Energy Analyzer Emulation for Energy Management Simulators

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Abstract. The simulation of microgrids to testing and validate energy management methodologies are an important step to take before the massive implementation of microgrids. However, microgrids are usually unavailable for R&D centers to perform tests and validations. To solve this issue is important to get the simulations closer to the reality, using real energy analyzers and loads. However, again, R&D centers lack from funding and space to buy and mount several loads in their laboratories. To solve this issue, this paper proposes a multi-agent system simulator for microgrids and an energy analyzer emulator that can be used to emulate individual loads or entire houses, and therefore, bringing the pure simulation closer to the reality.

Keywords: Energy analyzer emulator · Forecasting · Load emulation · Multi-agent system

1 Introduction

The power systems have been changing their paradigm from a centralized system to a decentralized system [1]. This has impact in the generation as well has in the energy management. The appearance of a smart grids with microgrids and smart homes are, in present day, becoming a reality, with more and more applications worldwide [2,3].

The application of microgrids in power system brings advantages for the majority of players [4]. However, to achieve the massive implementation of microgrids some steps are needed. There are a need of capable simulators that can represent microgrids in a way that energy management methodologies can be tested and validated.

The present work has been developed under the EUREKA - ITEA2 Project M2MGrids (ITEA-13011), Project SIMOCE (ANI|P2020 17690), and has received funding from FEDER Funds through COMPETE program and from National Funds through FCT under the project UID/EEA/00760/2013 and SFRH/BD/109248/2015.

The use of a Multi-Agent System (MAS) to analyze and improve microgrids behavior, regarding the energy management, is a perfect fit [5,6]. The use of MAS allows the representation microgrid players, where we have individual players cooperating with each other (trying to combine their individual goals with the group goals).

The consumption forecasting is an important part of the energy management systems. Usually, in energy management system, we work in future periods [7], like day-ahead or hour-ahead. It is only possible to manage energy for a future period if we know what will happen, or at least have an idea about how the things will unfold. Forecasting algorithms are necessary for in advance energy management solutions. And therefore, there are several works concerning this issue [8,9].

Having the simulations and the methodologies, is necessary to go further, close to the real implementation. This is a gap that most of works do not achieve. This paper proposes an energy analyzer emulator that can be integrated in the simulations. The emulator, named Virtual to Reality (V2R), works as a real analyzer and presents to the system as one. This enables the system to test and work with, what it seems, a real analyzer. The use of emulators brings advantages compared to the use of real analyzers. With real analyzers, the R&D center must buy real controllable loads and is not a scalable solution if we think in a simulation with 100 houses. Applying emulators, and going closer to reality is possible to have better simulations than the pure simulations existing today that do not deal with hardware [10,11], standing themselves far from real implementations in pilots and/or microgrids.

The main contribution of this paper in the integration of V2R in a microgrid management multi-agent system. This integration will enable the efficient and realistic simulation of microgrids in the multi-agent system. The paper presents the V2R and the multi-agent system, which started as a simulator and now is running with real buildings. The case study presents a consumption forecast of the microgrid, proving V2R capabilities of working as an energy analyzer emulator.

After this introduction section, the paper will describe the multi-agent system used for the microgrid implementation in section 2. A brief explanation of forecasting is given in section 3. Section 4 presents the proposed energy analyzer emulator. The case study is presented in section 5. And the main conclusions are presented in section 6.

2 Multi-Agent System for Microgrid Implementation

This paper will use the Multi-Agent Smart Grid Platform (MASGriP) to simulate a microgrid. MASGriP is a complete platform used for studies along the years [12]. It was developed in Java and can combine simulated agents (representing simulated buildings) with real agents (representing real buildings).

In order to test a microgrid, our R&D center implemented a microgrid in our buildings [13][14]. Using MASGriP is possible to represent each of the microgrid players in a computational platform. MASGriP was built using JADE framework, each player is independent from the each other and work together using a cooperation approach. The communication between agents are compliant to FIPA specifications. Fig. 1 shows the implementation used in this paper:

- ***Microgrid player*** – responsible for microgrid management, all the other players responds to him. The role of this agent is to manage the microgrid in benefit of their players, focusing on the group goals to increase the energy quality. This agent is a virtual agent, not representing a physical building, the location of this agent is in the microgrid operation room (available in GECAD [13]);
- ***Building I*** – responsible for Building I of ISEP (where GECAD is based). The agent monitors the energy using an energy analyzer with Ethernet connection. The agent stores the data, in a SQL Server, and represents the building in the microgrid;
- ***Building N*** – responsible for the Building N of ISEP where there is a Programmable Logic Controller (PLC) and a ZigBee gateway that monitors 5 energy analyzers interconnected through RS-485. Building N has 9 controllable air conditioners. The agent monitors, stores, in a SQL Server, and controls the building's energy;
- ***Simulated Building*** – this agent was integrated in the simulation for the paper use case. This agent will integrate energy analyzers emulators and store, in a SQL Server database, their data. The agent will then represent the energy analyzers emulators in the microgrid. Besides its name, the agent works in MAS as a real building agent, the agent do not know that its energy analyzers are emulated.

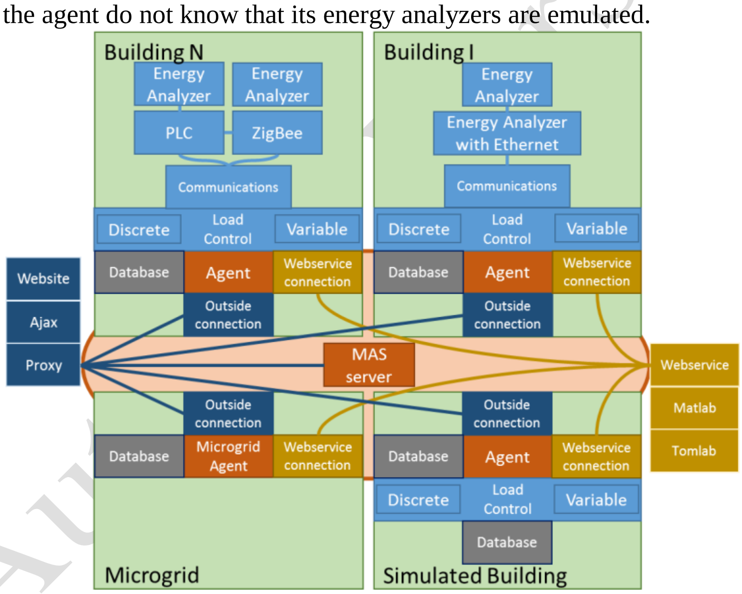

Fig. 1. MASGriP GECAD implementation

The communication between agents and energy analyzers, installed in the buildings, are done through Modbus/TCP, direct to the energy analyzers or using a PLC in the middle. The agent configuration if done using a XML file where is possible to specify the energy analyzers of the agent, agent name and MAS name and location. The Simulated Building agent and microgrid agent, do not have the knowledge that some loads are emulated. They work thinking that they have real loads installed in real buildings.

MASGriP includes algorithms needed for energy management, such as, forecasting algorithms [8] and scheduling algorithms [15]. The algorithms are available for all agents. The algorithms are open to the agents in a web service in order to improve the execution time and make all the algorithms available for all the agents. This web service supports the programming languages of: C; C++; C#; R; Matlab; and Tomlab.

MASGriP agents are accessible using a webpage. All the agents implements a simple API using JSON messages that provides monitoring and control requests. The webpage allows the users to visualize real-time and stored data. The microgrid agent webpage also allows the execution of energy management actions in the microgrid.

This implementation not use generation units in any agent. However, MASGriP is able to integrate generation. By default, microgrid agent asks the consumption value each second. But agents can refresh (monitor) their values (energy analyzers) using other time periods. For instance, Building N is using a time period of 10 seconds. A more detailed description of MASGriP implementation is present in [13, 8,14].

3 Consumption Forecasting

The forecasting algorithms are available to MASGriP agents using the platform web service. In there are two types of forecasting algorithms: Artificial Neural Networks (ANN); and Support Vector Machine (SVM). Both algorithm were created to learn from data and provide solutions according to what they learned. In MASGriP they are used to learn profiles of consumption, or generation, and then provide forecasts. Because they are algorithms based on learning models, they are highly dependent on the learn data [8]. For this reason, the inputs to use should be tested.

The ANN can be seen in [8] where a detailed analysis of ANN is done. In this paper the forecasting algorithm used is the SVM. The SVM available in the web services allows the specification of the kernel to use: Linear; Polynomial; Radial; and Sigmoid. The SVM algorithm tries to find a regression between previous data to predict/forecast new data.

