# ECO-MODEL FOR DC ELECTRICAL SYSTEMS IN STANDALONE BUILDINGS

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**ABSTRACT**
Global contribution from buildings towards energy consumption is becoming a serious and pressing matter in terms of sustainability and world economies. In addition, the continuous population growth influences the demand for building services and comfort levels significantly, ensuring that the trend in energy demand will continue to increase in the future. For this reason, energy efficiency in buildings is a primary objective for energy policy at regional, national and international levels. Standalone buildings using Photovoltaic modules on Direct Current can represent a good solution to stop climate change and a decisive input for the new production models of low carbon electricity. This article presents a model to help on the design of these installations able to keep current levels of comfort without any cutoff or interruption.

Keywords: photovoltaic energy, standalone buildings, DC

## 1. INTRODUCTION
Everything suggests that, far from diminishing, the global consumption of energy will continue to increase in the future years. Only in 2012, the total amount of consumption was around $560 \cdot 10^{18}$ Joules ($2016 \cdot 10^{21}$ Wh) (Blok et al. 2015). This significant increase in energy consumption is directly influenced by several variables such as population growth, increased quality of life, weak awareness about energy saving, extreme temperatures, insufficient energy policies, international energy context, and volatility of fuel prices. The impact of these variables may vary from one region to another in the world, and their evolution over time determines the variation on the degree of growth of energy consumption. (Díaz 2014).
Within this scope, the high amount of energy consumption in buildings represents a worrying matter. There is far too much energy being used whether for heating rooms, production of hot water, cooling, lighting, etc. In fact, 40% of the overall energy consumption in cities occur within residential buildings with only 31% coming from heating and domestic appliances (Blok et al. 2015). This represents an important problem for the distribution networks when balancing the high energy demand: when the amount of energy consumption increases, so does the ecological footprint (Ghita et al. 2016), as well as the unavailability of the conventional energy resources needed to meet the power demand. The main overcome to this problem is being led by the introduction of the renewable sources of energy generation. Out of the amount of renewable sources existent, solar energy is one the most used for powering cars, homes, electric devices, even serving as support for energy generation in some industries.
This work presents the use of solar photovoltaic (PV) energy for supply electricity in systems off grid with the purpose of avoiding the overcharge of the distribution networks and minimize the carbon footprint. According to Eurostat, 27.19% of the total energy produced in the Europe Union (Eurostat 2013) in 2013 had its origin in renewable resources with only 2.4% coming from solar PV. The use of a DC-microgrid (Ingale et al. 2016) benefits in the sense that it can be controlled locally and the energy can be provided to a local grid or can be consumed in a stand-alone manner. Microgrids are very useful during natural disasters since they improve the performance and overall efficiency of both the transmission and distribution networks, and they are also helpful for electrifying faraway towns.
In addition to the high consumption, we have to consider the low efficiency presented in all the current technology deployed worldwide. According to (Blok et al. 2015) we still squander more than 98% of all of the energy we produce through inefficient use and wasteful means of transport and production. It is possible to make a more efficient use of the energy with straightforward changes in the actual model consumption. For instance, (Sanjeev et al. 2015) conclude that this “comparison between AC and DC home shows that even though the cost of DC equipment is high, a significant reduction in losses and power consumption gives more importance to DC grid.”
There are two main models of PV generation, the most known are based on I nstallations connected to the network and the second one is off-grid, but both systems make use of inverters to convert direct current (DC) into alternating current (AC) that is injected into the grid or installation. Note that most home appliances have an AC rectifier to convert the AC obtained from the grid to DC to be used. Therefore, the conversion process DC-AC-DC is redundant. Moreover, the inverter is a high frequency switching device: when turned on, it increases

switching losses and heating dissipation which in turn cause power loses, therefore reducing the efficiency of the photovoltaic system. In addition, this component is one of the most expensive in a PV installation (Encinas et al. 2014)

The model developed in this work presents an enhanced standalone installation (a facility prepared for generating all the energy necessary for keeping on all the home appliances without retrieving energy from the commercial network) where conversion to AC has been eliminated, and include a storage system based on chemical ion-lithium batteries. The main advantages of this alternative are:

- It is **more efficient**, because the inverter generates the greatest losses in the entire photovoltaic system (Aguirre et al. 2014).
- It is **cheaper**, because the inverter is the second most expensive component of the PV installation (Encinas et al. 2014).
- It is **more robust**, because it is supported by batteries and has fewer components that can fail (IRENA-a 2015).

Energy generation from renewable sources is one of the most recognized solutions to stand up against climate change due to its social, environmental, and economic benefits. Any increment in the levels of contribution to global energy generation is a contribution to the sustainability of the planet itself. In this context, we propose the use of a DC model for energy generation and consumption as a way to reduce the impact derived from the use of fossil fuels, copper mining and the overall cost of the installation, increasing energy efficiency in domestic systems.

