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Article

Risk assessment of electric power generation systems using modified jellyfish search algorithm

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Abstract: An electric utility's main goal is to fulfil the requirements and expectations of its customers by providing power. When there are uncertainties, like equipment failures, system reliability evaluation offers a framework to guarantee that the system will still function properly. A modified Jellyfish Search Algorithm (JFSA) has been proposed for estimation of Electric power generation system reliability indices. Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and other modified versions of algorithms have been used in algorithms that use optimization methods for the assessment of reliability indices. Jelly Fish Search Algorithm has been used in power systems to find the economic load dispatch of generating units, for integration of Distributed Generation (DG) units, Maximum Power tracking of PV system and Optimal Power Flow solutions etc. However, JFSA has not been implemented for the evaluation of reliability indices for electric power generation system. In this context a modified JFSA algorithm is developed for evaluation of certain reliability indices such as Loss of Load Expectation (LOLE), and Expected Demand Not Supplied (EDNS), Loss of Load Probability (LOLP). The algorithm presented is implemented on two test system which are RBTS 6 bus system and IEEE 24 bus Reliability Test System. The Results obtained are compared for different models of Generation and Load and are analysed.

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Nomenclature

Abbreviations:

JFSA	Jellyfish Search Algorithm
LOLE	Loss of Load Expectation
EDNS	Expected Demand Not Supplied
LOLP	Loss of Load Probability

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LOL	Loss of Load
FOR	Forced Outage Rate
DNS	Demand Not Supplied
Max_{iter}	Maximum Iterations
U_B	Upper Limit
L_B	Lower Limit
N	Number of Possible states
N_f	Number of failure states
N_t	Total number of hours
Npop	Population size
X	Generation States
Y	Load States

1. Introduction

The primary goal of an electric power generation system's operation is to meet load demand of the system while providing an acceptable level of quality and consistency. The ability of a system to deliver an adequate supply of electrical energy is commonly referred to as reliability. Once a certain generating capacity is installed, it is expected that the necessary quantity of electricity will always be available to meet load demand. In real-world systems, however, this is not the case since the load grows yearly. To provide an example, the load doubles every 10 years in affluent nations and every seven years in underdeveloped ones. Reliability indices LOLP, LOLE, and EDNS are assessed in order to reduce the difference between generation and load during power system operation [1]. Reliability evaluation has been carried using analytical methods and Monte Carlo simulation (MCS) method [2]. Using the particle swarm optimization (PSO) algorithm and state sampling non-sequential Monte Carlo simulation, a technique for determining the best reliability indices for system components in a composite electric power system is provided Non-sequential MCS and a load curtailment model based on dc load flow are used to estimate the expected demand not serviced (EDNS) index [3]. A hybrid approach called ANLSA which combines the lightning search algorithm (LSA) and ant lion optimization algorithm (ALO) is used as a hybrid approach, the power system's reliability for planning generation growth using wind energy sources is assessed [4].

The values acquired for LOLP and LOLE will be useful in the future for the upkeep and creation of the suggested models. The outcomes contribute to building a solid foundation for smart cities. Smart cities are regarded as significant technological advancements in the field of special economic technology [5]. Reliability Indices are evaluated with the addition of Renewable Energy sources (RES) using PSO technique [6, 7].

Optimization problems in engineering are becoming more difficult. Mathematical techniques for handling large problems with limited computational capacity include classical gradient-based optimization methods. Because of their ease usage and results they provide; metaheuristics have gained popularity over other approaches in the optimization space [8]. Based on the way jellyfish locate food in the water, one such bio-inspired metaheuristic algorithm is developed called the Jelly Fish Search Algorithm (JFSA) [9]. It has recently been shown that a variety of optimization issues can be successfully solved using population-based bio-inspired algorithms. According to the literature, JFSA outperforms other widely used meta-heuristics in a range of benchmark functions and real-world applications [9]. The developed Jelly Fish Search Algorithm (JFSA) strategy is used in the PV frameworks to follow the Global Maximum Power Point (GMPP) under partial shading conditions [10]. To solve the distribution network reconfiguration issues and decrease power losses, a new load-flow technique was implemented using GA and PSO algorithms to improve the reliability [11].

A composite reliability assessment takes the unavailability of both generation and transmission equipment into account. Power flow analysis tools and corrective action algorithms are used in the static assessment of system conditions. These algorithms aim to refer to situations where load curtailments are confirmed, either due to inadequate generating capacity or limitations in the transmission capacity of the system. Hence, in several scenarios, the computing aspect of probabilistic dependability evaluation might result in significant costs [12].

