An Innovative Approach for Reliability Modeling of HVDC Converter Station

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Abstract

Assessment of reliability indices is important when availability and unavailability of the system or systems or components or group of components are to be assessed. There are various reliability indexes which are very important for overall performance of any complex engineering system. Reliability block diagram modeling is required to be formulated for evaluating different essential and important reliability parameters of any complex engineering system. In view of above, in this paper, reliability block diagram modeling of HVDC converter station is represented and formulated. The schematic diagram of the HVDC converter station is available in literature and based on that schematic diagram the modeling of HVDC converter station is formulated in this paper. After the reliability block diagram modeling of HVDC converter station, the mean time to failure (MTTF) of each and every components of HVDC converter station are also evaluated and represented in the result and discussion section. The reliability of each and every component of the HVDC converter station is evaluated and expressed in result section. Assessment of unavailability is also obtained and shown in result section.

Keywords: Reliability, Mean time to failure, HVDC converter station, availability, Reliability indices.

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]. 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 block diagram modeling of HVDC converter station is represented and formulated. The reliability of each and every component of the HVDC converter station is obtained. Mean time to failure (MTTF) of the components are also evaluated. Assessment of overall reliability of the system and overall mean time to failure is calculated and presented.

II. Reliability block diagram representation of HVDC converter station

Reliability block diagram which is a diagrammatic method for showing how different components are connected in a system is obtained for the HVDC converter station. The schematic diagram of the typical HVDC converter station is given by [30]. The HVDC converter station consists of 12 pulse converter, transformer, smoothing reactors, DC filters, tuned AC filters, HP AC filters. The reliability block diagram of HVDC converter station is shown in Fig. 1. From Fig. 1, it is clear that HP AC filter and tuned AC filters are connected in a parallel manner. While the 12 pulse converter, smoothing reactors and DC filters are connected in series configuration as shown.

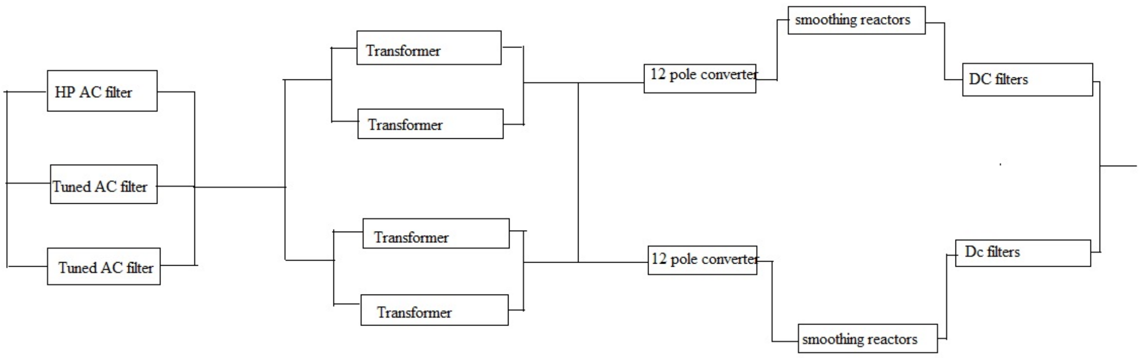

Figure 1: *Reliability block diagram of HVDC converter station*

III. Evaluation of reliability and its various indices of HVDC converter station

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.

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

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:

$$MTTF = 1/\lambda \quad (2)$$

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 r1, r2…rn, then reliability of series system is given as:

$$R_s = \prod_{i=1}^{n} r_i \quad (3)$$

In series configuration combined failure rate is calculated as follows.

$$\lambda_{Total} = \sum \lambda \quad (4)$$

Unavailability of series configuration is calculated by using following relation.

$$U_{Total} = \sum \lambda r \quad (5)$$

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

$$r_{Total} = \sum U/\lambda \quad (6)$$

The system or network fails, if all components fail and the system will perform its function even if a single component is working, such a system or network is known as parallel reliability system or network.

