MICROGRID STRATEGIES AND ALGORITHMS

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This paper describes a Microgrid controlled by multi- agent systems. A solution to supply high quality and non- polluting energy is the Microgrid concept. This network is based on renewable energy from units called distributed generation (DG). Microgrids integration in electricity networks is the next step towards the Smart Grid. A high -level design of microgrid is presented in this paper. By using multi -agent systems, problems are eliminated: flow control, integration of various sources of energy, self- healing, management of billing costs and real-time monitoring, energy storage, managing demand and load. The article contains strategies and algorithms that will provide an intelligent behavior for agents and multi -agent system so that it can be solved or prevented any abnormal functioning of a Microgrid network. In order to test the effectiveness of the strategies, a framework was implemented with real-time simulation and subsequent analysis of the results.

Keywords: Multi-Agent System, Smart Grid, Microgrid, Distributed Generation, Renewable Energy Sources, Power Quality and Reliability, Strategies, Optimization, Energy efficiency

1. Introduction

A Smart Grid is an electrical network in which the communication between involved entities in the energy market is made in both directions. The concept of smart grid integrates large and centralized production units and small, decentralized units, together with consumers in a single structure. Smart Grid allows power generation to be achieved even by consumers, and the renewable energy of any type (wind, sun, etc.) can be easily integrated into the system. Smart Grid increases the reliability, efficiency and safety of existing electrical network.

One of the promises that Smart Grid brings is a high quality of energy. Infrastructure modernization and replacement of old equipment and devices is a relatively quick way to reach the standards set by the Smart Grid. Another solution to supply high quality and non-polluting energy is the Microgrid concept.

Microgrid concept uses distributed generation to reduce the physical and electrical distance between generation and load. Distributed generation (DG) is made up of small power generators such as micro turbines, solar arrays, fuel cells, and small wind installations. These units are scattered near the customer, unlike

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traditional centralized power plants. Some of these units can even belong to customers who are connected to the network. This "distributed generation" also involves a distributed approach to data management and flow control.

The article contains strategies and algorithms that provide an intelligent behaviour to agents and to the multi-agent system in order to resolve or prevent any misbehaviour of a Microgrid network.

2. State of the art

Some researchers followed the path of modelling electrical grids while others studied physical solutions for energy generation or energy storage; a couple of them obtained really fascinating results e.g. extract energy from compressed air stored underground.

Distributed generation contributes to the improvement of power quality. In the areas where voltage support is difficult, distributed generation offers significant benefits for the voltage profile and power factor corrections. On the other hand, large-scale introduction of decentralized power generating units may lead to instability of the voltage profile. The bi-directional power flows and the complex reactive power management can be problematic and lead to voltage profile fluctuation. Additionally, short-circuits and overloads are supplied by multiple sources, each independently not detecting the anomaly [15].

A lot of research is done in the field of “energy storage”. Renewable energy is not a viable option unless energy can be stored on a large scale [5]. The solutions found can be very exotic e.g. “ultracapacitors” that can store huge amounts of electrical charge in atoms-thick layers next to the electrodes, and coils of superconducting wire able to store large amounts of circulating current indefinitely [5].

Agents and Multi-agent Systems render a new way of analyzing, designing, and implementing complex distributed cooperation and control systems [14]. An agent can receive sensory information from its execution environment and it can perform actions which bring modifications to the environment in some way [14]. Examples of environments in which agents may be situated include the physical world and control systems or the Internet [14]. In a real system, an agent may not interact directly with any environment. It is in charge of receiving information not via sensors, but through a user acting as an intermediary. In the same way, it need not act on any environment, but rather it can give feedback or suggestion to a third party [14][16].

Agents can be used to simulate real-world systems. Each Multi-agent system has a specific architecture that is chosen according to the application field of the system. In power field, various architectures are used e.g. in [2] a hierarchical structure was chosen and in [8] BDI (Belief-Desire-Intention) is presented. Also in [8] authors propose two types of agents (*Resource Agent and Power User Agent*) and an algorithm for solving conflicts using auctions. Moreover, in order to simplify coding the internal complexity of the agents, the authors implemented *Delegate Agents* which migrate during execution between network nodes. Another idea for agents in Microgrid field, presented in [2], is a hierarchical control system based on MAS. It is composed of three levels of agents—a distribution master station level, a distribution substation level and a distribution terminal level agents.

