Unified Scheduling of Pumped-Storage and Hydro-Thermal Units Based on Game Theory

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Abstract: Determining the main strategies in a country is performed with a long-term planning in order to reach sustainable development. Energy category and its delivery have more influence on economic and political development; thus, optimal scheduling should be performed in a way that considers mentioned attribute with comprehensive approach. Energy delivery and its efficiency increase in recent century and considering Next generation needs and their contribution in existing resources are contemplated as a significant challenge. Water is the most important natural resource in the World and it is vital to use these resources in an optimal way because of environmental issues and also political, economic, social issues, etc. One way to control and rein of surface water is to build dams on rivers. The dams are built for various reasons, but most serve multiple purposes: flood control power generation, irrigation, diversion, pisciculture, urban water reservoirs, livestock watering, and etc. The electric energy generation in majority of enormous dams is considered as a green power source with high efficiency. This paper introduces a new approach in order to control the existing fountains using pumped-storage systems based on game theory.

[Mohammad Sadegh Javadi, Bahram Noshad, Azim Nowbakht, Amin Javadinasab. Unified Scheduling of Pumped-Storage and Hydro-Thermal Units Based on Game Theory. Journal of American Science 2011;7(4):327-335]. (ISSN: 1545-1003). http://www.americanscience.org.

Keywords: Energy Market, Cournot Model, Game Theory, Pumped-storage Unit

1. Introduction

Rising fossil fuel costs and concerns about the environmental impact of burning fossil fuels have generated tremendous interest in the use of renewable energy sources to supply more and more of the electrical energy needs of society. The strong growth in renewable generation is expected to continue, and as its role increases, it will bring new challenges. These are principally related to the intermittency of renewable resources (Paul et al., 2008).

Increasing environmental concerns and advances in renewable energy technologies compose a favorable environment for the deployment of generators based on renewable energy sources. However, the operation of renewable energy units like wind generators presents the inconvenience of being intrinsically dependent on the variability of the wind resource (Lu´ıs, et al., 2008).

The primary energy sources for technologies like wind and solar power are not controllable and can be, at best, forecast. Energy storage used in conjunction with renewable energy has been suggested as a means to increase the use of renewable energy while maintaining a high quality of service reliability (Barton and Infield, 2004), (Schainker, 2004), (Leonhard, Grobe, 2004).

Using storage devices can help offset the effects of the inclusion of renewable energy sources and allow them to gain a larger penetration in the electrical energy supply. Storage may also be used to transfer energy from off-periods to on-peak periods, allowing the system to operate at a more constant level and reducing energy supply costs (Paul et al., 2008).

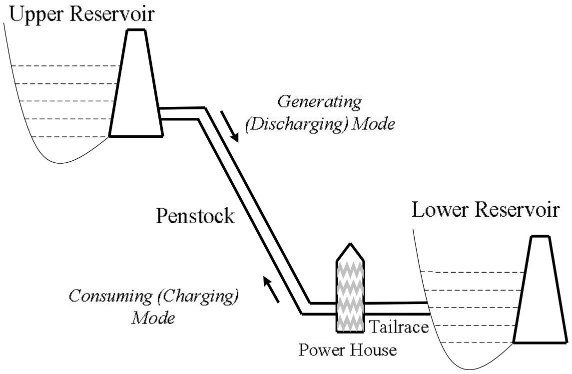

Figure.1 Simple Pump Storage Unit

A pumped-storage hydro-turbine is an energy storage device with water being recycled between an upper reservoir and a lower reservoir. Figure.1 illustrates the simple pumped-storage unit. In a vertically integrated market, hydrothermal coordination is used to reduce the fuel cost by letting the pumped-storage generators serve the peak load and then pumping the water back into the upper reservoir at light-load periods (Wood, Wollenberg, 1996), (Conejo, et al., 1990). Under a cost-based dispatch, it is not unusual for a pumped-storage unit to be always in either the generating or the pumping mode, except for the turnaround periods (Rau and Necsulescu, 1994).

In a competitive electricity market, companies having a large portfolio of generators may still use their pumped-storage units to coordinate with their thermal units to maximize the overall profit, but an individual pumped-storage unit owner will now buy and sell electricity either in the day-ahead and real-time markets or with bilateral contracts. This paper will focus on developing optimal bidding strategies for these individual pumped-storage unit owners to bid in the day-ahead market using game theory approach.