The main purpose of this investigation is to prove that Eco-Model for DC Electrical Systems in Standalone Buildings (PVDCB) is technically, economically, socially and environmentally has more advantages than the use of photovoltaic systems powered by AC photovoltaic generation for residential current networks in standalone buildings.

## 2. RELATED WORK

There are various models of PV generation and most of them use the inverter in the facility for the reasons given previously. This section presents some projects that have deployed PV systems using DC.

(Williamson et al. 2011) found motivation in the analysis of power losses due to the inefficiencies of the power supply unit (PSU) where significant amounts of the energy supplied are turned into heat. In addition to this, switch-mode power supplies (SMPS) often have a poor power factor and introduce significant harmonic distortions into the grid. Project Edison SMART-DC, introduced some changes in the energy consumption behaviour at the PC room of the University of Bath's Library and Learning Centre (LLC). The existing array of 50 computers was replaced with 50 new DC powered units with a centralized AC/DC converter and an integral energy storage facility. They achieved an important number of benefits with their DC powered network. The output heat was reduced and shifted away from the user to the converter, thus reducing fan noise and air conditioning use while a reduction in energy consumption was achieved as consequence of the use of both efficient components and demand response strategies. The magnitude of the 3rd – 9th current harmonics was also significantly reduced by a factor of approximately 2-4 times, and finally there was an increase in the security of supply to the network due to the use of storage in the system. Test over 18 months shows that the new DC network and its associated PCs consumed about 30% less electrical power than the AC-powered PCs they replaced (Aggarwal et al. 2015). They manage the local DC network so, during times of high energy tariff, they isolated it from the grid, with the batteries powering all 50 PCs and monitors for 8+ hours. Once the energy tariff falls, the rectifier can be switched back on, recharging the batteries, and powering the PCs. As consequence, the benefits and flexibility of the SMART-DC network lends itself ideally to the integration of intermittent renewables especially to the micro-wind turbines and photovoltaic panels (PV). The energy generated by PV is natively DC and through a simple charge controller, the inefficiencies normally associated with converting it to AC are all avoided.

(Pandey et al. 2015) show a cluster of buildings in stand-alone mode, these were a couple of small houses joined together to the DC bus, connected to a community battery bank for avoiding sudden charging/discharging of home cluster battery packs. This distributed grid (DG) is implemented from a hybrid solar and wind renewable energy generators. They studied his facility in two sceneries: one with a fixed wind generation (12 m/s) and variable solar irradiance until it reached 1000 W/m$^2$, and the second scenario studied the stochastic behavior of wind and solar power production to analyze the battery pack viability during over-generation and under-generation conditions. For the effective current sharing, a droop control loop is used and it gives further voltage reference to outer voltage loop control, which suffices the buck and boost mode for charging and discharging. To avoid instability issues of peak current mode control, the slope technique is used. The proposed control compensation technique is able to manage the power balance while extracting the maximum power from the wind and solar DG.

The research DC grid initiative in India (Sanjeev et al. 2015) make a comparison between AC and DC in home. The results of this project show that even though the cost of DC equipment is high a significant reduction in losses and power consumption gives more importance to DC grid. The DC micro grids can save up to 78.65% of energy make than AC grid. They studied two types of DC grids: the first one has a power sharing done by the power vs. voltage droop characteristics (John et al. 2013) and voltage is common control element for all the three homes and actual DC link voltage is always compared with reference for closed loop operation (Kakigano et al.

2010). This type of configuration provides more flexibility in power sharing among the homes and less fluctuations in DC voltage since they are all interconnected. In this case every home is having individual storage and its associated converters, this increases individual expenditure and maintenance cost.
The second type consists of three homes powered by DC that are not interconnected. Every home has a single AC-DC converter that is used to balance individual DC link voltage. Every home has an array of PV panels to meet the demand. When generation is greater than the load then it charges a battery otherwise the battery discharges to meet the demand. If battery is at minimum state of charge (SOC) then the power from the utility (AC grid) is used to compensate the power loss.

## 3. MODEL DESCRIPTION

The PVDCB is the model defined for the hall of residences (SR) belonging to the University of Deusto situated in Bilbao, a region in the north of Spain. The building is composed by 3 towers full of bedrooms with all the necessary services needed to provide comfort to 304 students: Wi-Fi, dining room, reception, laundry room, industrial kitchen, elevators, PC's room, hot water, central heating, medical and psychology attention, etc. during the whole year. The model, is composed of 6 subsystems: 4 of them represent the production and consumption of energy (generation, storage, control, consumption), and the other 2 involve the complementary measurement and protection subsystems. It has been implemented in SimPowerSystems (SPS) (Mathworks 2015), The block diagram in Figure 1 shows the conceptual diagram of the interaction between the different subsystems with the input being solar irradiance and temperature, and the output being the total current and power consumption. The subsystems are classified as follows:

1. **Consumption:** this subsystem simulates the energy consumption of the building.
2. **Generation:** this block is used to model the solar photovoltaic cells disposed for the solar energy harvesting.
3. **Storage:** this subsystem corresponds to the battery bank that acts as energy backup when there is not enough solar irradiation to feed the system.
4. **Control:** this subsystem models the DC-DC converter of the installation.
5. **Protection (complementary):** the purpose of this subsystem is to protect the whole installation against short circuits, voltage fluctuations, etc.
6. **Measuring (complementary):** subsystem which gathers all the instrumentation needed to monitor the system from the process of solar harvesting to the deployment of energy consumption.

