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A Sampling Method based on System State Transition for Distribution System Adequacy Assessment using Distributed Generation

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Abstract— *A sampling method is proposed related to-system state transition based Monte Carlo simulation (SSTMCS) for the adequacy assessment in the radial distribution system (RDS) in the presence of distributed generation (DG) termed as a composite distribution system (CDS). This method evaluates well-being indices such as probabilities, frequency, and duration indices in healthy, marginal, and risky states. A deterministic criterion is used for adequacy assessment. Samples are generated using a load flow program for RDS used in SSTMCS. The loss sensitivity factor is utilized for the positioning of DGs in RDS. DG capacity and load at buses are considered continuous random variables. Different cases are addressed to demonstrate the impact of varying DG capacities on well-being indices. Moreover, the results are compared with the state enumeration method (SEM). IEEE-33 bus RDS is considered for this study.*

Keywords—Distributed Generator (DG), Loss Sensitivity Factor (LSF), System state transition based Monte Carlo Simulation (SSTMCS), Radial Distribution System (RDS), State Enumeration Method (SEM)

1. INTRODUCTION

The distribution system is a mostly radial type and its function is to deliver power to a consumer without interruption. Load flow analysis is a very important tool for analyzing power system operation, planning, and maintenance. There are different methods of power flow analysis of RDS. A straightforward method for obtaining bus voltages addressed in literature[1] that is based on the construction of a constant sparse upper triangular matrix. The backward/forward sweep method is also presented in many papers for power flow solutions in RDS. Bompard et al. [2] tested this method on lines with different X/R ratios and various load types. Singh and Ghose [3] developed an efficient method that is based on matrix transformation techniques. To find load flow solutions, two designed matrices—the bus-injection to the branch-current matrix and the branch-current to the bus-voltage matrix- i.e. a straightforward matrix multiplication method is employed [4]. Nowadays distributed generators (DGs) are getting interconnected in the distribution system due to many advantages[5]. Many researchers worked on integrating DG units into the distribution system. The optimal location and sizing of DG units is an important optimization problem to fulfill load demand. The loss sensitivity factor is another well-liked technique for determining the best places to install DG units. LSF can be calculated for each bus. The buses having the highest value of LSF are considered optimal locations for DG unit placement [6]. For locating and scaling many DG in RDS, a Whale optimization method was developed [7]. The work in [8] investigated network reconfiguration as a method of reducing losses and enhancing distribution system reliability. The Grasshopper multi-objective optimization technique was used to resolve it. Numerous academic studies have shown that placing DG units in the right places and of the right sizes can solve two issues, reducing voltage drop and line losses. However, it can lead to a mismatch between the fuse and the recloser. The authors work on it and recover output miscoordination using SFCL[9]. Two key ways to increase the reliability of the distribution network were addressed by Salyani and Salehi [10]. System-oriented reliability planning (SORP) is used to optimize the system average interruption duration index and the second is to implement CORP (customer-oriented reliability planning) to decrease the expected energy not supplied (EENS). A microgrid is a compact electrical infrastructure that uses locally available renewable and nonrenewable energy sources to meet local demand. It's crucial to use energy storage systems (ESS) in microgrids. As a result, this literature [11] discusses how to calculate the ideal size of ESS in a microgrid to reduce loss of load expectation. A stochastic model is used to take system outages, ESS output uncertainty, and load uncertainty into account. Interruptible loads along DG and capacitors allocation and sizing are done simultaneously in RDS for secure and reliable operation in paper [12].

A novel Monte Carlo simulation method was created by Billiton and Li [13] for the reliability assessment of composite systems. It is based on a system state transition sampling technique that enables the calculation of an actual frequency index without the need for an additional enumeration process and its accompanying rough assumptions. The literature [14] provides a thorough comparison of MCS and state enumeration approach for adequacy assessment for the IEEE reliability test system. A cross-entropy-based three-stage sequential sampling method is addressed for composite system reliability evaluation [15]. Billinton and Lian[16] introduced well-being states in the composite distribution system and probability

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indices are calculated for all three states. Authors in [17] also introduced a technique that combines deterministic criteria with probability indices to observe well-being indices for generating systems.

Adequacy assessment approaches for composite distribution systems are reported in [18–26]. Moreover, it's a natural choice from the central limit theorem(CLT) to assume the capacity of load at each bus, and DG capacity is normally distributed [27, 28] because of the status (ON/OFF) of load and DG unit.

Adequacy assessment for a composite system may involve the evaluation of various probabilistic indices such as the probability of each state, and frequency and duration indices which involves all transition rates calculation between success and failure state. Two basic approaches are suggested in the literature for composite system reliability evaluation. Analytical enumeration method and Monte Carlo simulation [13]. As the first method is having difficulty with the dependency on the size of the system (e.g. No of components) for adequacy assessment [14]. As size increases require a higher number of states for adequacy assessments puts difficulty in the evaluation of adequacy assessment, especially frequency and duration indices, and preferably non-sequential Monte Carlo simulation (NSMCS) is used for accurate frequency index calculations [22] compared to other methods as does not require any conceptual approximation or an additional enumeration procedure and independency with the size of the system, therefore, adequacy indices evaluation for the radial distribution system becomes more challenging for the well-being framework as posses three states-healthy, marginal and risky states.

In view of the literature, it is observed that composite distribution system adequacy assessment needs more attention and work to be executed for RDS incorporating DG, especially with a well-being framework and needs appropriate methods for assessment of indices like probability, frequency indices, and duration indices. Therefore SSTMCS as NSMCS is proposed in the paper to carry out the following objectives based on deterministic criteria-

- Evaluation of probability indices in H, M, and R states.
- Calculation of average transition rates from one state to another state.
- Evaluation of frequency indices in all three states.
- Evaluation of the individual states mean up, mean down, and marginal times.
- Estimation of average availability in H and M states and unavailability in the risky state.