Several attempts have been made to reduce the amount of computation time required to assess reliability indices while dealing with large-scale power systems. The studies under consideration encompass a variety of techniques and methods, as evidenced by the inclusion of recently published works. These techniques and methods include various intelligent population-based optimization methods [13–15]. The literature show Reliability indices are calculated using different papulation-based optimization methods like GA, PSO, LSA and many more other methods, here an attempt is made to evaluate the Reliability Indices using newly proposed bio inspired optimization technique called Jelly Fish Search Algorithm. The main objective of this paper is establishing a way for accurately estimating the reliability indices of electric power generation systems. This approach utilizes the modified Jellyfish search algorithm to evaluate the reliability indices of the generation system in an efficient manner. The performance of the proposed algorithm is analysed by evaluating reliability indices for the RBTS 6 bus system and IEEE 24 bus Reliability Test system considering four different generation and load models. The test data for these systems is taken from the references [15–17]. The capacity of JFSA is to track failure states in an intelligent, regulated, and predetermined way by choosing an appropriate fitness function accounts for the established methods' superiority over other conventional approaches [18–21]. The suggested method calculates the Expected Demand Not Supplied (EDNS), Loss of Load Expectation (LOLE), Loss of Load Probability (LOLP).

The structure of the paper is explained as follows: In explained Section 2 explained about the Research Gap Analysis. Equations for Reliability indices have been explained in Section 3, Modified Jelly Search Algorithm has been explained in section 4. Methodology and work flow to calculate reliability indices have been presented in Section 5. Implementation, Result Analysis of the mentioned methodology has been explained in Section 6. In Section 7, conclusions are given. Limitations and Future Scope are explained in Section 8.

2. Research gap analysis

Reliability indices have been calculated using different optimized search algorithms such as PSO, GA, ANLSA etc but JFSA has not been used for the evaluation of reliability indices. Although many studies have been used two or three states for generation and load for calculating the reliability indices, there is a lack of research on using greater number of states for both generation and load for calculating reliability indices. Therefore, this study aims to use modified JFSA to calculate to reliability indices by incorporating various random numbers for generation model and load model. The accuracy the reliability indices is likely to be more realistic as the number of states have been increased.

3. Reliability indices of electric power generating system

3.1. Loss of load probability (LOLP)

A loss of load (LOL) occurs when the system is unable to satisfy the entire demand. (LOLP) is the likelihood of LOL events happening within a specified time frame:

$$\text{LOL} = \frac{(\text{Generation-Load})}{\text{Generation}} \ , \tag{1}$$

where,

$$\text{Generation} \leq G_{max} \ . \tag{2}$$

For state sampling in non-sequential Monte Carlo simulation, a random integer between 0 and 1 is assigned to each system component. When dealing with two-state components, they are considered to be in the down state if this value is less than its failure probability, and in the up state otherwise. The system's probability of losing load, represented as LOLP, is calculated by:

$$\text{LOLP} = \frac{N_f}{Ns} \ , \tag{3}$$

where N_f stands for all possible failure situations, and N_s is the total number of samples.

3.2. Loss of load expectation (LOLE)

Loss of Load Expectation (LOLE) occurs when the generating capability is exceeded by the daily peak load. It is calculated as follows:

$$\text{LOLE} = \sum_{t=1}^{Nt} \text{LOLP} * t \ , \tag{4}$$

where N_t is total hours Where t is the number of hours.

3.3. Expected demand not supplied (EDNS)

Average demand that can't be satisfied in a certain time period is referred to as Expected Demand Not Supplied (EDNS). When demand for energy exceeds the capacity of the existing generators, there is an energy shortage. EDNS is calculated by:

$$\text{EDNS} = \frac{1}{Ns} \sum_{i=1}^{Nf} (\text{Loss of Load}) \ . \tag{5}$$

where N_s is the number of samples simulated and Loss of Load is the loss that occurs when the load is greater than the generation.

