REAL-TIME SIMULATION FOR DISTRIBUTED GENERATION IN POWER SYSTEM

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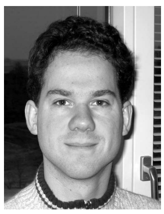
Abstract

Real-time simulation for power systems has been developed firstly on analogic platforms for testing actual equipments such as protection relays and power plant controllers. Since real-time simulator performances have followed the evolution in computing technology, it is now possible to have reliable and efficient solutions to achieve 'Hardware in the Loop' test benches. The purpose of this publication is to introduce the simulation setup based on a fully-digital real-time simulator. We present briefly in this paper different possible solutions in this specific field of application for real-time simulation. Initially, these simulators were developed for high or extra high voltage power systems. Nowadays testing small equipment dedicated to distribution network is a new challenge since the dynamic involved are much higher. First, we present an application of real-time simulation to the test of a small gas turbine connected to a distribution network. The application of real-time simulation is then widen to the control of distributed generators connected to a weak distribution network where real-time simulation is used to test advanced control strategies based of multiagent systems. The controllers for these distributed generators are located outside the real-time simulator. The interface with the simulator is based on IP network and complies with the new standard of communication in electrical substations.

Keywords: real-time simulation, electrical engineering, hardware-in-the-loop, agent-based systems

Presenting Author's biography



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1 Introduction

The total distributed generation capacity installed in the world has increased substantially during the last few years. Non real-time modelling and simulation have been traditionally used for carrying out research in this field. However, integrating actual hardware (control boards or complete control cabinets) into the simulation process is not possible in off-line simulation. Real-time simulation is now a mature technology for 'Hardware in the Loop' testing of power system equipments. This paper presents in a first part a review on the major systems which are used nowadays and some typical applications as testing of protection relays, thyristor or GTO based HVDC controllers [1] or SVC systems. Recently, new applications concerning wind energy conversion system ([2] [3]) and distribution network [4] have been proposed. One of the major technological advances consists in using PC clusters to implement real-time simulation [5].

Integration testing of new generation sources and transistors connected to electrical networks represents a new challenge for these simulators. Indeed, the typical time step of a real-time simulation is about 50 μs. Even when possible to realize an interpolation method when one event is detected between two time steps, it is much more difficult when several events are occurring within the same period. This situation is encountered in case of Pulse Width Modulation transistor converters which are more and more used for small electrical generator. We illustrate this discussion with the example of a micro gas turbine connected to a low voltage network. The model is first explained and then real-time implementation is thoroughly presented.

By extending the real time simulation from a single unit to numerous units, one can evaluate the combined effect of a high level of penetration of distributed generation on a distribution network. Because high penetration of distributed generation in weak grids poses stability issues [6], testing of grid level controllers is a well suited use of real-time simulators. We present an application where a decentralized multiagent weak grid controller is tested on a real-time simulator. First the problem of controlling distributed generation in a weak grid with local loads is presented. Then, a testing methodology for the multiagent system is discussed.

2 Brief presentation of real-time simulation

2.1 General presentation

Testing of electrical equipments on a real power system is very difficult if not impossible. For example, implementing an actual short circuit to analyse a protection behaviour is usually too risky to be performed. To overcome these difficulties, real-time simulators has been developed and improved over the last 30 years. Firstly some analog homothetic simulators were built but due to their numerous drawbacks and high cost, hybrid real-time simulators appeared introducing digital models.

As parallel computing technology became more and more powerful and affordable, it became possible to develop fully digital simulators to overcome shortcomings of analog technology. The advantages of digital technology are well known: economies in operating costs and office space, versatility, shorter development time, lower maintenance cost, etc. Simulation cases can be set up rapidly and can be run automatically in batch mode requiring little or no user interaction.

