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Considerations for the Design and Implementation of Microgrids

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***Abstract*— The need of new generation systems have motivated the development of microgrids. This new concept may bring significant benefits to the transmission and distribution networks as losses reduction, high degree of efficiency and reliability. This paper presents generalities about microgrids, including general structure and different topologies; also it is proposed an original methodology for facilitating its design and evaluation. Finally, it's analyzed the microgrid located at the Parque Tecnológíco de Guatiguará at the Universidad Industrial de Santander, included an operation analysis for different operations stages of loads and generation, the performance of operation of storage systems, the interaction with the grid and an energy balance for all the system.**

***Index Terms* — Energy design, Energy implementation, Energy simulation, Microgrids, PV Wind system.**

I. Introduction

The industry of electric energy generation it is headed towards reducing its dependence on fossil fuels, through the integration of technologies that are more friendly to the environment.

This is due in part to the integration of distributed systems based on renewable energy sources. This strategy seeks to address new requirements of generation, operation and energy supply, provoking the modification of the current structure of the transmission and distribution system, to migrate it from a centralized to a decentralized structure [1].

A particular case of these systems are the smart electrical microgrids, where a consumer with in situ generation can also act as a small-scale generator due to bidirectional power flow.

The microgrids are characterized by a scheme of electric energy supply based on multiple sources of energy, known as hybrid generation.

The selection of energy generation systems depends on geographical and climatic conditions, availability of conventional energy sources at the site, as well as the overall financial characteristics of the project.

Its operation is based on energy supply management from monitoring the demand and generation, which allows: to mitigate the impact on the environment by prioritizing renewable generation over conventional generation, to reduce the energy consumption peaks of the grid by making use of local generation, and to increase the reliability of energy supply to avoid the effect of interruptions in transmission grids [2], among others.

For the design of an electric microgrid, information about the demand to be supply and the energy potential for in situ generation is required; then, the system configuration is set, from which the dimensioning of the components and electrical installations is made, and finally, the energy and financial analysis can be done.

Unfortunately, the development of the steps mentioned above can be confusing, since there is not a sequential approach that takes into account in detail various guidelines for the proper design of a microgrid.

For this reason, the aim of this work is to meet the manifest need; to achieve this, it begins with the mention of generalities and types of micro-grids. Next, the proposed design methodology and additional technical considerations are presented. Based on this, it proceeds to show the operation of a micro-grid to be located in university facilities, in order to facilitate the understanding of the micro-grid operation, for which we considered various generation and load scenarios. Finally, the conclusions of the work are presented.

II. General Structure of a Micro-grid

A microgrid is defined as a system consisting of generation sources, focuses on the use of renewable energies in the majority, storage equipment, and electrically connected loads, to meet a determined energy demand. It can operate connected to the main grid in medium voltage or low voltage, or isolated from the same [2], [3].

Energy sources in a microgrid can be renewable (e.g. photovoltaic, wind, thermal and geothermal generation, biomass, tidal and cogeneration, etc.), conventional in situ (e.g. diesel thermal plants) or the electric grid [4].

Fig. 1 shows the general structure of a microgrid, formed by different energy generation systems (conventional and unconventional), energy storage system, and power management units (e.g. converter, grid-tied inverter, pure inverter, regulator [5]) for the system operation and the possible connection to the grid.

The most advanced microgrids have a power management strategy (PMS) and an energy management strategy (EMS) [6], which are described in the information flow diagram of Fig. 2.

These management functions require a communication

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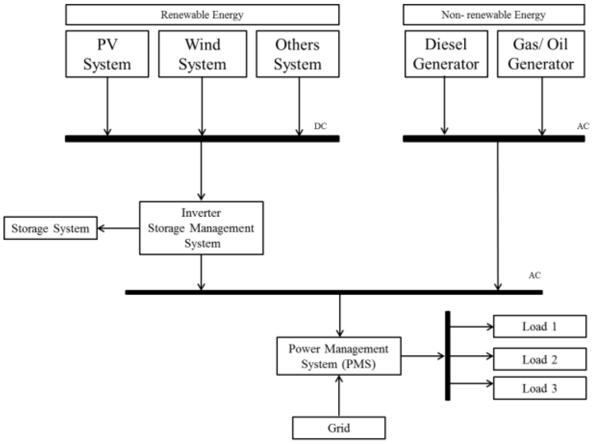


Fig. 1. General structure of a micro-grid.

infrastructure consisting of smart metering equipment [3], [7], to determine in real time the load, prioritize the renewable generation, calculate the power flow, do connections to the grid, operate conventional generators; in addition, to store energy and use it according to the criteria of operation.

