Calculation of generation system reliability index: Loss of Load Probability

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Abstract: Generation system reliability is an important factor in the long term planning for future system capacity expansion to make sure that the total installed capacity is sufficient to support demand. The planning process utilizes reliability indices as criteria to decide on new investments in new generation capacities. Generation system reliability is evaluated by using different indexes. In this paper, loss load of probability (LOLP) is simulated to evaluate the system reliability. Effects of the system parameters such as forced outage rate (FOR) are tested on the LOLP index.

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1. Introduction

Electricity has been the driving force for economies of the world and provides day-to-day necessity for the population in the world. The generation, transmission and retailing of electricity have existed hundreds of years in providing the much needed electricity. Due to the nature of electricity systems, the variable demand at every moment needs to be met by consistent electricity supply in making sure the continuous availability of the resources. Not meeting the demand in any case will lead to a huge loss of income to the generators as well as to the consumers. The reliability of the generation, transmission and distribution of electricity in this sense is crucial for the continuous supply of electricity to meet the demand.

A modern power system is complex, highly integrated and very large. Fortunately, the system can be divided into appropriate subsystems or functional areas that can be analyzed separately [1]. These functional areas are generation, transmission and distribution. The function of the generation system is to make sure enough capacity is available to meet the load/demand at any time. Transmission and distribution systems need to be reliable in making sure the electricity generator can be delivered to the consumers. System planners have been assigned the role of planning for forecasting the load into the future and plant capacity addition to meet the load and provide a level of reliability in case some of the plants are out on maintenance or breakdown. Probabilistic method is often used to determine the system reliability and the system reliability can be summed up into a single value, the reliability indices. Reliability studies are conducted for two purposes. Long-term evaluations are performed to assist in system planning and short-term evaluations to assist in day to day operating decisions. In short, these reliability indices (for long-term evaluations) are used by system planners and the authorities to decide on and advice for new investments in building new generation capacities [1].

Generation system reliability is an important aspect in the planning for future system capacity expansion. It provides a measurement of reliability or adequacy to make sure that the total generation system capacity is sufficient to provide adequate electricity when needed [1].

In this paper an important reliability index LOLP is evaluated for generation system. The proposed index is simulated by using analytically method. Effects of changing system parameters such as FOR are tested on the LOLP.

2. Generation system reliability

Reliability has been and always is one of the major factors in the planning, design, operation, and maintenance of electric power system. Generation system reliability focuses on the reliability of generators in the whole electric power system where electric power is produced from the conversion process of primary energy (fuel) to electricity before transmission. The generation system is an important part of the electricity supply chain and it is crucial that enough electricity is generated at every moment to meet the demand. Generating units will occasionally fail to operate and the system operator has to make sure that enough reserve is available to be operated when this situation happens [2-31].

Reliability of the generation system is divided into adequacy and security [32]. System adequacy relates to the existence of sufficient generators within the system to satisfy the consumer load demand or system operational constraints. System adequacy is associated with static conditions of the system and do not include system disturbances. System security on the other hand relates to the ability of the system to respond to disturbances arising within the system. Therefore system security is associated with the response of the system to whatever perturbation it is subjected to. In this study, the reliability evaluations will be focused on the generation system adequacy and will not take into account system security.

The basic modeling approach for the generating system adequacy assessment consists of three parts as shown in Figure 1. The generation and load models are convolved to form an appropriate risk model where the element of interest is the risk of generation capacity less than the load. In short, adequacy evaluation of generation systems consists of four general steps as Figure 1.

(i) Create a generation capacity model; (ii) create a load model; (iii) combined the generation capacity model with load model to obtain a risk model and (iv) calculating indexes.

