Reserve Costs Allocation Model for Energy and Reserve Market Simulation

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***Abstract*—This paper proposes a new model to allocate reserve costs among the involved players, considering the characteristics of the several entities, and the particular circumstances at each moment. The proposed model is integrated in the Multi-Agent Simulator of Competitive Electricity Markets (MASCEM), which enables complementing the multi-agent simulation of diverse electricity market models, by including the joint simulation of energy and reserve markets. In this context, the proposed model allows allocating the payment of reserve costs that result from the reserve market. A simulation based on real data from the Iberian electricity market – MIBEL, is presented. Simulation results show the advantages of the proposed model in sharing the reserve costs fairly and accordingly to the different circumstances. This work thus contributes the study of novel market models towards the evolution of power and energy systems by adapting current models to the new paradigm of high penetration of renewable energy generation.**

***Index Terms*—Electricity markets, MIBEL, Multi-Agent simulation, Reserve costs allocation.**

I. Introduction

With the massive introduction of renewable based generation in power systems, electricity markets are undergoing profound transformations [1]. These changes aim to cope with the particular characteristics of renewable generation (namely the variation due to their dependency on natural resources) and to promote the increase of an active participation from the consumers' side. Such changes, however, turn the electricity market sector into a highly demanding and complex environment [2]. In order to cope with this evolving, complex and dynamic reality, electricity market simulators are being increasingly used as a promising solution to enable the involved players gaining experience to act in the frame of a changing economic, financial, and regulatory environment. There are several experiences that sustain that a multiagent system with adequate simulation abilities is suitable to simulate electricity markets [3-6], considering the complex interactions between the involved players. Some reference examples of electricity market simulators are AMES (Agent-based Modeling of Electricity Systems) [3], EMCAS (Electricity Market Complex Adaptive System), [4] and MASCEM (Multi-Agent Simulator of Competitive Electricity Markets) [5, 6]. These are important contributions but, in general, lack flexibility as they adopt a limited number of market models and of players' methodologies. One of the most relevant limitations refers to the study and analysis of reserve markets, and their connection with energy markets, especially considering the current and future scenario of high penetration of renewable generation. In this scope, a relevant unsettled question is determining who should pay for the reserve costs.

In the literature, different works that propose models to allocate reserve costs have been presented. In [7], a method has been proposed to obtain optimal bidding of operating reserves in the sequential market clearing of the Spanish electricity market. The flexible Expected Energy Not Supplied (EENS) criteria and the load point reliability of customers have been presented to allocate the reserves, respectively in [8] and [9]. In [10], authors present the reserve cost allocation method through market agents based on the desired reliability level of electrical consumers. In [11], the reserve costs have been allocated between Distribution Companies (DisCos) based on their Value Of Lost Load (VOLL). A mechanism has been presented to determine the operating reserve and apportion the reserve costs between electrical customers and Generator Companies (GenCos) in [12]. In [13], a novel mechanism based on a decentralized approach has been introduced to allocate reserve costs between consumers, generating units and system operator in the simultaneous energy and reserve market clearing problem.

Moreover, different countries use different methods to allocate reserve costs. For example, in the UK electricity market, both GenCos and the electrical consumers are charged

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for reserve costs [14]. However, GenCos are in charge of paying the reserve costs in some electricity markets (e.g. Austria, Netherlands and Singapore) [15-17]. On the other hand, allocating the reserve costs between GenCos can affect negatively on the electrical consumers because GenCos increase their corresponding energy price to compensate their loss of reserve cost. Therefore, in Switzerland and most of the electricity markets in the world, the demand-side participants - consumers or DisCos - oversee paying the reserve costs [18].

In this paper, a new method is proposed to allocate reserve costs between electrical customers, to support reserve market integration with day-ahead spot, intra-day and balancing markets. The proposed model is integrated in the MASCEM electricity market simulator, and its impact on the reserve market is studied. For this, a simulation scenario comprising real data from the Iberian electricity market – MIBEL [19] is generated. The simulation considers the day-ahead spot market, the intra-day market, and finally a reserve market, from which results the reserve price based on the total amount on EENS. The proposed reserve costs allocation model is then applied to determine who should pay for the reserve costs.