All the indices discussed are calculated on annual basis. Therefore SSTMCS is used to calculate well-being indices and SEM is used to compare the results.

The paper is organized as follows: In Section 1, presents an introduction. Section 2 presents the modeling of different components in RDS. Section 3 presents a formulation of the system state transition technique based on Monte Carlo simulation. Section 4 gives implementation SSTMCS for adequacy indices evaluation. Section 5 describes the state enumeration method for well-being indices evaluation. Section 6 gives results for 33-bus RDS and Section 7 presents conclusions.

2. MODELING OF COMPONENTS IN RDS

The load on the distribution system is constantly changing due to customer requirements and the switching of load. Therefore real ($P_{l,i}$) and reactive ($Q_{l,i}$) power demand at bus i can be treated as a random variable and is assumed as a continuous random variable with a normal distribution function[22] which can be represented using (1) and (2).

$$f(P_{l,i}) = \frac{1}{\sqrt{2\pi}\sigma_{P_{l,i}}} e^{-0.5}\left(\frac{P_{l,i} - \overline{P_{l,i}}}{\sigma_{P_{l,i}}}\right)^2 \tag{1}$$

Where $\overline{P_{l,i}}$and $\sigma_{P_{l,i}}$is mean and standard deviation of real load demand at the ith bus respectively.

$$f(Q_{l,i}) = \frac{1}{\sqrt{2\pi}\sigma_{Q_{l,i}}} e^{-0.5}\left(\frac{Q_{l,i} - \overline{Q_{l,i}}}{\sigma_{Q_{l,i}}}\right)^2 \tag{2}$$

Where $\overline{Q_{l,i}}$and$\sigma_{Q_{l,i}}$is the mean and standard deviation of reactive load demand at ith bus respectively.

Total active load demand (P_d) of RDS can be evaluated using (3) as follows,

$$P_d = \sum_{i=1}^{nb} P_{l,i} \tag{3}$$

Where nb indicates the number of buses. The distributed generation capacity may vary according to customer requirements, weather conditions, etc. This uncertainty in DG capacity is assumed as Gaussian distributed random[22] variables represented in (4).

$$f(P_{dg,i}) = \frac{1}{\sqrt{2\pi}\sigma_{P_{dg,i}}} e^{-0.5}\left(\frac{P_{dg,i} - \overline{P_{dg,i}}}{\sigma_{P_{dg,i}}}\right)^2 \tag{4}$$

Where $P_{dg,i}$ is power injected through DG at the ith bus, $\overline{P_{dg,i}}$and $\sigma_{P_{dg,i}}$ represent the mean and standard deviation of DG [30]. With available DG units, the total available DG capacity(P_{Tdg}) can be calculated using (5).

$$P_{Tdg} = \sum_{i}^{NDG} P_{dg,i} \quad i \in \text{Selected optimal buses} \tag{5}$$

Where NDG is the total number of DG units connected in RDS.

In a distribution system substation capacity mostly fulfill the load demand plus losses. When solar distributed generators are integrated at the optimal location. It will inject real power only. Considering a solar-based DG is connected at the ith bus, power demand constraint can be represented by (6)

$$P_i = P_{dg,i} - P_{l,i} \tag{6}$$

where P_i is total power injected at the ith bus, $P_{dg,i}$ is real power injected by DG, and $P_{l,i}$ is active power demand at ith bus.

In a distribution system, the load flow equation is defined by the following equality constraints,

$$P_S + P_{Tdg} = P_d + P_{Tloss} \text{ where } P_{Tloss} = \sum_{i=1}^{NL} P_{loss,i} \tag{7}$$

Where *NL* is the number of lines present in the distribution system and P_{Tloss} is the total real power loss in RDS.

Samples of load and DG capacity are considered as Gaussian variables and load flow solution is obtained using (7). Therefore, total substation capacity will also be a random variable and may be represented as a Gaussian variable.

$$P_{TS} = P_S + P_{Tdg} \tag{8}$$

Where P_{TS} and P_S is the total substation capacity of RDS and capacity of distribution substation alone respectively.

Based on the LSF, optimal locations for placement of solar-based distributed generators are picked out in which real power losses are evaluated at each bus, and buses having the highest losses are selected for placement of DG's [6].

3. FORMULATION OF SYSTEM STATE TRANSITION BASED MONTE CARLO SIMULATION

A system to evaluate wellbeing indices is represented by three states healthy, marginal, and risky states as the Markov model [22]. These states are identified using deterministic criteria. When healthy, sufficient margin is available to satisfy demanded load. Operating limits are imposed in the marginal state, but enough