### 3.1. Consumption Subsystem

This subsystem simulates the energy consumption of the building by reproducing the load effects to the PVDCB. The load of SR had been simulated as a variable electrical load, as shown in Figure 2.

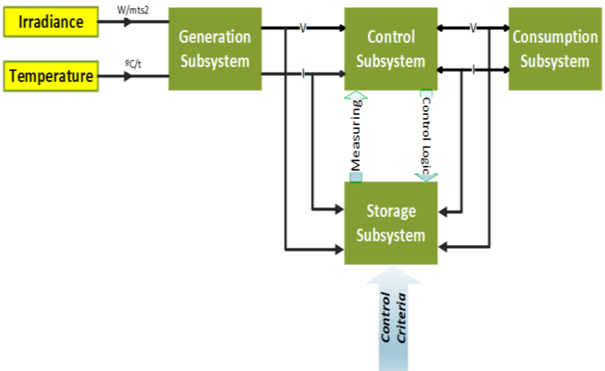


Figure 1. Block diagram of PVDCB.

The consumption data comes from the real reading of the electric meter, taken every 15 minutes for three years (2012, 2013 and 2014). These data have been collected into a spreadsheet and are loaded by the simulator in form of power (W) or energy (Wh). Moreover, this subsystem is fed by the battery bank, by voltage (V) and current (A).

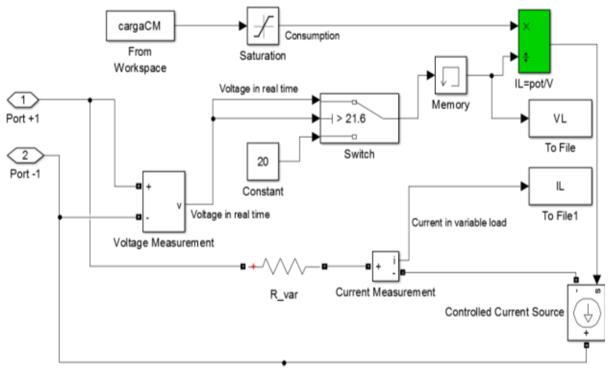


Figure 2. Consumption subsystem (variable load representation of the SR).

Figure 2 shows a diagram of the consumption subsystem. The current is calculated through dividing the power by the voltage ($I = \mathrm{P} \cdot V^{-1}$). According to the Ohm's Law ($I = V \cdot R^{-1}$), the SR is represented by a variable resistance.

### 3.2. Generation Subsystem

This subsystem reproduces the behavior of the solar array modules, which convert sunlight (direct, indirect and/or diffuse) into renewable DC energy. Figure 3 shows the inputs and PV panels that are part of the generation subsystem.
The generation subsystem is fed with real values of irradiance and temperature obtained from the analysis of the energy load of the SR. Figure 4 shows the physical model of the solar cell used.

Out of all the solar panel available, the Top Sun-TS 420TA1 solar panel was chosen for its good performance. Its principal characteristics are presented in Table 1 and the conceptual model is available in the SimPowersystem library.

Table 1. Electrical characteristics of the Top Sun-TS 420TA1 solar panel.

| Model | Monocrystalline 3 busbar [96 cells] |
|---|---|
| | TS-S420 |
| Power Output (Wp) | 420 |
| Max Voltage (V) | 49.70 |
| Max Current (A) | 8.45 |
| Open Circuit Voltage (V) | 60.77 |
| Short Circuit Current (A) | 9.00 |
| Efficiency (%) | 16.38 |
| Tolerance (%) | 0~+3 |

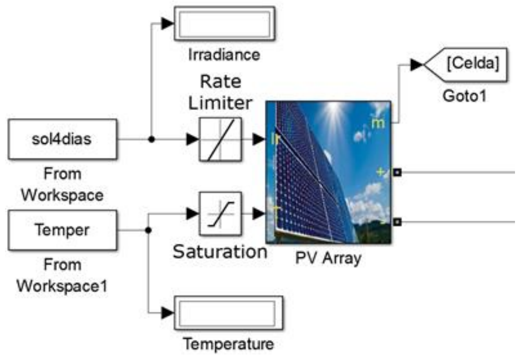

Figure 3. Generation Subsystem of PVDCB.

