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Reliability Assessment of Bangladesh Power System Using Recursive Algorithm

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Abstract**—**An electric utility's main concern is to plan, design, operate and maintain its power supply to provide an acceptable level of reliability to its users. This clearly requires that standards of reliability be specified and used in all three sectors of the power system, i.e., generation, transmission and distribution. That is why reliability of a power system is always a major concern to power system planners. This paper presents the reliability analysis of Bangladesh Power System (BPS). Reliability index, loss of load probability (LOLP) of BPS is evaluated using recursive algorithm and considering no de-rated states of generators. BPS has sixty one generators and a total installed capacity of 5275 MW. The maximum demand of BPS is about 5000 MW. The relevant data of the generators and hourly load profiles are collected from the National Load Dispatch Center (NLDC) of Bangladesh and reliability index 'LOLP' is assessed for the period of last ten years.

Keywords**—**recursive algorithm, LOLP, forced outage rate, cumulative probability

I. Introduction

THE primary objective of a power system is to provide electrical energy to its customers as economically as possible with an acceptable margin of quality. Reliability of power system is one of the major features of power quality. The two constraints of economics and reliability are competitive because increased reliability of supply generally requires increased capital investment. These two constraints are balanced in many different ways in different countries and by different utilities, although generally they are all based on various sets of criteria.

A survey of literature reveals the fact that there has been a considerable activity in the development and application of reliability techniques in electric power systems. In power system reliability evaluation, usually component failures are assumed independent and reliability indices are calculated using methods based on the multiplication rule of probabilities [2],[3]. But in some cases, for instance when the effects of fluctuating weather are considered, the previous assumption is invalid.

Generally, two kinds of methodologies are adopted to solve this problem, analytical methods based on Markov processes [4], [5] and Monte Carlo simulation [6], [7]. A DC-OPF based Markov cut-set method (DCOPF-MCSM) to evaluate composite power system reliability considering weather effects is presented in [8] where the DC-OPF approach is used to determine minimal cut sets (MCS) up to a preset order and then MCSM is used to calculate reliability indices.

The appropriate incorporation and presentation of the implications of uncertainty are widely recognized as fundamental components in the analyses of complex systems [9].There are two fundamentally different forms of uncertainty in power system reliability assessment [9], [10]. Aleatory and epistemic uncertainties are considered in power system reliability evaluation in [11] where aleatory uncertainty arises because the study system can potentially behave in many different ways. A method for incorporating the failures due to aging in power system reliability evaluation is presented in [12]. It includes the development of a calculation approach with two possible probability distribution models for unavailability due to aging failures and implementation in reliability evaluation. Adverse weather such as hurricanes can have significant impact on power system reliability [12], [13]. One of the challenges of incorporating weather effects in power system reliability evaluation is to assess how adverse weather affects the reliability parameters of system components. A fuzzy inference system (FIS) built by using fuzzy clustering method is combined with the regional weather model to solve the preceding problem is illustrated in [14]. A new computationally efficient methodology for calculating the reliability indices of a bulk power system using the state enumeration approach is depicted in [15]. The approach utilizes topological analysis to determine the contribution of each system state to the frequency and duration indices at both the system and the bus level.

Electrical demand in Bangladesh is increasing rapidly due to population and industrial growth. Though in recent years some generators have been added to the national grid, but frequency of load shedding has also been increased. Existing capacity is not sufficient to meet the demand. In this paper, a recursive algorithm is used to calculate the reliability of BPS for last ten years (2001-2010).

II. Generator and Load Model of BPS

A. Generator Model

The simplest model for a generating unit for continuous operation is a Run-Fail-Repair-Run cycle that states that every generator has two states. They are— i) Unit availability and ii) Unit unavailability or forced outage rate (FOR). The unit availability means the long term probability that the generating unit will reside in on state and unit unavailability or FOR means the long term probability that the generating unit will reside in off state. Mathematically FOR can be defined as,

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$$FOR, u = \frac{\lambda}{\lambda + \mu} = \frac{r}{m + r} \quad (1)$$

Where,

λ = time to failure

μ = time to repair

m= mean time to failure = $\frac{1}{\lambda}$

r = mean time to repair = $\frac{1}{\mu}$

Unit availability of a generating unit can be defined as,

$$Unit availability, a = \frac{\mu}{\lambda + \mu} = \frac{m}{m + r} = 1 - u \quad (2)$$

For a generating unit with capacity = C MW and FOR = u and unit availability = a, the probability density function (PDF) of forced outage capacity is shown in Fig.1.

