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Energy Management System For University Photovoltaic Microgrid

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ABSTRACT

This work addresses the problem of minimizing the cost of purchasing electrical energy and maximizing the income obtained from the sale of energy generated by a consumer University microgrid. This Microgrid comprises a photovoltaic system connected to a grid and an energy storage system. Colombian energy policies and standards are considered. The technical characteristics of the solar panel, the lead-acid battery, and the Colombian standards for small-scale photovoltaic self-generators are analyzed and included in the optimization model as constraints of the problem. Finally, a linear programming model of mixed integers solved using GAMS is proposed.

Keywords: Photovoltaic system, optimization, storage system.

I. INTRODUCTION

A microgrid is a form of distributed power generation capable of connecting on and off the grid. In a grid-connected mode of operation, a microgrid can exchange energy with the power grid (to absorb or inject energy); when power generation and demand are equal, the energy transferred between the Microgrid and the total power grid is zero. (Hatziargyriou, 2014). Interconnected photovoltaic systems as a microgrid are being used to complement conventional power generation in many countries (Besheer et al., 2019; Lu et al., 2017; Martins et al., 2008; Tsilingiridis & Ikonomopoulos, 2013). Today, there is also great interest in urban consumers connecting to distributed generation with the installation of photovoltaic systems on the roofs of buildings or residences. There are a variety of hybrid energy solutions (Bagarella et al., 2016; Mayer et al., 2015) and especially those with photovoltaic energy integration.

The microgrid control system must address several aspects involving various control perspectives and time scales. Rapid electrical control of individual resources' phase, frequency, and voltage should be performed less than one second. In contrast, economic dispatch, demand optimization, and energy exchanges with the power grid are performed with longer timescales (minutes, hours, days, or even months) (Carlos et al., 2019). From the perspective of control, there are three hierarchical levels: primary control, secondary control, and tertiary control (Vasquez et al., 2010)(Unamuno & Barrena, 2015)(Parisio et al., 2014)(Parisio & Glielmo, 2011)(Palizban & Kauhaniemi, 2015). En la figura 1 se muestran estos niveles.

