Generation Reliability Assessment in Electricity Markets using Market Power Concept and Neural networks

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Abstract

Deregulation policy has caused some changes in the power systems reliability assessment and enhancement. In this paper, generation reliability and market price are considered, and a method for their evaluation using market power concept, Monte Carlo simulation and neural networks is proposed. The proposed method is assessed on IEEE-Reliability Test System with satisfactory results.

Keywords: *Power market, Neural networks, Power generation reliability, Market price, 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 (HLI) and market price assessment 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.

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 preparation of basic data for Neural Network (N.N.) training.

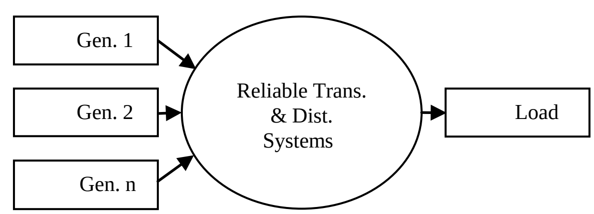

Fig.1. Power pool market schematic for HLI reliability assessment

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.

Till now, most of the methods have been offered for generation reliability assessment in power markets have used the methods that are similar to used methods in traditional systems; and problems that are related to market economic specifications have been ignored.

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.

Reference [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.

Reference [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.

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

Although all mentioned papers are related to deregulated power systems, but in all of them, generation reliability evaluation problem has been solved merely, under the generation and network constrains and there is no any attention to economics and its effects on the power system. It is to be noted that generally, economists divide the markets in four groups which vary between perfect competition market and monopoly market [9].

Therefore, this paper, meantime to analyze the economic subjects of power pool markets based on plants' flexibility, deals with reliability and market price evaluation based on these economic concepts and using neural networks. Also, sensitivity of reliability index and price to different price elasticity of demands will be evaluated. In section-II fundamental of power pool market is discussed. In section-III, the algorithm for HLI reliability and market price assessment in power pool 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 $P=a-bQ$. Therefore, price elasticity of demand is explained as indicated in (1).

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

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 in lieu of this power. As a result, demand function can be obtained as (2).

$$P = a - bQ = bQn - bQ = \frac{Qn}{Ed} - \frac{Q}{Ed} \qquad (2)$$

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 [9]. Also, total offer curve of all companies, is obtained from horizontal sum of each company's offer curve. This curve is a price increase step or 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 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]. A typical total offer curve and demand curve is shown in Fig. 2.

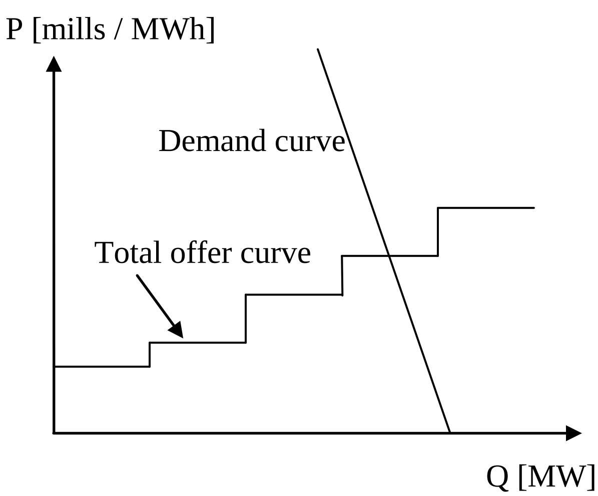

Fig. 2. Typical total offer and demand curves

There are different production technologies in a power system. These technologies have different properties with regard to their flexibility in increasing or decreasing production in the short term (on an hourly basis). For instance, wind and combined heat plants have inflexible production technologies; while hydropower, coal and gas plants have flexible technologies. The more concentrated the production based on flexible production technologies is, the more likely it is that it will be profitable for a producer to withhold production in order to increase price, since the short run response from other producers will be limited [16].

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

$$HHI = \sum_{NU} S_n \left[S_n + \frac{\bar{S}}{NU} \right] \qquad (3)$$

While *HHI* decrease, "market power" will decrease, too. Market power is the ability of mark up the price relative to weighted average of the marginal costs of the unconstrained companies; and it's measured by average Lerner index as indicated in (4) [16].

$$\bar{L} = \frac{HHI}{Ed} = \frac{P - \bar{C}}{P} \qquad (4)$$

Where:

$$\bar{C} = \sum_{NU} \left[S_n + \frac{\bar{S}}{NU} \right] \times MC_n \qquad (5)$$

Therefore, market price equation (regardless demand side) is obtained based on marginal cost of flexible companies as (6).

$$P = \frac{\overline{C}}{1-\overline{L}} = K_1 MC_1 + ... + K_{NU} MC_{NU} \quad (6)$$

Where, weight of marginal cost for n^{th} company is indicated in (7).

$$K_n = \frac{\partial (P)}{\partial (MC_n)} = \frac{(S_n + \frac{\overline{S}}{NU})}{1-\overline{L}} \quad (7)$$

3. The Proposed Method

Algorithm of HLI reliability and market price assessment in power pool markets using MCS is shown in Fig. 3. Steps of proposed algorithm are as following:

1- Calculation of total offer curve of power plants.
2- Determinations of a day and its 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. Also, market price is obtained using (6) for selected plants.
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. 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.
5- Steps 2 to 4 are repeated for calculation of *LOLE* and market price.

