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Reliability evaluation of ring and triple-bus distribution systems – General solution for *n*-feeder configurations

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ABSTRACT

Reliability of power distribution schemes can always be improved at the expense of cost and size. The addition of extra paths proves to increase the continuity of supply but it adds more complexity to the system and the system structure may become very complex. In complex distribution system, there are several difficulties in reliability evaluation: reliability, availability and MTBF. Subsystems may follow various failure distributions; subsystems may conform to arbitrary failure and repair distributions for maintained systems; the failure data of subsystems are sometimes not sufficient and reliability test sample sizes tend to be small. Hence, simplification for the reliability inputs, electrical parameters and load data are needed.

In this paper, a simple reliability-oriented method to calculate some complex distribution system reliability such as ring and triple-bus systems is presented. The major purpose is to simplify the reliability inputs, electrical parameters and load data. The simplification assumes that the repair time here is a random variable, and certain values of repair times are usually so small that can be neglected at each load point. Therefore complete reliability analysis with repair time omission and modified availability (reliability) and unavailability (h/year) can be obtained at each load feeder point using the simple methods of probability and the theory of sets. This approach is dealt with in this paper and a general formula for calculation of *n*-feeder ring-bus reliability is developed and applied to some practical distribution schemes.

In an *n*-feeder ring-bus system, it is found that the reliability of each feeder is decreased by increasing the number of the outgoing feeders, so it is recommended that the total number of the outgoing feeders in this scheme should be carefully decided.

A meshed network (triple-bus scheme), which makes it possible to serve the consumers from three sources is also considered. With this scheme, the reliability of the outgoing feeders is largely improved as compared with the ring-bus system.

1. Introduction

The dependence of society on modern complex electrical distribution system has emphasized the need for objective and quantitative service reliability analysis. A good power distribution system must operate at an adequate level of reliability. Therefore, the design philosophy of distribution networks has always recognized the risk involved due to the possibility of supply interruption. The pertinent literature shows that, extensive work has been carried out in this area for the purpose of developing models and techniques suitable for reliability evaluation of power distributers. Among these well known and conventional methods are, the cut set, tie set, event tree, fault tree and decomposition approach [1–11]. More recently, new methods such as Bayesian network (BN) algorithms and interval analysis techniques are also used to perform reliability analysis of complex distribution systems [12,13]. However, these approaches still not given mathematical formulae that can be generalized for the most practical systems used in power distributers, and in many cases are complicated to be solved. Therefore, the finding of an efficient and convenient way of power distribution reliability calculation is still needed.

In distribution reliability studies a detailed model of the substation feeder and all of its sub-feeder elements are usually involved. Load point indices are gathered at each of the customer locations and composite system wide indices are found based on all of the load point indices. In most of these reliability studies there is little detail given for the substation and it may be either represented by a transformer and switchgear or just bus bar and switchgear. Including a detailed substation model in distribution reliability studies can greatly increase the size and complexity of the entire system model. One possible solution to this problem is to separate

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the substation reliability analysis from the distribution feeder reliability analysis [14]. This would allow the use of specialized tools on the substation reliability analysis, while keeping the size and complexity down.

In this paper, a simple reliability-oriented method to calculate some complex distribution system reliability such as ring and triple-bus systems is presented. The major purpose is to simplify the reliability inputs, electrical parameters and load data. The simplifications involved are base on the fact that, in radial distribution systems, optimal values of repair times and failure rates of each section are important reliability indices to be considered [15]. However, in complex systems consist of ring or mesh configurations, a distributor segment which has failure rate and repair time, that decide the mean up time and mean down time at load points, the repair time here is a random variable, and in many cases certain values of repair times are so small that can be neglected at each load point [16]. Furthermore, the distribution network components and feeders are almost exclusively underground/indoor type and hence the effect of adverse (stormy) weather on components reliability does not to be taken into consideration. Hence, the failure rates are treated as constant under exponential recovery models and the effect of components with time-varying failure rates on distribution reliability can be neglected [17]. Therefore complete reliability analysis with repair time omission and modified availability (reliability) and unavailability (h/year) may be obtained at each load feeder point using the simple methods of probability and the theory of sets.

With the above non-standard assumptions, a general ring-main formula for feeder's reliability calculation is developed and applied successfully to several types of practical distribution schemes. Also more complex distribution systems such as the mesh system with three bus bars are considered. General formula for the triple-bus system reliability calculation is also developed and applied to multi-feeder system.

