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Demand-Side Management Through Load Control and Local Generation in a Medical Education Facility: a Case Study

Andrés Felipe Duque Montenegro[1], Javier Rosero García[1], Ernesto Pérez González[2]

Abstract – *Electric energy generation from renewable sources is widely accepted thanks to the cost reduction that enables its transformation in an increasingly optimal way. However, these systems depend on climate variability. Accordingly, they cannot provide fixed generation. In order to improve the reliability of these systems, demand-side management strategies have been developed to optimize the operation of renewable generation systems. This article presents a case study of a medical education building with distributed generation. A dynamic tariff scenario is simulated according to the national demand in order to perform demand-side management with three types of loads: refrigeration, air conditioning, and ventilation. The model is fed with data obtained from the telemetering of the PV system generation and demand of the building. The result shows that about 16.2% of the electrical energy consumed can be saved through the implemented energy management system and complies the operation ranges allowed by the system.*

***Keywords**: Demand Management, Demand Flexibility, Distributed Generation, Photovoltaic Generation Systems, Smart Metering*

Nomenclature

DSM	Demand-Side Management
DR	Demand Response
EE	Energy Efficiency
DLC	Direct Load Control
ToU	Time of Use
CPP	Critical Peak Pricing
RTP	Real-Time Pricing
CREG	Energy and Gas Regulatory Commission
TCL	Thermostatically Controlled Load

I. Introduction

The electricity sector has accelerated its decarbonization. The integration of renewable energy sources has made it possible to comply with the growing demand with a reduction in greenhouse gasses. In addition, the growing demand has been controlled thanks to optimized operation and technologies on the consumer side. These new technologies have changed the paradigm of the energy sector, favoring distributed generation and efficient energy consumption. Different strategies, which combine generation with renewable energy sources and economic incentives in distributed generation programs to plan energy management programs by means of economic incentives as well as to allow users to monitor their electricity consumption, have been developed [1].

This new paradigm and the growth of information technologies have made it possible to implement demand management techniques, facilitating the interaction between the end consumer and the network operator. In addition, they are making additional efforts to mitigate the increasing global demand in the future [2]. While these projections show increased electricity consumption, an interesting aspect to be analyzed is due to the COVID-19 pandemic in 2020. This demand has decreased about 5.5% compared to 2019, rather than increasing, because of lockdowns and economic closures. In some countries, it has decreased by as much as 20% due to total mobility restrictions [3]. This reveals a scenario that goes against forecasts and sends an encouraging message for the reduction of electrical energy consumption by means of programs to modify the load curve, without affecting socio-economic aspects [4]. In the Colombian case, according to economic growth projections performed in 2018, electricity demand will increase between 88,296 GWh and 92,383 GWh by 2030. The greatest burden to the system will be the integration of electric mobility [5]. Similar to global information, data reported by the XM (Colombian system management and administrative enterprise) monitoring center show that in March 2020 Colombia's electricity demand dropped by 17% due to restrictions imposed by the increase in COVID-19 cases.

This has modified the demand curves of the system and in turn the forecasts made for 2020 [6]. Although an economic downturn is not desirable, the transformation of the consumption habits plays a relevant role, in view of an economic recovery that promotes sustainability, as urged by the United Nations. The coronavirus pandemic has suddenly transformed societies life habits and consequently their energy consumption, leading to uncertainty from which new scenarios of interaction with the energy power service can be created. An example of

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this is the rise of ventilation and disinfection systems in buildings, which involve a new load that should be active when there are numerous people [7], and the increased energy consumption in the residential sector due to the displacement of loads related to teleworking [8] and to social distancing measures that had an effect on the demand-temperature relation in regions with high cooling and heating use [9]. Hospitals have also experienced variations in energy consumption because of the increased number of respirators and disinfection systems such as autoclaves and freezing systems for storing vaccines. This has resulted in higher electricity consumption. These elements are essential, since cooling, heating, and ventilation systems represent a high percentage of energy consumption that should be reduced in DSM programs [11]. Hospital facilities have demonstrated their important role in containing future crises, so it is necessary to ensure their energy sustainability. Different studies have combined electric systems for clinical or hospital use, the use of renewable energies, and DSM programs to balance supply and demand by means of economic incentives that serve as a basis for developing this type of projects [12]. Some of these case studies and reviews have revealed opportunities such as integration through energy management systems, the implementation of hybrid systems for clinical facilities, and the identification of new loads that could be included in DSM programs.

This new context poses great challenges and new possibilities of developing applications for a more intelligent use of resources. The pandemic has caused digitalization processes of different sectors to be accelerated. This has led to the adoption of virtual resources during lockdown to continue basic activities remotely and to increase digital capabilities in countries of the region [15]. This article explores the concept of DSM and its categories, focusing on a particular one that is a response to DR, a review of the tariff structure of the Colombian system and approaches to DR programs.

Finally, in this chapter, some technical considerations of these programs are shown. The second chapter details the implemented model of demand management and the simulated loads, in order to show the results of this model in the third chapter with a dynamic tariff scenario that allows changing the energy consumption pattern of the system.

II. Demand-Side Management (DSM) Strategy

The concept DSM has great relevance, as it refers to a group of actions designed to manage efficiently a site's energy consumption with the aim of reducing the costs incurred for the supply of electrical energy, from network charges to general system charges, including taxes. This group of actions also aims to modify consumption patterns to alleviate the power system in terms of the load curve associated with it. The actions can be categorized to their approach, which can be financial or technical, and propose a comprehensive demand management strategy [16]. Scenarios such as the increase of loads in certain sectors, such as hospitals, and the decrease in demand with reference to the overall curve of the total load of the electricity system can lead to an analysis of effective demand management. In doing so, other sectors can benefit from the decrease or transfer of energy consumption [17]. In addition, scenarios can be considered to strengthen the operation of the electric power supply. Although the pandemic has been sudden and has affected the world economy, figures show an effective relation between the modification of society's habits and energy consumption. This demonstrates the potential of a DSM program with planning that does not affect the socio-economic welfare of consumers. The technical and economic characteristics that can be developed in Colombian case study are explained below.

