Assessment of energy efficiency indicators on a residential building with plug-in electric vehicles and energy action plans for users

Andres D. Quevedo, Edwin G. Suarez, Sandra M. Arias, Francisco Santamaria and Jorge A. Alarcon.
Electromagnetic Compatibility and Interference Group - GCEM
Universidad Distrital Francisco José de Caldas
Bogotá, Colombia
adquevedor@correo.udistrital.edu.co, egsuarezf@correo.udistrital.edu.co, smariasz@correo.udistrital.edu.co,
fsantamariap@udistrital.edu.co, jaalarconv@udistrital.edu.co

***Abstract*— This paper presents a study case to improve Energy Efficiency (EE) in a residential building under two considerations: introducing a new load to the system corresponding to the charging of Plug-in Electric Vehicles (PEV), and proposing an action plan based on the modernization of technological devices. Initially, the simulation of the electric system is performed to calculate variables such as voltage, power demand and losses for different PEV penetration scenarios. After that, EE indicators required to assess each scenario are evaluated and individual and collective plans are proposed. Finally, plans are evaluated with respect to their contribution on EE improvement.**

***Index Terms*—Efficiency, Electrics Vehicles, Energy Efficiency Indicators, Management Strategies, Residential User.**

ABBREVIATIONS

CO_2	Carbon Dioxide
IEA	International Energy Agency
PEV	Plug-in Electric Vehicle
UPME	Mining and Energy Planning Unit
MHCP	Ministry of Finance and Public Credit
MADS	Ministry of Environmental, Housing and Territorial Development
PROURE	Program of rational and efficient use of energy
RETIE	Technical Regulations of Electrical Installations
% PEN	PEV Penetration Rate
EE	Energy Efficiency

I. INTRODUCTION

Currently, high energy consumption worldwide presents environmental challenges [1]-[3], including CO_2 emmissions, air pollution, dependence on fossil fuels and others, due to energy consumption habits. Moreover, conventional sources of energy produce very large impacts such as the disappearance of flora, fauna and ecosystems in the case of large hydroelectric plants or high CO_2 emissions from thermal power plants.

The transport sector is one of the highest contributors of CO_2 emissions [4], since most of fuels are petroleum products. According to IEA, in 2012, CO_2 emissions in this sector were as high as 23% [8]. Some European countries [5]-[7] have investigated on energy patterns in which renewable sources, management strategies, energy efficiency, and effective integration of PEV are involved, based on the improvement of existing systems and the implementation of new technologies [12],[14].

Management strategies are carried out by utilities and users, individually or jointly, through demand response programs to identify, assess, and provide possible solutions to the problems that arise when there is an increased power demand.

In Colombia, the national Government through different entities as UPME, MHCP, MADS, among others, is developing policies to promote the use of non-conventional sources of energy, such as renewable energy [17], and the implementation of programs as PROURE [9], which allows the introduction of the energy efficiency concept in the electric sector. The academy also has been studying the impact of the connection of non-conventional energy sources to the grid [10], its legislation [11], the rational and efficient use of energy [12] and the impacts of uncontrolled entrance of PEV in the distribution system [13],[14].

On the other hand, it is necessary to study positive and negative effects in the electric system efficiency when these technologies and policies are implemented, taking into account the use of PEVs by end users. Therefore, this paper assesses such effects when an energy action plan is implemented in a residential building with PEVs.

II. METHODOLOGY

A. Selection and modeling of electrical parameters for a residential complex

A residential complex including 4 buildings and 80 apartments located in the city of Bogota was selected for the study. This complex has a common area consisting of a parking lot, a place for meetings and some social spaces.

The power transformer had the following characteristics:

- Three-phase transformer, DY5, 11400/208/120 V
- Rated Power 225 kVA
- Seven branches of low voltage: one for each building, one for the common area, one for the water pump and one for the backup of the electric plant.

Measurements in the residential complex were carried out in the common point (power transformer) to construct the daily demand curve shown in Fig. 1.