In the MASGriP implementation of these paper it will be executed a forecasting for the next 24 hours of consumption in each consumer agent (Fig. 2). Is defined as a consumer agent, agents that have energy consumption loads (Building N, Building I and Simulated Building).

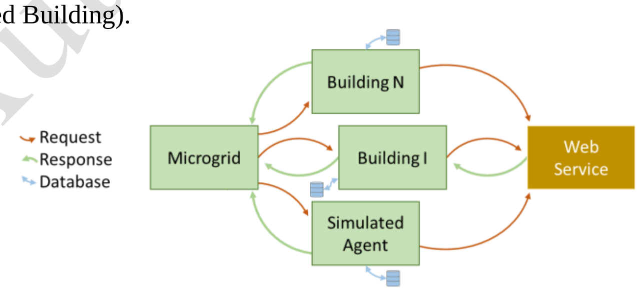

Fig. 2. Process for microgrid forecasting

A microgrid forecasting can be done using microgrid agent. Fig. 2 shows this process. The microgrid agent will individually, and simultaneous, request each consumer agent to provide a forecast for a given ahead period. At this moment, each agent/player should execute the forecast it wants (ANN or SVM). The agent uses the stored data to feed the input of the forecasting and then waits for the web service response. The forecasting are executed locally and in a distributed way throughout the MAS. After processing the forecast, the agents send the data back to the microgrid agent. Then, microgrid agent, will aggregate the forecasts and create a global forecast. This process requires more process in the web service side, however, it maintains the consumptions data in the consumer side (no stored data goes to the microgrid agent).

4 V2R - Energy Analyzer Emulator

Energy analyzers are a useful tool for energy monitoring in new and old buildings. These products can be found on the market with a widely range of prices. There are single-phase and three-phase. Some of them also allows the on/off control of an output port. They can be mounted in the entire building, a single room or a single load.

The capability of measuring energy is important for power systems R&D centers that have a need for build scenarios with real data. The protocol normally used for communications is Modbus. This is a simple request-response protocol that works in two communication standards: RS-485; and TCP/IP. Modbus/TCP is used through TCP/IP using Ethernet, in order to use this protocol the energy analyzer need an Ethernet connection or is needed a RS-485 to TCP/IP interface. Modbus/RTU is used through RS-485 and is adopted by the majority of manufactures.

The energy analyzers work perfectly if the goal is to measure real loads with real consumption. However, is not possible to use them to simulate loads. This is a problem for implemented and installed solutions that need to perform tests and validation of various scenarios. To solve this issue, this paper proposes the use of Virtual to Reality (V2R) emulator [16]. This is an emulator built to overpass the limitations of the energy analyzers. V2R allows the simulation of loads using the installed infrastructure. V2R is basically an energy analyzer for load emulation, which uses the same Modbus/RTU communication as an energy analyzer. Fig. 3 shows the V2R components.

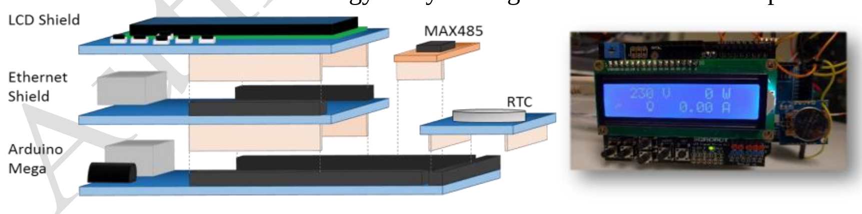

Fig. 3. V2R emulator (physical components)

V2R provides a LCD display to monitor and configure some parameters (Fig. 3). The emulator allows six types of emulations:

- ***Chart Load*** – this type of emulation follows the data in a chart using the Real-Time Clock (RTC) to mimic the input consumption using the data stamp. This is an uncontrolled load that follows a profile consumption, it is a good option for a refrigerator emulation without control;