II.1. Load Management Techniques

Load management techniques are represented by the modifications made to the power versus time graphs, showing the possible modifications to the load curve to perform demand management. The literature proposes several possible groupings according to load management, highlighting demand response and EE [18].

According to the modification of the consumption profile, demand management strategies can be classified into six categories (Figure 1).

DSM comprises three main categories: energy efficiency, DR, and strategic load planning. First, DR modifies the load curve in four ways: reducing peaks in high demand periods (peak clipping), increasing demand in off-peak periods (valley filling), moving peak demand to off-peak periods (load shifting), and giving incentive to user tariffs to reduce load by means of flexible load shaping.

Second, EE intends to modify the load curve by means of energy efficient technologies and programs that reduce energy consumption while maintaining or improving the quality of energy services. These technologies comprehend high-efficiency devices that use electrical energy optimally by fulfilling their functions and programs aimed at using electrical energy in socio-economic processes intelligently.

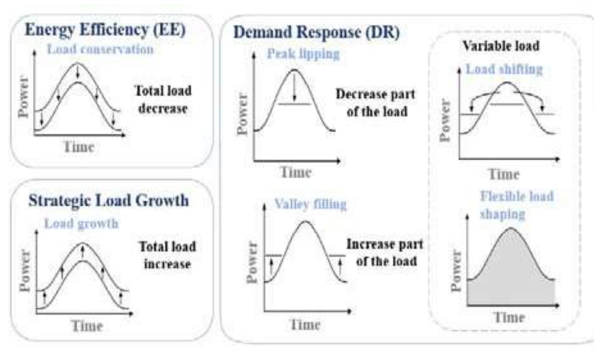


Fig. 1. DSM load management techniques, adapted from [19]

Third, the objective of strategic load planning is to increase the load through controlled incentives in order to carry out an analysis of the impact on the system for large volumes of a type of load, for instance, electrification of transport or heating systems (load growth) [20]. The DSM approach of this case study is DR, combining the possible techniques in DR that best suit the set of loads that will be controlled to develop the DSM strategy.

II.2. Demand Response

DR is an ancillary service for end users to be able to adjust their power consumption in response to a given signal. This DR signal may contain information on electricity prices, incentives, or system reliability emergencies [21], unlike main DR techniques, such as peak clipping or valley filling, which occur infrequently and mainly during network emergencies. In addition, in DR flexible load shaping techniques the demand side continuously responds to market price signals [22].

Flexible load shaping technologies enable a truly integrated network by facilitating dynamic control and response to both consumer load and their use of distributed generation and storage. Control can be direct or through autonomous agents, the use of controllable appliances, or energy management systems.

Demand response programs: Demand management programs refer to the tariff structure in the DR category. These relate to a set of programs that can be classified into two main categories: reliability-based programs or incentive-based programs, and price-based or market-based programs [2]. These programs are classified according to the transaction methods applied, either by defined time intervals or by the needs of the electricity system [21]. The simulation focuses on PBP through RTP. In this category, consumers can observe the tariffs at different times of the day to modify their energy behavior and generate an economic benefit [23]. Through the RTP scheme, customers pay fluctuating hourly rates that reflect the actual cost of electricity in the wholesale market. These customers receive price information for a defined interval of time.

II.3. Tariff Structure in Colombia

The Colombian market can be divided into two main sectors: the regulated market and the non-regulated market. The first one is directly contracted and served by distribution companies, and covers industrial, commercial, and residential users with energy demands of less than 55 MWh. In this market, the tariff structure is established by the CREG.

TABLE I
CATEGORIES OF DEMAND RESPONSE PROGRAMS

Incentive-Based Programs (IBP)	Price-Based Programs (PBP)
Direct Load Control (DLC)	Time of Use (ToU)
Interruptible or curtailable service	Critical Peak Pricing (CPP)
Emergency demand response	Real-Time Pricing (RTP)

The charging formula is approved by the regulator, and any user is served regardless of consumption. The industry and all those users with high energy consumption voluntarily participate in the non-regulated market. Unlike the regulated market, the marketing and generation price is freely agreed upon through a negotiation process between the consumer and the marketer [25]. Equation (1) shows the Unit Cost of Service Delivery (*CU*), which is equal to a Base Marketing Cost (*CUf*) plus a Variable Component Cost of the Unit Cost (*CUfv*). This variable component is included in equation (2), which also includes the costs of generation (G), transmission (T), distribution (D), commercialization (C), costs of losses (PR), and costs for restrictions and services associated with generation (R):

$$CU_{m,j} = CUf_{m,j} + CUfv_{m,j} \tag{1}$$

$$\begin{aligned} CUfv_{m,j} = G_{m,j} + T_m + D_{n,m} + \\ + Cv_{m,i,j} + PR_{n,m,i,j} + R_{m,i} \end{aligned} \tag{2}$$

The costs are calculated monthly. The sub-indexes refer to:

- n: User's connection voltage level;
- m: Month for which the Unit Cost of Service Delivery is calculated;
- i: Retail marketer;
- j: Commercialization.

Commercialization, distribution, transmission, and generation sectors are agents of the system that interact with the operator and administrator of the electric power market in Colombia.

Those entities make up the institutional structure of the electric sector to fulfil the demand of regulated and non-regulated users, they intend to reach a balance between demand and supply in the National Interconnected System (SIN for is acronym in Spanish).

Figure 2 shows the basic operation scheme of the electric system in Colombia with its respective voltage categories and levels [24]. The structure of the Colombian electrical system makes it possible to generate incentives in the unit tariffs of each agent with their respective voltage levels to develop DSM strategies, so the agents of the system can interact by generating signals to benefit operation of the SIN.