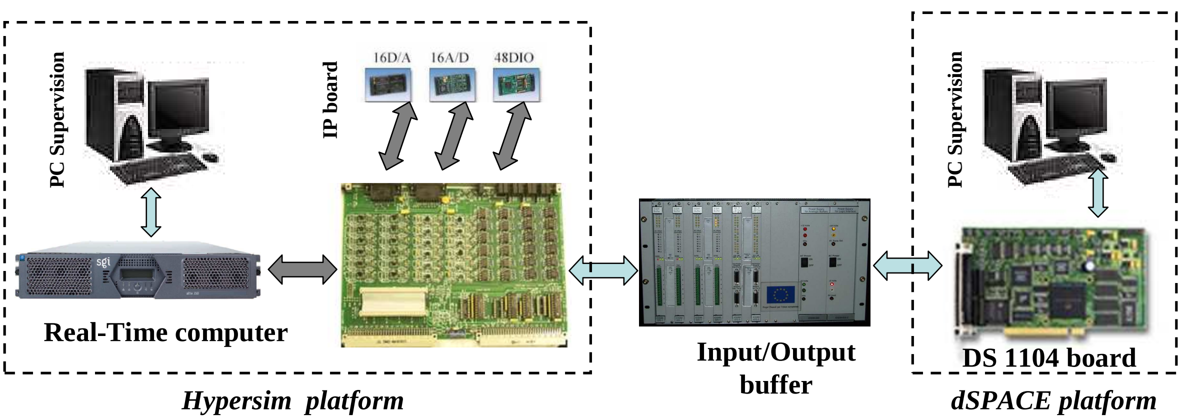

Fig. 1 : Real-time simulator interacting with an external electronic board

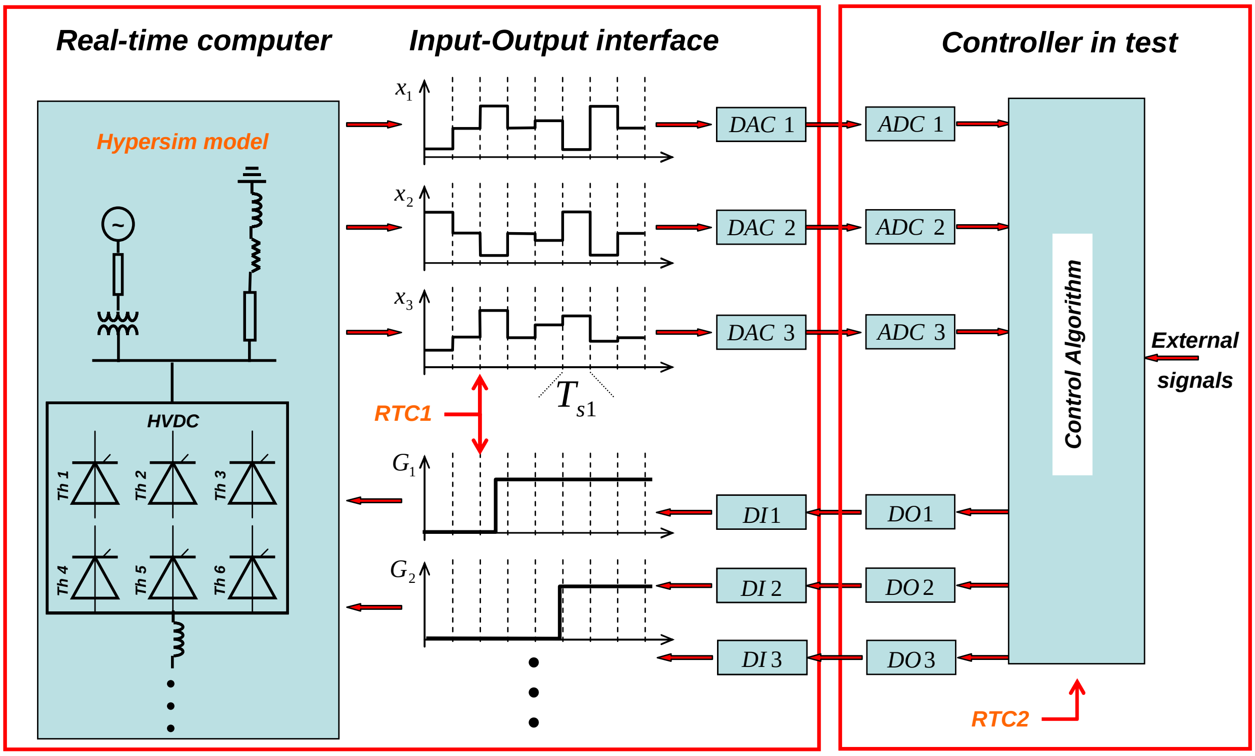

Fig. 2 : Typical thyristor application

One of the major commercial softwares, Hypersim, is presented in this paper. We introduce here in Fig. 1 the main hardware elements of the Hypersim real-time simulator which is organized around an SGI parallel computer. An external PC is connected to the simulation server. It contains the Graphical User Interface, a code generator and a visualization tool. The code is running either on the PC, for non real-time applications, or on the SGI parallel computer, for real-time or non real-time applications.

