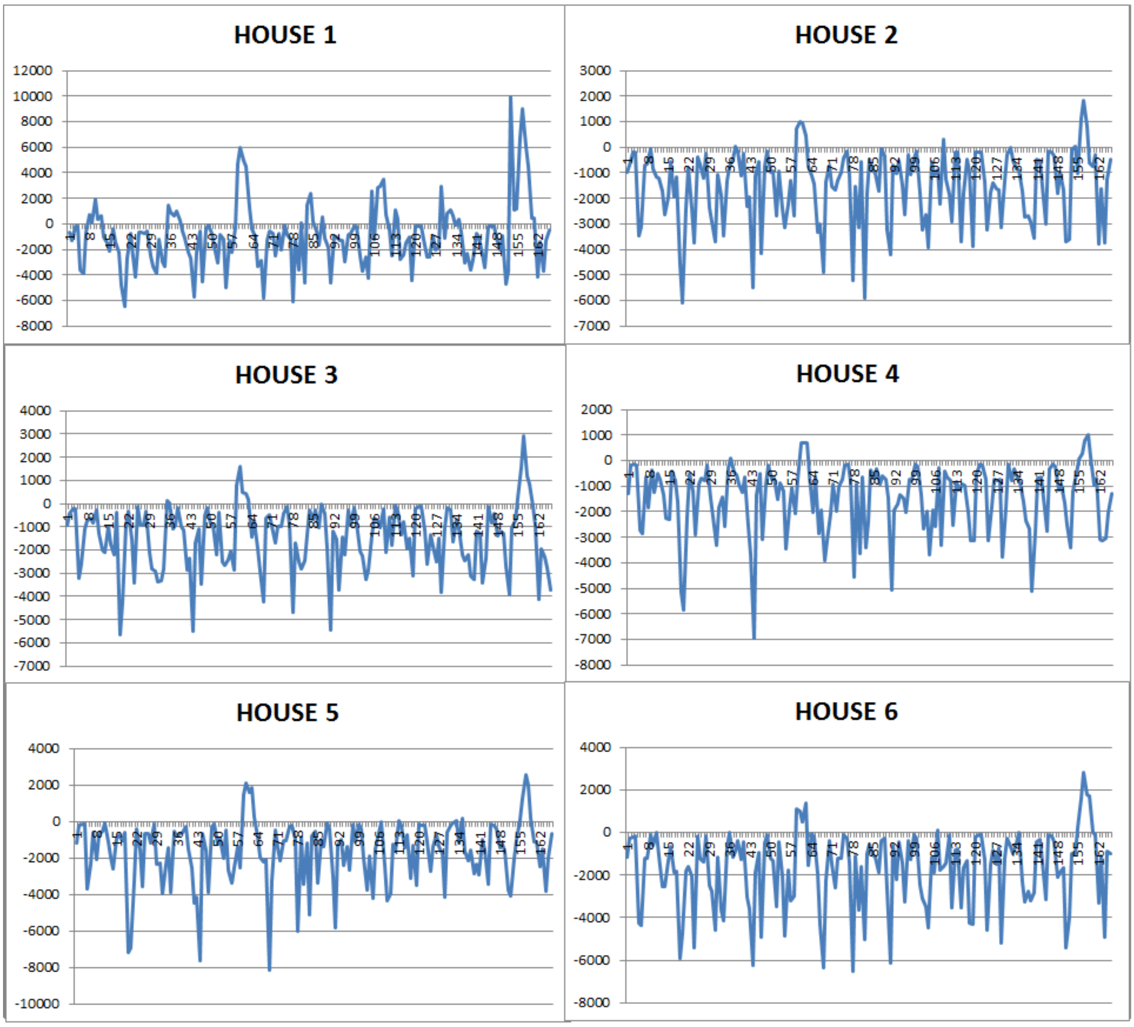

Figure 5-27: Energy exchanged with the grid

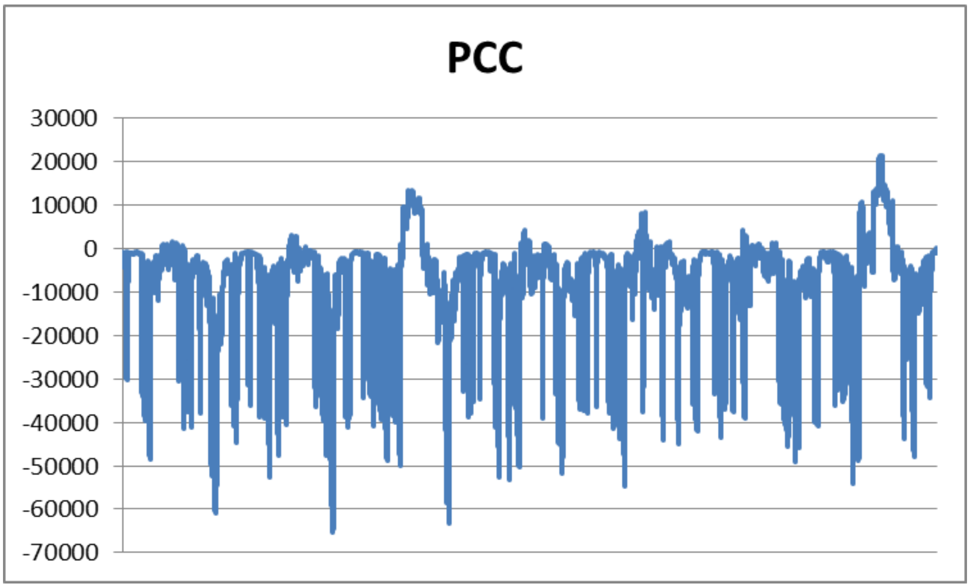

Figure 5-28: Energy exchanged in PCC

5.2.3 Without the battery and photovoltaics

In this case in addition to the “without the battery” configuration, , for the photovoltaics, a file input with all zero values is used..

5.2.3.1 Winter

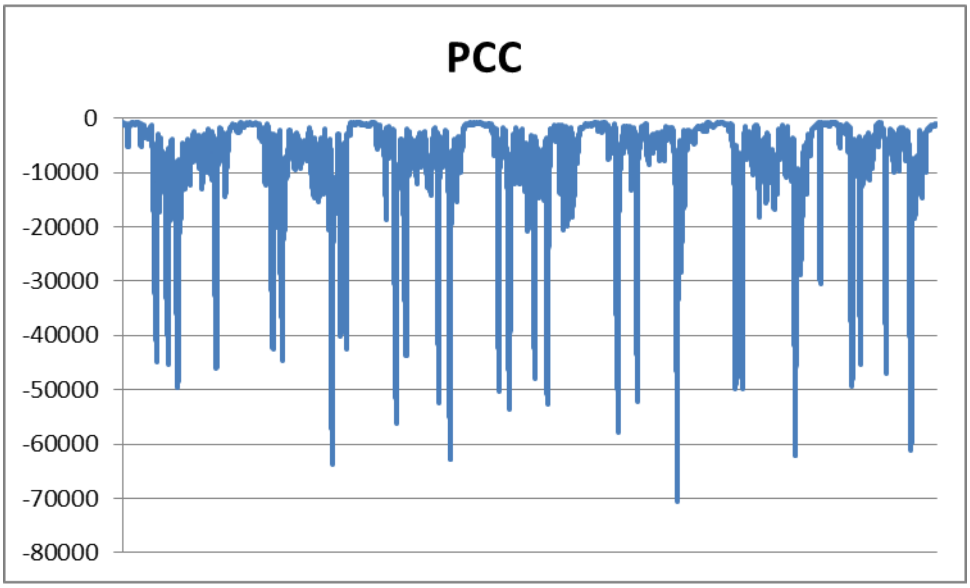

Figure 5-29: energy exchanger in PCC

5.2.3.2 Spring

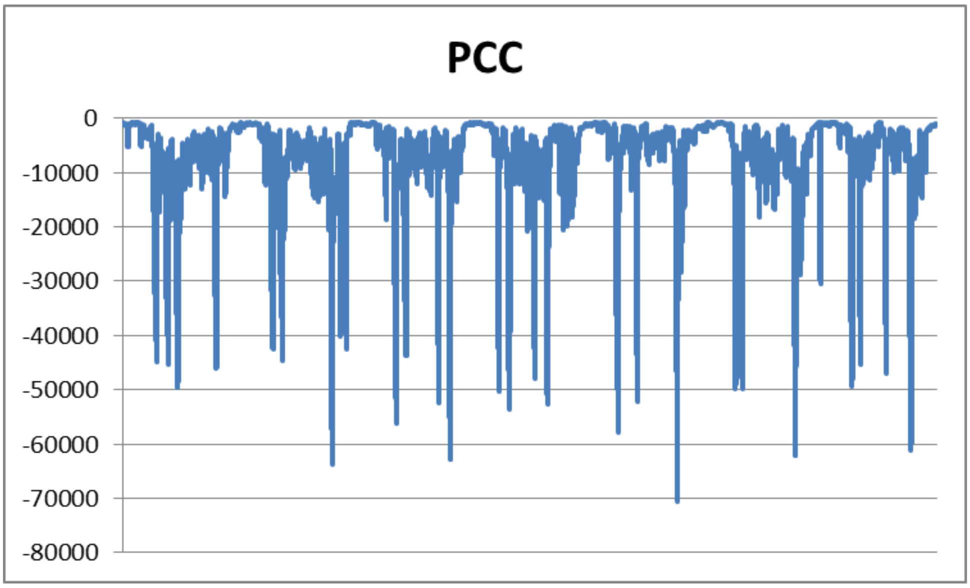

Figure 5-30:energy exchanger in PCC

5.2.3.3 Summer

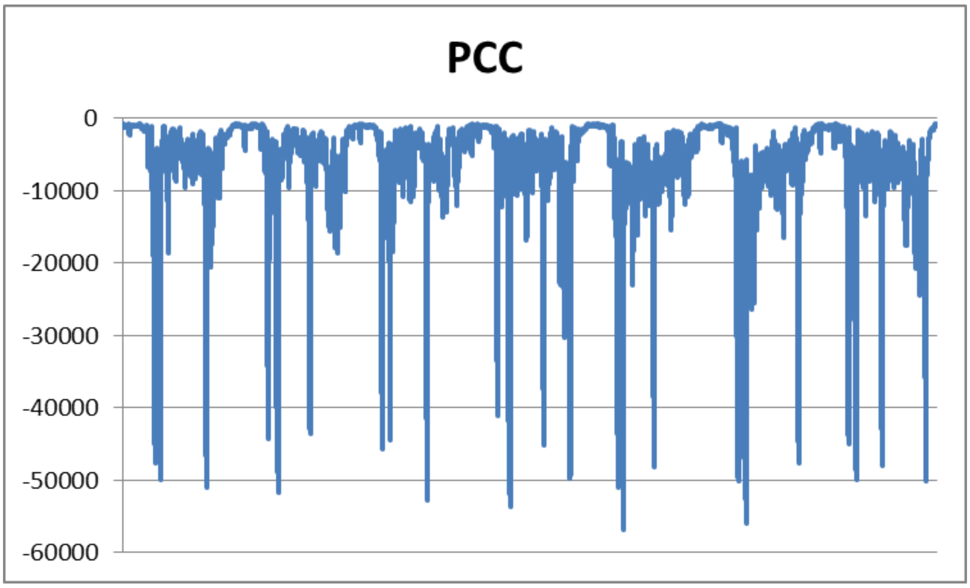

Figure 5-31: energy exchanger in PCC

5.2.3.4 Autumn

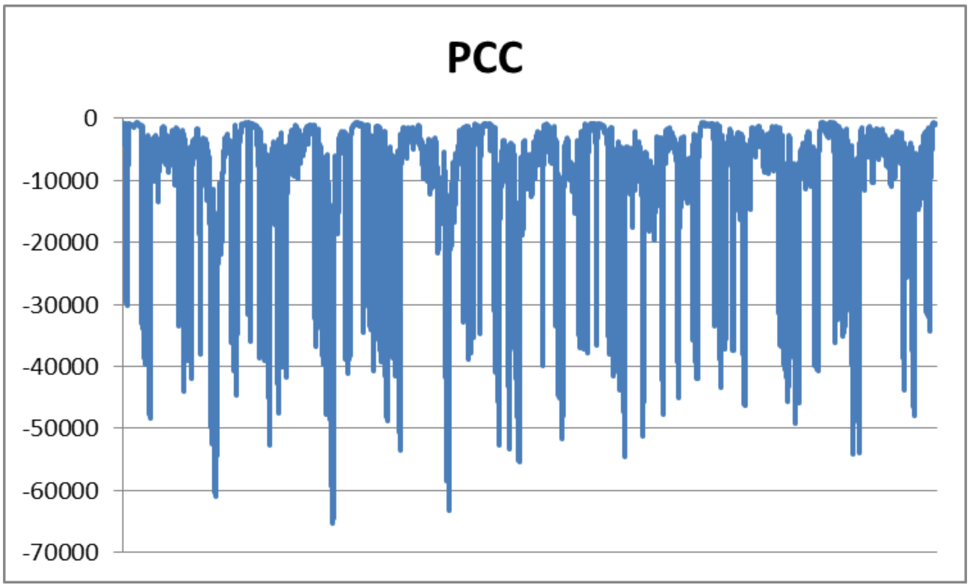

Figure 5-32: energy exchanger in PCC

5.3 Simulation for Italian model

The same simulations have been made using the Italian model parameters,. With the same configurations and the same conditions as were used for the German model. The photovoltaic production and the consumption are not shown, because above it said that the model supplied correct results, so it is not necessary to do a comparison with the input data.

