Design Functionalities for A Wholesale Electricity Market Simulator

Simona Vasilica Oprea
Ramona Ana Bologa
Anca Ioana Andreescu
The Bucharest University of Economic Studies, Romania
simona.oprea@csie.ase.ro
ramona.bologa@ie.ase.ro
anca.andreescu@ase.ro

Abstract

One of the most important and well-known characteristics of the electricity is the necessity to balance almost perfectly the load with generation for each moment of the power system operation. This characteristic, coming from the very beginnings of the power systems design and building, has shaped the operational rules of the power systems and more recently has also shaped the electricity markets structure. The basic parameter used for designing various electricity markets is time. Also, the recent developments of renewable energy lead to a higher complexity of the power systems operation and as a direct consequence a higher complexity of the electricity market structure. Hence, nowadays, it is very difficult for a generation owner to optimize the operation of his asset from all points of view: technical, financial, etc. The main objective of this paper is to develop an electricity market simulator that includes the basics of a good practice guide starting from the use cases for generators or producers that compete on different electricity markets in order to maximize their financial results and efficiency. Thus, this paper mainly proposes to uncover the functionalities a simulator should have to assist market players to access different electricity markets.

Key words: whole electricity market, simulator, functional model, functionalities, use case diagram
J.E.L. classification: Q41, C63, P47

1. Introduction on the wholesale electricity market structure and characteristics

The main goal of the electricity markets (i.e. for long-term contracts – Bilateral Wholesale Markets (BWM), mid-term contracts – Day Ahead Market (DAM) and Intra-Day Market (IDM), and short-term transactions– Balancing Market (BM)) is to provide a balance as accurate as possible between load and generation, for each time interval, while keeping a high quality of supply and a high level of financial efficiency. In parallel with the above-mentioned electricity markets there is a different market for the ancillary services (ASM). For a better understanding of the interactions between different markets we are providing a typical (for European countries) daily load curve as shown in Figure 1.

Figure no. 1. The typical daily load curve and the applicability areas for the electricity markets
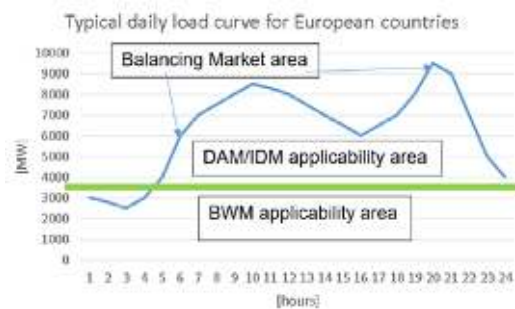
Source: www.transelectrica.ro

It should be mentioned that ASM has a different goal that is not directly related to the load curve and therefore it is not included in the Figure 1.

BWM deals in principles with the area of the load curve below the green line in Fig. 1. The transactions finalized using this electricity market are characterized by medium to long durations: from few months up to few years and by fixed hourly values during whole day. Nowadays, in Romania, on this type of market there is no possibility to have hourly values of electricity tailored for a consumer or group of consumer's needs (RERA, 2014b). Taking into consideration the above-mentioned aspects the electricity prices on this market are the lowest and therefore the transactions performed using this platform are intended to cover the base of the load curve. In order to perform transactions on this type of electricity market, in Romania, a special software platform managed by the Romanian Markey Operator is used. The software platform provides a safe and transparent market environment for all market participants.

DAM is a component of the wholesale electricity market on which the scheduled transactions of electricity with delivery on the day following the day of trading are carried out (RERA, 2014a). On the load curve presented in Figure 1, the transactions performed on this market are covering the area between the green line and the load curve itself. DAM provides the market participants with a functional tool to set the balance between the portfolio of bilateral contracts, the consumption forecast and the technical availability of the production units for the delivery day. Thus, the electricity surplus or shortage can be balanced by selling or buying it on the DAM. Participation in this market is voluntary. DAM is concluded on each day of trading, consisting in firm electricity transactions for each trading day of the next delivery day, based on the bids submitted by the DAM participants. Tenders may be placed in the trading system in accordance with the trading hours set as CET hours and only if the RON price scale is available and the exchange rate for the respective trading day has been published by the National Bank of Romania. In the normal conditions of coupled operation, DAM transactions are carried out by correlating the bids through the Auction Coupling Mechanism established according to the Price Coupling of Regions (PCR), following the bidding, validation and aggregation of bids, running of the coupling mechanism, allocation of the coupling results on the participants' portfolios.

