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GENERATION RELIABILITY ASSESSMENT IN OLIGOPOLY POWER MARKET USING MONTE CARLO SIMULATION

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ABSTRACT
Deregulation policy has caused some changes in the concepts of power systems reliability assessment and enhancement. In this paper, generation reliability is considered, and a method for its assessment in the oligopoly market based on Cournot–Nash model is proposed. Monte Carlo simulation is used for reliability evaluation. Generation reliability, merely focuses on interaction between generation complex and load. Therefore, this paper using oligopoly market economic subjects in Cournot–Nash model, deals with offer curve of power plants and demand curve. Then from intersection of these curves and regarding to other parameters, reliability index is determined. The proposed method is assessed on IEEE-Reliability Test System with satisfactory results. In all cases, generation reliability indices are evaluated with different reserve margins and various load levels.

KEY WORDS
Marketing- Power generation reliability- Monte Carlo Simulation.

1. Introduction

Power systems have evolved over decades. Their primary emphasis has been on providing a reliable and economic supply of electrical energy to their customers [1]. A real power system is complex, highly integrated and almost very large. It can be divided into appropriate subsystems or functional zones that can be analyzed separately [2]. This paper deals with generation reliability assessment (HLI) in power pool market, and transmission and distribution systems are considered reliable and adequate as shown in Fig. 1.

Most of the methods used for HLI reliability evaluation, are based on the "loss of load or energy" approach. One of the suitable indices that describes generation reliability level is "Loss Of Load Expectation" (*LOLE*); that is the time in which load is more than available generation.

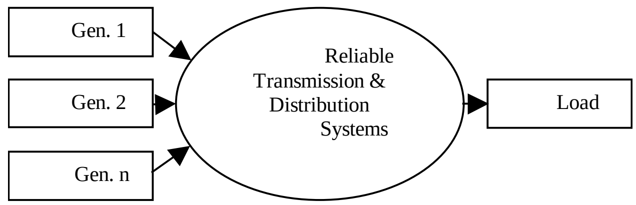


Fig.1. Power pool market schematic for HLI reliability assessment

Generally, the reliability indices of a system can be evaluated using one of two basic approaches [3]:

- Analytical techniques.
- Stochastic simulation.

Simulation techniques, estimate the reliability indices by simulating the actual process and random behavior of the system. Since power markets and generators' forced outages have stochastic behavior, Monte Carlo Simulation (MCS) which is one of the most powerful methods for statistical analysis of stochastic problems, is used for reliability assessment in this research.

HLI reliability depends absolutely on generating units specifications. The main function in traditional structure for Unit Commitment (UC) of generating units is generation cost minimization. Since beginning 21st century, many countries have been trying to deregulate their power systems and create power markets [4]-[8]. In power markets, the main function of players, is their own profit maximization; which severely depends on type of the market. As a result, reliability assessment in HLI completely depends on market type and its characteristics.

Generally, economists divide the markets in four groups [9]. This paper deals with evaluation of generation reliability in oligopoly power pool market.

In [10], independent power producers' impact on reliability and associated costs of existing power systems under deregulation environment has been presented. This paper has used "Expected Unserved Power" (*EUP*) as reliability index and economic dispatch problem is solved under some reliability and system constraints.

[11] has used "Effective Load Duration Curve" (*ELDC*) for evaluation of "Loss Of Load Expectation" (*LOLE*) and "Expected Energy Not Served" (*EENS*) as reliability indices in HLI.

[12] has presented some reliability models for different players in a power system. Generation system is represented by an equivalent multi-state generation provider (*EMGP*). The reliability parameters of each *EMGP* are shown by an available capacity probability table (*ACPT*) which is determined using conventional techniques. Then, the equivalent reliability parameters for each state (including state probability**,** frequency of encountering the state and the equivalent available generation capacity) are determined.

[13] has presented generation operational cost minimization problem under system constrains and load uncertainty for evaluation of "Expected Unserved Power" (*EUP*) as reliability index.

Most of the papers have been presented till now about reliability of deregulation power systems, only deal with power systems constrains; and kind of market (based on economics) and its effect on the power system is ignored. Therefore, this paper meantime to consider economic subject of oligopoly power market, deals with HLI reliability assessment in mentioned power pool market using MCS. Also, sensitivity of reliability index to different reserve margins and future times will be evaluated. In section-II fundamental of oligopoly power pool market is discussed. In section-III, the algorithm for HLI reliability assessment in the mentioned market will be proposed and finally in section IV case study results are presented and discussed.