5.3.1 Real configuration

5.3.1.1 Winter

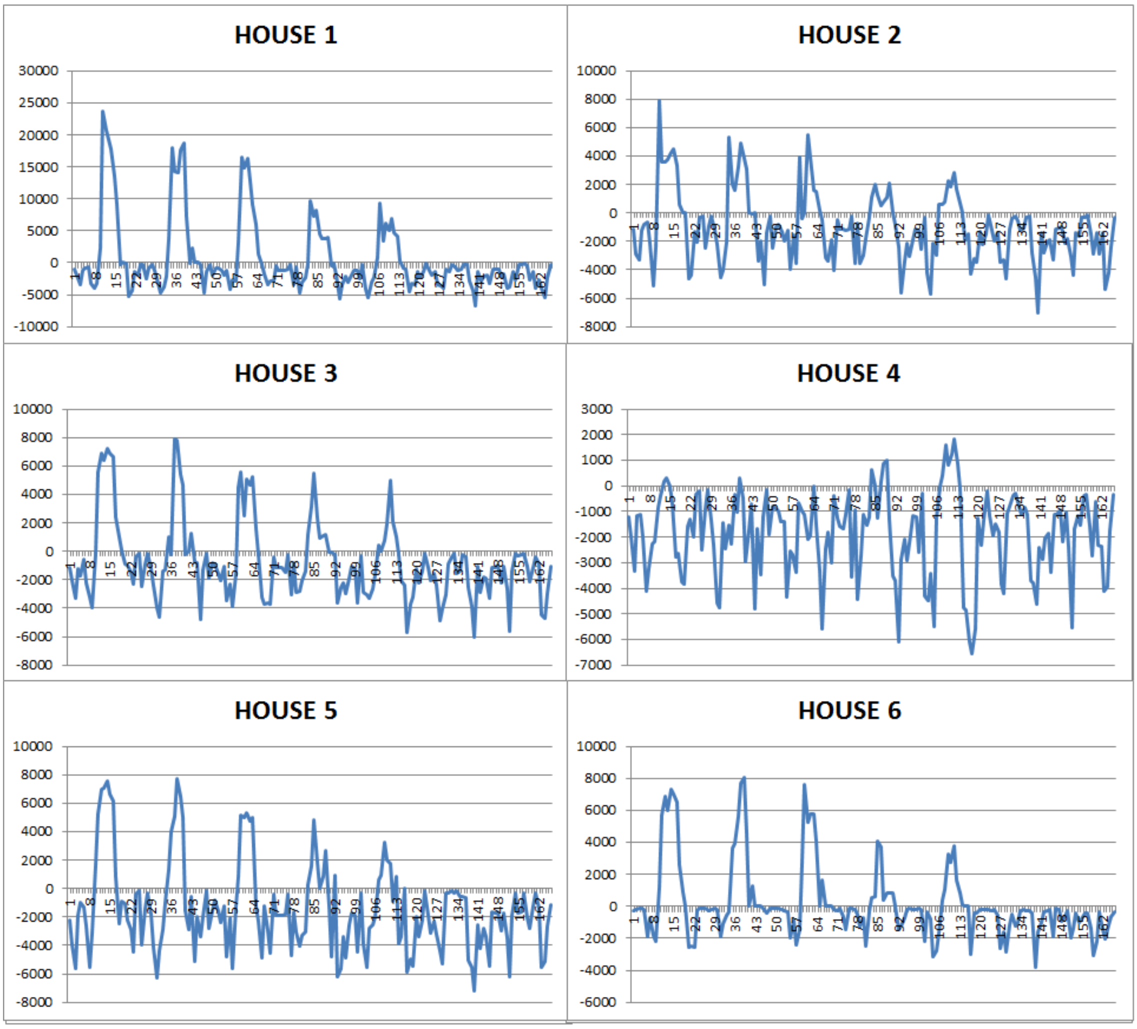

Figure 5-33:Energy exchanged with the grid

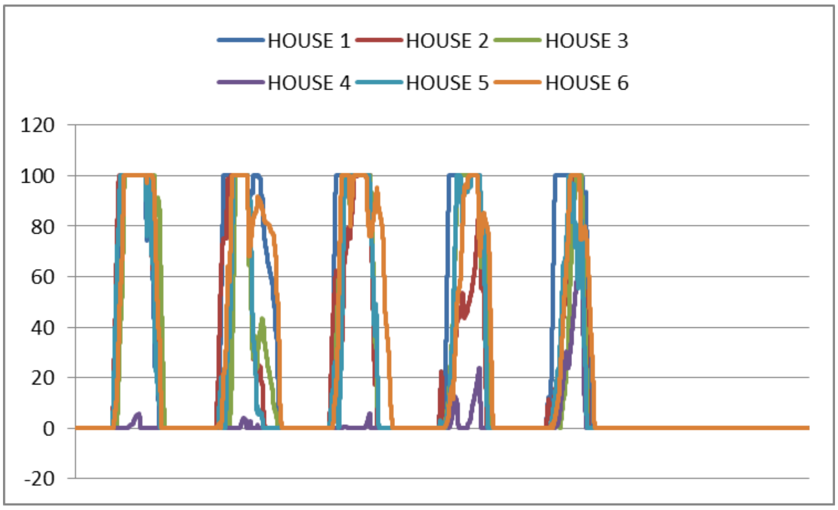

Figure 5-34: SOc of batteries

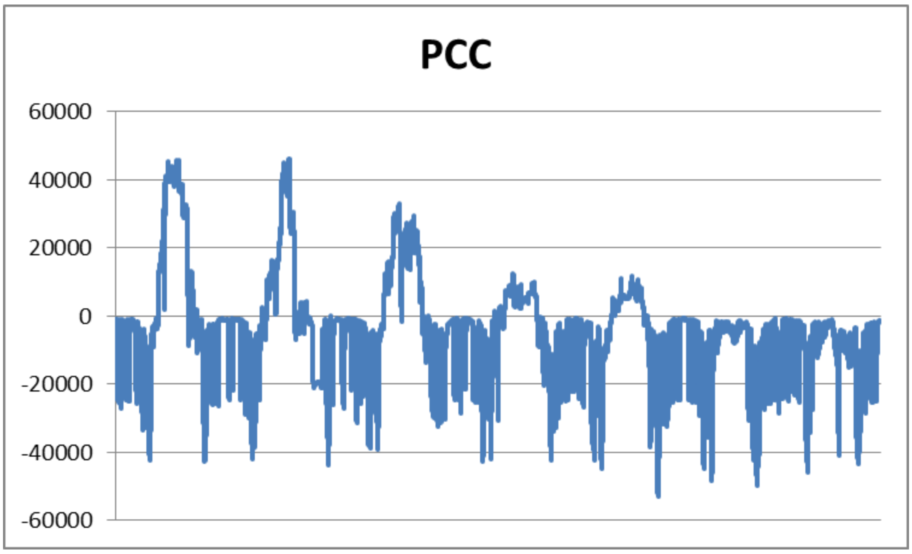

Figure 5-35: Energy exchanged in PCC

5.3.1.2 Spring

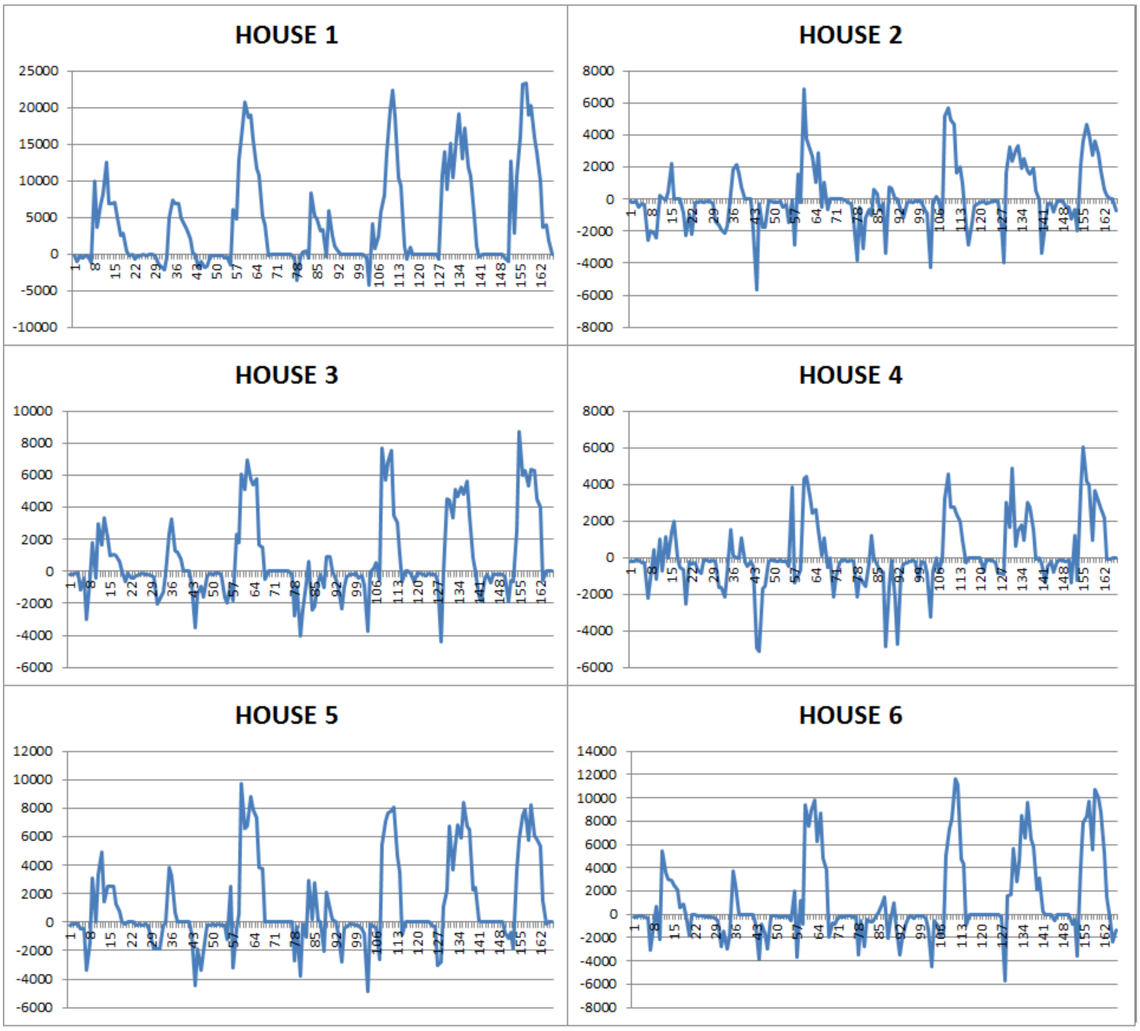

Figure 5-36: Energy exchanged with the grid

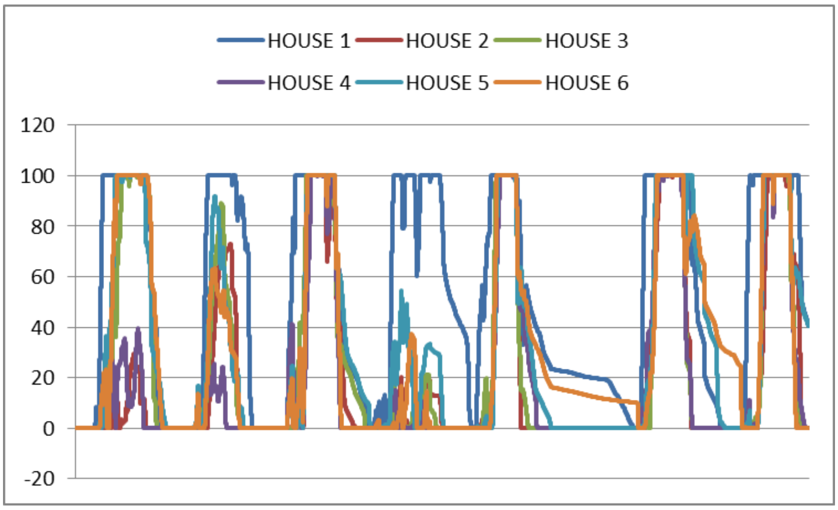

Figure 5-37:SOC of the batteries

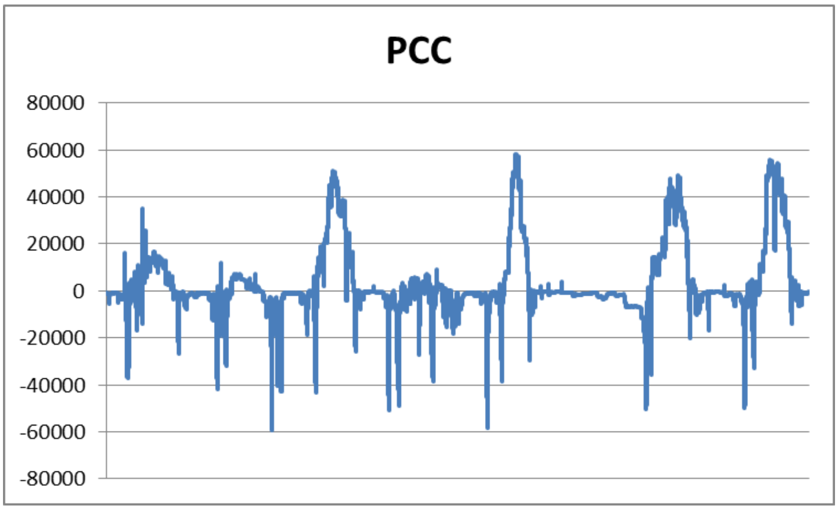

Figure 5-38: Energy exchanged in PCC

5.3.1.3 Summer

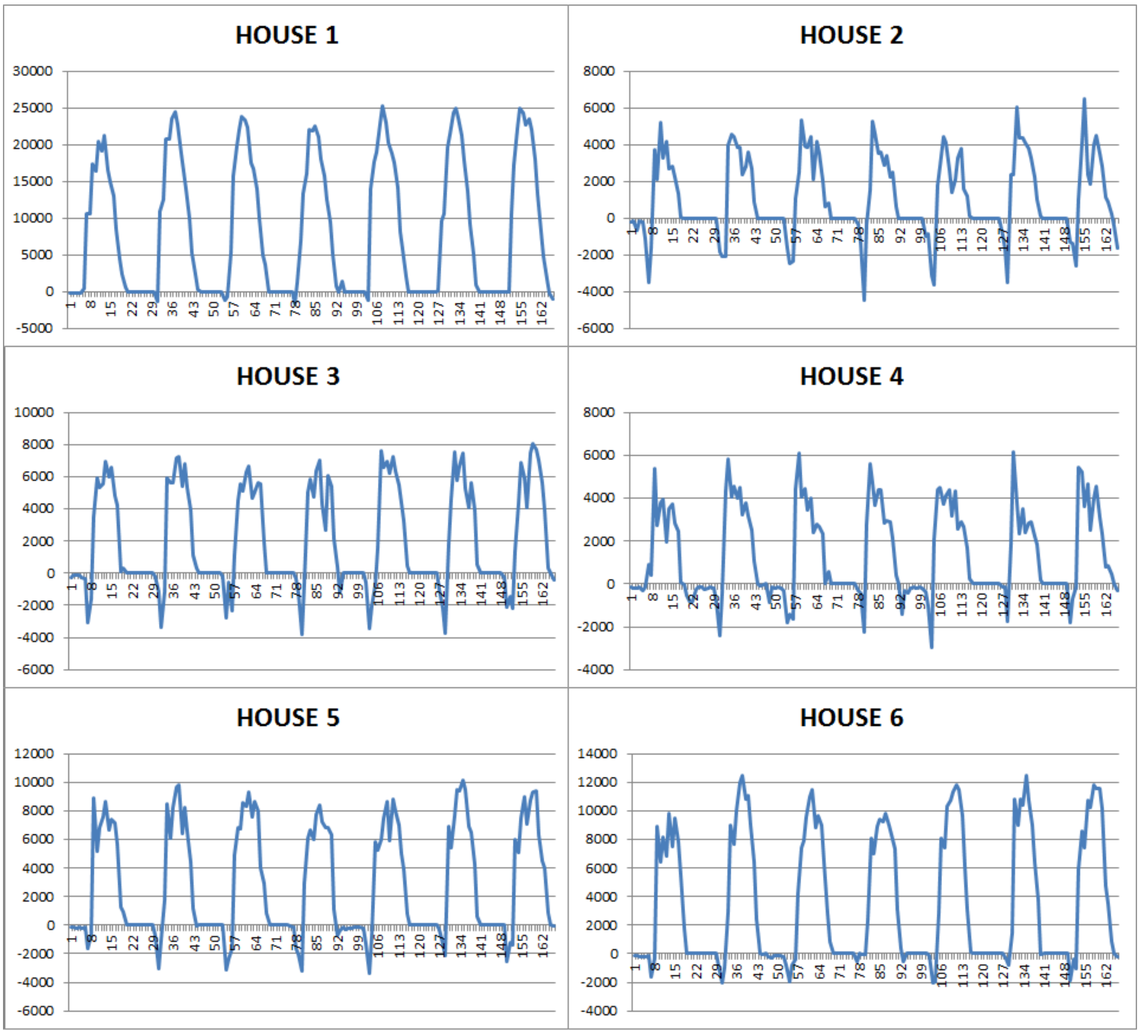

Figure 5-39: Energy exchanged with the grid

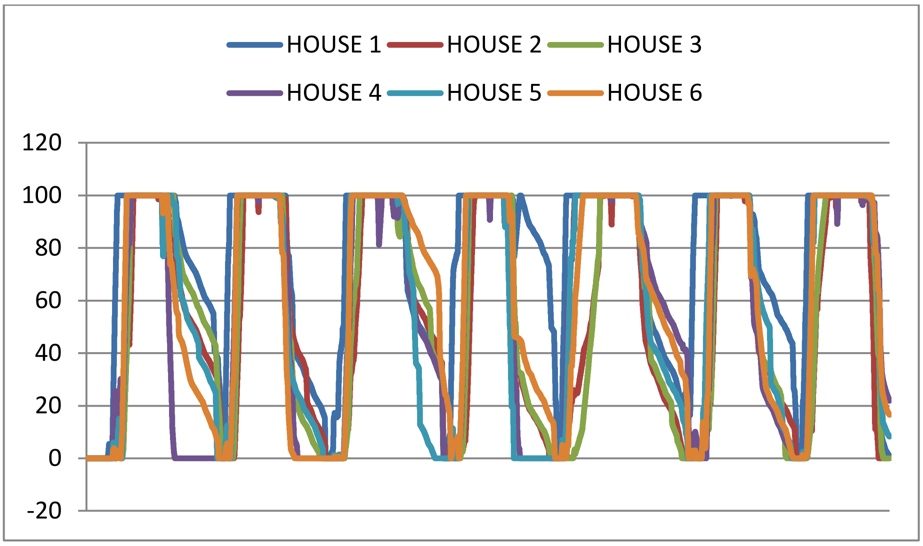

Figure 5-40: SOC of the batteries

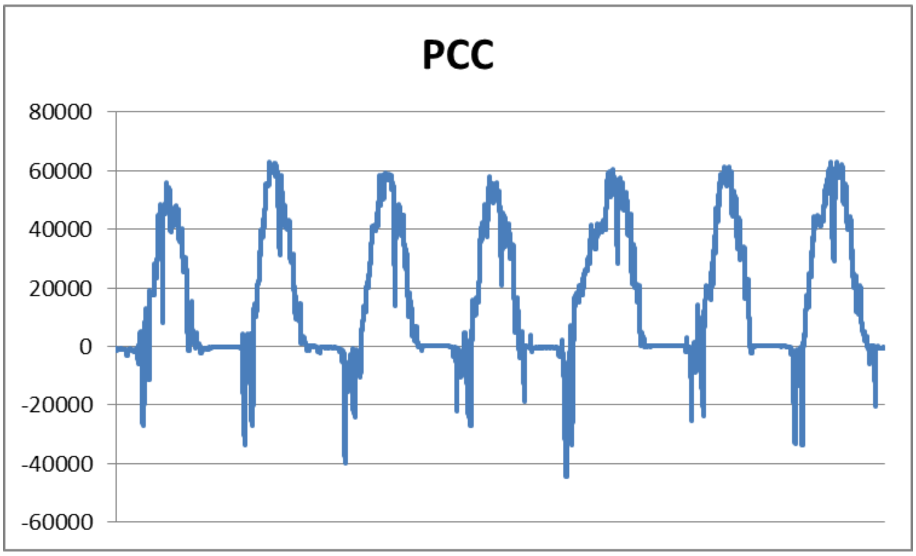

Figure 5-41:Energy exchanged in PCC

5.3.1.4 Autumn

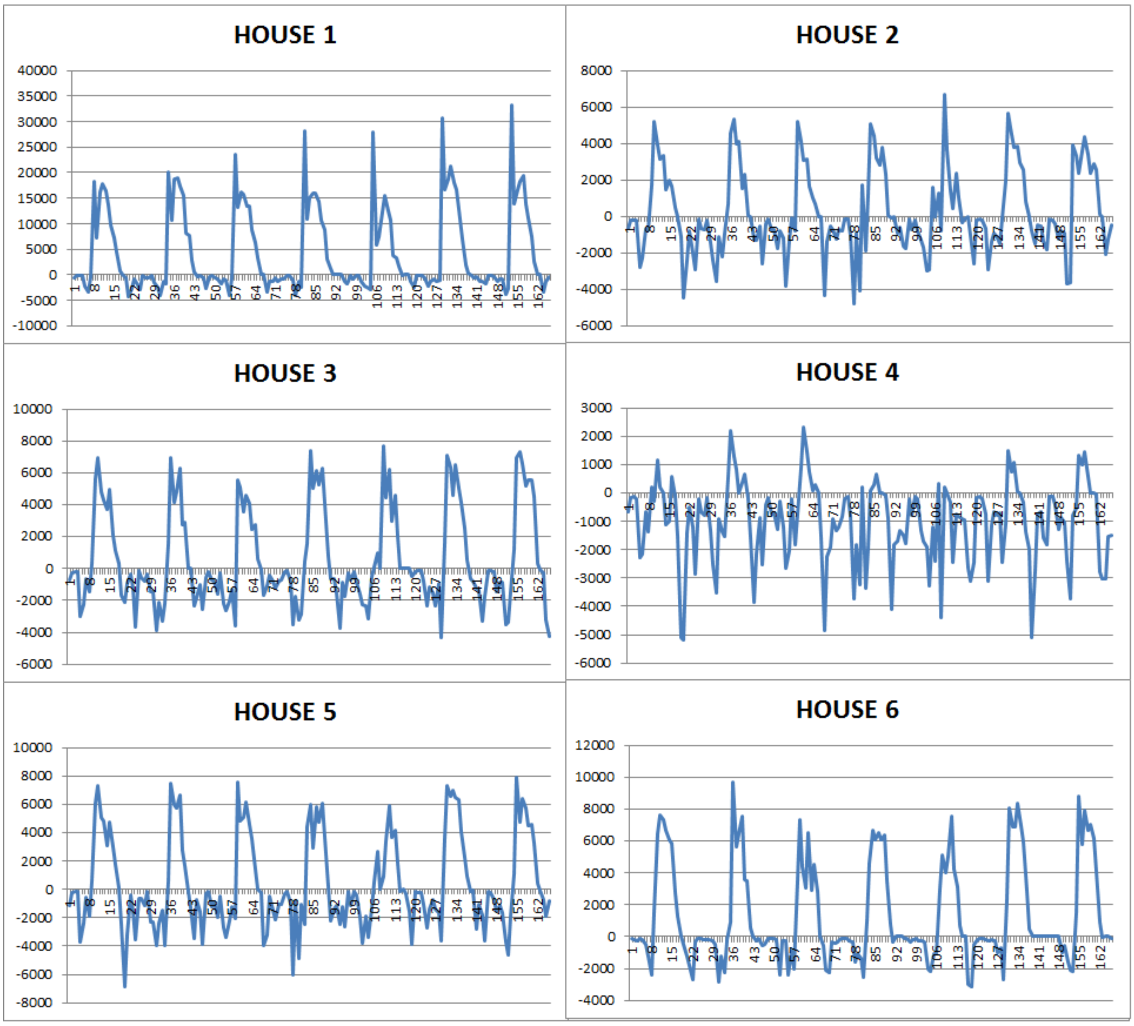

Figure 5-42: energy exchanged with the grid

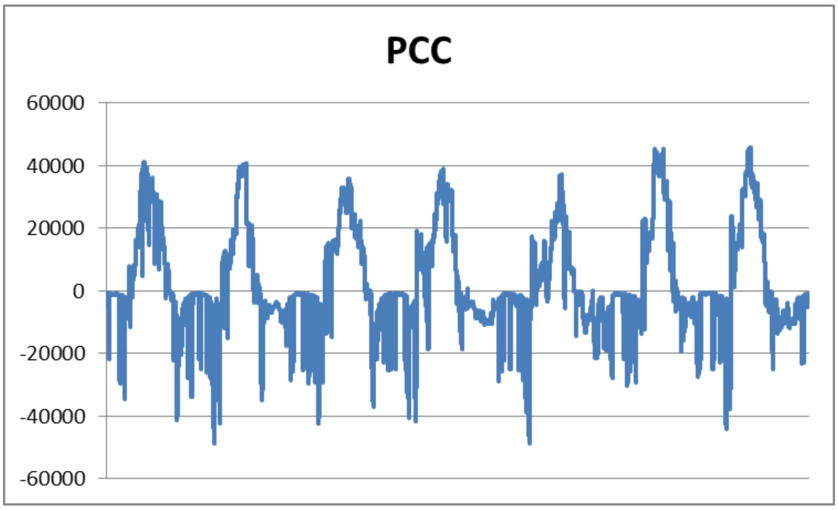

Figure 5-43: Eenrgy exchanged in PCC

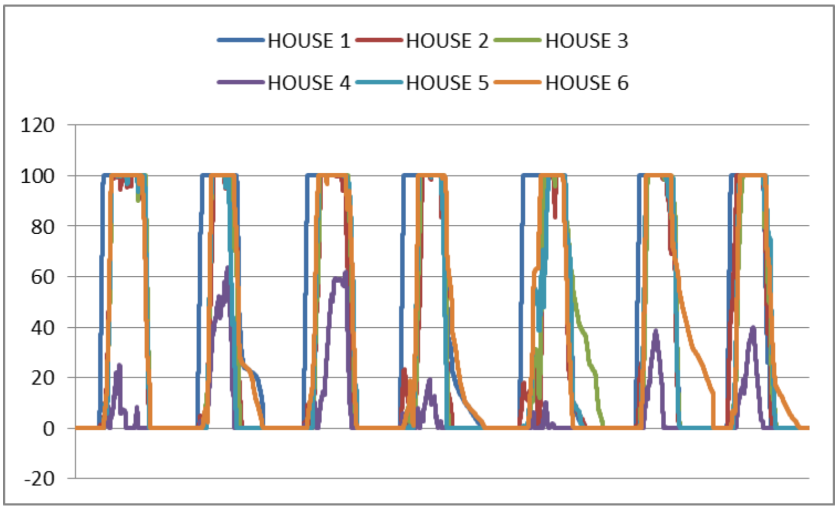

Figure 5-44:SOC of batteries

5.3.2 Without the battery

5.3.2.1 Winter

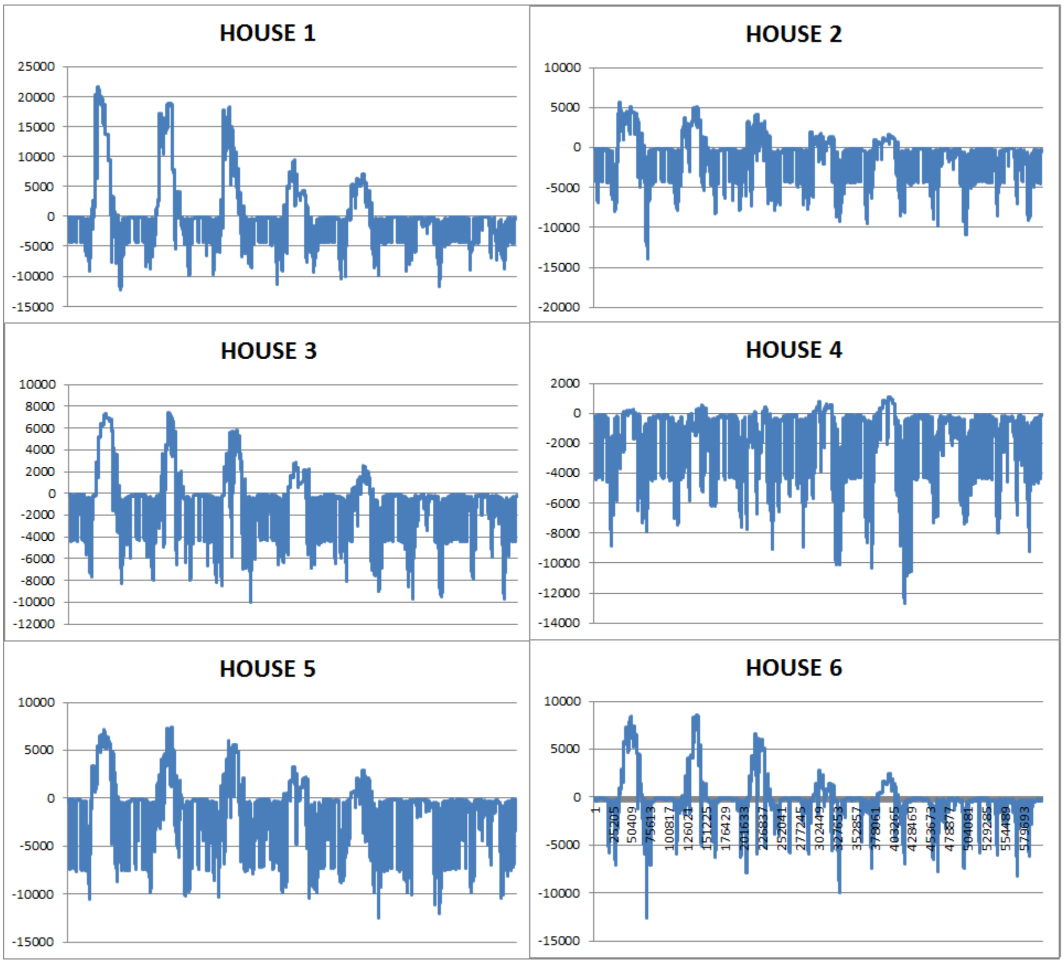

Figure 5-45:energy exchanged with the grid

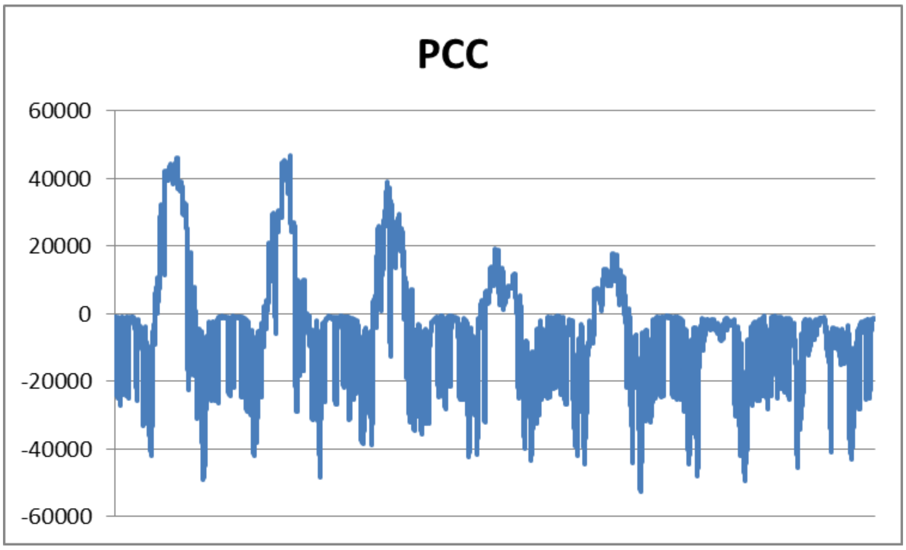

Figure 5-46: Energy exchanged in PCC

5.3.2.2 Spring

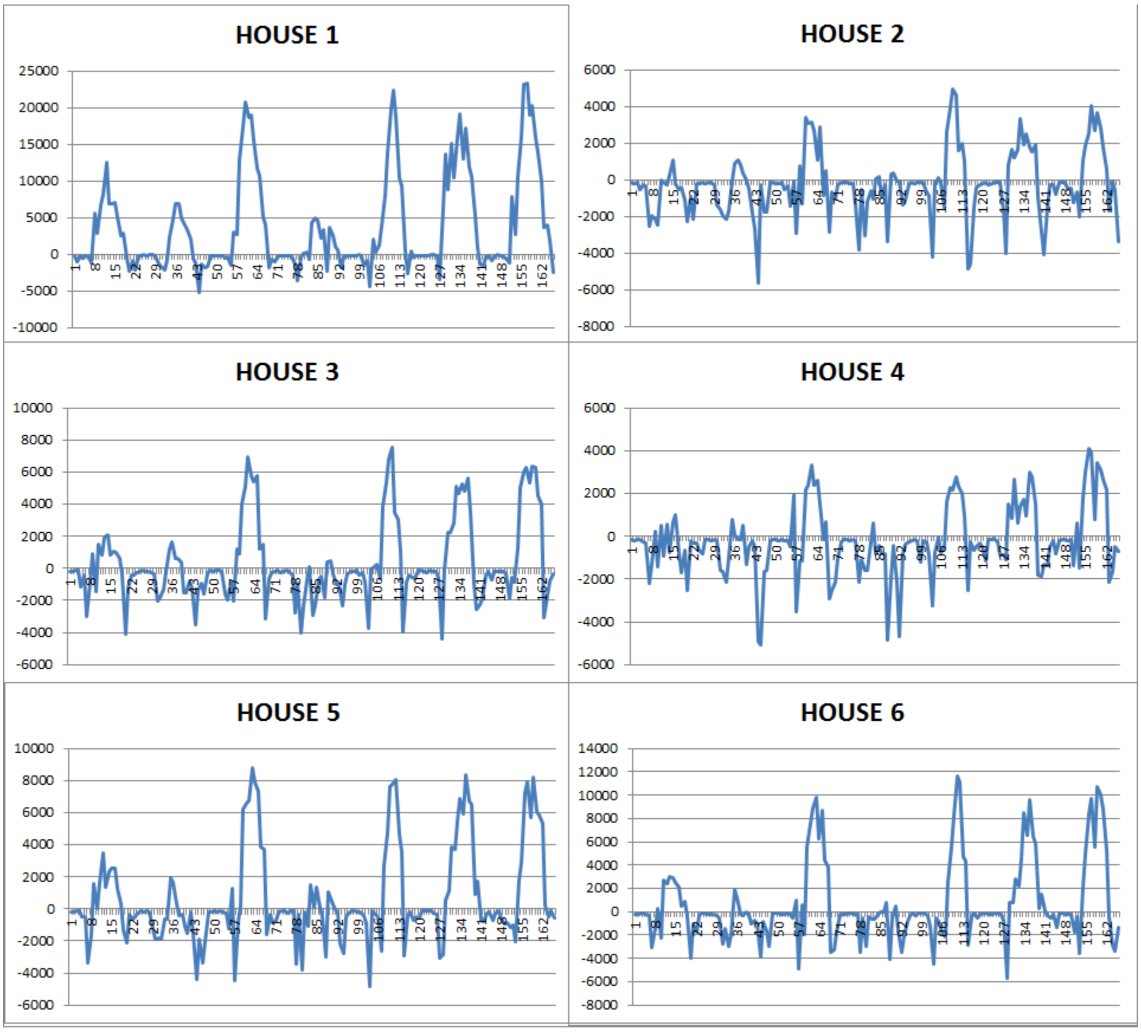

Figure 5-47: Energy exchanged with the grid

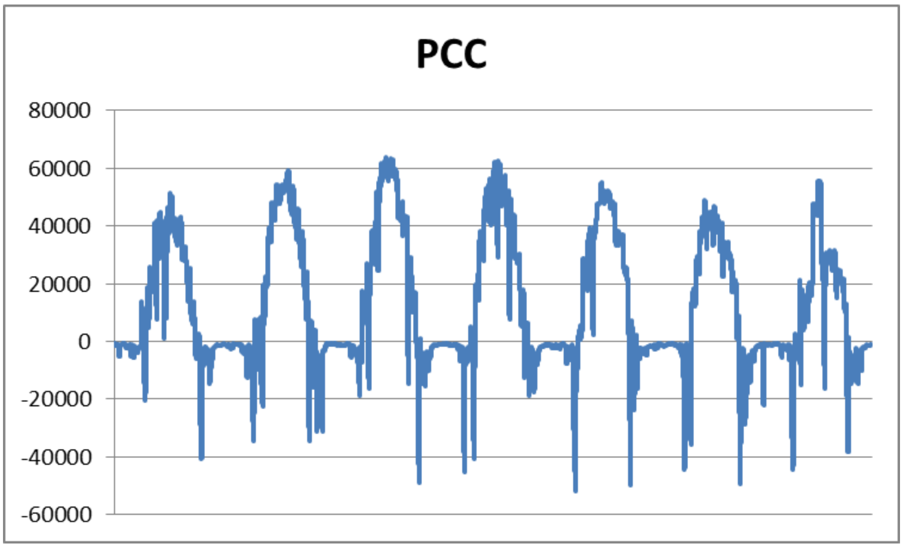

Figure 5-48: Energy exchanged in PCC

5.3.2.3 Summer

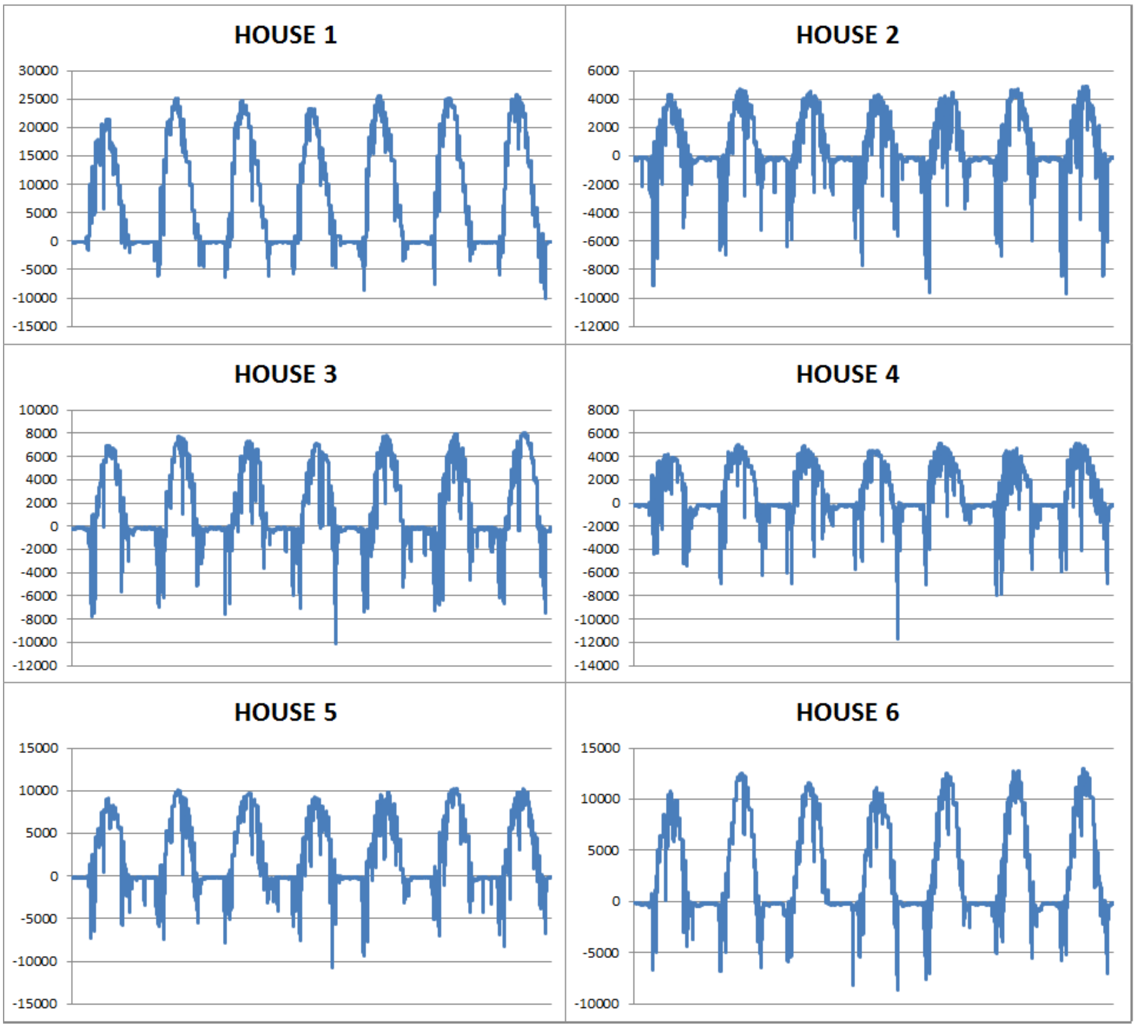

Figure 5-49: Energy exchanged with the grid

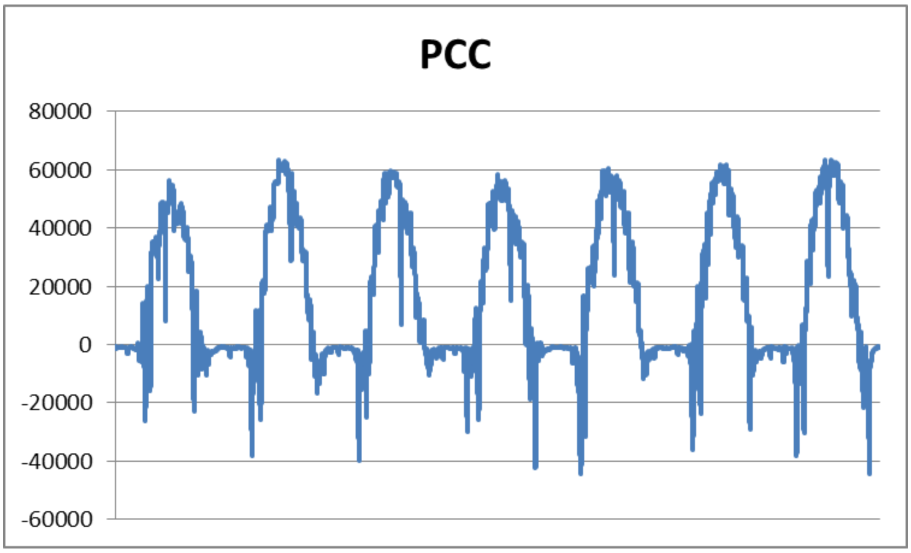

Figure 5-50: Energy exchanged in PCC

5.3.2.4 Autumn

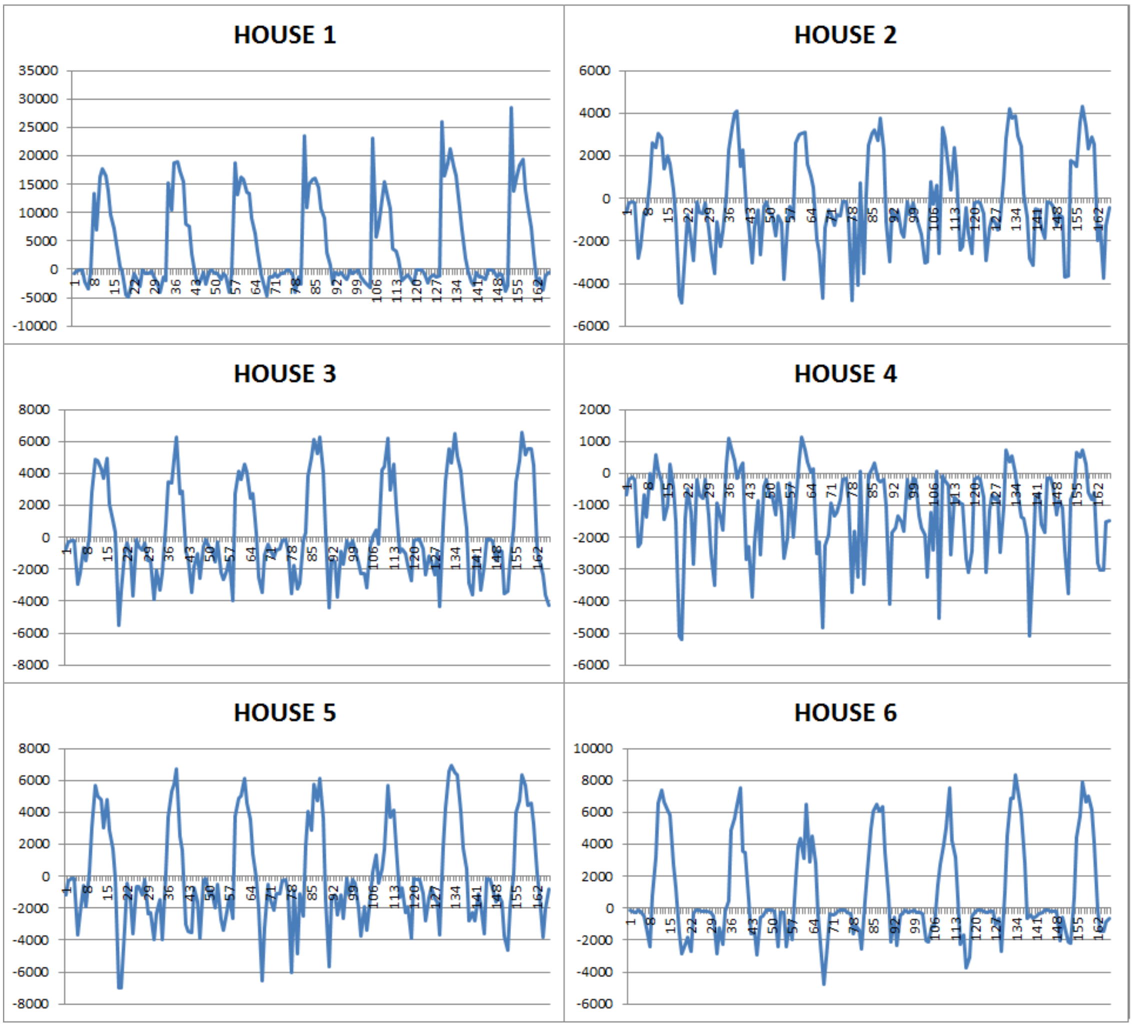

Figure 5-51: energy exchanged with the grid

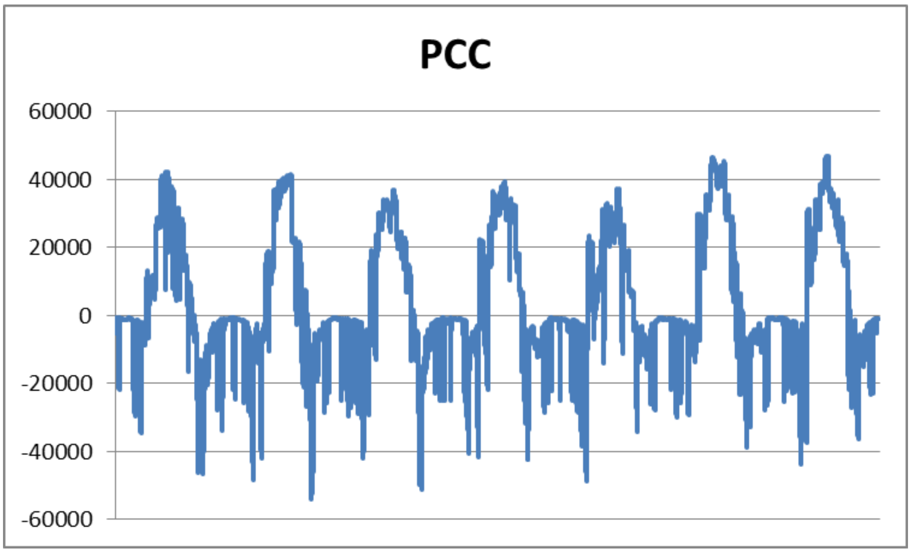

Figure 5-52: Energy exchanged in PCC

5.3.3 Without the battery and photovoltaics

5.3.3.1 Winter

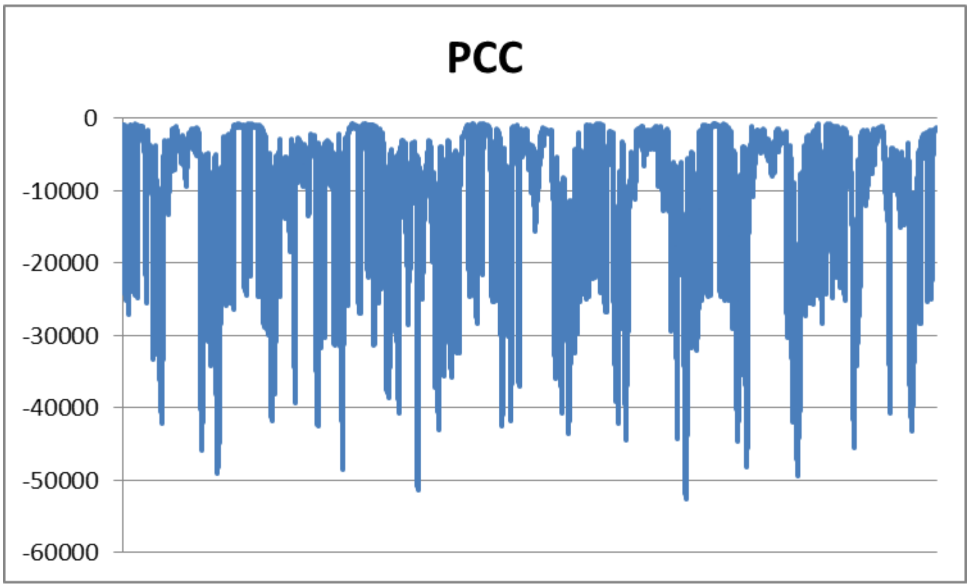

Figure 5-53: Energy exchanged in PCC

5.3.3.2 *Spring*

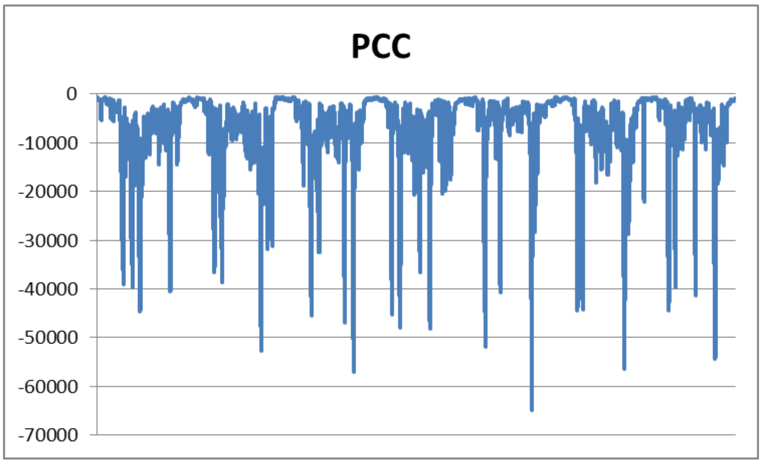

Figure 5-54: Energy exchanged in PCC

5.3.3.3 *Summer*

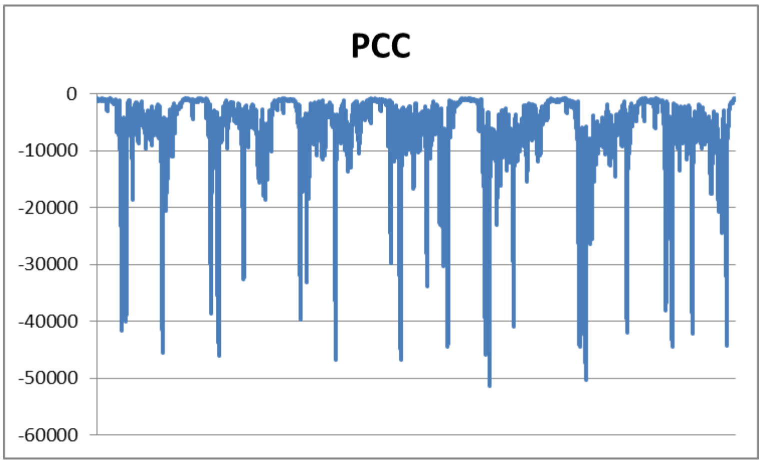

Figure 5-55: Energy exchanged in PCC

5.3.3.4 *Autumn*

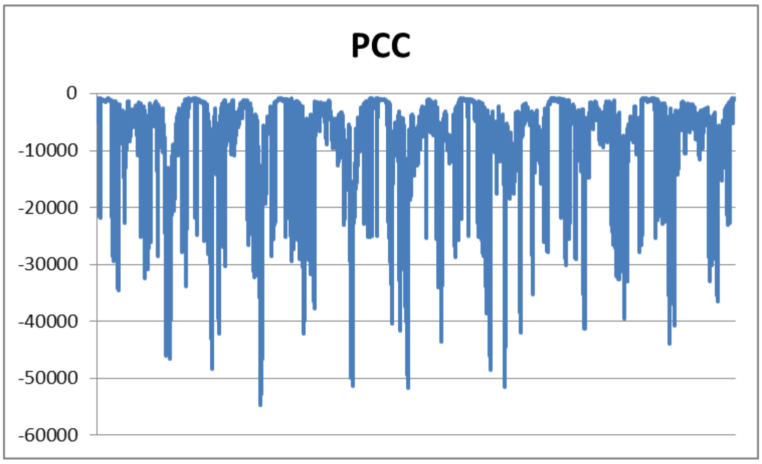

Figure 5-56:Energy exchanged in PCC

5.4 Security

As already stated in the introduction to the chapter, it is relevant to understand, if it is possible to work, in case of black out or failures, autonomously from the grid for a long time. Looking at the results in chapters 5.2.1 and 5.3.1, it is only feasible to do this in spring or summer, because the photovoltaic production is high. The battery installed in the houses is not big enough. 5 kWh is a significant energy capacity, but for security it is necessary to have a margin in the case of bad weather or other things that can decrease the photovoltaic production. The market offers more types of domestic battery, with higher capacities. For example, the Tesla Power Wall 2 CC is a battery with 13,5 kWh and it is perfect for this case. So the models are changed, using the data for this new battery and the simulations have been re-run.

5.4.1 German model

5.4.1.1 Spring

The Figure 5-57: SOC batteries shows the results of this simulation. The first days of the week there are no much photovoltaic production, so the battery do not charge completely, but when there is more photovoltaic production, there is the possibility to have the "Security".

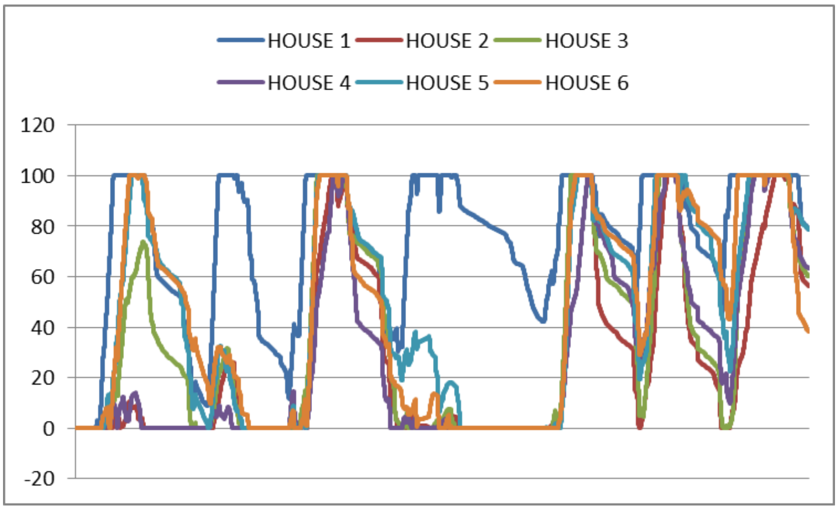

Figure 5-57: SOC batteries

5.4.1.2 Summer

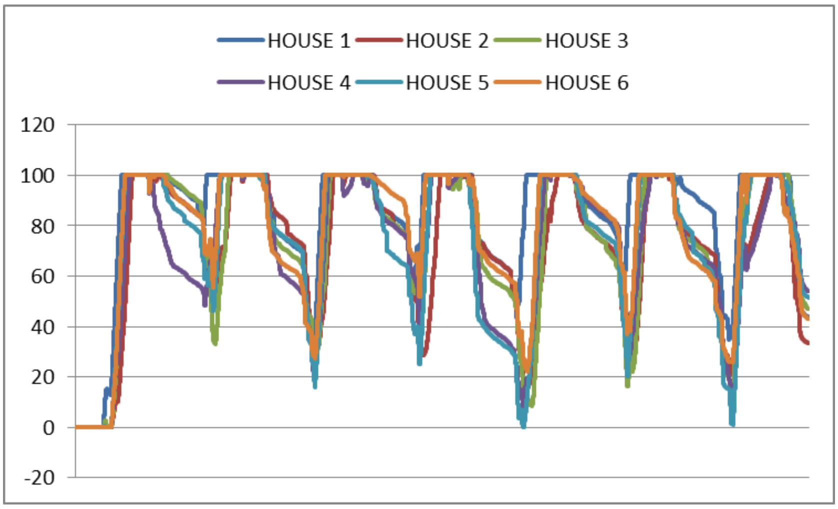

Figure 5-58: SOC batteries

5.4.2 Italian model

5.4.2.1 Spring

As above, if the photovoltaic production is small, there is no the possibility to charge the battery and to have "security". HOUSE 1 is autonomous the always days, this is much significant.

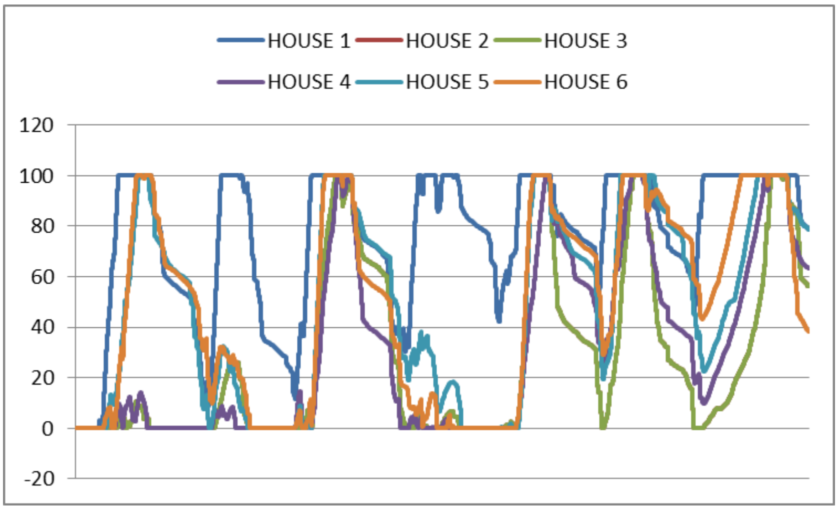

Figure 5-59: SOC batteries

5.4.2.2 Summer

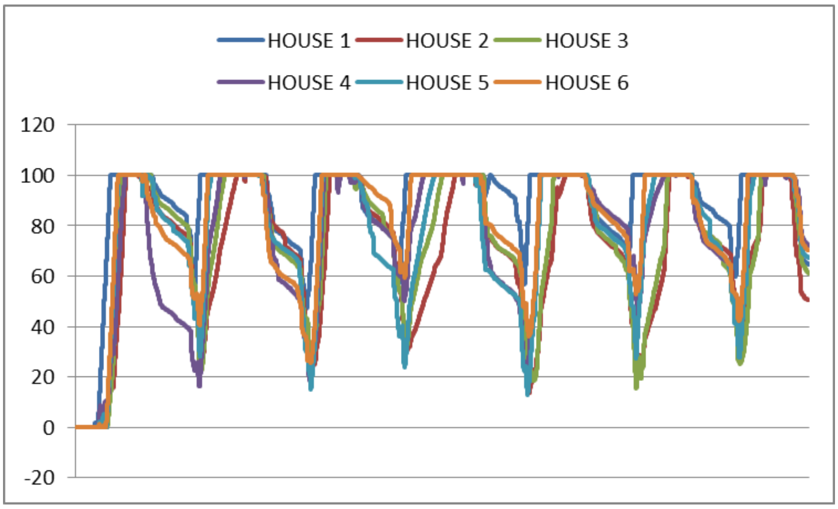

Figure 5-60: SOC batteries

6 MODELLING CENTRAL BATTERY

6.1 Introduction

In this chapter a virtual configuration is presented. So in this case, the real configuration of the microgrid is not considered in the rural zone, but a new solution for the six houses system is presented, which is useful for making an economic comparison. The real configuration of the microgrid is a system where each house has a battery and can be called a "decentralised battery" configuration. In this chapter, a system is analysed where there is only one battery for the six houses. This is called the "central battery" configuration. In this case the power losses in the cables increase compared to a solution with the six batteries, because the system regards the big battery as a generator, so the power flow is high. The new microgrid scheme is shown in the Figure 6-1: new microgrid scheme.

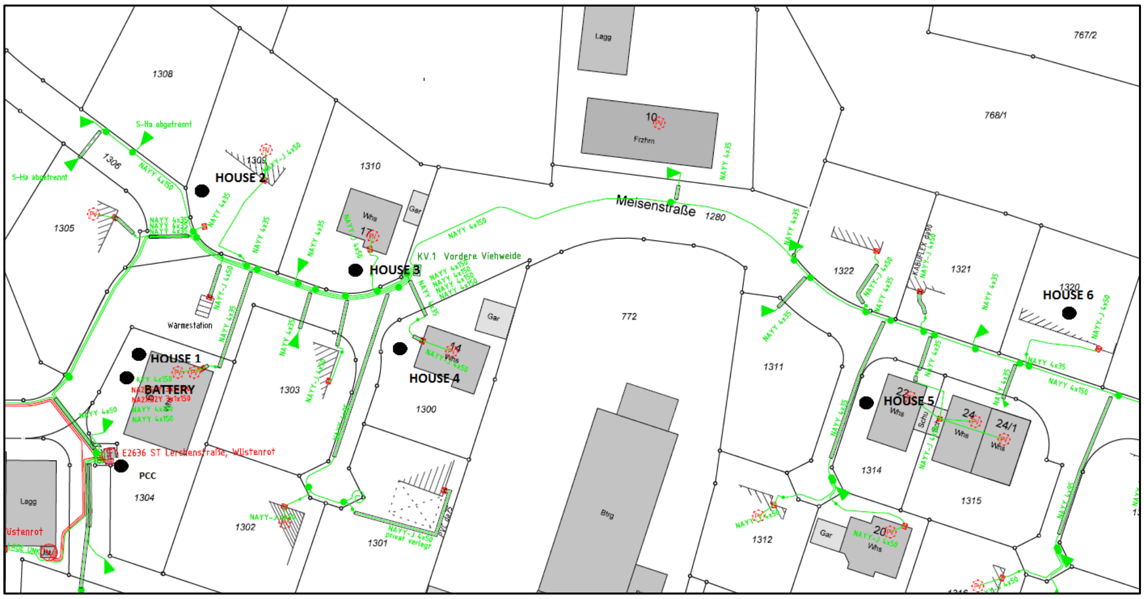