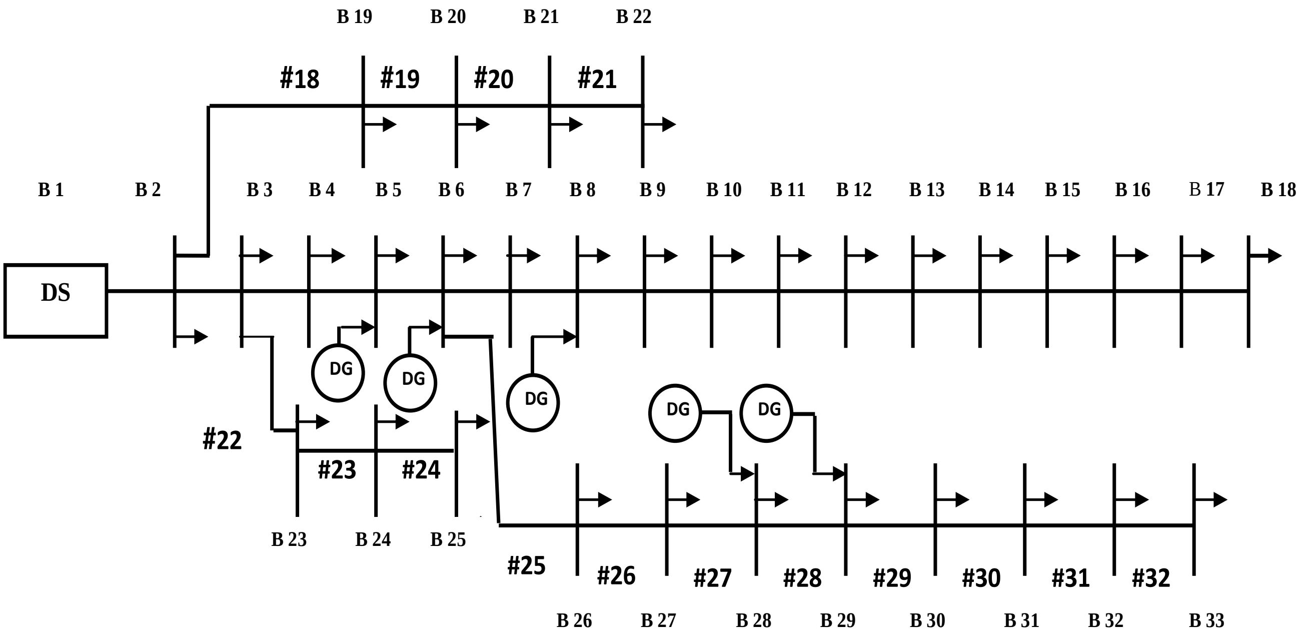

Fig. 1. IEEE-33 bus RDS with the incorporation of DG units

margin is not available to fulfill the deterministic criterion and for the system in a risky state due to violation of constraints, a load may be cut down. It gives important information to system engineers to work safely. So, the calculation of adequacy indices such as probability, frequency, duration, etc., in all three states is an important benchmark for CDS to take corrective measures for the system in good health.

In the composite distribution system the DG units are located at optimal locations as per LSF criteria and as the condition of DG units (ON/OFF) contributes to the system capacity thus the composite system state will be (H, M, or R) as per the deterministic criteria. And the transition of a unit from ON to OFF or vice versa may cause the present system state to transition to other states. Thus based on this philosophy the following procedure is used for sampling DG capacity. In the procedure for all the units in ON condition, the failure rates are considered as transition rates and for OFF condition the repair rates are considered as transition rates.

First, assume a normal state in which all DG units are available.

$$\lambda_{eq} = \lambda_1 + \lambda_2 + \cdots + \lambda_{NDG} \tag{9}$$

Where λ_1,λ_2,. . . , λ_{NDG} is a failure or transition rate of each DG.

The total rate of transition is calculated using (10).

$$Q = \sum_{t=1}^{NDG} \lambda_{eq} \tag{10}$$

The probability of a possible reached state is evaluated as,

$$p_j = \frac{\lambda_j}{Q} \text{ for j} = 1, 2, \ldots, \text{ NDG} \tag{11}$$

Time duration in that state is obtained using (12)

$$T = \frac{-1}{Q} \ln(a) \tag{12}$$

where a is a random number generated between 0 and 1.

Based on state residence time calculations given by (12) can be used further utilized for the calculation of adequacy indices explained in the next section.

4. COMPUTATIONAL ALGORITHM USING SSTMCS FOR ADEQUACY INDICES EVALUATION

SSTMCS is applied for well-being indices evaluation of composite distribution system as follows:

***Step* 1:** Read system data for load and lines of the selected RDS. With the initial assumption of node voltages as 1 per unit (p.u.), set V_1=V_2=V_3, . . . , V_n=1 p.u. and iteration count as K=0.

***Step* 2:** Read failure rate (λ) and repair rate (r) for each DG and initialize no of samples$ns = 1$.

***Step* 3:** Generate samples of load demand at each bus using (1) and (2). ***Step* 4:** Generate DG capacity at each optimal bus using (4) and place the DG units at optimal locations using LSF criteria based on the states of DG units.

***Step* 5:** Run the load flow program [4] and calculate P_d and P_{TS} by using (3) and (8).

***Step* 6:** State of samples i.e., healthy, marginal, and risky state is decided using deterministic criterion which is a function of total distribution substation capacity with DG capacity and total active power load demand as follows,
Healthy state if,

$$\frac{P_{TS}}{P_d} \geq 1.18 \tag{13}$$

Marginal state if,

$$1.16 \leq \frac{P_{TS}}{P_d} < 1.18 \tag{14}$$

Risky state if,

$$\frac{P_{TS}}{P_d} < 1.16 \tag{15}$$

***Step* 7:** System time duration in the respective state is calculated using (12).

***Step* 8:** With the change in the state of the system DG unit will result in the state transition of the system into either a healthy or marginal or risky state subjected to the deterministic criterion in use. So (11) is applied to decide the probability of reaching a possible state.

***Step* 9**: In the next state it can happen that all the DG wouldn't be available all the time. The transition of DG takes place. The

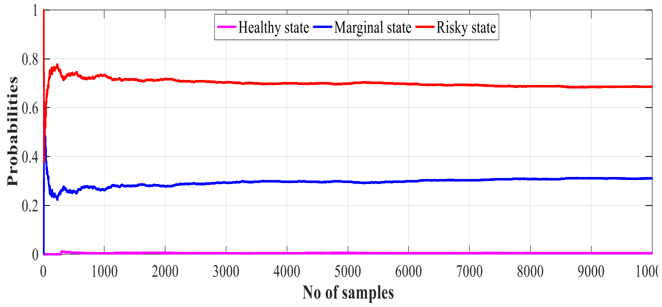

Fig. 2. Comparison of state probabilities for Case-1.