The reliability of parallel system (R_P) is given as [23]

$$R_p = 1 - \prod_{i=1}^{n}(1 - r_i) \quad (7)$$

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

Following relation are used to evaluate indices if two components are connected in parallel.

$$\lambda_{para} = \frac{\lambda_1 \lambda_2 (r_1 + r_2)}{8760} \quad (8)$$

$$r_{para} = \frac{r_1 . r_2}{r_1 + r_2} \tag{9}$$

$$U_{para} = \lambda_{para} . r_{para} \tag{10}$$

IV. Result and Discussion

Initial data for different components of the HVDC converter station is shown in Table 1 [30]. There are six components in the HVDC converter station 12 pulse converter, transformer, smoothing reactors, DC filters, tuned AC filters, HP AC filters having mean time to failure (MTTF) as 13.7, 16.1, 76.8, 19.7, 12.6 and 12.6 respectively [30]. The values of mean time to repair (MTTR) for the six components in hours are 6.1, 1700.0, 1700.0, 7.9, 9.3, 9.3 respectively.

Table 1: *Initial data for different components of the HVDC converter station [30].*

Components	MTTF (years)	MTTR (hours)
12 pulse converter (c1)	13.7	6.1
Transformer (c2)	16.1	1700.0
smoothing reactors (c3)	76.8	1700.0
DC filters (c4)	19.7	7.9
tuned AC filters (c5)	12.6	9.3
HP AC filters (c6)	12.6	9.3

Table 2 provides the evaluated values of the failure rate as obtained from equation (2), of the six components of the HVDC converter station, which are obtained as 0.0730, 0.0621, 0.0130, 0.0508, 0.0794 and 0.0794 respectively.

Table 2: *Evaluated failure rate of different components of the HVDC converter station.*

Component	failure rate
c1	0.0730
c2	0.0621
c3	0.0130
c4	0.0508
c5	0.0794
c6	0.0794

The evaluated values of the reliability as obtained from equation (1) for the HVDC converter station components are obtained as 0.9296, 0.9398, 0.9871, 0.9505, 0.9237 and 0.9237 respectively, are shown in Table 3.

Table 3: *Evaluated Reliability of each component of the HVDC converter station.*

Component	Reliability
c1	0.9296
c2	0.9398
c3	0.9871
c4	0.9505
c5	0.9237
c6	0.9237

Table 4 shows the values of evaluated unavailability which can be obtained from equation (5) for each and every individual component only is obtained as 0.4453, 105.57, 22.1, 0.4013, 0.7384 and 0.7384 respectively.

Table 4: *Evaluated unavailability for each and every component of the HVDC converter station.*

component	c1	c2	c3	c4	c5	c6
Unavailability	0.4453	105.57	22.1	0.4013	0.7384	0.7384

Fig. 2 shows the magnitude of failure rate of each component of the HVDC converter station. Magnitude of evaluated reliability of each component of the HVDC converter station is shown in Fig. 3. Fig. 4 and Fig. 5 shows the magnitude of evaluated Unavailability of all components of the HVDC converter station.

