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Demand response approaches for real-time renewable energy integration
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Applying real-time pricing for wind curtailment scenario using D2RD module of TOOCC

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Abstract

Multi-agent systems are widely used tools to simulate and study the energy sector because of their distributed architecture. There are several simulator tools available in literature, however, much of these prove to be very domain specific. The emergence of the Tools Control Center tool allows these simulators to cooperate in order to solve more comprehensive problems and more complex scenarios. This paper presents a module of this tool known as Demand Response Registration Digital, which allows the study of the model and programs of Demand Response. To understand the operation of this module, an example is given considering a wind curtailment scenario.

Keywords: demand response, energy resources management, multi-agent simulation, real-time simulation, semantic interoperability, smart gridIntroduction

1. Introduction

Achieving an increasingly clean and sustainable energy policy are the main objectives of the European Union for the coming years. To make this possible, the EU has set targets that will significantly change the behavior of electric power systems, as well as the role of participating entities. These targets are aimed at reducing greenhouse gas emissions, increasing the use of energy from renewable sources and increasing energy efficiency [1].

With the growth in the use of renewable energy sources, especially with Distributed Generation, network management has become a much more complex task due to its impact on the grid. Although it has great advantages such as reduced cost of on-peak operation, reduced losses, and increased quality of service, the unpredictable nature of this type of power source makes network balance and reliability a challenge. This way, it is necessary to find efficient mechanisms for the study of these systems that allow to detect failures, to plan the energy management and even to find more efficient models [2][3]. In this sense, the simulation tools have a great importance, since its versatility allows to support the diverse activities of the sector, from the operation of the network, to the final consumer [4]. In the literature can be found several simulators for the various areas of energy systems. Some examples are Eurostag [5], OMNeT ++ [6], MOCES [7], DRSim [8], GridLAB-D [9], among others. In addition to these, there are also several simulators that are based on multi-agent technology, which is particularly well adapted due to its distributed nature, such as EMCAS [10], MAN-REM [11], MASCEM [12], Power TAC [13], SGiC [14], AiD-EM [15], among others works.

Although there is a wide range of simulators in the area of energy systems, they have a major disadvantage: they are geared towards solving problems in specific areas of the industry, such as energy markets, network management, etc. To carry out studies closer to reality, where all areas are related, it is desirable that the different simulators from different areas are be able to talk in a way to simulate more comprehensive and complex scenarios with all their dynamicity. Although there are already simulators that try to interconnect the different areas of energy systems, such as EPOCHS [16], GECO [17] and Mosaik [18], they do not have the ability to dynamically construct scenarios for simulation, i.e., the user can not set up a scenario that does not has been pre-established.

The Tools Control Center framework (TOOCC) has been designed with the aim of filling the gap and thus allows the interoperability between heterogeneous simulation systems, by combining the simulation capabilities of each tool to be linked, allowing to simulate and analyze more comprehensive and complex scenarios. TOOCC allows the creation of scenarios with information on electricity markets, SG operation, modeling of concepts such as consumer, aggregator, pricing, real-time pricing, demand response programs, among others.

This paper intends to present the D2RD module of TOOCC, developed to model and simulate DR scenarios, considering consumers, producers, tariffs, real-time pricing, supply energy and DR programs. For its demonstration, the simulation of a real-time pricing scenario for wind curtailment with 6 consumers is described.

After this first introductory section, the TOOCC framework and D2RD module will be presented in Section 2. Section 3 shows a practical example how to use these tools and their features. Finally, Section 4 will present the main conclusions of this work.

2. Tools Control Center

The TOOCC framework [19] is a stand-alone multi-agent system that allows to take advantage of the strategic integration of other simulation tools. To this end, TOOCC acts as a facilitator in the integration of heterogeneous systems, using them as subsystems in the simulation of scenarios that consider different areas of energy systems. In the integration between systems, ontologies are used which allow the mapping of concepts and their relations. In addition, it is also possible to define the models that consider the necessary parameters, and run them on different machines in the domain, taking advantage of their features and installed software. At the end of the simulation are presented the results of each execution, allowing the user to draw conclusions and make decisions.

