Final degree project

Energy Systems Engineering.

Development of a graphical simulator for microgrids with renewable energies

Author: Ángel Durán López

Supervisor: Carlos Bordons Alba

Department of Systems and Automatic
Department of Energetic Engineering Higher Technical School of Engineering
University of Seville

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Profesor titular

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El tribunal nombrado para juzgar el Proyecto arriba indicado, compuesto por los siguientes miembros:

Presidente:

Vocales:

Secretario:

Acuerdan otorgarle la calificación de:

Sevilla, 2019

El secretario del Tribunal

To my family

To my teacher

ACKNOWLEDGEMENTS

I would like to express my gratitude to my family because of supporting during these years of University.

This work would not have been possible without the great knowledge of Carlos Bordons, who have spent time on my project.

Thank you all.

Ángel Durán López

Sevilla, 2019

RESUMEN

Actualmente, vivimos en una situación donde muchas tecnologías están cambiando rápidamente y necesitamos adaptarnos a ello.

Todos sabemos la existencia de la crisis energética y del cambio climático, por ello una posible solución es el desarrollo de las tecnologías renovables y de los sistemas de almacenamientos de la energía.

Los principales sistemas actualmente son las baterías de diferentes materiales (ión litio o ácido plomo) y secundariamente la tecnología de hidrógeno que aún se encuentra en desarrollo.

El principal objetivo de este proyecto es realizar un controlador que pueda gestionar diferentes sistemas de almacenamiento para así ahorrar energía primeria. Por eso se desarrollará un control específico para una microred.

Vamos a realizar el simulador usando bloques de simulink y modelos específicos (fotovoltaico, aerogenerador, demanda, batería y electrolizador). Vamos a usar las especificaciones técnicas de los sistemas reales, pero tendremos que adaptarlos para que la potencia sea la requerida por las fuentes renovables.

Vamos a desarrollar un control por medio de reglas heurísitcas, con el objetivo de alcanzar nuestras metas (una de ellas es poder trabajar en modo “isla”).

Seguiremos la estragia de control del INTA.

Además, realizaremos una serie de pruebas para poder verificar que la estrategia de control trabaja correctamente. En las pruebas modificaremos las condiciones ambientales y los estados iniciales de los sistemas de almacenamiento de energía.

Finalmente, esperamos obtener que nuestro control sea preciso y que pueda trabajar para la microred, aunque sabemos que no está optimizado.

ABSTRACT

Nowadays, we live in a moment that everything is changing fast and we need to adapt to these changes.

As all we know, there is an energy crisis, which we have to overcome, one possibility of solution is development of renewable energy and way of energy storage.

Mainly storage systems are batteries of different matter (lithium-ion or lead acid) and secondly hydrogen technology, which are being developed.

The aim of this project is to achieve a control which can manage different systems storage and then it can save primary energy. Hence, we will develop a control for a specific microgrid.

We are going to develop the simulator using Simulink's blocks and specific models (photovoltaic, wind turbine, battery, electrolyser and demand). We are going to use technical specifications of real systems, but we are going to adapt to power which is required by renewable energy systems.

We are going to develop the strategy of control based on heuristic rules, which we are going to look for achiving our goals (one of these goals is to work island).

We are going to follow the INTA' strategy of control.

Furthemore, we are going to perfom different tests to verify that our control is working right. During these tests, we are going to modify meteorological conditions and initial states of storage energy systems.

Finally, we expect to obtain accurenly control which can work for INTA's microgrd though we know that this control isn't optimized.

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Notation

SES	Storage energy system
RES	Renewable energy system
PE	Passsive element
Inv	Inverter
PV	Photovoltaic
WT	Windturbine
EV	Electric vehicle
PL	Programable load
BE	Better' energy
LB	Lead battery
LhB	Lithium battery
HV	Hibrid vehicle
SOC	State of charge

1 INTRODUCTION

1.1 Introduction:

[1] As we all know, the renewable energy systems (RES) are increasing in last years, as it is a way of looking for a sustainable world. Renewable are source clean, inexhaustible and it helps to innovation.

On the one hand, renewable resources have some troubles, these are not manageable, and these systems produce energy if there are correct meteorological conditions, for example photovoltaic plants need sun's radiation but it cannot work if there is strong wind.

On the other hand, renewable energy systems support to reduce emission of greenhouse's gases and to raise the economy.

Batteries will play a key role in few years because they can help to develop systems with different type of producers and they can solve the problem of RES. Besides, their capability of storing energy is decisive to achive the objectives of reducing use of fossils fuels.

[1]In fact, the management of energy will need to use batteries if the RES begins to gain high percentage in annual production because it may be moment what it is necessary to storage energy from grid or to hand energy over to it (Figure 1).

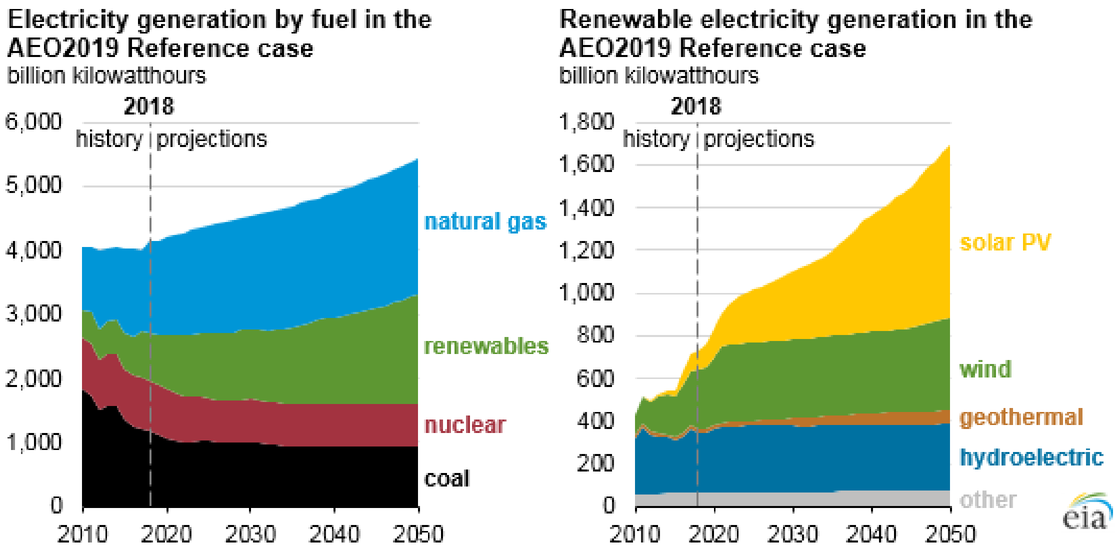


Figure 1. 1annual energy production (outlook 2019) from U.S Energy Information Administration-eia

1.2 Microgrid:

[2]The aim of microgrid is to manage different way of generation like photovoltaic or micro-gas turbine, and to use it, to storage and/or sold energy.

The finally of microgrid depends on situation, because it is not the same if microgrid is a public building like hospital than if it is a residential area.

In the first case we are looking for saving money while in the second we can have different proposals like sold energy or saving energy and money.

[1] Figure1 U.S Energy Information Administration

Besides we must keep in mind that the type of control because it may depend on what systems we have in our microgrid and how it is demand and generation power.

The scope of microgrid is to become independent from conventional grid or at least partial independent.

1.3 The goals:

There are four main objectives:

- First, Developing a simulator for microgrid with RES and other systems.
- Secondly, Developing a heuristic control for this microgrid.
- Third, microgrid can be able to work in island.
- Obtaining conclusions whether this type of control is accurate for this microgrid.

2 INTA MICROGRID

During the section, we are going to explain our microgrid, which is going to simulate, and how simulator is made and what simplifications have been carried out making the control and simulator.

2.1 Description of INTA microgrid.

In this section, we can see the different system which are involved in our microgrid (Figure 2).

We must dive systems in disparate categories and there will be four main categories.

The first category is only passive elements and we put name of passive element (PE).

The second category is whether the system only produces energy and we put name of generators.

The third category is whether the system only consumes energy and we put name of loads.

The forth category is weather the system exchange energy but depending on situation of microgrid and we put name of storage energy systems (SES).

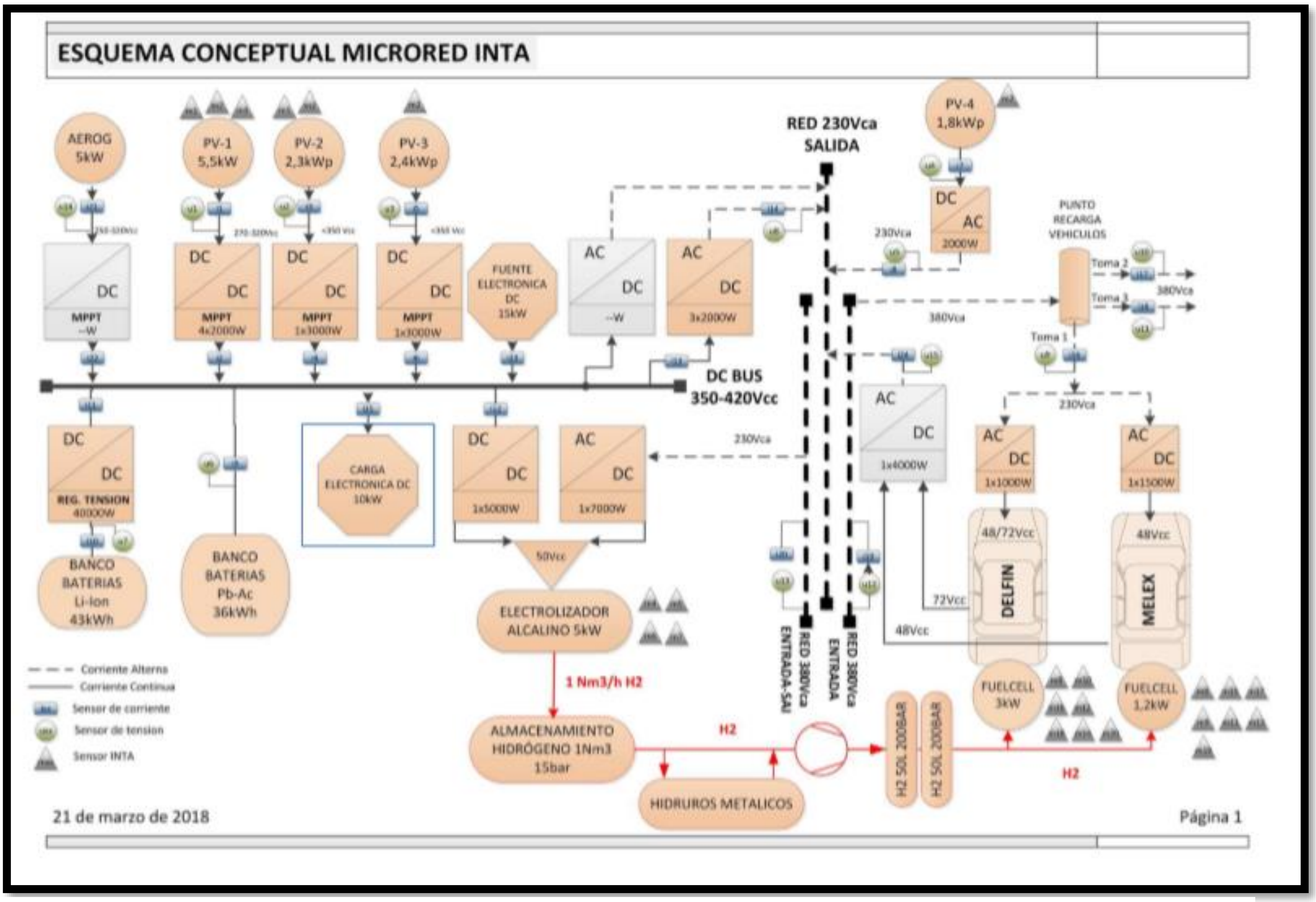


Figure 2. Scheme of INTA microgrid

2.2 Category.

In this section, we explain the different categories, which elements belong to the specific category and their objective.

2.2.1 Passive Element:

PS is element which doesn't produce neither properly consumes energy from bus. The aim of PS is to connect different systems to one side. In our case, this side is DC bus, because it is easy to refer almost all elements to that.

2.2.1.1 List of elements:

We have 6 inverters.

- Inverter 1-PV system 1 (inv1).
- Inverter 2-PV system 2 (inv2).
- Inverter 3-PV system 3 (inv3).
- Inverter 4-PV system 4 (inv4).
- Inverter 5-Wind turbine (inv5).
- Inverter 6-Load system (inv6).

2.2.1.2 Technical specification:

It is only necessary to know efficiency of inverters.

The efficiency may be estimated from 0.80 until 0.98, depending on level of power.

Table 1Efficiency of inverters

	Inv1	**Inv2**	**Inv3**	**Inv4**	**Inv5**	**Inv6**
Efficiency	0.80	0.80	0.80	0.80	0.90	0.98

2.2.2 Generators:

Generators only produce energy which will be consumed or storage, this last one will depend on situation of the microgrid.

Generators are connected to DC bus thankfulness to different inverters (inv1; inv2; inv3; inv4 and inv5).

2.2.2.1 List of elements:

We are going to have different RES which are one wind turbine and four photovoltaic fields, which do not have equal power production (Figure 3).

- PV system 1(PV1).
- PV system 2(PV2).
- PV system 3(PV3).
- PV system 4 (PV4).
- Wind turbine (WT).

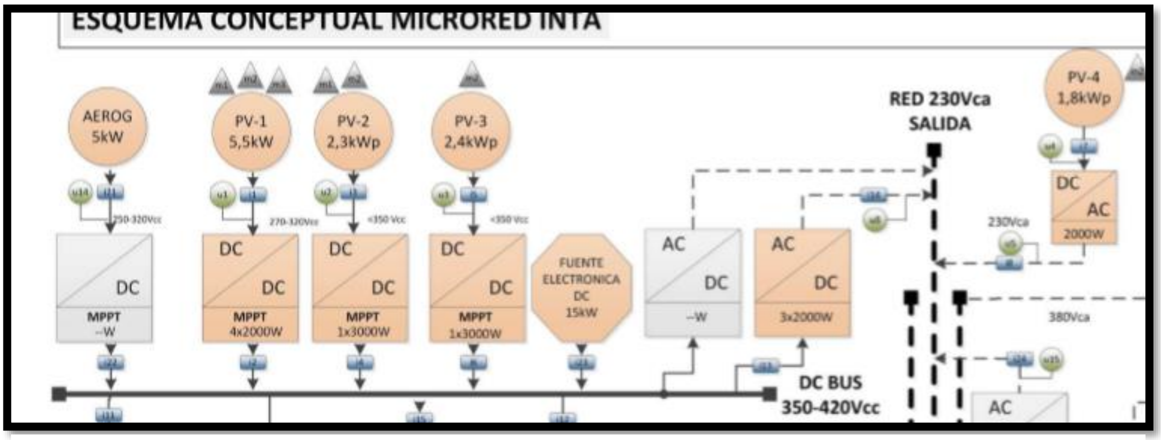


Figure 3. Scheme of mainly inverters

2.2.2.2 Technical specification

2.2.2.2.1 PV system 1:

PV1 is divided into four group which have the same peak power and then the same electrical specification.

Table 2Technical data PV1

	PV1(to refer to group)
W_{peak}	1300 W
$V_{open\ circuit}$ *(panel)*	21.5 V
$V_{max.\ power}$ *(panel)*	16 V
$Current_{short\ circuit}$ *(panel)*	3.35 A
Parallel panels	2
Series panels	17

2.2.2.2.2 PV system 2:

PV2' Panels are of brand "Solar Innova" and model ESF-M-BIPV-GG-P156-40-161W.

Table 3 Technical data PV2

	PV2
W_{peak}	2415 W
$V_{open\ circuit}$ *(panel)*	22,82 V
$V_{max.\ power}$ *(panel)*	14,6 V

Current$_{short\ circuit}$ (panel)	9,11 A
Parallel panels	1
Series panels	15

2.2.2.2.3 PV system 3:

PV3' Panels are of brand "Solar Innova "and flexible model.

	PV3
W_{peak}	1600 W
$V_{open\ circuit}$ (panel)	22 V
$V_{max.\ power}$ (panel)	17,4 V
Current$_{short\ circuit}$ (panel)	6,21 A
Parallel panels	1
Series panels	16

2.2.2.2.4 PV system4:

PV4' Panels are of brand "Wuxi" and model SI-ESF-M- P156-125W.

Table 4 Technical data PV4

	PV4
W_{peak}	1875 W
$V_{open\ circuit}$ *(panel)*	22,1 V
$V_{max.\ power}$ *(panel)*	16,3 V
$Current_{short\ circuit}$ *(panel)*	7,31 A
Parallel panels	1
Series panels	15

2.2.2.2.5 Wind turbine:

WT is model AERO5000W of 5 kW_{peak}, hence our WT will have a W_{peak} of 5 kW in our simulator.

2.2.3 Load.

Loads only consume energy.

2.2.3.1 List of components:

We are going to have different loads but not all loads are always connected to microgrid, then we must do this difference between them.

- Consumers: those are always connected to microgrid.
- Electric vehicle (EV): Depending on time simulation, it will be connected to microgrid.
- Programable load (PL): we can decide when it is connected to microgrid and what level of power.

2.2.3.2 Technical specification:

Only, we are going to have specification about electric vehicle because the rest of loads can be selected and modified in our approaches.

2.2.3.2.1 Electric vehicle:

[3]EV is of brand Nissan and model Leaf 30 kWh Visia 2017.

we are going to give some technical data which are important to estimate the battery capacity.

We are going to use **¡Error! No se encuentra el origen de la referencia.** for calculating battery capacity.

- Battery' energy (BE): 30 kWh.
- Voltage battery (V): 360 V.
- Nominal Capacity (C_{10h}): 83,33 Ah.
- Efficiency battery: 96%.
- Independent: 250 km.
- Electrical consumption (kWh/100 km): 15.
- Deep of discharge: 95%.

Equation 1 Calculate of battery capacity

$$EB = V_{battery} \times C_{10}$$

We must keep in mind that battery has certainly efficiency, in this case we are going to estimate around 96%, [2]then we can calculate useful capacity (**¡Error! No se encuentra el origen de la referencia.**).

- Useful capacity: 76,00 Ah (it is referred to C_{10h}).

Equation 2Efficiency

$$Efficiency = \frac{Useful\ capcity}{DoD \times Nominal\ capacity}$$

[4]The reason why we have estimated in 96% (Efficiency) because it is a normal value for ion lithium battery and it is known that the efficiency cannot be so high as battery efficiency depends on many time discharges. Besides, we suppose that battery can work in deep discharge (DoD) equal 95%.

The maximum state of charge (SOC) are going to be defined by user, so that we are going to suppose 95%.

2.2.4 Storage energy systems.

SES exchange power between bus and them, because the aim of SES is to achieve balance power, hence buss power has to be (Gross Power)equal 0 W.

SES can consume power, but they can also hand power.

In another section (4.3.2Diagram of flow:), we are going to talk about mode operation of SES.

- [2] Powertech (company).

2.2.4.1 List of components:

We are going to have different SES but not all are always connected to microgrid, then we must do this difference between them.

- Lead batteries [3](LB): Lb are always connected to bus.
- Lithium batteries [4](LhB): Lhb are always connected to bus.
- Hybrid vehicle [5]1 (hv1): Depending on time simulation, it will be connected to microgrid.
- Hybrid vehicle 2 [6](hv2): Depending on time simulation, it will be connected to microgrid.
- Electrolyser and storage of hydrogen[7]: It are always connected to bus.

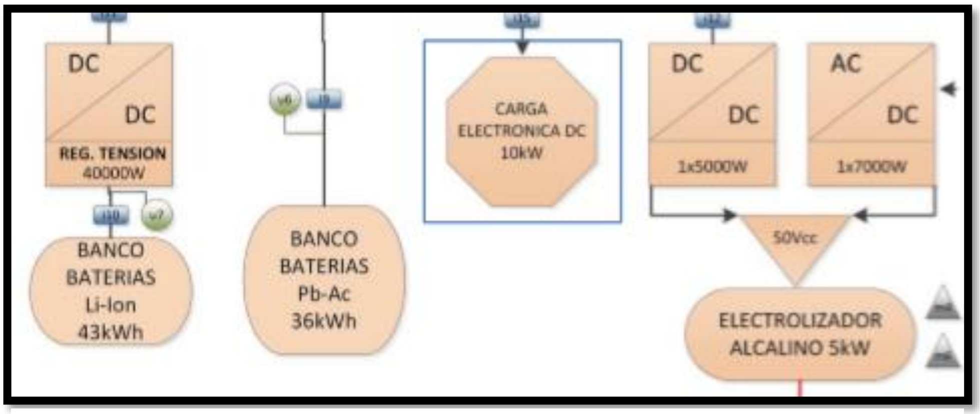


Figure 5. Scheme of SES (LB-LhB-Electrolyzer)

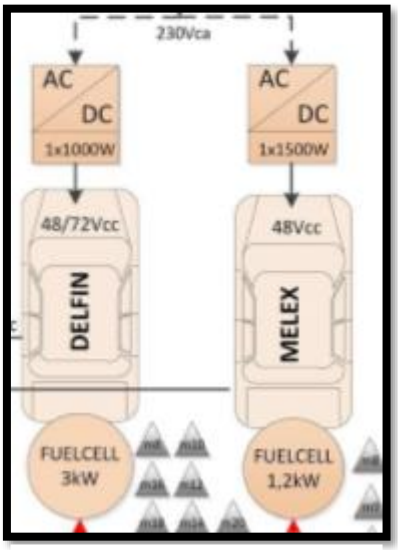


Figure 4. HV1 & HV2

1.1.1.1 Technical specification:

We are going to indicate all specification of SES, which are important for our-microgrid.

---

[3] Banco Bateria Pb-ac.
[4] Banco batería Li-ion
[5] Melex
[6] Delfin
[7] Electrolizador alcalino

2.2.4.1.1 Lead batteries:

LB is brand of UPower and model UP-100 (Figure 6).

We are going to provide useful information which is necessary for calculating the LB ‘capacity.

- LB’s technology is VRLA-AGM.
- Number of batteries in series: 30.
- Nominal voltage per battery: 12 V.
- Nominal Capacity (C_{10h}): 100 Ah.
- Total voltage: 360 V.
- Storage Energy: 36 kWh.

Figure 6. All LB from INTA

We can suppose that we are going to have a high efficiency around 100% because LB is a stationary group. We aren’t going to estimate DoD, because it will be a control variable.

2.2.4.1.1.1 Reference:

- UPower (company).

2.2.4.1.2 Lithium Battery:

Lhb is brand of CEGASA and model ROOK3 (Figure 7).

[5]We are going to provide useful information which is necessary for calculating the LB ‘capacity.

- LB’s technology is LiFePo4.
- Number of batteries in series: 5.
- Nominal voltage per battery: 48 V.
- Nominal Capacity (C_{10h}): 180 Ah.

- Total voltage: 240 V.
- Storage Energy: 43,2 kWh.

Figure 7. All LhB from INTA

We can suppose that we are going to have a high efficiency around 100% because LB is a stationary group. We aren't going to estimate DoD, because it will be a control variable.

2.2.4.1.2.1 Reference:

- CEGASA ROOK3 datasheet (company).

2.2.4.1.3 Hybrid vehicle 1:

Hv1 is a prototype of INTA (Figure 8).

we are going to make some supposition about technical data because we don't have many datas from that.

- Voltage: 48 V.
- Fuel cells power: 1,2 kW.
- Nominal capacity (C_{10h}): 83,33 Ah. (The same as EV).

2.2.4.1.4 Hybrid vehicle 2:

Hv1 is a prototype of INTA (Figure 8**¡Error! No se encuentra el origen de la referencia.**).

we are going to make some supposition about technical data because we don't have many datas from that.

- Voltage: 75 V.
- Fuel cells power: 3 kW.

- Nominal capacity (C_{10h}): 83,33 Ah. (The same as EV).

Figure 8. HV1 & HV2

2.2.4.1.5 Electrolyser and storage of hydrogen

Electrolyser is brand of NITIDOR (Figure 9).

we are going to have some technical specification which are important for our microgrid.

- Maximum Consumption power: 5 kW.

- Hydrogen production: $1Nm^3/h$.

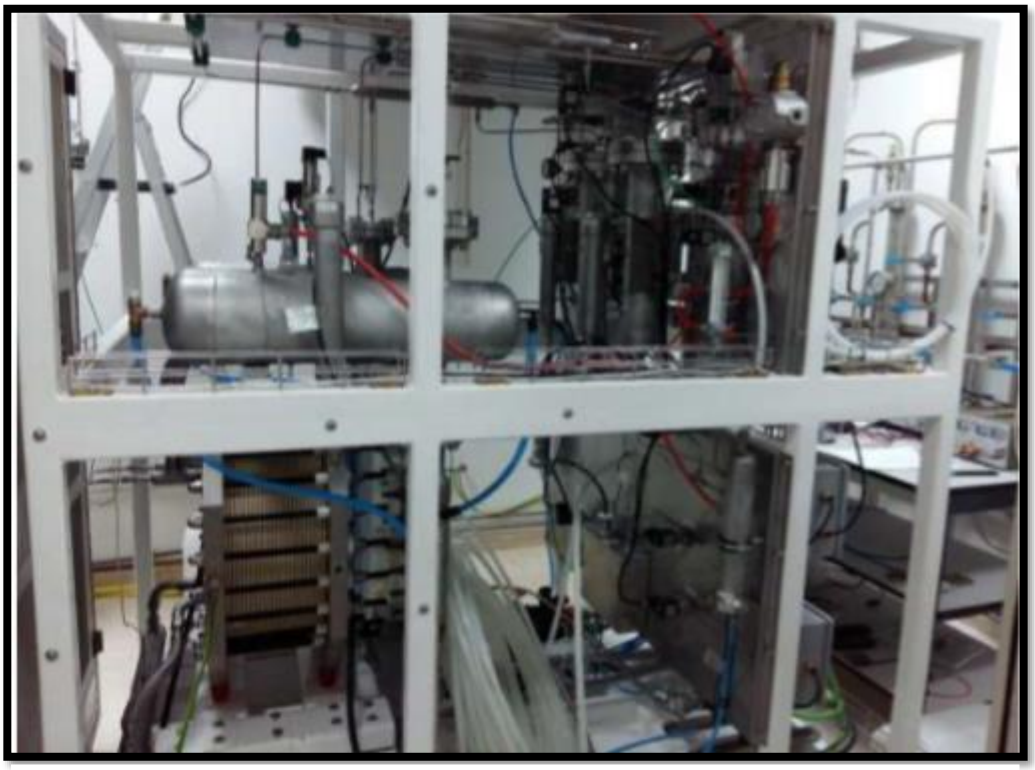


Figure 9. Electrolyser

In case of Hydrogen' storage, we only need to know capacity of storage and it is 50 l

3 SYSTEM SIMULATION

In this section, we are going to describe the simulator and the different [6] blocks, which we are going to use of doing simulations.

The software, which we are going to use, is "Simulink", moreover we are also going to develop some function for simulations.

Almost all model blocks have been developed by other members of the research group, except of the block named "vehicle management", this has been performed by my-self.

3.1 Simplifications:

- loss bus power equal 0 W.
- Not consider ultracapacitor because it has such a low level of energy storage if we compare to the rest of SES (Ultracapacitor energy is 0,440 Wh while LB energy 36 kWh).
- Not consider consume hydrogen from INTA laboratory because this data is unknow.
- Efficiency of SESs is around 100% because they are stationary.
- Electrolyser only consume energy if there is energy excess.

3.2 Subsystem categories:

In the simulator, we are going to have different subsystem.

Besides, we are dived SES in two different subsystems, this distinction is going to be explained in the section Subsystem of storage energy systems:.

3.2.1 Subsystem of generators:

In this subsystem, we are only going to have generators and to define specification for each block (Figure 10).

Besides, we can select the efficiency of each inverter, but we are going to use of specifications of Table 1Efficiency of inverters (14)

Parameters of generators are defined in the 2.2.2.2Technical specification for generators.

In addition, we are going to display mask about these systems.

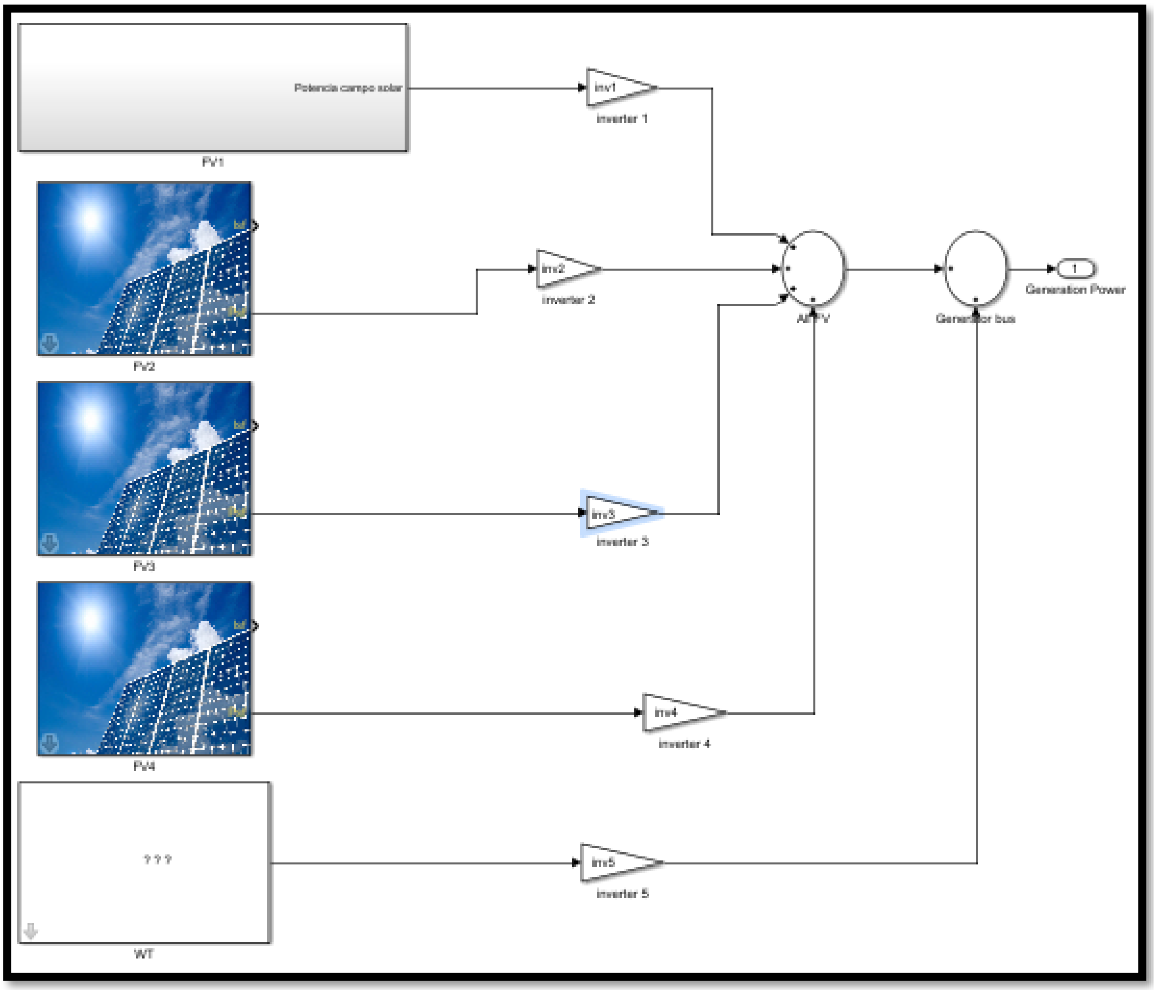


Figure 10. Subsystem of generators

In the mask of SESs (Figure 11) have to add a file which indicates meteorological conditions, in case of PV the name is **"Irradiancy file"** while in case of WT the name is **"Wind velocity file".** Both of them, we can select the type of condition for our simulations. These files have to be previously loading.

In the Test and results, we are going to explain different conditions which we are going to simulate.

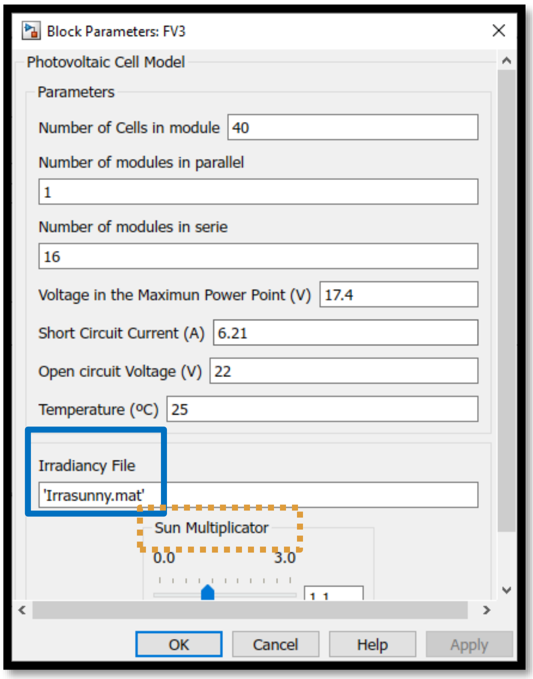


Figure 11. Example of RES 'Mask

Sun and wind multiplicator have been selected in function to be able to obtain peak power of each RES.

3.2.1.1 **Inverters:**

The mask of inverters is the following (Figure 12).

we must only specify the efficiencies which we want.

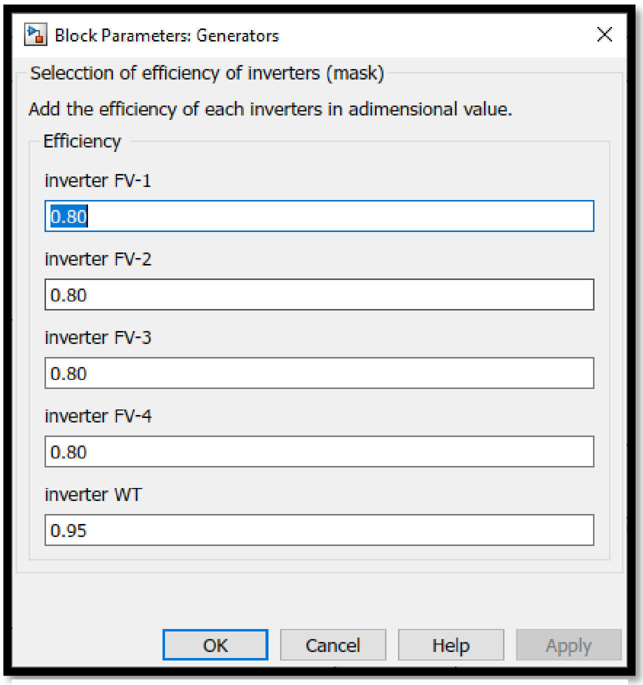


Figure 12. Mask of inverters for generators

3.2.1.2 **PV system 1:**

The mask of PV-1 is the following (Figure 13).

We must specify the following technical.

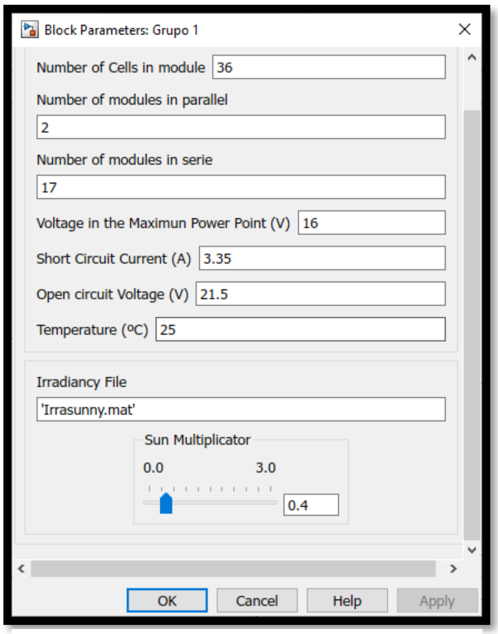


Figure 13. Mask of PV-1

3.2.1.3 **PV system 2:**

The mask of PV-2 is the following (Figure 14).

We must specify the following technical data.

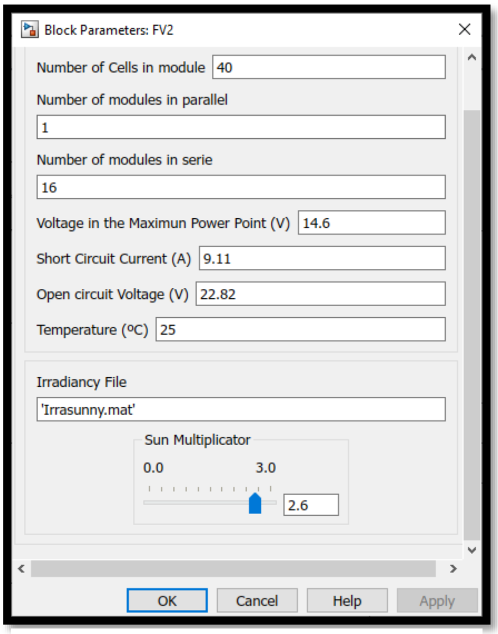


Figure 14. Mask of PV-2

3.2.1.4 **PV system 3:**

The mask PV-3 is the following (Figure 15).

We must specify the following technical data.

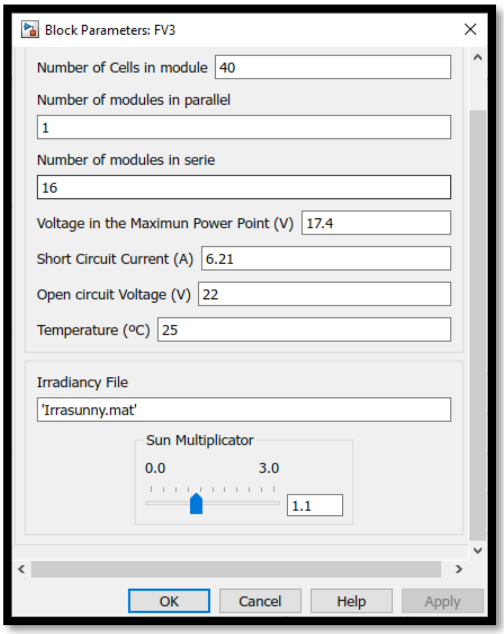


Figure 15. Mask of PV-3

3.2.1.5 **PV system 4:**

The mask PV-4 is the following (Figure 16).