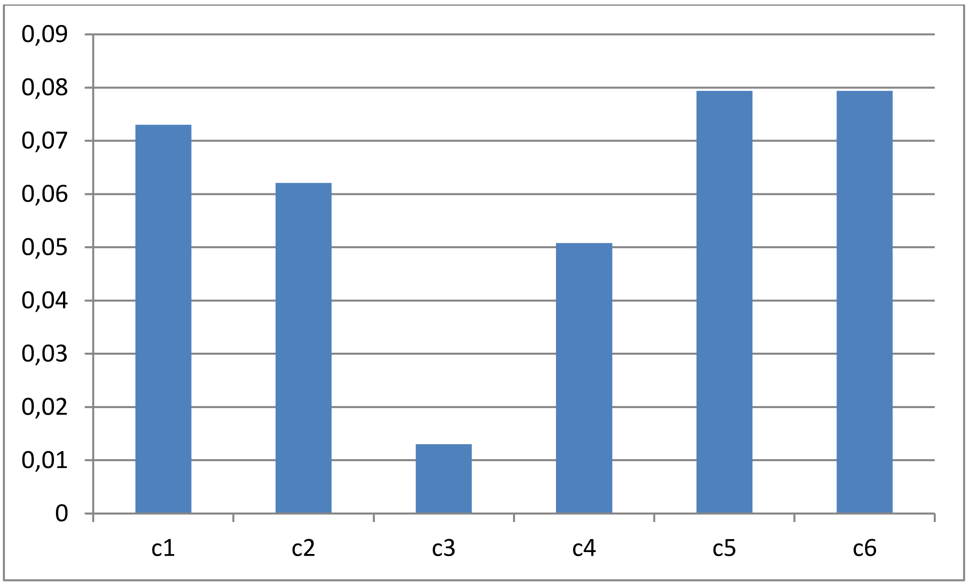

Figure 2: *Magnitude of failure rate of each component of the HVDC converter station.*

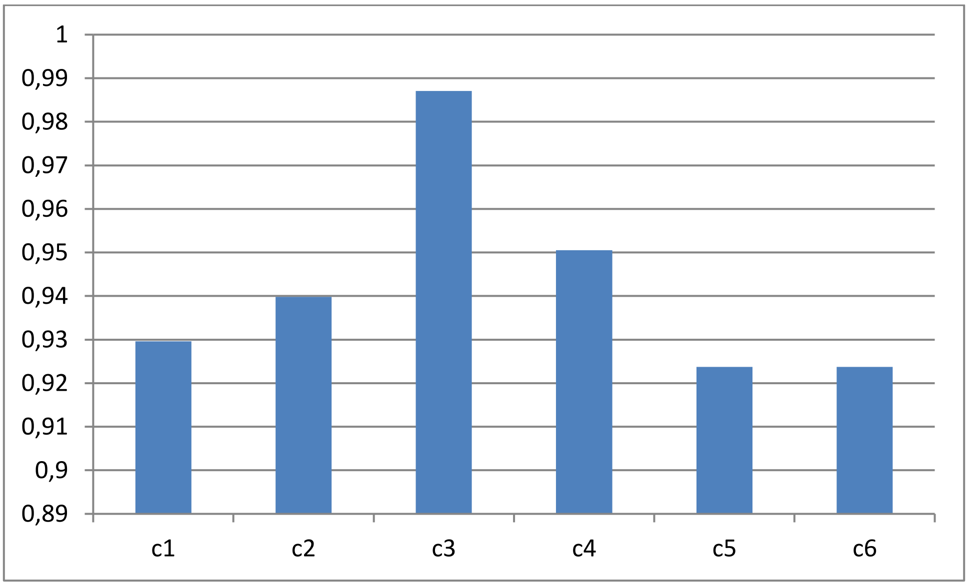

Figure 3: *Magnitude of evaluated reliability of each component of the HVDC converter station.*

