An Innovative Methodology for Evaluation of Reliability Indices of Electric Traction System

Aditya Tiwary, Swati Tiwary
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Entrepreneur, Vijay Nagar, Indore, India
raditya2002@gmail.com

Abstract

Evaluation of reliability is most important when we have to check the availability of supply in any electric power system. The basic reliability index which is of importance is failure rate, repair time and unavailability of the supply in any electric power system. In this paper evaluation of various basic reliability indices for the electric traction system is done. Electric traction system is very important as it is used for operation of passenger trains and freight trains across a large rail network throughout the world. As the traction system is very important therefore reliability evaluation of its various parameters are essential for proper and uninterrupted working of the whole electric traction system.

Keywords: Electric Traction System, Reliability, Failure Rate, Repair Rate.

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 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].

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 System Using Bare Bones Particle Swarm 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]. Tiwary et al. [21] 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 [22]. Tiwary et al. [23] has discussed a methodology for reliability evaluation of an electrical power distribution system, which is radial in nature. Sarantakos et al. [24] introduced a method to include component condition and substation reliability into distribution system reconfiguration. Tiwary et al. [25] 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 [26]. Battu et al. [27] 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 [28]. Tiwary and Tiwary [29] have developed an innovative methodology for evaluation of customer orientated indices and reliability study of electrical feeder system.

In this paper basic reliability indices, failure rate, repair rate and unavailability of the electric traction system is evaluated. Electric traction system is very important as it is used for operation of passenger trains and freight trains across a large rail network throughout the world. As the traction system is very important therefore reliability evaluation of its various parameters are essential for proper and uninterrupted working of the whole electric traction system. Reliability block diagram which is a diagrammatic method for showing how different components are connected in a system is designed for the traction system considered and various indices related to reliability are obtained.

II. Reliability block diagram representation of electric traction system

Reliability block diagram which is a diagrammatic method for showing how different components are connected in a system is obtained for the electric traction system. Electrical traction system is that system that uses electrical power for traction system i.e. for railways, trams, trolleys, etc. The track electrification means to the type of source which is used while powering the electric locomotive systems. The two main types of electric traction systems that exist are as Direct Current (DC) electrification system and Alternating Current (AC) electrification system. The reliability block diagram of Direct Current (DC) electrification system is shown in Fig. 1. It consist of source, overhead wire, pantograph, motor control and motor as its important parts. Each and every component of the system is connected in series manner.

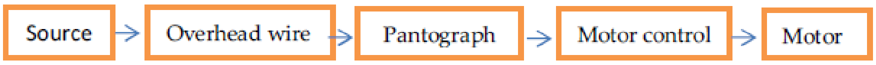

Fig. 1. Reliability block diagram of Direct Current (DC) electrification system

The reliability block diagram of Alternating Current (AC) electrification system is shown in Fig. 2. It consist of source, overhead wire, pantograph, transformer, rectifier, motor control and motor as its important parts. It can be seen from Fig. 2 that each and every component is connected in series.

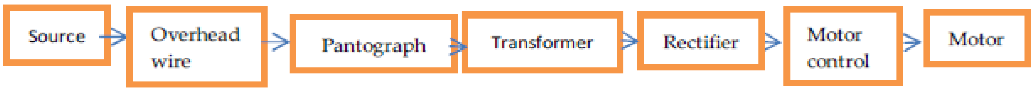

Fig. 2. Reliability block diagram of Alternating Current (AC) electrification system

III. Evaluation of reliability and its various indices of electric traction system

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.

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

Where R(t) represents the reliability of each and every component. λ represents the failure rate per year and t represents time period which is taken as one year.

The mean time to failure (MTTF) can be obtained as follows:

$$MTTF = \frac{1}{\lambda} \tag{2}$$

A series system is that system in which one component fails, the complete system will fail and for working of the whole system it is mandatory that all the component are in working condition. If one assumes time independent reliability r_1, $r_2 \ldots r_n$, then reliability of series system is given as:

$$R_s = \prod_{i=1}^{n} r_i \tag{3}$$

In series configuration combined failure rate is calculated as follows.

$$\lambda_{Total} = \sum \lambda \tag{4}$$

Unavailability of series configuration is calculated by using following relation.

$$U_{Total} = \sum \lambda r \tag{5}$$

Total repair rate of the components connected in series manner is obtained as follows.

$$r_{Total} = \frac{U}{\lambda} \tag{6}$$

IV. 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.

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

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.

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

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 provides the evaluated reliability of each component of DC electrification traction system as 0.9608, 0.9704, 0.9950 and 0.9960 respectively. The overall reliability of the DC electrification traction system obtained is as 0.9240.