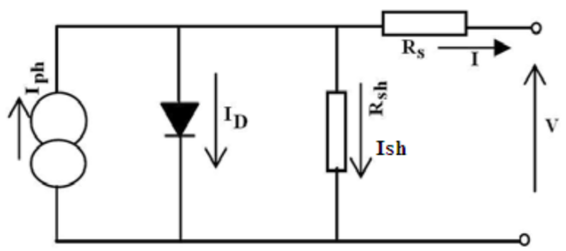

Figure 4. Approximate physical model for the solar cell (approximate).

The Equations 1 and 2 define the characteristics of I-V solar photovoltaic module plate:

$$I = I_{ph} - I_0 \cdot \left[exp^{\left(\frac{V+Rs\cdot I}{Vt\cdot a}\right)} - 1\right] - \frac{V+Rs\cdot I}{Rsh} \quad (1)$$

$$V_T = \frac{k\cdot T}{q} \cdot Ncell \quad (2)$$

where:
$I_{ph}$: photo current
V: open circuit voltage
$V_T$: Thermal voltage from the PV cell
$I_o$: saturation current of the diode
a: idealization factor diode, a number close to 1.0
Rs: series resistance ≈0Ω
Rp: parallel resistor (high value)
k: Boltzmann constant = $1.3806488\cdot10^{-23}$ J/K
q: electron charge = $1.6022\cdot10^{-19}$ C
T: cell temperature (K)
Ncell: number of cells connected in series to a module.

In order to ensure the energy supply for the SR, a review and analysis of the energy demand load was necessary in order to keep the operability of all the systems that constitute the SR. The analysis of the SR data determines the size of generation and storage subsystems based on values like the average consumption and the peak consumption of the facility. Table 2 shows the most important values that summarize the analysis of the energy consumption. Those data are important for the correct sizing of panels and batteries.

Table 2. SR study of behavior in energy consumption.

| Energy average (kWh) | Energy Peak (kWh) | Minimum Consumption (times) | Mode value (kWh) | Median value (kWh) |
|---|---|---|---|---|
| 13.96 | 37.25 | 43 | 9.75 | 11.75 |

The data in Table 2 make possible to define the conditions under which the facility should be prepared to meet energy peaks. Note that the value of the energy peaks is close to three times the average energy consumption. The implantation of PVDCB at SR expects to help decrease significantly the amount of energy consumption due to the fact that DC grids are much more efficient than AC powered buildings. For these reasons, the facility was sized to deliver twice the average energy consumption during the month with the highest consumption (June), and with the worst solar photovoltaic generation month being (December). The average consumption in June is 16.81 kWh, so the security value established is 33.61 kWh. Knowing that the panels are capable of delivering 420 Wh, setting 75 V voltage and 600 A of current. Therefore, we estimated that 2 arrays of 77 panels are needed in order to meet the energy consumption at the SR.

**3.3. Storage Subsystem**

The storage energy subsystem is composed of a set of batteries operating as a complementary energy source to the PVDCB system in order to ensure power supply to the building at night or when the weather conditions affect solar radiation. Batteries are now a standard component in photovoltaic installations, allowing the creation of standalone systems disconnected from the distribution network. Batteries are the only equipment used in this model to disconnect the installation of the commercial power grid, therefore, they are of great interest since they serve as main support and turn as PVDCB backup system (IRENA-b 2015)

The batteries selected for this research are the lithium-iron phosphate (LiFePO4), due to the fact that this type of batteries do not contain toxic elements, have an efficiency of 98%, and are lighter and have less volume than lead acid batteries. Besides that, they can be discharged at least up to 20% of their capacity while reaching a life of over 10,000 cycles. The current big disadvantage is the high initial price (about three times that of a lead battery), however it is decreasing continuously, and soon will be competitive enough to be considered as lead option (Energía Renovable Peru Con Deltavolt 2016). Therefore, we estimated that 2 arrays of 77 panels are needed in order to meet the energy consumption at the SR.

In this stage of the research, PVDCB uses batteries 6V 25 S Model 3 MIL from Australian manufacturer Raylite, specially made for solar applications. This battery is modelled in Simulink/SPS.

Another important point to measure the feasibility of the proposal factor is the size of the installation. In a first step to optimize the storage capacity (Mascarós 2015) was consulted in order to define the amount of batteries needed for the same work without interruption and without solar generation between three to eight days according to consumption of the installation. The Equations 3 and 4 defines the average daily consumption.

$$L_{MD,CC} = \sum\left(P_{CC,i} \cdot t_i\right) \quad (3)$$

Where:

$L_{MD,CC}$: is the average daily energy Wh consumed at the facility, current continues to the rated voltage of 24 V

$P_{CC,i}$: the power DC consumed in W into load

$t_i$: is the time of daily operation of the load in h

$$L_{MD,CC2} = \sum\left(P_{CC2,i} \cdot t_i\right) \quad (4)$$

Where:

$L_{(MD,\ CC2)}$: is the daily average energy Wh consumed at the facility in a different DC voltage at rated

$P_{(CC,\ i)}$: is the power DC consumed in W into load

$t_i$: is the time of daily operation of the load in hours

Note that we give two equations for the determination of the energy consumption for the SR. The first is focused at the rated voltage while the second focused on one different voltage to the rated voltage. At this first stage of the modelization we have used a voltage of 24 V for solar PV.

