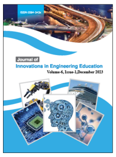

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Composite reliability evaluation of integrated Nepal power system

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Abstract

The worth of reliability has been increasing with the advancement of technology. Based on the involvement of the various functional zones, the assessment of the reliability of the power system is divided into 3 Hierarchy levels (HL). The composite reliability (HL II) involves the availability of generation systems and transmission systems in evaluating the reliability of power systems. In this paper, the composite reliability of the Integrated Nepal Power System (INPS) is assessed using sequential Monte Carlo Simulation (MCS). Based on the trip data of the various Hydro Electric Power Plant (HEPP) units of Nepal and of transmission line, the artificial UP and DOWN sequence of the composite system is simulated. The power output of the Hydro-Electric Power Plant (HEPP) is varied based on the variation of seasonal flow. The system state is compared with the hourly load data of various load centers of INPS to determine the reliability indices like LOLP, LOLE, and EENS. As the eastern part of INPS doesn't have a generating unit, it is found to have lower reliability. The reliability of INPS can be improved by improving the reliability of load centers that have a lower value of reliability indices.

1. Introduction

Nepal having an economically feasible capacity[1] of 42,000MW of power, only about 1262MW [2]of power is extracted from HEPP including 94 projects of capacity more than 1MW with a total capacity of 1250MW and 12MW by HEPP of Capacity less than 1MW. The other source of power in INPS are 2 thermal power plants with a total capacity of 53.41MW which are occasionally operated due to their high operating cost and grid-connected solar power plants of a total capacity of 32.87MW.In addition to this, there are locally operated small micro-hydro, solar power, a wind power plants that are not connected to the grid.

The power system adequacy depends on generation adequacy, transmission adequacy, and distribution. Power system reliability can be evaluated by different methods [3], [4]and at various hierarchy levels (HL). Different methods have some pros and cons [5]. The HLI reliability indices of INPS are evaluated by the analytical method [6] The power system is stochastic. The random behavior of the system can be properly incorporated into the simulation method. The HLI reliability of the IEEE 96 bus system is evaluated [7] using Monte Carlo which gives the necessary idea about generation adequacy. As the transmission line is exposed to the environment there is a huge chance of failure of the transmission lines [8]. The composite power system reliability can be evaluated by sequential as well as non-sequential simulation methods. Nonsequential Monte Carlo simulation doesn't preserve the chronology of the system. It randomly selects the system state whereas in sequential simulation the sequence of operation of the various components is generated with each state depending on its previous state. The composite reliability of the power system can be evaluated by the analytical method [9] and the simulation method[10, 11]. The analytical method provides the average value of the reliability indices and becomes complicated with a large system size. In this paper, the composite reliability of INPS is assessed using sequential Monte Carlo simulation. Reliability evaluation of INPS is important as reliability and economics play a major integrated role in the decision-making process [12, 13]. Various random failure events of transmission lines and generating units are also incorporated and contingency analysis is performed using DC load flow.

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2. Sequential Monte Carlo simulation

The sequential Monte Carlo simulation simulates the actual behavior of the system without breaking the chronological sequence of event that occurs in the system. The present state of the system is governed by the previous event and the time of occurrence of an event. This method also helps to generate the probability distribution of various reliability indices along with their average value which is the only parameter calculated by the analytical method. The probability distribution is of utmost importance to the power distributors when it comes to compensation to the consumer for the power cut. Such probability distribution can only be generated by sequential Monte Carlo simulation. It is assumed that each component state duration follows an exponential distribution.

$$F(t) = \mu e^{-\mu t} \tag{1}$$

Where, μ is the mean value F (t) is cumulative probability using inverse transformation, the value of random variable T can be determined. It is assumed that the duration of state follows an exponential distribution. The duration of the up state follows an exponential distribution with a mean value of MTTF and the duration of downstate follows an exponential distribution with a mean value of MTTR.