Figure 6-1: new microgrid scheme

The results from chapters 5.2.2 and 5.3.2 are used to create the new model, *viz* Simulink simulation "without battery", using a system with a central battery can be created. Excel software was used to make this model.

The results utilized for create, are the powers measured near the houses. The output names from Simulink are: GRID 1, 2, 3, 4, 5 and 6. These data represent the positive and negative or null values of power (demands and offers by the house), depending on if there are surpluses or deficits. The battery installed in the new model has a power of 28.8kW, considering that the previous model had a power of 4800W, it has been calculated as 6x4800 (thus the power for the home's battery)=28800.

6.2 Description

Five steps are necessary to make this model, which are the same for both countries.

The first step is to analyse the input data, it is necessary to take the positive values for each house, which are the surpluses of power, when the house feeds energy into the grid. These power quantities are summed to give the total surplus of the system. Then it is necessary to analyse this sum with a function that works: if it is less than the battery power, it gives the sum, otherwise it gives the maximum battery power. In this step is explained the charging phase of the battery.

The second step is take the negative values, when the grid supplies energy to the houses, so it is possible to know the power demand for each house. Considering the condition where the battery is installed near the first house (HOUSE 1), it is necessary to formulate a function that consider the discharge phase of the battery and the control of the contribution of the battery for the power demand of the houses. If the storage is installed near the first house and the battery is charged, then HOUSE 1 is the first to receive the power from the battery, and then HOUSE 2 receives the energy. Otherwise the grid supplies the houses, and then HOUSE 3, HOUSE 4, HOUSE 5 and HOUSE 6, using the same conditions. So to simulate the discharge phase, there must be a function that simulates the states above.

The third step is to create the battery control of the system, *viz* the charging and discharging phases of the battery in the same function. The battery contribution is made as was said above, where the storage supplies power to the first house, then if it is sufficiently charged gives power to the second house, and continues in this way until the last house. The total power demand for the battery is obtained summing the battery contribution for each house. The battery control function is created, knowing the power demand and charge phase of the microgrid together.

The last step is the calculation of the new consumption and production of power for the houses. For the former, it is easy to know the new demand, for the latter it is not so, because it is necessary to understand how much charge is contributed to the battery from each house. For the consumption, it is necessary to take the old power demand and subtract the battery contribution, this method is repeated for each house. For the production, it is necessary to calculate how much surplus power the microgrid system has, then it is necessary to know how this power surplus is divided between the houses. It is necessary to calculate the proportion of power that the houses supply to the battery. The new production (the new power surplus of the house) is calculated using this proportion and the power not used in the charge phase function.

7 MODELLING ENERGY EXCHANGE

7.1 Introduction

Another virtual configuration for the microgrid system is presented in this chapter. The important aspect of this new model is the energy exchange between the houses. Analysing the results of the chapters 5.2.1 and 5.3.1, the SOC of the batteries in spring and summer during the night is not 0%. So often the battery does not discharge completely. This represents an energy loss because is not utilized and maybe in the same instant there are other houses with the battery completely discharged and they were using energy from the grid. This is a waste of energy, is not a good thing for the environment and for the management of the grid.

There is a possible scenario, for example where there are two neighbouring houses with batteries, one with a family with an electric car and the other a small family, that does not consume more in the night. So it is possible to consider that in the night the first family charges the electric car, with a high load and maybe only a domestic battery is not enough. If the second family has a small load in the night, and maybe does not discharge the battery and it could for example supply this energy to charge the electric car, at a special price, so it is cheaper for both. This example could be applied in real life.

