DOI https://doi.org/10.35219/rce2067053268

Software Platform for an Electricity Market Trading Simulator

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Nowadays, it is exceedingly difficult for a market player to decide what the best combination of offers (prices/volumes) is, considering the multiple possibilities (electricity markets) available. The authors of this paper developed a simulator of the potential transactions on the main electricity markets, as a form of support for the identification of the optimal solution. The design of the simulator is based on the structure of the Romanian electricity market, recognized as representative for the European Union member states. The paper briefly presents the modules of the simulator, highlighting the required input data, recommendations, analysis capabilities, reporting, and editing facilities.

Keywords: electricity market, software platform, transactions on electricity market, power systems, optimization method, iterative methods

JEL Code: D47 Q41 D81

1. Introduction

One of the main reasons that substantiated the implementation of the unbundling in the power sector, more than 20 years ago, was the lack of competitiveness principles. At that time, the companies in the power sector were organized in a fully vertically integrated structure, including the entire business chain from the generation up to end users. Within this type of organizational structure, it was very difficult to incentivize operation efficiency for the entities included in the business chain, because the only effective financial indicator was the electricity price at the end-user level.

The implementation of the unbundling has dramatically boosted the competitiveness among the main actors of the power sector, by applying the market principles in all relevant activities: generation, transport, distribution, and supply. In this context, the electricity market (itself composed of several layers) has become the physical support for the commercial transactions.

Over time, the electricity market has increased in complexity with the aim of providing appropriate commercial and financial tools for each of the relevant aspects of the power systems operation. Currently, the are two main operational areas with associated, yet different electricity markets: electricity supply and reserves.

For the electricity supply there are three different markets, based on the transaction's timeframe: long term, day ahead and minutes ahead.

The structure of the reserves market is more complex, in accordance with the types of reserves in usage nowadays. Initially, only two types of reserves were subject to market transactions: secondary and tertiary reserves (recently the nominations of these reserves have changed to Frequency Restoration Reserves – FRR and Replacement Reserves – RR, respectively). Recent developments in the power systems, such as the installation of large amounts of RES powered generators using invertors for connecting to the grid, have raised the necessity of new types of reserves, thus leading to new markets.

In the last decades, one may notice a relevant and continuous increase in the complexity of the electricity market (mirroring the increase in complexity of the power systems operation) corroborated with the huge increase of the competitiveness level (for example, in Romania there are currently 2124 licenses for electricity generation, 787 licenses for supply, and 48 licenses for trading in force, as in portal.anre.ro / PublicLists / LicenteAutorizatii, 2020). In this context, it is exceedingly difficult for a market player to optimize their income, considering all transaction types, volumes, and prices available for a determined period and for a determined volume of resources.

In order to meet the present needs of the market players, the authors of this paper have developed a software platform for simulating the possible electricity market transactions, for each of the major players: generators, suppliers, traders, and end-users. The simulations are based on the electricity market structure currently implemented in Romania. The Romanian electricity market is a mature one after decades of operation, and there are reasonable grounds for it to be considered as representative of the EU. Of course, within EU member states, there are more sophisticated electricity markets, such as: Germany, France, or Ireland, but on the other hand, there are states where the electricity market is just beginning to develop. Also, the Romanian electricity market might be considered a good example, as it respects the integration at regional level.

The databases for prices, used for calculations and analysis, have been built upon the historical data registered on the Romanian electricity market in the last three to five years. All data included in this software databases are public and they were accessed from websites that are open to the large public, such as the Romanian National Regulatory Authority (ANRE) website, the Romanian Transmission System Operator (Transelectrica) website, and Romanian Electricity Market Operator (OPCOM) website.

The software was designed in a modular concept aiming for further development and completion, in line with the developments of the power systems operation foreseen for the future. Similar simulators calculating performance indicators and modeling the transactions on electricity markets have been built over time: [1], [3], [13], [15], etc.

2. Electricity Market Stakeholders and Main Components

The stakeholders of the electricity market are the market players (legal entities involved in transactions), the market operator (in charge of providing support for the financial and commercial operation), the power transmission system operator (in charge of providing the physical support for the transactions while maintaining the quality and safety in operation of the power system), and the regulatory authority (in charge of providing the legal and regulatory framework).

The main components of the electricity market are the bilateral wholesale market (involving long-term bilateral transactions validated by contracts) [9], the day ahead market and/or intraday market (involving stock exchange-type transactions in a time frame of 24 hours or less), the balancing market (involving stock exchange-type transactions in a time frame of minutes), and the ancillary services market (involving stock exchange type transactions with a time frame going from minutes to days).

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.

