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Financial planning for the preventive maintenance of the power distribution systems' critical components using the reliability-centered approach

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Among different maintenance strategies that exist for power distribution systems, the Reliability-Centered Maintenance (RCM) strategy attempts to introduce a structured framework for planning maintenance programs by relying on network reliability studies and cost/benefit considerations. For the implementation of the RCM strategy, the electricity distribution companies try to optimally utilize the existing financial resources in order to reduce the maintenance costs and improve the reliability of the network. The aim of this paper is to present a practical method for devising an appropriate maintenance strategy for network elements and for preventive maintenance budget planning, with the goal of improving the system reliability and reducing the maintenance costs. In the proposed method, the critical outage causes of the distribution system are determined on the basis of cost and reliability criteria, by the Technique for order preference by similarity to ideal solution (TOPSIS) method. Then, the optimum preventive maintenance budget is calculated by obtaining the cost functions of the critical elements and optimizing the overall cost function. In this investigation, the medium voltage distribution network of the "Haft Tir" district in Tehran has been chosen for the implementation of the proposed RCM strategy.

Key words: Reliability-centered maintenance (RCM), preventive maintenance (PM), technique for order preference by similarity to ideal solution (TOPSIS), power distribution system.

INTRODUCTION

One of the most important goals of power distribution companies is to provide uninterrupted and quality service to their customers (Brown, 2002). In this regard, the electricity distribution companies try to select an optimum maintenance strategy in order to reduce the failure rate of network equipment and increase the reliability of the system. This objective was not accomplished as desired in traditional maintenance methods in which the repair of network components was performed at specific time intervals. The huge maintenance expenditures and the inefficiency of these methods in reducing the outages in the system made it necessary to develop a more effective and comprehensive maintenance strategy; a strategy based on the ability to monitor network reliability and to consider the interrelationship between reliability and maintenance costs. These necessities gradually caused

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*Corresponding author. E-mail: noradin.ghadimi@yahoo.com the maintenance strategies to be inclined towards the reliability-centered strategies and away from the time-based strategies. The Reliability-Centered Maintenance (RCM) strategy attempts to present an organized framework for the improvement of network reliability and the reduction of maintenance expenses by relying on cost/benefit studies and the reliability analysis of networks (Schneider et al., 2006; Ghadimi, 2012; Ahadi et al., 2014a). In the RCM strategy, the corrective and preventive maintenance strategies are subjected to cost/benefit analysis, and the optimum strategy is selected (Ahadi et al., 2014b).

The preventive maintenance strategy has many complexities relative to the corrective maintenance strategy. Knowing the priorities of elements for preventive measures and determining the proper time intervals between these activities are some of the challenges faced by the preventive maintenance engineers of power distribution companies (Ahadi et al., 2014b; Hagh et al., 2011). However, one of the most important problems that need to be addressed in preventive maintenance planning is the manner of allocating the preventive maintenance budget to the weak points of the network. The assessment of a preventive maintenance budget has always been difficult because of certain factors such as the outages due to environmental and human causes and the unknown nature of some causes of outages, especially the transient ones.

The maintenance budget limitation of the distribution companies, on one hand, and the complexity of assessing the PM budget, on the other hand, have made it necessary to conduct fundamental studies on the subject of maintenance budget planning. This issue is so important that in some cases, due to an incorrect assessment of the maintenance budget, network reliability may not improve much, even though vast maintenance resources are spent.

The establishments of an appropriate relationship between the preventive maintenance of an electricity distribution system and its reliability and the achievement of a RCM strategy have always been of interest to the researchers (Bertling et al., 2005; Ghadimi, 2012). However, due to the lack of proper network information, so far, RCM strategy has not been implemented adequately (Bertling et al., 2005). In Ahadi et al. (2014b) and Bertling et al. (2005), the implementation of the RCM strategy in the power distribution system of Stockholm, Sweden, has been discussed. In this method, optimal scenarios for dealing with the outage causes in the system are selected based on network reliability and cost-benefit analyses. The implementation of RCM in the distribution system has also been studied in Schneider et al. (2006) and Ghadimi (2012). In this method, by determining the failure rate of the critical failure modes, the strategies for dealing with these failure causes undergo cost-benefit analysis.

