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Generation Reliability Evaluation and Comparison in Various Power Markets Using Monte Carlo Simulation and Neural Networks

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Abstract: Deregulation policy has caused some changes in the concepts of power systems reliability assessment and enhancement. Generation reliability comparison in 3 kinds of power pool markets was considered: perfect competition, monopoly and oligopoly power markets. Because of power market and generators' forced outages stochastic behavior, Monte Carlo Simulation was used for reliability evaluation. Also, for creating a unique structure, a feed forward neural network which has similar numerical results in comparison with MCS results, was used for generation reliability evaluation. The proposed method was assessed on IEEE-Reliability Test System. In all cases, generation reliability indices were evaluated with different reserve margins and various load levels. Results were in good agreement with theoretical considerations. If price elasticity of demand increases, reliability will improve. Also, if market becomes more concentrated, reliability will improve.

Key words: Power market, generation reliability, monte carlo simulation, neural networks

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 (Billinton *et al.*, 1996). 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 (Billinton *et al.*, 1996). This study deals with generation reliability assessment (Hierarchical Level I-HLI) in power pool markets and transmission and distribution systems are considered reliable and adequate as shown in Fig. 1.

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

Generally, the reliability indices of a system can be evaluated using 1 of 2 basic approaches (Billinton *et al.*, 1992):

- Analytical techniques.
- Stochastic simulation.

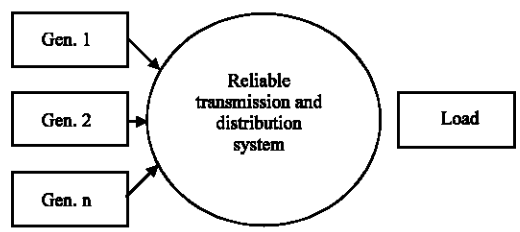

Fig. 1: Power pool market schematic for HLI reliability assessment

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 the research.

Generation reliability depends on generating units specifications, absolutely. The main function in traditional structure for Unit Commitment (UC) of generators is generation cost minimization. Since, beginning 21st century, many countries have been trying to deregulate their power systems and create power

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markets (Salvaderi, 2000; Mountford *et al*., 1999; Draper, 1998; Puttgen *et al*., 2001; Nordic Competition Authorities, 2003). In power markets, the main function of players is their own profit maximization, which severely depends on type of the market. Therefore, generation reliability assessment depends on market type and its economic characteristics, completely.

Generally, economists divide the markets in 4 groups (Pindyck *et al*., 2001):

- Perfect competition market.
- Monopoly market.
- Oligopoly market.
- Monopolistic competition market.

In Monopolistic competition market, it is assumed that qualities of goods which are produced by various companies are different. In this study, we consider generated power qualities of power plants as the same. Therefore, this kind of pool market is ignored in this research. Thus, this study deals with assessment and comparison of generation reliability in perfect competition, monopoly and oligopoly power pool markets.

Let's review some previous researches which have been proposed about power markets' reliability till now.

In Okada *et al*. (1999), independent power producers' impact on reliability and associated costs of existing power systems under deregulation environment has been presented. This study has used Expected Unserved Power (EUP) as reliability index and economic dispatch problem is solved under some reliability and system constraints.

Choi *et al*. (2001) 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.

Wang and Billinton (2003) has presented some reliability m odels 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.

Niioka *et al*. (2002) has presented generation operational cost minimization problem under system constrains and load uncertainty for evaluation of Expected Unserved Power (EUP) as reliability index.

Although, many worthwhile researches have been done till now about t his matter, but most of the papers only deal with power systems constrains and kind of market (based on economics) and its effect on the power system is ignored. This study meantime to consider economic subject of various power markets, deals with HLI reliability assessment and comparison of various power markets using MCS and Neural Networks (NN). Also, sensitivity of reliability index to different parameters will be evaluated.

PROPOSED METHOD FOR GENERATION RELIABILITY EVALUATION IN POWER MARKETS

Market demand curve has negative gradient. Amount of demand decrease is explained by price elasticity of demand. Since, in longer terms, customers can better adjust their load relative to price, price elasticity is small for short terms and it is big for longer terms (IEA, 2003). Demand function, generally, is described as P = a-b.Q (Pindyck *et al*., 2001). Therefore, price elasticity of demand is explained as Eq. (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 of price and it equals Q_n. Therefore, demand function can be obtained using Eq. (2):

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

Also, total revenue is obtained as Eq. (3).

$$TR = P.Q = a.Q - b.Q^2 \tag{3}$$

Typically, 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 as shown in Fig. 2 (IEA, 2003).