The Input/Output interface is composed of several standard IP boards: one for analog inputs, one for analog outputs and another for the digital inputs/outputs. Each board is placed on a carrier board where a DSP controller is driving all input/output exchange. Because this board is located in the parallel computer itself, it is necessary to protect this hardware from possible over-voltages. Input/output buffers are used for this purpose.

In our application, an external controller is implemented on a real-time dSPACE platform. The rapid prototyping concept provides a user-friendly environment to develop laboratory tests. For industrial applications, it is be possible to connect an off the shelf controller to the input/output buffers.

2.2 Typical thyristor application

Fig. 2 presents the information exchanged in a typical application where of an HVDC thyristor controller is under test. The network it self is simulated in the real-time plateform. Each electrical quantity (x_1, x_2, …), needed for the control algorithm, is sent to the controller through DAC converters. These operations are synchronised by the Real-Time Clock of the parallel computer (RTC1). The controller executes its control algorithm (Real-Time clock RTC2) and then generates the logical signals for the thyristor gates (G_1, G_2, …). The external controller reacts as if it was connected to the real system. Since a state change may occur between two Hypersim sampling times (see Fig. 2 – signal G_1), these signals are received on a special digital input buffers with a higher sampling rate which allows a precise acquisition of the time when the state change occured. An interpolation method is then implemented to take this information into account at the next Hypersim simulation step.

We can notice that two asynchronous Real-Time clocks (RTC1, RTC2) are running in order to allow both digital systems to be asynchronous from one another.

For such an application, the major drawbacks of real-time simulation are the time delay induced by modelling computation and the transfer time from digital to analog and back. Considering the dynamics which are involved in for thyristor applications or relay testing, this is not a major problem.

2.3 Specific problematic with a transistor converter application

If the case of Pulse Width Modulation (PWM) transistor converters, such as a Voltage Source Converter (VSC), the impact of simulation delay and signal conversions is completely different. Indeed, the usual switching frequency is between 1 and 10 kHz. Consequently, many state changes may occur between two simulation time steps. A more complex interface must therefore be implemented to take into account these events. Work on this topic is presented in [7].

If nothing special is done, it will not be possible to catch PWM signals. In these conditions, we have to use mean-time modelling. Then, control quantities which are transferred from the external controller to the real-time simulator are only duty cycles for each transistor. This idea is now illustrated with the example of a gas micro turbine.

3 Connection of a gas micro turbine on a distribution network

Fig. 3 presents the elementary network used for this application. A simple Low Voltage distribution network made of a MT/BT transformer, two lines and two loads are connected to this network. A gas micro turbine is connected to line 2. This two lines network allows us to study the Gas Micro Turbine behaviour in the case of a short circuit occurring on line 1.

3.1 From the micro turbine to the DC bus

In the gas turbine family, the micro turbines are the last born. Indeed, they require a specific mechanical technology since their rotor speed is very high (between 50 000 and 100 000 rpm). Their energetic efficiency is much lower than the bigger ones but they can be used, for example, in emergency applications. The high rotor speed allows a very compact mechanical design.

Because of the rotor speed, the wave form frequency generated by the synchronous machine coupled on the turbine shaft is very high. (more than 1 kHz). This is why, most of the time, the electric power is rectified toward the DC bus by a simple diode bridge. A classical Voltage Source Converter is then used to connect the system on the network. A precise modelling of a diode bridge connected directly to a capacitor is not an easy task. In the rectifier there are cases when 3 diodes are closed: each of the three diode current is not null. In other case, only two diodes are closed: one of the phased-current is null. A specific modelling may be developed for each case. A Petri net can be used to switch between both modelling. For this application, we have developed a simplified modelling based on RMS values of current and voltage in the synchronous machine.

The shaft speed is controlled by actionning the micro turbine fuel valve. Since it is not possible to control the diode bridge, the power delivered by the system is controlled by the voltage level of the DC bus.

