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Original Article

Choosing an optimal connecting place of a nuclear power plant to a power system using Monte Carlo and LHS methods

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ABSTRACT

The location selection for nuclear power plants (NPP) is a strategic decision, which has significant impact operation of the plant and sustainable development of the region. Further, the ranking of the alternative locations and selection of the most suitable and efficient locations for NPPs is an important multi-criteria decision-making problem. In this paper, the non-sequential Monte Carlo probabilistic method and the Latin hypercube sampling probabilistic method are used to evaluate and select the optimal locations for NPP. These locations are identified by the power plant's onsite loads and the average of the lowest number of relay protection after the NPP's trip, based on electricity considerations. The results obtained from the proposed method indicate that in selecting the optimal location for an NPP after a power plant trip with the purpose of internal onsite loads of the power plant and the average of the lowest number of relay protection power system, on the IEEE RTS 24-bus system network given. This paper provides an effective and systematic study of the decision-making process for evaluating and selecting optimal locations for an NPP.

1. Introduction

Faced with the need of achieving the highest possible efficiency in the utilization of primary resources, power system managers should consider nuclear power plants (NPPs) as a viable alternative or addition to their present fossil fuel or hydroelectric plants. The Problems of operating an NPP within an electric grid of limited capacity have long been a serious concern to electric utilities because of the grids direct bearing on the starting and running of the NPP.

Nuclear power plants are connected to the power system and both export their electrical energy to it and receive electrical power from, for the safe startup, operation and shutdown from it. In this regard, careful attention must be paid to the performance of the power system and the interface between the NPPs and the grid, in order to avoid events that might challenge the safety of the NPP [1].

Amongst many issues to be solved of NPPs, is the availability of electrical power supply from the grid to safety systems during safe shutdown or upon undesired events. It fulfills the need for removing the decay heat as the main specific issue of nuclear safety, even for a reactor in shutdown. Permanent electrical power is to be provided to the auxiliary systems to ensure system operation under normal and emergency conditions [2]. The availability of AC power in NPPs is thus essential for safe operations and accident recovery. The electrical grid to which the NPP is connected, referred to as “offsite power,” usually supplies this power. The loss of offsite power (LOOP) event occurs when the plant loses offsite power, i.e., all connections to the external grid. In that case, emergency diesel generators can provide “onsite power.” The simultaneous failure of offsite power and onsite power is called a station blackout (SBO). An SBO can lead to core damage [3]. Any increase in the frequency or duration of LOOP events increases the probability of SBO and hence that of core damage. RG 1.155 states that the specified duration of station blackout is determined based on four factors, one of which is “the expected frequency of LOOP, in addition to SBO coping features [4].

Total loss of offsite electric power has been experienced in many operating plants, and more occurrences are expected in the future.

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LOOP events are analyzed in several reports. In 1988, the NRC published NUREG-1032 [5] an evaluation of the risk from actual LOOP events that had occurred at NPPs within the United States up through 1985. NUREG/SR-1150, 1990 briefly, presents the percentage share of the SBO and LOOP in the obtained CDF for four operational plants and two advance designs as presented by the final summary report. The SBO-S and SBO-L are designations for the SBO shorter and longer than design blackout coping capability [6].

The disastrous SBO at Fukushima NPP reconfirmed the importance of electrical-related events to NPPs' safety [7,8].

Significant differences in LOOP event description, category, duration, and applicability between the [3,8] reports result in variable LOOP frequencies and calculation methods. Zhiping discussed different LOOP frequency calculation methods and compared them [9].

Reported loss of offsite power in NPPs is surveyed by A. Volkanovski et al. which reveals the dominant root cause of LOOP and the ways to decrease the number of LOOP events [10].

Electricity power plants need to use electrical energy inside the power plant to produce electrical energy and the proper functioning of the onside equipment. Generally, there is little difference between the onside power consumption of the power plants. Among different power plants, hydroelectric power plants have the lowest and thermal power plants have the highest onside consumption. Nuclear power plants also have an onside consumption of between 5% and 8%, in which new units using more modern systems have lower onside consumption than older ones. The transmission system is the source of power to the offsite power system of NPPs. It is demonstrated to have higher availability and reliability than the on-site emergency power system because of the diverse and multiple generators connected to the transmission system [11].

The power plant trip leads to power leakage, frequency drops, and oscillation in the power grid voltage. If protective systems and other existing power units in the circuit cannot restore the power system to its normal state, it will result in sequential outages and often falling off the power system. But this issue is once more important when an NPP is tripped. Then, power system engineers, while preventing the collapse (falling) of the power system, are tasked with supplying onsite power to the NPP as the main source (preferred source). Failure to power the NPP in all operating conditions and power plant trips by the connected power network and failures in the onsite power plant's power systems will greatly help in damaging the reactor and releasing radioactive materials, and events such as the Three Mile Island (1979), Chernobyl (1986) and the recent Fukushima (2011). Therefore, it is important that the power system connected to the NPP is a reliable power supply with sufficient capacity for all reactor operational conditions. This requires monitoring, protecting, Location selection to build an NPP and extensively controlling the electric power system.

As most research on LOOP frequency estimation is to improve the performance of emergency diesel generators, the design, testing, and maintenance of NPP protection systems, and less or less about Location selection to build a nuclear power plant from the point of view of supply The onsite power requirement of the power plant is not addressed by the power system when the NPP is tripped and the power system is in short supply, so it is necessary to Location selection for the construction of an NPP with the purpose of providing onsite power In the conditions of the NPP trip of damage heart of the reactor and the release of radioactive materials and environmental pollution preventable.

In this paper, using the non-sequential Monte Carlo (MC) probabilistic method and the Latin Hypercube Sampling (LHS) probabilistic method approach considering the exit rate for production units, lines, and relays, the NPP is trip and does not transmit power to the power grid, and on the other hand, the Power grid can be lack of power, as the main source (preferential source), we must meet the inside demand for NPP, to introduce the appropriate place for the construction of an NPP that has the necessary security.