Also in some studies, the manner of implementing an optimal preventive maintenance strategy in electricity distribution systems for the purpose of network reliability improvement has been investigated. In Lie and Chun (1986) an algorithm is introduced for determining what type of preventive maintenance to consider for the components of a distribution network and when to apply this particular PM strategy. Sobhani and Ghadimi (2013) and Wallnerströmand et al. (2013) and deal with preventive maintenance planning based on risk assessment. As the distribution system components continue to operate, their failure probability increases and therefore the resulting risk goes up. An optimal maintenance model reduces the risk of component failure. In Hagh and Ghadimi (2014), the instant causes of failure in Tehran’s electricity distribution system are classified and ranked, and the more important factors are selected for the implementation of preventive maintenance activities. In this reference, after finding the most prevalent causes of instantaneous failures, the variables with higher priorities are selected. In Mohammadi and Ghadimi (2014), the minimization of power outage cost and maintenance cost constitutes the objective function. Ultimately, the results of applying this method in the Birka system of Sweden are evaluated. In Teera-achariyakul et al. (2010), the duration of consumer power outage is minimized through the optimal allocation of a maintenance budget. In Maleh et al. (2013), the allocation of a maintenance budget for distribution feeders is investigated. In the proposed model, the failure rates of feeders are modeled as functions of PM budget, and the cost of PM is minimized by considering a suitable maintenance budget. Park et al. (2000), Canfield (1986) and Mohammadi and Ghadimi (2013) focus on the minimization of preventive maintenance cost. This cost includes the cost of power outage, cost of maintenance, cost of replacement and the annual cost of repairs. In Sittithumwat et al. (2004), the reliability indexes are expressed as probabilities, and by determining the maintenance level, it is attempted to reduce the system average interruption frequency index (SAIFI).

In large electricity distribution networks with numerous causes of power failure, the implementation of the RCM strategy based on determining the proper intervals between preventive activities and optimum maintenance scenarios faces many difficulties; because the assessment of different maintenance scenarios for network components and the reduction of component failures in these scenarios, and in brief, the cost/benefit analysis of maintenance scenarios is impossible without having a sufficient knowledge of the causes of network elements failures. Also, in planning for a maintenance budget, it is necessary to appropriately select a maintenance strategy for network components based on the costs incurred by component failures and the role of components in network reliability. Therefore, if an appropriate maintenance strategy is selected for the network components and the PM budget is optimally spent for the improvement of network reliability and the reduction of maintenance costs, a favorable RCM strategy can be achieved. This paper tries to present a practical method for selecting an optimal maintenance strategy and for the financial planning of a preventive maintenance budget for power distribution networks with the goals of improving network reliability and reducing maintenance costs. In this approach, after prioritizing the outage causes and recognizing the critical outage causes by the TOPSIS method, the maintenance cost functions of the outage causes are obtained with respect to the PM budget and network information, and then by minimizing the total maintenance cost, the optimum PM budget is calculated. To implement the proposed methods, the medium-voltage distribution network of the "Haft Tir" district in the city of Tehran has been selected as the sample network. The reliability information of this study is based on the outage information of the years 2005-2012 that has been extracted from the events logging software of the Greater Tehran Electricity Distribution Company (GTEDC) known as the ENOX Database.

Under proposed method of this paper, the process of PM budget allocation by the proposed method is described. This is followed by results of budget planning by this method for the sample distribution network. Effect of the proposed method on the improvement of network reliability and the reduction of maintenance cost in the studied network is further investigated, and the conclusion is presented.

PROPOSED METHODS

For proper maintenance budget planning, first, it is necessary to devise a suitable maintenance strategy for the outage causes. An appropriate maintenance strategy is selected based on the role of different elements in network reliability and the costs imposed on the system.

After choosing an appropriate maintenance strategy and a PM strategy for the critical outage causes, it is necessary to establish the right relationship between the PM budget and network reliability and to determine the cost of maintaining network components, which mostly includes the cost of repairs, cost of energy not supply, cost of human resources and the cost of preventive maintenance. After obtaining the maintenance cost functions, the optimal PM budget of critical outage causes is calculated by optimizing the overall cost function. If the allocated budget does not lead to the reduction of maintenance cost and the improvement of network reliability as desired, the total PM budget will have to be increased. Figure 1 shows the flowchart of PM budget allocation procedure.

As is shown in the flowchart of Figure 1, the PM budget planning process comprises three major steps:

1) Prioritizing the outage causes and choosing the critical outage causes
2) Estimating the maintenance cost functions of the critical outage causes
3) Calculating the optimum budget of the critical outage causes

Prioritizing the outage causes and choosing the critical outage causes

Certainly, choosing an appropriate preventive maintenance strategy for sensitive and effective equipment in the distribution network rather than spending huge sums of money on the maintenance of all network elements, regardless of their role and importance in the system, will lead to more economical as well as optimal decisions. Those outage causes that have a higher influence on network reliability and the maintenance cost imposed on the network are called the "critical outage causes".