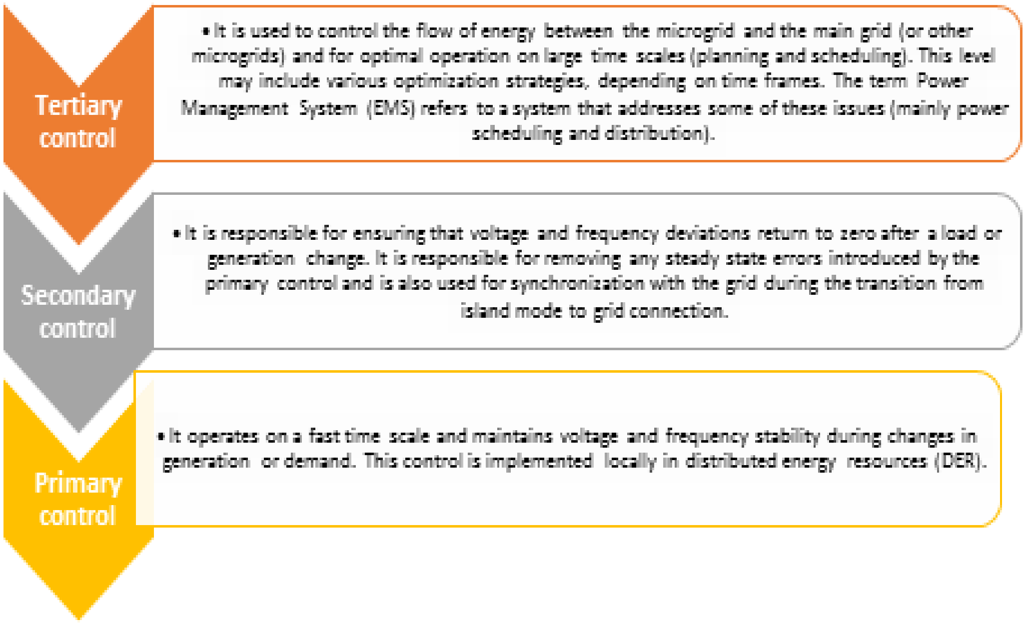

Figure 1: Levels of hierarchical control of a Microgrid

The electrical power system is transforming due to the massive incorporation of distributed generation sources (DER). One of the problems that we have at the technical level is the problem of increasing voltage at the distribution system level due to the reverse active power and the distribution feeders since their conventional structure is based on a unidirectional power flow (Carvalho et al., 2008). Therefore, there is an excellent opportunity to develop voltage regulation markets in distribution networks with high participation of distributed generation sources since reactive power cannot be transmitted over long distances due to the inductive nature of the lines. In Angelino et al., (2010), a simple nodal reactive energy pricing scheme is presented that is economically attractive to DER units and fair to consumers. It is based on the increase in apparent power resulting from injections of reactive energy. It also ensures that the DER continues to profit, even if the DER units have to reduce their active power production to provide voltage support to the distribution network.

This work aims to formulate an optimization approach by CREG resolution 174 of 2021 to maximize the gains, including the limitations of the quality of service of a university photovoltaic system connected to the grid with energy storage, considering the demand of the consumer.

II. METHODOLOGY

Unisucre's electrical system is powered by a 13.2 kV circuit that runs through the campus and energizes 11 transformers in different locations feeding loads of the different blocks; there are no distributed energy resources. However, installing a solar generator and a BESS is part of the project.

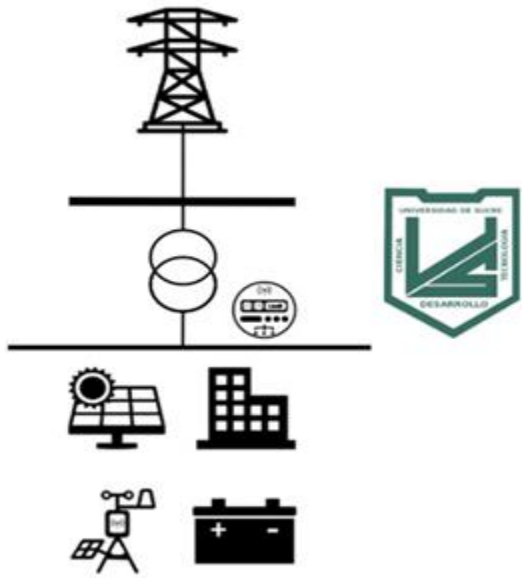

Figure 2: Unisucre Microgrid Scheme

Demand for the Unisucre Electricity System

For the analysis of the demand in each period and distribution it in each period, it was assumed that the power demanded would be more significant in the substations with the giant transformers. In other words, the power demanded was proportional to the size of the transformer; for this, the installed capacity was calculated (sum of the nominal capacities of the site) and was taken as a base value to determine the participation of each one in the total demand (see table 1).

Table 1: Distribution Power demanded by transformer.

Element	Capacity [kVA]	Participation [%]
Trf Administrativo	300	0.16
Trf B3	112.5	0.06
Trf Biblioteca	450	0.24
Trf112.5 kVA	112.5	0.06
Trf_112.5kVA_13.2kV/220V	112.5	0.06
Trf_225kVA	225	0.12
Trf_75 kVA	75	0.04
Trf_EdNuevoLabs	225	0
Trf_SalasProf	150	0.08
trf_150_kVA_13.2kV/220V	150	0.08
trf_225kVA_13.2kV/220V	225	0.12

It was also carried out in a demand profile for the faculty room of the faculty of engineering, taking into account the use of the room and the schedules of greater energy demand through the System Advisor Model software (see table 2). This data was used by the energy management system (EMS).

