AN APPROACH FOR ASSESSMENT OF RELIABILITY INDICES CONSIDERING OMISSION OF FIXED REPAIR TIME FOR ELECTRIC TRACTION SYSTEM APPLYING MONTE CARLO SIMULATION

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Abstract

Assessment of numerous reliability indices is essential when availability and unavailability of supply in any electric power system is talked about. The reliability index which are very important for overall performance of any complex engineering system are mean up time, mean down time and unavailability. In this paper, assessment of various reliability indices for the electric traction system is done based on Monte Carlo simulation. If an engineering system fails then its repair is required to be performed at proper time interval. Omission of a threshold value of fixed repair time will not have so much impact on the overall reliability of the engineering system taken together. Electric traction system is very important as it is utilized for operation of passenger trains and freight trains across a large rail network throughout the continents. In view of above, modified values of mean up time, mean down time and unavailability have been obtained accounting fixed repair time omission for the electrical traction system taken under consideration.

Keywords: Monte Carlo simulation, Electric traction system, Mean up time, Repair time, Reliability indices.

1. 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 micro grid including distribution generations. Reliability network equivalent approach to distribution system reliability assessment is proposed by Billinton and Wang [9].

Customer and energy based indices consideration for reliability enhancement of distribution system using Improved Teaching Learning based optimization is discussed [10]. An Innovative Self-Adaptive Multi-Population Jaya Algorithm based Technique for Evaluation and Improvement of Reliability Indices of Electrical Power Distribution System, Tiwary et al. [11]. Determination of reliability indices for distribution system using a state transition sampling technique accounting random down time omission, Tiwary et al. [12]. Tiwary et al. [13] proposed a methodology based on Inspection-Repair-Based Availability Optimization of Distribution System Using Bare Bones Particle Swarm Optimization. Bootstrapping based technique for evaluating reliability indices of RBTS distribution system neglecting random down time was evaluated [14].

Volkanavski et al. [15] proposed application of fault tree analysis for assessment of the power system reliability. Li et al. [16] studies the impact of covered overhead conductors on distribution reliability and safety. Self-Adaptive Multi-Population Jaya Algorithm based Reactive Power Reserve Optimization Considering Voltage Stability Margin Constraints was obtained in Tiwary et al. [17]. A smooth bootstrapping based technique for evaluating distribution system reliability indices neglecting random interruption duration is developed [18]. Tiwary et al. [19] have developed an inspection maintenance based availability optimization methodology for feeder section using particle swarm optimization. The impact of covered overhead conductors on distribution reliability and safety is discussed [20]. Tiwary et al. [21] has discussed a methodology for reliability evaluation of an electrical power distribution system, which is radial in nature. Sarantakos et al. [22] introduced a method to include component condition and substation reliability into distribution system reconfiguration. Tiwary et al. [23] has discussed a methodology for evaluation of customer orientated indices and reliability of a meshed power distribution system. Reliability evaluation of engineering system is discussed [24]. Battu et al. [25] discussed a method for reliability compliant distribution system planning using Monte Carlo simulation. Application of non-parametric bootstrap technique for evaluating MTTF and reliability of a complex network with non-identical component failure laws is discussed [26]. Tiwary and Tiwary [27] have developed an innovative methodology for evaluation of customer orientated indices and reliability study of electrical feeder system. Tiwary and Tiwary [28] proposed the evaluation of reliability indices of Roy Billinton Test System (RBTS) Bus-2 Distribution System.

Tiwary and Tiwary [29] have proposed a methodology for reliability block diagram representation of electric traction system and identification of various reliability indices. In view of the above, in this paper reliability indices such as mean up time, mean down time and unavailability are obtained for the electrical traction system considering Monte Carlo simulation technique. Fixed repair time omission has been taken into account for obtaining the various reliability indices of importance. The result obtained is been shown in the result section and various analysis has also been done based on proposed method.