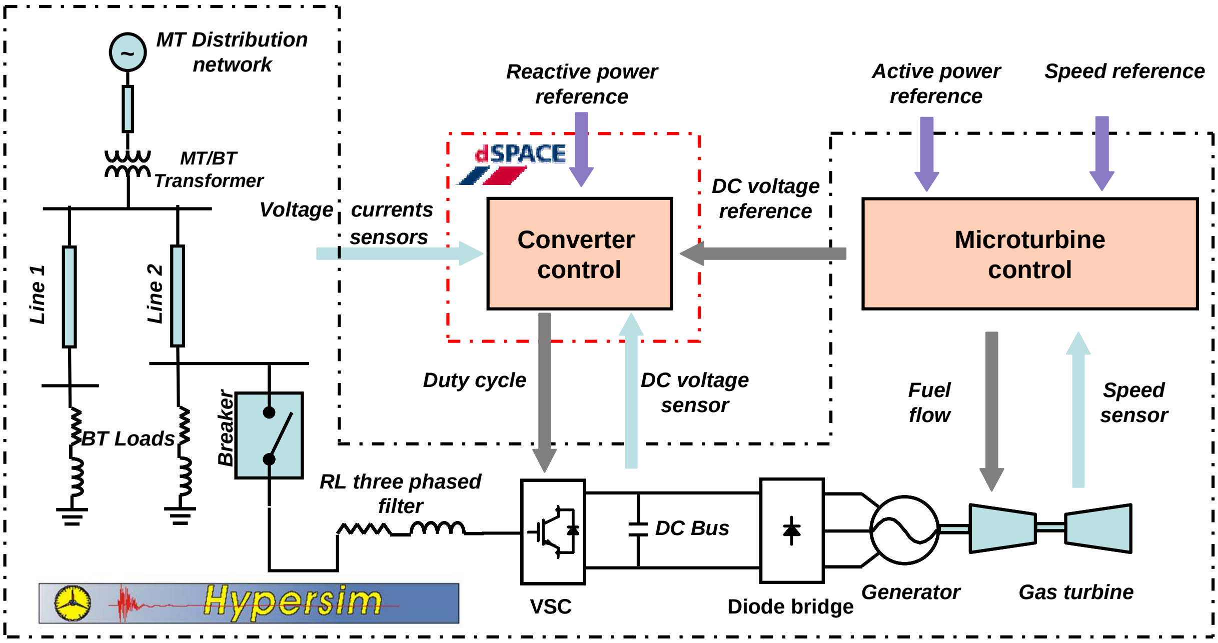

Fig. 3 Presentation of the real-time micro turbine application

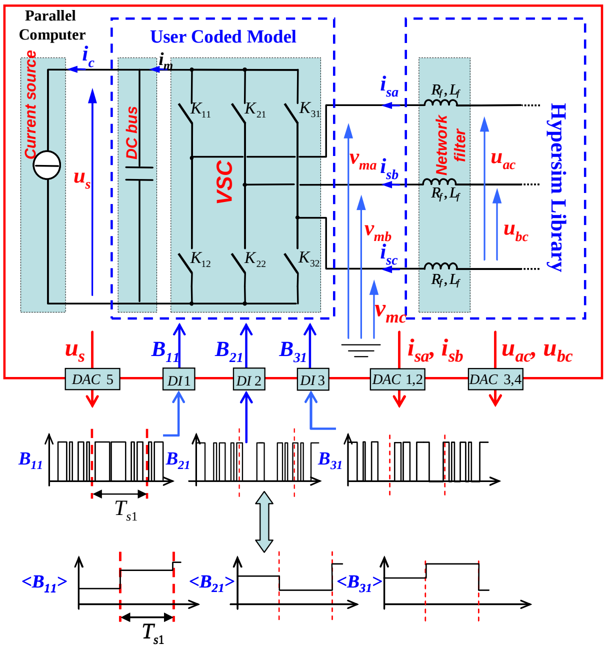

Fig. 4 Integration of VSC in Hypersim model

3.2 From DC bus to the grid

A classical VSC is used to connect the DC bus to the grid. Fig. 4 presents the information exchanged between the parallel computer and the dSPACE board assuming the VSC control law is implemented in this external board.