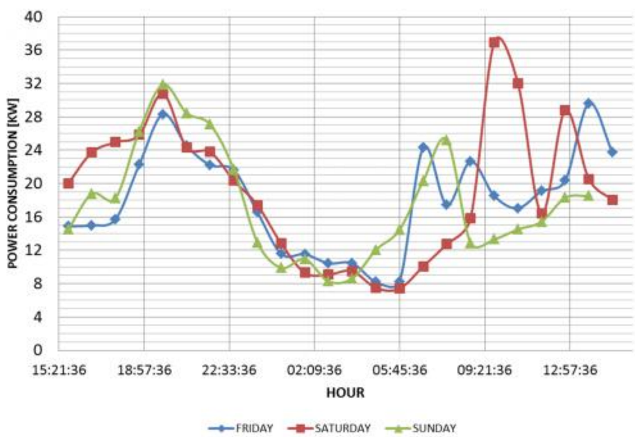

Fig. 1 Daily demand curve measured on the common point

Using the daily consumption data and the single line diagram of the system, the simulation of the system under normal operation conditions was performed and the behavior of the electric parameters was determined. Considering that power consumption varies during the day, 24 simulations were performed for obtaining the hourly behavior.

B. *Selection of Energy Efficiency indicators*

Energy Efficiency indicators were defined for three fundamental axes (environmental, economic and technical), and according to the selected indicators, the initial parameters of the study case were identified.

Energy Efficiency indicators are the main tools to make a detailed energy consumption assessment of an element or process with respect to another one [4]. Indicators are defined as quantitative measurements of certain condition to facilitate the understanding of a fact or a phenomenon and the changes on its behavior across time [15]. According to the study case conditions, the selection of indicators was based on the following three axes:

- Environmental axis: environmental indicators allow determining the amount of greenhouse gas emissions released into the atmosphere by a system [16].
- Economic axis: economic indicators allow establishing increments in energy costs, and obtaining projections based on the purchase of clean technologies, which are able of reducing energy consumption. Indicators are measured quantitatively and represent the maturity of a country or place about energy saving and efficiency [17].
- Technical axis: Energy efficiency provides different easily applicable alternatives. However, sometimes it is not enough to manage the use of energy from savings incentives. Because of that, new technologies with better efficiency and new components are incorporated, modifying the behavior of technical parameters and having an impact on indicators of this type, for example, power consumed by element, energy consumption, lumens per consumed kW, among others [4].

C. *Definition of availability scenarios of PEV*

At this stage, a selection of the following factors was performed:

- Kind of PEV: Vehicle powered only by the plug-in battery (Full ElectricVehicle)
- Battery recharge: Battery charges continuously at a rate of 1.5 kW per hour.
- Capacity and consumed energy by the battery: These two factors have a probabilistic behavior of a lognormal distribution. It is used the methodology developed by [14] for different battery capacities and for the consumed energy. Consumed energy was based on the distance traveled by the car.
- PEV penetration levels: There are three scenarios: 30%, 50% y 100%.
- Number of connections of PEV per hour: This factor was determined based in the methodology developed by [14], which takes into account the mobility patterns of private vehicles in the city (see Fig. 2).

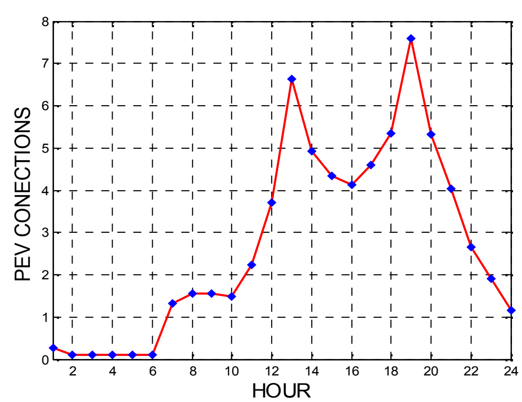

Fig. 2 PEV connections per hour

The values used to generate probability functions of battery capacity and power consumption are presented in Table 1.

TABLE 1. VALUES FOR THE LOGNORMAL DISTRIBUTION

	Range	μ	σ
Capacity	1-60 [kW]	2.951	0.591
Energy	1-25 [kWh]	1.893	0.403

With data connections and PEVs penetration level scenarios established, simulations of electric parameters for each scenario are made. The results of each simulation were compared with the base case, extracting the necessary data for the evaluation of energy efficiency indicators.