After this introductory section, section II presents an overview of MASCEM and section III describes the electricity market models that are used in this study. Section IV presents the proposed reserve costs allocation model formulation, and a case study is presented in section V to validate and assess the achieved results. Finally, section VI discusses the most relevant conclusions from this work.

II. MASCEM SIMULATOR

The MASCEM simulator has recently been restructured [6], among many reasons, in order to guarantee the compliance with the FIPA (Foundation for Intelligent Physical Agents) standards [20], allowing the integration with external platforms. FIPA is devoted to develop and promote open specifications that support interoperability among agents and agent-based applications [20]. Multi-agent systems using FIPA's standards should be able to interoperate, however, it does not mean that the agents are able to share useful information due to the employment of different ontologies.

Coping with FIPA standards meant implementing MASCEM's agent society in JADE (Java Agent DEvelopment Framework) [21], a development framework that simplifies the implementation of multi-agent systems, and supports the majority and most important FIPA specifications. This way MASCEM is able to interact with other multi-agent systems using a common language. However, so that messages and all the concerned concepts can be understood by different systems it is also necessary that they share a common vocabulary and semantics. To this end, ontologies are used, enabling the standardization of communications and interpretation of concepts between independent systems.

MASCEM includes only five different types of agents, besides the ones provided by JADE to control the user interfaces, and to manage communications, much like the previous version facilitators. The five agent types are:

- Main Agent – enables the user's interaction with the system. It is responsible for starting the market entities from the input file or user's interface; for converting the input data into the respective RDF knowledge bases and for sending them to the respective players and operators; for distributing the various agents by the machines available for the simulation, considering the machines' features and the agents' processing needs; and for properly killing the agents when the user decides to terminate the application;
- MIB Agent – it is responsible for reading the management information base of each machine, creating a report and sending it to the Main Agent so that it can decide which agents will move to each machine;
- Market Operator – regulates pool negotiations by validating and analysing the players' bids depending on the type of negotiation, and determines the market price, the accepted and refused bids, and the economical dispatch that will be sent to the system operator;
- System Operator (ISO) – examines the technical feasibility from the power system point of view and solves congestion problems that may arise. It is responsible for the system's security as well as to assure that all conditions are met within the system;
- Player – represents buyer, seller or aggregator agents. On one hand, it may be a consumer or distribution company which participates in the EM in order to buy certain amounts of power. On the other hand, it may simulate electricity producers or other entities able to sell energy in the market, or even aggregations of several entities.

These core agents allow a simple, yet effective electricity market simulation. More complex and advanced simulation studies are achieved through the collaboration between the different multi-agent systems, as presented in Figure 1.

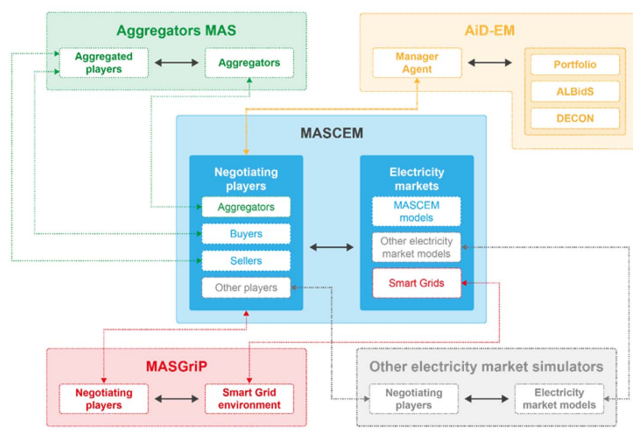

Figure 1. Collaboration between MASCEM and other multi-agent systems, from [6]

Regarding the market models, MASCEM allows the simulation of several market types: day-ahead pool (asymmetric or symmetric, with or without complex conditions), bilateral contracts, balancing market, forward markets and ancillary services. Hybrid simulations are also possible as a combination of the different market models. Other market types can be provided by different systems.

