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# Adaptive Multi-Agent System for Smart Grid Regulation with Norms and Incentives

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**Abstract.** Regulatory policies applied to traditional energy systems are not sufficient when considering smart grids' new requirements such as distributed and decentralised coordination. New management techniques are needed in order to shape consumers conducts by prohibiting, sanctioning or incentivising specific behaviours leading to more efficient utilisation of resources. This paper discusses the possibility of regulating demand in smart grids by the application of processes reflecting the utilisation of norms and incentives in order to better adjust supply to demand. Thus we consider this *soft-control* policy based on the business layer rather than traditional control for cyber-physical systems. The Business Process Modelling (BPM) approach will make easier the design, management and observation of the norms and incentives as flexible artefacts, highlighting decision and coordination processes.

**Keywords:** Smart Grids, Multi-Agent Systems, Regulation, Coordination, Norms, Incentives, Business Process Modelling

## 1 Introduction

The introduction of renewable power sources, storage appliances, and domestic production developed in the last years introduced complexities that exceed current systems management capabilities. From one hand, the natural evolution to a smart grid paradigm becomes very important since current structures are not efficient to control loads in a dynamic and decentralised fashion.

From the other hand, the possibility of direct and timing interaction (e.g. control/actuation) among the various actors in the system brings changes also in the structure of the electricity market. Currently, operators keep generation at peak demand level, leading to large load wastes of energy and monetary losses. Typical actors in market are generator companies (GenCo) and brokers (retailer companies) representing the energy *supply*, and consumers, such as big industrial facilities, households and electric vehicles representing the *demand*. In the smart grid concept consumers can have also production capabilities; this is the case of *prosumers*. The regulation of the demand means the application of control policies in order to lead the consumers to adopt specific conducts and dynamic adapting strategies will allow efficient supply-demand adjustments.

Spontaneously some research questions are rising about the way we can gain insights about the smart grid's ecosystem properties and processes. In which way is it possible to influence entities' behaviours and create those adaptive mechanisms that lead the system into an efficient coordination? And last, how could these strategies support managers in real-world's decision processes? The current work results from a first effort to tackle the aforementioned issues. During our research we will seek to address all the related issues that will come up.

Given the domain's inherent characteristics, such as distributed control through autonomous entities, decentralised approaches as Multi-Agent Systems (MAS) are being pointed as the most appropriate [1]. We intend to produce a MAS to represent a smart grid and the connected energy market. In this context, acting as smart grid actors, agents are connected by energy contracts and the regulatory policies are expressed through energy tariffs. Each agent in the system can represent either a supply-side organisation (e.g. GenCo, brokers) or demand-side individual entity (e.g. household, electric vehicles, or industrial facilities).

Our MAS benefits from Business Process Modelling (BPM) enabling the design of more flexible regulation mechanisms composed by norms and incentives represented as process artefacts.

This paper is structured as follows: Section 2 identifies the relationship of this work to cyber-physical systems; Section 3 gives an overview of related literature; Section 4 discusses the contributions and novelty aspects of the work; and Section 5 overviews the critical analysis of this project and forward research directions. Finally, Section 6 describes some conclusions and future work.

## 2 Relationship to Cyber-Physical Systems

Smart grids are characterised by the combination of physical power system with information processing and communication capabilities, and business layers. This synergy creates a large-scale distributed system that reflects the Cyber-Physical System (CPS) features [2]. Our contributions are projected to CPS concept in the way it comprises control and coordination of human-agents with autonomous artificial artefacts (with different behaviours and intentions), energy and information. Although CPS are mostly oriented in controlling physical entities through the actuation on hardware agents applying traditional control techniques, our attempts here comprise a type of control based on a behavioural-shift fashion. The controller does not try to regulate the distribution load, but instead tries to modulate the demand by shifting the load peaks. This is achieved by coordinating the consumption (of not necessarily cooperative agents) in order to avoid herding phenomena. Such *soft-control* [3] is obtained by using price signals, as they derived from the energy market evolution. Load usage will ensure the feedback for regulation. Many issues in this domain are still open and the full development of the smart grid depends on solving them.