Table 4 provides the evaluated reliability of each component c1, c2, c3, c4, c5 and c6 of AC electrification traction system as 0.9608, 0.9704, 0.9980, 0.9950, 0.9950 and 0.9960 respectively. The overall reliability of the AC electrification traction system obtained is as 0.9175.

Table 3 Evaluated Reliability of each component of DC electrification traction system

Component	Reliability
c1	0.9608
c2	0.9704
c3	0.9950
c4	0.9960

Table 4 Evaluated Reliability of each component of AC electrification traction system

Component	Reliability
c1	0.9608
c2	0.9704
c3	0.9980
c4	0.9950
c5	0.9950
c6	0.9960

Table 5 and Table 6 provide the evaluated mean time to failure of DC electrification traction system and evaluated mean time to failure of AC electrification traction system respectively.

Table 5 Evaluated mean time to failure of DC electrification traction system

Component	Evaluated mean time to failure
c1	25
c2	33.33
c3	200
c4	250

Table 6 Evaluated mean time to failure of AC electrification traction system

Component	Evaluated mean time to failure
c1	25
c2	33.33
c3	500
c4	333.33
c5	200
c6	250

Evaluated unavailability for each and every component of the DC electrification traction system is shown in Table 7. The evaluated unavailability obtained are 0.12, 0.12, 0.025 and 0.024 respectively. The evaluated unavailability of each component of the AC electrification traction system are 0.12, 0.12, 0.012, 0.012, 0.025 and 0.024 respectively as shown in Table 8.

Table 7 Evaluated unavailability for each and every component of the DC electrification traction system

component	c1	c2	c3	c4
Unavailability	0.12	0.12	0.025	0.024

Table 8 Evaluated unavailability for each and every component of the AC electrification traction system

component	c1	c2	c3	c4	c5	c6
Unavailability	0.12	0.12	0.012	0.012	0.025	0.024

Table 9 and Table 10 provide the component level evaluated failure rate, repair rate and unavailability for each and every component of the DC electrification traction system and AC electrification traction system respectively.

Table 9 Component level evaluated failure rate, repair rate and unavailability for each and every component of the DC electrification traction system.

Component Level	C1	C2	C3	C4
Failure rate	0.04	0.07	0.075	0.079
Repair rate	3	3.4286	3.5333	3.6582
Unavailability	0.12	0.24	0.265	0.289

Table 10 Component level evaluated failure rate, repair rate and unavailability for each and every component of the AC electrification traction system.

Component Level	C1	C2	C3	C4	C5	C6
Failure rate	0.04	0.07	0.072	0.075	0.08	0.084
Repair rate	3	3.4286	3.5	3.52	3.6125	3.7262
Unavailability	0.12	0.24	0.252	0.264	0.289	0.313

Fig. 3 and Fig. 4 provide the magnitude of evaluated reliability of each component of DC electrification traction system and AC electrification traction system respectively. Magnitude of evaluated mean time to failure of DC electrification traction system and that of AC electrification traction system is shown in Fig. 5 and Fig. 6 respectively.

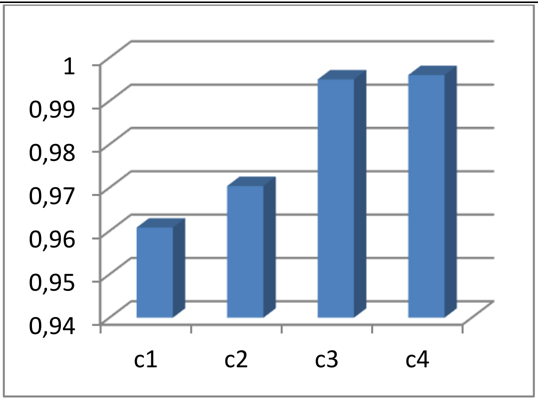

Fig. 3 Magnitude of evaluated reliability of each component of DC electrification traction system

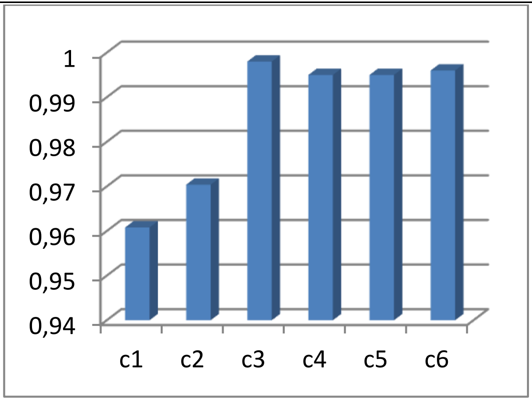

Fig. 4 Magnitude of evaluated reliability of each component of AC electrification traction system

