

# MASGriP – A Multi-Agent Smart Grid Simulation Platform

Pedro Oliveira, Tiago Pinto, Hugo Morais, *Member, IEEE*, Zita Vale, *Senior Member, IEEE*

**Abstract**— The increasing number of players that operate in power systems leads to a more complex management. In this paper a new multi-agent platform is proposed, which simulates the real operation of power system players. MASGriP – A Multi-Agent Smart Grid Simulation Platform is presented. Several consumer and producer agents are implemented and simulated, considering real characteristics and different goals and actuation strategies. Aggregator entities, such as Virtual Power Players and Curtailment Service Providers are also included. The integration of MASGriP agents in MASCEM (Multi-Agent System for Competitive Electricity Markets) simulator allows the simulation of technical and economical activities of several players. An energy resources management architecture used in microgrids is also explained.

**Index Terms**— Curtailment Service Providers, Energy Resources Management, Microgrids, Multi-Agent Systems, Smart grids, Virtual Power Players.

## I. INTRODUCTION

The increasing shortage in fossil fuels and the consequential rising of prices, supported by implicit environmental concerns that the consumption of this fuel brings, headed to an increase in the use of renewable energy resources. From the environment point of view, using renewable energy resources brings clear advantages. This is also a favorable scenario for distributed generation (DG) growth, which brings some other important aspects into consideration, of economic and technical nature. Problems such as the dispatch ability, the participation of small producers in the markets and the high cost of maintenance must be resolved to the intensive use of DG be an advantage [1].

To enable owners of renewable generation to gain technical and commercial advantages can be used aggregation strategies, achieving higher profits from the mix of several generation technologies (and other distributed energy resources) and overcoming serious disadvantages of some of those technologies.

The aggregation of DG plants gives place to a new concept: the Virtual Power Player (VPP). VPP are multi-technology and multi-site heterogeneous entities. In a VPP the producers can be sure their generators are optimally operated. At the same time, VPPs are able to have a more stable generation profile, raising the value of non-dispatchable generation technologies[2].

Another way to understand the potential of DG is to take a system approach where generation and associated loads are taken as a subsystem. This limits greenhouse gas emissions and permits to reduce the transmission power losses and delay the construction of new energy infrastructures. The coordination of a system of this type is quite challenging that requires distributed intelligence, the concept of Smart Grids[3].

Another important resource implemented in electricity markets considering that the loads demand is not rigid, mainly because of the electricity price, is Demand Response (DR). DR has been largely studied and proved to bring significant benefits for owner systems operation and planning[4].

For the purpose of simulate this market operations we use MASCEM simulator [5, 6] which is a modeling and simulation tool that has been developed for studying complex restructured electricity markets. It provides market players with simulation and decision-support resources, being able to give them competitive advantage in this market.

After this introductory section, Section II outlines the main features of the microgrids concept Section III describes the proposed Multi-Agents Smart Grid Simulation Platform (MASGriP) and the integration with a Multi-Agents System for Competitive Electricity Market Simulator (MASCEM). Section IV presents the intelligent microgrid management architecture. Finally Section V presents the most relevant conclusions and contributions of this paper.

## II. MICROGRIDS CONCEPT

The microgrid concept was proposed in [7], being defined as a “cluster of micro-sources, storage systems and loads which presents itself to the grid as a single entity that can respond to central control signals. The heart of the microgrid concept is the notion of a flexible, yet controllable interface between the microgrid and the wider power system. This interface essentially isolates the two sides electrically and yet connects them economically. On the tilde, the conditions and quality of service are determined by the microgrid, while

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*flows across the dividing line are motivated by the prevailing need of the transmission system*". In practice microgrids have an internal energy resource management system, with specific goals and own technical limits and quality parameters. From the power systems perspective, microgrids are a player that can consume or provide energy to the main network and should be considered as a "good citizen".

In [8] the application of microgrids concept in a large industry is proposed. An example of a paper manufacture with a continuous process is shown. The industry has a total consumption of 1MW and it is composed by 3 buildings. Several micro turbines are included in industry and an internal Demand Response (DR) program was also considered. Several studies are presented considering different scenarios of DG and DR. The main studies concern voltage profiles, power flows, system losses and a dynamic operation and control of micro turbines and loads.