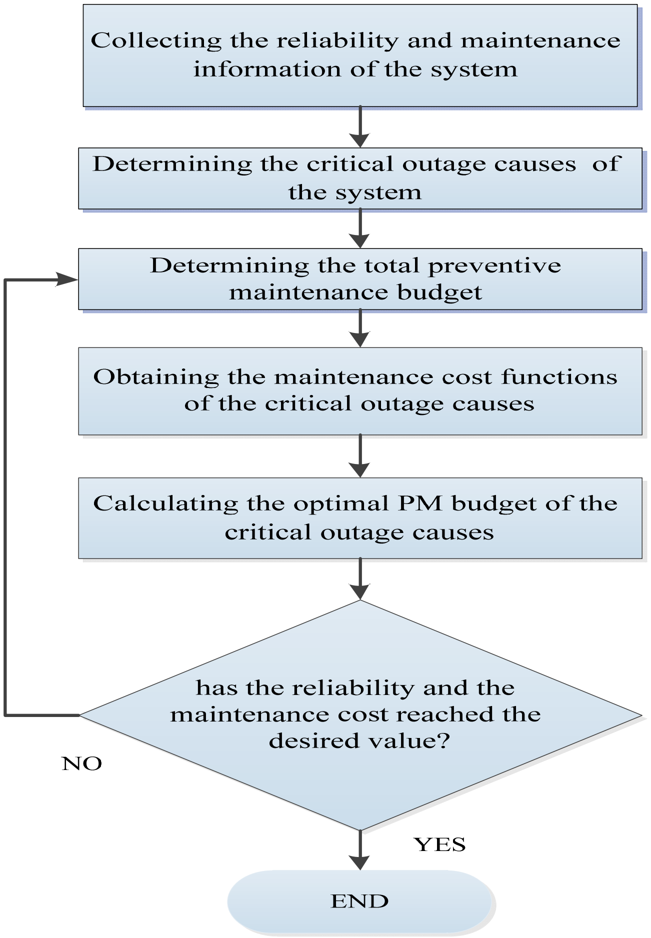

Figure 1. Flowchart for the allocation of preventive maintenance budget.

Since numerous factors such as the replacement cost of equipment, number of equipment, and the functions of elements in achieving network reliability must be considered in the selection of the critical outage causes, the multi-criteria decision-making methods (MCDMs) can be employed to prioritize the outage causes and to choose the right maintenance policy. In the proposed method, to prioritize the outage causes, these factors are compared with one another by the TOPSIS method by considering the indexes associated with network reliability, repair cost of components and the number of components. Weights are assigned to the main decision-making criteria based on the priorities of the electricity distribution companies and the opinions of these companies' maintenance engineers. After computing the priorities of the outage causes by the TOPSIS approach, the outage causes with higher priorities are selected for preventive maintenance strategy and those with lower priorities are selected for corrective maintenance strategy. Figure 2 shows the process of prioritizing the outage causes and selecting a maintenance strategy for them by the TOPSIS method.

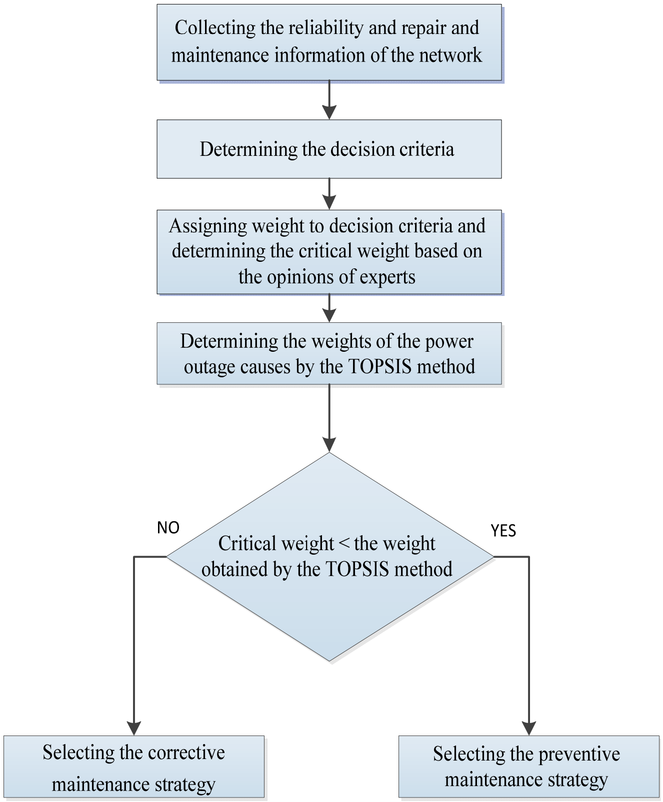

Figure 2. Flowchart for selecting a maintenance strategy for the outage causes by the TOPSIS method.

In the MCDMs of TOPSIS, which was presented in 1981 by Hwang and Yoon, the best solution is the one which is the closest to the positive-ideal solution and, at the same time, the farthest away from the negative-ideal solution (Ghadimi et al., 2014). The ideal solution represents a hypothetical choice which is the most favorable standardized weighted choice from each criterion among the considered choices; and the negative-ideal solution comprises the worst standardized weighted choice among the various choices.