Usually, storage systems are sized to operate under a minimum of 3 and a maximum of 8 days of autonomy (Aparicio 2010; Mascarós 2015; Sumathi et al. 2015; and Vallina 2010) with a depth of seasonal discharge of 70% for days without solar generation. For this specific model, the autonomy of the system is established for a period of 3 days with its current consumption without compromising any the comforts of the SR. Equation 5 shows the amount of the energy necessary to be storaged.

$$C_D = \frac{L_{MD,Total}}{PD_D \cdot V_N} = \frac{1451.5 kW \cdot h}{0.2 \cdot 24} = 302400 A \cdot h \quad (5)$$

Where:

$L_{MD,Total}$: is the average daily energy given in Wh consumed at the facility, current continues at rated voltage

$P_{DD}$: is the depth of discharge allowed daily

$V_N$: is the nominal battery voltage

The algorithm for designing the size of the storage subsystem takes into account the following aspects to calculate the appropriate configuration:

- Total daily energy to be supplied by the battery without discharge totally equal to 1451.5 kWh on a winter day (January 2, 2012).
- Depth of discharge daily equal to 20%. This level has been arbitrarily set after displaying what would be achieved with the same guarantee the life of the cells at approximately 5000 cycles.
- Depth of discharge seasonal (sunless days) maximum equals to 70%. This discharge is for cases than include the existence of sunless days.
- Short circuit current of the PV panels equal to 9.12 A. This value is given by the manufacturer of the panels PV.
- Number of branches of PV solar cells in parallel equal to 77. This value is the product of the previous step sizing of solar installation.
- Rated voltage cells used is equal to 6V batteries. This value is referred to the tension that handles each battery cell.
- Discharge capacity in C100 hours equals to 900 A. This value is the amount of current that can be extract from the battery in a period of 100 hours of continuous use.

In the case of a day with an energy consumption of 1451.5 kWh, as on January 2, 2012, the model implemented is shown in Figure 5, and results are as follows:

- Minimum Nominal Capacity (Ah): 302395.83
- Maximum Rated Capacity of the batteries (Ah): 17556
- Number of cells connected in series 6V: 4
- Number of parallel battery branches: 335.99
- DOD Allowable (%): 70%

For the success of this research, we need to analyze the optimal sizing of energy storage system so that the proposal of the present model can be economically viable. This could help to power small villages in developing countries because the process of energy harvesting is similar in worldwide. Any country could even receive economic benefits by pouring the excess of energy power into the grid in the energy market. This action can improve the power generation through the form of decentralization of energy generation.

### 3.4. Charge/Discharge Control Subsystem

Usually, a set of DC-DC buck converters are included in order to keep the panels operating at their point of maximum power (MPP) and to maintain the charging voltage of the batteries at optimum levels. This subsystem could recover between 10-30% of the energy losses of photovoltaic solar installations per year (Ghaffari et al. 2012). At the current level of development of this model, the converter is able to keep steady output of 24 V, so that it can be used either in the battery charging and/or to supply the SR (Figure 6).

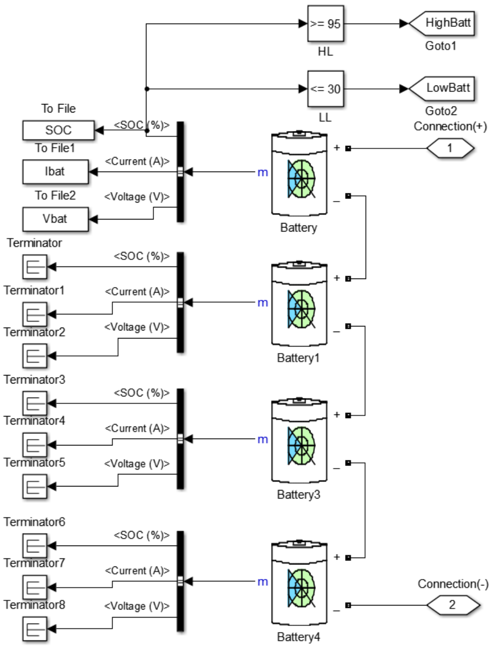


Figure 5. The association of the energy storage system conformed by 4 batteries of 6 V cells.

