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Estimation of distribution system reliability indices neglecting random interruption duration incorporating effect of distribution generation in standby mode

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ABSTRACT

Usually the reliability performance of distribution systems is assessed based on basic reliability indices at load points i.e. failure rate, average interruption duration and unavailability expressed as interruption duration in hours/year. Now a days the distribution systems contain distribution generations (DG) which affects these reliability indices. Further a certain interruption duration which in fact is a random variable can be neglected. Hence this paper describes a simulation approach for evaluating the basic reliability indices incorporating DG and omitting a random interruption duration. The algorithm has been implemented on a sample test system.

1. Introduction

The main function of an electrical distribution system is to provide energy to the consumers maintaining desired level of reliability. Normally the acceptable level of reliability performance is measured by evaluating average values of reliability indices at load points i.e. average interruption duration in hours per year and failure rate (occ./year). These indices are functions of failure rate and repair rate (reciprocal of repair time) of feeder sections involved up to load points [1]. Analytical as well as simulation based techniques have been developed for reliability indices evaluation [2–7]. Billinton and Grover [8] developed a methodology for evaluating reliability indices of composite power systems. Gangel and Ringlee [9] and Allan et al. [10] presented and developed various modeling aspects for determination of reliability indices of distribution system. Chowdhury and Custer [11] introduced a value based approach for designing urban distribution system. Li et al. [12] evaluated the impact of covered conductors in distribution system on reliability and safety. Recently owing to distributed generation (DG) incorporation in distribution system it has become complex. Addition of DG affects the reliability performance of the system. It is established that when a supply system (component) is added in standby mode, its reliability performance is modified [4]. Quantitatively this has been modeled in ‘Equivalent network modeling at load points with distributed generation’ and given by Eqs. (1) and (2). Bae and Kim [13] evaluated reliability of a distribution system accounting DG in operation mode. Arya et al. [14] evaluated reliability indices of distribution system incorporating effect of DG in standby mode. Trebolle et al. [15] proposed a method based on market mechanism which suggests distribution system operators with alternative solutions for investment including reliability options for distributed generations (RODGS). Hegazy et al. [16] employed Monte Carlo simulation (MCS) to determine reliability of distribution systems incorporating DG. The paper merely concern about reliability evaluation of distribution capacity of the system including DG without considering the network explicitly. No consideration has been given to failure rate and repair time of each distribution section. This can be viewed as adequate generating capacity evaluation. Further random repair time omission has not been considered. A methodology for obtaining delivery point reliability indices for a bulk power system was developed by Billinton and Wangdee [17] using sequential MCS. A non-sequential MCS technique was used to evaluate the reliability indices of composite distribution system in [18]. Bakkiyaraj and Kumarappan [19] developed an reliability planning algorithm using particle swarm optimization in co-relation with MCS for composite power system. Banerjee and Islam [20] presented a probabilistic approach for reliability maximization taking into account the effect of DG. Bae et al. [21] used hourly reliability

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Nomenclature

$\lambda_{sys,k}$	equivalent failure rate at *k*th load point
$r_{sys,k}$	equivalent interruption duration at *k*th load point
λ_{dg}	failure rate of DG
r_{dg}	repair time of DG
λ_{sw}	failure rate of changeover switch
s	restoration time of changeover switch
λ_{eq-k}	failure rate of equivalent single component with inclusion of DG
$r_{eq\text{-}k}$	repair time of equivalent single component with inclusion of DG
$\varphi_k(t)$	probability distribution function of omitted repair time
μ_k	mean of omitted repair time
σ_k	standard deviation of omitted repair time
τ_k	tolerable interruption duration
$\tau_{i\text{-}k}$	tolerable interruption duration sample for *k*th load point
$TTF_{i\text{-}k}$	time to failure
$TTI_{i\text{-}k}$	interruption duration
$T\tilde{T}F_{i-k}$	modified time to failure accounting repair time omission
$T\tilde{T}I_{i-k}$	modified interruption duration accounting repair time omission
$M\tilde{U}T_k$	modified mean up time accounting repair time omission
$M\tilde{D}T_k$	modified mean interruption duration accounting repair time omission
$\tilde{\lambda}_{sys,k}$	modified failure rate accounting repair time omission for *k*th load point
$\tilde{r}_{sys-k}$	modified average interruption duration accounting repair time omission for *k*th load point
$\tilde{U}_{sys-k}$	modified average interruption duration per year accounting repair time omission
$\hat{\sigma}_F^2$	variance of $T\tilde{T}F_{i-k}$
$\hat{\sigma}_I^2$	variance of $T\tilde{T}I_{i-k}$
s_F^2	standard deviation of $M\tilde{U}T_k$
s_I^2	standard deviation of $M\tilde{D}T_k$
β_{F-k}	coefficient of variation for $M\tilde{U}T_k$
β_{I-k}	coefficient of variation for $M\tilde{D}T_k$
ξ	tolerance time specified
λ_j^0	current failure rate of *j*th distributor section
r_j^0	current repair time of *j*th distributor section