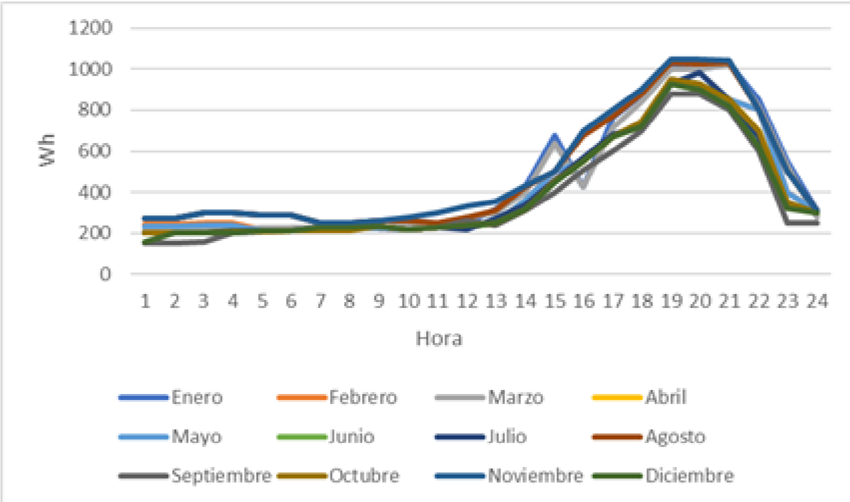

Figure 3: Demand Energy

In the case of Unisucre, a network with the following characteristics and costs was installed (see table 2).

Tabla 2: Characteristics of the Microgrid.

System	Capacity	Technology	Inverter/Charger	Cost of capital ($US)
Storage (BESS)	6.3 kWh	Li-ion	8.6 kVA	11600
Photovoltaic system (SFV)	20 kWh	Monocristalino (400 Wp)	18kWp	21000

This Microgrid will have the objective of importing or exporting energy to the distribution network depending on the load consumed and the excess energy generated during the day. The photovoltaic generation of each month is also calculated through Global Solar Atlas, as shown in Figure 3.

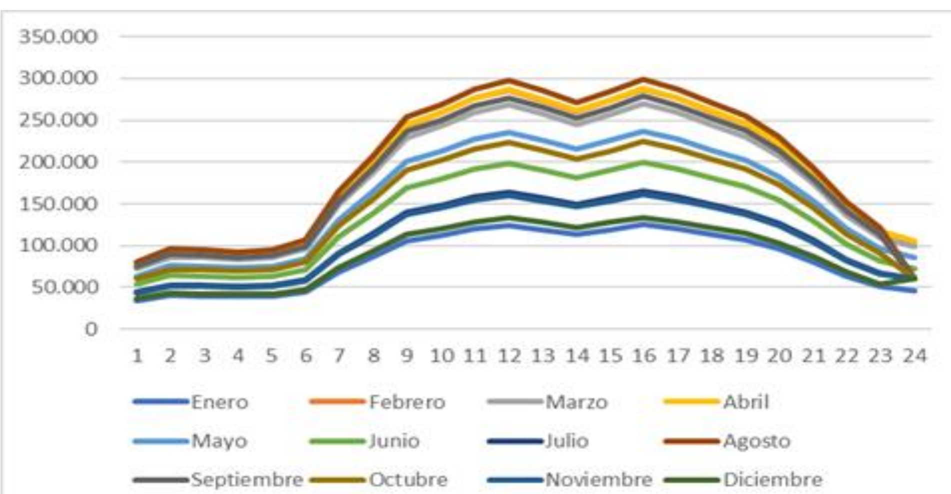

Figura 4: Average Generation of the Unisucre Microgrid

The GAMS software was used to analyze the economic dispatch, aiming to reduce energy import and maximize the use with the export to the distribution network.