For the management of this energy exchange it is necessary to create an energy flow control. A new model for the microgrid system that work as said previously, with an energy exchange between the six houses has been created. So, in addition to the continuous energy exchange with the grid , there is a new exchange between the houses. Excel software was also used the for the creation of the model.

7.2 Description

To define the exchange energy between the houses, it is necessary to have two inputs for each house. One is the SOC of the battery, the other is the measured power near the houses. The concept is to supply the neighbouring houses, using the excess power from the battery,. In the model, they are close, so it is possible to think of a supply from a battery the all houses.

The graphics of the SOC of the batteries show, that the HOUSES 1, 5 and 6 often do not discharge the batteries in the night in some days in spring and summer. It is necessary to create a control that allows the discharge of these batteries, but that leaves a security margin of power for an eventual peak load, which has been set at 15% of the battery capacity.

In the both countries the energy price is divided in two time slots, one daytime and one nightime. Only the night data is used in this model. So the new control is only for this period, for the daytime the control of the Simulink model is used.

Using the security margin and inputting the values of the SOC and power, it is necessary to define what is the priority of supply for the houses. This is defined in according to the distance between the house, in this way:

- HOUSE 1
- HOUSE 2
- HOUSE 3
- HOUSE 4
- HOUSE 5
- HOUSE 6

In this configuration additional to the traditional meters, for the German model (domestic load, photovoltaics and heat pump) and for Italian model (domestic load and photovoltaics), there are two new meters for the exchange energy between the houses. The first, it is for measuring the supplied energy, and second for the received energy.

For the simulation model two functions are necessary. For every house it is necessary to set the above conditions, then it is necessary to set the functions for the received and supplied energy. For the first, it must be verified if the neighbouring house has the necessary battery charge, respecting always the security margin. If this condition is not met, it must verified if another house, depending on distance, has the battery charge and so on. If all batteries do not meet the condition of the 15% margin, the grid supplies the houses. For the second function, it is necessary to set the limit of the security margin, if it is in the limits the battery can supply the other houses, this also depends if in that moment there are demands of energy. The supply of energy must comply with the condition of the distance, in accordance with what was said above. So the first house that is supplied is the nearest one, then the second and so on.

Is important to recalculate the new SOC every time that the battery supplies other houses, until it arrives at the margin limit. Another important thing is to calculate the new power cost at the grid. The first is calculated taking the old SOC and the power supplied at the other houses in the same instant is subtracted. For the second, it is necessary to take the old power demand of the house subtracted by the received power from the other houses, because the powers have different prices.

So in every moment of the night, it is possible to receive energy from the other five houses or the possibility of giving energy to the others.

8 SIMULATION CENTRAL BATTERY/ENERGY EXCHANGE

8.1 Introduction

Using the new models, “central battery” and “energy exchange” can give new results for comparisons with the real microgrid system. These two solutions could be adopted in real life, maybe the control of the whole system it is a little hard compared to the first model. Both use the input data from the results of chapters 5.2.2 and 5.3.2. Simulink simulations. In these cases there are not a verification control, because they are virtual solutions and there is no data verification. The simulation results are explained in different sub-chapters for both countries.

With these solutions, it is relevant to look at the new power flow between the houses and the grid, the SOC for the battery and the new measurement of power for the house. So for all simulations for the two models the following are measured:

- The new battery SOC
- The power measured in the PCC
- The power measured near the house, given by the new demand (loads) and offers (photovoltaics)

Also in these cases a simulation period of a week is used for both countries.

It is normal that in these cases the power flow in the cables is greater than the real configuration, between the houses and the battery there will be a continues exchange of energy. So in this case is not relevant to study the losses power in the cables, because there are not improvements in comparison the configuration “no battery”.

It is necessary to management the power “gave” and “asked” in the “energy exchange”. In the reality to have this solution it is necessary a control to decide the instant that use the cables, for the problem of power flow.

8.2 Central battery

The results for the German model and Italian model starting with the “central battery” solution are reported, for the different seasons. Four simulations have been made for each country.

8.2.1 German model

8.2.1.1 Winter

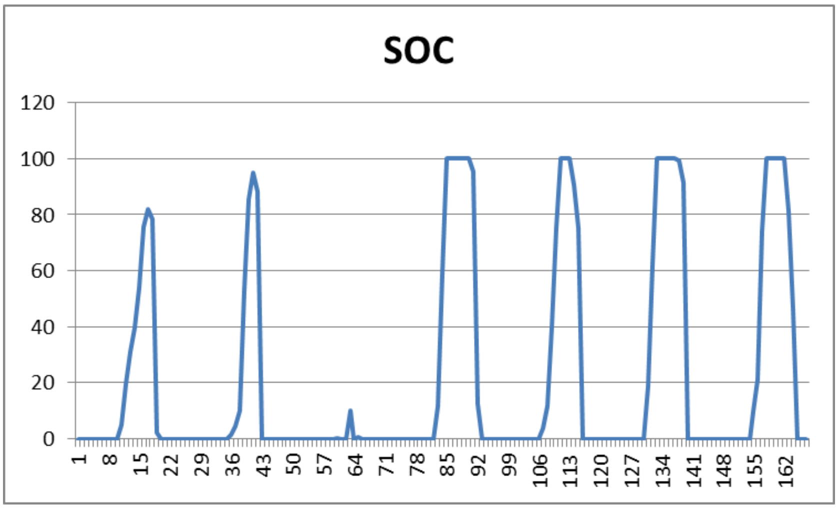

Figure 8-1: SOC of battery

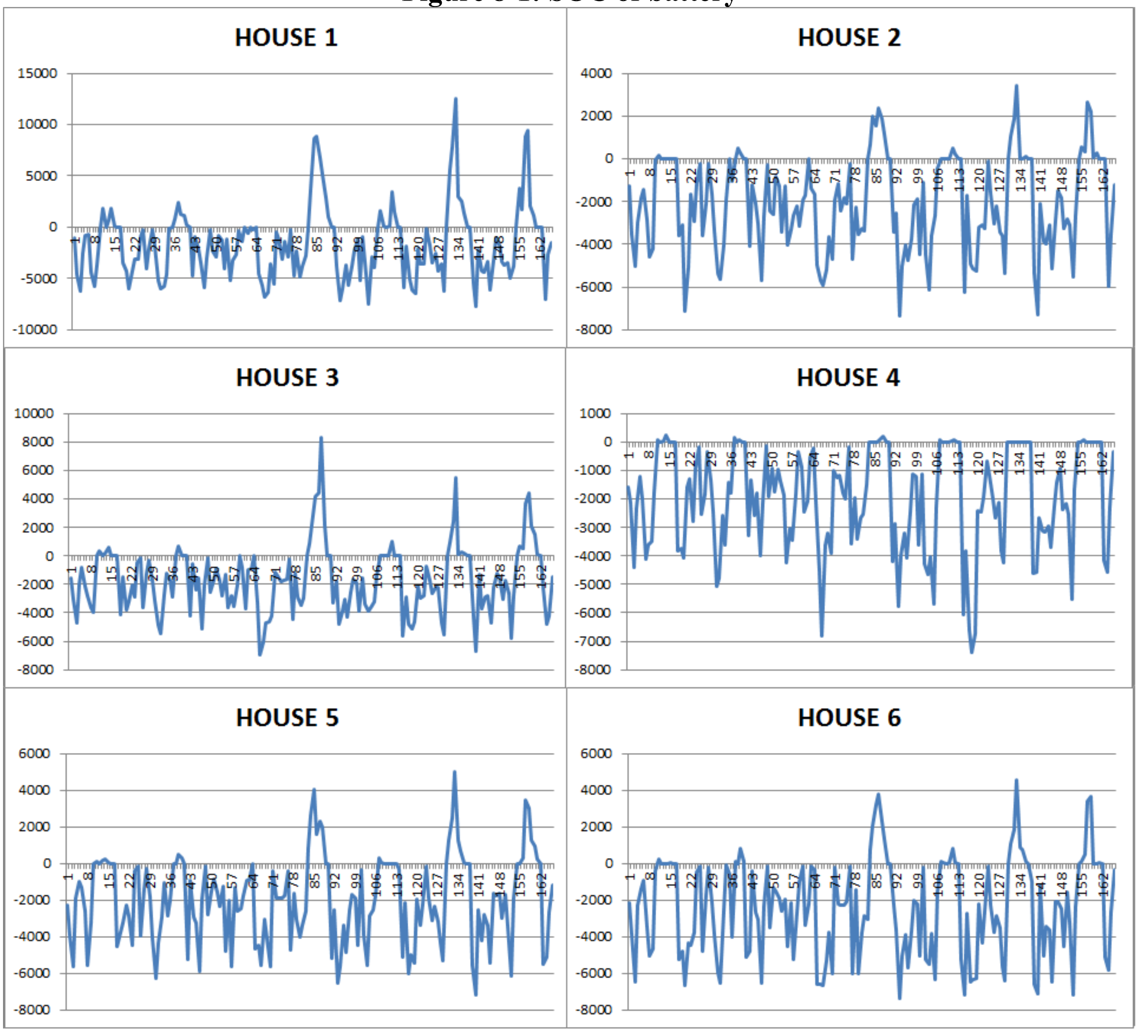

Figure 8-2: Energy exchanged with the grid

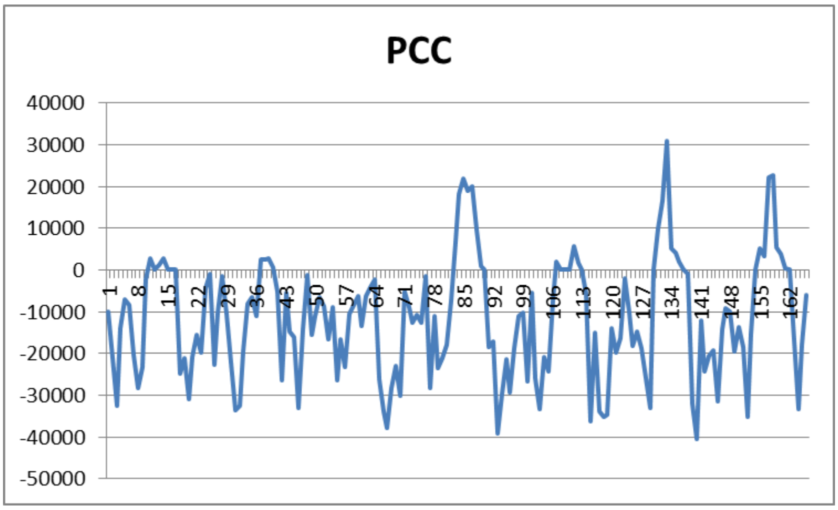

Figure 8-3::Energy exchanged in PCC

8.2.1.2 Spring

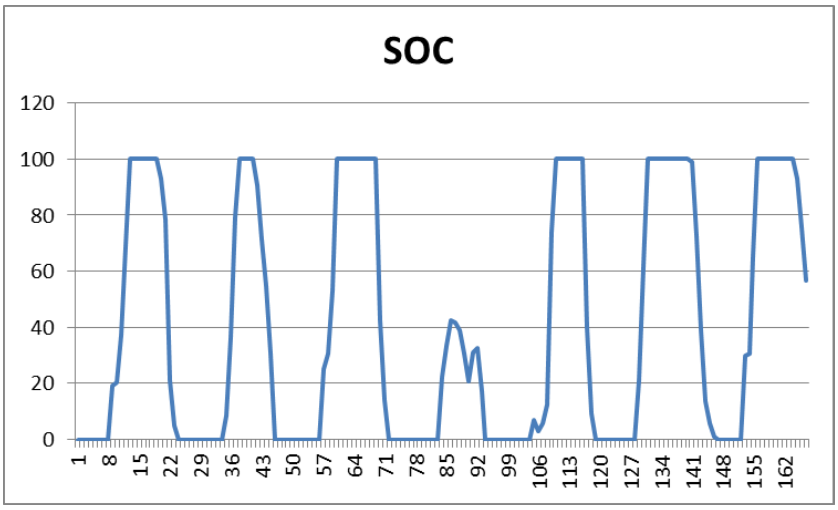

Figure 8-4: SOC of battery

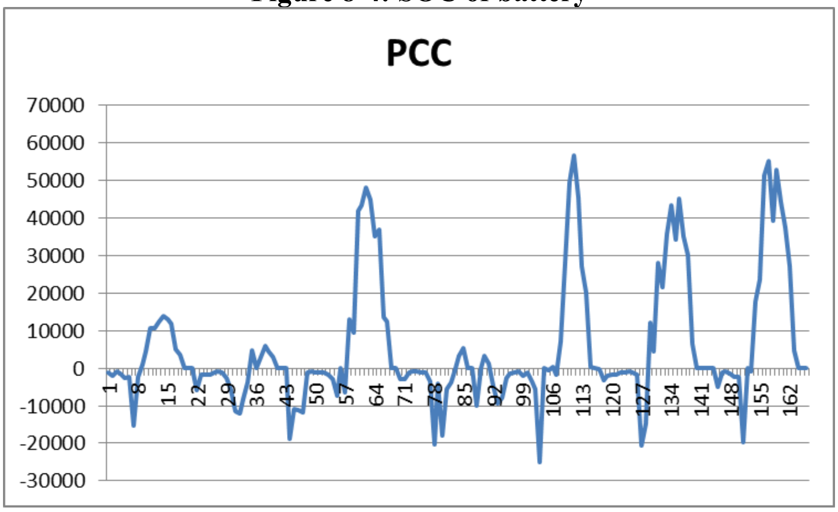

Figure 8-5:Energy exchanged in PCC

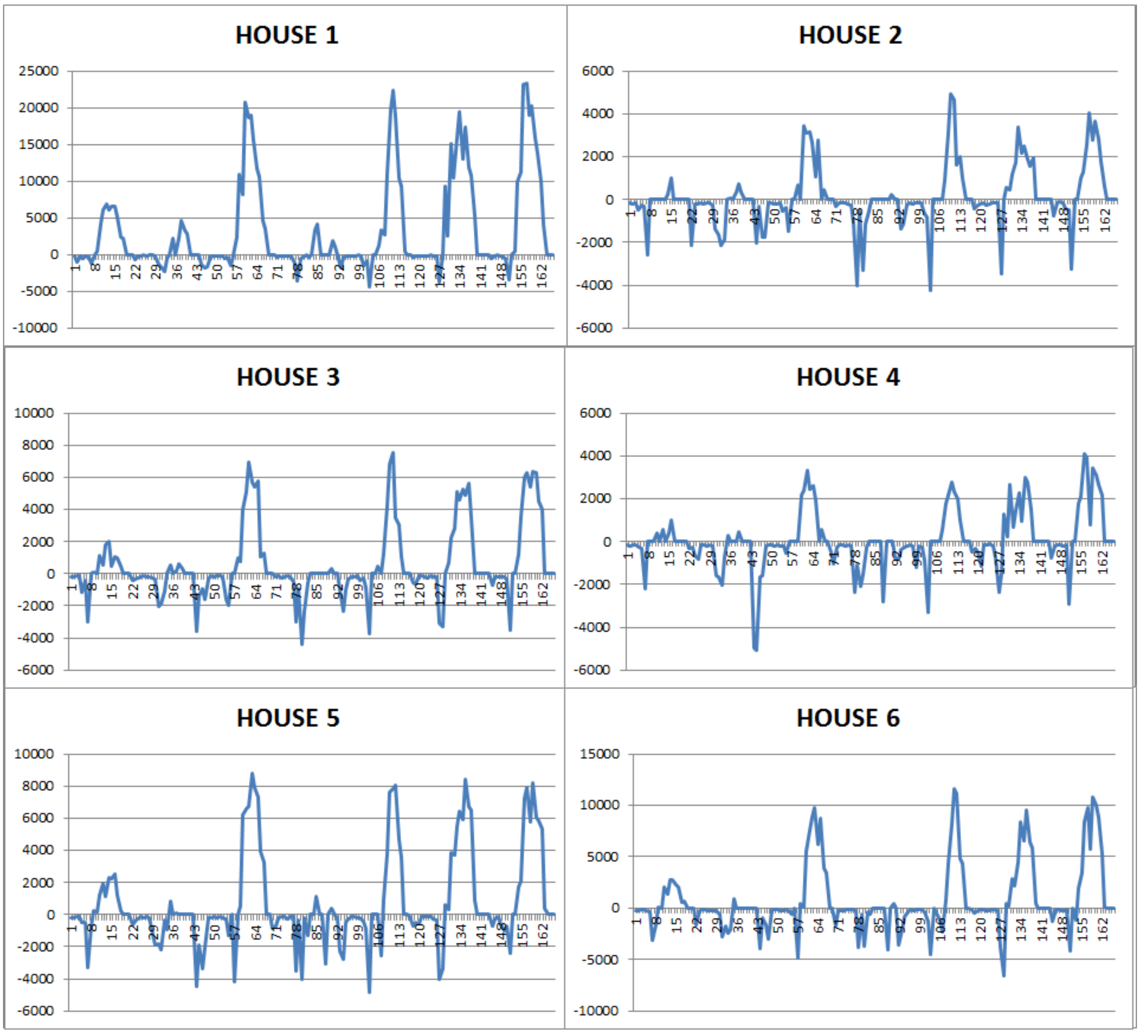

Figure 8-6:Energy exchanged with the gridSummer

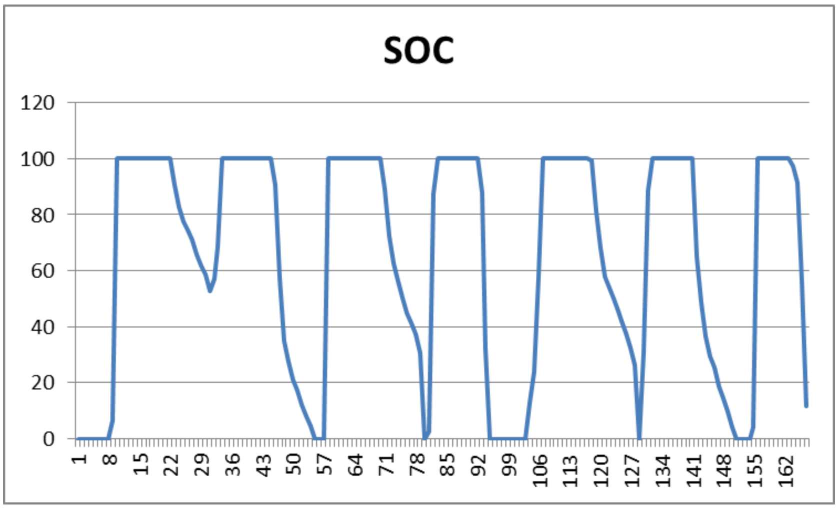

Figure 8-7: SOC of battery

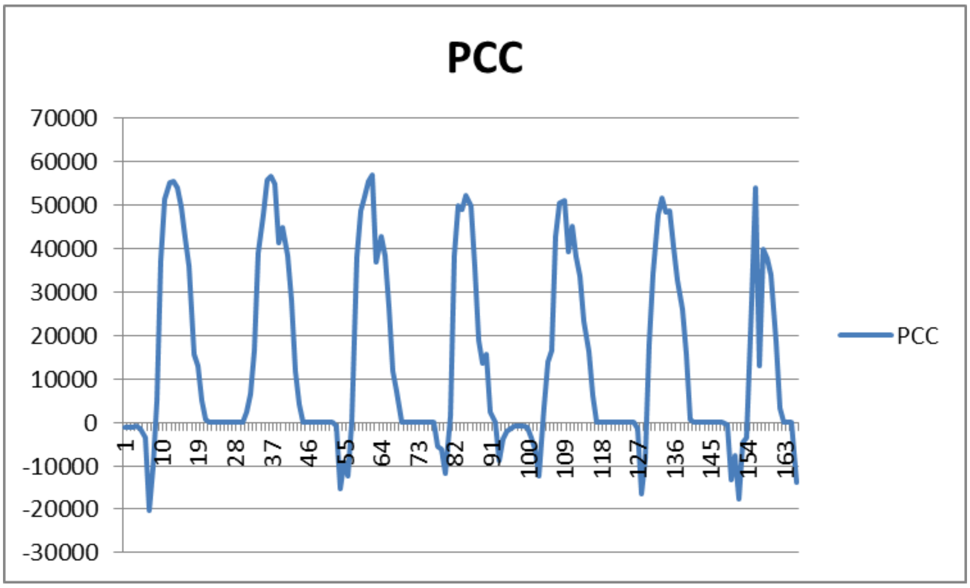

Figure 8-8:Energy exchanged in PCC

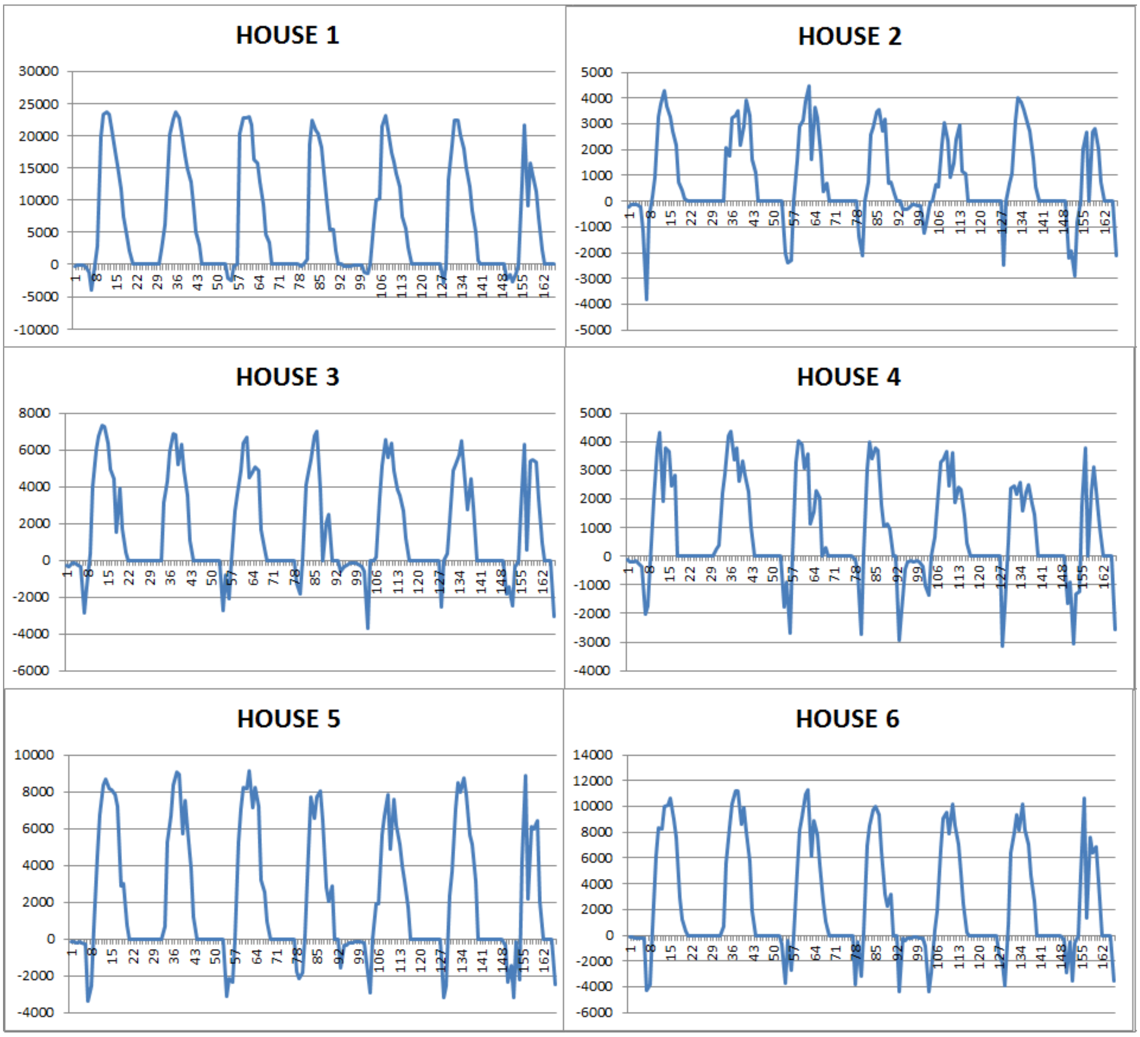

Figure 8-9:Energy exchanged with the grid

8.2.1.3 Autumn

The SOC, in much days of the week, is small, because the German photovoltaic production in Autumn is few. It is normal to think that in this case it is hard to have a "very" microgrid, because the principle grid must to help often and the microgrid do not have the autonomous. It is hard to have continuity of service in case of failure.

