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# Load Control Timescales Simulation in a Multi-Agent Smart Grid Platform

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***Abstract*—Environmental concerns and the shortage in the fossil fuel reserves have been potentiating the growth and globalization of distributed generation. Another resource that has been increasing its importance is the demand response, which is used to change consumers' consumption profile, helping to reduce peak demand. Aiming to support small players' participation in demand response events, the Curtailment Service Provider emerged. This player works as an aggregator for demand response events. The control of small and medium players which act in smart grid and micro grid environments is enhanced with a multi-agent system with artificial intelligence techniques – the MASGriP (Multi-Agent Smart Grid Platform). Using strategic behaviours in each player, this system simulates the profile of real players by using software agents. This paper shows the importance of modeling these behaviours for studying this type of scenarios. A case study with three examples shows the differences between each player and the best behaviour in order to achieve the higher profit in each situation.**

***Index Terms*-- Artificial Intelligence, Demand Response, Micro Grid, Multi-agent Simulation, Smart Grid**

## I. INTRODUCTION

The growing scarcity in fossil fuels and the resulting increase of prices, supported by environmental alarms that the consumption of this fuel brings, led to an increase in the use of distributed energy resources. The growing use of technologies from natural and endogenous resources such as wind, sun or water changes significantly the present and the future power system operation and management.

Another resource which has been increasing its importance is the Demand Response (DR). It has the capability of encouraging consumers to change their consumption profile, depending on the requirements at each moment. DR programs are implemented considering that loads are not rigid and that some of them can be reduced or increased using incentives or electricity price variations [1]. To the specific goal of enhancing the range of DR programs, an aggregator called Curtailment Service Provider (CSP) was proposed to demand response events management, to identify curtailable load, to enroll customers, to manage curtailment events, and to calculate payments or penalties for their customers [2].

The increase of the number of small players, the aggregation possibility and its inclusion in a smart grid (SG) and micro grid (MG) environment strengthens the resources management, bringing clear advantages [3]. However, the complexity increases exponentially, regarding all the resources integration, the proper management and interactions. Combining distributed artificial intelligence techniques, such as Multi-Agent Systems (MAS), with simulation we get a powerful tool for studying environments with a complex distributed nature. Modeling SG and MG with MAS allows model enlargements, including new players at any time and of very different kinds, and study their individual and internal performances.

The main focus of this paper is the simulation of small and medium consumers' strategic demand response events with voluntary participation considering the aggregation within a CSP with its own strategy. For this propose, it was used a MAS developed for future power systems simulation. MASGriP (Multi-Agent Smart Grid Platform) [4] supports the simulation of technical and economic environment. Players in MASGriP can also interact with physical agents that control physical resources. MASGriP is implemented in JADE and it is compliant with FIPA specifications.

After this introductory section, section II explains the MASGriP platform and its interactions. Section III focuses on the proposed behaviors and strategies implemented in MASGriP's CSP agent and in different consumers. Section IV presents a case study that demonstrates the application of these behaviors and strategies, and their benefits. Finally, section V exposes the most relevant conclusions of this work.

## II. MASGRIP FRAMWORK

MASGriP allows the simulation of future power systems operation, mainly in the distribution level. The considered hierarchical management implemented in MASGriP allows a

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large set of simulation focus in technical and/or economic aspects. Several players were implemented trying to reflect the real world, such as consumers, producers, the Distribution System Operator (DSO), the Independent System Operator (ISO), among others. However, MASGriP has also implemented several new agents who can have an important role in the future power systems management and operation, such as Virtual Power Players (VPPs) [5], the Curtailment Service Provider (CSP) [2], micro-grids operators, Energy Services Companies (ESCO), etc. These players introduce more complexity in the system management and more focus in negotiation and coalitions' processes. The inclusion of a large set of different players and the join of technical and economic treatment of future power systems are characteristics which distinguish MASGriP from the other existing simulators.

MASGriP is developed in order to be capable of performing simulations that reflect and coexist with the real world making it possible to observe and study the simulations' results [4]. For this reason, MASGriP has implemented virtual agents, using intelligent methodologies to simulate the real players operation, but also interface agents allowing the interaction with real players (humans) and with real hardware (loads, generators units, storage systems, protections, etc).