2. Reliability indices evaluation of electric traction system considering Omission of fixed Repair Time

Reliability block diagram modeling of the electric traction system is formulated and discussed by Tiwary and Tiwary [29]. The radial system which is taken into account, all the components is connected in series manner. System failure rate, repair time and unavailability are the parameters which are considered as important reliability parameters.

The system failure rate is expressed as follows:

$$\lambda_{sys} = \Sigma\lambda_i \tag{1}$$

λi is the failure rate of each and every components.
The unavailability of a series system can be written as:

$$U_{sys} = \Sigma\lambda_i . r_i \tag{2}$$

ri is the repair time of each and every component.
The system repair time can be obtained by following relation:

$$\mathrm{r_{sys}} = \frac{\mathrm{U_{sys}}}{\lambda_{\mathrm{sys}}} \tag{3}$$

3. Monte Carlo Simulation (MCS) Based Computational Algorithm

Certain value of the repair time which is fixed in nature can be omitted as it does not concern much to the system. A threshold value of the repair time can be omitted depending on the system under consideration. Evaluation of reliability indices with fixed repair time omission using Monte Carlo simulation (MCS) is discussed by Tiwary et al. [30].

Monte Carlo simulation is used to obtain the relevant reliability indices and the algorithm for the same is shown below:

Step 1: Obtain failure density function f(t) of the components, repair density function g(t) of the components and repair time omission (τ).

Step 2: Obtain random variates:
($T_{f,i}$,$T_{r,i}$) i=1……NS
$T_{f,i}$ =time to failure
$T_{r,i}$ = time to repair
NS = number of samples

Step 3: Obtain the modified value of the different reliability indices as follows:
If $T_{r,i} \le \tau$
Then

$$\widetilde{T_{f,i}} = T_{r,i} + T_{f,i}$$

If $T_{r,i} > \tau$
Then

$$\widetilde{T_{f,i}} = T_{f,i}$$

If $T_{r,i} \le \tau$
Then

$$\widetilde{T_{r,i}} = 0$$

If $T_{r,i} > \tau$
Then

$$\widetilde{T_{r,i}} = T_{r,i}$$

Where
$\widetilde{T_{f,i}}$ =modified time to failure
$\widetilde{T_{r,i}}$ =modified time to repair

Step 4: Repeat above steps for NS samples.

Step 5: Calculate the modified mean up time ($\widetilde{MUT}$) by using following relation:

$$\widetilde{MUT} = \frac{1}{\mathrm{NS}}\Sigma\widetilde{T_{f,i}}$$

Step 6: Calculate the modified mean down time ($\widetilde{MDT}$) by using following relation:

$$\widetilde{MDT} = \frac{1}{\text{NS}} \Sigma \widetilde{\text{T}_{r,\iota}}$$

Step 7: Calculate the modified mean unavailability ($\widetilde{U}$) by using following relation:

$$\widetilde{U} = \frac{\widetilde{MDT}}{\widetilde{MUT}}$$

4. Result and Discussion

Table 1 shows the initial data such as failure rate per year and repair time in hours for the components of direct current (DC) electrification traction system. There are four components in the DC electrification traction system which are overhead wire, pantograph, motor control and motor and shown as components c1, c2, c3 and c4 respectively [29].

Table 1: *Initial data for different components of the direct current electrification traction system [29].*

component	c1	c2	c3	c4
Failure rate/year	0.04	0.03	0.005	0.004
Repair time (hrs.)	3	4	5	6

Table 2 shows the initial data such as failure rate per year and repair time in hours for the components of alternating current (AC) electrification traction system. There are six components in the AC electrification traction system which are overhead wire, pantograph, transformer, rectifier, motor control and motor and shown as components c1, c2, c3, c4, c5 and c6 respectively [29].

Table 2: *Initial data for different components of the alternating current electrification traction system [29].*

component	c1	c2	c3	c4	c5	c6
Failure rate/year	0.04	0.03	0.002	0.003	0.005	0.004
Repair time (hrs.)	3	4	6	4	5	6

Table 3 and Table 4 provide the component level evaluated modified failure rate, modified repair rate and modified unavailability for each and every component of the DC electrification traction system and AC electrification traction system respectively.

