Development of a Demand Response System integrated to Photovoltaic Microgeneration and Energy Storage using Artificial Intelligence

***Abstract*— The present work aims to present a solution for a new technical and economic model of energy management for residential consumers. It's proposes a system for home automation based on Internet of Things concept, which has integration with the residential distributed energy resources, dynamic tariffs and enables actions to demand response. Artificial intelligence, will be used for decision making in order to seek the automatic load management such as light bulbs and air conditioners and combined heat and power systems. The system allows integration with Smart Meter, an important component in Smart Grid, in order to use monitored data such as voltage level, current electricity consumption and tariff. The integration with a battery energy storage management system will provide information when to use the energy produced by solar panels and to perform energy storage on batteries. This research shows case studies and results that will open new opportunities to residential electricity market.**

***Index Terms*—Residential Electricity Market, Internet of Things, Energy Storage, Photovoltaic System, Smart Grid, Smart Metering**

I. Introduction

The increase in the development and implementation of Smart Houses tends to bring several benefits to users, among them the appearance of more accessible technologies that can be used in a residential environment. Smart houses use the concept of home automation. Installation of automation home systems allows improving comfort and security of a house through the integration of the concepts traditionally associated with domestic environment with new generation technologies [1]. The use of Internet of Things (IoT) concepts in the creation of smart souses should play an important role in the architecture of electric power distribution Smart Grids. The Internet of Things can be understood in a general concept of things that are readable, recognizable, locatable, addressable, and controllable over the Internet - whether via radio frequency (RF), wireless local area networks, long distance networks, or other means [2]. It is a network of networks in which a large number of objects, sensors or devices are connected through the information and communications technology (ICT) infrastructure to provide value-added services [3]. By 2020, 50 to 100 billion devices will be connected to the Internet [4]. Important features in Smart Grids, the flow of energy and mainly information tends to take place in a bidirectional way, through the creation of the role of the prosumer user (the junction of the words producer and consumer). Thinking about it, Smart House tends to be present with great importance, the prosumer user will not only be a consumer of electricity, but also a producer and manager through some kind of storage and microgeneration systems, such as photovoltaic and wind systems.

The creation of energy management systems in the residential environment has increased. The RUDAS [5] has monitoring the conditions of the house, such as: temperature, humidity, gas leakage check, smoke detector, people detector. It uses the fuzzy logic, to adjust light intensity and air conditioning according to variables capped by sensors. [6] is an energy management system, which includes renewable energy (photovoltaic and wind) generated near the residence. It has a home server that gathers energy consumption data and power generation data from the distributed generation systems through the intelligent energy meter. The adaptation of the system is based on the improvement according to the standard of electric energy use.

The present work seeks to discuss a feasible technical and economic model to accompany the rapid changes proposed by residential automation, dynamic tariffs and the integration of distributed energy resources. The concept of demand response will be applied from different monitored data, including the network voltage level and the tariff value charged. The proposed system will seek to manage residential loads (lighting and temperature) as well as specific loads. This management will be given based on decision making through the application of Artificial Intelligence. Artificial intelligence will be used from the development of a demand and energy management center that uses the fuzzy logic. With the decision-making process created, the central control will make and send actions to different devices connected to the residential loads, thus enabling the action automatically. Monitored data and actions such as modification of the operating mode will be presented through WEB interface, which can be viewed by different devices that have some type of WEB browser installed.

The integration of the proposed system with an intelligent system for managing the batteries energy storage (BESS) installed in homes is of interest to both energy companies and the distribution system operator (DSO). The results presented in this article are part of a project under development between the best distribution energy utility in Latin America, COPEL DISTRIBUTION (PD 2866-0462 / 2016) and the Federal

University of Santa Maria (UFSM), controlled by Electrical Energy National Agency (ANEEL)-Strategic R&D for the Brazilian Electricity Sector-P021/2016.

Thus, this research presents case studies and results that will open new opportunities to residential electricity market. The use o Internet of Things to residential demand and energy management conduce to the best use of electric energy in order to mitigate impacts related to intermittence of the renewable sources, taking into account environmental, technical and economic constraints.

