STOCHASTIC OPTIMIZATION OF POWER SYSTEM OPERATION IN PRESENCE OF RENEWABLE ENERGY SOURCES

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Abstract – *The liberalization process of the energy market structure determined significant changes in the electric utility industry, from both generating and transmission perspectives, and new generation technologies emerged, deeply influencing the industry profile. Nowadays, based on the governmental incentives and free access to the power systems, the share of renewable energy sources in the bulk power system generation is increasing. With respect to the classical fuel-based sources, the renewable energy sources (like photovoltaic and wind turbines) have an intermittent character determined by the meteorological conditions. Their production cannot be known exactly, but can be forecasted with some degree of accuracy. Thus, within the power system, network measures must be adopted for ensuring its safe operation.*

Keywords –*renewable energy, optimization, electricity market, stochastic optimization*

OPTIMIZAREA STOCASTICĂ A FUNCȚIONĂRII SISTEMULUI ENERGETIC ÎN PREZENȚA SURSELOR DE ENERGIE REGENERABILE

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Rezumat – *Procesul de liberalizare a structurii pieței energiei a determinat schimbări semnificative în industria de furnizare a energiei electrice din atât perspectiva de generare și de transmisie, cât și a noilor tehnologii de generare apărute, influențând profund profilul industriei. Actualmente, datorită stimulentelor guvernamentale și accesului liber la sistemele energetice, ponderea surselor regenerabile în totalul energiei electrice generate este în creștere. În comparaţie cu sursele clasice pe bază de combustibili, sursele regenerabile de energie (cum ar fi turbinele eoliene și fotovoltaice) au un caracter intermitent determinat de condițiile meteorologice, producția lor nu poate fi cunoscută cu exactitate, dar poate fi prognozată cu un anumit grad de precizie. Astfel, în cadrul sistemului de alimentare, trebuie adoptate măsuri de rețea, în vederea asigurării unei funcționări în condiții de siguranță.*

Cuvinte cheie –*energie regenerabilă, optimizare, piaţa energiei electrice, optimizare stocastică.*

СТОХАСТИЧЕСКАЯ ОПТИМИЗАЦИЯ ЭКСПЛУАТАЦИИ ЭНЕРГОСИСТЕМЫ ПРИ НАЛИЧИИ ВОЗОБНОВЛЯЕМЫХ ИСТОЧНИКОВ ЭНЕРГИИ

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Реферат – *Либерализация структуры энергетического рынка привело к значительным изменениям в отрасли поставок электроэнергии с точки зрения как генерации и передачи, так и появившихся технологий нового поколения, оказала глубокое влияние на профиль отрасли. В настоящее время, благодаря государственным стимулам и свободный доступ к энергетическим системам, доля возобновляемых источников энергии в общем объеме вырабатываемой электроэнергии увеличивается. По сравнению с традиционными источниками на основе топлива, использование возобновляемых источников энергии (например, ветряные турбины и фотоэлектрические) имеют прерывистый характер, определяемый метеоусловиями, их производство не может быть известно точно, но можно предсказать с определенной степенью точности. Таким образом, внутри системы электроснабжения должны быть приняты сетевые меры в целях обеспечения безопасной эксплуатации*

Ключевые слова – *возобновляемая энергия, оптимизация, рынок электрической энергии, стохастическая оптимизация*
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1. INTRODUCTION

The electricity market is an economic concept, which has a complex content, and expresses all transactions of purchasing and selling of electrical energy in a specific geographical area [1], [2], [3]. The electricity market has as main function the correlation, through supply and demand, of production with electricity consumption, by fulfilling the buying - selling contracts. Romania has taken the decision to liberalize the electricity market, considering the customers security of supply and therefore the energy system will increase with the development of a coherent electricity market, in which the participants can have benefit from the competition. In order to join the EU, the electricity sector from Romania had not only to comply with the directives and community resolutions, but it must also take action to organize, create and implement procedures and legislative framework and harmonized regulatory which lead towards results provided by these directives.