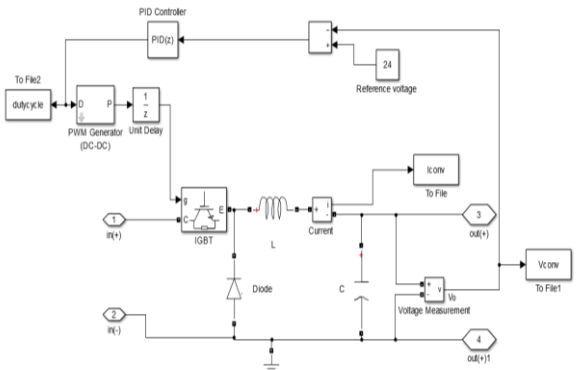


Figure 6. Buck converter SimPowerSystems diagram.

The 24V buck converter is managed by an IGBT an electronic solid state switch that is able to handle high levels of currents and high speed voltages.

The data used to design and implement the buck converter are as follows:

- The input voltage to the buck converter is the output received by the solar panels, which in turn becomes the system input.
- Rated output voltage equal to 24 V is the value to keep for battery charging.
- Load resistance is of 0.015 Ohm. The maximum value for the RL is obtained with the maximum consumption of current according to the
- This value is the minimum taking relationship $P = V^2 \cdot R^{-1} = R = V^2 \cdot P^{-1}$ at the time when the power consumed at SR takes its maximum value.
- Ripple maximum level is 5% (this level was arbitrarily set based on experience)
- Switching frequency equal to 10000 Hz, (this frequency is half the optimum frequency for this system but it was decided to reduce some simulation time).

After entering the above data at MATLAB script the following results were obtained:

- The duty cycle is: 0.21
- The inductor L is: $0.73 \cdot 10^{-6}$ H
- The capacitor "C" of the converter is: $26.667 \cdot 10^{-3}$ F

The value of the variable load is obtained at the time at which the SR reaches its peak consumption 37.25 kWh. The fixed input voltage of 110V, comes from the associated solar panels because, according to the manufacturer of the modules, the maximum output voltage of each one is 49.7 V, so output of two associated panels is 99.4 V. The voltage measured during the simulation was close to 110 V, because the plates were well irradiated.

The duty cycle is given by the PWM block which in turn receives the value of PI controller fed by the error with a set point of 24 V. A PI controller has been adjusted experimentally (P=0.15, I=0.5).

### 3.5. Protection Subsystem

This subsystem looks after the correct operation of the PVDCB and thus avoid deep discharge, overload, reverse currents and inverse voltages, that make unsteady the functioning of the PVDCB. It is noteworthy that, unlike the previous four subsystems, this and the monitoring subsystem are not located in a single place at the model, but are scattered throughout the whole facility.

Figure 7 shows the two elements of the protection subsystem. One is the voltage stabilization capacitor that works as a memory that stores the output voltage from the PV panels. This is required to maintain a steady input voltage to the DC-DC buck converter at all times and avoid sudden voltage fluctuations, thus minimizing the presence of noise at the input of the DC-DC converter than could create a miscalculation of the duty cycle.

A semiconductor power diode is placed exactly between the capacitor and the buck to prevent reverse currents toward the array of solar panels that could generate short circuit currents. In order to choose the correct diode, it is necessary to take into account the maximum current that will flow from the panels, and choose a power diode

capable of supporting at least the double of the value of current in reverse and the reverse peak voltage that could appear into the terminals from buck converter.
The subsystem has been designed to limit batteries discharges up to 20% daily, only if process of solar photovoltaic harvest does not occur. In addition, the subsystem is prepared to supply energy during 72 continuous hours, and in those cases, the storage subsystem could be discharged more that 20%. The facility is sized to allow discharges up to 70% of the energy stored in the batteries. Note that this condition should not be very recurrent because it can generate unexpected power outages, making necessary to make an appropriate sizing of the system of accumulation. In addition, Also a protection logic for the high or low level of the batteries has been designed. If the batteries reach 30% of its DOD, the low-level logic comparison block (LowBatt) issues a "true" value equivalent to a logic 1. That value is then transferred to the FROM LowBatt block. A value of 1 closes the switch, which means that current stops its flow.

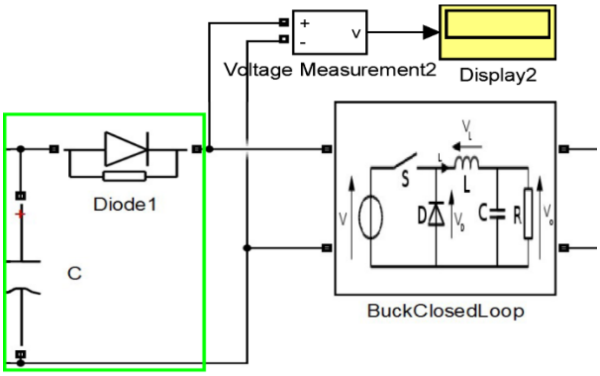


Figure 7. Components of protection subsystem.

