Analysis of the consumption profile of a refrigerator using an IoT architecture

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Abstract— **The increase in electronic devices in societies has increased electricity consumption, this increase is noticeable in the residential sector due to population growth, this is how strategies have been developed to try to make smarter use of electrical power particularly smart metering devices. This article presents an IoT architecture to extract the consumption profile of a refrigerator and analyze its behavior to propose demand management strategies.**

Keywords— Smart meters, cooling, IoT, demand management

I. INTRODUCTION

Studies carried out by the United Nations have shown that there is a clear trend of increase in the world population, which represents major challenges in terms of governance and the guarantee of quality of life for the inhabitants of the new population poles and world economy: the megacities. One of the biggest challenges is to guarantee the generation of the energy required to maintain the different sectors of the economy that support these megacities: industry, transport, public services, and commerce, while meeting increasing needs in people's homes. This growing need for energy has a high impact on the environment since at least 80% of the energy sources that cover the needs of the planet are of fossil origin. These fossil fuels are less efficient and are characterized by high CO2 emissions [1]. In this way they have a high impact on global climate change. Disruptive technologies such as IoT, will offer the possibility of implementing smart governance that supports the services demanded by a growing citizenry, timely attention to incidents and emergencies, analysis of trends for the generation of knowledge and rapid and effective decision-making on the various challenges of governance.

One of the sectors with the greatest interference in this growing demand for energy is residential users, who every day will be able to become more aware of their consumption through technologies that can be carried in their pocket and that can even help them make smarter decisions about the use of equipment that offers comfort at home [2].

Colombia is a country that has 70% of the energy matrix produced by water sources and when we face problems of climate variability such as the phenomenon of children, (which is caused by the occasional eruption of warm surface waters, located in the Pacific Ocean off the coast of South American territories, generating severe droughts in the country) which in turn affects the levels of hydroelectric generating reservoirs [3], two forced demand management strategies have been implemented at national level; the first occurred in 1992 with the energy crisis not foreseen by this climate phenomenon, where the main strategy was to run the calendar 1 hour in order to reduce the pressure of the electric charge on the Colombian power system, in some departments and municipalities of Colombia there were power cuts for certain times, Six days in prison were decreed for water wasters and in some municipalities the electricity service was cut for two full days [4].

In 2016 this climatic phenomenon was again presented; however, the country was more prepared, so the strategy was implemented at the national level of "Extinguish Pay" which was that residential and commercial users that save energy with a consumption lower than the month of February 2016, obtain as a benefit $450 for each kilowatt/hour saved. Also, users whose consumption is higher than recorded in February 2016 would have to pay an additional $450 for each kilowatt/hour they consume more, the strategy was successfully implemented by not only avoiding power outages but saving 1,179 gigawatts/hour with a proposed target of 400 gigawatts/hour [5].

Strategic planning of energy saving programmed can help to overcome rationing and bring economic benefits to the country, the possibility for users to monitor electricity consumption allows them to participate actively and in a planned way in the strategies of the national regulatory bodies. That is why we have decided to propose an energy management solution for residential users with Cloud IoT applied to Smart Grid, which is classified within the domain of Smart City, according to the proposal of E. Borja [6].

II. IOT IN SMART GRIDS

Smart grids are the new paradigm of power systems: an advanced, automated, and distributed power grid. The paradigm of the internet of things and its supporting technologies will enable the bidirectionality of the flow of energy and communications. Cloud computing integrated with the IoT will allow the storage and analysis of large amounts of data that are generated in real time in the field and will support new IoT applications in the different domains of the electrical system: generation, transmission, distribution, and use of energy. In this state of the art, we provide an overview of the state of the art of IoT Cloud-assisted SG systems, including architectures, technologies, applications. In the end we conclude with the opportunities and challenges of this topic.

A. Definitionss

Smart Grid: Smart grids or smart grid are the next generation of power systems that are characterized by having a two-way electricity and information flow strategy, to create an advanced power generation network, automated and distributed that ensures clean, safe, reliable, resilient, efficient and sustainable electricity [7]. Although IoT is just taking its first steps in development, it has a vital impact on the future of energy systems, as it will offer interaction between control systems and their representation in the digital world. The most effective solutions for this area of knowledge will be cloud storage and computing along with big data techniques due to the massive production of data from IoT devices.