We must specify the following technical data.

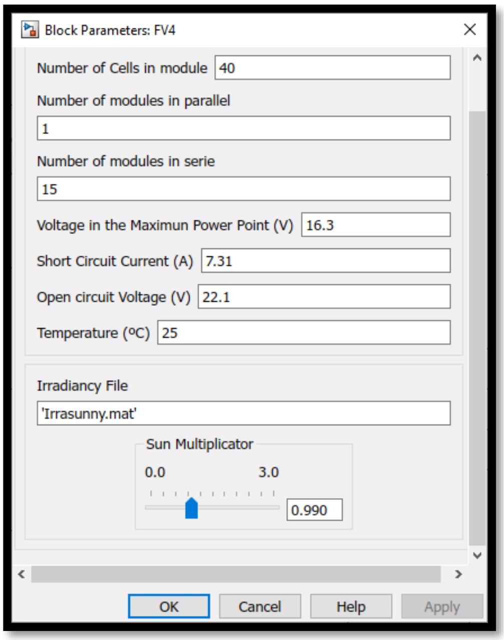


Figure 16. Mask of PV-4

3.2.1.6 **Wind turbine:**

The mask of WT is the following (Figure 17).

We must specify the following technical data.

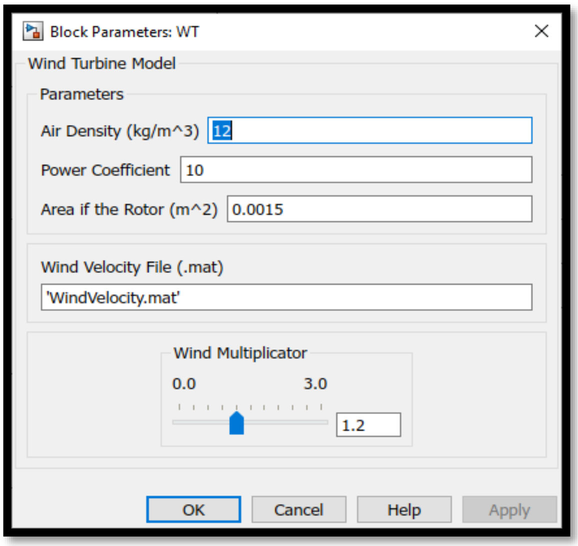


Figure 17. Mask of WT

3.2.2 Subsystem of loads:

In this subsystem, we are only going to have generators and to define specification for each block (Figure 18).

Besides, we can select the efficiency of the demand inverter, but we are going to use of specification of **¡Error! No se encuentra el origen de la referencia.**.

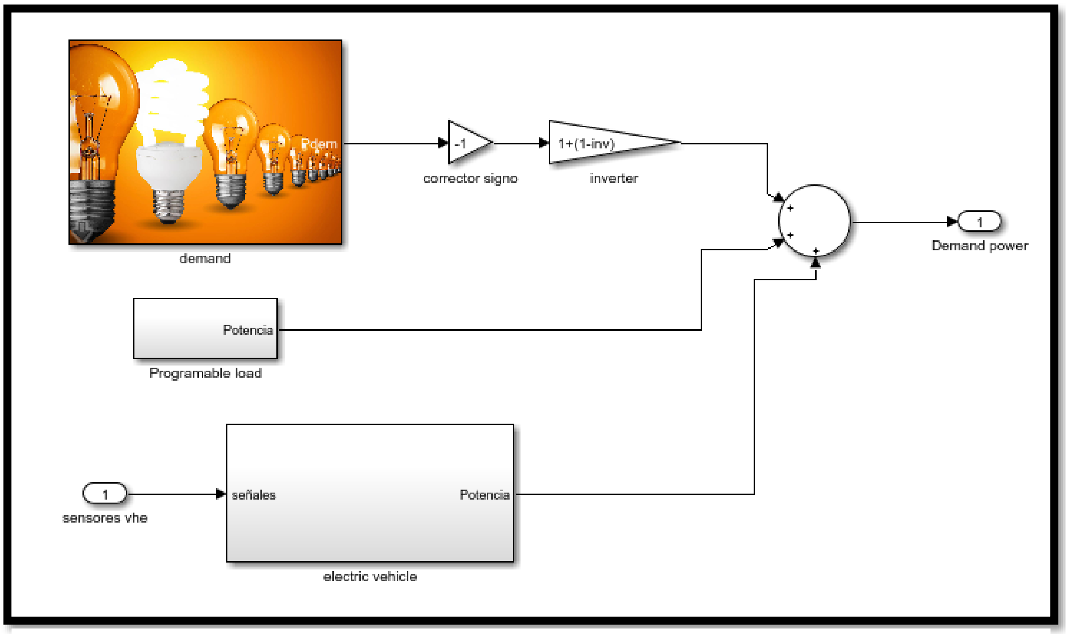


Figure 18. Scheme of loads

3.2.2.1 **The general mask of subsystem:**

The mask has different fields which we are going to define (Figure 19).

Table 5 Field and unit of the loads' Mask

Field	**Unit**
Power of EV 'charge	Watt
Power of EV 'discharge	Watt
Power of programable load	Watt
Time of programable load	Hour
Maximum SOC of EV	Percentage
Efficiency of inverter	dimensionless

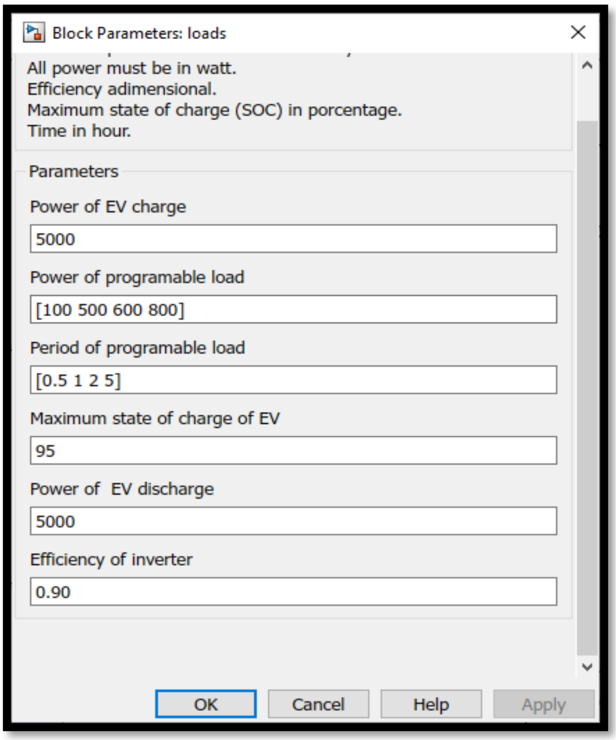


Figure 19. The general mask of loads

3.2.2.2 **Demand:**

The mask of demand is the following.

We are only going to load data of demand profile, which we want.

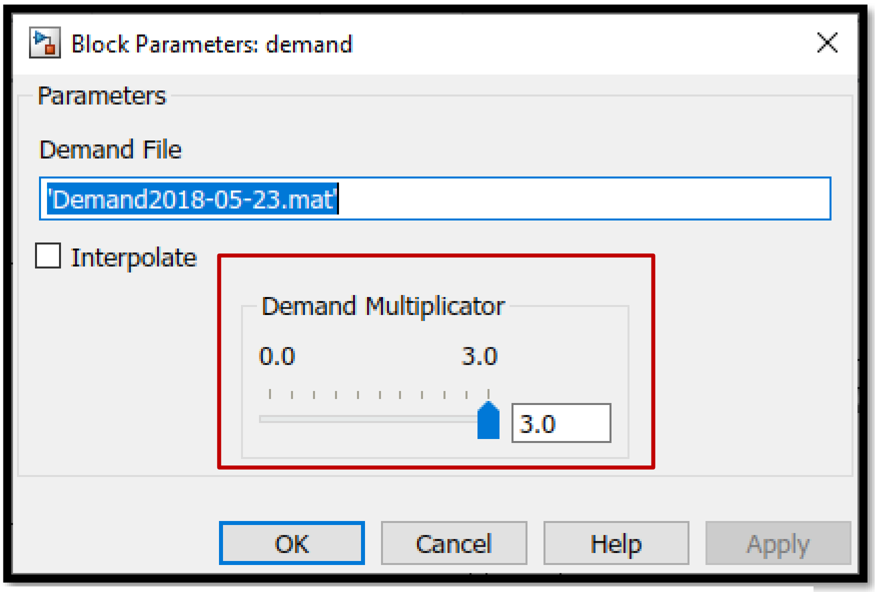


Figure 20. The mask of demand

Demand Multiplicator has been used to increasing it power.

Besides, we are going to define efficiency of inverter for that in a value of 0.90.

3.2.2.3 **Programable load:**

All data necessary for PL has to be defined in the general mask of demand (Figure 19).

- Power of programable load (W).
- Time of programable load (h).
- These values depend on user, so we are going to define the following table (Table 6values of PL):

You can define N-value, there isn't limit.

Table 6values of PL

value	**1**	**2**	**3**	**4**
Power of PL (W)	100	500	600	800
Time of PL (h)	1	8	15	22

3.2.2.4 **Electric vehicle:**

In case of EV there are there mask, which we are going to describe hereunder.

The first is the general mask, which you can define (Figure 19 Figure 21):

- Power of EV 'charge (W).
- Power of EV 'discharge (W).
- Maximum SOC (%).

Table 7Value of EV in the general mask of loads

Power of EV 'charge (W).	5000
Power of EV 'discharge (W).	50000
Maximum SOC of EV (%)	95

[7]EV has as maximum limit charging in 50 kW, this power is only in fast charge while in half-fast can be as maximum 7,3 kW. Therefore, if we wanted to use of conventional charge Power would be around 3,7 kW.

Then, we have decided an intermediate value between conventional charge and half-fast charge.

EV has a maximum limit discharge in 80 kW. [8]

The second mask is about technical data of battery (Figure 21).

We have to calculate the value of C_{120h} because we have the value of C_{10h}. We are going to suppose that $\underline{relation_1} \frac{C_{120h}}{C_{10h}} = 1{,}25$.

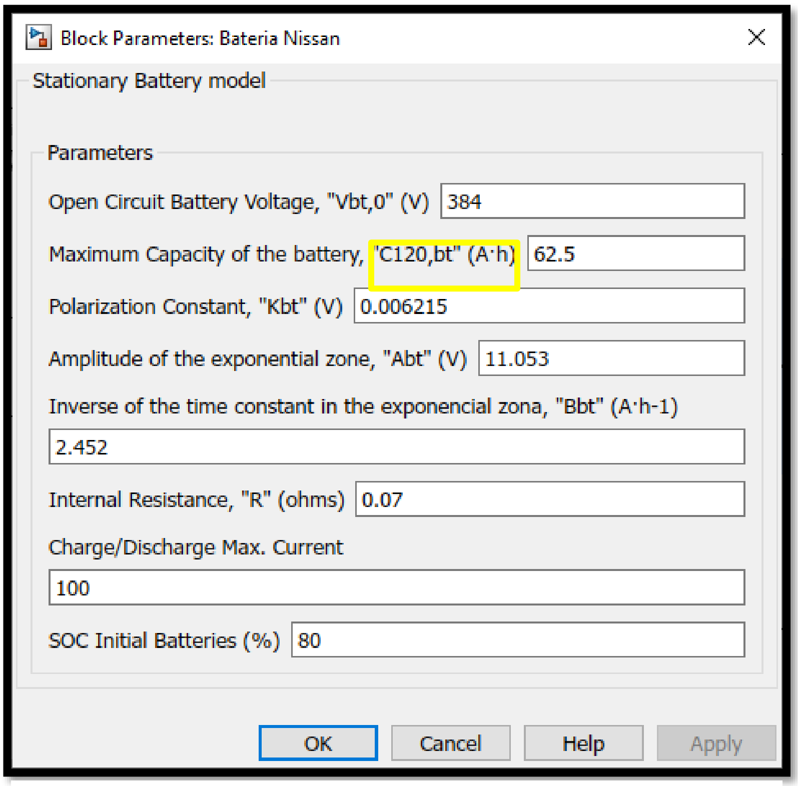


Figure 21. Mask of battery

Using *<u>relation1,</u>* we have obtained C_{120h}.

- C_{120h}: 95,00 Ah.

Voltage is known from technical specifications.

- Voltage: 360 V.

Finally, last mask is vehicle management (Figure 22).

- [8] Endesa (company).

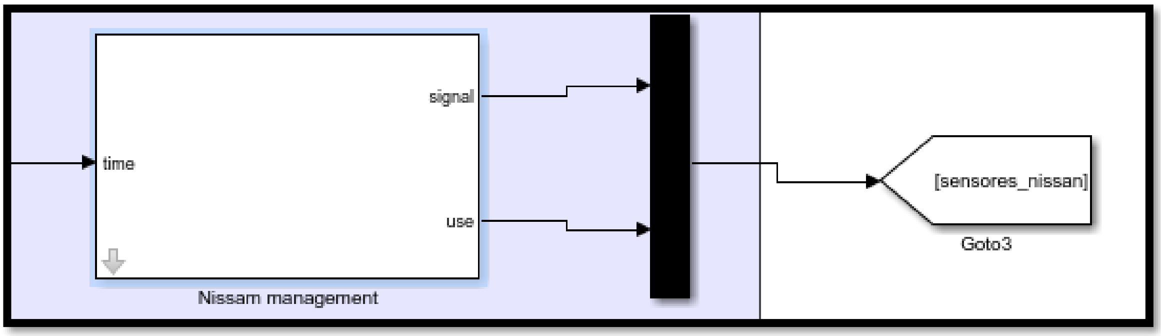


Figure 22. Block of vehicle management

This has two out signals, and both are type Boolean.

In the section Subsystem of vehicle management:, we are going to explain in more details that.

We are going to use it because it introduces different periods (Figure 23):

- Period of useful EV (use).
- Period of charged EV (signal).

The mask is the following.

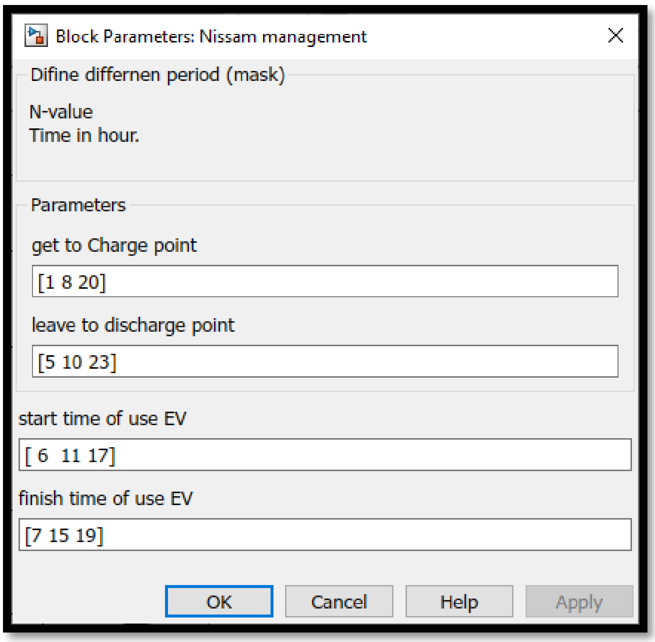


Figure 23. Mask of EV management

Value	1	2	3
Get to Charge point (h)	1	8	20
Leave Charge point (h)	5	10	23
Start time of use EV (h)	6	11	17

Finish time of use EV (h)	7	15	19

Table 24. Value of EV times

You can define N-value, there isn't limit.

3.2.3 Subsystem of storage energy systems:

Only, we are going to define in this subsystem SESs which are always connected to the microgrid, then hybrid vehicles are excluded from that (Figure 25).

This is formed by LB, LhB and electrolyser.

Parameters of SESs have been defined in 1.1.1.1Technical specification:

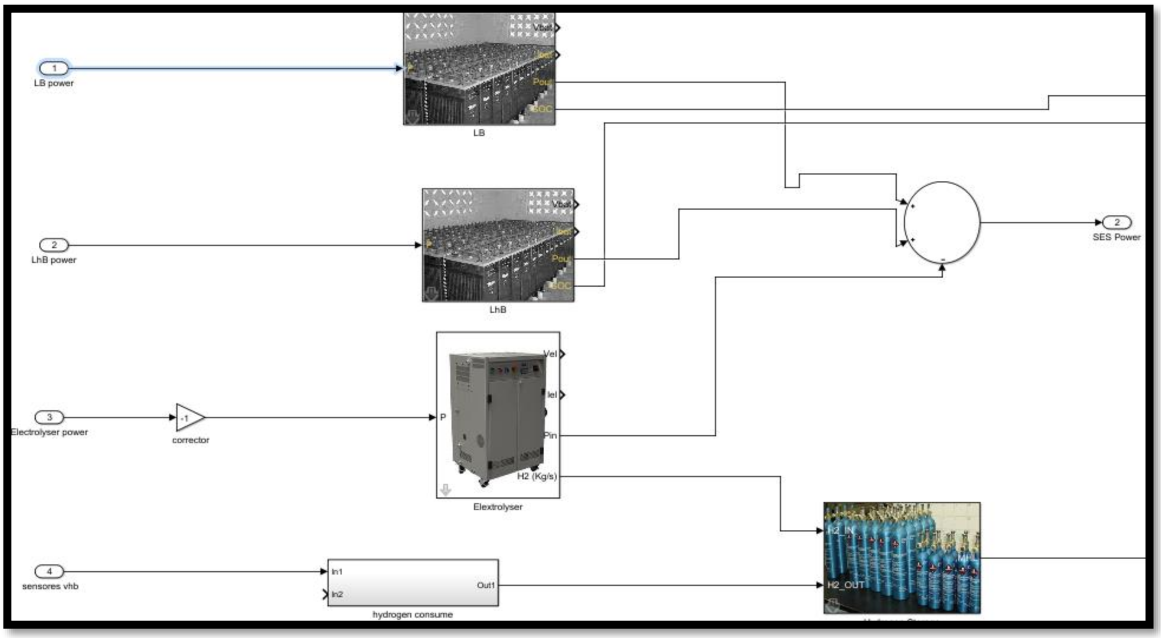


Figure 25. Scheme of SESs

1.1.1.2 The general mask of subsystem:

The mask has four different fields, which we are going to define (Figure 26).

Table 8 Fields and units of the general mask of SESs

Field	**Unit**
Initial SOC of LB	%
Initial SOC of LhB	%
Initial SOC of hydrogen	%
Flow hydrogen	l/h

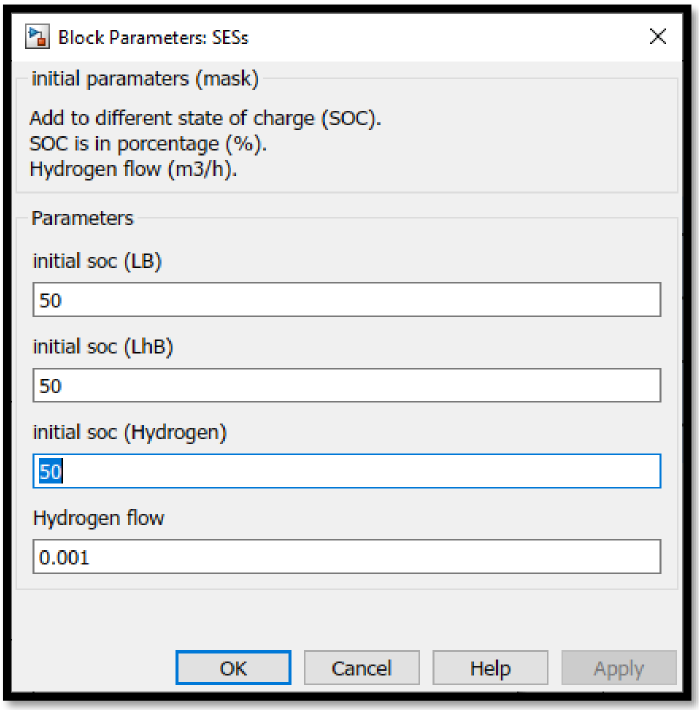


Figure 26. The general mask of SESs

1.1.1.3 **Lead battery:**

In case of LB, we are going to use two mask, which we are going to explain.

The First, it is general mask of SESs' subsystem which you can define (Figure 26).

Initial SOC of LB.

We are going to select as initial SOC 50%.

The second mask is about technical data of battery (Figure 27).

We have to calculate the value of C_{120h} because we have the value of C_{10h}. We are going to suppose that $\underline{relation_{I}}\frac{C_{120h}}{C_{10h}} = 1,25$.

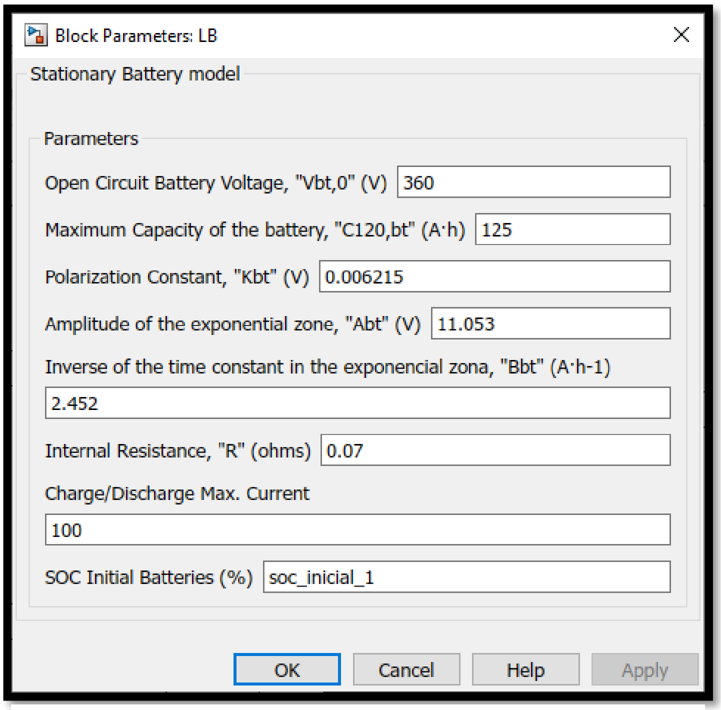


Figure 27. Mak of LB' battery

Using *relation$_{l,}$* we have obtained:

- C_{120h}: 125 Ah.

Voltage is known from technical specifications.

- Voltage: 360 V.

1.1.1.4 **Lithium battery:**

In case of LhB, we are going to use two mask, which we are going to explain.

The First, it is general mask of SESs' subsystem which you can define (Figure 26).

Initial SOC of LhB.

We are going to select as initial SOC 50%.

The second mask is about technical data of battery (Figure 28).

We have to calculate the value of C_{120h} because we have the value of C_{10h}. We are going to suppose that $\underline{relation_l}\frac{C_{120h}}{C_{10h}} = 1{,}25$.

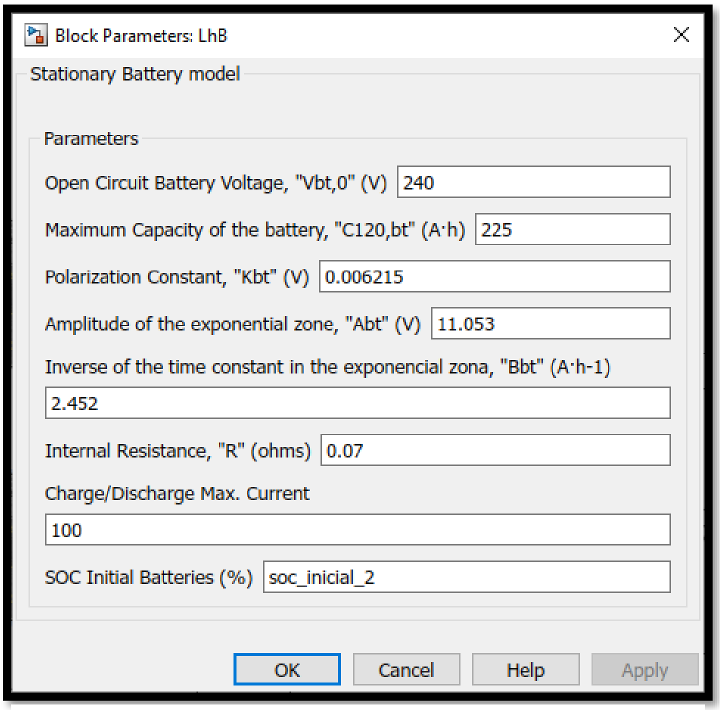


Figure 28. Mask of Lhb' battery

Using *relation$_{1}$,* we have obtained:

- C_{120h}: 225 Ah.

Voltage is known from technical specifications.

- Voltage: 240 V.

1.1.1.5 **Electrolyser and storage of hydrogen:**

In case of electrolyser, we are going to use three mask.

The first mask is the general mask, which you can define (Figure 26):

- Initial SOC of hydrogen.
- Flow of Hydrogen (consumed).

Table 9 value of general mask about electrolyser and storage of hydrogen

Initial SOC	50%
Flow of hydrogen	0,001 l/h

The second mask is about technical data of electrolyser (Figure 29).

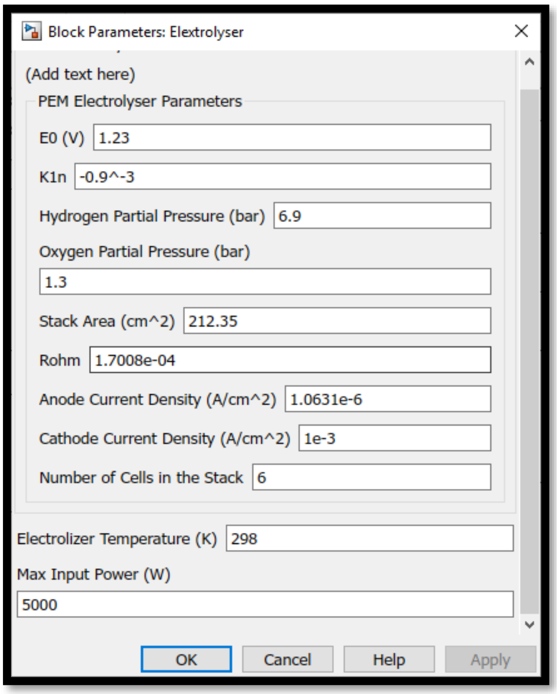


Figure 29. Mask of electrolyser

We only have to define the maximum input power, which we know from technical data (add section).

- Max. Input Power: 5000 W.

Finally, last mask is about Hydrogen' storage (Figure 30).

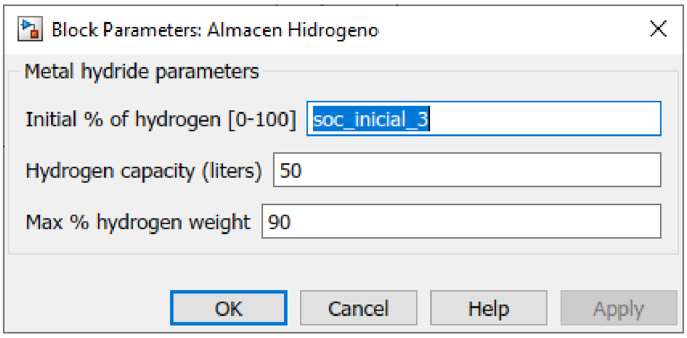


Figure 30. Mask of hydrogen storage

In this, we only have to add Hydrogen capacity, which is 50 l.

3.2.4 Subsystem of hybrid vehicles:

The reason why hvs aren't in SESs is because HVs is sometimes connected to microgrid, so that the subsystem is only formed by hybrid vehicle 1 and hybrid vehicle 2.

3.2.4.1 The general mask of subsystem:

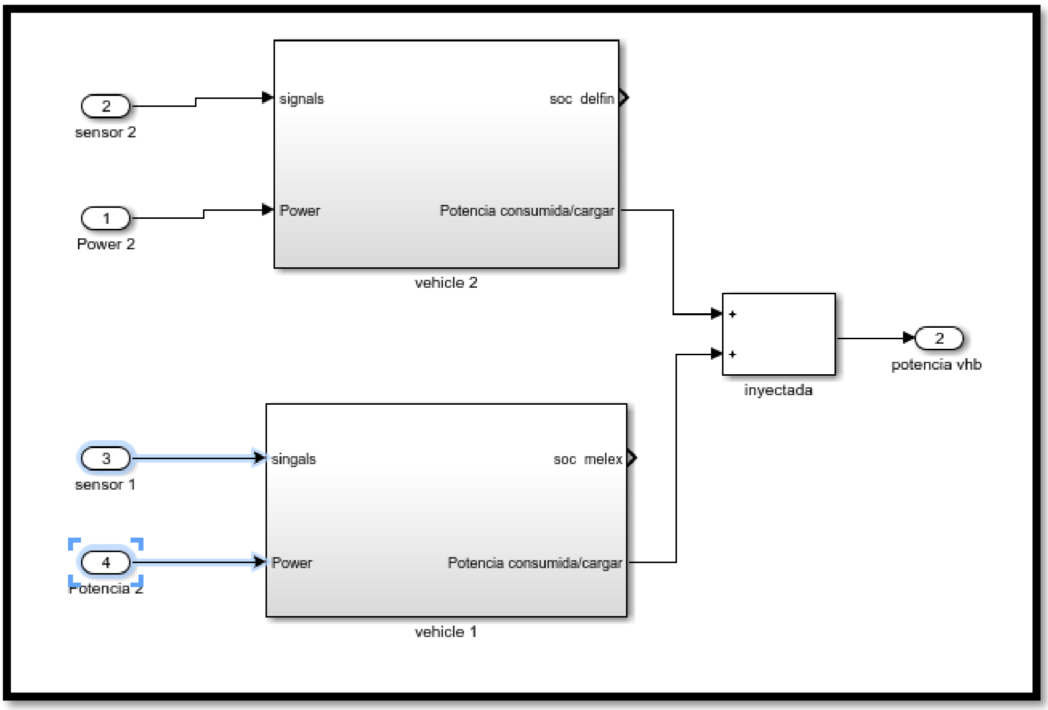


Figure 31. Scheme of hybrid vehicle

The mask has different fields which we are going to define.

Table 10 Field of the general mask of hybrid vehicle

Field	**Unit**
Power 1	Watt
Power 2	Watt
Initial SOC 1	Percentage
Initial SOC 2	Percentage

Both powers (1&2) is about discharge vehicle and NOT about charge vehicle, because vehicle are going to charge using exceed power.

However, it is going to explain with more details in the section add Hierarchy of control.

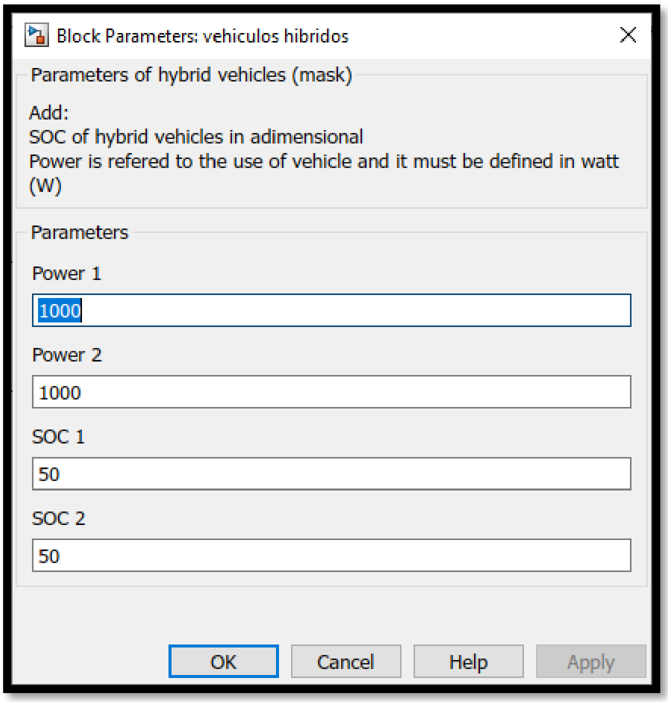


Figure 32. The general mask of hybrid vehicle

3.2.4.2 Hybrid vehicle-1:

In case of hy1 there are there mask, which we are going to describe hereunder.

The first is the general mask, which you can define (Figure 34):

- Power 1 (hy1'charge) (W).
- Maximum SOC (%).

Table 11Value of hv-1 in the general mask of loads

Power 1	1000 W
Initial SOC of hv1	50 %

We have to calculate the value of C_{120h} because we have the value of C_{10h}. We are going to suppose that *relation1* $\frac{C_{120h}}{C_{10h}} = 1,25$.

Using *relation1,* we have obtained C_{120h}.

- C_{120h}: 95,00 Ah.

Voltage is known from technical specifications.

- Voltage: 48V.

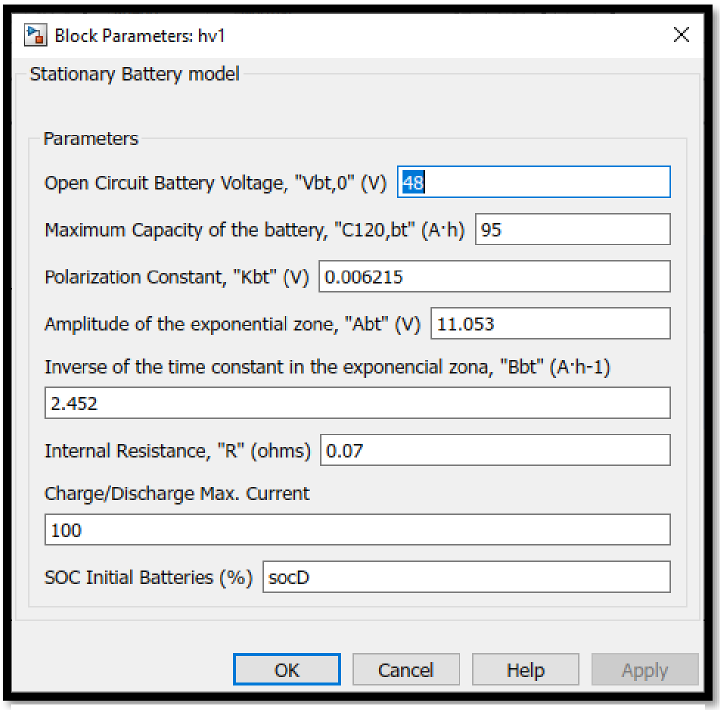


Figure 34. Mask of technical data of vh1

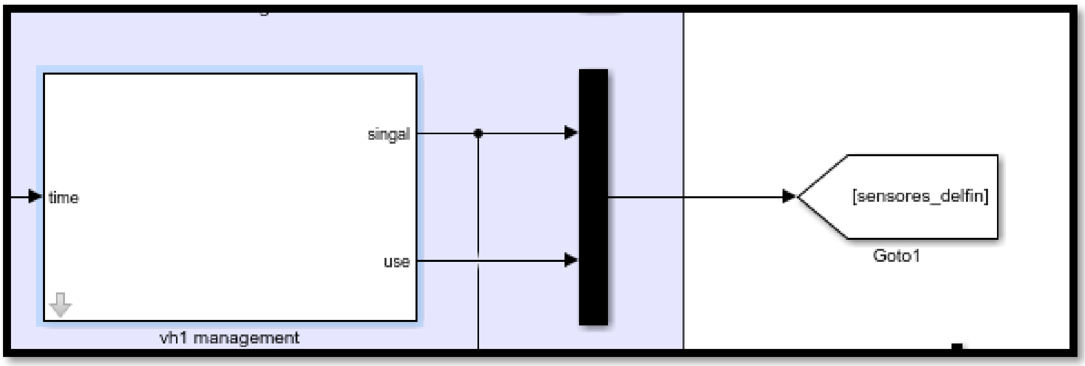


Figure 33. Mask of vh1 management

Finally, last mask is vehicle management (Figure 35).

This has two out signals, and both are type Boolean.

In the section Subsystem of vehicle management:, we are going to explain in more details that.

We are going to use it because it introduces different periods ():

- Period of useful vh1 (use).
- Period of charged vh1 (signal).

The mask is the following.

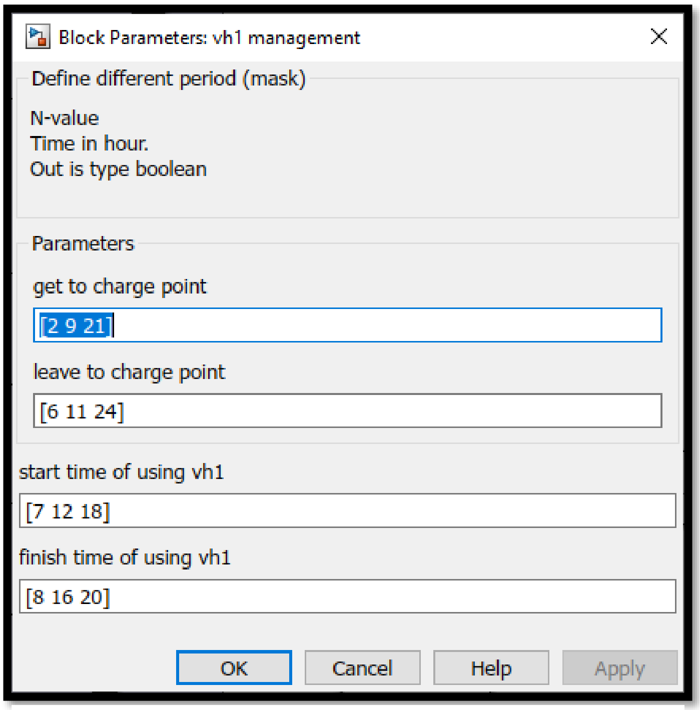


Figure 35. Mask of vh1 times

Table 12 value of vh1 times

Value	**1**	**2**	**3**
Get to Charge point (h)	2	9	21
Leave Charge point (h)	6	11	24
Start time of use vh1 (h)	7	12	18
Finish time of use vh1 (h)	8	16	20

You can define N-value, there isn't limit.