The algorithm can also be used to optimize the generation scheduling for other limited energy generation resources. Together with some price forecasting, the algorithm can be extended to evaluate the suitability of bilateral trade contracts (Ning, et al., 2004).

Pumped hydro power stations employ a long established method for storing mechanical potential energy by using surplus power for pumping water from a lower level, a reservoir or a river, to a higher level reservoir; when returning the water to the lower level, dispatchable peak- or controllable- power is generated at an efficiency of up to 80 %. Both modes of operation may be combined in a single hydraulic machine acting as a turbine or a pump. Based on the Electricity Storage Association report, worldwide close to 280 pumped hydro storage installations exist with a total power of about 90 GW or ca. 3 % of installed generating capacity, having power ratings up to several GW and storing energy for generating periods of hours to days (2010).

2. Power Market and Competition in Electric Energy Supply

The prosperous experiences of different industries privatization like communication, transportation and airlines in other countries caused the restructuring of energy industry. Therefore, the privatization progress has been begun. Considering the competitive and financial cases and their concentration on this continuum, each country authorizes some specific laws to face this issue. The main purpose of reconfiguration in power industry is to replace the governmental control with the private one, making competition, increasing the long-term revenue and the most important one, increasing the long-term social welfare that the law is authorized with this purpose. By reconfiguring and separating generation, transmission and distribution departments and moving from monopoly system (vertically integrated) to competitive one, new cases arrived to planning area. In these competitive conditions, investors follow the increase of their benefits and maximizing their profits in the power market. Thus, the purpose of an investor can be summarized in gaining the maximum benefit with the least risk. One of the most significant cases of planning in power system is long-term planning, including the expansion of generation and transmission infrastructures.

The horizon of long-term planning is usually described in several years and in which planning of generation and transmission systems expansion is performed to supply the load (Barton and Infield, 2004). The possible planning objectives include: facilitating market competition; providing nondiscriminatory access to cheap generation for all customers; enhancing reliability and maintaining sufficient capacity reserves; enhancing system security, etc (Zhao and Foster, 2010).

In traditional power systems, long-term planning was coherent and the electric energy was provided by independent institution in a centralized way. In traditional systems, the efficiency is extremely low because there is no motivation for generation units with low efficiency to improve the generation units and increase the efficiency and enhance the generation technology.

In this situation, the cost function is achieved according to generation level and imposed costs. In fact, the energy generation cost function is presented in generated power level. This cost function shows that how much power is generated for its corresponding cost. Then; these costs are aggregated and divided among customers.

In restructured and competitive markets, the situation is vice-versa; means like other economic systems based on supply and demand, the scale of generator tendency for each level of generation is determined and proposed to the market. Thus, the unit with more efficiency for a specific price tends to generate more than the one with lower efficiency.

Therefore, the power market is executed like a management-economic system. In this situation, units are required to notify their readiness for energy presentation or for instance, they are required to give the minimum acceptable price for each level of generation.

In traditional power systems, load forecasting should be first performed for generation scheduling. Thus, the amount of energy demands are estimated for next 24 hours, and then the least cost generation units are introduced in an economic dispatch program. In this state the load does not have cost elasticity and it is imposed to this case as a strict constraint. The decision making attribute for GenCos was offering their marginal price. It means that the unit selected for generation should have a generation cost equals to or less than system marginal price. The marginal price has a deep meaning in economy science that we can search these meanings in economy articles (Kirschen and Strbac, 2004). In this model, load, determines the marginal prices for each hour. In modern power systems, conditions are precisely vice-versa; it means that at first, generation companies are required to give the generation units marginal costs then the optimal generation level of each unit is determined by this cost. On the other side, the consumer's tendency for supplying their loads is received and by crossing the demand and aggregated offer, the market settlement cost is reached.

The price elasticity of electricity is too low because of its specific features and in this paper the non-elastic load is considered to simplify the analysis thus the independent system operator (ISO) denotes units which can supply load at the least cost for day-ahead power market (DA-market). In fact, in power market hourly generation level of each unit has been specified. The hourly cost is determined from proposed offers by specifying the generation units. Therefore, the most expensive accepted unit in power market determines the market price in that hour. The market clearing price (MCP) is paid to all GenCos in uniform pricing (UP) mechanism.