4. Proposed modified jelly fish search algorithm

The following summarizes the steps involved in implementation:

1. Define the objective function for Loss of Load (LOL), Generations States X, Load States Y, the maximum number of iterations (Max_{iter}), the upper limit search space (U_B), and the lower bound search space (L_B).
2. Evaluate the objective function at each population using the Equation (1).
3. The time-control method alternates between the jellyfish's two advanced motions. Determine motion using a time control device. Jellyfish motion can alternate among active motion along with passive motion. The control equation is given by:

$$\text{C(t)} = \left| \left(1 - \frac{t}{\text{Max}_{\text{iter}}}\right) * ((2 * \text{rand}(0,1) - 1) \right| \ . \tag{6}$$

   The search criteria are followed by the jellyfish. Jellyfish have a tendency to follow inside the swarm when its value is less than the predefined value $C(t)$. $C(t)$ is considered to have a predefined value.
4. Jellyfish moves inside the swarm if $C(t)$ is greater than this number. If its number is less than $C(t)$, they move within the motion.
5. If $C(t)$ is greater than the predefined value (Lies between 0 and 1), then follow the next steps:

(a) When rand (0,1) is greater than $(1 - c(t))$, and a new location is discovered, the jellyfish adopts Type A motion.

$$X_j(t+1) = X_j(t) + \text{rand}(0,1) * (U_B - L_B) \ , \tag{7}$$

$$Y_j(t+1) = Y_j(t) + \text{rand}(0,1) * (U_B - L_B) \ . \tag{8}$$

(b) When rand(0,1) is below the $(1 - c(t))$, the search criteria follow the Type B motion, and a new position is discovered by,

$$X_j(t+1) = X_j(t) + \overrightarrow{\text{Step1}} \ , \tag{9}$$

$$Y_j(t+1) = Y_j(t) + \overrightarrow{\text{Step2}} \ , \tag{10}$$

$$\overrightarrow{\text{Step1}} = \begin{cases} \text{rand}(0,1) * X_j(t) - X_i(t) & \text{if } f(x_i) \geq f(x_j) \\ \text{rand}(0,1) * X_j(t) - X_i(t) & \text{if } f(x_i) < f(x_j) \end{cases} \ , \tag{11}$$

$$\overrightarrow{\text{Step2}} = \begin{cases} \text{rand}(0,1) * Y_j(t) - Y_i(t) & \text{if } f(Y_i) \geq f(Y_j) \\ \text{rand}(0,1) * Y_j(t) - Y_i(t) & \text{if } f(Y_i) < f(Y_j) \end{cases} \ . \tag{12}$$

6. If $C(t)$ less than 0.5. Then follows the following steps:

$$X_j(t+1) = X_j(t) + \text{rand}(0,1) * \overrightarrow{\text{trend}} \ , \tag{11}$$

$$\overrightarrow{\text{trend}} = X_{\text{best}} - \beta \times \text{rand}(0,1) \times \mu \ . \tag{12}$$

In the above equation β represents the distribution coefficient and μ represents the mean position

7. The Loss of load has been calculated at the new position after checking the boundary conditions. LOLP, LOLE, EDNS values are calculated using Equations (3) to (5)
8. Stopping criteria: The initial stopping criteria involves the algorithm is terminated when certain number of generations are reached or when Load increases the capacity of the generating station.

5. Reliability evaluation modeling using proposed modified JFSA

The proposed Modified JFSA is developed in different Models based on the Number of states of Generation and Load. Two different Flow charts are given below the different Models. Flow chart 1 for Model I, II, III is considered as load states are constant and taken as two state model. Flow chart 2 is considered for Model IV as here both Generation and Load are considered as multiple states insteps of from nearly zero(with tolerance limit 0.0001) to nearly equal to (0.9999).

5.1. Model I

Consider Generation states X as 2 states and Load states as 2.X values are 0.0001 and 0.9999. New Generation and load values calculated by generating random number for the Generation and Load by using modified JFSA. Using these values LOL is calculated using Equation (1). If LOL is less than one the failure state is increased by 1. The procedure repeated and the failure states are calculated using JFSA. The reliability indices LOLP, LOLE and EDNS are evaluated using the Equations (2) to (4) respectively. Following the computation of each state's objective function within the present population, JFSA was used to apply the time control mechanism to the evolution of a new generation state. Up until a stopping requirement is reached, new JFSA generation states are generated. LOL is less than one means the loss

Table 1. Generation and Load states for Model I, II, III, and IV.

S.No.	Generation and Load States
Model I	Generation States X=2 (X=0.0001, 0.9999) Load States Y=2
Model II	Generation States X=3 (X=0.0001, 0.5, 0.9999) Load States Y=2
Model III	Generation States X=11 (X=0.0001, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.9999) Load States Y=2
Model IV	Generation States X=11 (X=0.0001, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.9999) Load States Y=11 (Y=0.0001, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.9999)

of load has been occurred and failure states Nf is incremented by 1. Now LOL value is calculated from the generation value. If the LOL <1 the Loss of Load occurs. Where LOLP is the system loss of load probability and N_f is the total number of failure state in the N_s samples.