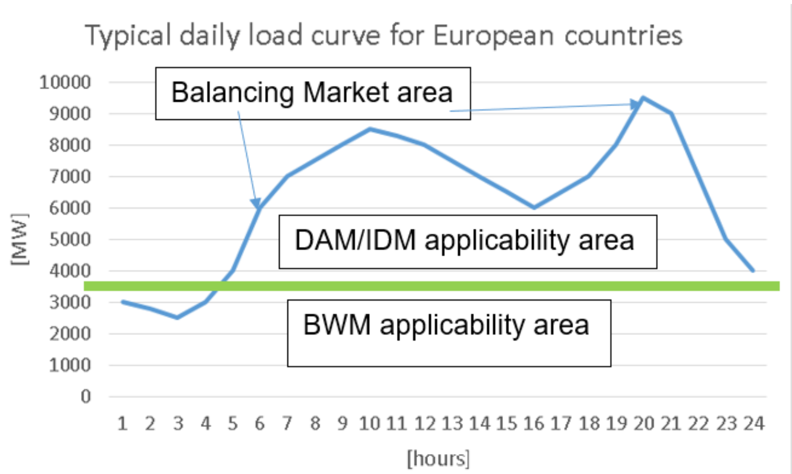

Figure 1. The typical daily load curve and the applicability areas for the electricity markets as in [14]

In this intricate context, it is very difficult for a market player, no matter its type (generator, supplier, consumer etc.), to make the proper financial decisions towards optimizing their resources usage, especially when there will be restrictions imposed by the available volume of resources.

To identify the optimal decision, it is necessary to solve a multi-criterial optimization problem with a set of restrictions. For this type of mathematical problems, it is usually not possible to find a unique, fully determined solution, and an iterative method is necessary instead. The iterative methods require large volumes of calculations because on one hand, achieving the optimum is performed in small steps and on the other hand, the result of an iteration may point in a wrong direction (not approaching, rather moving away from the optimum). This characteristic calls forth the necessity of a specialized software platform tool to keep an appropriate balance between the accuracy of the results and the volume of work (calculations).

3. Module for Simulation of Trading on Electricity Markets

The module of the software platform for simulating transactions on electricity markets is designed mainly to be a tool for electricity producers and suppliers. The authors called it MTM SIMULATOR and it is made in JDeveloper, based on test data previously loaded in the SMARTRADE project prototype database. MTM SIMULATOR allows the simulation of several scenarios involving transactions in the following electricity markets: Bilateral Contracts Market (PCCB), Day Ahead Market (PZU), Ancillary Services Market (PSS), and Balancing Market (PE). The scenarios may be developed for different types of users such us electricity generators, suppliers, traders and dispatchable consumers, providing useful results and findings in the process of identifying the optimal commercial decisions, while also taking into consideration the specific technical restrictions for each type of user. The module is implemented in Cloud Computing architecture, equipped with a user-friendly interface with many useful editing facilities, and may be accessed using one of the web browsers.

Access to the MTM SIMULATOR

The access to the simulator is personalized because some of the stored data and information are confidential data. Using a usual web browser like Internet Explorer/Edge, Mozilla Firefox, or Google Chrome, the software user can access the link indicated in the MTM Simulator Manual, 2020. The page used for login authentication is presented in Figure 2.