3. Pumped-Storage Unit Impacts on the Intra-day Markets

The use of the pumped storage principle to augment the run of the river, results in developing a dependable peaking resource which is greater by a factor of ten than would have been developed by the normal hydroelectric development of this same stretch of the river (Buygi, et al., 2004).

Maintenance problems would be reduced because there would be less stress induced by starting and stopping equipment. Whenever supply output was higher than load demand, the surplus would be stored in a storage facility. Whenever the load demand was higher than the supply output, the deficit would be released from the storage facility. Under such a scenario fewer plants would have to be built and the plants providing power would all be very efficient. There is only one practical storage method available, pumped storage (see Figure.2). Unfortunately, this has limited use because of geographic limitations. Nevertheless, wherever it is practical, pumped storage is very valuable. A pumped storage facility is a single mountainside hydro system in which there is limited or no inflow into the reservoir. At nighttime, when loads are low, the generator acts as a motor and the turbine acts as a pump. Water is pumped up the mountainside back to the reservoir. During the daytime when loads are high, the water is released from the reservoir, providing hydroelectric power (Mazer, 2007).

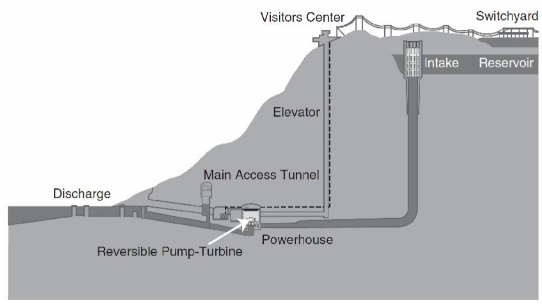

Figure 2. Pumped-Storage Plant as a Large-Scale Battery

In addition to power market and the competition in delivering the consumers energy as mentioned above, there are more markets in which the side services are tendered.

The market exists in the modern power systems is intra-day market in which the possibility of changing the primary offers from generation and distribution companies or retail companies are considered as a consumer shopping agency .

Intraday markets allow both retailers and producers to adjust their day-ahead schedules at predetermined times during delivery day. Both retailers and producers are interested in making adjustments as they update their delivery day requirements and output capabilities with information available throughout the delivery day. Retailers can sell back supply to the ISO or purchase additional supply as actual demand deviates from the day-ahead forecast. Similarly, producers may repurchase supply from the ISO or sell additional supply into the market. A market price is set by the ISO, which optimizes balancing resources that producers and retailers bid into the intraday markets.

Therefore, the market price is again determined by ISO that in this state ISO tries to optimize the generation and consumption equilibrium under intra-day markets. In such situation, pumped-storage units can be used to generate or store energy because of specific system conditions in the intra-day markets, which the hourly prices have been achieved. So the pumped-storage operator can perform its own optimal decision making with his information. Thus, this entity proceeds to buy energy in off-peaks periods in which the energy cost is low enough and functions as a load purchaser. On the other side, it means that hours in which the load demand and costs are high enough, the pumped-storage unit release its stored energy. There are too many advantages of having such units in modern and competitive power systems. In addition; such units can change the load profile and contribute to tabulate the load profile. Suppose we sort the hourly energy demand in an ascending to descending order system. Following figure shows one kind of these curves which are known as load duration curve (LDC).

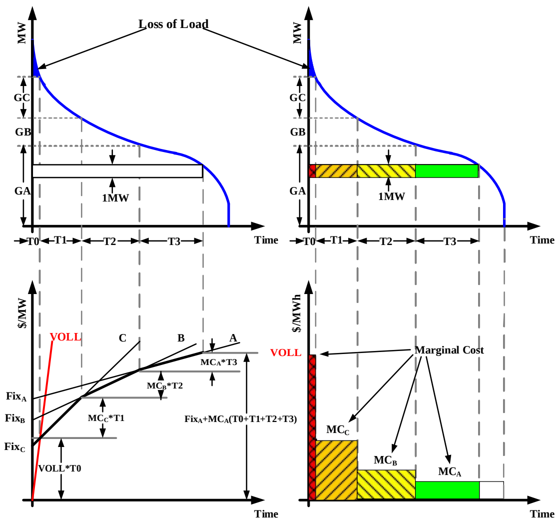

Figure 3. Cognitive model of Intermediary marketing

As it is obvious in above figures, energy price in on-peak period is appreciably high. Also, it is clear from above figures that for the base load, off-peak period, the energy price is low. Thus, a pumped-storage unit can change this curve in peak hours by purchasing energy in off-peak periods and generating energy in on-peak period.This issue from this point of view is similar to energy management persuasive policies. It leads the consumption pattern reform because of the tendency is to decrease consumption in on-peak periods and shift the unnecessary consumption to the off-peak periods (Javadi, B. Noshad, 2010).