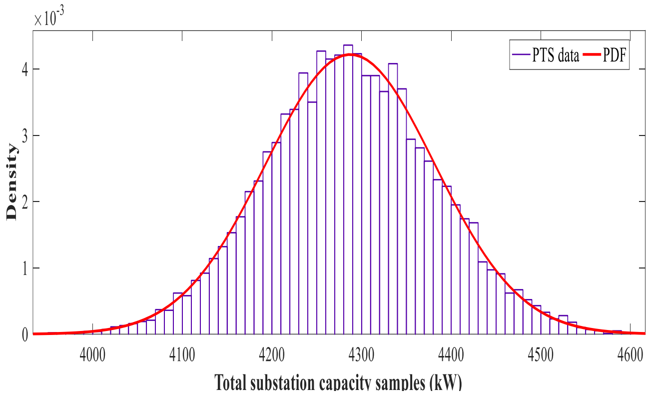

Fig. 3. PDF of P$_{TS}$ for Case-1.

next system state in probabilities of NDG reaching possible states is consecutively marked between 0 and 1.

***Step* 10:** Generate a random number U between 0 and 1. If U comes into a segment corresponding to P_j, jth DG unit transition will take place whereas all other components will carry the previous state.

***Step* 11:** Calculate probabilities of all the three states using (16)

$$P_X = \frac{T_X}{T_D} \tag{16}$$

$$T_D = \sum T_X \tag{17}$$

Where for healthy state $X \to H$, marginal state $X \to M$ and risky state $X \to R$ and T_D is total duration.

***Step* 12:** Calculate the coefficient of variation for each state probability with the help of (18).

$$\beta_X = \sqrt{\frac{(1 - P_X)}{ns \times P_X}} \tag{18}$$

Where for healthy state $X \to H$, marginal state $X \to M$, and risky state $X \to R$ and $T_D$is total duration.
If $\beta_X < 0.002$ then the convergence of the solution is reached and moves to the next step else
$ns = ns + 1$.For simulation maximum number of samples used is $ns = 10,000$.

***Step* 13:** Estimate the average rate of transition from one to another state on annual basis using (19).

$$\lambda_{XY} = \frac{n_{XY}}{T_X} \tag{19}$$

where for healthy state $X \to H$ and $Y \to M \ or \ R$, marginal state $X \to M$ and $Y \to H \ or \ R$ and risky state $X \to R$ and $Y \to H \ or \ M$.
where n_{XY}represents the number of transitions from state X to state Y.

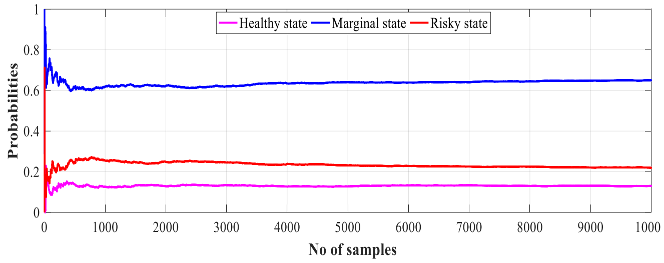

Fig. 4. Comparison of state probabilities for Case-2.

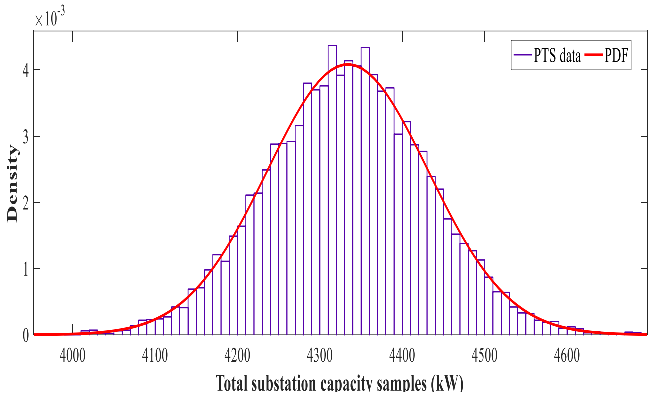

Fig. 5. PDF of P$_{TS}$ for Case-2.

***Step* 14:** Evaluate the average value of the frequency encountered in all three states given as follows:

$$f_X = \frac{n_{XY} + n_{XZ}}{T_D} \tag{20}$$

where for healthy state $X \to H$, $Y \to M$ and $Z \to R$, marginal state $X \to M$, $Y \to H$, and $Z \to R$ and risky state $X \to R$, $Y \to H$ and $Z \to M$.

***Step* 15:** Mean up, down and marginal time of system evaluated as,

$$MUT = \frac{1}{\lambda_{HM} + \lambda_{HR}} \tag{21}$$

$$MDT = \frac{1}{\lambda_{RH} + \lambda_{RM}} \tag{22}$$

$$MMT = \frac{1}{\lambda_{MH} + \lambda_{MR}} \tag{23}$$

Where MUT,$MMT$and $MDT$are the mean value of up, down, and marginal time.

***Step* 16:** Evaluate average system availability in H and M states and unavailability as follows

$$A_X = P_X \times 8760 \tag{24}$$

Where for healthy state $X \to H$, marginal state $X \to M$, and risky state $X \to R$
$A_H$and $A_M$represent the average availability of the system in H and M states respectively and A_R is the average system unavailability.