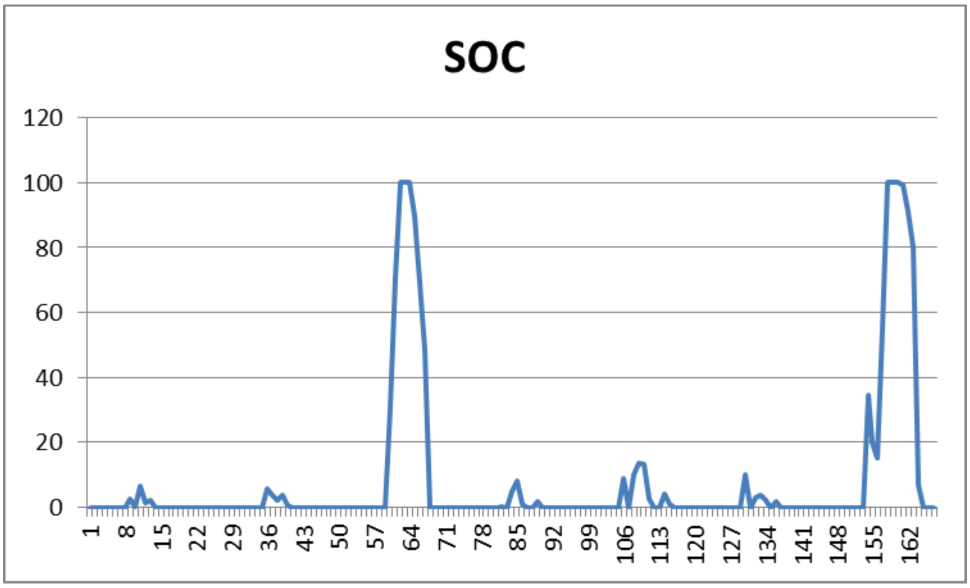

Figure 8-10: SOC of battery

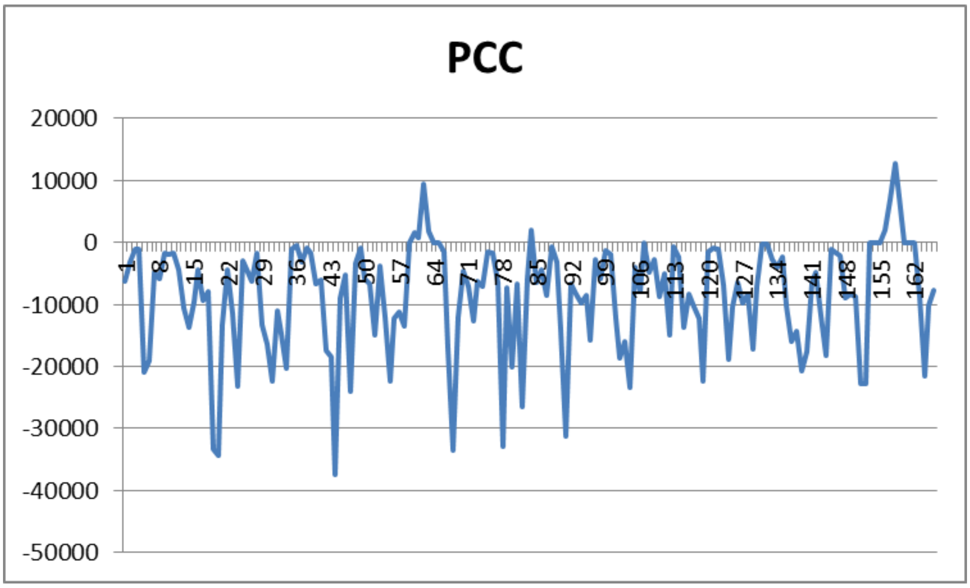

Figure 8-11:Energy exchanged in PCC

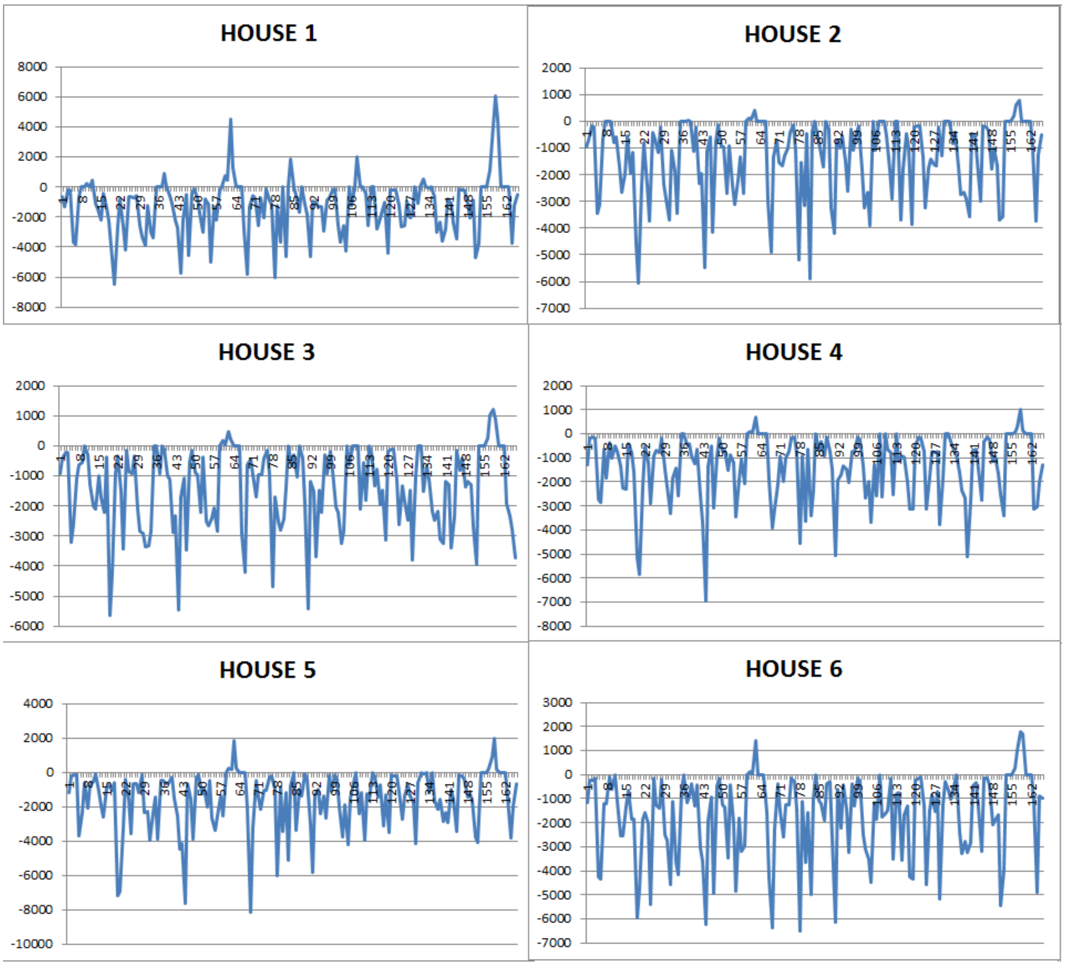

Figure 8-12:Energy exchanged with the grid

8.2.2 Italian model

8.2.2.1 Winter

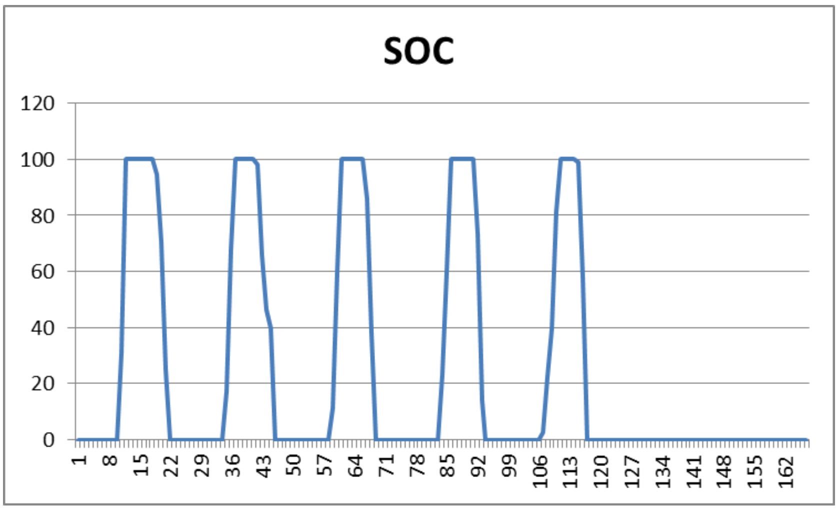

Figure 8-13: SOC of battery

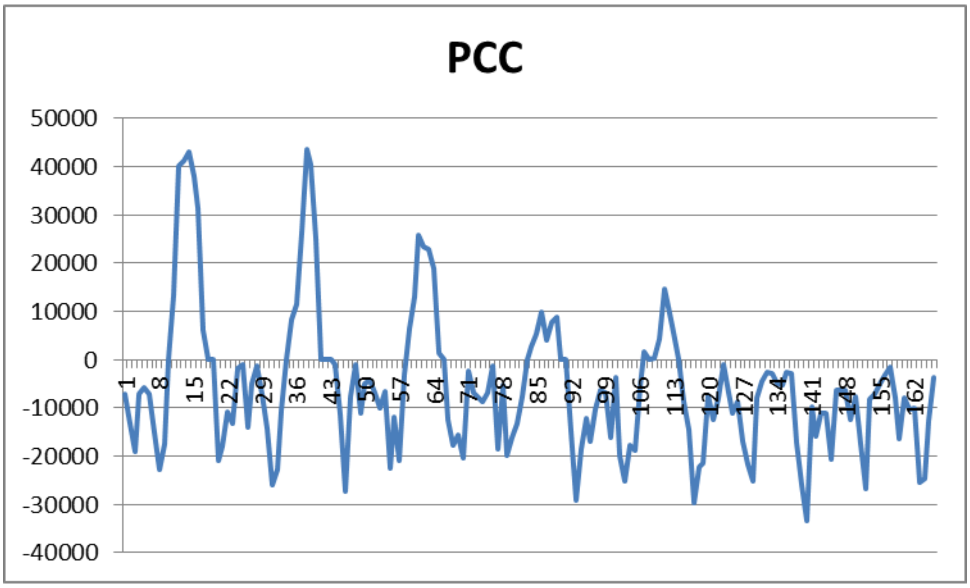

Figure 8-14:Energy exchanged in PCC

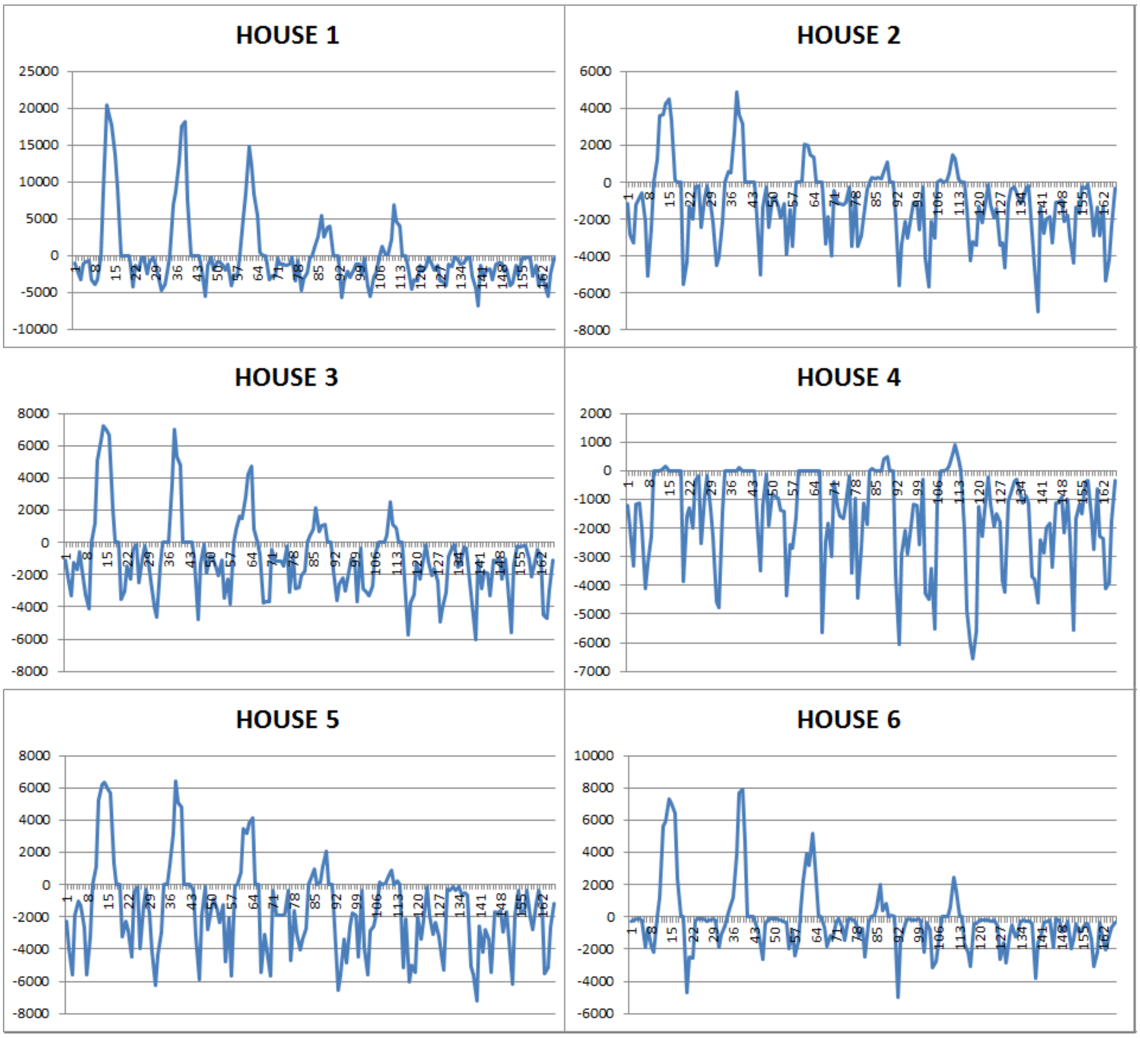

Figure 8-15:Energy exchanged with the grid

8.2.2.2 Spring

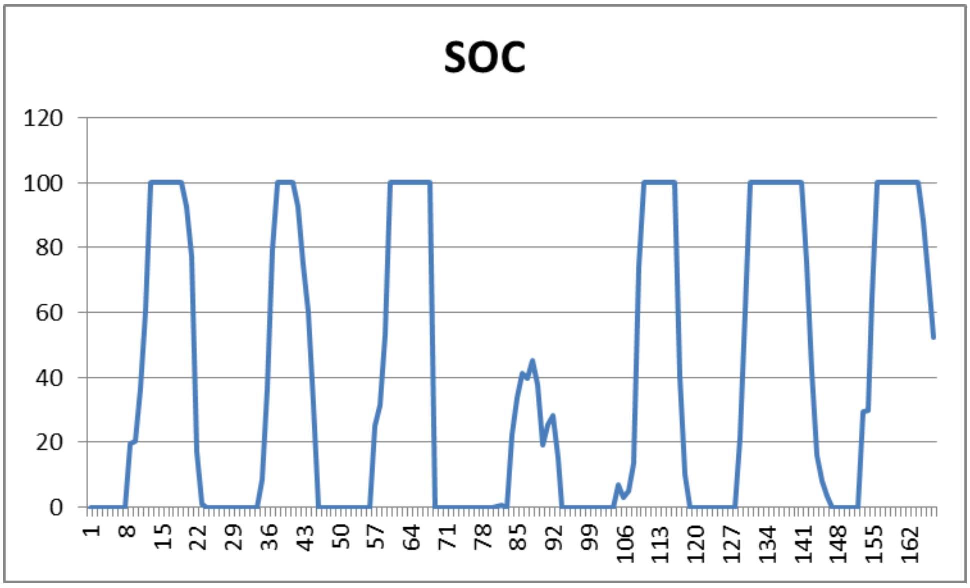

Figure 8-16: SOC of battery

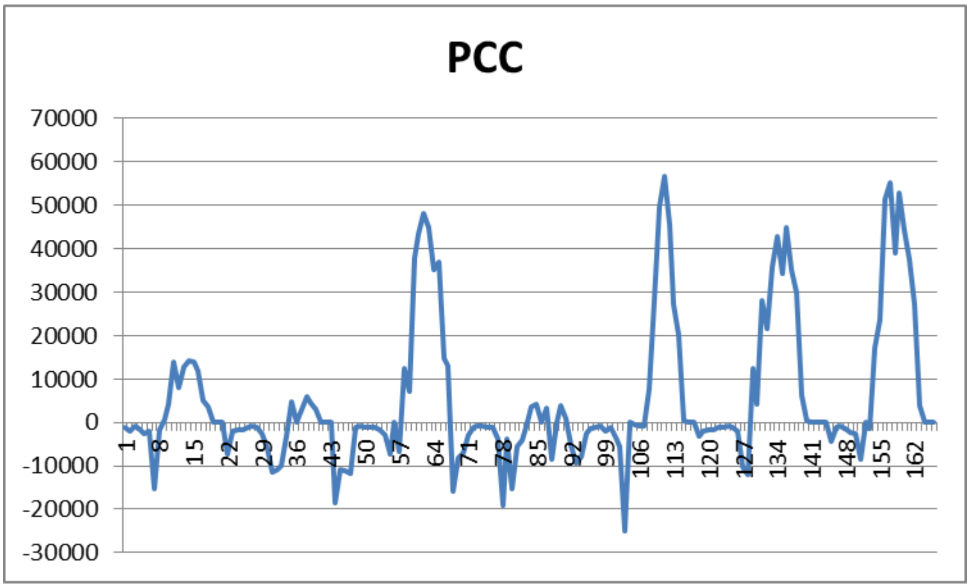

Figure 8-17:Energy exchanged in PCC

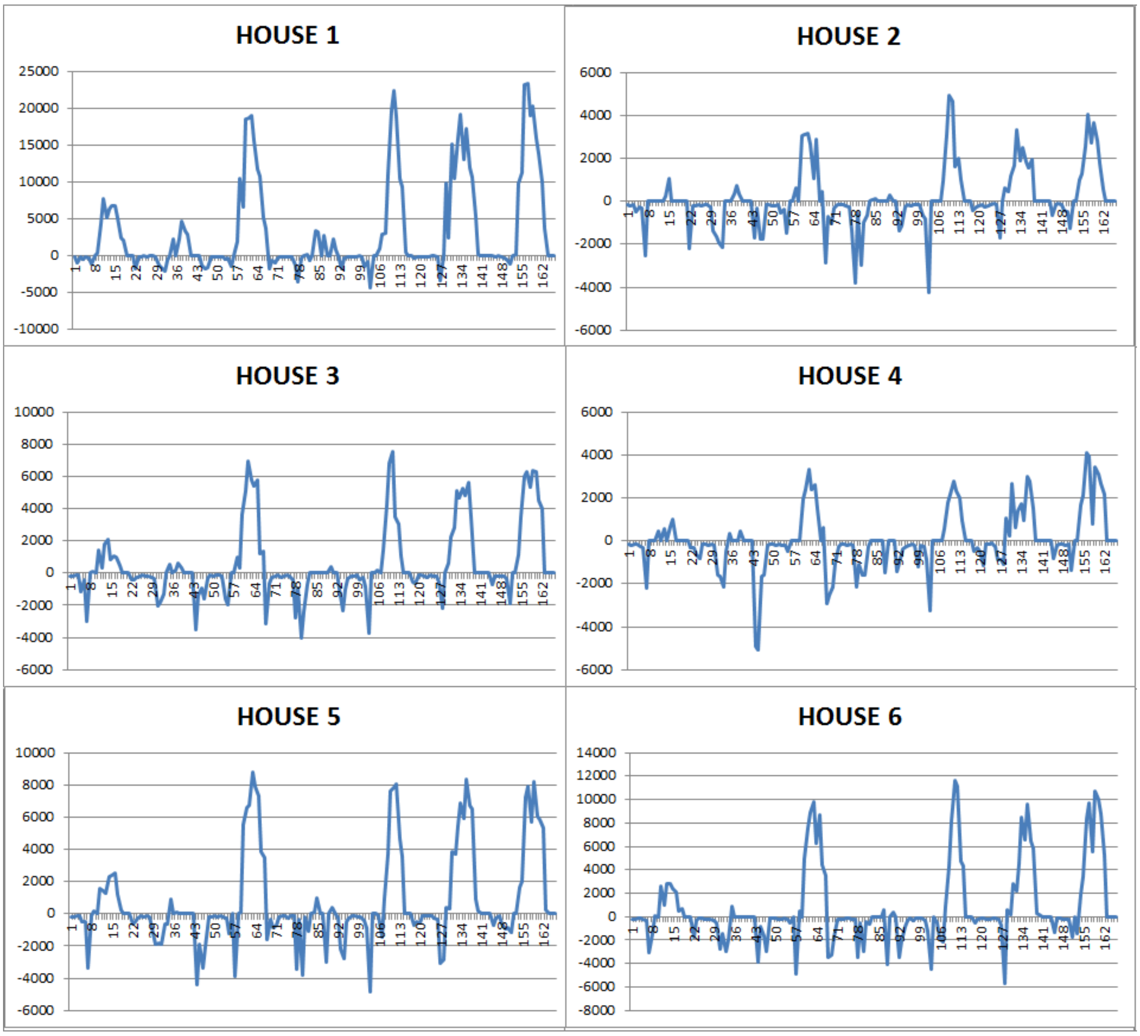

Figure 8-18:Energy exchanged with the grid

8.2.2.3 Summer

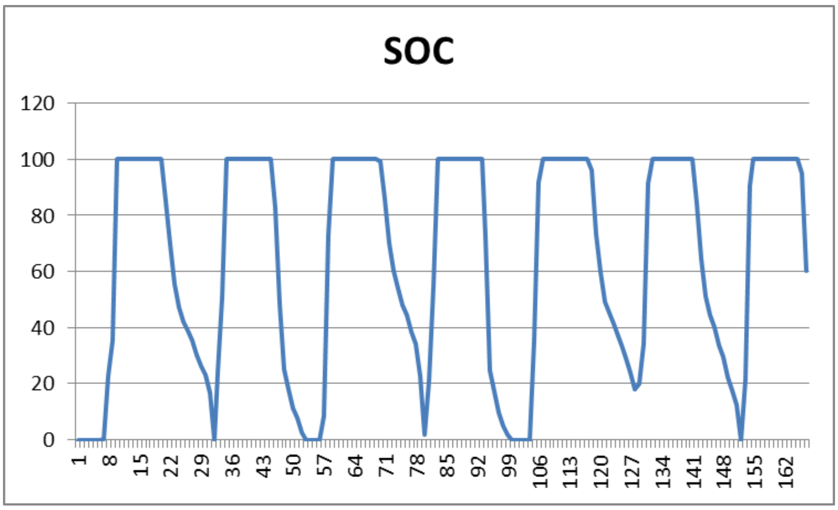

Figure 8-19: SOC of battery

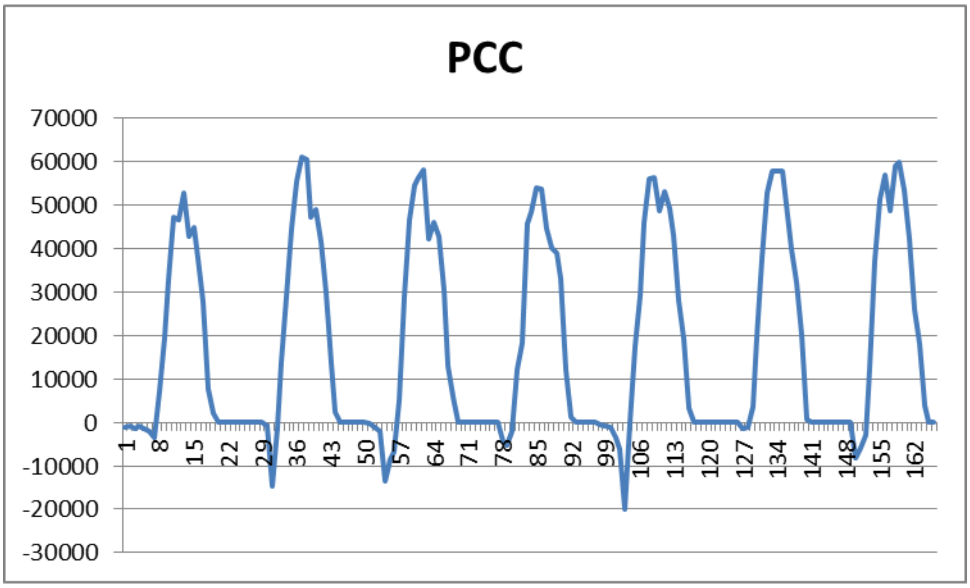

Figure 8-20:Energy exchanged in PCC

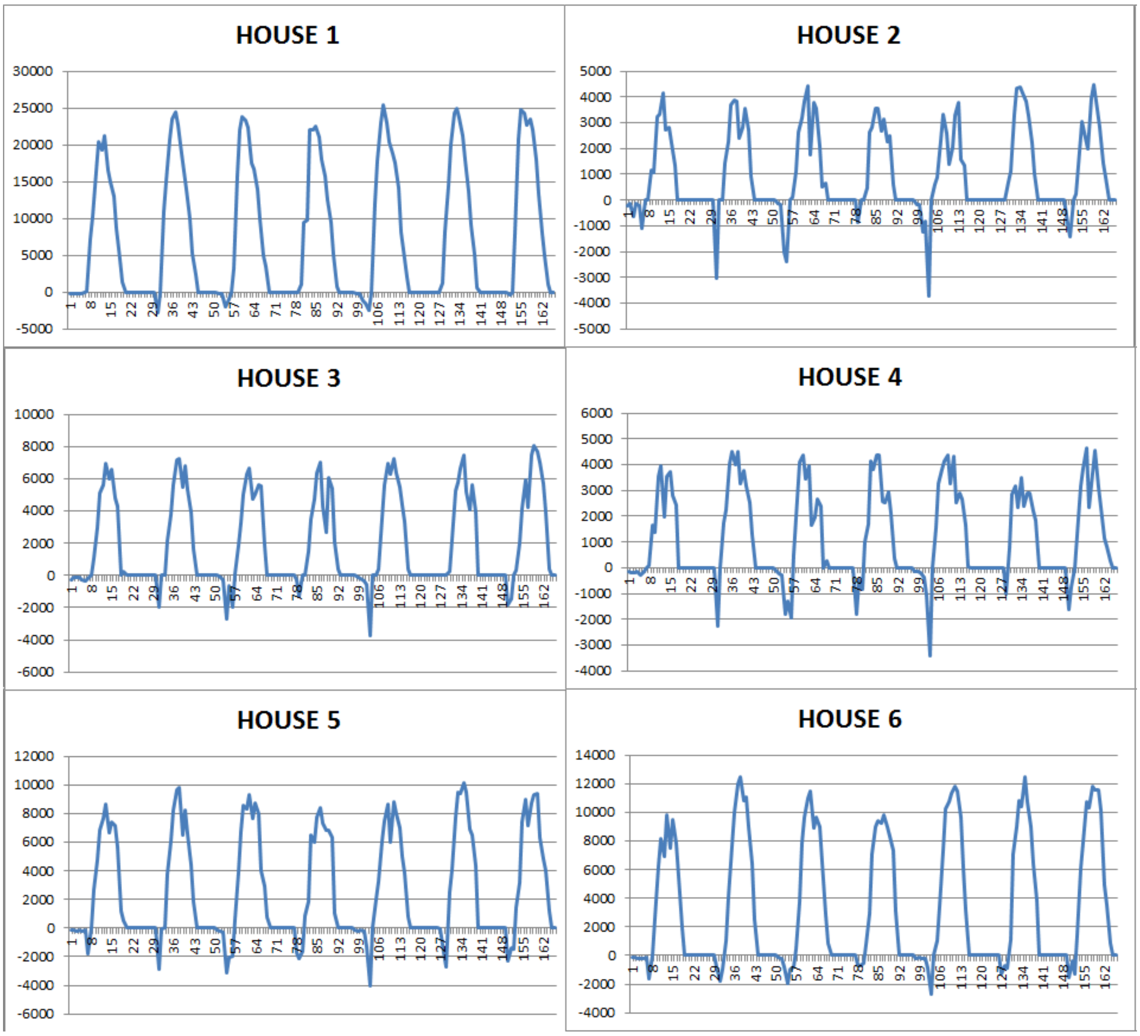

Figure 8-21:Energy exchanged with the grid

8.2.2.4 Autumn

The different are much in comparison with the German case. The Autumn in Sicily has a good weather. So there is a constant photovoltaic production.