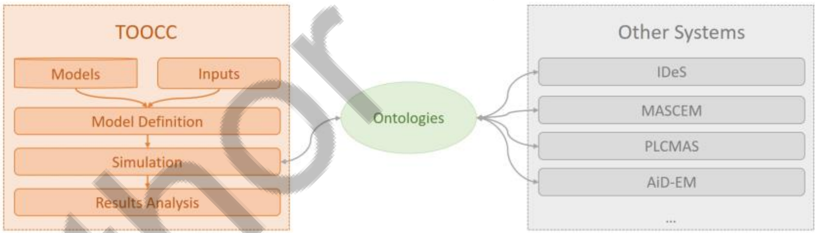

Fig. 31: Global perspective of TOOCC framework.

As can be seen in the Fig. 31, the tool is executed in three phases: model definition, simulation and results analysis. To fill the models can be considered simulated or real data, derived from a wide variety of sensors, consumers, production units and tariffs. The models are designed according to the tools that will be used in the simulation. For the simulation, more or less systems and/or algorithms may be included, depending on the complexity of the problem. The tools with which TOOCC connects for the purpose of executing the simulation are: the Intelligence and Decision Support Multi-agent System (IDeS) that allows the execution of different DR optimization, scheduling, forecasting, and decision support algorithms; Multi-Agent Simulator for Competitive Electricity Markets (MASCEM), which performs simulation of electricity markets; Adaptive Decision Support for Electricity Market Negotiation (AiD-EM), which provides decision support to participating players in electricity market negotiations; Network Manager (NM) is a system that allows to simulate the network manager, analyzing the satisfaction of consumer needs and network balance; Facility Manager (FM), which simulates energy management within a facility, managing current-connected devices such as home appliances; and Programmable Logic Controller Multi-Agent System (PLCMAS), which allows to simulate the results obtained in real environment, represented in a laboratory. These tools can communicate through the use of ontologies, which allow the mapping of the concepts between inputs and outputs, ensuring that different systems are able to understand the same concepts, and avoiding different interpretations of the same information. These ontologies are public and can be consulted in [20].

2.1 Demand Response Registration Digital

Demand Response Registration Digital (D2RD) is a TOOCC module designed to study and simulate DR programs and models. The models were developed according to the characteristics of the markets for electricity and smart grids and what is expected to be their evolution, by defining a set of characteristics. These are composed of information about participating entities (ISOs, curtailment service providers, and aggregators, including VPPs, and consumers of several types); the ways that can be used for their interaction in short and real-time DR events and the required technologic means; and DR contracts and consumer remuneration methodologies [21].

The graphical interface developed for this module allows consumers to register the expected consumption, flexibility and envisaged incentives prices for each moment, which later, together with the information of other consumers, allow to manage the DR using the available programs (Fig. 32). In the end, the network energy is optimized according to the needs of all consumers, avoiding waste and taking advantage of lower prices from the energy market.

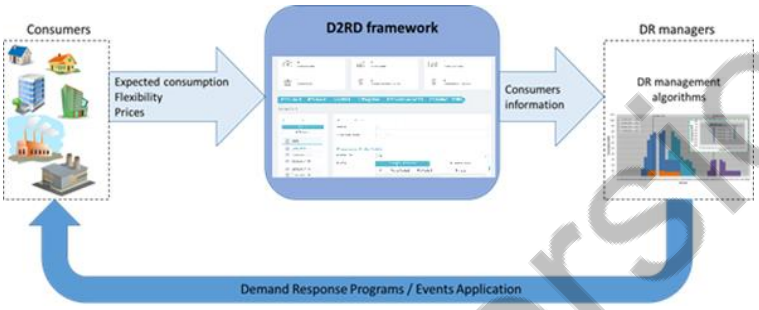

Fig. 32: D2RD module general perspective.

An architectural perspective of the module is represented in Fig. 33. The diagram shows the interaction of the several components for register the consumers information, such as the other entities, and simulate demand response models.

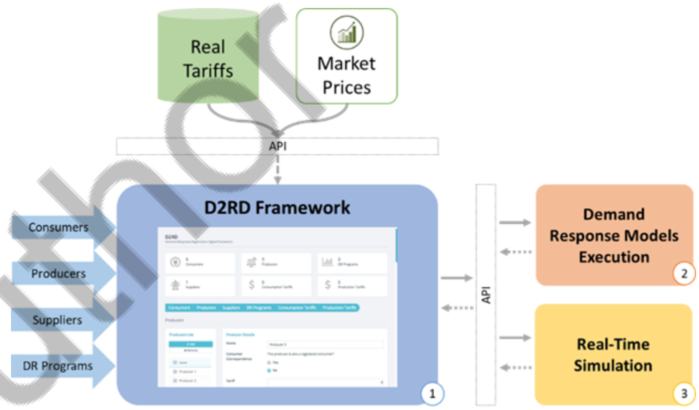

Fig. 33: Architecture model representation of D2RD module.

