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Ranking of feeder sections of distribution systems for maintenance prioritization accounting distributed generations and loads using diagnostic importance factor (DIF)

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ABSTRACT

This paper presents an algorithm for deciding preferences in maintenance activities for feeder sections of distribution systems. A component importance measure, known as diagnostic importance factor (DIF), has been used for this purpose. A methodology has been developed to compute a newly framed weighted cumulative diagnostic importance factor (WCDIF) for each feeder section which represents quantitatively relative significance for prioritization of maintenance activities. The developed methodology includes the effect of distributed generations (DG) and loads. It has been implemented on two sample distribution systems and ranking lists of feeder sections for maintenance activities have been obtained.

Introduction

Availability analysis of distribution systems is of significant importance for deciding the adequate performance of the system. Availability of the existing distribution system configuration may be improved by modifying failure rates and repair times of feeder sections. These modifications are achieved by preventive and corrective maintenance activities [1,2]. Usually budget allocated for availability improvement is limited and to be used in best possible way. Component importance analysis has been used in various disciplines of engineering to achieve the objective of minimizing the investment for preventive and corrective maintenance. Various indices have been described in literature to signify the component importance [3,4] for reliability studies. Usually component importance measure has not been considered for prioritizing maintenance activities in electrical distribution systems. Component importance measure shows the relative significance of a component from reliability viewpoint. Diagnostic importance factor (DIF) has been found most suitable for attaching component importance from maintenance viewpoint [4].

Various strategies have been presented for modification of failure rate and repair time for reliability enhancement of distribution system which do not account component importance analysis. Su and Lii [5] allocated optimum forced outage rate (FOR) for each feeder section using modified genetic algorithm. Chowdhury and Custer [6] described a value based probabilistic approach for designing urban distribution system. Chang and Wu [7] described an algorithm for optimal reliability design of distribution system using a polynomial-time algorithm. Arya and Choube [8] obtained reliability improvement for distribution systems using differential evolution. Bakkiyaraj and Kumarappan [9] developed an algorithm for reliability improvement in a composite power system employing particle swarm optimization along with Monte Carlo simulation. A reliability centered maintenance optimization algorithm has been developed by Yssaad et al. [10] for adequate performance of distribution systems. A maintenance scheduling algorithm using genetic optimization technique has been developed for power system by Wang and Handschin [11].

Hoseinabadi [12] employed Birnbaum's and critically importance measure for substation automation system reliability assessment. Si et al. [13] employed component importance analysis for general reconfigurable systems. Hilber and Bertling [14] developed a methodology for identifying the importance of individual component in power network accounting total interruption cost. Fangxing and Brown [15] used system reliability and cost effectiveness to prioritize maintenance activities in a distribution network. Shaomin et al. [16] developed a component importance measure which is an extension of oldest Birnbaun's measure incorporating in it maintenance cost. But Birnbaun measure it self-suffers from

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Nomenclature

DIF	diagnostic importance factor
FOR	forced outage rate
WCDIF	weighted cumulative diagnostic importance factor
LP	load point
$\overline{SYS}$	system failure
λ_n	failure rate of *n*th feeder section
L_j	average load at *j*th LP
U_n	unavailability of *n*th feeder section
r_n	average repair time of *n*th feeder section
U_{ser}	unavailability of series combination
U_{para}	unavailability of parallel combination
$d_{n\text{-}k}$	DIF of *n*th feeder for *k*th load point
$U_{LP\text{-}k}(\bar{n})$	unavailability at *k*th load point for the failure of *n*th section
$U_{LP\text{-}k}$	unavailability at *k*th load point
$\widehat{U}_{LP\text{-}k}$	unavailability at *k*th load point with DG
$\widehat{U}_{LP\text{-}k}(\bar{n})$	unavailability at *k*th load point with DG for the failure of *n*th section
cf_n	WCDIF of *n*th section
$\lambda_{sw\text{-}k}$	failure rate of changeover switch at load point *k*
$r_{dg\text{-}k}$	repair time of DG at load point *k*
s_k	restoration time of change over switch at *k*th load point
NLP	number of load points
NC	number of feeder sections

limitation of correctability in reliability improvement of individual component. Shourkaei et al. [22] developed an optimal maintenance strategy for distribution system accounting service quality regulation. Conti et al. [23] presented an analytical method for reliability assessment of distribution systems to investigate the effect of tele controlled switches and microgrids. Melchor-Hernandez et al. [24] developed an optimal maintenance policy for power equipment. The method includes imperfect preventive maintenance model using Weibull distribution and incorporates the current over haul interval and obtained optimal over haul interval.