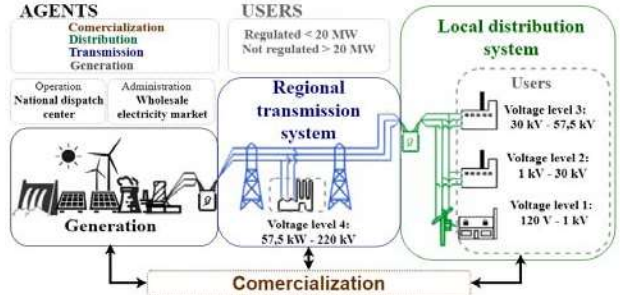


Fig. 2. Structure of the National Interconnected System. Adapted from [25]

CREG has regulated three DSM programs to date. The first one, regulated under Resolution CREG-063 of 2010, established the Voluntary Disconnectable Demand (DDV for its acronym in Spanish) is a mechanism that supports the firm energy obligations of generation units through the Reliability Charge. The tests for verifying the availability of the DDV have been regulated under Resolution CREG-098 of 2018 [26]. The second program is the Demand Response program regulated under Resolution 011 of 2015, which established the regulation for the daily market in critical condition [27]. Finally, *Apagar Paga* (turn off pay) is a program that defines differential tariff schemes to promote voluntary saving by users. It was regulated under Resolution CREG-029 and CREG-051 of 2016 [28].

II.4. Technical Considerations on DR

The implementation of DR programs needs a series of metering, control, and communication infrastructure requirements that allow interaction between the user and the network operator.

Measurement and control infrastructure: Among the different components of the enabling infrastructure, smart meters and AMI advanced metering infrastructure are essential to implement DR strategies. Smart meters are new generation electronic meters that have the capability of bi-directional communication between the end user and the entity operating commercialization [29].

Communication infrastructure: A fundamental requirement for an effective implementation of a DR program is the ability to manage a significant amount of data transfer and low latency between the parties involved (EMS of end user, loads to be controlled, retailer, and aggregator, among others) [30]. Interoperability between devices is essential for them to communicate, so the multiple communication protocols in each layer of an AMI network should be identified.

Protocols and standards: Multiple protocols for the communication of control and measurement devices allow flexibility when implementing an AMI network. Once the implementation area, the existing communication networks, and the demand management strategy have been identified, it is possible to identify each layer of the AMI network with their respective protocols and standards [31].

III. Electrical System in Faculty of Medicine Building of the University Campus

The internal network of Bogota Campus of National University of Colombia consists of a local distribution system (LDS) of voltage levels 1 and 2. It has two branches that are interconnected to the main node in the substation of Calle 26, which is fed by the SIN at 11.4 kV. This connection point defines the commercial border between the campus and the distribution system. Figure 3 shows the topology of the distribution system, which has a primary distribution circuit with radial topology of 11.4 kV, a secondary distribution system of 208 V, and a photovoltaic generation system at the Faculty of Medicine. The 60 kW photovoltaic system is located at the building of the Faculty of Medicine and interconnected to the network at a 208 V connection point. The photovoltaic system has a generation capacity of 74.8 kWp and occupies 988 square meters of the building terrace with 187 photovoltaic modules. The power per square meter is 75.7 W/m^2. Figure 4 shows the measurement scheme of the system in the Faculty of Medicine substation.

Electrical behavior of loads at the Faculty of Medicine building: The Faculty of Medicine is characterized by loads like the ones of a clinical center and the loads of an educational institution. It has about 35 clinical laboratories, in which refrigeration and disinfection are carried out, in addition to teaching spaces with about 245 classrooms and 4 auditoriums. Due to pandemic restrictions, activities in the building decreased, but mainly research processes were authorized. Figure 5 shows two load profiles: blue refers to a normal academic day, red shows a day during the pandemic. There is a strong difference mainly at noon.

The university campus is located at the center of Colombia's capital city: Bogota. This city has an altitude of 2,630 meters above sea level, with an average temperature of 14.55 °C and high cloudiness [32].

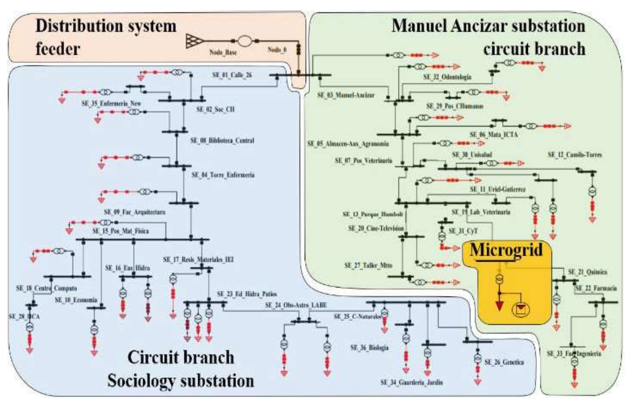


Fig. 3. Single-line diagram of the distribution system of the university campus

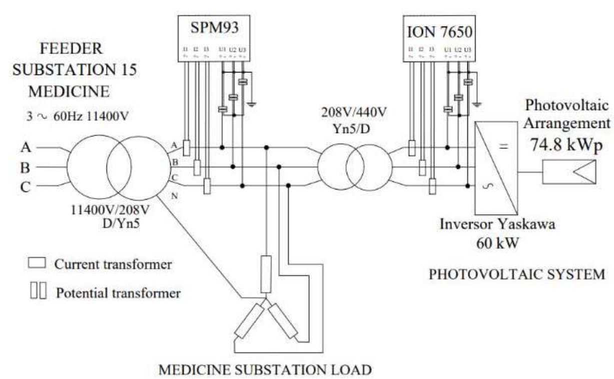


Fig. 4. Electrical system and metering devices in the substation of the Faculty of Medicine

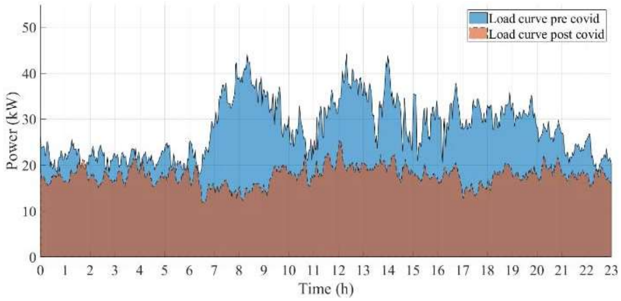


Fig. 5. Electrical system load curve before and during the COVID-19 pandemic

These characteristics determine the behavior of the photovoltaic system located in the building: there is strong variability in generation due to the cloudiness of the city. Figure 6 shows the solar generation profile and the load curve during the pandemic of the building. There is surplus energy in some periods.