5. STATE ENUMERATION METHOD FOR ADEQUACY INDICES EVALUATION

The state enumeration method (SEM)[29] is applied as follows well-being indices evaluation of radial distribution system incorporation DG units:

***Step* 1:** Read the failure rate and repair rate of DG units.

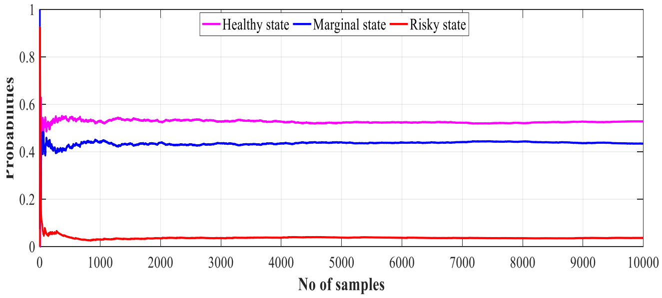

Fig. 6. Comparison of state probabilities for Case-3.

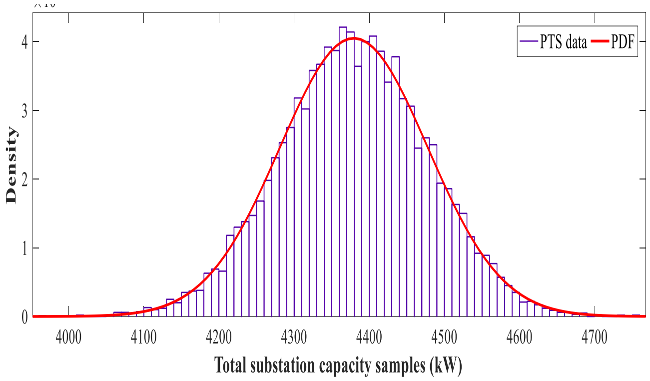

Fig. 7. PDF of P_{TS} for Case-3

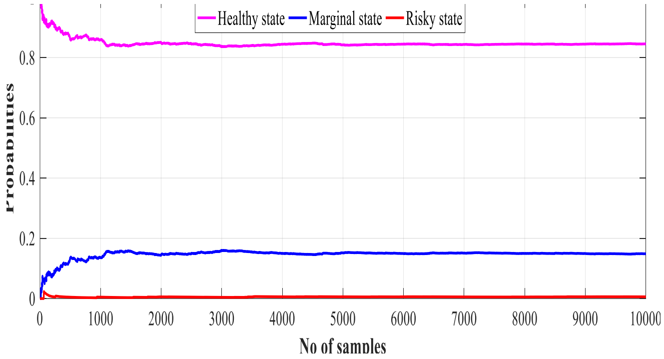

Fig. 8. Comparison of state probabilities for Case-4.

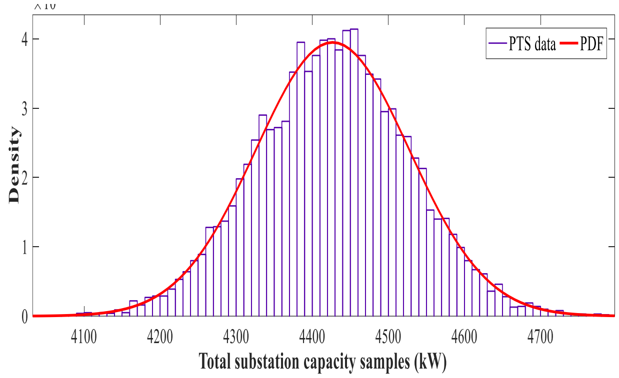

Fig. 9. PDF of P_{TS} for Case-4

***Step* 2:** The capacity outage probability table is prepared using deterministic criteria, and equations (13)– (15) are used to identify the H, M, and R states.

***Step* 3:** Use the following equations to obtain the steady-state probability for all three states.

$$P_H = \sum_{i\in H} P_i \tag{25}$$

$$P_M = \sum_{i\in M} P_i \tag{26}$$

$$P_R = \sum_{i\in R} P_i \tag{27}$$

***Step* 4:** Obtain the frequency of encounters in all three states using the following relationships

$$f_H = \sum_{i\in H} P_i \sum_{\substack{j\in M\\ j\in R}} q_{ij} \tag{28}$$

$$f_M = \sum_{i\in M} P_i \sum_{\substack{j\in R\\ j\in H}} q_{ij} \tag{29}$$

$$f_R = \sum_{i\in R} P_i \sum_{\substack{j\in H\\ j\in M}} q_{ij} \tag{30}$$

where q_{ij}= Transition rates from ith state to jth state.

***Step* 5:** Equivalent failure or repair rates of each state are evaluated using equation (31) as follows

$$\lambda_{eq,X} = \frac{f_X}{P_X} \tag{31}$$

Where for healthy state $X \to H$, marginal state $X \to M$, and risky state $X \to R$

***Step* 6:** Mean up time (MUT), Mean marginal time (MMT), and mean down time (MDT) is evaluated as follows

$$MUT = \frac{1}{\lambda_{eq,H}} \tag{32}$$

$$MMT = \frac{1}{\lambda_{eq,M}} \tag{33}$$

$$MDT = \frac{1}{\lambda_{eq,R}} \tag{34}$$

***Step* 7:** Evaluate average system availability in H and M states and unavailability as follows

$$A_H = P_H \times 8760 \tag{35}$$

$$A_M = P_M \times 8760 \tag{36}$$

$$A_R = P_R \times 8760 \tag{37}$$

Table 1. Best five optimal locations for IEEE-33 bus RDS

Bus number	LSF	Normalized voltage (V_{norm}) in p.u.
6	1661.47	0.9994
28	1321.78	0.9827
29	933.89	0.9740
8	784.66	0.9814
5	779.08	1.018

Table 2. Failure and repair rate of DG units [22]

Unit	DG1	DG2	DG3	DG4	DG5
Bus location	6	28	29	8	5
Failure rate(/hr)	0.001	0.0024	0.003	0.004	0.007
Repair rate(/hr)	0.003	0.005	0.006	0.0045	0.005

6. RESULTS AND DISCUSSION

Well-being indices are evaluated for IEEE-33 bus RDS [7] which consists of 33 buses and 32 branches as revealed in Fig. 1 which is considered CDS.