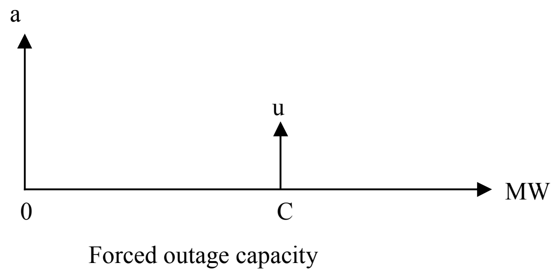

Fig. 1 PDF of forced outage capacity of a generating unit

In 2010, BPS had sixty one generators and a total installed capacity of 5275 MW. The individual capacity and FOR of the generators are shown in Table I.

TABLE I
CAPACITY AND FOR OF THE GENERATORS OF BPS

Gen No.	Capacity (MW)	FOR	Gen No.	Capacity (MW)	FOR
1	40	0.014	32	15	0.15
2	40	0.014	33	15	0.15
3	50	0.014	34	15	0.15
4	50	0.014	35	15	0.15
5	50	0.014	36	35	0.10
6	210	0.16	37	35	0.10
7	50	0.113	38	21	0.122
8	109	0.07	39	120	0.04
9	55	0.185	40	77	0.101
10	55	0.185	41	100	0.04
11	210	0.095	42	125	0.10
12	210	0.019	43	125	0.10
13	210	0.08	44	110	0.301
14	210	0.08	45	60	0.402
15	64	0.116	46	28	0.50
16	64	0.116	47	28	0.50
17	150	0.013	48	20	0.045
18	150	0.014	49	20	0.20
19	150	0.014	50	20	0.20
20	56	0.321	51	20	0.119
21	56	0.321	52	60	0.50
22	30	0.15	53	8	0.30
23	100	0.30	54	450	0.07
24	210	0.197	55	235	0.07
25	210	0.197	56	125	0.07
26	60	0.117	57	142	0.07
27	28	0.60	58	45	0.07
28	28	0.60	59	45	0.07
29	12	0.15	60	110	0.11
30	12	0.15	61	110	0.07
31	12	0.15			

B. Load Model

In order to develop the load model of BPS, hourly loads of last ten years (2001-2010) are collected from NLDC of Bangladesh. Hourly loads are divided in 12 groups having a group size of 250 MW. The occurrence of each group is then counted for specific year. The probability of occurrence of each group is calculated as,

$$P_g = \frac{N_g}{N_t} \quad (3)$$

Where,

P_g = Probability of occurrence of a group

N_g = No. of occurring days of that group in observation period of 1 year

N_t = Total no. of days in observation period

Finally the average value of each group is taken and the corresponding probabilities reside for that average value of the load. Table II shows the load model of BPS in 2010.

TABLE II
LOAD MODEL OF BPS IN 2010

Load range (MW)	Average load (MW)	Frequency	Occurrence probability
1500-1750	1625	0	0
1750-2000	1875	0	0
2000-2250	2125	0	0
2250-2500	2375	1	2.73×10^{-3}
2500-2750	2625	2	5.47×10^{-3}
2750-3000	2875	4	10.95×10^{-3}
3000-3250	3125	5	13.69×10^{-3}
3250-3500	3375	22	60.27×10^{-3}
3500-3750	3625	63	172.60×10^{-3}

3750-4000	3875	117	320.54×10^{-3}
4000-4250	4125	137	375.34×10^{-3}
4250-4500	4375	13	35.61×10^{-3}

III. Recursive Algorithm

BPS has 61 generators. Thus possible states will be $2^{61} = 2.305 \times 10^{18}$. This is considerably a large number for fundamental approach (State enumeration technique) and calculation become too complex. More practical approach for large system is recursive technique which is described in what follows.

The recursive expression for a state of X MW on forced outage after the addition of a generating unit of capacity C MW with forced outage rate U is given by,

$$p(X) = p'(X)(1-u) + p'(X-C)u \tag{4}$$

Where, p(X) = the individual state probability.

If X is less than C,

$$p'(X-C) = 0 \tag{5}$$

Consider a power system with three generators of capacity C_1, C_2 and C_3. Unit's availability is a_1, a_2 and a_3, respectively and FOR is u_1, u_2 and u_3, respectively. The steps of recursive algorithm for this small system are presented below in tabular format.

TABLE III
1ST UNIT IS ADDED

State No.	Capacity on outage	$p'(X)(1-u)$	$p'(X-C)u$	$p(X)$
1	0	$1 \times (1-u_1)$	$0 \times (u_1)$	p_1
2	C_1	$0 \times (1-u_1)$	$1 \times (u_1)$	p_2

TABLE IV
2ND UNIT IS ADDED

State No.	Capacity on outage	$p'(X)(1-u)$	$p'(X-C)u$	$p(X)$
1	0	$p_1 \times (1-u_2)$	$0 \times (u_2)$	p_1
2	C_1	$p_2 \times (1-u_2)$	$0 \times (u_2)$	p_2
3	C_2	$0 \times (1-u_2)$	$p_1 \times (u_2)$	p_3
4	C_1+C_2	$0 \times (1-u_2)$	$p_2 \times (u_2)$	p_4