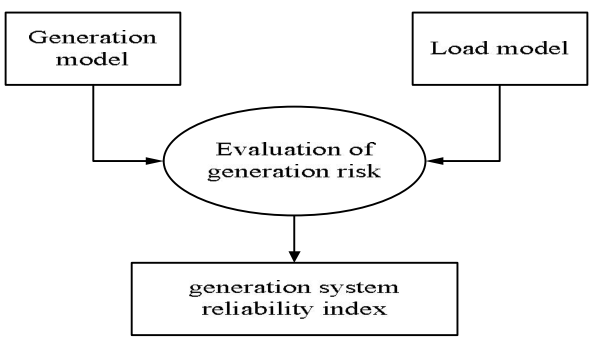

Figure 1. Generation reliability evaluation process

Analytical methods or Monte Carlo simulation [33] can be used to calculate the reliability indices. Analytical techniques represent the system by analytical models and evaluate the indices from these models using mathematical solutions. Monte Carlo simulations, on the other hand estimate the indices by simulating the actual process and random behavior of the system, treating the problem as a series of experiments. The reliability indices obtained indicate the ability of the generating facilities to meet the system demand.

In the analytical method, the generating system model used for generation capacity adequacy assessment is a Capacity Outage Probability Table (COPT) which can be created using the recursive technique. As for the load model, the daily peak load or hourly load for a period of one year is normally used to form the Load Probability Table (LPT).

3. Load model

The load in a power system in any time period is a stochastic process, which is difficult to describe with a simple mathematical formula. Different models are created, starting from rimary load data and according to the need to calculate reliability. Primary load data will provide a minimum amount of data that is needed to establish an hourly chronological load profile. Most primary load data consist of the percentage of maximum monthly load or weekly load in a year, the load in 24 hours in a typical day in each season and the maximum load in each day in a week. With the percentages of these data available and the annual peak load known, the hourly chronological load profile can be established.

4. Forced Outage Rate

There are many concepts in reliability evaluation such as: failure rate, repair time, unavailability, forced outage rate (FOR) and etc. Unit unavailability is also known conventionally as "forced outage rate" (FOR), although the value is not a rate. The FOR is defined as below.

$$\text{FOR} = \frac{\text{Forced outage hours}}{\text{In service hours} + \text{Forced outage hours}} \quad (1)$$

The FOR is calculated for a long period of time (e.g. 365 days), is the same index as the unavailability.

5. Generation system reliability indices

The quantification of reliability is an important aspect of generation system reliability assessment. The measurement used to quantify reliability of a generation system is given various reliability indices. These reliability indices are used to assess the reliability performance of a generation system against some predetermined minimum requirements or reliability standards, compare alternative designs, identify weak spots and determine ways for correction in the generation system and to be integrated with costs and performance considerations for decision making. These indices are better understood as estimates of system-wide generation adequacy and not as absolute measures of system reliability [18].

Basically, system reliability evaluations can be divided into deterministic and probabilistic. The most common deterministic indices are the Reserve Margin and the largest set in the system. An important shortcoming of these methods is that they do not account for the stochastic nature of system behavior.

Probabilistic methods can provide more meaningful information to be used in design and resource in planning and allocation. There are two approaches that use probabilistic evaluation. The analytical methods and Monte Carlo simulation as can be seen from Figure 2. The analytical methods represent the system by mathematical models and use direct analytical solutions to evaluate reliability indices from the model. As for the Monte Carlo simulation, reliability indices are estimated by simulating the actual random behavior of the system. So of the commonly used probabilistic reliability indices are Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE), Loss of Energy Probability (LOEP), Loss of Energy Expectation (LOEE), Expected Energy Not Served (EENS), and Loss of Load Frequency (LOLF) and Loss of Load Duration (LOLD). Most of these indices are basically expected values of a random variable. Expectation indices provide valid adequacy indicators which reflect various factors such as system component availability and capacity, load characteristics and uncertainty, system configurations and operational conditions, etc [1]. Typical reliability indices used in power system evaluations and their categorizing is shown in Figure 2.

