Reliability Assessment using Monte Carlo method of Iraqi Power Grid

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Abstract

Now day's reliability evaluation of bulk power generation using many techniques is helpful engineers to assess indices of real system to feed customers with reliable power service. In this paper, the Monte Carlo Simulation (MCS) presented to find three indices (LOLP, LOLE, ENS) applying outage conditions and failure events of generators for Iraqi 400 kV grid. The carryout of MCS simulated results compared with analytical approach.

Keywords: reliability assessment, failure events, LOLP, LOLE, ENS, MSC.

1. INTRODUCTION

A crucial role of an electric power system is to generate electricity to meet the customer demands, with an acceptable level of reliability in an economical manner. The main functional areas in an electric power system 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 to ensure the electricity can be delivered to the consumers.

Therefore, reliability assessment is one of the most significant assignments of power system operation. In other sides, it is important to make proper plan and maintain a reliable electric power system because the expenditure of outages, and the cost of power interruptions contribute to economic influence on the companies and its customers. With a view to resolve the odds between the economic and reliability limitations, a wide range of techniques and standards have been developed such as the failure and repair rates of equipment and operating practices, Monte Carlo (MC) simulation technique, and maintenance schedules.

Generally Monte Carlo simulation requires a large amount of computing time compared to analytical methods. There are two basic techniques can be utilized when Monte Carlo methods are applied to power system reliability evaluation. These methods are known as the sequential and non-sequential techniques. In the basic state sampling technique, the states of all components are sampled and a non-chronological system state is obtained. Research work in the area of composite system adequacy evaluation using the sequential Monte Carlo simulation approach has been done at university of Saskatchewan (Billinton and Jonnavithula, 1997).

The standard deviation of load level uncertainty in power system reliability assessment has a different value for each load level that leading to complexity of iterations required in the convergence of MC algorithm. The MC has been defined as one of the stochastic techniques (Brown, 2002; Haroonabadi and Haghifam, 2008), that is based on the use of random numbers and possibilities calculations for investigating the problems.

This means that the problem of the variables changing with the times affecting the reliability has caused inaccurate results of system operation, which are still lacking in most approaches. Another problem is in the calculation of the standard deviation of load level uncertainty in power system reliability assessment, which has a different value for each load level. This has led to complexity iterations required in the convergence of MC methods.

2. POWER SYSTEM RELIABILITY AND RELATED CONCEPTS

The term reliability, when used in the context of power networks, is generally defined as the concern regarding the ability of a power system to provide an adequate supply of electrical energy. In order to be more specific, it is usual to divide the term into two aspects, i.e., adequacy and security such as shown in Figure 1. (Billinton and Allan, 1984).

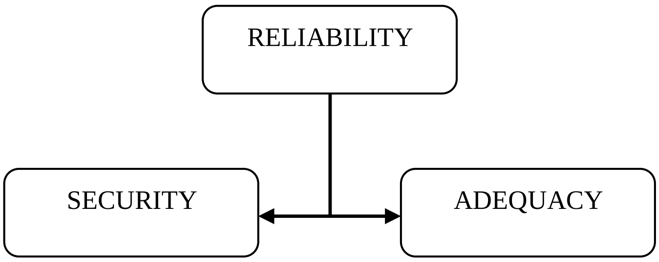

Figure 1. Subdivision of reliability in power system

An overall power system can be divided into three basic functional zones of generation, transmission, and distribution, and be organized into three hierarchical levels (HL) as shown in Figure 2. Hierarchical Level I (HL-I) involves only the generation facilities. Hierarchical Level II (HL-II) involves both the generation and transmission facilities. Hierarchical Level III (HL-III) involves all three functional zones. Two basic tools i.e. analytic method and Monte Carlo Simulation have been extensively utilized for HL-I reliability evaluation. Similar techniques have been applied to HL-II evaluation (Northwest Power Planning Council, 2001).