2. Stability analysis function

Under both balanced and unbalanced conditions, the root means square (RMS) simulation tool in Power Factory can be used to analyses mid-term and long-term transients, incorporating a simulation scan feature. DIgSILENT Simulation Language (DSL) is used for model definition, and a large library of IEEE standard models is reachable. Flexible co-simulation options are reachable, too.

Limitations in Study on the House Load probability (HLP) of NPP study consist of voltage limit, frequency limit, and branch thermal and transient stability. In this paper, thermal and voltage constraints were considered, and the transient power flow has been used to Calculation HLP.

The mathematical formulation used in the power system is based on the power flow method as follows [12]:

$$\mathrm{P_{Gi} - P_{Li} - V_i \sum_{j\in N} V_j Y_{ij} \cos(\theta_{ij} + \delta_i - \delta_j) = 0} \tag{1}$$

where:

P_{Gi} : Active power output of generation at bus i
P_{Li} : Active power load at bus i
V_i, δ_i : Magnitude and angle of voltage at bus i
V_j, δ_j : Magnitude and angle of voltage at bus j
Y_{ij}, θ_{ij} : Magnitude and angle of ijth element of the admittance matrix Y

Equation (1) shows the equality of real power generation and active power consumption of the power system. The power in this regard is active power and the purpose of power consumption is the total power consumption and power system losses. The difference in active power production and consumption in transient mode simulations in the event of an incident in the power system generates changes in the speed of power units and frequency changes of power plants.

$$Q_{Gi} - Q_{Li} - V_i \sum_{j\in N} V_j Y_{ij} \sin(\theta_{ij} + \delta_i - \delta_j) = 0 \tag{2}$$

wwhere:

Q_{Gi} : Reactive power output of generation at bus i
Q_{Li} : Reactive power load at bus i

Equation (2), the equivalence of reactive power production with reactive power of consumable loads and reactive losses is shown. Obviously, in the transient state of the power system, the inequality of the reactive power generated in the grid and the reactive power used in the grid will lead to a change in the voltage of the bus.

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \tag{3}$$

where:

$P_{Gi}^{min}, P_{Gi}^{max}$: Minimum and maximum active power output of generator i

Equation (3) shows the production limitations of power plants. The maximum Power Generation and the minimum Power Generation of power plants should be considered in the transient state and power system state of the power system calculation.

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \tag{4}$$

where:

Q_{Gi}^{min}, Q_{Gi}^{max} : Minimum and maximum reactive power output of generator *i*

This constraint indicates the limitation of the reactive power of power plants. This limitation is also very important, and if it does not pay attention to it, the coil of excitation may be damaged. This constraint and limitation of the active power plant production are usually considered on the P-Q curve, which includes the thermal constraints of the rotor winding, stator winding, torque angle limitations, and turbine mechanical limitations.

$$\frac{Q_{Lj}}{P_{Lj}} = cons \tag{5}$$

The ratio of load changes on the network should be considered. If the power system simulations undergo changes in network power consumption, the active and reactive power loads of the consumables should be the same.

$$V_i^{min} \leq V_i \leq V_i^{max} \quad , \forall i \in Buses \tag{6}$$

where:

V_i^{min},V_i^{max}: Minimum and maximum of voltage magnitude at bus *i*

The power system bus voltage is subject to limitations. These buses should be operated under normal operating conditions between 0.95 and 1.05 and in emergency conditions between 0.9 and 1.1 per unit (PU).

$$S_{i-j} \leq S_{i-j}^{max} \quad , \forall (i-j) \in Line \tag{7}$$

where:

S_{i-j}: Apparent power flow in transitions line between bus i and j
S_{i-j}^{max}: Maximum allowed apparent power flow in the transmission line between bus *i* and *j*

Finally, the last limitation in this article is the limitation of the flow limit of the lines. From the point of view of the thermal points and the stability of the maximum lines, the power transmission through the lines should be considered in all power system operations.

In the simulation provided for the NPP, all constraints are enforced by relay protection and will operate in the event of a passage from the prescribed limits of the relay protection.

3. Probabilistic evaluation

As different reasons including changes in equipment outage and the structure of the system result in the variant nature of the power system, a constant value cannot be considered for the Calculation HLP. Hence, HLP is regarded as a dependent index that is affected by changes in the system states. As mentioned before, probabilistic approaches are the best tools to evaluate HLP. Monte Carlo simulation random sampling (MCS-RS) combined with Latin Hypercube Sampling (LHS) is one of the most popular probabilistic approaches which provide a wide range of data for HLP. The base case is one of the secure operational states of the system under study whose all constraints lay in the permitted limits.

Probabilistic simulation methods are less accurate compared with mathematical models (although this difference is very small) but have become more applicable because of their much higher speed. MCS procedures for the propagation of uncertainty are very popular and many examples of their use exist [13,14]. The main advantage of this method is its simplicity and perfect accuracy. The MC method requires a relatively long time to respond convergence but can be used to increase the speed of MC convergence using methods such as variance reduction. In order to facilitate convergence, variance reduction methods such as contrasting variables, the use of common random numbers, controlled variables, point sampling, and class sampling are used [15].

Latin Hypercube Sampling (LHS) is a statistical method for generating a random sample of parameter values from a multidimensional distribution. The LHS sampling method can be considered as a bridge between class sampling and random sampling to speed up convergence in the MC method. Therefore, by combining these two methods of variance reduction, the LHS method employs a new method to reduce variance. The superiority of the convergence rate of response in the LHS method over the Monte Carlo method can be considered in the intelligent selection of the evaluating samples. The results of the papers [16,17] show that the LHS computational method converges to a similar solution to the MC method, so the LHS can be considered a finite sample of the MC method. Because of the higher convergence rate in response, this method is a good alternative to the current MC method for research the uncertain power system.

In this paper, many uncertainties have been used to calculate HLP. Considering the uncertainties of the power system in simulating the HLP of NPP will bring the studies closer to the actual situation of the system. In this paper, the uncertainties intended to calculate the HLP uncertainty in the output of power plants, the uncertainty in the transmission lines and the uncertainty in the correct operation of the relay protection. Also, this paper attempts to model the relay for current protection, voltage, and frequency.