The importance of adjusting demand and supply and the mobility of energy, linking multiple grids are discussed in [4], [5]. Concerns exist also regarding political gridlocks, market inefficiency, and short-sighted planning as some of the existing bottlenecks. In this sense, BPM is presented as a systematic approach to support the

understanding of the interaction between business and control layers to achieve compliance. Moreover, regulatory mechanisms and incentives for small consumers are requirements to achieve success with smart grids [6].

### 3 State of The Art

According to the European Commission, "A smart grid is an electricity network that can cost efficiently integrate behaviours and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" [7].

Regulation in the current grid is almost exclusively lead by governmental regulatory policies that control supply and demand. In a fully operational smart grid, new regulatory policies will address the necessary coordination for efficient management. Some examples of regulation practises are: legal restrictions, contract regulations, self-regulations, or social regulations [8].

Norms represent means to control interactions between individuals to achieve desired behaviours and responses [9]. Normative MAS can be created for environments where agents can decide whether to follow or not the explicit norms [10]. Incentives, on the other hand are the instrument that can push agents in a desired way [11], [12], [13]. Some characteristics of the MAS paradigm [1], [14] make this an appropriate paradigm to model smart grids. Recent works using MAS in smart grids address coalition formation, distributed control, and market-driven competition [15].

BPM allows to decouple the business logic layer from agent's inner reasoning and behaviours, centring the focus on the functional aspects of the system management [16], [17]. Few research relates BPM and MAS, although some works on translating from one to another can be found in [18] and [19]. Efforts on the combination of normative systems with incentives mechanisms still lack implementation and analysis, as seen in [20]. Besides, new models might be created to help solving challenging problems as the participation of Electric Vehicles (EVs) [21], tariff composition and efficient appliance scheduling [13].

### 4 Contributions and Innovative Aspects

Smart grid managers may benefit from regulation since agents should be able to adapt their strategies given system's responses and their own goals [22]. Customers can also benefit from agents automatic negotiation by improving their ability to buy and sell energy [4]. However, selfish behaviours are present and managers will try to minimise their impact for the sake of social welfare [21]. Recent works [9], [12] show some efforts in decentralised approaches to regulate dynamic environments. Due to the inherent complexity of smart grids, big challenges are still open [4].

Research on MAS has, in the last years, devoted a strong attention to demand regulation. Although other existing proposals concern the use of norms and incentives to regulate multi-agent systems separately, appropriate models that combine norms

and incentives in order to promote cooperative behaviours still lack flexibility and realistic characteristics. The challenge of using regulation as coordination mechanism is among the objectives of our research effort. Figure 1 show the four cornerstones in our smart grid representation. Customers (end-users), market agents (managers), operators and transmission are the main parts of the environment. Regulation is a pervasive element that coordinates all the actions: managers establish contracts that govern customer's consumption and production, constrained by energy availability and prices from both physical (transmission) and operational (economics) parts.

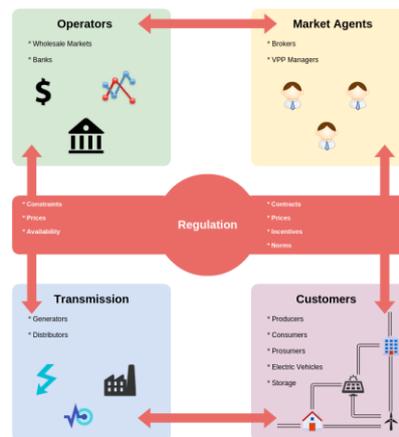


Fig. 1. Regulation in a Smart Grid architecture

#### 4.1 Incentives and Norms as Processes Artefacts

In this work we discuss the use of BPM aspects that could help users (either acting on supply, or in demand side) to define and authorise agent to act on their behalf and trigger the proper processes. BPM systems consist on the systematic characterisation of the actor's actions when executing a process. Figure 2 shows a typical process, represented with BPMN. The process carry all the logic flow that correspond to the control tasks in a specific scenario, without defining the lower-level actions. Our approach intends to merge processes' tasks into agent's actions and benefit from such flexibility.