IV. Demand-Side Management Model with on-Site Generation

The DSM model should include aspects such as load type, load management techniques, DR programs, tariff structure, and technical load control considerations to maintain the functionality of the electrical device. In this case, the electrical system of the Bogota campus of National University of Colombia is simulated. This has been used to develop smart grid applications [33].

IV.1. Target Loads of the DR Program

The Medicine Faculty has a high load on thermal equipment such as refrigerators for sample storage and air conditioning for standardizing laboratory tests. This type of load allows the development of TCL applications [34]. In addition, there is a new load of ventilators arising from the security measures that could be generated due to the pandemic, as shown in Figure 7. Those two models are simulated on Simulink by means of a second-order system for the laboratory thermal model and a function diagram for the classroom model, as shown in Figures 8.

This aims to analyze the electrical behavior and the final use of the energy of each load to be studied. The laboratory model receives the room temperature measured for one day as input.

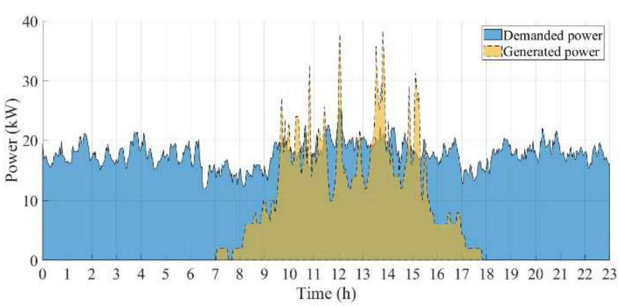


Fig. 6. Demand load curve and solar photovoltaic generation during the pandemic

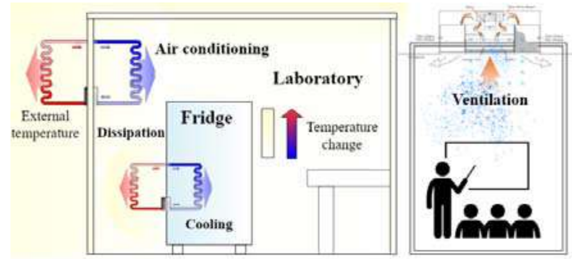
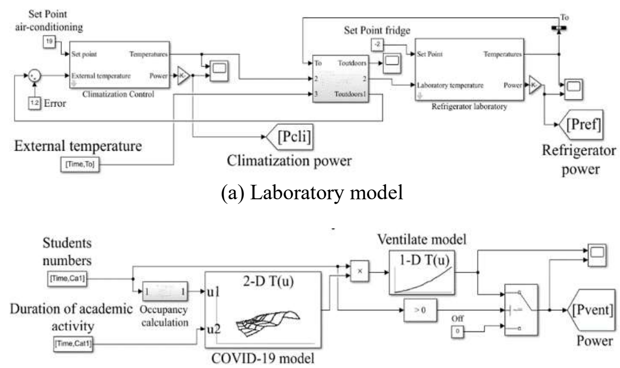


Fig. 7. Left: Interaction between thermal loads. Right: Classroom ventilation



(a) Laboratory model

(b) Classroom model

Figs. 8. Model of the systems involved in demand management

The temperature for air conditioning is set through a set point. Once the temperature is controlled, it is communicated as input to the refrigerator block, which also has a set point that maintains the required temperatures inside the compartment. This thermodynamic principle exchanges heat, which generates a slight temperature increase in the laboratory.

Loads grouped as ventilators: The behavior of the load of ventilators is like air conditioning. However, their objective is to reduce the load of pollutants in those spaces where they are used [7]. For example, ventilators can be installed in laboratories where toxic substances are handled and in auditoriums and classrooms in order to reduce the risk of respiratory diseases. The model is based on the relation between occupancy percentage, ventilation rate, and occupancy time from a model developed in [35] in order to determine the optimal ventilation and to reach an infection probability of less than 20%. Once the ventilation rate is determined, the power consumed is established. In this case, an AIRMASTER AM 1200 ventilation unit is used. It has a maximum power consumption of 1,300 W and its power consumed can be regulated [36]. The participation of this load occurs through the scheduling of classes and students.

Loads grouped as air conditioning: For the simulation of this load, a block diagram is proposed to model the thermodynamic and electrical behavior of an air conditioner, as shown in Figure 9. All air conditioners are grouped in a single block to facilitate the simulation.

Since there are no air conditioners in all laboratories of the Medicine Faculty, this load is simulated for 35 laboratories with a power consumption of 380 W.

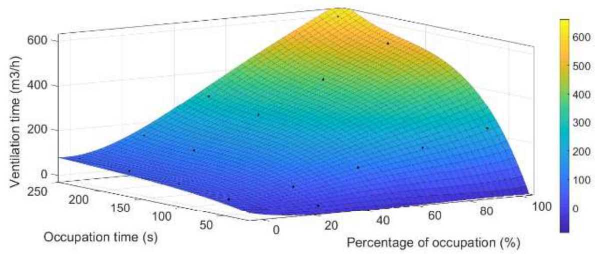


Fig. 9. Optimized ventilation model for classrooms

The temperature of these devices can be adjusted between 18 °C and 20 °C with a variation of 5 °C in the laboratories, in order to ensure that the procedures performed are under controlled conditions. The participation of this load occurs through the variation of the set point [34] and the disconnection of the device when there are no programmed activities in the laboratory.

Loads grouped as refrigerators: The second load to be studied is refrigerators. These have an off on their behavior, so the main load to be studied is the compressor that performs the cooling process. The model, like the previous one, permits the study of the thermodynamic section by varying the number of times the refrigerator door is opened. Figure 10 shows the simulation scheme with its inputs and outputs. One 480 W refrigerator per laboratory is simulated.