3.1. MCS − RS method

The steps used to calculate the HLP of an NPP during a power plant trip using the MCS can be described as follows [18].

Step 1: Specify power plant statuses by producing uniform random variables and compare them with forced outage rates (FOR) of power plant:

$$\mu_i = \begin{cases} 0, & x \leq FOR_i \\ 1, & x > FOR_i \end{cases} \tag{8}$$

If the random number is less FOR than the unit's power, the unit must be disconnected from the circuit.

Step 2: Specify transmission lines statuses by producing uniform random variables and compare them with FOR of the transmission line. According to Equation (8), if the random number is less FOR than the transmission lines, the transmission line must be disconnected from the circuit.

Step 3: Specify the function of relay protection statuses by producing uniform random variables and compare them with FOR of protective relays. According to Equation (8), if the

random number is less FOR than the protection relay, it means that the relay is not functioning correctly.
Step 4: Transient mode studies of power system based on the nuclear unit's outage and the study of the HLP for NPP.
Step 5: Averaging results and storing data
Step 6: If the stop criterion is certain, the algorithm is over. If the terminating criterion is not meet go to step 1.

In this paper, FOR for transmission lines and protective relays are 0.02 (FOR = 0.02) and FOR of the power plant is considered in accordance with Table 1.

To terminate the implementation of the MC Computational Algorithm program, it should set a stopping point for this method. The stopping criterion should be such that the algorithm's response is accurately assured. For this purpose one of the following criteria can be used:

Number of repetitions of the MCS.

Use the coefficient of variation (CV).

In using the first criterion to end the calculations of the Monte Carlo algorithm, we need to know how we repeat algorithm to reach an accurate answer. This can only be achieved by executing the program several times and knowing the system's behavior and determining the number of experimental repetitions.

In the second criterion, according to Equations 9 to (3-7), the coefficient of variation is calculated in each step, and if the coefficient of variation is small from a very small number, the program stops. Obviously, a comparison of the coefficient of dispersion with a smaller number, despite the increase in the accuracy of the calculation, also increases the execution time of the program.

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{9}$$

where, x_i is represents the variable under consideration, and N is the number of iterations. Here,x_i can indicate whether the electrical power is conducted to the power plant or not. In other studies, the number of relay functions or the number of equipment withdrawn from the circuit can be considered.

$$V(X_i) = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{X})^2 \tag{10}$$

Equation (10) shows the variancex_i. The variance is a measure that shows how data is spread around the average. The less variance means that it is expected that if a sample of the distribution is selected, its value is near to the average. The unit of square variance is the initial quantity. The second root of the variance, called the criterion deviation, has the same unit as the initial variable.

Table 1
Generating unit data [19].

Unit size (MW)	Unit Type	Unit FOR
12 (5)	Oil	0.02
20 (4)	Oil	0.10
50 (6)	Hydro	0.01
76 (4)	Coal	0.02
100 (3)	Oil	0.04
155 (4)	Coal	0.04
197 (3)	Oil	0.05
350 (1)	Coal	0.08
400 (2)	Nuclear	0.12

$$V(\overline{X}_i) = \frac{V(X_i)}{N} = \frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - \overline{X})^2 \tag{11}$$

Equation (11) shows the covariance average of variance variation.

$$\sigma = \sqrt{V(\overline{X}_i)} \tag{12}$$

Equation (12) shows the standard deviation. If the standard deviation of the data set is near to zero, this indicates that the data is near to the average and has little dispersion; while the large standard deviation represents a significant dispersion of the data. In scientific studies, data with a difference of more than two standard deviations from the mean value are considered as offset data and are removed from the analysis.

$$C_v = \frac{\sigma}{\overline{X}} \tag{13}$$

Equation (13) shows the coefficient of variation (CV). The CV theory is a criterion for the distribution of data, which is calculated by dividing the standard deviation into the average.

In this paper, first, using the stop criterion based on the CV, the HLP the NPP by offsite power system after the power plant trip was examined. After ensuring the desired response, in order to reduce the time and simplicity of the calculations, the stop criterion was used based on the number of repetitions. After 998 repetitions, we obtained the optimal response and the same stop criterion based on the CV Monte Carlo method scattering coefficient. Therefore, in this paper, the MCS-RS method was selected as a computational measure based on the number of replicates and 998 replications.

In the Monte Carlo method, by observing the results of variance and covariance, after 998 replications, the accuracy is acceptable and there is little change in the convergent response. For this reason, 998 repetitions were selected as the optimal repetition in order to ensure the answer in the shortest possible time, and the analysis in this article reports on this number of repetitions.

The flowchart of the algorithm used in this paper to simulate the HLP to an NPP by an offsite power system after the power plants trip, using the non-ordination MCS-RS method taking into account the uncertainties of the power system in Fig. 1 shown.

3.2. LHS Method

The procedure of LHS can be divided into two main steps including sampling and permutation. The objective of sampling is to generate representative samples to reflect the distribution of each input random variable. For a problem with several independent input random variables, the permutation is needed and aims at reducing the correlations between samples of different input random variables. In this section, the details of the sampling are described. Finally, the LHS algorithm used in this paper is described [17].