II. INTELLIGENT RESIDENTIAL SYSTEM OF MONITORING AND CONTROL OF ELECTRICAL ENERGY (IRSMCEE)

A. *System Features*

The system proposed is an integrated micro-generation system, used as a second way of supplying electric energy. It has as main functionality the automatic management of lighting loads, air conditioners and combined heat and power systems (CHP). Specific loads such as: washing and dryer machine are also managed. With these functionalities, the system aims to be guaranteed: the best use of electric energy. The management takes place from the establishment of rules for decision in real time. For this, Artificial Intelligence technology is applied in the creation of a management center, which will be more detailed in the course of the work.

The system works according to various monitoring data, such as: current cost of the tariff and power consumption, network voltage level, available with the integration of the system as the smart meter. From these data, the proposed adaptively system seeks to adjust the work shape, thus being able to manage present automated loads in order to have a more economic end efficient consume.

From the variation of the voltage level at peak times, the proposed system seeks to use either the energy generated by the photovoltaic system or BEES. Voltage levels below the limit can be interpreted as signals to decrease the demand for electricity from the utility, and in case of a voltage level above the limit, an indication not to inject the distributed energy to the network. With this, the demand response is characterized. At periods of high demand, the voltage drop can be large [7]. This means that the utility responsible for the electricity supply can resort innovative and viable alternatives to guarantee the quality of supply.

The generation of energy from the photovoltaic system and the opinion of the energy storage management system are extremely important for the creation of decision-making in the proposed system. With the use of fuzzy logic it was possible to create different operating modes for each type of residential load to be automated. This was possible due to the possibility of use different fuzzy rules in each mode of operation developed. With this, it was possible to work with different scenarios, such as: electricity low generation by the distributed generation system, oscillation in the network voltage level or temperature.

The following subsystems are present in the work, according to Figure 1:

- Monitoring and Acting Device (MAD): Devices that monitor and act on residential loads, such as light bulbs air conditioners and CHP systems. Monitored data is sent to the Residential Loads Management Center.
- Residential Loads Management Center (RLMC): Central that uses artificial intelligence to perform the management of residential loads. It works in different ways, according to the modes of operation developed. It uses different data, such as: Power Storage Management System information and MAD's installed data.
- System of management of storage of electrical energy in batteries (SMSEEB): System developed in project of Research and Development. It provides information such as the need to reduce the demand for electricity.

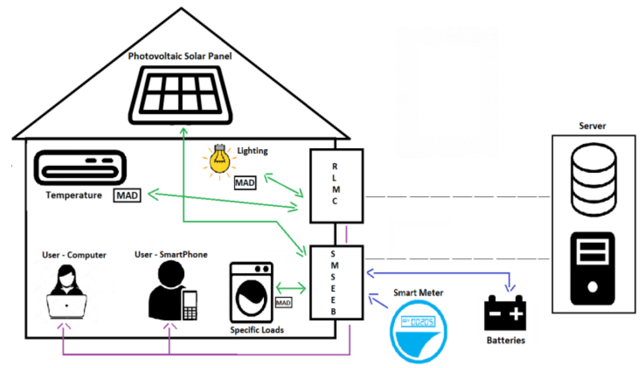

Figure 1 - Representation of the Proposed System

The system provides the user with a WEB interface, so that they can view the data monitored through their Smartphone, computer or any device that has access to a WEB browser. Updated data and control actions are available in real time, such as: electric power consumption; generation by the photovoltaic system and level of energy storage in a BESS; updated value of the tariff charged by the contracted electric energy utility; automated overload monitored data.

B. *Monitoring and Acting Device (MAD)*

They are elements installed in the different loads present in rooms of the residence, which have sensors and actuators. Each room can have more than one. They have the objective of sensing the luminosity, temperature and the performance in automated loads. The monitored data is sent to the Residential Load Management Center (RLMC). RLMC uses incoming data and creates individual decision-making for each MAD. With the control actions created, the plant sends its respective action to each MAD. Each MAD receives actions according to its specialty, that is, for each type of automated load. Examples: Types of MADs created:

- MAD Lighting: Actuation in lamps;
- MAD Air conditioning: Acting on air conditioners;
- MAD Specific: Washing machine, dishwasher, etc.