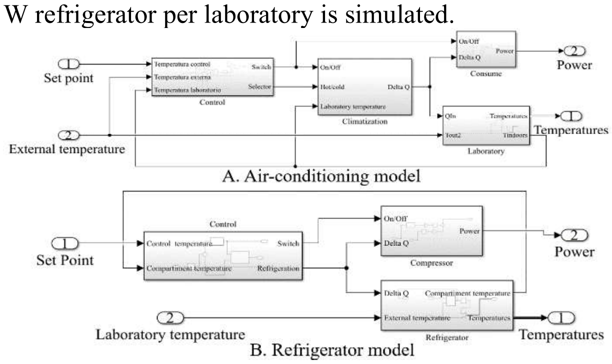


Fig. 10. Mathematical model of refrigerators

Some characteristics to be considered regarding refrigerators are operation temperature, temperature range, electrical power, electrical current, and capacity.

In this case, an operation range is set between 3 °C and -6 °C with a maximum variation of 2 °C. The inclusion of this charge occurs through the scheduling of times to open the refrigerator.

Battery: In order to give flexibility to the system, a 20 kW battery is simulated to perform demand management based on the charge and discharge cycles of the battery. The participation of this charge occurs through the purchase and sale of electrical energy. The BESS is determined by equation (3), which evaluates photovoltaic power, demand, and market prices. It receives signals from the energy management system to change the power consumed or delivered with the constraint of maintaining the battery SOC between 30% and 80%:

$$Pb_{Discharge} = \left(P_{pv} - P_D\right)\left(C/\lambda\right) \quad (3)$$

$$Pb_{charge} = Pb_{Discharge} \times 0,8 \quad (4)$$

Figure 11 shows the integration of each block by means of a common busbar, which is interconnected with the 11.4 kV/208 V transformer to be fed by the main supply.

IV.2. Demand Response Program

The DR program in the case study is under the real-time pricing scheme. This tariff is defined by the network operator and sent to an energy management system.

Their function is to manage four loads interpreted as agents that decide whether to participate by modifying their consumption. In this case, flexible load shaping techniques are used for air conditioning and battery loads, and load shifting for cooling and ventilation loads.

Figure 12 shows the agent model scheme. The tariff is determined by equation (1), with a fixed tariff of $150 Colombian pesos and a dynamic tariff that is calculated by means of the exchange price according to the national demand and the contracts established between the agents.

Figure 13 shows the simulation scheme with measurements from the LAB+I smart grid laboratory to propose the communication topology between the different simulation software programs [37]. It consists of three blocks that communicate with each other to send data. Based on this, it simulates the behavior of the system with the aggregated loads and measured data. The physical model block contains the measurement of electrical variables with a sampling time of five minutes, the management block contains storage and data management, and the simulated model block contains this case study.

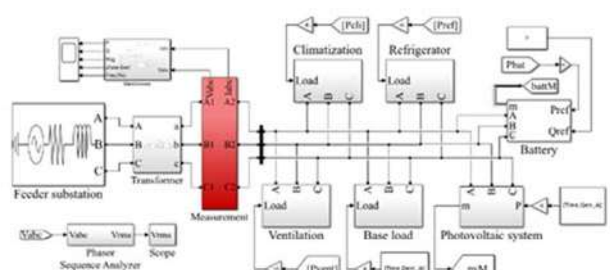


Fig. 11. Electrical scheme implemented in the simulation

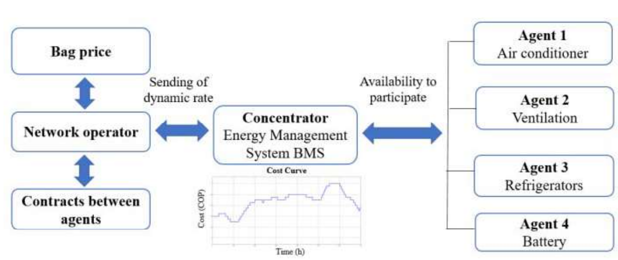


Fig. 12. DSM strategy agent model

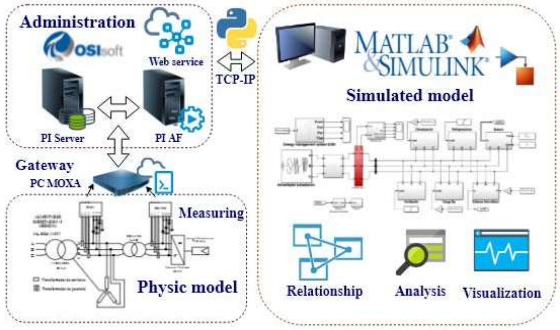


Fig. 13. Architecture of the simulated DSM strategy

V. Results

Simulations are performed based on the model described in the previous section. Figure 14 shows the behavior of each power of the loads used. Considering the context of lockdowns, measurements made in the pandemic are used as the base load; the orange line represents its curve. The dash green line represents the grouped power of the air conditioner reaching a peak of 13.3 kW, which is dependent on the outside temperature.

The dot blue line represents the power of the refrigerator that depends on the laboratory control temperature and the number of times the refrigerator is opened with a peak power of 16.8 kW. The cross purple line represents the fan power that depends on the students and classes scheduled with a peak power of 13.3 kW. Finally, the dash black line represents the battery power, which varies with respect to the tariff and energy surpluses. Figure 15 represents the thermal behavior of the laboratory. The first section shows the temperature of the laboratory, with the power of the air conditioner; and the second section shows the temperature of the refrigerator, with the power of the compressor. The variation in the thermal pattern of each model can be observed. In the case of the laboratory, the air conditioning is turned off during non-productive hours and the offset is varied by 2 °C during the period when the tariff rises. This modification of the load curve leads to a 30.28% decrease in energy consumption. In the refrigeration load, the number of times the door is opened and the time the door remains open are changed. In the first case, it is opened four times at an interval of seven minutes, and in the second case, it is opened three times at an interval of four minutes.