3.2.1. Sampling

In the sampling method, let $X_1, X_2, \ldots, X_M$ be the M input random variables in a probabilistic problem. The probability cumulative function(Y_M) of X_M, which belongs to $X_1, X_2, \ldots, X_M$, is represented as follows:

$$Y_M = F_M(X_M) \tag{14}$$

For a sample size N, when the range of Y_M (i.e., from 0 to 1.0) is divided into N non-overlapping intervals of equivalent length, the length of each interval is *1/N*. In LHS calculations, the batch agent is

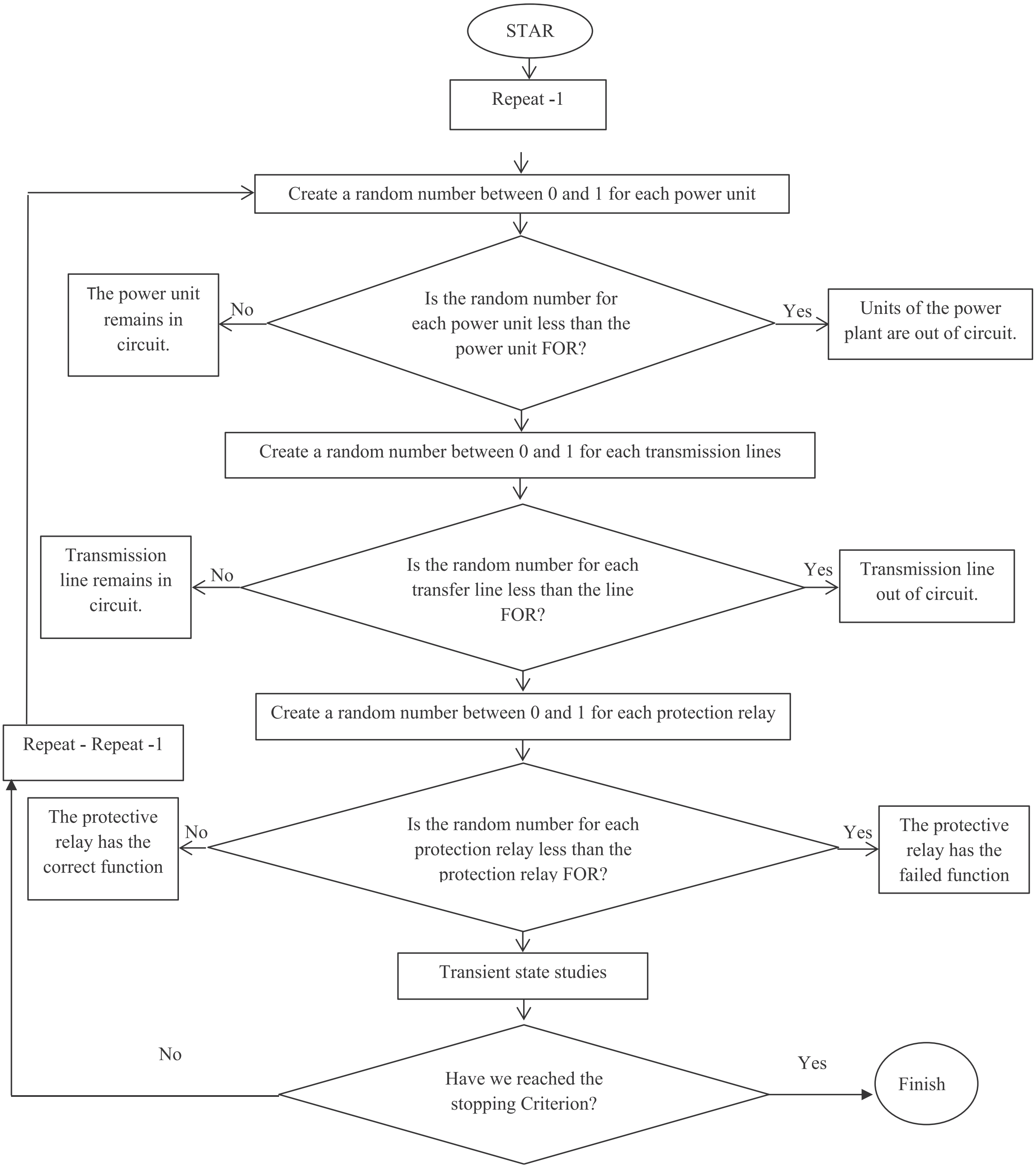

Fig. 1. The flowchart of the MCS-RS algorithm used in this paper.

used instead of all batch data. Representation of any of the following subsections can be done using Equation (15):

$$X_m = F_m\left(\frac{n - rand}{N}\right) \tag{15}$$

where N is the number of maximum samples. The sample values of X_M is then assembled in a row of the sampling matrix, [$X_1, X_2, \ldots, X_M$]. Once all the M input random variables are sampled, an $M \times N$ primary sampling matrix X can be obtained.

3.2.2. LHS method algorithm

In this paper, considering uncertainty in the output of power plants, the uncertainty in the transmission lines and the uncertainty in the correct operation of the relay protection. Also, this paper attempts to model the relay for current protection, voltage, and frequency.

This section examines the process of the LHS algorithm in this paper. The implementation of the LHS algorithm is as follows:

Step 1: Sample size determination:

The size of the sample determines the accuracy and timing of the calculations. As the size of the sample increases, the accuracy of the computation and the execution time of the program also increase.

Step 2: Given the N iteration for the LHS method, the number of the output of power plants should be equal to Equation (16). After determining the number of output modes of the power plants, they should be scattered in random permutations.

$$\text{Number of the output of power plant} = \text{FOR} \times N \tag{16}$$

Step 3: Calculation of the number of times the protective relays failed to function correctly and their random permutations according to the sampling size and output rate FOR the relays.
Step 4: Calculate the number of times the output of the transmission lines and their random permutations according to the sampling size and output rate FOR the transmission lines.
Step 5: Select a representative from each subsection for the variable and delete the subsection
Step 6: Using the representative of each subsection and determining the values of the variables that contain uncertainty, the new system structure is outlined and ready for computation
Step 7: Using the new system structure of the study of the HLP for NPP
Step 8: Exits the program if the number of iterations has reached N, Otherwise, go back to step 4 and proceed with the simulation procedure by selecting another subsection.

4. Numerical studies

This paper assesses the choice of a suitable location for the construction of an NPP, after a power plant trip and supplying electricity to the HLP of the power plant, by offsite power system using IEEE Reliability Test System (IEEE-RTS) [19]. It has 24 Buses (10 generation Buses and 17 load buses), 38 lines and 32 units. The system's annual peak load is 285OMW. The total installed generating capacity is 3405 MW and the generation data are given in Table 1. The Single line diagram of the system is shown in Fig. 2.