Actually, MASGriP has an interface agent allowing the communication with a real house managing system [6] and consequently with its users. The communication with the house management system is made using Internet Protocol (IP) to communicate with a Programmable Logic Controller (PLC) and RS-485 to communicate with soft-starters, measurement units, etc. The integration of more real hardware is an important development focus of MASGriP team mainly in the integration of consumers with different characteristics (commerce, industry, etc) and in the integration of distribution network real time simulator provided by the development of an interface agent to communicate with Opal-RT system available in GECAD laboratories.

Communications in MASGriP play an important role and are implemented through the JADE platform, compliant to FIPA specifications. FIPA supports agents' interoperability by standardizing their communications and content languages. To facilitate the exchange of information that is needed, our own ontology was developed from scratch. Each event has its own predicates and characteristics. By using FIPA-ACL, when our ontology goes public, external developed players will also be able to play in MASGriP through the implemented communication system.

## III. CSP AND CONSUMERS PROFILES

Demand Response (DR) programs are a very useful tool to improve the power systems operation [7]. On the other hand, they can also be very attractive to small players. These programs are normally blocked to small players due to the minimum amount of curtailment. However, in present and especially in future power systems, new aggregation players such as Curtailment Service Providers (CSP) can prove to be useful. This operation scenario was implemented in MASGriP, where the small players are aggregated to a CSP, becoming able to participate in DR events promoted by the ISO or by DSOs. These events can be with voluntary or mandatory participation depending on the contract made between the parts.

The CSP must have the ability of making and using the contracts made with the players in its interest [2]. These contracts can be simple, like the payment for the amount of load curtailed, or more complex like the Direct Load Control (DLC) [9]. In the DLC, the CSP pays a fee regularly for the player availability and later, when it is necessary, the CSP can control (cut or reduce) directly the consumer loads only with a prior notification. The player gets an additional payment for the amount of power reduction. The players can also use the contracts to increase their profits. This problem can be properly studied with the negotiation and context analysis that a MAS environment provides.

The CSP can have different types of behaviors, as shown in Figure 1: (i) the aggressive type, where proposals focus mainly on the profits since the beginning, practicing aggressive prices from the start; (ii) the balanced (normal) type - a CSP that makes a balanced first offer and then increases it a little if needed, balancing its profits with the probability of positive responses; and (iii) the cautious, which sends an offer almost too good to refuse to their players, trying to fulfill the needed curtailment fast and without problems. These behaviours affect the price but also the response time given to the player. For instance, an aggressive CSP can send a low price with small response time, hoping that players will rush to answer and accept without much thinking. In the case of a cautious CSP, it will send a high price with a high response time, in order to ensure as most positive answers as possible.

Another characteristic of a CSP is the possibility of presenting more curtailment to the same players in the following events. This can be applied in two ways: rewarding the players who contributed more in the previous event, increasing the trust in their behaviour and allowing them to achieve more profits; or demanding more from those that contributed less, inviting them to participate more.

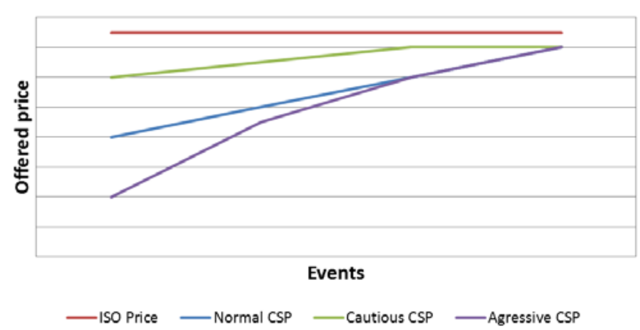


Figure 1 - Types of CSP behaviours

With regard to players, three types of different behaviours were implemented. The first type comprises a player that performs a context analysis of its user and its location, and then decides if the remuneration is acceptable according to the amount of discomfort that it will cause. For example, the MASGriP physical loads player studies the behaviour of the user and it attributes weights to the loads at certain times. Another player can have an adapted behaviour, in which the user defines the required price for reducing the load, and in each event the player adapts the amount to be reduced to the difference between the price proposed by the CSP and the required value. Finally, there is the radical player that uses the price defined by the user as a boundary and all the offers below that reference value are refused.