2. The basic single-bus bar scheme

The development of the general formulae for the ring and triple-bus systems is started with studying of the simplest and cheapest type of practical switchgear connection which is the single-bus bar scheme shown in Fig. 1. This scheme consists of two isolators (*A* and *C*), and one circuit breaker (*B*). The complete reliability analysis for this scheme with repair time omission and modified availability (reliability) which is considered as the probability of success (*P*) of a system or component may be obtained using the simple methods of probability and theory of sets. Hence, the resultant system of Fig. 1 is available if the three elements are simultaneously in operation state, i.e., the probability of success of the system is

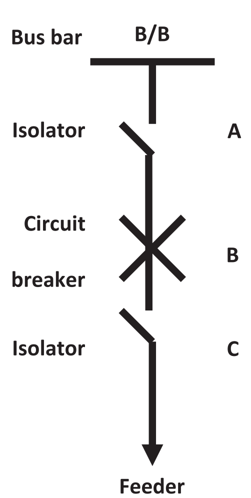

Fig. 1. Single-bus bar scheme.

$$P_I = P(A \cap B \cap C) = P_a P_b P_c \tag{1}$$

where P_I is the probability of success of the system; P_a is the probability of success of the isolator *A*; P_b is the probability of success of the circuit breaker *B*; and P_c is the probability of success of the isolator *C*.

In order to adopt an appropriate reliability model for this system, it is well known that, the reliability model can be categorized into two groups: reliability and availability. Of the two, availability model tend to be more complex. However, system model may be simplified dramatically to a manageable scale by focusing on upper or lower bound of system reliability or availability, by neglecting event with very small probability. The outcomes usually come to a very simple system model that approximately represents the system behavior and this is what has been done in this paper. By omitting the repair time of the system components, due to its small value and assuming the system is not repairable, the system reliability can always be derived by Boolean technique. Hence, system reliability can be expressed as a function of component reliability, or

$$R_s = f(R_1, R_2, \ldots, R_n) \tag{2}$$

where R_i is the reliability of the *i*th component in the system. Hence the steady-state or average availability here can be considered simply as the reliability and vice versa. Hence the reliability of the single-bus bar scheme of Fig. 1 will be

$$R_I = P_I = R_a R_b R_c \tag{3}$$

The probability of load point failure (here we consider it as a feeder point failure) can be found as

$$Q = 1 - P \tag{4}$$

Hence, the probability of system failure (unreliability) at the load point can be found using Eq. (4). Thus, if the assumption is made that there are no distribution component constrains and that connection to 100% reliable bus bar is the sole criterion then,

$$Q_s = 1 - R_s \tag{5}$$

and the unreliability Q_I of single bus bar scheme is thus given by

$$\begin{aligned} Q_I &= 1 - R_I \; 1 - R_a R_b R_c = 1 - (1 - Q_a)(1 - Q_b)(1 - Q_c) \\ &= Q_a + Q_b + Q_c - Q_a Q_b - Q_a Q_c - Q_b Q_c - Q_a Q_b Q_c \end{aligned} \tag{6}$$

If the two isolators *A* and *C* are identical, then $R_a = R_c$ and $Q_a = Q_c$, and

$$R_I = R_a^2 R_b \tag{7}$$

and

$$Q_I = 2Q_a + Q_b - Q_a^2 - 2Q_a Q_b + Q_a^2 Qb \tag{8}$$

The yearly expected outage time in hours of this system may be given by the following formula:

$$T_{fI} = 8760\, Q_I \text{ Hours} \tag{9}$$

3. General solution of *n*-feeder ring-bus schemes

The ring bus bar scheme has the appearance of possessing almost all the desirable features. As the ring is closed, each feeder has two sources of supply, and any circuit breaker may be taken out of service for repair or maintenance without affecting the supply [18]. However, in distribution systems with more than one source of supply, as in the case of a ring-bus system, the scheduled

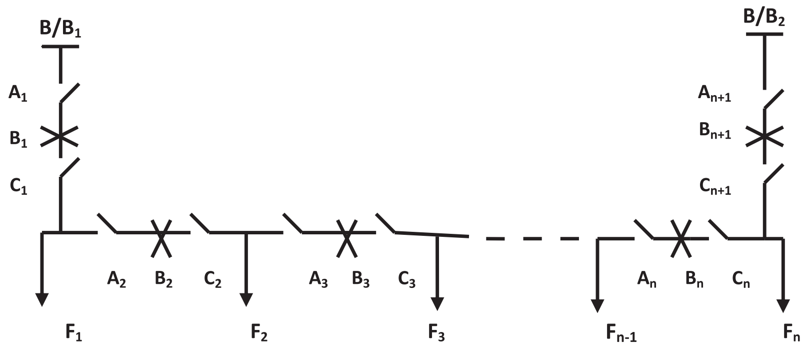

Fig. 2. Ring-bus system with *n*-outgoing power feeders.