TABLE V
3RD UNIT IS ADDED

State No.	Capacity on outage	$p'(X)(1-u)$	$p'(X-C)u$	$p(X)$
1	0	$p_1 \times (1-u_3)$	$0 \times (u_3)$	p_1
2	C_1	$p_2 \times (1-u_3)$	$0 \times (u_3)$	p_2
3	C_2	$p_3 \times (1-u_3)$	$0 \times (u_3)$	p_3
4	C_1+C_2	$p_4 \times (1-u_3)$	$0 \times (u_3)$	p_4
5	C_3	$0 \times (1-u_3)$	$p_1 \times (u_3)$	p_5
6	C_1+C_3	$0 \times (1-u_3)$	$p_2 \times (u_3)$	p_6
7	C_2+C_3	$0 \times (1-u_3)$	$p_3 \times (u_3)$	p_7
8	$C_1+C_2+C_3$	$0 \times (1-u_3)$	$p_4 \times (u_3)$	p_8

This is apparent from above calculation that for n machine there will be 2n states to calculate. But in practical case it is improbable to find 2n number different states. If any two or more states have similar values their probability will be added under same state. As for an example, in table V if C1= C2 then state 2 and 3, 6 and 7 will be equal. In that case at state 2 value of probability. Similarly at state 6, probability, . Thus there is no need to have state 3 and 7 for further consideration. Numbers of states are reduced to 6. This method is applied in every step of unit addition. As a result total numbers of states reduce to 5230 from 2.305×10^{18}.

After considering all the states, they are sorted in ascending order and cumulative probabilities are calculated. A sample calculation is shown in Table VI.

TABLE VI
SAMPLE CALCULATION

State No.	Capacity on outage	$p(X)$	Cumulative probability
1	0	p_1	$p_8 + p_7 + p_6 + p_5 + p_4 + p_3 + p_2 + p_1 = 1$
2	C1	p_2	$p_8 + p_7 + p_6 + p_5 + p_4 + p_3 + p_2$
3	C2	p_3	$p_8 + p_7 + p_6 + p_5 + p_4 + p_3$
4	C1+C2	p_4	$p_8 + p_7 + p_6 + p_5 + p_4$
5	C3	p_5	$p_8 + p_7 + p_6 + p_5$
6	C1+C3	p_6	$p_8 + p_7 + p_6$
7	C2+C3	p_7	$p_8 + p_7$
8	C1+C2+C3	p_8	p_8

After arranging all the states in ascending order, reserve of the power system is calculated using,

$$\text{Reserve} = \text{Installed capacity} - \text{Load} \tag{6}$$

LOLP of a particular load is then calculated using,

$$LOLP_{load} = probability\,(Outage > \mathrm{Re}\,serve) \quad (7)$$

And finally, Total LOLP of the system is calculated using,

$$LOLP = \sum (LOLP_{load})\,(pr.of\ load) \quad (8)$$

Where, Pr. of load = Occurrence probability of a particular load.

IV. Results and Discussion

BPS has sixty one generators and a total installed capacity of 5275 MW. Using the recursive algorithm, LOLP of BPS from year 2001 to 2010 is evaluated. Table VII presents the values of LOLP for the period of last ten years.

TABLE VII
LOLP of BPS for Last Ten Years

Year	LOLP
2010	2.14%
2009	2.05%
2008	2.54%
2007	2.39%
2006	1.96%
2005	1.93%
2004	1.86%
2003	1.79%
2002	2.34%
2001	2.22%

Reliability of a system is good if LOLP is low. In 2001 LOLP was 2.22% which is considerably high. The following year in 2002 LOLP increased as demand increased but capacity remains almost same. In the very next year new 3 generators were added and total capacity became 4013 MW. Thus LOLP decreased in 2003. This capacity was same for next year so that LOLP increased with ongoing power demand. In 2005 generator number was increased up to 59 and total capacity became 5055 MW. With that amount of generation, LOLP didn't fall significantly because demand increased extensively due to the development in rural areas, industries and communication sector. Up to year 2008 no additional generator came to the grid. Thus LOLP increased gradually and amount of load shedding increased. In 2009 & 2010 capacity became 5275 MW with 61 generator and LOLP improved slightly with respect to 2008.

V. Conclusion

The objective of a power system is to supply electrical energy to both large and small consumers as economically as possible with an acceptable degree of reliability and quality. Reliability is the ability of a power system to provide service to consumers while maintaining the quality and price of electricity at an acceptable level. In this paper reliability index 'LOLP' of BPS using recursive algorithm is evaluated for the period of last ten years. A considerably high LOLP is observed in this period that indicates the poor reliability of the power system of Bangladesh.

Thus the reliability analysis of BPS will help estimating the service quality of the system. It will also create awareness among the utility and the consumers of the system and will assist in planning and operation of BPS.

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