Before this, each player must conduct an optimization of its loads in order to reach the real amount that can be reduced. The optimization process and the process of choosing the response to give can be selected to adapt to the response time. In some cases, players fail to respond because these processes take longer to compute, than the time that is available.

## IV. Case Study

This case study concerns a SG environment, which includes six consumer agents, one ISO agent and one CSP agent. It simulates a Locational Marginal Price (LMP) based ISO DR event and the consequent CSP actions to promote the DR event within its aggregated players. The main goal of this case study is to identify the CSP acting strategy which generates more profits and, on the other side, the security of event participation.

The ISO agent identifies high LMP values and attempts to reduce the consumption by using a DR event. This event is sent to every player in the network with the minimum amount of curtailment capacity and with mandatory response.

The focus is set in one particular CSP that aggregates two commercial, two industrial and two residential players. Each player has a voluntary participation contract with the CSP, which allows refusing the participation in the DR events or defining freely the amount of load to curtail up to a limit. Both residential and one industrial player (I1) have a DLC contract with the CSP. The House2 agent has physical load control and it is linked to an interface controlled by the real user, taking his preferences into account.

Three types of CSP actuation profiles (Aggressive, Normal and Cautious) were simulated. Regarding the players, the following behaviours were attributed:

- House1 and Industry1 have Adaptive behaviour;
- House2 and Commerce2 have the Context Analysis;
- Industry1 and Commerce1 are Radical players.

ISO defines a curtailment for the CSP of 40kW with a remuneration of 15 monetary units (m.u.) for each curtailed kW, with a 20 minutes response ramp for 30 minutes of DR event duration.

### A. *CSP Profile - Aggressive*

In this first simulation, an Aggressive CSP is used. Considering its DR contracts portfolio, the CSP tries to increase its profits proposing a voluntary DR event with a low remuneration (4 m.u.). Being an Aggressive CSP, no preventive measures are taken, so the amount asked is the amount necessary, and a very short event ramp is proposed (5 minutes). Figure 2 shows the sequence diagram of this event.