The definition of micro resources is more clearly explained in [9]. Several technologies are studied but in general the micro resources are the resources with installed capacity lower than 250 kW. However, in [10] the installed capacity limit of micro resources is 100 kW. In a Microgrids European project is presented [11], which defines a different concept of microgrid. In this case, microgrid only considers the aggregation of resources connected in a low voltage network. Another important difference concerning this study is the consideration of heat necessities in the energy resources management.

In [12] a definition of microgrid is presented, according the European paradigm. A Microgrid can be defined as *"a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources. Microgrid components include; distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management"*.

Several studies are being made considering different topics of the microgrids operation. In [13] the problem of stability of load sharing control is addressed and in [14] an important task for the implementation of microgrids is presented, namely the operation in island mode. In normal operation the microgrid works while connected to the main grid. However, in case of an incident or in specific situations, the microgrid can be operated in islanded mode. The work presented in [14] details a micro sources model and the control strategies to operate the microgrids in isolated mode.

The power quality issues are presented in [15], proposing a flexible distributed generation to improve the system power factor while mitigating harmonics and correcting unbalance. The power losses reduction problem is analyzed in [16], concluding that the DG could significantly influence the power losses in the distribution network. However, the use of DG does not always reduce the losses. In many tested

scenarios, exposed in [16] the power losses increases. In [17] three models are proposed, which reduce emissions in a microgrid by maximizing the fuel efficiency and using energy storage systems. In microgrids it is possible to explore the potential of DG to provide ancillary services [18], such as tackling the harmonic distortion and compensating the reactive power needs to support the voltage control in the distribution network.

In [19] a Multi-Agent System (MAS) that simulates microgrids operation is proposed. The main advantages are the simulation of DG owners and their decisions, the communication facilities and the introduction of intelligence in DG units operation in a liberalized and competitive electricity markets context. Different MAS architectures to control a future distribution network considering a Virtual Power Player (VPP) energy resources management is proposed in [20]. Depending on the size and complexity of the distribution network, three different MAS architectures are proposed. In the simplest architecture, VPP centralizes the management of all energy resources. In the second MAS architecture an aggregation by resources type and technology are proposed. In the most complex operation system, two decisions levels are proposed. At the bottom level, the microgrids manage the Low Voltage (LV) resources and at the upper level the VPP manages the microgrids and the Medium Voltage (MV) resources. The operation in electricity markets is also important to microgrids. In [21] a local microgrid market is proposed, based on uniform price market clearing rules for the day-ahead energy market. The authors of [22] propose two different approaches. In the first one, the microgrid satisfies the local demand considering its generation, and the market price forecast. In the second approach the microgrid participates in a distribution area market and tries to sell or buy active and/or reactive energy via an aggregator.

### III. MULTI-AGENTS SMART GRID SIMULATION PLATFORM (MASGrIP)

MASGrIP is a multi-agent system that models the internal operation of smart grids. This system considers all the typically involved players, each player being represented by one agent with the capability of representing the actual corresponding player and to simulate its actions.

Modeling a smart grid environment as a multi-agent allows studying and analyzing both the individual and internal performance of each distinct player; as well as also the global and specific interactions between all the involved players.

In order to efficiently analyze the quality of the simulated smart grid management, it is essential to provide the means for the MASGrIP system to be able to perform the required negotiations in the electricity market. This way it becomes possible to quantify the gains of using such type of resources management, by analyzing the resulting profits. Including the electricity market negotiations feature in MASGrIP meant integrating this system with a Multi-Agent System that Simulates Competitive Electricity Markets (MASCEM).