Yssaad and Abene [25] developed a rational reliability centered maintenance optimization for distribution systems. Canizes et al. [26] developed a methodology for optimizing reliability of radial distribution network accounting customer and energy based indices.

It is observed from the mentioned research articles in previous paragraphs that the methodologies developed for reliability improvement of distribution system do not prioritize maintenance of the feeder sections for modification of failure and repair rate. Further modern distribution systems contain distributed generations which need consideration in modifying failure and repair rate of feeder section in addition to impact of loads.

It is important to intensify the maintenance activities at selected sections based on a ranking list obtained using component importance and including all the load points. The ranking list is based on the current failure and repair rates of the feeder sections. The selection of feeder sections for maintenance activities for achieving desired reliability goal in terms of modification of current failure/repair rate is essential because (a) a fraction of sections may contribute significantly to improvement of reliability indices at load points, (b) considerations of all the feeder sections in a methodology increases the size of the problem in terms of number of variables and further modifications for many sections obtained may be insignificant, and (c) distributed generation present in a distribution system has to be incorporated which will have impact on efforts for preventive/corrective maintenance.

In view of this motivation for this paper is to develop a technique for selecting the feeder sections to be used for maintenance activities to achieve reliability goals. Diagnostic importance factor (DIF) has been found most suitable for this purpose and has been used for computer networks [4].

Hence the objective of this paper is to rank the feeder sections for selecting them for modifying their current failure rate and repair time by additional maintenance measures. Thus based on ranking list minimum feeder sections may be identified for additional preventive and corrective maintenance activities. Ultimately the severity of outage of a feeder section has been reflected by formulating an index known as weighted cumulative diagnostic importance factor (WCDIF) (Section 'Determination of weighted cumulative diagnostic importance factor (WCDIF) of a feeder section'). The index in turn depends on failure rate and repair time of a feeder section. The novelty of this paper lies in the fact that DIF index has been employed for prioritization of maintenance activity (preventive as well as corrective) for electrical distribution system accounting DG and loads at various load points. A new modified index WCDIF has been derived for this purpose.

The organization of the paper is as follows. Section 'Diagnostic importance factor (DIF): An overview' presents an overview of DIF. Section 'Determination of weighted cumulative diagnostic importance factor (WCDIF) of a feeder section' presents concept of weighted cumulative diagnostic importance factor (WCDIF) of a feeder section for all load points. Section 'Determination of DIF of a section for load point having DG' describes methodology for calculating equivalent failure rate, repair time and DIF accounting distributed generation. Section 'Computational algorithm' gives computational algorithm for preparation of ranking list. Section 'Results and discussions' presents implementation of the algorithm on two sample test systems.

Diagnostic importance factor (DIF): An overview

Magnitude of diagnostic importance factor signifies the relative importance of a component for maintenance activities in a system. It is identified as the fraction of system failure which involves failure of the component in consideration [4]. Mathematically it is a conditional probability and defined as follows [17]

$$d_n = P[\bar{n}/\overline{SYS}] \tag{1}$$

where

d_n DIF of *n*th component

$\bar{n}$ denotes failure of *n*th component

$\overline{SYS}$ denote system failure

$P[\bar{n}/\overline{SYS}]$ is probability of *n*th component failure provided that system failure has occurred.

Relation (1) is written as follows using basic probability formulae

$$d_n = P[\bar{n} \cap \overline{SYS}]/P(\overline{SYS}) \tag{2}$$

Further it is observed as

$$P[\bar{n} \cap \overline{SYS}] = P[\overline{SYS}/\bar{n}]P(\bar{n}) \tag{3}$$

Putting (3) in (2) following expression is obtained for DIF

$$d_n = \frac{P[\overline{SYS}/\bar{n}]P[\bar{n}]}{P[\overline{SYS}]} \tag{4}$$

where

$P[\bar{n}]$ denotes probability of failure or unavailability of nth component

$P[\overline{SYS}]$ denotes probability of system failure

$P[\overline{SYS}/\bar{n}]$ denotes probability of system failure provided nth component has failed.