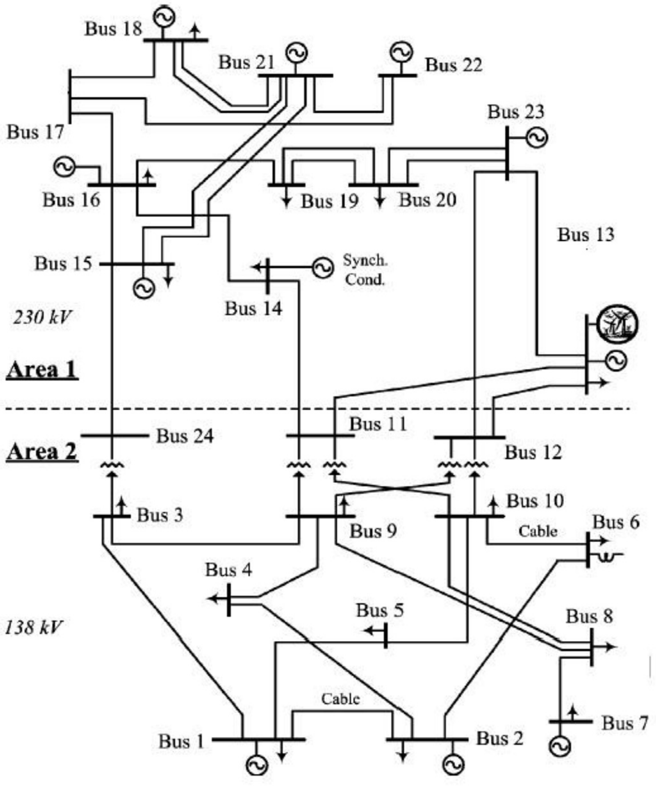

Fig. 2. Single line diagram for IEEE-RTS [19].

It is designed on all Buses of the frequency relay network and voltage relay. Current relays are also set up in the network, in the event of overcurrent on the equipment and activated. The current relays are activated at 1.8 kA and if the current flow increases, after 1 s the relays will operate. The number of current samples by CT is 50 times per second. Voltage relays are in the range of 0.3 pu (voltage increase or decrease) in active mode and operate after 0.2 s. The voltage sampling rate is set to 10 times per second. Frequency relays will operate after leaving a range of 45 Hz or 55 Hz. The activation time is set to 0.2 s for the frequency relay operation; the number of frequency sampling units of the power plants is also 10. In this study, for a better performance of the power system and the simulation of the actual conditions of the two power plants equipped with the frequency control loop and the automatic regulator, which can respond to the frequency variations of the network.

5. Results and discussion

The NPP has produced about 400 MW before the incident and has 18 test systems on the bus. But in order to accurately check the network conditions after the accident for the NPP and to examine the conditions of the transient state and HLP of the power plant, the NPP is placed on different buses respectively.

The calculated results are given in Table 2. This table is based on the change of location of the NPP and is calculated using the MCS and LHS probabilistic analysis. In the calculation of probabilistic methods used in this paper, uncertainty in the output of power plants and network transmission lines and lack of proper functioning of protective relays is considered. Shown in Table 2 mean numbers function of the relay protection after the trip and mean the number of non-feeding power plants by power system after the trip and the number of feeding NPP by Power System after the trip and mean outage of equipment after the trip.

If we want to do some precise studies on how to function of the relay protection after an NPP trip, according to Table 2, we will examine the average number of relays operation in different buses.

Bar Chart the numbers function of the relay protection in the event of an accident (trip) for an NPP is shown in Fig. 3.

According to Table 2 and Fig. 3 the highest mean function of the relay protection for probabilistic methods used in this paper has occurred at the time when the NPP was located on Bus No. 7, which is the same for both methods, and the lowest mean function of the relay protection has occurred at the time when the NPP was located on Bus No. 6 for the MCS probability method and Bus No. 9 for the LHS probability method. Therefore, from the perspective of the number function of the relay protection in the event trip for an NPP, the best Bus location is No. 6 or No. 9. But to location selection for the located of a nuclear power plant, only the function of the relay protection cannot be considered, we also need to look at other uncertainties.

In Fig. 4, the mean outage of equipment after 998 repetitions is plotted using the MCS and LHS methods.

According to Fig. 4, the least amount of outage of equipment in the MCS method when the NPP is located on Bus No. 12 and has the largest amount on Buses No. 5 and 6. According to Table 2, the mean outage of equipment for different buses is approximately the same. The mean outage of equipment in the MCS method and after placing the NPP in different buss was estimated at 5.4.

It should be noted that the mean outage of equipment in the LHS method is calculated for all identical states. The reason is that it is

Table 2
MCS and LHS outputs.

Bus Number	Voltage (KV)	Mean number function of the relay protection after the Trip		Mean number of power supply failure power plants by power system after the Trip		Mean of power supply NPP by Power System after the Trip		Mean outage of equipment after the trip	
		Monte Carlo	LHS	Monte Carlo	LHS	Monte Carlo	LHS	Monte Carlo	LHS
1	138	4.0521	3.5782	0.024	0.019	974	979	5.4309	5.4108
2	138	4.1473	4.2585	0.02	0.021	978	977	5.4269	5.4108
3	138	4.2425	3.4990	0.001	0	997	998	5.3848	5.4108
4	138	4.3437	3.7024	0.002	0.002	996	996	5.4719	5.4108
5	138	4.0521	4.0631	0.0261	0.023	972	975	5.4719	5.4108
6	138	3.9970	3.8096	0.022	0.024	976	974	5.4108	5.4108
7	138	6.3527	7.2916	0.019	0.019	979	979	5.4228	5.4108
8	138	4.0611	3.5291	0.017	0.018	981	980	5.4269	5.4108
9	138	4.0311	3.4389	0.0251	0.024	973	974	5.4269	5.4108
10	138	4.0992	3.7234	0.019	0.018	979	980	5.3848	5.4108
11	230	4.3287	3.9980	0.017	0.018	981	980	5.4118	5.4108
12	230	4.3116	3.8818	0.017	0.008	991	990	5.3407	5.4108
13	230	4.3958	4.2854	0.018	0.017	980	981	5.3948	5.4108
14	230	4.2194	4.013	0.0251	0.022	973	976	5.3778	5.4108
15	230	4.2766	3.7275	0.021	0.024	977	974	5.3577	5.4108
16	230	4.1232	4.0356	0.016	0.022	982	976	5.4579	5.4108
17	230	4.2786	3.8808	0.011	0.018	987	980	5.3918	5.4108
18	230	4.2986	4.011	0.018	0.008	980	990	5.3737	5.4108
19	230	4.2976	3.9860	0.0160	0.014	982	984	5.4048	5.4108
20	230	4.2685	4.1693	0.018	0.0251	980	973	5.3647	5.4108
21	230	4.2395	4.1152	0.021	0.021	977	977	5.4479	5.4108
22	230	4.2575	4.0832	0.023	0.02	975	978	5.4148	5.4108
23	230	4.2104	3.9584	0.017	0.016	981	982	5.3467	5.4108
24	230	4.2645	3.8477	0.018	0.022	980	976	5.3808	5.4108