This approach offer a dynamic way to analyse and design managers' goals and user's actions, coordinating their interactions. Connecting the business logic layer to physical and economical aspects that constrain agent's actions allows to create a modular configuration for the smart grid scenario.

Describing the business processes in the setting of current and future grids will help to understand and develop novel regulation strategies. Figure 3 shows that processes will develop a major role on organising the interactions of the agents. We propose that the soft-control should occur in business-logic level activities.

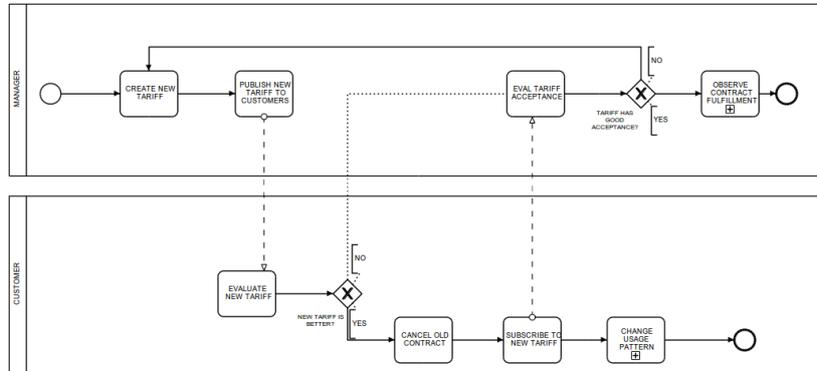


Fig. 2. A typical BPMN Process

Managers can observe and act accordingly to enforce system's states and achieve their goals. To do so, we will study how to design norms and incentives as artefacts, such as sub-processes that can be triggered and respond to system's changes on-line. On the other hand, customers will use processes as the linking element that can respond to the environment. Manipulating preferences and contract restrictions, customers can act changing behaviour or facing consequences. Automatic scheduling from agent's decisions will allow customers to optimise demand, decrease costs and improve budgeting.

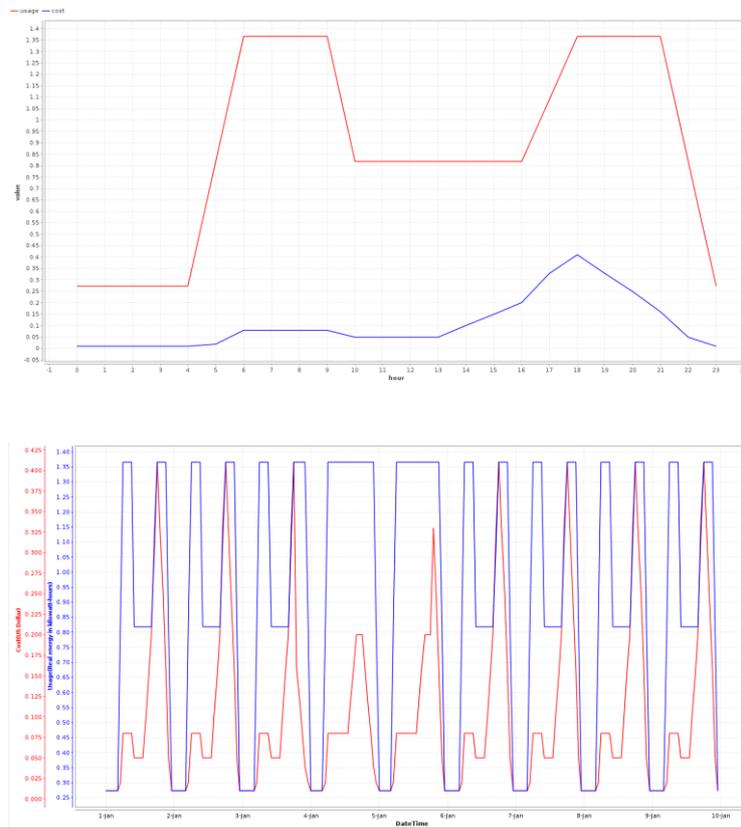
Following a BPM approach, our models will comprise the process design cycle, describing regulation in current grids **as-is** and new processes proposed for coordination in the smart grid context **to-be**. The problems tackled will focus the creation and adaptation of tariffs in order to ensure management efficiency (e.g. demand peak avoidance). Therefore, the test bed and validation of the current work is being considered in this context.



