Intelligent load management in local and wholesale demand response markets

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Virtual to Reality Emulator for Electrical Loads

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Abstract

The test and validation of demand side management systems are a priority before installing this systems in real environments. This paper presents a load emulator that acts as an energy analyzer. This emulator enables its installation in physical environments, fooling the metering systems. This capability allows the placement of the emulator in a physical metering system while emulating a load that is not there. In a R&D center the emulator can be used to create buildings by placing several emulators for load emulation and using a real and physical metering system to read the consumption data while demand side management algorithms and techniques are used. Using the proposed emulator, the gap between research and real implementations can be fulfill in the laboratories to test and validate demand side management systems. The paper presents the emulator and its results.

Keywords: energy analyser, load emulation, metering

1. Introduction

The change of paradigm in power systems enables the active participation of small and medium players in the smart grid environment [1]. The integration of Demand Side Management (DSM) systems in end-consumers is also enabled by the new paradigm and it will allow end-consumers to manage their energy [2]. Therefore, the design, development, test and validation of DSM systems should be done fast in order to implemented them, in near future, in end-consumers houses and buildings.

There are a vast variety of DSM research works that try to provide valid solutions for DSM systems, some examples are [3], [4], [5], [6], [7] and [8]. However, the majority of these research works lack of real implementations to test and validate their solutions in uncontrollable environments.

The main contribution of this paper is the load emulator proposed. The Virtual to Reality (V2R) emulator enables the emulation of loads, in an hardware device, that can replace an energy analyser. This enables the placement of V2R in a RS-485 network with other energy analysers, fooling the system.

By using the proposed load emulator, is possible to build a building in laboratory to test DSM systems. The ability of V2R to work as an energy analyser enables the integration with real monitoring and control systems. Therefore, the laboratory can build a building using three layers: load emulators, a physical monitoring and control system, and the DSM solution to be tested and validated. With these three layers the monitoring and control system and the DSM solution think that they are dealing with real loads, approaching the solution to a real implementation.

After this first introductory section, the V2R emulator will be presented in Section 2. Section 3 will present some of emulation results. While Section 4 will present the main conclusions of this work.

2. Virtual to Reality Emulator

The main contribution of this paper is the test and validation of Virtual to Reality (V2R) emulator [9]. V2R was designed and developed to solve a problem in most of the power system R&D centres: the lack of residential electrical loads. It is important for R&D centres to test machine learning techniques and optimization algorithms. Therefore, the use of residential loads can benefit the test and validation of solutions regarding demand side management.

Fig. shows the V2R architecture. The emulator works as a common energy analyser. Therefore, the architecture was designed to enable the emulator to communicate using Modbus/RTU through RS-485. This way, V2R is able to be connect to a Programmable Logic Controller (PLC) similar to energy analysers. The real-time clock enables real-time emulations, and the data storage is used to store the data and information that V2R must emulate. For configuration and database connection, V2R has a TCP/IP block that enables the users to configure the emulation and enables the V2R to store the emulation data into a database.
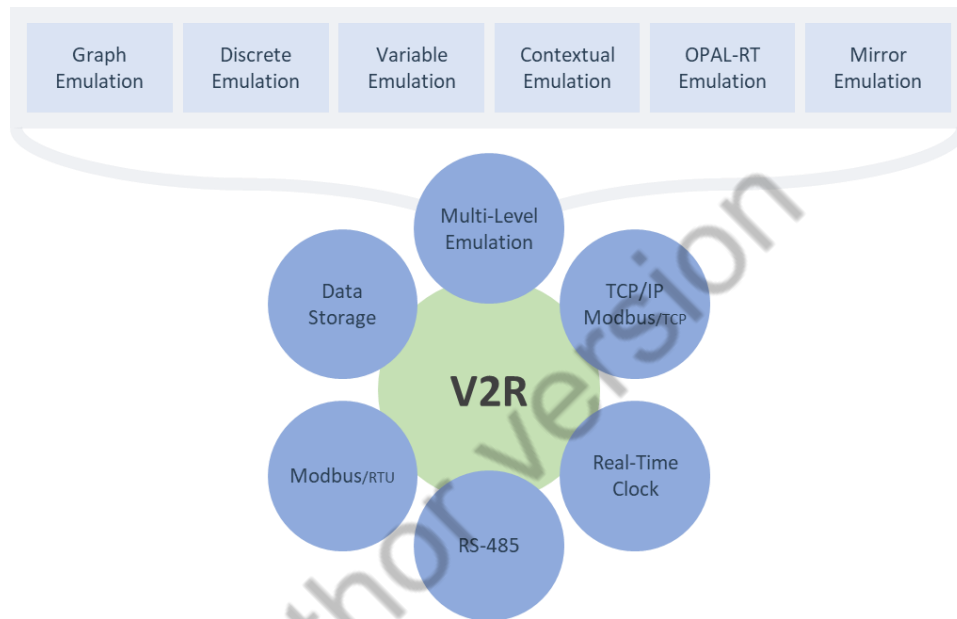