Table 3: *Component level modified evaluated Reliability indices for each and every component of the DC electrification traction system.*

Component Level	MUT, year	MDT, h	U, h/year	$\widetilde{MUT}$, year	$\widetilde{MDT}$, h	$\widetilde{U}$, h/year
C1	25.0000	3.0000	0.1200	25.3569	2.8856	0.1138
C2	14.2857	3.4286	0.2400	14.3569	3.1546	0.2197
C3	13.3333	3.5333	0.2650	13.8596	3.2548	0.2348
C4	12.6582	3.6582	0.2890	12.8896	3.4568	0.2682

Table 4: *Component level modified evaluated Reliability indices for each and every component of the AC electrification traction system.*

Component Level	MUT, year	MDT, h	U, h/year	$\widetilde{MUT}$, year	$\widetilde{MDT}$, h	$\widetilde{U}$, h/year
C1	25.0000	3.0000	0.1200	25.2365	2.8965	0.1148
C2	14.2857	3.4286	0.2400	14.3895	3.2245	0.2241
C3	13.8889	3.5000	0.2520	13.9623	3.3654	0.2410
C4	13.3333	3.5200	0.2640	13.5623	3.2361	0.2386
C5	12.5000	3.6125	0.2890	12.6985	3.4521	0.2718
C6	11.9048	3.7262	0.3130	11.9965	3.4523	0.2878

Fig. 1 shows the magnitude of modified mean up time at Component level C1, C2, C3 and C4 of DC electrification traction system. The magnitude of MUT has increased from 25.0000 to 25.3569 for the component C1. Components C2, C3 and C4 are having increase from 14.2857 to 14.3569, 13.3333 to 13.8596 and 12.6582 to 12.8896 respectively. Magnitude of modified mean down time and modified unavailability at Component level C1, C2, C3 and C4 of DC electrification traction system is shown in Fig. 2 and Fig. 3 respectively. Modified mean down time are 2.8856, 3.1546, 3.2548 and 3.4568 respectively. Improvement in the modified unavailability is 0.0062, 0.0203, 0.0302 and 0.0208 respectively.

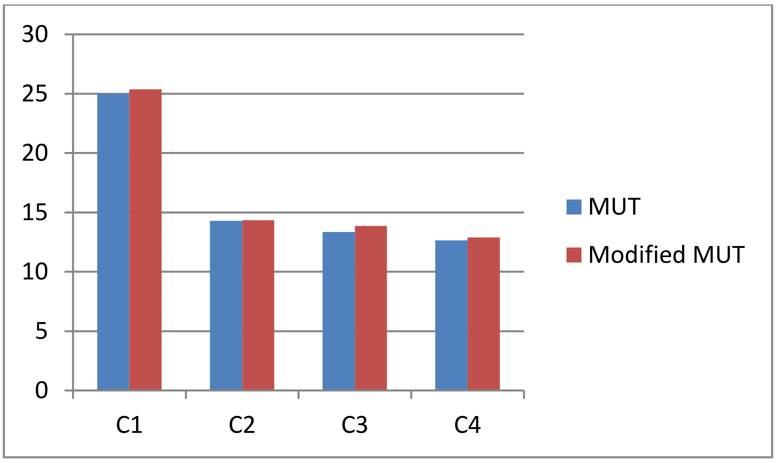

Figure 1: *Magnitude of modified mean up time at Component level C1, C2, C3 and C4 of DC electrification traction system.*