$$T = -\frac{\ln(U)}{\mu} \tag{2}$$

To simulate the chronological system; the up and down sequence of each component is generated based on the MTTR and MTTF of each component.

$$\mathrm{MTTF} = \frac{\text{Total uptime}}{N} \tag{3}$$

N is the total number of failures
The up and down sequence of each component is created as

$$T_{\mathrm{i}}^{\mathrm{up}} = -\frac{\ln\left(U_{\mathrm{i}}\right)}{\mathrm{MTTF}} \tag{4}$$

$$T_{\mathrm{i}}^{\mathrm{down}} = -\frac{\ln\left(U_{\mathrm{i}}\right)}{\mathrm{MTTR}} \tag{5}$$

Ui is a uniformly distributed random number, MTTF is the meantime to fail and MTTR is the meantime to repair

The above step generates the artificial operating sequence of each component for a year. The system state is obtained by superimposing the state of each component in each small transition time. The initial state of each system is assumed to be up to the state.

3. Contingency analysis

Failure is a random event and can cause interruption of load at any time in the system. The failure of the generator doesn't necessarily cause the load interruption if there is an alternative line to flow power to load. The contingency analysis is one of the important parts in determining the composite reliability. DC load flow is used for this purpose as it provides a result that is sufficient for reliability evaluation with less computational time and storage.

DC load flow is carried out to determine the power at each substation during each interval between the system state transitions. Since the DC load flow is based on assumption that the line resistance is negligible, it doesn't provide information about the power loss in the system. The DC load flow is constrained by the maximum generation capacity of each generator unit and the capacity of each line. The Upper Marsyangdi Hydro Electric Power Plant is taken as the reference bus.

$$P_K = \sum_{\substack{j=1 \\ j \neq k}}^{N} B_{kj}(\theta_k - \theta_j) \tag{6}$$

Subject to:

$$G < G^{\mathrm{MAX}}$$
$$LF < LF^{\mathrm{MAX}}$$

G is the power generated by each generator, G^{MAX} is the maximum capacity of the generator, LF is the power flow in the transmission line and $LF^{MAX}$is the maximum capacity of the line

In matrix form the line flow is represented as:

$$[P] = [B][\theta] \tag{7}$$

P is the power injected from each bus, B is the bus admittance matrix and θ is the power angle of the bus

4. Methodology

The above-described steps for composite reliability evaluation are implemented to determine the HL II reliability of INPS. The majority of power plants in INPS are ROR type HEPP. The power generation by such plants is largely affected by the flow rate in the river. Twelve months in a year are divided into three groups, with four wet months; 4 spring/fall and 4 dry months. The capacity during wet months is 100%; that of spring/fall is 80% and that of dry is 50%. In this paper, failure of units of HEPP of capacity greater than 10MW is only considered. The HEPP with a capacity of less than 10MW is taken as a negative load whose demand varies with the season.