Internet of Things: Defined as a network that can connect any object to the internet, based on a protocol for the exchange of information and communications between various smart devices to achieve monitoring, tracking, management and location identification [8].

The Cloud: Cloud computing is a model that allows the accessibility of computer resources in any location on demand [9]. In cloud space you pay only for the resources that are used.

B. Types of cloud

Public Cloud: Consists of infrastructure services available to subscribers and customers via the public internet. The space is supervised and managed by the service provider.

Private Cloud: This type of cloud is primarily dedicated for each power network operator to have private access to the services of the platform. It offers a higher level of cybersecurity and more customization options.

Hybrid Cloud: It is a combination of several types of cloud: private and public and between them there is communication and information exchange.

Community Cloud: This type of cloud offers features that some customers with similar needs and objectives can take advantage of to share and achieve a more economically competitive service.

C. Models of cloud services:

Interface as a Service (IaaS): Allows power service operators to use resources such as storage or processing tools.

Platform-as-a-Service (PaaS): Enables platform subscribers to deploy applications without compromising on the complexity of platform purchase, management, and maintenance. In this model the user has no control over the infrastructure or operating systems but controls the deployment and deployment of the applications.

Software as a Service (PaaS): In this model, subscribers have access to cloud infrastructure and applications. Customers do not require storing, installing, or supporting applications on their corporate platform.

Smart meters: The smart meter is an advanced energy device that obtains information about the electrical variables of the loads of end users, measures the energy consumption of consumers and then provides additional information to the utility and/or system operator for better tracking and billing. The smart meter supports bidirectional communications between the meter and the central system. In addition, the smart meter has the built-in ability to disconnect-reconnect certain loads remotely and can be used to monitor and control users' devices to manage demands and loads within "smart buildings" in the future.

Sometimes a smart meter can also communicate with other smart devices. From a consumer perspective, smart meters offer several potential benefits; for example, consumers can estimate bills from billing information and thus manage their energy consumption to reduce their electricity bills. From the perspective of the utility, they can use information collected from smart meters to estimate prices in real time, by which undertakings may limit the maximum electricity consumption and seek to encourage users to reduce their demands in peak load periods [10].

Cloud IoT: According to Farahzadi, Shams, Razazadeh, and Farahbakhsh [11] it is highlighted that with the growing number of devices with needs for sending and receiving information through their sensors and actuators, there are challenges such as management, aggregation, and storage for large amounts of data. The integration of cloud computing and the Internet of Things solves some of these issues and is defined as CoT by "Cloud of Things". Considering this cooperative action an intermediary between things and applications is necessary to deal with the problems of heterogeneity of objects, the intermediate layers "middleware" is the answer to this challenge.

The main IoT applications in smart energy networks can be classified according to the data flow and region they cover in domains, as proposed by Saleem [8].

Home area networks (HAN): These are the applications that are closest to the consumer, including advanced energy measurement, energy efficiency, smart home, vehicle load management, vehicle information management, general consumption and appliance management, integration of solar or wind energy sources, and in the future is expected to support platforms where the consumer will also be able to market the energy he generates in his home.

Neighborhood area networks (NAN): Consists of networks of smart meters belonging to multiple HAN that belong to a common geographic area (some blocks). Supports energy distribution networks and residential users. Possible applications include intelligent power distribution, field equipment management and operation, and support for billing and maintenance operations.

Wide area networks (WAN): These applications support the power generation and transmission system. For the transmission system the applications could be transmission line monitoring, transmission tower protection and field equipment monitoring and control.

For the generation system, applications such as energy consumption, control of generation units, control of wind, solar and biomass plants and farms, power prediction, energy storage, solar farms, among others, are included.

A very important application is the Energy transaction, which consists of a set of techniques to manage the energy exchange at the level of system operation and the energy market.

D. Demand response programs:

DR demand response is an ancillary service in which end users could adjust their energy consumption in response to a given DR signal. This DR signal may contain information about the price of electricity, incentives, or system reliability emergencies [12]. Unlike mainstream DR techniques such as peak shaving or valley filling that occur infrequently and mainly during grid emergencies, in flexible DR load shaping techniques, the demand side responds continuously to market price signals [13]. Flexible load-shaping technologies are what enable a truly integrated grid by facilitating dynamic control and response to both consumer load and their use of distributed generation and storage.