The platform chosen for the development of the monitoring and actuation device was the Arduino Mega, which has ATMEL ATmega2560 microcontroller. The Microcontroller 802.11 b / g / n ESP8266 Wireless Module was installed, which allows the device to communicate bilaterally with RLMC. For the communication between the MAD and the RLMC, which was necessary for sending and receiving information, it was decided to use the Message Queue Telemetry Transport (MQTT) protocol because of the hardware implementation of highly restricted devices and in limited bandwidth and high latency. We attempted to use the MQTT protocol over HTTP for the following reasons: [8]: HTTP protocol is considered dense, with many headers and rules, besides being a synchronous protocol, that is, the client expects the server to respond, thus causing low scalability, which can be a problem in environments with large number of devices; MQTT protocol is an asynchronous protocol, much more suitable for IoT applications. Sensors can send readings and allow the network to discover the optimal path and synchronization to deliver to target devices and services.

In order to monitor the luminosity of the room where the MAD is present, the Light Dependent Resistor (LDR) sensor of 5 mm was chosen. Environmental temperature monitoring was ensured using the DHT11 sensor. The DYP-ME003 PIR module presence sensor (Pyroelectric Infra-Red sensor) was used to check the presence of people where the MAD is installed. The automation of lighting and turn on/turn off action on specific equipment (washing machine, clothes dryer, etc.) was guaranteed from the inclusion of relays. The chosen module has operating voltage of 5V, allowing to control residential loads with 220V power. For the operation in temperature in the residential environment was used the infrared (IR) emitter 940nm for sending cloned commands of the remote control.

It was established the creation of a MAD device for each load to be automated, characteristic of the Internet concept of Things. It is sought to work with the connection of each MAD to the network, making it possible to collect and transmit data to the RLMC. Each MAD connected to the created Wireless network will receive control actions, as shown in Figure 2.

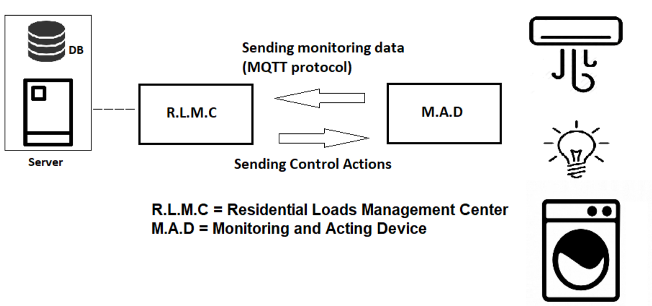

Figure 2 - Flow of Information – MAD-RLMC

C. *Residential Loads Management Center (RLMC)*

The Raspberry Pi 3 model B was chosen as a hosting platform for the Residential Loads Management Center (RLMC), in addition to the system user access WEB interface. It was possible to install Apache Tomcat and Postgresql database, making it possible to store sensed data. It was possible to implement a real-time decision-making center through the implementation of Fuzzy Logic using JFuzzyLogic library. The Raspberry Pi 3 model B has been widely used in the development of home automation systems, for example, for the monitoring of home energy [9]. It is a small computer that has as specifications: Quad Core Processor 1.2GHz, 1 GB RAM, 40 GPIO pins, 4 USB ports, etc. [10].

The application of the Fuzzy Logic in the RLMC to make decision making was chosen by better treating inaccuracies of different types of data monitored in the system. Unlike Boolean Logic, which only supports Boolean values, that is, true and false, the Fuzzy Logic deals with values ranging from 0 to 1. Thus, a pertinence between 0.5 can represent half truth, so 0.9 and 0.1 represent almost true and almost false, respectively, thus being more flexible with monitored data than Boolean logic [11]. Considering this, the best treatment of input variables such as temperature (hot, cold and normal separation), according to Figure 3, was possible. Fuzzy logic is used in made a control system that to control the brightness level to be applied in accordance with the amount of light captured in the environment [12]. They (authors) propose a remote interface controller for Smart Homes as a part of Home Automation and Demand Side Management. The controller make the decision based on dynamic tariff rates using Fuzzy Logic [13].

From the study of which data from monitoring would be important to aid decision making on different occasions, the following general inputs were established for the application of fuzzy logic: network voltage level and updated tariff cost charged by the contracted utility; generation of electric energy by the photovoltaic system and current consumption of energy in the residence; smart decision of energy storage management system.