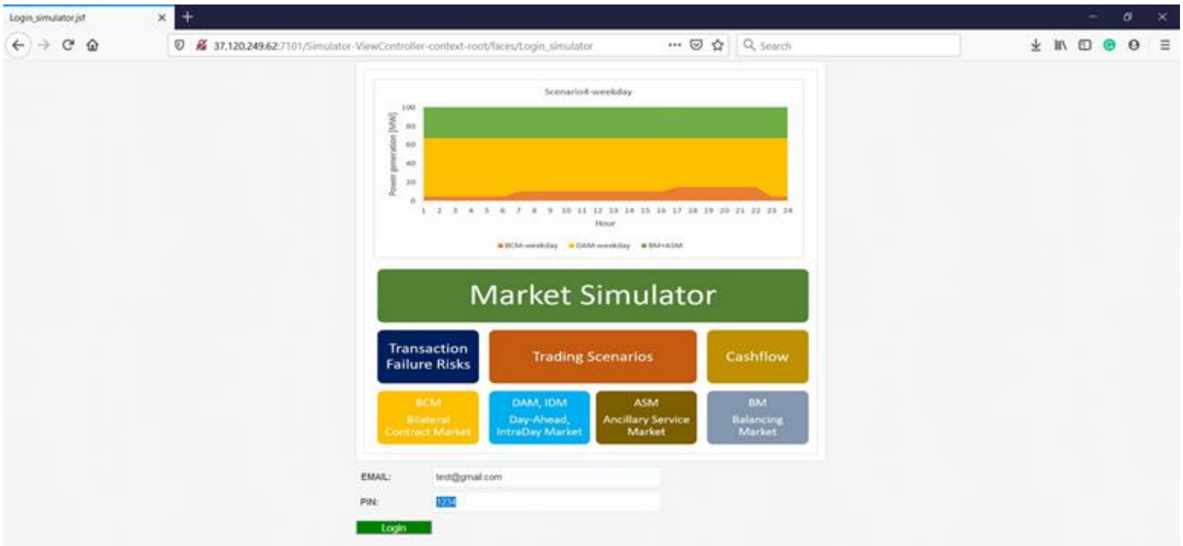

Figure 2. User login authentication page

Following the successful login, the user has access to all the data stored by him in the previous uses of the software, all the previously performed simulations, and all the relevant results that were achieved. In Figure 3 the starting page of the MTM SIMULATOR is presented, personalized for the user logged in. The page displays the relevant information regarding the user and provides several facilities (indicated by specialized buttons) for accessing the results of previous simulations and/or editing new ones. The results of the previous simulations are displayed in a user-friendly format including all the relevant technical and commercial aspects, such as the type of transaction (selling or purchasing electricity), season and duration of the simulation, volumes of electricity, prices, etc. The software user may review the input data they used for previous simulations and compare them to the historical data and information stored in the databases included in the MTM SIMULATOR. These databases are periodically updated by the authors of the software, based on the reports elaborated by ANRE, TRANSELECTRICA, and OPCOM, in line with the transparency regulations currently in force. In case the user requires a new simulation, the appropriate button must be activated (New Simulation).

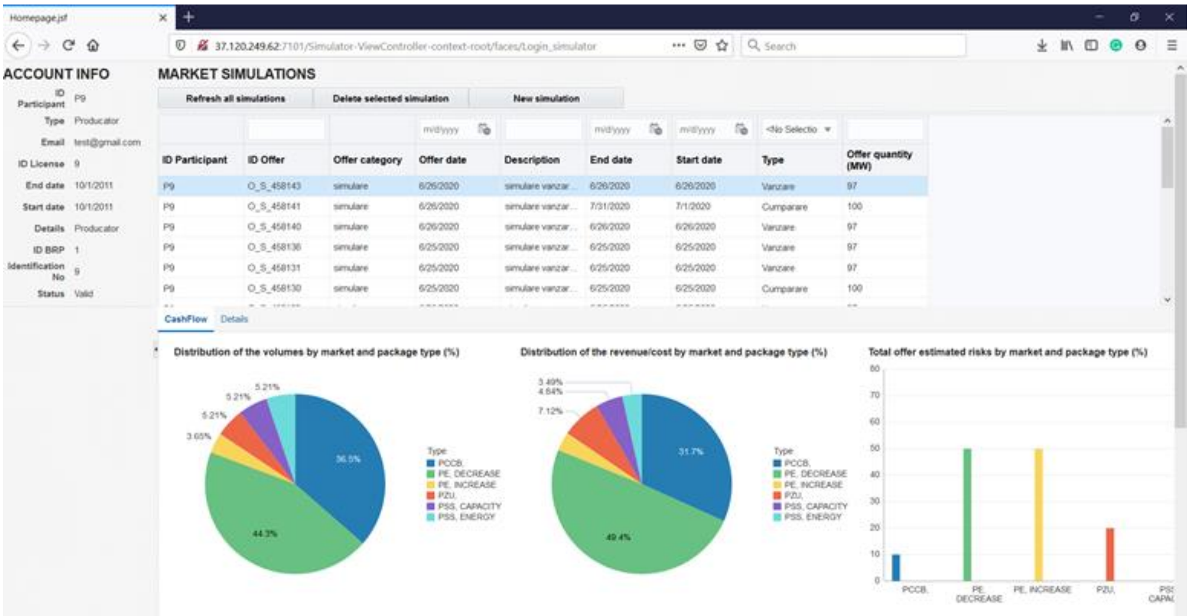

Figure 3. Personalized starting page of the MTM SIMULATOR

4. Input Data for Electricity Markets Simulations

The first step in the development of the simulation is to determine the required input data, according to the needs indicated by the results. Figure 4 below shows the interface page used for the establishment of the options.

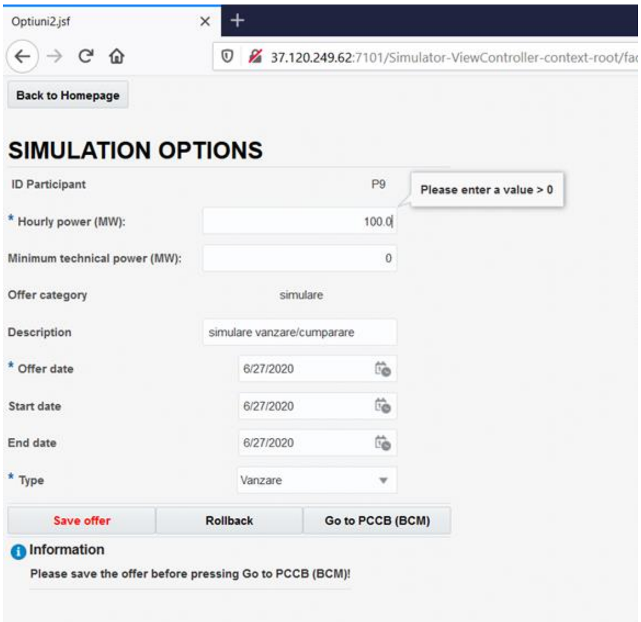

Figure 4. Page for establishment of the simulation options

The page presented in Figure 4 provides all the necessary facilities (options) for tailoring the simulations and associated analysis, to the user characteristics and needs. The design of the interface page is very flexible and user-friendly, suitable for different types of electricity generators (powered by fossil fuels, hydro, nuclear fuels, or RES), suppliers, aggregators, end-users, and others. Once the user type is established, the Simulation Options page provides support for selecting all the relevant data and information necessary to perform the simulation with a high level of accuracy: season of the year, duration, volume of resources available for the selected duration, and others. The input dataset may be stored at any moment and it is available for further updates and/or use if needed.