The framework takes advantage of the use of real tariffs and real-time pricing. When the model is prepared, the demand response manager can execute the demand response algorithm, and then proceed to the simulation in real-time in a laboratory which is able to simulate a house and its appliances. In this way, it is possible to analyze the impact of different entities and models in demand response management.

3. Real-Time Pricing for Wind Curtailment Example

In the present section, a case study will be presented for an real-time pricing for wind curtailment scenario, already used in [22]. To this end, 6 consumers will be registered. In their registration they should indicate to the manager of the DR their flexibility to increase or decrease power, at each instant of time. This information will be processed by a demand response manager who will distribute the energy in the appropriate way, considering the fluctuations in the energy price. Those results will be launched in OPAL-Simulink simulation, in a real environment [23].

Once all the constituent features of the scenario have been set up, the next step is the real-time simulation of the data. For this purpose, OP5600 real-time simulator has been used, which is a powerful Hardware-In-the-Loop (HIL) machine able to integrate the simulation environments with the real world. OP5600 can run MATLAB/Simulink models in real-time for controlling the real hardware resources and obtaining the actual results.

The TOOCC platform has been connected to the OP5600 via MODBUS TCP/IP protocol for exchanging the data, as figure illustrates. In fact, the main purpose of this integration is firstly to perform the optimization algorithm for TOOCC user data, and then execute the optimized results in the real hardware resources.

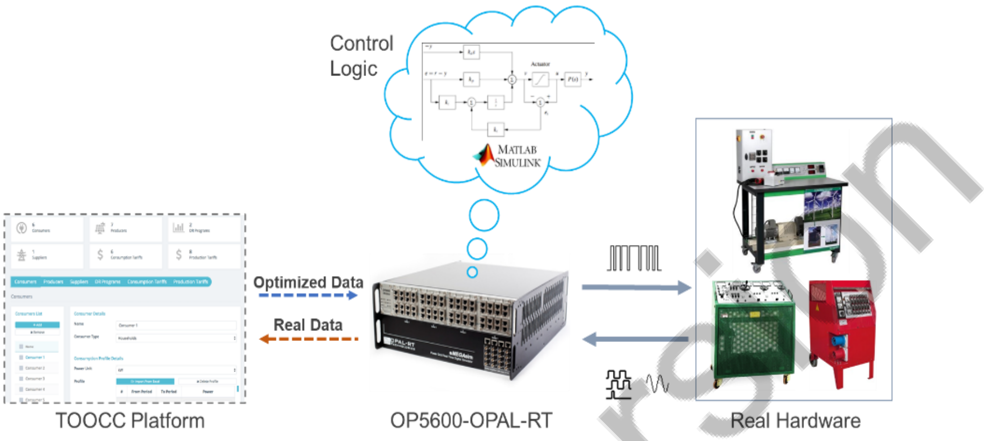

Fig. 34: TOOCC plataform integrated with real-time simulator.

As it can be seen in Fig. 34, the TOOCC platform starts the simulation by transmitting the input data to the DR Provider algorithm to perform the optimization, and the optimized consumption and generation data is sent to the OP5600. After that, the real-time simulator employs the MATLAB/Simulink model embedded in the machine and execute it in real-time. In other words, OP5600 sends controlling commands to the real hardware resources and receives the real-time consumption/generation of them. In the last stage, OP5600 transmits these real-time data to the TOOCC platform in order to be displayed as a chart to the user. In this process, the real-time market prices are also considered.

