Energy Resource Management Integrating Generation, Load Control and Change in Consumption Habits at the Residential Level

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Abstract- This paper presents the design and development of a scenario where the residential user is involved, with three fundamental elements such as home energy management systems (HEMS), photovoltaic (PV) systems and efficient behavior by means of changes in consumption habits. The objective is to analyze its impact on the household electricity conservation through programs focused on active demand side management (ADSM). The proposed scenario starts from incentives arisen from changes in consumption habits of all the load by 30%, the control of automatic loads and energy self-generation in two different locations in Colombia: Bogota and Cajica. As a result, a monthly reduction of 35.49% is observed in relation to the habitual consumption when the user modifies his habits of using energy in his residence.

1. Introduction

The population of the planet is increasing and therefore energy consumption. The construction and operation of buildings are responsible for 40% of total primary energy consumption and 30% of greenhouse gas emissions [1]. A large amount of electrical energy is misused due to behavior, attitudes and cultural tendencies of people.

However, they have become aware of the Earth and the importance of solar radiation to regulate the climate, since the exchange of energy between the atmospheric pressure and the surface of the Earth causes an imbalance. This exchange has been affected recently due to the greenhouse effect [2], with measurable results like the decrease in solar irradiance.

It is possible to save energy through the change of energy consumption habits from 3% to 20% approximately as stated by the authors in [3] Other researchers have emphasized efficient energy consumption in order to save between 10% and 24.12% by combining scenarios that integrate design alternatives with the change of habits as exposed in [4]. In [5] they observed that usage habits of household appliances have a direct impact on energy efficiency: the greater the degree of influence of the equipment, the lower the efficiency.

Another important element is the smart grid, which through systems that monitor and control energy provide detailed information with bidirectional communication for the reduction of the maximum demand, through smart metering [6].

Energy management through change of habits is effective, specifically in the residential sector [7]. It also provides flexibility and active contribution of the consumers in order to extend the efficiency of the system [8]. There are initiatives to strengthen changes in energy users such as Active Demand Side Management (ADSM). This is an effective manner to use energy through programs designed to regulate the optimization of resources by integrating generation mechanisms such as photovoltaic systems and load control [9], by means of home energy management systems (HEMS), which provide information on end-user energy consumption in order to feed back and see the impact of demand [10]. It is equally important to combine the costs associated with the uncertainty of distributed generation and the costs of CO2 emissions expected because influence in decision-making on investment returns and the value of money over time [11].

This study presents the results of implementing two types of active demand management programs, in order to analyze the behavior when residential users apply energy consumption habits and how PV systems and HEMS influence the programs. The work is structured as follows: Section 2 presents the methodology and the analysis approach, Section 3 describes the results and discussion, and Section 4 presents the conclusions.

2. Methodology and Analysis Approach

There are several active demand management programs to implement, such as social, where the state finances the technology and it is supported by the collection of taxes. Another option is to transmit the risk to the market, that is to say that the provider covers the costs of the devices [12].

The proposed scenario starts from incentives arisen from changes in consumption habits of all the load by 30% during the day, the control of automatic loads and energy self-generation in two different locations in Colombia, South America: Bogota and Cajica. The development of the scenario is based on the methodology presented in Fig.1; it shows ADSM programs as the central axis, based on consumption habits, HEMS and PV systems, as well as the possible impacts on the load curve, at the economic and environmental levels due to their implementation during the following periods: 6:00-9:00 and 18:00-21:00.
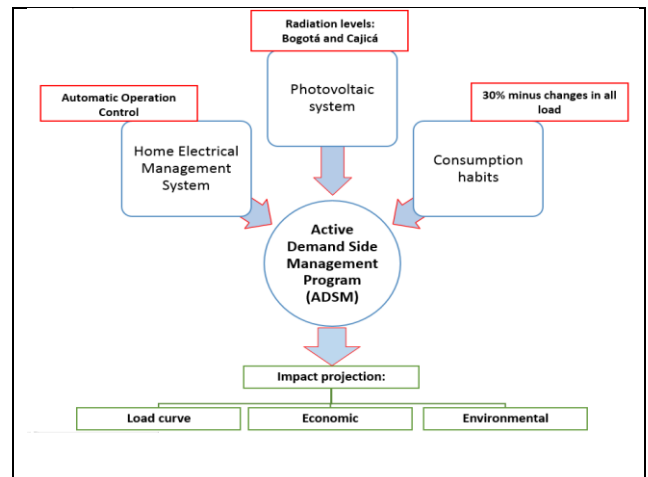

Fig.1. Methodology developed in the research.

