A Software Agent Framework for exploiting Demand-side Consumer Social Networks in Power Systems

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Abstract

This work introduces EnergyCity, a multi-agent framework designed and developed in order to simulate the power system and explore the potential of Consumer Social Networks (CSNs) as a means to promote demand-side response and raise social awareness towards energy consumption. The power system with all its involved actors (Consumers, Producers, Electricity Suppliers, Transmission and Distribution Operators) and their requirements are modeled. The semantic infrastructure for the formation and analysis of electricity CSNs is discussed, and the basic consumer attributes and CSN functionality are identified. Authors argue that the formation of such CSNs is expected to increase the electricity consumer market power by enabling them to act in a collective way.

1. Introduction

Energy markets have undergone very important changes at the conceptual level over the last years. The necessity for sustainability has transformed the traditional power production scheme to a distributed energy resource one. The future dictates towards a great number of decentralized, small-scale production sites based on renewable energy sources or on efficient production systems like mini and micro co- and tri-generators. Moreover, the deregulation of energy markets has produced great business potential for energy-related companies, along however with a number of both technical and policy challenges.

Finally, the Smart Grid paradigm is here to stay. The great advancements in ICT have boosted R&D activities aiming to automate the monitoring and control of power grids, enhance their management, offer alternatives to individual electricity consumers, and achieve large scale energy savings. The Smart Grids are extensively researched at academic and commercial level; however, what is even more important, is that they have found their way into international strategic planning directives [1].

All these changes offer substantial opportunities for all energy market stakeholders which, however, remain largely unexploited. On the one hand, the small-scale consumers comprising the vast majority of the energy market stakeholders are individually insignificant, and their market power is practically non-existent. On the other hand, there is currently a lack of tools for the modeling of the energy market with respect to the complexity introduced by the aforementioned changes. As a result, even the significant market stakeholders are often reluctant to implement novel techniques based on the new opportunities offered to them, as they are unable to anticipate the possible benefits.

The necessity rises, thus, for the development of dynamic models, which could be used in order to help energy market stakeholders improve their market power, as well as in order to assess the impact and possible consequences of certain policies and actions imposed on energy markets in general, before their actual implementation.

EnergygyCity provides a tool for modeling all market stakeholders, as well as the essential grid components. Through *EnergyCity* one may specify consumption habits and patterns, consumer types and behaviors, intermediaries and policy regulations, so that these are diffused in the simulated community, in order to identify behavior drivers or policy makers.

What is most important, though, is that *EnergyCity* strives to upgrade the role and market power of small-scale electricity consumers utilizing the concept of consumer social networks (CSN) [2]. Within this context, *EnergyCity* provides both the essential infrastructure for the development and transparent operation of CSN, as well as the theoretical background concerning the utilization of CSN for the improvement of network reliability and quality of service.

In the remainder of this paper, Section 2 briefly

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discusses state-of-the-art on consumer modeling and ICT tools for power system simulation/ optimization. Section 3 identifies the basic entities involved, provides the semantic representation of a power system and discusses the *EnergyCity* architecture and functionality. Finally, Section 4 elaborates on the CSN concept and concludes the paper.

2. Background work

2.1. Consumer Modeling

A number of paradigms exist in the literature, modeling the daily load curve of an electricity consumer. The approaches followed are roughly divided into two categories. The first one corresponds to the cognitive approaches, where methods such as neural networks and fuzzy logic are used, along with past consumption data, in order to predict future load profiles. Nevertheless, these approaches are strongly dependent on the nature of the past data used for their training procedure, thus not being able to follow changes in consumption patterns.

The second category heavily employs heuristics. Various sets of rules are used in order to develop basic load profiles and probability distributions are used in order to produce profiles based on the initial ones. The set of rules used for the determination of the initial load profiles may be arbitrarily complex, and it may take into consideration demographical data, historic consumption data, information regarding all the involved consumption appliances, seasonal variations, etc [3, 4]. Nevertheless, none of the approaches provides the ability to add/update consumption models and habits, or monitor the influence of a specific factor in an easy and comprehensive way.

2.2. Software tools for power system simulation/optimization

With respect to software tools that either optimize or simulate power systems, two types of approaches exist:

i) tools that focus on the optimization of energy performance given a set of hard constraints (not allowing versatility/dynamicity and exploration) and,
ii) tools that simulate more dynamic scenarios and are investigating for the optimal strategy/solution.

In the former case, neural networks, genetic algorithms, support vector machines and temporal data mining techniques have been employed for solving specific problems related to load prediction, market equilibrium identification and decision support.

In the latter case, agent modeling and machine learning approaches are adopted in order to ensure dynamicity and uncertainty. Once should mention SEPIA [5], EMCAS [6], MASCEM [7] and FERC [8] as the most representative cases.

Although interesting, no generic purpose methodology and platform exists, in order to support the exact modeling of the energy market, in a specific, nevertheless configurable manner. *EnergyCity* provides an expandable architecture in order to model the versatility and dynamic nature of all involved entities in the energy market. Additionally, it provides an easy-to-use interface to experiment on and test various user defined scenarios/system parameters.

