International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 9 (2019) pp. 2252-2259

Reliability Evaluation of Power System using Monte carlo simulation in Pspice

Hemansu Patel
PG Student, Department of Electrical Engineering, Faculty of Technology and Engineering, M. S. University of Baroda, Vadodara, 390001, India.

Anuradha Deshpande
Associate professor, Department of Electrical Engineering, Faculty of Technology and Engineering, M. S. University of Baroda, Vadodara, 390001, India.

Abstract

Power systems reliability is a precondition step to design and planning of the modern power system. This paper focuses on evaluation of power system reliability with nonchronological load by Monte Carlo simulation (MCS) technique using Pspice. In paper power system Reliability is found out in terms of Probability of system success from the probability of system failure. In this regard, failure probability of elements of the system is estimated using the probability distribution histogram from Monte Carlo simulation. By applying outage conditions on every element, considering most general possible failure occurrence and Reliability in terms of probability is estimated. To estimate failure probability random seed generation and sequences of trials generated from simulation histogram in Pspice is considered. The results of simulated system from MCS approach is compared with the results of analytical method.

Keywords: Electric power system, Reliability Evaluation, Monte carlo simulation (MCS), Pspice.

1 INTRODUCTION

Reliability evaluation of power systems by simulation technique is helpful to find reliability of real system to supply customers with reliable power service. Power system reliability evaluation is concerned with the determination of the adequacy of the combined generation and transmission system for providing a suitable supply at the load points. For reliability assessment, there are two main approaches analytical and simulation. Analytical methods are mostly used in past because simulation generally takes large amount of computing time and results of analytical model sufficient for planners and designers to make objective decisions for small system. But in recent years, increasing interest towards modelling the actual system behaviour in simulating software to estimate system reliability used for all type of system [1].

In analytical techniques, system is represented by mathematical models to evaluate reliability using numerical solutions in which assumptions are required for simplification of problems to produce analytical model. Assumptions required particularly for complex system to be modeled. So, some significance can be lost in resulting analysis. Due to this simulation technique is important for reliability assessment. Simulation technique estimates reliability by actual process and random behaviour of system. The techniques take into the planning, designing, and operation of power system which considers random events like outages of elements, dependent events and component behaviour, queuing of failed component, load variation, variations in energy source and different operating conditions. In simulation techniques Monte Carlo simulation (MCS) method is used to evaluate system reliability. MCS method has two approaches random and sequential. Random approach simulates system lifetime intervals randomly in nonchronological order and sequential approach simulates interval in chronological order [2].

Non-sequential Monte Carlo simulation and contingency enumerations are the common state selection techniques used in probabilistic reliability evaluation of bulk power systems. State enumeration is easier and the computational effort for single order contingencies. Rei and Schilling [3] studied Monte Carlo simulation requires larger computational effort but is very versatile to model random behaviour of components. It may be easiest way to evaluate adequately higher order contingencies of bulk system. To improve the computational speed. Kai Hou et al. [4] proposed approach of “impact-increment-based decoupled reliability assessment (IID)”. In which new formulation of reliability indices obtained by decoupling the reliability index of composite systems into generation adequacy and transmission reliability. Then, impact-increment-based reliability assessment method is implemented to both and reduction technique used for the higher order contingency states is developed for the transmission reliability evaluation. Then the number of analysed contingencies can be significantly reduced, which improves the computational speed significantly.

In composite power system, Hua et al. [5] proposes a framework for “system reliability evaluation with subset simulation. For that a small failure probability can be expressed as a product of larger conditional probabilities and turning the problem of simulating a rare failure event into several conditional simulations of more frequent intermediate failure events. The inefficiency of Monte Carlo simulation in simulating rare failure events is overcome by breaking the problem into estimating a sequence of conditional probabilities, which reduces Computational burden by extracting the subset of system states with significant contribution to reliability indices". For very reliable system, González-Fernández et al. [6] consider the method which combines the concepts of Cross-Entropy and Importance Sampling to obtain an optimal distortion for the probabilistic parameters of system components. The state probabilities are, thus, "properly distorted so that important failure events are sampled more to deal with large and complex power systems".