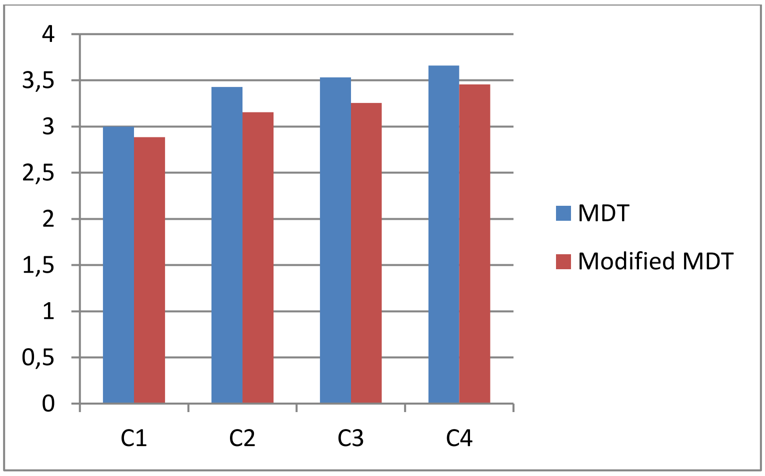

Figure 2: *Magnitude of modified mean down time at Component level C1, C2, C3 and C4 of DC electrification traction system.*

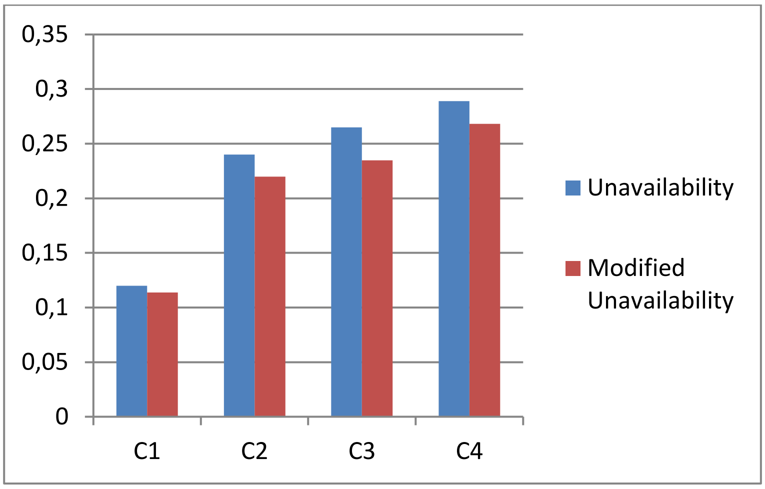

Figure 3: *Magnitude of modified unavailability at Component level C1, C2, C3 and C4 of DC electrification traction system.*

Fig. 4 shows the magnitude of modified mean up time at Component level C1, C2, C3, C4, C5 and C6 of AC electrification traction system. The magnitude of MUT has increased from 25.0000 to 25.2365 for the component C1. Components C2, C3, C4, C5 and C6 are having increase from 14.2857 to 14.3895, 13.8889 to 13.9623, 13.3333 to 13.5623, 12.5000 to 12.6985 and 11.9048 to 11.9965 respectively. Magnitude of modified mean down time and modified unavailability at Component level C1, C2, C3, C4, C5 and C6 of AC electrification traction system is shown in Fig. 5 and Fig. 6 respectively. Modified mean down time are 2.8965, 3.2245, 3.3654, 3.2361, 3.4521 and 3.4523 respectively. Improvement in the modified unavailability is 0.0052, 0.0159, 0.0110, 0.0254, 0.0172 and 0.0252 respectively.

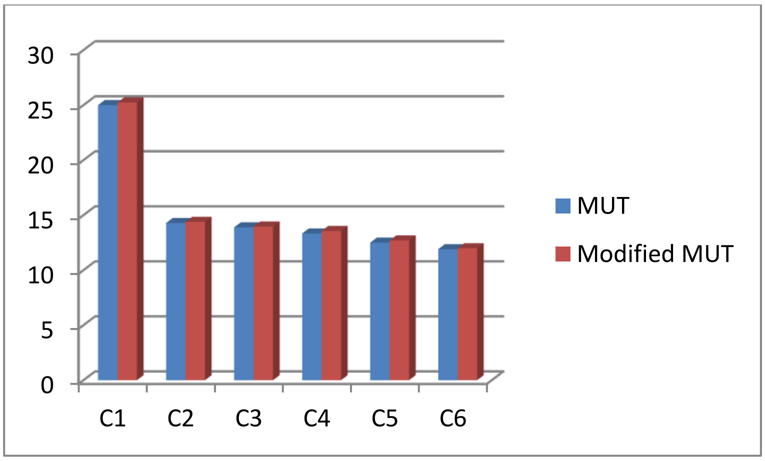

Figure 4: *Magnitude of modified mean up time at Component level C1, C2, C3, C4, C5 and C6 of AC electrification traction system.*