DG units are placed at the best five optimal location-based on LSF [6]. Table 1 represents the best five optimal locations for placing solar-based DG. The computational algorithm using SSTMCS and SEM are explained in sections 4 and 5 respectively are used to evaluate well-being indices. Samples for load demand at each bus and DG capacities at five optimal locations are generated using equations ((1), (2), and (4)) respectively. The mean of load demand at each bus is considered as its actual value [7] and the standard deviation is considered as 10% of the mean value. A detailed case study is done to analyze the effect of variation of DG capacities on well-being indices for an RDS. Distributed generator mean capacity is varied from 80 kW to 120 kW with a standard deviation of 5% of mean capacity represented as case-1 to case-5 in Table 3. Table **??** represents the failure and repair rate of DG units at the best five optimal locations. Table 3 provides a thorough comparison of SSTMCS and SEM for the evaluation of well-being indices for IEEE-33 bus RDS in presence of DG units.

A. Case-1: When the load flow program is first to run, it is observed that the majority of samples occur in the risky state, followed by a small number of samples in the marginal state, and very few samples occur in the healthy state when the mean DG capacity at the best five optimal locations is assumed to be 80 kW and the standard deviation is 4 kW. A comparison of the probability in all three states derived using SSTMCS is shown in Fig. 2. Table 3 demonstrates that the probability obtained using the state enumeration method (SEM) and the SSTMCS are substantially identical. As a result, the probability of a risky state is higher than that of a marginal or healthy state. According to SSTMCS, the average system availability in a healthy state is 37.668 hours, and with SEM, it is 36.792 hours. In a marginal state, the average system availability obtained by SSTMCS is 2718.222 hours, while the average system availability obtained by SEM is 2689.32 hours. Similarly, unavailability got by SSTMCS and SEM are 6004.104 hr and 6033.888 hr.

The probability distribution function (PDF) of P_{TS} is obtained in addition to the samples acquired using the load flow equation (7), as illustrated in Fig. 3. It has been noted that the mean value of P_{TS} is 4287.26 kW. **B. Case-2**: In this case, it is assumed that the mean DG capacity at each ideal location is 90 kW, with a standard deviation of 4.5 kW. When compared to case-1, improvement is observed, with more samples occurring in the marginal state and less in a risky state, as well as some samples occurring in a healthy state. Using SSTMCS, Fig. 4 compares the probability in all three states for case-2. Table 3 shows that the probabilities obtained using the two methods are remarkably similar. Therefore, compared to a risky and healthy state, the probability is higher in the marginal state.

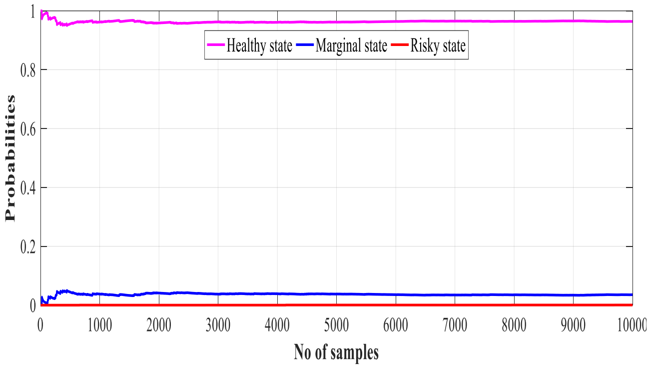

Fig. 10. Comparison of state probabilities for Case-5.

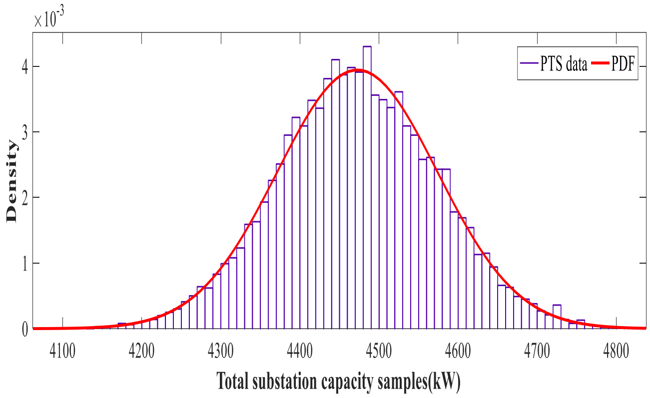

Fig. 11. PDF of P_{TS} for Case-5.