In bulk power system the number of possible outage states are extremely large. Billinton and Zhang [7] proposed approach of the "state extension algorithm which extend the knowledge of the investigated system states to collectively include the effects of a large number of the investigated system states. The algorithm provides more accurate adequacy indices without investigating extensive system contingencies and therefore without significantly increasing the required computational effort". Sometimes bulk system has several outages for that, Nahman [8] proposed a method for "Modeling simultaneous multiple station originated and common cause transmission line outages for bulk-power system reliability analysis. The failure-event vs system-element outage correlation-matrix is defined and used for system outage Modeling". P. Hu et al. [9] and Parvini et al. [10] represent the impact of renewable sources in assessment of operational reliability of power system and analyse the effect of energy storage system for reliability improvement of the system.

2 METHODOLOGY

For reliability assessment mainly two approaches are used 1) Analytical (probabilistic) 2) Failure sequences in MCS method. Probabilistic method represents reliability of system in terms of probability. Which is evaluated from data of components availability and unavailability. MCS method estimate the failure probability of system component from failure sequences using simulated samples. From failure probability, success probability of system can be obtained which represents the system reliability.

2.1 Analytical method

In this method, every component has at least two outcomes from which one considered as successive outcomes and another considered as failure outcomes. From this probability of component given as below.

$$p(success) = P = \frac{No.\ of\ success}{No.\ of\ possible\ outcomes}$$

$$p(failure) = Q = \frac{No.\ of\ failure}{No.\ of\ possible\ outcomes} \tag{1}$$

$$\text{And,}\quad P + Q = 1 \tag{2}$$

In power system, number of components are more and sometimes failure of component depends on other failure events. For that binominal distribution is used which associated with the combinational problems. Binominal distribution represented by expression $(P + Q)^n$. If component has n trials with r success or $(n - r)$ failure then probability can be evaluated from,

$$Pr = \frac{n!}{r!(n-r)!}\, P^r Q^{n-r}$$

$$Pr = nCr\, P^r Q^{n-r} \tag{3}$$

In above equation, P (Availability of component) and Q (Unavailability of component) remain constant and n must be fixed number of trial.

2.2 MCS method

This method is class of computational algorithm which relies on repeated random sampling to evaluate numerical results. In this method random numbers are generated by the random number generators in digital computer with uniform random number found in interval of (0,1). These numbers are tested for component random behaviour and failure sequences are generated from failure event of component. These sequences are helpful to estimate the failure probability near true value.

2.2.1 Generation of Random Number

Random numbers are essential in simulation technique. They are variables which values are uniformly distributed in range of (0,1). Expression for congruential generators is shown below in which the previous value Xi used to evaluated sequence of new number X_{i+1}.

$$X_{i+1} = AX_i + C\ (mod\ B) \tag{4}$$

Where B (modulus), C (increment) and A (multiplier) are non negative numbers such that $A, C, X_0 < B$ and $A \neq 0$. Sequence X_{i+1} stars with value X_0 known as seed. Meaning of modulo notation given as,

$$X_{i+1} = (AX_i + C) - B, \text{ for } 0 < X_{i+1} < B \tag{5}$$

Then sequence is produced automatically and repeats itself till the step value is equal to a value not greater than B. After obtaining sequence of random numbers X_i, a uniform random number U_i in the interval (0,1) can be found as,

$$U_i = \frac{X_i}{B} \tag{6}$$

2.2.2 Sequence Simulation of Two Component System

Consider a system with two identical components and one component is essential for success of system. If both components are in failure, only that state cause the system failure. For this example, let the availability is 0.8 and unavailability is 0.2 for both component. In practice this data can be obtained from experimental testing of individual component. Then analytically failure probability of system is given as, Probability of system failure = 0.2 x 0.2 = 0.04

Now this probability can be obtained from failure sequences by simulation. For that one simulated sequence is shown in Fig.1 in which 'o' represent component found in failure state at a trial.