One important function accomplished by means of this interface page is the definition of the restrictions set. The restrictions might be technical (installed power), administrative (volume of fuel stocks) and/or financial (available funds for a determined period). Each type of user must define their restrictions set according to their characteristics and as accurately as possible, in order to obtain the most reliable results following the simulations. The restrictions set itself might be subject to optimization if useful and/or necessary, and the software platform simulator provides the ideal means of achieving this goal.

MTM SIMULATOR is designed to operate in a "chain type" system, where the relevant data established in one stage is transferred to the next stage. This type of interrelationship is necessary to permanently control the full compliance of the restrictions set.

5. Simulation of the Transactions on the Bilateral Contracts Market (PCCB)

The electricity market for bilateral transactions [12] is usually the largest of the electricity markets, from the point of view of volumes traded. The transactions on PCCB may be characterized by a large timeframe scale, starting from one week and going on for years. Considering the above-mentioned particularity, the transactions are usually performed using pre-defined schedules (so called "standard trading products") for the hourly values of electricity. At the same time, the prices are theoretically negotiated independently to the hourly schedule, but in practice there is a strong interrelation between them.

The interface page for the simulation of the transactions on the PCCB it is showed in Figure 5 below.

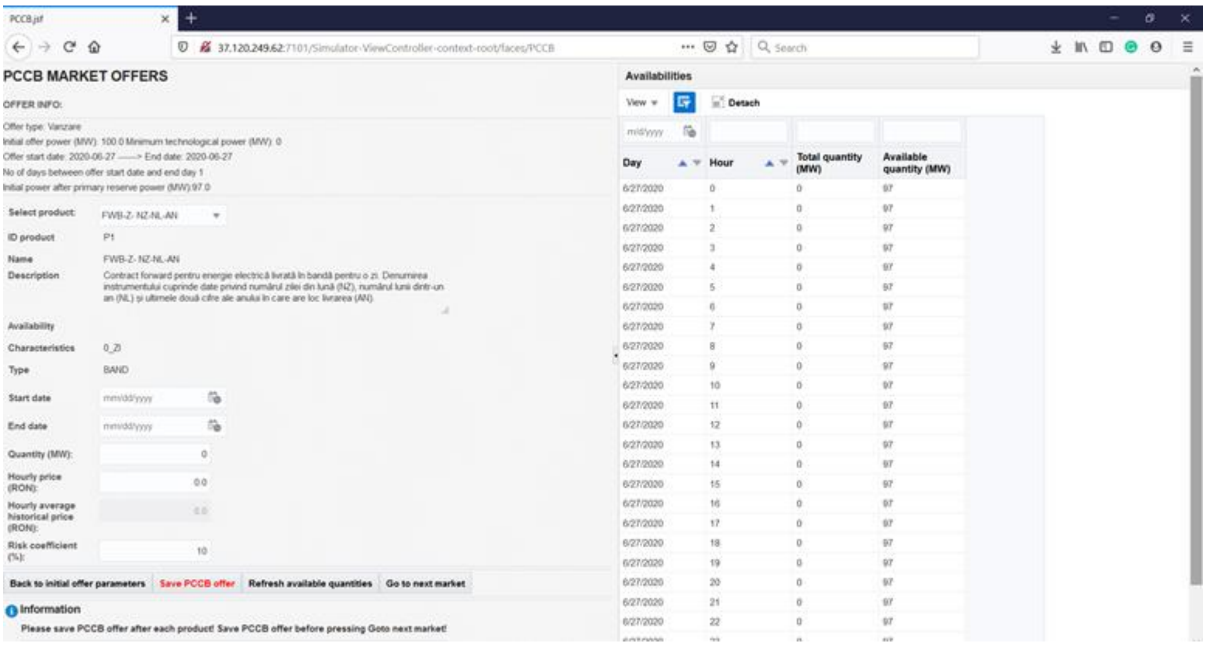

Figure 5. Simulation of the transactions on PCCB

The left section of the page shows the available trading products [7] and provides the facilities for selecting the season of the year, the duration of the simulation and the hourly prices to be considered. MTM SIMULATOR provides recommendations regarding the hourly prices based on its internal database built upon the historical prices registered in the last five years. The users are free to follow the recommendations or to choose other values according to their information. On the same side of the interface page, the risk for imbalances is specified in percentages. The potential hourly imbalances between the scheduled and generated powers are converted into financial losses to be considered in further calculations.