Simulation scenarios in MASCEM are automatically defined, using the Realistic Scenario Generator (RealScen) [22]. RealScen uses real data that is available online, usually in market operators' websites. The gathered data concerns market proposals, including quantities and prices; accepted proposals and established market prices; proposals details; execution of physical bilateral contracts; statement outages, accumulated by unit type and technology; among others. By combining real extracted data with the data resulting from simulations, RealScen offers the possibility of generating scenarios for different types of electricity markets. Taking advantage on MASCEM's ability to simulate a broad range of different market mechanisms, this framework enables users to consider scenarios that are the representation of real markets of a specific region; or even consider different configurations, to test the operation of the same players under changed, thoroughly defined scenarios [22]. When smaller scenarios, representative of the market reality are desired (to decrease simulations' execution time or facilitate the interpretation of results), data mining techniques are applied to define the players that act in each market. Real players are grouped according to their characteristics' similarity, resulting in a diversity of agent types that represent real market participants.

MASCEM is also integrated with AiD-EM (Adaptive Decision Support for Electricity Markets Negotiations), a decision support system that supports players decisions in their market negotiations. The AiD-EM system has been developed with the purpose of providing decision support to electricity market negotiating players. This system is composed by several distinct and independent decision support systems, each directed to the resolution of different specific problems. ALBidS (Adaptive Learning Strategic Bidding System) [23-25] focuses on the support of market players' decisions when participating in auction-based markets. The participation in bilateral contract negotiation is supported by yet another multi-agent-based decision support system – DECON (Decision Support for Energy Contracts Negotiations) [26]. The multiagent approach of AiD-EM facilitates the interactions between the different components and also the communication with external agents, such as market players that make use of the decision support.

III. Regulatory Electricity Market Models

As a result of the constant evolution of the electricity market environment, and the inclusion and change in the operation and players' participation in the market, it became imperative for professionals in the area to entirely understand the markets' principles and how to evaluate their investment under such a competitive environment. The shared interest of regulators and market players in foreseeing market behaviour required a clear understanding of market principles, and the impact of power systems physics on market dynamics and vice-versa [2, 27]. Additionally, a suitable understanding of the diversity of market types and regulatory models that have been introduced is critical for the success of involved players.

The typical electricity market environment in Europe usually consists of a day-ahead pool (symmetric or asymmetric) where energy for the following day is negotiated. Typically, a floor for bilateral contracts is also considered [28]. Moreover, intraday markets are required to provide the means to renegotiate the previously traded power in order to meet the required adjustments towards the feasibility of the daily program and of the last scheduling [29]. Given the different market opportunities, each market player must decide whether to, and how to, participate in each market type.

In addition to players (the buyers and sellers who negotiate in the market), these markets also include the market and system operators. The market operator is the entity responsible for operating the market. It manages the pool by using a market-clearing tool which establishes the market price for each trading period and the accepted and refused selling and buying bids. On the other hand, the system operator is the entity responsible for the management of the transmission grid and its technical constraints. After the establishment of a contract, the agreement is communicated to the system operator, which analyses its technical feasibility in the power system perspective; regardless of it being established through bilateral contracts or through the pool.

A. Symmetric pool

In the symmetric pool the market price definition is based on a double auction mechanism, being therefore characterized by a competition between buyer and seller agents. This means that, in this type of pool, both buyers and sellers submit bids.

The market operator orders the supply and demand offers: the supply bids are sorted from the lowest price to the highest; and the demand bids are arranged from the highest price to the lowest. Hereinafter, the submitted bids compose the supply and demand step curves, and the market price is determined at the point in which both curves intersect. The market price is the value per MWh that each accepted consumer must pay to the respective supplier. The supply bids offering prices lower than the established market price will be accepted, as well as the demand bids offering prices higher than the market price. Depending on the demand, the last seller to trade, i.e. the one who establishes the market price, may not be able to negotiate all of its available supply, trading only partially. This process is repeated for each trading period of the day. Figure 2 illustrates the dispatch procedure of the symmetric pool.