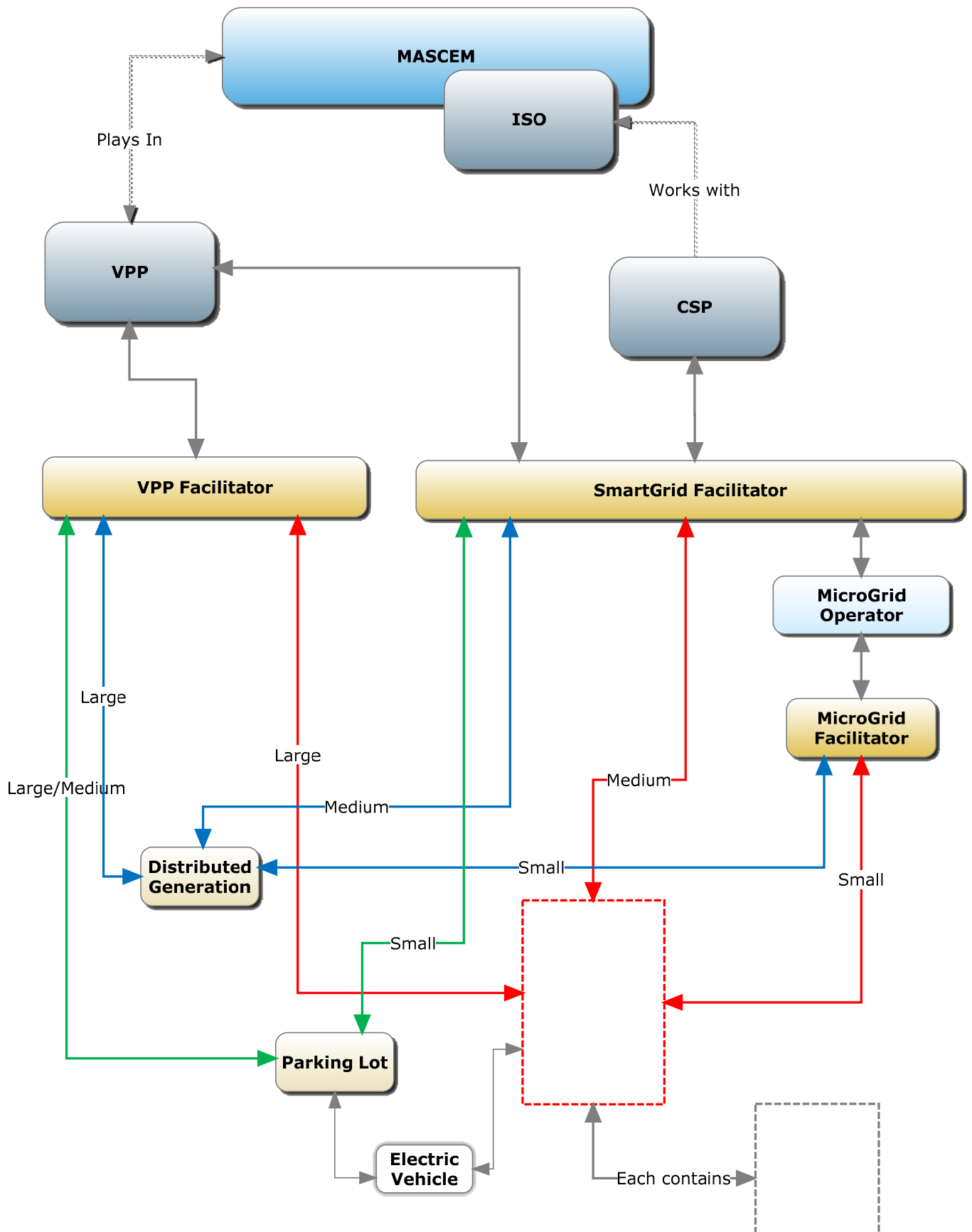


Figure 2 – MASGriP architecture.

The simulated smart grid considers the existence of different players, such as: Domestic Consumers (DM) only with demand response contracts (DM-DR); domestic consumers with demand response and micro-generation units (DM-DR/DG), and domestic consumers with demand response, micro-generation and/or electric and plug-in hybrid electric vehicles (DM-DR/DG/EV); Small Commerce (SC) considering demand response and/or micro-generation and/or EV (SC-DR/DG/EV); Medium Commerce (MC) considering demand response and/or mini-generation and/or EV parks (MC-DR/DG/EV); Large Commerce (LC) considering demand response and/or mini-generation and/or EV parks (LC-DR/DG/EV); Medium Industrial (MI) considering demand response and/or mini-generation and/or EV parks (MI-DR/DG/EV); and Large Industrial (LI) considering demand response and/or mini-generation and/or EV parks; Rural Consumers (RC) considering demand response and/or mini-generation and/or EVs (RC-DR/DG/EV); Distributed Generation (DG); EV Parks with the capability to charge EVs (EVP-C); and EV Parks with the capability to charge and discharge EVs (EVP-V2G).