4. Game Theory Approach Implementation on Intra-day Power Market

Before introducing the game theory approach and its application to this problem, brief activities associated with power delivery from day-ahead until delivery time, will be addressed. It provides the operational to do list for setting the dispatch and managing real-time load balancing. In doing so, the section frames the issues that are addressed in subsequent sections. First we denote the short-term planning and its mathematical formulation, and then we address the intra-day market and game theory approach, which is used to improve the simultaneous operation of thermal and pumped-storage units.

This section provides the fundamentals of short-term planning and operations within a utility environment, assuming that each utility is responsible for operating their generation units.

Since generators cannot instantly turn on and produce power, unit commitment (UC) must be planned in advance so that enough generation is always available to handle system demand with an adequate reserve margin in the event that generators or transmission lines go out or load demand increases.

Unit commitment handles the unit generation schedule in a power system for minimizing operating cost and satisfying prevailing constraints such as load demand and system reserve requirements over a set of time periods (Javadi, et al., 2009). The classic UC problem is aimed at determining the start-up and shutdown schedules of thermal units to meet forecasted demand over certain time periods (24 h to 1 week) and belongs to a class of combinatorial optimization problems (Zhu, 2009).

The objective function of vertically integrated utility system was minimizing the operation cost. This model is identified as a cost-based operation. Actually, the output of the UC program has two parts, namely defining the units in operation, which are determined by “0” and “1” (integer variables) for on and off units respectively, and determining the quantity of the generation level of operating units. Security-Constrained Unit Commitment (SCUC) provides a financially viable unit commitment (UC) that is physically feasible. The generation dispatch based on SCUC is made available to corresponding market participants (Javadi, et al., 2009).

The objective function of vertically integrated utility system was minimizing the operation cost. Therefore, this model is named cost-based operating system where the cost-based production, startup, and shutdown functions are considered in the UC formulation (Singh, 1999).

UC can provide an hourly commitment of generating units with minimum bid-based dispatch cost. The objective function (1) is composed of bid-based fuel costs for producing electric power and startup and shutdown costs of individual units for the given period. A typical set of constraints in UC includes:

1) Power balance;
2) Generating unit capacity;
3) System reserve requirements;
4) Ramping up/down limits;
5) Minimum up/down time limits;
6) Maximum number of simultaneous on/offs in a plant;

7) Maximum number of on/offs of a unit in a given period;
8) Maximum energy of a unit in a given period

In monopolized and vertically integrated utility the objective was to meet the forecasted demand plus the spinning reserve to minimize the production cost, subject to each individual unit's operation constraints and system constraints.

In this part the UC problem is formulated. The objective function is shown in (1) which consists of three parameters: cost of generation, start-up and shutdown costs. The cost function was described by a quadratic or linear piecewise function. The hourly UC constraints listed below include the system power balance (2), system spinning and operating reserve requirements (3), (4), ramping up/down limits (5), (6), minimum up/down time limits (7), (8) and unit generation limits (9). Additional system-wide constraints such as fuel constraints (10) and emission limits (11) are included in this formulation for representing the market interdependencies.

$$Min \sum_{i=1}^{NG}\sum_{t=1}^{NT}[F_{ci}(P_{it})*I_{it}+SU_{it}+SD_{it}] \quad (1)$$