IDM is a component of the wholesale electricity market on which hourly transactions of active energy are made for each day of delivery from the day before the day of delivery, after the transactions on the DAM are concluded and up to a certain amount of time before the start of delivery/consumption. The rules of the IDM are laid down in (RERA, 2013) and they very similar with the rules of DAM. IDM creates a centralized framework for the sale and purchase of electricity by participants in the wholesale electricity market in Romania, required by: facilitating the competition, transparency and non-discrimination formation on the wholesale electricity market and creating fairly and transparent electricity trading prices. IDM provides the participants with an additional functional tool to set up the day-to-day schedule for adjusting its own portfolio of contracts to strike a balance between the bilateral contracts' portfolio, the consumption forecast and the technical availability of production units as close as possible to delivery time. The surplus or contracted electricity shortage can be balanced by selling or buying it on IDM. Participation in this market is also voluntary.

On the *BM*, the Romanian Transmission and System Operator (Transelectrica S.A.) buys and sells active energy from or to the generators, in order to compensate the deviations from the electricity production and consumption schedules (Transelectrica S.A., 2018), (ENTSO-E, 2017a). The dispatchable units are obliged to offer on this market for power increase the entire quantity of available energy in addition to the notified electricity quantity and all the notified electricity quantity for power decrease.

As for the *ASM*, ensuring enough ancillary services necessary to the Transmission System Operator and Distribution Operators is usually done through non-discriminatory market mechanisms, fixed-term auctions and bilateral contracts (RERA, 2007), (RERA, 2011), (ENTSO-E, 2017b). Providing the Frequency Containment Reserve (also known as primary reserve) and maintaining the availability of the power necessary for performing this action are mandatory for all electricity generators in accordance with the provisions of the Technical Code of the Electric Transport Network. Generators who have contracted Ancillary Services (Frequency Restoration Reserve – secondary regulation reserve and Replacement Reserve – tertiary regulation reserve) are obliged to offer on the BM at least the quantities of electricity corresponding to the volumes of contracted ancillary services.

This paper is structured in 5 sections. In the second section, a couple of related works are discussed emphasizing on informatics system analysis process, UML and similar simulators. Section 3 is dedicated to the functional model in the process of informatics system analysis, whereas section 4 underlines the findings of our research in terms of use cases for the wholesale electricity market. In the fifth section, conclusion is draw and future works are depicted.

2. Literature review

In this article, the use cases technique was chosen to model the first stages of the proposed simulator development cycle: identification of requirements and system analysis. This technique is commonly used in software design and is often associated with the well-known Unified Modelling Language (UML, 2019) (Dennis et al, 2015), a standard commonly used for object-oriented modelling.

But use cases have been proposed and used successfully since 1986, when Ivar Jacobson proposed use cases to meet functional requirements (Jacobson, 1986). Being written in natural language, the use cases offer a good documentation of the project and easy communication with the clients. They help in a good structuring of complex systems, the perspective being that of the users. This technique is highly recommended for: specifying the boundary system and the users, capturing the system requirements; validation of the system architecture; implementation management; development of first user interface templates (Dennis et al, 2015; Kulak & Guiney, 2012).

Simulation tools can be very useful for electricity markets because these are very complex environments, with a large number of involved parties. A simulator for electricity market is proposed in (Pinto et al., 2014) alongside with a methodology that combines different strategies to build actions proposals. The solution applies learning algorithms and uses different mechanisms such as for managing the efficiency/effectiveness balance of the system and for competitor players' profiles definition.

An agent-based simulation model is illustrated in (Bublitz, et al., 2014). The paper emphasis that, as a modelling approach, agent-based simulation is especially suitable for modelling wholesale electricity markets with market participants making individual decisions on interrelated markets. This model can simulate wholesale electricity markets with respect to time and point of delivery of electrical energy. Another agent-based approach for electricity market simulation is proposed by (Sueyoshi et al., 2008). This research intended to numerically examine the influence of a transmission line limit on the dynamics of a wholesale electricity market, with application on DAM and IDM.

Research shown in (Simoglou et al., 2014) are focused on an analysis of the Greek electricity market based on an hour-by-hour simulation in order to determine the impact of integrating renewable energy sources on the electricity market operation. Moreover, a proposed software tool is used for simulating current and future day-ahead market clearing algorithm of the Greek wholesale electricity market.

Decision making process in an electricity market environment is also considered by (Teixeira et al., 2015). Their approach is based on artificial intelligence and data mining algorithms and provides a simulation tool that processes data from real electricity markets in order to create realistic scenarios that take into account the modelling of electricity market players' characteristics and behaviour. The main scope was to clarify the understanding of the interactions between involved parties.