An Optimization Model for the Colombian Case

According to resolution CREG 174 of 2021, a Small-Scale Self-Generation (Spanish: AGPE) is carried out by natural or legal persons who produce electricity with less than 100KW for their own needs and sell the surplus. The marketer who receives energy from an AGPE is responsible for the settlement and billing, incorporating detailed information on consumption, exports, and collections. With the following rules:

- Accumulated surpluses of energy ($Exc1_{i,j,m,u}$) which are less than or equal to their import of energy ($Imp_{i,j,m,u}$) from the grid will be exchanged, in the same amount, for their import of electrical energy from the grid in the billing period.
- For the accumulated surplus energy exchanged, the marketer will charge the AGPE for each kWh, the marketing cost corresponding to the component (Cv), or that which modifies or replaces it. If you are an unregulated user, the marketing cost corresponds to the agreed cost.
- For the quantities of surplus energy ($Exc2_{i,j,m,h,u}$) that exceed their import of energy ($Imp_{i,j,m,u}$)) from the grid in the billing period will be settled at the hourly exchange price ($Pbolsa_{h,m}$) of corresponding energy.

$$VE_{i,j,n,m,u} = \left(Exc1_{i,j,m,u} - Imp_{i,j,m,u}\right) * CUv_{n,m,i,j} - \left[Exc1_{i,j,m,u} * Cv_{m,i,j}\right] + \sum_{h=hx,hx+1,\ldots,H} Exc2_{i,j,m,h,u} * Pbolsa_{h,m} \quad (1)$$

In addition, for each previous variable, we have:

M: Month for which the Unit Cost of Service Provision is calculated.

I: Retailer and.

J: Marketing market j.

H: hour h of month m-1 (H is the total hours in month m-1).

To represent the objective function that minimizes the cost of purchasing electrical power and maximizes the revenue obtained from the sale of energy generated from photovoltaic energy with grid and battery restrictions is presented below:

$$\text{Min} \sum_{t=1}^{tk} \left(Exc1(tk) - Imp(tk)\right) * CU_m - (Exc1(tk) * Cv_m) + Exc2(tk) * PB_m + (Soc_{bat}^{max} - Soc_{bat}(tk))CU_m * \left(0.1\left(\$\frac{US}{KWh}\right)\right) \quad (2)$$

With the following network and battery restrictions

$$Soc_{bat}^{min} \leq Soc_{bat}(tk) \leq Soc_{bat}^{max} \quad (3)$$

$$0 \leq P_{bat}^{d}(tk) \leq -P_{bat}^{min}(tk) * \delta_{bat}^{d}(tk) \quad (4)$$

$$0 \leq P_{bat}^{c}(tk) \leq P_{bat}^{max}(tk) * \delta_{bat}^{c}(tk) \quad (5)$$

$$Soc_{bat}(tk) = Soc_{bat}(tk-1) + P_{bat}^{c}(tk) * \frac{\eta_{bat}^{c}}{C_{bat}} - P_{bat}^{d}(tk)/(\eta_{bat}^{d})C_{bat} \quad (6)$$

$$\left(1-\delta_{bat}^{c}(tk)\right)+\left(1-\delta_{bat}^{d}(tk)\right)=1 \quad (7)$$

$$0 \le Imp(tk) \le P_{load}(tk) \quad (8)$$

$$0 \le Exc1(tk) \le P_{pv}(tk) \quad (9)$$

$$Exc_{t}(tk) = Exc1(tk) + Exc2(tk) \quad (10)$$

$$0 \le Exc1(tk) \le Imp(tk) \quad (11)$$

$$P_{res}(tk) = P_{pv}(tk) - P_{load} \quad (12)$$

$$P_{grid}(tk) = Exc_{t}(tk) + Imp(tk) \quad (13)$$

$$P_{res}(tk) = P_{grid}(tk) + P_{bat}^{c}(tk) - P_{bat}^{d}(tk) + P_{sc}^{c}(tk) - P_{sc}^{d}(tk) \quad (14)$$

With the following variable definitions.