The TOPSIS method evaluates a decision matrix that has M choices and N indices. A_i indicates the ith choice, X_j indicates the jth index and X_{ij} is the numerical value obtained from ith choice and jth index. In the following, the step-by-step prioritization of the choices by the TOPSIS method is described according to Ghadimi et al. (2014).

Step 1: Normalization of the decision matrix

This process tries to non-dimensionalize the existing quantities in the decision matrix. To do this, each value is divided by the magnitude of the vector corresponding to the same index. Every entry of the normalized decision matrix is obtained from Equation (1).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \tag{1}$$

Step 2: Assigning weight to the normalized matrix

The decision matrix is, in fact, parametric and it needs to become quantified. To this end, the decision-maker assigns a weight to each index and the sum of weights (W) is multiplied by the normalized matrix R.

$$W = (W_1, \ldots, W_n) \tag{2}$$

$$\sum_{j=1}^{n} W_j = 1 \tag{3}$$

Step 3: Determining the ideal and negative-ideal solutions

The two virtual choices of A^* and A^- are defined as follows:

$$A^* = \{(\max_i V_{ij} \mid j \varepsilon J), (\min_i V_{ij} \mid j \varepsilon J') \mid i = 1,2,\ldots,m\} \\ = \{V_1^*, \ldots, V_n^*\} \tag{4}$$

$$A^- = \{(\min_i V_{ij} \mid j \varepsilon J), (\max_i V_{ij} \mid j \varepsilon J') \mid i = 1,2,\ldots,m\} \\ = \{V_1^-, \ldots, V_n^-\} \tag{5}$$

A^* is the positive-ideal and A^- is the negative-ideal solutions, J is the benefit criterion column and J' indicates the cost criterion column.

Step 4: Obtaining the separation measures

The separation of choice i from the positive- and negative-ideal solutions is estimated.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^*)^2} \quad i = 1,2,.., m \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \quad i = 1,2,.., m \tag{7}$$

Step 5: Calculating the relative closeness to the ideal solution

This criterion is obtained from Equation (8).

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-} \quad 0 < C_i^* < 1 \tag{8}$$

Obviously, the less the separation of choice is from the ideal solution, the closer the relative closeness will be to 1.0.

Step 6: Ranking the choices

Finally, the choices are ranked in a descending order.

Table 1. Weights of selected criteria for the prioritization of the studied system's.

Decision criteria	Weights of the decision criteria
Number of outages	0.265
Duration of outages	0.24
Energy Not Supply	0.24
Equipment Replacement Cost	0.125
Number of Existing Elements	0.13

Estimating the maintenance cost functions of critical outage causes

To obtain the maintenance functions of the outage causes, it is necessary to determine their failure rate functions with respect to the PM budget. It is obvious that the bigger the PM budget is, the more the failure rate of components will be reduced. The function of failure rate versus PM budget is expressed as a function with exponential distribution according to Equation (9) (Schneider et al., 2006; Ghadimi, 2012; Maleh et al., 2013; Sarchiz et al., 2009)

$$\lambda(PM_i) = A_i + B_i e^{-C_i PM_i} \tag{9}$$

After determining the failure rate functions of the critical outage causes, the functions of repair cost, energy not supply cost and human resources cost are obtained by Equation (10) through Equation (12).

$$TC_i^{re} = \lambda(PM_i).C_i^{re} \tag{10}$$

$$TC_i^{ENS} = \lambda(PM_i).ENS_i^{avg}.C_{ENS} \tag{11}$$

$$TC_i^{hr} = \lambda(PM_i).hr_i^{avg}.C_{hr} \tag{12}$$

Calculating the optimum PM budget of the critical outage causes

The total maintenance cost is obtained by summing the repair cost, energy not supply cost, human resources cost and the preventive maintenance cost. By considering the total PM budget and the changes of the elements' failure rates, the optimum preventive maintenance budget is obtained by minimizing the total maintenance cost of the critical outage causes. The objective function and the governing constraints of the problem are according to Equation (13) through Equation (15).

$$Minimize: TCCM = \sum_{i=1}^{n} TC_i^{re} + TC_i^{ENS} + TC_i^{hr} \tag{13}$$

$$\sum_{i=1}^{n} PM_i = TCPM \tag{14}$$

$$\lambda_i^{\min} \le \lambda_i \le \lambda_i^{\max} \tag{15}$$

CASE STUDY RESULTS

To implement the proposed methods, the medium-voltage distribution network of the "Haft Tir" district in the city of Tehran has been selected as the sample system. The "Haft Tir" electricity distribution district, with an area encompassing about 140 km^2, is one of the largest regions in Tehran municipality. This investigation has been based on the outage information of the mentioned network for the years 2005-2012, which has been extracted from the incidents logging software (known as ENOX) of the Greater Tehran Electricity Distribution Company (GTEDC). The goal of this investigation is to plan the PM budget of the year 2013 for this system based on the system reliability and cost information of this system.

