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Agent-based modeling of the energy network for hybrid cars

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ABSTRACT

Studies in complex energy networks devoted to the modeling of electrical power grids, were extended in previous work, where a computational multi-layered ontology, implemented using agent-based methods, was adopted. This structure is compatible with recently introduced Multiplex Networks which using Multi-linear Algebra generalize some of classical results for single-layer networks, to multilayer networks in steady state. Static results do not assist overly in understanding dynamic networks in which the values of the variables in the nodes and edges can change suddenly, driven by events, and even where new nodes or edges may appear or disappear, also because of other events. To address this gap, a computational agent-based model is developed to extend the multi-layer and multiplex approaches. In order to demonstrate the benefits of a dynamical extension, a model of the energy network in a hybrid car is presented as a case study.

1. Introduction

For some time now, the importance of Smart Energy Networks has been published repeatedly by energy organizations in Europe and worldwide [1–3]. These networks use advanced information and communication technologies to monitor and manage the energy flows from multiple energy sources to meet the demand of end users.

A large number of studies and articles that deal with combined mechanical, electrical, chemical, heat [4] and other technologies have been published. However, as far as we know there is no standard representation in which one can schematically view all the system, even at a top level. So current published studies are difficult to understand mainly because they do not use a clear way of representation but instead they adopt technology-close special drawings to try to explain things.

On the other hand there are mathematical like studies which use standard notations and graphic elements so they are very easy to understand for all people who know these standard notations. So it seems clear that any step towards standard representations of these complex systems could help to understand their associated applications.

One of those mathematical like studies are electrical systems. These systems are modeled as networks, using a weighted graph where node weights represent voltages and edge weights represent intensities in the network.

In the case of combined mechanical, electrical, chemical, heath and other technologies, using a multilayer network may be a convenient method for establishing models. And although its mathematical background is in a developing phase today (using multilinear algebra), its conceptual ideas can be used now as well as the representation scheme arising from them. The main idea here is to try to extend the graph-like ideas and representations used in electrical networks, to the more complex multilayer networks [5], using layers to represent the different energy kinds [6].

This idea is not original, but it has been used before by a number of authors [7], relevant to our studies.

In our opinion energy networks are the best candidate to represent complex combined (mechanical, electrical, chemical, heath, etc.) systems [8–10], due to the following reasons:

- They admit a graph-type representation.
- Multilayer and multiplex network theory, at developing state, can be used for modeling in some instances.
- Practically any physical system can be represented as an energy network, from the smaller ones at biological levels to the bigger ones at the entire world level [11].

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Nomenclature

m	mechanical energy	I_d	input intensity for torque reference
e	electrical energy	I_t	torque controlled intensity output
g	chemical energy	k_c	torque control tuning coefficient
h	thermal energy	PS	power-split system
p	power flow	s, c, p, r	sun, carrier, planetary, ring
l	load flow	F_{sc}, F_{cr}	interaction forces
i, j	type indices $\in \{m, e, g, h\}$	$\omega_s, \omega_p, \omega_r$	planetary angular velocities
S_i	i-type input socket	τ_s, τ_p, τ_r	planetary torques
p_i, l_i	i-type p or l	r_s, r_p, r_r	planetary radii
p_{ij}, l_{ij}	p or l converted from i to j	d_{sc}, d_{cr}	planetary angular dampings
c_{ij}	fractional coupling factors	a_{ij}, b_{ij}	A, B state space matrix entries
r_{ij}	output store coupling factors	c_{ij}, d_{ij}	C, D state space matrix entries
η_{ij}	conversion efficiencies	g	gravity acceleration
e_i	stored energy	M	mass of vehicle
DC	direct current	$v_{abs_{air}}$	velocity of vehicle
u, i	motor electrical voltage or current	α	road slope
R	motor induced resistance	R_{air}	air resistance
L	autoinduction coefficient	R_{slope}	weight resistance at slop
J	moment of inertia	R_{roll}	asphalt friction resistance
B	viscous friction coefficient	ρ	air density
ω	angular velocity	C_d	vehicle drag coefficient
τ	mechanical torque	Ad	vehicle frontal area
V_t	supply voltage to motor	τ_{ext}	external resistance torque
k_t	motor torque constant	D	$\frac{d}{dt}$ operator
T_e	torque input to motor	SD	System Dynamics

- Some experiments may be done in which further “energy” carriers will be added, such as money flow and product flow and try to model the influence from one to the others.

Our approach consists of using these ideas to develop an agent based modeling method which serves at the same time to represent the system and to calculate the flows in the network.

2. Previous work

The idea of a network, its rationale being founded on classical graph theory, has been widely used to represent complex systems like the electricity grid, microgrids [12], transport networks, fluid and mechanical structures and lately more complex systems such as computer networks, communication systems, socio-technical systems [13–16], and the Internet. Major development of science and technology during the last two centuries, has however been implemented in a piecemeal manner. Different engineering disciplines (mechanical, electrical, chemical, energy, communications, etc.) have developed mathematical apparatus and tools and, although based in graph theory, evolved iteratively to simplify disciplinary needs with the result that the basis of the method is recognizable only by true specialists in each discipline.

This situation has worsened further with the advent of progressive software tools, also increasingly specialized in each discipline, so that some specialist engineers only know how to manage some specific software tools for solving special (even complicated) application problems. But today, in order to solve problems relating to networked complex systems, in which different energy flows are involved, interdisciplinary teams are required, and the mismatches in disciplinary specializations (language, methods, etc.) creates significant barriers to integration.

As a way to deal with this situation, an abstract and rather general agent-based representation, in which the idea of *hub* [7], has been proposed [17].

In order to arrange that, previous work of the authors on electrical power grids [18] and microgrids [19], was extended to include complex energy networks, by modeling a computational multi-layered approach using agent-based methods.

The main contribution of this approach, which the authors try to show, in part, in this paper, is that it allows representation of multi-carrier energy networks, using a single sheet view in which the different energy flows (mechanical, electrical, chemical, heat etc.) are shown at once, and also calculates them dynamically in a local way at each agent (see Fig. 1).

As far as the authors know, no other studies with similar features have been published yet.

Using this scheme, a model with five layers, one layer for each energy type (mechanical, electrical, chemical and thermal), and another one for communications, was developed.

A description of these methods was published in [17], but only one example was provided due to space limitations, in which a microgrid specified in [20] was slightly modified in order to apply them. It is complicated to define a scenario and model it, because of the large amount of data required for any instance, even small.

Therefore, looking for some simple but complete instance, we have chosen the modeling of a hybrid car. There are well documented descriptions of some of them, the model is reduced in size and includes the four types of energy (m, e, g, h) referred in our approach (see Fig. 2).

Furthermore, the choice may be interesting to see the flexibility, versatility and generality of our method because just as in the former study calculations were made for three-phase alternating current, using the known *Power-Flow* algorithm, in this case the method of flows calculation is totally different, solving directly the differential equations arising at each node, using the System Dynamics computational method, by which the values of the dynamic variables at the nodes are calculated for each time t, and then, from these values, the power flows are calculated in a concurrent way.