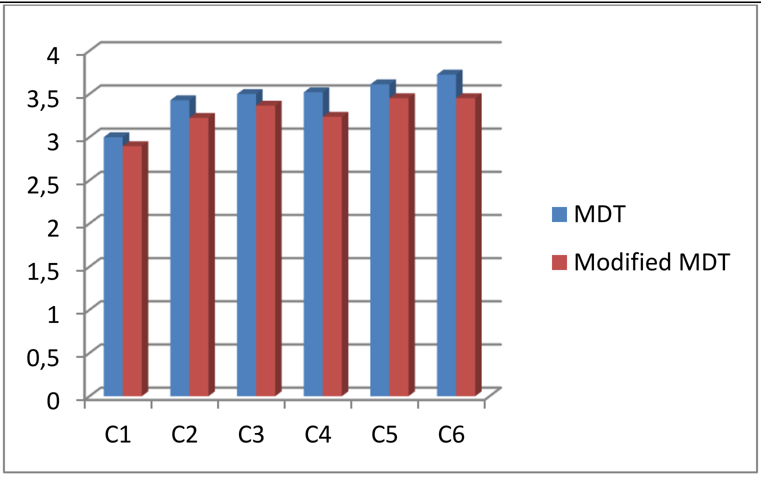

Figure 5: *Magnitude of modified mean down time at Component level C1, C2, C3, C4, C5 and C6 of AC electrification traction system.*

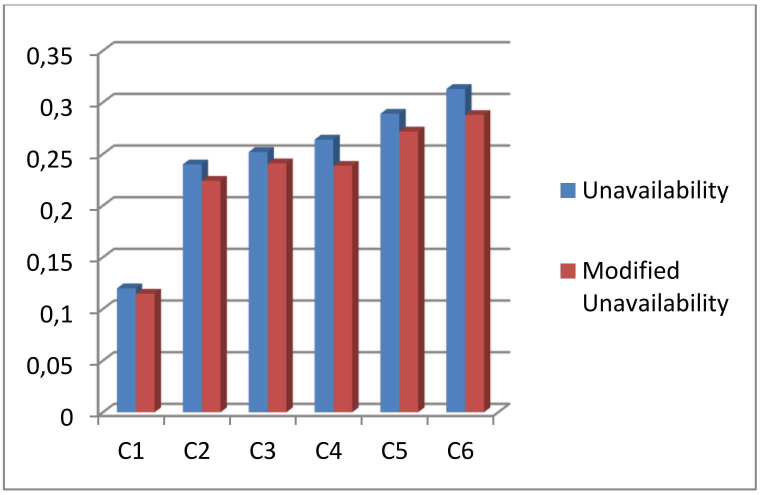

Figure 6: *Magnitude of modified unavailability at Component level C1, C2, C3, C4, C5 and C6 of AC electrification traction system.*

5. Conclusion

Evaluation of reliability of complex engineering system is necessary in order to obtain its overall availability. In view of the above, in this paper calculation of various reliability indices for the electric traction system is obtained based on Monte Carlo simulation methodology. Considering the omission of the threshold value of fixed repair time, the overall reliability indices of the engineering system taken into account is obtained. Based on the Monte Carlo simulation computational algorithm the component level modified evaluated reliability indices for each and every component of the DC and AC electrification traction system is obtained and shown. Modified mean up time, modified mean down time and modified mean unavailability are obtained and shown in result and discussion section for DC and AC electrification traction system respectively. The magnitude of modified mean up time at Component level of DC and AC electrification traction system in shown. It also provides the magnitude of modified mean down time at Component level of DC and AC electrification traction system. Magnitude of modified mean unavailability for both the electrification traction system is shown in result section.

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