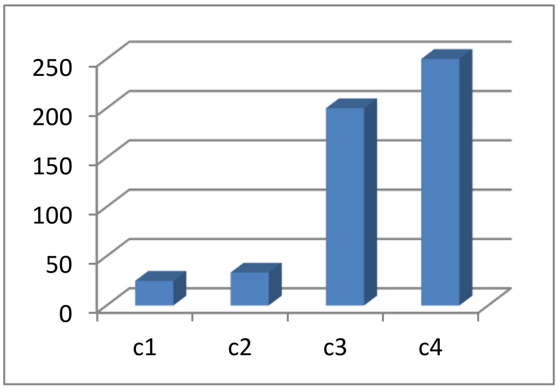

Fig. 5 Magnitude of evaluated mean time to failure of DC electrification traction system

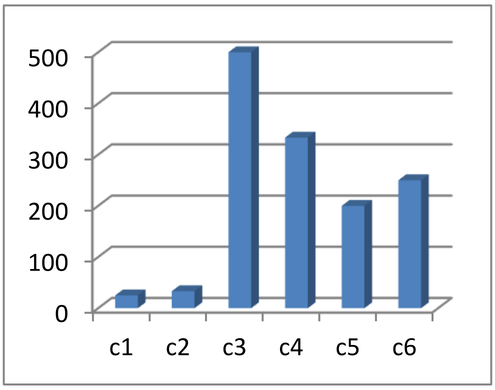

Fig. 6 Magnitude of evaluated mean time to failure of AC electrification traction system

Fig. 7 and Fig. 8 provide the magnitude of evaluated unavailability for each and every component of the DC electrification traction system and AC electrification traction system respectively.

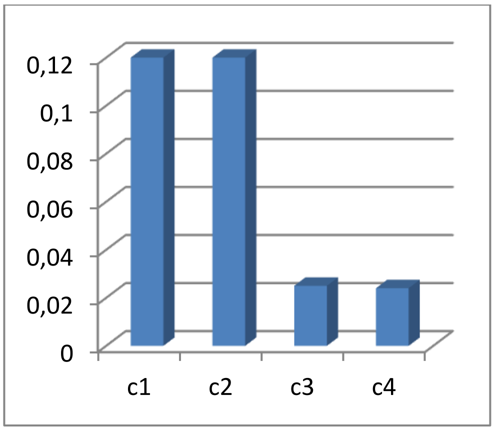

Fig. 7 Magnitude of evaluated unavailability for each and every component of the DC electrification traction system

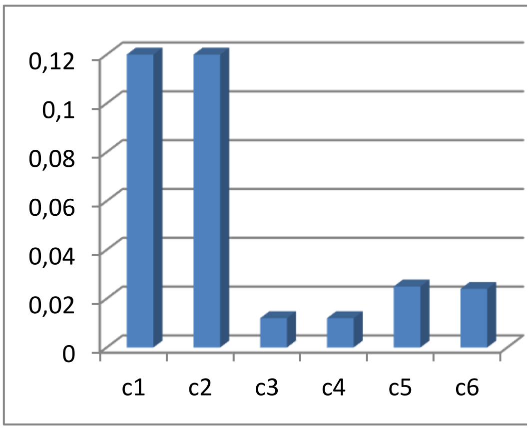

Fig. 8 Magnitude of evaluated unavailability for each and every component of the AC electrification traction system

Magnitude of component level evaluated failure rate for each and every component of the DC electrification traction system, magnitude of component level evaluated failure rate for each and every component of the AC electrification traction system, magnitude of component level evaluated repair rate for each and every component of the DC electrification traction system, magnitude of component level evaluated repair rate for each and every component of the AC electrification traction system are provided in Fig. 9, Fig. 10, Fig. 11 and Fig. 12 respectively.

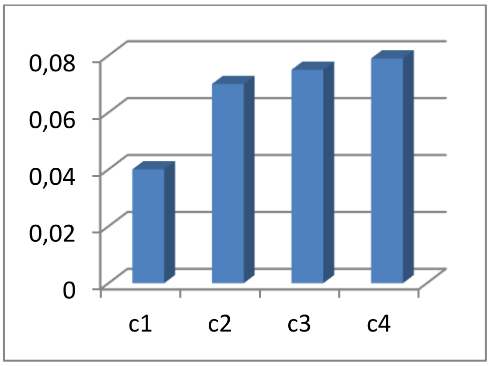

Fig. 9 Magnitude of component level evaluated failure rate for each and every component of the DC electrification traction system.