3.2.4.3 **Hybrid vehicle-2:**

In case of hy2 there are there mask, which we are going to describe hereunder.

The first is the general mask, which you can define (Figure 32):

- Power 2 (hy2'charge) (W).
- Initial SOC (%).

Table 13Value of hv-2 in the general mask of loads

Power 1	1000 W
Initial SOC of hv2	50 %

We have to calculate the value of C_{120h} because we have the value of C_{10h}. We are going to suppose that

$\underline{relation_1}\frac{C_{120h}}{C_{10h}} = 1,25$.

Using *relation1,* we have obtained C_{120h}.

- C_{120h}: 95,00 Ah.

Voltage is known from technical specifications.

- Voltage: 78V.

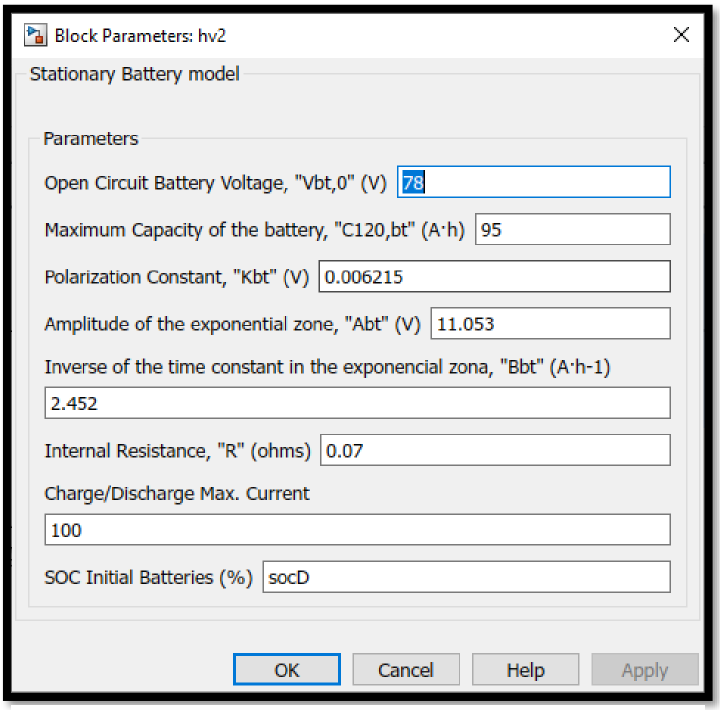


Figure 36. Mask of techincal data of hv2

Finally, last mask is vehicle management (Figure 37).

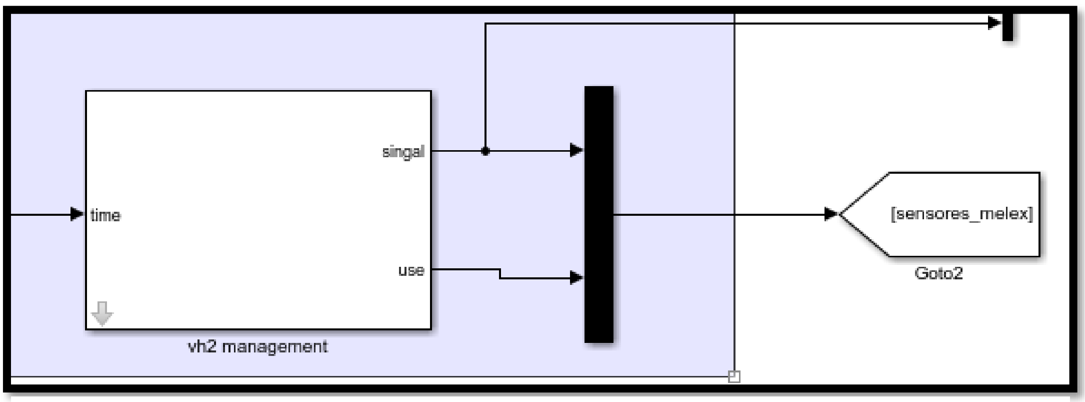


Figure 37. Mask of vh2 management

This has two out signals, and both are type Boolean.

In the section Subsystem of vehicle management:, we are going to explain in more details that.

We are going to use it because it introduces different periods (Figure 38):

- Period of useful vh2 (use).
- Period of charged vh2 (signal).

The mask is the following.

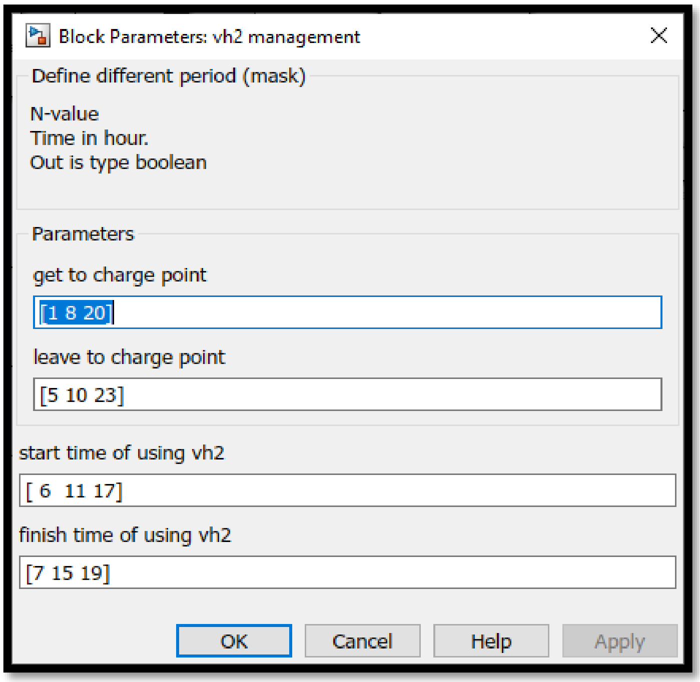


Figure 38. Mask of vh2 times

Table 14value of vh2 times

Value	1	2	3
Get to Charge point (h)	1	8	20
Leave Charge point (h)	5	10	23
Start time of use vh2 (h)	6	11	17
Finish time of use vh2 (h)	7	15	19

You can define N-value, there isn't limit.

3.2.5 Subsystem of grid:

This subsystem represents conventional grid.

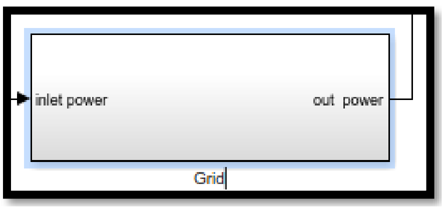


Figure 39. The subsystem of conventional grid

3.2.6 Subsystem of vehicle management:

This subsystem has been made by the author of this document.

The aim of vehicle management is to send a signal which represent gotten and left vehicles of charge point and useful time.

We have used of MATLAB for making up a function which is able to read input date from interface and depending on simulation time, output is true or false.

If output is true meaning that vehicle is at charge point or being used.

If output is false meaning that vehicle isn't at charge point or isn't being used.

3.2.6.1 Features of the function:

- 3 input data:
  - Time 1 (gotten or stared to use).
  - Time 2 (left or finished to use).
  - Simulation time.
- 1 output data:
  - Signal: True or False.

3.2.6.1.1 Scrip of the function:

```
function [ out ] = gestor_vehiculos( in )

%% en esta funcion buscamos experimentar el comportamiento de los vehiculos con baterias variando.
```

```
t1= [];
t2=[];
out=double(0.00);
sensor=0;
N=length(in);
n_1=N-1;
M=(N-1)/2;
M_1=(N-1)/2;
m=1;
p=1;
t1=in(1:M_1);
t2=in(M_1+1:n_1);
r=length(t1);
    t_s=in(N);
   aux_1=t1.*3600;
   aux_2=t2.*3600;

     for k=1:r

        if aux_1(k)<t_s &&
t_s<aux_2(k)
            sensor=1;
        end
    end
    if sensor == 1 ;
        out=1;
    else
        out=0;
end
end
```

3.2.6.2 **Scheme of the vehicle management:**

In the figure shows the structure of vehicle management, which you can see that it is referred to the charge point because there gotten and left time. The structure is similar in case of another case (useful time).

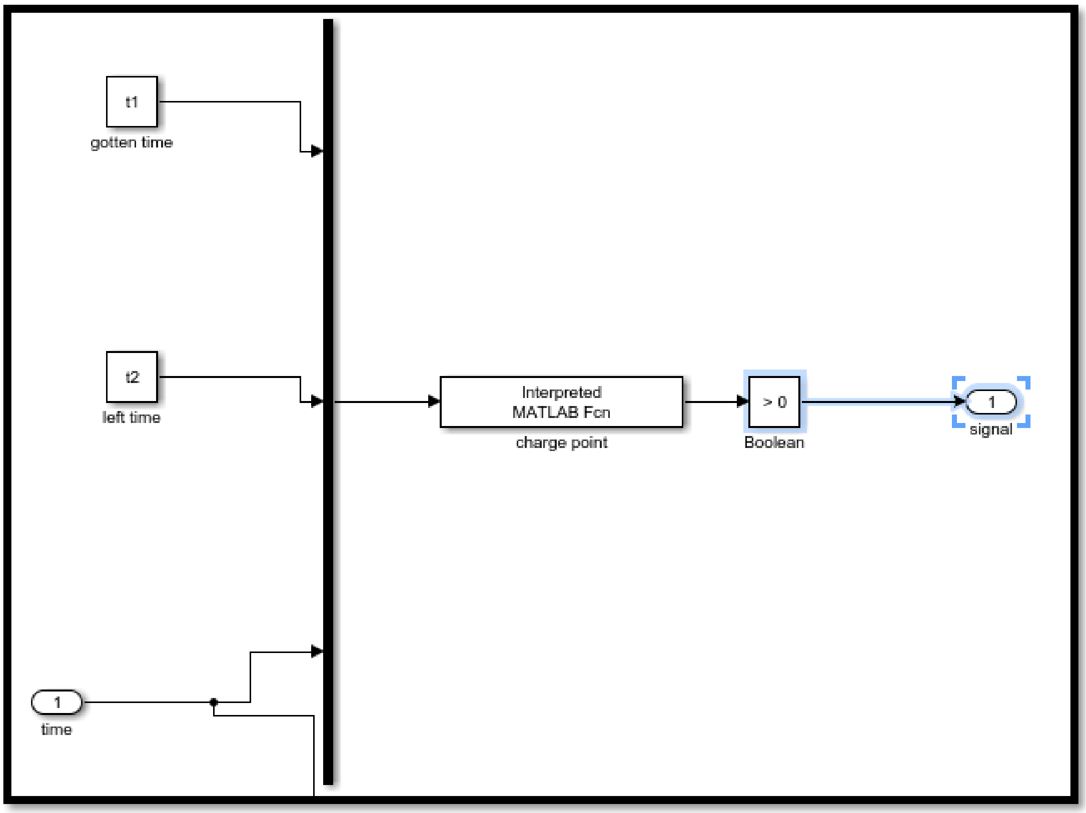


Figure 41. Scheme of vehicle management

Different data are read from mask.

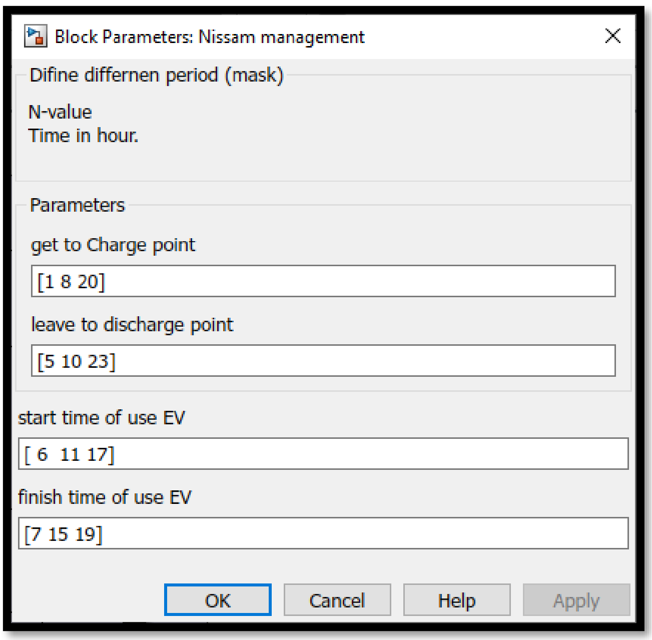


Figure 40. Example of mask.

4 ENERGY MANAGEMENT IN THE MICROGRID

4.1 Overview of control in microgrid:

We are going to explain (strength and weakness) and to give some example of each control technic

[8], [6], [2]There are essentially four technics of control, Heuristic rule (HR), fuzzy control(FC), mode predictive control (MPC) and artificial intelligent (AI).

4.1.1 Heuristic rule:

[9]Heuristic rule is based in Boolean logic; hence it takes action following a rule and conditions.

This control compares signal from a process with a reference value and then the controller takes action according to the condition of the rule. Then it doesn't have intermediate situations in the strategy.

For example, if you want to star the engine you have to push a button, then if you push the button the engine starts. if not, the engine doesn't do it.

The rule

If Push button is" TRUE" then Start the engine.

If not push button is "FALSE" then not start the engine.

Strength:

- It is the most useful.
- Simple strategy.
- It is easy to implement.
- Use of few systems.

Weakness:

- Complex for many systems.
- Few operational modes.
- Limited for dynamic systems (example conventional grid).
- It isn't optimized.
- It can only be active a system.
- Without intermediate states.
- It doesn't consider efficiency of the system.
- Boolean logic.

Example:

- It can be used of insulated house with few systems in countryside.
- It can be used of photovoltaic plant with batteries (Not or Yes , to charge battery).

4.1.2 Fuzzy control:

[10], [11]FC is based on fuzzy logic and this control follows a collection of rules.

This control compares signal from a process with reference values and then the controller takes action according to the deviation and control' strategy. Then it has intermediate situations in the strategy.

For example, A temperature controller uses fuzzy control that would compare actual temperature with reference temperature (the set point) and would decide how far from the set point. Depending on rules controller would add more or less heat.

Strength:

- It can work with more system than HR.
- It has intermediate states.
- It can keep in mind efficiency of the system.
- It can have different strategies.
- It has easy formulation for different strategies.

Weakness:

- It is necessary to stablish set-points.
- It is more difficult than HR.
- Not being optimized.

Example:

- It is used of automotive industry (fuel injection depending on different parameters) .
- It is used in washing machine.

4.1.3 Mode predictive control:

[12], [13]MPC is an advanced control for multivariable.

MPC consists on a dynamic system of the process whose measurements (input variable) can be used to predict the future value of output variables. Depending on these outputs the controller takes actions for charging input variables.

Strength:

- It is optimized.
- Multivariable process.
- It introduces Feed forward.
- Dynamic systems.

Weakness:

- It needs an accurate process mode
- Very complex.
- It isn't very used.
- Computation cost.

Example:

- Application with multivariable or many variables on a process like chemical industry.

4.1.4 Artificial intelligent:

AI is the simulation of human intelligence processes by machines. Those processes is learning, reasoning and self-correction.

Learning: The acquisition of information and rules.

Reasoning: Using rules for archive conclusions.

Strength:

- Useful in complex process.

Weakness:

- High computational cost.

- Low respond.
- It is necessary many files.

Example:

- Nowadays, it isn't used of commercial way.

During the section, we are going to explain the control which we are going to be used in our microgrid.

4.2 Description of the control.

In this section, we are going to define what type of control is used.

We are going to develop power control which are going to archive power balance.

In particular, we are going to use classical control.

Besides, we are going to have several control variables, such as SOC of different systems and level of power.

4.3 Simplifications:

- Only primary control.
- Not voltage management.
- Not frequency management.
- Not reactive power management.
- We only do balance of power.
- We haven't considered a continuous control for charging battery, and it may be damaged if charging is very fast.

4.3.1 Hierarchy of control.

We are going to follow the hierarchy of INTA' microgrid.

We are going to refer power respect to DC buss because all modes follow that criteria.

- *Criteria:*
    - Power is positive if it gets in bus.
    - Power is negative if it leaves bus.

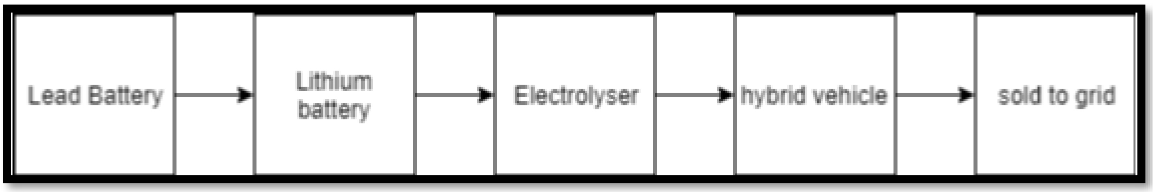
The control looks for Power system equal to 0 W.

4.3.1.1 Definitions:

- Excess of energy: $Power_{generation} > Power_{load}$
- Deficit of energy: $Power_{generation} < Power_{load}$
- Gross Power (P_G): $P_G = Power_{\ generation} - Power_{load}$
- Storage Power (P_S): It is power of SESs (LB,LhB and electrolyser).
- Balance Power (P_B): $P_B = P_G - P_s$
- Grid Power (P_{grid}): It is power of grid.
- System Power (P_{system}): $P_{system} = P_B - P_{grid}$

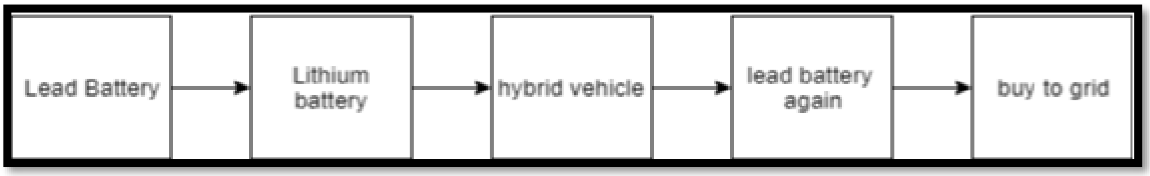
4.3.1.2 **Excess of energy:**

Hierarchy is the following.



4.3.1.3 **Deficit of energy:**

Hierarchy is the following.



4.3.2 Diagram of flow:

For explain our control, we are going to use SFC.

it is necessary to know different control variables for developing that control.

4.3.2.1 **Variable of control:**

- SOC of LB.
- SOC of LhB.
- SOC of hydrogen' storage.
- SOC of vh1.
- SOC of vh2.
- Gross power.

SOCs are very important because it is a way of knowing energy storage in each system.

Gross power is important as depending on level of power change the operational mode.

4.3.2.2 **Mode of excess of energy:**

The SFC is the following

In the SFC, SOC_{hv} is referred to either hv1 or hv2, though if both hybrid vehicle got to charge point at the same time the hv1 would have preference for charging than hv2.

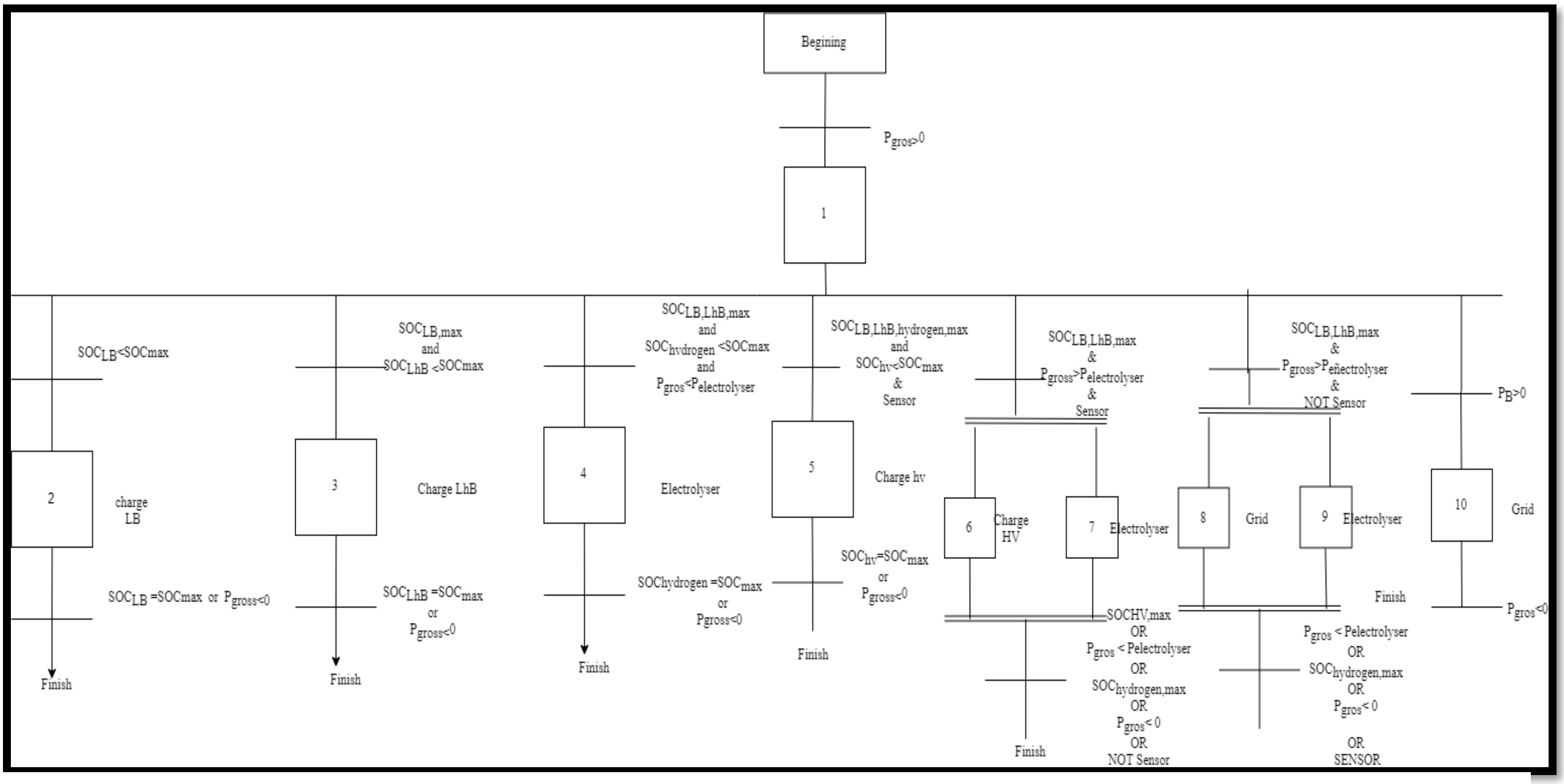


Figure 42. SFC of energy excess

4.3.2.3 Mode of deficit of energy:

The SFC is the following.

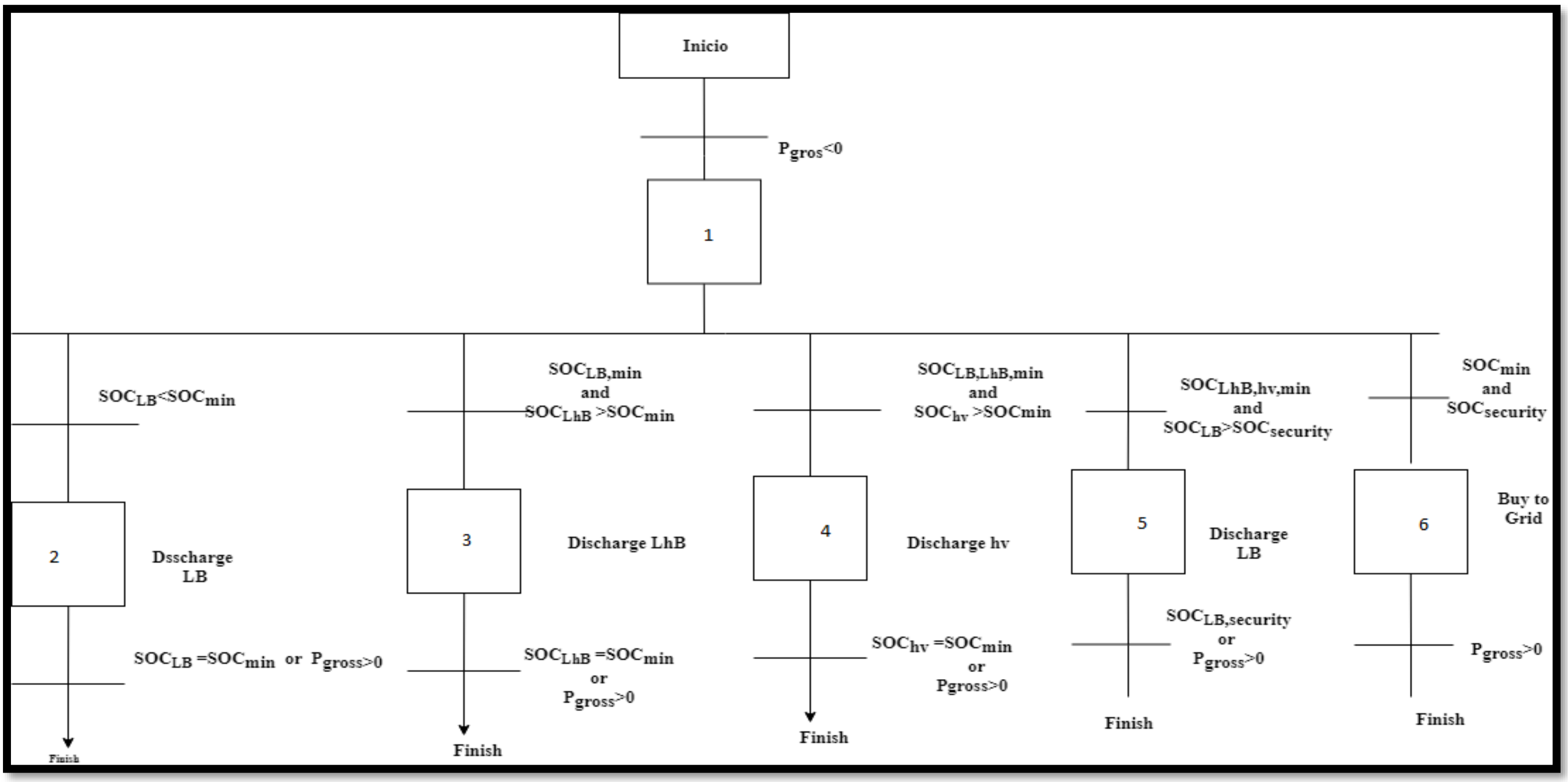


Figure 43. SFC of energy deficit

In the SFC, SOC_{hv} is referred to either hv1 or hv2, though if both hybrid vehicle got to charge point at the same time the hv1 would have preference for discharging than hv2.

LB can discharge twice because It has two different operational mode.

In first time LB discharges until minimum operational SOC but LB can discharge until another level of SOC (security SOC), though this situation can only happen in last time before to buy grid.

4.4 Blocks of the control.

In this section, we are going to describe subsystem and implementation of the control.

We are going to have two different parts, first part is abput SESs' control while the second part is about hvs' control.

We are going to use essential logical operators for building our control (AND, OR, NOT and comparators) and moreover switches.

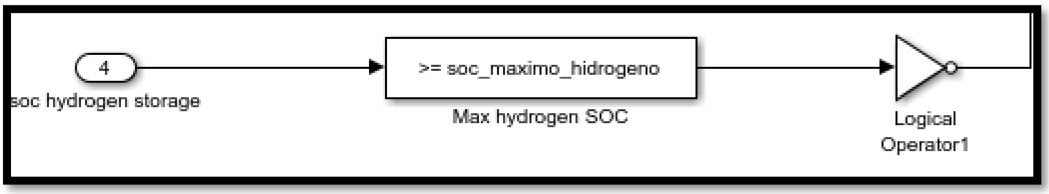


Figure 44. Example of logical operators

4.4.1 Blocks of the SESs' control.

We are going to show in detail the control of different SESs.

4.4.1.1 The general mask of SESs' control.

This mask has 9 fields which we are going to define.

Table 15Fields of the general mask

Field	**Unit**
Maximum LB SOC	Percentage
Minimum operational LB SOC	Percentage
Maximum LhB SOC	Percentage
Minimum LhB SOC	Percentage
Maximum hydrogen SOC	Percentage
Security LB SOC	Percentage
Minimum hv1 SOC	Percentage
Minimum hv2 SOC	Percentage
Maximum hv SOC	Percentage

We are going to explain difference between security and minimum LB SOC.

It is known that LB can discharge twice, hence it needs to have two level of SOC. Minimum SOC is referred to the first time LB discharges while security SOC is referred to the second time LB does.

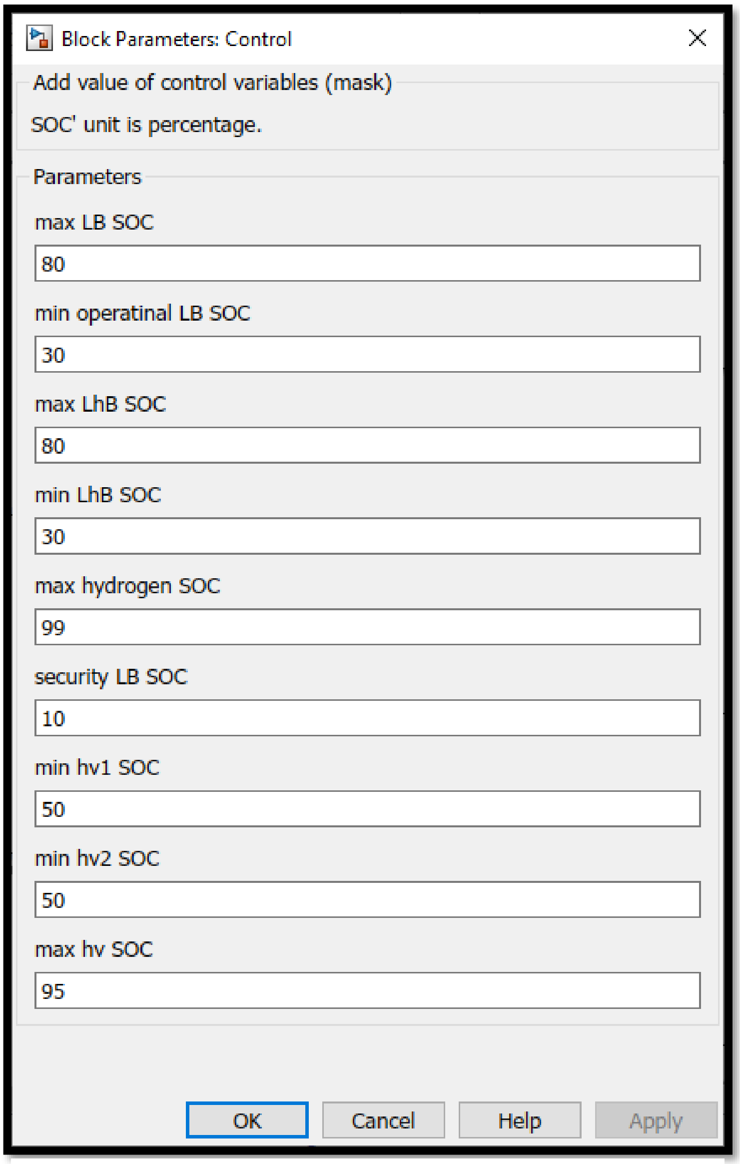


Figure 45. Mask of SES' control

4.4.1.2 **Lead battery control**

We are going to dived in three different part because LB may discharge twice, then in first time LB dischargese, we are going to name stage 2 while the second time we are going to name stage 3. Stage 1 if LB is charging.

LB' SOC is reading and it is compared with maximum or minimum SOC, which is defined by user, depending on gross power.

4.4.1.2.1 Stage 1

This situation happens when LB are charging, and it is simple .

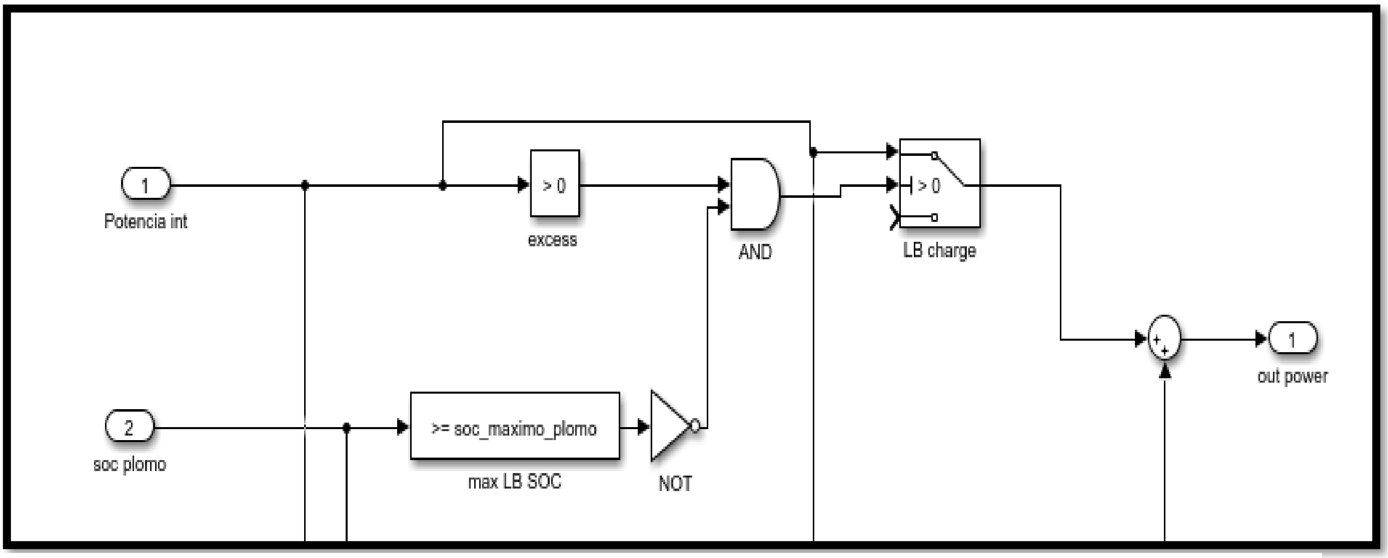


Figure 46. Scheme ofControl

4.4.1.2.2 Stage 2

It is the first time LB' battery discharges.

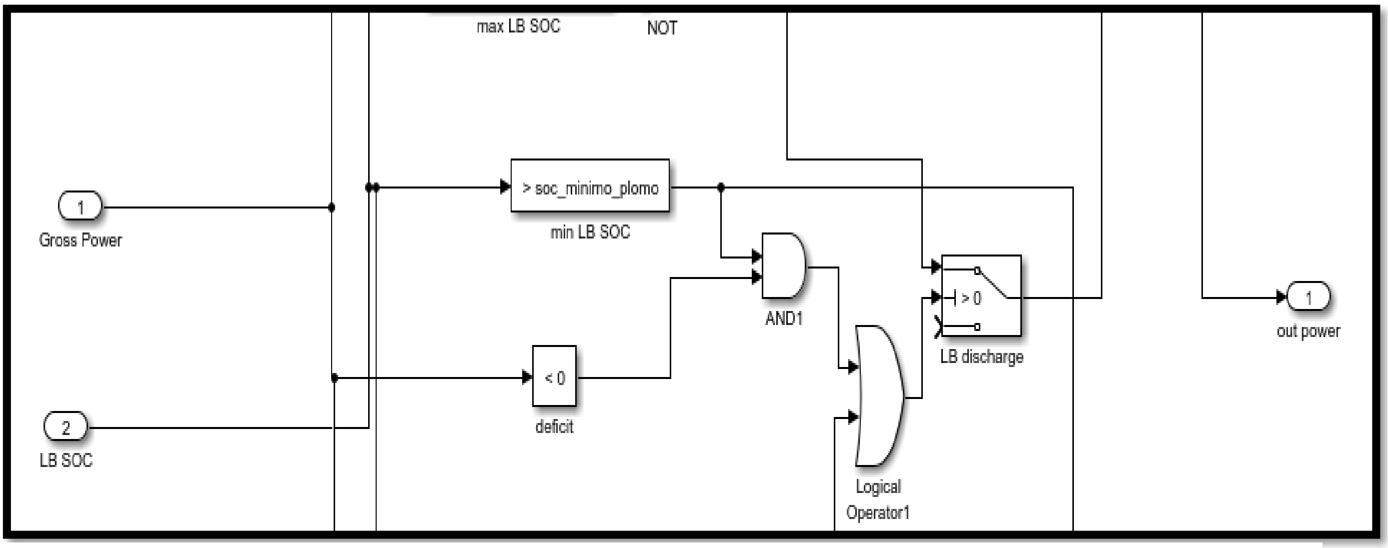


Figure 47. Scheme of control

4.4.1.2.3 Stage 2

This situation is when LB's battery discharge until security SOC and It is last SESs.