3. Functional model in the process of informatics system analysis

As described in (Dennis et al, 2015), during the process of informatics systems analysis, functional models are used to represent business processes and the interaction of an information system with its environment. Object oriented approaches propose two types of models in order to describe the functionality of an information system: use cases and activity diagrams. Use cases are a high level representation of the main functions that an information system will provide.

Use case diagram has the role of representing, in a graphical form, the functionalities that the information system should fulfil in its final phase. Use case diagrams are made up of actors and use cases, on the one hand, and the relationships between them, on the other. Actors are human users or information systems that interact with the system under development. It is important to remember that one external entity can play multiple roles and one role can characterize more external entities.

Use cases represent sequences of transactions that take place in the dialogue with the information system. Therefore, a use case models a dialogue between an actor and the information system. The set of identified use cases represents all the ways in which the system can be used. Use cases are purpose oriented: they represent what the system should do and not how. Hence, they are technologically neutral and can be used in any process or application architecture.
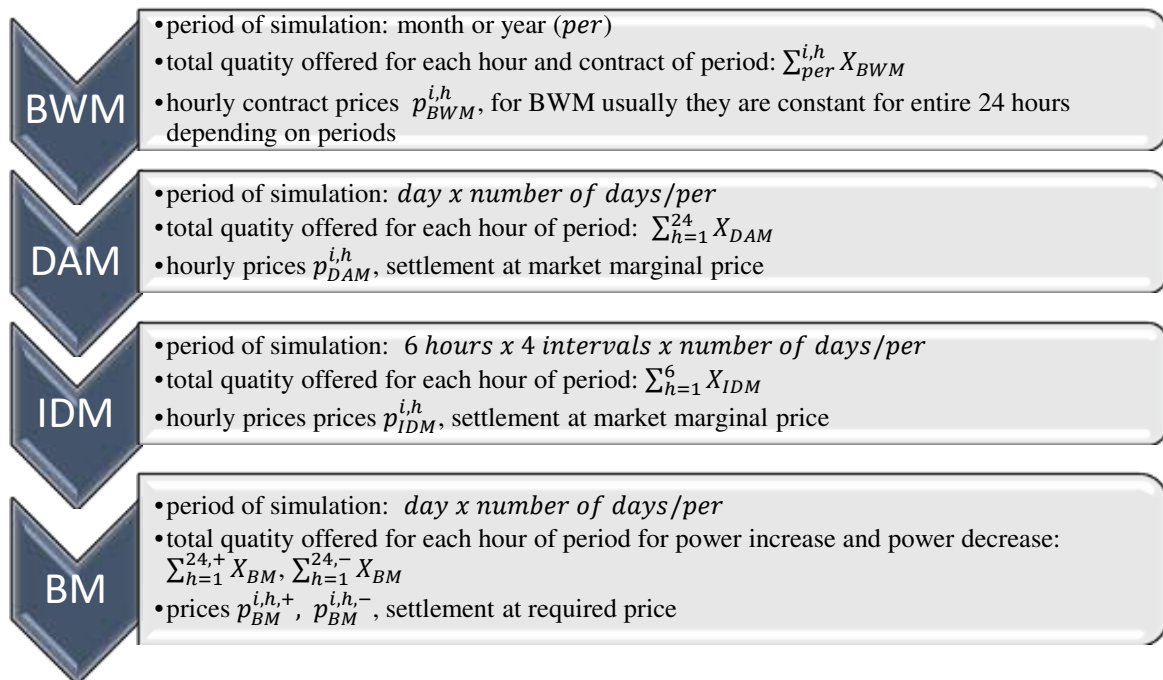
There can be no simple relationships between two use cases that refer to the same information system. Each describes a complete use of the system. The UML standard states that between the use cases there can be three qualified types of relationships, which will be presented in the following paragraph. Generalization is used when there are two or more use cases that have common behaviour, structure and purpose. The behaviour of the parent use case can be overwritten. Only the differences between the two are specified in the specialized use case. The "include" relationship aims to integrate a use case into another use case, the first thus becoming a logical part of that use case. Inclusion is used when there are common behavioural parts in several use cases or to simplify large use cases. This relationship is equivalent to calling a subroutine in programming and denotes mandatory behaviour, not optional. The extend relationship describes a behaviour that occurs only under certain different conditions that can be specified based on the selection of an actor.

All the processes to be executed by the information system should be found in a use case. The processes are then described textually or in a sequence of steps.