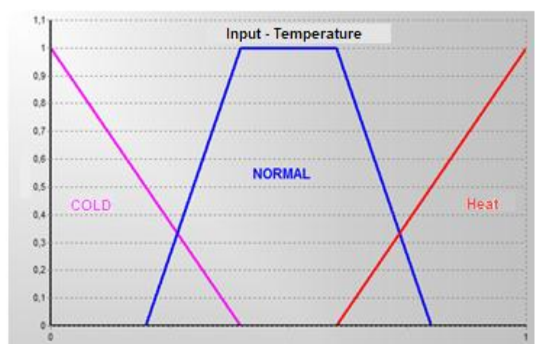

Figure 3 - Fuzzification - Variable Temperature

In addition to general inputs, additional roads were chosen, different for each type of automated load: Temperature, humidity and presence of people in the room for air conditioning loads; Brightness and presence of people in the room for lamps.

Figure 4 presents the inputs used in the application of the Fuzzy controller, as well as the respective outputs of control actions for each type of load to be automated, detailed as follows: Brightness action (on and off), designed for lighting load (lamps); Temperature action (Heat, normal, cold), designed for the activation of air conditioners; Turn on/Turn off action, for special loads that are used automation, such as: washing machine and tumble dryers.

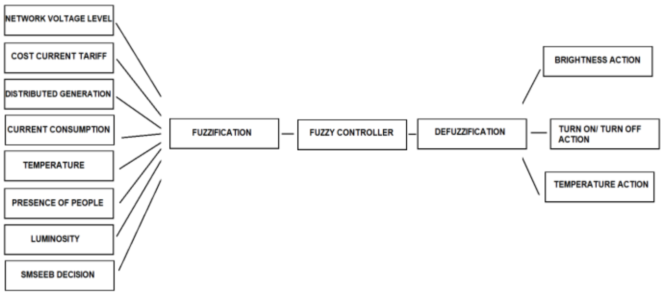

Figure 4 - Fuzzy logic

The definition of input variables from monitoring and output variables to control residential loads allowed the creation of several Fuzzy rules for the controller. With the creation of different blocks of rules, it was possible to create different modes of operation, as follows: Comfort: less emphasis on energy consumption, allowing for greater comfort; Economy Moderate: better use of electricity generated by the photovoltaic system, but with some comfort to users. Established as the standard mode of operation of the system; Total Economy: greater emphasis on the reduction of electricity consumption.

For the inclusion of data related to the electric energy consumption from the Intelligent Meter, it was necessary to develop Real-time Monitoring Thread. It used the photovoltaic system installed at the Polytechnic College, located on the campus of UFSM. In order to use data related to the generation of energy by the photovoltaic system it was necessary to develop in the RLMC a Thread of execution in real time. This Thread performs queries to the access address provided. Through the query, a reply was received in JSON format, being necessary to separate only the necessary data and store in database.

Each device installed, as explained earlier, is linked to a load, whether lighting or even specific. To cover this specificity of loads present in a residence, separate Fuzzy rules were developed for each type of load, counting the modes of operation. That is, you have created specific rule blocks files for each type of load next to the chosen operating mode. Example: "Lighting-Economy-Mode", "Lighting-Mood Economy", "Conditioner-Air-Comfort Mode", etc. By separating in this way, it was possible to create FLS files (manipulated through the JFuzzy library).

The following is a step by step operation of the application of the Fuzzy Logic, present in the RLMC: 1. RLMC verifies how many monitoring and actuation devices are installed in the residence. 2. The control unit verifies the types of loads connected to the MAD's, and checks which types of Fuzzy controllers are initialized. A separate Fuzzy Controller is initialized for each MAD present, that is, an Execute Thread for each device. 3. RLMC verifies which mode of operation was chosen by the user in order to search for compatible Fuzzy rules. 4. Searches for the most recent records belonging to the selected input variables. 5. The fuzzification of these registers is done, that is, the values are placed in the universe between 0 and 1, to be fed the Fuzzy with normalized values. Execute the Fuzzy rules belonging to the controller. 6. The defuzzification of the output is made in order to take control action decision. A number is assigned to the action output. 7. After action verification, it is sent to the respective MAD via the MQQT protocol.

D. *System of management of storage of electrical energy in batteries (SMSEEB)*

According to [14], BESS offers an option to mitigate the intermittent impacts associated with photovoltaic systems. BESS can be used to store excess electricity produced from photovoltaic modules during the day and provide electricity at night and during non-sunny hours. With this, there is the best use of energy (less waste) and greater sensitivity during sudden changes in electric demand [15]. The decision taken by the SMSEEB was inserted in the development of the Fuzzy controllers in the RLMC. Its purpose is to seek to define the moment of use of energy generated and moment of realization of energy storage in batteries. Decision making occurs from several variables in real time, such as: battery storage level, existence of electric power generation and cost charged by electric power at the time of analysis and mainly the demand response.