The used optimization algorithm is developed with the objective of operate distribution network and manage the available resources, by maximizing the social welfare. This considers the values of the demand forecast and of the demand increase and the respective prices (initial price and price reduction), for each consumer, of each type. The distributed generation resources (as the case of wind power generation), are divided into ordinary (ODG) and prioritary (PDG). The prioritary ones regard the resources that should be entirely used, as the case of non-dispatchable energy generation resources that are not storable. Otherwise, a cost (curtailment cost) is paid due to the generation curtailment. The energy acquired from the upstream network from one or several suppliers is divided into a quantity previously obtained (from Supplier Sp) at a given price, and an additional amount available at a distinct price. The objective function is presented in equation (1).

$$
= \left[\sum_{Type=1}^{NType} \sum_{C=1}^{NC} \left[\begin{array}{l} \left(E_{Demand(Type,C)}^{Forecast} + E_{Demand(Type,C)}^{Increase} \right) \\ \times \left(C_{Demand(Type,C)}^{Initial} - C_{Demand(Type,C)}^{Reduction} \right) \end{array} \right] - \left(\begin{array}{l} \sum_{Sp=1}^{NSp} \left[E_{Supplier(Sp)} \times C_{Supplier(Sp)} \right] \\ + E_{Supplier(Sp)}^{Additional} \times C_{Supplier(Sp)}^{Additional} \\ + \sum_{PDG=1}^{NPDG} \left[\begin{array}{l} E_{DG(PDG)}^{Prioritary} \times C_{DG(PDG)}^{Prioritary} \\ + E_{DG(PDG)}^{Curtailment} \times C_{DG(PDG)}^{Curtailment} \end{array} \right] \\ + \sum_{ODG=1}^{NODG} \left[E_{DG(ODG)}^{Ordinary} \times C_{DG(ODG)}^{Ordinary} \right] \end{array} \right) \right] \qquad (1)
$$

Fig. 35 shows the results of real-time simulation using TOOCC platform and several laboratory consumers and generators. These results are for 96 periods of 10 seconds (960 seconds in total), which means OP5600 transmits the desired rate of consumption/generation to the resources for each 10 seconds, and the resources send their real-time consumption/generation rates to the OP5600 with 1 second time interval.

The first chart in Fig. 35 is related to the consumption profile of a community of consumers (known as Consumer 2 in the TOOCC), and the second and last charts are related to the laboratory emulators that have been employed by OP5600 for emulating the consumption of generation profile of a customer.

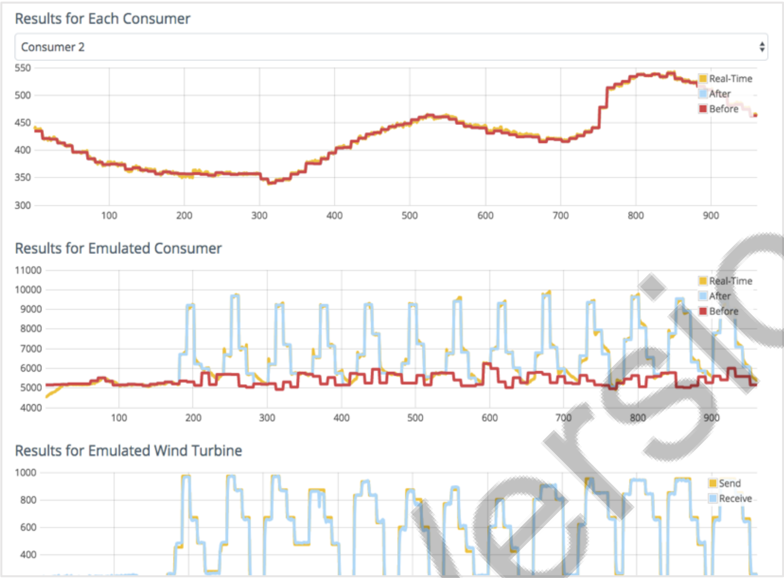

Fig. 35: Real-time simualtion results.

4. Conclusions

There are several advantages and challenges that the DG's implementation brings to the energy sector. To address some of these challenges, simulation tools, especially multi-agent architecture, are essential for its evolutionary process. However, much of the state-of-the-art tools are designed to solve problems in very specific domains, losing the essence of an industry where all areas are interconnected with a high level of complexity. In this context, the TOOCC tool emerges, which allows the interconnection of different systems in order to solve problems that cover the various domains of energy systems.

This paper presents the D2RD module of TOOCC. The D2RD module allows the study of DR models and programs through the consumers' registration of flexibility, expected consumption, and envisaged costs for using such flexibility. This is important information that can be managed by different entities, namely network managers, in order to manage the available energy and the needs of its consumers, avoiding waste and taking advantage of fluctuating market prices, reducing costs.

To better understand the operation of the module and its advantages is presented an example of a wind curtailment scenario, where are demonstrated some features; the steps necessary for the user to use the tool; and how to interpret the results.

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