We notice three main parts in Fig. 3. On the left we illustrate the equivalent model of the source composed of a micro-turbine and a diode rectifier. It generates the DC current i_c. On the right we represent a part of the electrical network which is implemented by an Hypersim real-time power system library. The VSC is placed in the central part. The model inputs are i_c, on the DC bus and the three-phased currents i_{sa}, i_{sb}, i_{sc}. The model outputs are the DC voltage (u_s) and the modulated three-phased voltages v_{ma}, v_{mb}, v_{mc}. In an ideal case, we assimilate these states to the transistor control order (B_{11}, B_{21}, B_{31}), assuming the three other base quantities (B_{12}, B_{22} B_{32}) are complementary. As we said before, it is not possible to have a real-time implementation of the logical control signals. These information B_{11}, B_{21}, and B_{31} must be assimilated to the duty cycles $<B_{11}>$, $<B_{21}>$, and $<B_{31}>$. for each corresponding switching (K_{11}, K_{21}, K_{31}).

From the grid point of view, the VSC is considered as a three-phased voltage source whose magnitudes (v_{ma}, v_{mb}, v_{mc}) depend on the DC voltage u_s and the duty cycles from the DC bus. The VSC may be also assimilated to a voltage source u_s whose magnitude depends on the modulated current i_m and the source current i_c.

The VSC itself is implemented in a user coded model. For this purpose, the user may program it directly in C or in Matlab Simulink. An automatic code generator (RTW) then produces the C code of the system which is then interfaced easily to Hypersim and compiled by it. It is then possible to define the quantities which are exchanged with the "outside".

For the whole control, the grid voltage (u_{ac}, u_{bc}), the grid current (i_{sa}, i_{sb}) and the DC bus voltage are needed. On the reverse, the VSC modelling needs the duty cycle $<B_{11}>$, $<B_{21}>$, and $<B_{31}>$..
We must take into account that numerical constraints may induce one or two time step delay.

3.3 Experimental results

The system studied consists of the following parts: a micro-turbine, a rectifier, a VSC and an electrical grid, connected to each other by Hypersim real-time simulator, as illustrated in Fig. 3. Before running the simulation, the software estimates the time needed to compute the whole model and compares it to the chosen time step.

For this application, the time step is 50 µs and the execution time is 13 µs. It means that we could implement several gas micro turbines on one single processor in the SGI parallel computer. It we would need more computing resources, we could use one or two more processors of the parallel computer.
Fig.5 presents a result in case of a hard voltage dip consecutive to a short circuit occurring on Line1. The DC bus increases immediately and 20 seconds transient is then following.

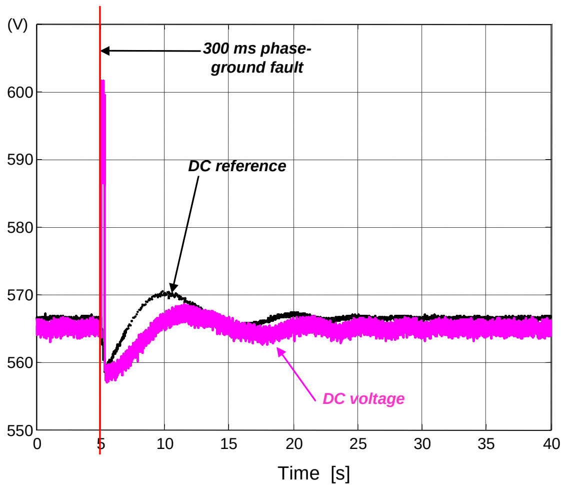

Fig. 5 Short circuit evolution of DC bus voltage

4 Control of distributed generation in weak grid

4.1 Presenting the problem

Weak grids are often present when a distribution network spreads over a large geographical area. This situation can be found as an example in rural communities. Nowadays, many farmers are looking at different kinds of energy resources (solar, wind, micro hydro, geothermal) as a second revenue stream for their businesses. But installing distributed energy resources (DER) in weak grids poses specific problems of power line stability caused by long lines and lower short circuit power. Also, it is important to maintain power quality for neighbouring loads since there is only one feed line.

Coordinating energy production at every DER location is a possible method of enhancing grid stability [8]. Decentralized control by a multiagent system is a candidate for the implementation of a control system able to perform this coordination task [9]. This system would be in contact with the larger grid energy management system (EMS) in order to:

- Communicate available production.
- Receive global set points for DERs under its control.

Fig. 6 illustrates such a system where DERs are connected at distribution level on a weak grid with local loads. The decentralized control system is in communication with the EMS and coordinates the action of DERs to maintain grid stability and to maximize energy production.