E. *User access WEB Interface*

The WEB interface developed for user access to monitored data, possibility of modifying system operation mode and actions on lamps and air conditioners was programmed in Java language for WEB. For its creation were chosen the following programming technologies: JSP (Java Server Pages) and Spring MVC (Model-View-Controller). For its execution was used Apache Tomcat server installed on Raspberry Pi. Pages were created for each room, showing information of one or more MAD's installed, according to the amount of residential loads present that have automation. For the dynamic reception of data monitored in MAD and updating on the WEB page in real time was used the language Javascript. Ajax and JSON technology were used to request the monitored data.

III. RESULTS AND DISCUSSIONS

From the development of Fuzzy controllers in the RLMC for each MAD installed, it was possible to create different decision making according to different monitored data. The use of the voltage level allowed the system created to modify the electricity use from the concessionaire in the period of greatest demand, taking into account the incentive to respond to demand. Meanwhile, the power storage management system, integrated with the proposed system, has brought an important analysis input into the Fuzzy Logic, allowing for smarter decision making. The option to choose operating modes by the residential user worked correctly, allowing the same the possibility of modifying consumption patterns according to their financial reality. With the integration of Smart Meter, the possibility of integrating with Smart Grid environments was obtained by obtaining and presenting variables in real time.

To operate transparently it was necessary to provide information managed via WEB to the residential user. The WEB interface (Figure 5), involving updating monitored data, modifying operating mode, and sending actions to lamps and air conditioners proved to be fast and efficient. The interface was agile in constantly updating data received from different installed MAD's and data stored in databases present in Raspberry Pi. The control of lamp made directly by the user occurred without a great delay in sending the command to the respective MAD, while the temperature control had a greater delay due to the necessity of emission of pulses by the infrared emitter installed in Arduino Mega.

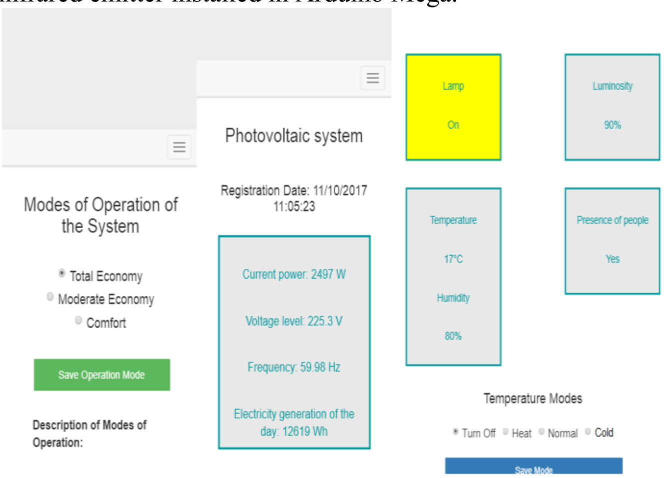

Figure 5 - WEB Interface

IV. CONCLUSIONS

The proposed system allowed the search for intelligent ways of introducing the Internet of Things in residential environment that will participate heavily of the electricity market in the coming years. Through the management of electric energy, the authors propose a system that seeks to improve the cost benefit ratio in the operation of residential distributed energy resources. The decision-making process made by the SMSEEB can be shared and acts in the decision process for the adjustment of luminosity and temperature in the residential environment by the proposed system. The development of the Fuzzy Logic in the RLMC for decision making allowed the system to act without the user making major interventions. With the placement of functionality to the user to modify the system's mode of operation has brought greater power to control spending. By visualizing monitored data in a transparent way, the user tends to understand the functioning of the system and how best to use the energy generated by the distributed generation system installed in his home. This kind of analyses and development shows the importance of Internet of Thinks in the electric market and conduce to new possibilities to generate, consume and market energy in residential sector.

ACKNOWLEDGMENT

The authors are grateful for the technical and financial support to UFSM, PROEX CAPES, CNPq (PQ 1D 311516/2014-9), CNPq (465640 / 2014-1), CAPES (23038.000776 / 2017-54), FAPERGS (17/2551-0000517-1), Polytechnic College, ANEEL Strategic Calling P021/2016, COPEL- DIS (PD 2866-0462 / 2016).

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