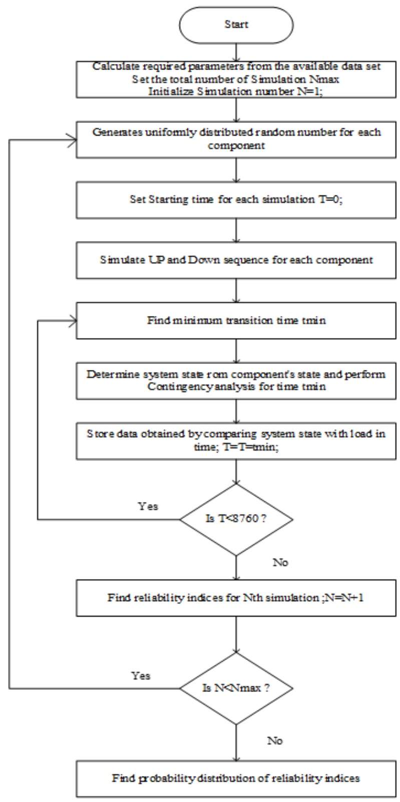

Figure 1: Flowchart to evaluate composite reliability

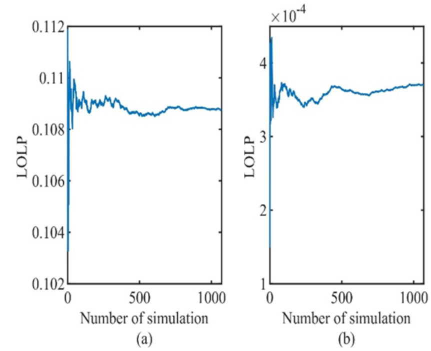

Figure 2: LOLP of (a) Lahan and (b) Maatatritha

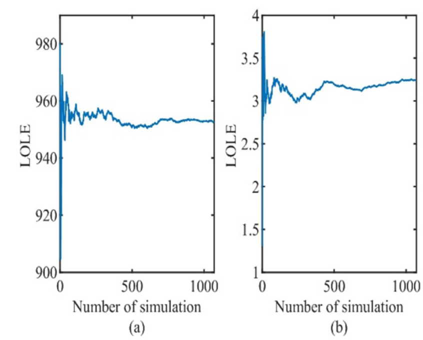

Figure 3: LOLE of (a) Lahan and (b) Maatathritha

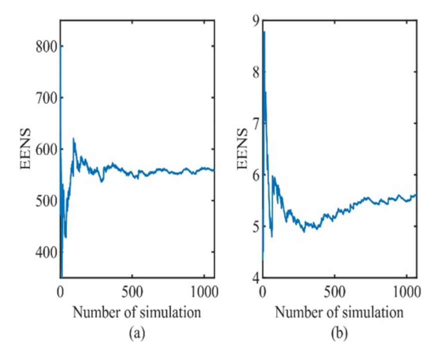

Figure 4: EENS of (a) Lahan and (b) Matatritha

The loss in INPS is 44.5MW [14].This loss is added to each substation as load in proportion to their peak load. The individual units present in the HEPP are considered as individual components of the power system. The capacity of each unit is equal to the total capacity of the plant by the number of units present in that plant. The MTTF and MTTR of the component whose trip data are available are calculated. For the plant whose data are not available the average of available data is considered. The reliability of power import from India is considered the same as that of the 132KV line through which power is imported. 132KV and 66KV lines are considered. Each line is considered as an individual component and their MTTR and MTTF are calculated based on the trip data available. The flowchart shown below describes the overall steps involved in finding the composite reliability of the Integrated Nepal Power System and the reliability of individual load centers of INPS. In each simulation, the hourly load is the same but the generation capacity and the line contingency are different in each simulation based on the UP and DOWN state generated.

The reliability indices LOLP, LOLE, and EENS are evaluated for each 55 load center of Nepal. The power import from India is 335MW. The power is imported from 4 different points with a 132KV line. Figures 2, 3, and 4 show the LOLP, LOLE, and EENS verse number of simulations of Matatirtha and Lahan substation. Matatirtha has the highest reliability with LOLP 0.000369794, LOLE 3.239395156 hrs/yr, and EENS 5.585504367 MWhr/yr. Lahan has the least reliability with LOLP 0.108720591, LOLE 952.3923781 hrs/yr, and EENS 559.7448915 MWhr/yr.