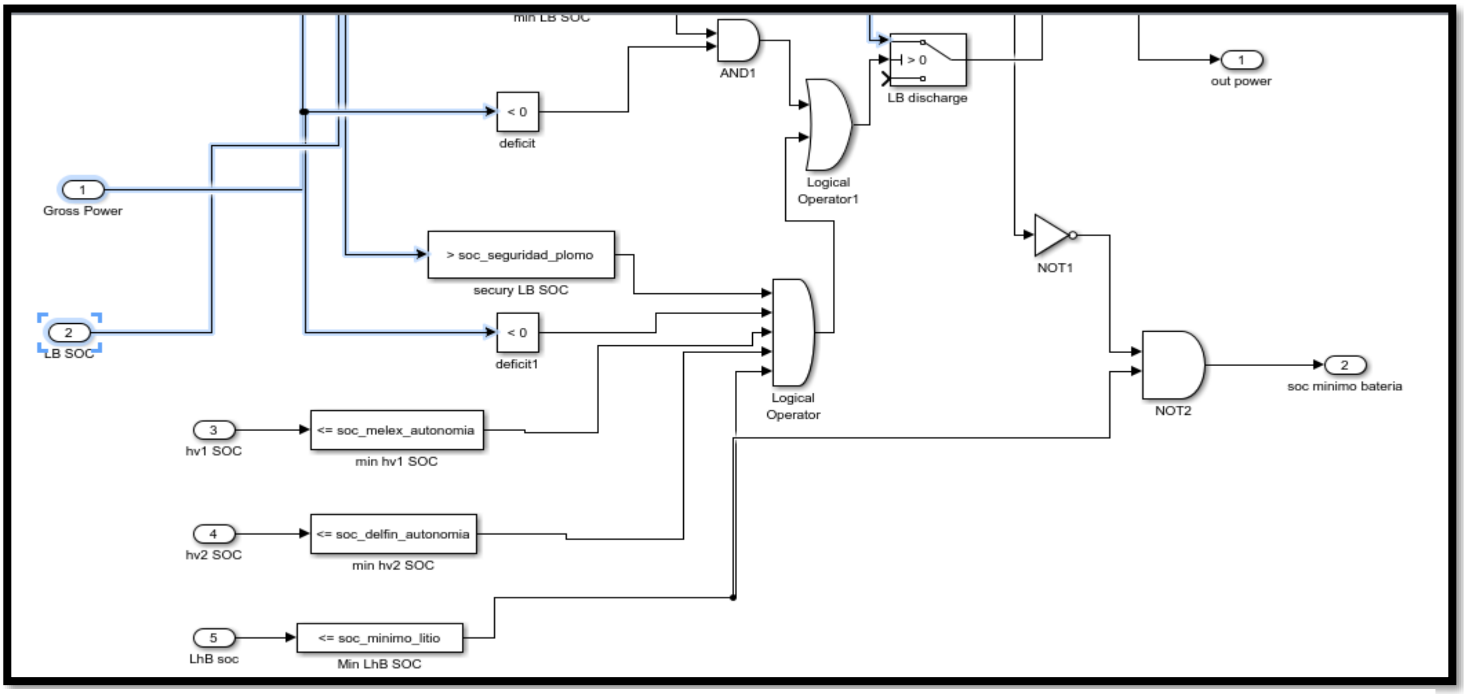


Figure 48. Scheme of control

4.4.1.3 **Lithium battery**

We are going to dived in two different part. We are going to name stage 1 if LhB is charging while stage 2 if LhB is discharging.

LhB' SOC is reading and it is compared with maximum or minimum SOC, which is defined by user, depending on gross power.

4.4.1.3.1 Stage 1

This situation happens when LhB are charging, and it is simple.

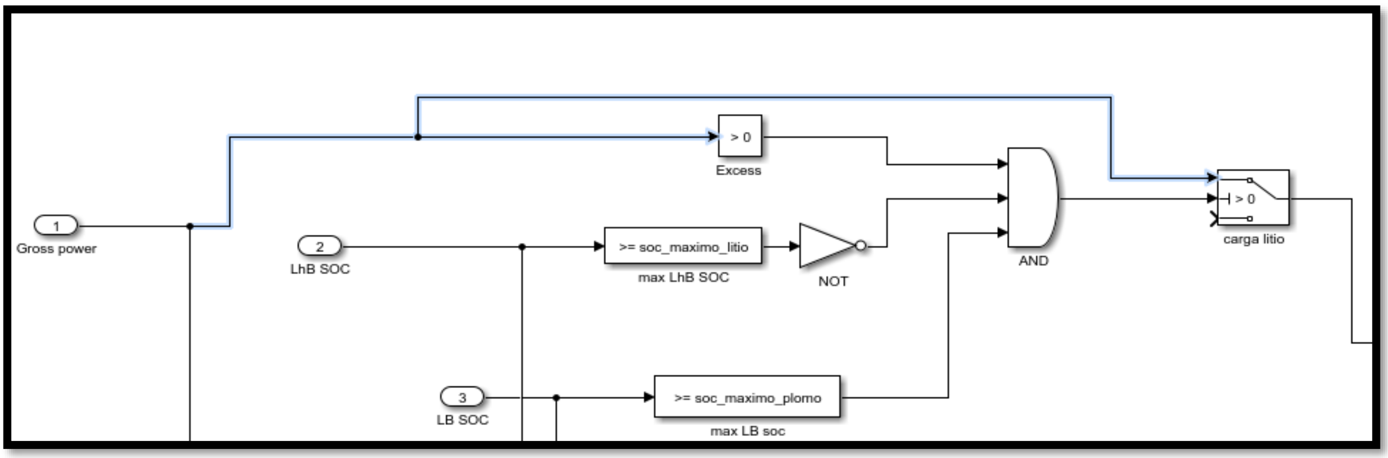


Figure 49. Scheme of control

4.4.1.3.2 Stage 2

this situation happens when LhB are discharging, and it is simple .

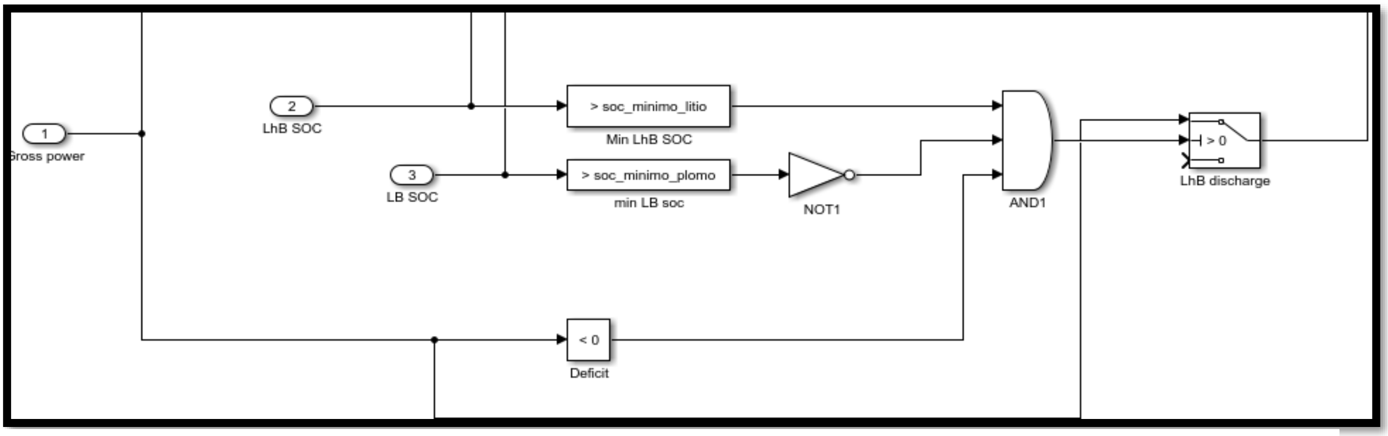


Figure 50. Scheme of control

4.4.1.4 **Electrolyser**

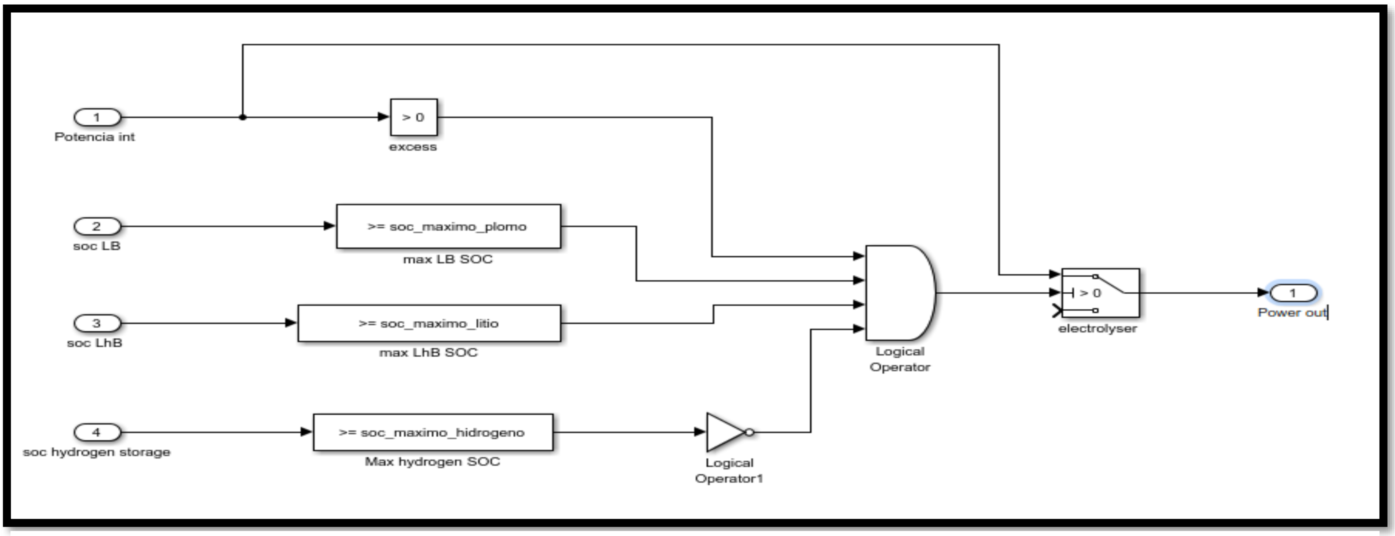


Figure 51. Scheme of control

Electrolyser can only work if there is power excess, hence it is simple.

4.4.2 Blocks of the hvs' control.

We are going to show in detail the control of different hybrid vehicles.

Besides, we shouldn't forget hybrid vehicle aren't always connected to microgrid.

4.4.2.1 **The general mask of hv' control:**

The general mask has four fields.

Table 16 FIelds of the general mask of hv' control

Field	**Unit**
Maximum hv1 SOC	Percentage
Maximum hv2 SOC	Percentage

Minimum hv1 SOC	Percentage
Minimum hv2 SOC	Percentage

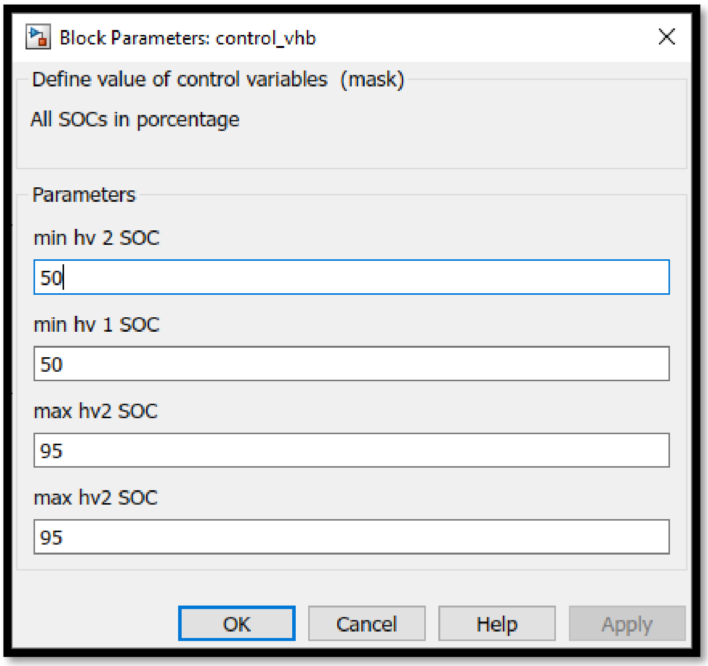


Figure 52. Mask of HV control

4.4.2.2 Hybrid vehicle 1

Hv1 has more preference than hv2.

We are going to dived in three different part because HV1 may charge in two way, then in first time HV1 chargese, we are going to name stage 1 while the second time we are going to name stage 2 andStage 3 if LB is discharging.

HV1' SOC is reading and it is compared with maximum or minimum SOC, which is defined by user, depending on gross power.

4.4.2.2.1 Stage 1&2

This situation happens when hv1 are charging, and it is simple.

Stage 1 is refered to only charge HV and Electrolyser isn't working.

Stage 2 is refered to charge HV and Electrolyser is working.

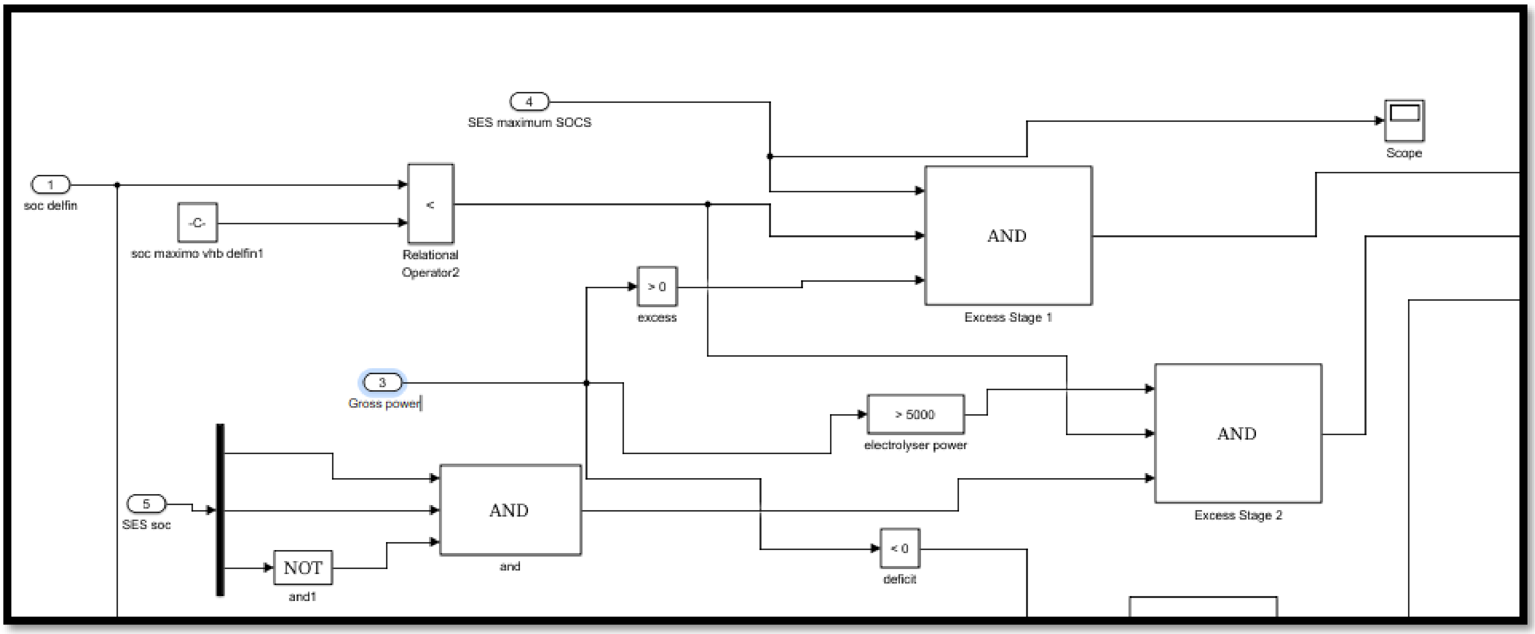


Figure 53. Scheme of charging HV1

4.4.2.2.2 Stage 3

this situation happens when hv1 are discharging, and it is simple ().

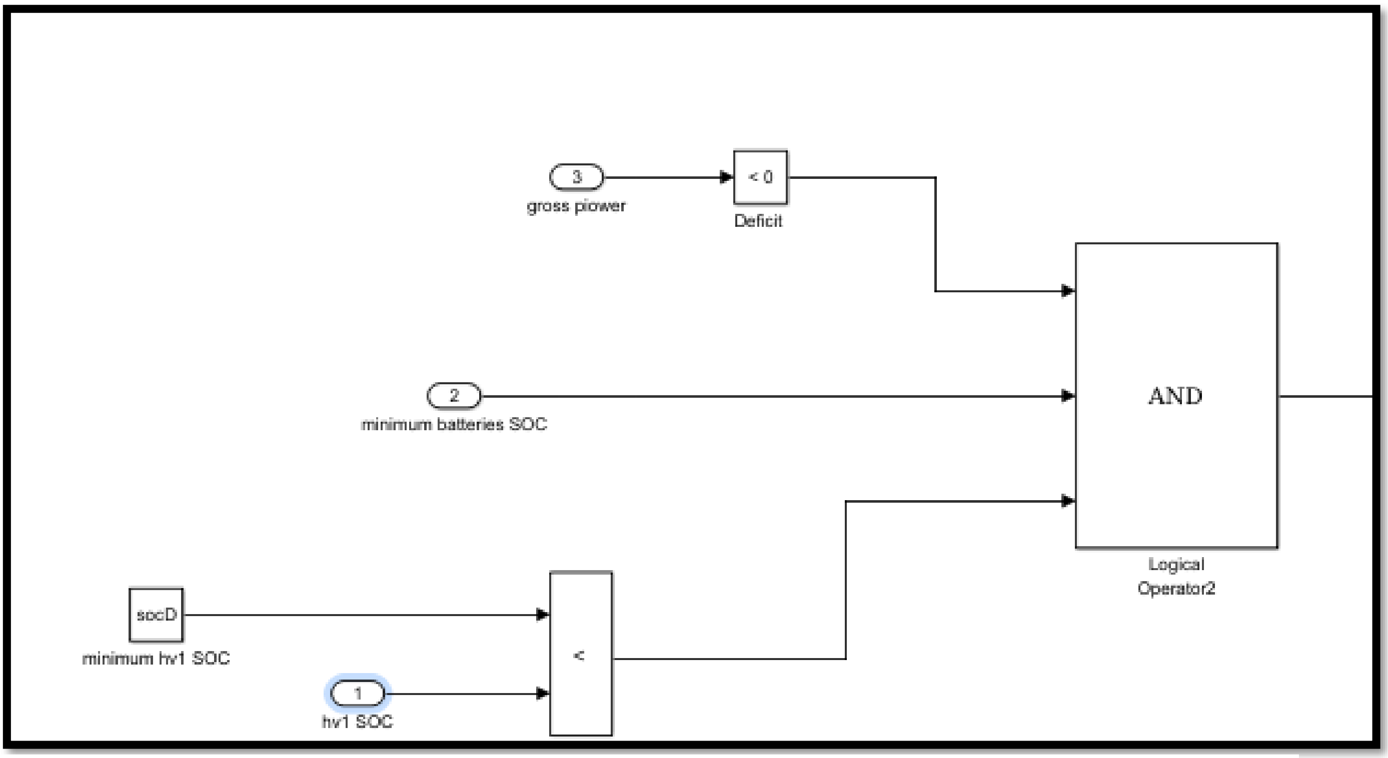


Figure 54. Scheme of discharging HV1

4.4.2.3 **Hybrid vehicle 2:**

We are going to dived in three different part because HV1 may charge in two way, then in first time HV12chargese, we are going to name stage 1 while the second time we are going to name stage 2 andStage 3 if LB is discharging.

HV2' SOC is reading and it is compared with maximum or minimum SOC, which is defined by user, depending on gross power.

4.4.2.3.1 Stage 1 & 2

This situation happens when hv1 are charging, and it is simple.

Stage 1 is refered to only charge HV and Electrolyser isn't working.

Stage 2 is refered to charge HV and Electrolyser is working.

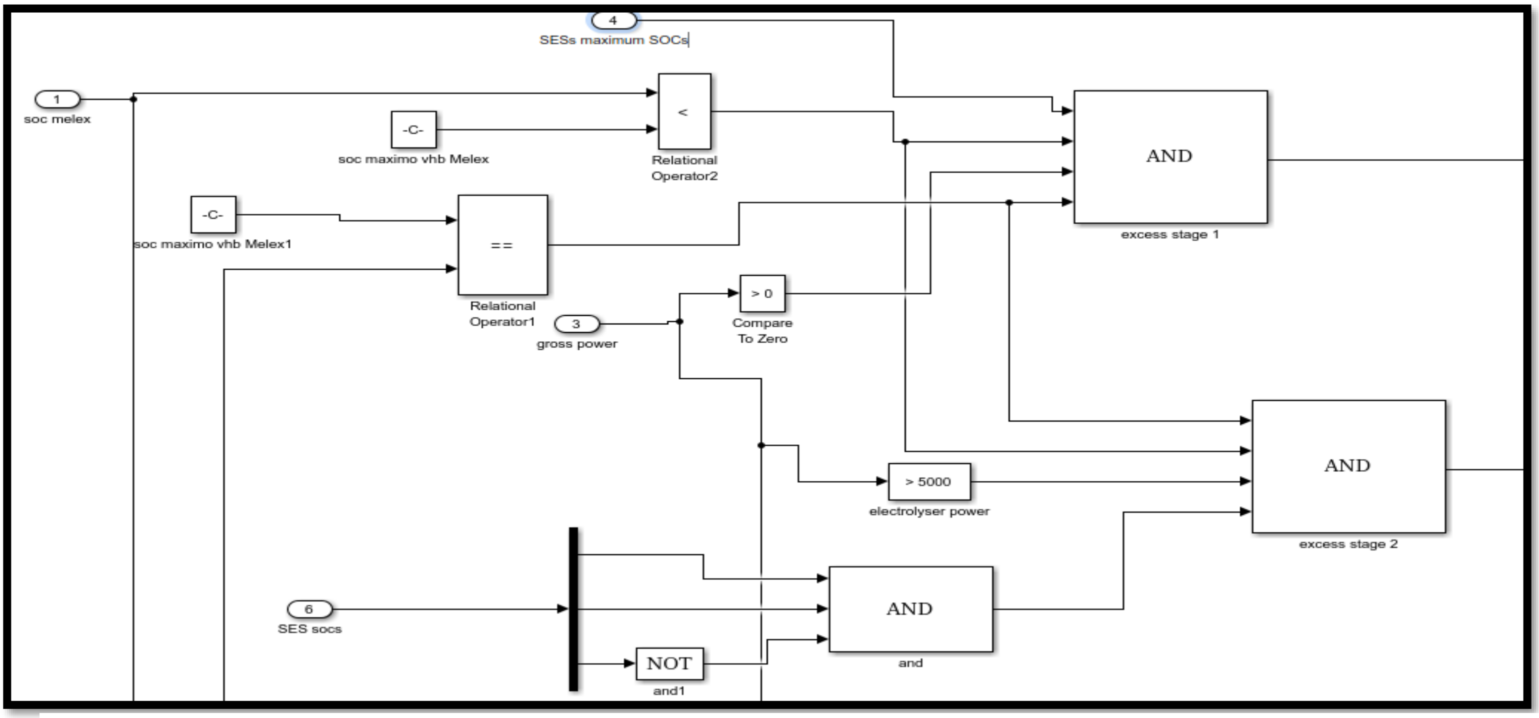


Figure 55. Scheme of charging HV2

4.4.2.3.2 Stage 3

This situation happens when hv2 are discharging, and it is simple ().

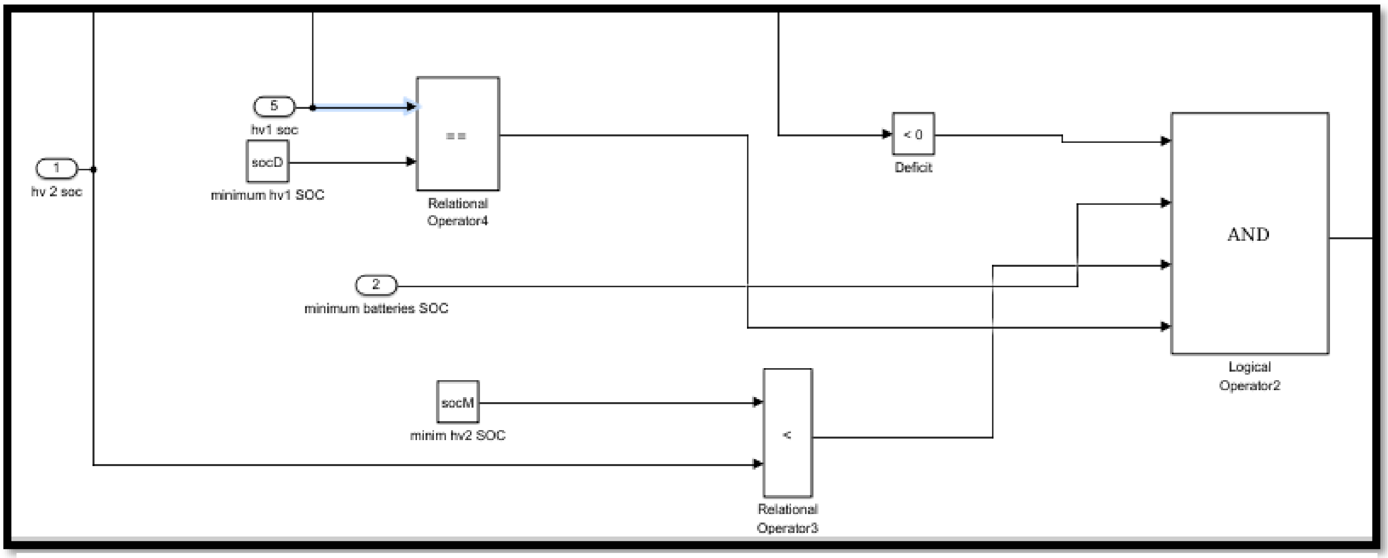


Figure 56. Scheme of discharging HV2

4.5 Variable of control

We are going to have few input variable which control the system and we are going to have output variables which are controlled.

Table 17 Control variable

INPUT	**OUTPUT**
LB' SOC	LB' Power
LhB' SOC	LhB' Power
Hydrogen' SOC	Electrolyser' Power
HV1' SOC	HV1' Power
HV2' SOC	HV2' Power

4.5.1 Control of SESs:

We are going to show value of control variable of each SESs and hv.

The value of variable are selected by users

Variable values are the following.

Table 18Value of different variables

Field	**Value**
Maximum LB SOC	80%
Minimum operational LB SOC	30%
Maximum LhB SOC	80%

Minimum LhB SOC	30%
Maximum hydrogen SOC	99%
Security LB SOC	10%
Minimum hv1 SOC	50%
Minimum hv2 SOC	50%
Maximum hv SOC	95%

The reason why LB and LB don't have as maximum SOC of 100% because if they worked within values of 80% their cycle life is longer than if they worked within values of 100%. These similar happen if they work with high DoD, hence we have preferred to work within value of 30%.[9]

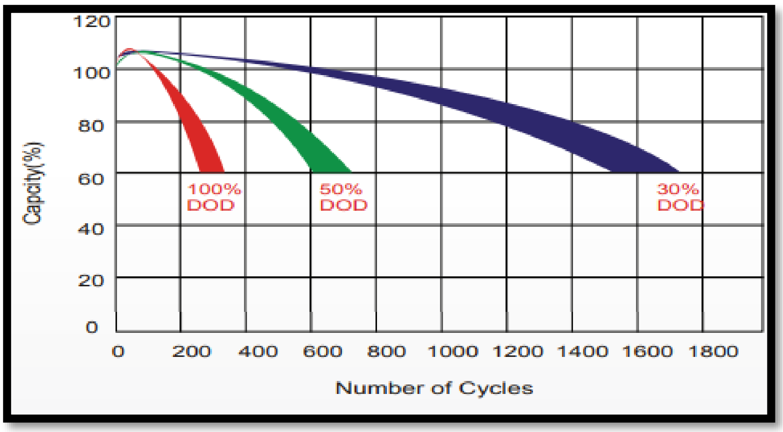


Figure 57. SOC vs Cycle (depending on DoD)

4.5.1.1 Reference

- Ultracel (company)

- [9] Ultracel (company)

5 TEST AND RESULTS

In this chapter, we are going to define different tests whose initial variables are going to be modified moreover meteorological condition, this it will have a big influence in operational mode.

5.1 Test:

In this section, we are going to define initial conditions which simulator are going to use.

We are going to modify:

- Initial SOC.
- Meteorological conditions.
- Connective systems.

We are going to show different graph about results.

Graphs:

- Generation Power.
- Load Power.
- Gross Power.
- Balance Power.
- Grid Power.
- HV Power.
- System Power.
- SOC of SESs.

SESs SOCs will support us to kwon if control are working right, because it is easy to realize if SESs are working within their operational conditions.

All graphs are in seconds.

5.1.1 Test 1:

We are going to archive four test with a good meteorological condition because we are going to have high sun' radiation.

Table 19. Variable Values

Sub-test	1	2	3	4
Initial LB SOC	50	75	35	75
Initial LhB SOC	50	70	40	40
Initial hydrogen SOC	50	90	30	50
Initial vh1 SOC	50	80	20	80
Initial vh2 SOC	50	82	25	25
Initial EV SOC	50	85	30	50
Generation	Isunny and windvelocity			
Demand	Demand1			

The reason why we are going to make these tests is to know how microgrid control is affected by different initial socs, but we can suppose that power gross will be more than 0 (excess of power) in multiplies times, so storage systems may charger energy hence we can see the charge algorithm works

5.1.2 Test 2:

We are going to archive four test with a good meteorological condition because we are going to have bad sun' radiation.

Table 20. Variable values

Sub-test	1	2	3	4
Initial LB SOC	50	75	35	75
Initial LhB SOC	50	70	40	40
Initial hydrogen SOC	50	90	30	50
Initial vh1 SOC	50	80	20	80
Initial vh2 SOC	50	82	25	25
Initial EV SOC	50	85	30	50
Generation	Icloudy and windvelocity			
Demand	Demand1			

The reason why we are going to make these tests is to know how microgrid control is affected by different initial SOCs, but we can suppose that power gross will be less than 0 (defect of power) in multiplies times.

Then storage systems must discharge their energy and we can see as the discharge algorithm works.

5.1.3 Test 3:

We are going to archive this test without power generation but with initial SESs' SOC equal maximum SOC().

Test	Value
Maximum LB SOC	80%
Maximum LhB SOC	80%
Maximum hydrogen SOC	99%
Maximum hv SOC	95%

Table 21. variable values

This case is an extreme case of study because We don't have any generation.

However, It is important to know if microgrid can work in extreme condition of power.

5.2 Results and discussion:

We are going to show the whole of results which have been simulated and to discuss about that.

Load Power is going to change depending on initial EV' SOC.

5.2.1 Tests1:

In these tests, we are going to have the same meteorological condition, hence power generation is similar.

Generation power

You can see different generators and their curve of power.

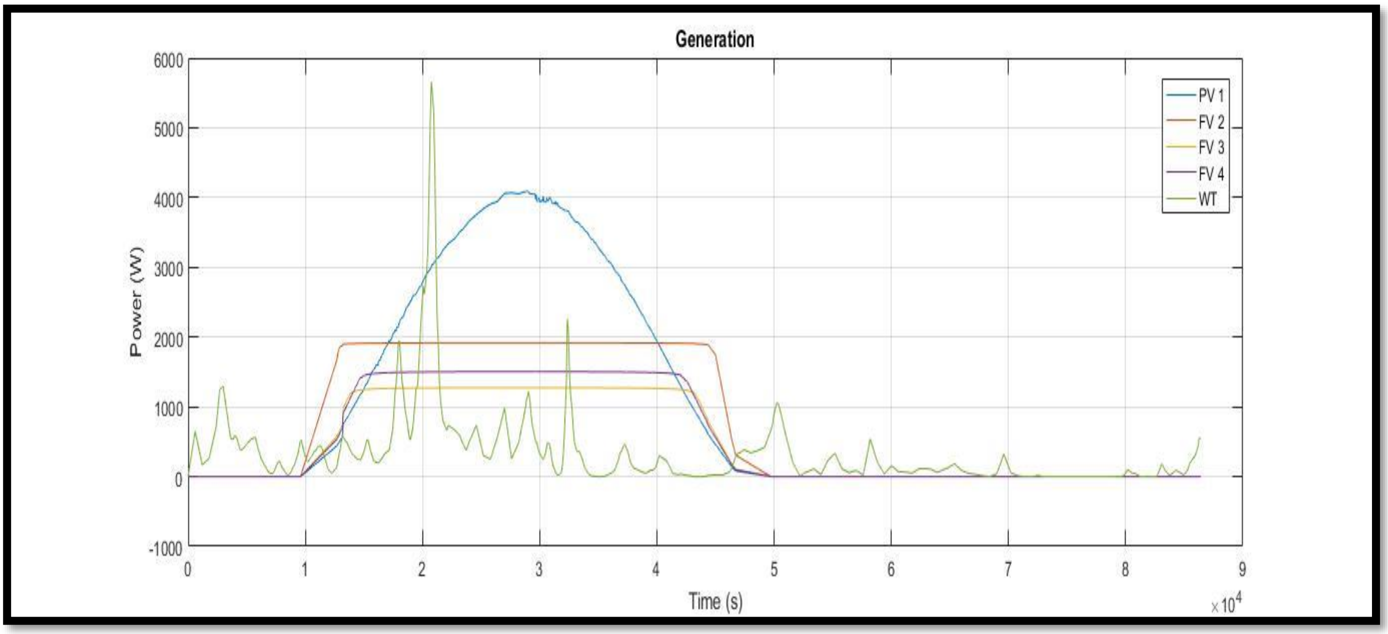


Figure 58. Generation power 1

5.2.1.1 **Subtest-1.**

We are going to have a situation which initial SOCs are intermediate (50%).

Load power

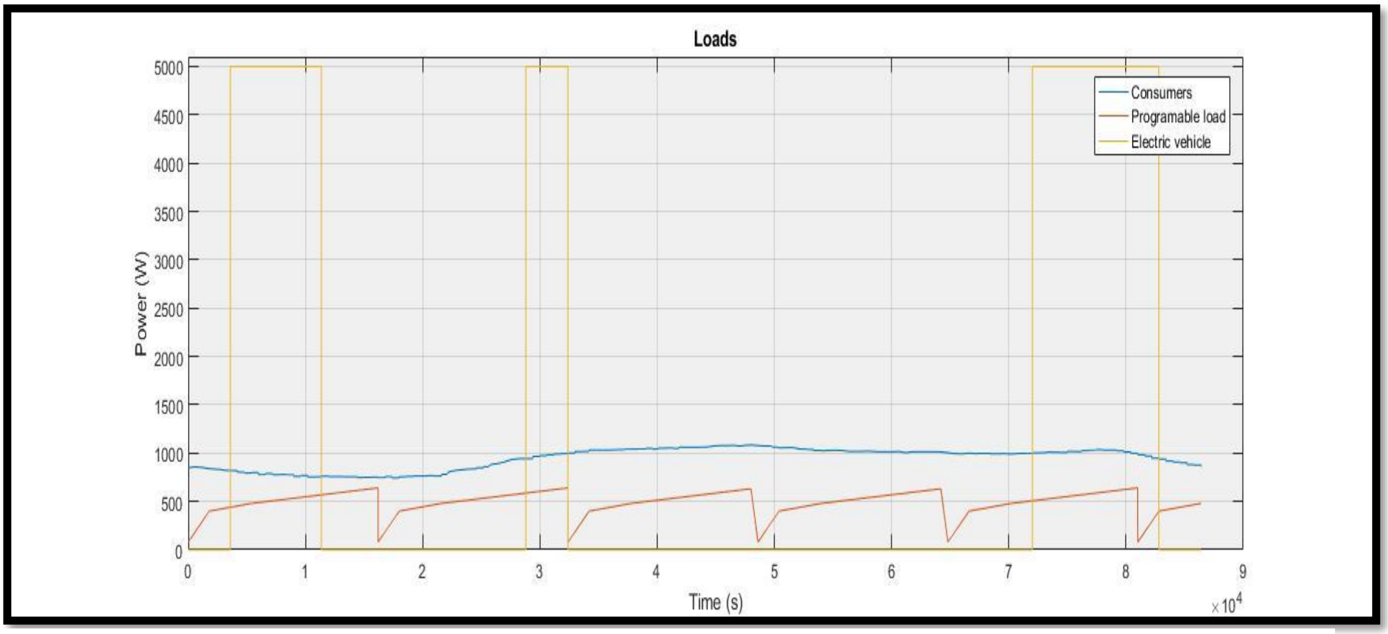


Figure 59. Load Power 1.1

EV has a high demand because of having SOC of 50%, hence EV's SOC will be important in Load Power.

Gross power

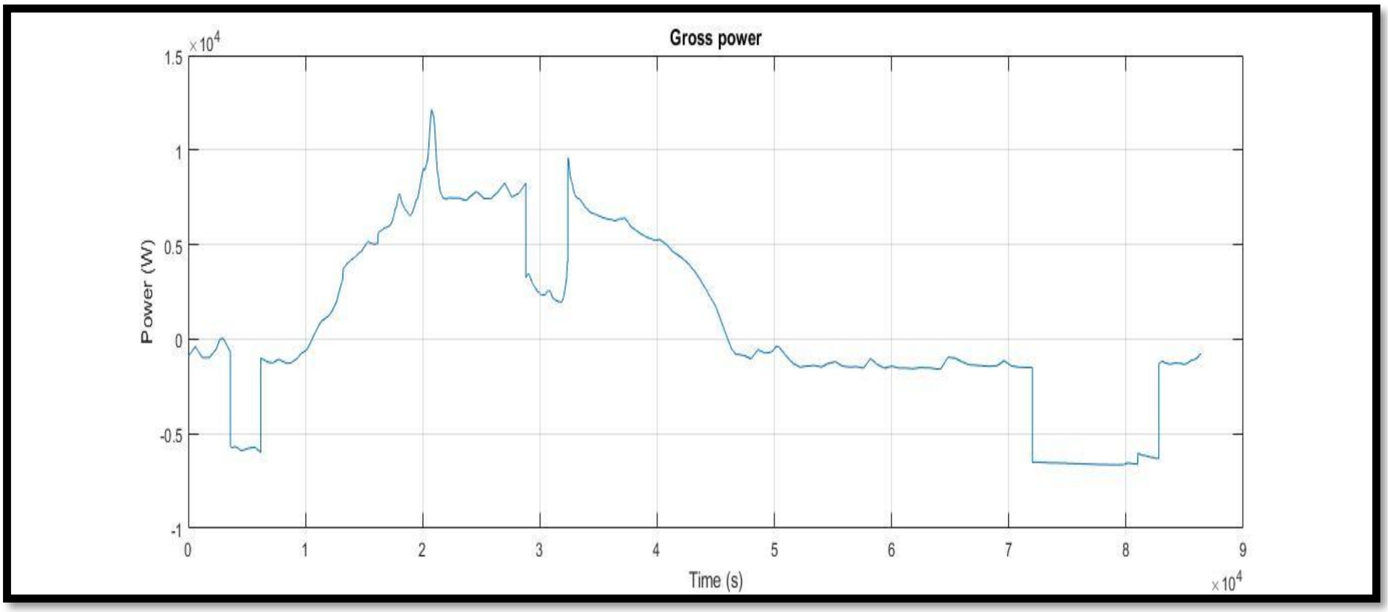


Figure 60. Gross Power 1.1

As we can see, gross power is positive a long time, hence we are going to work in excess mode above all.