In [6], the authors define three types of agents: Control Agents: these agents control directly the physical units of the system; Management Agents. These agents coordinate the MAS and take decisions regarding the state of it; Ancillary Agents: these agents perform ancillary services like communication tasks or data storage.

Java Agent DEvelopment Framework, or JADE, is a software for the development of agents, implemented in Java. Many researchers from the power field (e.g.[7],[17]) used JADE because it allows development of unique Java-based agents that can perform many tasks while interacting with other agents towards achievement of a desired outcome [7]. In this paper, a similar framework was implemented with the same capabilities but with the great advantage of not being limited by the built-in features of the existing applications.

3. Microgrid. Multi-agent system architecture

By studying the problems of current electrical grid, some entities have been identified as being essential in a Microgrid:

- Consumer Unit (CO)– entity that consumes energy
- Distributed Generation (DG) – entity that generates energy
- Energy Storage (ES) – entity that stores energy
- Operator (OP) – entity that provides energy from the electrical grid

All entities have a direct connection to the network and, if possible, a set of connections with other entities that are part of the MG. For example, a CO entity can be connected to a DG or an ES, but will always have a direct connection to the network. An entity may have many connections, but it is not necessary for these to be active at the same time, in some cases, it is not physically possible.

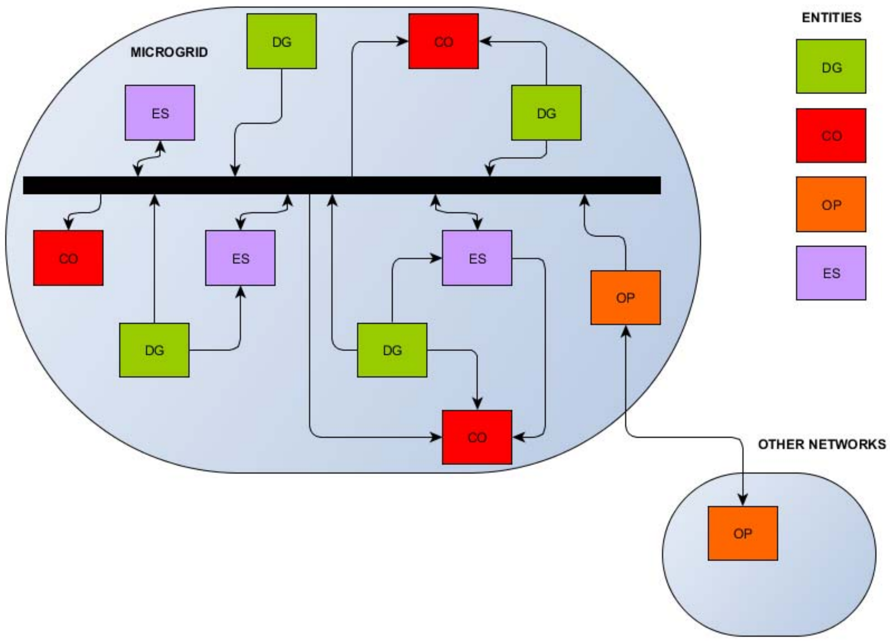

Fig. 1. Microgrid Design

3.1 Solving problems in Microgrid

If an entity is disconnected from the network, the microgrid entities must take steps to counteract this incident. If, for example, a DG entity becomes inactive, the CO that is powered from DG, must close connection with the inactive entity and switch to another link that meets its needs.

In case of power failure within the microgrid, several actions can be performed. DG type entities that are not working at full capacity, can increase power generation in the grid and batteries can unload any energy they have stored. Operator entities can negotiate with other operator entities that are connected to the grid, and may require additional energy to be delivered in microgrid.

Another problem that can occur in Microgrid is having too much power in the network. It can be solved by storage entities using the procedure of absorption and energy storage in order to keep the network load at a reasonable threshold . This energy can be used at a later time when the energy level drops in MG .

A multi-agent system is a combination of agents that collaborate through tasks performed to achieve a final goal of the system. Multi-agent systems can be a powerful tool in developing complex systems which use agent properties: autonomy, sociability (communicate through a language of communication with other agents), reactivity (agents perceive and react to the environment where it is) even proactive items (can take initiative).

