Efficient Home Energy Management based on Incentives of the Colombian Law 1715/2014[1]

Gestión eficiente de energía eléctrica domiciliaria con base en los incentivos de la Ley colombiana 1715 de 2014[2]

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Abstract

This paper proposes a home energy management model called GEDE, outlined in the Colombian Law 1715/2014. Different operation ways that can be applied in the proposed residential energy system are presented. The system has a variable topology, so that it is fed by distributed generation sources or by the interconnected system, and they are related to a control system. Three scenarios were analyzed: (1) Distributed generation during peak hours and the user manually activates the system; (2) the user decides to connect several loads that require high power levels in peak hours, and then the service of distributed generation is reserved until this hour to supply the high power, thus this scenario is semiautomatic, and (3) the system saves energy in an autonomous way through intelligent infrastructure controlling the appliances and lighting utilization. This proposal allows providing new energy consumption patterns through mechanisms that make a significant contribution to the efficient energy by utilizing monitoring, control, and supervision techniques together with distributed generation. In the proposal household users participate making decisions related to energy consumption and generation, through the incentives provided by Law 1715.

Keywords

energy efficiency; distributed generation; Colombian Law 1715; energy value chain; smart infrastructure.

Resumen

Este artículo propone un modelo de gestión de energía eléctrica domiciliaria (GEDE), en el marco de la Ley colombiana 1715 de 2014. Se plantean diferentes modos de operación que se pueden aplicar en el prototipo sugerido de la red de energía domiciliaria. El sistema es de topología variable, de manera que se alimenta por fuentes de generación distribuida o por el sistema interconectado, y se relacionan con un sistema de control. Se analizaron tres escenarios: 1) generación distribuida en una hora pico, donde el usuario activa el sistema manualmente; 2) cargas prioritarias, donde el usuario decide qué conectar en las horas pico, y el servicio de generación distribuida se reserva para estas horas (este escenario es el semiautomático), y 3) sistema autónomo, donde se ahorra energía por medio de infraestructura inteligente que controla el uso de electrodomésticos e iluminación. Se prevé aportar nuevos esquemas de consumo de energía mediante dispositivos que aporten a la eficiencia energética empleando técnicas de monitoreo, control y supervisión de la energía, unidas a la generación distribuida. En esta propuesta, los usuarios domiciliarios tendrán participación en la toma de decisiones energéticas relacionadas con el consumo o generación, por medio de los incentivos ofrecidos en la Ley 1715.

Palabras clave

eficiencia energética; generación distribuida; Ley colombiana 1715; cadena de valor energética; infraestructura inteligente.

Introduction

In May 2014, the Colombian Congress issued Law 1715, which regulates the integration of non-conventional renewable energy to the national energy system with the intention to promote efficient energy management through taxation mechanisms, cooperation arrangements, and investment incentives. This law also aimed to promote investigation in the production and use of non-conventional energy resources. This law consists of ten chapters divided into 46 articles [1]. In titles 1 and 2, the ruling for electricity generation and the incentives for the investment in projects of non-conventional energy sources are described and synthesized like this: Promotion of small scale self-generating and distributed generation, delivery of energy surpluses, bi-directional metering systems, and simplified connection mechanisms; incentives for non-conventional energy generation; and tax incentives. At this time, there are changes of technological nature that point to move from conventional distribution network to the smart grid. Likewise, the home electrical installations must be modernized into management systems that allow processes to measure, monitor, and control in order to help users in making decisions about consumption and/or generation. The model that is proposed in this paper helps with the integration between technology and norms. The residences in Colombia should be prepared for the changes that must deal with distributed generation and obtain the potential benefits that the regulation can offer to the Law 1715/2014.

This paper presents the preliminary operation of an experimental scale prototype, which is based on the proposal of the model of home energy management called GEDE. The model involves distributed generation for self-supplying, communication protocols, sensors, and intelligent metering systems. Also, the model allows the interaction between the end user and the electric energy value chain, offering a new role as an active user and being able to manage generation and/or consumption transactions. With the operation of the experimental prototype presented in this paper, the implementation of the following scenarios is observed: In the first scenario the energy generated by the self-generator is used in the peak hour adjusting the system in a manual way. In the second scenario, the user decides to connect several loads that require high power levels in peak hours and the service of distributed generation is delayed one hour to start from 19 hours. In the third scenario, the active user implements the management system in an automatic mode saving energy consumed by appliances and lighting systems.