Fig. 3. Acting on the business process layer will help to achieve the desired states

## 5 Results and Critical View

The insights of this work are to create a vision and to formalise concepts necessary to future lines of research. Regarding the regulatory tools on smart grids, default control is related to the physical transmission lines and the electrical system. The other way, used on this work, is a system management based on tariff actuation.



**Fig. 4.** Consumption vs Price in a typical day (left) and Consumption vs Average daily price during a week (right)

Representing the contract between the broker (manager) and the customer, tariffs can wrap financial tools enabling regulation.

Our preliminary work on this thread considers the PowerTAC<sup>1</sup> framework, a suitable simulation focused on the tariff composition problem. We have created and validated a new model for tariff creation, based on fuzzy logic that uses energy imbalances as a feature for incentivising specific prosumer behaviours [23]. The model creates new tariffs aiming for controlling broker's portfolio and improving its participation on the market. Results showed great potential in our fuzzy strategy. The broker agent is being refined in order to be able to compete in PowerTAC homonym official international competition.

Changing tariff features, such as the energy price, sign-up or withdraw fees can lead to customers' behaviour changes [24]. The first step in order to characterise

<sup>1</sup> [www.powertac.org](http://www.powertac.org)

relationship between the consumption and tariffs consists on analysing real consumption data-sets. Using smart metering data from the U.S. Department of Energy's Green Button initiative<sup>2</sup> we observe that there are some consumption changes accordingly to energy prices. Figure 4 (left) shows the patterns for a typical day on the data-set. Market prices goes higher as consumption increases. In the same way, Figure 4 (right) shows similar patterns for both consumption and prices on working days. Weekend days are evidenced on days 4th and 5th. It appears that exists a correlation between consumption behaviour and energy prices. This is in line with our intentions to apply control mechanisms for shaping customers' behaviour to desired states.

Finally, our best efforts will consider norms and incentives as process artefacts.

## 6 Conclusions and Future Work

The adoption of smart grids brings new challenges in energy management and thus in the society [4]. The development of an enhanced business layer infrastructure will allow the analysis and design of more complex and distributed strategies for demand coordination. Adopting *soft-control* mechanisms allow some kind of social management, based on incentivising specific behaviours while avoiding others.

Here, a flexible process-oriented approach for regulation in multi-agent systems is proposed, describing how management on the business layer can include norms and incentives as flexible process artefacts. For this purpose the BPM approach is discussed. Following, some preliminary studies are considered. First we have used an existing electricity market simulation framework to address the tariff creation problem in order to incentivise specific customer behaviours. Results indicate the feasibility of applying demand-side soft control based on tariff actuation.

Next, we have analysed the relationship between consumption and energy price from real data-sets. This opens the possibility for exploring the correlation between consumption behaviour and energy prices.

Future work will deploy data-mining techniques for prediction and creation of synthetic load profiles. We will also study how the combination of norms and incentives can suppress or support the emergence of behaviours that are not benevolent to the system.

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