After collecting the reliability and maintenance cost information of the sample system, the process of PM budget allocation, according to the procedure described in proposed method, includes the steps of prioritizing the outage causes and determining a suitable maintenance strategy, obtaining the maintenance cost functions and calculating the optimal PM budget for the critical outage causes.

Prioritizing the outage causes and choosing the critical outage causes by the TOPSIS method

Identifying the critical outage causes is very important for the purpose of choosing an appropriate maintenance strategy. For certain outage causes such as operator error, equipment theft, disastrous climatic conditions and unanticipated events, proper preventive measures cannot be considered. After collecting the outage information of the sample system, separated by the cause of outage, the selected outage causes are classified into 13 groups for the selection of preventive and corrective maintenance policies. Table 2 shows the unplanned outage causes of the studied system.

The main selected criteria for the prioritization of outage causes include the number of outages, duration of outages, energy not supply, equipment replacement cost and the number of existing elements in the system. The weights of the decision criteria are determined based on the priorities of the Tehran power distribution company and the knowledge of the maintenance engineers of this company, according to Table 1.

Based on the information of the studied system, the columns and rows of the decision matrix are established

Table 2. Determining the priorities of the studied system's outage causes on the basis of decision criteria by the TOPSIS method.

Group	Failure cause	TOPSIS weight
1	Failure of capacitor bank	0.1174
2	Fault of the medium voltage cable	0.397
3	Failure of structure	0.298
4	Failure of transformer	0.575
5	Failure of lightning arrester	0.148
6	Failure of Insulator	0.125
7	Failure of disconnector switch	0.274
8	Failure of circuit breaker	0.437
9	Failure of cutout switches	0.134
10	Failure of cable terminations	0.204
11	Failure of recloser	0.1748
12	Fault in the main switch or the low voltage board	0.0439
13	Tree contact	0.259

Table 3. Critical outage causes of the studied system.

Group	Outage cause
A	Failure of transformer
B	Failure of cable terminations
C	Failure of circuit breaker
D	Failure of structure
E	Fault of the medium voltage cable
F	Failure of disconnector switch
G	Tree contact

based on the decision criteria and the information of outage causes, respectively; and the priorities of the outage causes are calculated by the TOPSIS method. The priorities of the outage causes of the studied system obtained by the TOPSIS method have been listed in Table 2. After determining the outage causes and considering a critical weight of 0.15 based on the opinions of the Greater Tehran Electricity Distribution Company's Engineers, seven groups of outage causes with priorities larger than the critical weight are selected for preventive maintenance strategy and the remaining outage causes are chosen for corrective maintenance strategy. Table 3 shows the outage causes of the studied system selected for PM budget planning.

Determining the maintenance cost functions and calculating the PM budget of critical outage causes

After selecting the critical outage causes of the system under study, based on the information of this system, the failure rate functions of the critical outage causes are determined as a function of PM budget, according to Equation (9). Table 4 shows the coefficients of the failure rate functions of the studied systems' critical outage causes.

The maintenance cost is obtained by adding up the repair cost, energy not supply cost, human resources cost and the preventive maintenance cost. The preventive maintenance budget of the critical outage causes is calculated according to Equation (13) through Equation (15) by optimizing the maintenance cost, considering the limitation of the total PM budget and taking into account the failure rate changes of the critical outage causes. Table 5 shows the information related to the studied system for determining the optimum PM budget, which includes the coefficients of the failure rate functions, average repair cost of elements, minimum and maximum failure rates of critical elements and the average amount of energy not supply and human resources for each time an element failures. The total PM budget of the investigated system for the year 2013 is 543,472 dollars, based on the planned budget of the Greater Tehran Electricity Distribution Company. Also, the cost of energy not supplied (C_{ENS}) has been considered as 8 dollars per kWh and the human resources

Table 4. coefficients of the failure rate functions of the sample systems's critical outage causes.

Group	A_λ (int/year)	B_λ (int/year)	$C_\lambda * 10^5$
A	39	129.5	3.4
B	59	123.9	7.78
C	41	162.2	1.81
D	18	66.1	5.9
E	41	194.3	1.79
F	31	88.1	5.94
G	26	124.45	1.55

Table 5. Determining the priorities of the studied system's outage causes on the basis of decision criteria by the TOPSIS method.