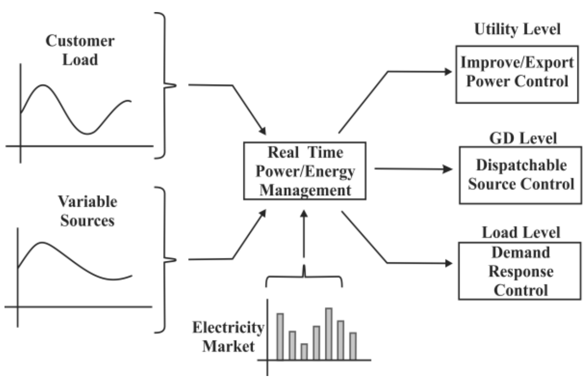


Fig. 2. Information flow and functions of a real time PMS/EMS for a micro-grid [6].

III. Micro-grids Topologies

Microgrids can be designed according to criteria such as connection with the grid, support, relations with types and number of energy sources, and according to load; all this determinate by the needs to be satisfied. The most common configurations are shown in Table I. The following are the first two classes.

TABLE I
MICROGRIDS CONFIGURATIONS

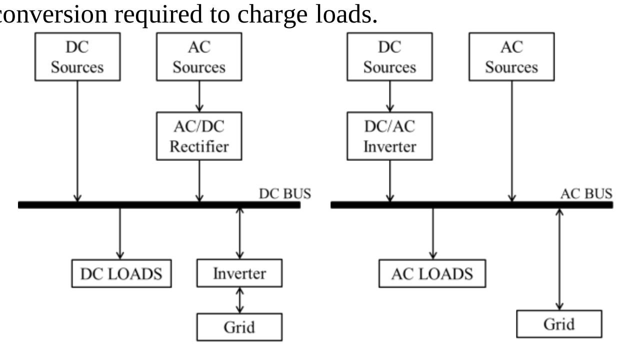
Criteria	Configurations
Bus	CC bus CA bus Mixed bus
Interaction with the grid	Remote Complement Support
Back-up energy system	Grid Emergency Plant Batteries
Types of energy sources	Renewables Conventional Hybrid
Numbers of energy sources	Individual Hybrid Generation
Types of Loads	DC Loads AC Loads

AC and DC loads

A. *According to the type of bus*

The microgrids can be classified according to the type of bus through which the energy exchange happens: direct current (DC), alternating current (AC) or mixed [2], which depends on the load.

Fig. 3.a) shows the basic structure of a micro-grid with AC source and that requires a rectifier to supply power. Similarly, Fig. 3b) shows a micro-grid with DC load that requires and inverter to charge the AC loads. Both types of microgrids can be connected to the grid, taking into account the signal conversion required to charge loads.



a) Basic structure of a DC bus b) Basic structure of an AC bus

Fig. 3. Microgrid topology by bus kind.

B. *According to the level of interaction with the grid*

The interaction of a microgrid with the main grid and the loads allows classifying micro-grids into three types: remote microgrids, that are those that are located in distant areas where it is too expensive to make the interconnection to the main grid; complementary microgrids, that are those that are used to meet a given load; and support micro-grids, that are also connected, although they generate a considerable percentage of energy. Its installation is ideal in areas with limited availability of fossil fuels [8].

IV. Methodology for the Design of Micro-grids

The design of a microgrid is complex due to factors related to the generation, the system configuration, the dimensioning and components selection, and the analysis of the operation.

Most of the guidelines required for the design of a microgrid are scattered; while the dispositions about electrical installations are found in codes, standards and/or regulations of general application [9], [10].

Therefore, it was considered necessary to establish a sequential approach as a tool for the assisted design of micro-grids, which explains the most important considerations.

This methodology consists of five phases and it is based on the design experience of three micro-grids to be implemented in the Universidad Industrial de Santander, based on research carried out by Osma [9] and Rey and Vergara [10].

A. *Energy Potential*

A micro-grid can incorporate both renewable energy sources (e.g. photovoltaic, wind) and conventional sources (e.g. diesel fuel, gasoline), and also, have support from electric and natural gas networks.

1) Solar Potential

The historical global solar radiation must be quantified; either by consulting solar maps or by monitoring in the site.

These data allow analyzing typical and extreme conditions of operation of photovoltaic panels as well as the potential benefit of solar static or dynamic tracking.

2) Wind Potential

It must be set from monitoring the speed and direction of the wind, is expressed from the wind rose and a histogram of the frequency of the wind speed.

Data analysis allows establishing the energy potential per square meter and the utility that this resource could offer, either for energy generation or natural ventilation.

3) Availability of other energy sources

The access to biomass, natural gas, diesel fuel and gasoline, among others must be studied. It is important to note that these sources involve thermal processes and consequently generating greenhouse gases.

B. Generalities of the microgrid

In this phase, the dimensioning of the system based on the study of energy demand, the configuration of the micro-grid required and the design restrictions is made.

