Customer Orientated Indices and Reliability Evaluation of Meshed Power Distribution System

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Abstract

Reliability evaluation of a system or component or element is very important in order to predict its availability and other relevant indices. Reliability is the parameter, which tells about the availability of the system under proper working conditions for a given period of time. The study of different reliability indices are very important considering the complex and uncertain nature of the power system. In this paper reliability, evaluation of the meshed distribution system is presented. This paper also evaluates basic indices such as average failure rate, average outage time and average annual outage time. Along with basic indices, customer orientated indices such as system average interruption frequency index, system average interruption duration index and customer average interruption duration index of an electrical power distribution system is also evaluated. The electrical power distribution system taken for study is meshed distribution system in nature.

Keywords: Reliability; Availability; Meshed distribution system; average interruption frequency index; system average interruption duration index.

I. Introduction

Reliability evaluation of a system or component or element is very important in order to predict its availability and other relevant indices. Reliability is the parameter which tells about the availability of the system under proper working conditions for a given period of time. A Markov cut-set composite approach to the reliability evaluation of transmission and distribution systems involving dependent failures was proposed by Singh et al. [1]. The reliability indices have been determined at any point of composite system by conditional probability approach by Billinton et al. [2]. Wojczynski et al. [3] discussed distribution system simulation studies which investigate the effect of interruption duration distributions and cost curve shapes on interruption cost estimates. New indices to reflect the integration of probabilistic models and fuzzy concepts was proposed by Verma et al. [4].

Zheng et al. [5] developed a model for a single unit and derived expression for availability of a component accounting tolerable repair time. Distributions of reliability indices resulting from two sampling techniques are presented and analyzed along with those from MCS by Jirutitijaroen and Singh [6]. Dzobe et al. [7] investigated the use of probability distribution function in reliability worth analysis of electric power system. Bae and Kim [8] presented an analytical technique to evaluate the reliability of customers in a microgrid including distribution generations. Reliability network equivalent approach to distribution system reliability assessment is proposed by Billinton and Wang [9].

Evaluation of Reliability indices accounting omission of random repair time for distribution systems using Monte Carlo simulation [10]. Determination of Optimum period between Inspections for Distribution system based on Availability Accounting Uncertainties in Inspection Time and Repair Time, Tiwary et al. [11]. Jirutitijaroen et al. [12] developed a comparison of simulation methods for power system reliability indexes and their distribution. Determination of reliability indices for distribution system using a state transition sampling technique accounting random down time omission Tiwary et al. [13]. Tiwary et al. [14] proposed a methodology based on inspection repair based availability optimization of distribution systems using Teaching Learning based Optimization. Bootstrapping based technique for evaluating reliability indices of RBTS distribution system neglecting random down time was evaluated [15].

Volkanavski et al. [16] proposed application of fault tree analysis for assessment of the power system reliability. Li et al. [17] studies the impact of covered overhead conductors on distribution reliability and safety. Reliability enhancement of distribution system using Teaching Learning based optimization considering customer and energy based indices was obtained in Tiwary et al. [18]. Self-Adaptive Multi-Population Jaya Algorithm based Reactive Power Reserve Optimization Considering Voltage Stability Margin Constraints was obtained in Tiwary et al. [19]. A smooth bootstrapping based technique for evaluating distribution system reliability indices neglecting random interruption duration is developed [20]. The impact of covered overhead conductors on distribution reliability and safety is discussed [21]. Sarantakos et al. [22] introduced a method to include component condition and substation reliability into distribution system reconfiguration. Battu et al. [23] discussed a method for reliability compliant distribution system planning using Monte Carlo simulation. Tiwary et al. [24] has discussed a methodology for reliability evaluation of an electrical power distribution system, which is radial in nature. Uspensky et al. [25] has developed a method for reliability assessment of the digital relay protection system. Sharma et al. [26] deals with the reliability analysis of a two identical unit system model with safe and unsafe failures, switching device and rebooting.

II. Reliability evaluation of electrical distribution system

Physically a system configuration will be a series reliability network if system fails even if a single component fails or system survives if all the components are working successfully.

The system is having a constant failure rate and therefore the reliability of the system having constant failure rate is evaluated by using the following relation.

$$R(t)=e^{(-\lambda t)} \quad (1)$$

Where R(t) represents the reliability of each distribution section. Λ represents the failure rate per year and t represents time period which is taken as one year.

If one assumes reliability of each component as r1,r2…rn, then reliability of series system (Rs) is given as

$$Rs=\prod ri \quad (2)$$

Where ri represents the reliability of components from i=1….n.

A system configuration will be a parallel reliability network, the system fails, if all components fail. System performs its function even if a single component is working.