Relation (4) is used to evaluate DIF of nth component. It clearly spells out the importance of nth component in system structure. Numerator represents the importance which is the product of component failure probability and structural importance of the component which is represented by the conditional probability term. Hence this index accounts not only component failure probability but significance of its position in the system. For example $P[\bar{n}]$ may be high but if $P[\overline{SYS}/\bar{n}]$ is insignificant then the *DIP* measure will be small.

Determination of weighted cumulative diagnostic importance factor (WCDIF) of a feeder section

A distribution system consists of various load points (LP) involving many feeder sections. A feeder section has different values of DIF for different load points. Hence a cumulative DIF which accounts the effect of all load points is required. It is also stressed here that load at each load point is different and weightage to DIF for each load point must be assigned using a weighting factor.

A feeder section is a repairable component involving failure rate and repair time. The unavailability of the section is given as follows [18]

$$U_n = \lambda_n \cdot r_n \tag{5}$$

where

U_n is unavailability of the section expressed as h/year

λ_n is failure rate of nth section in occurrence/year

r_n is average repair time in h for nth section.

Eq. (5) may also be expressed as probability of failure as follows

$$U_n = \lambda_n \cdot r_n/8760 \tag{6}$$

If unavailability of each feeder section is known then system unavailability at each load point is calculated using series parallel relations [18]. If sections are in series then unavailability of the series combination is given as

$$U_{ser} = \sum_{i=1}^{NC} \lambda_i r_i \tag{7}$$

If two feeder sections are operating in parallel then unavailability of parallel combination is given as follows

$$U_{para} = (\lambda_1 r_1)(\lambda_2 r_2)/8760 \text{ h/year} \tag{8}$$

By successive application of (7) and (8) unavailabilities at the load points are calculated. Now in relation (4), $P(\bar{n})$ is replaced by unavailability of the feeder section i.e. U_n and $P[\overline{SYS}/\bar{n}]$ is replaced by unavailability at load point provided nth section is not available i.e. $U_{LP\text{-}k}(\bar{n})$. $P[\overline{SYS}]$ is replaced by unavailability at kth load point i.e. $U_{LP\text{-}k}$.

In view of this DIF of nth section for kth load point is written using relation (4) as follows

$$d_{n\text{-}k} = \frac{U_{LP\text{-}k}(\bar{n})}{U_{LP\text{-}k}} \cdot U_n \tag{9}$$

where

$U_{LP\text{-}k}(\bar{n})$ is unavailability at kth load point (LP) given that nth section is out. This represents the term $P[\overline{SYS}/\bar{n}]$ in relation (4)

$U_{LP\text{-}k}$ is the usual unavailability at kth load point and represents the term $P[\overline{SYS}]$ in relation (4)

U_n is unavailability of nth section and corresponds to term $P[\bar{n}]$ in Eq. (4)

It is observed that $d_{n\text{-}k}$ as given by relation (9) gives the importance of nth section for kth load point. This importance factor can be reduced if unavailability of this section is reduced. This U_n may be reduced by modifying failure rate and repair time. Hence ranking list has to be prepared based on the magnitudes of $d_{n\text{-}k}$. As stressed earlier $d_{n\text{-}k}$ accounts structural importance in addition to modification capabilities in failure rate and repair time of feeder section. A feeder section will have varying magnitude $d_{n\text{-}k}$ for various load points. Hence overall importance of a section for all the load point is calculated as follows

$$cf_n = \sum_{k=1}^{NLP} W_k \cdot d_{n\text{-}k} \tag{10}$$

where

cf_n is weighted cumulative DIF of nth section (WCDIF$_n$).

NLP denotes total number of load points.

W_k is weighting factor of kth load point.

A differentiation in $d_{n\text{-}k}$ has been obtained by weighting factor W_k. This weighting factor is fraction of total average load connected at kth load point and defined as follows

$$W_k = \frac{L_k}{\sum_{j=1}^{NLP} L_j} \tag{11}$$

where L_k and L_j are average loads at kth and jth load point

Further not only magnitude of load but other factors may also be considered in deciding the weighting factors e.g. socio-economic factors, nature of load etc. Magnitude of weighted cumulative diagnostic importance factor (WCDIF$_n$), cf_n gives its importance for improvement of reliability by intensifying maintenance measures. Hence a selection list based on the values of cf_n is prepared for prioritization of maintenance activities.