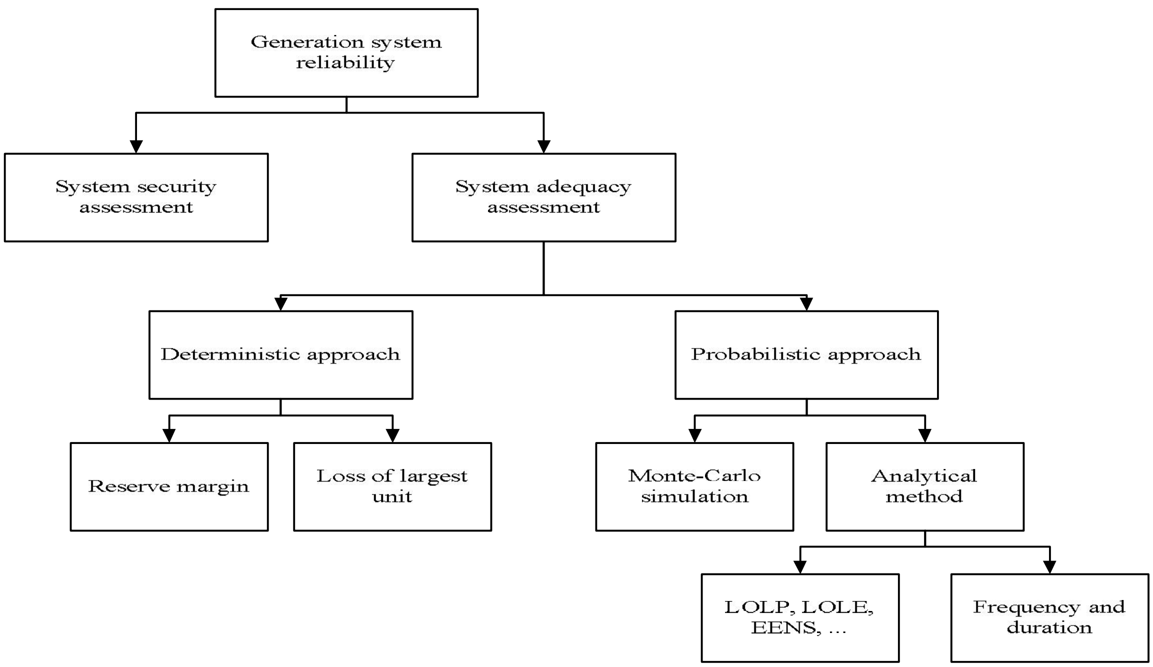

Figure 2. Generation system reliability assessment indices category

6. Loss of load probability

Loss of load occurs when the system load exceeds the generating capacity available for use. Loss of Load Probability (LOLP) is a projected value of how much time, in the long run, the load on a power system is expected to be greater than the capacity of the available generating resources. It is defined as the probability of the system load exceeding the available generating capacity under the assumption that the peak load of each day lasts all day [1].

LOLP is based on combining the probability of generation capacity states with the daily peak probability so as to assess the number of days during the year in which the generation system may be unable to meet the daily peak. LOLP can be calculated considering the daily peak loads for one year duration or sometimes on each hour's load for a 24 hours day. Therefore, the same system may have two or more values of LOLP depending on how the calculation is being done. The mathematical formula for calculation of LOLP is shown as below [1].

$$LOLP = \sum_j p[C_A = C_j].P[L > C_j] = \sum_j \frac{P_j.t_j}{100} \tag{2}$$

where;

P: the probability; L: expected load; C_A: available generation capacity; C_j: remaining generation capacity; p_j: probability of capacity outage; t_j: percentage of time when the load exceeds C_j.

Alternatively, a load duration curve consists of daily peak loads arranged in descending order can be used to measure LOLP for long term generation capacity evaluation. The assumption used in this case is that the peak load of the day would last all day. The LOLP calculation is illustrated with a daily peak load curve in Figure 3 [1].

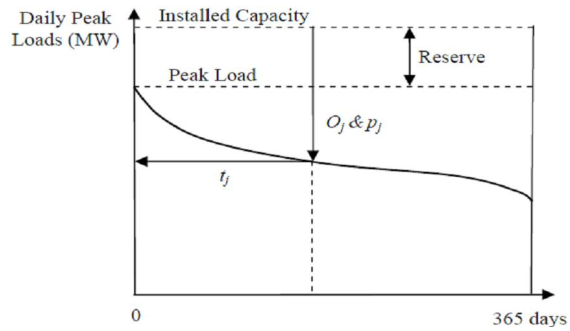

Figure 3. LOLP Calculation using Load Duration Curve

In the figure, the parameters are defined as following; O_j: is the magnitude of the j_{th} outage in the system; p_j: is the probability of a capacity outage of magnitude O_j; t_j: is the number of days that an outage of magnitude O_j would cause a loss of load in the system.