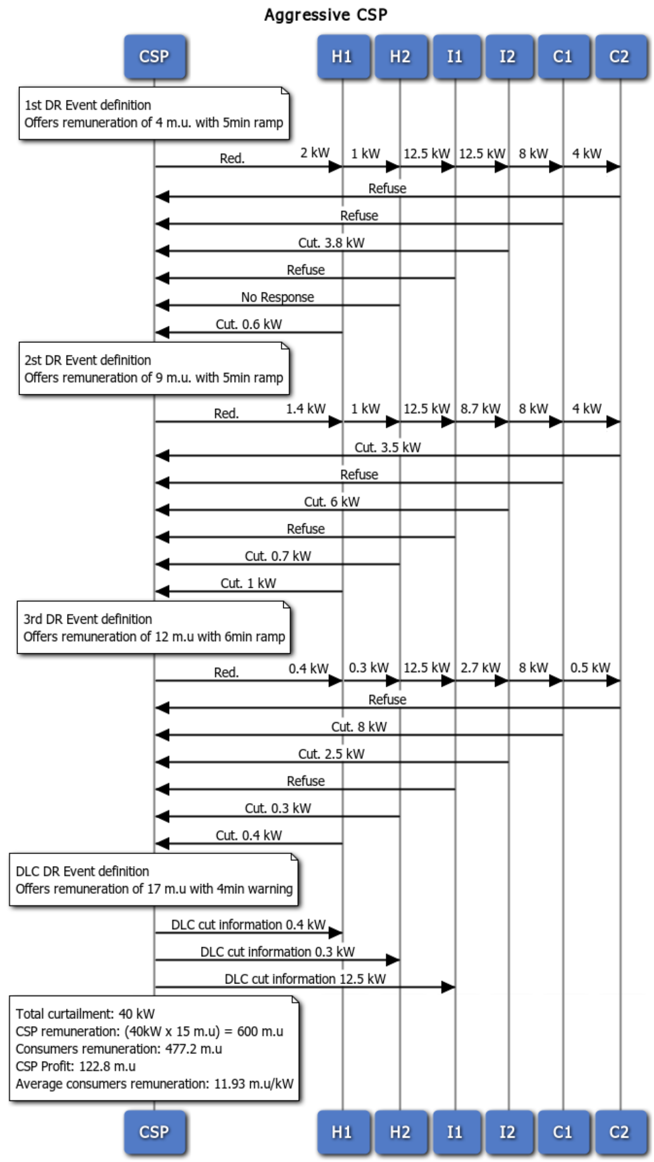


Figure 2 – Example of a sequence diagram of an Aggressive CSP

As it can be seen in Figure 2, the strategy adopted by the CSP does not result as it was expected. The CSP needs to promote new DR events to participate in ISO DR event. This happens due to the price proposed by the CSP being below the price wanted by the players. Industry1 is a radical player and refuses to reduce due to the low price. House2 must take into account the physical load control and user preferences. In this case, the user is not available to participate in the DR event and, consequently, does not respond to the CSP event.

The second (remuneration of 9 m.u) and third (remuneration of 12 m.u) voluntary events were sent with higher remunerations to the players, and even then the CSP failed to achieve the desired reduction. House2 now responds because the process is already concluded. Commerce1, a radical player, accepts the third price because it achieves the defined desired price (10 m.u).

Finally, without much time to participate in the ISO DR event, a DLC mandatory event is launched by the CSP with great remuneration (17 m.u) for consumers, penalizing the CSP profits. Therefore, regarding the participation in this DR event, the CSP with aggressive profile contracted 40 kW of curtailed load with its aggregated consumers with an average paid of 11.93 m.u/kW. Considering the income of 600 m.u paid by the ISO, the CSP with aggressive profile had a profit of 122.80 m.u.

## *B. CSP Profile - Normal*

The second simulation explains the procedure of a CSP with Normal profile. It launches a DR event with regular remuneration (8 m.u.) and ramp time (10 minutes), and asks for 10% more than what was determined by the ISO (44 kW). Figure 3 shows the sequence diagram of the DR event in the CSP with Normal profile.

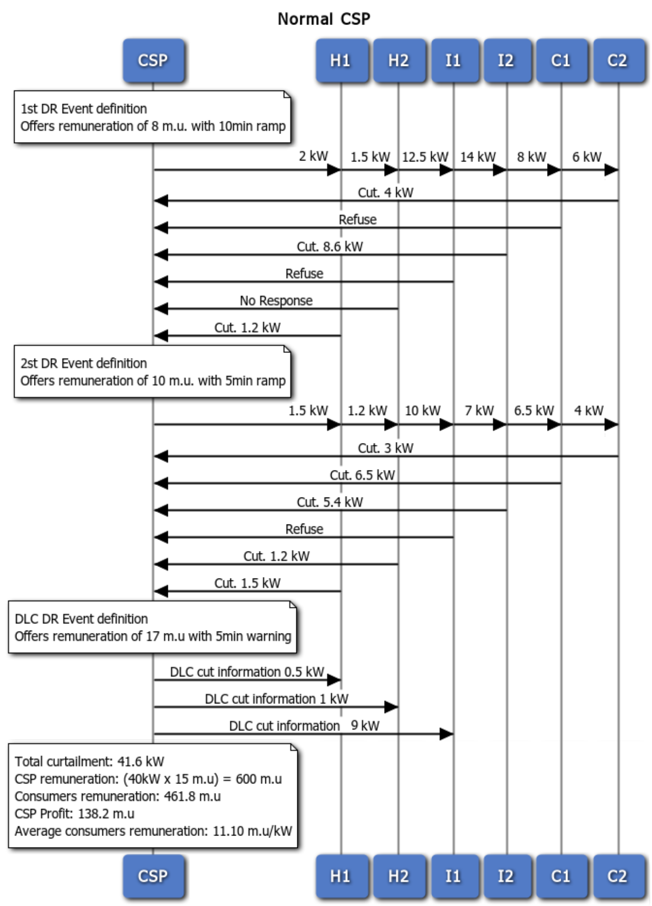


Figure 3 – Example of a sequence diagram of a Normal CSP

Concerning the first event, House2 spends too much time and fails to answer, and the radical players refuse to participate due to the proposed remuneration. In this CSP, it was implemented a rewarding system to penalize the consumers which refuse or do not participate in the events, benefiting the consumers which participate the most. This means that these players receive proposals with a higher amount of load to curtail in the next event, having the possibility of earning more money.