Fig. 5 (a) and Fig. 5 (b) show the probability distribution of LOLE of Lahan and Matatirtha. The LOLE of Lahan follows a normal distribution with a mean of 952.392 and a standard deviation of 72.6522. Similarly,

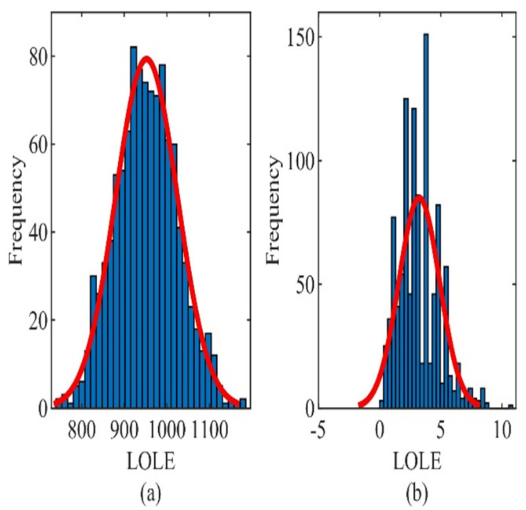

Figure 5: Probability distribution of LOLE for (a) Lahan and (b) Matatritha

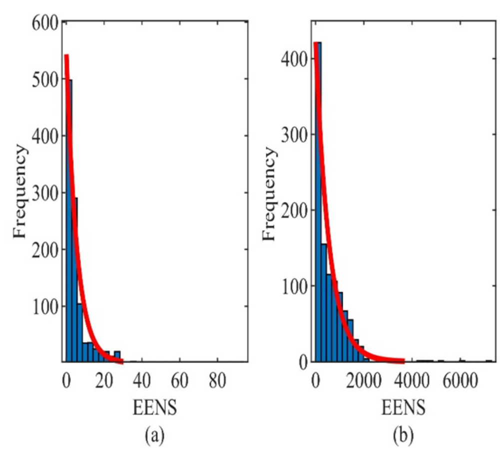

Figure 6: Probability distribution of EENS for (a) Lahan and (b) Matatritha

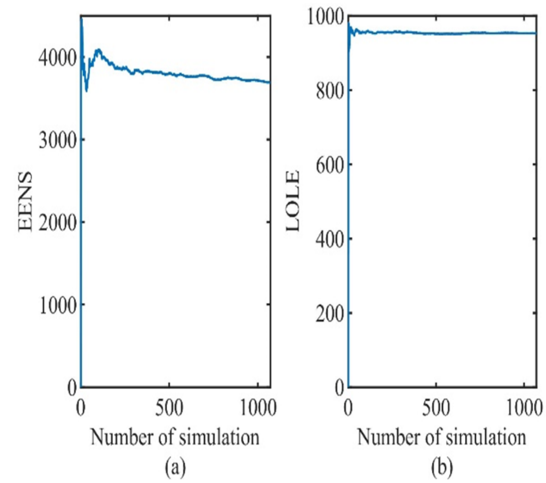

Figure 7: (a) EENS and (b) LOLE of INPS

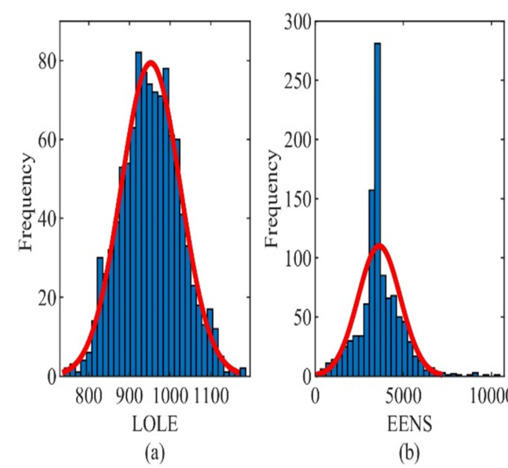

Figure 8: Probability distribution of (a) LOLE and (b) EENS for INPS

the LOLE of Matathitha follows the normal distribution with a mean of 3.2394 and a standard deviation of 1.6596.

Fig. 6(a) and Fig .6(b) show the probability distribution of EENS of Lahan and Matatirtha. The EENS of Lahan and Matatirtha follows an exponential distribution with a mean of 559.745 and 5.58966 respectively.