The reliability of parallel system (Rp) is given as

$$R_p = 1 - \prod_{i=1}^{n} (1 - r_i) \tag{3}$$

Where ri represents the reliability of components from i=1….n.

III. Basic reliability indices evaluation of series and parallel system

When reliability studies are concerns, three basic reliability parameters are average failure rate, average outage time and average annual outage time, which are mentioned as follows for series system.

$$\lambda s = \sum \lambda i \tag{4}$$

$$Us = \sum \lambda i.ri \tag{5}$$

$$rs = (\sum \lambda iri)/(\sum \lambda i) \tag{6}$$

For parallel system the three basic reliability indices can be evaluated as follows

$$\lambda_{para} = \frac{\lambda_i \lambda_j (r_i + r_j)}{8760} \tag{7}$$

$$r_{para} = \frac{r_i r_j}{r_i + r_j} \tag{8}$$

$$U_{para} = \lambda_{para} \cdot r_{para} \tag{9}$$

Where λj is failure rate per year
ri , rj is average repair time, hours

IV. Evaluation of customer orientated indices

Customer orientated indices related to reliability studies are system average interruption frequency index, system average interruption duration index and customer average interruption duration index, which are mentioned as follows.

System average interruption frequency index (SAIFI)

$$SAIFI = \frac{total\ number\ of\ customer\ interruptions}{total\ number\ of\ customers\ served} \tag{10}$$

System average interruption duration index (SAIDI)

$$SAIDI = \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customers} \tag{11}$$

Customer average interruption duration index (CAIDI)

$$CAIDI = \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customer\ interruptions} \tag{12}$$

V. Results and Discussions

Meshed distribution system consists of 18 distributor segments and 4 load points from LP-1 to LP-4 Fig. 1, [10].

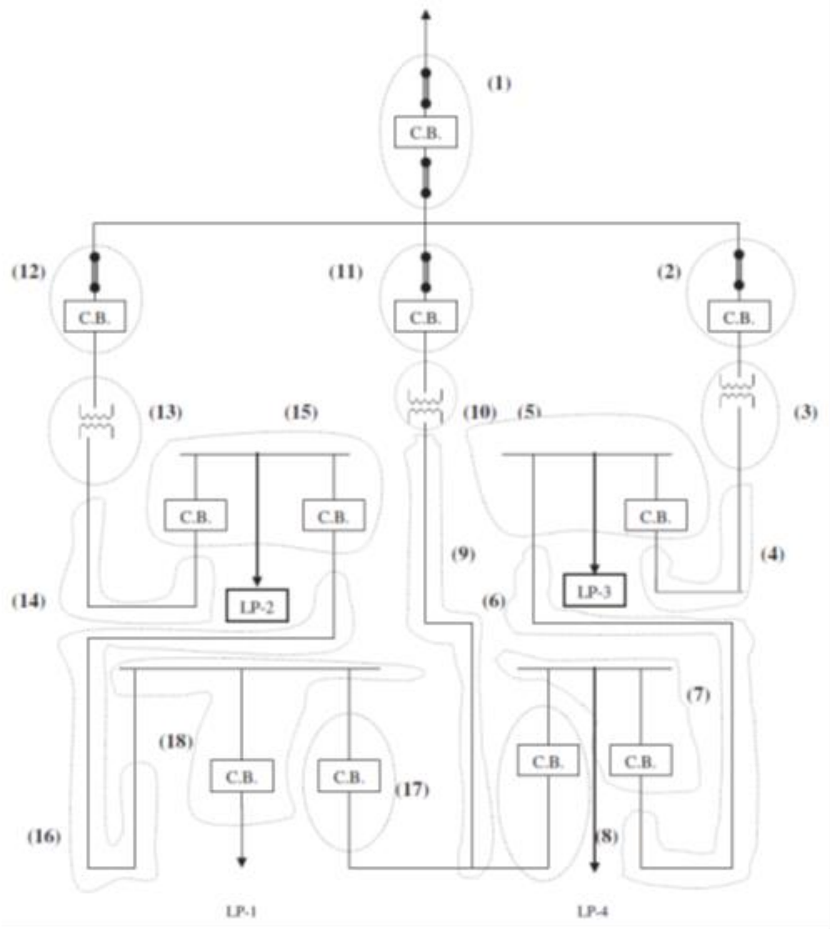

Figure 1 Sample Meshed Distribution System

Table I [10] provides the initial data for the meshed distribution system. Table I consists of failure rate per year and repair time in hours of each distribution section from 1 to 18 of the meshed distribution system. Table II consists of number of customers at each load point LP-1 to LP-4.
Evaluated Reliability at each distribution section is provided in Table III. The reliability at each distribution section is evaluated by using equation 1. Fig.2 provides magnitude of reliability at different distribution sections. Table IV gives the calculated value of the reliability at each and every load point of the meshed distribution system. The reliability at each and every load point is obtained by using the equation 2 and 3. Fig.3 provides magnitude of reliability at different load points of the distribution system.