The right section of the interface page displays, in a user-friendly format, the most relevant features of the transaction or transactions which is/are to be further included in the simulations. This section has several editing facilities such as: switching the display format between drawings and tables, searching a date or period, and others. This facility is especially useful for reviewing the options previously selected (especially the hourly pairs electricity/price) and validating or correcting them if necessary.

As mentioned in the previous paragraph, all the options selected in this interface page and the associated data are stored by request under the simulation's indices and they will be further used in the calculations and analysis. Also, all the options selected by the user are checked against the restrictions set and unless validated, the user is promptly informed and requested to correct the respective option.

6. Simulation of the Transactions on the Day Ahead Market (PZU)

The interface page for simulating the potential transactions for selling on PZU [10], [11] is showed in the Figure 6 below.

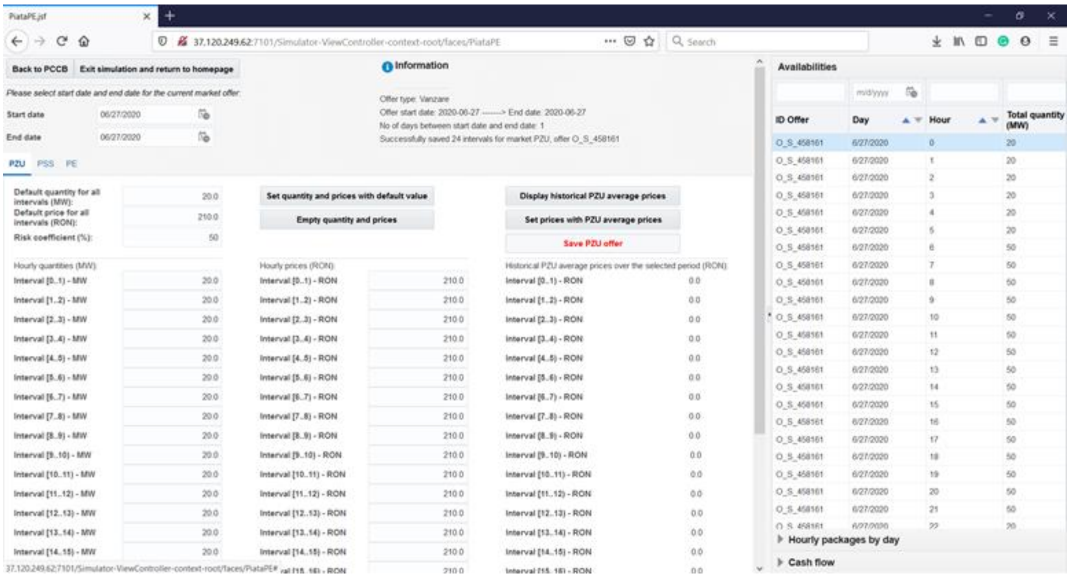

Figure 6. Simulation of the transactions on PZU for selling

PZU is a stock exchange-type market, using the "marginal price" as the criteria for closing the transactions [2]. In these conditions, the interface page must support the user to elaborate a competitive offer on one hand and to consider the risk of not finalizing some of the transactions on the other hand. The displaying and editing facilities included in this interface page are appropriate for the features of PZU.

The level of risk of not finalizing the trades must be specified by the user, MTM SIMULATOR providing recommendations based on the internal databases. Similar to the PCCB, the level of risk it is converted into financial values and further considered in the calculations and analysis.

The options selected in this interface page and the associated data are stored by request under the simulation's indices and they will be further used in the calculations and analysis. Also, the options selected by the user are checked against the restrictions set and if not validated the user is promptly informed and requested to correct the respective option. For an acquisition bid, the results are showed in Figure 7.