1) Energy Needs

The quantification of the demand is made based on load monitoring and the desired technical characteristics of the microgrid (e.g. autonomy and reliability).

2) Microgrid Configuration

The configuration is defined primarily according to energy needs and energy sources available on site.

3) Design Restrictions

The maximum installed capacity (*ICMax*) of each generation systems can be restricted according to the energy demand on site, the initial investment and the area.

$$ICMax = Min(ICD, ICII, ICA) \quad (1)$$

Based on the energy needs, the installed capacity for energy demand (*ICD*) for generation systems is established.

The installed capacity according to the initial investment (*ICII*) is calculated based on the value per Watt installed. Table II presents as an example the cost associated in Colombia for three types of systems.

TABLE II

RESTRICTION BY AREA AND INITIAL INVESTMENT

System	Device to use
PV	From 7.0 to 10.0 dollars per Watt installed
Wind	From 5.0 to 8.0 dollars per Watt installed
Cogeneration	From 2.0 to 4.0 dollars per Watt installed

Regarding the boundary area of the project, an analysis should be undertaken by generation system; for example, according to [9] the maximum installed capacity due to the area available (*ICA*) for a photovoltaic system, it can be expressed from (2) where A is the area in square meters.

$$CIA_{PV} = 140 \cdot A \quad [W] \quad (2)$$

4) Dimensioning of the system

Next step, is to proceed to do the dimensioning of generation systems, such is shown in [9], [10], thereby establishing a block diagram of the micro-grid to associate the electrical characteristics (power, voltage and current) of each component and system flow. For batteries additionally takes into account the desired autonomy time.

Finally, the normal operating values of each component are related in the block diagram, in order to provide the necessary information for the selection of the equipment to be used.

C. Equipment Selection

Below are technical considerations for equipment selection. The financial factor can also be included in the analysis.

1) Generation Components

Photovoltaic panels should be selected according to the operating voltage level settings; they will be type on-grid for a grid-tied system or off-grid type for the case or stand-alone.

If there is not area restriction, it must look for photovoltaic panels whose price per installed Watt is less than USD 2.5/W, for panels with efficiency close to 14%. The panels are responsible for 60% of the cost of a generation system.

The selection of turbines should be based on an analysis of the power generated by the power curve and wind resource; in addition, the noise level of the units should be considered.

The wind turbines of micro-generation (<3 kW) available on the market are equipped with power conditioning stage, so it only requires a connection to a bus (24 Vdc or 48 Vdc).

In the case of small-scale cogeneration, it is known that Capstone units are the best choice.

2) Conditioning and Management Units

These units allow the successful use of the energy generated, the voltage level adjustment, the interaction with other units and with the load. Its selection must be done according to the configuration of the microgrid and power generation sources.

The description of some units is made in Table III. Detailed information can be found in [9], [10].

TABLE III.

CONDITIONING UNITS ACCORDING TO THE TYPE OF SYSTEM

Unit	Function
Inverter	**Grid-tied.** Synchronize and inject energy to the grid. **Off-grid.** Supply AC power with pure sinusoidal signal. Optimize the photovoltaic panels generation.
Regulator or charge controller	Manage photovoltaic panels, battery and load or converter operation. Optimize the photovoltaic panels generation.
DC/DC Converter	Perform the reduction or elevation of DC voltage.
Flexpower One Flexpower Two	Allows load supply by three sources: photovoltaic panels, batteries and support system (electrical grid or alternate generator). Inject the surplus energy to the main grid.
NPS 1000	Allows load supply by three sources: photovoltaic panels, batteries and main grid. Requires of an external regulator.
STATYS-100	The Static Transfer System guarantees the uninterrupted supply to the load from the management of the distributed energy sources and the grid.

3) Energy Storage (batteries)

The storage system configuration depends on the nominal system voltage (V_{syst}), of the battery voltage and the nominal operating current required.

The capacity of the battery bank (C_{bb}) is set with the higher value of two requirements: maximum load current (CB_{charge})

and maximum discharge current ($CB_{discharge}$).

Because the charging process must be done at a rate no greater than 20% of the nominal battery capacity, CB_{charge} can be calculated according to [9] as expressed in (3).

$$CB_{charge} > \frac{Maximum\ Generating\ Power}{0{,}2 \cdot V_{syst}} \quad (3)$$

Nominal discharge capacity is determined according to [9] from (4), and considers compensation for quick discharge (CQD), the depth of discharge (DD) and the efficiency (η).

$$CB_{discharge} = \frac{Maximum\ Power\ Requiered}{V_{syst} \cdot DD \cdot \eta \cdot CQD} \quad (4)$$

4) Monitoring and communication components

These components are intended to facilitate the tracking and control of the operation of the system; also to provide sufficient data for its analysis. Some units have these functions integrated, which reduces the required infrastructure. It is recommended that information be provided in an open format.