It is stressed here that calculation of $d_{n\text{-}k}$, using Eq. (9) involves calculation of unavailabilities at load points. Modern distribution systems may contain distributed generation (DG) at load points and its effect on unavailability calculations must be included. Hence next section gives modeling aspects for calculating unavailabilities at load points incorporating DG.

Determination of DIF of a section for load point having DG

Unavailability at the load point where DG is available is calculated in a different manner. The modeling aspect for such calculation have been presented by Arya et al. [19] and further used in Ref. [20]. Addition of DG affects the reliability performance of the system. It is well established that when a supply system e.g. DG is added in standby mode its reliability indices gets modified. In this section this has been modeled as equivalent network at load points. The distribution system is replaced by single component at load point having equivalent failure rates ($\lambda_{eq\text{-}k}$) and equivalent interruption duration ($r_{eq\text{-}k}$) accounting effect of DG. Various types of DG facilities are available depending on the suitability of location of load points. These types may include combined heat and power (CHP) systems, wind energy conversion systems, solar photovoltaic systems, small scale hydroelectric generation, or other renewable energy sources storage devices [21]. Irrespective of type

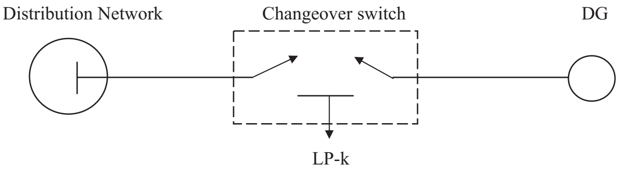

Fig. 1. Configuration at load point containing DG (LP-*k*).

of DG present one requires only failure rate and average repair time of it. DG in this paper has been considered in standby mode whose equivalent reliability network has been shown in Fig. 2. If one considers the DG in active parallel mode then modeling is simple and equivalent reliability network will be as shown in Fig. 2(a). This will not require any restoration time and failure rate of change over switch. In this paper standby mode is preferred due to the fact that energy purchased from private DG owners may be costlier than the energy supplied by main distribution source and hence an additional cost may be involved [19,21]. The typical situation has been shown in Fig. 1 where DG is in standby mode in addition to supply availability from a distribution network. The changeover switch is replaced by its failure rate (λ_{sw}) and restoration time (s). The resulting reliability network at load point with DG is obtained as given in Fig. 2. Reliability network of Fig. 2 is reduced to single component using series–parallel relations (7) and (8) and following relations for equivalent failure rate ($\lambda_{eq\text{-}k}$) and repair time ($r_{eq\text{-}k}$) are obtained and written as follows [19]

$$\lambda_{eq\text{-}k} = \lambda_{sys\text{-}k} \cdot \lambda_{dg\text{-}k}(r_{sys\text{-}k} + r_{dg\text{-}k}) + \lambda_{sw\text{-}k} \tag{12}$$

$$r_{eq\text{-}k} = \frac{\lambda_{sys\text{-}k} \cdot \lambda_{dg\text{-}k} \cdot r_{sys\text{-}k} + \lambda_{sw\text{-}k} \cdot s_k}{\lambda_{sys\text{-}k} \cdot \lambda_{dg\text{-}k}(r_{sys\text{-}k} + r_{dg\text{-}k}) + \lambda_{sw\text{-}k}} \tag{13}$$

Hence unavailability at load point having DG is calculated using relation (5) as

$$\widehat{U}_{LP\text{-}k} = \lambda_{eq\text{-}k} \cdot r_{eq\text{-}k} \tag{14}$$

Further at the LP having DG, DIF is obtained as

$$d_{n\text{-}k} = \frac{\widehat{U}_{LP\text{-}k}(\bar{n})}{\widehat{U}_{LP\text{-}k}} \cdot U_n \tag{15}$$

In above relations

$\lambda_{eq\text{-}k}$ equivalent failure rate at *k*th load point with DG
$r_{eq\text{-}k}$ equivalent interruption duration at *k*th load point with DG
$\widehat{U}_{LP\text{-}k}$ unavailability at *k*th load point accounting DG
$\widehat{U}_{LP\text{-}k}(\bar{n})$ unavailability at *k*th load point accounting DG and calculated using (12) and (13) assuming *n*th component has failed
$\lambda_{sys\text{-}k}$ failure rate at *k*th load point without DG
$\lambda_{dg\text{-}k}$ failure rate of DG at load point *k*
$r_{sys\text{-}k}$ interruption duration at *k*th load point without DG
$\lambda_{sw\text{-}k}$ failure rate of changeover switch at load point *k*
$r_{dg\text{-}k}$ repair time of DG al load point *k*
s_k restoration time of changeover switch at load point *k*