These players are the base agents of MASGrIP's architecture, and establish contracts with two types of aggregators: the Virtual Power Players (VPP) or the Curtailment Service Provider (CSP). A CSP can be defined as a special player aggregating consumers' demand response participation, enabling small and medium consumers to participate in DR events. Small and medium consumers without the reduction capacity required by the DR program managing entity (usually an ISO) establish a contract with a CSP, which aggregates several small and medium consumers and participates in the DR program. CSP main tasks are to identify curtailable loads, to enroll customers, to manage curtailment events, and to calculate payments or penalties for its customers [23]. A VPP can be defined as a multi-recourse and multi-geographic heterogeneous entity with main goals of effectively managing the aggregated resources (DG, DR programs, Storage Systems (SS) and EVs) and participating in the energy negotiation process, mainly in DR contracts, in competitive electricity markets and in bilateral negotiation [24]. Figure 3 shows the types of aggregations reachable by VPPs and by CSPs.

Typically, CSP works directly with the ISO agent, which represents the system operator. The ISO can use DR programs in several contexts, some of them representing critical situations. Some players, such as large industries and large commerce (usually with contracted power higher than 1 MW) are able to participate directly in the DR event, therefore discarding the need of joining an aggregation entity. However, small consumers are not allowed by the ISO to participate directly in these events; hence they need to be aggregated to a CSP or to a VPP.

Besides the ISO agent, the integration between these two systems also considers the union between these systems' VPP agents.

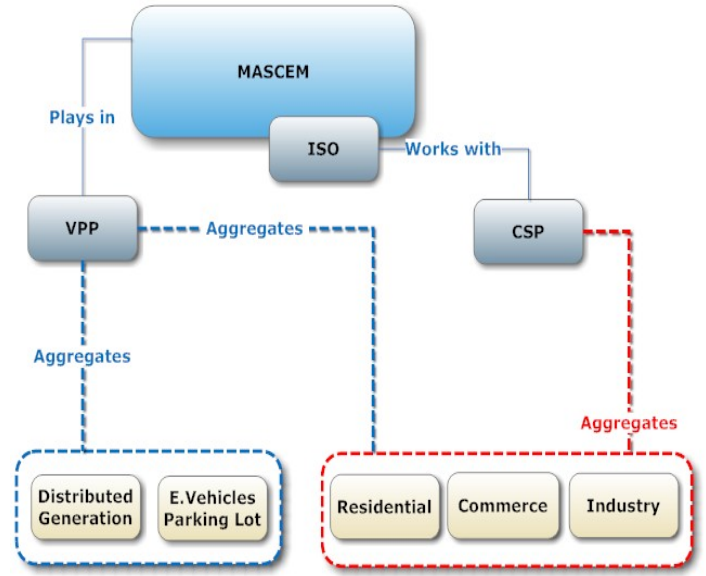


Figure 3 – CSP and VPP aggregation types.

VPPs in MASCEM act as aggregator entities, performing the required negotiations in the market on behalf of the aggregated players. In MASGrIP VPPs perform the internal management of the coalition, considering different types of resources, such as DG, DR programs, SUs, and EVs. The combination between these two previously independent agents created what can now be called in fact a VPP by definition. By detaining the capabilities to perform actual market negotiations, representing the aggregated players; negotiating and managing members' DR contracts; and at the same time performing all the required internal management, and profits adequate distribution among the members, depending on their contracts, the created VPP is now able to accomplish all the purposes a real VPP is intended to achieve [3]. Figure 4 presents the architecture of simulator resulting from MASGrIP's integration with MASCEM.

From Figure 4 it is visible that the CSP communicates with the ISO, receiving requests for DR programs triggering. The ISO is also able to send these requests directly to smart grid operators, enabling larger players to use DR programs without needing to resort to the CSP. The CSP, after receiving requests from the ISO, communicates with the smart grid and micro grid operators, through the use of these players' facilitators, letting them know about the DR requirements at each moment.

Microgrid operators are responsible for managing aggregations of smaller players, and smartgrid operators manage coalitions of medium players, including microgrids themselves. Both these types of aggregations' internal communications are treated independently from the rest of the simulation, by using individual facilitators. The market negotiations in the scope of smart and microgrids, are performed with resort to VPPs. VPPs negotiate in the market, and are responsible for managing a certain network area. They are also able to aggregate all types of players (small, medium

and large size) directly, when they are not connected to a smart or microgrid.