2. Power Pool Market Fundamentals

Market demand curve has negative gradient. Amount of demand decrease is explained by "price elasticity of demand". This index is small for short term, and big for long term; because in longer term, customers can better adjust their load relative to price [14]. Demand function, generally, is described as $P=a-b.Q$. Therefore, price elasticity of demand is explained as indicated in (1).

$$E_d = \left|\frac{dQ}{dP}\right| = \frac{1}{b} \tag{1}$$

Let's suppose forecasted load by dispatching and control centers is an independent power from price and it equals Qn. Therefore, price of electrical energy is zero. As a result, demand function can be obtained as (2).

$$P = a - b.Q = b.Qn - b.Q = \frac{Qn}{E_d} - \frac{Q}{E_d} \tag{2}$$

Typically as shown in Fig. 2, price elasticity in power markets, is 0.1-0.2 for 2-3 future years and 0.3-0.7 for 10-20 future years [14]. In short term, costumers can't completely adjust their consumption with price, and price elasticity is small and in long term it is high.

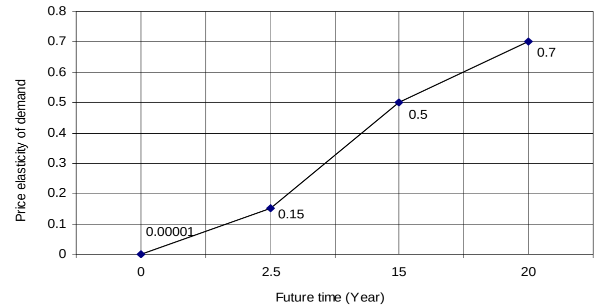


Fig. 2. Price elasticity of demand for various times

In economics, if sale price in a market becomes less than minimum average variable cost, the company will stop production; because the company will not cover variable cost in addition to fixed cost [9]. Because of changing efficiency and heat rate in power plants, marginal cost becomes less than average variable cost. Therefore, in power plants, average variable cost replaces marginal cost [15].

In power markets, Hirschman - Herfindahl Index (*HHI*) which is obtained from (3), is used for market concentration measurement [16]:

$$HHI = \sum_{M} q_n{}^2 \tag{3}$$

As *HHI* becomes less, concentration gets less too, and each plant will have less proportion of total installed capacity. Therefore, "market power" becomes less. Market power is the ability of a plant to mark up the price relative to its marginal cost in the market [17]. Market power for plant "n" is obtained using Lerner index as (4) [17].

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} \tag{4}$$

With differentiation from revenue function of company "n" in Cournot-Nash model of oligopoly power market, (5) is obtained [17].

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} = \frac{s_n}{E_d} \tag{5}$$

where:

$$s_n = \frac{q_n}{Q} \quad , \quad Q = q_1 + q_2 + \ldots + q_M$$

Therefore, the most profitable offer price for plant "n" with q_n generation capacity is obtained from (6).

$$P_n = \left(\frac{E_d}{E_d - s_n}\right) \times MC(q_n) \tag{6}$$

As it is understood from (5-6), as the market share of the company increases, that company will have more market power and can mark up the price, more. Also, as the price elasticity of demand is reduced, companies can mark up electricity price, more.

Total offer curve of all plants is obtained from horizontal sum of each plant's offer curve. This curve is a price increase step or merit order function. Finally, equilibrium price and equilibrium amount in oligopoly power pool market are obtained from intersection of total offer and demand curves. A typical total offer curve and demand curve is shown in Fig. 3.

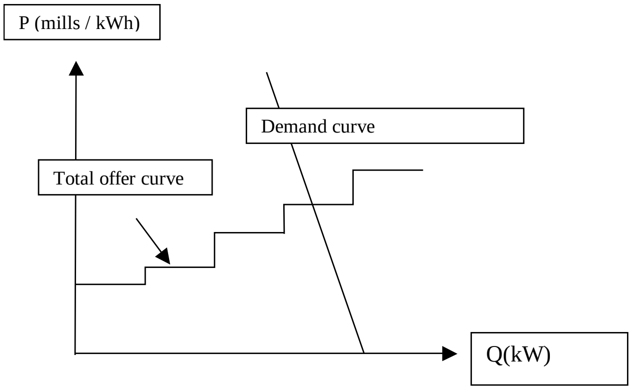


Fig. 3. Typical total offer and demand curves

3. Proposed Method for HLI Reliability Evaluation in Oligopoly Power Market

Generation reliability of a power system depends on many parameters. One of these parameters which has an important role, is reserve margin that is defined as (7) [18].