Soc	Battery Charge Status
P_{bat}	Battery power
P_{pv}	Panel output power
P_{load}	Load demand
δ_{Bat}	Variable Binary Battery
tk	Time Period
Bat	Battery

III. SIMULATION AND DISCUSSION OF RESULT

The first step in writing the code in GAMS was to define the variables and constraints, such as photovoltaic power, excess energy, energy import, and hourly load demand. In addition, it is necessary to define some system specifications, such as the capacity of the photovoltaic generator, the capacity of the storage battery, the permissible battery depth of the battery, and the efficiency and discharge efficiency.

Figure 5 shows the power generated by the photovoltaic panels and the behavior of the load for February of greater solar irradiance. The average of the month in 24 hours was determined. It is also appreciated that there is a surplus of electrical energy from 8 hours to 17 hours; here, the optimization algorithm comes to work to decide to charge the battery and send the surplus to the distribution network.

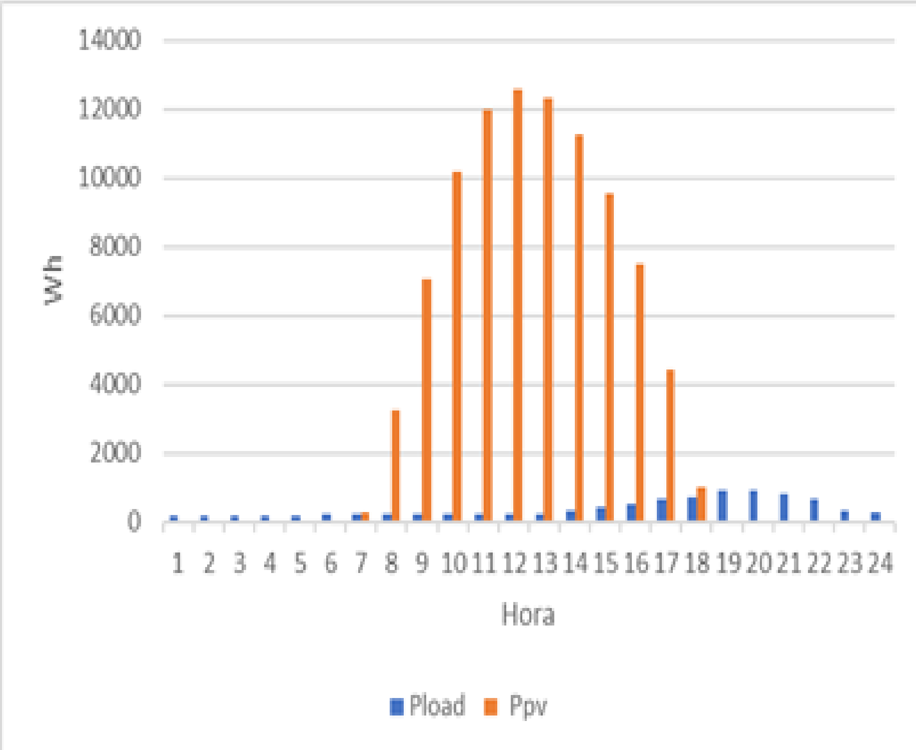

Figure 5: Demand load and photovoltaic power

Figure 6 shows the result obtained with the total import and export algorithm. For import, energy is absorbed from the grid when there is not enough solar irradiance to generate photovoltaic solar energy.