D. Implementation of management strategy and plan to improve Energy Efficiency

A management strategy to facilitate entry of PEVs as a load was employed, seeking to improve residential building energy efficiency through an energy improvement plan; was carried out by housing unit.

The management strategy for PEVs was based on load shedding, using as restriction that the maximum load of the circuit is the nominal power of the transformer.

Considering the results from the inclusion of PEVs, it is important to highlight other energy efficiency strategies that allow obtaining energy savings despite the load of PEVs. These strategies are presented individually for the system users, i.e. for each apartment. One of these plans is the substitution of old appliances with more efficient ones, which allows obtaining return on investment and energy savings in a certain term, and also preventing overloads and system damage.

E. Calculation and evaluation of energy efficiency indicators

Finally, energy efficiency indicators used to obtain the results of each improvement plan of energy efficiency were calculated in order to make the comparison of results.

III. RESULTS AND DISCUSSION

A. Simulation of the residential complex

The simulations of the electric system parameters correspond to the Saturday, since this day presents a greater variation of the load curve (Fig. 1). Three parameters are studied: voltages at nodes to verify that they are within the limits defined by RETIE [19]; total system losses; and the load curve to determine if the transformer is overloaded. In the simulation was also considered that the residential complex has the necessary conditions to recharge an PEV in each parking place. Charging mode battery is 2, according to IEC 61851 standard [19].

Voltage Regulation (Fig. 3): The ranges of voltages in the system during normal operation conditions (red) and with a 100% of PEVs penetration (green) are presented. Blue lines show the limits established by the Colombian regulation. It is observed that the voltage profile improves when PEV charging stations are available.

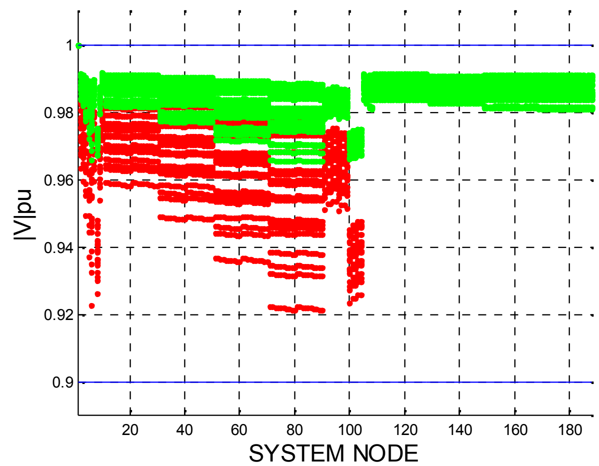

Fig. 3 Voltage range of the system without PEV (red) and with PEV (green)

- Losses in the system: Total system losses (the sum of the losses during the day) decreased considerably due to the improvement of voltage profile and PEVs penetration (Fig. 4).

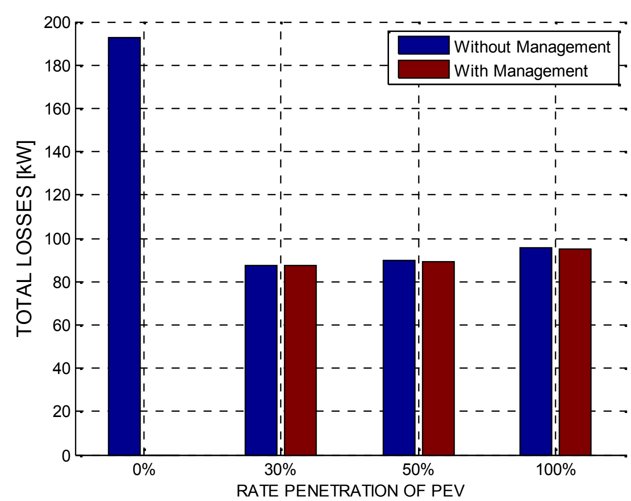

Fig. 4 Total system losses

- Load Curve (Fig. 5): Red line indicates the maximum transformer capacity. It is observed that the management strategy for PEVs shifts the load curve peaks to maintain the transformer in normal operation without overload it.