D. Electrical and complementary installations

This phase includes the dimensioning of conductors, ducts, protection and grounding system.

1) Conductors, ducts and protections

In Colombia, it should be applied what is indicated in NTC 2050, particularly sections 220 and 310. For DC areas of the microgrid can be used the indications of Section 690.

The use of flexible cable is recommended when mobile parts exist such as photovoltaic trackers, in order to withstand the mechanical stress (see section 400 of the NTC-2050).

A microgrid must have different types of protection to safeguard the lives of individuals and the integrity of its components, like overvoltage, overcurrent, inverse current flux, disconnecting means, etc.

2) Grounding system and panels

The grounding system should be in accordance to NTC-2050 (section 250 and subsection 690-E). System panels must comply with the discussion in sections 370, 373 and 384 and Article 110-16 of the NTC-2050.

3) Graphic Representation

Consists of block diagrams of the microgrid aims to describe the system components and the technical characteristics. Additionally, involves the making of plant electrical drawings, details and line diagrams.

E. System Behaviour

The system behavior can be described from the energy and financial analysis.

1) Energy Analysis

The energy analysis refers to know what, how, where, and how much is consumed. The quantification must be made from the modeling of the microgrid as a system based on a graph, described in blocks (components) interrelated [9].

The modeling can be exhaustive, when the mathematical formulation is based on the detailed operation of each component, or simplified if only is considered the efficiency.

Subsequently, with monitoring data of operation, the energy analysis can be made directly.

2) Financial Analysis

In case of interest on the financial goodness of the micro-grid, it can be analyzed as an investment project, for which it is required the projection of cash flow during its lifetime and the determination of indicators such as net present value (NPV) and internal rate of return (IRR).

V. Complementary Technical Considerations

To establish a system with a more technical level, it is necessary to address the following issues.

A. Solar Tracking

Solar trackers are devices that serve to increase the generation of a photovoltaic system allowing a better uptake of solar radiation to the same area [11]. They can be static or dynamic [12–14].

Static tracking is maximized when the inclination is close to the latitude and the orientation opposite to the direction of this. For Colombia, this increment is less than 2% due to its proximity to the Ecuador [9]. With respect to the dynamic cases, the increment for Colombia is between 20% and 30%.

B. Temperature effect on PV generation

The operation of the panels in a tropical area is significantly different to the nominal conditions, due to increasing operating temperature of the semiconductor material [9]. This makes the generation decreases about 15%; for that is adjust the values of operation and sizing of the system.

The effect of temperature on the generation of a specific PV panel can be analyzed as stated in [9], [10].

C. Limitations of the DC current supply

The microgrids with DC loads involves a higher level of efficiency due to the omission of the inversion and rectification processes; but the inflexibility in the voltage ranges of some devices and the lower performance of these compared to their AC counterparts, do that for the moment, their use does not represents minor energy losses [9].

D. Wind potential for low wind speeds

It's recommended to avoid the use of micro wind turbines when the wind potential is less than 40 kWh/m^2 per year (wind speed is below 2 m/s), since most wind turbines do not operate in such conditions [9].

VI. Considerations For Micro-grid's Operation

In order to describe the possible energy behavior of a microgrid, an analysis is done to the case of the microgrid of the Energy Integration Laboratory (EIL) located on the PTG [10] in Piedecuesta, Santander. The general structure of this micro-grid can be seen in Fig. 4.

This experimental micro-grid aims to the appropriation of technology and the study of operation scenarios to support teacher training and future research.

As part of the initial considerations, the assumptions

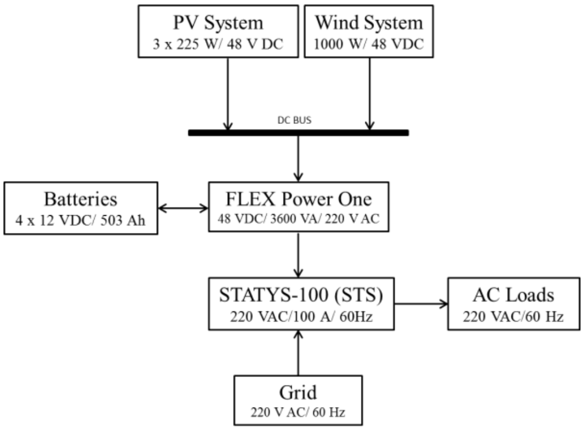
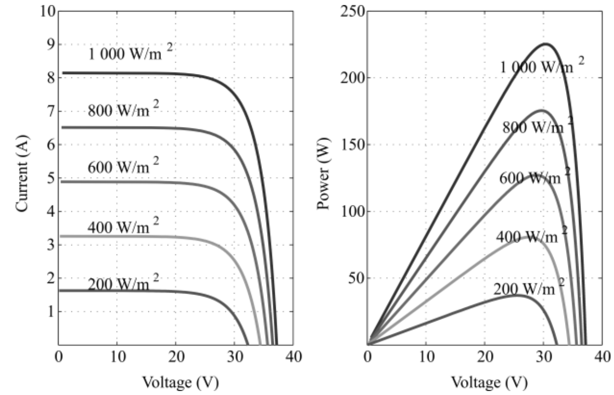