Each entity in MG is controlled by an agent. An agent is a hardware or software component located in an environment that is capable of flexible autonomous actions. Autonomy is a difficult concept to define precisely. In a simple sense, this means that the system should be able to act without the direct intervention of humans or other agents, and that it should have control over their own behavior and internal states [14]. By flexible we mean that the system is: **reactive**: agents should perceive the environment and respond in a short time to dynamic changes that occur; **proactive**: agents should not simply act in response to their environment, they should be able to provide opportunistic behavior, "goal-oriented" and take the initiative if necessary; **social**: agents should be able to interact, when appropriate, with other agents or people in order to accomplish their own tasks and help others with their activities. [14]

The features described above are the essence of agents. All this combined makes a very powerful agent for distributed applications. The Microgrid presented in this article is controlled using these types of agents: *facilitator agent*, *consumer agent*, *generation agent*, *storage agent* and *operator agent*. Each agent has characteristics and special features, depending on the entity that it controls.

3.2. Agents and the environment

Agents react to the environment; they perceive changes, communicate with other agents, analyze the situation and take action to achieve their objectives and obligations. Agents are loaded into the environment whenever their controlled entities connect to the MG and are unloaded from the environment in case the entity is disconnected from the MG. Each agent updates its current state in the environment at regular intervals.

Therefore, using agents to control such grids brings the advantage of a distributed control and also the advantage of agents autonomy. Depending on the intelligence of agents, they can act without constant tracking and so without human intervention. Agents can adapt to their environment, which is extremely useful for a smart electrical grid in which production units (energy generators) will connect and disconnect from the grid in a random manner.

Multi-agent systems (MAS) have perfect skills for this type of control. Agents are autonomous, flexible, can work together towards a common goal, namely the welfare of the whole Microgrid. This means high quality, uninterrupted power for consumers, a low impact on the environment, lower prices for both the generation and consumption of energy, faster recovery after failures.

Unlike existing MAS concepts for MG, each agent is designed to control a specific microgrid entity: CO-agents for consumers (loads), DG agents for generators (supplies), ES-agents for batteries (storage) and OP-agents for operators. Also a facilitator agent type is used in the framework to help overcome unexpected events or solve various conflictual situations in MG. Each agent will update internal information about what he wants, what he needs to know or think according to the entity that it controls.

Agents can communicate between them when data from environment is insufficient or in contradiction with some rules of normal operation and will be able to reach a commonly accepted decision by all the agents involved. All agents are honest and can participate in negotiations, auctions.

Optimal use of DER (Distributed Energy Resources) and monitoring the energy flow in the grid are just some of the tasks of multi-agent system that will control the Microgrid. Agents are able to make autonomous decisions in response to unexpected situations considering both objectives related to the entity that serves the welfare of the whole multi-agent system.

The strategy must take into account many factors such as: market, response to disasters, information from sensors, agents participation in auctions or resolve conflicts or unexpected situations, information about the energy flow in the grid or analyzing external data such as weather conditions or human intervention in the environment. Another important aspect in the design of "perfect strategy" is prioritizing the usage for categories of information, also the frequency of accessing such information can lead to proactive agents' decisions, decisions that can improve the overall condition of the system. A smart strategy can help multi-agent system to evolve, to learn to effectively control the energy flow and entities from the environment.

In an expanded vision of the system, agents can communicate outside the Microgrid, e.g. they can negotiate energy costs between them or switch the energy feeding of a grid, to another grid that has too much energy stored, solving by this the problems in both grids. Existing energy storage methods are not effective and thus in time, large amounts of energy can be lost instead of being distributed to another grid that needs this energy.

4. Strategies and Algorithms

4.1. Strategies for agents

The environment is still an extremely important source of information, agents having a role in monitoring various activities and events in the grid. Any defect can cause a chain of many other problems within the network and even outside of it. For this reason, Microgrid network connection to macrogrid is still regarded as a wild card and is avoided by choosing the option of Microgrid in island-mode (independent microgrid) especially for locations at a considerable distance from the conservative network. Agents belong to an environment where self-healing property is very important. They make decisions using information from local knowledge base (KB) and messages provided from the communication between them. Of course, the environment is still an extremely important source of information, agencies with a role in monitoring and various activities and events in the grid. Any defect in the chain can cause a multitude of other problems within the network and even outside it. Continuous monitoring has very important role to reduce the accidents and cascading blackouts, so the facilitator has the task to the top of his list. An algorithm used by the facilitator for power flow control is presented in Fig 2.