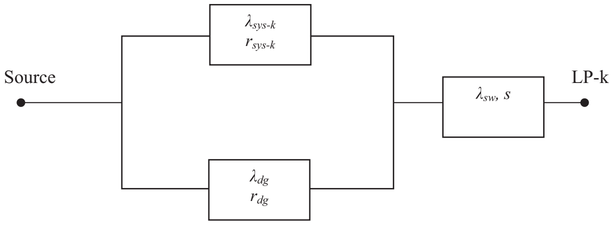

Fig. 2. Equivalent reliability network with DG in standby mode at LP-*k*.

Hence relations (12)–(15) are used to evaluate DIF of a section at a load point involving DG. Next section presents computational algorithm for preparing ranking list for prioritization of maintenance activities.

Computational algorithm

Relations for computing system unavailability with and without DG were developed which are to be used for computing weighted cumulative diagnostic importance factor, cf_n for all feeder sections. Based on these magnitudes ranking list for prioritizing maintenance activities for feeder sections is prepared. The sequence of computation is given as follows:

Step-1 Data Input: (i) λ_n, r_n for each section (ii) system configuration for each load point (iii) average load at each load point (iv) $\lambda_{dg\text{-}k}$, $r_{dg\text{-}k}$ for DG at load points (v) failure rate of change over switch, $\lambda_{sw\text{-}k}$, and its restoration time s_k.
Step-2 Determine unavailability U_n, for each feeder section using relation (5).
Step-3 Calculate weighting factor W_k for load points using relation (11).
Step-4 Calculate unavailability, $U_{LP\text{-}k}$, using relation (7) and (8) for all the load points without DG.
Step-5 Evaluate unavailability, $\widehat{U}_{LP\text{-}k}$, at the load point having DG using relations (12)–(14).
Step-6 Initialize feeder section, $n = 1$.
Step-7 Initialize load point, $k = 1$.
Step-8 Calculate DIF, $d_{n\text{-}k}$, using relation (9) if the load point k does not have DG facility. If the load point has DG facility, calculate $d_{n\text{-}k}$ using relation (15).
Step-9 Increment: $k = k + 1$.
Step-10 If $k > \text{NLP}$, then go to Step-11, otherwise repeat from Step-8.
Step-11 Calculate WCDIF, cf_n using relation (10)
Step-12 Increment: $n = n + 1$.
Step-13 If $n > \text{NC}$, then go to Step-14, otherwise repeat from Step-7.
Step-14 Prepare a ranking list by sorting the magnitudes, cf_n, $n = 1,\ldots,\text{NC}$ in decreasing order.

Results and discussions

The developed algorithm has been implemented on two test systems i.e. radial and mesh.

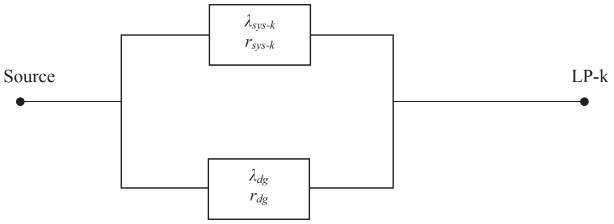

Fig. 2(a). Equivalent reliability network with DG in active parallel mode at LP-*k*.

Table 1
System data for sample radial distribution system of Fig. 3.

Distributor segment	#1	#2	#3	#4	#5	#6	#7
λ_j^0/year	0.4	0.2	0.3	0.5	0.2	0.1	0.1
Average repair time r_j^0 (h)	10	9	12	20	15	8	12
Unavailability (h/year)	4	1.8	3.6	10	3	0.8	1.2