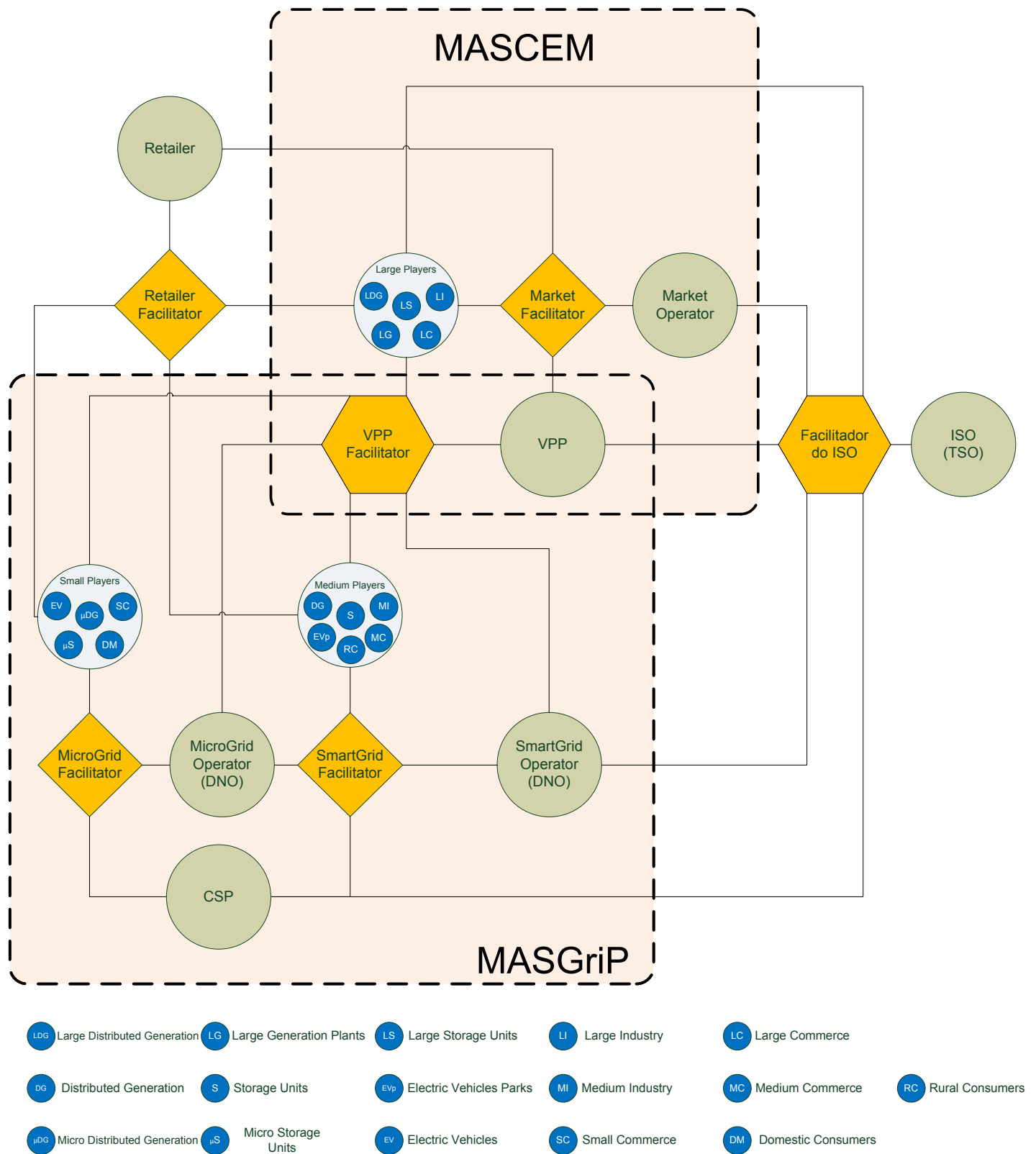


Figure 4 – MASGrIP's new architecture.

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Another alternative when negotiating in the market is resorting to retailers. These entities are able to aggregate other players as well, but with the unique purpose of taking care of energy negotiations, and monetary transactions. The communications between players represented by retailers are also treated independently, by using the retailer facilitator.

Retailers enter market negotiations with VPPs and with independent large players which do not desire to take part in any kind of aggregations. The market negotiations occur through MASCEM's implemented processes, supervised by the market operator. The communications in this type of negotiations are performed using the MASCEM's market facilitator.

The use of several distinct and independent facilitators, responsible for managing communications referring to different types of aggregations or operations, which, by nature, are also independent, assures that the simulations degradation of performance, in what concerns the required execution time, takes the correct measure.