The following are the main elements required for the projection of the scenario in order to evaluate the effects of ADSM programs in the cities analyzed. However, it must be borne in mind that the responsibility of the operators of the system is to guarantee the reliability of the supply, despite the fact that there are other types of energy supply such as renewable energy, since their production may change unexpectedly [13].

2.1 Simulation of changes in consumption habits reducing 30% of the entire load

A simulation was established for the changes in the consumption habits of the entire load of the residence, in which the user varies the use of his appliances 30% minus throughout the day. For that purpose, a stochastic model was previously developed in PowerSim® software to verify the random behavior of consumption, as shown in Fig. **2**. Consumption of 110.32 kWh/month was determined, equivalent to a monthly reduction of 35.49% in consumption compared to the base curve with an average value of 171.1 kWh/month.
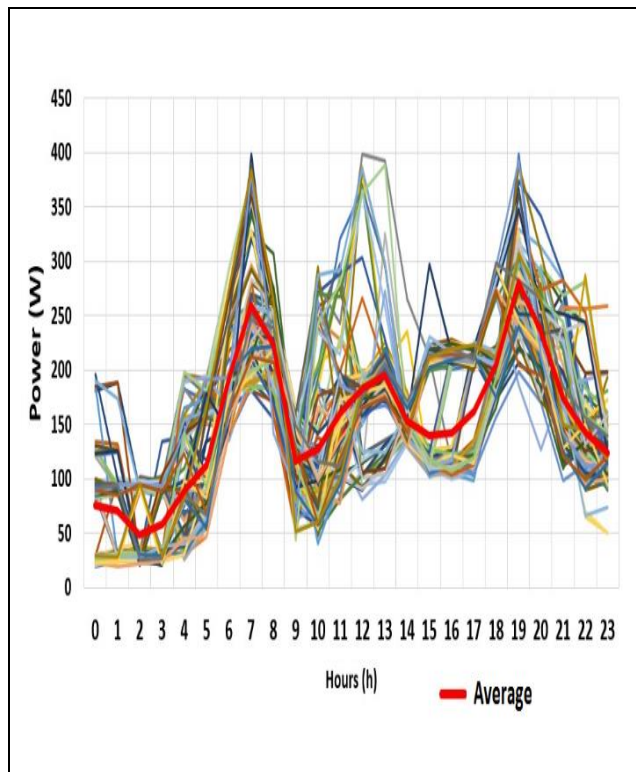
Fig. 2. Simulation: 30% minus in consumption habits in the entire load per day

2.2 Home Energy Management System (HEMS)

HEMSs relate networked appliances for remote management [14]. In 2015, Putra et al. [15] developed a prototype system capable of controlling and supervising appliances; this system reduces consumption by 59%. In 2016, Lee et al. [16] presented the relation of an HEMS and its energy saving; they concluded that a saving of 39.5% is obtained in artificial lighting systems. In [17], other authors expose the strategy that includes deferrable loads and energy storage, with reductions between 19.06% and 39.90%, to relate the cost, effectiveness and comfort. In 2017, Abubakar et al. [18] presented a review of the scientific literature on energy management through automatic load control showing savings of 10%. Therefore, automatic control was chosen for this research, with a reduction of 10% in the two periods of analysis (6:00-9:00 and 18:00-21:00).

2.3 Photovoltaic System Design

The use of renewable energy sources increases due to the depletion of natural resources and increasing contamination level of energy production [19]. Developed countries promote distributed generation systems, but it is recommended to control the production of energy in order to reduce impacts on grid and energy markets [20].

A photovoltaic system with a storage capacity of 4,800 Wh per day, three panels CS6X-320P with nominal power of 320 W, inverter of 1,000 W and the regulator of the system was established, so as to observe its behavior according to the irradiance levels of the analyzed places. The costs of the system, including those related to the structure and the assembly, are projected at US 2,301.81. The supply of the proposed photovoltaic design is simulated with the irradiance data; this data is used to calculate the approximate energy produced by the PV system: for Bogota, 114.54 kWh/month and for Cajica, 121.47 kWh/month.