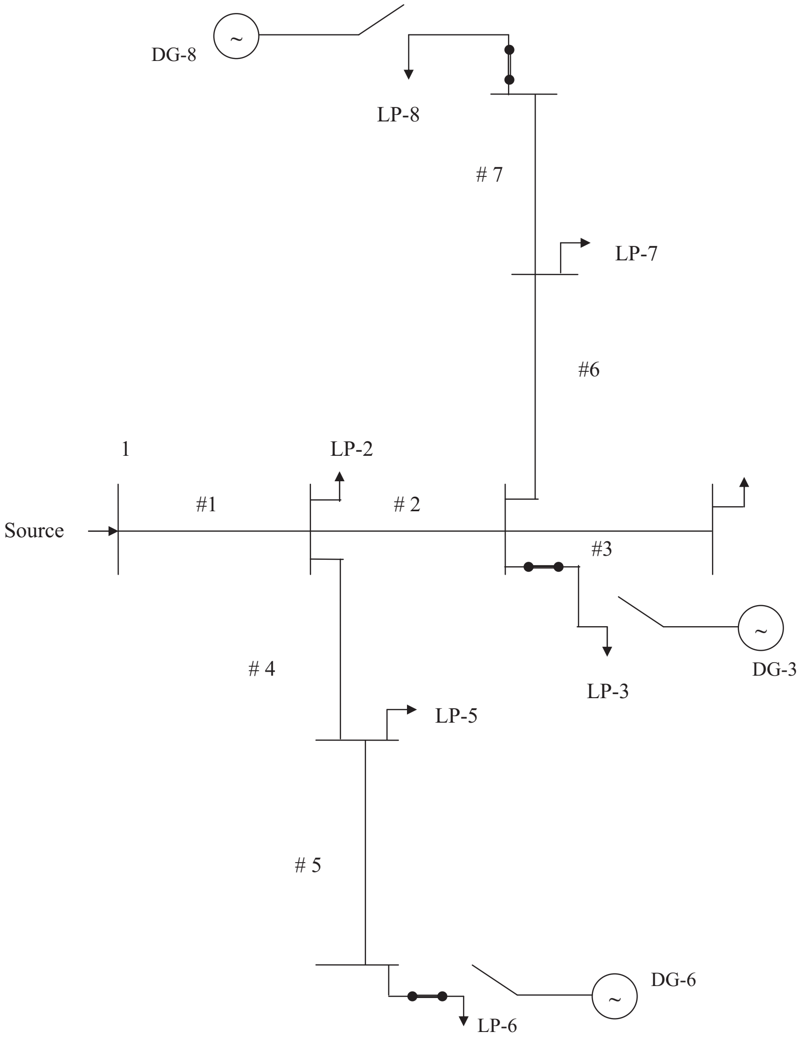

Fig. 3. Radial distribution system with DG at selected load points.

Table 2
Average load at load points for radial distribution system of Fig. 3.

Load point LP-k	2	3	4	5	6	7	8
Average load, L_k, kW	1000	700	400	500	300	200	150

Table 3
Failure rate and average down time for distributed generation alongwith failure rate and service restoration time of manual switch for radial distribution system of Fig. 3.

S. no.	DG	Failure rate λ_{dg} (1/year)	Down time r_{dg} (h)	Failure rate of manual switch λ_{sw} (1/year)	Service restoration time s (h)
1	DG-3	1.50	15.78	0.5	1.5
2	DG-6	1.75	18.68	0.5	1.5
3	DG-8	2.00	20.61	0.5	1.5

Case-1 Radial distribution system

The system data have been taken from Refs. [19,20] and provided in Table 1. The schematic representation of the system is shown in Fig. 3. The distribution system consists of seven load points and contains seven distribution sections. The system has DG at load points 3, 6, and 8. Table 2 provides average load at all the load points. Table 3 gives Failure rate and average down time for distributed generation alongwith failure rate and service restoration time of changeover switch. Unavailabilities at load points 2, 4, 5, and 7 have been calculated using usual relations (7) and (8) successively whereas unavailabilities at load points involving DG have been evaluated using relations (12)–(14) in addition to relation (7) and (8). Table 4 gives ranking list of feeder sections for prioritization of maintenance activities. Top three ranked feeder sections are 1, 4, and 3. Last column of Table 4 gives the normalized WCDIF$_n$ with respect to highest magnitude. Further it is interesting to note that WCDIF$_n$ corresponding to section #5 and #7 are practically zero. This is due to fact that these sections

Table 4
Ranking list of feeder section based on weighted cumulative diagnostic importance factor (WCDIF$_n$) for radial distribution system of Fig. 3.

S. no.	Rank	Feeder section, n	WCDIF$_n$	Normalized WCDIF$_n$
1	1	1	3865.94170	1.000
2	2	4	962.63736	0.249
3	3	3	412.90998	0.107
4	4	2	353.47597	0.091
5	5	6	65.342657	0.017
6	6	5	0.00000	0.000
7	7	7	0.00000	0.000

Table 5
System data for meshed distribution system of Fig. 4.