Fig. 4. Structure and nominal values of a PTG micro-grid



(a) Current (A) vs Voltage (V) (a) Power (W) vs Voltage (V)
Fig. 5. Characteristic operations curves for the 225 W panel.

presented by [15] are taken, in order to establish its performance in real time, using MATLAB®. For this, is considered that generating systems work optimally (e.g. MPP mode), the losses in electric networks are negligible, and the controller, inverter and STS operate without generating disturbances signal.

A. Behavior of the solar radiation and wind

The weather station installed has allowed concluding that the average daily solar radiation in the PTG is 4.27 kWh/m^2. It is observed that the average peak value is equal to 678 W/m^2 and the maximum peak value is 994 W/m^2.

On the another hand, is observed that the wind potential is low, since almost 60% of the time the speed is between 0 and 1 m/s. While only 20% of the time the speed exceeds 3 m/s, values that have greater potential for power generation.

B. Photovoltaic Array and MPPT Regulator Model

The PV panel model considers radiation and temperature as input to establish the values of voltage and current. In Fig. 5 can be seem the characteristic curve of the selected panel for different values of radiation. The maximum power value is obtained for a radiation of 1 000 W/m^2 at 25 °C (SCT conditions).

The maximum operating condition for a panel of solar radiation and ambient temperature given is calculated from (5), depending on the maximum power voltage V_m given by (6) and the maximum power current I_m given by (7) [16].

$$P_m = V_m I_m \tag{5}$$

$$V_m = V_T \cdot N_S \cdot ln\left(1 + \frac{I_{SC} - I_m}{I_{SC}}\left(e^{\frac{VOC}{VT \cdot N_S}} - 1\right)\right) - I_m \cdot R_S \tag{6}$$

$$I_m = I_{mpr}\frac{G}{1000}\left(1 + \propto_{mp} \cdot (T_{cell} - T_r)\right) \tag{7}$$

As the photovoltaic system of the micro-grid consists of three panels in parallel, the output power is three times the value of P_m, given by (8).

$$P_{array} = 3P_m \tag{8}$$

Table IV summarizes the values used for the simulation of the photovoltaic system.

TABLE IV.
SIMULATION PARAMETERS FOR THE PV SYSTEM

V_T	Thermal Voltage	*	(V)
N_S	Number of cell per panel	60	-
V_{OC}	Open circuit voltage	37.3	(V)
I_{SC}	Short circuit voltage	8.13	(A)
R_S	Series resistance of a cell	*	(Ω)
I_{mpr}	Current at SCT conditions	7.59	(A)
G	Insolation	**	(W/m^2)
$\propto_{mp}$	Thermal Coefficient at maximum output current	*	(1/°C)
T_r	Reference temperature	*	(°C).
T_{cell}	Cell temperature	*	(°C).
$NOCT$	Cell temperature at SCT	47	(°C).
T_a	Temperature	**	(°C).

* Calculated by the model given by [17] using G and T_a as an input data.
**Input data, measured in the PTG.

To ensure the operation of the photovoltaic system under maximum power is connected a MPPT regulator [17]. The output power of the regulator P_R is given by (9):

$$P_R = P_{in}\eta_{MPPT} \tag{9}$$

Where, P_{in} corresponds to the power of the array (W), and η_{MPPT} corresponds to the efficiency of equipment, specified by the manufacturer at 99%. It is important to note that this is valid as long as the input voltage of the array is within the operating voltage range of the regulator.

C. Wind Turbine Model

The wind turbine model considers as input data the instantaneous wind speed [7]. Therefore, the power output of the wind turbine P_{WT} is given by (10):

$$P_{WT} = \begin{cases} 0 & v < v_{ci} \text{ or } v \geq v_{co} \\ P_N \dfrac{v^3 - v_{ci}^3}{v_N^3 - v_{ci}^3} & v_{ci} \leq v < v_n \\ P_N & \leq v < v_{co} \end{cases} \tag{10}$$

Where υ is the wind speed (m/s), v_{ci} is the initial speed (m/s) equal to 0.5 m/s, v_{co} is the cutting speed (m/s) equal to 5 m/s, v_N corresponds to the nominal speed (m/s) equal to 2.5 m/s, P_N is the nominal power of the equipment (W) equal to 1000 W, according to the manufacturer's data.