$$RM\% = \frac{Installed \quad Capacity - Peak \quad Demand}{Peak \quad Demand} \times 100 \qquad (7)$$

Algorithm of HLI reliability assessment in oligopoly power pool markets using MCS is shown in Fig. 4. Steps of proposed algorithm are as following:

1- Calculation of total offer curve of power plants.
2- Determinations of day and related load (*Qn*) randomly, and demand curve using (2).
3- The power plants which are selected for generation in the selected day are determined from intersection of power plants' total offer curve and demand curve with regards to reserve margin.
4- For each selected power plant in previous step, a random number between [0-1] is generated. If the generated number is more than power plant's *FOR*, the power plant is considered available in mentioned iteration; otherwise it encounters forced outage and can't generate power. This process is performed for all power plants using an independent random number generated for each one of them. Finally, sum of the available power plants' generations is calculated.
5- If the sum becomes less than intersection of power plants' total offer curve and demand curve, we will have interruption in the iteration, and therefore, *LOLE* increases one unit; otherwise, we go to the next iteration.
6- Steps 2 to 5 are repeated for calculation of *LOLE*.

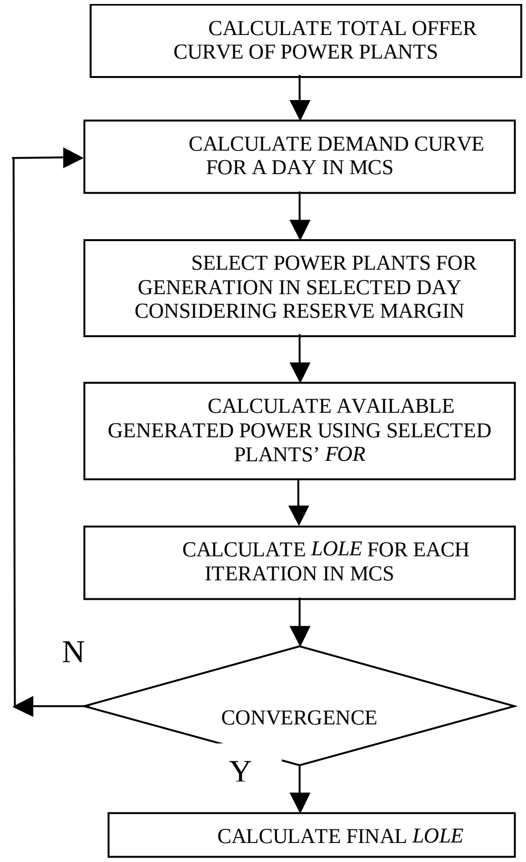


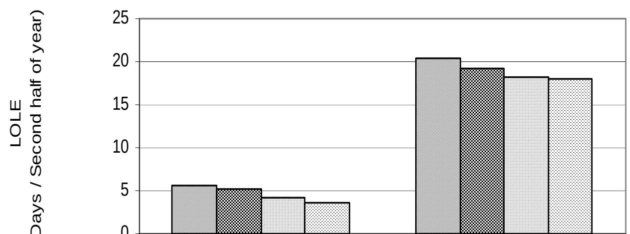
Fig. 4. Flow chart of HLI reliability assessment in oligopoly power pool markets using MCS

4. Numerical Studies

IEEE - Reliability Test System (IEEE – RTS) is used for case studies. Data for IEEE-RTS can be found in [19]. In various case studies following assumptions are applied:

1- All studies are simulated for second half of year, based on daily peak load of mentioned test system.
2- All simulations are done with 10000 iterations.
3- Each study is simulated for two different times (2nd and 5th future years), and in lieu of four various reserve margins (0%, 4.8%, 9%, 13%).
4- Fuels costs and O&M average variable costs which have been mentioned in IEEE-RTS, are considered as basic amount of these costs at present time. Also, plants' *FOR* which have been mentioned in the test system, are considered as their base rate in simulations.
5- Annual growth rates of power plants' generation capacity and consumed load are considered 3.4% and 3.34% as their base rate, respectively.
6- Annual growth rates of oil and coal costs are considered 4% and 1% as their base rate, respectively. Nuclear fuel cost (including uranium, enrichment and fabrication) is considered as a fixed rate. Also, basic annual growth rate of variable O&M cost is considered 1%.
7- Each plant belongs to an independent company.