1. Introduction

The modernization of the electric energy value chain (generation, transmission, distribution, and end user) [2], is a new scenario where energy sources coming from Distributed Generation (DG, non-conventional renewable sources) and from the interconnected system are integrated. In this scenario, a monitoring and metering intelligent infrastructure is needed, together with information and communication technologies [3] to contribute with the energy efficiency, managing the new bi-directional flow of electric energy.

Monitoring and metering infrastructure along with Information and Communication Technology (ICT) are supported in Smart Grids, which are an improvement in the infrastructure of the energy supply system [4], and in communication, software, and hardware intelligent systems. This contributes to the incorporation of new energy services to the energy value chain, as well as their diversification and expansion, with strategies to obtain competitive advantage as the expansion in related areas (gas and water), and new telecommunication business to be offered together with energy [5]. Home Energy Management Systems (HEMS) use domiciliary electric energy with energy efficiency principles together with Advanced Metering Infrastructure (AMI) [6]. This allows the user to interact in real time with appliances in a remote or centralized way, based on the combination of the original grid and the internet to save energy [7]. Since recent years, there has been an increase in the works about home management electric systems. The most important advances in this field for the last years are presented in [8].

1.1. Metering and Monitoring Infrastructure

AMI is used for demand management [9] and it integrates technologies such as: smart meters, communication in grids of different hierarchy levels, data management systems, and platforms of software applications. Moreover, the sensors have functions such as detection, calibration, self-testing, desicion making, communication, and even their combinations [10]. Algorithms based on pattern recognition are used too and are implemented together with an infrastructure of sensors allow monitoring the appliances demand in order to meter the variation of electric parametres when those appliances are on or off [11], [12].

In this regard, in 2013, a system for Internet access gateways which receives and propagates the consumer information for integration with smart grids was developed, allowing households to implement technologies such as AMI and Virtual Power Plants (VPP) [13]. Furthermore, in 2014 a distributed demand response system was proposed; it includes an AMI for each user in order to measure electricity consumption. It also shows pricing through an energy management controller that facilitates communication between devices [14].

1.2. Communication Protocols

Energy Management Systems use protocols, which are procedures used for the communication between appliances connected to the grid [15]. Communication protocols guarantee the information reliability in real time, with the purpose of monitoring, controlling, and supervising the appliances connected to the grid [16]. For example, in 2012, the Autonomous Balancing of Load Energy (ABLE), which provides feedback of energy consumption for users, was developed [17]. Additionally, Wireless Communication Technology (WCT) allows the measurement of electrical parameters, such as voltage and power, and the wireless transmission through ZigBee protocol by current appliances [18].

1.3. Software Algorithms

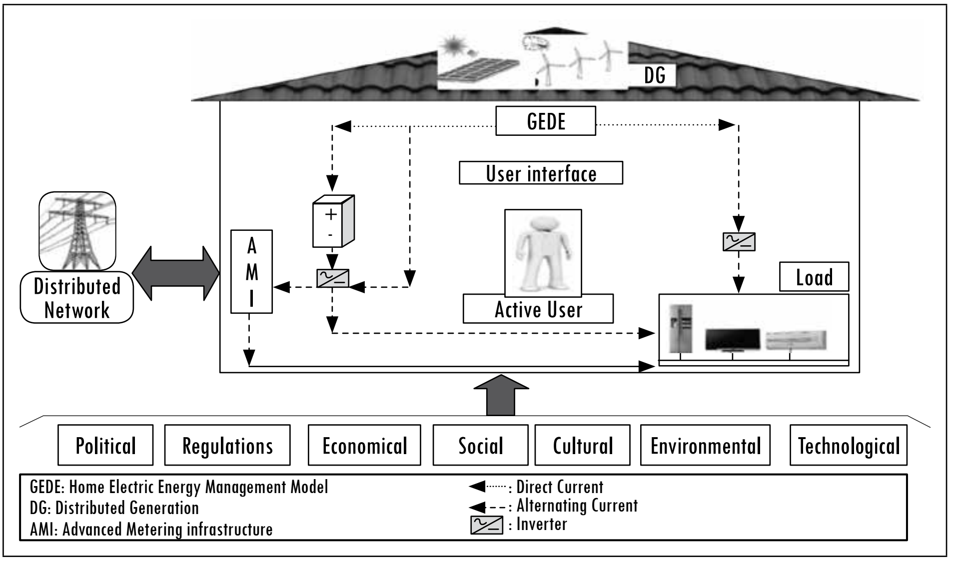
The implementation of simple software algorithms together with an intelligent infrastructure at home and sensors for controlling, monitoring, and supervising electric variables allows the consumption reduction during peak hours [19]. It is possible to find in scientific literature different developments in this area; authors such as [20] show a software algorithm for load desagregation that compares each change of operating range of the appliance with the total energy signal. Other authors propose software models based on neural networks that look for scenarios in different conditions to find the best energy efficiency and demand response [21]. Some developments employed in this kind of systems are: Service Oriented Architecture (SOA), which is an approach for building distributed systems [22]. Furthermore, the Intelligent Energy Management System (IEMS) proposed in [21] is able to find the best energy-efficiency scenario in different situations.