D. Inverter Model

Under the assumptions made for the simulation, the output power of the inverter P_{INV} is modeled according to [15] as shown in (11), based on the input power P_{in} and the efficiency η in function of the normalized input power or operating point where P_N is the nominal power of the equipment, which corresponds to 3.6 kW.

$$P_{INV} = P_{in}\eta\left(\frac{P_{in}}{P_N}\right) \tag{11}$$

E. Battery Model

To describe the process of charging and discharging of the batteries the model presented in [18] and [19] is considered, which is set in the expressions of the load (12), the nominal current (13), the load in a case given (14) and the state of charge (15).

$$Q = I\Delta t \tag{12}$$

$$I_N = \frac{C_N}{t_N} \tag{13}$$

$$C = \frac{1.67C_N}{1 + 0.67\left(\frac{|I(t)|}{I_N}\right)^{0.9}} \cdot (1 + 0.005\Delta T) \tag{14}$$

$$SOC = \frac{Q}{C} \tag{15}$$

Where Q is the quantity of battery charge (A-h), I is the current of the battery (A), Δt is the time in which the battery acquires the charge (h), I_N is the nominal current (A), C_N is the nominal storage capacity (A-h), t_N is the nominal regime of charge and discharge of the battery (h) , ΔT is the accumulator heating (presumably identical for all elements) in comparison with the ambient temperature (^{o}C) and SOC is the state of charge.

Three states are considered: charging, saturation and discharging, from the ranges described in Table V.

TABLE V.
ARRANGEMENTS AND FUNCTIONING OF BATTERIES.

Regime	Conditions
Charge	$V_{BAT} < V_{ec}$ and $I_{BAT} > 0$ and $SOC < 1$
Saturation	$I_{BAT} > 0$ and $SOC = 1$
Discharge	$I_{BAT} < 0$

Where V_{ec} is the ending charge (V) and is given by (16).

$$V_{ec} = \left(2.45 + 2{,}011 \cdot \ln\left(1 + \frac{I}{C_N}\right)\right) \cdot (1 - 0.002 \cdot \Delta T) \tag{16}$$

The expressions describing the voltage in the batteries during different intervals are shown in (17), (18) and (19). Model of the voltage of the battery for charge regime:

$$V_{BAT} = (2 + 0.16 \cdot SOC) + \frac{I}{C_N}\left(\frac{6}{1 + I^{0{,}86}} + \frac{0{,}48}{(1 - SOC)^{1{,}2}} + 0.036\right) \cdot (1 - 0.025\Delta T) \tag{17}$$

Model of the voltage of the battery for saturation regime:

$$V_{BAT} = V_{ec} \tag{18}$$

Model of the voltage of a battery for discharge regime:

$$V_{BAT} = (1{,}965 + 0{,}12SOC) - \frac{|I|}{C_N}\left(\frac{4}{1 + |I|^{1{,}3}} + \frac{0{,}27}{SOC^{1{,}5}} + 0{,}02\right)(1 - 0{,}007\Delta T) \tag{19}$$

The model can generate a discontinuity in the battery voltage between the saturation and discharge zone. To ensure continuity to the function is possible to linearize an interval that allows connecting the discontinuous points of the function [20].

F. Charge Controller

The main function of the charge controller is to ensure the charging and discharging processes of the batteries as well as to prevent damages. This equipment can be modeled as in (20), and have an efficiency value η_{Ch} equal to 97.5%, according to the manufacturer.

$$P_{out} = P_{in}\eta_{Ch} \tag{20}$$

G. Static Transfer Switch - STS

The main function of the STS is to allow transfer between the generation of the microgrid and the grid, to meet the different charge conditions. This transfer depends on the availability of power generation systems and storage, and allows increasing the reliability of the power supply.

The modeling can be done from (21), and the efficiency value η_{STS} will be equal to 98.7%, according to the manufacturer.

$$P_{out} = P_{in}\eta_{STS} \tag{21}$$

H. Operation analysis

This analysis allows establishing the operation scenarios, calculate the power flows and study the interaction with the grid.

Fig. 6 shows the flow diagrams corresponding to three scenarios of the experimental micro-grid, (a) in situ generation of the microgrid is greater than load, (b) the load must be served by in situ generation and batteries, and (c) the grid supplies the load Because the generation in situ and batteries are not enough.