Now for creation a unique structure, a four layers perceptron neural network is used for reliability and market price evaluation as shown in Fig. 4. Number of neurons in each layer is 20, 15, 12 and 2 neurons, respectively. Neurons of each layer have full connection with previous and next layers' neurons. All neurons have POSLIN transfer function. Input indices of neural network are *HHI* and *Ed* which are two main characteristics of generation set and load; and its outputs are *LOLE* and market price. Monte Carlo simulation results which obtained using mentioned algorithm are used for training of

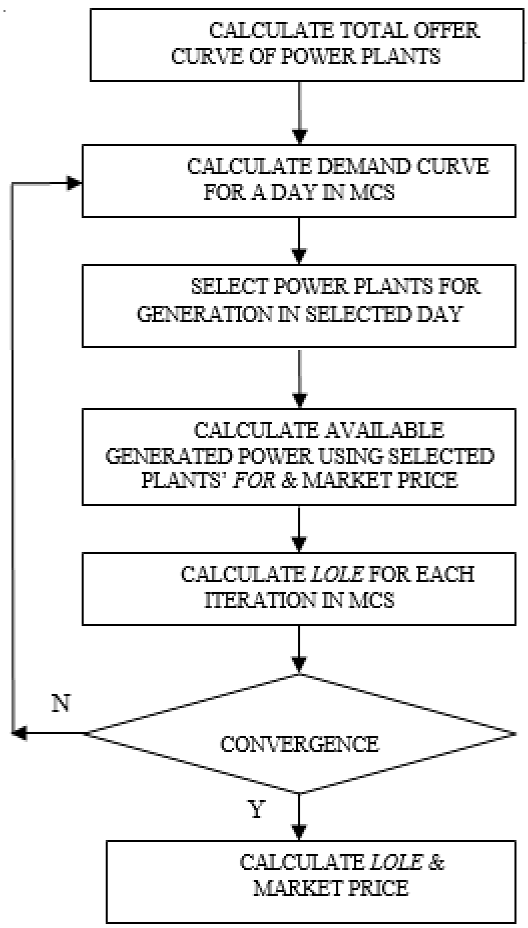

Fig. 3. Flow chart of HLI reliability and market price assessment in power pool markets using MCS

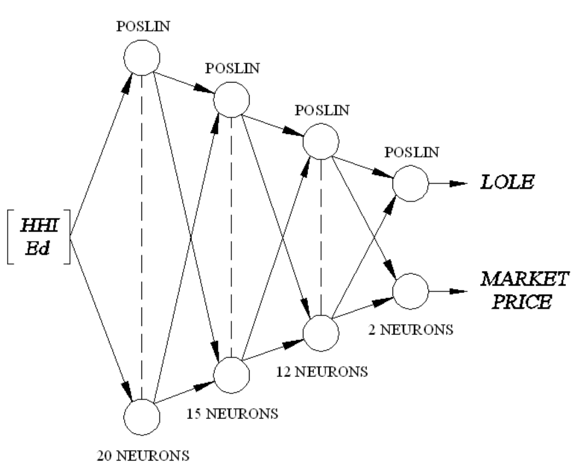

Fig. 4. Proposed neural network for HLI reliability and market price evaluation

4. Numerical Studies

The proposed method, meantime to considering economic subjects of power market and their effects on reliability and market price, is valid for all kinds of power pool markets with different degrees of market concentration. Also, the proposed neural network creates a direct and rapid relation between two input parameters and the outputs, based on offline training of MCS results.

IEEE-Reliability Test System (IEEE-RTS) is used for case studies. Data for IEEE-RTS can be found in [17]. 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 in MCS are done with 5000 iterations.
3- Each study is simulated for four various price elasticity of demands (0.2, 0.3, 0.4 and 0.5).
4- Neural network is trained with TRAINLM method in MATLAB 7.0 software with 150 epochs and finds 10e-6 Mean Square Error (MSE).

Two following case studies are evaluated:

A. In the first study, each flexible power plant is assumed as an independent company. Therefore, *HHI* equals 0.0414. Based on this assumption and using MCS algorithm and the neural network, *LOLE* and market price values are obtained versus different price elasticity of demands as shown in Fig. 5 and Fig. 6, respectively.