2. Model of Home Energy Management

Different authors have oriented the electric energy management models towards aspects related to component architecture, communication protocols, software development, and relation with the end user. However, the work in the interaction among all these aspects and with monitoring, control, and supervision elements of appliances is in development. The goal is to guarantee information reliability in real-time through up-to-date computing tools [23].

Figure 1 presents a home energy management model: GEDE [24], which comprises infrastructure, communication, and a software algorithm for data control, monitoring, and supervision. This model involves Renewable Energy Sources (RES), which are part of the electric system by means of self- generation for self-consumption or delivering energy surpluses to the distribution system, bi-directional measurement systems, and simplified connection mechanisms. In the new Colombian context, the model allows the active user to interact through aggregators with the energy market contributing with the demand response strategies [25].

Figure 1. Model of home energy management: GEDE



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GEDE works in an automatic, semi-automatic, or manual way, depending on the active user necessities according to the possible consumption and/or generation scenarios. The Active User can make decisions involving consumption or generation. Also, the Active User can respond to price signals and economic incentives, changing standards of consumption in peak hours or when lower costs are offered, and also sells energy surpluses. In the case of GEDE, any user can participate through an aggregator, which receives information from all active users and market, and executes management strategies at the distribution grid level. The energy consumed in the house has two supply sources: From the distribution system or through distributed generation (solar panels or wind turbines); additionally, these energy resources can be stored in battery banks or they can be consumed in a direct way.

In the proposed model, the influence of external variables on the system is observed. Some of the variables observed are: political, regulatory, environmental, economic, social, cultural, and technological. In this preset work, however, the impact of only the first three factors on the electrical system are assessed:

- Political: The tendencies of the State to implement models of home energy management to enhance possible weaknesses in this sector for society.
- Regulations: Laws, norms, or rules influencing in a direct or indirect way over this type of home management initiatives, such as Law 1715/2014.
- Environmental: The pollution reduction utilizing distributed generation in houses as well as strategies to reduce electric energy consumption.

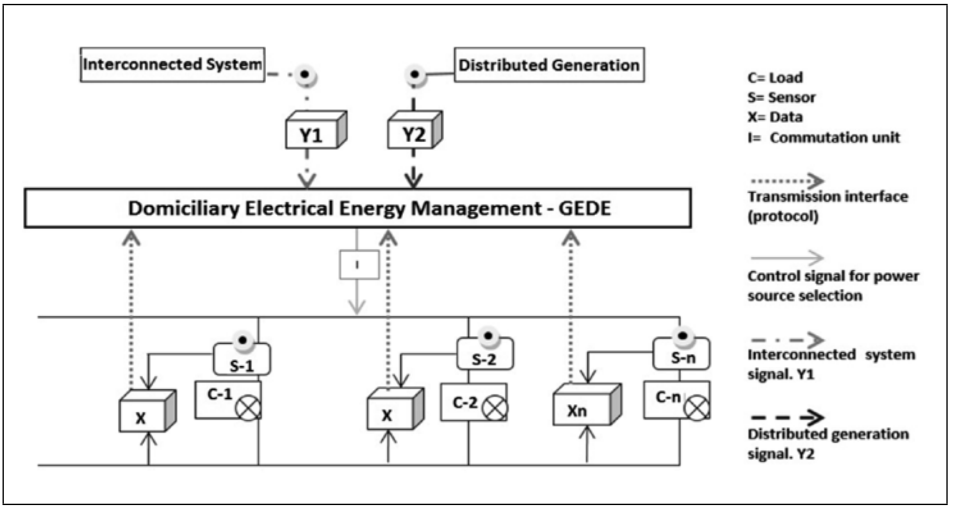
This model involves infrastructure and communication elements, which are based on the promotion of distributed generation that contributes with energy efficiency.