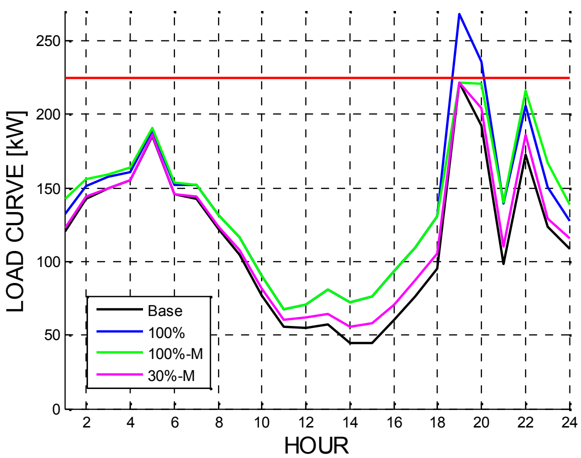

Fig. 5 Different system load curves

B. *Efficiency Indicators*

Based on the three main axes of energy efficiency indicators, the most relevant indicators for the study were identified (Fig. 6), including residential installations and PEVs. The study not only includes some proposed indicators by IEA in the environmental axis such as CO_2 emmissions per total area and person, but also new indicators that fit the conditions and requirements of the facility under study. Fig. 6 shows the selected energy efficiency indicators.

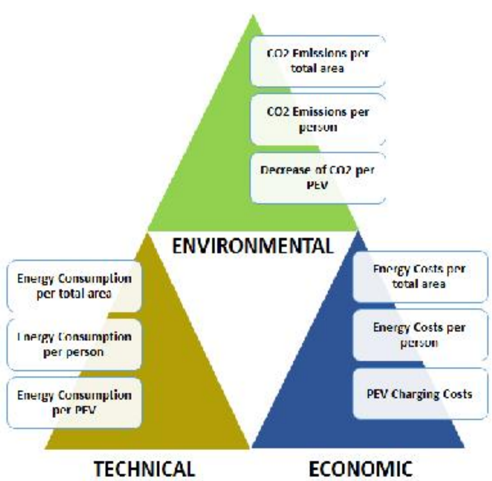

Fig. 6 Selection of technical, economic and environmental indicators

These indicators allow carrying out an assessment of energy efficiency with respect to variables that appear in different scenarios. It is important to highlight that indicators are mainly associated to the user.

In this phase of the work, a management strategy was implemented, in which residential users made a substitution of high energy consumption appliances by others with lower energy consumption in order to evaluate the effect that each scenario has over the indicators.

1) *Indicator of energy consumed per person*

a) *Scenario with conventional appliances*

A study of the main loads in a house was developed, obtaining nominal powers, time of use per day, and total energy in Wh/day as presented in Fig. 7.

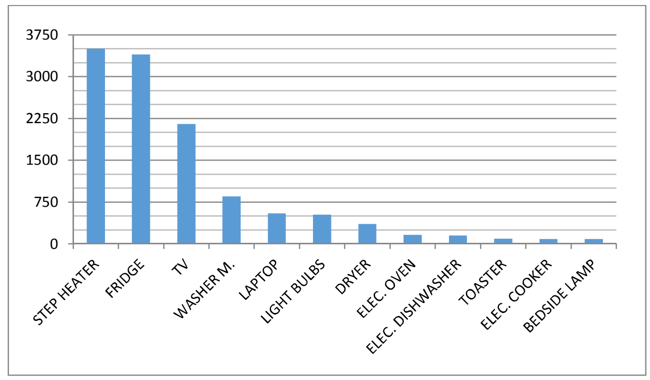

Fig. 7 Power consumption due to high consumption residential loads

Fig. 7 shows the appliances with the largest consumption representing a total consumption of 11.93 kWh/day. Other loads with lower energy consumptions, such as a blender, a coffee maker, among others, represent an approximate consumption of 0.66 kWh/day.

Therefore, conventional residential appliances consume about 12.59 kWh/day. Considering that each household has an average of three people, the energy consumed by each one is calculated using the equation (1):

$$Ec = \frac{Total\ Energy\ Consumed}{Number\ of\ people} \quad (1)$$

Then, for the indicator energy consumed per person (Ec) in the first scenario, a result of 4.2 kWh/day was obtained.

b) *Efficient substitution of appliances scenario*

The second scenario takes into account the same procedure to determine the energy consumed per person during the day, in which a management strategy per apartment is implemented by performing the replacement of appliances with more efficient ones. Fig. 9 shows that, in this case, high energy residential loads consume about 5.17 kWh/day and less impact loads consume about 0.78 kWh/day. The increment in the consumption of less impact loads (0.66 kWh/day to 0.78 kWh/day) is because some loads considered as high energy expenditure under first scenario became low energy expenditure due substitution in the second scenario. Therefore, the total energy consumption in the appliance substitution scenario is 5.95 kWh/day.