In first study, base rate of plants' *FOR*, annual growth rate of plants' capacity, consumed load, fuel costs and variable O&M cost are used in simulations. Based on mentioned assumptions and using the proposed algorithm, *LOLE* values are obtained versus different times and reserve margins according to graph and table shown in Fig. 5.

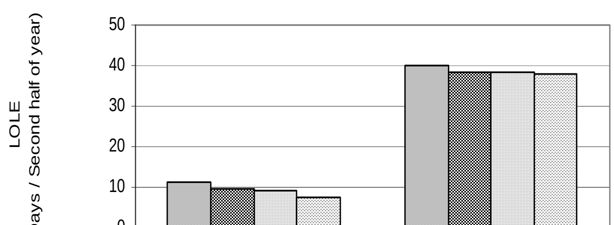


	2	5
RM=0%	5.53	20.45
RM=4.8%	5.22	19.22
RM=9%	4.19	18.19
RM=13%	3.51	18.07

Future years

Fig. 5. *LOLE* values for first study

In second study, annual growth rate of plants' capacity, consumed load, fuel costs and variable O&M cost are equal to their base rate; but all plants' *FOR* are considered twice their base rate. Based on these assumptions and using the algorithm, *LOLE* values are calculated versus various times and reserve margins according to graph and table shown in Fig. 6.

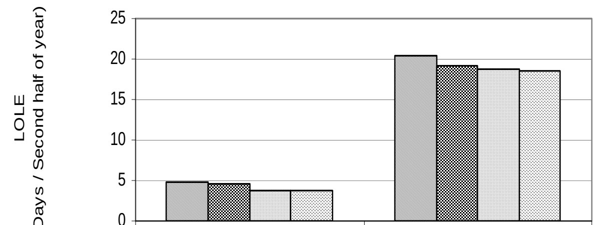


	2	5
RM=0%	11.12	39.95
RM=4.8%	9.65	38.44
RM=9%	9.01	38.18
RM=13%	7.53	38

Future years

Fig. 6. *LOLE* values for second study

In third and last study, plants' *FOR*, annual growth rate of plants' capacity and consumed load are equal to their base rate; but annual growth rate of fuel costs and variable O&M cost are considered twice their base rate. Based on these assumptions and using the proposed algorithm, *LOLE* values are calculated versus different times and reserve margins according to graph and table shown in Fig. 7.



	2	5
RM=0%	4.71	20.51
RM=4.8%	4.51	19.27
RM=9%	3.73	18.76
RM=13%	3.73	18.51

Future years

Fig. 7. *LOLE* values for third study

In all case studies, if reserve margin increases *LOLE* will decrease and reliability will improve.

In all studies, the main reason of *LOLE* increase in the future fifth year relative to the future second year, is the change of plants' offer price; and therefore, causing change in plants' arrangement according to price. For example, in studies 1, 3 and 4, in the future fifth year, *FOR* of the last plant which is selected for generation, is 0.12. This is while, for mentioned studies, in the future second year, *FOR* of the last plant which is selected for generation, is 0.02. Evidently, change of plants' offer price, is because of price elasticity of demand change in different future times.

Let's consider first study as basic one. As it's remarkable, increase of plants' *FOR* has the most effect on *LOLE* increase (second study).

In third study, annual growth rate increase of fuels and average variable O&M costs has no effect on arrangement of plants relative to basic study. Therefore, *LOLE* changes compared to its values in basic study is very small. In fact, between last two studies, third study has the least changes compared to basic study.

It is to be noted that since in IEEE- RTS available capacity of hydro plants are different in first and second half of year, therefore simulations have been done for second half of year. Evidently, the proposed method can be utilized for every simulation time. Also, in this paper, it is supposed that annual additional generation capacity, distributes between all present generators, uniformly. If in a power system, generation planning scenarios are specified, they can be used in the proposed method.