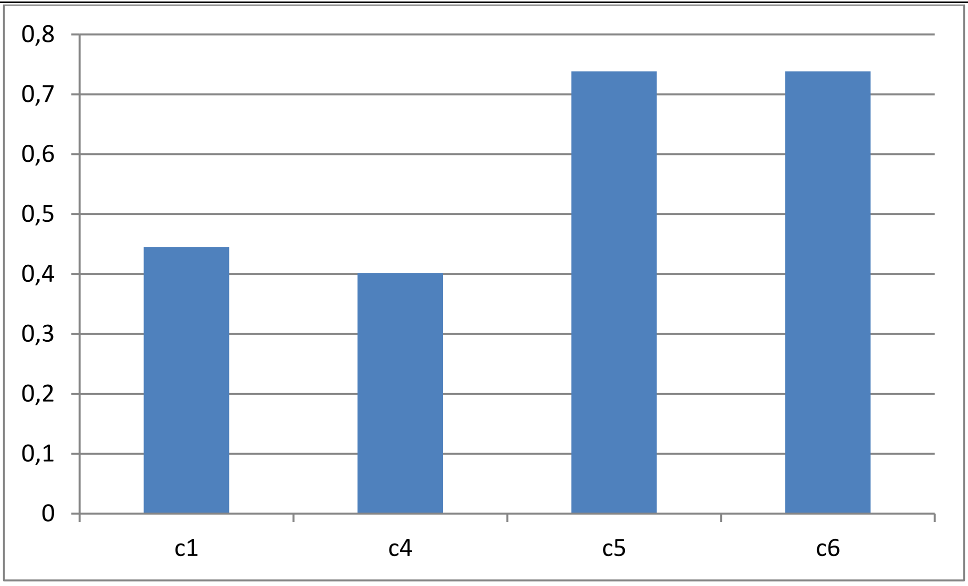

Figure 4: *Magnitude of evaluated Unavailability of components c1, c4, c5, c6 of the HVDC converter station.*

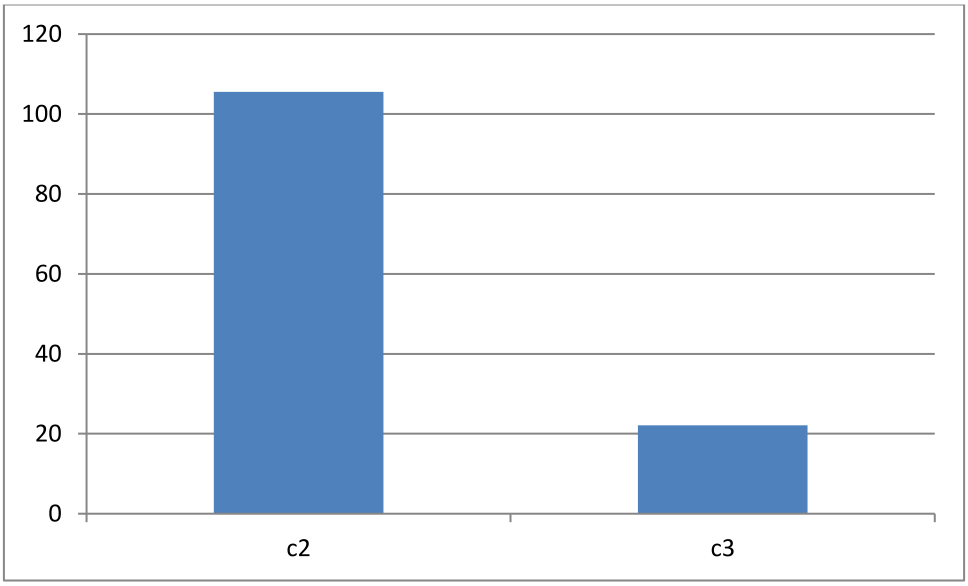

Figure 5: *Magnitude of evaluated Unavailability of components c2, c3 of the HVDC converter station.*

V Conclusion

Evaluation of reliability of engineering system is important and necessary for the overall impact of the system. The reliability of the system depends on its different components and the manner of their existence. This paper proposes the reliability block diagram representation of HVDC converter station. The HVDC converter station whose modeling has been done consists of six components, namely 12 pulse converter, transformer, smoothing reactors, DC filters, tuned AC filters and HP AC filters, which are connected in a manner which is shown in the block diagram. Reliability parameters such as failure rate and reliability are obtained for each component and are discussed in the result section. Unavailability for each and every component of the HVDC converter station is also obtained and discussed in result section. Result section also shows the magnitude of the parameters which are evaluated.

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