Proceedings of 10th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: October Volume: 10

Probabilistic Performance Index(PPI) based Contingency Screening for Integrated Nepal Power System Reliability Evaluation

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Abstract

Continuous supply of adequate quantity of quality electrical energy to the customer is prime objective of overall power system operation. As power system behavior is stochastic in nature, random failure of component is a major challenge associated with power system reliability. The study and evaluation on power system reliability is most important aspects for planning, design and operation of power system network. This research work comprises the reliability evaluation of our Integrated Nepal Power System(INPS) operation based on probabilistic approach of reliability assessment. Ten(10) number of contingencies which are most probable to be operated are studied and analyzed. In this study, 39 generating plants and 71 transmission lines all together 110 number of component are taken. The loads, maximum demand(MW) has taken as fixed. State values of individual component are calculated with binomial probability distribution. Truncation of state space has been carried to truncate the state spaces having insignificant probabilities. Transition rate and state frequency of individual contingencies are calculated using reliability indices based on probability values. The load curtailment to be occurred in each contingency has been assessed with DIgsilent powerfactory simulation, where contingencies are individually run for getting load curtail level. Finally, PPI index for all contingencies are calculated, PPI values indicates the severity of that contingency, higher the PPI higher the severity and vice-versa. This research concluded that, only the load curtailment value do not truly reflect the severity to be expected with that operation rather it is due to the combine effect of load curtail and state frequency of that state operation.

Keywords

Reliability evaluation, INPS , Probabilistic Performance Index, Contingency Analysis

1. Introduction

The modern power system has become a highly complex network with integration of large number of generating sources, transmission lines and distribution networks on it. To provide adequate amount of quality electricity to consumer is the main requirement of power system. Due to random failures of equipment in power system network, difficulty has to be faced on continuous supplying of required amount of quality energy to customer. The development and advancement in power system planning and operation for reliable, efficient and economical utilization of energy is the core research area in power system engineering field. As to plan and operate the composite power system on a long term basis, the reliability assessment is very necessary which are determined by system configurations, load levels, and component availability. There are mainly two approaches for reliability assessment, deterministic and probabilistic. Deterministic approaches is used for the adequacy and security assessment in power system operation whereas the probabilistic approach of assessment can combine consequences and probabilities of power system operation together. The reliability evaluation of composite power system or combination of both generation and transmission system is known as hierarchical level 2 (HL2) reliability evaluation. All possible combination of power system component are represented with state space. Obtaining the most significant state spaces is the main basis for creating the contingencies of power system operation to be studied and analyzed. Use of more realistic reliability indices data gives practical useful result for decision making.Earlier research were centered on computation of deterministic performance index(PI) based on power flow simulation method. But the contingency by definition has a great degree of uncertainty included in it. The previous deterministic approach of contingency study may not guarantee randomness in computation, which was the major problem to be addressed. This purposed Probabilistic Performance Index(PPI) integrates randomness in computation processes for the composite power system reliability evaluation [1]. In this research, contingency screening of Integrated Nepal Power System(INPS) based on PPI method is been done with its Results and Discussion.

2. Composite power system reliability evaluation

The term reliability refers to the measure of overall ability of a system to perform its intended function for intended period of observation. The concept of a power system reliability covers all aspects of system ability to satisfy the consumer demand with acceptable quality. The composite power system refers to the combination of both generation and transmission facilities on interconnected power network. Reliability assessment of composite power system is based on the probabilistic states of components in generation and transmission systems [2]. The assessment of reliability indices for individual component are the key factor on assessing the system reliability.

3. Reliability indices

Reliability assessment of individual component of the power system network is very important for the analysis of its wholesome operation. Each component in composite power system network is considered as continuously operated system. For the quantitative assessment of reliability, the past performance is to be analyzed to predict for the future performance. Since, the power system constituents are familiar objects that have been developed and performed for quite reasonable period of time let's say more than hundred years of its developing history, so we can easily have it's performance data in terms of failure and repairing pattern. The failure and repair rate is sufficient to generate the reliability data of individual unit or component, equation 1 and 2 are for the reliability calculation of the component which is in terms of availability and unavailability of the component to be analyzed and further processed.