Group	A_λ (Int/year)	B_λ (Int/year)	$C_\lambda * 10^5$ (Int/year)	C^{rp} ($)	ENS_i^{avg} (KWh)	$\lambda_{\min}$ (Int/year)	$\lambda_{\max}$ (Int/year)	hr_i^{avg} (individual *hour)
A	39	129.5	3.4	285	1327	46	109	18
B	59	123.9	7.78	58	201	59	106	11
C	41	162.2	1.81	181	1021	58	156	14
D	18	66.1	5.9	170	936	18	28	21
E	41	194.3	1.79	123	1421	58	160	12
F	31	88.1	5.94	110	353	31	57	16
G	26	124.45	1.55	62	926	55	116	12

cost (C_{hr}) has been set as 11 dollars per individual per hour. The GAMS software and the nonlinear programming method have been employed to analyze the existing problem. Figure 3 shows the PM budget of the investigated system's critical outage causes estimated by the proposed method.

DISCUSSION

Here, the proposed method were implemented in the studied system. In addition to these method, it can be assumed that the share of each group of critical outage causes from the total PM budget of 2013 is similar to that of 2012 budget, and that no change is made in the budget planning method of 2013 relative to 2012. Thus, the PM budget of 2013 for the outage causes can be computed based on the 2012 budget for these causes. Figure 4 shows the PM budget planning for the studied system's outage causes by the proposed method along with the PM budget planning based on the 2012 budgeting procedure. In order to estimate the improvement of system reliability due to PM budget planning through the two said methods, the index of system reliability improvement is defined by Equation (16) (Ghadimi, 2012).

$$RII = \alpha \frac{\lambda - \lambda_{base}}{\lambda_{base}} + \beta \frac{U - U_{base}}{U_{base}} + \gamma \frac{ENS - ENS_{base}}{ENS_{base}} \qquad (16)$$

Weighting coefficients α, β, γ are determined based on the priorities of the electricity distribution companies. To calculate the system reliability indexes of the two budget planning methods in the system under investigation, the functions of failure rate, outage duration and energy not supply versus PM budget are considered as exponential distribution functions according to Equation (17) through Equation (19).

$$\lambda(PM_i) = A_i^{\lambda} + B_i^{\lambda} e^{-C_i^{\lambda} PM_i} \qquad (17)$$

$$U(PM_i) = A_i^{U} + B_i^{U} e^{-C_i^{U} PM_i} \qquad (18)$$

$$ENS(PM_i) = A_i^{ENS} + B_i^{ENS} e^{-C_i^{ENS} PM_i} \qquad (19)$$

The coefficients of functions (17) through (19) can be calculated with regards to the information of the studied system. Table 6 show the coefficients of failure rate, outage duration and energy not supply functions of the investigated network's critical outage causes.Thus, based on the obtained functions and the amount of PM budget,