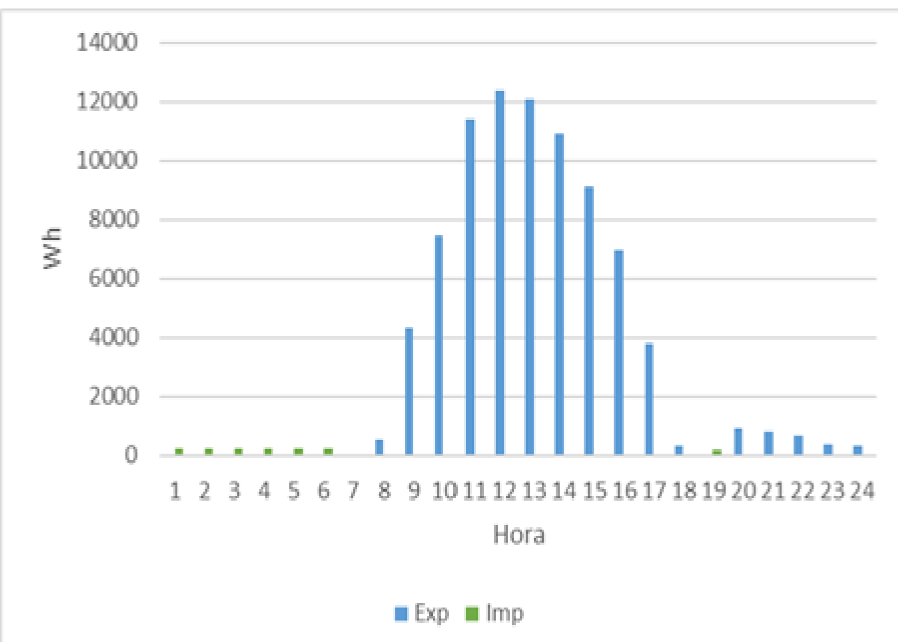

Figure 6: Import and export of energy

The battery dynamics show its operation correctly; it is charged from 8 hours to 11 hours of greater solar irradiance when the photovoltaic panels generate greater power. It also begins to discharge when the demand for the load is greater than the energy supplied by the panels at that time and must take electrical energy from the distribution network.

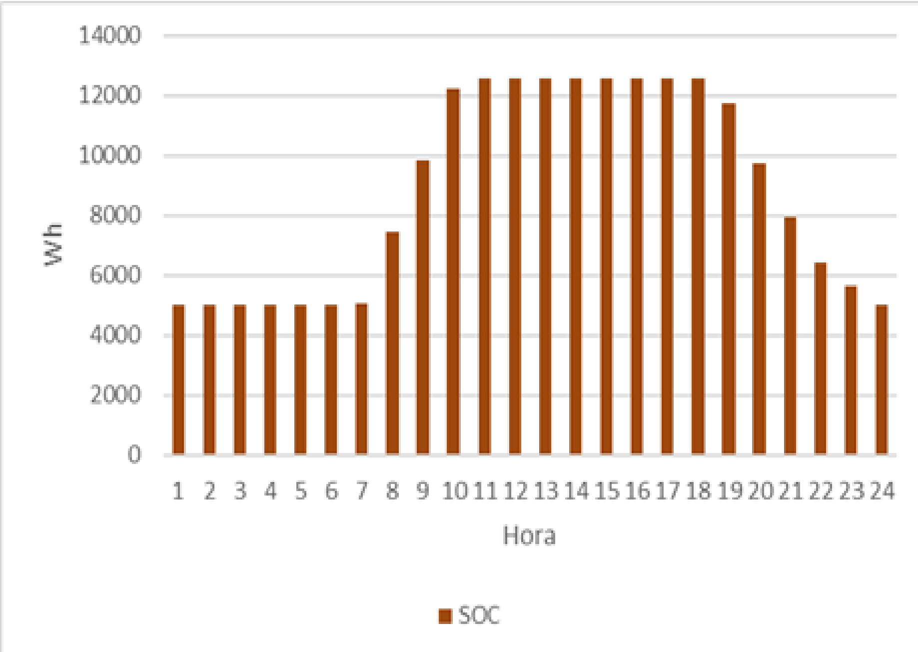

Figure 7: Battery charge status

IV. CONCLUSIONS

Battery dynamics are correctly included and simulated in the cost function. The optimization allows to contextualize the problem of tertiary control to the national regulation, and the model allows for evaluating the sensitivity of the parameters in the export and import results.

Unisucre's Microgrids allow evaluating real dynamics of generation and self-generation, responding effectively to the dynamics of the load and the photovoltaic power.

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