A second event is launched with an increase in the remuneration (10 m.u), yet with a low ramp time (5 minutes). House2 participates, but the Industry1 refuses once again. In this case, the CSP chooses a DLC event to obtain the required energy curtailment. Since the DLC program is mandatory, the CSP ensures the participation of consumers and, consequently, does not need additional DR participation. In this case, the CSP contracts a total of 41.6 kW load curtailment, 1.6 kW (4%) more than the required by the ISO. This value ensures some security to the CSP in case of failing to get some consumers' participation.

In this way, the CSP with normal profile contracted 41.6 kW of the curtailed load with its aggregated consumers with an average paid of 11.10 m.u/kW. Considering the income of 600 m.u paid by the ISO, the CSP with normal profile had a profit of 138.2 m.u.

## *C. CSP Profile - Cautious*

The third simulation shows the functioning of a Cautious CSP. The first event launched has already a higher remuneration (12 m.u.) and a higher ramp time (12 minutes), expecting to solve the DR participation in the first event. Figure 4 shows the event sequence.

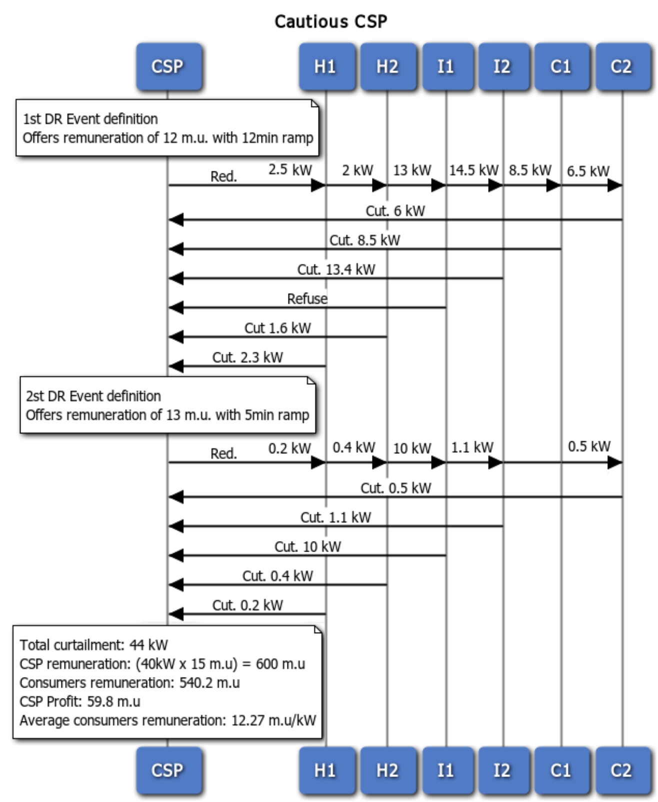


Figure 4 - Example of a sequence diagram of a Cautious CSP

This enables House2 to answer on time and Commerce2 to participate. It was also asked for more load curtailment than the ISO request (45kW). However, Industry1 only participates with a remuneration of 13 m.u., therefore, not participating in the first event of the Cautious CSP.

A second event is necessary and launched with an even higher remuneration (13 m.u.), yet with small ramp time (5 minutes) due to the ISO limit. The objective is achieved in this event and the DLC is not necessary. The amount asked by the ISO of curtailment is also surpassed.

Thus, the CSP with cautious profile contracted 44 kW of curtailed load with its aggregated consumers with an average paid of 12.28 m.u/kW. Considering the income of 600 m.u paid by the ISO, the CSP with a cautious profile had a profit of 59.8 m.u. The profits of Cautious CSP are penalized by the contract of 44 kW, i.e., 10% more than the value required by the ISO.