maintenance is not usually included in the reliability evaluation of load point due to the fact that customers can be notified in advance or alternative arrangement can be made and therefore the load point is outaged deliberately, which cannot be considered as a random occurring event [19]. In addition, uncoordinated maintenance is usually performed, by many utilities, on each component in a distribution system for not more than 8 h and in many cases each component of a given branch is maintained simultaneously. This means that the total exposure time in a year during which component in another branch may fail is reduced and therefore the probability of system failure is also reduced. Hence, it is obvious that, inclusion of maintenance in some distribution systems such as ring-bus system is not so important.

Consider now the scheme shown in Fig. 2, by neglecting the repair time and maintenance, the probability of successes of feeder 1 can be simply found as follows:

$$\begin{aligned} P_{F1} &= P[(A_1 \cap B_1 \cap C_1) U (A_2 \cap B_2 \cap C_2 \cap A_3 \cap B_3 \cap C_3 \cap \cdots \cap A_{n+1} \\ &\quad \cap B_{n+1} \cap C_{n+1})] \\ &= P(A_1 \cap B_1 \cap C_1) + P(A_2 \cap B_2 \cap C_2 \cap A_3 \cap B_3 \cap C_3 \cap \cdots \cap A_{n+1} \\ &\quad \cap B_{n+1} \cap C_{n+1}) - P(A_1 \cap B_1 \cap C_1 \cap A_2 \cap B_2 \cap C_2 \cap A_3 \cap B_3 \cap C_3 \\ &\quad \cap \cdots \cap A_{n+1} \cap B_{n+1} \cap C_{n+1}) \\ &= P_{a1}P_{b1}P_{c1} + P_{a2}P_{b2}P_{c2} + P_{a3}P_{b3}P_{c3} + \cdots + P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \\ &\quad - P_{a1}P_{b1}P_{c1}P_{a2}P_{b2}P_{c2}P_{a3}P_{b3}P_{c3} \cdots P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \end{aligned}$$

Now, if $P_{a1} = P_{a2} = P_{a3} = \cdots = P_{a(n+1)} = P_a$, $P_{b1} = P_{b1} = P_{b1} = \cdots P_{b(n+1)} = P_b$, and $P_{c1} = P_{c2} = P_{c3} = \cdots \; P_{c(n+1)} = P_c$, keeping in mind that $P_l = P_a^2 P_b$ therefore,

$$P_{F1} = P_l + P_l^n - P_l^{(n+1)} \tag{10}$$

Also the probability of successes of feeder 2 is given by:

$$\begin{aligned} P_{F2} &= P[(A1 \cap B_1 \cap C_1) \cap (A_2 \cap B_2 \cap C_2) U (A_3 \cap B_3 \cap C_3 \cap \cdots \cap A_{n+1} \\ &\quad \cap B_{n+1} \cap C_{n+1})] \\ &= P(A1 \cap B_1 \cap C_1 \cap A_2 \cap B_2 \cap C_2) + P(A_3 \cap B_3 \cap C_3 \cap \cdots \cap A_{n+1} \\ &\quad \cap B_{n+1} \cap C_{n+1}) - P(A1 \cap B_1 \cap C_1 \cap A_2 \cap B_2 \cap C_2 \cap A_3 \cap B_3 \cap C_3 \\ &\quad \cap \cdots \cap A_{n+1} \cap B_{n+1} \cap C_{n+1}) \\ &= P_{a1}P_{b1}P_{c1}P_{a2}P_{b2}P_{c2} + P_{a3}P_{b3}P_{c3} \cdots P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \\ &\quad - P_{a1}P_{b1}P_{c1}P_{a2}P_{b2}P_{c2}P_{a3}P_{b3}P_{c3} \cdots P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \end{aligned}$$