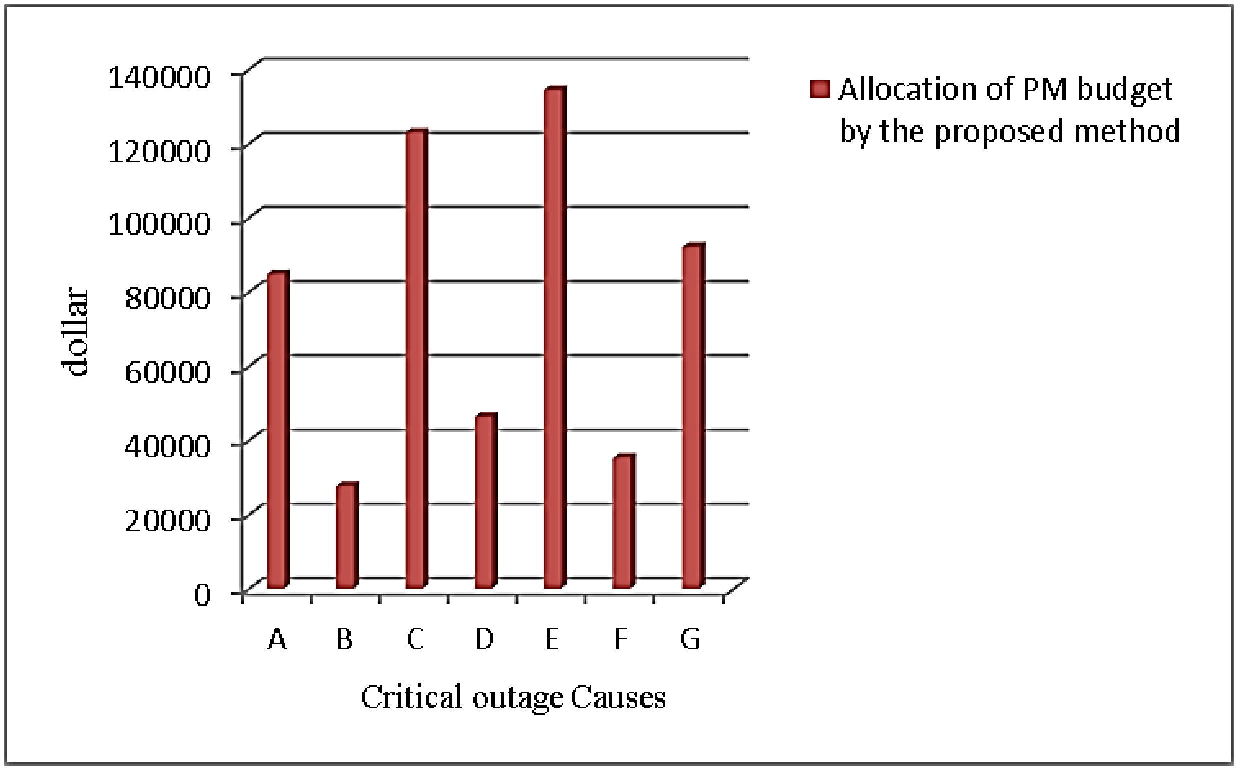

Figure 3. Allocation of PM budget to the studied system's critical outage causes by the cost optimization method.

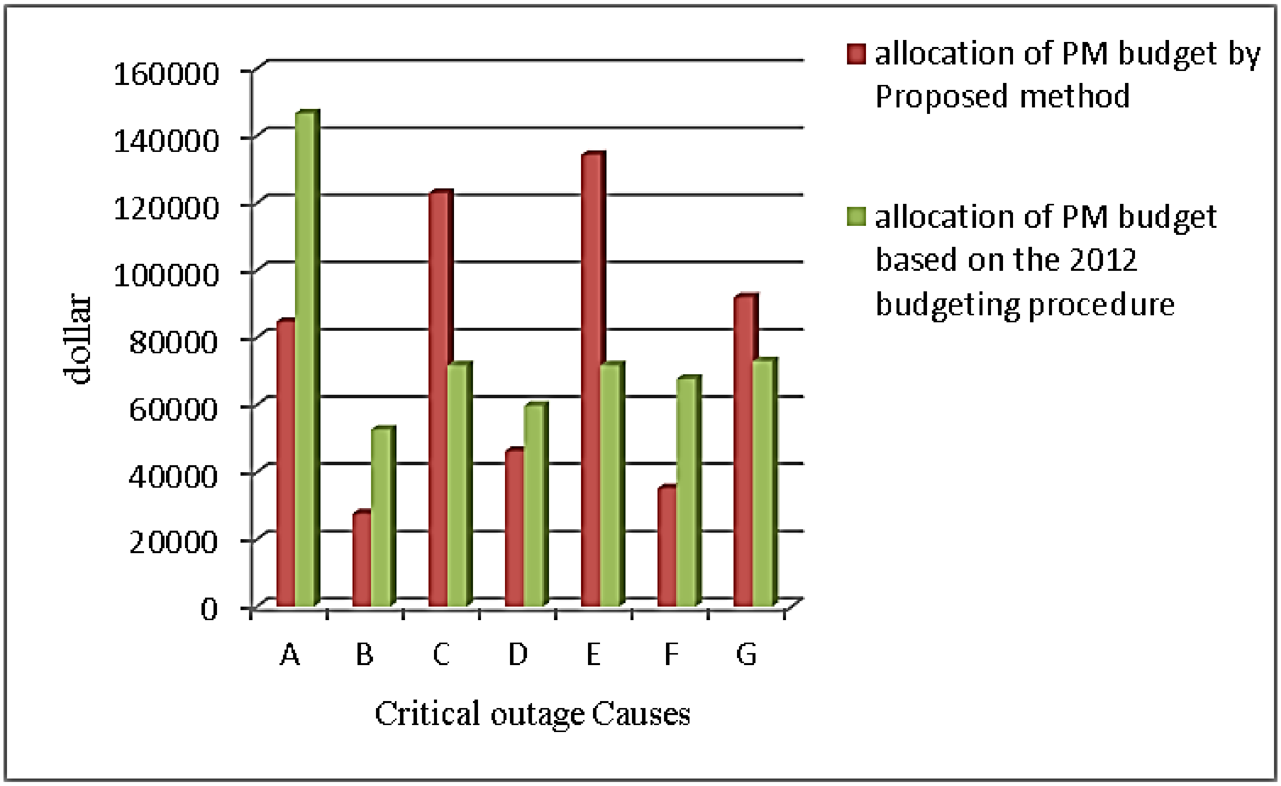

Figure 4. PM budgets of the studied network's critical outage causes obtained by the proposed method and by the budgeting procedure of the year 2012.

Table 6. Coefficients of failure rate, outage duration and energy not supply functions of the studied system's critical outage causes.