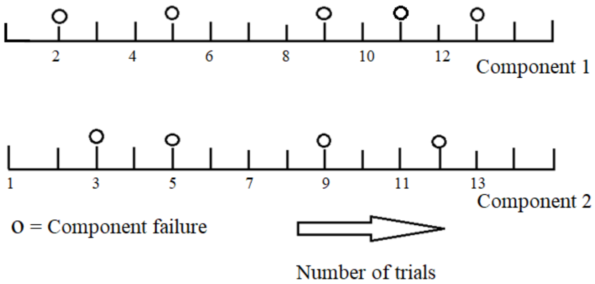

Fig.1 Simulated failure sequence

Fig.1 indicate that component 1 suffers 5 failures and component 2 suffers 4 failures in simulated period and two failures are overlapping for same trial. So, the system in failure state at trials 5 and 9. If series system containing these two components has 7 failures (overlapping component failures responsible for system failure) and parallel system containing these two components has 2 failures (only overlapping failures responsible for system failures). The simulated results for two parallel components shown in fig.2.

In simulated result three sequences are considered for 1000 trials. Each sequence starts with new seed generated randomly. From Fig.2 sequence 1 has two overlapping failures at first 100 trial which gives probability of system failure as 2/100 = 0.02. In first 200 trials, it has 7 overlapping failure which is cumulative value considering the 2 overlapping failure from 100 trials. Then cumulative probability of failure at 200 trial is 7/200 = 0.035. Expression of sequence given as,

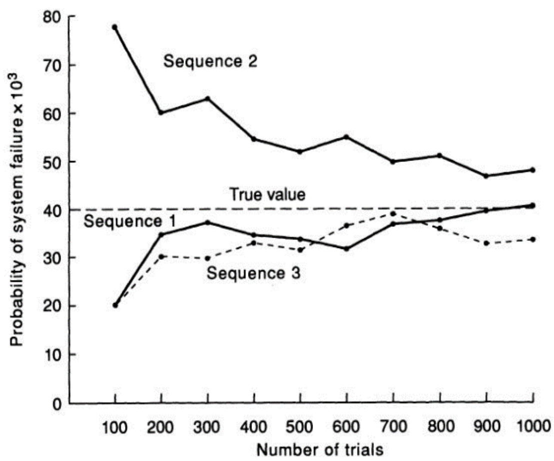

Fig.2 Simulated sequence results

$$S_{ij} = \frac{I_{ij}}{NMCSij} \tag{7}$$

Where S_i = sequence number at j trial, I_{ij} = number of cumulative overlapping failure, N_{MCSij} = simulation trials. From Fig.2, implies that as the number of trials increases the sequences oscillates near the true value which is matching wit analytical probability 0.04. The results continue to oscillate even after a large number of trials. sometimes oscillating above, sometimes below and sometimes around the true value. So, from this concept probability of system failure can be estimated.

2.3 System Reliability

For power system reliability evaluation, obtain the failure probability of system components using above concept with possible outage combination. Then the failure probability of power system is given as,

$$Q = \sum_j \, [P(Bj)\, P1j]$$

$$Q = \sum_j \, Pj \tag{8}$$

$$R = 1 - Q \tag{9}$$

Where Bj = an outage condition in power system network, $p(Bj)$ = failure probability of outage element and $P1j$ = 'probability of load at bus exceeding the maximum load which can be supplied at that bus without failure'. R is the reliability of power system.

3 SYSTEM NETWORK and SOFTWARE MODELLING

3.1 Description of Power System

Single line diagram of Power system shown in Fig.3, consisting two generating plant G1 and G2. Plant 1 has four generating units each of 20 MW and Plant 2 has two generating units each of 30MW. Peak load of the system is 110 MW and assuming that it's remaining constant.