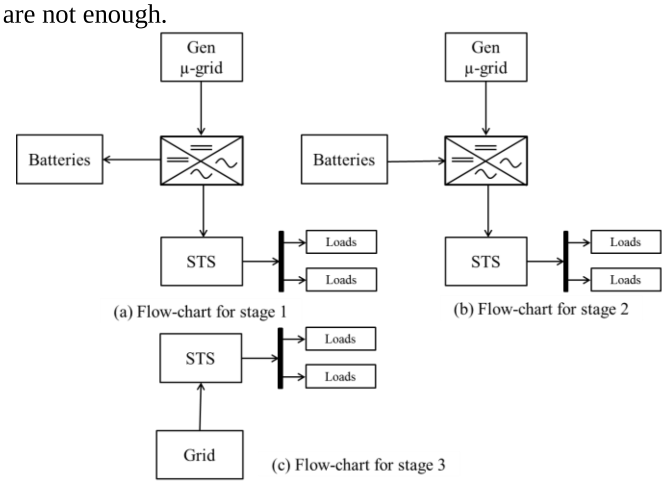


Fig.. 6. Performance scenarios

VII. Study Results

Below are presented the simulation results on the generation, storage and energy balance of the micro-grid located in the PTG.

A. *Energy Generation*

The analysis of solar resource allowed determining that the photovoltaic generation is very favorable since radiation values close to 1 000 W/m^2 were reached during the day.

It was also found that the wind potential of the PTG is not significant, as the average wind speed is in the order of 1 m/s; however, it's possible to use micro-generators.

Fig. 7 shows the variation of the efficiency of the PV array. The maximum efficiency achieved is 13.4%, allowing a maximum generation of 668 W. Under these conditions it is estimated that the average generation of the array is within 2.60 kWh.

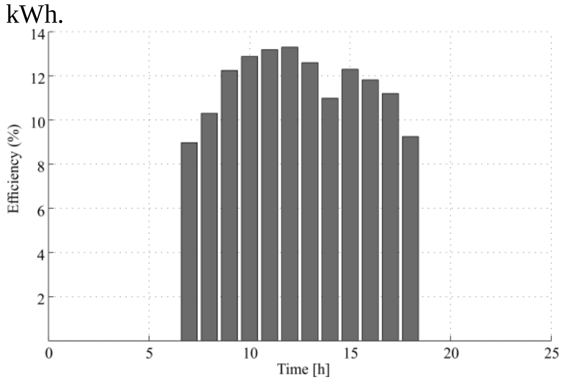


Fig. 7. Efficiency of PV array on the location of the microgrid.

It was found that the photovoltaic system injects energy into the system only when solar radiation exceeds 15 W/m^2, since only in this condition the minimum operation voltage of the regulator is achieved.

Fig. 8 shows the histogram of total renewable generation for the total hours of measurement to account for this study. It is observed that for 48.9%, the power generated by the microgrid is negligible. This is because the photovoltaic system only operates for 12 hours a day, and over 41.3% of annual wind hours, it did not exceed a speed of 0.5 m/s [10].

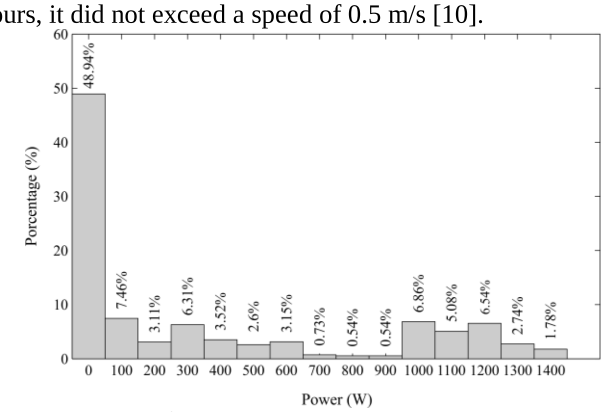


Fig. 8. Histogram of the power generation microgrid designed at the PTG

However, during the day is possible to reach maximums of 1,34 kW. To increase the generation capacity of the microgrid, it is possible to evaluate the PV system expansion or use conventional generation. For the proposed design of the micro-grid in EIL, 6 kW diesel generator is considered, but not included in the analysis exposed in this paper.

B. *Storage*

Fig. 9 shows the behavior of the batteries SOC for a constant load of 100 W and 500 W. The charging process occurs because the excess of power generated by the micro-grid sources with respect to the load is stored by the batteries, that even though supplying power to the load when the sources do not generate enough energy, they store surpluses that accumulate during each daily cycle.

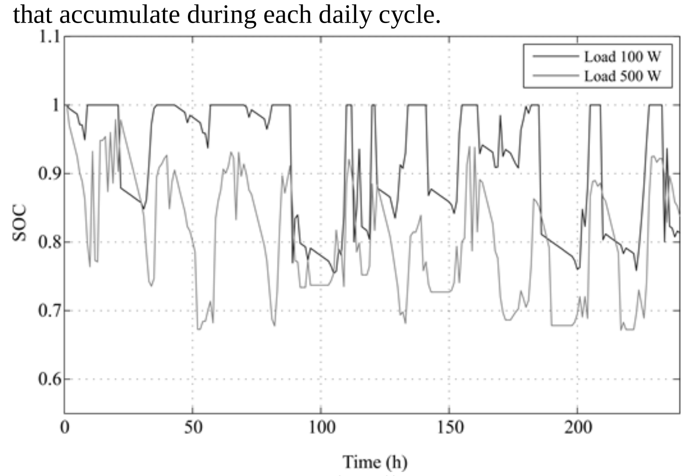


Fig. 9. Battery SOC for different load values.