SESs power

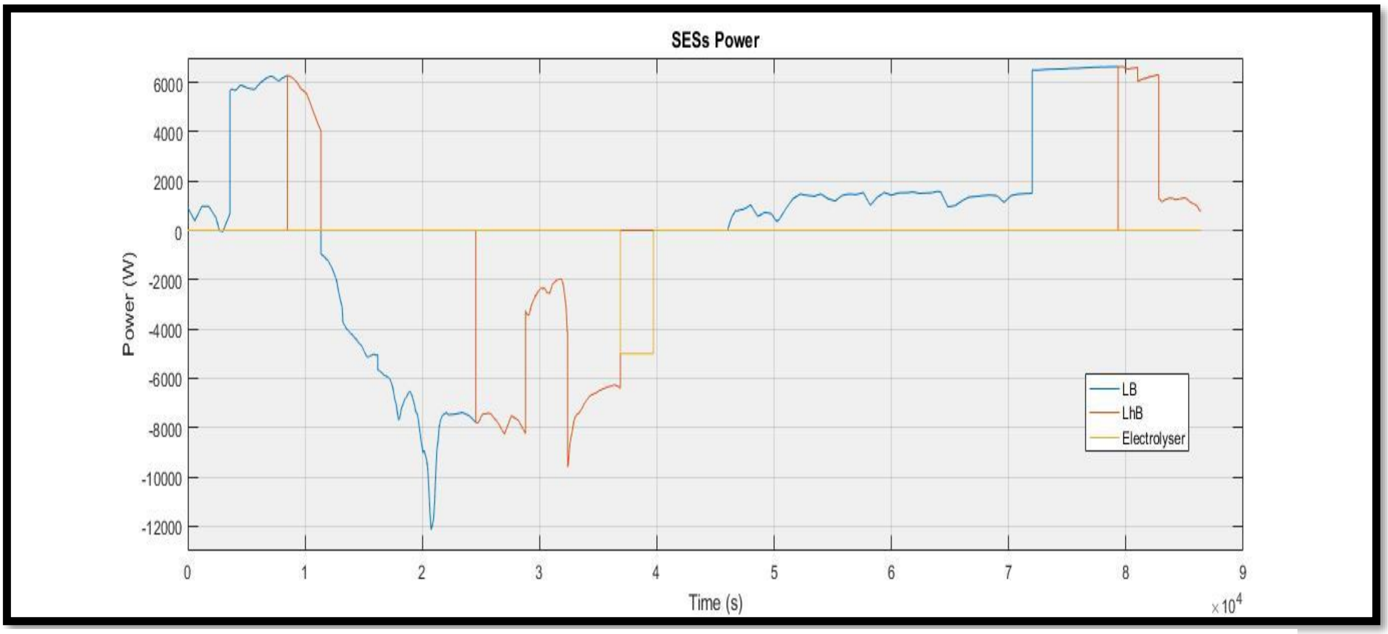


Figure 61. SESs power 1.1

It is expected that SESs storage power excess because of having a long time that, but the best way of seeing this aspect is to show the SOC' graphic.

Change of SOC

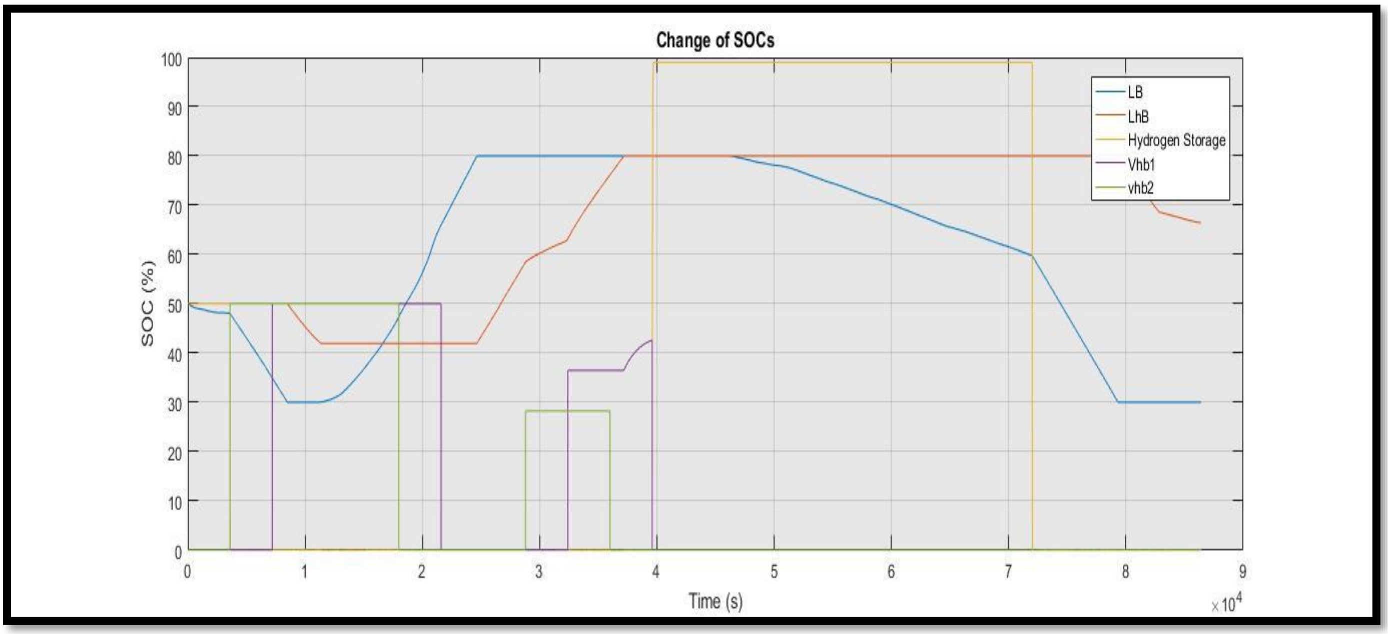


Figure 62. SESs SOCs 1.1

In this graph, it is easy to see that control is working correctly because SESs are following the control hierarchy.

We have to consider that hybrid vehicles aren't always connected, hence we can see that their SOC is sometimes 0% because we only know their soc when they are connected.

However, we can see that HV1 is absorbing power from the DC buss because it is charging.

Balance power

Exist excess power because all SESs are full and HVs are discounted to microgrid.

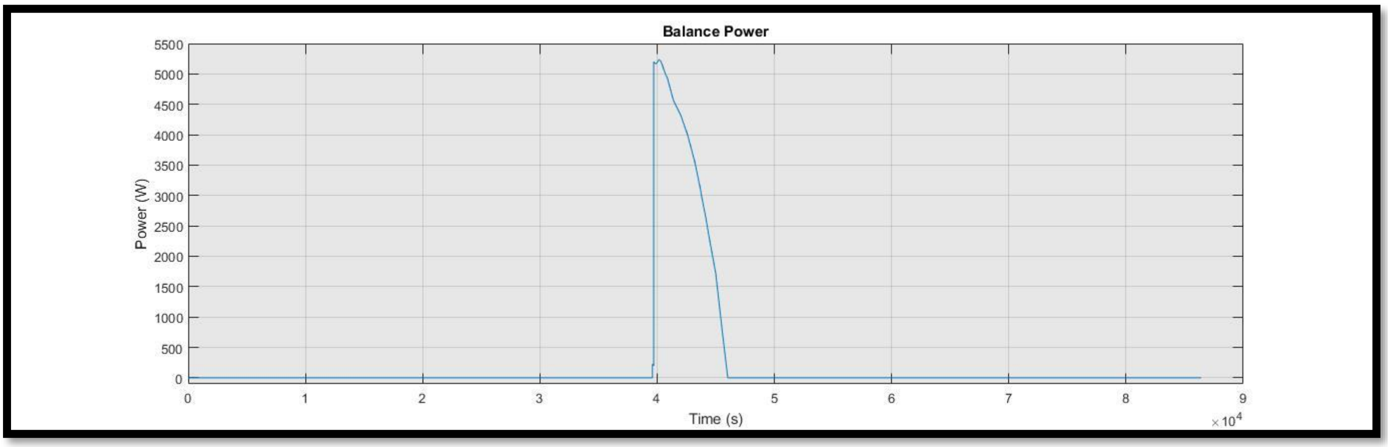


Figure 63. Balance Power 1.1

Grid power

The conventional Grid absorbs power excess.

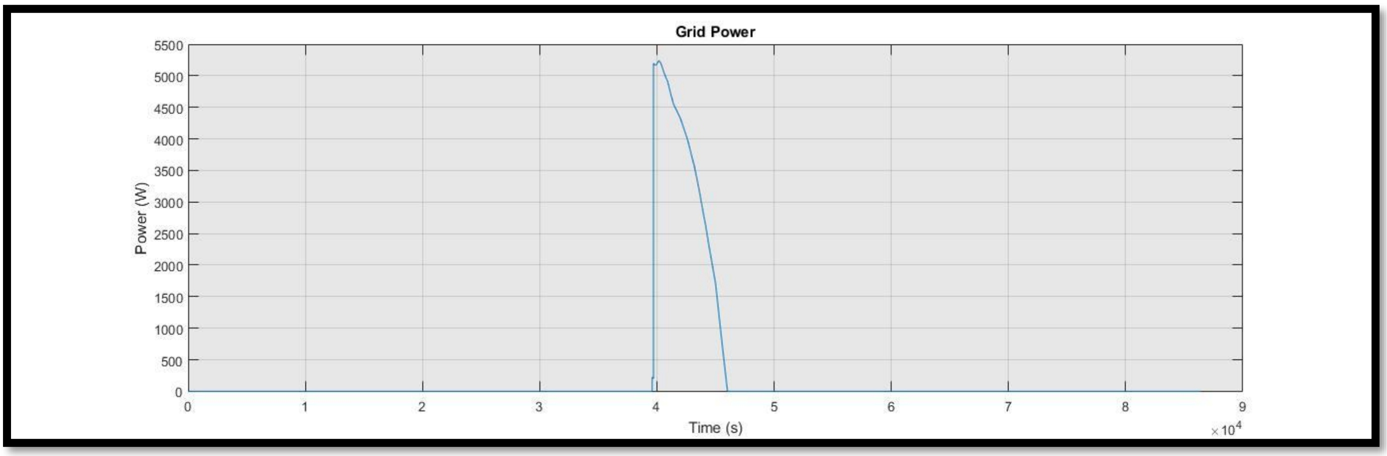


Figure 64. Grid power 1.1

System power

Last graph only shows that system power is 0 W and it is our main goal, hence we aren't going to show againg this graph.

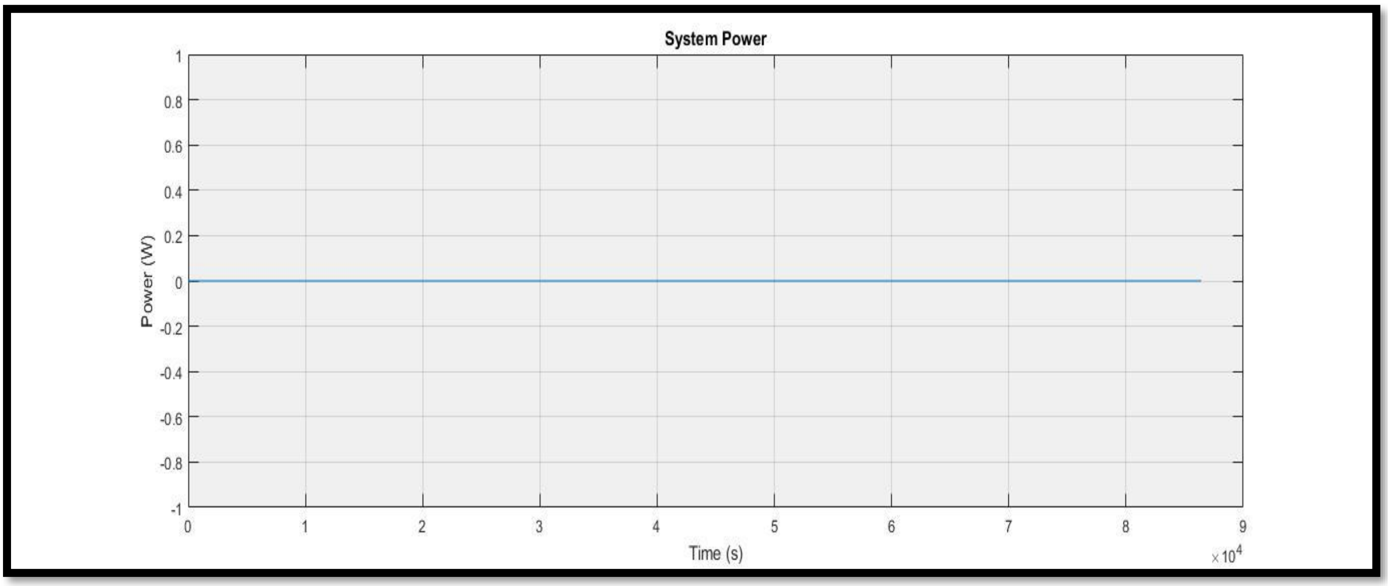


Figure 65. System power 1.1

5.2.1.2 Subtest-2.

We are going to have a situation within high level of SOCs, which are near maximum SOC.

Load power

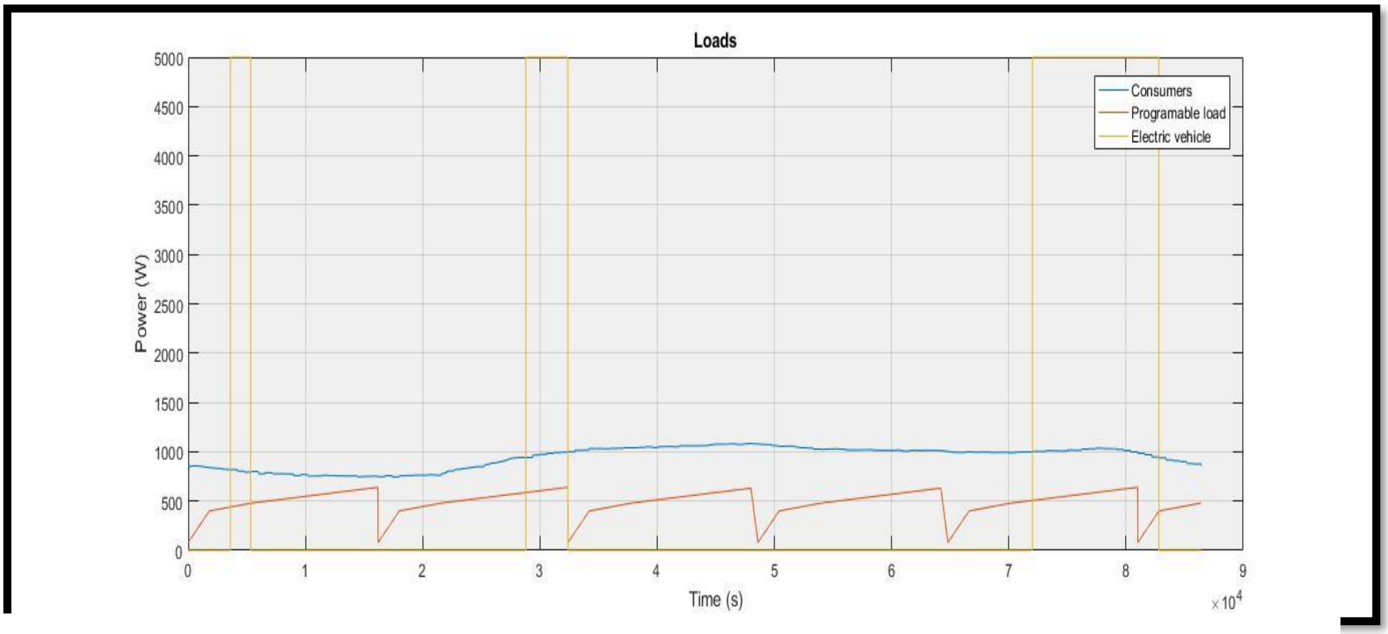


Figure 66. Load Power 1.2

In this case, EV' SOC is of 85%, so it consumes less power than previous subtest.

Gross power

As we can see, gross power is positive a long time, hence we are going to work in operational excess mode above all.

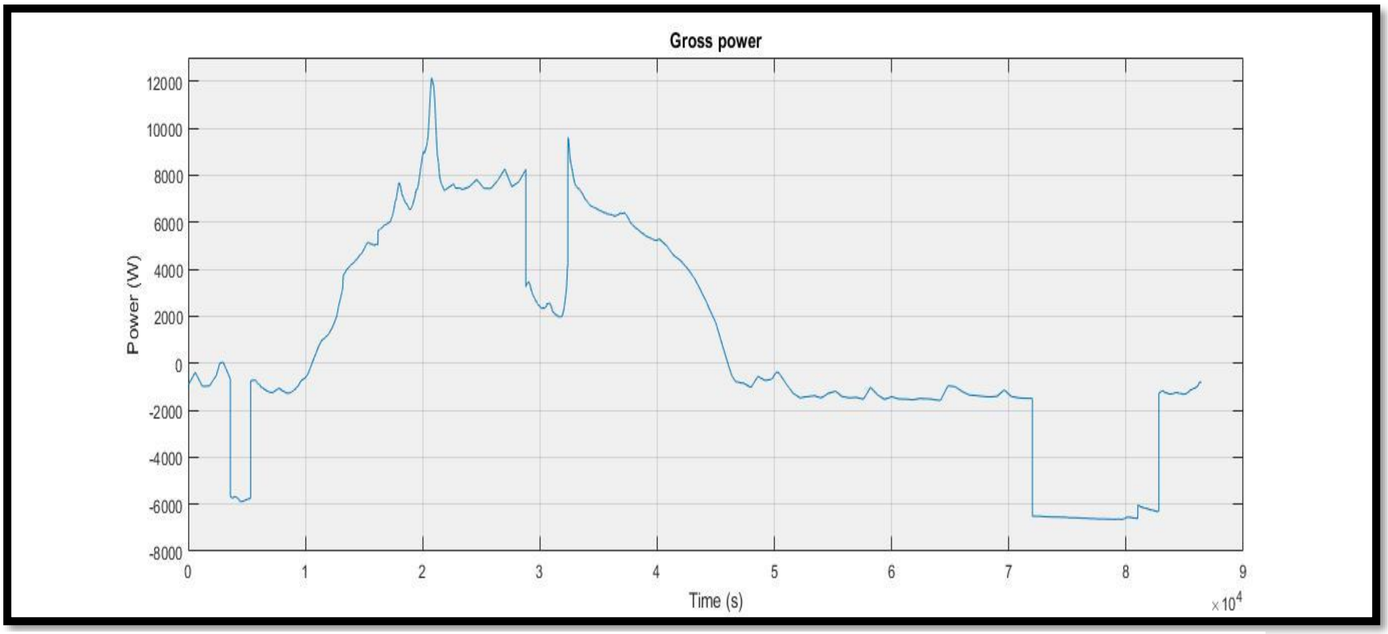


Figure 67. Gross power 1.2

SESs' power

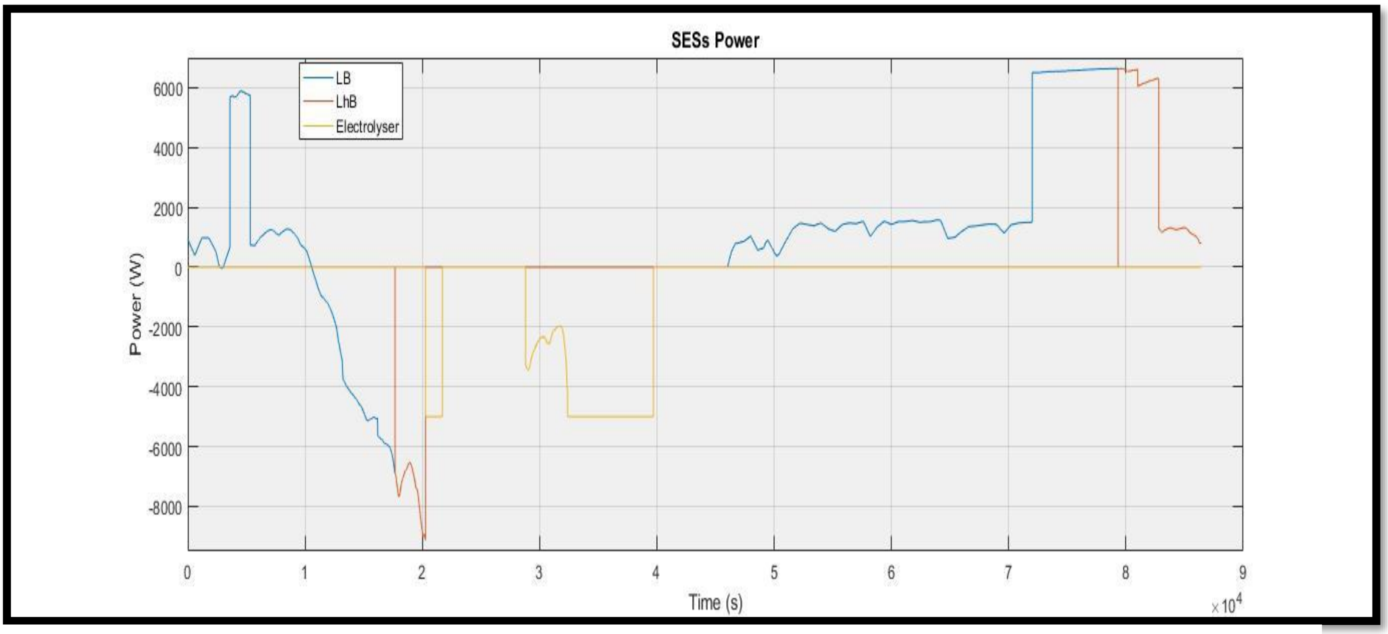


Figure 68. SESs Power 1.2

It is expected that SESs storage power excess because of having a long time that, but the best way of seeing this aspect is to show the SOC' graphic

Change of SOSs

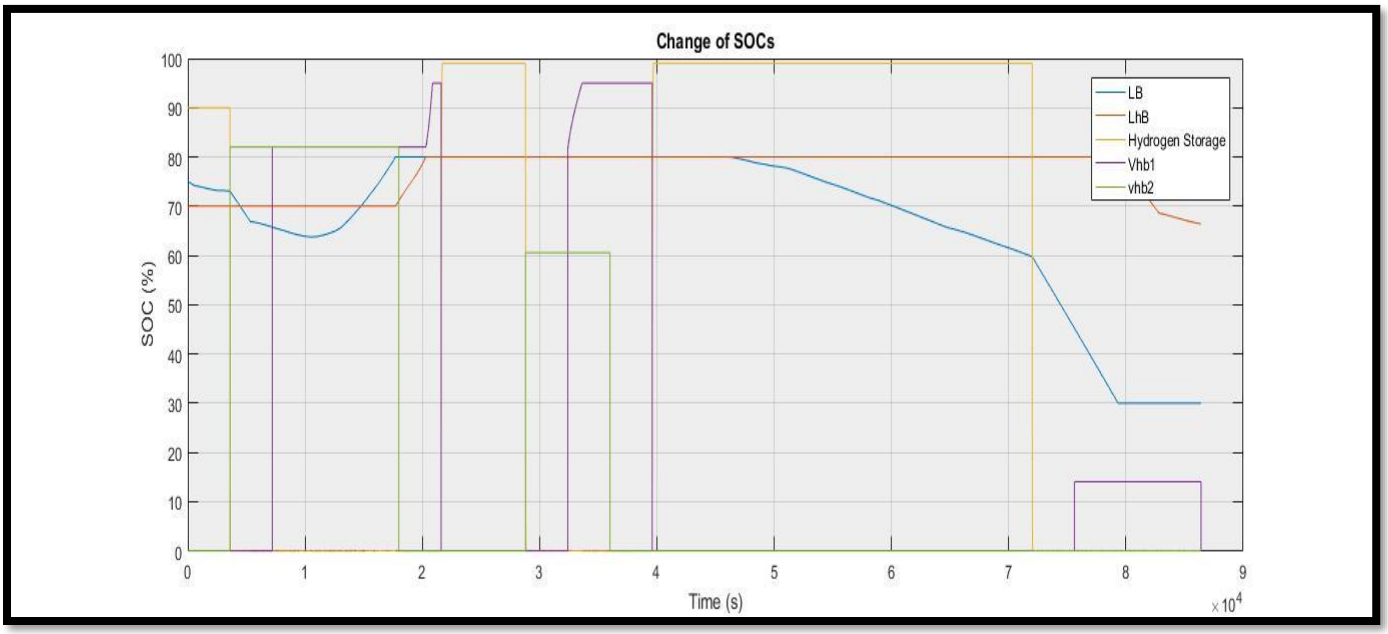


Figure 69. Change of SOCs 1.2

In this graph, it is easy to see that control is working correctly because SESs are following the control hierarchy.

Besides, it validates our control in case of power excess because SESs are absorbing the power excess until maximum SOCs of each SESs.

Balance power

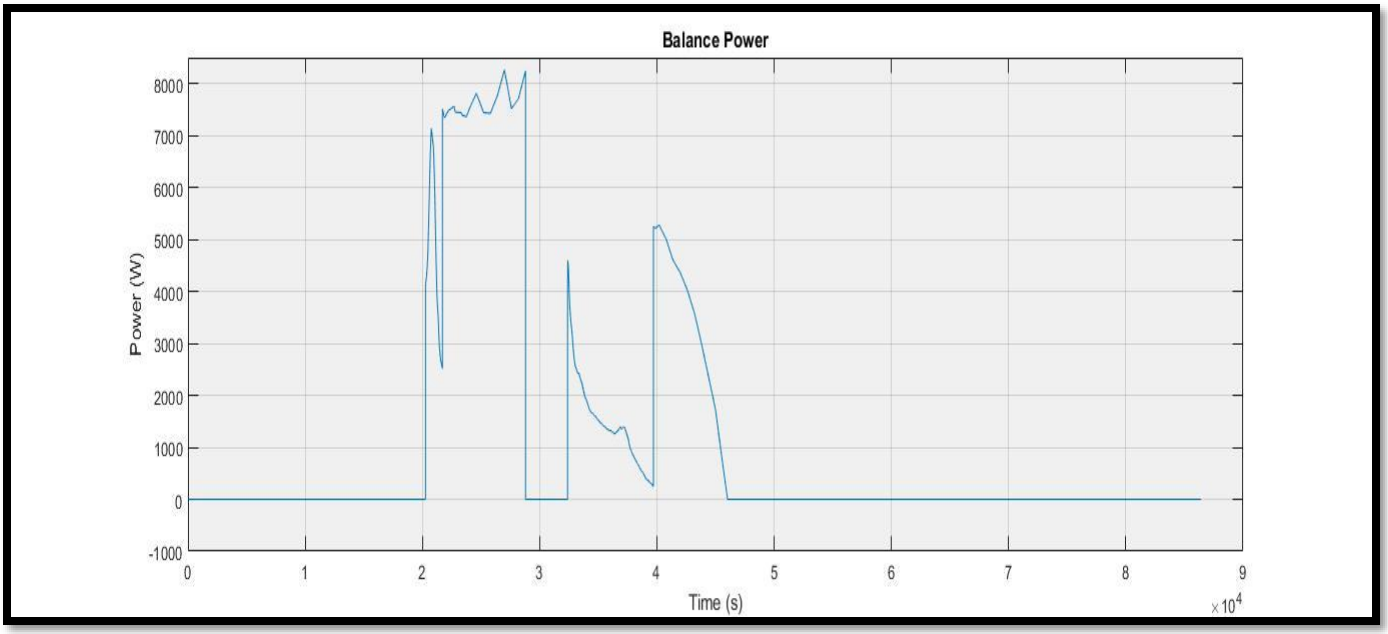


Figure 70. Balance Power 1.2

Grid power

In this graph, we can see that we are going to inject a mount of power in conventional grid.

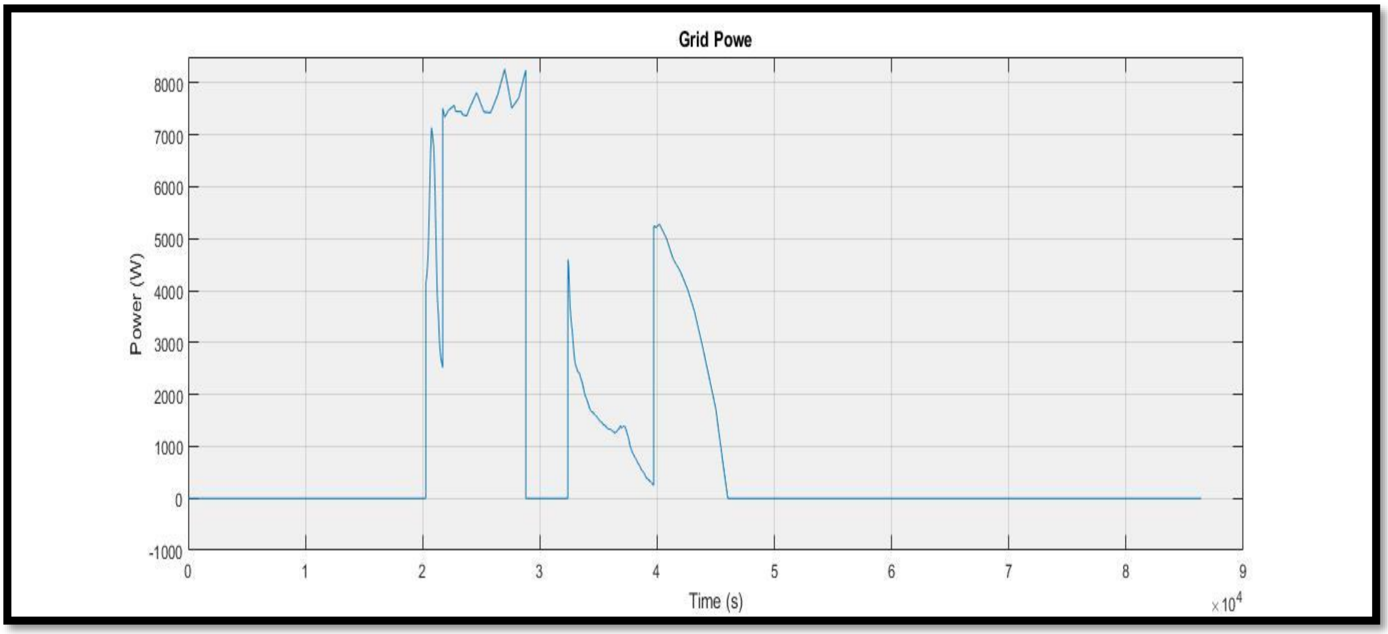


Figure 71. Grid power 1.2

System power

The system power is 0 W and it is our main goal.

5.2.1.3 **Subtest-3**

We are going to have a situation whose SOCs are near minimum SOC.

Load power

It is expected that EV' power raise due to have initial low level of SOC (30%).

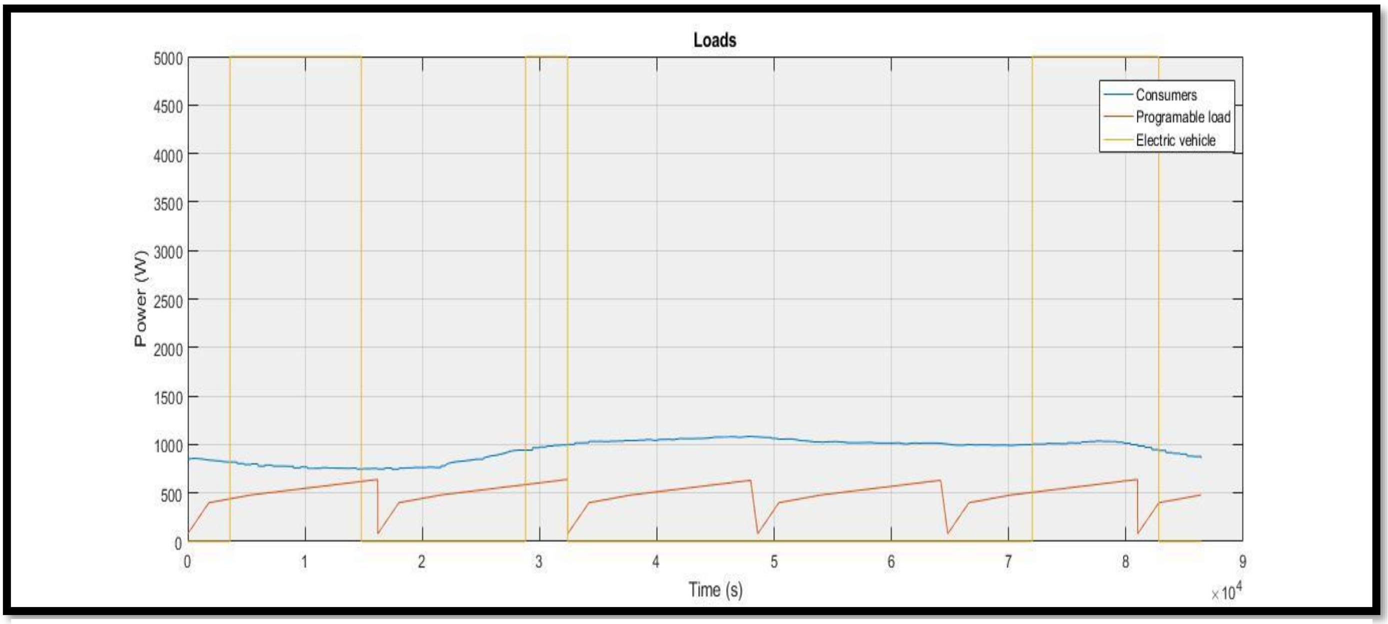


Figure 72. Load Power 1.3

Gross power

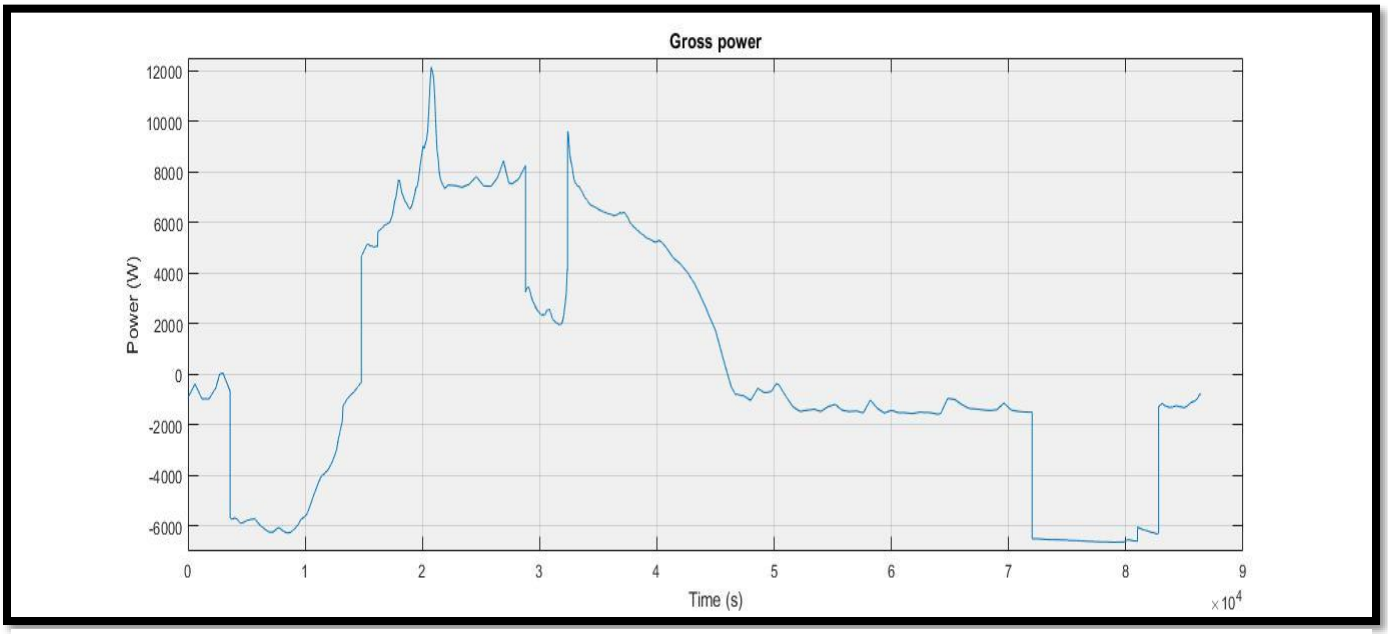


Figure 73. Gross Power 1.3

If we compeer this graph with the case of subtest1.2 we can realize that system is divided in two part essentially, excess and deficit of power, hence the control is going to change both modes.