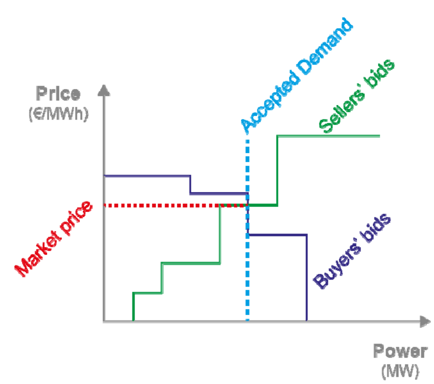

Figure 2. Symmetric pool, adapted from [6]

The efficiency of this market pool depends on the number of participating players, as well as on their bids provision. Players submitting their bids in this type of market reveal the existence of behaviours with price sensitive consumptions.

B. *Asymmetric pool*

The asymmetric pool is exclusive to the submission of supply bids. In this type of pool, buyers do not submit their bids, only indicate an estimate of consumption. In this model the demand is considered inelastic, since it is assumed that buyers participating in it are willing to pay any price resulting from the market operation. In this market type, seller agents submit their bids and the market operator orders them from the lowest price to the highest. As for buyers, they only express their demand needs. Afterwards, the market operator accepts only the supply necessary to fulfil the demand. The price to be paid to all the accepted suppliers is determined by the last accepted bid, i.e. the market price. Figure 3 shows the dispatch procedure of the asymmetric pool, for each negotiation period. Market prices in this pool are highly influenced by the prices of sale bids and by the amount of demand.

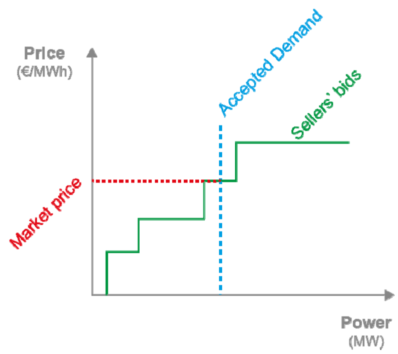

Figure 3. Asymmetric pool, adapted from [6]

IV. PROPOSED RESERVE COSTS ALLOCATION MODEL

Electrical customers play an essential role on needed reserve in the power system. Providing electrical demand of consumers and reliability of the power systems are two main reasons why reserve is needed. Hence, Demand Factors (DFs) of electrical consumers that are defined for the first time in [12] are considered in this paper, in order to express the corresponding reliability level of customers. Effects of electrical demand and Expected Energy Not Supplied (EENS), as a reliability criteria, are considered in DF as in (1):

$$DF_{jt} = \frac{EENS_{jt}}{L_{jt}} \quad (1)$$

where L_{jt} represents the total load of consumer j in time t. Customers are classified into different groups based on their DFs as seen in (2). A total number of M groups is considered. In this case, DF_{jt}^{1} has the highest corresponding DF and lowest corresponding reliability level. Hence, ΔDF_{jt} is defined as in (3), as a difference between DF_{jt}^{1} and DF_{jt}.

$$DF_{jt}^{M} \leq \cdots \leq DF_{jt}^{2} \leq DF_{jt}^{1} \quad (2)$$

$$\Delta DF_{jt} = DF_{jt}^{1} - DF_{jt} \quad (3)$$

As highlighted, when more reserve is needed to maintain system's reliability level, the reserve costs will be increased. This increment of reserve costs should be paid by customers who have their corresponding reliability level ΔDF higher than others. Therefore, the portion of electrical customers to pay the cost of reserve (*RC*) is achieved by (4).

$$RC_{jt} = \frac{\Delta DF_{jt}}{\sum_{j=1}^{N_c} \Delta DF_{jt}} \times RC_t \quad (4)$$

As a result from this model, each customer who has higher ΔDF is allocated to pay more reserve costs. Moreover, electrical consumers who have highest DF are not in charge of paying reserve costs based on this proposed method.

V. CASE STUDY

This case study aims at assessing the envisaged energy and reserve market simulation, using the proposed reserve cost allocation model, through its integration in the MASCEM simulator. The case study considers the simulation of the day-ahead electricity market of MIBEL, which is complemented by the intra-day market. In the following step, the reserve market is executed, considering an asymmetric auction, in which generators bid their available capacity for reserve and corresponding price. Considering the total expected energy non-supplied, the reserve cost is achieved from this market. The payment of this cost is then determined by the proposed reserve cost allocation model.

