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EMULATION AS A MEANS TO EVALUATE ENERGY MANAGEMENT ALGORITHMS

This article describes a Smart Grid Emulator. Its major goal is to demonstrate each block of the emulator as well as the simulator that supports it. It also shows the interdependencies between emulator and simulator. Using examples, it is described what test possibilities such an emulator provides.

EMULACJA JAKO ŚRODEK DO OCENY ALGORYTMÓW ZARZĄDZANIA ENERGIĄ

Artykuł ten przedstawia emulator inteligentnej sieci energetycznej. Opisuje wszystkie bloki wraz z symulatorem, który wspiera jego działanie. Przedstawiono w nim również zależności pomiędzy emulatorem a symulatorem. Na podstawie przykładów przedstawiono możliwości testowe jakie zapewnia opisywany emulator.

1. MOTIVATION

As the number of electrical devices linked to the power grid grows, so does the amount of electricity demand. As a result, careful management of the generated and consumed energy is required. One solution is to manage the electricity grid from the customer's perspective on home device level.

It is impossible to deploy new management algorithms into a live electrical grid without first testing them. The reason is that testing these algorithms can expose the grid to dangerous situations, in the worst case, leading to a blackout. An emulator that mimics the grid behaviors is convenient in this situation.

Emulation is the process of modeling a particular system on different hardware, or on a different system using software [1]. Emulation is accomplished by the use of an emulator, which is a particular piece of hardware [2]. Emulators of varying complexity can be created. When emulating a system, such as a power grid, it is also a good idea to replicate the physical components. Presented emulator can be characterized as a complex, distributed measurement and control system. The goal of this paper is the presentation of method for emulating the power grid in order to test and evaluate power management systems.

2. PROPOSED APPROACH

The entire system is split into two parts – hardware and software. The Smart Grid Emulator is the hardware part, and the Simulator is the software part. The combination of these two parts enables the testing of a variety of situations. These parts exchange measurement and control data that has an impact on the grid's operation and behavior.

2.1. Smart Grid Emulator

Each block has a Smart Meter, which is a measuring and communication device. It is made up of two Texas Instruments MSP430 16-bit microcontrollers. The first assesses electrical parameters such as: Current RMS, Voltage RMS, Frequency, Power factor (cos), Total active power, Active power, Reactive power, and Apparent power.

Measurements are made on three different AC channels [3], which have a measurement rate of 4092 measurements per second. Each Smart Meter channel can be calibrated independently. This is done to improve measurement precision. The first MSP430 is also responsible for executing control commands

[4]. It receives these commands from a second device based on the MSP430 microcontroller, which is responsible for communication. The transmission of these commands can be achieved through wired (USB UART interface) or wireless (radio transceiver cc1101) connections. For this purpose, a special communication protocol was developed, which was also documented as a master thesis [4].

In order to create different grid topologies, it was necessary to create blocks, where each block has a specific purpose. Subsections below describe all blocks of the smart grid emulator.

Primary Substation

It is equivalent to the high to middle voltage transformer station. Its purpose is to reduce the grid voltage to 48 volts in order to improve safety of the emulator. The 48-volt level in the emulator corresponds to the medium voltage in a full-scale power grid. It is also feasible to operate the Transmission Lines connected to it from its level. This gives a possibility of disconnecting and testing scenarios related to switching of power sources for sub-grids of the grid. The Smart Meter in this block calculates the total electrical values of all grid devices.

Secondary Substation

Its function is similar to that of the Primary Substation. Its purpose is to change the voltage between medium and low, which is 24 volts. Like the Primary Substation, it also operates the algorithms for controlling the transmission lines connected to it. It is also in charge of calculating the overall energy in the sub-grid that is connected to it.

Transmission Line

This block emulates transmission lines. It is controlled by master devices such Primary and Secondary Substations. Its unique board design enables the attachment of passive components to simulate transmission line lengths or losses that occur during the energy transmission process. Transmission lines can be used to split a single source into three different connections. By delivering a control command, these connections can be disconnected programmatically.

Prosumant

It is the most complex block of the entire Smart Grid Emulator. It consists of three major components: an energy meter, an Inverter Board, and a Consumer Board. This is the block that gets data from the Household Simulator and converts it into actual grid consumption and production. It is modeling a household (or a collection of these) that uses and generates power. The presence of such a block allows for the testing of energy management algorithms without the presence of humans. The exact operation of this block is described in Section 2.2 that describes the operation of the Simulator.

Fig. 1 shows the simplest topology using all blocks. It also shows the dependencies between the emulator and the simulator. This topology can be extended depending on the test scenario.

2.2. Simulator

The Simulator is responsible for generating data to control the hardware part of both grid and Prosumant blocks behavior. The simulator itself is an application that needs more hardware resources and therefore runs on separate hardware, in this case, BeagleBone Black. The BeagleBone Black exchanges data with the Smart Meter over the USB UART interface using a Java application called the Smart Grid Adapter [4].