5.2. Model II

Generation is considered in 3states and Load is considered for two states i.e. partial or derated state of 50% of generation. Here in this algorithm random generation is calculated considering three levels. Load is considered only 2 states Up or Down. Following the computation of each state's objective function within the present population, JFSA was used to apply the time control mechanism to the evolution of a new generation state. Here Initial population is considered 3 means random number is generated between 0,1 to get the corresponding generation value within the limits of 0 to 240MW. Now LOL value is calculated from the generation value using Equation (1).

5.3. Model III

Generation is considered in 11 states and Load is considered for two states. Here in this algorithm random generation is calculated considering 11 levels. Load is also considered 11 states.

5.4. Model IV

Generation is considered in 11 states and Load is considered for 11 states. In this model number of states for load is increased. The random number is generated both for generation and load. Loss of Load is calculated for a greater number of generation and load values. The accuracy of the reliability indices will be more realistic as the no of states are increased. Based on the above Models presented, the flowchart of the algorithms developed for Model I,II,II is as shown in Figure 1. Similarly for Model IV, it is as shown in Figure 2.

6. Simulation results and discussion

The proposed method of optimal reliability indices calculations using Modified JFSA algorithm has been tested on a RBTS 6 bus system and IEEE 24-bus system. Results are discussed below for different models of Generation and Load states.

6.1. RBTS 6 bus system

Total generation of 6 Bus RBTS system is 240MW and load is considered as 70% percentage of generation. Modified JFSA is tested on RBTS 6 bus system and IEEE 24 bus system. Some percentage