Fig. 1: V2R architecture

Regarding emulations, V2R was designed to provide a total of six emulations with a total of sixteen subvariations of emulations:

- *Graph Emulation* – the graph emulation emulates a load based on a real load profile using real readings taken in the past. For example, is possible to measure a refrigerator during a 24 hours period and then order V2R to emulate that refrigerator. The refrigerator data is stored in the data storage block. This type of load allows the emulation to run in real-time (following the hours of the real data) or in emulation time (following the hours of the emulation);

- *Discrete Emulation* – the discrete emulation emulates a discrete load built by the user, this is a load with only two states: on, and off. The user must set the load consumption when the load is off (usually set to zero), and the load consumption when the load is on. Also, the user can define if the initial state of the load is set to on or off;

- *Variable Emulation* – this emulation is similar to the discrete emulation. However, in this emulation the load has more than two working states, it can have multiple working states with different consumptions levels or a range of states with a range of consumption – for instance, a dimmer lamp;

- *Contextual Emulation* – the contextual emulation was provided to emulate loads with working cycles. Imagine a washing machine that has a working program with a specific consumption profile, the contextual emulation receives the consumption profile and emulate it every time the load is set to on, when the profile finishes the load is automatically set to off;

- *OPAL-RT Emulation* – for more detailed emulations, V2R is able to work together with OPAL-RT [10], using real-time simulations. The benefit of V2R with OPAL-RT is the ability to put the consumption values generated by OPAL-RT into an energy analyser emulator;

- *Mirror Emulation* – the mirror emulation enables V2R to mirror the consumptions of another energy analyser using Modbus/TCP communication between V2R and energy analyser. This enables to put the consumption of on building or load in a different geographic region without the need of dislocations.

Beside all the emulations available, V2R has the possibility to apply a random variation into emulations, excluding only the OPAL-RT and Mirror emulations where this option is disabled. The randomness emulates the variation of consumptions that occurs in energy analysers where the voltage, current and power has small variations in time. The random variations in V2R are applied each second and according to the user definition.

Fig. 2 shows the implementation of V2R used in this paper. The implementation used an Arduino and Arduino Shields for the components in order to simplify its development. The only component that was not used in a Shield format was the MAX485. The board of MAX485 was handmade following the connection schema provided in the datasheet.

