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Agent based modeling of energy networks

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ABSTRACT

Attempts to model any present or future power grid face a huge challenge because a power grid is a complex system, with feedback and multi-agent behaviors, integrated by generation, distribution, storage and consumption systems, using various control and automation computing systems to manage electricity flows.

Our approach to modeling is to build upon an established model of the low voltage electricity network which is tested and proven, by extending it to a generalized energy model.

But, in order to address the crucial issues of energy efficiency, additional processes like energy conversion and storage, and further energy carriers, such as gas, heat, etc., besides the traditional electrical one, must be considered. Therefore a more powerful model, provided with enhanced nodes or conversion points, able to deal with multidimensional flows, is being required.

This article addresses the issue of modeling a local multi-carrier energy network. This problem can be considered as an extension of modeling a low voltage distribution network located at some urban or rural geographic area. But instead of using an external power flow analysis package to do the power flow calculations, as used in electric networks, in this work we integrate a multiagent algorithm to perform the task, in a concurrent way to the other simulation tasks, and not only for the electric fluid but also for a number of additional energy carriers. As the model is mainly focused in system operation, generation and load models are not developed.

1. Introduction

It is an indisputable fact that levels of welfare, health and life expectancy that distinguish our present civilization are due to the progressive development of technology and the increasing use of energy. But it is clearly not possible to follow a development model based on continuous growth since, because our world is finite, there comes a time, sooner or later, in which the phenomenon called saturation appears: the finite resources are exhausted or reach intolerable levels.

After the first warnings on climate change were observed about 40 years ago, a number of scientists, experts and organizations began to do research and to publish alarming results on probable climate change. That number has grown steadily and today almost all nations of the world have scientists, experts and institutions dedicated to the study of the subject and promote initiatives to mitigate their effects, so there are thousands of organizations across the world devoted to climate studies, effects and corrective actions [1–3].

1.1. Energy systems research

Some of the most important guidelines arising from practically all directives, policies and rules, with special significance to us are: increasing the use of renewable energy and improving efficiencies in generation, consumption and storage of energy.

Of special interest to our work are protection, monitoring and control systems at all voltage levels, equipment aiming at two-way digital communication, intelligent monitoring and management of electricity generation, transmission, distribution and consumption.

In addition to distributed electricity generation, the recommendations are for diversification of energy sources without relying too heavily on a single source of energy. So they are supporting the use of natural gas and cogeneration systems, cooperating with the electric network leading to a new *energy network* [2].

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1.2. Related work and scope

A number of special software tools exist for simulation of electrical and hybrid systems, like HOMER, RETScreen, RAPSIM, Hybrid2, ViPOR, etc. However, although they allow the user for evaluating and optimizing designs, using their built-in load models procedures and specialized procedures, all of them are closed systems that must be used as they are.

Regarding agent-based methodology, others have used it for energy network modeling. However, some applications are closely related to a particular technology, such as for example sensors and communication protocols [4] and others try to model very special problems, such as for example outages and faults in the power grid [5]. Even the idea of the creation of an agent based modeling of energy networks has been published in other papers [6], but mainly focused on optimization problems.

The original contribution presented in this paper consists of setting up a general approach for modeling multi-carrier energy systems, in a completely open and self-contained way, only based in the mathematical equations of energy networks, and therefore independent of any technology, with ability to model any energy system, from small systems (as for example the power network in an electric car), to bigger ones (as for example the power network in a neighborhood). Furthermore, our development is extensible: it was obtained by extending the simple electrical network to a larger energy network, really a *multiplex network* [7], and it could be expanded further, to try to model even more complex systems, such as so-called *sociotechnical systems* [8].

2. Power grid evolution

The electricity grid has been in continuous evolution, from its beginning in the early nineteenth century until now and probably will do so in the future, affecting to its structure and elements.

In the classical grid, electric generators located at power stations obtain electric energy with high signal quality from classical energy sources. The transmission lines carry the electric power flow from generators to consumers, and the transformers serve to step-up for transmission and step-down for consumption of the energy [9]. The electric power flow is controlled in a centralized way and prices are fixed to be constant over long periods by the supply company.

This situation is changed and now, due to the use of renewable energy resources (solar, wind, biomass, etc.), the electrical distributed generation is characterized by high level of intermittency and poor signal quality, which strengthens the need to take action to compensate. To make better use of the discontinuous generation, two possibilities exist:

1. Establishing, demand-side management to seek plugging the more powerful loads in periods with higher generation and disconnect them during the lowest generation ones.
2. Storing excess energy produced during periods of peak generation and use when it is needed.

The first possibility has been the object of modeling in some of the authors previous works [10–12]. Clearly, a better performance would be obtained if the two possibilities are used simultaneously [13].

2.1. Microgrids

A microgrid is a cluster of electricity users and microsources that operate as a single controllable system for generating and using power. It encompasses a variety of distributed generation (DG), distributed storage (DS) and end-use loads. The microgrid enables the production and storage of renewable energy, as well as the exchange of electricity between energy providers and consumers, to take place locally. Microgrids can be considered as autonomous subsystems inside the powergrid. They can operate as "islands", but their most prominent common perspective is the integration of DG. Previous work of the authors on microgrids can be found in [11,14–18].

2.2. The smart grid

The increasing incorporation of new elements of information and communication technologies (ICT), such *smart meters*, confers a much more complicated structure to the network, and must now be considered as a complex *system of systems* [17], the so called Smart-Grid [12,19].

2.3. The future energy network

In descriptions of the Smart-Grid, only electrical elements are invariably considered. But, as indicated in Section 1, many directives and recommendations are aimed at improving the energy efficiency in production, transport, storage, transform and consumption processes. This makes the modeling process very attractive since experimenting on systems of systems is not generally feasible. It also makes modeling rather complicated because as described later, new elements to transform and store energy, and more networks in addition to the electrical one, for other energy carriers, like water, gas, fuel, etc., must be considered.

In this paper we build upon a published approach in order to develop a model for multi-carrier energy networks: the *intelligent hub* [18], used in electrical grid modeling, the aim has been to extend its functionality for multi-carrier energy computational approaches such as Energy Hubs [6].

3. Model conceptualization and design

When trying to model the electricity grid one has two ways: first using specific electrical engineering tools and second using non-specific mathematical tools, mainly from graph theory [20,21], or computational, using object oriented programming, agent-based modeling, network modeling and simulation. In the first case the approaches have been successful for modeling the classical grid. But problems arise when trying to model the current grid because those tools are not enough to cope well with its real situation nor with the future Smart Grid. Some reasons are:

1. Possible switching behavior of generators and loads, due to renewable distributed generators and demand side management, respectively.
2. Event driven behaviors of generators and loads.
3. Network structural changes. This is evident in operations of connection and disconnection of a microgrid, and also when accidental or catastrophic failures occurs.
4. Definition of a more powerful data structure for nodes. It becomes necessary in order to model some more powerful nodes [13] for the Smart Grid, with capacity to hold more data than the complex voltage value.
5. Working with interdisciplinary teams usually requires more general tools than the specialist ones used by electric engineers.

So some years ago we proceeded the second way. With practically no classical electrical software being reusable, our first attempt was to represent the electricity network using the