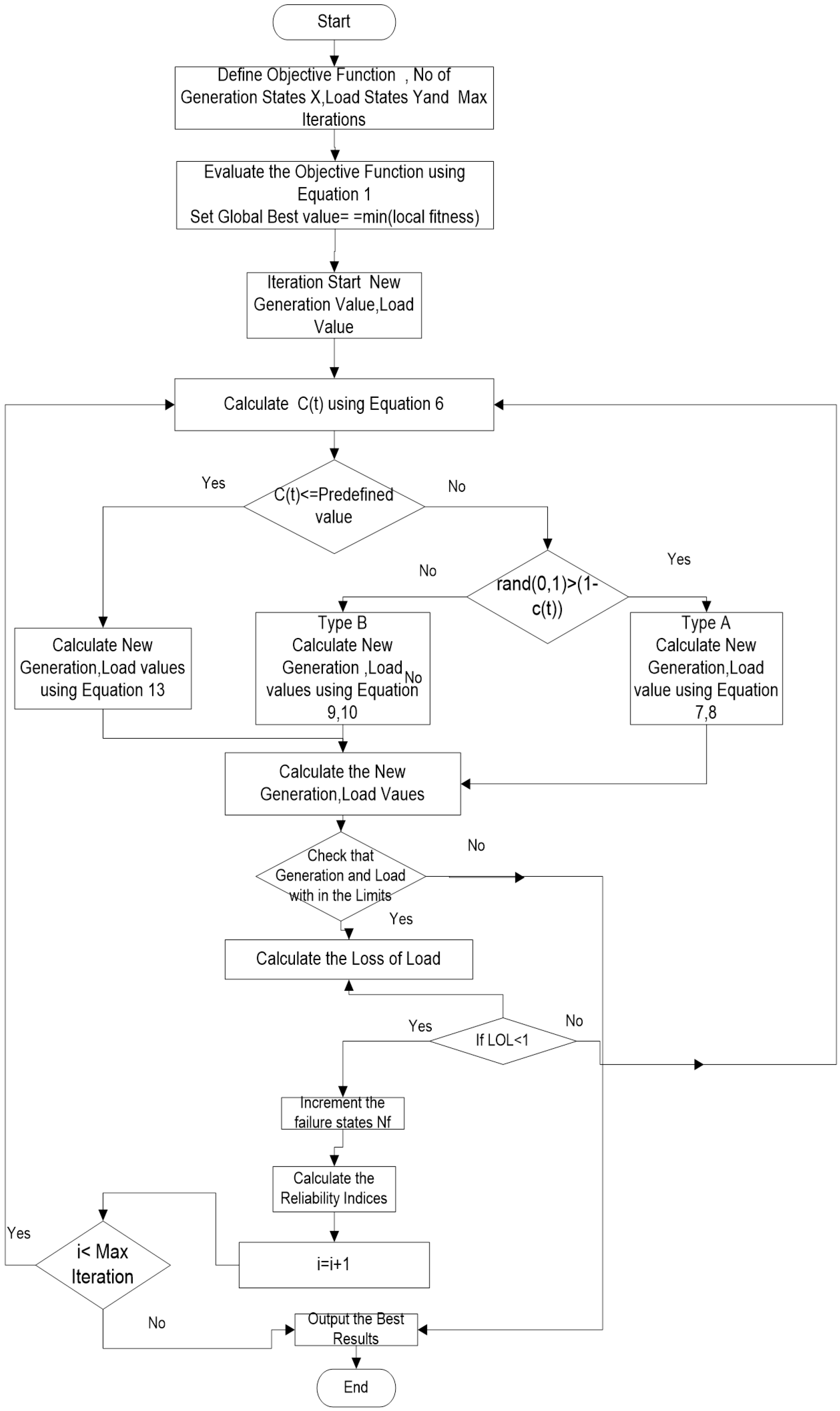

Figure 1. Flow chart for model I,II,III.