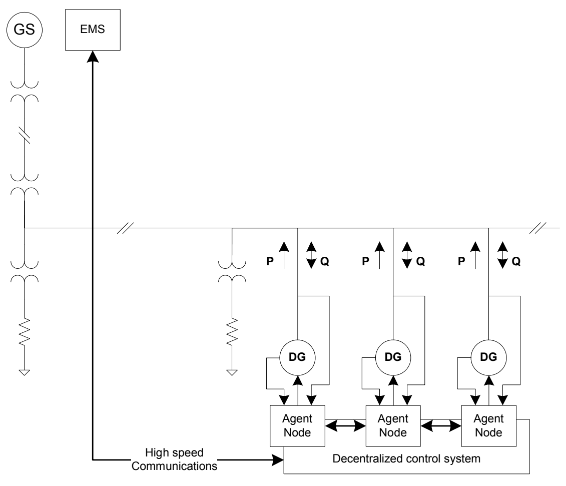

Fig. 6 DG control in a weak grid

4.2 Testing methodology

Testing such a control strategy in a real life system poses technical, legal and safety difficulties. For this reason, a testing methodology was developed based on a real-time simulator. In this case, the decentralized control system is implemented in hardware while the DERs and the grid itself are modeled inside of the simulator.

The decentralized control system that is based on multiagent technology is implemented using modular off the shelf equipment as displayed in Fig. 7. The following components were used:

- Hybrid optical/copper network switch
- National Instrument input/output board
- High end PC

Software wise, the system is built on the Java Agent DEvelopment framework (JADE) and runs on Linux Gentoo.

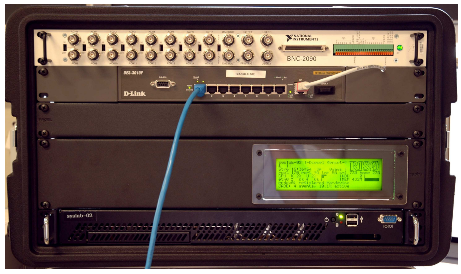

Fig. 7 : Decentralized controller node

The electrical grid components are implemented using HyperSim native models while the DER models are implemented using Matlab/Simulink, then compiled and imported in the real-time simulator.

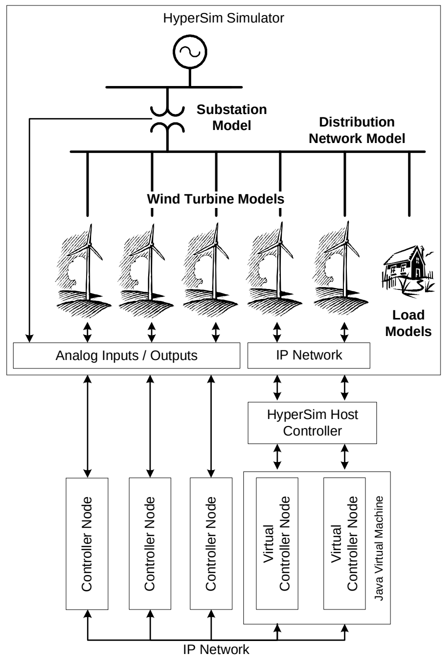

Fig. 8 Decentralized controller testing setup

For experimentations, both grid models and DER models are implemented in Hypersim real-time simulator. In the first experimental step, DER models are connected to their controllers using analog and digital inputs and outputs provided by the Hypersim input/output interface. This is the most efficient and reliable way to connect controllers to DERs because the real-time simulator HyperSim was designed for this type of application.

In a second step, some decentralized controller nodes will be implemented in a Java Virtual Machine communicating state information with DERs in the real-time simulator, through process mapping in the host controller, using only network communications (IP). This should allow the extension of the number of DER and control nodes without having to invest in new testing hardware. Figure 8 shows the testing setup for the decentralized controller using both real-life and virtual nodes.

5 Conclusion

Digital real-time simulation will certainly be more and more useful in the future for testing new equipments connected to electrical networks. We have presented the state of art of this technology with its advantages but also its drawbacks which still remain due to the very hard numerical constraint represented by computation in less than 50 µs. After a presentation of the gas micro turbine principles, we have explained the implementation of the whole system in a real-time context.

Then, extending the simulation to a distribution network with many local DERs, we have shown the application of the real-time simulation for testing a grid level decentralized controller based on multiagent technology.

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