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Probabilistic reliability indices evaluation of electrical distribution system accounting outage due to overloading and repair time omission

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ABSTRACT

This paper presents a methodology for modifying failure rate and repair time of a distributor segment accounting the outage due to overloading and omission of critical repair time termed as repair tolerance time. Necessary relations have been derived for modifications of failure rate and repair time of a distributor and these modified failure rate/repair time have been used to evaluate average failure rate, average outage duration and average outage duration per year for distribution systems. The methodology has been implemented on a meshed distribution network and results have been compared with those obtained with unmodified failure rates/repair times.

1. Introduction

Reliability assessment of power system is an important issue. Considerable attention has been focussed on reliability evaluation of bulk power system in comparison to distribution systems. Hence distribution system has been the weakest link between the source of supply and customer. This is due to the fact that generation and transmission system are capital intensive and outages in these systems may affect large area and large number of customers. It has been standard practice to evaluate reliability of distribution system separately because: (i) distribution networks mostly connected to transmission system through one supply point and the load point indices evaluated for bulk power system may be used if needed as input values for the reliability evaluation of distribution network and (ii) on average 90% interruptions of the customer is observed due to distribution network. Average failure rate, average outage duration, and average annual outage time are the basic indices evaluated based on the exponential distribution functions for failure time and repair time. This leads to justification for assuming constant failure rates and repair rates for each distributor segment. Various analytical methods for reliability evaluation of a distribution network has been described in literature. Since repair rate is much larger than failure rate, approximate relations are used for obtaining reliability indices of series parallel systems. Average reliability indices are evaluated using analytical techniques whereas simulation techniques are used to generate distribution of these indices [1,2].

Allan et al. [3] developed modelling aspects and evaluated reliability indices of distribution systems. Billinton and Grover [4] developed methodology for reliability evaluation of transmission and distribution systems. Billinton and Kumar [5] considered common cause outages and weather effects and developed a procedure for reliability evaluation of transmission network. Gangel and Ringlee [6] presented techniques for the estimation of service interruptions initiated in a distribution system. Various modelling aspects to determine failure and repair rates have been presented. Wojczynski and Billinton [7] discussed and developed a procedure for evaluating the effects of distribution system reliability index distribution on interruption costs for reliability worth estimates. Volkanavski et al. [8] developed an algorithm for power system reliability assessment using fault tree analysis. Minimal cut-set and the frequency duration methods have been used for planning and design of industrial power distribution system [9–12]. Several variations of Monte Carlo simulation methods have been developed to probabilistically evaluate long term reliability of power system [13–15]. Li et al. [20] investigated the impact of covered conductors on distribution reliability and safety. Ghosh et al. [21]

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Nomenclature

$p_{L1,k}$	probability of section being in up state considering load
$p_{L2,k}$	probability of outage of section due to overloading
d_k	mean cycle time of loading pattern
$l_k d_k$	mean duration for which the component is out due to overloading
$(1 - l_k)d_k$	mean duration for which section is available considering only overloading
$\lambda_{H,k}$	outage rate due to overloading
$\lambda_{L,k}$	transition rate from overloading state to low load state
λ_k, μ_k	failure rate and repair rate of kth section
$\lambda_{e,k}$, $\mu_{e,k}$	equivalent failure rate and repair rate of kth section accounting outage due to overloading
MUT, MDT	mean up time and mean down time respectively
τ_k	repair time omitted
$\tilde{\lambda}_k$, $\tilde{\mu}_k$	modified failure and repair rate of kth section accounting repair time omission
$\widetilde{MUT}$, $\widetilde{MDT}$	modified mean up time and mean down time accounting repair time omission
$\lambda_{eys,q}$	system failure rate (1 year) for qth load point
$U_{sys,q}$	unavailability in h/year for qth load point
$r_{sys,q}$	average interruption duration for qth load point
$E[\cdot]$	expected value
λ_{ser}	series sub-system failure rate
U_{ser}	series sub-system unavailability (h/year)
r_{ser}	series sub-system average outage time duration (h)
λ_{para}	failure rate of components in parallel
r_{para}	average outage duration of components in parallel
U_{para}	unavailability of components in parallel

presented a technique for optimal sizing and placement of distributed generation in a distribution network.