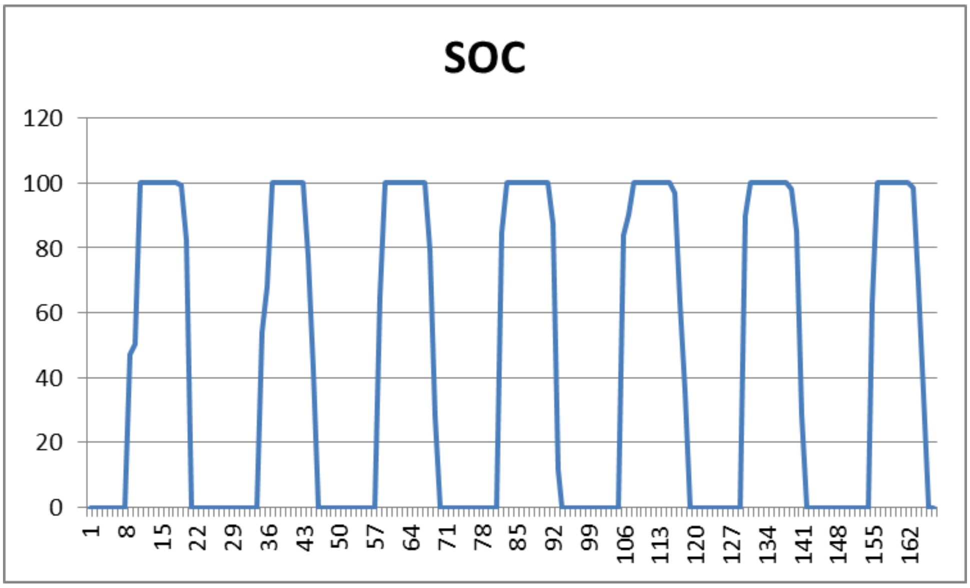

Figure 8-22: SOC of battery

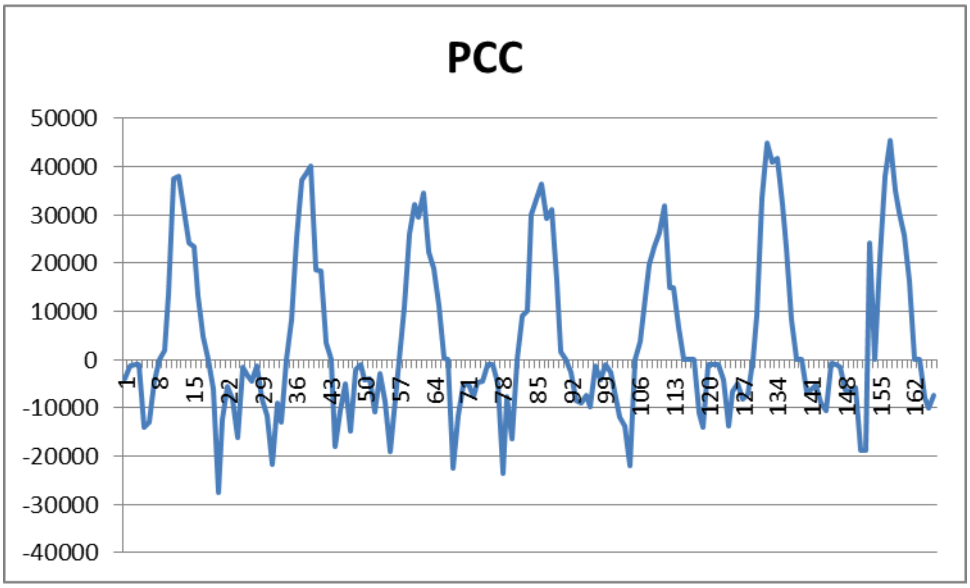

Figure 8-23:Energy exchanged in PCC

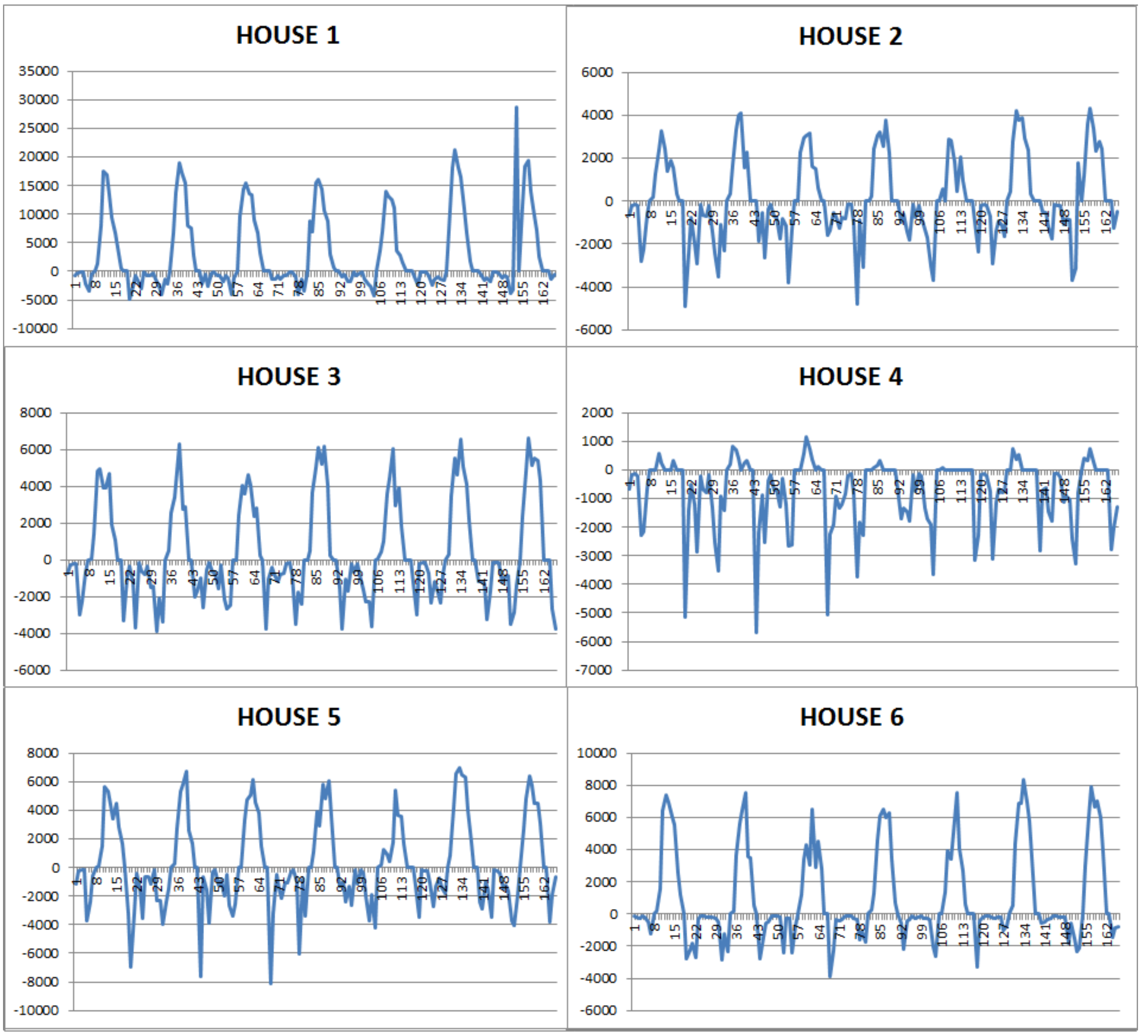

Figure 8-24:Energy exchanged with the grid

8.3 Energy exchange

The model has been changed to make the simulations for the "energy exchange". In this case for every country two simulations (spring and summer) will are made, because in winter and autumn the battery during the night is completely discharged.

8.3.1 German model

8.3.1.1 Spring

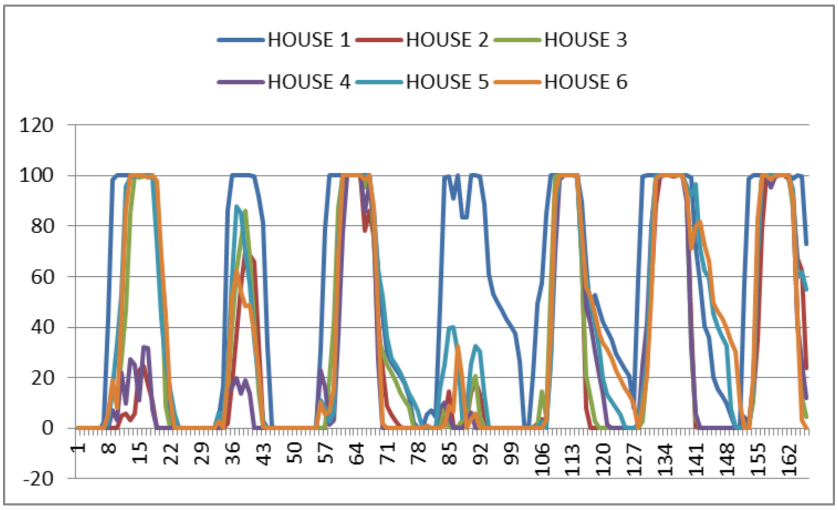

Figure 8-25: SOC of batteries

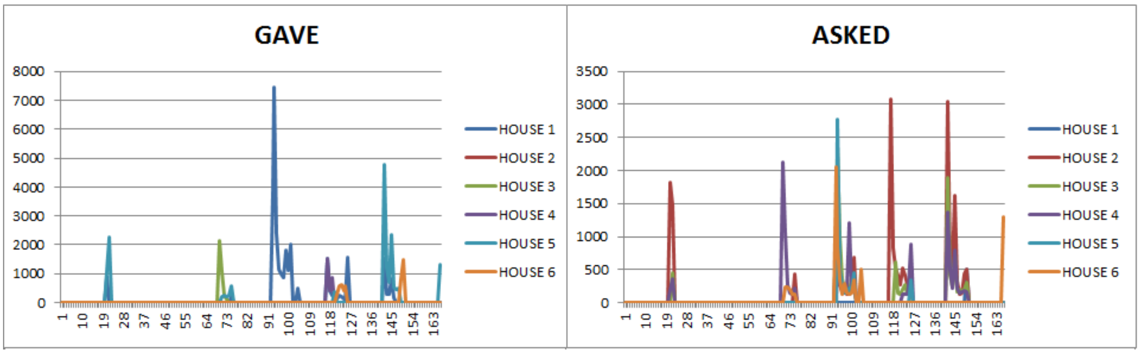

Figure 8-26: Energy exchanged

8.3.1.2 Summer

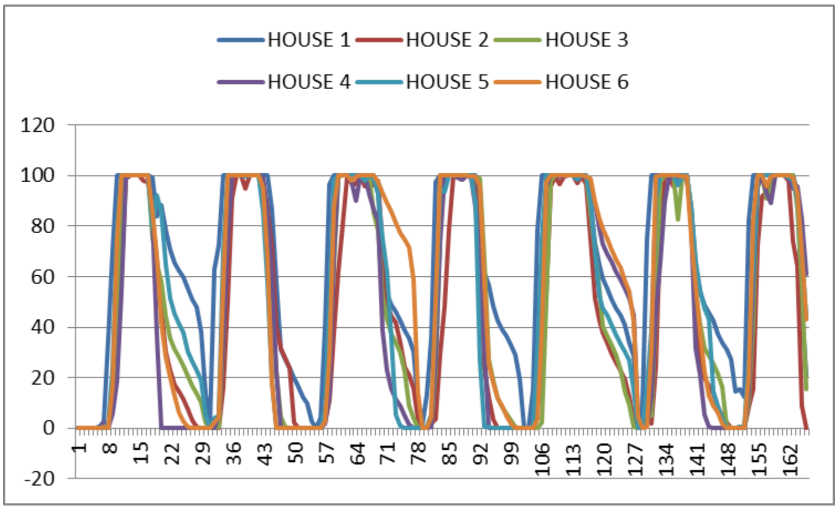

Figure 8-27:SOC of batteries

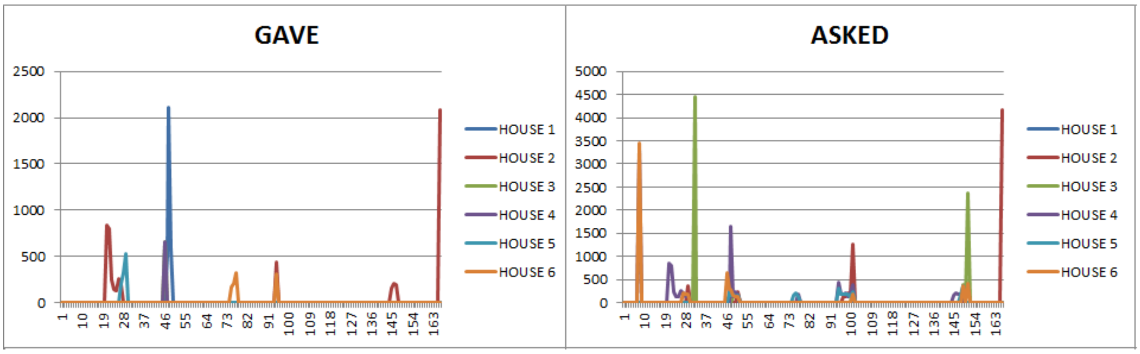

Figure 8-28: Energy exchanged

8.3.2 Italian model

8.3.2.1 Spring

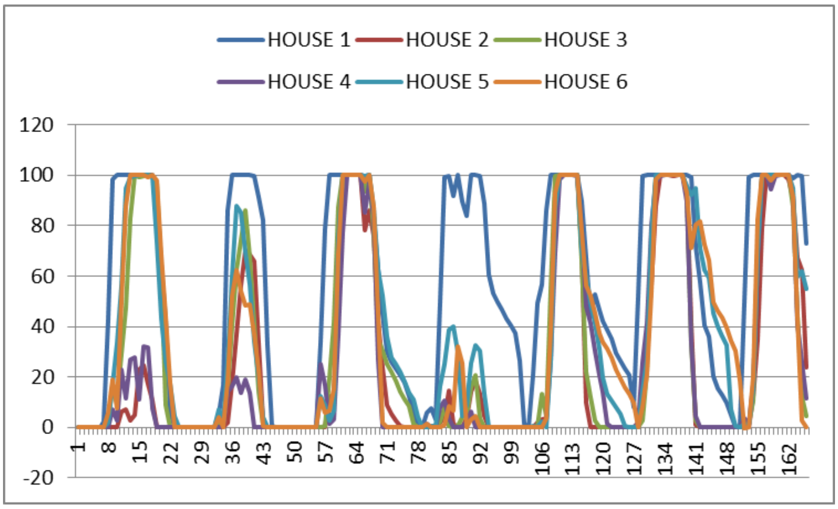

Figure 8-29:SOC of batteries

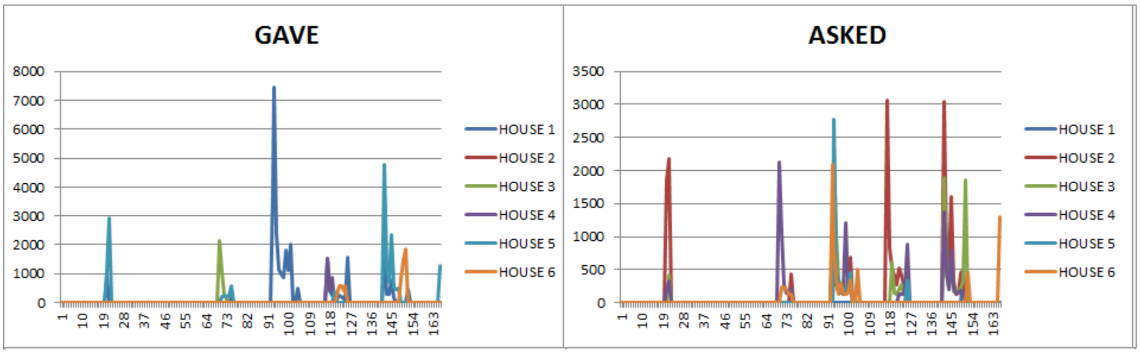

Figure 8-30: Energy exchanged

8.3.2.2 Summer

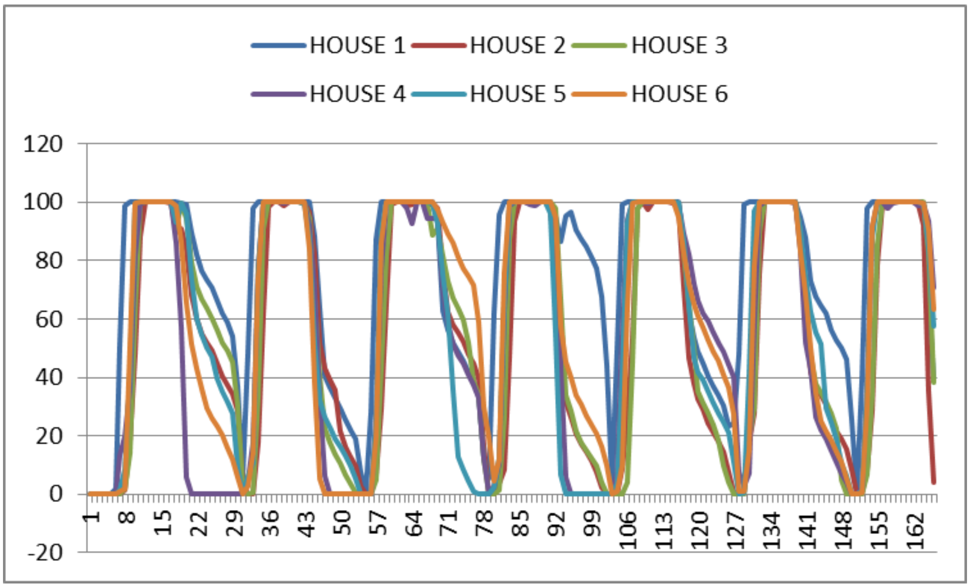

Figure 8-31:SOC of batteries

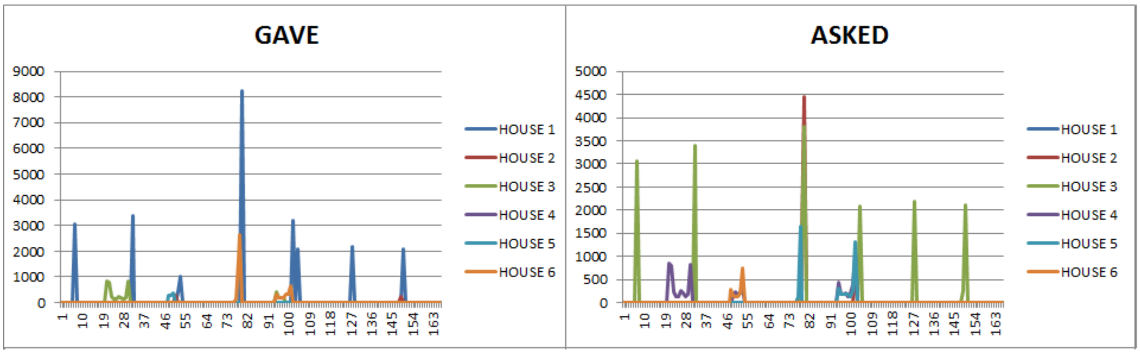

Figure 8-32: Energy exchanged

9 ECONOMIC COMPARISON

9.1 Introduction

In this chapter the economic analyses are presented, using the simulation results from the other chapters. More configurations have been made for the microgrid model.

- The real ("decentralised battery")
- Without battery
- Without battery and photovoltaics (this case it is not significant in this analyse)
- Central battery
- Energy exchange

To evaluate the best solution for the microgrid system, it is necessary to make an economic comparison, considering these parameters:

- Which country is being considered, because the economic standards, the energy price and energy cost is different between the Germany and Italy
- Inflation
- The cost of batteries
- The cost of photovoltaics
- The life span batteries and photovoltaics

For each house it is necessary to make an economic comparison between the configurations and then for the global system. It is possible, for example that the first solution is better for HOUSE 1 and is the worse for HOUSE 2. So it is important to analyse which is the best global solution.

For the two countries the cost of the batteries and photovoltaics are considered along with inflation to be the same. The parameters are:

- Inflation: 1,5% for years
- Battery cost: 7000 €
- Photovoltaic cost:
    - HOUSE 1
    - HOUSE 2
    - HOUSE 3
    - HOUSE 4
    - HOUSE 5
    - HOUSE 6

Also, the time slots used to divide the day are the same, the daytime is between 08.00 and 20.00, the night time is between 20.00 and 08.00, taking into consideration the different prices in the two countries between the day and the night.

The duration of the economic comparison is twenty years, because usually a photovoltaic system has a life span of twenty five years and considering the characteristics shown in Figure 4-21 a battery has a lifespan of twenty years. This last assumption is relevant even if it seems a very long life for a battery but for this economic comparison it is acceptable, given that the analysis will not specify the payback period and the real economic gain. Instead these comparisons are meant to analyse the best configurations for the microgrid system. So it was decided to do the comparisons with a twenty year duration.

Assuming inflation to be 1,5% for each year, it is necessary to decide which function to use. For these cases it is decided to use a discounting function.

9.2 Germany

In the two countries the economic standards, the energy saving incentives, the cost and price energy are different. In 2016 Germany's energy ministry formulated an incentive scheme for small solar batteries, for photovoltaic systems that do not exceed 30 kWp. It was possible to obtain a discount of up to 25% for the system and installation costs. The period for this incentive is between the March 2016 and December 2018, but with a progressive decrease of the discount. The rebate level is shown in Table 9-1,considering the decreasing incentive.

Table 9-1: The rebate level of the incentive

Application period	Rebate level
March-June 2016	25%
July-December 2016	22%
January-June 2017	19%
July-December 2017	16%
January-June 2018	13%
July-December 2018	10%

Considering for this economic comparison the year 2017, the value for January-June 2017 is taken as 19%. So in this case the price of the battery decreases to €5670. It is necessary to say that Germany's Federal Ministry for Economic Affairs and Energy decided to reduce the discount by a further 3%, in the period July-December 2017.

Considering the incentives for the price of the photovoltaic energy, the standard said that up to a system of 100kWp the incentives are the same, if this value is exceeded there is a reduction for each six month period. In a year there are considerable price changes, considering the incentives for 2017 and the electric market factors, it is correct to assume a price of 0,11 Cent/kWh. This has been calculated using a decrement calculated according to 49 EEG 2017.

As said in the previous chapters, in Germany there is a meter only for the heat pump, it is necessary to have a contract dedicated to this load. The prices of the energy cost for the domestic loads and heat pump have been taken from data for a local energy distribution firm Energieversorgung Mainhardt Wustenrot. The prices for the services and energies are:

- Domestic load: for the daytime 25,20 Cent/kWh and for the nightime 22,10 Cent/kWh
- Heat pump: there is only a price 20,80 Cent/kWh

In Figure 9-1 the contracts for the supply firm are shown.

Wir möchten mit emw-Strom 2018 beliefert werden. emw energieversorgung mainhardt wüstenrot

(Gültig in den Gemeinden Mainhardt und Wüstenrot für eine Abnahmemenge bis zu 10.000 kWh im Jahr)

Vertragspartner (Kunde)		Abnahmestelle (falls abweichend)	
Vorname, Name:		Auftragsnummer:	
Straße, HNr.:		Straße, HNr.:	
PLZ und Ort:		PLZ und Ort:	
Email:		Telefonnummer:	

☐ Eintarifzähler ☐ Zweitarifzähler ☐ Mitglied im Verein: ____________

Bonus von 25 € wird Ihrem Verein nach Ablauf der Widerrufsfrist gutgeschrieben.

Hiermit beauftragen wir die Energieversorgung Mainhardt Wüstenrot GmbH & Co. KG (emw), Hauptstraße 1, 74535 Mainhardt, mit der Stromlieferung an oben genannte Adresse zu folgenden Vertragsbedingungen und den Allgemeinen Geschäftsbedingungen für emw-Strom (AGB emw):

Preise:

Grundpreis pro Jahr		Netto	Brutto	Verbrauchspreis pro kWh		Netto [1]	Brutto [2]
Eintarifzähler	Euro	85,71	102,00	Tagstrom (HT)	Cent	11,582	25,20
Zweitarifzähler	Euro	122,69	146,00	Nachtstrom (NT) [3]	Cent	8,977	22,10

Wir möchten mit EMW-Strom Wärmepumpe 2018 beliefert werden. emw energieversorgung mainhardt wüstenrot

(Gültig in den Gemeinden Mainhardt und Wüstenrot)

Vertragspartner (Kunde)		Abnahmestelle (falls abweichend)	
Vorname, Name:		Auftragsnummer:	
Straße, HNr.:		Straße, HNr.:	
PLZ und Ort:		PLZ und Ort:	
Email:		Telefonnummer:	

☐ Eintarifzähler ☐ Mitglied im Verein: ____________

Bonus von 25 € wird Ihrem Verein nach Ablauf der Widerrufsfrist gutgeschrieben.

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Preise:

Grundpreis pro Jahr		Netto	Brutto	Verbrauchspreis pro kWh		Netto [1]	Brutto [2]
Eintarifzähler	Euro	70,59	84,00	Tagstrom (HT)	Cent	7,885	20,80

Figure 9-1: home load contracts of a local distribution firm

So, having the prices of the photovoltaics, the domestic load (daytime and nightime) and heat pump, it is possible to calculate the costs and the gain for each house. Excel software is used for the calculations, together with Matlab software to analyse the data input.

It is necessary for the input to know the energy exchanged with the grid and the domestic and heat pump consumption. One might consider that it is only necessary to have the first factor, but there are two different prices for the loads, so the last two inputs are necessary for a consideration of payment priorities, because in the daytime the price of the domestic load is greater than the heat pump price. So, using a new function, the new heat pump and domestic consumptions are calculated, considering the priority between the heat pump and the grid supply. The photovoltaic energy is easy to calculate, using the positive values from the energy exchange.

In Table 9-2 the costs and prices of the energy for the German case are shown.

Table 9-2: Price of the energy

Price	
loadDaytime €/KWh	0,252
loadNightime €/KWh	0,221
HP €/KWh	0,208
PV€/KWh	0,11

For the case of exchanged energy it is necessary to set the price of the supplied power from one house to another. There is no standard price governing this type of case. It was decided to set the price at 0,16 Cent/kWh, because it is an average between the cost of energy in the night and the price of photovoltaic energy.

All configurations are compared with the “without battery and photovoltaic” solution, because it is possible to have a similar comparison between the configurations and it is possible to understand the economic gain for each year.

The Figure 9-2 shows the results for HOUSE 1. It is possible to see, that the “energy exchanged” is the best solution. Considering this type of comparison, at the eighth year there is an economic gain. The problem for this is that in reality there is not a standard that governs the energy exchanged between the houses. It is interesting to do a comparison between the other possibilities that use the batteries. There is a big difference in the yearly gain between the cases “real”(decentral battery) and “central battery”, even if HOUSE 1 is the first to receive energy in the “central battery” case because this house has a large photovoltaic production. Figure 9-2 shows the difference with the other houses, as for HOUSE 1 the photovoltaics operate for more time in a day compared to the others. Also the “no battery” solution is better in comparison to the “central battery”. It is important to say that the figures for the gain in the twentieth year are not accurate. It is not a business plan because only four weeks in a year are analysed. It is significant to see that when the solutions repay the total investment cost, “No battery” is the first, despite the annual gain being less than others.