The proposed integration between MASGrIP and MASCEM provides the means for simulating appropriately the resources management in the scope of smartgrids, including all the most important features it requires, such as the internal management of smartgrids and microgrids, the use of DR, the management by VPPs, and the actual market negotiations.

#### IV. INTELLIGENT MICROGRID MANAGEMENT

In real power system operation, each player has its own goals and uses different strategies to achieve its objectives. Simulating a player in MAS requires the implementation of "intelligent" algorithms in agents, considering the real actuation strategies. In microgrids agents represent consumers connected to low voltage (LV) distribution network, namely domestic consumers (DM) and small commerce consumers (SC). Most of these consumers require the management of electricity consumption and efficiency. In some cases the management of heat is also required to satisfy their necessities. In order to participate in DR events, each consumer needs a control system. These systems can vary in what concerns their functionalities, complexity and prices. Many systems are already installed, however in the majority of installations new control systems are necessary. These systems should be reimbursed by the VPPs and/or system

operators. The management system can be applied only to some equipment, such as boilers, freezers, air conditioning, etc.

Considering the user's needs (electricity and heat), many micro DG are combined heating production (CHP) with low capacity. Other common DG technology connected to the LV network is the photovoltaic panels. Many countries have incentives to install this type of generation technologies. The micro storage units in LV network are used directly to the VPP to guaranty the microgrid operation in islanded mode.

Due to the capacity of both consuming and generating energy according the necessities, the electric and plug-in hybrid electric vehicles (EV) with gridable capability are one of the most interesting resources for the microgrids management. Another important advantage of this resource is that it is near the consumption place. However, EVs are the electric resource with the higher complexity in the management process. The VPP does not operate EVs directly; rather EVs are connected to houses, commerce, industry or parks. These places have their own control and management systems.

In order to correctly manage their resources, microgrids need an energy resource management system. Figure 5 shows a proposed methodology considering the initial information a VPP detains. After the resources management process, microgrids send the information to the VPP including their necessities or available resources. Microgrids perform their final energy resources scheduling after the conclusion of the VPP scheduling process.

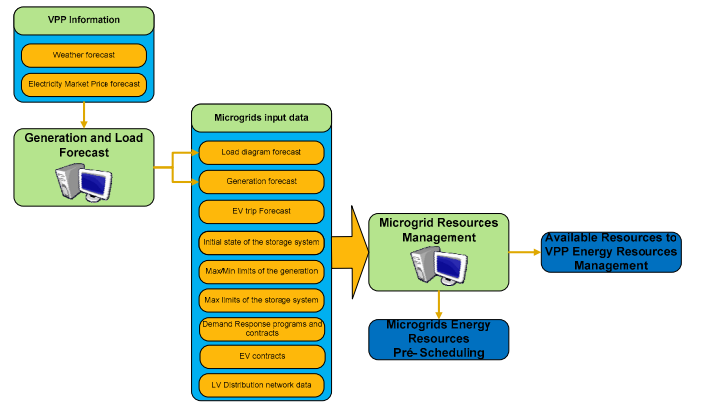


Figure 5 – Microgrids energy management resources

The microgrids concept can be applied to specific installations, such a buildings or industry. The management of these microgrids is easier than the management by VPPs and smart grids for larger areas, since all resources are installed in the same place.

#### V. CONCLUSIONS

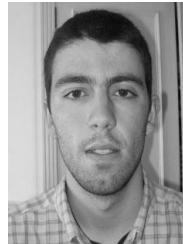
This paper proposes a Multi-Agent System to simulate future power system operations. MASGrIP – A Multi-Agent Smart Grid Simulation Platform is described and each agent is explained. MASGrIP includes several facilitators, one for each Virtual Power Player, one for each smart grid and one for each

microgrid. VPP agents are used both by MASGrIP and MASCEM. In MASCEM, a VPP tries to sell or buy energy according to its internal energy resources management. In MASGrIP, VPPs manage their aggregated resources according to the established contracts. The smart grids agents are responsible for the technical management of medium voltage distribution network, and microgrids agents are responsible for the low voltage distribution network management. The small and medium players (consumers and producers), can aggregate several resources (Demand Response, Distributed Generation, Storage Systems and Electrical Vehicles) according to their real profile. Each agent has their own goals and strategies and needs some controlling and management systems. The architecture of energy resources management process in microgrids was also presented. In the microgrids scope, the resources scheduling depends on the smart grids and on the VPP scheduling.

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## VII. BIOGRAPHIES



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