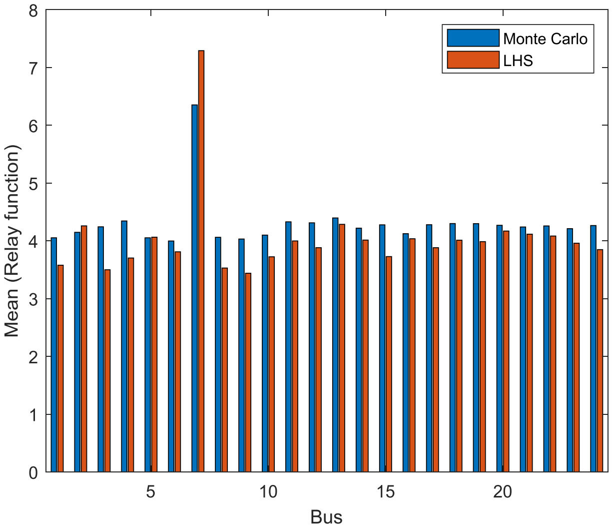

Fig. 3. Mean number function of the relay protection after the Trip.

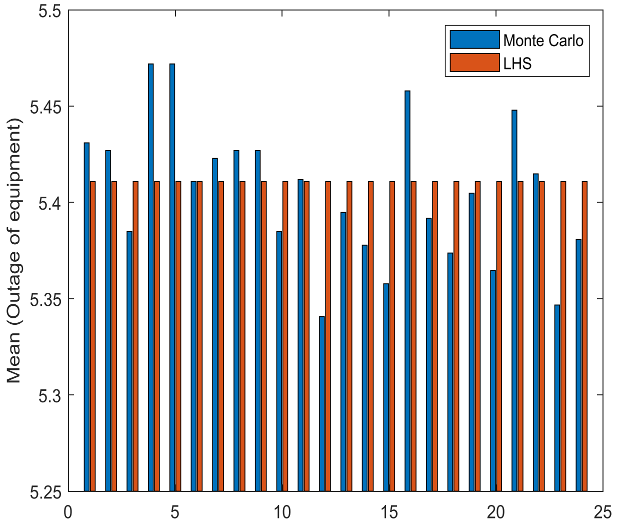

Fig. 4. Mean outage of equipment after the trip.

necessary to consider a certain number of an outage of equipment in the N repeating LHS method, calculated by Equation (16). As explained in the previous section, According to FOR and LHS sampling numbers, all cases with random permutations should be applied to the power system. Therefore the mean number of outage equipment modes in all buses is similar because N and FOR equipment is constant.

But, as already stated, the performance criteria of the protection relay and the outage of equipment from the power system, including power plants and transmission lines, alone cannot provide the necessary criteria for location selection to build an NPP. Therefore, all the stated uncertainties should be in the direction that, after the nuclear power plant's trip, the power required by the power plant to cool the reactor from the offsite power system. Therefore, the main criterion of this paper is to select the location selection for connecting the NPP to the power system with the purpose of gaining power from the power grid after the power plant trip.

Fig. 5 shows the number of power supply to the NPP by the power grid after the power plants trip with the MCS and LHS methods. At each stage of the simulation, the power plant is connected to the study bus.

According to Fig. 5, the lowest amount of power supply failure to the NPP occurred at a time when the NPP was located on Bus No. 5 by the MCS method and Bus No. 20 by the LHS method. The most ideal mode and the greatest amount of power supply to the HLP of

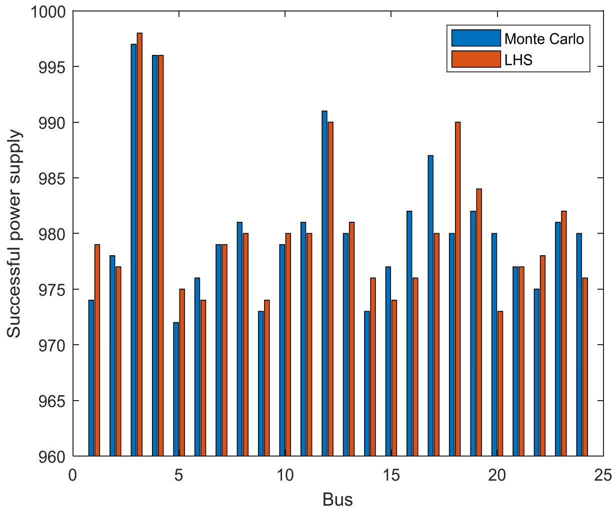

Fig. 5. Number of power supply failure to the NPP by the power grid After 998 repetitions in the MCS and LHS.

the NPP occurred at a time when NPP was located on bus No. 3, and the results of both probabilistic methods used in this paper point to this. Considering the uncertainty in the function of relay protection and uncertainty power units and grid lines, of the 998 repetitions of the MCS method, the only 1-time power supply has failed and 997 times the successful power supply has been reported. While the LHS method has been successful for all states of power supply to the HLP of the NPP, this means it has the highest likelihood of power supply HLP of the NPP and this is the best location selection to securely NPP is Bus No. 3.