The advantages of the competitive environment take into consideration, the mainly think the direct competition to win, maintain and expand the market section, the effective cost management, free prices formation and not least providing incentives in order to reduce costs and efficient use of resources [4], [5]. The introduction of the competition in the activities that not lead the specific natural monopolies (production and supply of electricity) is beneficial and necessary but clear rules on trade arrangements, the rights and the duties of the competitions, trading mechanisms and establishing collection rights and payment obligations [6].

This paper deals with the study of a system supplied by a set of classical power plants, wind power plants and photovoltaic installation, all these participating to the electricity markets. A share of generation of each of these power producers is supplying loads with which they have established bilateral contracts. The rest of their generation is used for submitting bids on the day-ahead market. The mathematical model proposed within this paper optimizes the operation of these power producers, determining the power exchanged with the day-ahead market. In addition, the optimization model seek to ensure the operation of the power system determining the reserve requirements and its associated cost in vision of the stochastic character of the renewable sources, under different production scenarios for renewable sources.

2. ELECTRICITY MARKET STRUCTURE

The wholesale electricity is an organized framework where the electricity is purchased by the suppliers from producers and other suppliers, for further selling or for their own use, and also by the network operators to balance their own energy consumption [7], [8]. On the wholesale electricity market, have access to fulfil transactions:

• the producers and the auto-producers of electricity;
• the suppliers;
• the network operators.

The transactions on the wholesale electricity market have the objective of selling and buying: electricity, ancillary services, transport services, green certificates, and distribution services. The connections between the markets are illustrated in figure 1.

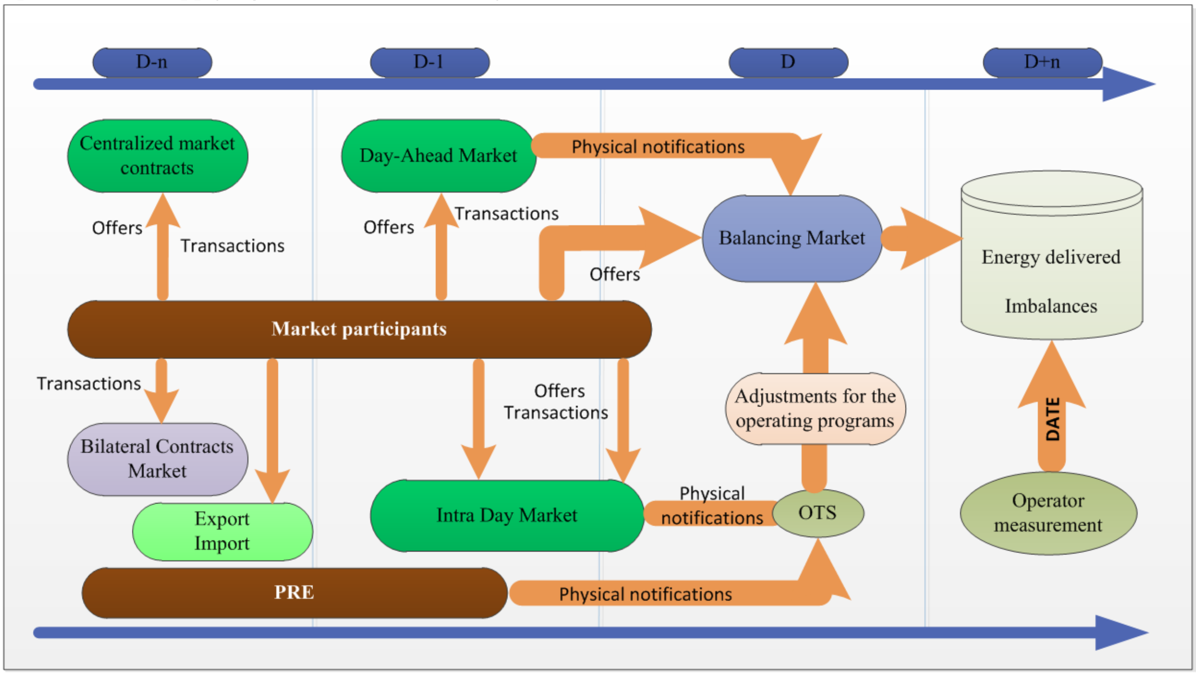

Fig. 1. The schematic structure of the wholesale market

2.1 Spot Market

Day Ahead Market is a component of the wholesale electricity market, on which can realize hourly active transactions with next day delivery. Day Ahead Market is operational in Romania from June 2005. It is a centralized market for buying and selling electricity in short term.