- ***Discrete Load*** – this is a controllable load (using the LCD shield buttons), the configuration defines the on state consumption and the off state consumption. Them the emulator turns the load on and off according to the pressing of the button (by the user or using a webpage interface). This can be indicated for heater;
- ***Variable Load*** – similar to the discrete load but the load is dimmable, this is a good choice for a lamp;
- ***Contextual Load*** – this emulation is the combination of the chart load with the discrete load. This load is controllable but follows a consumption profile when it is on. For instance, this emulation can be used for a washing machine, that when is turned on it will follow the consumption profile of a washing program;
- ***OPAL-RT Load*** – some loads cannot be easily emulated, for this reason V2R can connects to OPAL-RT that is a real-time simulator able to simulate even the most complex loads. V2R will connect to OPAL-RT and display the consumptions simulated in OPAL-RT. This can be indicated for a wind turbine;
- ***Modbus/TCP Mirror Load*** – the mirror load enables the use of loads in a system where they are not, this type reads the consumption of a distant load (using Modbus/TCP), that can be in the other side of the world, and mirrors its' consumptions.

5 Case Study

For this case study it will be used the MASGriP platform for the multi-agent system to represent the implementation of Fig. 1. The user requests a forecast to the microgrid agent. This request starts three new requests simultaneous where the microgrid agent requests the other players (Building N, Building I and the Simulated Building) to execute a forecasting for next day consumptions.

Building N and Building I agent will use real data of the buildings. For the forecasting, it will be used the two last months for training. The forecast of one day is composed by 24 values (one value of consumption per hour). The agents will execute the forecasting using SVM algorithm, which are available in the web service and was previously discussed in Section 3.

The Simulated Building was created using V2R. The agent, representing the Simulated Building in MASGriP, don't know it's working with simulated loads, the V2R loads are integrated as real loads. The V2R emulates the loads using chart emulation that execute emulations using previous store data. The Simulated agent has three V2R connected: one that emulates a refrigerator; on for a water heater emulation; and other that represents the rest of the house. For the last V2R is used a data set available in the Intelligent Data Mining and Analysis Working Group website[1], identified with the name Private Home 6. For the Simulated Building forecasting, it is used a two month period for training, equal to the other agents.

The microgrid agent waits for the agents individual responses and then combine them to obtain the microgrid forecast. Fig. 4 shows the microgrid forecast using the

[1] http://sites.ieee.org/pes-iss

discrimination of the agents. Building N and Building I are offices with a high volume of consumption, while the Simulated Building represents a single house.

Remember, that the Simulated Building agent don't know that the loads it is reading are emulated. The results shows that the V2R worked perfectly, given the system the impression that the building was real with real energy analyzers reading real loads.

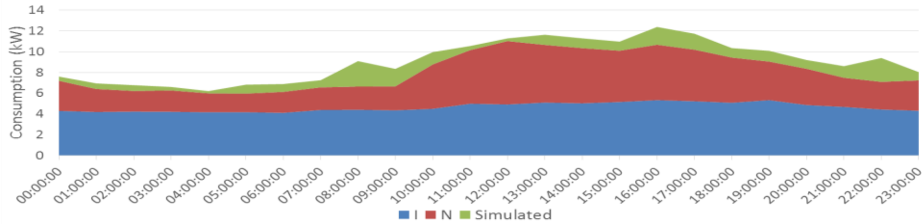

Fig. 4. Microgrid forecast by buildings

The forecasting algorithm result represents the forecast of the microgrid. The highest consumption during the day will be between 10 a.m. and 7 p.m.. In the opposite side, in the Simulated Building, because is a residential house, the highest consumption are at 8 a.m. and 10 p.m., these are the periods where people tend to have bigger consumption inside their houses. Building I, because of their characteristics, do not present significant changes of consumption through the entire day. In order to improve the forecast, new inputs must be studied and analyzed.

6 Conclusions

The need for microgrids studies is a reality, the power system paradigm demands new solutions involving distributed generation and distributed energy management systems. But in the other hand, the execution of tests and validations from the scientific community is limit to the available hardware, in very uncommon for the R&D groups to have an operational microgrid to test on.

The use of multi-agent systems and load emulation enables quick and efficient tests and validation, regarding energy management methodologies (but not in a hardware point of view). Multi-agent systems are already used for power systems, this paper proposes the use of a multi-agent system with load emulators that can be used with real systems, combining both worlds. The application of energy analyzers emulators, bring the systems closer to reality. The case study shows exactly this capability. In the case study the multi-agent system, which is implemented in real buildings, worked also with a simulated building (built with load emulators) without knowing that the building do not exist.

The combination between multi-agent systems, real buildings and emulators are an important step towards the real implementation of energy management systems in pilots' sites and new microgrids' sites.

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