In order to set up this market environment, a simulation scenario was generated using RealScen. The considered scenario concerns 48 market negotiating agents. The main decision factor for the simulated agents' representation is the real players' competitiveness, *i.e.* their bid prices' approximation to the established electricity market price. The objective is to represent the electricity market environment, which includes hundreds of players negotiating in each negotiating period, in a reduced simulated scenario that reflects the reality in the fullest possible extent. In order to enable the simulator to represent the reality in a summarized way, the automatic data extraction tool has been used to gather data from the Iberian electricity market – MIBEL [19]. The simulated scenarios refer to the 24 hourly periods of the day-ahead spot market, in one negotiating day – June, 1st 2012. The simulated agents consider the log of real players' bids to the market during this day, in order to create their own action portfolio in the market. Figure 4 shows the electricity market price and total amount of transacted and non-transacted energy in the day-ahead spot market simulation, during the 24 hourly periods of the considered simulation day.

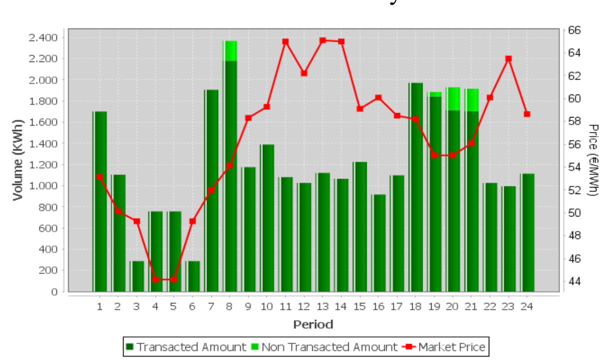

Figure 4. Day-ahead market results

From Figure 4 it is visible that the day-ahead market prices in the considered day range from 44 €/MWh to 66 €/MWh. It is also visible that most of the available energy has been transacted, with the exception of 4 periods. One of these is period 20, for which Figure 5 shows some details, namely referring to the demand and supply bid curves, which are composed by the price and volume offers made by the participating agents.

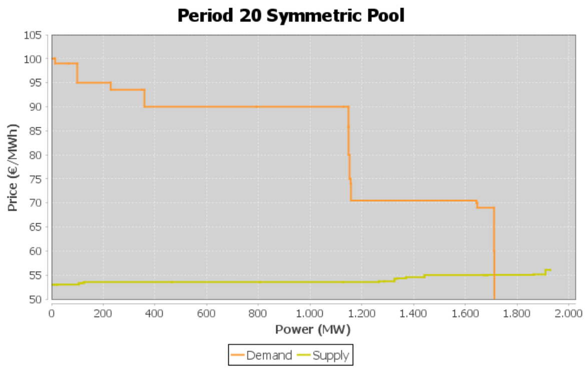

Figure 5. Day-ahead spot market bid curves for period 20

From Figure 5 one can see that the point where the demand and supply curves intersect in this period corresponds to the price of 55,03 €/MWh – the established market price for this period. It is also visible that some supply is not dispatched, namely the amount that is associated to prices higher than the market price.

Departing from the day-ahead spot market results and considering the variations in expected consumption and generation from the previous day towards the delivery time, the intra-day market is executed. This market, according to the MIBEL rules [19], considers 6 market sessions, which cover all the periods of the delivery day, and which are executed in different time horizons. Based on the results of the intra-day market and on the individual strategies and goals, generators submit their bids to the reserve market, which are composed by the volume of energy that is available for reserve, and the associated price. In this case, the market runs as an asymmetric auction, considering only the bids from generators. The reserve market price is established depending on the amount of reserve that is required. Figure 6 shows the supply bid curve for the asymmetric reserve market auction, still referring to hourly period 20.