Section	Failure rate (1/year) λ	Repair time (h) r	Unavailability (h/year), U_n $\lambda \times r$
1	0.310400	10.28041	3.191039264
2	0.127600	05.01066	0.639360216
3	0.070000	33.98571	2.3789997
4	0.013520	14.33550	0.19381596
5	0.084600	10.55745	0.89316027
6	0.017640	13.55510	0.239111964
7	0.084600	10.55745	0.89316027
8	0.078000	11.02308	0.85980024
9	0.084600	15.80000	1.33668
10	0.069000	27.56522	1.90200018
11	0.155200	06.86598	1.065600096
12	0.155200	06.86598	1.065600096
13	0.070000	33.98571	2.3789997
14	0.013520	14.33550	0.19381596
15	0.156100	10.71494	1.672602134
16	0.017640	13.55510	0.239111964
17	0.078000	11.02308	0.85980024
18	0.084600	10.55744	0.893159424

connect supply to load points 6 and 8 respectively. But load points 6 and 8 are also connected to DG and thus alternative sources are available. So these two sections have least importance as far as additional maintenance activities are concerned.

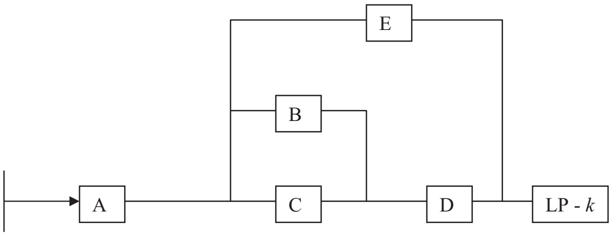

Fig. 5. Reliability network of the meshed distribution system.

Case-2 Meshed distribution system

The system data have been taken from Ref. [5] and provided in Table 5. Fig. 4 represents the system configuration of meshed distribution system. DG have been assumed at LP-1 and LP-4. Fig. 5 gives reliability network of the meshed distribution system. System consists of 4 load points and 18 sections. Table 6 provides sections involved in each sub-system for LP-1 to LP-4. Average load at load points are given in Table 7. Table 8 provides failure rate and