$ST:$

$$\sum_{i=1}^{NG} P_{it}*I_{it}=P_{D,t}+P_{L,t} \quad (t=1,...,NT) \quad (2)$$

$$\sum_{i=1}^{NG} R_{S,it}*I_{it}\geq R_{S,t} \quad (t=1,...,NT) \quad (3)$$

$$\sum_{i=1}^{NG} R_{O,it}*I_{it}\geq R_{O,t} \quad (t=1,...,NT) \quad (4)$$

$$P_{it}-P_{i(t-1)}\leq [1-I_{it}(1-I_{i(t-1)})]UR_i+I_{it}(1-I_{i(t-1)})P_{i,\min} \quad (i=1,...,NG)(t=1,...,NT) \quad (5)$$

$$P_{i(t-1)}-P_{it}\leq [1-I_{i(t-1)}(1-I_{it})]DR_i+I_{i(t-1)}(1-I_{it})P_{i,\min} \quad (i=1,...,NG)(t=1,...,NT) \quad (6)$$

$$[x_{i(t-1)}^{on}-T_i^{on}]*[I_{i(t-1)}-I_{it}]\geq 0 \quad (i=1,...,NG)(t=1,...,NT) \quad (7)$$

$$[x_{i(t-1)}^{off}-T_i^{off}]*[I_{it}-I_{i(t-1)}]\geq 0 \quad (i=1,...,NG)(t=1,...,NT) \quad (8)$$

$$P_{i\min}\leq R_{it}+P_{it}\leq P_{i\max} \quad i=1,2,...,NG \quad t=1,2,...,T \quad (9)$$

$$\sum_{t=1}^{NT}\sum_{i\in FT}[F_{fi}(P_{it})*I_{it}+SU_{f,it}+SD_{f,it}]\leq F_{FT}^{\max} \quad (10)$$

$$\sum_{t=1}^{NT}\sum_{i=1}^{NG}[F_{ei}(P_{it})*I_{it}+SU_{e,it}+SD_{e,it}]\leq E_S^{\max} \quad (11)$$

Broadly speaking, decision theory is a mean of analyzing in which a series of options should be taken when it is uncertain exactly what the result of taking the option will be (Raiffa, 1968). Decision theory concentrates on identifying the “best” decision option, where the notion of “best” is allowed to have a number of different meanings, of which the most common is that which maximizes the expected utility of the decision maker. Decision theory provides a powerful tool by which to analyze scenarios in which an agent must make decisions in an unpredictable environment.

Game theory is a close relative of decision theory, which studies interactions between self-interested agents (Binmore, 1992). In particular, it studies the problems of how interaction strategies can be designed that will maximize the welfare of an agent in a multi-agent encounter, and how protocols or mechanisms can be designed that have certain desirable properties. Notice that decision theory can be considered to be the study of games against nature, where nature is an opponent that does not seek to gain the best payout, but rather acts randomly. Given this brief description, it comes as no surprise to learn that many of the applications of game theory in agent systems have been to analyze multi-agent interactions, particularly those involving negotiation and co-ordination (Parsons and Wooldridge, 2000).

Cournot model of oligopoly competition is one of the prevalent models, was introduced by Augustin Cournot (Cournot, 1897).

In the Cournot model of duopoly, two firms produce a homogenous product and must decide how much to produce without knowing the decision of the other. There are several similarities between the Cournot model and the energy generation in intra-day market. This makes the Cournot model applicable to the competitive electricity market.

After formulating the short-term operation behaviors for players, the key task is to find Cournot equilibrium. In the Cournot duopoly model, the Cournot equilibrium is a quantity pair that maximizes the profit of each firm, given other firm’s output quantity (Cournot, 1897). In terms of mathematics, the optimal quantity pair (q_1^*,q_2^*) is the Cournot equilibrium if, for firm 1, q_1^* solves:

$$\underset{q_1}{Max}\,\pi_1=(q_1,q_2^*) \quad (12)$$

Where:

π_i: Profit for firm "*i*"; *i*=1,2;

q_i: Quantities produced by firm "*i*";

q_i^*: Optimal quantities produced by firm "*i*";

The profit function for firm 1 can be represented by (13)

$$\pi_1 = (q_1, q_2) = p(q_1 + q_2)q_1 - c_1(q_1) \quad (13)$$

Where:

$p(.)$: Market price for aggregate quantity.

$c_i(.)$: Cost function for firm "*i*".

After executing the UC program, the units generation amount and the start-up and shutdown time interval of each unit is determined. Also, the energy market hourly prices are determined by executing this program. Now, it is time to execute the intra-day market. In this state, the generation companies, independent power producers, retailers, purchase agencies and distribution companies proceed to perform essential reforms to get more benefit considering the more accurate load forecasts and their hourly prices. This opportunity from the pumped-storage unit operator point of view is individual and valuable considering its unit technical constraints (Javadi, Monsef, 2009).