$$A = \frac{\mu}{\lambda+\mu} \tag{1}$$

$$U = \frac{\lambda}{\lambda+\mu} \tag{2}$$

Where,
λ= number of failures per year
μ= number of repairs per year

From chronological time graph of component failure and repair time, the mean value of up and down times can also be useful for calculating the failure rate and repair rate of component using the equation 3 and 4.

$$\lambda = \frac{1}{MTTF} \tag{3}$$

$$\mu = \frac{1}{MTTR} \tag{4}$$

Where,
$MTTF$= Mean time to failure
$MTTR$= Mean time to repair
$MTBF$= Mean time between failure

4. Reliability assessment of Generating plant and transmission lines

For the reliability assessment of composite power system we need to have the reliability indices of generating plants [3] and transmission lines of that system at first. In this study, we are focusing for failure rate and repair rate of individual component for overall power system reliability evaluation. The failure rate and repair rate of generating plants has been assessed with reference to the data recorded by NEA.

For transmission lines, the observation of various failures and its repairing manner is very elusive and getting its exact real time value is difficult. Here for this study, assessment of the failure and repair rates of transmission system has been calculated with referencing the research paper. As per this research paper [4], the equation 5 and data were used for our transmission lines.

$$\lambda = \begin{cases} 0.65, \text{per hunderd miles per year, for 132 kV line} \\ 1.1, \text{per hundered miles per year, for 66 kV line} \end{cases}$$

(5)

Mean time to repair for 132 and 66 kV lines are 9 and 6 hour respectively. From this MTTR value, we have calculated the repair rate(μ) of respective transmission lines with equation 4.

5. State value computation

For each power system component like generating plant or transmission line, the state denotes all the possible operating mode of that component.The state value denotes the probability of the component to be remain on that state of operation. The state values of a particular component includes all distinct operating mode including zero unit in operation to all unit running with their full capacities. In our study of INPS, there are 39 number of generating plants and 71 number of transmission lines in total 110 number of component we have been considered. The state values of this 110 individual power system component is calculated with binomial probability distribution function as formula given in equation 6.

$$P_r = \frac{n!}{r!(n-r)!} p^r q^{n-r} \tag{6}$$

Where,
p= Availability
q= Unavailability=1-p
n=Total number of unit in a component
r=Number of success unit in a component

In this computation of state values 110 of INPS component, some state have very insignificant possibilities as numerically suggested that they have very little chances to be in that state in power system operation. So in order to take considerable higher probability value of state, we need to truncate that low level values from our state value tabulation for the further processing of it.

Here, in our study, we have truncated the state values less than (0.05), hence the states having the values more than (0.05) are only considered for further processing.

6. State space enumeration and contingency creation

Set of all possible outcomes of a random phenomenon of a power system can be designed as state space. In terms of power system network, the combination of individual state of various components like generators, transmission lines and load may be termed as a state space of a power system. For mathematical illustration, let vector X be the state space of a power system.

$$X = [x_1, x_2, \ldots\ldots, x_n] \tag{7}$$

where, $x_1, x_2 \ldots\ldots, x_n$ are states of individual components like generators, transmission lines, load and so on. The bulk power system may result billions number of state space if we make all combination of power system components. To minimize the number of state space as to make the most significant state space only, there are various techniques we could adopt. Truncation of state space(TSS) is a techniques which reduces the number of state spaces by truncating the insignificant state probabilities [1]. For creating the contingencies the state probabilities which have below the value (0.025) is ignored for this study. This method limits the state spaces numbers to limit it to ten(10) most probable contingencies.

7. Transition rate concept

In reliability assessment, it concerns with system that are in discrete in space, i.e., they exist in one of a number of discrete and identifiable states, they exist continuously in one of the system states until a transition occurs which takes them to another state. For a system of repairable component, the transition rate is defined by the failure or repair rate of the component to transit from its operational condition to the failed and vice versa [5].