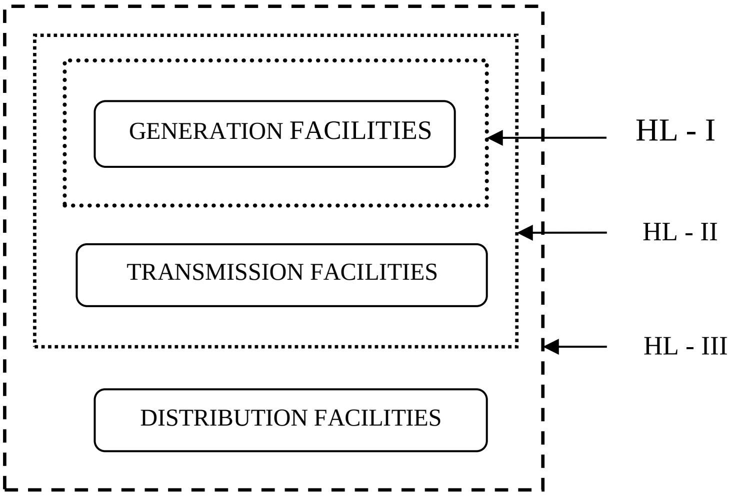

Figure 2. Power system hierarchical levels

3. Generating System Reliability Indices

The MC method uses the transition rate parameters of the failure rate "λ " and the repair rate "μ" in addition to availability and unavailability. It indicates the time in which the load is more than the available generation. The reliability expresses the proportion time of the component if it is "in service" or "available for". However, the availability (A) of a component is expressed by Equation (1) as (José, 1999):

$$A = \frac{\sum(uptime)}{\left(\sum(uptime) + \sum(downtime)\right)} \quad (1)$$

Where the *"up time"* is the total time when the component is in service and *"down time"* is the total time when component is not in service. Availability may be expressed in terms of Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) as given by Equation (2):

$$A = \frac{MTTF}{MTTF + MTTR} \quad (2)$$

The Mean Time between Failures (MTBF) is the sum of MTTF and MTTR

Power system components can be characterized by discrete system states with constant transition rates between these states. State "0" represents the healthy component in an operating condition. As for state "1" (failed state) when the component cannot perform its intended function. Transition occurs between state "0" and "1" and the transition rates between these states are the failure rate *"λ "* and the repair rate *"μ"* as shown in Figure 3. Therefore, Equation 2 can be re-expressed in terms of failure rate and repair rate such that.

$$A = \frac{\mu}{\mu + \lambda} \quad (3)$$

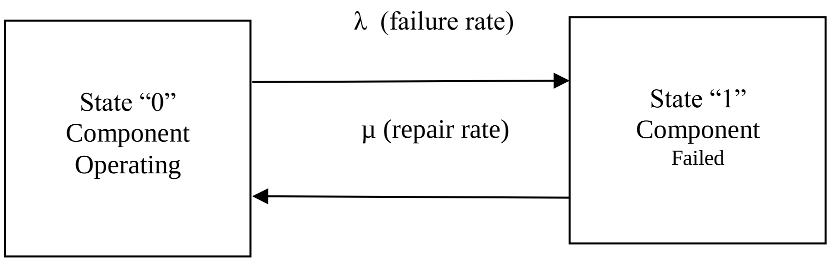

Figure 3. State space diagram of transition rates

The unavailability *(Q)* is sometimes known as Forced Outage Rate (FOR), its converse of the availability and can be defined in similar terms as in Equation 4 or in terms of failure rate and repair rate as in Equation 5.

$$Q = \frac{\sum(downtime)}{\left(\sum(uptime)+\sum(downtime)\right)} \quad (4)$$

From Equation 1, it can be rewritten in terms of failure rate and repair rate such that:

$$Q = \frac{\lambda}{\lambda + \mu} \quad (5)$$

4. RELIABILITY INDICES

Firstly, for reliable system, the installed capacity in power system must be higher than expected consumption. One of the methods used to measure the reliability is the loss of the largest generating unit method which provides a degree of sophistication over the percent reserve margin method by reflecting the effect of unit size on reserve requirements. A reserve power needs to be provided for frequency regulation and in case of major aggregate loss of capacity

The reliability expresses the proportion time of the component if it is “in service” or “available for”. The availability (A) of a component has been expressed as in Equation (2). The unit unavailability is a good approximation of a unit failure probability even when preventive maintenance is considered, which is maintenance scheduled during low demand periods. Normally, the failure and repair rates are not constant, but may be a function of time such as the Normal, Lognormal, Exponential, Gamma, Weibull, Binomial and Poisson. In this research work, Binomial Distribution Method (BDM) that has been used by Costas and Grace, (1996) is adopted. The binomial distribution can be represented by the Equation (6).

$$probabiliy = (A + Q)^n \quad (6)$$

Equation (6) is applicable if the fixed number of trials *“n”* is known and has resulted in either a success or a failure with corresponding probabilities A and Q respectively (Marko, 2011).

The basic probability principles and combining the different generating units are used for calculating the LOLP. The success probability or availability and its complement (i.e., failure probability or unavailability of each generating unit), are the input data. All combinations of available and unavailable generating units are presented in tabular form together with the calculated system availability.

Most of the basic indices used in the generating system adequacy evaluation are expected value of random variables. Among these indices are LOLP and LOLE. LOLP is the index used to test the probabilities of simultaneous outages of generating capacity together with a model of daily peak-hour loads which determine the number of days per year of expected capacity shortages that presented in Equation (7):

$$LOLP = \sum_{i=1}^{n} p_i t_i \qquad (7)$$

where, p_i is the probability of system state i , t_i is the time interval of capacity in outage.