worth and developed an algorithm for optimal operating strategy for distributed generation. An algorithm for evaluating optimal interval for preventive maintenance for distribution system was developed by Louit et al. [22]. MCS and least square support vector machine (LSSVM) classifier have been combined to evaluate reliability of composite power system by Pindoriya et al. [23]. Alvehag and Soder [24] described a reliability model by modifying failure rate and restoration time accounting variation in weather conditions. Dzobe et al. [25] employed beta probability distribution function and time dependent customer interruption cost model for reliability worth analysis. Lai et al. [31] presented an algorithm for determination of optimal preventive maintenance accounting availability with Hypo exponential failure distribution. Yassad et al. [32] developed a reliability centered maintenance optimization algorithm for distribution system.

It has been observed that certain interruption duration at a load point may be tolerable and may be neglected for a repairable system. From this view point Zheng et al. [26] probably introduced and developed model for calculating availability/unavailability of a single repairable unit with random repair time omission. In recent references the concept of omission of random interruption has been incorporated to evaluate reliability indices for distribution systems [27,28]. In these mentioned references effect of DG has not been considered. In view of this the objective of this paper is to evaluate basic reliability indices of distribution system accounting the effect of distributed generation on reliability indices and simultaneously incorporating the effect of omission of random interruption duration.

2. Equivalent network modeling at load points with distributed generation

The objective is to develop equivalent failure rate and interruption duration at load point (LP) where distributed generation is connected via a change over switch. This typical situation is shown in Fig. 1. The modeling aspects of such situation have been discussed by Arya et al. [14].

From the reliability point of view the distribution system is replaced by an equivalent failure rate ($\lambda_{sys,k}$) and equivalent interruption duration ($r_{sys,k}$) at load point k. It is stressed here that various means of distributed generation (DG) facilities are available depending on the suitability of locations e.g. combined heat and power (CHP) systems, wind energy conversion systems (WECS), solar photovoltaic systems (PVS), small scale hydroelectric generation, other renewable energy sources, storage devices [30]. Whichever means is applied in the system this type of analysis only requires failure rate and repair time of DG as is clear from the Eqs. (1) and (2). Hence DG may be replaced by its failure rate and repair time. Further the changeover switch is replaced by its failure rate and restoration time. The resulting reliability network will appear as shown in Fig. 2, in which λ_{dg} is failure rate of DG, r_{dg} is repair time of DG, λ_{sw} is failure rate of changeover switch, s is restoration time of changeover switch. $\lambda_{sys,k}$, $r_{sys,k}$ are equivalent failure rate and interruption duration at load point with respect to distribution system alone.

The reliability network of Fig. 2 is reduced to a single component by employing approximate series–parallel formulae [1,4]. The expression for equivalent failure and average interruption duration at load point which accounts the effect of DG are written as follows

$$\lambda_{eq-k} = \lambda_{sys,k}\lambda_{dg}(r_{sys,k} + r_{dg}) + \lambda_{sw} \quad (1)$$

$$r_{eq-k} = \frac{\lambda_{sys,k}\lambda_{dg}r_{sys,k}r_{dg} + \lambda_{sw}s}{\lambda_{sys,k}\lambda_{dg}(r_{sys,k} + r_{dg}) + \lambda_{sw}} \quad (2)$$

λ_{eq-k} and r_{eq-k} may be treated as the failure rate and repair time of an equivalent single component which accounts the effect of DG in addition to main substation source for kth load point. Hence λ_{eq-k} and r_{eq-k} are evaluated for all load points having DG and then Monte-Carlo simulation is employed to evaluate modified reliability indices accounting the effect of random repair time omission.

3. Omission of random interruption duration at load point

It is observed that a repairable system has random uptime and random down time and large samples of such time to failure and time to repair may be obtained. One calculates based on these values the basic reliability indices. Since certain time to repair is tolerable or can be omitted [27] then reliability indices have to be modified. The interruption duration sample which is tolerable is