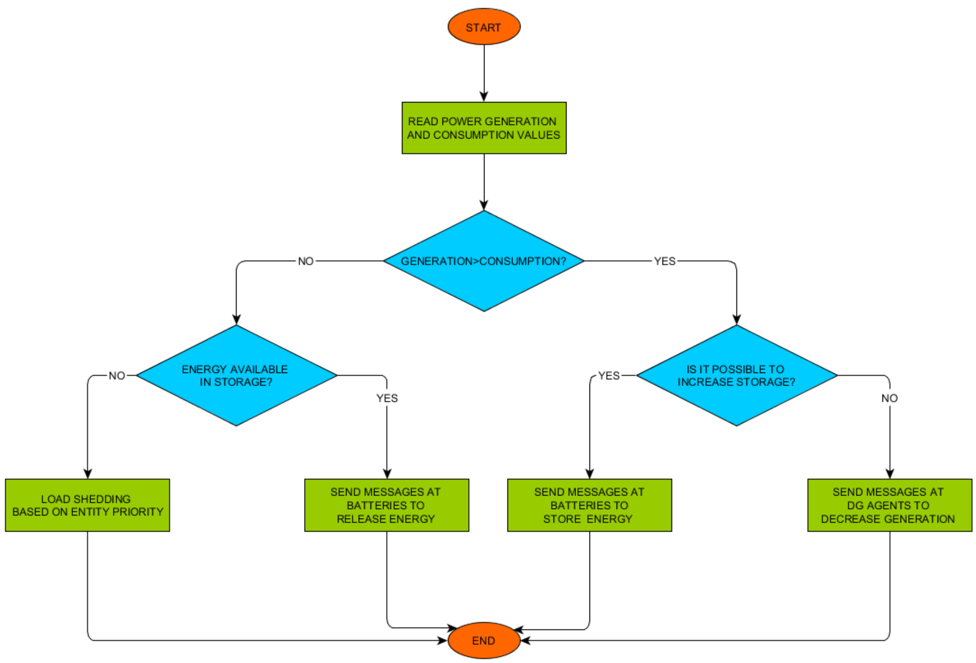

Fig. 2. Power Flow Control

Agents work together in a collaborative environment. An ideal strategy in this case means solving the agent needs without affecting or disadvantage of another agent involved. Therefore such a strategy can be implemented using solutions based on opportunity cost. For example, an agent can choose that its source of energy to be provided by an agent who controls an entity that produces more renewable energy at the time, even if there is available energy with a lower cost in the market. Renewable energy is usually unpredictable with an energy level that can fluctuate throughout the day (the sun entering the clouds, the wind can vary from non-existent to strong gusts). An important factor in the economy of grid operation is the efficient use of produced energy and that is why the agent would get more expensive for the good of the whole multi-agent system.

Another method for a smart strategy is using the energy in the interval where the curve of energy consumption reaches minimum, such as at night or midday. The price of energy unit decreases in this interval and the consumer can take advantage of this through a proactive program of activities. Other examples of strategies for an agent: a better price for energy (valid for both consumers and generators), greener (cleaner) energy.

If a problem occurs in the grid, it must be resolved quickly. Current society is dependent on electricity. An eventual "blackout" can cause very large losses, and a surprisingly large percentage of the cost is not accounted for repairing broken equipment, but for the duration of the blackout phenomenon. The higher it is, the higher the losses. Of course, prevention of such incidents is indicated, but obviously not all can be controlled and avoided. There are situations when monitoring the condition of the grid can significantly reduce such problems and furthermore, some strategies of flow control in the grid are presented.

4.2. Control strategies for multi-agent system

There are several important aspects of a distributed system that need to be taken into consideration. An efficient strategy has to manage and control multiple tasks regarding the following properties:

- Power-level monitoring - network flow control is one of the most important aspects of normal operation in a microgrid. Power level value should not exceed the 2 alarm thresholds (MinThreshold and MaxThreshold). If this happens, flow correction procedures are activated. It is preferable not to activatate these procedures, that’s why there have been introduced pre-alarm thresholds which helps taking preventive measures.