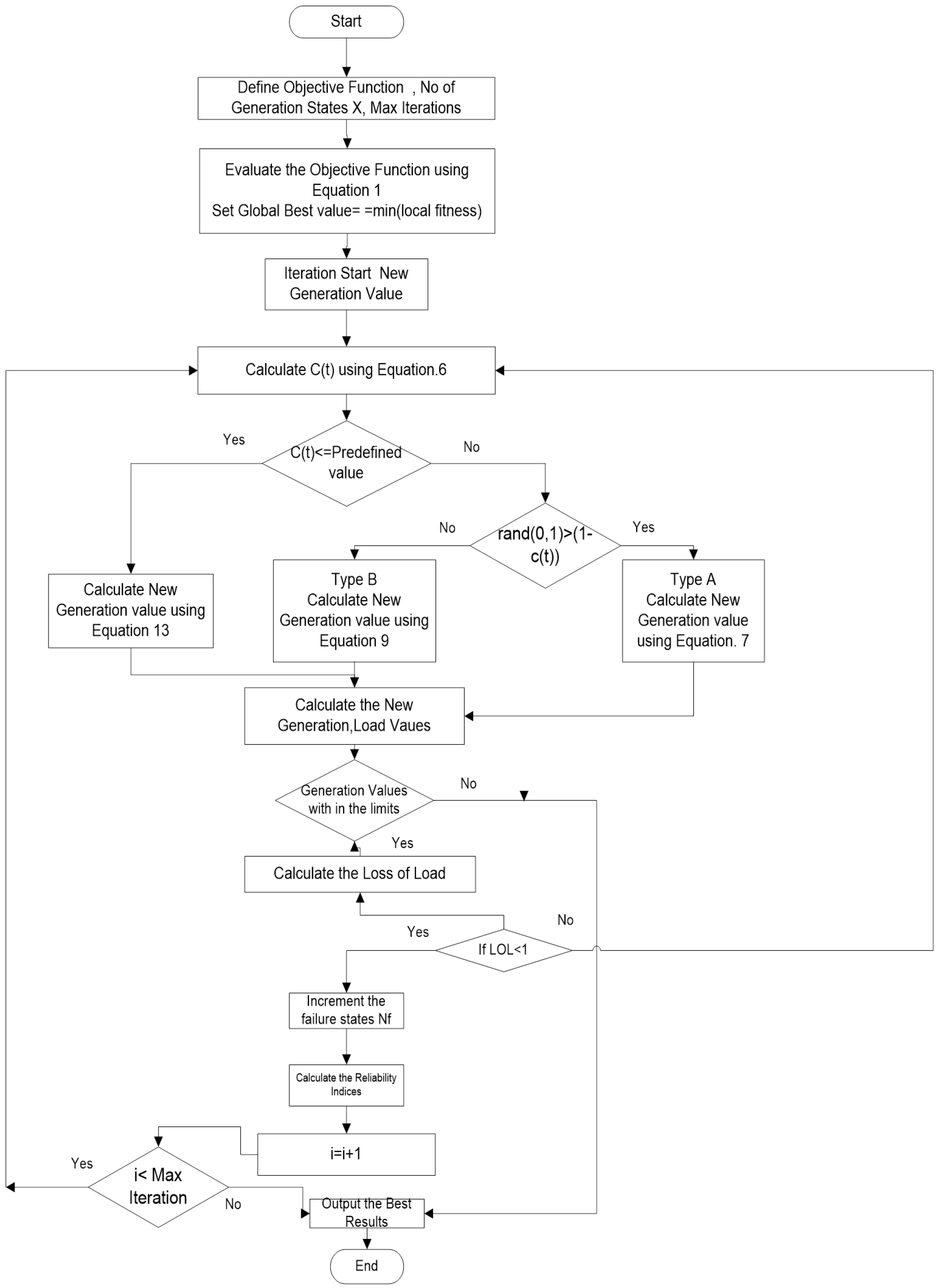

Figure 2. Flow chart for Model IV.

of Generation is considered as Load for the evaluation of Reliability Indices. Generation states and Load states are considered as per the Models explained in the Table 1. The simulation results are tabulated in the Table 2. Though the values increase using JFSA these are the values near to actual values. In the proposed algorithm the number of states is increased compare to conventional methods.

Table 2. Simulation Results for RBTS 6 Bus system

Indices	Model I	Model II	Model III	Model IV
LOLP	0.044752	0.053343	0.067872	0.24664
LOLE (Hours/Year)	392.0298	467.2831	594.5549	2160.5921
EDNS (MW)	0.62129	0.84345	1.1556	2.5051

6.2. IEEE 24 bus Reliability Test System

Total generation of IEEE 24 Bus RTS 6 bus system is 3450 MW and load is considered as some percentage of generation. Generation states and Load states are considered as per the Models explained in the Table 1. The simulation results are tabulated in the Table 3.

Table 3. Simulation Results for IEEE 24 bus Reliability Test System

Indices	Model I	Model II	Model III	Model IV
LOLP	0.044205	0.048261	0.0654	0.54978
LOLE (Hours/Year)	387.2345	422.7679	572.9025	4816.0501
EDNS (MW)	0.71524	0.94513	1.0372	6.4314

The results obtained for 6 Bus RBTS system and IEEE 24 bus Reliability Test system for LOLP, LOLE and EDNS are shown in Figure 3, 4 and 5 respectively. As the multiple states are considered for the both the generation and load the results obtained are more accurate compare the conventional methods [5, 19]. In the figures, Series 1 represents the RBTS 6 bus RBTS system and Series 2 represents the IEEE 24 bus RTS.

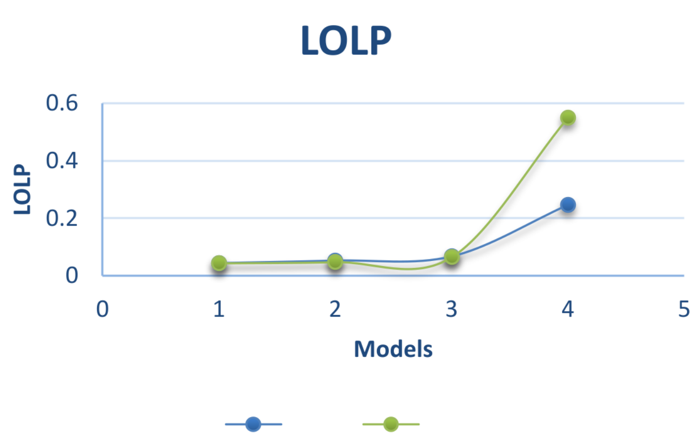

Figure 3. LOLP comparison for 6 bus RBTS and IEEE 24 bus system.

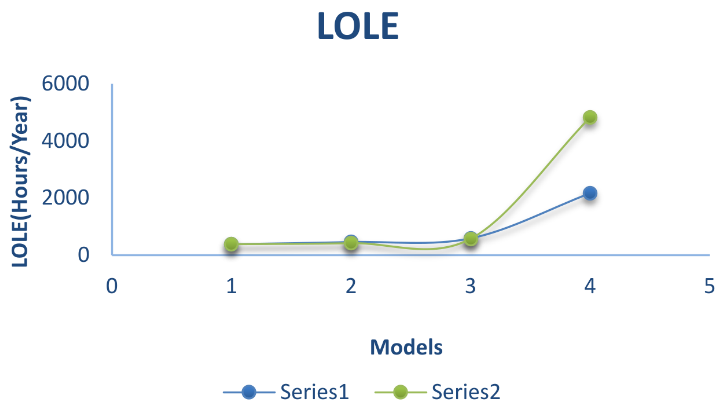

Figure 4. LOLE comparison for 6 bus RBTS and IEEE 24 bus system.