4. Findings: Use-case diagrams for wholesale electricity market simulator

The interaction of the electricity markets in terms of generators' strategies is obvious since the components of the whole electricity market tend to the same target. Hence, the main purpose of a producer is to allocate the generated electricity to different types of markets and periods of time so that to maximize the efficiency of trading on such markets and to estimate the income for existing generators or new ones.

Figure no. 2 Main stages of the simulation for an optimized electricity market participation

BWM
- period of simulation: month or year (per)
- total quatity offered for each hour and contract of period: $\sum_{per}^{i,h} X_{BWM}$
- hourly contract prices $p_{BWM}^{i,h}$, for BWM usually they are constant for entire 24 hours depending on periods

DAM
- period of simulation: $day \; x \; number \; of \; days/per$
- total quatity offered for each hour of period: $\sum_{h=1}^{24} X_{DAM}$
- hourly prices $p_{DAM}^{i,h}$, settlement at market marginal price

IDM
- period of simulation: $6 \; hours \; x \; 4 \; intervals \; x \; number \; of \; days/per$
- total quatity offered for each hour of period: $\sum_{h=1}^{6} X_{IDM}$
- hourly prices prices $p_{IDM}^{i,h}$, settlement at market marginal price

BM
- period of simulation: $day \; x \; number \; of \; days/per$
- total quatity offered for each hour of period for power increase and power decrease: $\sum_{h=1}^{24,+} X_{BM}, \sum_{h=1}^{24,-} X_{BM}$
- prices $p_{BM}^{i,h,+}$, $p_{BM}^{i,h,-}$, settlement at required price

Source: Authors' contribution

A software tool for simulating the participation of a producer / supplier / trader / consumer of electricity in different types of markets aims to identify how decisions regarding the price or quantities offered can influence profit optimization. We have used UML use case diagrams in order to describe the simulator's functionalities. Figure 3 depicts the main functions that can be performed by the four types of users. It also presents the interaction of Data Administrator with the simulator, which has the role of collecting, cleaning and bringing the historical data to the desired granularity level.

Figure no. 3. Main use case diagram for the Electricity market behaviour simulation system
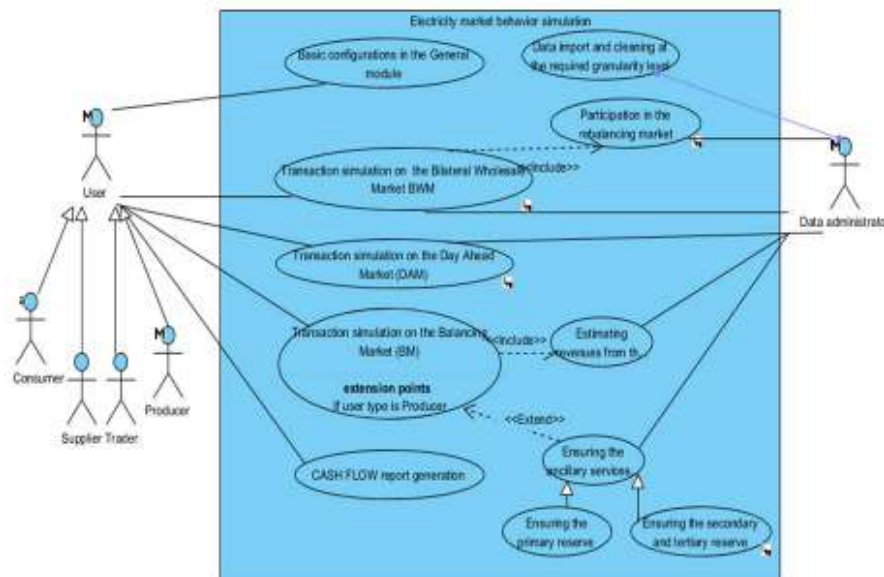
Source: Authors' computation

First of all, some basic configurations are needed to be made before simulating the market trading, such as: a) choose, from a predefined list, what type of business is simulated: producer, supplier, consumer or trader. Further, a producer can be controllable (thermo, hydro, nuclear) and has to indicate the volume of electricity available for trading or uncontrollable (photovoltaic, wind) and his forecast will be based on average historical data in Romania; b) indicate the total available power, this being the installed power for a producer or the power required for trading or buying for a supplier or trader; c) specify a technological minimum below which the production cannot be lowered; d) indicate the duration for which the simulation is performed (1/3/6/12 months). These setting will be implemented using the interface presented in Figure 4.

Figure no. 4. General settings for the Producer

Source: Authors' computation

Next, we describe the simulator's functionalities regarding the transactions on the following markets: BWM, DAM and BM.