If we want to analyze the mean number of times that the power supply has failed to analyze the HLP of an NPP, we need to analyze Fig. 6. Obviously, the results of Fig. 6 should confirm the results of Fig. 5.

Fig. 6 also shows that the lowest percentage of power supply failure is to the HLP of the NPP related to Bus No. 3, which is the biggest chance for the power plant in the event of an accident for an NPP (NPP trip). As a result, according to Figs. 5 and 6, for both probabilistic method used in this article, the best place for a nuclear power plant to connect to the power system is Bus No. 3, Bus No. 4 is ranked second and Bus No. 5 in the MCS method and Bus No. 9 in the LHS method is the last in terms of power supply to the NPP.

Bus No. 3 was introduced as the first place to connect the NPP to the power system in order to transmit and receive electrical power according to the MCS and LHS. Now, the performance of the relay protection, the mean output of the equipment, including power units, transmission lines, and protective relays, the HLP voltage of the NPP, the frequency of the power system after the NPP trip and the variation Power transmission through the intermediate line between the NPP and the power system on the Bus No. 3, should be investigated.

According to Table 2, after 998 repetitions in the MCS method, the mean performance of the relay on Bus No. 3 obtained from Equation (9) is 4.2425, which is the amount of mean relay function the protection for 24 Bus is 4.2979 less, and the mean relay performance in the LHS method for this bus is 3.4990, That amount of is less than the mean relay function protection for 24 Bus is equal to 4.0368. Fig. 7 shows the convergence rate of the performance of the relay on Bus 3 after 998 repetitions in the MCS and LHS methods. As it can be seen, after 998 times the mean relay protection performance is 4.2425 in the MC method and 3.4990 in LHS method.

The second case to check the status of the network when the NPP is located on Bus No.3 and tripped, the mean number of outage equipment in the MCS and LHS methods. According to Table 2, in the MCS method, the mean outage of equipment after 998 repetitions based on Equation (9) is 5.3848, which is less than the mean outage of equipment 5.4052 for 24 buses. In the LHS method, the mean number of outage equipment modes in all Buses is similar, because *N* and FOR equipment is constant. For all Buses, this is equal to 5.4108.

As described earlier, one of the most important points in using the LHS method is to determine the number of sampling sizes in this algorithm. In all previous studies, the sample size was set equal to the number of duplicates of the MC method to allow comparison between methods. But Table 3 presents the analysis of the number of iterations of the simulation results when the nuclear power plant is connected to bus No. 3.

As can be seen in Table 3, the LHS method outperforms the MC method by considering all possible states in the number of less repetition. For this reason, the convergence time of the response is reduced in the LHS method and converges to the earlier response. As can be seen in this table, reducing the number of sample sizes

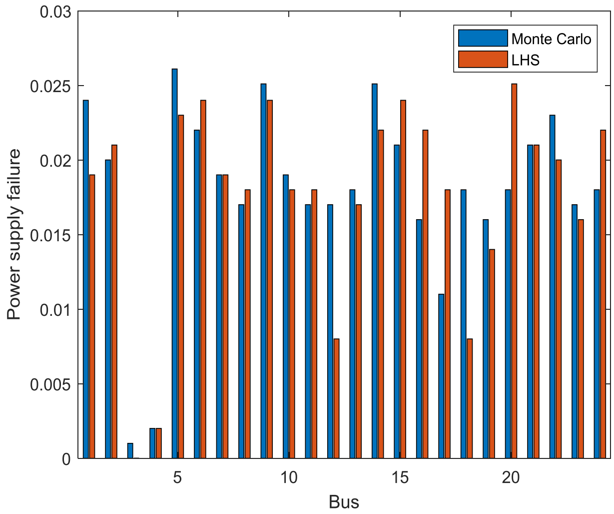

Fig. 6. The average number of power supply failure modes to the HLP of the NPP.

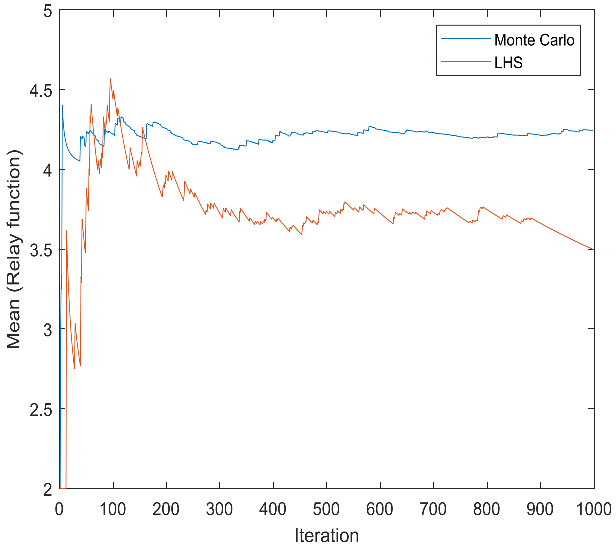

Fig. 7. Mean performance of relay protection in Bus No. 3 based on MCS and LHS.

Table 3
Changes in the number of sampling sizes in the LHS method.

