A Multi-Agent Architecture for Simulating and Managing Microgrids

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***Abstract*—With the increasing demand for electric power, new theories have been studied by the scientific community. One of the most promising consists in splitting the electric grid in microgrids, each one composed by renewable and not renewable sources and various loads. These microgrids aim to be as much autonomous as it is possible in producing the energy they need. Energy once produced must be transferred to the loads. This paper proposes a MAS used to simulate the control of the transportation grid. The system is able to react to feeders overloading and failures by redirecting the energy flow and protecting itself.**

I. Introduction

Nowadays Microgrids (MG) are expected to contribute to an improved energy efficiency and power supply reliability as well as an increase in the use of renewable energy [1],[2], thanks to the role of Renewable Energy Sources (RES) and power electronic in supplying clean electric energy.

A microgrid encompasses a portion of an electric power distribution system that is located downstream of the distribution substation, it includes a variety of distributed generation (DG) and distributed storage (DS) units, and different types of end users of electricity and/or heat. The microgrid presents an electrical connection point to the utility, known as the point of common coupling, generally it is located at the low-voltage bus of the substation transformer. Several customers can be served by a microgrid as residential buildings, commercial entities, and industrial parks.

Among the new issues there is the optimal generation schedule of DG sources aimed at minimizing the production costs and balancing the demand and supply which comes from RES and distribution feeders.

The management philosophy is crucial for the MG features exploitation [3]. Multi-agent systems have been proposed to provide intelligent energy control and management systems in microgrids. Multi-agent systems offer their inherent benefits of flexibility, extensibility, autonomy, reduced maintenance and more. As a consequence, the design and implementation of a control grid based on multi-agent systems, that is capable of making intelligent decisions on behalf of the user, has become an area of intense research. In a previous work we studied some different policies that can be adopted to fully exploit the contribution of renewable sources and the accumulation system to the management of a microgrid [4]. The paper is based on the idea of creating an e-market for energy where sources and loads participate in a collaborative way.

The aim we pursue with the simulation proposed in this paper lies in a different scope: we want to study the distribution of electrical power in a MG taking into consideration the topology of the MG (feeders, nodes, protections), the impedance of the single feeder and the corresponding voltage drops and joule losses. As a matter of fact the inadequate management of the power network may cause an unstable behavior of it with consequent blackouts on a large scale. We suppose the grid is composed of totally passive feeders (as they are in real word) and of intelligent connection nodes. Such devices allow for the runtime connection/disconnection of their feeders. This gives to the Electrical System manager the possibility to act on each single branch of the grid thus avoiding system breakdown chain effect.

II. Problem Description

The goals that are at the basis of the proposed approach are to overcome the limits of a centralized approach to the management of energy flow on a large scale. Each MG will maintain an internal e-market to assign energy produced from sources under its control to the loads it has to take care of. Each MG may include renewable power sources (wind turbines, photovoltaic arrays), non renewable power sources (conventional plants), power storage devices (for instance super-condensers, fuel cells . . .), and, finally, loads (industrial, residential and public emergency services). Briefly speaking, the management process is composed by the following steps. Initially, at each discrete simulation time step, a verification of the power balance is performed. This is a crucial step of the work: if the power produced by internal sources (plus what is made available for use from storage devices) is sufficient to provide power to internal loads, the MG is autonomous and it can decide whether to store or to sell the surplus of energy. The policy of energy storage is a sensitive one and we already made some studies about that [4]. This policy, however, is out of the scope of this paper.If the MG is not autonomous it can buy energy from the grid. The availability of energy is not a sufficient condition for the successful solution of the problem. In fact, energy has to be conveyed from the generator (power sources or storage devices) to the requiring loads. Energy transportation induces a loss of power for thermal loss due to the internal resistance of feeders. Sometimes it may happen that the power produced by a source is sufficient to feed a load but a feeder along the path connecting the two is not able to transport the required amount of power. If this is the case, our system is able to disconnect some feeders (the overheated ones) and if this is not sufficient, it may even disconnect some loads. Disconnection of loads is made according to a priority list that has at the top public emergency services, followed by industrial loads and finally residential ones. Disconnection starts from lower priority loads and it is performed by means of the intelligent nodes. If a feeder (or a load) is disconnected, it is reconnected when the conditions (for instance flow of power) allow that or after a fixed amount of time (for allowing heat dispersion and temperature drop in the feeder). In the next subsection the MAS architecture used to realize this approach will be introduced.