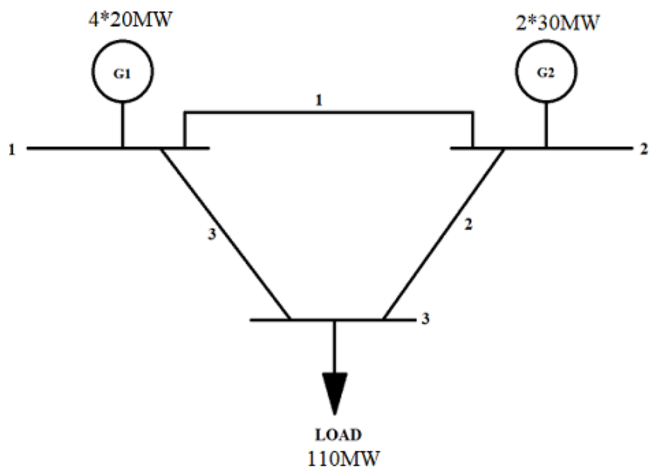

Fig.3 Three bus network

Table1: Generation Data

Plant	No. of Units	Capacity (MW)	Unavailability
1	4	20	0.01
2	2	30	0.05

Table 2: Transmission Line Data

Line	R	X	B/2	Unavailability
1	0.0912	0.4800	0.0282	0.00363667
2	0.0800	0.5000	0.0212	0.00454545
3	0.0798	0.4200	0.0275	0.00341297

For above system network results of analytical approach shown in table 1. There are 17 states of outage condition on network as *Bj*. Probability of outage element obtain from binominal distribution. *Pj* is failure probability of outage element and its summation is the failure probability of system.

3.2 Software Modelling

Three phase Power system network of Fig.4 is modeled in schematic of Pspice which is shown in Fig.5, in which plant 1 has total generation capacity of 80 MW with four generating units and plant 2 has 60 MW with two generating units. Total generation of system is 140 MW and system peak load is 110 MW.

4 SIMULATION RESULTS and DISCUSSION

The proposed system model analyses with MCS in Pspice and failure sequences are obtained from MCS histogram for Outage elements. Samples generated from histogram for outage condition of generation plant 1 is shown in Fig.6. for every state two sequences are considered and each sequence starts with new seed generated randomly. Number of failures are obtained from probability distribution of samples from histogram.

In simulation, total 17 outage states are considered which are mentioned in analytical result. From which the result of outage state at plant 1 (one unit in outage), plant 2 (two units in outage) and transmission line L3 shown in Fig.6,7, and 8 respectively. Similarly, sequences of remaining states are obtained.

Table 3: Analytical Results of outage elements

State B_j	Element on Outage	Outage Probability of $P(B_j)$	P_{1j}	Failure probability P_j
1	G1	0.03462309	0	-
2	G1, G1	0.00052449	1	0.00052449
3	G1, G2	0.00364454	1	0.00364454
4	G1, L1	0.00012648	0	-
5	G1, L2	0.00015810	0	-
6	G1, L3	0.00011857	0	-
7	G2	0.09020227	1	0.09020227
8	G2, G2	0.00237374	1	0.00237374
9	G2, L1	0.00032951	1	0.00032951
10	G2, L2	0.00041188	1	0.00041188
11	G2, L3	0.00030891	1	0.00030891
12	L1	0.00313030	0	-
13	L1, L2	0.00001430	1	0.00001430
14	L1, L3	0.00001072	1	0.00001072
15	L2	0.00391288	0	-
16	L2, L3	0.00001340	1	0.00001340
17	L3	0.00293466	0	-