The objective function (14) represents the revenues of pumped-storage plant including the trading in energy and regulation markets.

$$Max \sum_{t=1}^{T} [P_g(t) - P_p(t)] * \lambda(t) \quad (14)$$

The above objective function represents that the market price has a vital role in maximizing the profit of selling energy or in purchasing the energy from limited energy units in intra-day market. $\lambda(t)$ is the energy market clearing price at time "$_t$", $P_p(t)$ and $P_g(t)$ are the pumping power to the reservoir and generating energy from the reservoir, respectively. The constraints are as follow:

$$U_g(t) * P_{\min} \le P_g(t) \le U_g(t) * P_{\max} \quad (15)$$

$$U_p(t) * P_{\min} \le P_p(t) \le U_p(t) * P_{\max} \quad (16)$$

$$U_g(t) + U_p(t) \le 1 \quad (17)$$

$$U_g(t-1) + U_p(t) \le 1 \quad (18)$$

$$U_p(t-1) + U_g(t) \le 1 \quad (19)$$

$$E(t) = E(t-1) - P_g(t) + \eta P_p(t) \quad (20)$$

$$E_{\min} \le E(t) \le E_{\max} \quad (21)$$

$$E_{end} \ge \beta E_0 \quad (22)$$

Equations (15) and (16) show the lower and upper limits of the generating, pumping powers respectively. To eliminate conflict between different modes in a specific hour, equation (17) is considered. Equations (18) and (19) are applied to satisfy the changeover times. The changeover time of a pumped-storage plant is typically between 15 to 30 minutes. For a DA market operated on an hourly basis, this constraint translates to a plant having a buffer of at least one hour at zero generation between generating and pumping modes (Lu, et al., 2004). Equations (20) to (22) are related to the amount of energy stored in the upper reservoir. The amount of energy stored in the upper reservoir in each hour is calculated by (20). The ratio of the transformation rates of water into energy during pumping and generating modes is called round-trip efficiency (η). The lower and upper limits of energy stored amount in the upper reservoir are presented by (21). In addition, in order to reserve enough energy to be stored for the subsequent week, equation (22) is applied. The parameter β adjusts the amount of energy that should be stored for the subsequent week. If lower prices for the next week are forecasted, the pumped storage plant owner will choose a low value for β. This parameter can be varied while energy stored constraints are satisfied. The optimization problem of equations (14) to (22) is a mixed integer programming (MIP) problem.

Note that the efficiency of such unit is about 70% to 90% that 80% percent is considered in this paper. (η =0.8)

As mentioned above, purchasing energy from market causes the system load to increase and on the other hand, selling energy to the market causes the hourly price to decrease. These subjects are in contrast with each other and the pumped-storage unit operator's strategy alters according to its own function to participating in the power market. Thus, this issue is such a one based on non-cooperative game theory and it is not a simple optimization issue anymore. The best model for executing and evaluating this is Cournot duopoly model in which one side is pumped-storage unit's operator decision making and the other side is intra-day market with all participants. In Cournot duopoly model, two institutions are generating the homogenous product and they choose their own optimal strategy without any knowledge about other sides. In this model, there are too many similarities to such a model that it can be used to perform the best strategy determination program in the intra-day market.

The first step in operation of the intra-day market for the pumped-storage unit's operator decides whether the under control unit wants to sell the generation capacity or wants to purchase the energy from the market. On the other side, there is energy market and other competitors in which disregarding to the proposed offers and amount of loads, hourly prices and generation amount and the capacity of each accepted entity are determined. Thus, the decision variable for each participant is the strategy of purchasing energy or selling capacity. In the energy market, the production of each unit is the same.

After formulating the rivals attribute in the energy and intra-day market, the purpose is to find the optimal point in Cournot equilibrium. In Cournot duopoly model, the optimal point regards to Cournot equilibrium is the state in which for that regular pair, it maximizes the both side's benefits from purchasing or selling the capacity.