Demand management programs refer to the tariff structure in the demand response category, they relate a set of programs that can be classified into two main categories which are reliability-based or incentive-based programs, and price-based or market-based programs [13]. These programs have the particularity of being classified according to the transaction methods applied either by defined time intervals or by the needs of the electric system.

III. Measurement System Based on IoT Architecture

For the development of the measuring system were used 1 energy meter SPM91, DS18b20 temperature sensor and a Raspberry, the energy meter is communicated by means of Modbus RS-485 to the Raspberry by means of a converter Modbus RS-485 to USB, by means of Python are called the measurements of the voltage, current and power registers of the meter. Once the information is read, the data is organized in a JSON to be sent via MQTT to a cloud platform that acts as an aggregator, the function of the aggregator is to analyses the energy consumption of the appliance and to send disconnection signals according to the needs of the electrical system, this signal is sent again to the Raspberry that takes care of disconnecting by means of a relay the connected load. Figure 1 shows the architecture used for the measuring system, it is chosen as an appliance to measure the refrigerator because it is one of the most energy-consuming in the electrical system and either in the residential, commercial, and industrial sector.

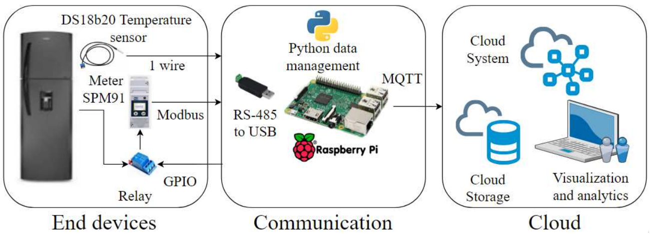

Fig 1. Measure system architecture

The refrigerator to be studied is brand MABE reference RML 235Y, this refrigerator is No Frost technology, has a capacity of 235 liters, a rated power of 129.4 W and a current of 1.8 A. This refrigerator has two compartments the cooling and the freezer.

A demand response program is defined that reacts by means of a signal that is defined by the operator, in this case it is sent to the raspberry through the MQTT communication. Once the incentive is sent by the operator, some restrictions are defined that will depend on the internal temperature of the refrigerator, the operating point can be displaced up to 3%, allowing the refrigerator to be turned on or off according to its temperature limit values.

IV. Results

The measurements of the system were made to obtain the consumption profile of the refrigerator, in Figure 2 the power profile is shown, showing that it is a periodic load that has off time between 35 to 38 minutes and on time between 15 to 17 minutes, which gives an energy consumption per cycle of 36.83 W/h without opening the refrigerator, this value can be increased depending on the opening time of the refrigerator. The start of the charge gives a peak that stabilizes after a while, this is because the refrigerator works with a compressor and this to break the inertia must have a high starting current.

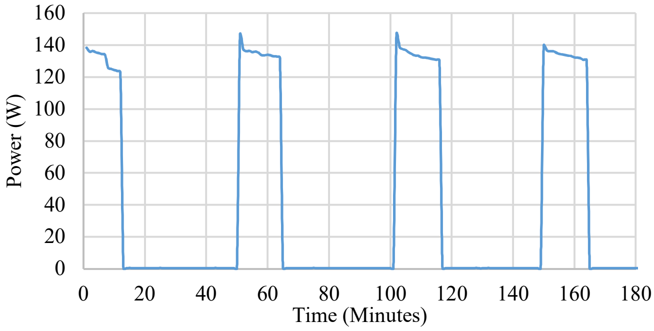

Fig 2. Power profile

The current profile is like the power profile as shown in Figure 3, the current is about 2 Amperes and the peaks are evidenced when the charge is switched on, however since the sampling time is 1 minute the starting current is not actually evidenced exactly for this could use a higher sampling time to record the peaks more accurately.