Participating in this market is voluntary and is permitted to all license holders registered at OPCOM for Day Ahead Market. License holders can become participants in the Day Ahead Market if they are:

• electricity producers;

• electricity suppliers;
• network operators who can become participants in the Day Ahead Market and may attend at this market only if they carry out the functions explicitly mentioned in the commercial code.
Network operators have not the right to trade on the Day Ahead Market in order to obtain profit. Moreover, excluding electricity`s sales by the TSO to compensate the unplanned exchanges with other TSO transmission system operator has not the right to sell electricity on the Day Ahead Market.
On the Day Ahead Market each hour of the delivery day is considered as an independent market. Each transaction corresponds to a supply of electricity at a constant power over the respectively trading range.
Each delivery day has 24 consecutive trading intervals and each interval lasts one hour, the first trading period is from 00:00 on the delivery day. Exceptions are the days crossing the municipality during the summer time to winter time and respectively from the winter time towards the summer time when the delivery day is 25 or 23 trading range.

2.2 Centralized Market for Bilateral Contracts Electricity

On the wholesale market of electricity, license holders may conclude bilateral transactions electricity, including bilateral contracts to export or import electricity, in compliance with specific provisions of the Commercial Code of the wholesale electricity and license conditions. Bilateral contracts for buying and selling electricity can be:
• Bilateral contracts with minimum content established by the competent authority (ANRE);
• Deregulated contracts, where the content is determined by direct negotiation between the parties, compliance with the requirements of the Commercial Code.

2.3 Bilateral Contracts Market with Continuous Negotiation

Published offers are kind of sale offers or purchase for standard delivery periods and for the daily use of standard power. Participation in the auction sessions is conditioned by the guarantees to tender.
On the centralized market for bilateral contracts electricity with continuous negotiation can be traded forward contracts with hourly power 1 MW. The contracts may be concluded for the delivery period of a week, a month, a quarter or a year. In terms of the daily power usage tenders may be: flat offers, half-flat offer, peak hourly offers, and off peak hourly offers.
Characteristic of this market is the possibility of continuous negotiation, starting from an initial offer (opening price) until an agreement between seller and buyer. This market is designed for producers, suppliers and large consumers. To participate at this bidding session, the participants must constitute guarantees of participation.
Each contract includes: the quantity of electricity contracted, contract price, delivery period, the delivery date.

3. STOCHASTIC OPTIMIZATION MODEL

The mathematical optimization model seeks to minimize the operational costs associated with the electricity market requirements facing the stochastic production of wind power plants and photovoltaic installations [9], [10]. The objective function is expressed as:

$$\begin{aligned}&[\mathrm{MIN}] \sum_{g\in GC}\left(C_g\left(P_g\right)+SU_g+SD_g\right)+\\&+\sum_{s\in SCEN}\pi_s\cdot\sum_{g\in GC}\left(C_g^U R_{g,s}^U - C_g^D R_{g,s}^D\right)+\\&\sum_{s\in Scen}\pi_s\cdot\left[\begin{array}{l}\sum_{r\in RES} C_r\begin{pmatrix}WT_{r,s}-WT_{r,s}^{spill}+PV_{r,s}-\\-PV_{r,s}^{spill}\end{pmatrix}+\\+\sum_{l\in Load} v_l^{LOL} L_{l,s}^{shed}\end{array}\right]\end{aligned} \tag{1}$$