Table1. Unit operational constraint

Unit	Unit Constraints								
	Pmax	Pmin	Ramp Up	Ramp Down	CSt	CSh	Init	MUT	MDT
1	500	150	100	100	4500	600	8	5	5
2	500	150	250	100	5000	620	8	5	5
3	130	20	35	40	550	670	-5	2	2
4	130	20	35	40	560	700	4	2	2
5	162	25	40	40	900	1100	-6	3	2
6	80	20	15	20	170	370	3	2	2
7	85	25	20	20	260	300	3	2	2
8	55	10	10	10	40	40	-1	0	1
9	55	10	10	10	30	40	-1	0	1
10	55	10	10	10	35	40	-1	0	1

5. Case Study and Simulation

To evaluate the proposed algorithm in the energy market, recommended network has been considered (Javadi, Monsef, 2009). This test system consists of 10 generation buses that participate in energy market.

Each bus includes several generators that each one offers their cost to the market. Table 1 shows the generation units operating constraints. In this paper it is assumed that the market is executed in perfect single-side market and only generation units offer price, it means that demands have a price elasticity of zero and considered as a solely constraint. Also, it is supposed that there is only one pumped-storage unit in the system and it only participate in intraday market. This unit capacity is 100 MW and its daily release energy constraint is 1000 MWh. The generation hourly limit to switch mode is considered about an hour. At the first hour of this study, energy production capability considered as 400 MWh. Figures 4 and 5 show the mentioned unit effect on the daily load profile and load duration curve, respectively. In Figure 4, the continuous curve is daily load in the day-ahead market and the dotted line curve shows a state in which a pumped-storage unit participates in the intra-day market.

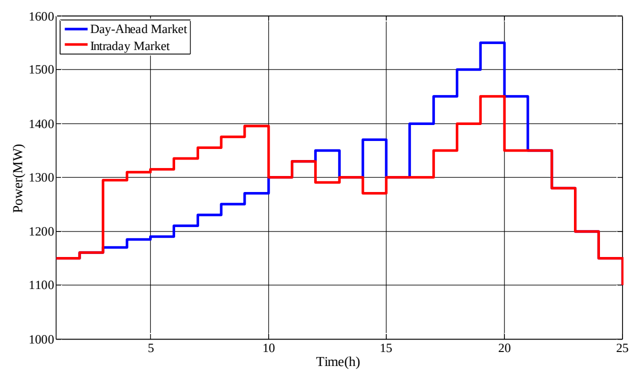

Figure. 4 Load curve in day-ahead market (continuous curve) and intra-day market (dotted line curve)

6. Discussion and Conclusion

In this paper the generation unit participation in energy day-ahead and intra-day market has been analyzed and evaluated according to the game theory approach. As mentioned before, one of the limited energy units is pumped-storage unit, which uses the water energy in the best conditions in addition to an appropriate water resource management. The pumped-storage unit has more advantages than the cascaded hydroelectric units which are installed on a dam. And the specified amount of water can be used for a long-time to generate energy and each time it is necessary, the penstock can be opened for other intentions such as drinking water or agriculture utilizations.

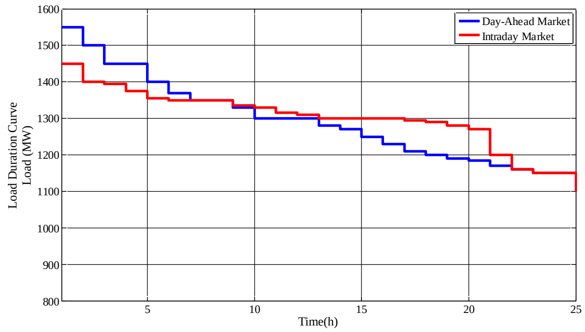

Figure. 5 Load duration curve in executing two markets with and without the pumped-storage unit attendance

Acknowledgements

This work is granted and supported by Islamic Azad University, Mahshahr Branch, Mahshahr, Iran.