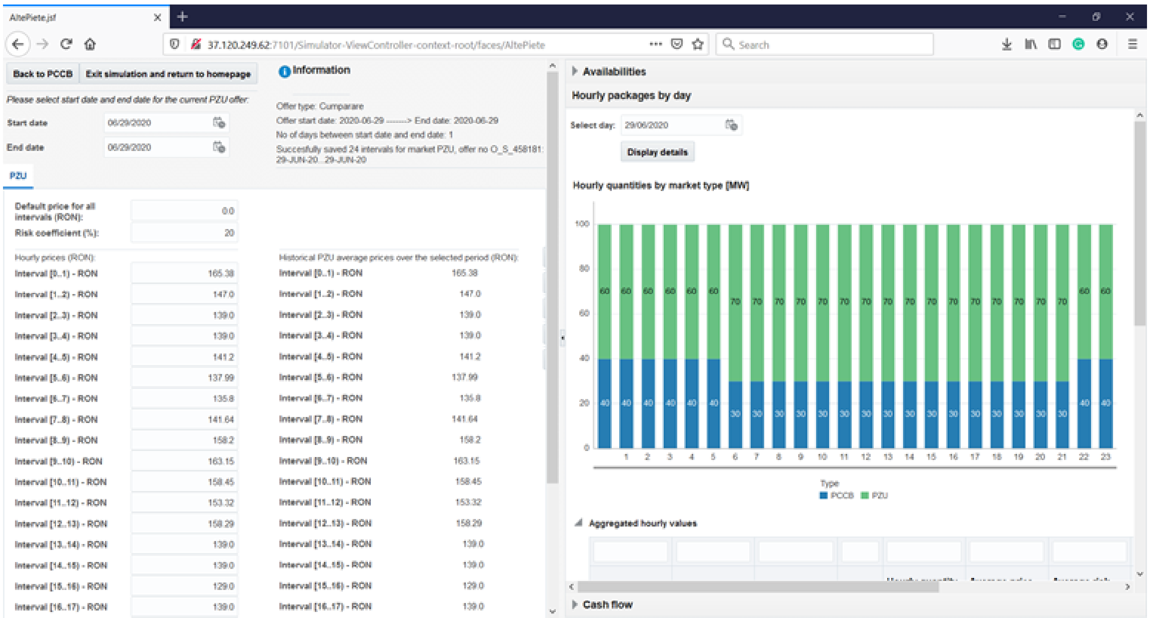

Figure 7. Simulation of the transactions on PZU for acquiring

7. Simulation of the Transactions on Ancillary Service Market (PSS)

PSS is an optional electricity market traditionally available only for electricity generators, [8] and [9]. Recently, the developments in technology and the significant increase in RES powered generation have imposed the acceptance of other players such as storage facilities, aggregators, virtual power plants. The current approach [4] and [5] in most of the EU members states is that a legal entity is accepted to be a member on PSS if it proves the required capabilities to deliver the services traded on the respective market.

The transactions performed on PSS are intended to provide to the TSO the necessary and appropriate means for timely solution of the most important issues raised by the operation of the power systems: frequency regulation, congestion management, and outages impact.

The transactions on PSS have a dual structure: contracted power and delivered electricity. The contracted power represents the amount of power contracted by the TSO based on the offers received from the PSS players, to be available in the operation of the power system. The PSS never uses the entire volume of contracted power, rather the availability itself is reimbursed in line with the trading performed on PSS. If during the power system operation, the TSO needs the activation of a certain amount of power (contracted on PSS) for a determined duration, the respective amount of electricity is called delivered electricity, and it is reimbursed supplementary to the contracted power, at a different price. Figure 8 shows the interface page for the simulation of the potential transactions on PSS.

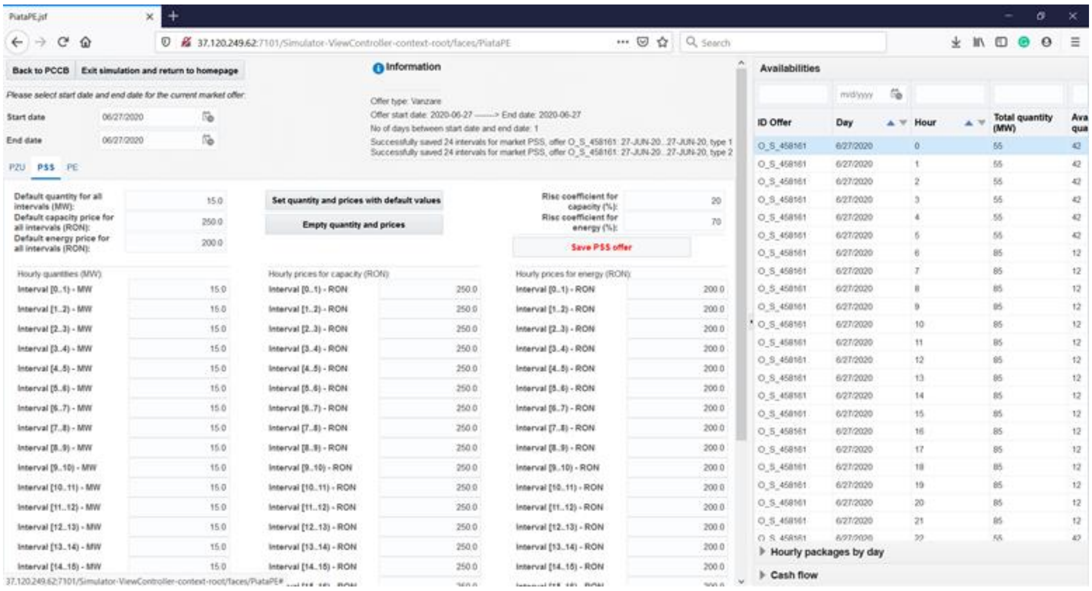

Figure 8. Simulation of the transactions on PSS

The level of risk of not finalizing the trades (not being selected by the TSO for contracted power) is significant and must be specified by the user. MTM SIMULATOR provides recommendations based on the internal databases. Similar to the PCCB and PZU, the level of risk is converted into financial values and further considered in calculations and analysis.