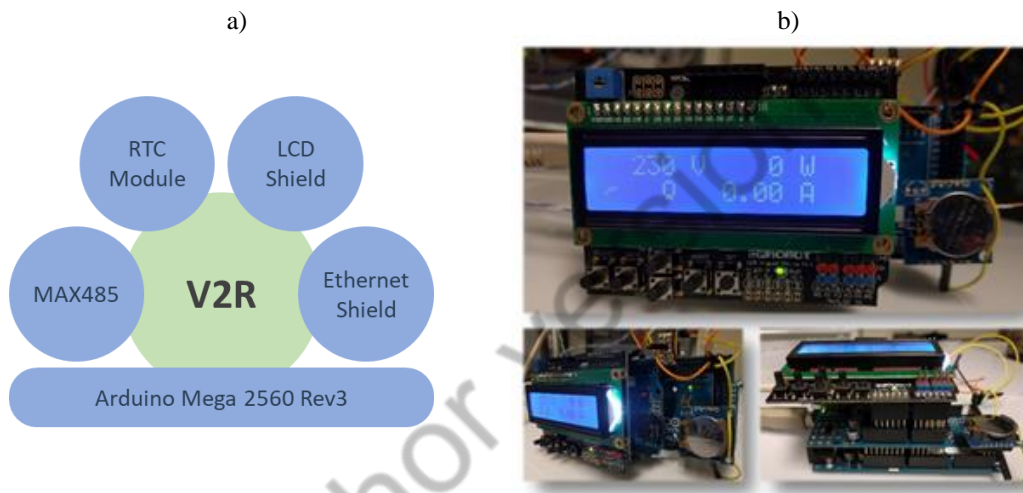a)   b)

Fig. 2: V2R implementation using an Arduino: a) Used components, b) Final implementation

V2R has a simple architecture that enables the emulation of a common energy analyser. The emulation is accomplished using Modbus/RTU protocol through RS-485 serial communication. It is possible to connect the V2R to any RS-485 master device. Table shows the readable Modbus/RTU registers available in the V2R. The values of registers are represented in IEEE Standard for Floating-Point Arithmetic (IEEE 754).

Table 1. V2R Registers Addresses

Address (hex)	Size (bytes)	Data Type	Description
0x01	4	IEEE 754	Voltage
0x05	4	IEEE 754	Current
0x09	4	IEEE 754	Power consumption

Using a LCD Shield, basic information is displayed to the user. The buttons, available in the LCD Shield, controls a menu with the following options: server IP, publishing status, RS-485 slave identifier, V2R IP address, and V2R unique identifier.

Fig. 3 shows the configuration website of V2R for a discrete emulation. V2R integrates a TCP/IP communication layer for remote configuration, monitoring and control. For configuration is needed the IP address of V2R that can be found in the device menu.
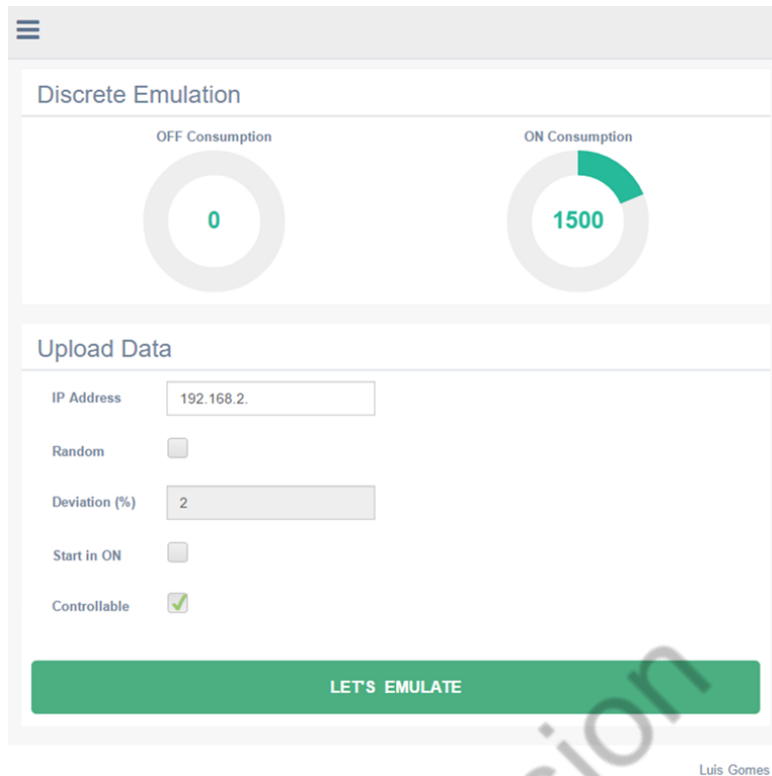
Fig. 3: V2R configuration webpage for discrete load

During the configuration is possible to define a random value to be applied in the emulation. The value is a percentage of randomness that will be applied to the consumption emulated by V2R. This gives the illusion of the variation founded in real load measurements made by energy analysers. The random value is applied each second during the emulation execution. The random variation is also applied when the emulated load is turned off, in this case the random variation is applied in the voltage value.