The LOLE index gives the expected (or mean) number of days or hours (days/year or hours/year) in a given period (usually on year) in which the daily peak load or hourly load exceeds the available generating capacity as in Equation (8).

$$LOLE = \sum_{i \in s} p_i T \qquad (8)$$

Where, T is the time unit of the index (i.e., either one day or one hour), S is a set of all possible system states associated with loss of load. The term LOLP is closely related to the term LOLE that can be obtained using the daily peak load variation curve. It can be used to calculate the area under the load duration curve. The most widely used indices in electrical energy are Loss of Energy Expectation (LOEE), Energy not Supplied (ENS).

5. Case study

The primary transmission of the Iraqi electrical grid consists of the 400 kV network (the super grid network) and part of the 132 kV network connected to it. The aim of this work is limited to the study of only the 400 kV network with all its bus-bars and generators. The network under consideration consists of 32 bus bars

And 51 transmission lines (the total transmission line 3984.6Km) and configuration of this network shown in Fig.4.

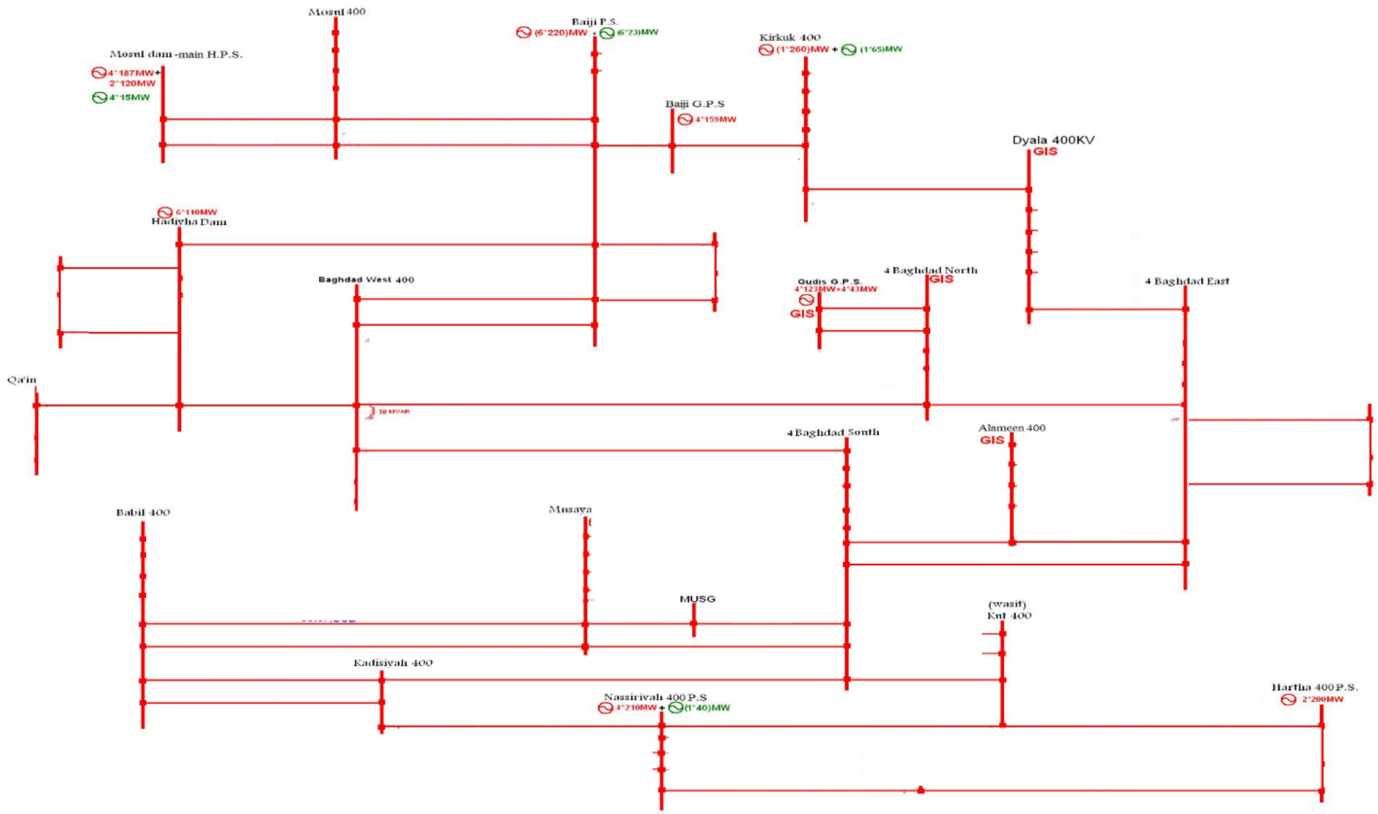

Fig. 4. 400 kV of Iraqi super Grid network

6. Result and discussions

The program start from the normal system state in which all the generating units are in the system is available. Then examine the generation of random numbers (0,1) that is necessary for MC simulation if the generated number is more than an unavailability of the generator. The generator will be considered available in the mentioned iteration. The fundamental necessity for the numbers to be random is that of each and every number should have an equal probability by choosing any one of the possible sizes of generator to feed load. Thus, random numbers in a certain range follows a BDM. The random numbers applied are highlighted by a computer program and shown in Table 1. This table depicts many probabilities of generating units in service. The capacity limits or the number of generating units in service and values are expected to be within a range.

For example, in Table 1, when the total load is supplied by two units (187 MW + 120 MW = 207MW), in order to evaluate reliability indices when MCs starts sending the results of the probability of generated outage to energy indices. Table 1 show the results of the LOLE at different peak load by analytical method. Many probabilities that limit the size and number of generator. The probability without reserve margin, can be seen in Table 2.

Table 1 Calculations of LOLP and LOLE based on probability

Bus Gen	Time interval of capacity (Minute)	Capacity of generators in service(MW)	LOLP	LOLE
Mosal dam P.S	2	(4*187)+(2*120)	0.9264	1.903
Baiji P.S	4	6*220	0.8909	1.0406