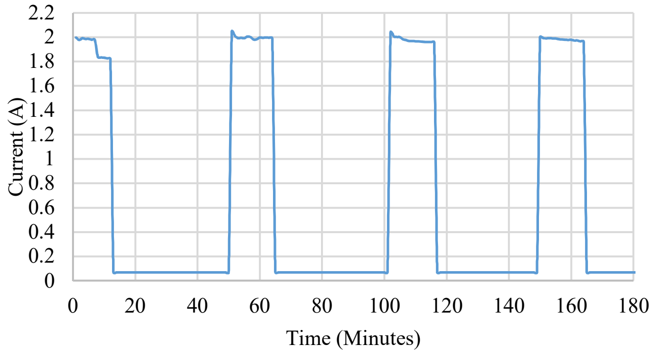

Fig 3. Current profile

This starter current is reflected in the voltage drop in the system coming down the voltage abruptly up to 5 units as seen in Figure 4 in the minute 215, this scenario occurs mainly with the opening of the refrigerator for a long time, The voltage drops of the first few minutes do not seem to be related to the ignition of the refrigerator but of the quality of the network. The ignition time of the compressor increases, from having an average ignition of 16 minutes in the normal ignition of the compressor to remaining on 27 minutes by the opening of the refrigerator.

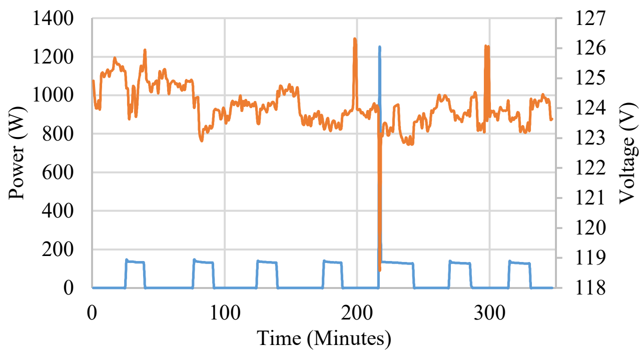

Fig 4. Voltage profile

Once some electrical parameters of the chiller have been analyzed, the analysis of the temperature data related to the power consumption of the system is performed. Figure 4 shows the curves of power consumed and the internal temperature of the cooler for 4 hours, having an operating point of 3.7 ° C ranging from 2.2 ° C lower limit to 5.7 ° C upper limit, in the previous graphs the operating point was defined in 8 ° C so the times that is activated in Figure 3 is much lower than the case presented in Figure 4. In this case, a temperature peak can be observed at minute 30, which represents the opening of the refrigerator for a significant time; these peaks can be observed to a lesser extent at minute 100, minute 170 and minute 220.

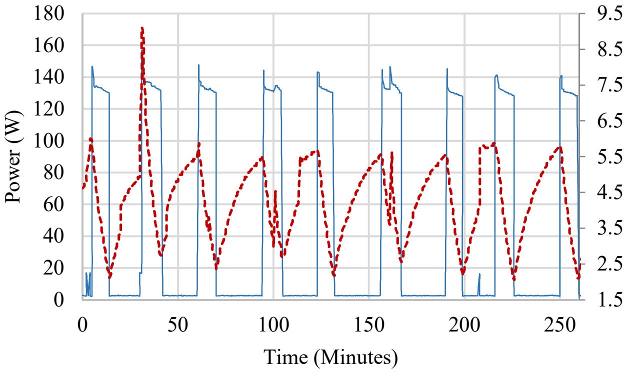

Fig 5. Temperature profile with operation point in 3.7 °C

The operating point of the cooler is changed to 0.5 °C having a lower limit of -1.2 °C and an upper limit of 2.6 °C, having a much lower temperature to maintain the number of times that the compressor is activated in the same time interval with respect to the previous case is lower. For this case, a uniform behavior can be observed because the refrigerator was not opened during the time interval studied, which allows to have a better conservation of the internal temperature.