2.1. Infrastructure of the Home Energy Management Model

The infrastructure components for the management system must allow the capture of reliable data in real time. Figure 2 shows a block diagram for the infrastructure of the GEDE model, where the energy source is selected through the control signal to select the source, which has two options: from the interconnected energy system (Y1) or through the distributed generation (Y2) installed at home. The central processing unit, the core of GEDE called Domiciliary Electrical Energy Management, is located in the middle of the Figure. In that place, data is recorded and analyzed, and management strategies are executed. The system manages the loads (C) according to the necessities of the "active user," they are connected to a sensor of electrical variables (S) that sends the data

(X) though the transmission interface or communication protocol to control, monitor, and supervise through the management system-GEDE.

Figure 2. Blocks diagram – infrastructure of the GEDE model



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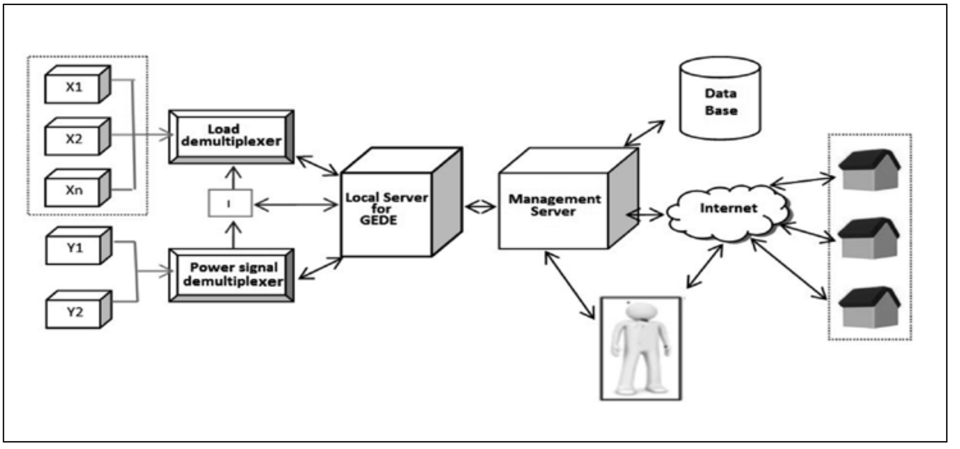
2.2. Communication of the Home Energy Management Model

An important aspect for the implementation of the energy management model GEDE is the utilization of protocols adjusted to the reference model Open System Interconnection (OSI). In Figure 3, the blocks diagram of the communication scheme GEDE is presented, where a demultiplexer takes state signals of load operation in order to obtain voltage and current data acquired by the sensors. Likewise, there is a demultiplexer for power signals, which constantly registers the basic parameters of the different supply sources. At this point the energy generation using non-conventional sources proposed by Law 1715 is included as one of the contributions of the presented model. The model also has two servers: the "management server" that manages the electrical variables to be monitored, controlled, and supervised by the active user in a centralized or remote way having the registered signals in a database; and the "local server for GEDE," which determines or establishes the way in which the energy transfer between sources and loads must be done according to an algorithm.

Figure 3. Blocks diagram of the communication model GEDE



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Taking all of the above into consideration, if the conditions of the resources allow it, after satisfying the users' own consumption, the system decides if it is convenient to deliver the surplus energy to the distribution grid.