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References
1. Paul D. Brown, J. A. Peças Lopes, Manuel A. Matos, Optimization of Pumped Storage Capacity in an Isolated Power System with Large Renewable Penetration, IEEE Trans. Power System, 2008, 23(2):523-31.
2. Lu´ıs M. Costa, et al, Management of Energy Storage Coordinated with Wind Power under Electricity Market Conditions, Probabilistic Methods Applied to Power Systems, 25-29 May 2008.
3. Ning Lu, Joe H. Chow, Alan A. Desrochers, Pumped-Storage Hydro-Turbine Bidding Strategies in a Competitive Electricity Market, IEEE Trans. Power System, 2004,19(2):834-41.
4. W. Leonhard, Emeritus, M. Grobe, Sustainable Electrical Energy Supply with Wind, Biomass and Pumped-Hydro Storage– A Realistic Long-term Strategy or Utopia?, IEEE Power Engineering Society General Meeting Conference, June 2004.
5. N. Lu, J.H. Chow and A.A. Desrochers, Pumped-storage hydro-turbine bidding strategies in competitive electricity market, IEEE Trans. Power System; 2004, 19(2):834-41.
6. Junhua Zhao and John Foster, Flexible Transmission Network Planning Considering the Impacts of Distributed Generation, October 2010.
7. M.O. Buygi, H.M. Shanechi, G. Balzer, M. Shahidehpour, N. Pariz, Network planning in unbundled power systems, Power Systems, IEEE Transactions; 2006,21(3):331;38.
8. Simon Parsons, Michael Wooldridge, Game Theory and Decision Theory in Multi-Agent Systems, (Kluwer Academic Publishers. Printed in the Netherlands 2000).
9. H. Raiffa. Decision Analysis: Introductory Lectures on Choices under Uncertainty. Addison Wesley, Reading, MA., 1968.
10. K. Binmore. Fun and Games: A Text on Game Theory. D. C. Heath and Company: Lexington, MA, 1992.
11. A. Cournot, Research into the Mathematical Principles of the Theory of Wealth, (New York, Macmillan, translated by Nathaniel Bacon, 1897).
12. S. Jalal Kazempour, et al, A MIP-Based Optimal Operation Scheduling of Pumped-Storage Plant in the Energy and RegulationMarkets, UPEC Conference 2008.
13. H. Haghighat, H. Seifi and A.R. Kian, on the self-scheduling of a power producer in uncertain trading environment, Electric power System Research, 2007, 311-7.
14. J. Barton and D. Infield, "Energy storage and its use with intermittent renewable energy," IEEE Trans. Energy Conversion, 2004, 19(2): 441-8.
15. R. Schainker, "Executive overview: Energy storage options for a sustainable energy future," in Proc. IEEE Power Eng. Soc General Meeting, 2004:2309-14.
16. W. Leonhard and E. Grobe, "Sustainable electrical energy supply with wind and pumped storage—A realistic long-term strategy or utopia?" in Proc. IEEE Power Eng. Soc. General Meeting, 2004: 1221-5.
17. A. J. Wood and B. F. Wollenberg, Power Generation Operation and Control.(New York: Wiley, 1996).
18. A. J. Conejo, M. C. Caramanis, and J. A. Bloom, "An efficient algorithm for optimal reservoir utilization in probabilistic production costing," IEEE Trans. Power System, 1990, 5(3):439–47.
19. N. S. Rau and C. M. Necsulescu, "Economics of energy storage devices in interconnected systems—A new approach," IEEE Trans. Power App. System, 1984, 103:1217-23. (Electricity Storage Association: Large scale electricity storage technologies, http://www.electricitystorage.org.
20. M.O. Buygi, G. Balzer, H.M. Shanechi, M. Shahidehpour, "Market-based transmission expansion planning", Power Systems, IEEE Transactions on, 2004,19(4):300-12.

21. Arthur Mazer, Electric Power Planning for Regulated and Deregulated Markets, (John Wiley, 2007).
22. D. Kirschen, G. Strbac, Fundamentals of Power System Economics (John Wiley & Sons,2004)
23. M. Javadi, R. Azami, H. Monsef, Security Constrained Unit Commitment of Interconnected Power Systems, International Review of Electrical Engineering I.R.E.E, 2009, 4(2): 199-205.
24. M. Shahidehpour, H. Yamin, and Z. Y. Li, Market Operations in Electric Power Systems. (New York: Wiley, 2002)
25. Electricity Storage Association: Large scale electricity storage technologies, http://www.electricitystorage.org.(May-2010)
26. M. S. Javadi, B. Noshad, Energy Market Clearing Mechanism in Iran Electricity Market, Iran 1404 visionary conference, Ahwaz, 2010.
27. Jizhong Zhu, Optimization of Power System Operation, (Wiley-IEEE Press-2009).
28. H. Singh, Introduction to game theory and its application in electric power markets, Computer Application Power, IEEE, 1999, 12(4):18–22.
29. M. S. Javadi, H. Monsef, Security-Constrained Unit Commitment in Restructured Power system considering the reliability issues, Power System Conference 23rd, Nov. 2009, Iran.

2011-03-29