It is observed that none of the methodologies referred above has accounted outage due to overloading and incorporation of repair time omission for evaluating the reliability indices of the system. In view of the above this paper describes an approach for reliability indices evaluation for distribution systems. Two important aspects have been considered in assessing the reliability of the system i.e. (i) account the effective loss of load due to load exceeding the capacity of a section and (ii) ignoring a certain critical value of repair time of the section. The necessary relations have been derived to get modified failure rates and repair time of each distributor segment and utilized to obtain overall reliability indices of the system. The modified failure rate and repair time for each section has been obtained using Markov analysis. The important contributions of this paper are (i) development of relations for obtaining modified failure rate ($\tilde{\lambda}_k$) and modified repair time ($\tilde{r}_k$) for each section of a distribution system accounting outage due to overloading and repair time omission, and (ii) obtaining primary reliability indices for a meshed distribution system using modified failure rate and repair time.

2. Failure rate and repair time modification of a section accounting outages due to overloading

It is assumed that λ_k and r_k are failure rate and average repair time (reciprocal of repair rate) of kth section. These random failure rate/repair rate does not include loss of availability of section due to excessive overloading at times. Analysis in this paper is based on constant failure rate and repair rate of a section for the useful period of a section. Further any degradation due to physical behaviour of the component due to any reason (failure modes) are modelled separately and are included in initial failure rate (λ_k) of the component. Further failure rate in many situations is kept practically constant due to proper preventive maintenance and replacement of sub-components e.g. insulation in time [19]. In this paper 'outage due to overloading' implies that the section/component is removed from service with the help of protective system and put back to service as soon as overload is over. Hence 'outage due to overloading' has nothing to do with any other modes of failures.

The availability (p_{k1}) and unavailability (p_{k2}) of the component due to section failure is given as

$$p_{k1} = \frac{\mu_k}{\lambda_k + \mu_k} \tag{1}$$

$$p_{2,k} = \frac{\lambda_k}{\lambda_k + \mu_k} \tag{2}$$

The state transition diagram for the section is given in Fig. 1. λ_k includes all random failure modes of the distribution sub-components. Similarly μ_k represents repair rates accounting all random repairs of sub-components.

A two step Markov modelling is represented in Fig. 2 for evaluating rate of transition from low load level to high load level considering unavailability of the section. $l_k d_k$ is the average period for which load exceeds the capacity of a section. Where l_k is probability of load exceeding the capacity of the distributor. d_k is average cycle time. The state transition diagram is shown in Fig. 3. $\lambda_{H,k}$ denotes the rate of transition from up state to down state due to overloading and $\lambda_{L,k}$ denotes rate of transition from higher load state (causing unavailability of section) to a lower load level and the section is in operable condition. The state probabilities and rate of transition are written as follows from Figs. 2 and 3.

$$p_{L1,k} = (1 - l_k) \tag{3}$$

$$p_{L2,k} = l_k \tag{4}$$

$$\lambda_{H,k} = [(1 - l_k)d_k]^{-1} \tag{5}$$

$$\lambda_{L,k} = [l_k d_k]^{-1} \tag{6}$$

Equivalent failure rate ($\lambda_{e,k}$) and repair rate ($\mu_{e,k}$) is obtained by combining state transition diagram of Figs. 1 and 3. The combined state transition diagram is shown in Fig. 4. State probabilities of this combined state transition diagram are given as follows:

$$\begin{aligned} p_{c1} &= p_{1,k} \cdot p_{L1,k} \\ p_{c2} &= p_{1,k} \cdot p_{L2,k} \\ p_{c3} &= p_{2,k} \cdot p_{L1,k} \\ p_{c4} &= p_{2,k} \cdot p_{L2,k} \end{aligned} \tag{7}$$

The modified availability of the section is given as the state probability of state 1 as follows:

$$A_k = p_{c1} = p_{1,k} \cdot p_{L1,k} \tag{8}$$

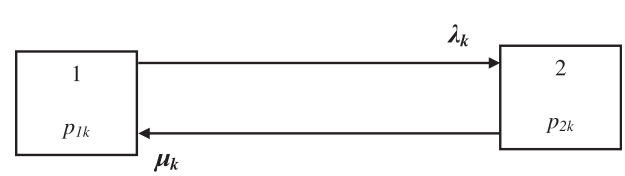

Fig. 1. State transition diagram for kth distributor section.