The EENS and LOLE verse number of simulations of INPS is shown in Fig. 7(a) and Fig. 7(b). From the figure it is found that LOLP of INPS is 0.108724437, LOLE of INPS is 952.4260674 hrs/yr and EENS of INPS is 3693.096244 MWhr/yr.

Fig. 8 (a) and Fig. 8 (b) show the probability distribution of LOLE and EENS of INPS. LOLE of INPS follows the normal distribution with a mean of 952.426 and a standard deviation of 72.5965. Similarly, EENS follows the normal distribution with a mean of 3693.1 and a standard deviation of 1400.62.

5. Conclusion

The reliability of various substations of Nepal is assessed using sequential Monte Carlo simulation. After 800 simulations the constant value of reliability indices is obtained. The value of reliability indices of INPS shows that the reliability of INPS needs to be improved. For improving the reliability of INPS reliability of the load centers with lower reliability needs to be improved.

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Table 1: RELIABILITY OF INPS

BUS	LOLP	LOLE (hrs/yr)	EENS (MWhr/yr)
Mahendranagar	0.0006	5.0962	10.4192
Syaule	0.0007	5.7292	11.1583
Attaria	0.0195	170.7096	70.5116
Pahalmanpur	0.0195	171.1752	74.2923
Lamki	0.0190	166.4999	57.5184
Bhurigaon	0.0188	165.0609	46.1326
Kohalpur	0.0203	178.1966	93.9834
Kusum	0.0235	206.0111	114.8136
Hapure	0.0094	82.6038	33.8373
Lamahi	0.0196	171.5665	76.6049
Ghorahi	0.0030	26.1795	17.5424
Chanauta	0.0247	216.3813	115.0882
Butwal	0.0253	221.6267	126.2502
Bardghat	0.0010	8.9558	15.3123
Kawasoti	0.0189	165.6351	47.3310
Bharatpur	0.0192	168.0211	60.6073
Damauli	0.0004	3.2703	7.6174
Lekhnath	0.0004	3.3456	7.6593
Pokhara	0.0005	4.1046	8.1922
Syangja	0.0004	3.4816	7.6832
Markichowk	0.0092	80.4160	20.1916
Hetauda	0.0104	90.8117	34.6707
Chapali	0.0142	124.6208	39.2976
Siuchatar	0.0196	171.9148	84.5621
Balaju	0.0224	196.0578	111.6753
Chapali	0.0071	62.6038	19.8344
Chabel	0.0012	10.2096	17.0081
Lamosanghu	0.0004	3.3222	7.6408
Lainchour	0.0005	4.2869	8.2609
Patan	0.0039	34.4220	17.9329
Baneswor	0.0496	434.8819	175.5069
Bhaktapur	0.0204	178.4503	96.3810
Banepa	0.0005	4.5992	9.3074
Panchkhal	0.0004	3.8415	7.7654
Teku	0.0006	5.0788	9.5574
K3	0.0005	4.6196	9.3955
Kamane	0.0193	169.0265	63.1476
Pathlaiya	0.0094	82.4722	20.5333
Chandranigahapur	0.0193	169.4893	69.9062
Parwanipur I	0.0008	7.1002	12.8180
Dhalkebar	0.0178	156.3066	40.7596
Mirchaiya	0.0193	169.0199	61.0864
Lahan	0.1087	952.3924	559.7449
Rupani	0.0005	4.3938	9.1204
Duhabi	0.0011	9.3769	15.3340
Anarmani	0.0712	623.5005	306.4261
Damak	0.0009	8.2865	13.5025
Godak	0.0008	6.6510	11.4013
Phidim	0.0183	160.0533	44.8019
Amarpur	0.0182	159.6889	41.0855
Birgunj	0.0838	734.4190	506.5799
Simra	0.0392	343.1612	129.3268
Amlek hgunj	0.0191	167.0440	58.4105
Mata tirtha	0.0004	3.2394	5.5855
Parwa nipur II	0.0190	166.2603	51.9824