5. Conclusion

In this paper, HLI reliability of oligopoly power pool market (Cournot-Nash model) is evaluated. Because of market and generators' *FOR* random behavior, MCS is used for simulations. In this research, based on plants' total offer curve and load curve and considering various parameters, reliability index is calculated. *LOLE* is considered as reliability index; and following results are obtained:

- Plants can use market power to maximize their revenue.
- If a plant's market share in the market increases or price elasticity decreases, the plant can mark up the price, more.
- The main reason for *LOLE* increase in different times, is change of plants' offer price; and therefore, change in plants arrangement according to price.
- Plants' *FOR* has the most effect on *LOLE* increase; and annual growth rate increase of fuels and average variable O&M costs has the least effect on *LOLE* change compared to basic study.

References

[1] Billinton R., Allan R., *Reliability Evaluation of Power Systems*, Second edition. New York: Plenum press, 1996, p. 1.

[2] Billinton R., Allan R., *Reliability Evaluation of Power Systems*, Second edition. New York: Plenum press, 1996, p. 10.

[3] Billinton R., Allan R., *Reliability Evaluation of Engineering Systems*, Second edition. New York: Plenum press, 1992, p. 372.

[4] Energy Information Administration (EIA), "The changing structure of the electric power industry: An update, DOE/EIA-0562(96)," Washington DC, December 1996

[5] Energy Information Administration (EIA), "Electric sales and revenue, DOE/EIA-0450(96)," Washington DC, December 1996.

[6] Office of Gas and Electricity Market (OFGEM), Department of Trade and Industry (DTI), "An overview of the New Electricity Trading Arrangement (NETA)," V. 1, England, 31 May 2000.

[7] Office of Gas and Electricity Market (OFGEM), DTI, "News release, New electricity market goes live," England, 27 March 2001.

[8] http://www.ks.dk/publikationer/konkurrence/2003/nordisk

[9] Robert S. Pindyck, D. L. Rubinfeld. *Microeconomics*, Fifth edition. USA: Prentice Hall, 2001.

[10] K. Okada, H. Asano, R. Yokoyama, T. Niimura, "Reliability-based impact analysis of independent power producers for power system operations under deregulation," in Proc. 1999 IEEE Canadian conference on electrical and computer engineering, pp. 1325- 1330.

[11] Jaeseok Choi, Hongsik Kim, Junmin Cha, Roy Billinton, "Nodal probabilistic congestion and reliability evaluations of a transmission system under the deregulated electricity market," 2001 IEEE Power engineering society summer meeting, pp. 497-502.

[12] Peng Wang, R.Billinton, "Implementation of non-uniform reliability in a deregulated power market," 2003 IEE Proc.-Gener. Transm. Distrib., Vol. 150, No. 5, pp. 857- 861.

[13] Satoru Niioka, Akira Kozu, Masachika Ishimaru, Ryuichi Yokoyama, "Supply reliability evaluation method for deregulated electric power market considering customers uncertainty," in Proc. 2002 IEEE International conference on power system technology, Proceedings PowerCon , vol. 3, pp. 1782-1786.

[14] International Energy Agency (IEA), *The Power to Choose- Demand Response in Liberalized Electricity Markets*. France: IEA, 2003, p. 21.

[15] Severin Borenstain, "Understanding competitive pricing and market power in wholesale electricity market," University of California energy institute, Feb.1999.

[16] International Energy Agency (IEA), *The Power to Choose- Demand Response in Liberalized Electricity Markets*. France: IEA, 2003, p. 54.

[17] http://www.ks.dk/publikationer/konkurrence/2003/nordisk/kap03.

[18] International Energy Agency (IEA), *Security of Supply in Electricity Markets - Evidence and Policy Issues*. France: IEA, 2002, p. 16.

[19] "IEEE- Reliability Test System (IEEE- RTS)," Nov./Dec.1979 IEEE Trans. Power Apparatus Syst.,Vol. Pas-98, No.6, pp. 2047-2054.

Appendix: List of Symbol

MC: Marginal cost (mills/kWh)
Q: Quantity of power (kW)
P: Electrical energy price (mills/kWh)
RM: Reserve margin (%)
E_d : Price elasticity of demand ($kW^2h/mills$)
Qn: Forecasted load (kW)
LOLE: Loss of load expectation (Days / Simulated time)
FOR: Forced outage rate of power plants
q_n : nth company share of total installed power in the pool market (%)
M: Number of independent companies in the market
a: Demand curve cross of basis (mills/kWh)
b: Demand curve gradient ($mills/kW^2h$)
HHI: Hirschman - Herfindahl index
L_n : Lerner index of nth company