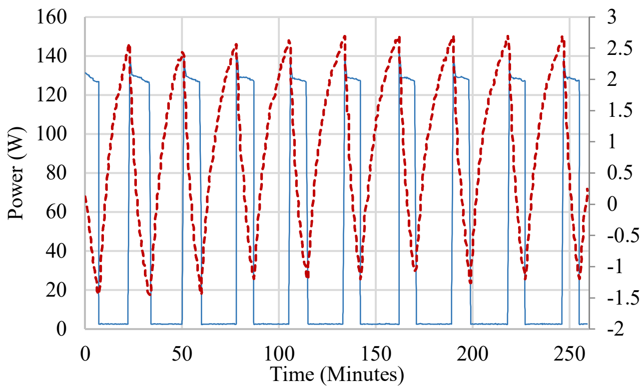

Fig 6. Temperature profile with operation point in 0.5 °C

The power profile with DR is displayed in Figure 6 without any unusual starting currents, in which a disconnection signal is applied to the refrigerator in a 7-minute window having a decrease in consumption of 15.11 W/h at that moment of time, however, this energy is subsequently consumed to bring the refrigerator to the appropriate temperature, the application of this signal does not represent as such a saving in energy consumption however if it can be used by means of incentives of the network operator in order to relieve congestion in the system or regulate the voltage profile.

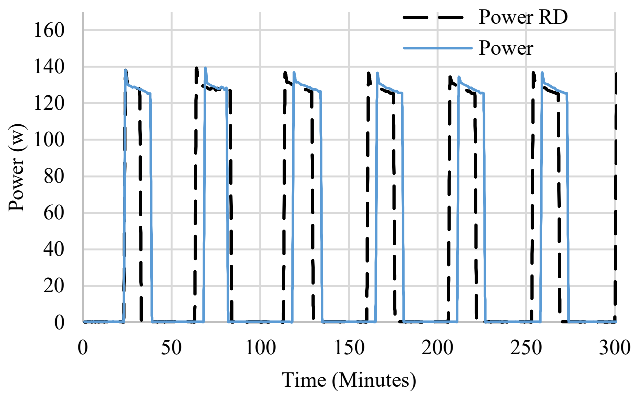

Fig 7. Demand Response scenario

Finally, figure 6 shows the effect of the application of the DR signal when the refrigerator is operating at minute 29, although the temperature has not reached its lower limit it is possible to disconnect the refrigerator without affecting the average temperature of the refrigerator, after this the upper temperature limit is moved to respond to the event for an interval of 14 minutes, returning to the cooling cycle at minute 43. It can be observed that while there is a decrease in consumption during that time interval, the refrigerator must use the energy that this did not use before to achieve programmed refrigeration.

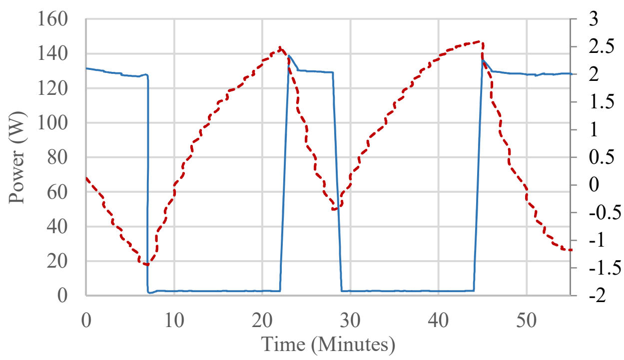

Fig 8. Demand response with the refrigerator ON

V. Conclusions

The implemented architecture facilitated the installation of the power meter and relay such that no cables were needed for data communication, and he sent signals, so storage, analysis and visualization was less complicated than without the IoT architecture. The Raspberry as a Gateway allows to adhere the IoT component to the system simulating what would be a two-way communication between the user and the aggregator in a demand response scenario.

The refrigerator is an essential household appliance since it allows to store food and keep it fresh, however, it is the biggest consumer burden in the residential sector and in some cases in the industrial and commercial sector, this is mainly due to its periodic behavior as it works by means of a compressor. It was established that without opening the refrigerator this has 27 cycles of on and off over a day which means that the studied model consumes about 885 W/h per day. The development of this measuring system allowed to extract valuable information on the behavior of the refrigerator such as on and off times, actual power consumed and abnormal current peaks for future simulations.

The demand response scenario allows to see how serious the individual behavior of the refrigerator before an operator signal although there is no energy saving, if there can be an economic saving for both the user and the network operator, since it will have a decrease in the load of the system and can avoid the disconnection by overloading more important loads, of course that for the impact on the network to be significant several refrigerators must be grouped. The benefit for the user can be reflected in a payment of between 30% and 50% on the tariff for the displacement of the load, this can be determined by the behavior of the system and the event that want to mitigate.

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