Offer curve of a company which participates in a market without any market power, is the part of marginal cost curve that is more than minimum average variable cost (Pindyck *et al*., 2001). Also, total offer curve of all companies, is obtained from horizontal sum of each company's offer curve. This curve is a merit order function.

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

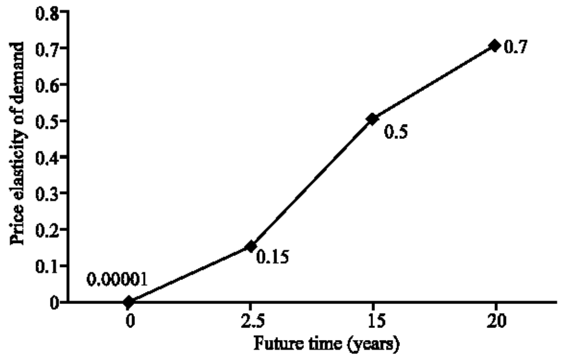

Fig. 2: Price elasticity of demand for various times

variable cost in addition to the fixed cost (Pindyck *et al.*, 2001). On the other side, because of efficiency and heat rate changes in power plants, marginal cost is less than average variable cost. Therefore, in power plants, average variable cost replaces marginal cost (Borenstein, 1999).

In a perfect competition market, equilibrium amount are obtained from intersection of total offer curve and demand curve (Pindyck *et al.*, 2001).

In a monopoly market, the monopolist considers the production level which maximizes his profit. It is proved that monopolist considers the level of production in which marginal cost of each firm (and total marginal cost of all firms) equals the marginal revenue of the monopolist (Pindyck *et al.*, 2001).

$$MC_1 = MC_2 = \ldots = MC = MR \tag{4}$$

where,

$$MR = \frac{d(TR)}{d(Q)} a - 2b.Q = \frac{Q_n}{E_d} - \frac{2.Q}{E_d} \tag{5}$$

Comparison Eq. (2) and (5) shows that offer curve of plants for both mentioned markets equals total marginal cost curve, but demand exponent curve equals demand curve in perfect competition market and it equals marginal revenue curve in monopoly market.

In a power market, Hirschman-Herfindahl Index (HHI) which is obtained using Eq. (6), is used for market concentration measurement (IEA, 2003):

$$HHI = \sum_{M} q_n{}^2 \tag{6}$$

If market share of each company in Eq. (6) is measured in percentages, HHI will vary between 0 (an atomistic market) and 10000 (monopoly). In one usual grouping, the US merger guidelines stipulates an assumption that markets with a HHI below 1000 is unconcentrated, a HHI between 1000 and 1800 is moderately concentrate and a HHI above 1800 is highly concentrated (Nordic Competition Authorities, 2003).

In an oligopoly power market, each company can mark up the price based on its plants specifications and the load's price elasticity. If concentration becomes less, each company's share in the market will be decreased. Therefore, market power becomes less. Market power is the ability of a company to mark up the price in comparison with its marginal cost. Market power for company n in an oligopoly power market is obtained using Lerner index as Eq. (7) (Nordic Competition Authorities, 2003).

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} \tag{7}$$

By differentiation from revenue function of company n in Cournot-Nash model of oligopoly power market Eq. (8) is obtained (Nordic Competition Authorities, 2003).

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} = \frac{s_n}{E_d} \tag{8}$$

where,

$$s_n = \frac{q_n}{Q},\ Q = q_1 + q_2 + \ldots + q_M \tag{9}$$

Therefore, the most profitable offer price for company n with generated power q_n is obtained using Eq. (10).

$$P_n = (\frac{E_d}{E_d - s_n}) \times MC(q_n) \tag{10}$$

Formulas Eq. (8 and 10) shows that if the market share of a company increases, the company can mark up the price, more. Also, if price elasticity decreases, companies can mark up market price, more.

Finally, in all kinds of power markets, equilibrium amount (generated power) is obtained by intersection of total offer curve and demand exponent curve. A typical total offer curve and demand exponent curve is shown in Fig. 3.