On the BWM market different kind of specific products can be sold or purchased. A graphical representation of the use case Transaction simulation on the Bilateral Wholesale Market can be found in Figure 5.

Figure no. 5. Use case diagram for Transaction simulation on the Bilateral Wholesale Market
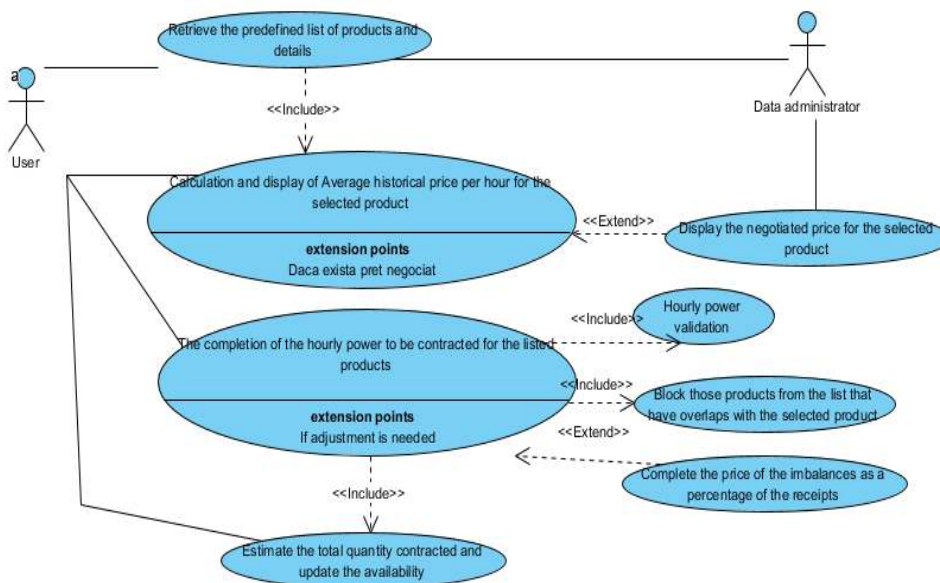
Source: Authors' computation

In order to simulate the participation on BWM, there are several steps to be performed, the first being the selection from a predefined list of products offered by the Romanian Gas and Electricity Market Operator (OPCOM). For the selected product, a desired hourly power is specified. For selling, this will be validated in order not to exceed the availability declared in the general settings. It must be noticed that the available products that have overlaps with the selected product will be blocked. If there is a negotiated average price for the selected product, this will be taken into account. Otherwise, the historical average price provided by OPCOM will be displayed, with the possibility of being modified by the user. Also, a cost of imbalances is provided, as a percentage of incomes, with a default value of 10%. Figure 6 depicts the interface responsible for implementing BWM transaction simulator for sales.

Figure no. 6. Interface layout for Sales simulation on the Bilateral Wholesale Market for the Producer
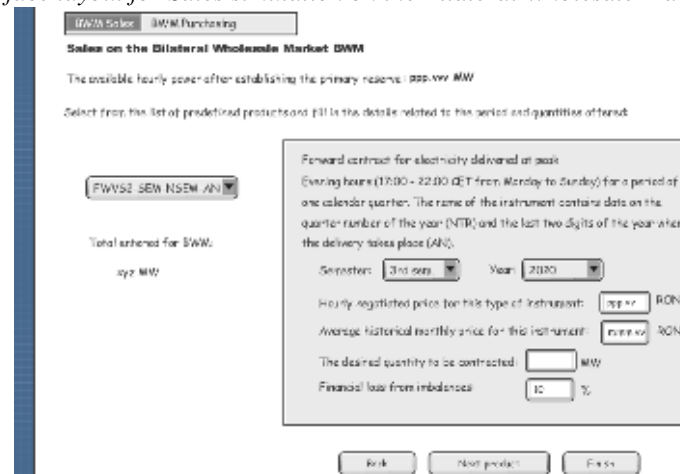
Source: Authors' computation

The participation on DAM market is voluntary, the price being higher than the one on BWM. Hourly prices are different per day, per hour and per season. For simulation, a monthly hourly average will be used to estimate the price, based on historical data available on the Transelectrica website. The general steps required to perform the use case Transaction simulation on Day Ahead Market can be seen in Figure 7.