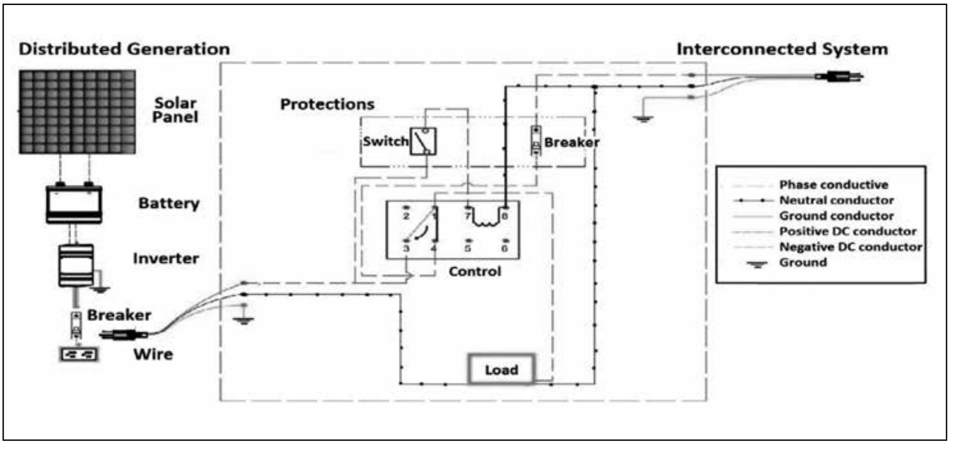
In relation with the transference of variables the following protocols are used: "http" (Hypertext Transfer Protocol), for the application level; "TCP/UDP" (Transmission Control Protocol/User Datagram Protocol), for the transport level; "IP" (Internet Protocol), for the network level, and "Ethernet" variations, for the link level. In the physical level, supported modulation for power line communication PLC is used. In the process of integration with the network operator or the connection to any other environment, industrial protocols, such as Modbus and Profibus are used. The system allows the acquisition and storage of basic data such as voltage, current, phase, and system frequency to determine power and energy, in order to establish the contribution to the energy efficiency of the system based on the use of renewable energy generation and in the hourly rate variation established. The methodological process to be implemented using data from the system for decision-making is as follows:

1. Data is obtained by the system, which is done in the management server.
2. Management scenarios are established according to efficiency strategies.
3. Data is processed.
4. Decisions are made by the user or the system according to different alternatives: manual, automatic, or semiautomatic.

3. Results

For this paper a prototype was developed where the system counts on the energy provision coming from the distributed generation, which is supported in the Article 8 of Law 1715 by means of one of the mechanisms for the promotion of small scale self-generation. Figure 4 shows the physical components of the prototype proposed to supply a load through two feeding types in order to be a variable topology. On one hand, there is a distributed generation source by means of a solar panel and on the other hand there is a source from the interconnected system. These sources are connected to the control system proposed to supply the load at home. The developed prototype is manually operated, this means that the user controls the energy he wants to use based on indicators such as prices and DG availability; however, this process can be made automatically or semi-automatically.

Figure 4. Component Diagram of the hybrid system (photovoltaic – interconnected)



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A solar panel connected to a battery and an inverter correspond to the distributed generation. It is connected to a control system that has the following components: an electromechanical relay for the commutation of the supply source, a protection set in case of short circuit, the load and the manual switch that allows to make the change of supply source. Table 1 shows the specifications of the developed prototype.

Table 1. Specifications of experimental scale prototype

PV panel	Peak Power (Pmax): 5W, Maximum Power Current (Imp): 0.27 A, Maximum Power Voltage (Vmp): 18.36 V
Battery	Nominal voltage: 12 V, Capacity: 1.2 Ah, Energy capacity: 14,4 Wh
Inverter	Input Voltage: 12 V, Output Voltage: 120 V, Frequency: 60 Hz, Efficiency 85 – 90%, Power: 300 W, Current: 2.72 A
Protection	Current: 6 A, Voltage: 120 V, Operation Level: Until 230 V

Source: authors' own elaboration

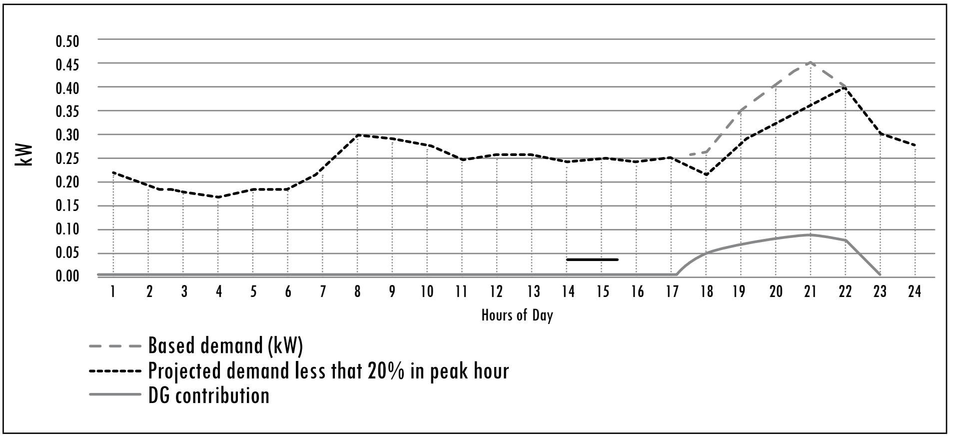
Many interesting scenarios can be explored in GEDE. However for this paper three of them were taken into consideration. The first scenario works with distributed generation during a peak hour according to the user needs; in the second scenario the user selects the critical loads that must keep connected during peak hours while the other loads are disconnected and their usage is postponed until the next hour; and the third scenario, has approximately a 10%- contribution to energy savings during the day due to the use of sensors that send information to reduce the consumption in lightning systems, decrease the luminous intensity in different places of the home, turn off appliances that are not being used, etc.