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 Eq. (11) (IEA, 2002).

$$\mathrm{RM\%} = \frac{\text{Installed capacity} - \text{Peak demand}}{\text{Peak demand}} \times 100 \quad (11)$$

The proposed algorithm for generation reliability assessment in power pool markets using MCS is shown in Fig. 4. Steps of proposed algorithm are as following:

- Calculate total offer curve of power plants for each kind of power market.
- Select a day and its load (Q_n) randomly in MCS and calculate demand curve for competition and oligopoly power markets and calculate marginal revenue curve for monopoly power market.
- The plants which are selected for generation in the selected day are determined by intersection of power plants' total offer curve and demand exponent curve considering reserve margin.
- 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 Forced Outage Rate (FOR), the 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. Finally, sum of the available power plants' generations is calculated.
- If the sum becomes less than intersection of power plants' total offer curve and demand exponent curve, we will have interruption in the iteration and therefore, LOLE increases one unit; otherwise, we go to the next iteration.
- Steps 2-5 are repeated in MCS for final LOLE calculation.

Now, for creating a unique structure, a 4 layers perceptron neural network is used for reliability assessment in power markets. Number of neurons in each layer is 15, 12, 8 and 1, respectively as shown in Fig. 5.

All neurons in first, third and last layers have POSLIN transfer function and second layer has TANSIG transfer function. Input of the neural network includes:

MT : Market type (1 is used for perfect competition, 2 is used for monopoly and 3 is used for oligopoly markets).
Y : Simulated future year.
RM : Reserve margin.

Also, LOLE is neural network's output.

Some of MCS results which obtained using MCS algorithm are used for neural network training.

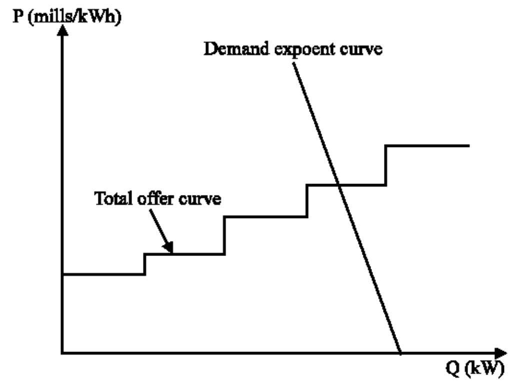

Fig. 3: Typical total offer and demand exponent curves

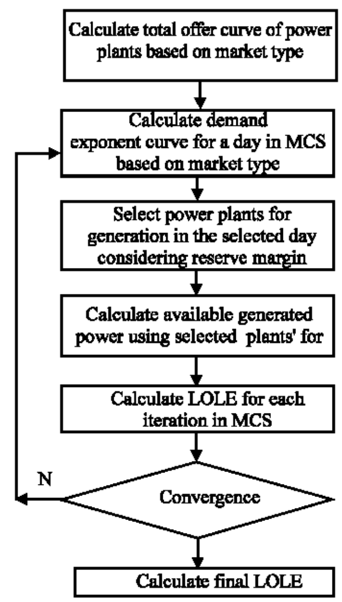

Fig. 4: Flowchart of HLI reliability assessment in various power markets using MCS

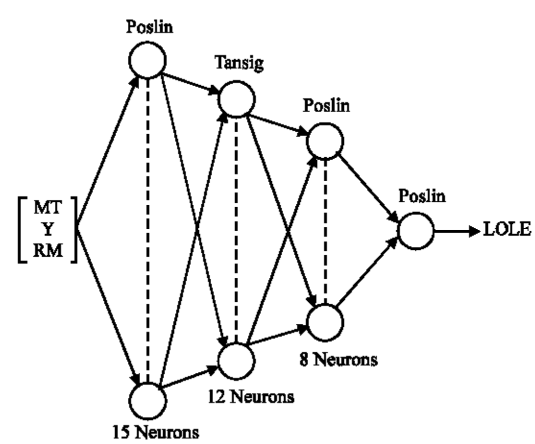

Fig. 5: Proposed neural network for generation reliability evaluation in power markets

RESULTS AND DISCUSSION

IEEE-Reliability Test System (IEEE-RTS) is used for case studies. Data for IEEE-RTS can be found in (Reliability Test System, 1979). In various case studies using MCS, following assumptions are applied:

- All studies are simulated for second half of year, based on daily peak load of the test system.
- All simulations are done with 10000 iterations in MCS.
- Each study is simulated for 2 different times (2nd and 5th future years) and 2 various reserve margins (0 and 9%).
- Fuels costs and O and 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 rates in simulations.
- Annual growth rates of power plants' generation capacity and consumed load are considered 3.4 and 3.34% as their base rates, respectively.
- Annual growth rates of oil and coal costs are considered 4 and 1% as their base rates, respectively. Nuclear fuel cost (including uranium, enrichment and fabrication) is considered as a fixed rate. Also, basic annual growth rate of variable O and M cost is considered 1%.
- It is assumed that in perfect competition and oligopoly power markets, each power plant belongs to an independent company. Therefore, HHI equals 634 in these markets. In monopoly market, it is assumed that all plants belong to one monopolist. Therefore, HHI equals 10000 in monopoly power market.

In first study, market is perfect competition and each power plant belongs to an independent company (MT = 1). LOLE values are obtained for different times and reserve margins using MCS lgorithm and proposed neural network as shown in Fig. 6 and 7, respectively.

In second study, it is assumed that all power plants belong to a monopolist and the market will be fully concentrated and monopoly (MT = 2). Based on this assumption, LOLE values are obtained versus different times and reserve margins using MCS algorithm and proposed neural network as shown in Fig. 8 and 9, respectively.

In third study, it is assumed that market is oligopoly (MT = 3) and each power plant belongs to an independent company. Based on this assumption, LOLE values are obtained versus different times and reserve margins using MCS algorithm and proposed neural network as shown in Fig. 10 and 11, respectively.

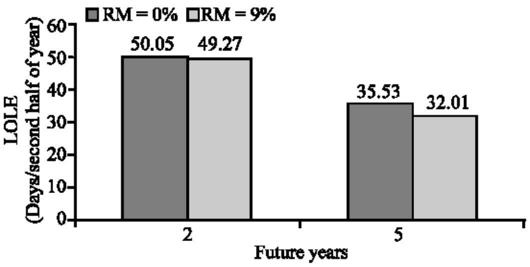

Fig. 6: LOLE values for first study using MCS

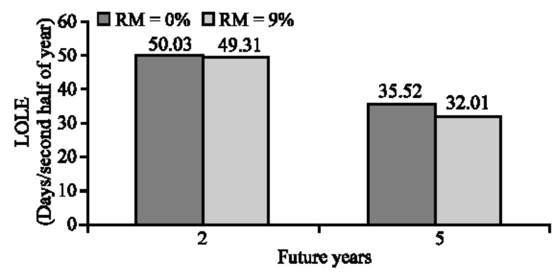

Fig. 7: LOLE values for first study using neural network

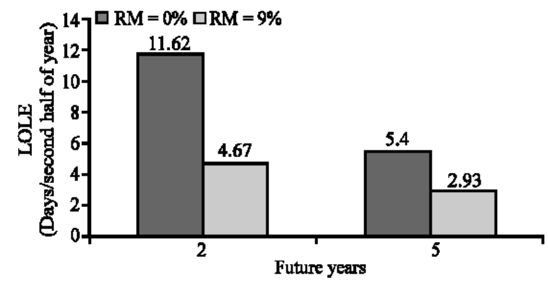

Fig. 8: LOLE values for second study using MCS

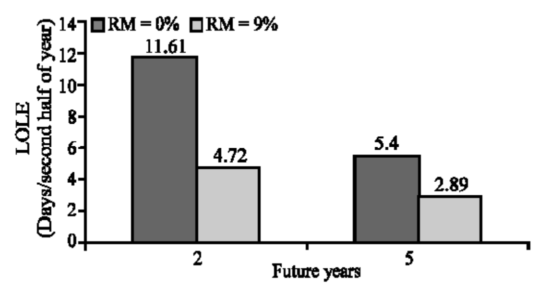

Fig. 9: LOLE values for second study using neural network

As it's remarkable, LOLE values in neural network method are very similar to MCS results.

It can be seen that in all case studies, if reserve margin increases, LOLE will decrease and reliability will improve.