B. In the second study, all flexible power plants based on their types, merger.

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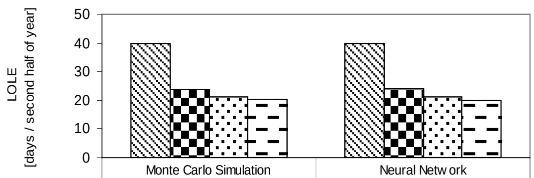
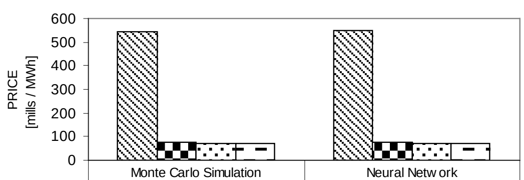
Therefore, *HHI* equals 0.1843. Based on this assumption and using MCS algorithm and the neural network, *LOLE* and market price values are obtained versus different price elasticity of demands as shown in Fig. 7 and Fig. 8, respectively.



	Monte Carlo Simulation	Neural Network
Ed=0.2	39.84	40
Ed=0.3	23.77	24
Ed=0.4	21.25	21
Ed=0.5	20.24	20

METHOD

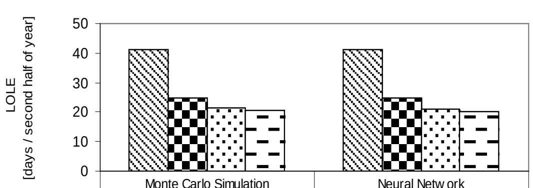
Fig. 5. *LOLE* values for first study



	Monte Carlo Simulation	Neural Network
Ed=0.2	546.5	547
Ed=0.3	73.89	74
Ed=0.4	71.05	71
Ed=0.5	69.45	69

METHOD

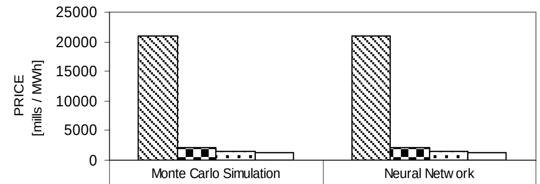
Fig. 6. Market price values for first study



	Monte Carlo Simulation	Neural Network
Ed=0.2	41.13	41
Ed=0.3	24.93	25
Ed=0.4	21.22	21
Ed=0.5	20.45	20

METHOD

Fig. 7. *LOLE* values for second study



	Monte Carlo Simulation	Neural Network
Ed=0.2	20942	20943
Ed=0.3	2074	2074
Ed=0.4	1483	1483
Ed=0.5	1267	1268

METHOD

Fig. 8. Market price values for second study

As it's remarkable, *LOLE* and market price values in neural network are very similar to MCS values. Also, *LOLE* values in two studies are almost the same; but market prices in second study are very bigger than prices in first study. If price elasticity of demand increases, gradient of demand curve will decrease. Therefore, intersection of plants' total offer curve and demand curve occurs at less demand (Fig. 2). This matter, leads to in service plants increasing and *LOLE* will decrease. Also, while price elasticity increases, Lerner index decreases, and according to (6), market price will decrease. It is to be noted that since the market is pool type, sale price of energy for all selected plants are the same.

After flexible plants merger, *NU* decreases and *HHI* increases. Therefore, market prices increase in second study relative to first one. Generally, if flexible plants merger more, market price will increase.

It is to be noted that since in IEEE-RTS available capacity of hydro plants are different in first and second half of year, simulations have been done for second half of year. Evidently, the proposed method can be utilized for every simulation time.

5. Conclusion

In this paper, HLI reliability and market price in power pool markets are evaluated based on plants' flexibility characteristic and using a neural network. The proposed method considers economic subjects and is valid for all kinds of power pool markets with different degrees of market concentration. The neural network creates a direct and rapid structure for online estimation of HLI reliability and market price. MCS results are used for neural network offline training.

In this research, *LOLE* is used as reliability index; and following main results are obtained:

a. If price elasticity of demand increases, reliability will improve and market price will decrease.

b. Flexible plants can merger and uplift the market price. While flexible plants merger more, market price will increase.

Symbol List:

MC: Marginal cost [mills/MWh]
Q: Quantity of power [MW]
P: Electrical energy price [mills/MWh]
Ed: Price elasticity of demand [$MW^2h/mills$]
Qn: Forecasted load [MW]
LOLE: Loss of load expectation [days / simulated time]
FOR: Forced outage rate of power plants
a: Demand curve cross of basis [mills/MWh]
b: Demand curve gradient [$mills/MW^2h$]
HHI: Hirschman - Herfindahl index
$\overline{L}$: Lerner index
$\overline{C}$: Weighted average of the marginal costs of the unconstrained companies
NU : Number of independent flexible companies
$\overline{S}$: Total market share of constrained companies
S_n: Share of n[th] flexible company of market capacity
K_n: Weight of marginal cost for n[th] flexible company in market price equation

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