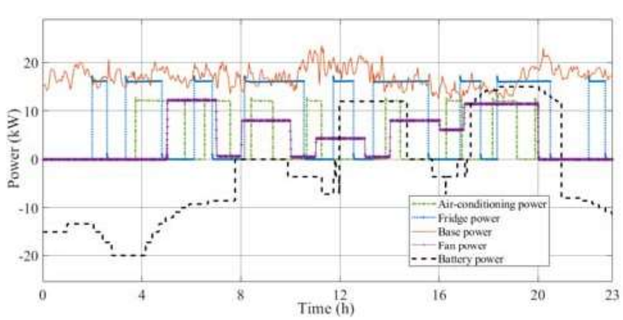


Fig. 14. Powers of system loads

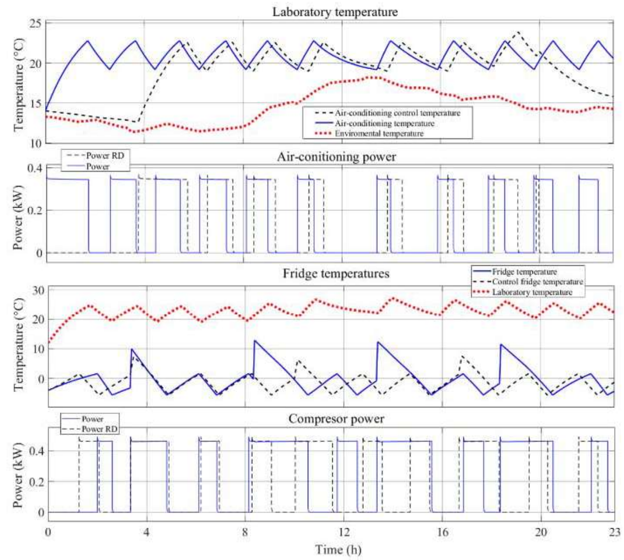


Fig. 15. Temperature control

This action saves 12.34% of the energy consumed. For the load of ventilators, 110 students per classroom are programmed. However, the schedule and number of students varies in two cases. The dash purple line in Figure 16 refers to the case, in which students are programmed more uniformly, whereas the continuous blue line refers to the second case, in which students are scheduled with a gap of fewer students at noon. The second case represents a 7.3% saving in energy consumption compared to the first case. Finally, Figure 17 shows the electrical variables resulting from the simulation. There are variations in the frequency and voltage of the system. The battery SOC and the powers of the feeder, the photovoltaic system, and the battery can also be observed. The battery, in addition to generating energy savings, provides economic returns through load shifting. This allows the system to have a 23.6% reduction in the tariff through the purchase and sale of energy, without considering investment, operation, and maintenance costs.

VI. Discussion

The creation of systems that integrate real data and simulated assumptions are increasingly used to model hypothetical scenarios.

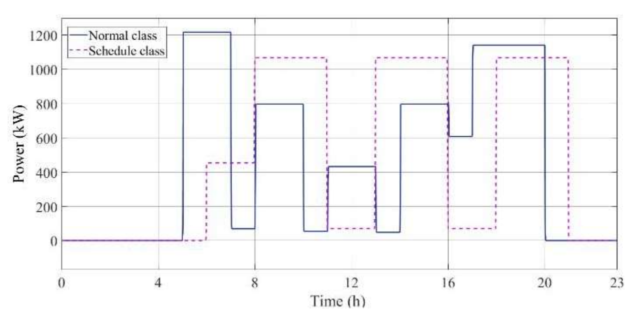


Fig. 16. Fan power with normal class and with scheduled class

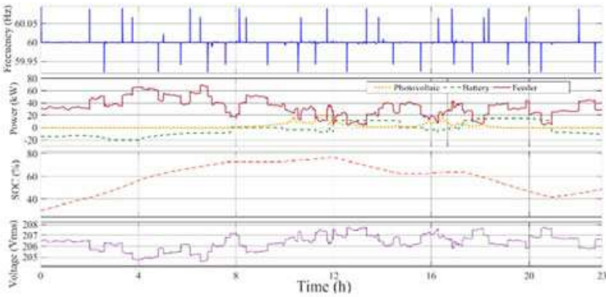


Fig. 17. Electrical variables of the system

The implemented model uses this principle by creating a digital twin of the medicine building integrating the actual measurements of the system with elements such as batteries, loads and the simulated tariff model. This system allows evaluating the suitability of implementing different technologies in the system, allowing establishing savings and approximate electrical behaviors. The model simulates a real electric system with a demand response program hypothetical that allows through a concentrator receive signals from the market and the operator to establish an EMS. The EMS integrates the characterized loads to participate in the DR program to respond to market signals, maintaining the operating points required for their end use. It is important to emphasize that the dynamic tariff generates the incentives for the EMS to decide that loads move according to the conditions of the network. The operators can generate a dynamic tariff that allows integrating requests of the agents of the network in Generation, Transmission or Distribution to respond to system events, allowing to vary the costs of each section of equation (2) to establish the participation thresholds in DR programs. Finally, the integration of end-use energy models allows the setting of participation limits in DR program of the selected loads, being very particular of each load the way in which their final energy use is modeled and that will depend on the user's need. This model includes the characterization of each of the loads selected to set the disconnection and load displacement limits. This work generates inputs for the characterization of loads for DR programs simulating their end use, establishes the characteristics that the DR program should have considering the selected loads and allows the simulation of a real system with the hypothetical DR program.

VII. Conclusion

Advanced metering infrastructure is essential to develop demand management strategies, as it allows the network operator to verify in real or short time intervals whether the contracted demand has been decreased by the user or to send signals for the user to decrease their consumption in accordance with the tariff price.

In the case study, photovoltaic generation and the main busbar of the substation are measured. However, there is no individual measurement of the circuits to disaggregate the demand in certain loads. In this case, the simulation of the systems combined with real measurement data has allowed the development of a hypothetical case with thermal and dimmable loads whose set point can be controlled according to market signals to fulfil their end use. This allows generating a digital twin to study DR programs by means of simulations that shows behaviors approximating reality.

DSM programs can lead to a balance by giving flexibility to energy consumption. This behavior can affect the voltage and the frequency profile and decrease the power quality or increase it if the voltage variation is linked to a signal that enhances voltage. The application of signals by a grid operator agent to a grouped load can be given in a controlled way to prevent sag and swell voltage contributing to avoiding grid fluctuations. In the simulation, a voltage profile is obtained with a variation of ±2% of the nominal value within the ranges established by the regulation. Frequency, in contrast, has a lower variation of ±0.15% with a more limited range, close to exceeding the allowed limits. These variations can be identified by the operator to regulate the quality of the voltage and frequency on the system, including more agents that may interact in the distribution system and the energy management model. The analyzed case takes the measured base demand of the building and generates hypothetical loads based on the functions of the building.