Figure no. 7. Interface layout for Sales simulation on the Bilateral Wholesale Market for the Producer
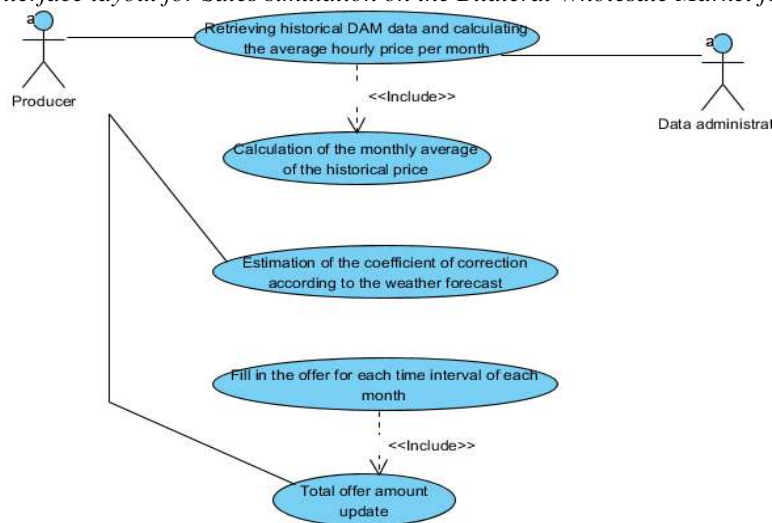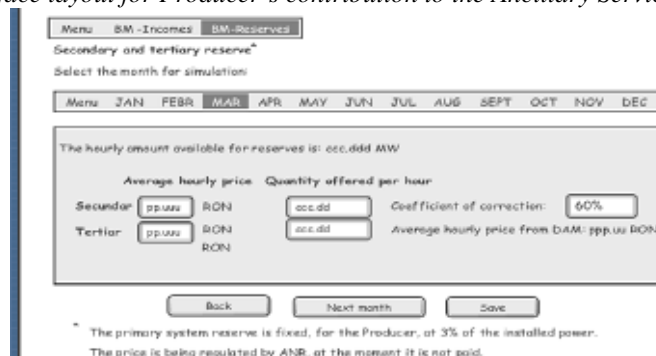

Source: Authors' computation

The user can choose one of the options for sale or purchase on the DAM and the desired month for simulation. The number of months for which the simulation is performed must be less than the period specified in the general settings and correspond to the periods of a possible simulation performed on the BWM.

The available hourly power is displayed, by correlating the general settings with any sales on the BWM and with the primary system reserve (for Producers). The user can sell more than the installed power if he previously bought from the BWM. Also, a historical monthly average price for the chosen month is displayed. Several information is provided to the user, such as a correction coefficient for the chosen month, which defaults to 25% and hourly historical prices, averages per month for the user-chosen period. The default values can be modified. The user had to specify the hourly power that is to be traded. For sales, it should be checked that the maximum available power is not exceeded.

The participation on the Ancillary Services Market is mandatory for energy producers. Depending on the type of producer, offers can be simulated for taking part to the balancing market for primary, secondary or tertiary regulation reserve. From the very beginning, the primary system reserve is fixed for the producer, at 3% of the installed power. The price is being regulated by Romanian Energy Regulatory Authority (ANRE) and at the moment it is not paid. Figure 8 depicts the interface responsible for implementing the Producer's contribution to the Ancillary Services Market.

Figure no. 8. Interface layout for Producer's contribution to the Ancillary Services Market
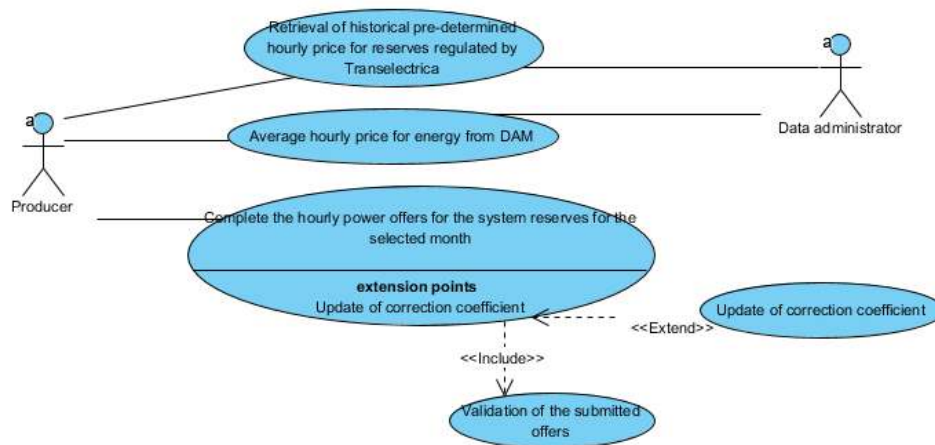

Source: Authors' computation

The general steps required to perform the use case for simulating Producer's contribution to the Ancillary Services Market are provided in Figure 9. The user can select the desired month for simulation. The number of months for which the simulation is performed must be less than the period specified in the general module and correspond to the periods of any simulation carried out on BWM or DAM.