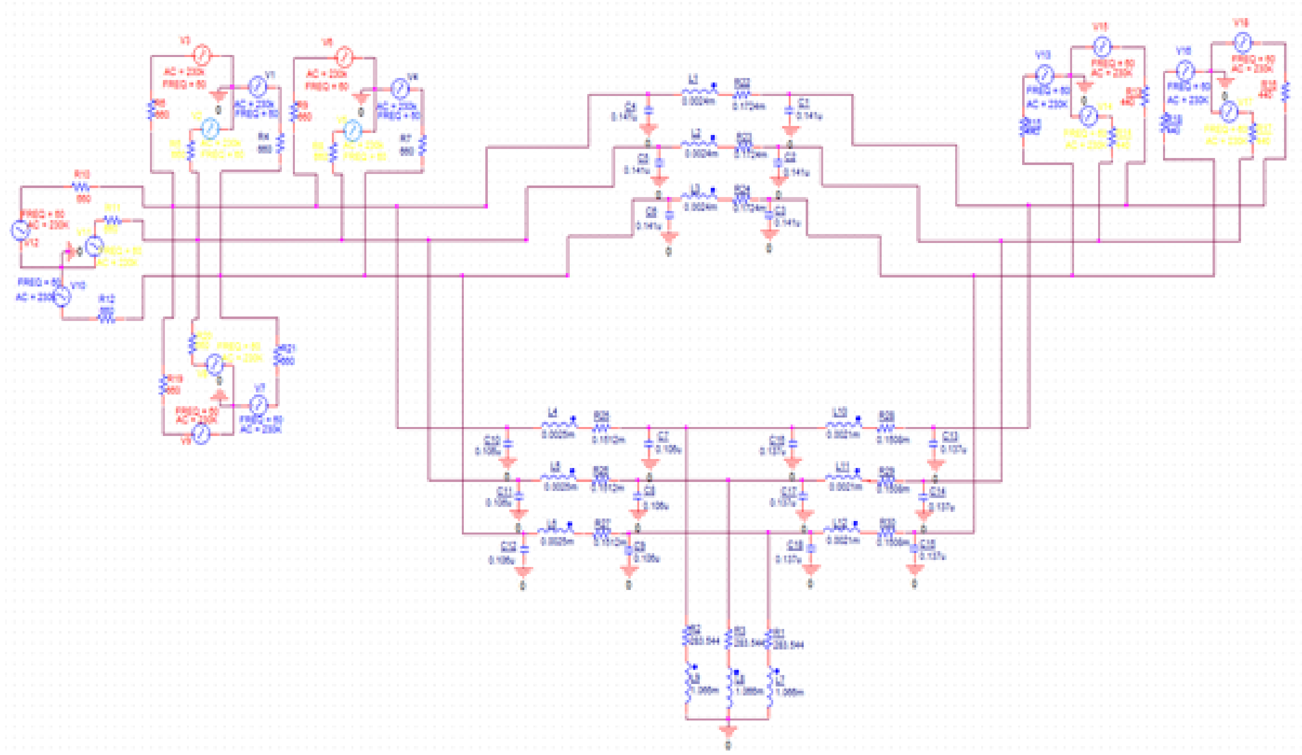

Fig.5 Power system model in Pspice

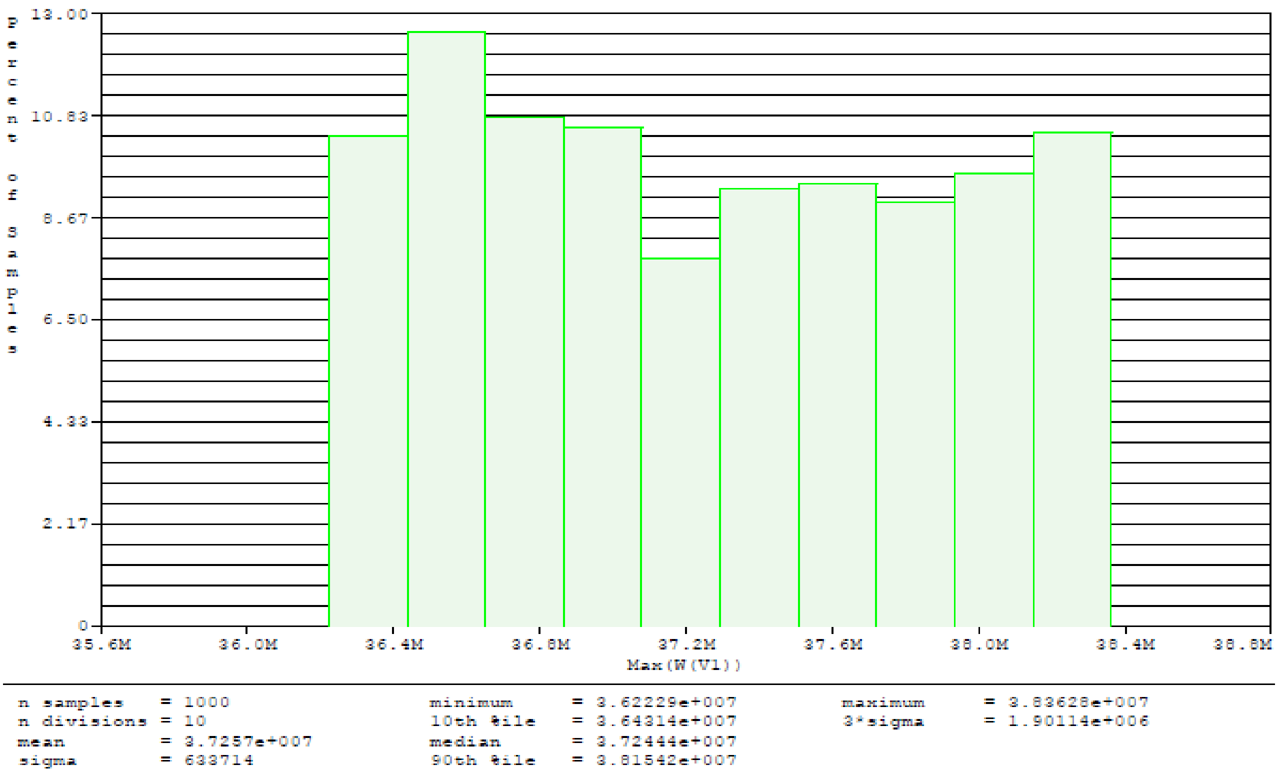

Fig.6 MCS histogram

Simulated sequences oscillated around the true value and failure probability of element estimated. Form Fig.6,7 and 8, the results are in error with less number of trials. This error decreases as the number of trial increases. These results of probability compared with the analytical results which are shown in table 4. G1 is generating unit of plant1, G2 is generating unit of plant2 and L1, L2 and L3 are transmission line. Here, general outages of power system are considered. Each state elements are on outage except that remaining elements are considered as fully reliable.