### 3.6. Measurement subsystem

This subsystem comprises all the instruments that collect information regarding the behavior of the PVDCB and that make possible the management and monitoring of all the signals generated by the system. Some of these signals, recorded and saved in SimPowerSystems blocks “To File”, refer to inputs for the model, but the majority relate to data necessary to analyze the performance of the PVDCB and propose improvements.

## 4. COMPONENTS AND DATA FOR SIMULATION

Currently, the environment and simulation time is fixed. As mentioned in Section 3, the facility used for study is the hall of residence of the University of Deusto, mainly because of the possibility to access historical data related to the energy consumption of the building. The simulation time was set to 48 hours due to the computational time required to execute a simulation. The software used was Matlab/Simulink 2015b, specifically the SimPowerSystem library. The PC used was a DELL laptop Inspiron 5559, with Intel Core i5-6200U processor, 2.3 GHz, 8GB of RAM, running on 64 bits Windows 10 operating system.

The efficiency of the solar panel is mainly affected by two variables (assuming that the orientation of the panels is optimal and that shading over does not exist). In order to build a realistic model, we used the actual temperature and irradiance values referring to the coordinates of the SR: Bilbao latitude 43.3º North, longitude 2.9º West, and height 24 meters. These values were obtained by the collaboration of the European Commision through its Photovoltaic Geographical Information System PVGIS (“PV Potential Estimation Utility” 2015). The simulation data from a repository of official meteorological data from the European Union (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php) are used, as is the Geographic Information System with Photovoltaics. Thus it is possible to emulate the process of measuring and recording data of a real solar system.
The energy consumption data was directly obtained from the energy manager at the SR. The data comprises three years of data consumption and helps emulate the behavior between the energy generation at the coordinates indicated above and he consumption in the building studied every day for the different seasons of the year.

## 5. RESULTS AND DISCUSSION

As preliminary results, the evolution of several parameters from a 48 hours simulation are presented. Figure 8 shows the DC current demanded by the load based on energy real data consumption. It shows that current peaks are close to 1000 A, but, in average, the current consumption is lower in the morning hours and bigger in evening hours.

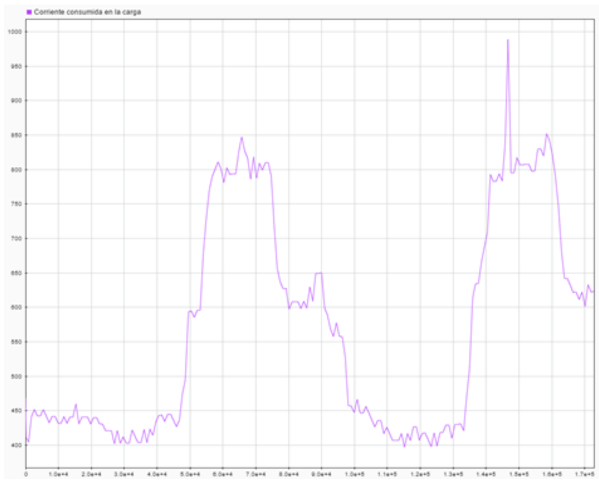

Figure 8. DC current consumption SR during 48 hours.

Figure 9 shows the output voltage of the energy storage system. Its behavior is the expected: an inverse voltage peak is produced at the same time than occurs the biggest current consumption, but in average the voltage is kept into the output expected value.

Figure 10 shows all outputs measured in the photovoltaic modules during 12 hours, this is the order:

1. The power caught from solar irradiance

2. The current I_PV
3. The irradiance peak at this day
4. The output voltage of the modules
5. The output current than flow across the panel diode
6. The maximum value of temperature for the day simulated

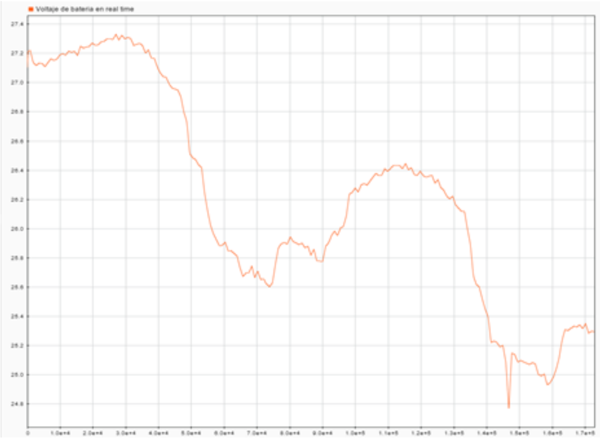

Figure 9. Performance of DC voltage SR for 48 hours.