3.1. Scenario 1: Users with DG and Reduction during Peak Hours

Manual operation has technical and economic implications for the consumers. For example, in the first scenario the goal is to reduce the peak hours of the distribution system during peak hours [26]; in this way, the demanded energy by the user during peak hours (18-22 hours) is mainly supplied by the distribution system (red line), but 20% of the demand is provided by the DG of each user, without affecting the energy supply at any moment, as shown in Figure 5. This indicates that the implementation of this kind of strategies in a large scale with many users, given the incentives established in the Law 1715, would contribute to the different processes in the chain value of electric energy.

By supplying 20% of the demanded energy in this period of time: 18-22 hours, with distributed generation systems, an approximate energy contribution of 0.292 kWh is made. It is important to highlight that in this scenario a reduction of the consumed energy is not evidenced, therefore, there are no benefits in terms of energy efficiency for the user. However, an important reduction in the energy consumption for the distribution system is clearly observed, which produces system loss reduction and an increment in the availability of the existing infrastructure, delaying the required investments for the expansion of the system capacity, consequently it helps to protect the environment.

Figure 5. First scenario – Reduction of the peak hours through DG implementation



Source: authors' own elaboration

3.2. Scenario 2: Users with DG and Demand Response Automatic

In the second scenario, through a strategy of active demand management, which aims to provide more flexibility and active participation of electrical consumers [27], the user decides to connect several loads that require high power levels in peak hours and the service of distributed generation is delayed one hour to start from 19 hours (Figure 6). Installed power in addition to the distribution system and DG keep the same conditions as in the previous scenario, while the demand reaches a peak value of 0.450 kW at 21 hours, and therefore it is necessary to shed non-critical loads in such a way that peak hours do not exceed the maximum value the system can provide at that time.

In this scenario, DG supplies 10% of the demand, using the "Time of Use (To)" strategy where one day is divided according to the period of consumption assigning percentages of use [28], which corresponds to 0.144 kWh of energy, while the distribution system supplies the rest of the energy required by the loads equivalent to 1.440 kWh. Under these conditions, a reduction of 2.97% is estimated in the consumption of supplied energy by the distribution grid during the day.

3.3. Scenario 3: Consumers using a Percentage of DG and Contributing to the Energy Efficiency

In the third proposed scenario, GEDE provides an estimated energy saving of 10% during all day, which means that the user consumes less with appliances and lighting systems using sensors that send information to reduce the light intensity in the different places of the house, guaranteeing comfortable levels, decreasing the heating temperature levels, and turning off the detected appliances not being used during certain period of time [30]. In addition, 10% of the energy used by these appliances is provided by DG in peak hours. In Figure 7, three lines illustrating the following are observed: the based demand, 10% of the contribution to efficiency by GEDE, and the contribution of distributed generation in peak hours projected in 10%.