The values of emulation can be sent to an external server to save de data in a database. For this work is used a SQL Server database to store the data. The period of data storing was set to one second, and the values stored are: *arduino_id*, date, voltage, current and consumption. The TCP/IP block of V2R also enables the remote control of the emulation. Fig. 4 shows the webpage where is possible to remotely control a V2R emulator, the IP address can be found in the emulator's LCD menu.
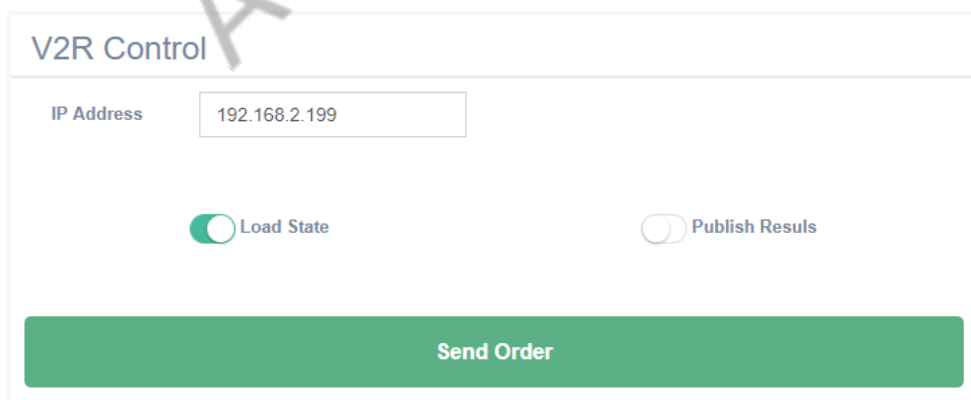

Fig. 4: V2R remote control

The capability of V2R to mimic an energy analyser gives the possibility to place V2R in monitoring and SCADA systems fooling the system. The SCADA will read V2R and see a consumption load, that do not exist in reality. This enables the integration of unavailable loads in physical monitoring and SCADA systems to test and validate the management of new loads. This feature of bringing emulations to physical systems and the versatility of V2R provides the R&D centres with the means to build residential homes or office buildings in their laboratories without the need of buying and acquiring consumption loads.

3. Results

For this paper, four emulations were executed in V2R and the results are presented below. These demonstrations of V2R use the discrete load and graph load emulations with and without random variation. The presented values were taken using a PLC that measures energy parameters in an office building and save them to a database. The PLC is a master in its RS-485 network and is responsible for the storage of energy analysers measurements. The PLC communicates with V2R in equal form that it communicates with the energy analysers, the PLC do not know that V2R is an emulator and not a real load.