SESs' power

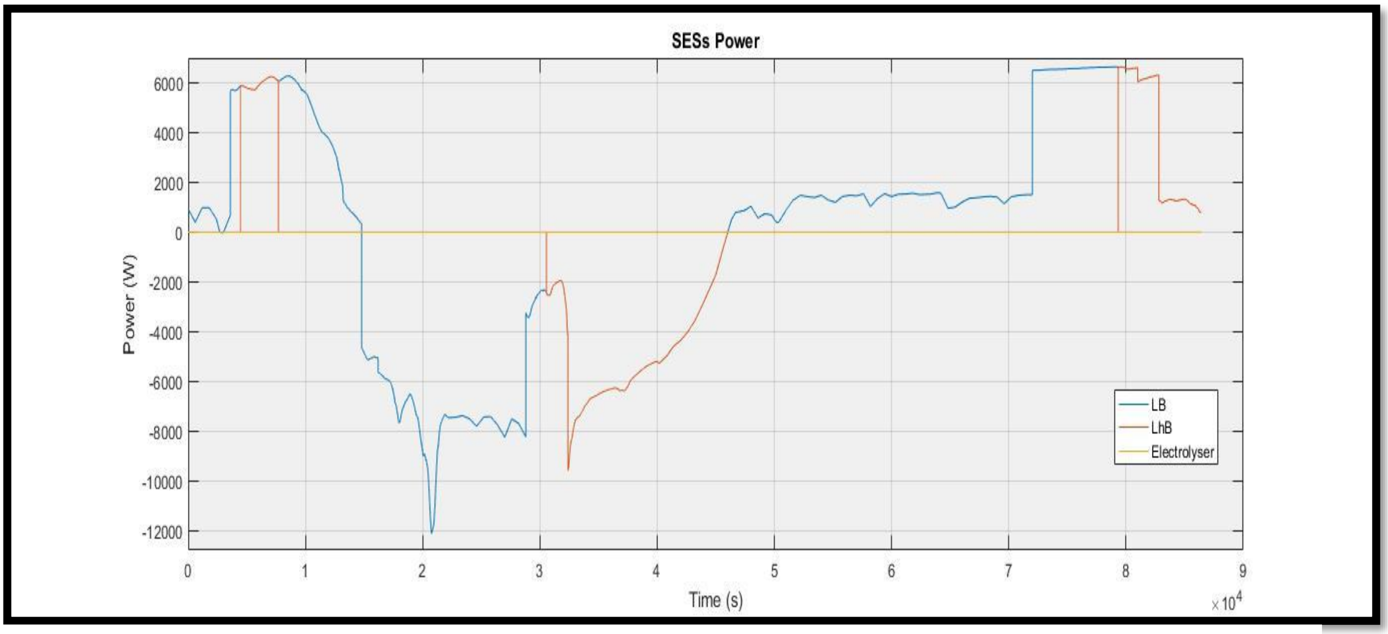


Figure 74. SESs Power 1.3

In this graph shows as SESs have to work injecting and absorbing power, so we can satisfy with control because it is working correctly.

Change of SOSs

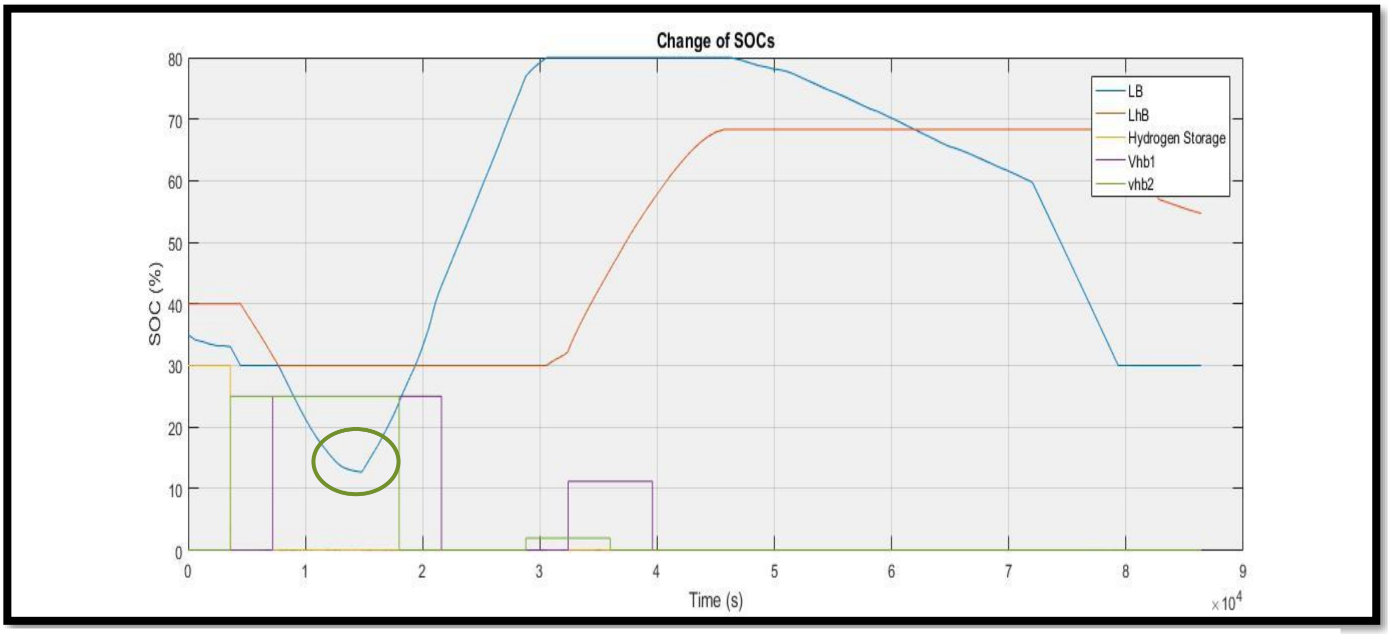


Figure 75. Change of SOCs 1.3

In this situation, SOCs of LB and LhB work within the minimum limits and moreover **LB is working almost until security SOC.**

Then, we can suppose that control is working accurately.

Balance power

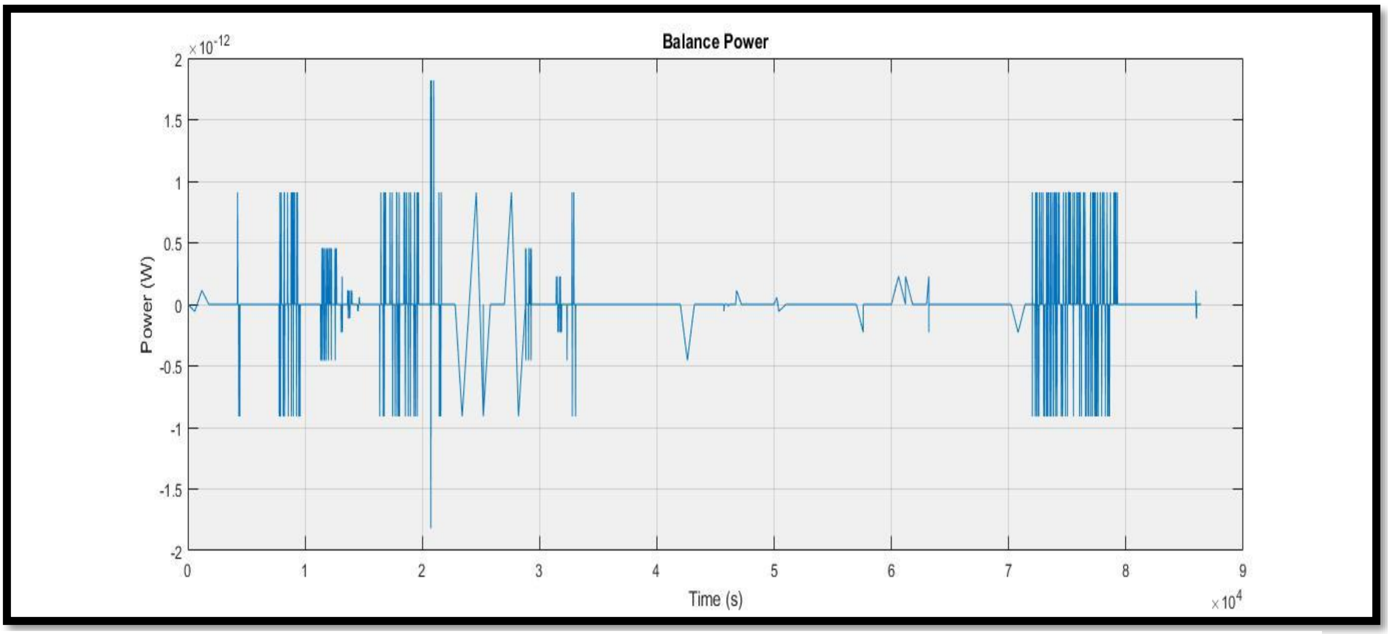
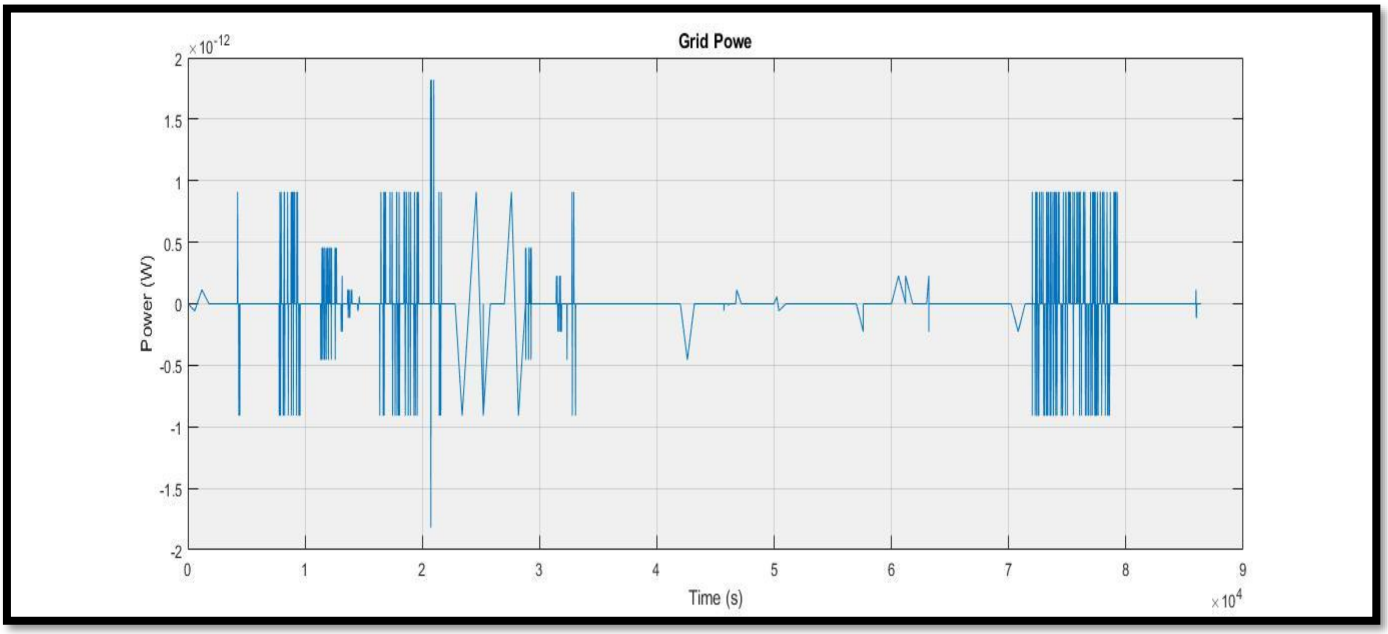


Figure 76. Balance Power 1.3

Although It isn't 0 W, we can consider that system is right because of having difference of power of 10^{-12} W. Regardless that is admissible because it is difficult to measure with that tolerance ($1x10^{-12}$ W).

We can considerer Balance power equal 0 W.

Grid power



System power

The system power is 0 W and it is our main goal.

5.2.1.4 Subtest-4

We are going to have a situation which is a mixture of subtes2-3.

Load power

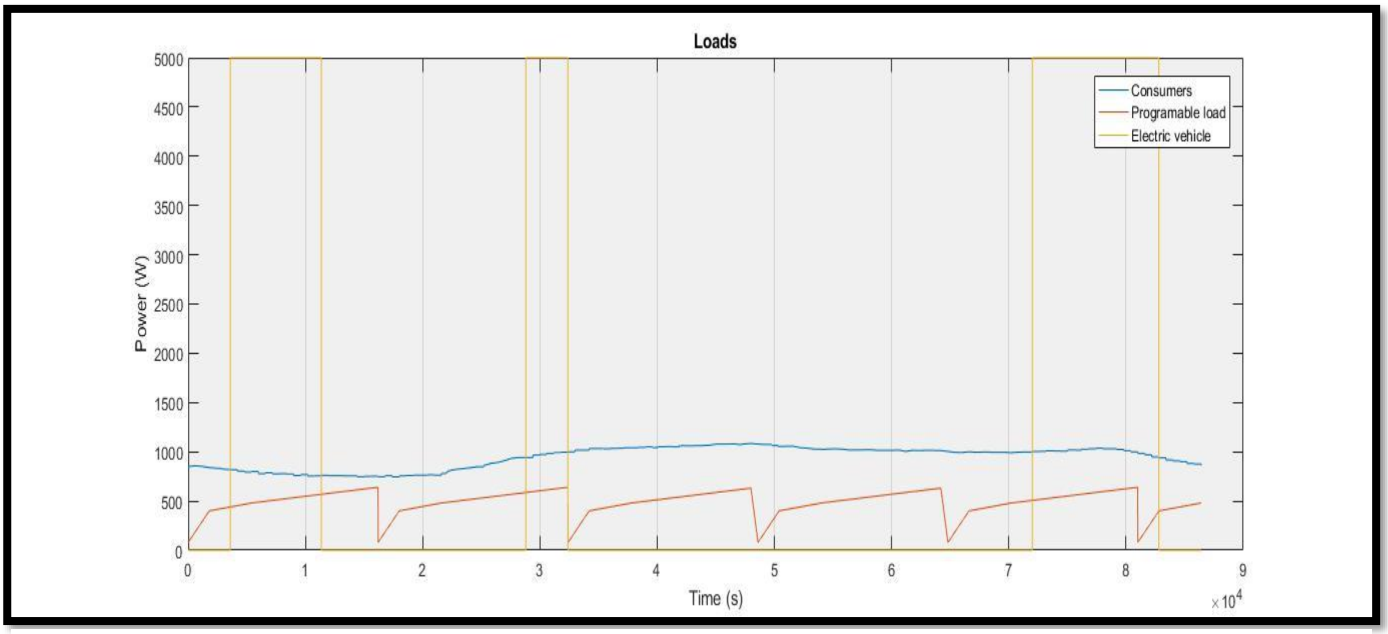


Figure 77. Load Power 1.4

Gross power

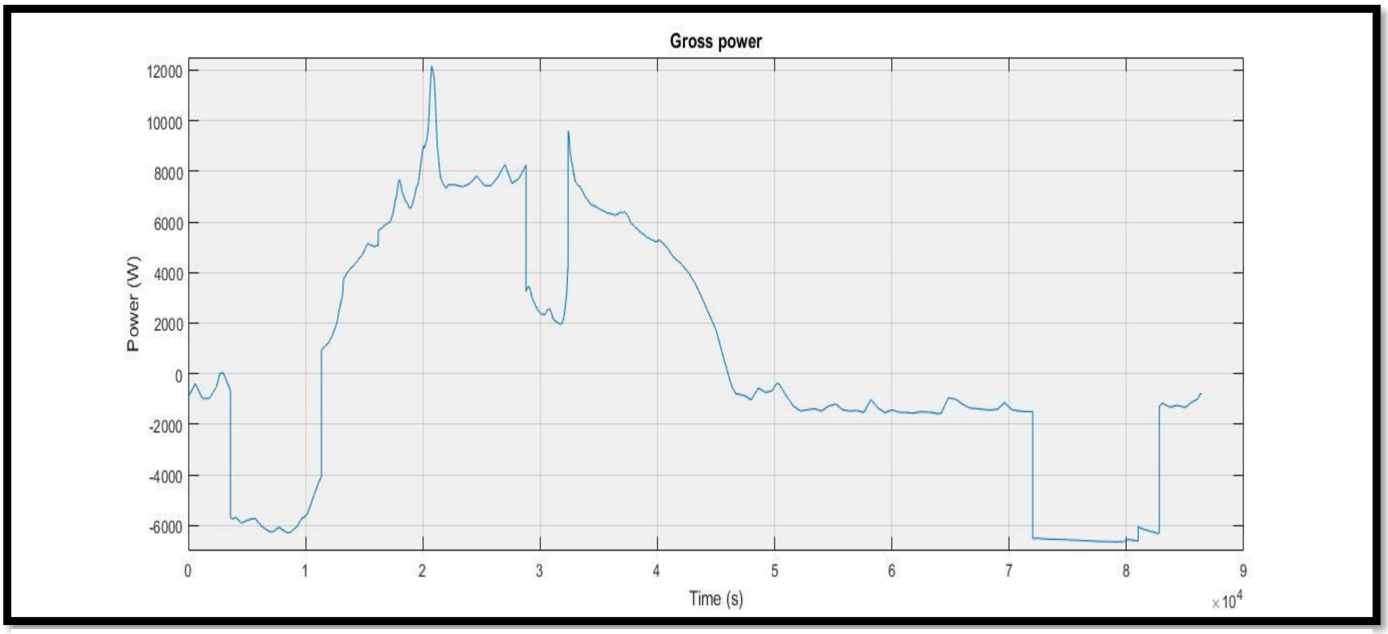


Figure 78. Gross Power 1.4

SESs' power

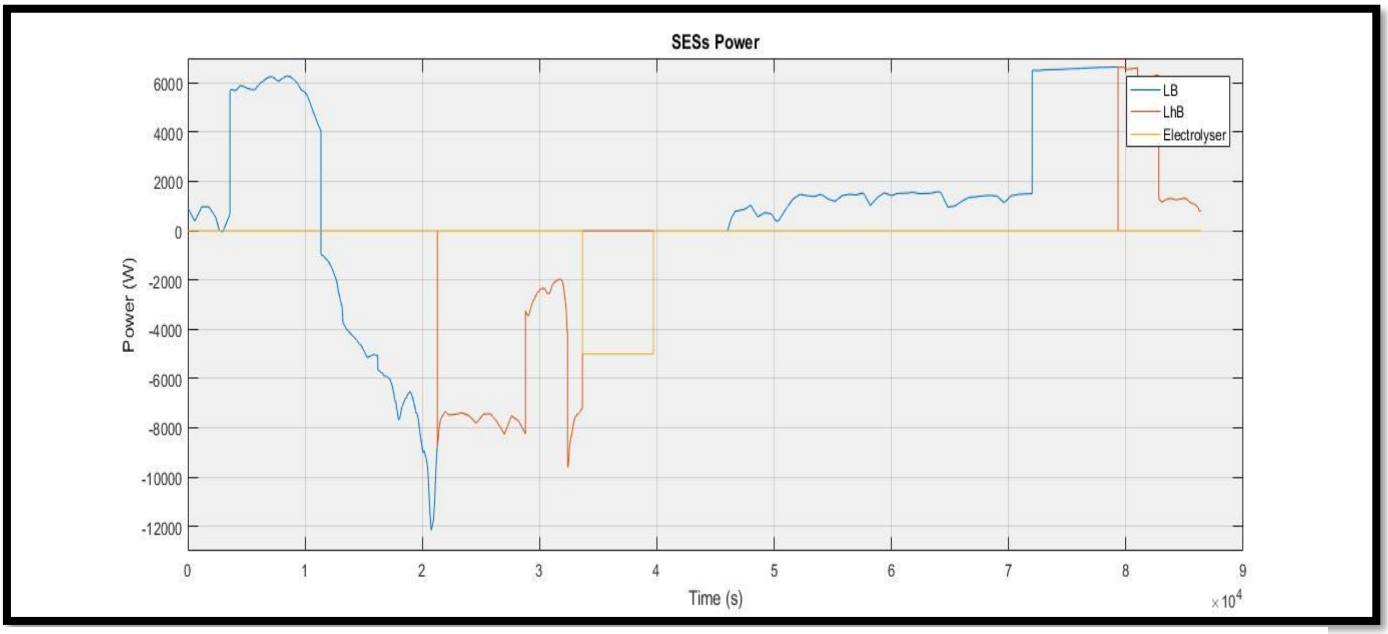


Figure 79. SEss Power 1.4

In this case, SESs can work in both modes.

Change of SOSs

This graph supports us to see that system is seemed to subtest 1 because of working within limits but not extreme limit (security LB' SOC).

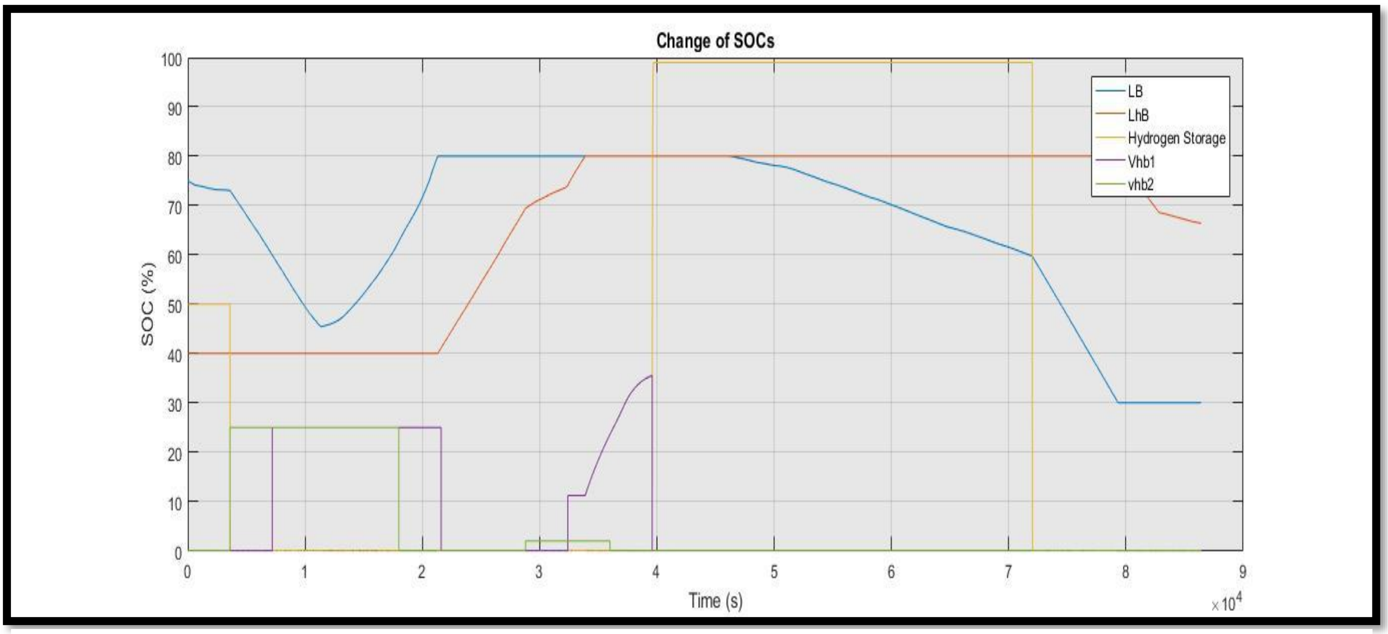


Figure 80. Change of SOCs 1.4

Balance power

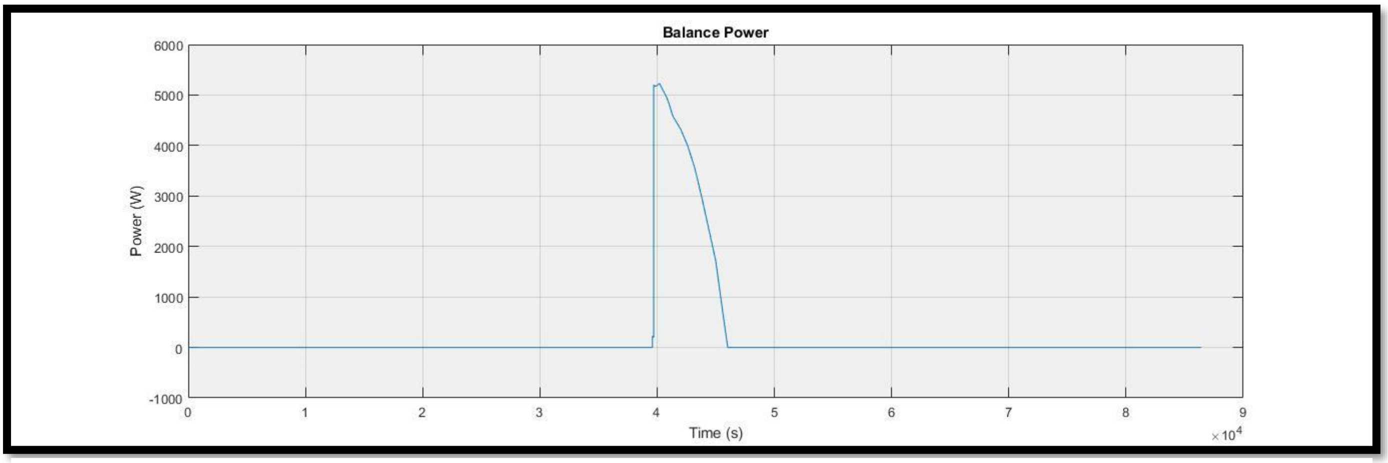


Figure 81. Balance power 1.4

This graph is similar of subtest1.Then it shows that EV' SOC has such important effect on operational modes. Because in both of subtest (1&4) EV's SOC is same.

Grid power

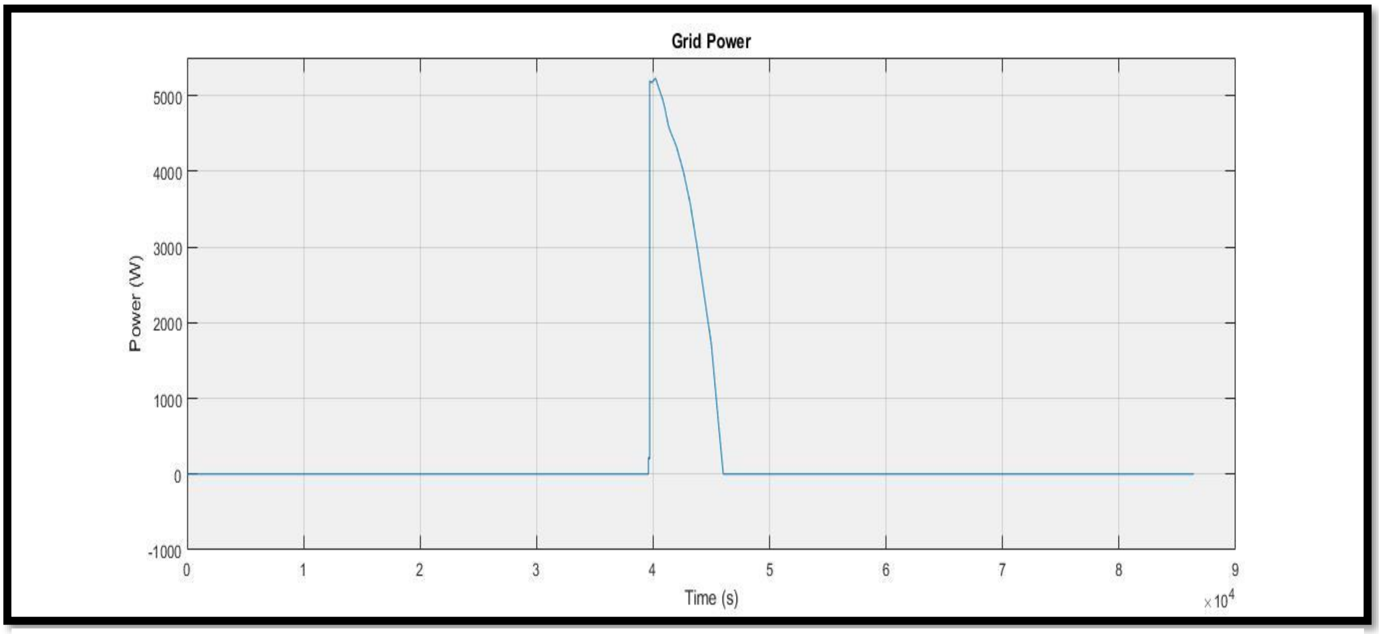


Figure 82. Grid power 1.4

System power

The power system is 0 W and it is our main goal.

5.2.2 Tests2:

In these tests, we are going to have the same meteorological condition, hence power generation is similar.

Generation power

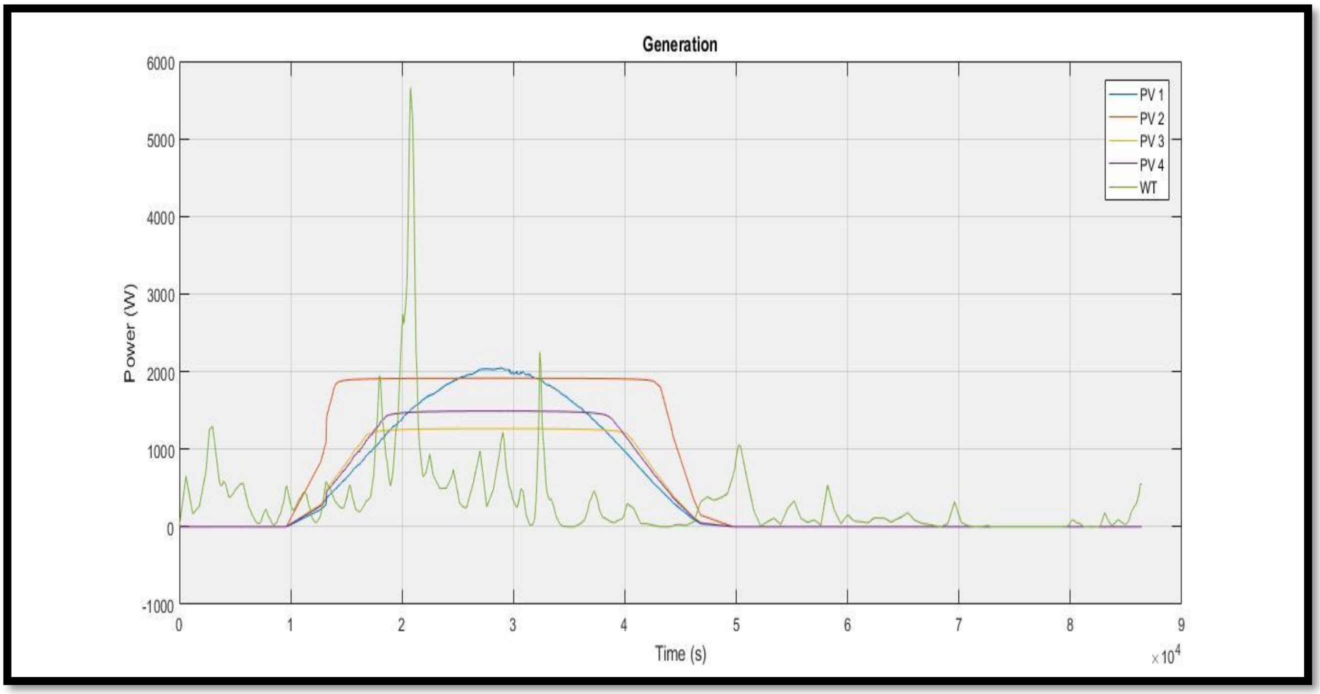


Figure 83. Generations 2

You can see different generators and their curve of power.

5.2.2.1 Subtest-1

We are going to have a situation which initial SOCs are intermediate (50%).

Load power

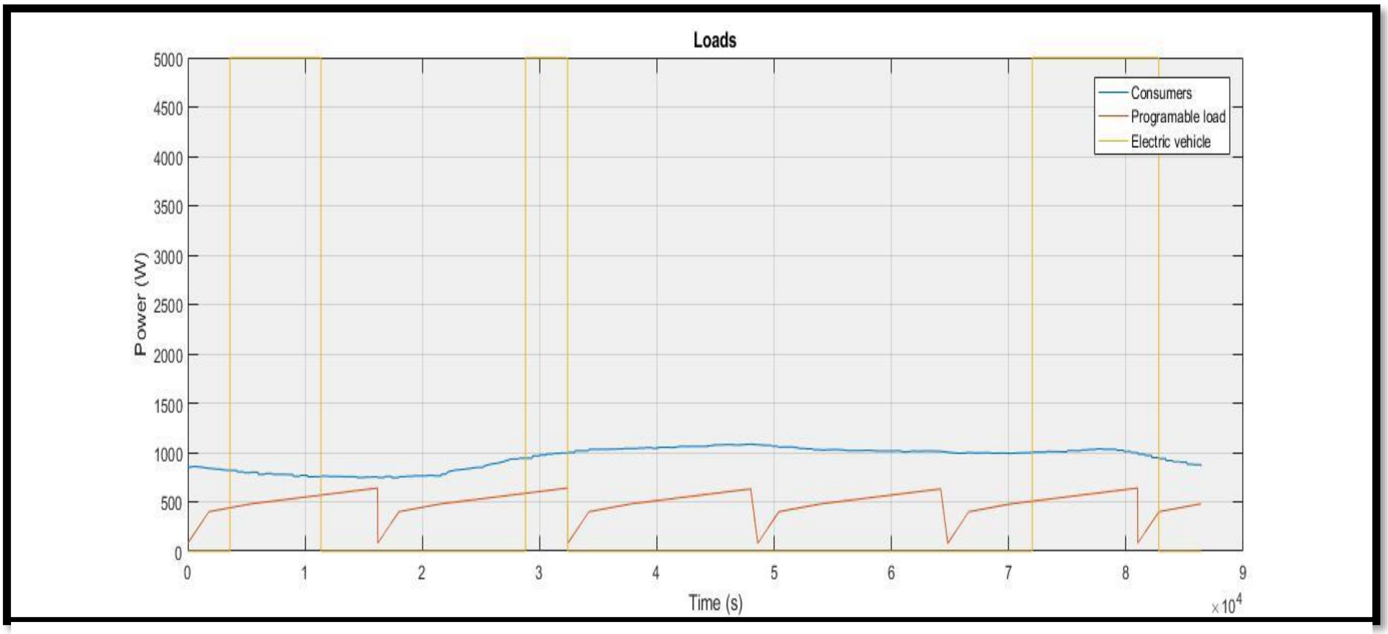


Figure 84. Load Power 2.1

EV has a high demand because of having SOC of 50%, hence EV's SOC will be important in Load Power

Gross Power

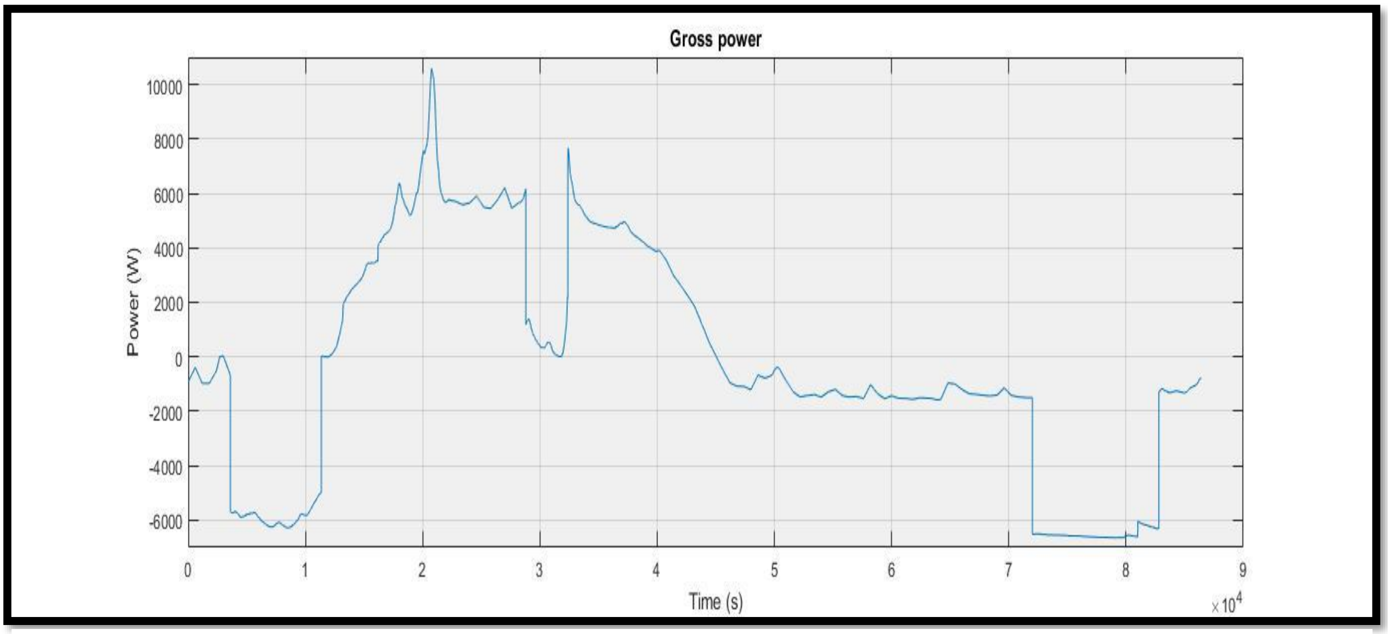


Figure 85. Gross power 2.1

It is expected that gross power is usually negative, hence the control are going to work in operational deficit mode.