For system services the historical price is displayed and used. It can be modified. The power available for reserves is completed and validated based on the total power offered in the General Module and the power contracted on BWM and DAM.

Figure no. 9. Use case diagram for simulating Producer's contribution to the Ancillary Services Market
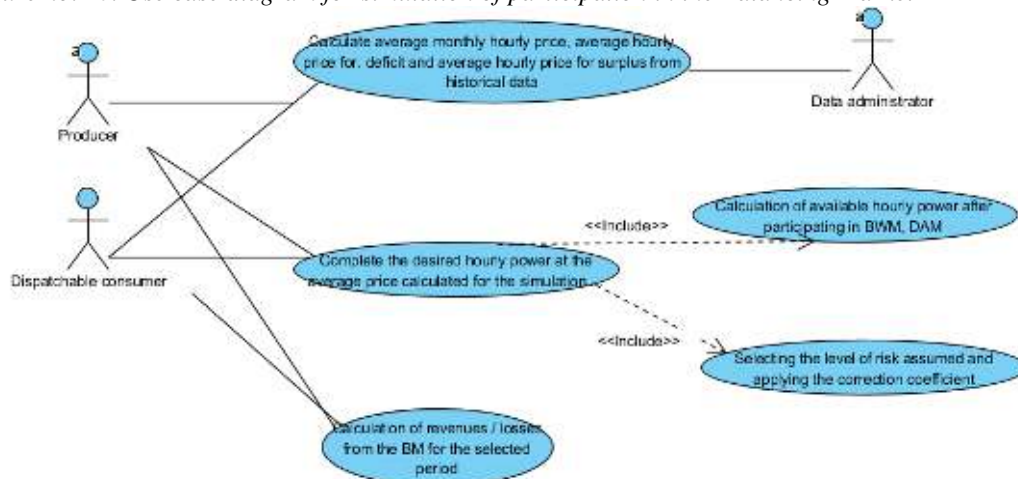

Source: Authors' computation

If the producer is activated, additional revenues are obtained, only for the period of activation, in addition to the revenues from power. A correction coefficient for activation is displayed. It has a default value of 60% and can be modified. In calculating the activation revenues, the average hourly price in the DAM for that month will be used.

Figure 10 presents the main functionalities of the simulator for the Balancing Market. Participation on the Balancing Market is mandatory, the power offered is calculated as the difference between the total power completed in the general module and the quantities contracted by participating in the other types of markets. The technological minimum that can be reached per hour will also be considered.

Figure no. 10. Use case diagram for simulation of participation in the Balancing Market

Source: Authors' computation

The price on the BM is very high compared to other markets. A monthly estimate is made for deficit and surplus based on historical average monthly prices per hour. The historical prices for the deficit and for the surplus will be taken from the OPCOM web-site. The displayed prices can be changed.

The user will choose a level of risk, which by default is 30% and can be modified. Thus, a percentage correction is applied to the estimated revenues or expenditures for the simulated period.

In order to calculate the total balance income, the price for the increase and the price for the decrease are weighted by 50%, the probability of the surplus or deficit occurring being equal.

The results of the simulation will be presented in a Cash Flow report that will show the values, the quantities of energy traded, by month, market, and type of transaction. This report aims to provide a centralized perspective of the monthly revenues and expenses for the requested period, including the associated risks for each type of transaction, but also an overall risk of the entire simulation.

5. Conclusion

The existing complexity of the electricity markets structure makes very difficult for any market player (electricity generator, consumer, trader, supplier, etc.) to optimize his participation both from technical and financial point of view. Looking forward to meeting the needs of the main market players, this paper proposes a simulator for the participation in the electricity markets, being focused on the aspects related to the optimization of the income. The issues related to the maintenance and long-term financial assessments will be the subject of a future work. This paper models the main functionalities for a market simulator. The simulation platform is organized in several steps from a general menu for setting the user type, available power and simulation period to each market type considering its characteristics. It takes into account the risks associated with each market and the probability of trading, as well as the unbalancing costs. The scope of the simulator is to evaluate the expected cashflow and traded energy for each market, helping the user to make decisions in regards with fuel stocks, trading activities approaching different markets and investment sector. The calculations and assessments are performed using updated large data sets with the financial results of the existing electricity markets in Romania.