3. Results and Discussions

Two initiatives of ADSM programs are proposed. The first includes HEMS and PV systems. The second, in addition to the two systems, includes the changes in consumption habits. Each of them is explained below. For calculations, the number of subscribers in Cajica: 1,994 [21] and in Bogota: 219,842 [22], as well as the average basic tariff: US 0.15/kWh [23] for the month of August 2016, were considered. However these projections, due to the variable nature of solar radiation, the energy production of photovoltaic solar energy fluctuates, that is why the cost of energy can change at different times [24].

ADSM Program with HEMS and PV system

According to this program, the approximate saving percentage of monthly consumption is 53.13%, with the possibility of injecting the surplus energy generated in Bogota (15.52 kWh/month) and Cajica (21.06 kWh/month) into the grid.

ADSM Program with HEMS, PV systems and consumption habits

This program includes changes in consumption habits, reducing energy use by 30% throughout the day with a monthly saving of 65.12% in both places and surpassing the first program by 12%. Fig. *3* shows the comparison of the load curves generated in relation to the base curve. As can be seen, when the changes in consumption habits, HEMS and PV systems are combined, the curve would be impacted in the periods of 6:00-9:00 and 18:00-21:00, since all consumption is assumed by renewable energy.
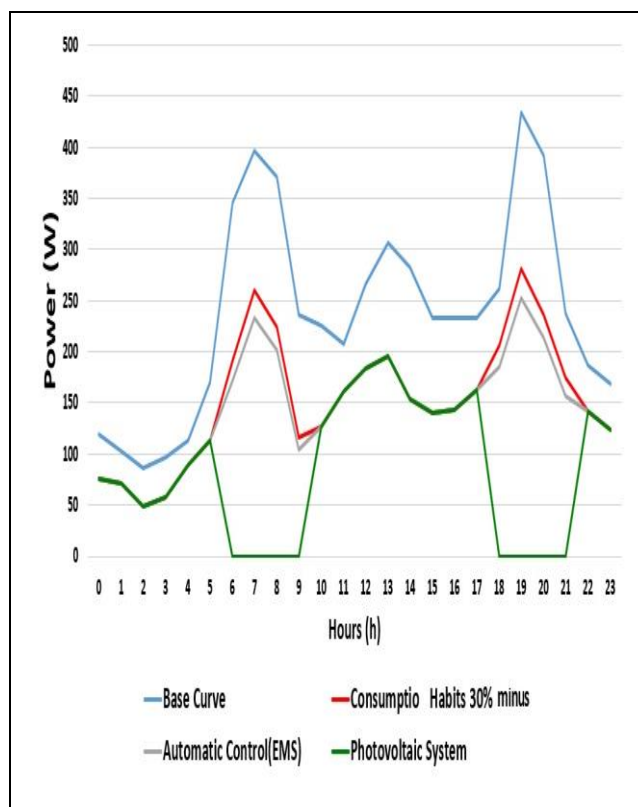
Fig. 3. Impact on the curve with ADSM programs

Table 1. Saving when performing ADSM programs

GAD Program	BOGOTA	CAJICA	BOGOTA	CAJICA
	HEMS and PVS (US)		HEMS, PVS and Consumption habits (US)	
Incentive feeding surplus to grid / year (US$)	$ 11	$ 15	$ 33	$ 376
Money Saving Year (US$)	$ 145	$ 145	$ 202	$ 202
Incentive + Saving / year 1 user (US$)	$ 157	$ 161	$ 236	$ 240
Incentive + Savings / month Total Users (US$)	$ 2.880.611	$ 26.798	$ 4.328.558	$ 39.931
Incentive + Saving /Year Total Users (US$)	$ 34.567.333	$321.579	$51.942.699	$479.176

3.1 Economic impact when implementing ADSM programs

Different experiences were verified to pay users for the energy injected into the grid. In Spain, the government pays 5.75 times the purchase cost for 1 kWh [25]. The United Kingdom and Denmark pay 50% of the commercial price for surpluses [26]. In Chile, surpluses have a value close to 40% of which electricity is purchased [27], in addition, it has promoted renewable energy and attracted foreign direct investment for large-scale projects, in order to increase energy security, supply electricity to remote mines and lower energy costs [28]. In Argentina, there is legislation for each province; in Santa Fe, for instance, the energy generated at the purchase price in the electricity market is deducted from the bill [29]. Uruguay, by Decree 173/2010, pays the same price of the energy charge for 1 kWh. [30]. According to this, the payment for the surpluses injected is projected at 40% of the base price, based on the case of Chile as its conditions are similar to those of Colombia.