Basic reliability indices at each load point i.e average failure rate, average outage time and average annual outage time are evaluated are presented in Table V. Fig.4 provides magnitude of average failure rate at different load points of the distribution system. Fig.5 and Fig.6 provides magnitude of average outage time and average annual outage time at different load points of the meshed distribution system.

Customer orientated indices such as system average interruption frequency index (SAIFI) is evaluated as 0.3965, system average interruption duration index (SAIDI) is obtained as 4.1057 and customer average interruption duration index (CAIDI) is evaluated as 10.3556 for the meshed distribution system.

Table 1 [10]

System data for sample meshed distribution system.

Distribution section	λ_i^0, failure/year	Average repair time r_i^0, h
#1	0.310400	10.280412
#2	0.127600	5.010658
#3	0.070000	33.985714
#4	0.013520	14.335503
#5	0.084600	10.557447
#6	0.017640	13.555102
#7	0.008460	10.557447
#8	0.078000	11.023077
#9	0.008460	15.800000
#10	0.069000	27.565217
#11	0.155200	6.865979
#12	0.155200	6.865979
#13	0.070000	33.985714
#14	0.013520	14.335503
#15	0.156600	10.714943
#16	0.017640	13.555100
#17	0.078000	11.023077
#18	0.084600	10.557447

Table 2 Initial data for the load points

Load Point	1	2	3	4
Number of customers	1000	800	600	700

Table 3 Evaluated Reliability at each distribution section

Distribution Section	Reliability
1	0.7331
2	0.8802
3	0.9324
4	0.9866
5	0.9189
6	0.9825
7	0.9916
8	0.9250
9	0.9916
10	0.9333
11	0.8562
12	0.8562
13	0.9324
14	0.9866
15	0.8550
16	0.9825
17	0.9250
18	0.9189

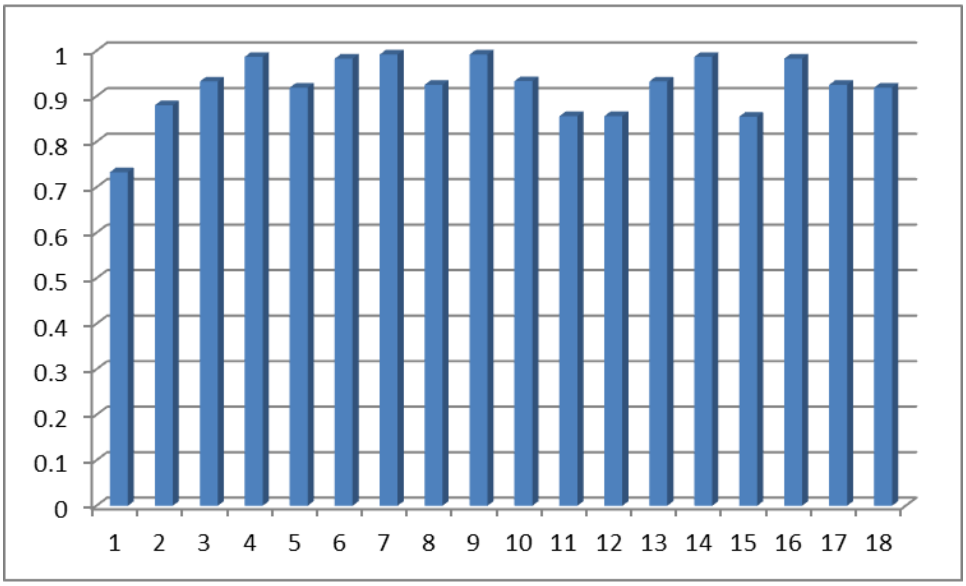

Figure 2 Magnitude of Reliability for distribution sections 1 to 18.