It is observed that the SOC for a load of 100 W, reaches a value of 100% in all daily cycles, while in discharge processes it remains above 75%.

For the case of the load of 500 W, it was found that the SOC never becomes 100% neither drops the lowest possible value of SOC (60%). The latter occurs because the STS unit states that the combined supply of renewable generation and batteries is not sufficient to supply the load, thus it does the transfer to the grid.

C. *Energy Balance*

Fig. 10 shows the power values of the sources and the batteries of the microgrid for a period of 72 hours when the load has a constant value of 315 W. The behavior of the stored power (negative) and delivered (positive) of the batteries, is due to excess or shortage of the generated power.

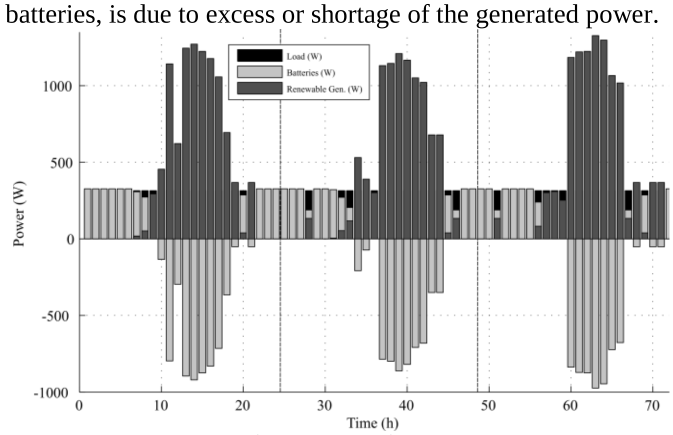


Fig. 10. Energy analysis of the microgrid for one day with 315 W as load.

From the simulation it was found that for loads of less than 315 W, the storage system has the ability to provide the energy required by the load, so the STS do not need to do the generation transfer to the grid. This type of analysis allows estimating the power provided by the grid and under what conditions the micro-grid is not capable of providing the required power.

Fig. 11 shows the power behavior of the micro-grid for a load of 500 W. The value of the charge is considerably high to allow battery charging in all cycles, the STS does the commutation, allowing to supply directly from the grid.

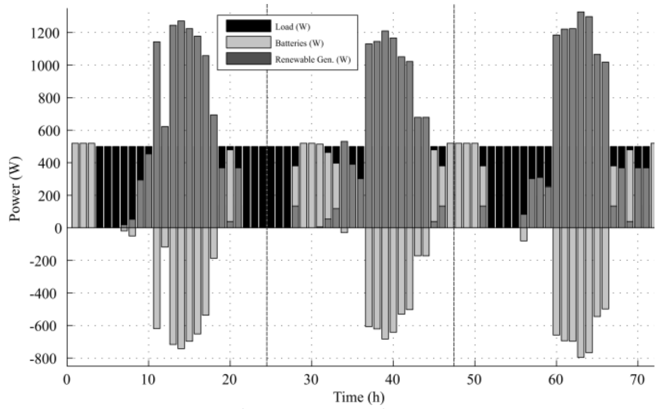


Fig. 11. Energy analysis of the micro-grid for one days with 500 W as load

VIII. Conclusions

The study of microgrids can have an important impact if is focuses into solve problems as the supply of non-interconnected zones, since it uses the in-situ energy potential and can require a low investment in comparison with the interconnection infrastructure with the grid.

The design and implementation of pilot microgrids projects in universities entities favors the technological appropriation in these applications, especially for environmental conditions of his social influence.

In general, the design of a microgrid depends on the designer's expertise in the interpretation of information as energy needs and available energy potential, as well as the level of his technical appropriation of topics as renewable energy systems and energy management for such applications.

The design methodology presented is a first effort to establish in a better way the design of the scheme and the dimensioning of microgrids.

This methodological approach can be improved from its implementation as an assisted design computer tool for the optimization, according to the lower financial cost and a better energetic use of the system, considering both energy and financial analysis; in addition, this tool could perform automatically the dimension of the electric installations.

The ad-hoc applications about the energy behavior based on modular approach and simplified modeling of the components of a microgrid, allow the realization of energy analysis for several scenarios of load and generation, as was the case presented in this document.

In order to facilitate and standardize the analysis of microgrid energy behavior is required the development of applications that incorporate graphical interfaces to set the desired configuration and display results. Preliminary, it should define the generation and load analysis scenarios, and also the relevant indicators about the quality of a microgrid.

VIII. References

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