Similarly,

$$P_{F2} = P_l^2 + P_l^{(n-1)} - P_l^{(n+1)} \tag{11}$$

Now, for any feeder k in the ring system, the probability of successes can be found as,

$$\begin{aligned} P_{Fk} &= P[(A_1 \cap B_1 \cap C_1 \cap A_2 \cap B_2 \cap C_2 \cap \cdots \cap A_k \cap B_k \cap C_k) U (A_{k+1} \\ &\quad \cap B_{k+1} \cap C_{k+1} \cap \cdots \cap A_{n+1} \cap B_{n+1} \cap C_{n+1})] \\ &= P(A_1 \cap B_1 \cap C_1 \cap A_2 \cap B_2 \cap C_2 \cap \cdots A_k \cap B_k \cap C_k) + P(A_{k+1} \\ &\quad \cap B_{k+1} \cap C_{k+1} \cap \cdots \cap A_{n+1} \cap B_{n+1} \cap C_{n+1}) - P(A_1 \cap B_1 \cap C_1 \cap A_2 \\ &\quad \cap B_2 \cap C_2 \cap \cdots A_k \cap B_k \cap C_k \cap \cdots \cap A_{n+1} \cap B_{n+1} \cap C_{n+1}) \\ &= P_{a1}P_{b1}P_{c1}P_{a2}P_{b2}P_{c2} \cdots P_{ak}P_{bk}P_{ck} \\ &\quad + P_{ak+1}P_{bk+1}P_{ck+1} \cdots P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \\ &\quad - P_{a1}P_{b1}P_{c1}P_{a2}P_{b2}P_{c2} \cdots P_{ak}P_{bk}P_{ck} \cdots P_{a(n+1)}P_{b(n+1)}P_{c(n+1)} \end{aligned}$$

Using the same assumptions given in Eq. (10) above we get,

$$P_{Fk} = P_l^k + P_l^{(n+1-k)} - P_l^{(n+1)} \tag{12}$$

In terms of reliability, in general, the *j*th feeder reliability in an *n*-feeder ring-bus system can be obtained from the following general formula:

$$R_j = R_l^j + R_l^{(n+1-j)} - R_l^{(n+1)} \tag{13}$$

It is worth to be noted that, the reliability indices are usually estimated for load points (bus bars) but in our case, the reliability of the outgoing feeders is only considered. Hence the failure rate and repair time concepts are not applicable, and the unreliability and the outage time in hours per year, as reliability indices, are fairly applicable. Therefore, the unreliability of the *j*th feeder is given by,

$$\begin{aligned} Q_j &= 1 - R_j = 1 - R_l^j - R_l^{(n+1-j)} + R_l^{(n+1)} \\ &= (1 - R_l^j)(1 - R_l^{(n+1-j)}) \end{aligned} \tag{14}$$

and the yearly expected outage time in hours for the *j*th feeder is

$$T_{fj} = 8760\ Q_j = 8760(1 - R_l^j)(1 - R_l^{(n+1-j)}) \tag{15}$$

Eqs. (13)–(15) are programmed and worked on Matlab program in order to study the reliability characteristics for each feeder in the ring system when the number of the feeders is varied. The results are given in Tables 1 and 2.

The effect of variation of the number of feeders in the system on the reliabilities on the individual feeders is shown in Fig. 3 (system with 9 feeders). It is noticed that the reliability of each feeder is decreased as the number of the outgoing feeders is increased. Also it can be seen that the most reliable feeders are those which are near the feeding points, feeders 1 and 9 in this case. Fig. 4 shows the variation of the yearly expected feeder's outage time for different values of *n*.

Table 1
Variation of the feeder's reliability of a 3-feeder ring system with the individual element reliability.

Element reliability	Feeder No. 1		Feeder No. 2		Feeder No. 3	
	R_{F1}	T_{F1}	R_{F2}	T_{F2}	R_{F3}	T_{F3}
0.9000	0.83399	1454.241	0.78045	1923.23	0.83390	1454.241
0.9900	0.997431	22.503	0.99657	30.000	0.997431	22.503
0.9990	0.999973	0.237050	0.99996	0.314326	0.999973	0.237070
0.9999	0.999999	0.002088	0.99999	0.004177	0.9999999	0.002088

Table 2
Variation of feeder's outage time for a 7-feeder ring system with element reliability = 0.9900.

n	Feeder-1	Feeder-2	Feeder-3	Feeder-4	Feeder-5	Feeder-6	Feeder-7
Outage time in hours/year $T_F = 8760\ (1-R_F)$							
1	7.72866	–	–	–	–	–	–
2	15.227	15.227	–	–	–	–	–
3	22.503	30.000	22.503	–	–	–	–
4	29.562	44.336	44.336	29.562	–	–	–
5	36.413	58.245	65.521	58.245	36.413	–	–
6	43.057	71.74	86.0773	86.0773	71.74	43.057	–
7	49.507	84.837	106.024	113.081	106.024	84.837	49.507