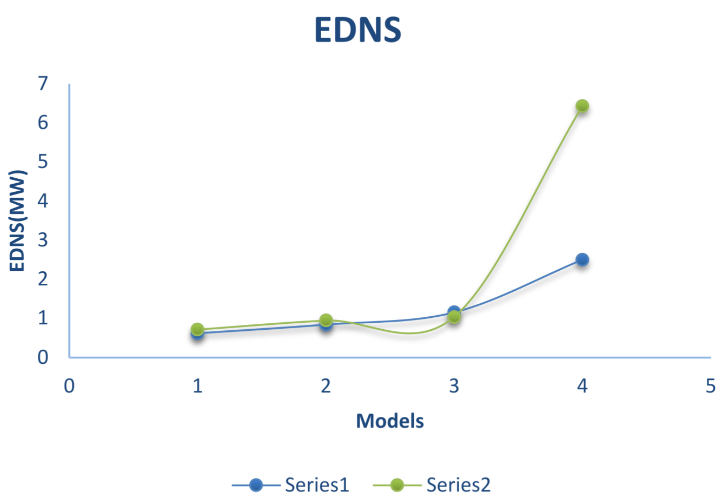

Figure 5. EDNS comparison for 6 bus RBTS and IEEE 24 bus system.

7. Conclusions

In this work it is proposed an efficient algorithm to evaluate reliability indices of electrical power generation system, with the combined generation and load models represented. The value calculated from JFSA is more accurate compared to conventional method. The number of states are increased in JSFA are more compared to conventional method and it reduces the complexity of calculations and the values obtained are more accurate than the conventional method. The proposed algorithm is accurate than the conventional method because of its potential for intelligent search through its objective function. In this paper different generation state models are considered viz., 2- state (up or down), 3 state (up, down, partial derated with 50% generation), multiple state model (nearly 10%, 90% generation, nearly zero, full generation) and similarly for the load also multiple states are considered accordingly and algorithm have been developed to calculate the electric power generation system reliability indices. Although the algorithm is superior the reliability indices decrease because mode number of states have been considered where are few states are considered earlier in the literature. Hence the results are near to the actual values.

8. Limitations and future scope

Sometimes, the algorithm can experience early convergence, get stuck in local optima, or take a long time to converge. It can be overcome by regulating the exploration and exploitation search, maintaining the search's variety, and quickening convergence can all lead to the necessary improvements. Machine Learning techniques can be combined with the nature inspired algorithm like Jelly Fish Search Algorithm to optimize the solution to solve any problem.

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Author contributions: K.C.Archana developed methodology and performed the calculations/simulations, analysed the data and wrote the manuscript. Y.V.Sivareddy and V.Sankar supervised at every stage and contributed to the final version of the manuscript.

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Appendices

Appendix A: 6 bus RBTS system

The 6 bus RBTS system is as shown in the Figure A1. The line, generation and load data is presented in Table A1.

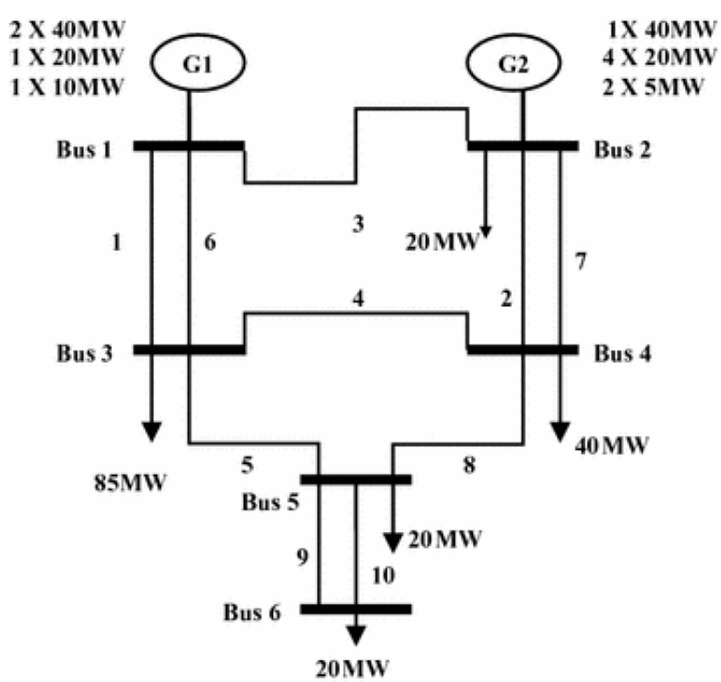

Figure A1. 6 bus RBTS system.