where $C_g(Pg)$ is the power plants cost for producing P_g, SU_g and SD_g are the start-up and shut-down costs, πs is the scenario probability associated to the renewable energy sources (RES) production, C_g^U and C_g^D are the costs of upward/downward reserve (R_g^U and R_g^D), WT_r and PV_r are the wind and photovoltaic productions of RES, WT_r^{spill} and PV_r^{spill} are the curtailed WT and PV productions, and the last term is the cost associated with load shedding L_l^{shed}.
The constraints of the model are presented by the each bus balance equation and capacity constraints:

$$\begin{aligned}&\sum_{g\in GC} P_g+\sum_{r\in RES} WT_r-\\&-\sum_{l\in Load} L_l \pm \sum_{b\in Branch} PF_b=0,\ \forall n\in Buses\end{aligned} \tag{2}$$

$$\begin{aligned}&\sum_{g\in GC}\left(R_{g,s}^U-R_{g,s}^D\right)+\sum_{l\in Load} L_{l,s}^{shed}+\\&+\sum_{r\in RES}\left(WT_{r,s}-W_{r,s}^{spill}\right)+\sum_{b\in Branch} PF_{b,s}=0,\ \forall n\in Buses,\\&\forall s\in Scen\end{aligned} \tag{3}$$

$$\begin{aligned}&PF_b\le PF_b^{\max},\forall b\in Branch\\&P_g+R_g^U\le P_g^{\max},\forall g\in GC\\&P_g-R_g^D\ge 0,\forall g\in GC\\&L_{l,s}^{shed}\le L_l,\forall l\in Load,\forall s\in Scen\\&W_{r,s}^{spill}\le W_{r,s},\forall r\in RES,\forall s\in Scen\end{aligned} \tag{4}$$

where PF^{max} is the maximum allowed power flow, P^{max} is the maximum produced power of the classical generators.

4. CASE STUDY

The case study is applied on the modified IEEE RTS-24 test system [11], where large scale classical generators were replaced with wind power plants and photovoltaic power plants, illustrated in figure 2. The load demand is reported in table 1. The shares of electrical energy generated by the units within the test system used for the bilateral contracts and bided on the spot market are reported in table 2 and table 3.

Table 1 – Demand at each bus

Bus	Demand (MW)	Bus	Demand (MW)	Bus	Demand (MW)
1	108	7	100	15	317
2	97	8	71	16	225
3	80	9	75	18	333
4	74	10	95	19	281
5	71	13	265	20	240
6	124	14	294		

Table 2 – Shares of electrical energy generated by the units [MW].

ID	GC	PV	WT	GC - RES	60%× (GC-RES)	40%× (GC-RES)
G1	40			40	24	16
G2	152			152	91.2	60.8
G3	40			40	24	16
G4	152			152	91.2	60.8
G5	300	50		250	150	100
G6	591		150	441	264.6	176.4
G7	0			0	0	0
G8	60			60	36	24
G9	155			155	93	62
G10	155			155	93	62
G11	400		100	300	180	120
G12	400	150		250	150	100
G13	300	100		200	120	80
G14	310			310	186	124
G15	350		100	250	150	100