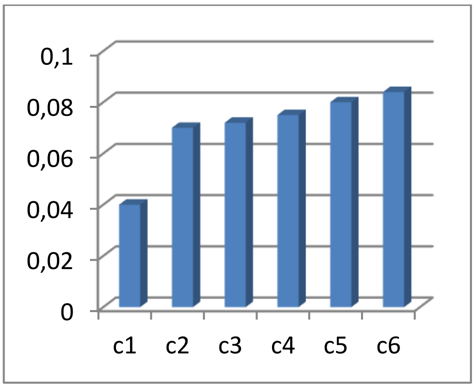

Fig. 10 Magnitude of component level evaluated failure rate for each and every component of the AC electrification traction system.

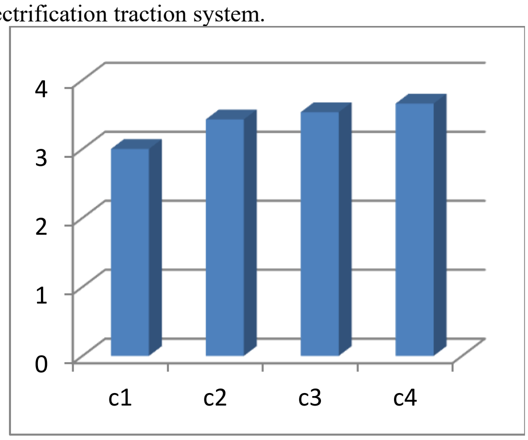

Fig. 11 Magnitude of component level evaluated repair rate for each and every component of the DC electrification traction system.

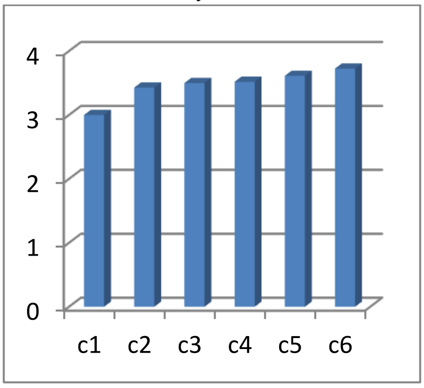

Fig. 12 Magnitude of component level evaluated repair rate for each and every component of the AC electrification traction system.

Fig. 13 and Fig. 14 provides magnitude of component level evaluated unavailability for each and every component of the DC electrification traction system and magnitude of component level evaluated unavailability for each and every component of the AC electrification traction system respectively.

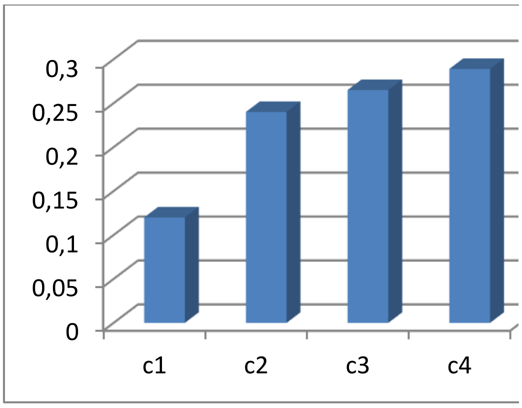

Fig. 13 Magnitude of component level evaluated unavailability for each and every component of the DC electrification traction system.

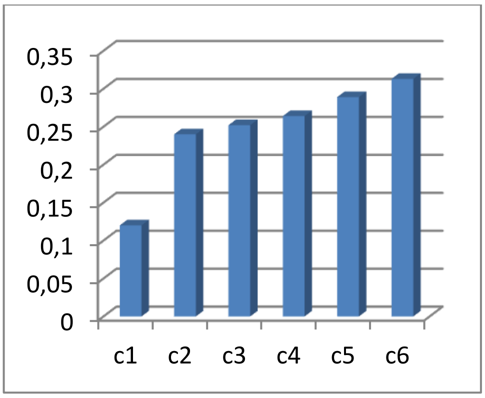

Fig. 14 Magnitude of component level evaluated unavailability for each and every component of the AC electrification traction system.

V. Conclusion

Identifying various values of reliability is most important when we have to check the availability of supply in any system. Electric traction system is very important as it is used for operation of passenger trains and freight trains across a large rail network throughout the world. Reliability of each component of DC electrification traction system and AC electrification traction system is obtained. Mean time to failure and unavailability for each and every component of the DC electrification traction system and AC electrification traction system is also calculated. This paper has also evaluated the basic reliability indices such as failure rate, repair rate and unavailability at the component level for the DC electrification traction system and AC electrification traction system respectively.

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