SESs power

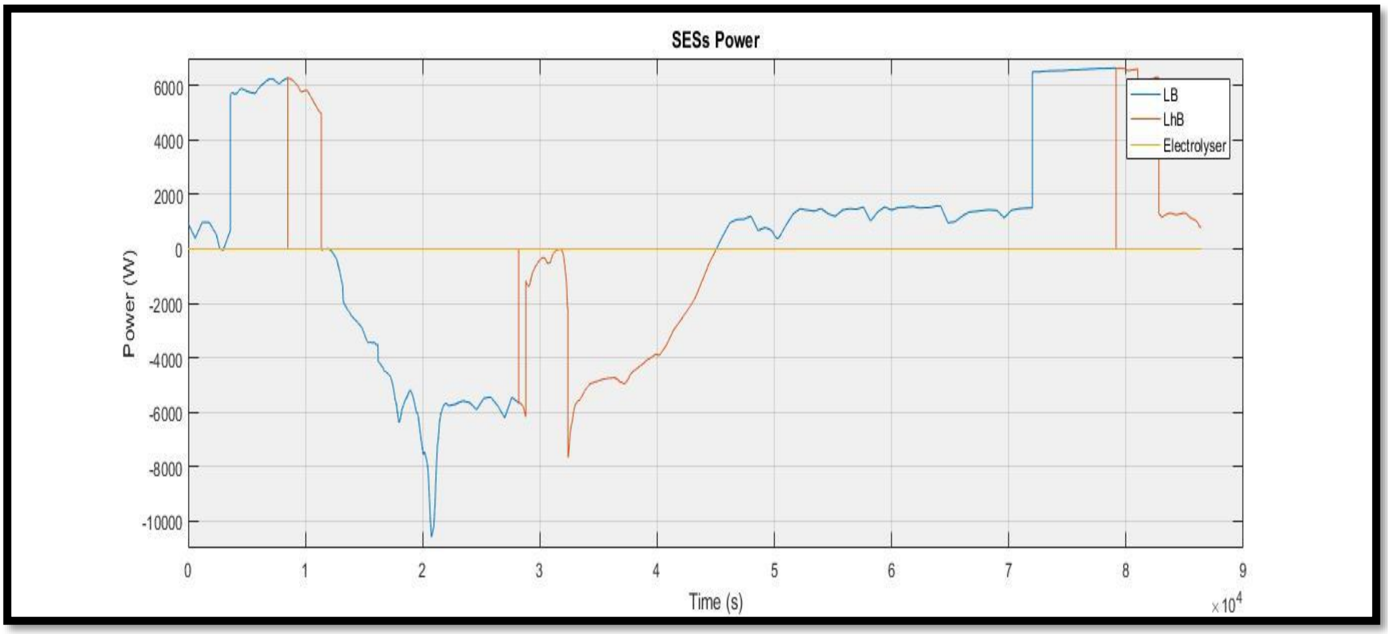


Figure 86. SESs power 2.1

This graph shows as above all SESs are injecting power in DC bus.

Change of SOCs

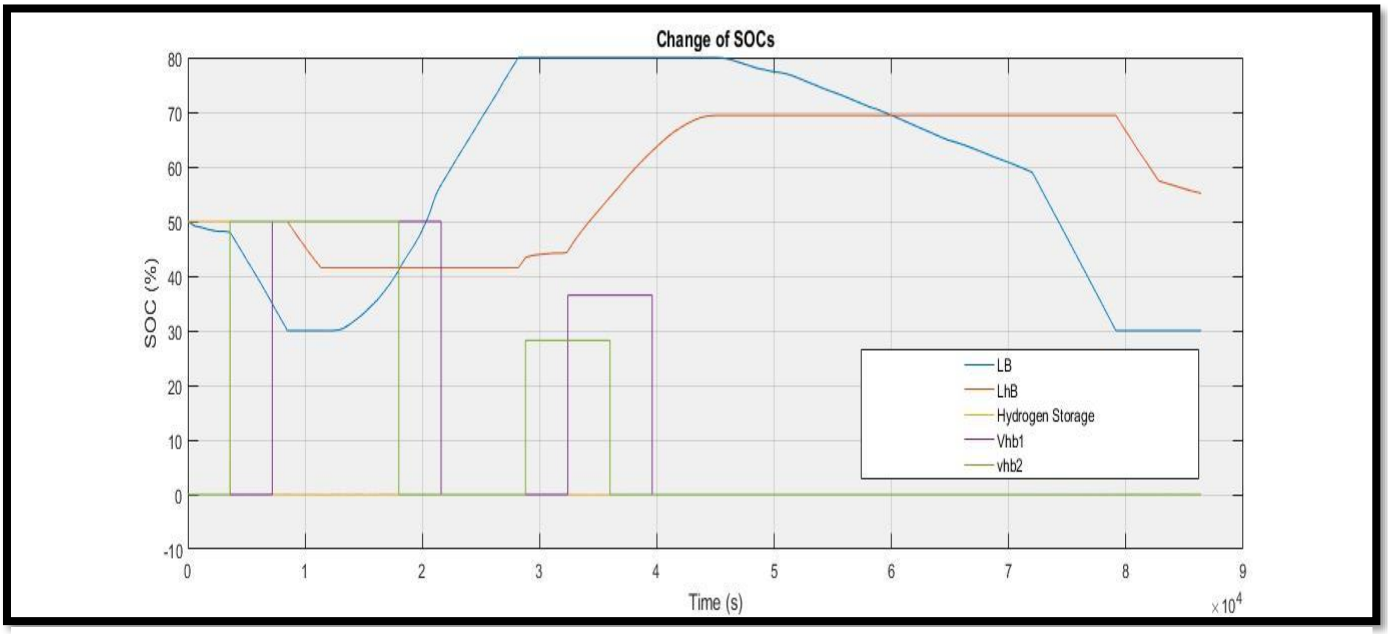


Figure 87. Change of SOCs 2.1

This graph shows as above all SESs get their SOCs increased, but they are within the operational limits.

Balance power

Although It isn't 0 W, we can consider that system is right because of having difference of power of 10^{-12} W, it

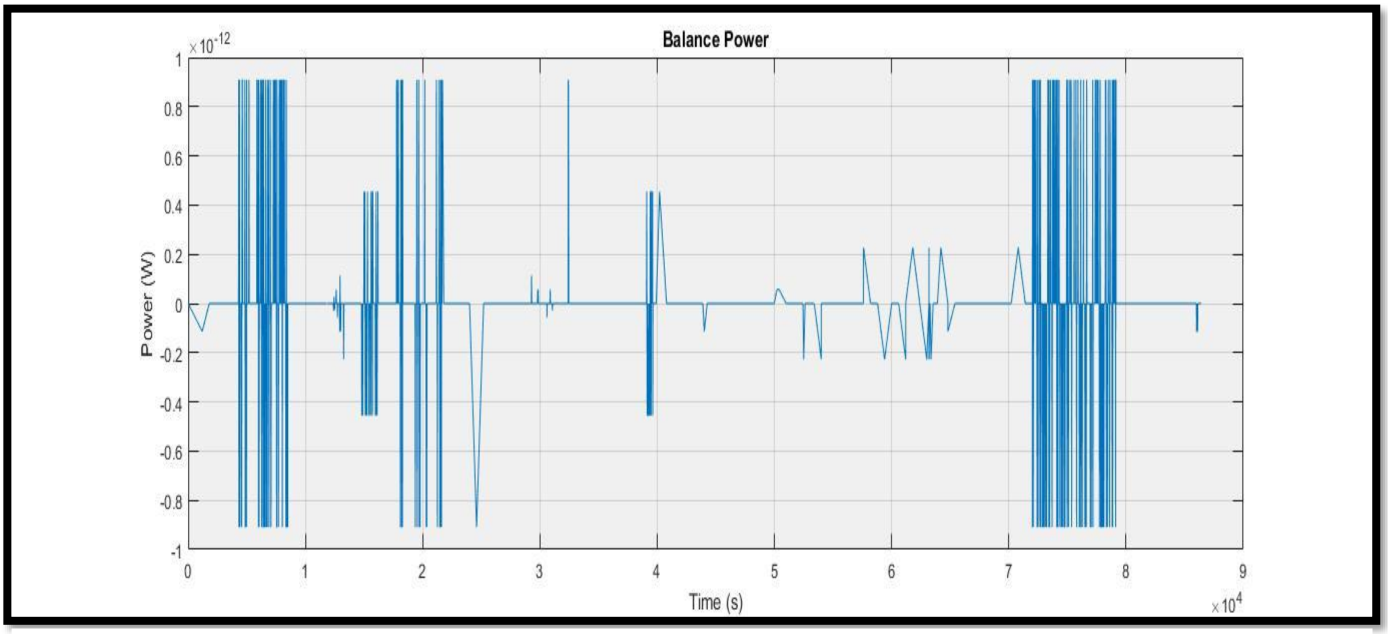


Figure 88. Balance Power 2.1

We can consider Balance power equal 0 W.

Grid power

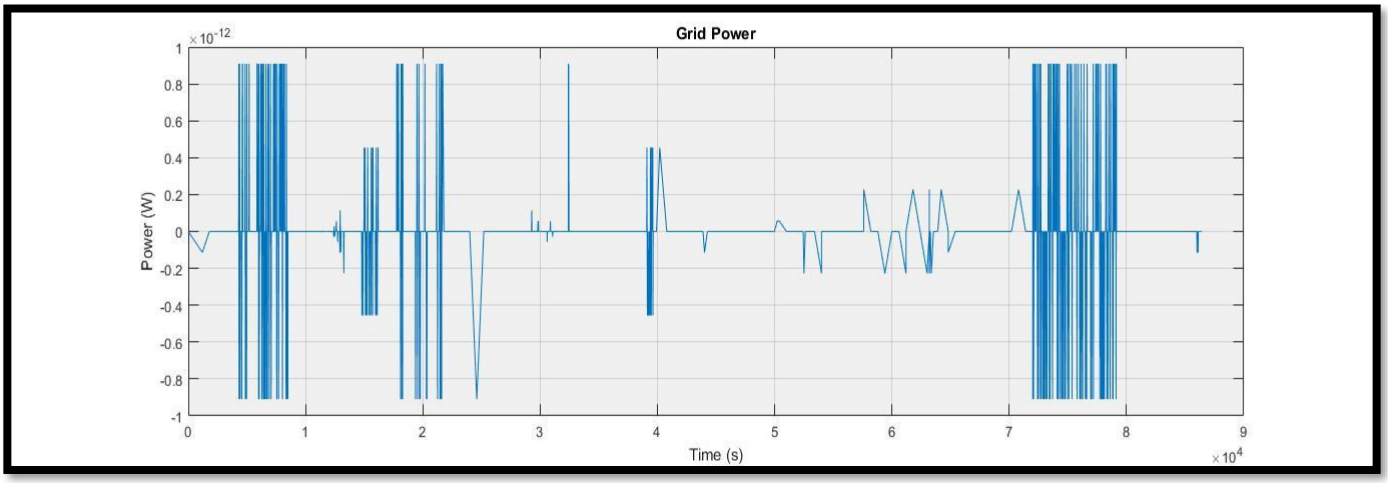


Figure 89. Gris Power 2.1

System power

The system power is 0 W and it is our main goal.

5.2.2.2 **Subtest-2**

We are going to have a situation with high level of SOCs, which are near maximum SOC.

Load power

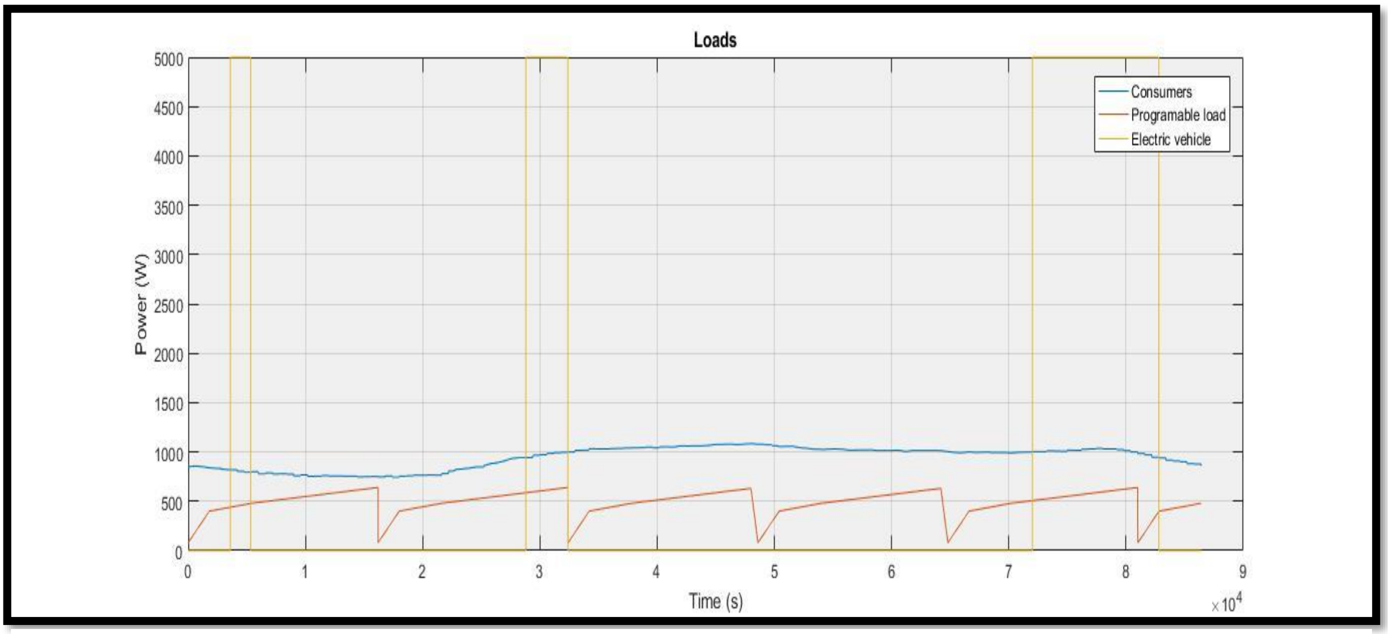


Figure 90. Load power 2.2

In this case, EV' SOC is of 85%, so it consumes less power than previous subtest.

Gross power

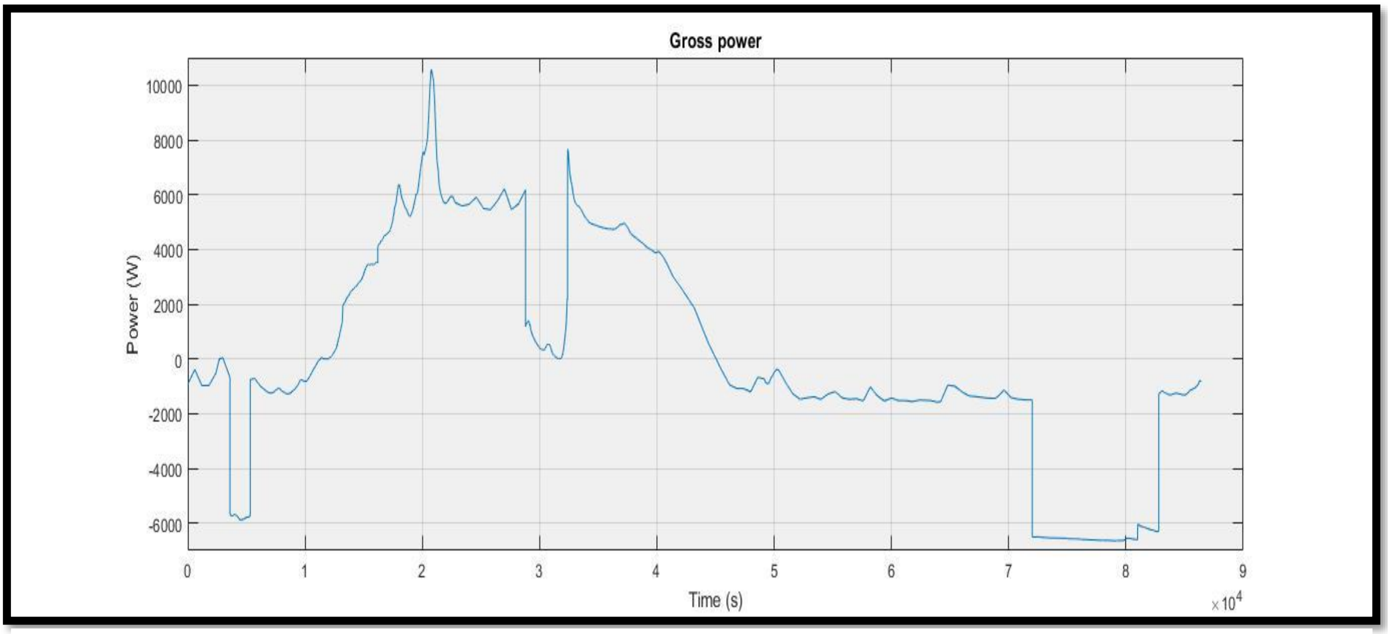


Figure 91. Gross power 2.2

As we can see, gross power is positive a long time, hence we are going to work in operational deficit mode above all.

SESs Power

As EV' SOC is high , there are power excess and then electrolyser can work too.

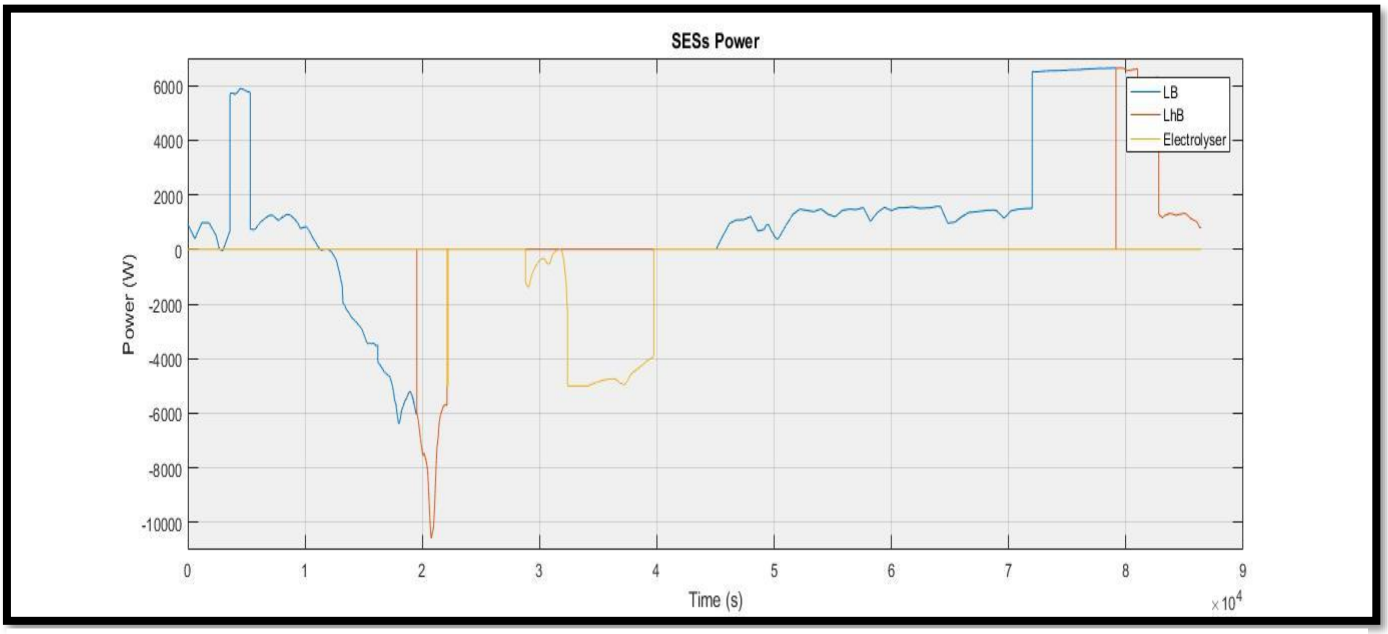


Figure 92. SESs Power 2.2

Change of SOCs

In this graph is easy to see that both operational modes can be working at the same day. You can see that hydrogen SOC has been increased although there is a bad meteorological condition.

Besides, it indicates that EV' SOC is essential for performance of the microgrid,because when EV'SOC is high

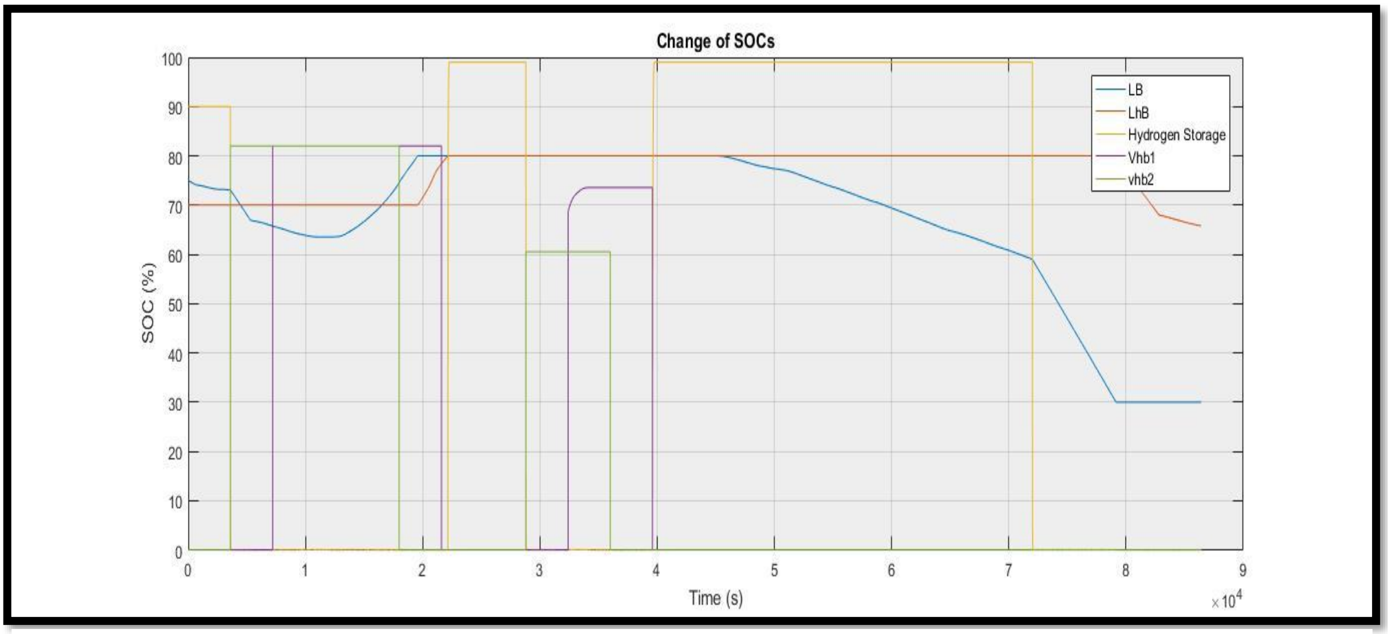


Figure 93. Change of SOCs 2.2

then controller can work as excellent meteorological conditions like Test1.

Balance power

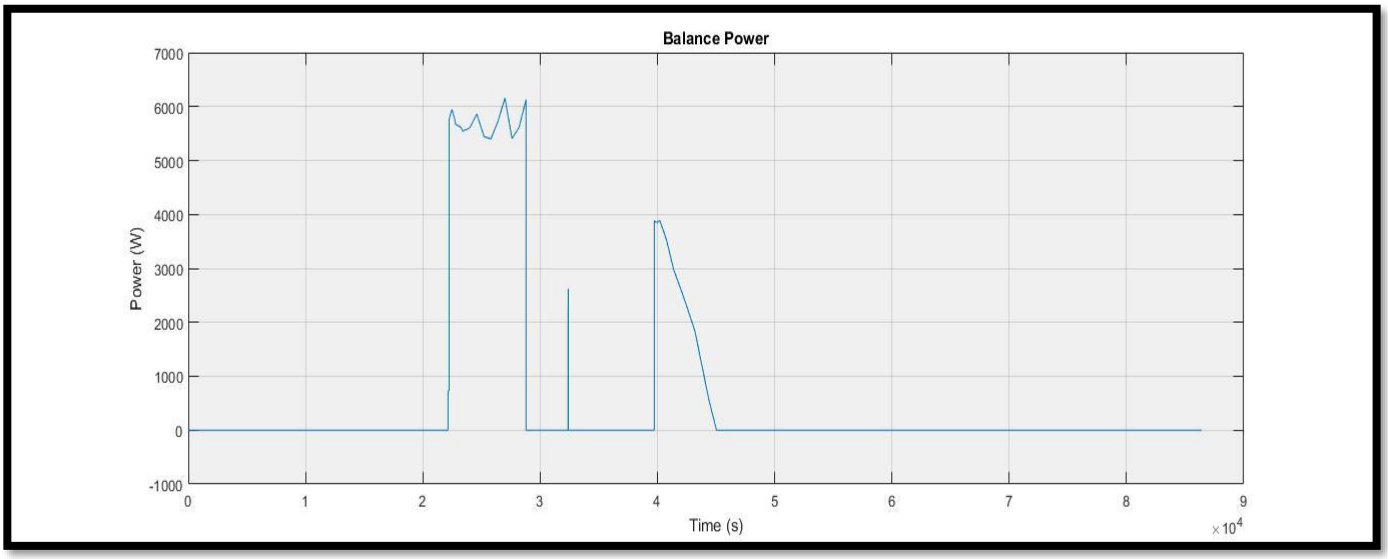


Figure 94. Balance Power 2.2

Grid power

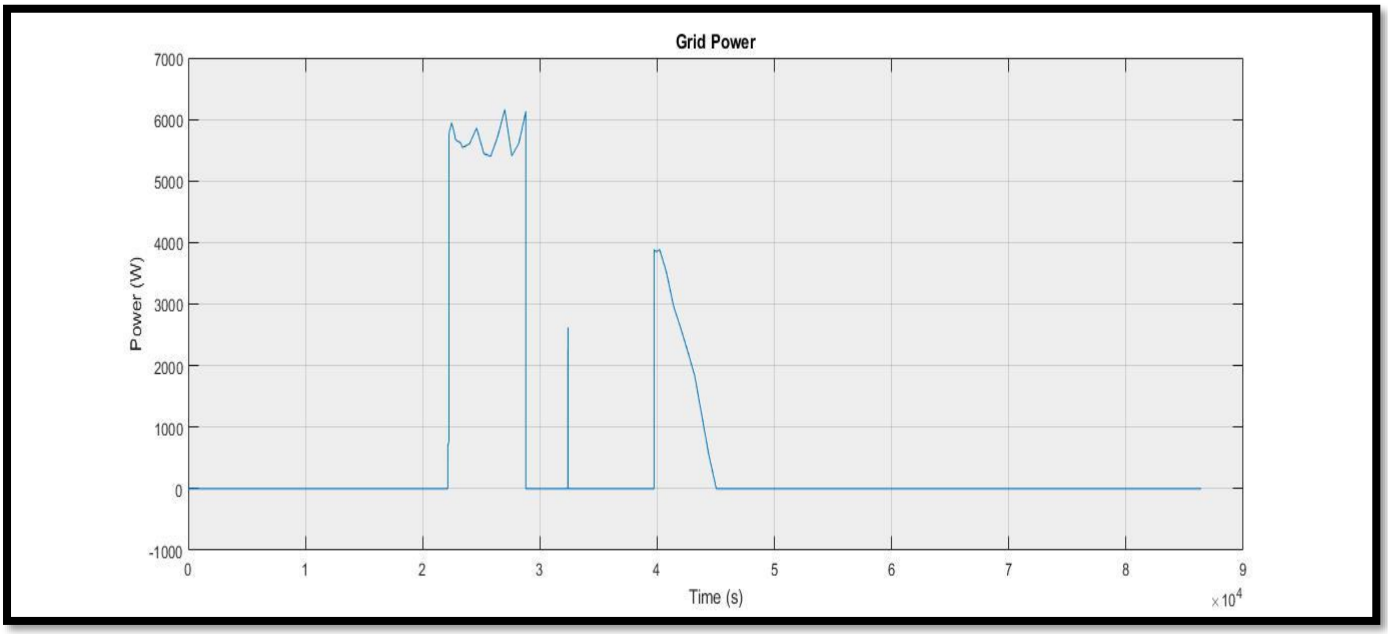


Figure 95. Grid Power 2.2

System power

The power system is 0 W.

5.2.2.3 **Subtest-3**

Load power

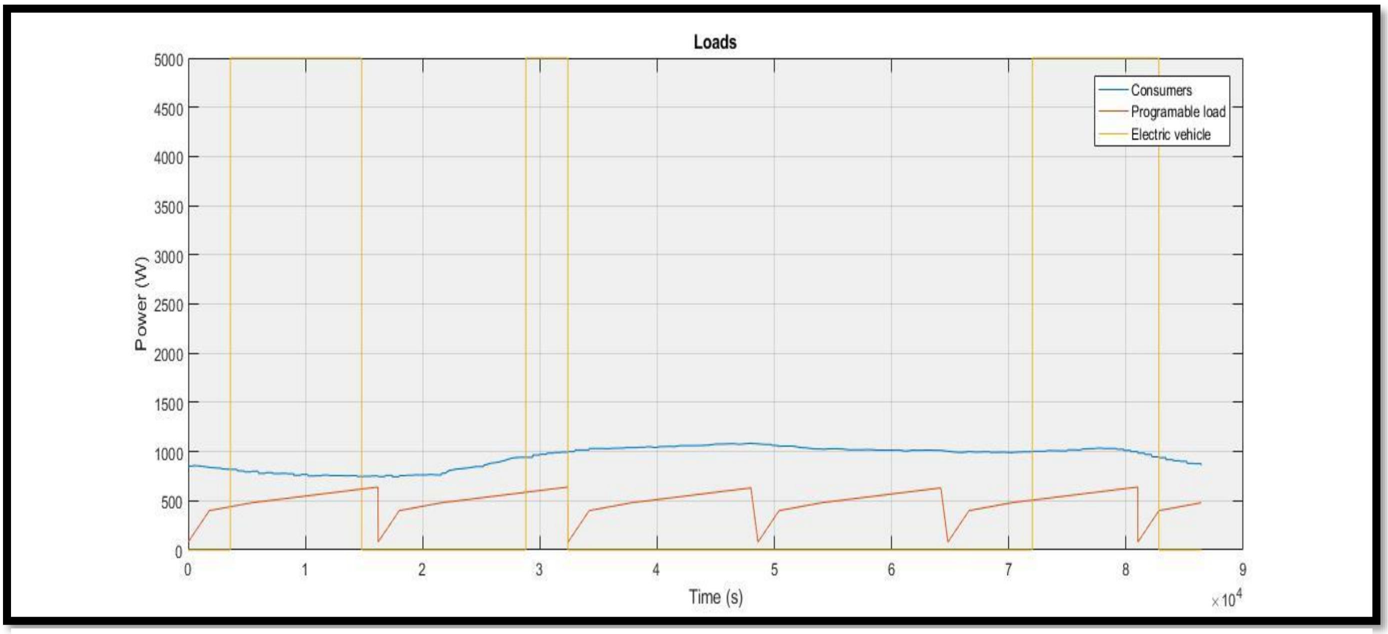


Figure 96. Load power 2.3

It is expected that EV' power raise due to have initial low level of SOC

Gross power

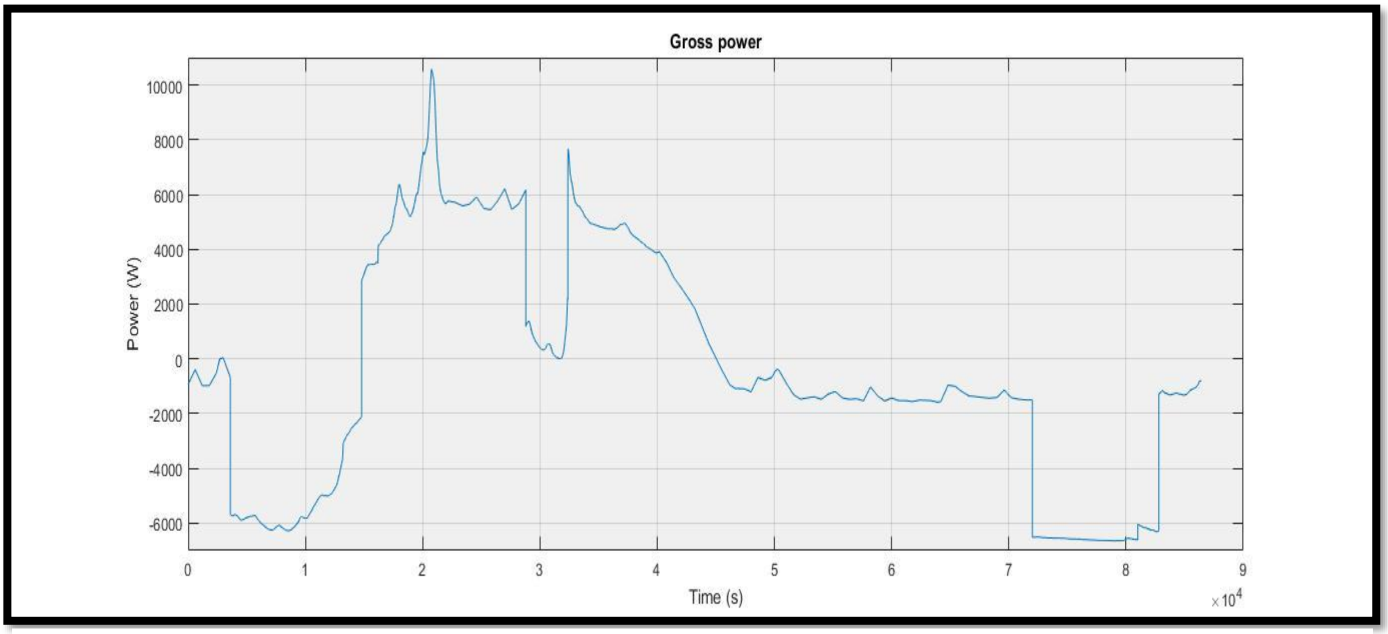


Figure 97. Gross power 2.3

If we compeer this graph with the case of subtest2.2 we can realize that system is divided in two part essentially, excess and deficit of power, hence the control is going to change both operational modes.

SESs power

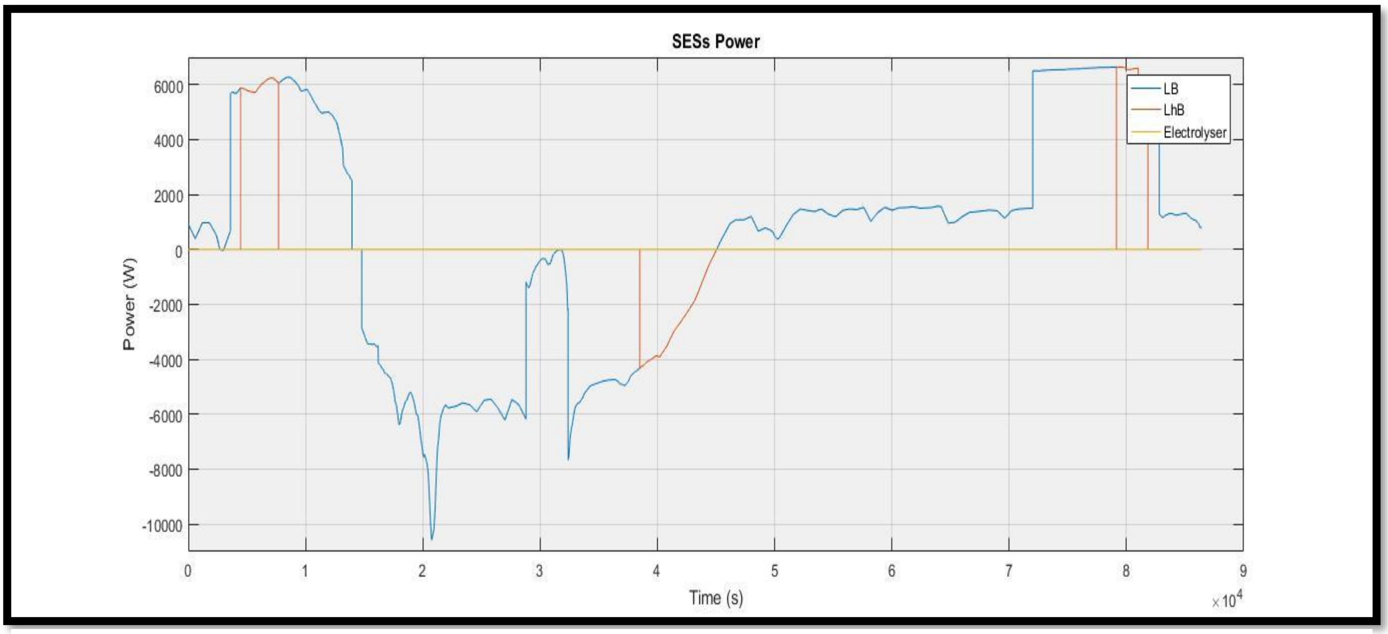


Figure 98. SES Power 2.3

In this graph shows as SESs have to work injecting and absorbing power, so we can satisfy with control because it is working correctly.