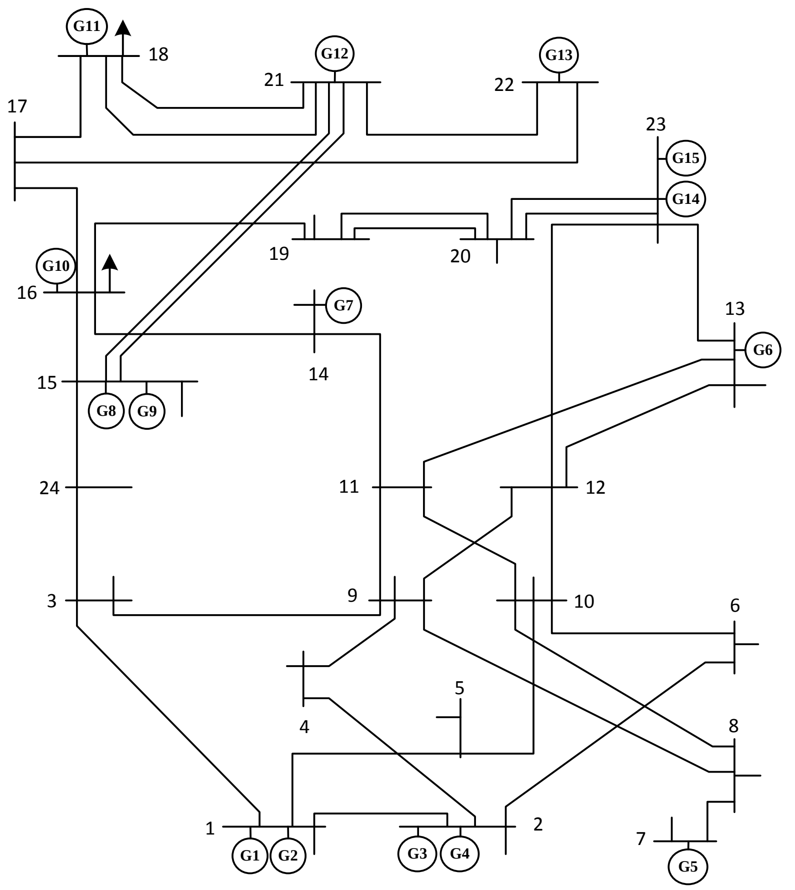

Fig. 2. IEEE RTS-24 bus test system

Table 3 – Shares of electrical energy generated by the units [MW].

RES production	min	med	max
WT	0	40%	100%
PV	0	35%	90%
Scenario probability π	20%	50%	30%

The obtained optimization results are illustrated in figure 3, showing the produced power by the classical generators and renewable energy sources for supplying the load demand, at each bus of the IEEE RTS-24 bus test system. The value of the objective function is 33738 u.m.

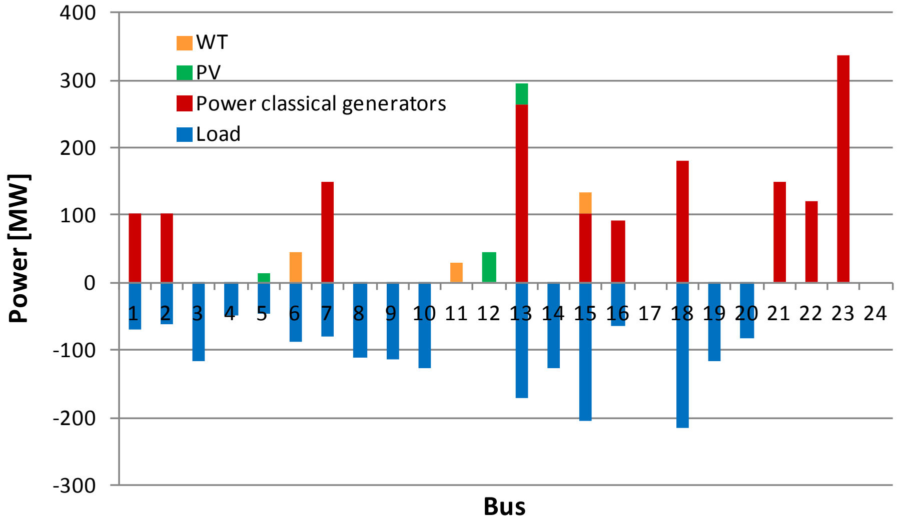

Fig. 3. Obtained optimization results of the generation units.

5. CONCLUSIONS

The paper optimizes the operation of a power system with the classical generation units and renewable energy sources (wind power plants and photovoltaic installation), all these participating to the electricity markets. The loads within the power system has bilateral contracts with the power suppliers, the rest of generation is bided on the spot market. The mathematical model proposed within this paper optimizes the operation of these power producers seeking to minimize the overall costs. In addition, the optimization model seek to ensure the operation of the power system determining the reserve requirements and its associated cost in vision of the stochastic character of the renewable sources, under different production scenarios for renewable sources.

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