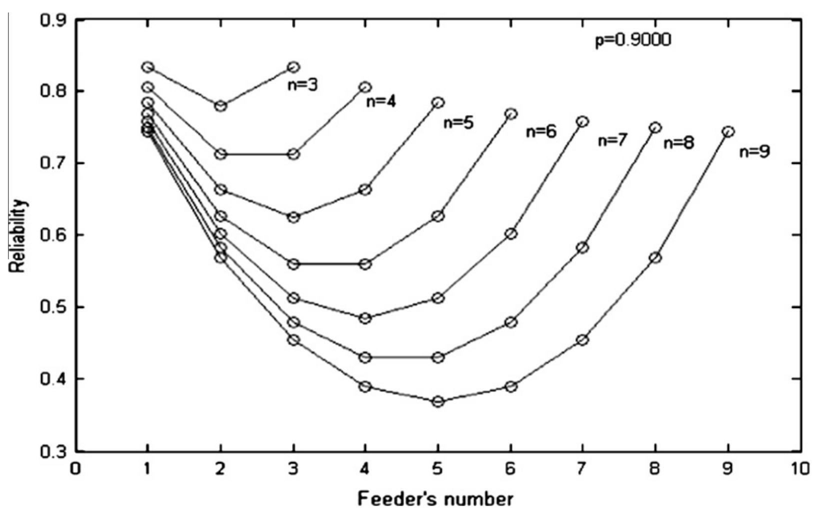

Fig. 3. Reliability variation of individual feeder with the number of feeders in a ring-bus system.

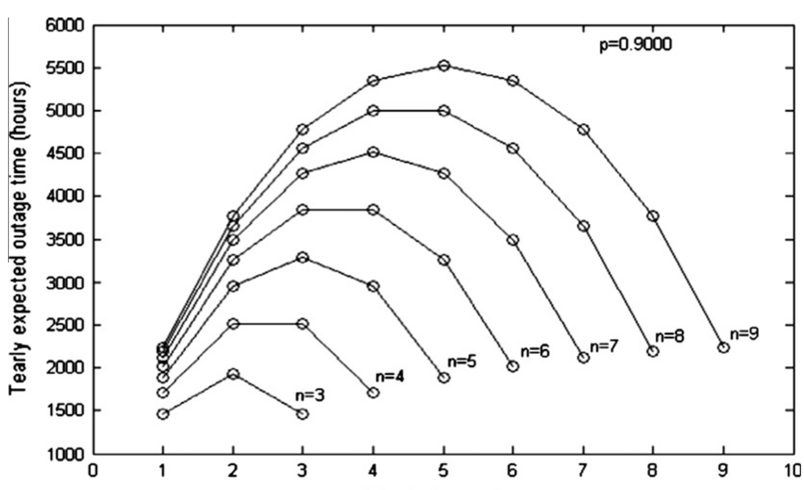

Fig. 4. Variation of yearly expected feeder outage time for different values of n.

4. Practical applications of the general ring-bus formulae

The general ring-bus reliability formulae given in Eqs. (13)–(15) are now applied to different practical power supply schemes in order to find the reliability, unreliability and outage time of the individual system feeders. The application of these formulae for these schemes is done by replacing (n) in Eq. (13) by its actual number which represents the number of feeders supplying loads in the scheme; this may be done as follows:

(1) For the double bus bar double breaker scheme shown in Fig. 5, the general ring-bus reliability formula can be applied directly by setting $n = 1$ (since the number of feeders = 1) and $j = 1$. The reliability of this scheme which may be designated by R_{II} is therefore,

$$R_{II} = 2R_I - R_I^2 \tag{16}$$

The unreliability of the system is given by

$$Q_{II} = 1 - R_{II} = 1 - 2R_I + R_I^2 \tag{17}$$

and the yearly expected outage time in hours is given by

$$T_{fII} = 8760\ Q_{II} = 8760(1 - R_I)^2 \tag{18}$$

(2) For the double bus bar with breaker and a half scheme shown in Fig. 6, the general ring bus formula can be applied by setting $n = 2$ (since the number of feeders = 2) and $j = 1, 2$. The reliability of feeders 1 and 2 in this scheme are therefore,