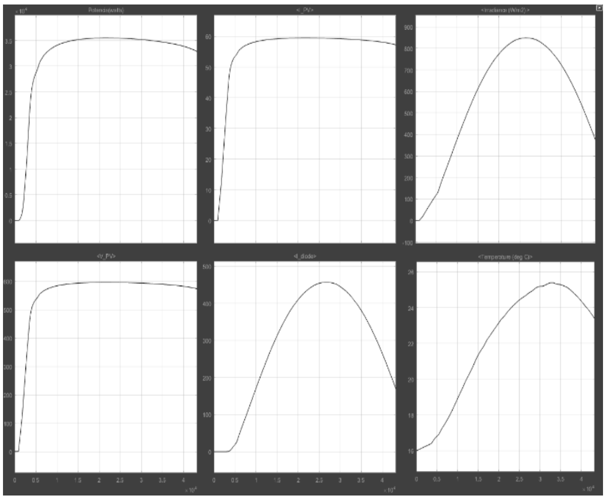

Figure 10. Oscilloscope screens.

The behavior of one of the batteries is represented in Figure 11. As the simulation is carried out without solar energy supply, charge level decreases continuously. Charge level goes to 65% and voltage, from its maximum value, 7 V, goes to 6.6 V.

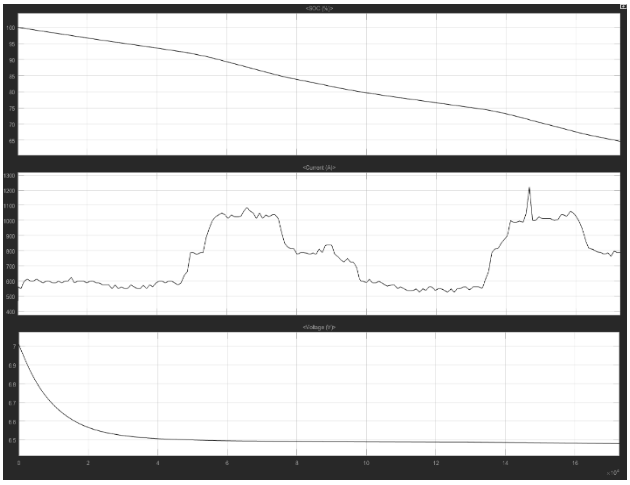

Figure 11. Battery behavior after 48 hours.

The behavior of the converter buck DC-DC is shown in Figure 12. It shows that the system is working into the desired values of control, avoiding too high fluctuations in DC output voltage.

After the several simulations preliminaries of the SR buildings, we can observe that a distributed generation is a feasible way to overcome the climate change, because it is technically viable, and the graphs shows that it is possible support power systems as kitchen, elevator, heat commodities, etc. This is very interesting because the DC energy is being used in applications that does not demand too much power for the system.

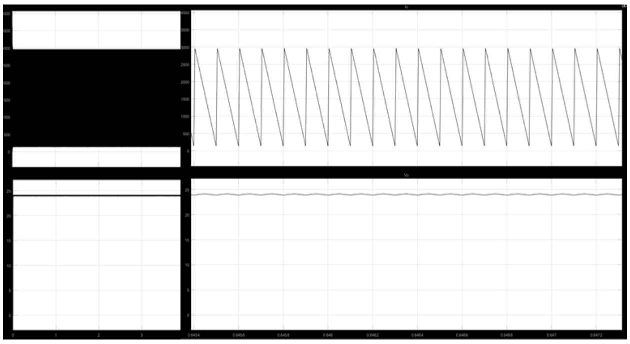

Figure 12. Output for the buck of the subsystem of control.

## 6. CONCLUSIONS AND FUTURE WORK

The model presented in this paper is a first approximation of a real future DC installation which intends to show that the use of a distributed generation system is a feasible option for the generation of energy from renewable resources. The system modelled is strong enough to meet the energy demand of a service building such as a student’s residence. The greatest contribution of this work is the development of a comprehensive DC model for a standalone building based on real data consumption and photovoltaic solar energy generation, using the MATLAB and Simulink libraries. So far, in the state of the art, there is a great amount of research directed towards developing models for energy generation and supply in microgrids powered by AC. Currently, there are applications that use DC power such as street lighting, intelligent traffic lights or telecommunication antennas. However, there is no model generation and supply DC developed to maintain security systems and comfort of standalone buildings exclusively with DC electricity, since all the models developed to date make use of the DC-AC conversion to power domestic installations.

The future developments considered as a follow up of the work presented in this paper are detailed as follows:

- **Design of an intelligent control** to balance and manage the charge and discharge of the batteries that give support to the standalone PV installation. Batteries experience a wide range of operational conditions in PV applications, including varying rates of charge and discharge, frequency and depth of discharges, temperature fluctuations, and the methods and limits of charge regulation. These variables make it very difficult to accurately predict battery performance and lifetime in PV systems.
- **Design of a control of Maximum Power Point Tracker (MPPT)** for keep photovoltaic modules operating at its optimal level. The MPPT algorithm is a method for maintaining the modules at its maximum power point. Currently, is the only method available for extracting the maximum energy possible and, in consequence, avoid losing efficiency in the solar panel.
- **Develop of a sizing optimization model** in order to make economical, technician, and environmentally feasible this purpose.

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