8. Simulation of the Transactions on the Balancing Market (PE)

The participation in PE is mandatory for all the electricity generators, as both types of offers increase and decrease electricity generation. Each electricity generation unit must notify the TSO (the notification has the legal status of an offer) regarding the amount of power available for the increase of generation (determined as the difference between the installed power and the sum of the amounts contracted on all the other electricity markets) and the decrease of generation (determined as the difference between the sum of the amounts contracted on all other electricity markets and the technical minimum of the respective generation unit). Figure 9 below, shows the interface page for simulating the potential transactions on PE.

The information and data included in the built-in databases prove that the prices on this market are attractive, but the risk of not finalizing the trades is extremely high. Therefore, MTM SIMULATOR is providing recommendations with the aim to keep the appropriate balance between the income and the associated risks. Obviously, the final decision belongs to the user of the software.

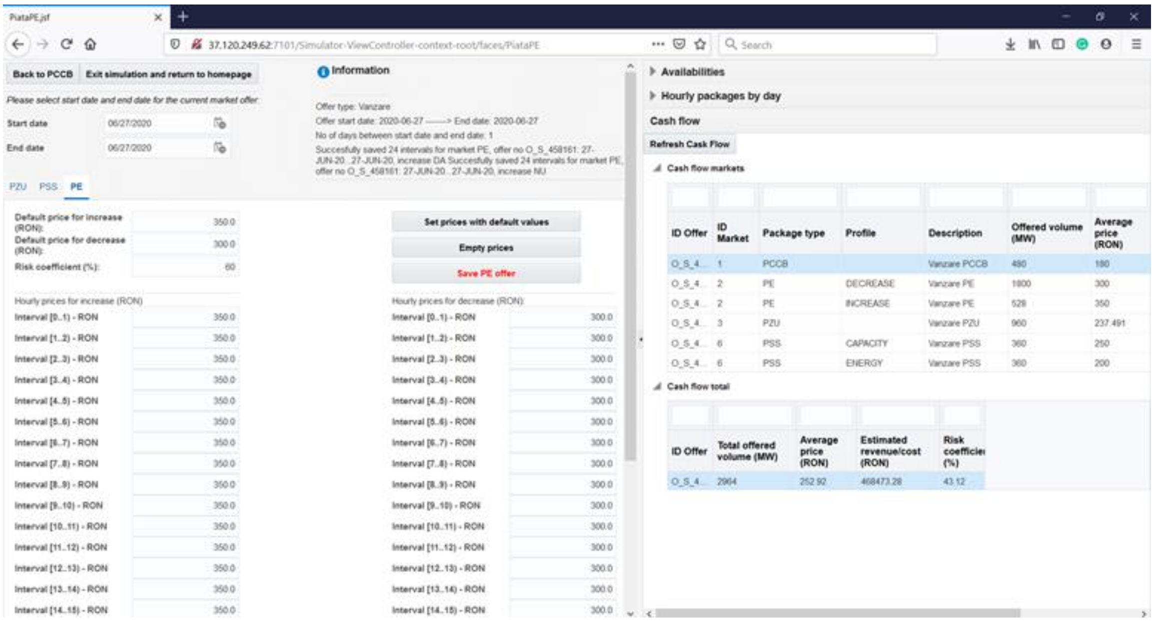

Figure 9. Simulation of the transactions on PE

9. Results and next steps

The input of the data inserted in the interface page for PE is the last data block required to be included in the mathematical model before starting the simulation. The user may run the simulation and visualize the results in the reports displayed in separate specialized windows.

The most important report includes the cash flow. Figure 10 below, shows the cash flow report that may be visualized when the simulation is finalized. The report may be focused on a certain electricity market or may include all of them, as requested by the MTM SIMULATOR user.

Cash flow

Refresh Cask Flow

Cash flow markets

ID Offer	ID Market	Package type	Profile	Description	Offered volume (MW)	Average price (RON)	Risc coefficier (%)	Estimated revenue/cost (RON)
O_S_4...	1	PCCB		Vanzare PCCB	480	180	10	77760
O_S_4...	2	PE	DECREASE	Vanzare PE	1800	300	60	216000
O_S_4...	2	PE	INCREASE	Vanzare PE	528	350	60	73920
O_S_4...	3	PZU		Vanzare PZU	960	237.491	35	152153.28
O_S_4...	6	PSS	CAPACITY	Vanzare PSS	360	250	20	72000
O_S_4...	6	PSS	ENERGY	Vanzare PSS	360	200	70	21600

Cash flow total

ID Offer	Total offered volume (MW)	Average price (RON)	Estimated revenue/cost (RON)	Risk coefficiei (%)
O_S_4...	2964	252.92	468473.28	43.12

Figure 10. Cash flow resulted from simulation

The cash flow is the result of this iteration (as mentioned before, the mathematical method for solving this type of problem is iterative). In case it is the first iteration, even if the results are satisfying for the user, it is recommended to perform a second iteration to be certain that it is an optimal solution. In case it is not the first iteration, the resulted cash flow must be stored for further comparison with the cash flows resulted from the previous iteration(s).