These loads are managed by agents that interact with the signals sent by the operator. This strategy has resulted in an approximate saving of 28.6% in the tariff, not including the costs associated with investment and maintenance to simplify the model. The battery is the most flexible element of the system due to its capacity to consume and deliver energy, simplifying investment and operating costs, off-peak charging and on-peak discharging generate revenue from the purchase and sale of energy to the customer, which establishes a profitability by buying low and selling high. The proposed loads depend on the user's energy behavior and the university's institutional logistics. This is a great opportunity in the scheduling of classes and laboratory practices.

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References

[1] X. Deng and T. Lv, Power system planning with increasing variable renewable energy: A review of optimization models, *Journal of Cleaner Production*, vol. 246, p. 118962, 2020. doi: 10.1016/j.jclepro.2019.118962

[2] H. Jabir, J. Teh, D. Ishak, and H. Abunima, Impacts of Demand-Side Management on Electrical Power Systems: A Review,

Energies, vol. 11, no. 5, Apr. 2018, p. 1050.
doi: 10.3390/en11051050

[3] H. Zhong, Z. Tan, Y. He, L. Xie and C. Kang, Implications of COVID-19 for the electricity industry: A comprehensive review, in CSEE *Journal of Power and Energy Systems*, *vol.* 6, no. 3, Sept. 2020, pp. 489-495.
doi: 10.17775/CSEEJPES.2020.02500

[4] W. Kanda and P. Kivimaa, What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility?, *Energy Research & Social Science*, *vol.* 68, 2020, p. 101666.
doi: 10.1016/j.erss.2020.101666

[5] Miner-Energy Planning Unit UPME, Regional Projection of Electric Energy Demand and Maximum Power, *Colombian electrical information system,* (2019).

[6] S. Ortega, E. Ángel, A. Jaramillo, Energetic Scenarios For Colombia In Covid-19 Context, Montevideo 2020.26 p.
http://repository.eia.edu.co/handle/11190/2530

[7] L. Morawska et al., How can airborne transmission of COVID- 19 indoors be minimised?, *Environment International*, vol. 142, 2020.
doi: 10.1016/j.envint.2020.105832

[8] M. Krarti and M. Aldubyan, Review analysis of COVID-19 impact on electricity demand for residential buildings, *Renewable and Sustainable Energy Reviews*, vol. 143, 2021, p. 110888.
doi: 10.1016/j.rser.2021. 110888

[9] M. Alkhraijah, M. Alowaifeer, M. Alsaleh, A. Alfaris, D.K. Molzahn, The Effects of Social Distancing on Electricity Demand Considering Temperature Dependency, *Energies*, vol. 14 no. 2, p. 473, 2021.

[10] J. J. Klemeš, Y. Van Fan, and P. Jiang, The energy and environmental footprints of COVID-19 fighting measures – PPE, disinfection, supply chains, *Energy*, vol. 211, 2020, p. 118701.
doi: 10.1016/j.energy.2020.118701

[11] V. Congradac, B. Prebiracˇevic´, N. Jorgovanovic´, and D. Stanišic´, Assessing the energy consumption for heating and cooling in hospitals, *Energy and Buildings*, vol. 48, 2012, pp. 146–154.
doi: 10.1016/j.enbuild.2012.01.022

[12] J. D. Acosta Dangond, I. Oliveros Pantoja, J. D. Soto, L. Ripoll Solano, and L. Lopez, A review of use of non-conventional renewable energies in healthcare facilities and hospitals, *2020 IEEE ANDESCON*, 2020, pp. 1-6.
doi: 10.1109/ANDES- CON50619.2020.9272060

[13] L. Olatomiwa, R. E. Blanchard, and J. Uligwe, Demand side management strategies for solar-PV penetration in powering rural healthcare centre in Africa, In: Hidoussi, F. (ed.) *Proceedings of the International Conference on Innovative Applied Energy (IAPE 18)*, 2019.
Available: https://repository.lboro.ac.uk/articles/Demand_side_management_strategies_for_solar-PV_penetration_in_powering_rural_healthcare_centre_in_Africa/9553880

[14] A. S. Alsagri, A. A. Alrobaian, and M. Nejlaoui, Techno-economic evaluation of an off-grid health clinic considering the current and future energy challenges: A rural case study, *Renewable Energy*, vol. 169, 2021, pp. 34–52.
doi: 10.1016/j.renene.2021.01.017

[15] CAF, C.-S. technical ELAC, D. P. and Law, and Te. A. S. LLC, Digitalization in Latin America facing Covid-19, *Andean Corporation for Development*, *United Nations*, 2020, pp. 2–33.

[16] C. W. Gellings, Evolving practice of demand-side management *Journal of Modern Power Systems and Clean Energy,* vol. 5, no. 1, 2017, pp. 1–9.
doi: 10.1007/s40565-016-0252-1

[17] Montaña, S., Correa, C., Optimal Programming of flexible electrical loads in Covid-19 times, *INGE CUC,* vol. 17, no. 1, 2021.
doi: https://doi.org/10.17981/ingecuc.17.1.2021.05

[18] P. Jiang, Y. Van Fan, and J. J. Klemeš, Impacts of COVID- 19 on energy demand and consumption: Challenges, lessons and emerging opportunities *Applied Energy, vol.* 285, 2021, p. 116441.
doi: 10.1016/j.apenergy.2021.116441

[19] I. Lampropoulos, W. L. Kling, P. F. Ribeiro, and J. Van Den Berg, History of demand side management and classification of demand response control schemes, 013 *IEEE Power & Energy Society General Meeting*, 2013, pp. 1–5.
doi: 10.1109/PESMG.2013.6672715

[20] G. Strbac, Demand side management: Benefits and challenges, *Energy Policy,* vol. 36, no. 12, 2008, pp. 4419–4426.
doi: 10.1016/j.enpol.2008.09.030

[21] N. G. Paterakis, O. Erdinç, and J. P. S. Catalão, An overview of Demand Response: Key-elements and international experience, *Renewable and Sustainable Energy*, vol. 69, pp. 871–891, 2017.
doi: 10.1016/j.rser.2016.11.167

[22] Dyson, Mark, James Mandel, et al., *The Economics of Demand Flexibility: How "flexiwatts" create quantifiable value for customers and the grid*, Rocky Mountain Institute, August 2015.
http://www.rmi.org/electricity_demand_flexibility

[23] A. R. Jordehi, Optimisation of demand response in electric power systems, a review, *Renewable and Sustainable Energy,* vol. 103, pp. 308–319, 2019.
doi: 10.1016/j.rser.2018.12.054

[24] D. M. López González, S. Z. Tabares Álvarez, *Study of remuneration rate of national electric transmission system in Colombia*, University EAFIT, Economy AND Finance School, 2014.