Kirkuk	6	1*260	0.7909	1.1101
Baiji G.P.S	8	4*159	0.7918	1.4027
Hadiyth a dam	10	6*110	0.9878	1.0921
Qudis GPS	12	(4*123)+(2*43)	0.9661	1.2080
Nassiriyi h	14	4*210	0.9860	1.1035
Khor Azber	16	(4*63)+(2*123)	0.9060	1.3072

P.S				
Musayab P.S	18	4*300	0.9659	1.2074
Hartha P.S	20	2*200	0.9755	1.3072

Table 2 Simulated values of index LOLE without reserve margin

Load MW	LOLE Case 1	LOLE Case 2	LOLE Case 3	LOLE Case 4
43	1.2080	1.205	0.9465	0.9452
63	1.3072	1.3092	1.0936	1.0936
110	1.0921	-	-	-
120	1.903	1.205	0.9465	0.9452
123	1.2080	1.2055	0.9075	0.9044
159	1.4052	-	-	-
187	1.903	1.9018	0.9282	0.9153
200	1.3072	-	-	-
210	1.0406	-	-	-
220	1.9647	-	-	-
260	1.1101	-	-	-
300	1.2074	-	-	-

The results of index LOLE reliability are shown in Tables 2 for daily peak load = 400 MW. In Table 2, the result is 1.205 when capacity levels less than or equal peak load with a probability of analytical, while 1.220 is when the capacity levels less than or equal peak load with probability MCs. The energy not supplied would be 650 MW when the system has 990 MW , an analytical method .

Table 3 LOLE at different capacity levels by analytical & MCS when load 400 MW

Bus Genertor	No.of genertors	total generations in service (MW)	LOLE by Analytical	LOLE by MCS
Mosal dam P.S	6	748	1.205	1.220
Baiji P.S	6	990	1.0406	1.0665
Kirkuk	1	193.05	-	-
Baiji G.P.S	4	477	1.4027	1.4091
Hadiytha dam	6	495	0.9452	0.9661
Qudis GPS	6	433.5	0.9452	0.9688
Nassiriyih	4	630	1.1035	1.106
Khor Azber P.S	6	373.5	-	-
Musayab P.S	4	900	1.2074	1.208
Hartha P.S	2	300	-	-

7. CONCLUSION

The MCs has been used to evaluate indices reliability in a power grid as one of the solutions to the power system problems. The results have shown different levels of reliability measurements for the two cases i.e., system without and with reverse margin. If the load demand is distributed on the capacity of identical generators with small size, the value of reliability indices is decreases and therefore, the reliability of the power system could be improved. The calculated values of indices such as LOLE in different time intervals will give guidelines for the weakest buses in a power network. In the second part, the results have been shown that the probability of tie lines effecting of tie line capacity to determine the risk levels in the assisted system using ENS. When the interconnected capacity is increased beyond the reserve margin, the risk level is decreased.

The randomness of uncertainty loads have offered a new comprehensive in assessing a better limitation of reliability indices in power system. Subsequently, the results provides the appropriate values of mean and standard deviation for load level uncertainty that make more precise calculations for engineers to assess indices of the reliability.

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