Table 4 Evaluated Reliability at each load points

Load point	Reliability
1	0.6421
2	0.5973
3	0.6504
4	0.6958

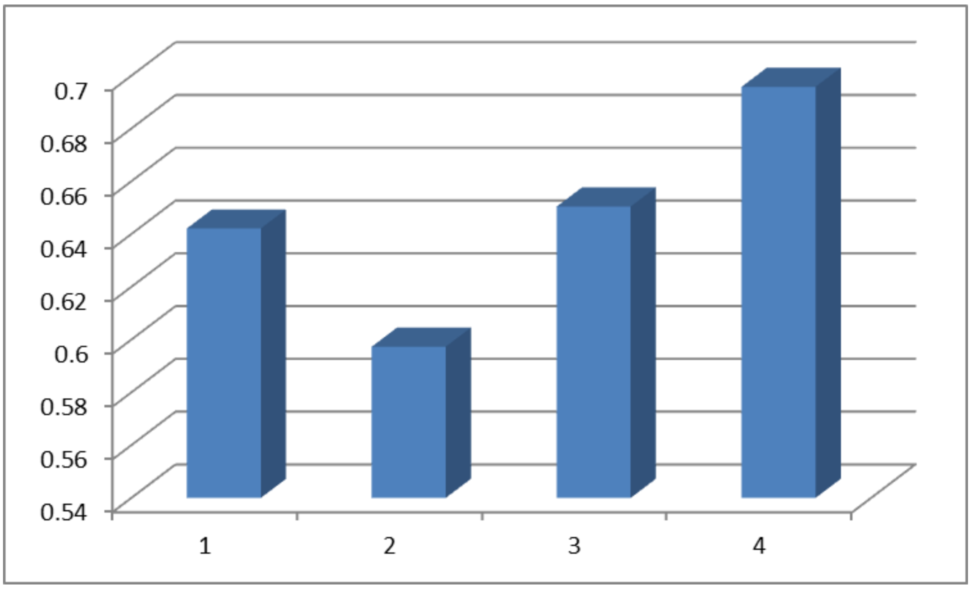

Figure3 Magnitude of Reliability at different Load Points 1 to 4.

Table 5 Evaluated Basic Reliability indices at each load points

Load point	1	2	3	4
average failure rate	0.3951	0.4671	0.3951	0.3189
average outage time	10.3384	10.4247	10.3381	10.2875
average annual outage time	4.0847	4.8697	4.0846	3.2807

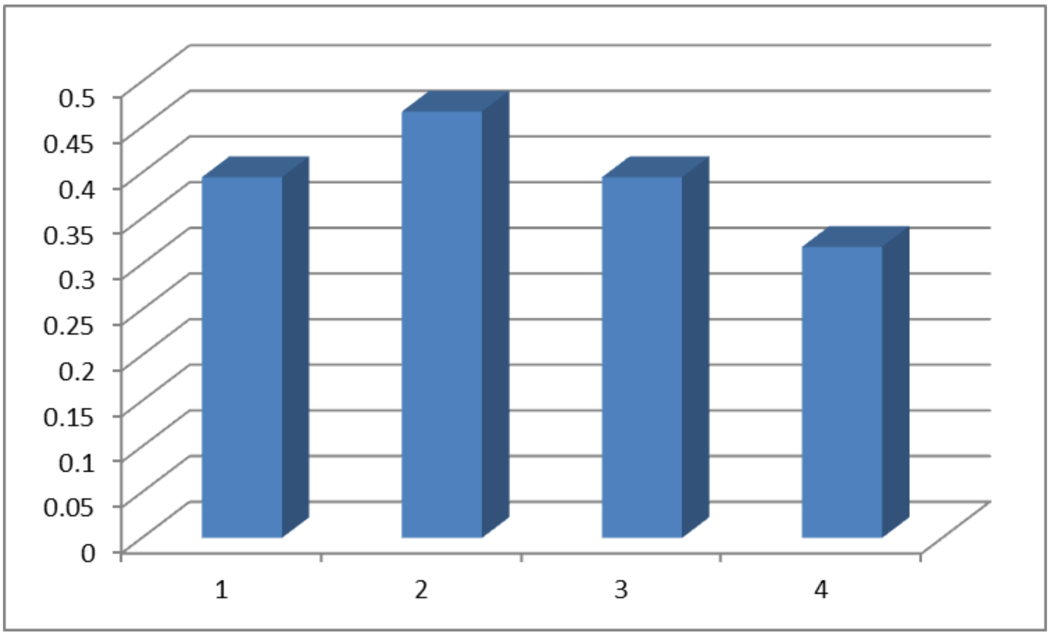

Figure 4 Magnitude of average failure rate at different Load Points 1 to 4.