A.   *Discrete emulation*

For this example, it was emulated an industrial heater of 3.2 kW. Because the idea was to control the emulation manually, the discrete emulation was chosen without any random variation. The manually control was made using the LCD Shield buttons and the webpage provided by the TCP/IP connection of V2R. Fig. 5 shows the results from the PLC, regarding the measurements read by the PLC.
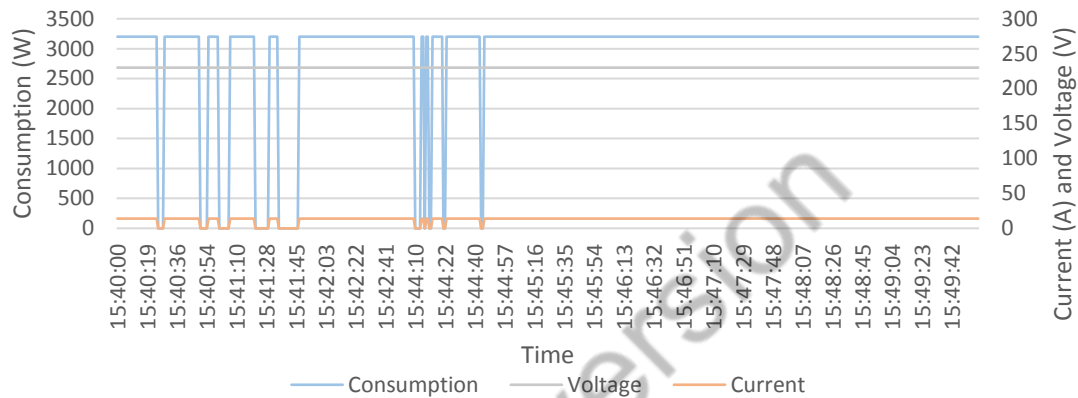

Fig. 5: Discrete emulation of an industrial heater

B.   *Discrete emulation with random variation*

To show the possibilities of the random variation, the emulation of the previous section, regarding an industrial heater, was run again using a random variation of 2%. The results are shown in Fig. 6. By comparing Fig. 5 and Fig. 6 is possible to see the impact of the random variation, the consumption measurements appear to be more real with random variation.
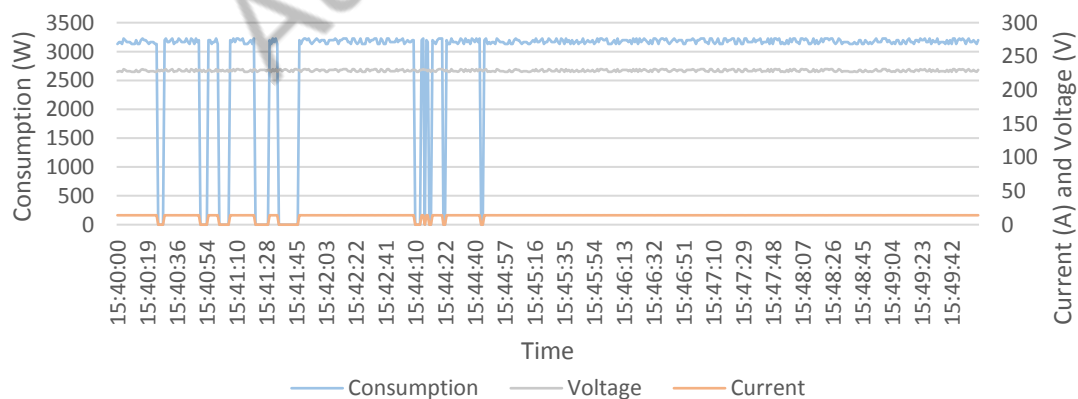

Fig. 6: Discrete emulation of an industrial heater with a random variation of 2%

C.   *Graph emulation in emulation time*

As seen before, the graph emulation is ideal to emulate load profiles that cannot be controllable. This example shows a graph emulation using a refrigerator profile. The emulations will not apply any random variation and it will run using the emulation time, this means that at the start of emulation the profile will