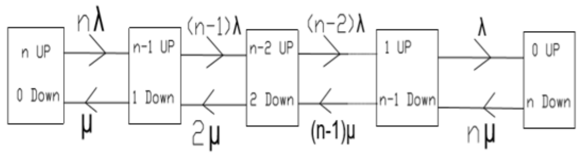

Figure 1: Transition rate diagram for multiple no of component

8. State frequency concept

Frequency of encountering a system state is the average duration of residing in that state. Calculation of state frequency helps to evaluate the reliability indices for system that are continuously operated, repaired and maintained. For Markov technique, the frequency of encountering that state is equals to the multiplication of state probability and rate of departure from that state. [5]

Frequency of encountering the individual state = Individual state probability×Rate of departure from that state

$$F_j = F_j \times \text{rate of departure from that state}(P_j) \quad (8)$$

9. Computation of Probabilistic Performance Index(PPI)

In this study, an index called PPI- Probabilistic Performance Index is used to evaluate the reliability value of contingencies. The contingencies we are going to create is the different combination of generating plant and transmission lines. The calculation of the index will be based on probabilistic approach rather than conventional deterministic method so this way of power system reliability evaluation overcomes the shortcomings of the conventional Performance Index(PI) method, hence this new methodology for ranking the contingencies is quite promising. The formula for proposed index as per equation 9, PPI is defined as [1]:

$$PPI_j = \frac{W}{Y}\frac{L_{curtailed,j}F_j}{L_{max}} \quad (9)$$

where,
W= Real non-negative weighting factor
Y= Order of exponent
j= number of contingencies
$L_{curtailed,j}$= number of contingencies
F_j= Frequency of failure for j^{th} contingency
L_{max}= Maximum load on the system in MW
The value of weighting factor(W) may be taken as 1. The value of order of exponent(Y) has to be optimally selected. Lower or higher values of Y may result in masking and non-linearity problems in ranking the contingencies respectively.

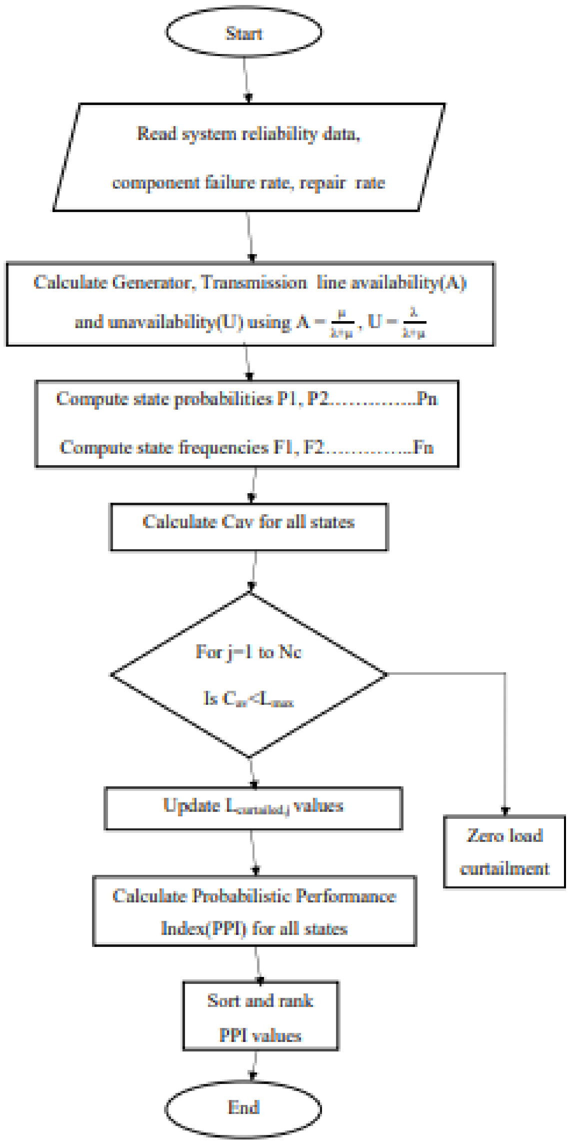

Figure 2: Flow chart for PPI calculation

10. State probabilities, transition rate and state frequency of contingencies

After creating the ten(10) number of contingencies within our INPS network. State probability, transition rate and state frequency are required to calculate for each contingency for indexing and ranking them. State probability is the product of component state value which constitutes for that contingency. Similarly transition rate can be calculated by already got component failure rate and repair rate values. After the calculation of state probabilities and transition rate, state frequency can be calculated by equation 8. The table 2 shows the state probabilities(P_j), Transition rate(Tr. rate), and state frequency(F_j) values of respective contingencies.