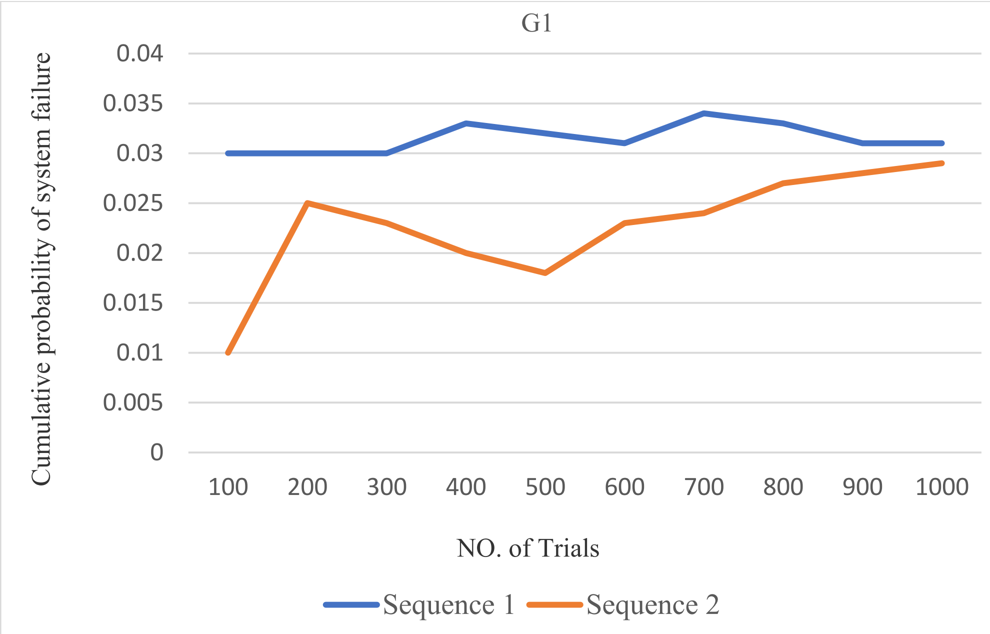

Fig.6 Failure sequence of outage G1

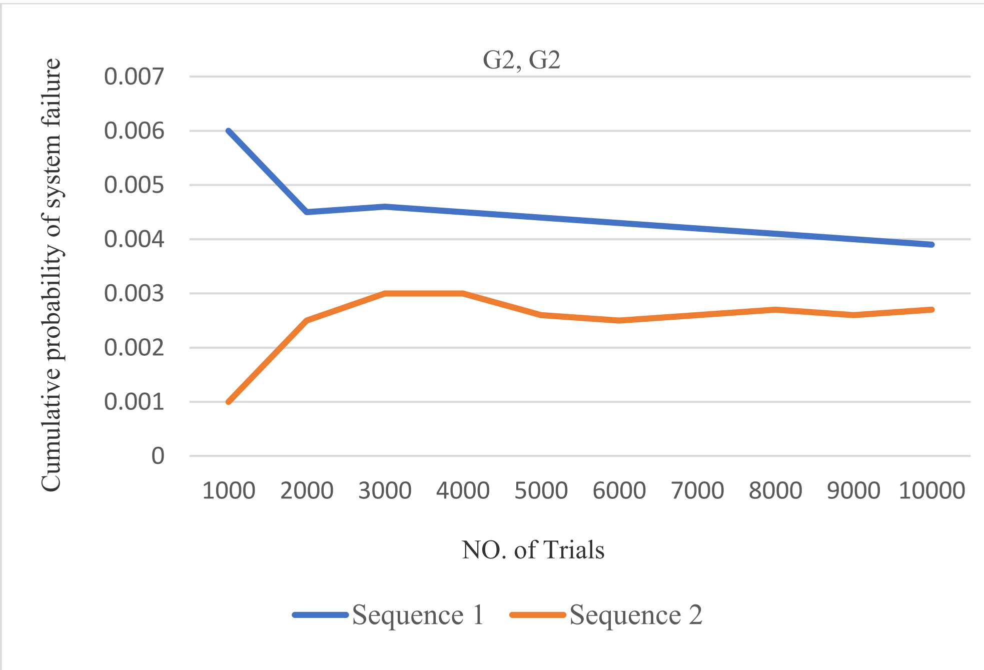

Fig.7 Failure sequence of outage G2, G2

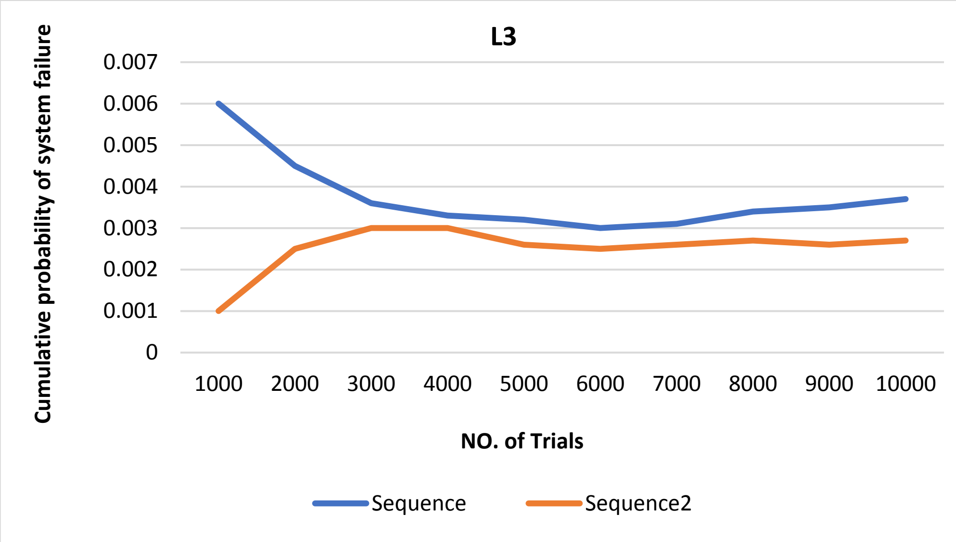

Fig.8 Failure sequence of line L3

Simulated sequences oscillated around the true value and failure probability of element estimated. Form Fig.6,7 and 8, the results are in error with less number of trials. This error decreases as the number of trial increases. These results of probability compared with the analytical results which are shown in table 4. G1 is generating unit of plant1, G2 is generating unit of plant2 and L1, L2 and L3 are transmission line. Here, general outages of power system are considered. Each state elements are on outage except that remaining elements are considered as fully reliable.

From table 4, we can see that generating units has high failure probability level compared to transmission line failure probability. Results estimated from MCS technique are nearly similar with analytical results. From that the failure probability of system is obtained using eq. (8) and from that the reliability of system is obtained using eq. (9) which is quite similar with analytical result.

Table 4: Comparison of Analytical and MCS result

State B_j	Element on Outage	Outage Probability of $P(B_j)$		P_{1j}	Failure probability P_j	
		Analytical	MCS		Analytical	MCS
1	G1	0.03462309	0.03100	0	-	-
2	G1, G1	0.00052449	0.00062	1	0.00052449	0.00062
3	G1, G2	0.00364454	0.00350	1	0.00364454	0.00350
4	G1, L1	0.00012648	0.00025	0	-	-
5	G1, L2	0.00015810	0.00025	0	-	-
6	G1, L3	0.00011857	0.00028	0	-	-