Figure 11 below, presents the page that allows the user to compare the results of several performed iterations and to decide which one of them is the optimal solution he is looking for.

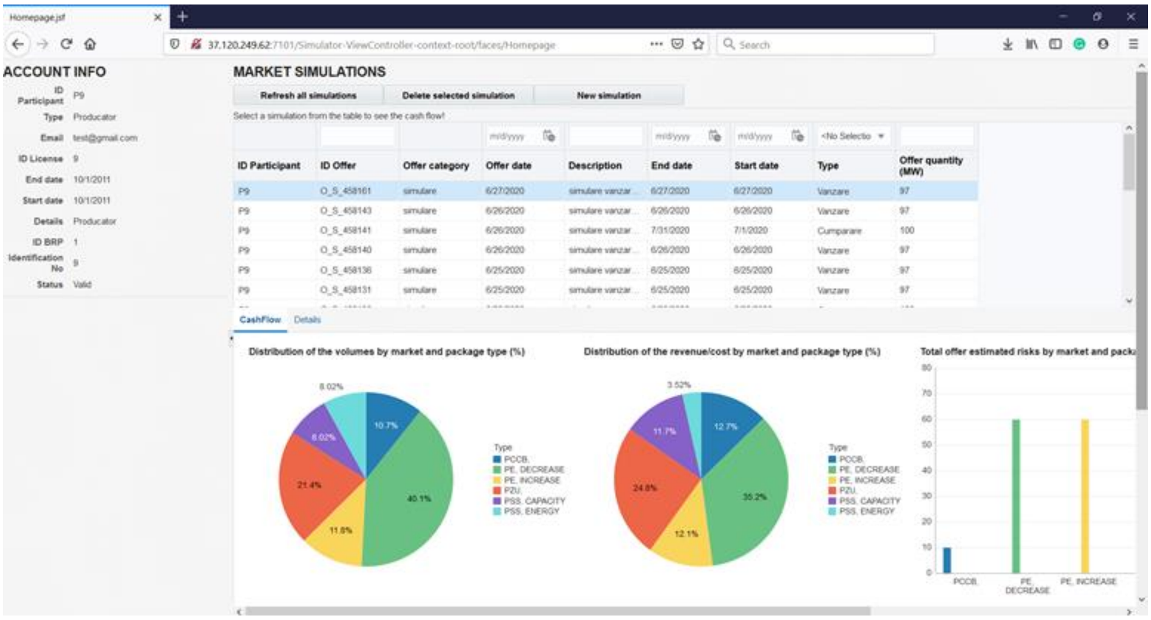

Figure 11. Comparative report of the iterations results

In case the user is not satisfied with any of the achieved results, they may continue the iterative process by starting a new simulation (iteration). All the input data used for the previous performed simulations are stored in the MTM SIMULATOR and are available to be used in new simulations if requested by the user.

The criteria for identification of the optimal solution are the total income/cost for the period analyzed, volume of traded electricity, income/cost per MWh traded, the level of risk associated to the simulation and the price/volume of the fuel associated to the transactions included in the simulation.

10. Conclusions

The advancement of the global warming phenomenon has imposed an intensified implementation of the measures designed to slow down or even revert it as soon as possible. Among these measures one of the most important is the replacement of the fossil fuels with RES in electricity generation.

The massive integration of RES powered electricity generation in the power systems of the EU member states (EU is currently one of the world leaders in this respect) had a significant impact on the structure and operation of the associated electricity markets.

Considering this trend will continue for at least the mid-term if not the long-term, it becomes obvious that electricity market participants need appropriate tools to support them in making the commercial decisions. Several specialized software platforms have been developed globally, looking to meet the requirements of different market players: generators, suppliers, end-users, and others. The authors of this paper have developed MTM SIMULATOR as a very useful and user friendly software platform module for supporting the electricity market players in the identification of the optimal commercial solution, while considering the restrictions imposed by the limited volume of resources (funds, fuel stocks, prices, etc.). The MTM SIMULATOR is made in JDeveloper, based on test data previously loaded in the SMARTRADE project prototype database.

The software provides capabilities for simulating potential transactions in the main electricity markets: PCCB, PZU, PSS and PE, considering a set of restrictions imposed by the user and historical data.

Acknowledgments
This paper presents the scientific results of the project "Intelligent system for trading on wholesale electricity market" (SMARTRADE), co-financed by the European Regional Development Fund (ERDF), through the Competitiveness Operational Programme (COP) 2014-2020, priority axis 1 – Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4-Attracting high-level personnel from abroad in order to enhance the RD capacity, contract ID P_37_418, no. 62/05.09.2016, beneficiary: The Bucharest University of Economic Studies.

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