Table 1 shows the saving values that can result when performing ADSM programs in the residential sector. The incentive received for injecting power into the grid is a little higher in Cajica since that area receives more solar irradiance than Bogota. The dimension of saving will actually occur if a sufficiently large group of users come together to implement these programs.

The financial projection of the feasibility of the design of a PV system was carried out, considering: Battery replacement costs every five (5) years, 25-year projection related to the useful life of the panel, variation of prices according to the consumer price index (CPI) for Colombia of 5.75% in 2016 [31], the opportunity interest rate (OIR) by 10%, the cost of the HEMS by US 414.77 with source switching system and eight outputs, and the cost of the grid injector by US 345.64. To carry out the cash flow for different years, the collection and saving of the first year per user were projected, when there are or are not consumption habits (

	ADSM without consumption habits		ADSM with consumption habits	
	Bogotá	Cajicá	Bogotá	Cajicá
Energy Saving by Habits kWh/ month	0	0	60,69	60,69
Energy Saving by HEMS kWh/ month	4,04	4,04	5,07	5,07
Energy Saving by PVS periods 6-9 and 18-21 hours kWh/ month	76,11	76,11	45,60	45,60
Energy surplus PVS kWh/ month	15,52	21,06	46,03	51,58
Bill savings ADSM / month (US$)	$ 12,16	$ 12,16	$ 16,90	$ 16,90
Money when feeding surplus to the grid month (40%) (US$)	0,94	$ 1,28	$ 2,79	$ 3,13
Total money / year (US$)	$ 157,24	$ 161,27	$ 236,27	$ 240,31

).

Table 2. Projection of the annual value collected per user from ADSM programs.

	ADSM without consumption habits		ADSM with consumption habits	
	Bogotá	Cajicá	Bogotá	Cajicá
Energy Saving by Habits kWh/ month	0	0	60,69	60,69
Energy Saving by HEMS kWh/ month	4,04	4,04	5,07	5,07
Energy Saving by PVS periods 6-9 and 18-21 hours kWh/ month	76,11	76,11	45,60	45,60
Energy surplus PVS kWh/ month	15,52	21,06	46,03	51,58
Bill savings ADSM / month (US$)	$ 12,16	$ 12,16	$ 16,90	$ 16,90
Money when feeding surplus to the grid month (40%) (US$)	0,94	$ 1,28	$ 2,79	$ 3,13
Total money / year (US$)	$ 157,24	$ 161,27	$ 236,27	$ 240,31

Assuming that the user does not make changes in consumption habits, the return on investment occurs in both places in 21 years. When making the projection for the return on investment over 20, 15, 10 and 5 years, the net present value (NPV) gives negative values and the projected kWh prices for these periods are very high: US 0.67 approximately. Regarding the internal rate of return (IRR), it was never equal to the OIR in the calculations, so the investment is not feasible.

When considering changes in consumption habits, the return on investment occurs in both places over 15 years, that is, 6 years less than if changes in consumption habits were not made. However, when making the projection of the return on investment over 10 and 5 years, the NPV gives negative values; the projected kWh prices always exceed the price considered as base and the IRR was not equal to the OIR (

	BOGOTÁ			CAJICÁ		
Years	Price (US)	NPV (US)	IRR	Price (US)	NPV (US)	IRR
10	$ 0,21	- $ 738,78	4%	$ 0,21	- $ 737,89	4%
5	$ 0,45	- $ 650,45	0%	$ 0,44	- $ 650,88	0%

). Therefore, the investment is not feasible.