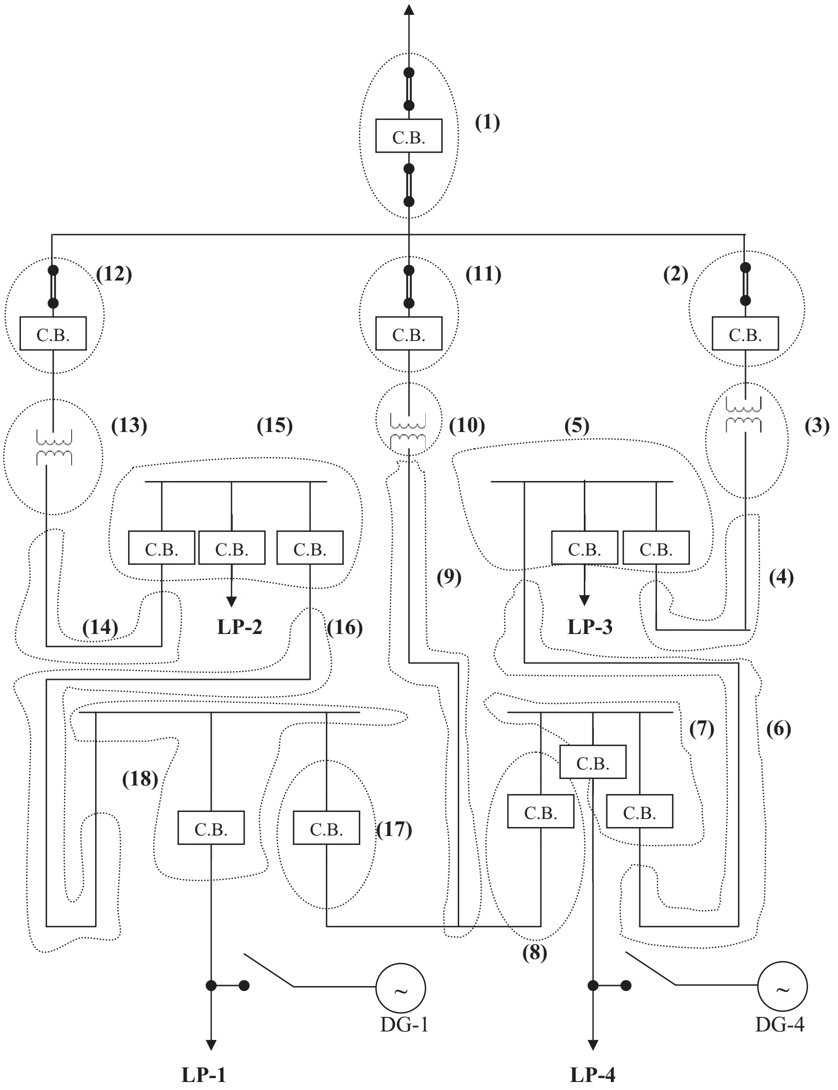

Fig. 4. Meshed distribution system with DG at selected load points.

average down time for distributed generation alongwith failure rate and service restoration time of changeover switch. Unavailabilities at load points 2 and 3 have been calculated using usual relations (7) and (8) successively whereas unavailabilities at load points 1 and 4 involving DG have been evaluated using relations (12)–(14) in addition to relation (7) and (8). Table 9 gives ranking for prioritization of maintenance activities for all the feeder section. Top three ranked feeder sections are 1, 15, and 5. Last column of Table 9 gives normalized WCDIF*n* with respect to highest magnitude of WCDIF$_n$.

Table 6
Sections involved in each sub-system for LP-1 to LP-4 of Fig. 5.

Load points	Blocks	Sections involved
LP-1	A	1, 18
	B	9, 10, 11
	C	2, 3, 4, 5, 6, 7, 8
	D	17
	E	12, 13, 14, 15, 16
LP-2	A	1, 15
	B	9, 10, 11
	C	2, 3, 4, 5, 6, 7, 8
	D	16, 17, 18
	E	12, 13, 14
LP-3	A	1, 5
	B	9, 10, 11
	C	12, 13, 14, 15, 16, 17, 18
	D	6, 7, 8
	E	2, 3, 4
LP-4	A	1, 7
	B	9, 10, 11
	C	12, 13, 14, 15, 16, 17, 18
	D	8
	E	2, 3, 4, 5, 6

Table 7
Average load at load points for meshed distribution system of Fig. 4.

Load point LP-*k*	1	2	3	4
Average load, L_k, kW	1500	1000	1000	2000

Table 8
Failure rate and average down time for distributed generation for meshed distribution system of Fig. 4.

S. no.	DG	Failure rate λ_{dg} (1/year)	Down time r_{dg} (h)	Failure rate of switch λ_{sw} (1/year)	Service restoration time *s* (h)
1	DG-1	1.50	15.78	0.5	1.5
2	DG-4	2.00	20.61	0.5	1.5

Table 9
Ranking list of feeder section based on weighted cumulative diagnostic importance factor (WCDIF$_n$) for meshed distribution system of Fig. 4.

S. no.	Rank	Feeder section, *n*	WCDIF$_n$	Normalized WCDIF$_n$
1	1	1	160.72982	1.00000
2	2	15	24.78741	0.15422
3	3	5	12.77939	0.07951
4	4	7	9.85150	0.06129
5	5	18	9.20175	0.05725
6	6	3	0.06182	0.00038
7	7	13	0.06177	0.00038
8	8	10	0.04471	0.00028
9	9	8	0.03398	0.00021
10	10	17	0.03386	0.00021
11	11	9	0.03142	0.00020
12	12	12	0.02767	0.00017
13	13	11	0.02505	0.00016
14	14	2	0.01661	0.00010
15	15	16	0.00810	0.00005
16	16	6	0.00804	0.00005
17	17	4	0.00504	0.00003
18	18	14	0.00503	0.00003

Hence ranking list provides a guideline for selecting feeder sections for achieving the desired reliability goal. This also signifies that major contribution for achieving reliability goal is due to intensifying maintenance activities at feeder section which are on the top in Tables 4 and 9.

Conclusion

Achieving reliability goal in terms of indices has been important issue. The goal is mainly achieved for the existing system by intensifying maintenance efforts. It is important to invest money where it is most effective. Hence in this paper a methodology has been developed for selecting feeders sections for maintenance. A severity index, WCDIF$_n$, has been developed for ranking the outage of a section accounting the presence of DG and due weightage to the loads. The algorithm of this paper is of importance for selecting minimum number of feeder sections for maintenance activities.

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