Figure 6. Second scenario — curve displacement with automatic demand response

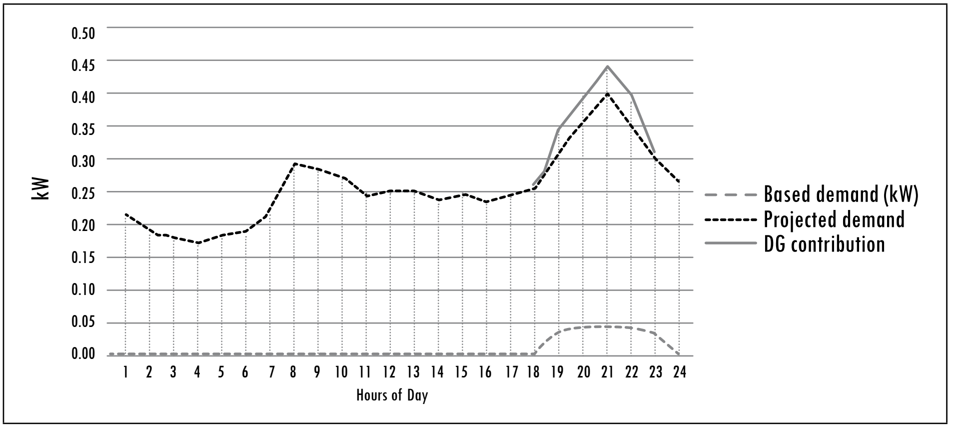


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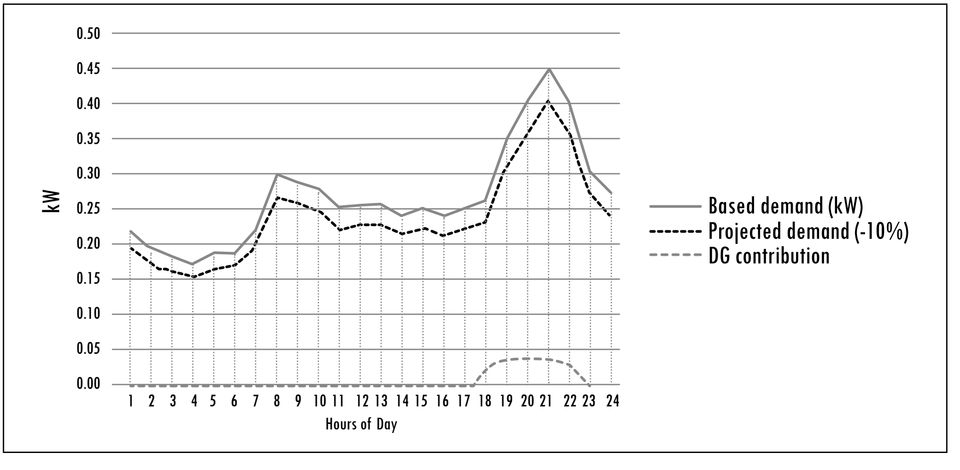
Figure 7. Third scenario — curve displacement with energy saving supported by GEDE



Source: authors' own elaboration

In this scenario, the energy supply received from the public grid is approximately 1.314 kWh, which means that 87.3% of this supply is used during the day. If this information is analyzed at a macro level, the contribution to the system would be of considerable benefit for the energy efficiency. Table 2 is the summary of the main data obtained in each of the scenarios previously explained.

Table 2. Energy consumed by the user during peak hours

	Scenario 1	Scenario 2	Scenario 3
Energy Supply with DG (kWh)	0.292	0.160	0.146
Energy supply by the distribution grid (kWh)	1.168	1.440	1.314
Indicator - Use of the distribution grid (%)	97.49	99.96	87.3
Projected energy efficiency (%)	0	0	10
Percentage of distributed generation (%)	20	10	10

Source: authors' own elaboration

For the three scenarios, it can be observed that the contribution of distributed generation at home allows obtaining a lower use of the resources in the interconnected system. However, by means of the indicator "Use of the distribution grid," it is possible to state that Scenario 3 is the one that contributes to lessen this level of use, and if the scenario is replicated on a large scale, it could reduce the demand during peak hours.

Conclusions

GEDE (Home energy management) system is focused on establishing a new energy model based on the "active user" commitment and on being environmentally friendly. Additionally, GEDE is aligned with the commitments made by Colombia with the International Renewable Energy Agency through Law 1665 of 2013, which approves the statute of the agency for Colombia, aimed to the use of renewable energies.

The "active user" is central part of the GEDE system, which leads to get cultural awareness on energy efficiency and saving. This essential component in Law 1715 is developed in the proposed system as a fundamental contribution at the implementation moment, with the three scenarios described as: manual, automatic, and semi-automatic, which are expected to contribute to the demand response supported in consumer habits.

The presented scenario 3 allows obtaining more benefits, not only for the end user, but also for the whole chain value due to the lower use of the energy supplied by the interconnected system, reducing the impact on the environment.

It also allows the loss reduction in the transmission and distribution system, and therefore a better use of the electric infrastructure is made. If it is replicated on a large scale it would contribute to solve the demand problem evidenced in peak hours. The proposed scenarios would have great success possibilities if the regulation of Law 1715 allows the remuneration to the users investing in this kind of systems.

Acknowledgments

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