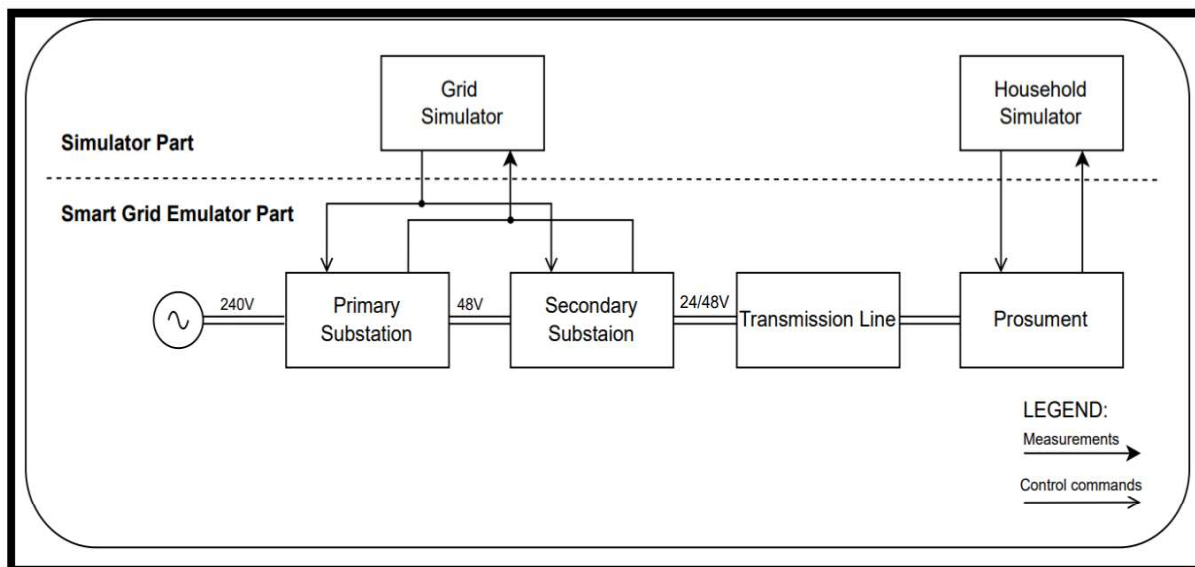


Fig. 1. Interdependencies between the emulator's parts
Rys. 1. Współzależności pomiędzy częściami emulatora

The Household Simulator

The Household Simulator [6] generates control commands for Prosumer block. The current status of the simulation (information on generated consumption and production) is displayed via a graphical interface. A consumption curve is generated based on previously collected electricity consumption data for various electronic household equipment. The big advantage of such a simulator is that it can simulate smart devices, which are still limited in number. A second advantage is that it can use real production data collected by a meter connected to the photovoltaic panels. The combination of these solutions allows for the creation of reliable simulations of households.

The Grid Simulator

Grid Simulator allows to generate different power grid behaviors. It controls the Primary and Secondary Substation blocks. It is programmed to produce a variety of random events, such as failure of transmission lines. Its task is to respond correctly to the generated events, for example, switching the power source off immediately.

3. EVALUATION OF POWER MANAGEMENT ALGORITHMS USING THE SMART GRID EMULATOR

3.1. Testing of Island mode

Island mode is an example of an algorithm that can be evaluated using the Smart Grid Emulator. This test is relevant to determining the sub-grids' self-sufficiency. Transmission lines are used by Primary and Secondary Substations to isolate their individual sub-grids from the power source. The test allows determining how long the sub-grid can remain self-sufficient, if another power source is not automatically connected. The algorithm should automatically switch to a high-energy-saving mode.

3.2. Testing of power flow

Power flow test is a test where the Household Simulator increases the demand for electricity at random times. The entire system's response is to switch energy sources so that one of them is not overused. The correct execution of such an algorithm depends on the correct behavior of the other unloaded parts of the grid. This test is used to ensure that electricity is distributed evenly throughout the transmission lines in order to avoid overloading.

3.3. Testing the impact of electricity prices

The smart grid should respond to increases and decreases in electricity prices. The test involves manipulating energy prices in a simulator and analyzing the system's response. The grid should switch to renewable energy if energy prices rise, and when prices fall, the grid should recharge energy storage. This approach can smooth out price volatility and improve people's perceptions of smart grids. It also enables testing of energy management algorithms.

4. CONCLUSION

The test capabilities described in this paper are just a small sample of the emulator's capabilities. The most crucial aspect is that it allows for the testing of artificial intelligence systems without involving humans. This allows for the testing of algorithms that humans may not agree with due to the inconvenience they entail.

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