III. The Proposed Agent-Based Solution

From the software architecture point of view, each MG can be regarded as composed of a society of agents. This society is in turn composed of local sub-societies (each sub-society can be a society of agents itself), each one modeling one of the main elements of the cell with the adjunction of a Supervisor society responsible for ensuring a strategic supervision of the energy flow in the cell. The local management of power flow inside each cell element (source/load) is left to single societies responsible for the cell element itself. These societies are self-interested. In the figure 1 we can see the following four agent societies: Loads, Sources, Supervisor, Transportation.

The **Supervisor society** is composed of three agents: Broker, Policy Manager, and Disconnection Manager. The *Broker* agent is responsible for the brokerage between energy consumers and suppliers. The *Policy Manager* decides: (i) how much power should be provided by each source; (ii) if a battery should recharge or discharge; (iii) if the grid is going to sell or buy energy to/from the cell. In the actual implementation of the decision process, the agent includes a rule system that optimizes energy flow in terms of cost [4]. The *Disconnection Manager* agent is responsible for applying the established disconnection plan of loads or adapting it as a consequence of unforeseen events. It is worth to note that the proposed architecture, spontaneously responds to blackouts propagation since it gives priority to the independence of the

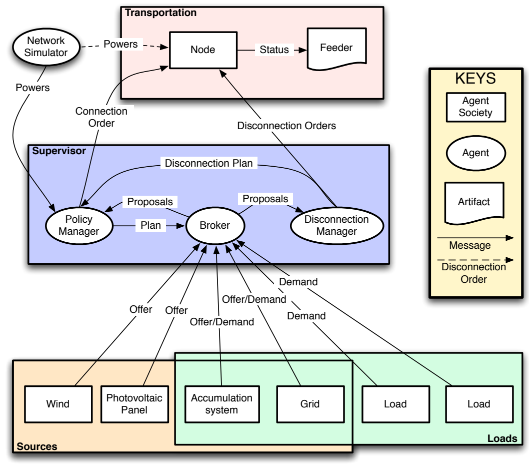

Fig. 1. The agent societies constituting a simple microgrid

cell and it asks for power or provides power to the remaining part of the grid only if necessary/available.

The **Sources Society** is composed of all cell elements that can generate power. Each of them is a society of agents too. Since some elements (e.g. the batteries) can sometime generate and other times consume power, these elements are both members of the Sources and Loads societies. When an element provides power it plays the role of Producer in the Source society. When an element buys power, it plays the role of Consumer in the Loads society. Typical members of a Sources society belong to renewable and non renewable sources, batteries (while providing power), and the grid. A more extended discussion may be found in [4].

The **Loads society** is composed of cell elements that consume power [4]. They can be actual loads as well as power accumulation elements.

The **Transportation society** is composed of the Node sub-society and the feeder artifact. According to the approach we adopted, transportation is managed by way of intelligent nodes that can connect/disconnect each feeder they control, according to a connection plan used to minimize transportation losses of power. Several instances exist at runtime of the Node sub-society, one for each actual node of the MG. Each Node sub-society is composed of the below discussed agents. The *Local Manager* agent is responsible for the node management. It communicates with the Policy Manager in order to receive expected configuration data (expected power levels, connection status) for every feeder connected to the node. According to this data, the Local Manager agent orders the connection/disconnection of each feeder to the Connector agent (see below). The *Connector* agent is responsible for physically controlling the node connections with feeders. The *Monitor* agent is responsible for reading real power data from the MG. In the proposed simulation experiment, it interacts with the Network Simulator agent in order to obtain a good approximation of what the behavior of the real MG would be. If the power read in the connection of some feeder differs from the expected one of more than a specific threshold (set to 5%

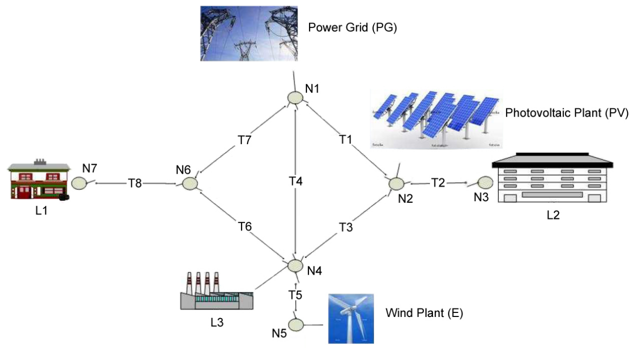

Fig. 2. The microgrid used for the simulation experiment

in the proposed experiment), this agent sends a message to the Local Manager. The *Network Simulator* is responsible for the simulation of the MG that is obtained with the application of the Newton-Raphson algorithm.