N	Mean number function of the relay protection after the Trip	Mean number of power supply failure power plants by power system after the Trip	Mean of power supply NPP by Power System after the Trip	Mean outage of equipment after the trip
988	3.4990	0	998	5.4108
800	3.4424	0.0013	799	5.4135
600	3.3545	0.0017	599	5.4181
500	3.5924	0	500	5.4217
400	3.3794	0.0025	399	5.4271

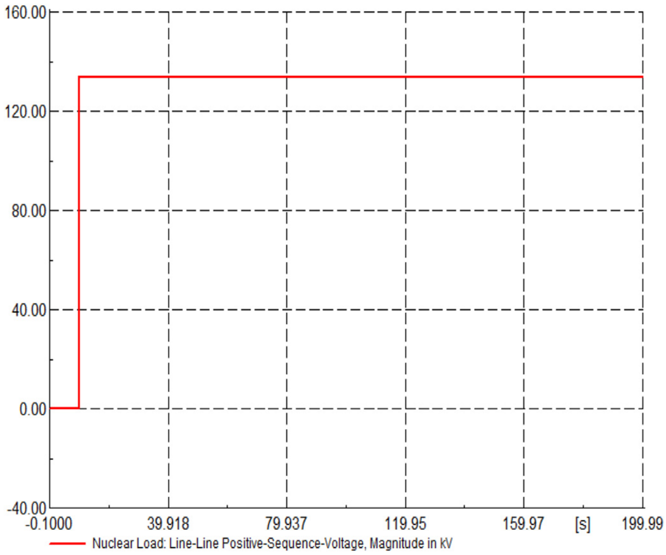

Fig. 8. Power supply voltage changes for internal consumption of NPP on bus 3.

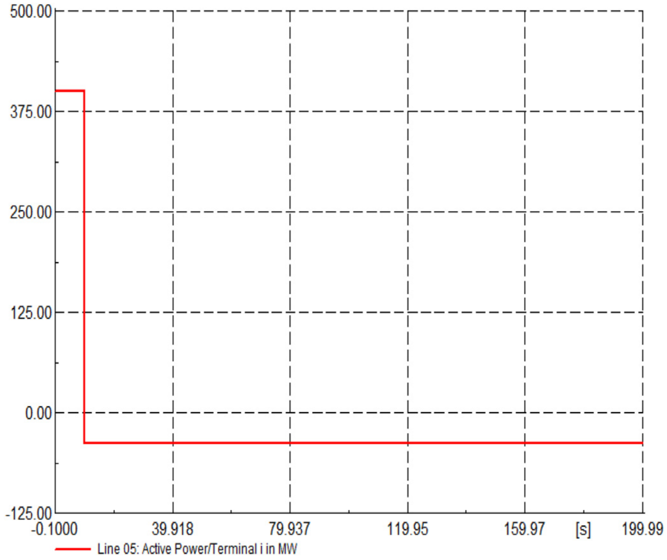

Fig. 10. Power transmission through the intermediate line between the power unit and the power system on the bus 3.

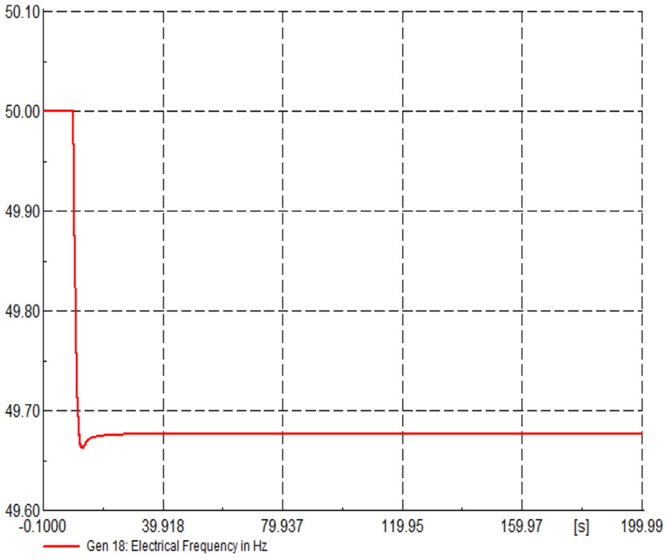

Fig. 9. Changing the frequency of the network in the event of an NPP trip on bus 3.

did not result in reduced accuracy and the algorithm converges to the final answer with reasonable accuracy.

The next item is the voltage measurement of the internal consumption of the power plant, which should be considered. Because the quality of the voltage, if it is lower or higher than the desired level, results in the protection of the relay and normal voltage cannot be normalized. In Fig. 8, the bus voltage variation of the internal power consumption of the NPP is shown in the event of an error. As is known, transient state studies of the power system in 20 s immediately after the NPP trips the bus voltage 3–138 kV, as a result, the internal NPP consumption voltage is supplied.

A 400 MW NPP trip can also have an effect on the frequency of the power network, lack of function the frequency control and governor control systems will cause high-frequency loss and the operation of the frequency relay in the power system, which will outage the cascade of other power plants. In the system under consideration, with the consideration of the governor for other power plants, a severe frequency drop is prevented. As shown in Fig. 9, the network frequency after an NPP trip in 20 s and the entry of the house load of NPP has dropped into the frequency network, which, after fast functioning of control systems, has found some frequency constant.

The last thing that has to be considered in this simulation, the variation Power transmission through the intermediate line between the NPP and the power system is when the power plant is located on bus 3. As shown in Fig. 10, before the NPP is trip, the power plant will send 400 MW to the grid, in 20 s and after the NPP trip, the power system will send 40 MW power to the NPP, which will confirm the correctness of the calculations, as well as the choice of the location suitable for connection the NPP is in power system.

6. Conclusion

Considering the importance of power supply the NPP offsite power system as a reliable power source in normal and emergency conditions with the purpose of cooling the reactor and preventing the melting of the reactors core and release of radioactive material, location selection for the construction of an NPP and the connection to the power system is of particular importance. In this paper, we were able to use the MCS-RS method and based on the number of repetitions, after 998 repetitions and a nuclear power plant trip in 20 s, the location selected for the construction of an NPP and the connection to the power system and NPP receives 10% of its power rating from the power grid with confidence. Also using the probabilistic LHS method, this process was repeated and the accuracy of the MC method evaluated, both of which identified the best location for building an NPP as Bus No.3.

Based on the results of Table 2 and Figs. 3–to10, all this confirms that taking into account the uncertainty in the withdrawal of equipment including power plants, transmission lines, and protective relays, and performing power flow in the transient state of the power network and Feeding the house loads of the power plant during the power plants trip, The location selection of the NPP on Bus No. 3 is completely correct.

Declaration of ompeting interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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