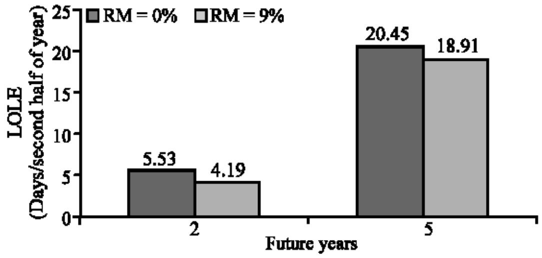

Fig. 10: LOLE values for third study using MCS

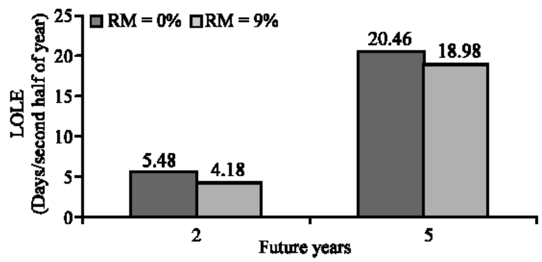

Fig. 11: LOLE values for third study using neural network

As mentioned before, in longer terms, customers can better adjust their load in lieu of energy price. Therefore, price elasticity increases and according to 2 and 5, demand exponent curve finds less gradient. As a result, intersection of power plants' total offer curve and demand exponent curve occurs at less demand. This matter leads to operate from fewer power plants. Therefore, in each case study, if time increases, LOLE will decrease. Although, annual growth rate of power plants' capacity has small effect, too.

Since, gradient of MR curve in monopoly market is twice gradient of demand curve in perfect competition market, intersection of plants' total offer curve and demand exponent curve in monopoly market occurs at less demand. This matter leads to operate from fewer power plants. Therefore, LOLE has smaller values in monopoly power market in comparison with perfect competition power market.

In oligopoly market, the main reason for LOLE increase in the future 5th year in comparison with the future second year, is the change of plants' offer price and therefore, change in plants' arrangement according to price. In third case study, in the future 5th year, FOR of the last plant which is selected for generation, is 0.12. This is while, for mentioned case study, in the future second year, for of the last plant which is selected for generation, is 0.02. Evidently, change in plants' offer price is because of price elasticity change in different future times.

It is to be noted that since in IEEE-RTS, hydro plants have different available capacities 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 study, 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.

CONCLUSION

In this study, generation reliability for perfect competition, monopoly and oligopoly power pool markets is evaluated and compared. Because of market and generators' FOR random behavior, MCS is used for simulations. In this research, based on plants' total offer curve and demand exponent curve and regarding to various parameters, reliability index is calculated. Also, for creating a unique structure for reliability assessment in various power markets, a neural network is used which its outputs are very similar to MCS results. LOLE is considered as reliability index and following results are obtained:

- Whatever price elasticity of demand increases, reliability will improve.
- Comparison of perfect competition and monopoly power markets shows that whatever market becomes more concentrated, LOLE will decrease and reliability will improve.
- In an oligopoly power market, plants can use market power to mark up the market price.
- In an oligopoly power market if a plant's share in the market increases or price elasticity decreases, the plant can mark up the price, more.
- In an oligopoly market, the main reason for LOLE changes in different times, is change of plants' offer price.

In the future research, reliability parameters can be evaluated in various power markets considering transmission and distribution systems as well generation (HLII, HLIII). Also, bilateral contracts between customers and producers can be considered in the power markets in addition to power pool markets.

Notations:

MC = Marginal cost (mills/kWh) (1 mills = 0.001 $).
MR = Marginal revenue (mills/kWh).
TR = Total revenue (mills/h).
Q = Quantity of power (kW).
P = Electrical energy price (mills/kWh).

RM = Reserve margin (%).
E_d = Price elasticity of demand (kW^2h/mills).
q_i = ith company share from total installed capacity in the pool market (%).
M = Number of independent companies in the market.
Q_n = Forecasted load (kW).
LOLE= Loss of load expectation (Days/Second half of year).
FOR = Forced outage rate of power plants.
M = Number of independent companies in the pool market.
a = Demand exponent curve cross of basis (mills/kWh).
b = Demand exponent curve gradient (mills/kW^2h).
HHI = Hirschman-Herfindahl index.
L_n = Lerner index of n^{th} company.
MT = Market type.
Y = Simulated future yearz.

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