3. The *EnergyCity* framework

3.1. *EnergyCity* entities

The basic entities comprising the power system, which are designed within the context of *EnergyCity* are:

- The *Transmission System Operator* (TSO) that is responsible for the overall power system operation. TSO imposes own restrictions, or offers incentives to other stakeholders in order to overcome operational difficulties.
- The *Distribution System Operator* (DSO) that is responsible for the power distribution within an area (such as a city). As such, the DSO has the capability to model its interactions with the other market stake-holders in order to provide incentives towards an optimum overall demand profile for its grid.
- The *Producers* (PROs) that correspond to the power production entities.
- The *Energy Suppliers* (ES) – also known as ESCOs – that are the intermediaries between the DSO and the consumers. They have contracts with the consumers and account for their customers' consumption to the DSO.
- The *Consumers* (COs) –residential, commercial or industrial– that are the core elements of *EnergyCity* and are modeled individually in a bottom-up approach. They have the ability to efficiently control own power consumption. CO is the only actor that knows the utility (satisfaction/benefit) received from consuming and can determine whether consumption can be partly avoided or postponed. Given the appropriate incentive, a CO is able to react to high prices and control own demand, helping ameliorate system emergencies and getting rewarded for it. Moreover, CO has the option to selectively join coalitions (Consumer Social Networks – CSNs), thus gaining market power.

3.2. Consumer Social Networks (CSNs)

The concept of CSNs comprises the basis of the solution proposed in this work. A consumer corresponds to a macroscopically insignificant consumption with a rather limited margin for demand

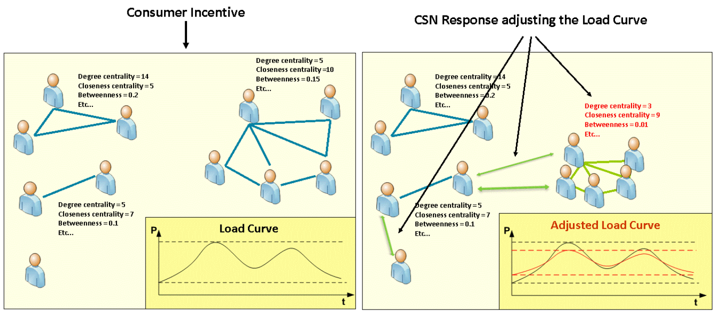

Figure 2. ES sends an incentive to COs aiming to smoothen its load curve and the already formatted CSNs respond to adjust load curve

control. Therefore, the market power of such a customer is also limited, and the respective incentives offered to him may be insignificant for him to act.

It is only in the cumulative consumption of a number of consumers that the aggregate demand peaks become important. Therefore, the concept of Consumer Social Networks (CSNs) is expected to increase the consumers' market power, and thus their motivation to optimize the operation of the power distribution network by controlling their demand (Figure 1).

3.3. *EnergyCity* Architecture

Apart from the power system entities that are modeled as agent types, *EnergyCity* also comprises a number of system agent types:

- the *GroupAgent*, representing the social group formed by two or more *ConsumerAgents*
- the *MatchAgent*, which is responsible for applying the grouping processes with respect to specific consumption and socio-economic criteria.
- the *MediaAgent*, which simulates all forms of mass media influence within a society, providing information on energy environmental awareness, and finally,
- the *SuperAgent*, which is the coordinator of the system and the *GUIAgent*. *SuperAgent* has full control over all agents and is capable of changing all system parameters in real time (if deemed necessary).

The society is defined as a two-dimensional (x × y) grid with no movement permitted beyond its borders. Each one of the grid cells represents a site of the consumer network and can be referenced through its coordinates. Each cell in the grid may be either a vacant space, a *ConsumerAgent* or a *GroupAgent*. Cell proximity defines power system topology.

3.4. The *ConsumerAgent* Model

All *ConsumerAgents* residing in the Power System grid are motivated towards forming coalitions with others, in order to increase their market power. In order to decide on the "perfect match", a variety of parameters are taken into consideration, i.e. the consumption "behavior" and social status of both the agent and the candidates, as well as the degree of environmental awareness and economic incentives provided. A more detailed analysis goes next.

3.4.1. The genetic code of the ConsumerAgent. Upon initializing of a new *ConsumerAgent*, a 24-gene (bits) chromosome is created imprinting the energy-related (11 genes/bits) and societal/functional characteristics of the agent (17 genes/bits). Table I provides information on these attributes of the agents, along with a short description and the possible values of each gene.