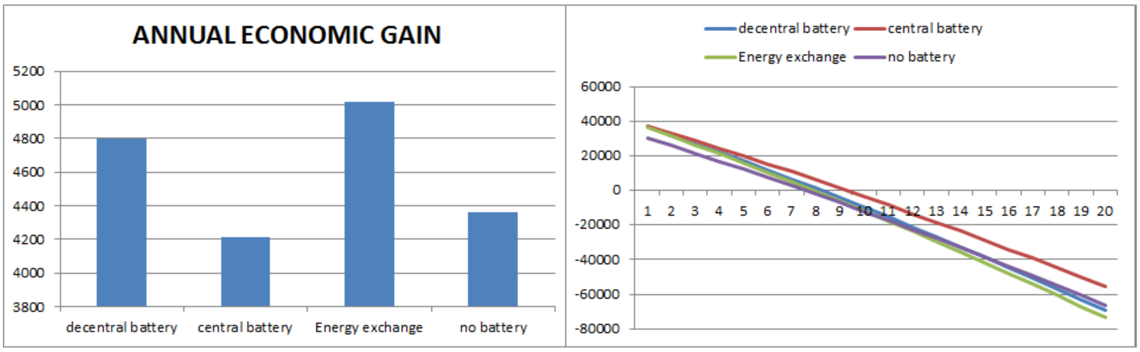


Figure 9-2: Results of HOUSE 1

The Figure 9-3 show the results of the HOUSE 2. The "energy exchanged" is the best solution, it is significant to see that in this house the central battery is better compared to the decentralised batteries. This because the PV production is small compared to the first house and also because of the important case when there is the energy demand for the house. The annual gain for the first year shows a difference of 200 €. In the real configuration only in the ninth year is the battery and PV system paid for. There is a large difference between the "no battery" and "energy exchanged" solutions.

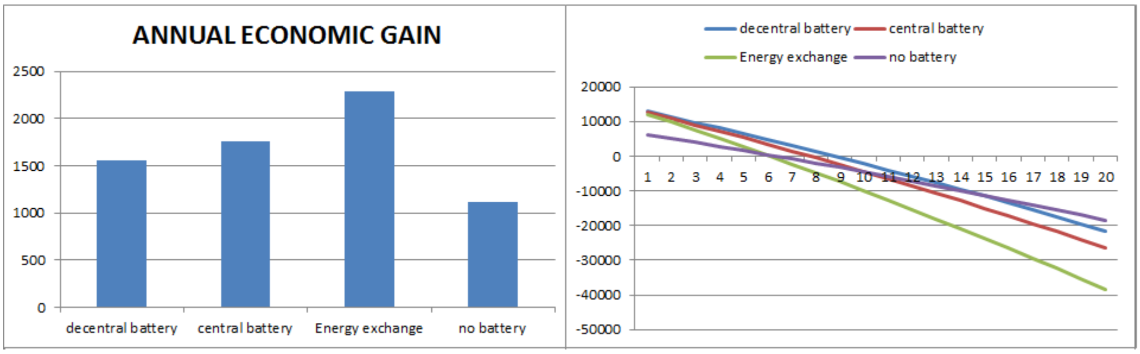


Figure 9-3: Results of the HOUSE 1

The results for HOUSE 3 show that there is not a large difference between the real, central battery and exchanged energy configuration, as the Figure 9-4 show. In the twentieth year the difference in total gain between the real, no battery and decentralised battery is small. For example if there were to be a failure in the battery and it must be replaced, there is no advantage to having a battery.

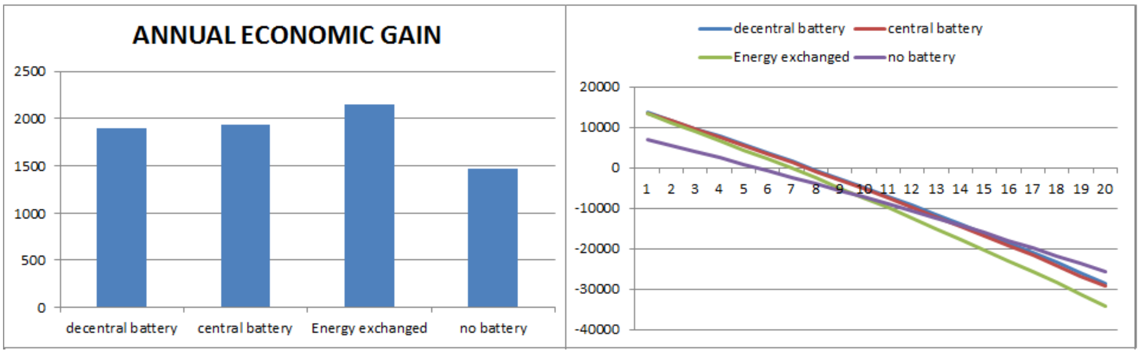


Figure 9-4: Results of the HOUSE 3

HOUSE 4 has a small photovoltaic system, so does not contribute much to the charging of the "central battery", and thus this is the best configuration for the house. even if there are three houses before HOUSE 3, but much depends on the instantaneous energy demand. The repayment of the system occurs after the tenth year for the real configuration.

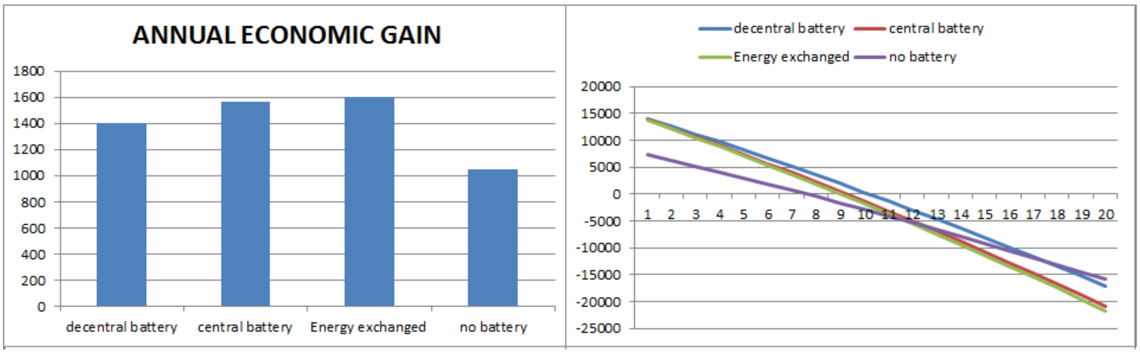


Figure 9-5: Results of the HOUSE 4

The last two houses, HOUSE 5 and HOUSE 6, have very similar results, because the characteristics of the houses are the same. For both, the best configuration is "energy exchanged", they also have large photovoltaic systems, so they have a high potential to supply loads for more time. The annual gain for the real configuration is greater than for the centralised battery. In Figure 9-6 and Figure 9-7 show the results for both houses.

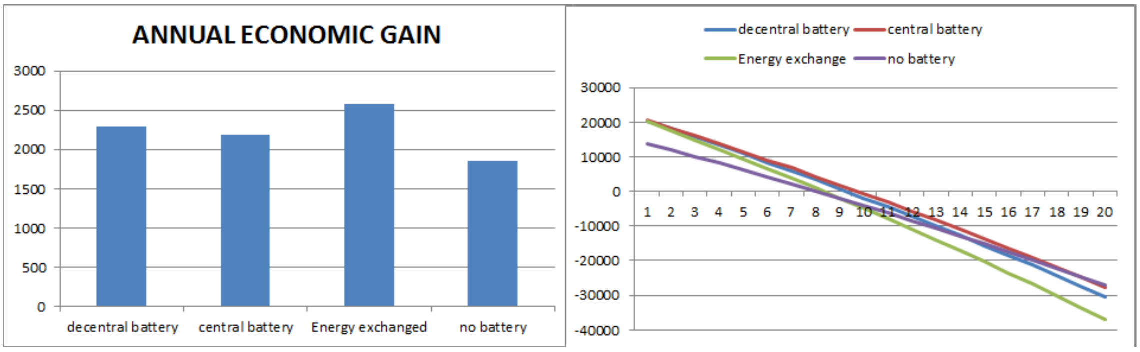


Figure 9-6: Results of the HOUSE 5

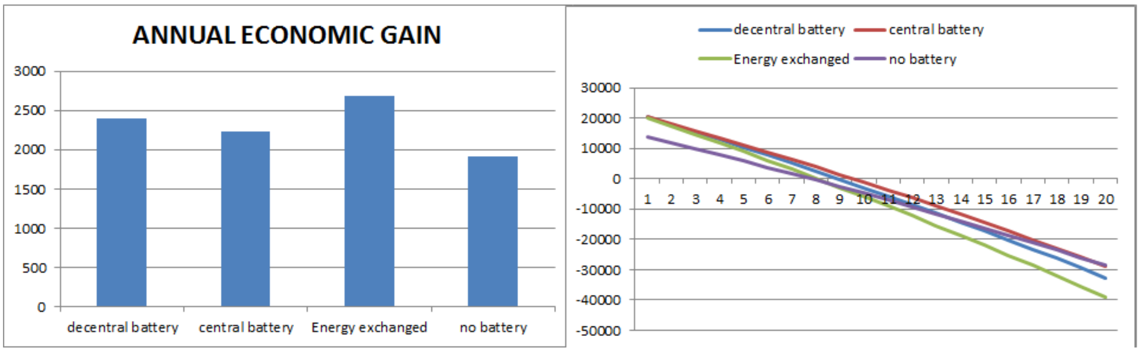


Figure 9-7: Results of the HOUSE 6

It is important to analyse the global result. For each house the best results are those for the “energy exchanged” case, because the is no energy wastage and the price of energy sale and purchase is advantageous for all. But as outlined above, it is not currently possible to implement this in reality.

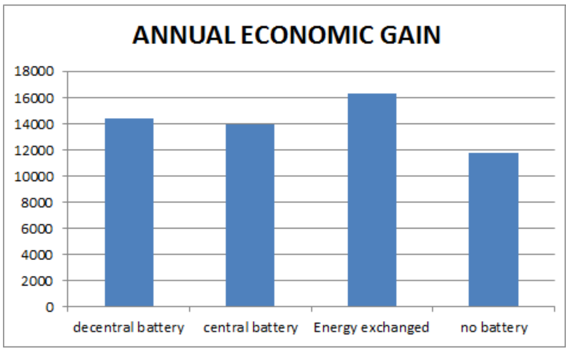
The Table 9-3 shows the optimal solutions for the houses comparing between the real and central battery configurations. The houses are divided into two groups, HOUSES 1, 5 and 6 are the real configuration and HOUSES 2, 3 and 4 the centralised battery configuration. It is necessary to find the best global solution.

Table 9-3: Optimal solutions for each house

	decentral battery	central battery
HOUSE 1		
HOUSE 2		
HOUSE 3		
HOUSE 4		
HOUSE 5		
HOUSE 6		

BETTER

The Figure 9-8 show the global results. The real configuration is better in comparison to the central battery. So the configuration with six batteries, one for each house is a good solution but it is the best only for three houses. It is possible to see the marginal gain in the twentieth year, between the real configuration and no battery. In the case of failure or replacement of the battery there is an advantage only if there is sufficient margin, *viz* the price of the battery. Table ?? shows whether there are sufficient margins for each case. Examining the data, it is possible to see that there is no house with a sufficient margin. The Table 9-4: Economic margin at the twentieh year for each house, comparing real configuration with no battery shows that the real configuration of the global results is repaid in ten years.



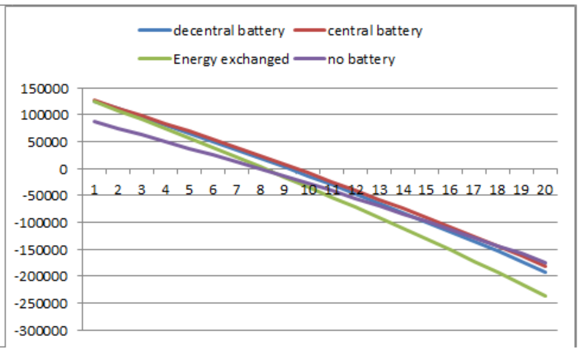


Figure 9-8: Global results

Table 9-4: Economic margin at the twentieh year for each house, comparing real configuration with no battery

	decentral battery	decentral battery	Margin
HOUSE 1	-69448,85136	-66365,80539	-3083,05
HOUSE 2	-21513,1022	-18449,45502	-3063,65
HOUSE 3	-28488,4379	-25610,73644	-2877,7
HOUSE 4	-17095,92901	-15871,10887	-1224,82
HOUSE 5	-30402,32402	-27151,60642	-3250,72
HOUSE 6	-32716,66684	-28636,71008	-4079,96

9.3 Italian

Levels of financial incentives have changed in the last few years. The incentive scheme for the photovoltaic system, “Conto Energia” was terminated in July 2013. Currently, the only possibilities are tax deductions and the “scambio sul posto”(SSP) mechanism. Using SSP the non-consumed electric energy produced from the photovoltaic system can be given to the grid. Additionally it is possible at other times to take energy from the grid. The SSP thus works as a virtual battery, available all the time. But this service, of virtual battery, is not free. “Gestore dei Servizi Energetici” (GSE) controls the economic phase of the system. The energy given to the grid is repaid at a lower price in comparison at the price of the energy supplied from the grid. The GSE, with SSP, gives the economic contribution each year, using “Conto Scambio” (CS), this is calculated as:

$$CS=\min(OE; CEi)+CUSf*ES$$

Where:

- OE is the multiplication of the quantity of energy supplied from the grid by the “Prezzo Unico Nazionale” (PUN), the energy price which is the same throughout Italy.
- CEi the value of the energy given to the grid. It is based on the local market zonal prices of the day before.
- CUSf is the recompense for annual flat exchange.
- ES is the electric energy exchanged with the grid and is the difference between the energy supplied from the grid and the energy given to the grid. ES is the quantity of energy that is called virtual battery.

The calculation of CUSf is very complicated, this data is taken from Table 9-5: CUSf by Electric Energy Authoritypublicized each year by the Electric Energy Authority (the last data available are for 2016). The “Domestico D1”is taken in this case because this is the rate for the heat pump.

Table 9-5: CUSf by Electric Energy Authority

	Anno 2016		
	CU_{Sf} [c€/kWh]	CU_{Sf}^{reti} [c€/kWh]	CU_{Sf}^{ogs} [c€/kWh]
Domestico D1	10,835	3,453	7,382
Domestico D2			
consumo ≤ 1.800 kWh/anno	6,135	2,212	3,923
1.800 kWh/anno < consumo ≤ 2.640 kWh/anno	10,529	4,762	5,767
2.640 kWh/anno < consumo ≤ 4.440 kWh/anno	16,653	8,404	8,249
consumo > 4.440 kWh/anno	16,653	8,404	8,249
Domestico D3			
consumo ≤ 1.800 kWh/anno	12,362	4,113	8,249
1.800 kWh/anno < consumo ≤ 2.640 kWh/anno	14,004	5,755	8,249
2.640 kWh/anno < consumo ≤ 4.440 kWh/anno	14,004	5,755	8,249
consumo > 4.440 kWh/anno	14,004	5,755	8,249

The local zonal prices are taken from Table 9-6: Energy price by Terna supplied from Terna. Trapani is a city in Sicily, so for this case it is necessary to take the data from Sicily. The values for the PUN are taken from the same table.

Table 9-6: Energy price by Terna

	PUN [€/ MWh]	NORD	CNOR	CSUD	SUD	SICILIA	SARD
JANUARY	71.767	77.79	73.45	61.05	58.66	62.52	61.05
FEBRUARY	55.058	55.89	54.75	53.49	51.28	56.21	53.49
MARCH	43.945	43.62	43.72	43.89	42.65	49.55	43.89
APRIL	42.378	41.59	41.70	41.66	41.63	55.16	41.65
MAY	42.587	41.08	42.68	42.74	42.64	56.07	42.65
JUNE	48.357	47.63	48.43	48.00	45.99	58.93	47.11
JULY	49.827	49.52	50.04	47.14	46.42	64.69	47.14
AUGUST	55.284	54.98	55.09	54.08	49.06	68.53	54.08
SEPTEMBER	48.114	48.32	48.43	47.10	45.89	52.25	46.55
OCTOBER	54.242	54.59	54.54	49.47	48.96	74.00	48.87
NOVEMBER	65.293	67.34	65.71	62.35	59.35	60.42	62.19
DECEMBER	64.634	65.33	65.00	63.46	60.22	65.23	64.15

The price of energy purchase is calculated using the data supplied by the Electric Grid Authority (ARERA). Figure 9-9 shows how the purchase price is calculated. The calculation considers the energy price, expense for transporting the energy and the managing of the meter, expenditure for the system services and tax. The data are supplied each season.

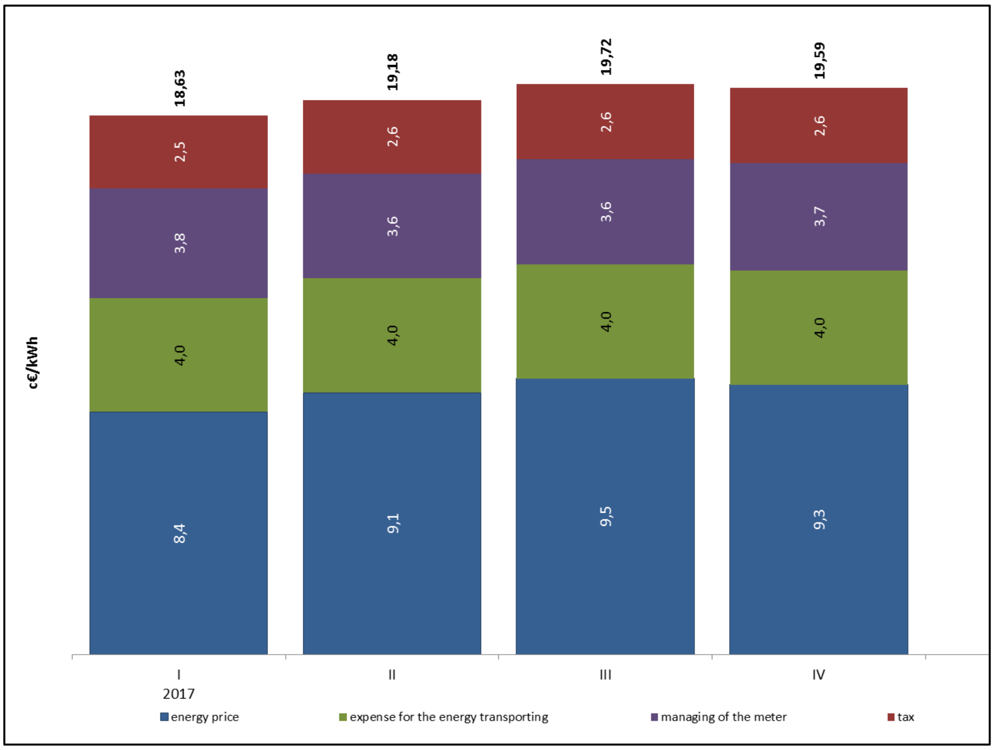


Figure 9-9: Energy Cost by ARERA

The prices data used for the calculation are shown below. They are divided for the four seasons.

Winter

Price	
PUN	0,071767
Zonal Price	0,06252
CUSf	0,0108
Purchase Price	0,1863

Spring

Price	
PUN	0,042587
Zonal Price	0,05607
CUSf	0,0108
Purchase Price	0,1918

Summer

Price	
PUN	0,049827
Zonal Price	0,06469
CUSf	0,0108
Purchase Price	0,1972

Autumn

Price	
PUN	0,054242
Zonal Price	0,074
CUSf	0,0108
Purchase Price	0,1959

There are no incentives for the installation of a battery, only the Lombardy Region gives such finance. But the city in this case is in Sicily.

In Italy there is only one meter for the load. So it is not important to divide the load between the "domestic load" and heat pump, because there is only one contract for both. As above Excel and Matlab software are used for the calculations. Having only one meter, the input is the energy exchanged with the grid. The production and consumption of energy for the house are calculated starting from this input data. The positive values are the photovoltaic production and the negative the consumption.

For the case of exchanged energy, as above it is necessary to set the price of the supplied power from one house to another. Also in Italy there is no standard price governing this type of case. It was decided to set the price at 0,16 Cent/kWh. As in the German economic comparison, all configurations are compared for the “without battery and photovoltaic” solution, because it is possible to have a similar comparison between the configurations and it is possible to understand the economic gain for each year. The Figure 9-10 show the results for HOUSE 1. It is possible to see, that the “energy exchange” is the best solution. As in the German economic comparison, there is a big difference in the yearly gain between the cases “real”(decentralised battery) and “central battery”, even if HOUSE 1 is the first to receive energy in the “central battery” case because this house has a large photovoltaic production.

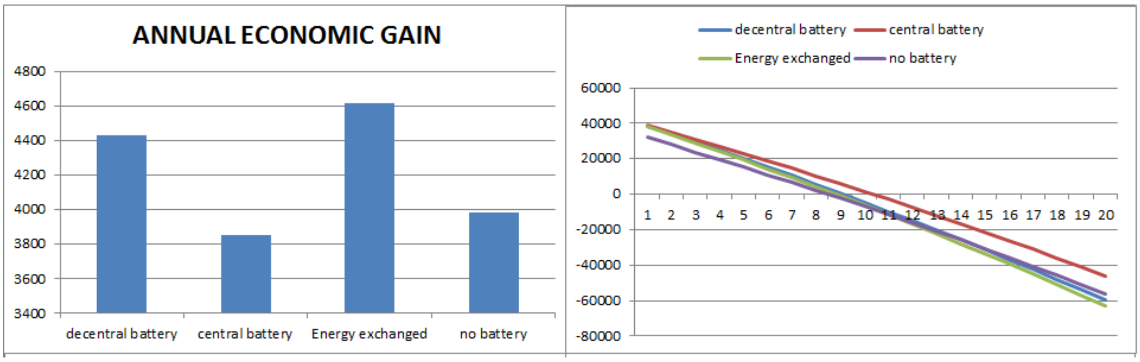


Figure 9-10: results for HOUSE 1

Figure 9-11 show the results for HOUSE 2. The “energy exchange” is the best solution, it is significant to see that in this house the central battery is better in comparison to the decentralised batteries. This because the PV production is small compared to the first house. Compared to the same case in Germany, there is not so much difference between the annual gain of the real, central battery and "energy exchange" configurations, this can be seen in Figure 9-3.

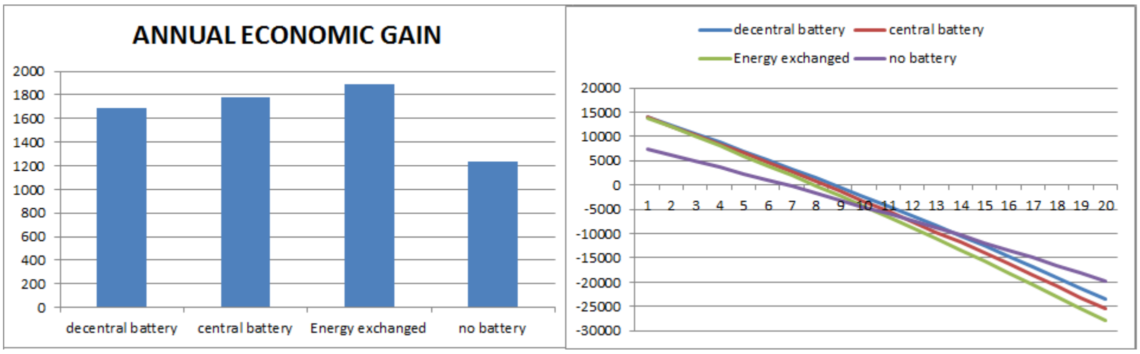


Figure 9-11: results for HOUSE 2

The results for HOUSE 3 are shown in Figure 9-12. The central battery is the best solution, it is optimal because the advantages given by the energy exchange configuration in spring and summer are not so significant in comparison to the central battery in autumn, as shown in the Table 9-7. In the twentieth year, the economic gain of the “no battery” configuration is greater than the real configuration. The cost of battery is not repaid in this case.

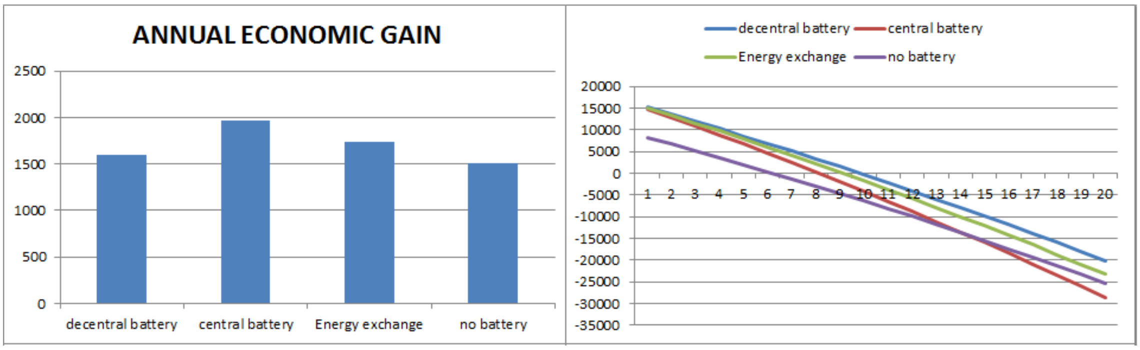


Figure 9-12: Results for HOUSE 3

Table 9-7: comparison in Autumn

		central battery				Energy exchange					
		home	hp	pv	results	home	hp	ask	pv	give	results
autumn	week	24,87779		15,81941	9,058375	47,82341			10,77227		37,05115
	day	3,55397	0	2,259916	1,294054	6,831916	0	0	1,538895	0	5,293021
	seasons	323,4112	0	205,6524	117,7589	621,7044	0	0	140,0395	0	481,6649

As above for HOUSE 3, the “central battery” is seen to be the best solution for HOUSE 4 for the same reasons. Figure 9-13 show the results. In this case also the cost of the battery is not repaid, because in the twentieth year the economic gains for the real and no battery configurations is similar.

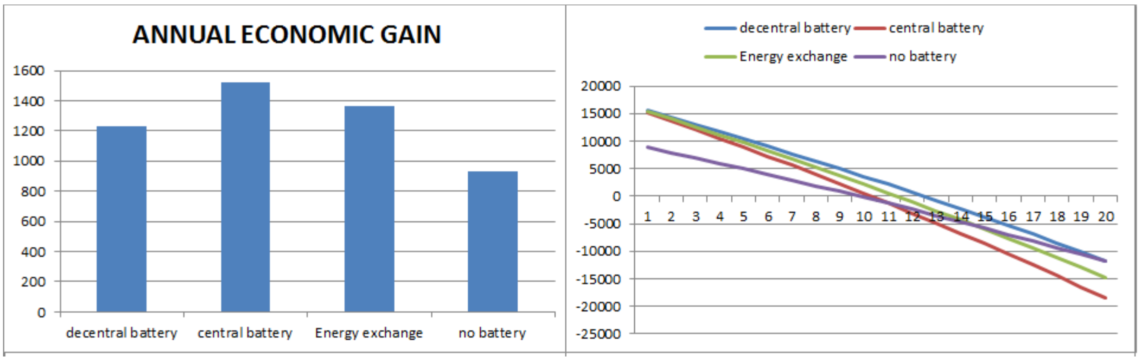


Figure 9-13: results for HOUSE 4

For HOUSES 5 and 6 the best solution, is the "energy exchange" case, as Figure 9-14 and Figure 9-15 show. The “central battery” configuration is the worst solution, because the houses are distant from the battery.