$$R_1 = R_2 = R_I + R_I^2 - R_I^3 \tag{19}$$

And the reliability of this scheme which may be designated by R_{III} is therefore,

$$R_{III} = R_I + R_I^2 - R_I^3 \tag{20}$$

The unreliability of the system is given by

$$Q_{III} = 1 - R_{III} = 1 - R_I - R_I^2 + R_I^3 \tag{21}$$

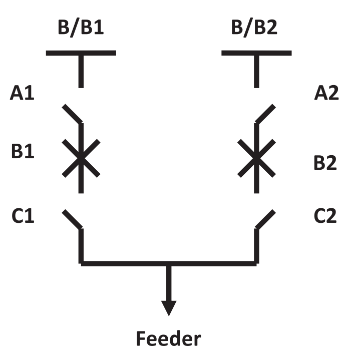

Fig. 5. Double-bus bar double-beaker scheme.

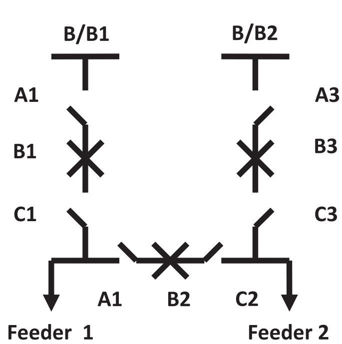

Fig. 6. Double-bus bar with breaker and a half scheme.

Table 3
System parameters for breaker and a half scheme.

Element reliability $R_a = R_b = R_c$	Feeders 1 and 2 reliability R_{III}	Yearly expected outage time in hours T_{fIII}
0.9000	0.873020	1112.342
0.9900	0.998261	15.22759
0.9990	0.999982	0. 158729
0.9999	0.999999	0.004177

and the yearly expected outage time in hours is given by

$$T_{fIII} = 8760\ Q_{III} = 8760(1 - R_I - R_I^2 + R_I^3) \tag{22}$$

Table 3 shows the reliability and the yearly expected outage time in hours for the double bus bar with breaker and a half scheme for different values of elements reliability.

5. The triple-bus distribution schemes (mesh systems)

The ring-bus schemes studied in previous section are not the only arrangement finding application. It is extensive practice to use many feeding source systems in the secondary networks. The interconnection of circuits is done when these are located in close proximity to each other, in this way three or more feeding sources are available.

Now, with the permanent addition of third source of power supply in any chosen point of a ring system, we obtain a simple meshed network (triple-bus scheme), which makes it possible to serve the consumers from three points. With this additional source, the reliability (availability) of the outgoing feeders in the ring system will be drastically improved.

In order to obtain a general mathematical reliability formulation for the outgoing feeders of a triple-bus scheme, consider the nth feeder three bus bar distribution network shown in Fig. 7.

Let:

System I which contains of one circuit breaker and two isolators are represented by a rectangle.

M_1, M_2, M_3 and S_i ($i = 1, 2, 3, \ldots, n$) each represents the series components as shown in Fig. 7. m = number of feeders between bus bars I and II where the second bus bar is installed. r = number of series components between bus bars II and III. n = total number of feeders where the third bus bar is installed, such that $n = r + m + 1$.

Now, for any feeder k in the system, the feeder is fed from the following paths,

- Path (1) = X through ($M_1 \cap S_1 \cap S_2 \cap S_3 \cap \cdots \cap S_{k-1}$)
- Path (2) = Y through ($M_2 \cap S_k \cap S_{k+1} \cap \cdots \cap S_{m-1}$)
- Path (3) = Z through ($M_3 \cap S_{n-1} \cap S_{n-2} \cap \cdots \cap S_k$)

and, feeder F_k is available if one or more of the above paths are available, and this is given by, (XUYUZ). The probability of this condition is:

$$P = P(X) + P(Y) + P(Z) - P(X \cap Y) - P(X \cap Z) - P(Y \cap Z) + P(X \cap Y \cap Z)$$