IV. Simulation Setup and Results

In the simulation the time is discrete and we mainly worked with hours since we wanted to study the steady state of the system, not the transitory state. At the beginning of each simulation, the Broker agent receives the requests of buying/selling power from the MG loads and sources. This information is used by the Policy Manager agent to define a plan used for satisfying the market requests at the specific time slots. This plan is enacted by the Broker agent. That, if it is not possible to satisfy all the requests, delegates the Disconnection Manager to command the disconnection of lower priority loads. The Disconnection Manager defines which loads may be disconnected and it orders to the related nodes to perform this action. If the available power is sufficient, the Policy Manager requests to the Network Simulator a computation of the power flows in each of the nodes of the grid, according to their current connection status. If the flows do not violate the feeders limit powers, this plan is passed to the Nodes of the Transportation society in form of Connection Orders. Each Node sets the status of the feeders connected to it. During the time slot, the Network Simulator agent is queried by the Monitor agent of each node in order to simulate the reading of the power flowing through the feeders connected to the node. If some feeder is supporting a power that is beyond its rated power, the disconnection policies occur.

During the proposed experiment, the system reacts to an overload occurring on some feeder of the MG. This demonstrates the self-protecting feature of the MG that disconnects the feeder and redirects the power through other branches of the grid. Of course if it not possible to find a path, the load requiring such a huge power must be disconnected.

The simulation scenario concerns a microgrid that includes eight feeders which are labeled T1-T8 and seven nodes labeled N1-N7 (Figure 2).

To make the simulation more realistic, some sets of historical data about wind speed and solar irradiation have been used. Similarly, load characteristics used to feed the simulator have been obtained by actual and historical sets of data coming from industrial and residential areas.

The reported experiment consists in a simulation in which the MG works for about a day and a half, starting at 05:00 and ending at 18:00 of the second day; this interval of time has been chosen to better show the behavior of some components. For instance, in Figure 3 it is possible to note the increase in the electric power supplied by the photovoltaic source (PV), and how it reaches a peak on midday. It is also possible to note as the power required by the domestic installations L1 and L2 appears congruent with the expectations, highlighting a periodical behavior and a power drop durings nighttime (from 03:00 to 06:00). Instead, the industrial load never goes below the 30 Kw of power.

Each feeder in the MG is oriented, and the positive direction for the power flow is assumed to be from the node labeled with the smaller index towards that one with the greater one.

Figure 5 shows the substantial congruence between the power transmitted by the border feeders (T2, T8, T5) with the values of L3, L2 and E (Wind Turbines) respectively. Some minimal differences may be noticed and they are due to feeder losses. The negative values on T5 feeder indicate, as said before, a flow from N5 towards N4.

Looking at the other curves in Figures 3, and 4, it can be seen that from 14:00 the demand by the loads increases up until 19:00 of the first day; simultaneously the power supplied by the photovoltaic system decreases. As a consequence, the PG (Power Grid) must increase the supply, except when E has a peak of power. These events cause that the load in the three feeders coming out from N1 (T1, T4, T7) increases too.

When the electric power on a feeder overcomes the nominal value but it remains below the short circuit value, the PolicyManager agent starts a control action. The agent, in order to evaluate the disconnection condition, uses a rule that measures how long the nominal power has been exceeded. This is what happens in the interval time ranging from 08:00 to 16:00. The PolicyManager agent calculates that the threshold of the nominal power, of feeder T4, has been exceeded beyond the time allowed for that and then it sends the disconnection command to the LocalManager agents of the nodes N1 and N4. So, at 16:00 of the first day, the feeder T4 has been disconnected and the power, coming from the PG, has to be redistributed between the remaining feeders. Consequently, the load increases not only on feeders T1 and T7 but also on T3 and T6. The maximum stress on the feeders occurs around 21:00 of the first day simultaneously with the maximum load conditions. The negative values of the electric power on the feeder T6 indicates a flow directed from N6 towards N4.

From the 21:00 of the first day onwards, until about 06:00 of the second day, the overall power requested by loads decreases thus causing a reduced power withdrawal from the PG and thus a lightening of the load on the feeders. In fact, at 02:00 of the second day, The PolicyManager agent authorizes the nodes N1 and N4 to the reconnection of the T4 feeder.