- Efficient resource allocation - based on criteria such as time, distance, quantity, cost, degree of resource use, success rate for specific task (from resources’ log). Each criteria has a priority (weight), a coefficient is calculated and then associated to the resource. Depending on these goals, the tasks are distributed to the agents. In a MG, agents are the main resources of the system.

- Resolving events, critical/unforeseen situations – the facilitator agent has a very important role, proposing solutions and communicating with agents involved.

- Logs with evaluation of strategy actions (self improvement) – valid also for agent strategies

- Decisions based on information corresponding to non-critical/less relevant knowledge base, for incidents prevention (ex. strong wind was announced, the wind production is increased even up to capacity, and if necessary, action is supplemented by activating batteries)

- Compliance with the strategy of each agent - In most of the situations, the agents are not forced to act against their own beliefs. But in critical conditions, violations of these rules may occur. The main goal is damage reduction and keeping most of the entities in normal working condition. In fig. 3 is presented the software architecture of the system.

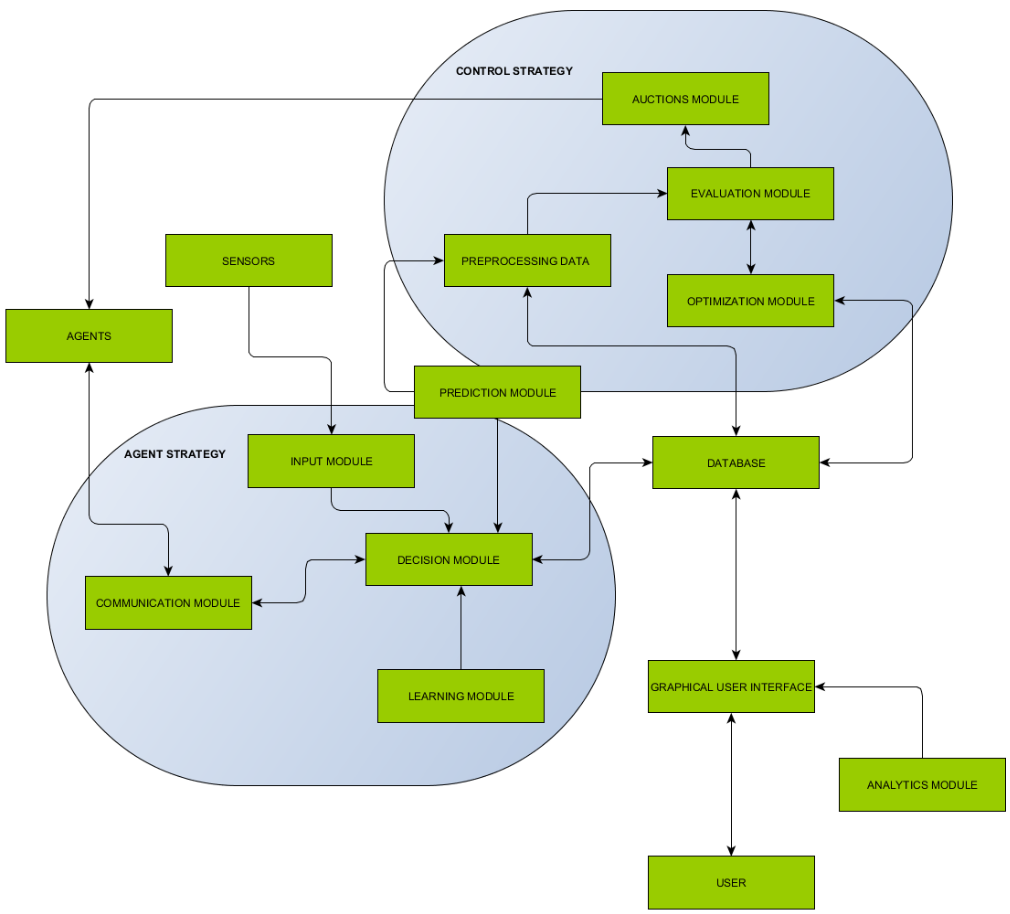

Fig. 3. Software architecture

- Using a coefficient (Koptim) - for evaluating the strategy on each simulation.

Strategies are tested to meet as many properties as possible from a well defined set. It is not imperative that each and every strategy to respect all properties from the set but obviously will get 0 mark for the ignored properties.