6. Acknowledgment

7. References

- Bublitz, A. et al., 2014. Agent-based simulation of interrelated wholesale electricity markets. *Proceedings - International Workshop on Database and Expert Systems Applications*, Munich, Germany.
- Dennis, A., Wixom, B. H. and Tegarden, D., 2015. *System Analysis and Design: An object-oriented approach with UML.* 5th ed. John Wiley & Sons, Inc.
- ENTSO-E., 2017a. Guideline on Electricity Balancing. Retrieved July 31, 2019, from https://www.entsoe.eu/network_codes/eb/
- ENTSO-E., 2017b. Guideline on Electricity Transmission System Operation. Retrieved July 31, 2019, from https://www.entsoe.eu/network_codes/sys-ops/
- Jacobson, I., 1986. Language support for changeable large real time systems. In *ACM Sigplan Notices*, Vol. 21, No. 11, pp. 377-384). ACM.UML
- Kulak, D., & Guiney, E., 2012. *Use cases: requirements in context.* Addison-Wesley.
- Pinto, T. et al., 2014. Adaptive learning in agents behaviour: A framework for electricity markets simulation. *Integrated Computer-Aided Engineering*, 21(4), pp. 399-415.
- RERA, 2007. *Framework contract for ancillary services approved by RERA.* Retrieved August 27, 2019, from https://lege5.ro/Gratuit/geydonrqge/ordinul-nr-21-2007-privind-aprobarea-contractului-cadru-de-vanzare-cumparare-a-serviciilor-tehnologice-de-sistem-intre-furnizorul-de-servicii-tehnologice-de-sistem-si-operatorul-de-transport-si-de-sis
- RERA, 2011. *Modifications on framework contract for ancillary services approved by RERA.* Retrieved August 27, 1BC, from https://lege5.ro/Gratuit/gi3denrxgu/ordinul-nr-40-2011-pentru-modificarea-si-completarea-contractului-cadru-de-vanzare-cumparare-a-serviciilor-tehnologice-de-sistem-intre-furnizorul-de-servicii-tehnologice-de-sistem-si-operatorul-de-tra

- RERA, 2013. *Regulation regarding intra-day market operation of Romanian Energy Regulatory Authority (RERA)*. Retrieved August 27, 2019, from https://www.anre.ro/ro/legislatie/documente-de-discutie-ee1/proceduri-oper-regl-comerciale/regulamentul-de-organizare-si-functionare-a-pietei-intrazilnice-de-energie-electrica1387366406
- RERA, 2014a. *Regulation regarding day ahead market operation of Romanian Energy Regulatory Authority (RERA)*. Retrieved August 27, 2019, from https://www.anre.ro/ro/energie-electrica/legislatie/documente-de-discutie-ee/proceduri-oper-regl-comerciale/regulament-de-organizare-si-functionare-a-pietei-pentru-ziua-urmatoare-de-energie-electrica-cu-respectarea-mecanismului-de-cuplare-prin-pret-a-pietelor&page=1
- RERA, 2014b. *Regulation regarding negocitated contracts of Romanian Energy Regulatory Authority (RERA)*. Retrieved August 27, 2019, from https://www.anre.ro/ro/legislatie/documente-de-discutie-ee1/proceduri-oper-regl-comerciale/regulament-privind-modalitatile-de-incheiere-a-contractelor-bilaterale-de-energie-electrica-prin-licitatie-extinsa-si-negociere-continua-si-prin-contracte-de-procesare
- Simoglou, C. K. et al, 2014. Electricity market models and RES integration: The Greek case, *Energy Policy*, 67(April 2014), pp. 531-542.
- Sueyoshi, T. and Tadiparthi, G., 2008. Wholesale power price dynamics under transmission line limits: A use of an agent-based intelligent simulator. *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, 38(2), pp. 229-241.
- Teixeira, B. et al, 2015. Data mining approach to support the generation of Realistic Scenarios for multi-agent simulation of electricity markets. *IEEE SSCI 2014 - 2014 IEEE Symposium Series on Computational Intelligence - IA 2014: 2014 IEEE Symposium on Intelligent Agents, Proceedings*, Orlando, FL, USA.
- Transelectrica S.A., 2018. *Registering, updating, withdrawing and cancelling a Balancing Responsible Party - Operational procedure.* Retrieved July 30, 2019, from http://www.transelectrica.ro/web/tel/inregistrare-revocare-pre
- UML, 2019. *Unified Modeling Language Specifications.* Retrieved September 12, 2019, from https://www.omg.org/spec/UML/2.5/About-UML/