Therefore,

$$\begin{aligned} P_{Fk} = {} & P(M_1 \cap S_1 \cap S_2 \cap S_3 \cap \cdots \cap S_{k-1}) + P(M_2 \cap S_k \cap S_{k+1} \cap \cdots \\ & \cap S_{m-1}) + P(M_3 \cap S_{n-1} \cap S_{n-2} \cap \cdots \cap S_k) - P(M_1 \cap S_1 \cap S_2 \cap S_3 \\ & \cap \cdots \cap S_{k-1} \cap M_2 \cap S_k \cap S_{k+1} \cap \cdots \cap S_{m-1}) - P(M_1 \cap S_1 \cap S_2 \\ & \cap S_3 \cap \cdots \cap S_{k-1} \cap C \cap S_{n-1} \cap S_{n-2} \cap \cdots \cap S_k) - P(M_2 \cap S_k \cap S_{k+1} \\ & \cap \cdots \cap S_{m-1} \cap M_3 \cap S_{n-1} \cap S_{n-2} \cap \cdots \cap S_k) + P(M_1 \cap S_1 \cap S_2 \\ & \cap S_3 \cap \cdots \cap S_{k-1} \cap M_2 \cap S_k \cap S_{k+1} \cap \cdots \cap S_{m-1} \cap C \cap S_{n-1} \cap S_{n-2} \\ & \cap \cdots \cap S_k) \end{aligned}$$

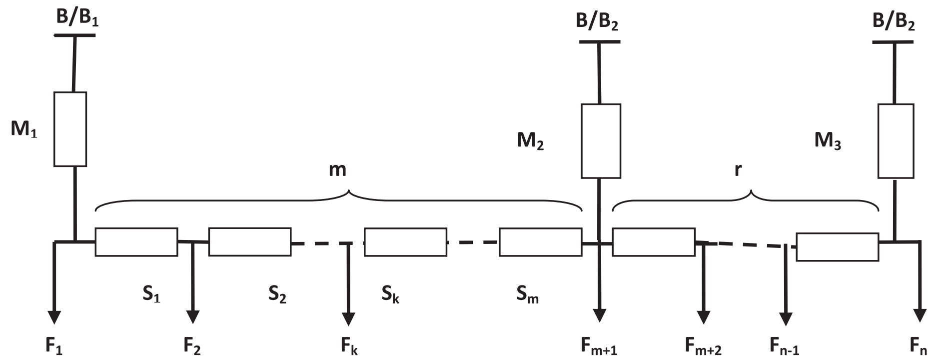

Fig. 7. Triple-bus system.

Table 4
Variation of the individual feeder availability of a 3-feeder triple-bus system with element reliability.

Element reliability	Feeder No. 1		Feeder No. 2		Feeder No. 3	
	R_{F1}	T_{f1}	R_{F2}	T_{F2}	R_{F3}	T_{F3}
0.9000	0.98829	102.57	0.99639	31.62	0.98829	102.57
0.9900	0.999898	0.89325	0.999996	0.03469	0.999898	0.89325
0.9990	0.999998	0.00877	0.999999	0.000035	0.999998	0.00877
0.9999	1.000000	0.00000	1.000000	0.000000	1.000000	0.00000

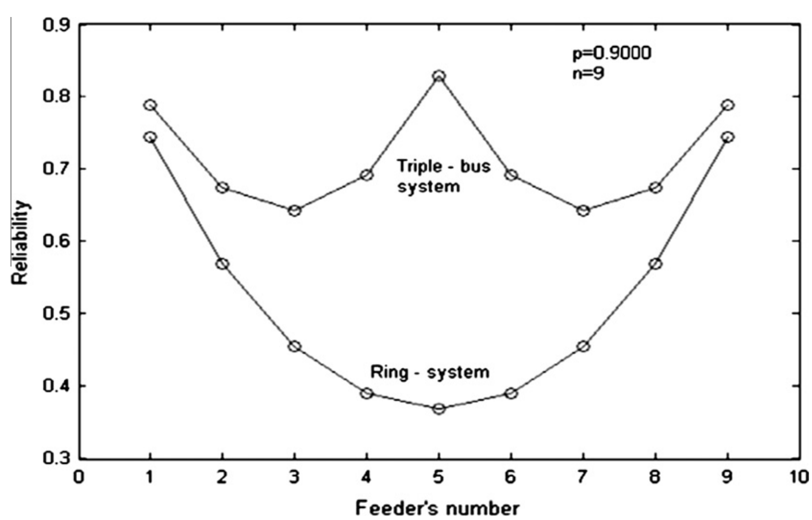

Fig. 8. Comparison between reliabilities of the individual feeders for ring-bus and triple-bus systems for $n = 9$.