According to SSTMCS, A_H and A_M states is 1138.80 hours and 5699.256 hours, respectively, while SEM results are 1121.28 hours and 5556.468 hours, respectively. Using SSTMCS and SEM, the system was unavailable for 1921.94 hours and 2082.252 hours, respectively. When compared to case-1, it is found that the system's unavailability decreased. The PDF [30] of P_{TS} these samples, which are generated using the load flow algorithm, is shown in Fig. 5. The typical mean value of P_{TS} is reported as 4333.81 kW. **C. Case-3:** At the top five locations, the mean DG capacity is now 100 kW, and the standard deviation is 5 kW. In comparison to case 2, more samples are observed in a healthy state, a reasonable number in a marginal state, and fewer in a risky state. A comparison of state probabilities achieved using SSTMCS is shown in Fig. 6. Table 3 compares frequency duration indices like MUT, MMT, MDT, etc, and well-being indices like P_H, P_M, and P_R using SSTMCS and SEM. By using both methodologies, it was found that the probability of a healthy state is higher than in earlier instances. When using both techniques, the average system availability in a healthy state gradually improves compared to earlier states, and unavailability is significantly decreased compared to earlier instances.

The PDF of P_{TS} for this case is computed using samples as shown

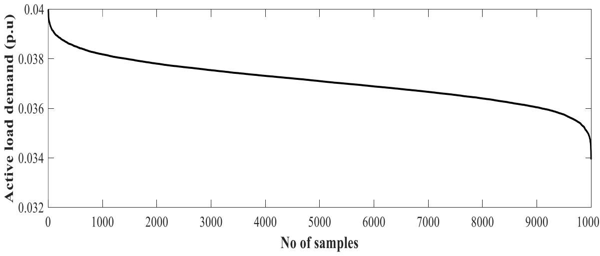

Fig. 12. Load duration curve

Table 3. Comparison of SSTMCS and SEM for well-being indices evaluation for CDS

Parameter	Case-1		Case-2		Case-3		Case-4		Case-5	
$P_{dg,i}$ (kW)	80		90		100		110		120	
$\sigma_{Pdg,i}$ (kW)	4		4.5		5		5.5		6	
Method	SST MCS	SEM	SST MCS	SEM	SST MCS	SEM	SST MCS	SEM	SST MCS	SEM
P_H	0.0043	0.0042	0.1300	0.128	0.5289	0.5262	0.8457	0.8451	0.9640	0.9638
P_M	0.3103	0.307	0.6506	0.6343	0.4343	0.4321	0.1485	0.1489	0.0355	0.0354
P_R	0.6854	0.6888	0.2194	0.2377	0.0367	0.0417	0.0059	0.006	0.000495	0.00056
λ_{HM} (/yr)	0.0053	0.0054	0.0117	0.0119	0.0082	0.0084	0.0028	0.00295	0.000659	0.000698
λ_{HR} (/yr)	0.0137	0.0138	0.0039	0.00397	0.00071	0.00074	0.000117	0.000121	0.000013	0.000014
λ_{MH} (/yr)	0.000066	0.000073	0.0023	0.0024	0.01	0.0102	0.0159	0.0167	0.0179	0.019
λ_{MR} (/yr)	0.0131	0.0132	0.0041	0.0046	0.00074	0.00084	0.000113	0.00009	0.00001	0.00001
λ_{RH} (/yr)	0.000088	0.0000842	0.0024	0.0021	0.0103	0.0093	0.0176	0.0169	0.0256	0.02409
λ_{RM} (/yr)	0.0059	0.0059	0.0122	0.0124	0.0087	0.0088	0.0022	0.0023	0.00001	0.00001
f_H (occ/yr)	0.00008	0.000082	0.002	0.00203	0.0047	0.0048	0.0025	0.0026	0.000649	0.00068
f_M (occ/yr)	0.0041	0.00407	0.0042	0.0044	0.0046	0.0048	0.0024	0.0025	0.000636	0.00067
f_R (occ/yr)	0.0041	0.0042	0.0032	0.0034	0.00069	0.000755	0.000116	0.00012	0.000013	0.000013
MUT (hr/yr)	52.646	52.631	63.888	63.011	112.43	109.409	344.152	325.131	1484.6	1404.494
MDT (hr/yr)	166.567	167.106	68.504	68.965	52.541	55.248	50.369	51.907	37.53	41.509
MMT (hr/yr)	76.101	75.3092	155.183	142.857	93.481	90.579	62.62	59.559	55.768	52.6315
A_H (hr/yr)	37.668	36.792	1138.8	1121.28	4633.164	4609.512	7408.332	7403.076	8444.640	8442.888
A_M (hr/yr)	2718.228	2689.32	5699.256	5556.468	3804.468	3785.196	1300.86	1304.364	310.98	310.104
A_R (hr/yr)	6004.104	6033.888	1921.94	2082.252	321.492	365.292	51.684	52.56	4.3362	4.9056

in Fig. 7, and its mean value is found 4379.45 kW, which is higher than it was for the previous two cases.

D. Case-4: Mean DG capacity at the best five locations is considered as 110 kW and standard deviation as 5.5 kW. It was observed that the number of samples that occurred in a healthy state is improved as compared to case-3. Fig. 8 represents the comparison of probabilities in all three states using SSTMCS.

By both methods, probability in a healthy state is superior to that in a marginal and risky state. By using both approaches, the probability of a risky situation dramatically decreases in comparison to earlier instances. In the healthy and marginal states, the average system availability is, according to SSTMCS, 7408.332 hours and 1300.86 hours, respectively, while SEM findings are, respectively, 7403.076 hours and 1304.364 hours. The system was down using SSTMCS and SEM for 50.369 hours and 51.907 hours, respectively. It was discovered that the system's unavailability was significantly reduced when compared to the previous circumstance. The PDF of P_{TS} for this case was computed using samples shown in Fig. 9, and its mean value was found to be 4426.89 kW.