Values for marks are chosen in the range [1,10]. Properties have associated priorities (weight / importance) that will be used in calculating the final coefficient. Strategy receives a grade for each property of the system, in the end an average for all grades will be calculated.

$$Koptim = \sum_{Property_i}^{n} grade_i * weight_i$$

All agents are flexible and strategies use that advantage to get higher grades in realizing the proposed objectives. The ultimate goal is that the multi - agent system to behave as a single entity that maximizes coefficient Koptim.

5. Results. Simulation framework

The network can be easily built using a software application made in C# language. The major advantage of this framework is the graphical user interface (GUI) which eliminates the inconvenience of entering data into text files or tracking results in the console. For example, the entities presented in Fig. 4 are added using "drag and drop" and during the simulation, entire data is displayed in real time for each entity.

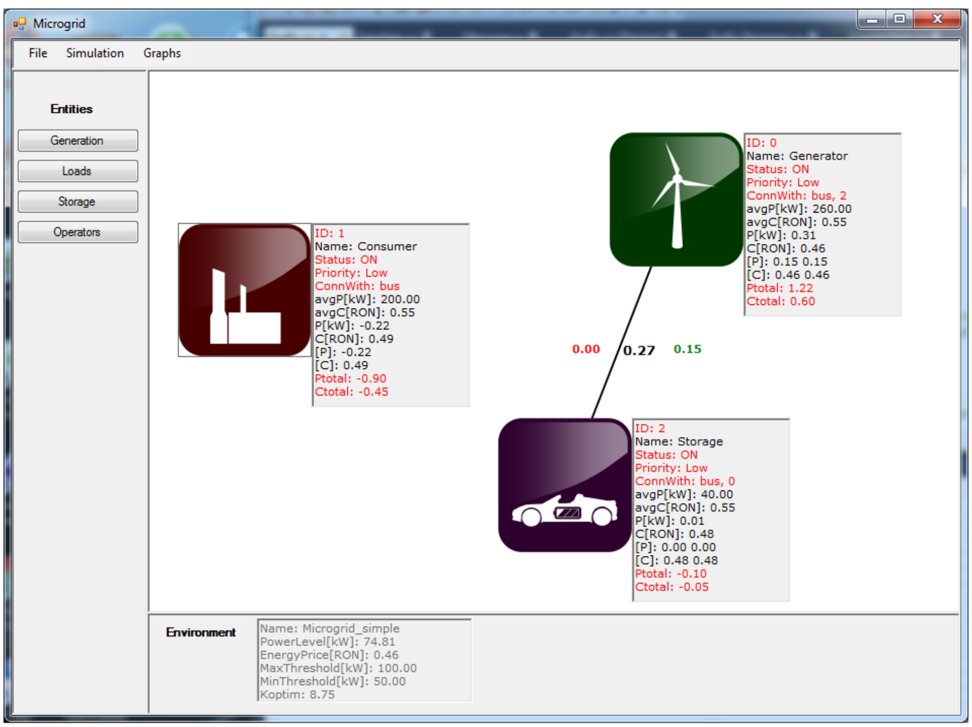

Fig. 4. Simulation Framework

Furthermore, each entity is represented by an agent. Entities can be added, inserted, removed from Microgrid network structure and of course from the multi -agent system. The application is scalable and flexible like intrinsic properties of a multi -agent system. The configuration is stored in an XML file and can be used, adapted and resumed in other configurations.

Agents have a knowledge base (KB) consisting of several KB 's from various fields such as energy system, geographical environment and climate, weather information , price market , consumers, historic.

Test case

Below is presented a small experiment to show how MAS solves the need of energy in MG in an unexpected event (i.e. disconnection of a DG unit). An MG with 5 entities is created: 2 DGs, 3 COs. One CO is inactive. The results of the simulations are presented below. In fig 5 and fig 6, the powers for each entity are represented. For each simulation, the same strategy was used and the same event was reproduced: the disconnection of entity DG0. The response of the MAS in each simulation can be observed in fig 5 and fig 6. The only difference was that CO1 and CO2 had bigger power values in simulation 2.