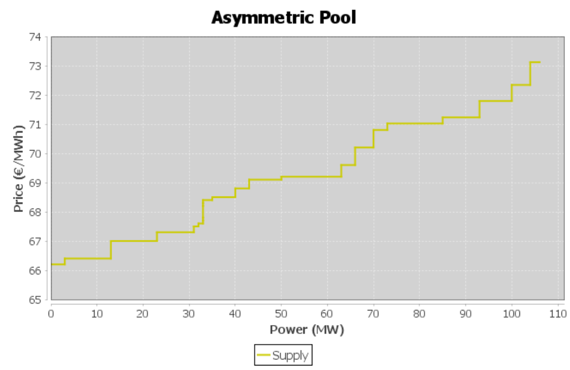

Figure 6. Reserve market supply bid curve for period 20

TABLE I. RESERVE COSTS ALLOCATION RESULTS

Consumer	LOAD (MWh)	ENS (MWh)	DF	ΔDF	Group	RC (€)
Buyer 1	1,3	1,3	1	0	1	0
Buyer 2	64,7	4,3	0,066461	0,933539	8	256,6547446
Buyer 3	3,2	3,2	1	0	1	0
Buyer 4	485	12,3	0,025361	0,974639	14	267,9541594
Buyer 5	1,2	0	0	1	15	274,9265227
Buyer 6	3,1	0,4	0,129032	0,870968	3	239,4521327
Buyer 7	1,4	0	0	1	15	274,9265227
Buyer 8	0,1	0	0	1	15	274,9265227
Buyer 9	3,7	0,6	0,162162	0,837838	2	230,3438434
Buyer 10	0,4	0	0	1	15	274,9265227
Buyer 11	0,1	0	0	1	15	274,9265227
Buyer 12	433,7	21,3	0,049112	0,950888	10	261,4242517
Buyer 13	336,8	16,7	0,049584	0,950416	9	261,2944772
Buyer 14	18,6	2,3	0,123656	0,876344	4	240,9302323
Buyer 15	119,7	4,6	0,038429	0,961571	12	264,3612595
Buyer 16	10,4	1,2	0,115385	0,884615	5	243,2042316
Buyer 17	129,3	8,7	0,067285	0,932715	7	256,4279864
Buyer 18	0,4	0	0	1	15	274,9265227
Buyer 19	51,9	1,6	0,030829	0,969171	13	266,4509459
Buyer 20	33,3	1,4	0,042042	0,957958	11	263,3680503
Buyer 21	9,6	1,1	0,114583	0,885417	6	243,4245253
Buyer 22	3,1	0	0	1	15	274,9265227
Buyer 23	0,9	0	0	1	15	274,9265227
Buyer 24	0,5	0	0	1	15	274,9265227

Figure 6 shows the bids that have been submitted to the reserve market by the several generators. The total energy no-supplied in this scenario has been of 81MWh. From Figure 6 it is possible to verify that this volume represents a reserve market price of 71,23 €/MWh, which leads to a total reserve cost of 5769,63 € in this period. The proposed reserve costs allocation model is applied to determine who should pay for this reserve cost. Table I shows the results from the reserve costs allocation model, considering *M*=15.

As seen in Table I, reserve cost is allocated between consumers based on the proposed method. In this way, consumers 1 and 3 have their *DF* equal to one, and are therefore not responsible for paying reserve costs. Also, their DF_{jt}^{1} is equal to zero. Table I shows that customers should pay more reserve costs when they have higher ΔDF_{jt}. Hence, in this case study, the allocated reserve costs related to consumers 5, 7, 8, 10, 11, 18, 22, 23 and 24 is highest because their corresponding ΔDF_{jt} has the highest amount in the system.

VI. CONCLUSIONS

This paper addresses the simulation of energy and reserve markets, using a proposed model for reserve costs allocation as means to distribute the reserve costs that result from the market negotiations. Results from a case study based on real data from MIBEL, simulated using MASCEM, show that the proposed reserve costs allocation model enables distributing the reserve costs among the most appropriate consumers, in order to guarantee the payment for the reserve that is negotiated in the reserve market. The presented simulations also enable considering the proposed approach as a promising solution for the evolution of electricity markets.

Future work will consider alternative models for reserve costs allocation, as well as the assessment of other possible solutions for reserve market mechanisms, in order to smooth the connection with the current day-ahead, intra-day and balancing market models.

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