Table 1: State probability, transition rate and state frequency of contingencies

$Cont_j$	P_j	Tr. rate	F_j
1	0.025950	2345.06	60.85
2	0.026278	2151.86	56.55
3	0.026763	2109.62	56.46
4	0.027657	2191.86	60.62
5	0.028250	2018.42	57.02
6	0.028772	1976.18	56.86
7	0.030019	1889.46	56.72
8	0.030370	1884.98	57.25
9	0.031686	1789.3	56.70
10	0.033838	1693.62	57.31

11. Result

In order to rank the contingencies we have formulated, the procedures required are described in computation of Probabilistic Performance Index(PPI) and the necessary calculation has been carried out in above clauses. The table 2 shows the state frequency(F_j), Mega Watt(MW)Load curtailment ($L_{curt,j}$), PPI index and rank of the contingencies we created and studied.

Table 2: PPI index and contingency ranking

$Cont_j$	F_j	$L_{curt,j}$	PPI	Rank
1	60.85	29	0.10444	10
2	56.55	76.87	0.25727	8
3	56.46	89.82	0.30014	7
4	60.62	51.81	0.18588	9
5	57.02	139.76	0.47165	6
6	56.86	151.81	0.51088	5
7	56.72	185.85	0.62390	3
8	57.25	173.82	0.58897	4
9	56.70	207.54	0.69647	2
10	57.31	270.76	0.91840	1

12. INPS Contingencies

For recognizing the contingencies we studied in simple, the below list shows the contingencies with its respective number. It shows the information about which generating plant and transmission lines will be operated for the respected contingencies.

1. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola and Kabeli B-1
2. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1 and Madyku khola
3. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola
4. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola and Kabeli B-1
5. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1,Madyku khola, Sipring and Upper madi
6. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1,Madyku khola, Sipring, Upper madi and Upper mai
7. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1,Madyku khola, Sipring, Upper madi, Upper mai and IPP 7.5-10
8. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1,Madyku khola, Sipring, Upper madi, Upper mai and IPP 5-7.5
9. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli B-1,Madyku khola, Sipring, Upper madi, Upper mai, IPP 7.5-10 and IPP 5-7.5
10. All transmission, all generation with out-Modikhola, Sunkoshi, Puwa Khola, NEA Small, Hetauda Diesel Plant, Kulekhani-III, Lower Modi, Bhotekoshi, Mai Khola, Kabeli

B-1,Madyku khola, Sipring, Upper madi, Upper mai, IPP 7.5-10, IPP 5-7.5 and IPP 2.5-5

With the help of this contingencies naming and numbering, We can easily evaluate and analyze the contingencies parameter with information given in result table.

13. Discussion and conclusion

Here, reliability evaluation of INPS with probabilistic approach is performed with considering the maximum demand on respective load buses. All the generation, transmission lines and load that are integrated and connected on the existing INPS has been considered for this study. The individual component wise generation and transmission lines reliability indices were calculated on the basis of real time past historical data as much as possibly. Contingencies created here for the analysis are the combination of generation and transmission line on making the whole power system operation that would have the higher probable value to be operated hence the probabilistic way of contingency creation applied for this study promised the best result for the reliability evaluation of power system. For the sake of simplicity for the analysis and study, only ten(10) number of contingencies were created here. The state probability, frequency of failure and load curtailment for each contingency were calculated as to rank the contingencies for the analysis. The index called PPI is used to rank the contingencies, on which the higher value of PPI denotes higher severity to the system and vice versa. The most weighting factor for the PPI index are state probability, frequency of failure and load curtailment of contingency. The only load curtailment level of contingency would not show the severity level of that contingency rather it depends on the collective weight of state frequency and load curtailment both. In PPI table above we can observe that, the only load curtailment level do not reflect the severity of that contingency. The contingency which have higher load curtailment value may not be high severe contingency and vice versa.

With probabilistic approach of study the value of state frequency which is probable value to leave that state is also the guiding factor along with the load curtailment level on finding the severity of power system operational mode. The state frequency constitutes the two factors on it, that are transition rate and state probability value of that state. The probabilistic approached used for creating contingencies of INPS results for giving the most probable combination of our INPS operation. Screening and ranking of these contingencies what we have formulated based on PPI index value indicates the severity level of that contingency run in our real time power system operation.

With this study we can easily recognize or understand about the mostly operating or not operating components within our system. From the results and finding with probabilistic performance index it is very helpful for the planner to identify the vulnerable areas on power system network and assist in developing reinforcement method as to make the system more reliable as far as possible.

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