3.4.2. Information Degree – Media Influence – Environmental Awareness. In real life, information on energy saving policies comes from versatile sources, namely environmental education, mass media (newspapers, television, radio and internet), as well as everyday interaction. In order to incorporate this parameter into the system, we have specified an *Information Degree* for the *ConsumerAgents* that represents the incoming economic incentive. The factors that affect this parameter are *MediaAgent* influence, *Moore Neighborhood Learning* (one's societal "neighborhood"), degree of *Acceptance* (information uptake) and *Environmental Awareness*. In general, the *Information Degree* and *Environmental Awareness* characteristics are related to each other. An *environmentally aware* person with no *Information*, and a person with high *Information Degree* but with no *Environmental Awareness*, will perform sub-optimally: the first in ignorance and the second in recklessness.

3.4.3. Grouping Preference Value. When *Consumer Agents* decide to group (a percentage of the total population, specified through the GUI interface), they have to decide on the best "match". To do so, they make a list of all candidates (ΣAg_j), and evaluate them with respect to a number of own preferences. These preferences are *Consumption proximity* (a qualitative metric), *Physical proximity* (defining topology), *Trustworthiness, Prosperity* and *Savings Policy, Information Degree* and *Environmental Awareness.*

The *Consumption proximity* of agent Ag_1 to Ag_2 is defined as:

$$consumption\Pr oximity(Ag_1, Ag_2) = 1 \Big/ \left[\frac{\left| ConValue_{Ag1} - ConValue_{Ag2} \right|}{\max(ConValue_{Ag1}, ConValue_{Ag2})} \right] \quad (1)$$

where $ConValue_{Agi}$ is a consumption behavior metric, defined as a value of a Gaussian distribution around the respective Ag_i type typical consumption mean.

The *Physical proximity* of agent Ag_1 to Ag_2 is defined as:

$$physical\Pr oximity = \tanh\left[\frac{VisionGene(Sight)}{\sqrt{(x_{Ag1}+x_{Ag2})^2+(y_{Ag1}+y_{Ag2})^2}}\right] \quad (2)$$

where $<x_{Agi}, y_{Agi}>$ the Ag_i coordinates on the grid, and *VisionGene* the extended Moore neighborhood defined by the *Sight* characteristic (in the chromosome).

The overall *grouping preference value function* employed for agent Ag_1 to rank Ag_2 (applied for all candidates) and consequently choose the highest ranking one is provided in Equation 3:

$$\begin{aligned} preferenceValue(Ag_1, Ag_2) &== w_1 * consumption\Pr oximity(Ag_1, Ag_2) + \\ &+ w_2 * physical\Pr oximity(Ag_1, Ag_2) + w_3 * trustworthiness(Ag_2) + \\ &+ \frac{w_4 * (\Pr osperity(Ag_2) + SavingsPolicy(Ag_2))}{InformationDegree(Ag_1) + EnvronmentalAwareness(Ag_1)} \end{aligned} \quad (3)$$

where w_1-w_4 are user-specified weights.

In order to best group agents based on their preferences, an adaptation of the approach introduced by Gale and Shapley (also known as the "Stable Marriage Problem") has been implemented.

Table 1. *ConsumerAgent* chromosome

Attribute (No Bits)	Description and Values	
Consumer Type (2)	- (00): ~1000W[1] - (01): ~2000W	- (11): ~3000W - (10): ~2500W
Consumer Utility Satisfaction (2)	- Very satisfied (00)[2] - Quite satisfied (01)	- Troubled (10) - Dissatisfied (11)
Trustworthiness (1)	- Very trustworthy (1)[3] - Don't know (0)	
Environmental Awareness (2)	- Motivated (00)[2] - Interested (01)	- Aware (10) - Dissatisfied (11)
Acceptance (4)	- Determines whether an agent wants to uptake new technologies	
Prosperity (3)	- Financial status (ranging 1-8).	
Savings policy (2)	- Expense management (ranging 1-4).	
Influence (3)	- The degree an agent can influence others (ranging 1-8).	
Sight (5)	- How well an agent can select candidate groups that are further away on the grid.	

[1] Typical consumption (following a Gaussian distribution)
[2] Satisfaction counter analogous to the probability of forming groups with other agents
[3] In order to reduce cheating/manipulation

3.5. *EnergyCity* Implementation

EnergyCity comes with a multi-functional user interface to facilitate researchers in their experiments. It has been implemented in Java (v.1.6.3) and all the agents are developed over the Java Agent Development Framework (JADE) framework. Through the "Settings" menu, the user can configure all the energy-related, as well as the demographical and sociological parameters of the simulation at hand. The system provides a number of indicators, as well as information on the agents of the system and the groups formulated. All data generated during the simulation are recorded and stored in text files for posterior analysis.

4. Conclusion and Future Work

In this work, a simulation multi-agent system called *EnergyCity* is presented as a power system modeling tool, aiming to investigate the potential of Consumer Social Networks. Authors argue that CSNs may tackle a number of problems related to the demand side of traditional power systems and may provide significant benefits for all stakeholders of the energy market. The architecture and functionality of *EnergyCity* is discussed in brief due to limited space. The next steps of the deployment and utilization of *EnergyCity* include the thorough study of the objective attributes of consumers that could be used in the aforementioned context in order to result to the optimum formation of CSNs.

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