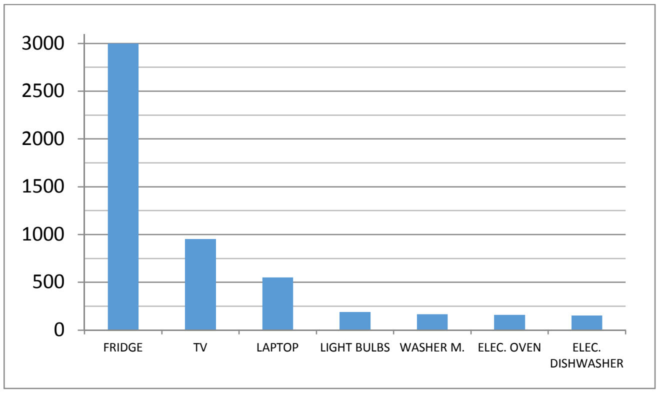

Fig. 8 Energy consumption implementing the replacement of residential loads

The indicator of energy consumed per person in the second scenario is 1.98 kWh/day. To evaluate the efficiency obtained by a management strategy for each apartment, equation (2) was used.

$$Saving = Energy_{Scenario\ 1} - Energy_{Scenario\ 2} \quad (2)$$

From (2), it was found that the technologic improvement in appliances can generate an energy saving of 2.21 kWh/day.

2) Indicator of energy cost saving per person

To perform an analysis of the economic indicator, the energy saving per person was obtained as shown in the previous section. In Bogotá, the value in US dollars per kWh consumed is 0.16 USD [18]. To calculate the economic indicator cost saving per person, equation (3) was used.

$$Cost\ Saving = Saving * Price\ per\ KWh \quad (3)$$

Results showed that one person is saving 0.34 USD, and 1 USD per household is saved daily, meaning that a home replacing appliances strategy would save 30.24 USD per month.

3) Indicator of energy consumed per PEV

To determine the energy consumed per PEV, the total energy consumed in each evaluated scenario (30%, 50% and 100%) and the number of PEV were used.

TABLE 2. ENERGY CONSUMPTION PER PEV

	Without PEV [kWh-day]	% PEN [kWh-day]		
		30%	50%	100%
Total Energy	2749.47	2891.97	2987.97	3260.97
Consumed Energy per PEV	0	5.9375	5.9625	6.39375

4) Indicator of PEV charging costs

To set PEV charging costs per day, the energy value per kWh consumed of 0.16 USD [18] and the energy consumed by PEV defined in the previous indicator are taken into account.

TABLE 3. PEV CHARGING COST

%PEN		
30%	50%	100%
$ 0.95 USD	$ 0.954 USD	$ 1.02 USD

Table 2 shows that the energy consumption can be considered constant, independent of the different penetration levels. Therefore, the cost of recharging a PEV was $30 USD per month.

C. Summarized Results

Finally, the most significant results obtained in this work are:

Voltage regulation improved when charging stations for PEVs are implemented in the parking lots, although voltage always remained within the limits established by Colombian regulation.

Losses in the system reduced between 40% and 50% due the improvement of the voltage profile in charging nodes, and therefore conduction losses decreased. In addition, management strategy restricts the maximum demand on the system, up to the nominal power of the transformer, helping to improve its useful life.

It is possible to improve efficiency by replacing appliances achieving a saving of 2.21 kWh/day per user.

CONCLUSIONS

For evaluating management strategies, it is necessary to adjust the regulatory framework and technical constraints of the system, additionally energy efficiency indicators from different perspectives is important too, since it allows establishing the strengths and weaknesses when these strategies are implemented.

With the inclusion of PVEs, energy consumption increases and an overload can occur. Therefore the implementation of management strategies is necessary in order to remain within the operation limits.

When management strategies and plans are implemented, energy efficiency and savings can be achieved in energy costs, regardless of the PEV penetration level.

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