7	G2	0.09020227	0.08400	1	0.09020227	0.08400
8	G2, G2	0.00237374	0.00260	1	0.00237374	0.00260
9	G2, L1	0.00032951	0.00043	1	0.00032951	0.00043
10	G2, L2	0.00041188	0.00042	1	0.00041188	0.00042
11	G2, L3	0.00030891	0.00042	1	0.00030891	0.00042
12	L1	0.00313030	0.00370	0	-	-
13	L1, L2	0.00001430	0.00012	1	0.00001430	0.00012
14	L1, L3	0.00001072	0.00011	1	0.00001072	0.00011
15	L2	0.00391288	0.00400	0	-	-
16	L2, L3	0.00001340	0	1	0.00001340	0
17	L3	0.00293466	0.00260	0	-	-
				Q =	**0.09783386**	**0.09222**
				Reliability = 1 – Q =	**0.90216614**	**0.9078**

5 CONCLUSION

This paper has presented a simulation approach to estimate the power system reliability using Monte Carlo simulation in Pspice. By applying Outages on different element of power system modelled in Pspice and simulating the failure states to obtain failure probability for that element which is obtained from probability sequences generated using simulation samples in MCS process. For generating unit and transmission line outages considered whose occurrences are highly possible in the system.

The simulation results showed that the proposed simulation method significantly estimate the reliability of given system. Also, Monte Carlo simulation in Pspice confirms that and can estimate reliability of modelled system. In this paper considered system has less number of elements compare to the practical power system, to verify the simulation results with the analytical results. So, this proposed approach can be used to estimate power system with higher number of components.

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