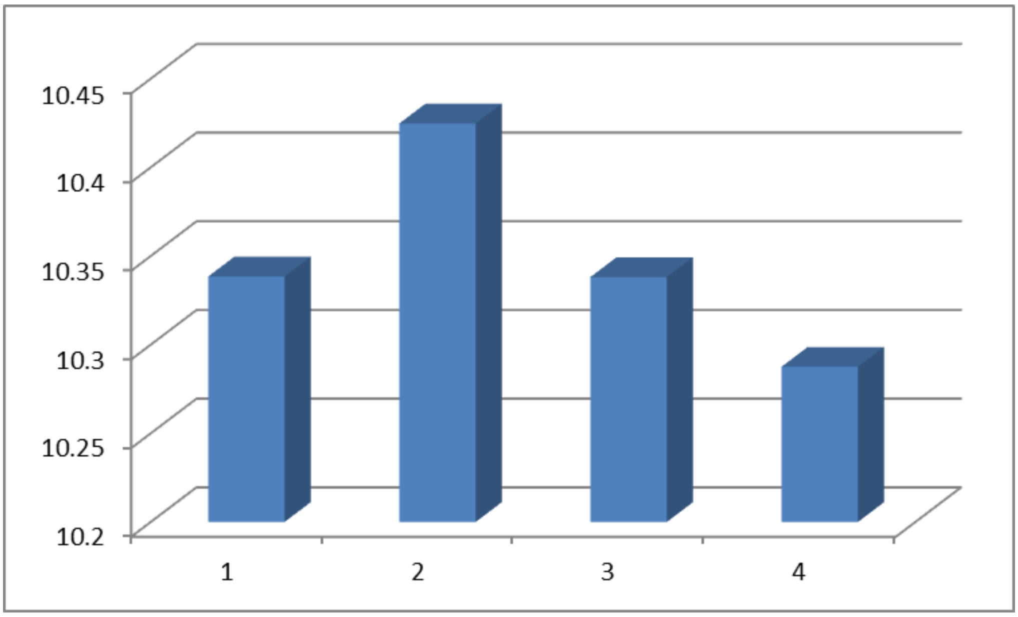

Figure 5 Magnitude of average outage time at different Load Points 1 to 4.

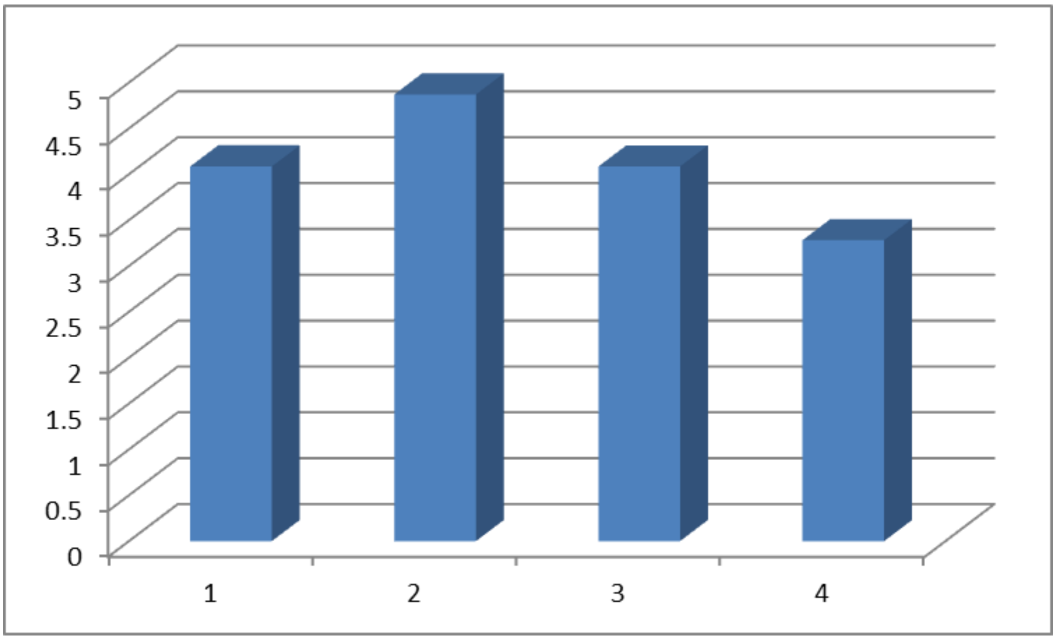

Figure 6 Magnitude of average annual outage time at different Load Points 1 to 4.

VI. Conclusion

Evaluation of reliability for a power distribution system is very essential. In this paper a meshed distribution system is taken in consideration. Reliability of each and every distribution section is calculated. Load point reliability is also obtained for the meshed distribution system for each and every load point. The three basic reliability parameters of importance average failure rate, average outage time and average annual outage time are also obtained for the load points considered. Important customer orientated indices such as system average interruption frequency index, system average interruption duration index and customer average interruption duration index are also evaluated for the meshed distribution system.

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