Table A1. Generation data of 6 Bus RBTS

Unit size (MW)	Type	No of units	Total Generation capacity
5	Hydro	2	10
10	Thermal	1	10
20	Hydro	4	80
20	Thermal	1	20
40	Hydro	1	40
40	Thermal	2	80
Total system Generation capacity			240 MW

Appendix B: IEEE 24 Bus Reliability Test System

The IEEE 24 Bus Reliability Test System is as shown in the Figure B1.The line, generation and load data is presented in Table B1.

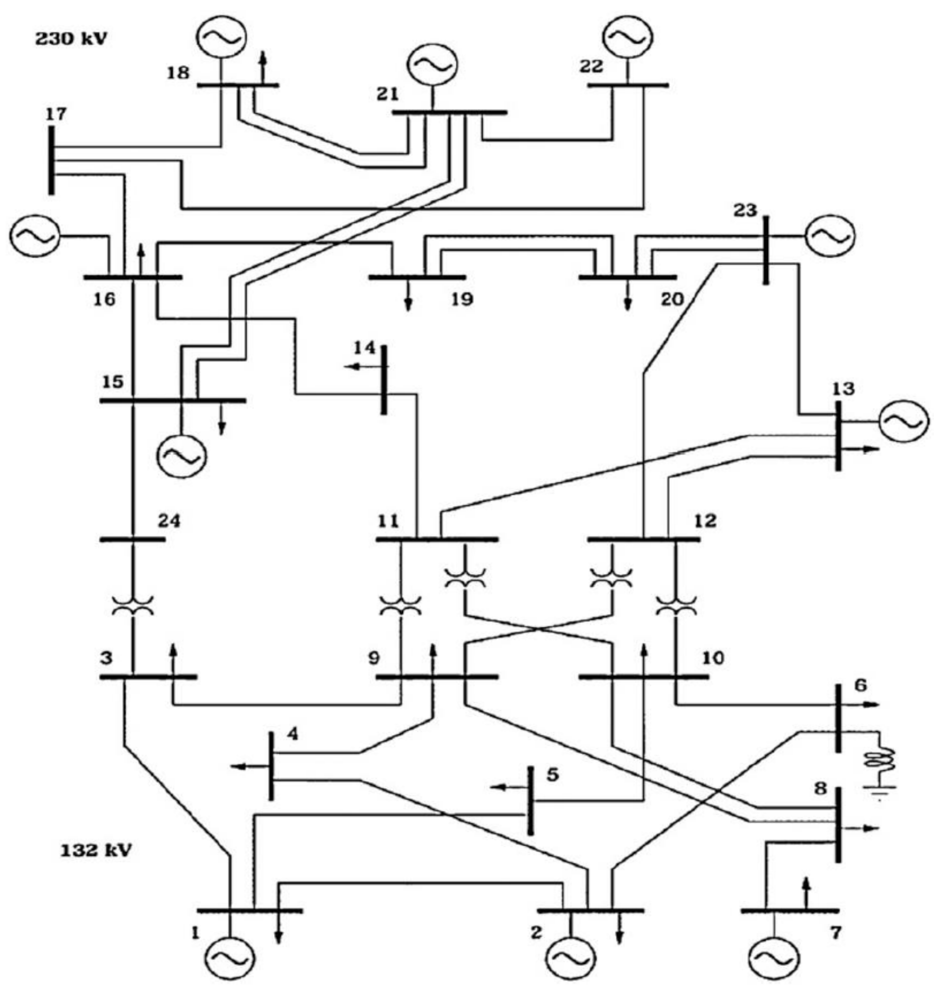

Figure B1. IEEE 24 Bus Reliability Test System.

Table B1. Generation data of IEEE 24 bus System

Type of Generation	Generation Capacity of Each Unit (MW)	No. of Units	Total Generation Capacity (MW)
Oil	12	5	60
Oil	20	4	80
Hydro	50	6	300
Coal	76	4	304
Oil	100	3	300
Coal	155	4	620
Oil	197	3	591
Coal	350	1	350
Nuclear	400	2	800
Total System Generation Capacity			3405

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