Capacity outage less than the amount of reserves will not contribute to a loss of load. When a particular capacity outage is greater than the reserve, the risk in this case will be $p_j \times t_j$.

7. Case study

In this section a numerical case study is carried out for reliability evaluation. Table 1 shows the proposed generation test system. This system contains four generation companies with six units. The system data and capacity of units are considered as typical. The load model is also considered as Figure 4.

Table 1. Generation system details

Generation Company	Number of units	Capacity of each unit (MW)	FOR
1	2	25	0.03
2	2	40	0.02
3	1	50	0.01
4	1	100	0.01

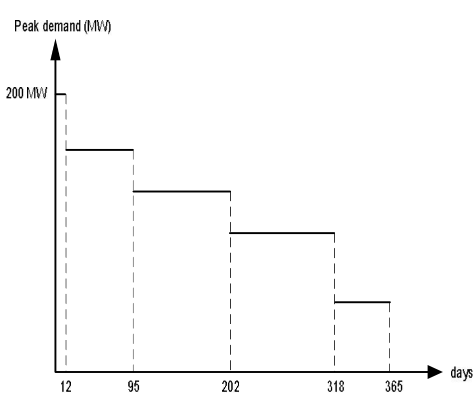

Figure 4. Daily peak demand of year

In this section LOLP index is calculated for the proposed test system. The procedure presented in section 6 is used to computing LOLP. In first the Capacity Outage Probability Table (COPT) is derived. Table 2 shows the COPT and the probability of different outages is listed.

Table 2. COPT for the test system

Capacity Outage (MW)	Probability
0	0.88565791683600000
25	0.05478296392800000
40	0.03614930272800000
50	0.00894603956400000
50	0.00084715923600000
65	0.00223603934400000
75	0.00055336327200000
80	0.00036887043600000
90	0.00036514447200000
90	3.45779280000000e-05
100	0.00894603956400000
100	8.55716400000000e-06
105	2.28167280000000e-05
115	2.25862560000000e-05
125	0.00055336327200000
130	3.72596400000000e-06
130	3.52836000000000e-07
140	0.00036514447200000
140	3.49272000000000e-07
150	9.03640360000000e-05
150	8.55716400000000e-06
155	2.30472000000000e-07
165	2.25862560000000e-05
175	5.58952800000000e-06
180	3.72596400000000e-06
180	3.56400000000000e-09
190	3.68832800000000e-06
190	3.49272000000000e-07
200	8.64360000000000e-08
205	2.30472000000000e-07
215	2.28144000000000e-07
230	3.76360000000000e-08
230	3.56400000000000e-09
240	3.52800000000000e-09
255	2.32800000000000e-09
280	3.60000000000000e-11
	Sum of probabilities=1

LOLP index is calculated as mentioned above. In this regard, the LOLP is obtained as below.

$$LOLP = 5.968138239671235e{-}004 \quad (3)$$

In order to show the sensitivity of LOLP index to the system parameters, an evaluation is carried out and the results are listed in Table 3. It is seen that changing FORs and load has a direct effect of the reliability of generation system.

6. Conclusions

In this paper a commonly used reliability index of generation system LOLP was successfully calculated and evaluated. Different conditions and changing were considered. COPT was carried out and then the reliability calculated. Simulation results showed that changing components FOR and load level can directly affect of the system total reliability.

Table 3. Effect of changing parameters on the LOLP index

Parameter changing	LOLP
FOR unit 25 MW=0.01	5.043705938958903e-004
FOR unit 25 MW=0.05	6.889275761643836e-004
FOR unit 40 MW=0.05	7.691760586986303e-004
FOR unit 50 MW=0.05	7.519234803835614e-004
FOR unit 100 MW=0.1	0.0058208871141920000
Increasing load by 10% in all levels	8.500825094465753e-004
decreasing load by 10% in all levels	1.611630195397260e-004

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