### *D. Case Study - Summary*

Due to the behaviour of the first type of CSP (agressive), it was able to propose 4 different events, which allowed achieving the amount requested by the ISO with a profit of 122.8 m.u.. This CSP takes a big risk; however it reaches the objective without suffering price losses due to the existence of more curtailment than what was needed.

The second CSP type (balanced) reaches the necessary amount with only an insignificant extra (1.6 kW), so the reduction in profits becomes irrelevant. The strategy adopted by normal CSP is the strategy with most profits and it ensures 4% of extra load curtailment.

The third type proved to be the less profitable; however, it was the fastest to achieve the objective. In this CSP, the final kW price was affected by the amount of curtailment paid to the players that was not needed. Table 1 and Table 2 show the global results of the three simulations.

TABLE I. CSP RESULTS BY CASE

| | House 1 (Adaptive) | House 2 (Context) | Industry 1 (Radical) | Industry 2 (Adaptive) | Comm. 1 (Radical) | Comm. 2 (Context) |
|---|---|---|---|---|---|---|
| **Aggressive CSP case** | | | | | | |
| **Average Remuneration** (m.u./kW) | 9,6 | 11,5 | 17 | 8,1 | 12 | 9 |
| **Curtailled Load** (kW) | 2,4 | 1,3 | 12,5 | 12,3 | 8 | 3,5 |
| **Total Remuneration** (m.u./kW) | 23 | 15 | 212,5 | 99,2 | 96 | 31,5 |
| **Normal CSP case** | | | | | | |
| **Average Remuneration** (m.u./kW) | 10,4 | 13,2 | 17 | 8,8 | 10 | 8,9 |
| **Curtailled Load** (kW) | 2,9 | 2,2 | 9 | 14 | 6,5 | 7 |
| **Total Remuneration** (m.u./kW) | 30,1 | 29 | 153 | 122,8 | 65 | 62 |
| **Cautious CSP case** | | | | | | |
| **Average Remuneration** (m.u./kW) | 12 | 12,2 | 13 | 12,1 | 12 | 12,1 |
| **Curtailled Load** (kW) | 2,5 | 2 | 10 | 14,5 | 8,5 | 6,5 |
| **Total Remuneration** (m.u./kW) | 30,2 | 24,4 | 130 | 175,1 | 102 | 78,5 |

TABLE II. TOTAL CSP RESULTS

| | **Average Paid** (m.u./kW) | **Curtailled Load** (kW) | **Profit** (m.u.) |
|---|---|---|---|
| **Aggressive CSP** | 11,93 | 40 | 122,8 |
| **Normal CSP** | 11,1 | 41,6 | 138,1 |
| **Cautious CSP** | 12,27 | 45 | 59,8 |

## V. CONCLUSIONS

This paper presents a Multi-Agent System, which models Smart Grids and Micro Grids, the players involved in these environments, and their interactions – the MASGriP platform. In a Micro Grid scenario, MASGriP is capable of applying and managing resources such as the DR and distributed generation. The players, including aggregators such as CSPs are endowed with intelligent behaviours and strategies.

As shown in this paper, the behaviours implemented by each agent provide the system with the possibility of making different studies on the operation of the Curtailment Service Providers (CSP) and its relations with the aggregated players.

The results show that each type of player behaviour works better for a certain behaviour of the CSP. A radical player has more profits by having a Direct Load Control contract with a CSP that is not cautious. Overall, the adaptive players are best suited to work with all types of CSP. The aggressive CSP plays a very risky move by not having requested more curtailment than what is necessary. In the case of the cautious CSP, it has been problematic as the curtailment was so high that the amount of m.u. per kW suffers a reduction, which influences the profits. The normal CSP achieves more profits by balancing the proposed price and the ramp time.

The achievements of this paper provide contributions to the testing of DR events in MASGriP, involving the ISO, the CSP, and several consumers with diferent characteristics and strategies. This paper also shows the advantage of using a multi-agent platform in the analysis of DR events. Finally, the paper proposes a strategic participation of consumers in voluntary and sequencial DR events.

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