Table 3. Projection of return on investment when making changes in consumption habits

	BOGOTÁ			CAJICÁ		
Years	Price (US)	NPV (US)	IRR	Price (US)	NPV (US)	IRR
10	$ 0,21	- $ 738,78	4%	$ 0,21	- $ 737,89	4%
5	$ 0,45	- $ 650,45	0%	$ 0,44	- $ 650,88	0%

The implementation of ADSM strategies requires the investment of PV systems and HEMS by the residential users. The cost of the photovoltaic system does not make this kind of projects feasible. However, a new financial

analysis was carried out with the assumption that the government would contribute 100% of the PV system and the grid injector as an incentive to the home user.

The financial projection was performed. The results indicated that the return on investment would occur in two years for both places, being Cajica the most appropriate given its higher solar irradiance. In all projections, the NPV and the IRR give favorable values, with rates above the OIR, which represent good behavior of the investment of the user (see

	BOGOTÁ		CAJICÁ	
Years	NPV	IRR	NPV	IRR
25	US $ 2.986,45	63%	US $ 3.044,56	64%
20	US $ 2.516,03	63%	US $ 2.566,10	64%
15	US $ 1.943,17	63%	US $ 1.983,45	64%
10	US $ 1.245,57	61%	US $ 1.273,93	62%
5	US $ 396,05	48%	US $ 409,90	49%

).

Table 4. NPV and IRR projection with incentives from the Government

	BOGOTÁ		CAJICÁ	
Years	NPV	IRR	NPV	IRR
25	US $ 2.986,45	63%	US $ 3.044,56	64%
20	US $ 2.516,03	63%	US $ 2.566,10	64%
15	US $ 1.943,17	63%	US $ 1.983,45	64%
10	US $ 1.245,57	61%	US $ 1.273,93	62%
5	US $ 396,05	48%	US $ 409,90	49%

3.2 *Impact on the environment*

Regarding the impact on the environment, the emission factor of the energy production process for polycrystalline silicon (p-Si) panels was considered; these panels were selected for the PV system design. For this study, the factor proposed in 2016 by the authors in [32] was used; it was 56 g CO_2/kWh, one of the most recent. Regarding the emission factor of the interconnected system, the one established by the Colombian regulations was employed: 0.388 Ton CO_2/MWh in 2016 [33].

A comparison was made between the two places analyzed by applying the respective emission factors according to the following characteristics: average irradiance, average energy storage, projection of energy consumption in the periods of 6:00-9:00 and 18:00-21:00, surplus or deficit energy and emissions of CO_2. Regarding the PV sysem, it is observed that there are more CO_2 emissions in Cajicá due to its higher irradiance level for energy generation.

When comparing the use of PV systems with the interconnected system, the emissions decrease approximately between 77% and 78% per day, since 354,374.03 g CO_2/kWh per year are no longer emitted. This contributes to the environment even though it is not economically feasible (see Table 5).

Table 5. CO_2 emissions by using PV systems

BOGOTA	CAJICA

Generated Total PVS kWh/years	1374,50	1457,63
Emissions g-CO_2 / kWh year PVS	76,972,05	81,627,55
Emissions g-CO_2 /kWh year Interconn System - not produc	354,374,03	354,374,03
Difference g-CO_2 /kWh	277401,98	272746,48
Contribution Percentage of to be used PVS	78%	77%

4. Conclusion

When developing ADSM programs involving HEMS, PV systems and changes in consumption habits, monthly savings of 65.12% per residential user can be obtained. Strategies to promote these changes do not represent additional costs and are an option to meet the demand instead of increasing energy generation. However, the dimension of savings in monetary terms actually occurs if a sufficiently large group of users come together to implement these programs.

Developing ADSM programs can lead to higher costs and the response is not guaranteed on lower electricity bills. As a result, consumers are not motivated to rationalize consumption or to invest in devices whose financial feasibility is negative, despite the proliferation of locally generated energy at the residential level; this gives the opportunity to supply its surplus electricity to the grid. Replacing power generation by friendly technologies may not imply a lower bill but future contributions to the environment; for instance, this study shows that in the periods analyzed emissions decrease approximately between 77% and 78% as 354,374.03 g CO_2/kWh per year are no longer emitted.

It is important that the government propose incentives for residential users on the use of renewable energy, which must be accompanied by other elements such as HEMS and changes in consumption habits. This results in very favorable values of NPV and IRR, with rates above the IOR up to 64%, which means a good behavior of the investment of the user.

Acknowledgements

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