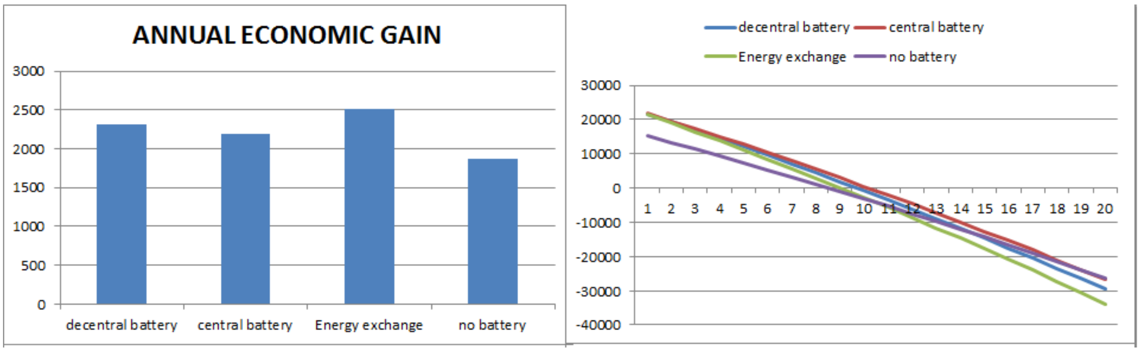


Figure 9-14: results for HOUSE 5

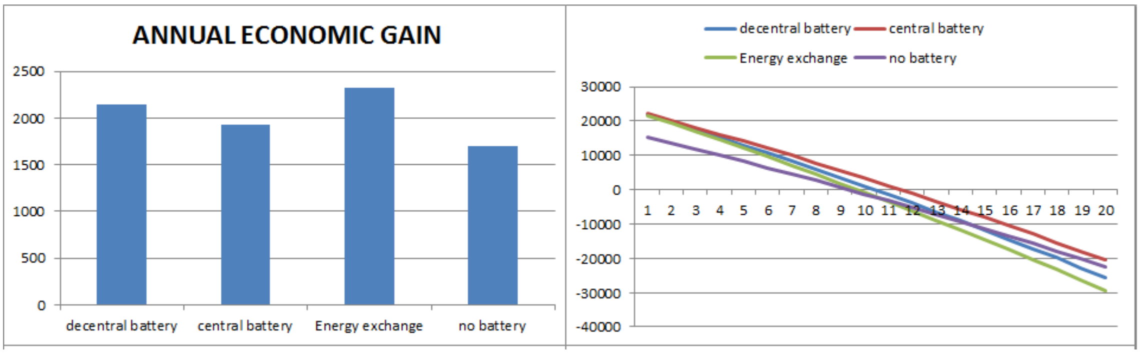


Figure 9-15: results for HOUSE 6

Only two possible configurations are considered since the "energy exchange" configuration is not possible without a regular standard. As above the houses are divided in two groups and Table 9-8 shows the results. HOUSES 1, 5, 6 have the real configuration and HOUSES 2, 3 and 4 the centralised battery configuration. It is necessary to find the best global solution.

Table 9-8: Optimal solution for each house

	decentral battery	central battery
HOUSE 1		
HOUSE 2		
HOUSE 3		
HOUSE 4		
HOUSE 5		
HOUSE 6		

BETTER

The real configuration is better in comparison to the central battery, as Figure 9-16 shows. But in the Italian case the annual economic gain is very small in comparison to the German case. It is possible to see that in the twentieth year the economic gains for the "real", "central battery" and "no battery" configurations are similar. The economic advantage to having a battery is small and with a failure or other adverse event, having a battery is disadvantageous. There is a large difference in comparison with the German results, one because there is no incentive for the battery and the other, for the SSP the energy given to the grid is repaid at a low price. Table 9-9 shows the average price that the GSE repays this energy.

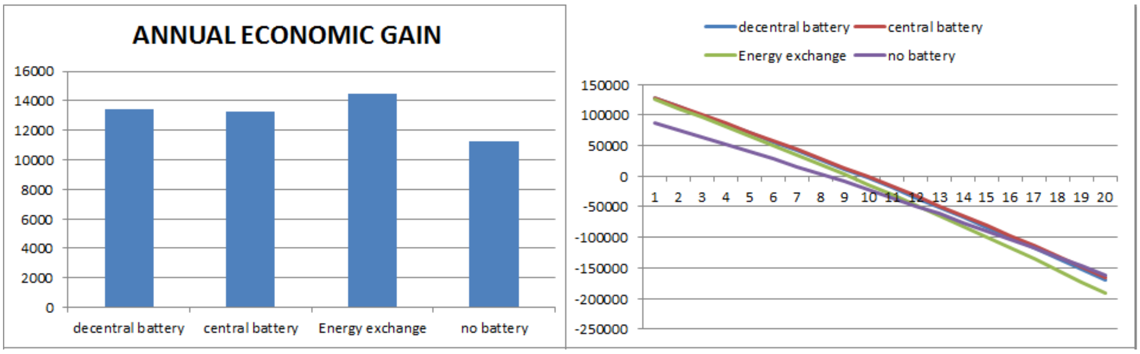


Figure 9-16: Global results

Table 9-9: Average price repaid GSE

	HOUSE 1	HOUSE 2	HOUSE 3	HOUSE 4	HOUSE 5	HOUSE 6
WINTER (€/KWh)	0,070223	0,07352	0,07352	0,07352	0,07352	0,070652
SPRING (€/KWh)	0,056586	0,065909	0,060395	0,065136	0,065136	0,059588
SUMMER (€/KWh)	0,064756	0,067107	0,066001	0,066013	0,065546	0,065083
AUTUMN (€/KWh)	0,075471	0,082577	0,085	0,085	0,082169	0,076734

Despite there being a greater photovoltaic production in Italy, in Germany there is a better economic gain, thanks to the different incentives for the photovoltaics.

9.4 Italian using the German standard

Considering the results in chapter 5.2, there large differences between the German model and Italian models for production and consumption. Using the Italian standards the economic gain of the Italian model is small in comparison the German model. This chapter will analyse the economic comparison of the Italian model, but using the German standards. The conditions and parameters are the same as in chapter of German case.

The Figure 9-17 show the results for HOUSE 1. As in the other economic comparison, the “energy exchange” is the best configuration. But of significance are the annual economic gains for each configuration, these are high in comparison to the results above. The “Real” configuration repaid the cost of the photovoltaics and battery in the sixth year. In the twentieth year there is a greater margin of economic gain between the “real” and “no battery”, even in the case of battery failure there is an advantage.

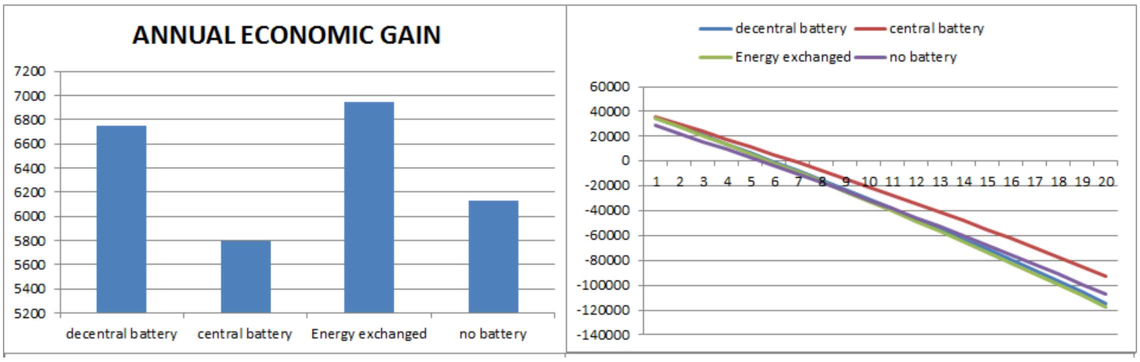


Figure 9-17: results for HOUSE 1

HOUSE 2 also has a high annual economic gain, as Figure 9-18 show. The best configurations are the same as in the previous chapters. The "no battery" case is significant in that all costs were repaid in four years . The advantageous incentives and prices for a high photovoltaic production help the houses repay the cost of the whole the system in few years.

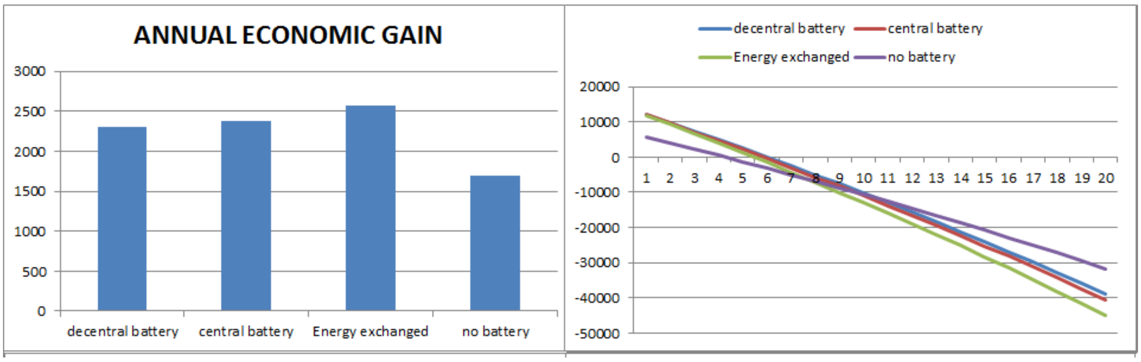


Figure 9-18: results for HOUSE 2

The "real" configuration is better in comparison to the "central battery" in HOUSE 3 using these conditions. The two economic gains are very similar. Figure 9-19 show the results.

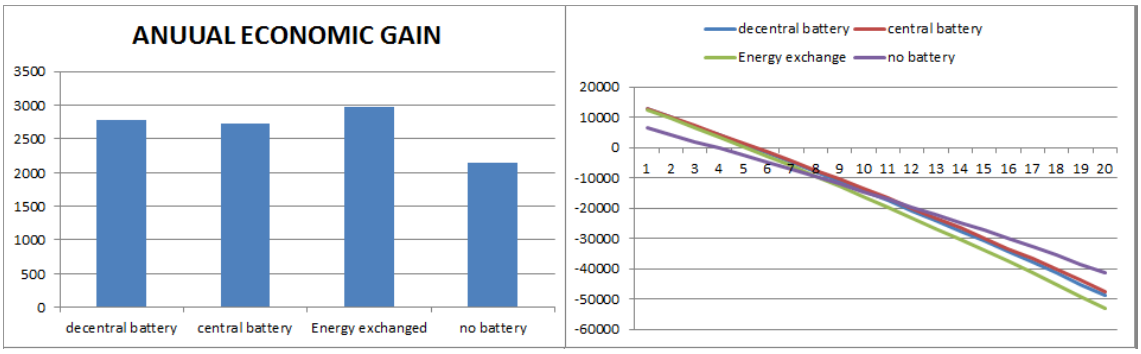


Figure 9-19: results for HOUSE 3

As above, the “central battery” is the best solution for HOUSE 4. In the twentieth year there is not much economic gain between the “real” and “no battery” configurations. If it is necessary to change the battery, this will be disadvantageous.

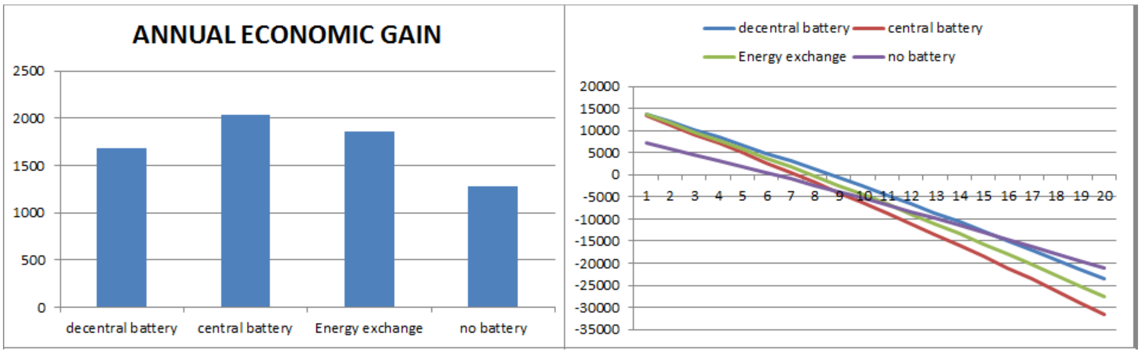


Figure 9-20: results for HOUSE 4

The best solution for HOUSES 5 and 6 is the “energy exchange” configuration. For both, the “real” case is better in comparison with the “central battery”. Figure 9-21 and Figure 9-22 show the results for each house. In the twentieth year there is a good margin of economic gain comparing the “real” and “no battery” cases.

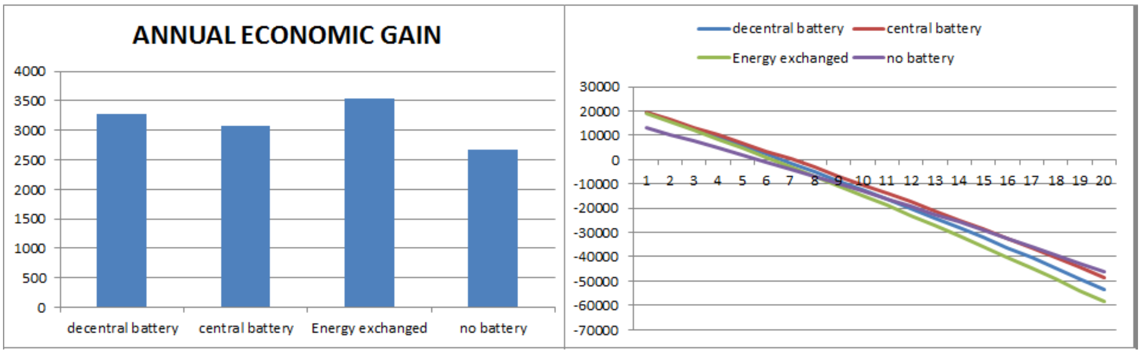


Figure 9-21: results for HOUSE 5

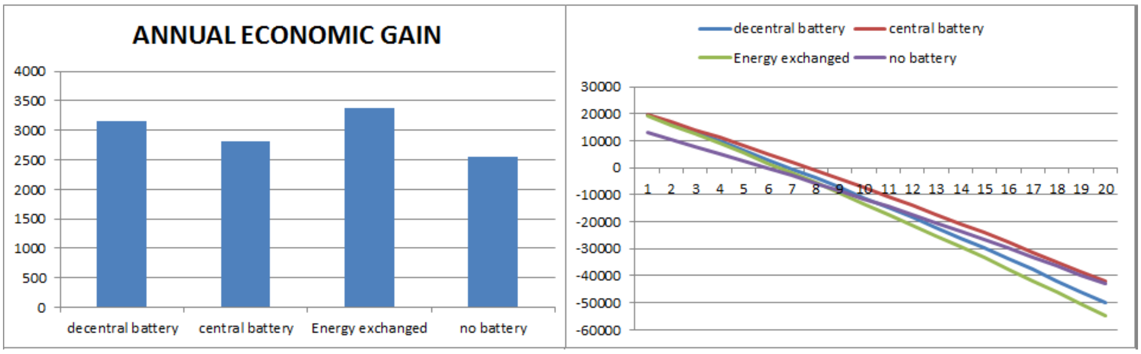


Figure 9-22: results for HOUSE 6

Table 9-10 shows the better solution comparing the “real” and “central battery” configurations. As in the sections above, there are two groups. But in this case in the first, "real" configuration, there are HOUSES 1, 3,5 and 6 and in the second, "central battery" there are HOUSES 2 and 4.

Table 9-10: Optimal solution for each house

	decentral battery	central battery
HOUSE 1		
HOUSE 2		
HOUSE 3		
HOUSE 4		
HOUSE 5		
HOUSE 6		

BETTER

Figure 9-23 show the global results. In this case also the real configuration is better in comparison to the central battery. The difference with the other comparisons is the marginal gain in the twentieth year, between the "real" configuration and "no battery" cases. In this case the global marginal gain is very high and often the marginal gain in each house in high. This case is very interesting, because it uses the very high German incentives together with the Italian photovoltaic production.

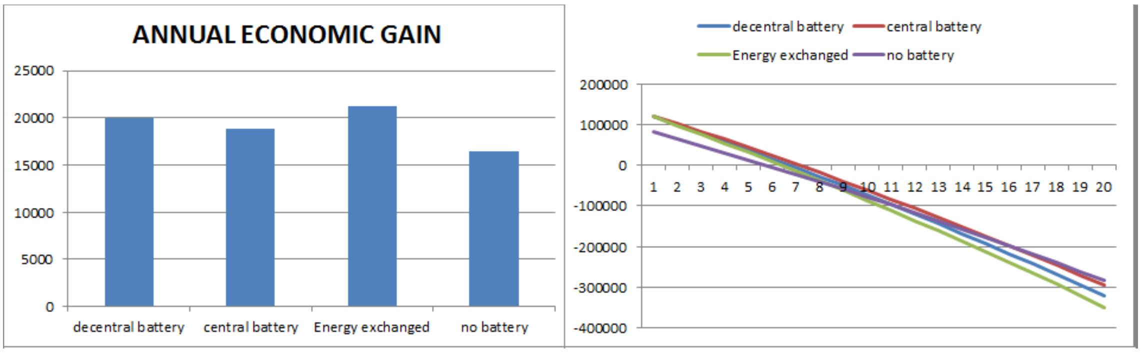


Figure 9-23: Global results

10 POWER LOSSES ANALYSIS

10.1 Introduction

In this chapter the analyses of power losses are presented using the simulation results from Chapter 5. More configurations have been done for the microgrid model, but only the two most significant cases are analysed; *viz* the real and the no battery. The scope of this analysis is to understand the advantage for the distribution firm to having a battery for each house The advantage is a reduction of power losses in the distribution cables. It is necessary divide the German and Italian cases because there are different prices in the two countries. The power losses are calculated for each season for both configurations, so it is possible to have the sum total of the losses for the year and then the two totals for the real and no battery configurations are compared.

10.2 German analyses

In order to calculate the economic part of these losses it is necessary to set the price. The idea is to use the average price between night-time, day-time and heat pump prices, the result is 0,23 €/kWh. Figure 10-1 shows the results of this analysis.

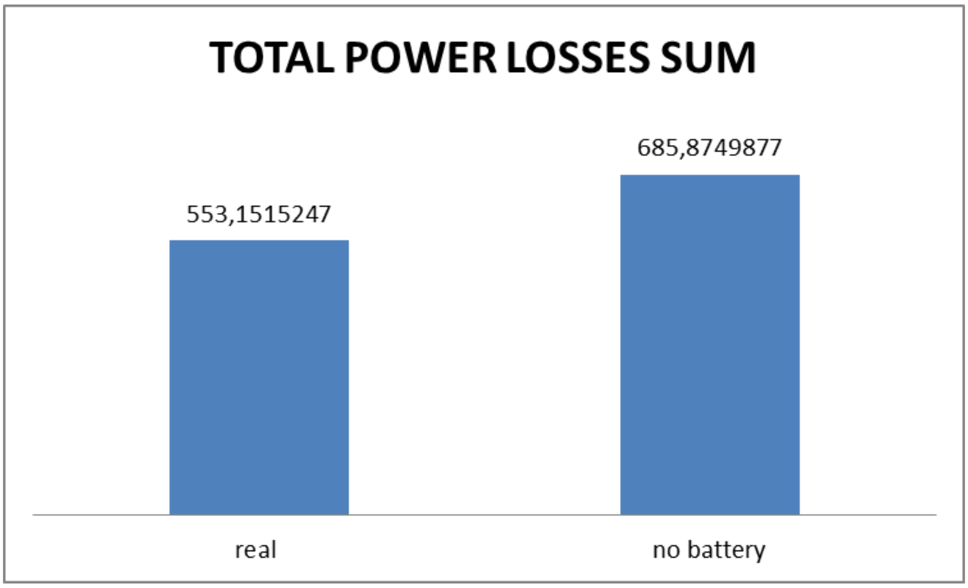


Figure 10-1: Total power losses for the German case.

It is necessary to take these totals and with a price of 0,23€/kWh to calculate the loss of money for the distribution firm.

- Real: 553,151*0.23= € 127,225
- No battery: 685,875*0,23= € 157,751

The saving of € 30 for year is not a high value, especially for a distribution firm. The problem is that the lines are oversized and thus the losses are reduced. The total loads for the six houses are not high, so there is not a high load to supply. If same analysis were remade for a small city the results would be different and the saving would be greater for the distribution firm.

10.3 Italian analyses

As above the same analysis was made for Italy. In this case, the price was calculated using an average of the prices for different seasons. Thus a the price of 0,1918 €/kWh was used and the results are shown in Figure 10-2.

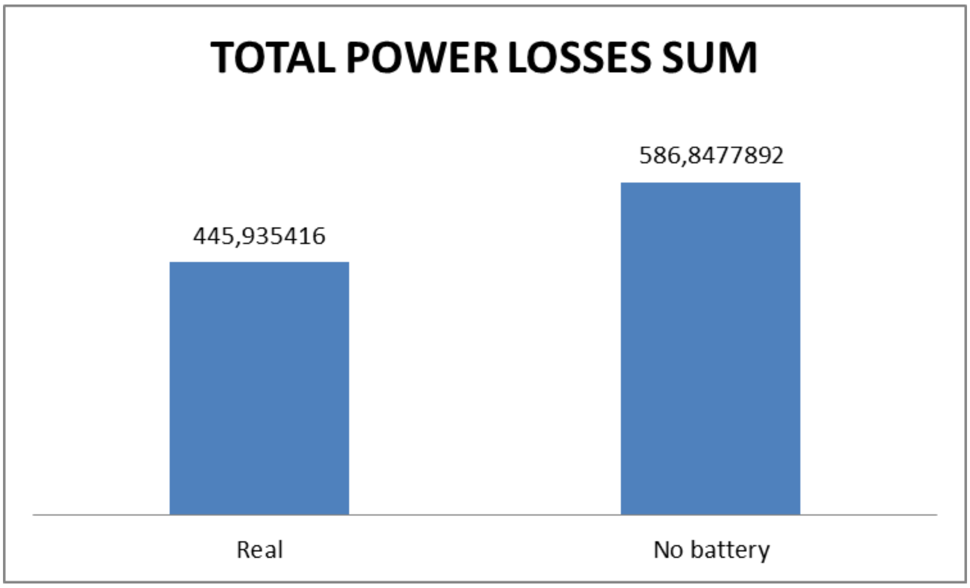


Figure 10-2: Total power losses sum in Italy

The economic losses are calculated as:

- Real: 445,935/0,1918= € 85,53
- No battery: 586,848*0,1918=€ 112,557

In this case the saving is small, only € 27 in a year, the reasons being the same as above.

The calculations have been remade with the German prices, for the purposes of making a direct comparison.

- Real: 445,935/0,23= € 102,565
- No battery: 586,848*0,23=€ 134,975

With the German prices the saving is a little greater, € 32,41. But the three results are very similar, and they are too small to give an important economic saving.

11 COMMENTS

Primary energy resources are not “endless”, so the international community needs to incentivise the use of new energy resources (photovoltaics, etc,). The continued increase in demand for energy generates further problem relating to primary energy sources (e.g. fossil). It is necessary to evolve new technology and management systems for these problems.

An absolute priority is to change the type of production and the traditional management of electric energy, using distributed generation but this can bring problems. One of these, is that energy flow is not from high voltage to low voltage (unidirectional distribution), but there are more levels of supply of energy. The problem is that the distribution grid is not designed to flow in two different directions in the cables. Another problem is when there is more production of green energy, and the demand is low, there is more energy in the cables and the resulting power losses increase. A solution for the management of the impact of decentralised photovoltaic power generation is the Microgrid.

In this work, the impact of decentralised photovoltaic generation was studied in a rural area of Germany, simulating the various configurations that the system could assume. An Italian location, with a different climate was also chosen for a comparison.

The simulations were made with different configurations, those with the battery (central and decentral)can be considered as building level microgrid. Configurations without batteries are considered as distributed generation.

The battery is an important element for the management of the impact of decentralised photovoltaics production, because it is possible to accumulate the surplus energy and manage this energy in a period of low generation.

The simulation of real and ideal cases represents a powerful tool for engineers and researchers. With limited input data, it is possible to obtain many results for the different cases and comparison of these results can give the best configuration or solution for the system and could also provide analyses for different years.

The principal aim was to build models that observed the standards of different countries and the configurations of the rural zones. At the same time the models needed to be easy to adapt to the different configurations for the two countries.

The results obtained with the comparisons are similar for the two countries, with different consumptions and generations, but the scope of this work was to understand a method for managing and resolving the environmental and generated distribution problems.

For each country in each season the best configuration was the “energy exchange”. The results show that with this configuration in summer and spring it is possible to work autonomously from the grid. This is a significant result because the quality and security of energy provision is increased.

The houses, in the real configuration, used a battery in each house and this configuration was called “decentralised battery”. The real configuration, in each country, is better in comparison to the “central battery” for global results. But this is not the case for each house, because often the central configuration is better for a house that has a low photovoltaic production, as for HOUSES 2, 3 and 4. But in the case where there was a mix with results and standards between the two countries, the central battery is better only for the HOUSES 2 and 4. This was because of the effects of high Italian photovoltaic production and the high price incentives in Germany. This helped the real configuration for HOUSE 3. There was one case where HOUSE 4 did not repay the battery cost, because the annual economic gain was not sufficient.

It is important to repeat that these results are not business plans, because only four weeks in a year have been analysed providing qualitative comparisons.

The advantages for the power losses were not so high, because the lines are oversized, so it was hard to see any big advantages to having a battery. It should be considered however that the analysis was only for a small group of six houses and there might be a larger benefit if a greater area were to be considered.

Having a battery, there is the possibility to work with security of supply autonomously from the grid. The battery is used for control management such that in the case of failure there is a longer period of security but it is necessary to reduce the loads.

The grid remains important for the supply of energy, even if there is more battery capacity, because the green energies are not constant. So microgrids working with the grid provide a high quality service, because of the increase in continuity of service. In future this new technology will be used more, reducing the cost of the batteries and green energy (photovoltaic, wind onshore, etc.) and changing the traditional distribution grid gives the possibility of connecting more users. These points are very important for the development of microgrids.

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