Change of SOCs

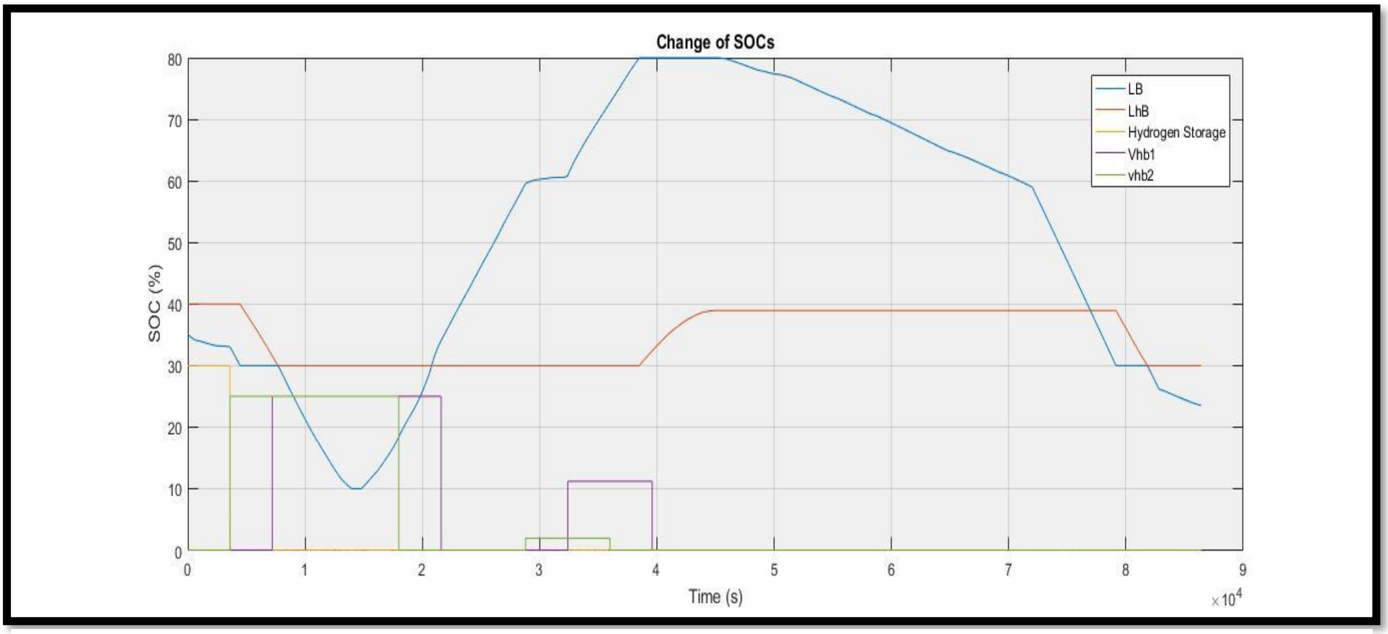
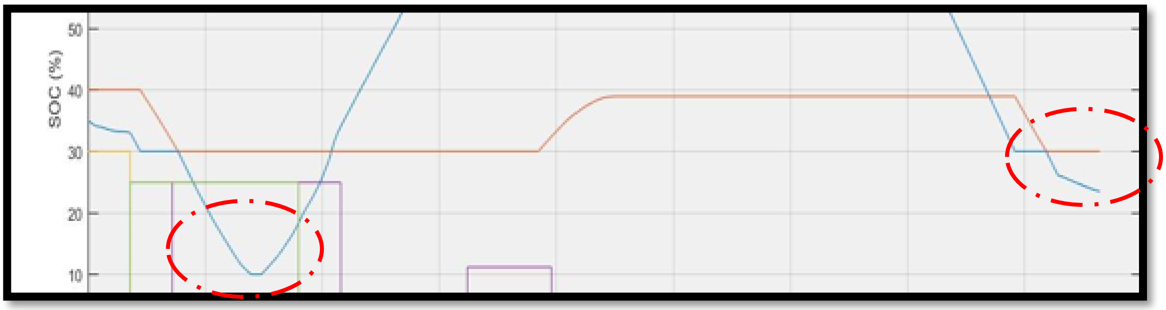


Figure 99. Change of SOCs 2.3

In this situation, SOCs of LB and LhB work within the minimum limits and moreover LB is working almost until security SOC.



We can suppose that the control is working correctly.

Besides, HV cannot discharge because they have a SOC under of minimum one.

Balance power

We need to buy electricity from conventional grid because we don't have more storage energy.

In fact, hybrid vehicle can't inject power because their SOCs are less than minimum ones.

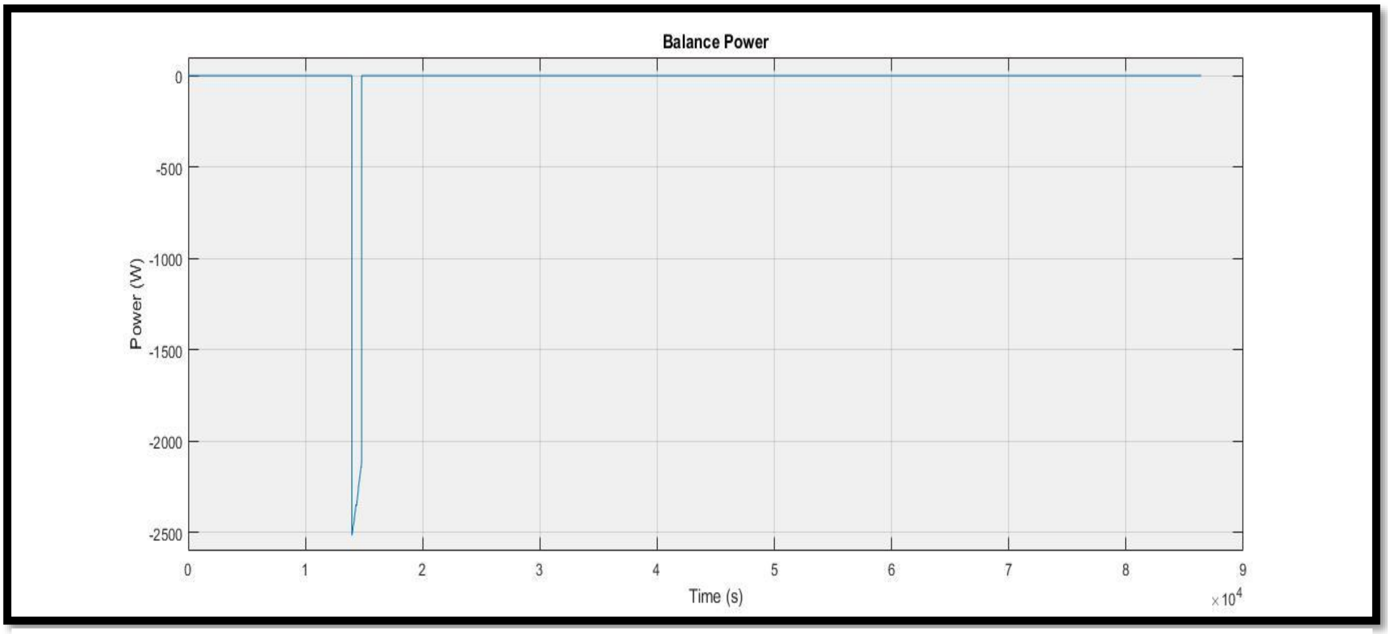


Figure 100. Balance Power 2.3

Grid power

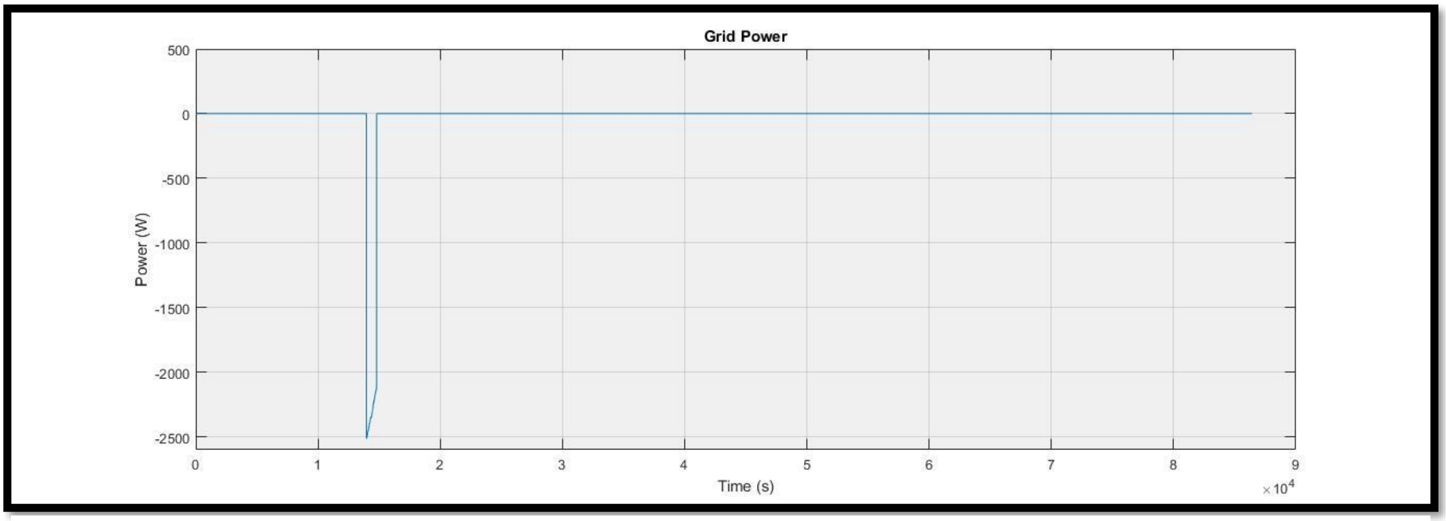


Figure 101. Grid Power 2.3

System power

The power system is 0 W.

5.2.2.4 **Subtest-4**

We are going to have a situation which is a mixture of subtes2-3.

Load power

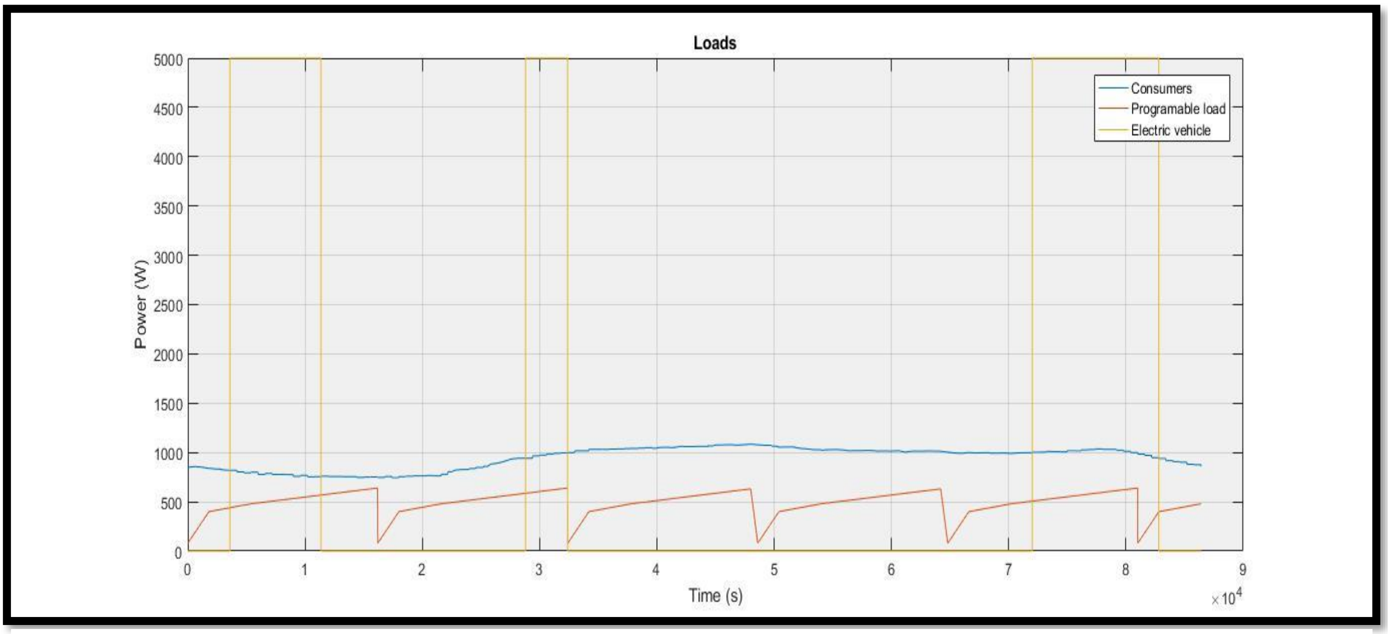


Figure 102. Load Power 2.4

Gross power

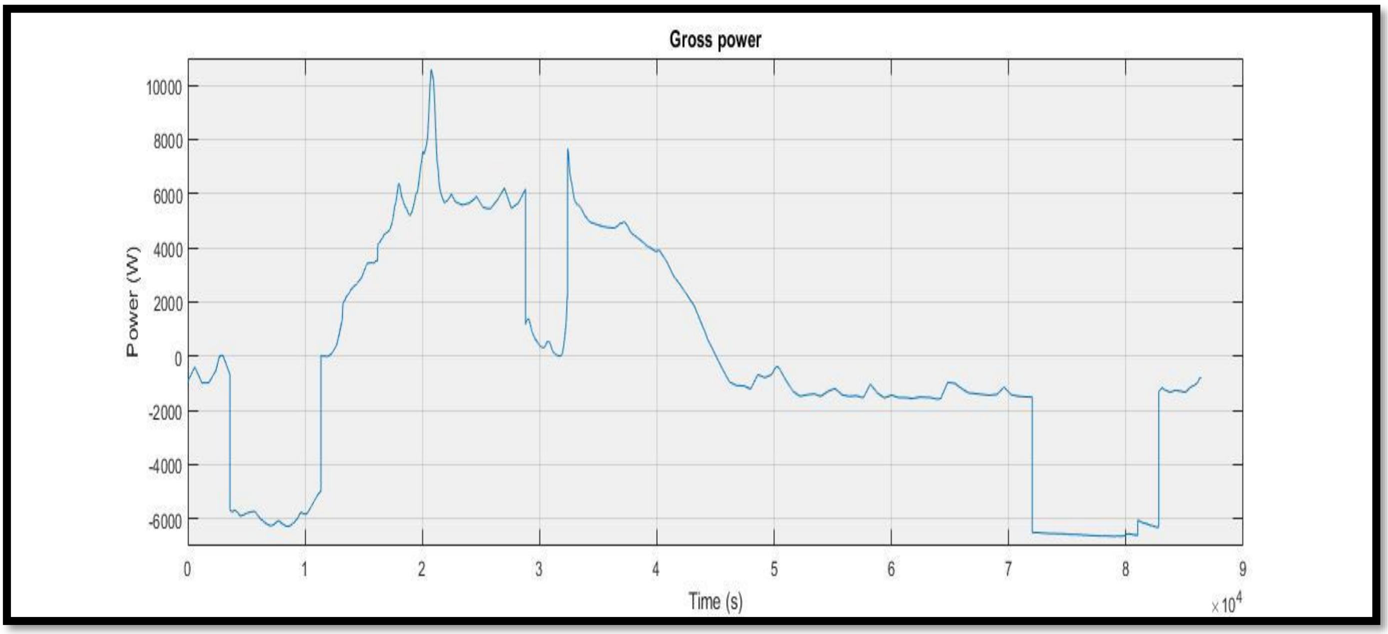


Figure 103. Gross Power 2.41

SESs power

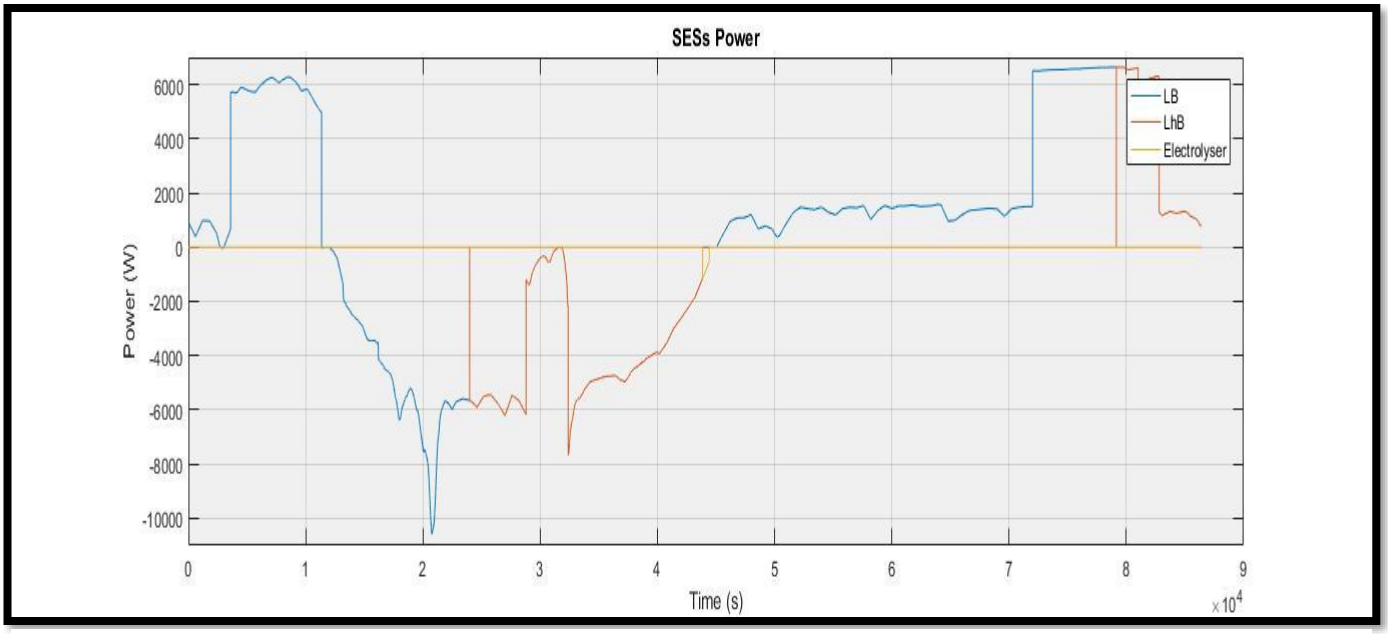


Figure 104. SESs Power 2.4

In this case, SESs can work in both operational modes thought, it has to work in operational deficit mode.

Change of SOCs

This graph supports us to see that system is seemed to subtest 1 because of working within limits but not extreme limit (security LB' SOC).

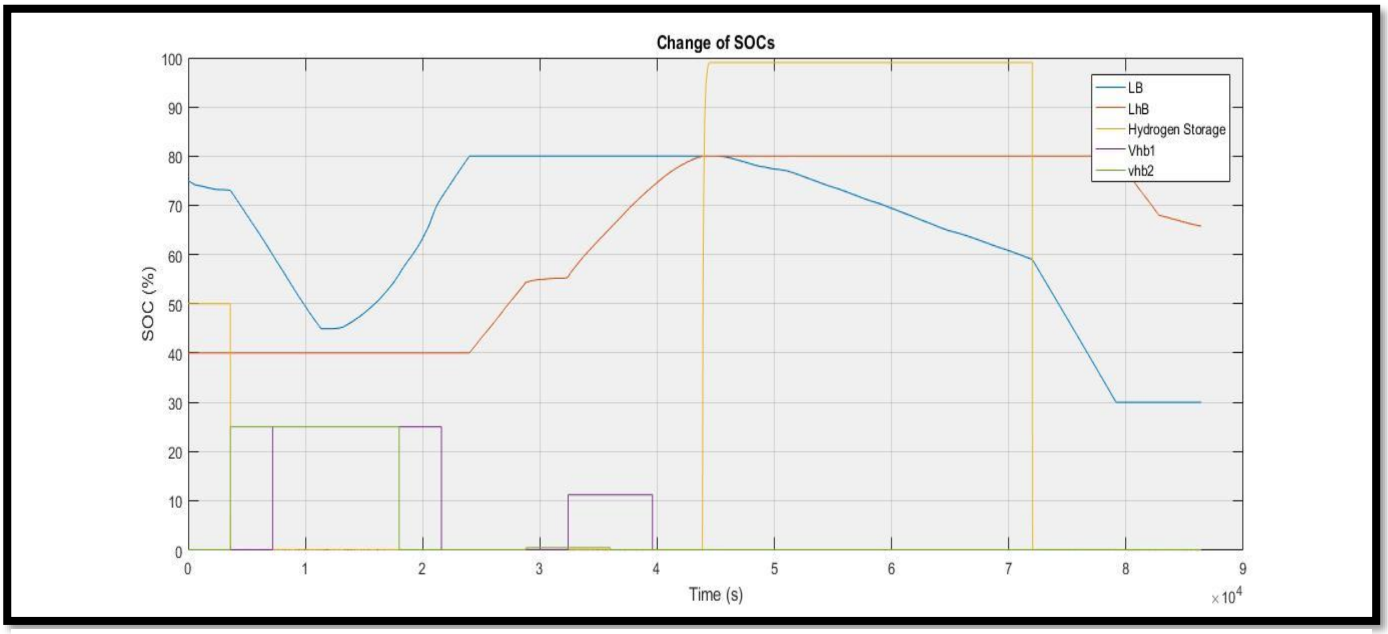


Figure 105. Change of SOCs 2.4

Balance power

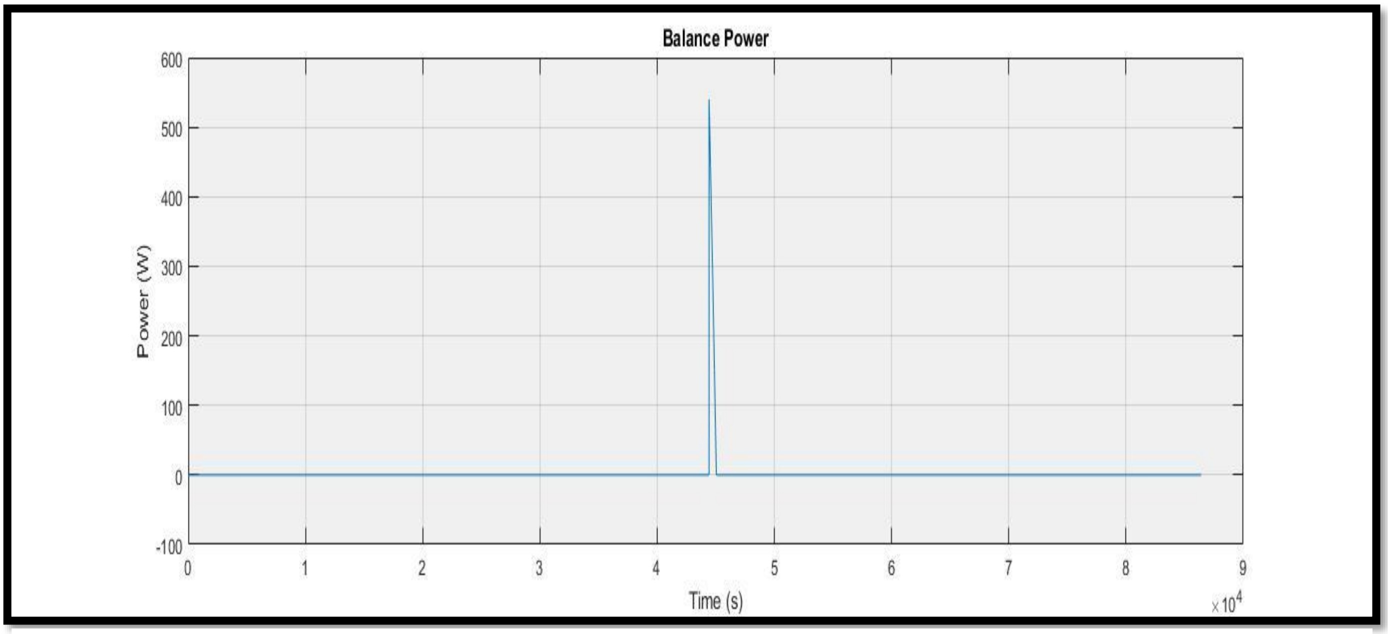


Figure 106. Balance Power 2.4

Amount of sold energy is little.

Grid power

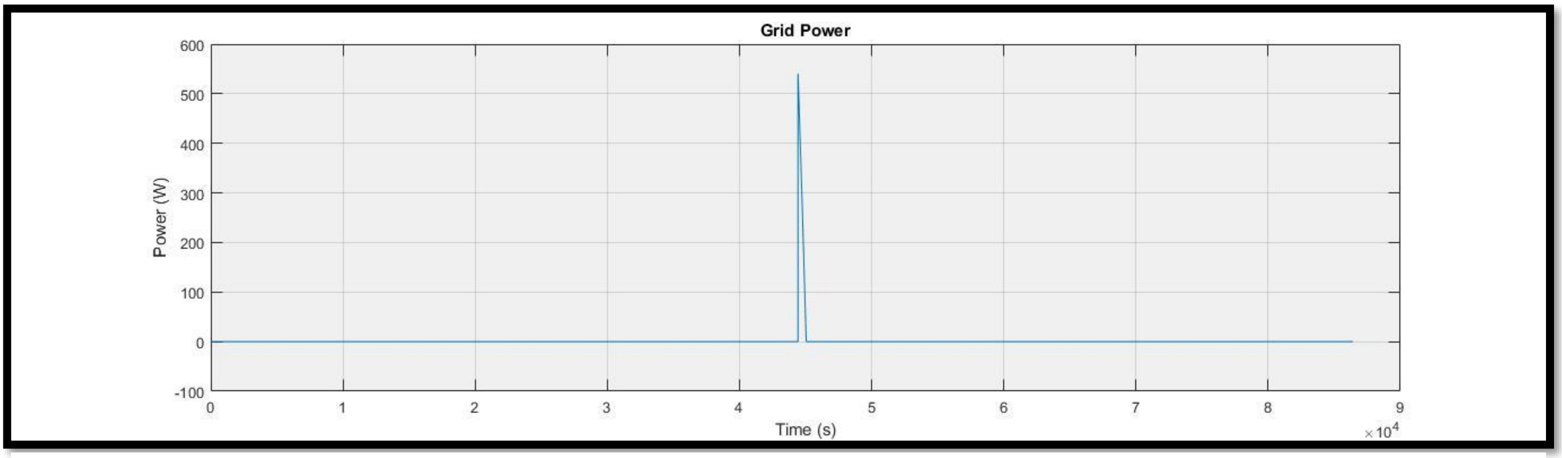


Figure 107. Grid power 2.4

System power

The power system is 0 W.

5.2.3 Test3:

In these tests, we aren't going to have generation power.

Load power

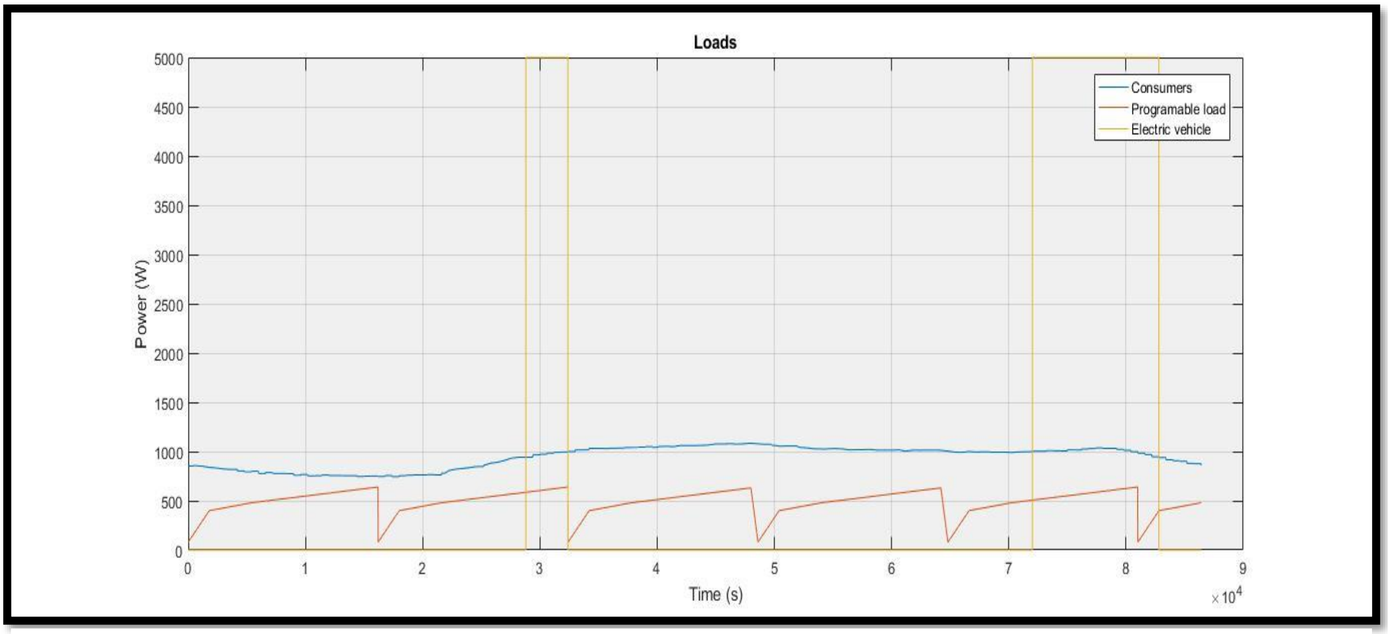


Figure 108. LOAD POWER 3

We can see that EV' SOC is maximum then EV consumes power further less.

SESs power

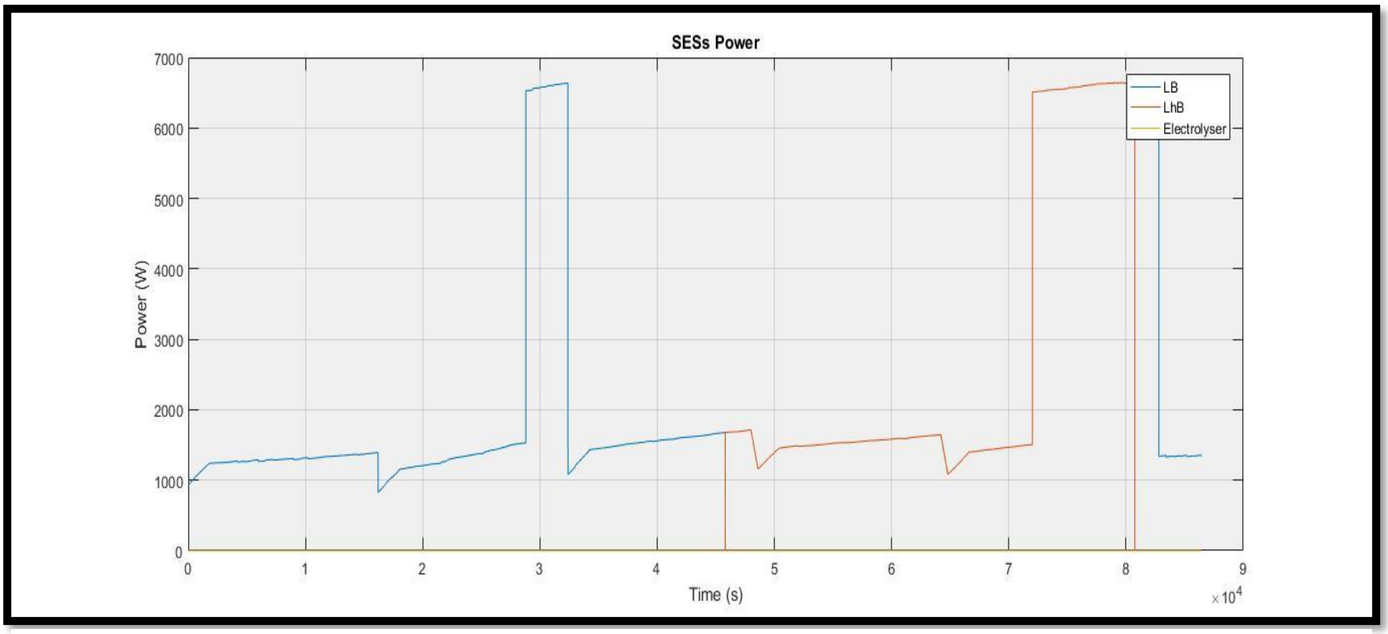


Figure 109. SES Power 3

It is obviously that SESs are going to inject power to DC bus even there are able to inject all necessary power.

Change of SOCs

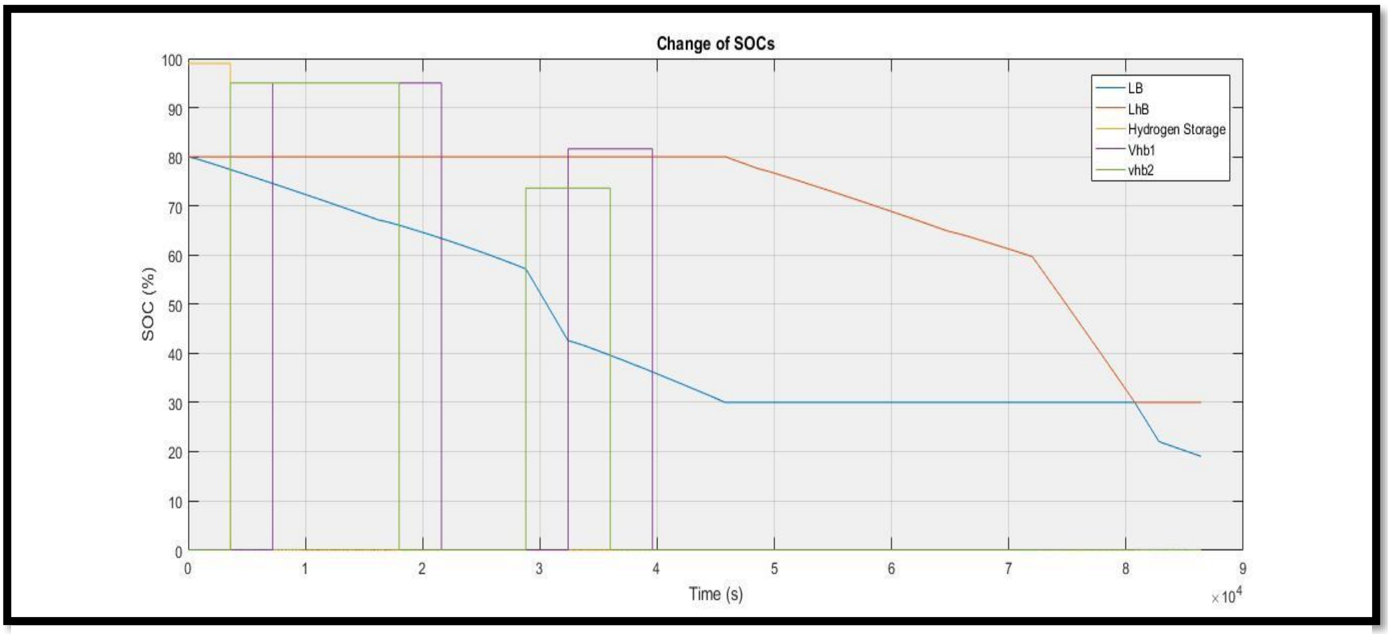


Figure 110. Change of SOcs 3

This graph shows that microgrid is operating in Island respect to conventional grid.

Balance power

we can assume that Balance power is 0 W because the real value is 1x10^{-12} W.

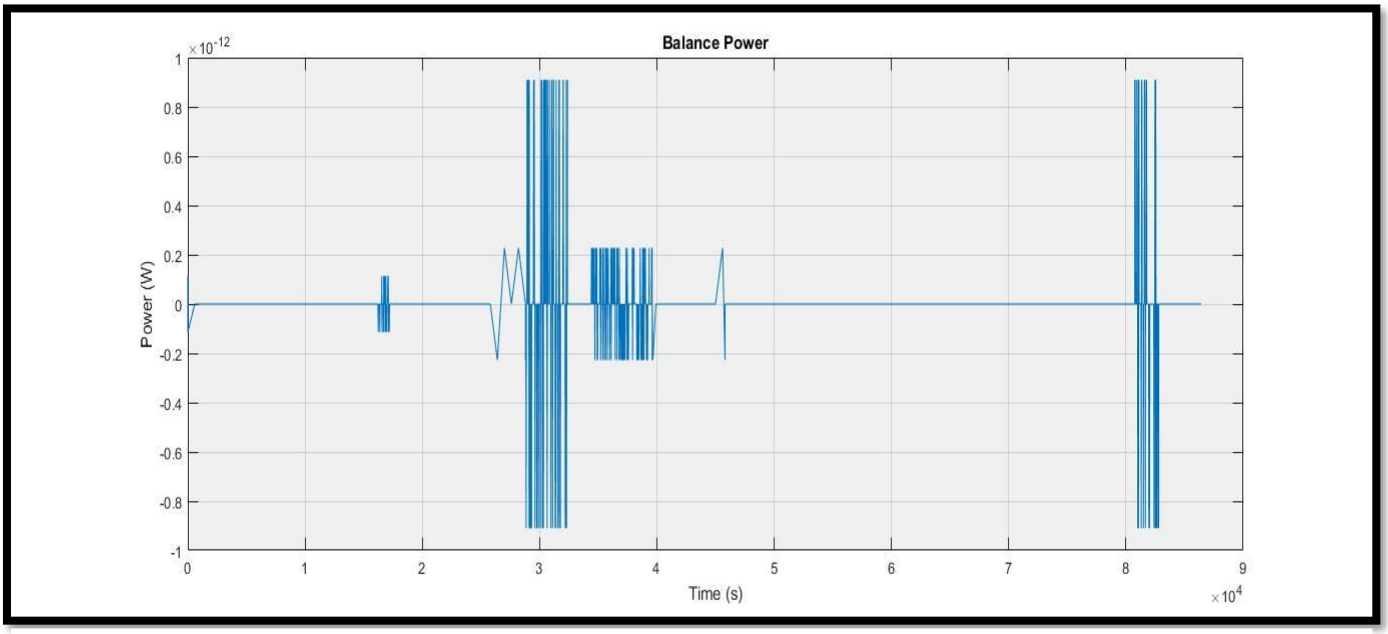


Figure 111. Balance Power 3

6 CONCLUSIONS.

In the last chapter, we have simulated different situation which can be happened with different initial conditions. In the whole of tests, Controller has been able to respond correlty.

In fact, the system can work in Island mode for one day, this we have seen in Test3.

Furthermore, we can conclude that using a simple stategy and control (heuristic rule in our case), we can satisfy our objectives and reach our goals (Satisfy demadand of electrical energy.).

It will be likely interesting that as future projects develop different type of controls for example MPC or fuzzy control and even new strategy of that.

We are going to compare with another type of control.

MPC is interesting because we are woking with multivariable such as power, voltage and current (which we haven't paid attention in this project the whole of them), then we can obtain an optimized system. Then, at future MPC can be used in distribution generation.

However, it is known that MPC has high level of computational cost therefore MPC is slower than HR. I suppose that MPC will have great tolerance because of having computational cost.

Besides, MPC isn't commercial while HR is that.

If we compere FC and HR, FC can work with a large range of systems using a simple model while we have seen that HR begings to complate when we have a lot of systems.

Nevetheless, FC needs to stablish set-point which is necessary to have diferene experiences (it is difficult to know), therefore using FC we may modify statagy of control easer than HR.

We are going to summary and to compare with HR.

	Heuristic rules	**Fuzzy control**	**MPC**
Strenght	• Easy to develop. • Fast. • Comercial. • Simple	• Easy to change of strategy. • Set-points	• Optimized. • Working with multivariable.
Weakness	• Not optimized. • Difficul to change of strategy.	• Set-points (necessary to have experience). • Less commercial. • More optimized	• Very complex. • No commercial. • High computational cost.

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