Upon expansion and further simplification, it can be prove that for practical condition where $P(M_1) = P(M_2) = P(M_3) = P(S_i) = P_I$, then the probability of successes of feeder k is,

For $k \leqslant m$

$$P_{Fk} = P_I^k + P_I^{m-k+1} + P_I^{n-k+1} - P_I^{m+1} - P_I^{n+1} - P_I^{n-k+2} + P_I^{n+2} \tag{23}$$

For $k \geqslant m$

$$P_{Fk} = P_I^k + P_I^{k-m+1} + P_I^{n-k+1} - P_I^{k+1} - P_I^{n+1} - P_I^{n-m+2} + P_I^{n+2} \tag{24}$$

In general, the reliability of the jth feeder in an n-feeder triple-bus system, where the second bus bar is installed on the mth feeder can be obtained from the following general formulae:

For $j \leqslant m$

$$R_j = P_I^j + R_I^{m-j+1} + R_I^{n-j+1} - R_I^{m+1} - R_I^{n+1} - R_I^{n-j+2} + R_I^{n+2} \tag{25}$$

For $j \geqslant m$

$$R_j = P_I^j + R_I^{j-m+1} + R_I^{n-j+1} - R_I^{j+1} - R_I^{n+1} - R_I^{n-m+2} + R_I^{n+2} \tag{26}$$

The unreliability of the jth feeder is given by,

$$Q_j = 1 - R_j \tag{27}$$

and the yearly expected outage time in hours for the jth feeder is,

$$T_{fj} = 8760\ Q_j = 8760(1 - R_j) \tag{28}$$

Eqs. (25)–(28) are programmed on Matlab in order to study the reliability characteristics for each feeder in the three feeders triple-bus system to compare results with those of three feeders ring system given in Table 1. The results are given in Table 4. It is clear from Table 4 that the reliabilities of the individual feeders are largely improved, and the yearly expected outage times are drastically reduced as compared with the 3-feeder ring system values given in Tables 2 and 3 respectively.

The improvement in feeder's reliability in the triple-bus system as compared with ring-bus system is clearly shown in Fig. 8 for 9-feeder systems. It is clear that the reliabilities of all individual feeders $(1, 2, 3, \ldots, 9)$ are largely improved by adding the third bus bar.

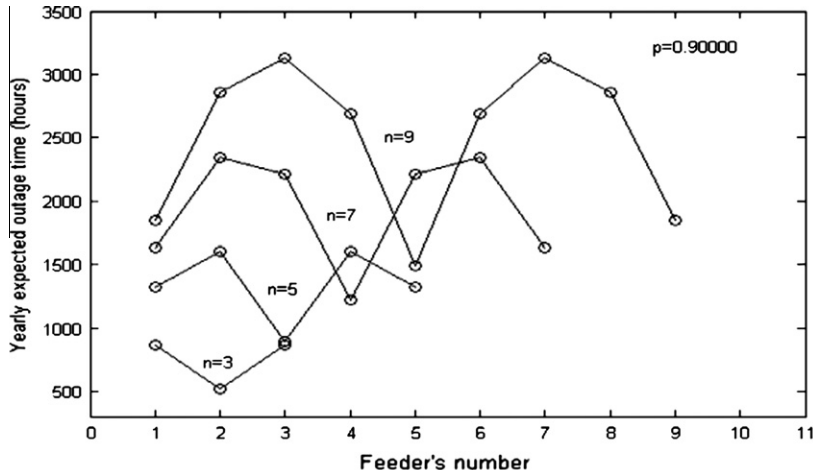

Fig. 9. Yearly expected outage times for triple-bus systems with different numbers of outgoing feeders.

The yearly expected outage times for the triple-bus systems with different numbers of outgoing feeders are shown in Fig. 9.

6. Conclusion

This paper has presented mathematical formulae for the reliability calculations of n-feeder ring-bus and triple-bus power distribution system. The developed formula for the ring bus system is also applied to some practical distribution schemes such as the double bus bar double breaker and the double bus bar with breaker and a half schemes to demonstrated the feasibility of the general n feeder ring-bus formulae. In a practical ring-bus system, it is found that the reliability of each feeder is decreased by increasing the number of the outgoing feeders, and also the most reliable feeders are those which are near the feeding (bus bar) points. However; for the worst case applications when the reliabilities of the individual elements are low (0.9000 and less) it is recommended that no more than six feeders are to be connected on such a system. It is also found that, more than six feeders are better to be connected in mesh or triple-bus configuration for system reliability improvement. The triple-bus configuration can largely be improve the reliability of the outgoing system feeders as compared with ring-bus configuration.

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