[25] A. Roger, *Final Report on the Blackout in the United States and Canada: Causes and Recommendations*, U.S.-Canada Power System Outage Task Force, 2004.

[26] Á. R. Restrepo, S. E. Nope, and D. E. Enríquez, Economic Benefits of Demand Management and Self-Generated energy in the Context of Colombian Regulations, *Technological information, vol.* 29, no. 1, 2018, pp. 105–116.
doi: 10.4067/S0718-07642018000100012

[27] Cely Garzón, D., *Definition of politic guidelines and energetic regulation to incentivize response mechanism of energy market demand of Colombia*, Medellín - Mines Faculty - Master on Engineering - Energetic Systems, 2021.

[28] D. Contreras, Impact of El Niño phenomenon in Colombia, *Journal Fasecolda,* vol. 163, 2016, pp. 42–46.

[29] A. E. Saldaña-González, A. Sumper, M. Aragüés-Peñalba, and M. Smolnikar, Advanced distribution measurement technologies and data applications for smart grids: A review, *Energies*, vol. 13, no. 14, 2020, pp. 1–34.
doi: 10.3390/en13143730

[30] N. G. Paterakis, O. Erdinç, and J. P. S. Catalão, An overview of Demand Response: Key-elements and international experience *Renewable and Sustainable Energy Reviews,* vol. 69, 2017, pp. 871–891.
doi: 10.1016/j.rser.2016.11.167

[31] Rocky Mountain Institute, *Demand Response: An Introduction – Overview of Programs, Technologies, Lessons Learned*, Rocky Mountain Institute: Boulder, 2006, p. 46.

[32] O. A. Villarreal Mesa and J. Rosero, *Solar resources analysis through short-term prediction of the Bogota Savannah*, p. 88, 2020, [Online].
Available: https://repositorio.unal.edu.co/handle/unal/77790

[33] S. Téllez-Gutiérrez, O. Duarte-Velasco, and J. Rosero-Garciá, Demand-side management strategies based on energy key performance indicators in real-time: Case study, *CT&F - Science, Technology and Future,* vol. 10, no. 1, 2020, pp. 5–16.
doi: 10.29047/01225383.128

[34] N. Mehta, N. A. Sinitsyn, S. Backhaus, and B. C. Lesieutre, Safe control of thermostatically controlled loads with installed timers for demand side management, *Energy Conversion and Management,* vol. 86, 2014 pp. 784–791.

[35] C. Sun and Z. Zhai, The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission, *Sustainable Cities and Society,* vol. 62, 2020, p. 102390.
doi: 10.1016/j.scs.2020.102390

[36] D. Lawrence Berkeley National Laboratory Washington, *Improving Fan System Performance: A Sourcebook for Industry* U.S. Dep. Energy, p. 83, 2003.

[37] C. Paper, S. Milena, and O. Germ, Grid Intelligent National Laboratory (Lab + I) As Educational Tool For Engineers Formation, *International Meeting of Engineering Education ACOFI 2014*, 2014.

Authors' information

[1]National University of Colombia, Bogota Headquarters, Engineering Faculty, Colombia.

[2]National University of Colombia, Medellin Headquarters, Engineering Faculty, Colombia.

Andrés Felipe Duque was born in Bogotá, Colombia. He received his B.Sc from Universidad Nacional de Colombia in Bogotá D.C. in 2021. He works at the National Laboratory of Smart Grids of Universidad Nacional de Colombia – sede Bogotá "LAB+i", specifically on analytical data and its application in systems. Andrés has been a researcher of the Electrical Machines and Drives research group, EM&D, since 2019. His research interests include data science, smart grids, engineering education, and control systems.

Javier Rosero Garcia was born in Potosi, Colombia, in 1978. He received his BSC in Electrical Engineering from the Universidad of Valle, Cali, Colombia, in 2002. He worked for construction and maintenance of power systems and substations in Bogotá, Colombia, between 2002 and 2004. He received a PhD degree from the Technical University of Catalonia (UPC) in 2007. Dr Rosero received the IEEE AESS Harry Rowe Mimno award for excellence in technical communications for 2007 from the Aerospace and Electronic Systems Society (AESS) IEEE 2007. He worked with Asea Brown Boveri (ABB), Barcelona, Spain, from 2007 to 2009 providing service and technical support for drives for industrial and windmill systems. He is currently an Associate Professor in the Universidad Nacional de Colombia's Electrical and Electronic Engineering Department in Bogota. Dr. Rosero has published more than 50 referred journal and conference papers. Dr. Rosero is a Member of the Institute of Electrical and Electronics Engineers, IEEE, International Society of Automation, ISA. His research interests are focused on the areas of modelling, diagnosis and control of electrical machines and drives, electric mobility and smart grids.

Ernesto Pérez was born in Bogotá, Colombia. He received the B.S. (1999), M.Sc. (2002), and Ph.D. (2006) degrees in electrical engineering from the Universidad Nacional de Colombia, Bogotá, Colombia. He stayed 1 year in 2003 with the Power System Research Group, University of Bologna, Bologna, Italy, working on lightning induced voltages. Dr. Pérez has been with the Research Group PAAS-UN, Colombia since 1998. Dr. Pérez is currently an Associate Professor with the Universidad Nacional de Colombia at Medellín, Medellín, Colombia. His research interests include lightning phenomena and power system protection.