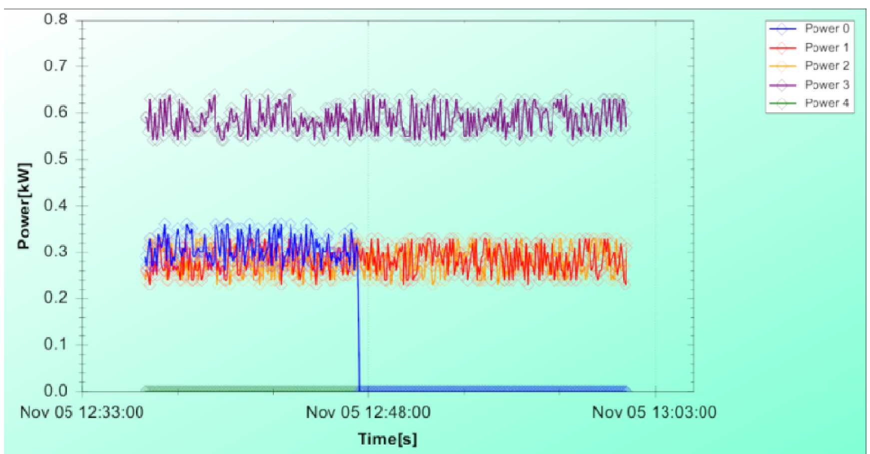

Fig. 5. Simulation 1 with 5 entities

In the first simulation, the system did not react to the disconnection of entity DG0 because DG3 could feed both consumers. In the second simulation, DG3 increased his production with 10% periodically to meet the values of the 2 loads.

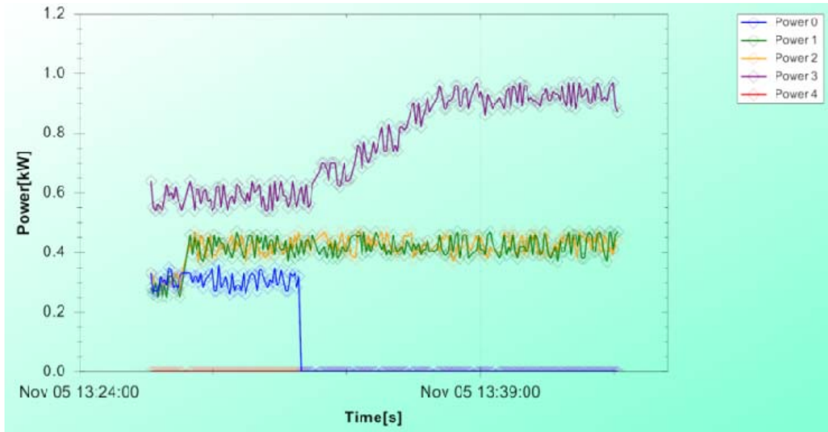

Fig. 6. Simulation 2 with 5 entities

In fig 7, the evolution in time of the Koptim coefficient is presented. Koptim belongs to the strategy used in the two simulations described above. The prompt and efficient response of the agent DG3 gave a boost to the global coefficient of the strategy.

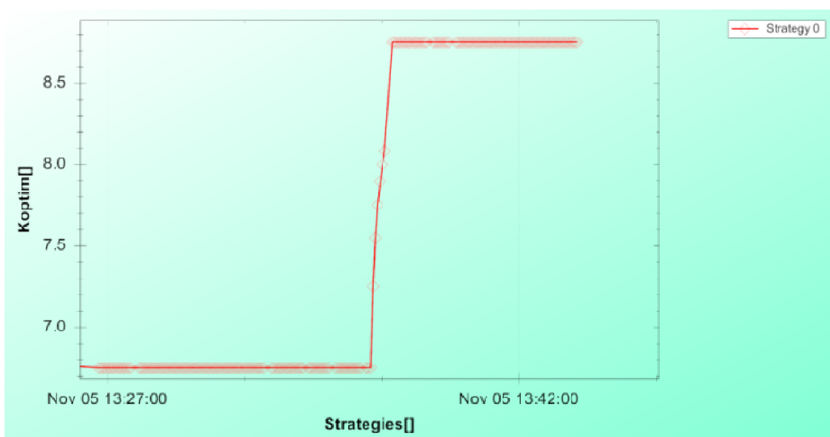

Fig. 7. Koptim evolution

6. Conclusions

Application of multi-agent technology is proving very strong in this area and could provide "fault-free" integration of Microgrids in the current power grid.

The proposed strategies bring original contributions in theory by adapting or developing specific algorithms for monitoring and control Microgrid networks and to the applied research using multi-agent technology by solving problems related to modernization of electrical networks.

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