E. Case-5: For this case mean DG capacity at each ideal location is taken as 120 kW and the standard deviation is 6 kW. In contrast to case-4, it was found that the majority of the samples occurred in a healthy state and relatively few in a marginal one. A comparison of state probabilities computed using SSTMCS is shown in Fig. 10. The average system availability in a healthy state, as determined by SSTMCS, is 8444.64 hours; with SEM, it is 8442.888 hours. The average system availability in a marginal state, as determined by SSTMCS, is 310.98 hours, but the average system availability, as determined by SEM, is 310.104 hours. Noteworthy reduction is observed for the average unavailability of SSTMCS and SEM for 4.3362 hours and 4.9056 hours, respectively compared to earlier cases.

Fig. 11 depicts the probability distribution function of P_{TS} that is calculated for this case. It was noted that the mean value of P_{TS} was 4472.5 kW, which is significantly better than it was in the other cases.

The total load requirements of RDS for all scenarios are determined and plotted as an annual load duration curve using samples in Fig. 12. It demonstrates that the system's maximum and minimum loads are 4020 kW and 3336 kW, respectively.

From Fig. 13 it was observed that mean up time goes on increasing by varying DG capacities at optimal places by both methods.

Using cases 1 through 5 shown in Fig. 14, the average mean down time is reduced using SSTMCS and SEM.

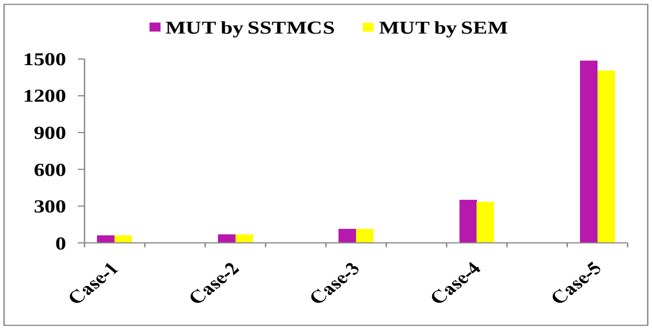

Fig. 13. Comparison of the system mean up time by both methods for different cases

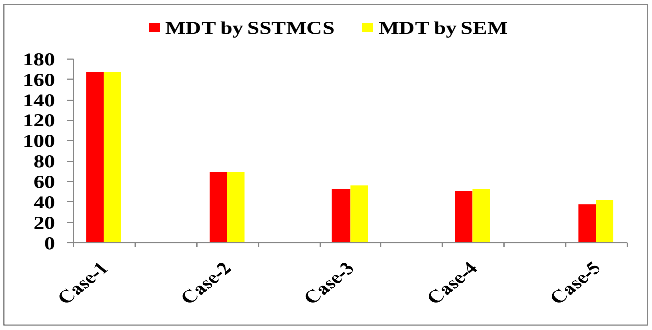

Fig. 14. Comparison of the system mean down time by both methods for different cases

A comparison of the average system availability for a healthy state for all cases using both methodologies is shown in Fig. 15. It is seen that it continues to rise from cases 1 through 5.

7. CONCLUSION

This paper presents an adequacy assessment of the radial distribution system with the incorporation of solar-based distributed generation at an optimal location based on LSF. Two adequacy assessment methods were used in this evaluation study. Utilizing the Monte Carlo simulation and state enumeration method, study results were achieved. Using SSTMCS and SEM, a thorough case study is carried out to estimate several reliability indices, such as probabilities, average transition rates, average mean times,

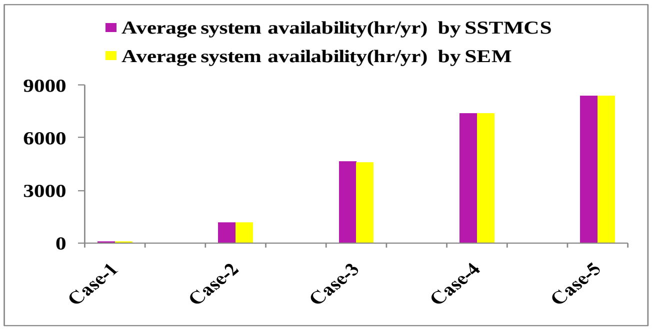

Fig. 15. Comparison of the system availability by both methods for different cases

and system availability and unavailability. The study's findings demonstrate that, in most instances, the correlation of outcomes from the two methodologies is almost identical but not exactly.

Well-being indices (P_H) are calculated using SSTMCS as 0.0043 for case-1 and 0.964 for case-5, respectively. These values are in close agreement with SEM, which increases from cases 1 to 5. Similarly, P_R is calculated using the SSTMCS as 0.6854 for case 1 and 0.000495 for case 5, which decreases from cases 1 to 5. Reliability indices, such as MUT and MDT are calculated using SSTMCS for case-1 are 52.646 hours and 166.567 hours, respectively, while the SEM results are 52.631 hours and 167.106 hours. For case-5, MUT and MDT are estimated as 1404.494 hours and 41.509 hours by SEM and 1484.6 hours and 37.53 hours by SSTMCS. MUT is observed as rising while MDT is falling from case-1 to 5. Results from SSTMCS are a little bit better than those from SEM. For all cases, frequency indices are observed in close agreement using both methods. The average system availability in a healthy state obtained using both methods is observed as an increasing trend from case-1 to 5. Average system unavailability determined by both approaches continues to decrease from case-1 to 5, and the results determined by SEM are almost identical to those determined by SSTMCS.

In terms of estimating power system reliability, both approaches have advantages. When several systems and contingencies are taken into account, SSTMCS may be superior. In comparison to the state enumeration method and more accurate because it uses a larger number of samples. While SEM is ideal for tiny systems where few contingencies are taken into account. The obtained results demonstrate that the best positioning and sizing of DG units can improve the overall distribution system reliability indices, and can be utilized to plan and assist the distribution system in the event of anticipated load rise.

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