At 3:00 of the second day there is a drastic drop in power

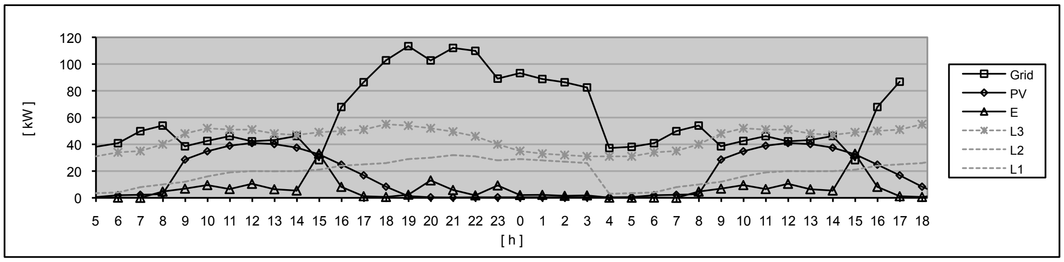

Fig. 3. The power produced by the sources and provided to loads (L1 and L2 curves overlap each other)

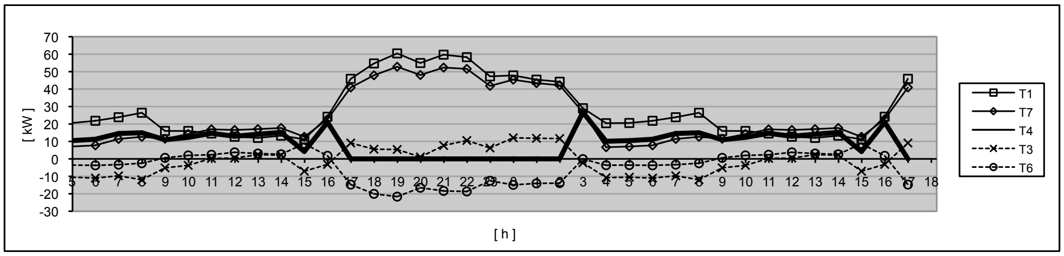

Fig. 4. The power passing through some feeders

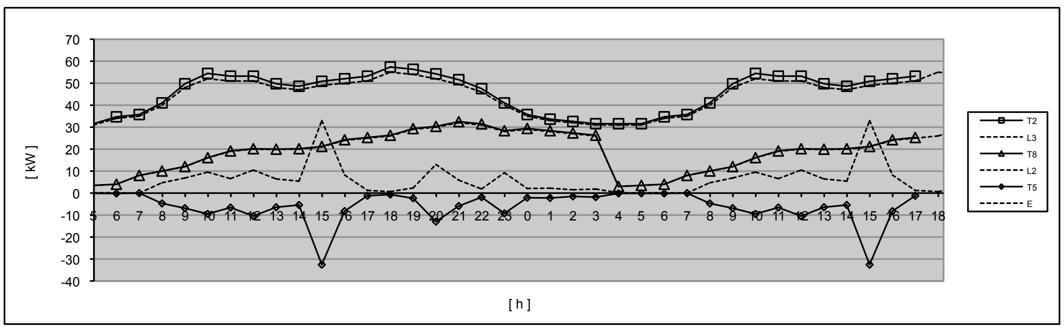

Fig. 5. The power levels in loads and in border feeders

in the loads L1 and L2, which reduces from 26 kW to 3 kW; this event affects the supply of energy from the grid and gives a decisive contribution to the maintenance of the connection feeder T4. In fact, the power peak that happens when feeder T4 is reconnected wears off quickly to avoid overheating and avoiding a new cable disconnection.

In conclusion, the simulation has shown how the system privileges the absorption of energy from renewable sources compared to the PG, and how it can perform a dynamic reconfiguration of the MG as a result of the overloading of a feeder with corresponding disconnection of some feeders.

V. Conclusions

In this paper we have proposed a MAS-based approach for the solution of the energy transportation problem providing a system that is able to react to feeders overloading and failures by redirecting the energy flow and protecting itself.

From the infrastructural point of view, this would imply the adoption of intelligent nodes in the grid. Such nodes enable the dynamic connection/disconnection of feeders thus allowing the redirection of energy flows as well as the disconnection of loads that may cause overloading problems to the grid.

The system, here presented, assigns a relevant level of decision autonomy to the microgrids thus creating a perfect scenario for the adoption of distributed agent-based solutions.

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