read from midnight to midnight – from the beginning of the profile file till its end. Fig. 7 shows the results of this emulation during a three-hour period.
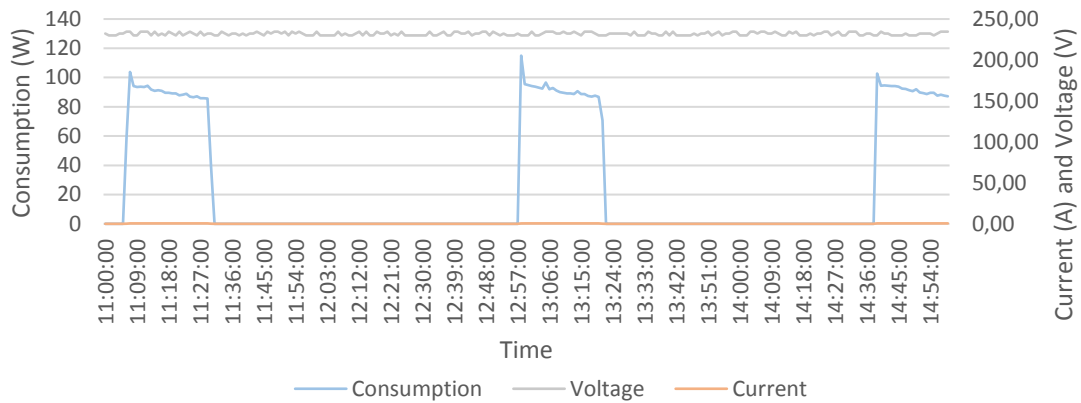

Fig. 7: Graph emulation of a refrigerator

D. *Graph emulation in real-time with random variation*

This example uses the same profile of previous section but using a random variation of 2% and using real-time. This means that the profile will be executed using the timestamp of the data file – for instance, at 08:00 a.m. it will be shown the values measured in refrigerator at 08:00 a.m. Fig. 8 shows the results of this emulation. The three-hour period used in Fig. 7 and Fig. 8 are the same but the consumption profile is not. This happens because the first emulation, of Fig. 7, uses emulation time and the data of the graph corresponds to the midnight of the refrigerator profile – beginning of the data file. In Fig. 8 is used real-time, meaning that the timestamp of the graph is equal to the timestamp of the profile data. And because is launch time, is possible to see two openings of the door, one at 12:37 and the other at 13:37. Because this emulation uses a real consumption profile, that has intrinsic variation on the consumption data, the random variation is not visible in the results
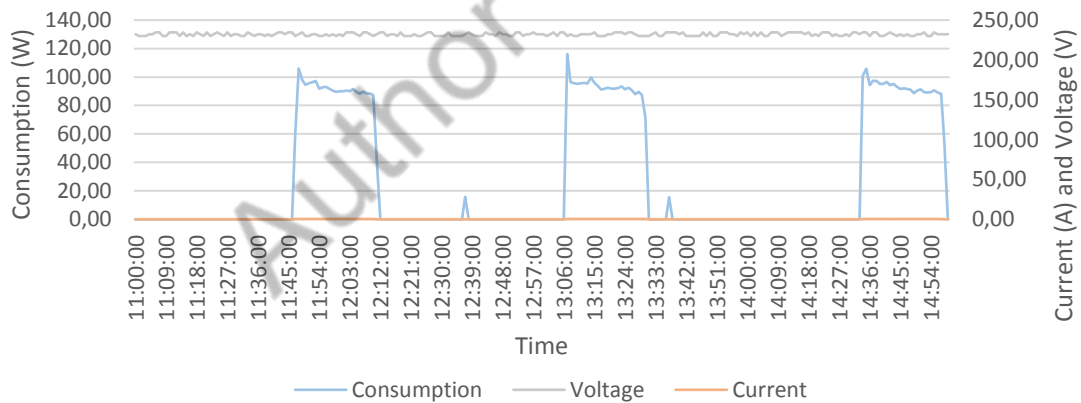

Fig. 8: Graph emulation of a refrigerator with random variation and using real-time

4. Conclusions

This paper presents a load emulator that acts as an energy analyser and for this reason it can be installed in a physical metering, monitoring or SCADA system. The emulator architecture is presented as well as the necessary components to build the emulator.

The results of several emulations were measured using a metering system of an office building. This metering system had a RS-485 network where the emulator was installed. The metering system treated the emulator as an energy analyser and was able to read the consumptions data and stored it in its database.

The obtained results were a success and prove the capabilities of the proposed emulator. The emulator can be used in physical systems and act as energy analysers, fooling the system. This enables the test and validation of demand side management systems using loads that are not available in the buildings.

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