Group	A^{λ} *(Int/year)*	B^{λ} *(Int/year)*	$C^{\lambda} *10^5$	A^{U} *(Minute)*	B^{U} *(Minute)*	$C^{U} *10^5$	A^{ENS} *(MWh)*	B^{ENS} *(MWh)*	$C^{ENS} *10^5$
A	39	129.5	3.4	1411	14280	0.637	19	114.39	0.691
B	59	123.9	7.78	1100	6234	0.221	6	12.04	0.241
C	41	162.2	1.81	1623	13650	0.690	26	108.37	0.351
D	18	66.1	5.9	1152	11260	0.487	12	62.22	0.256
E	41	194.3	1.79	1920	19680	0.392	41	125.4	0.314
F	31	88.1	5.94	905	6729	0.415	9	12.03	0.451
G	26	124.45	1.55	1423	13140	0.490	19	75.33	0.207

Table 7. Maintenance cost and reliability improvement index of the studied system obtained by proposed method and budget planning based on the year 2012 budget with considering $\alpha = 0.448$, $\beta = 0.338$, $\gamma = 0.214$.

Method	RII	Maintenance cost (dollar)
Proposed method	0.054	3,096,528
budget allocation of the year 2012 method	0.01	3,683,660

the reliability improvement index is determined according to Equation (16). Also, the maintenance costs of the studied system through the two budget planning approaches can be found by Equation (10) through Equation (13). Table 7 presents the indexes of reliability improvement and maintenance cost of the investigated system obtained by the proposed method and by budgeting procedure of the year 2012 with considering $\alpha = 0.448$, $\beta = 0.338$, $\gamma = 0.214$.

As is observed, by considering an identical total PM budget, the degree of network reliability improvement and the maintenance cost are higher in the proposed method compared to those obtained by the budget planning method of 2012. The establishment of an appropriate relationship between preventive maintenance, maintenance cost and network reliability in this method leads to the optimal expenditure of the PM budget for the improvement of network reliability and the reduction of maintenance costs.

Conclusion

Two major objectives are pursued in the implementation of preventive maintenance programs for an electricity distribution system: the improvement of network reliability and the reduction of maintenance costs. In this paper, a method has been presented for selecting the proper strategy for the maintenance of network components and for planning an appropriate preventive maintenance budget, with the goal of improving network reliability and reducing the maintenance cost. In this approach, after prioritizing the power outage causes and determining the critical power outage factors by the TOPSIS method, the maintenance cost function is obtained, and based on the reliability information of the network, the amount of budget that leads to a minimum maintenance cost is calculated.

The results of implementing this method in the medium voltage distribution network of the "Haft Tir" district in the city of Tehran indicate that by using this method in PM budget planning, network reliability improves and the maintenance cost is lowered. The establishment of an appropriate relationship between preventive maintenance, network reliability and maintenance cost in this method makes it possible to optimally spend the PM budget for the improvement of network reliability and the reduction of maintenance cost. Since the implementation of the RCM strategy based on the cost/benefit studies of different maintenance scenarios for network components runs into many difficulties in electricity distribution networks with numerous power outage causes, by applying this method, a favorable RCM strategy can be implemented.

Conflict of Interest

The authors have not declared any conflict of interest.

NOMENCLATURE; A^*, Positive ideal solution in the TOPSIS method; A^-, negative ideal solution in the TOPSIS method; $A_i^{ENS}, B_i^{ENS}, C_i^{ENS}$, coefficients of energy not supply functions with respect to the PM budget of the *i*th component; A_i^U, B_i^U, C_i^U, coefficients of outage duration functions with respect to the PM budget of the *i*th component; $A_i^\lambda, B_i^\lambda, C_i^\lambda$, coefficients of failure rate functions with respect to the PM budget of the *i*th component; C_{ENS}, cost of 1.0 kWh of energy not supply (in dollars); C_{hr}, average cost of one hour of human resources (in dollars); C_i^{re}, average repair cost of the *i*th component forevery failure (in dollars); ENS_i, annual energy not supply of the *i*th component (in MWh); ENS_i^{av}, average energy not supply in the failure of the *i*th component (inKwh); hr_i^{av}, average human resources needed in the failure of the *i*th component (in individual *hour); J, set of profit indexes in the TOPSIS method; J', set of cost indexes in the TOPSIS method ; PM_i, PM budget of the *i*th component (in dollars); RII, system reliability improvement index; r_{ij}, element of the *i*th row and *j*th column of the decision matrix normalized by the TOPSIS method; S_i^+, ideal separation in the TOPSIS method; S_i^-, negative ideal separation in the TOPSIS method; TC_i^{re}, annual repair cost of the *i*th component (in dollars) ; TC_i^{ENS}, annual energy not supply cost of the *i*th component (in dollars); TC_i^{hr}, annual human resources cost of the *i*th component (in dollars); $TCPM$, total cost of preventive maintenance (in dollars); U_i, annual outage duration of the *i*th component (in minutes);m TCM, total cost of maintenance (in dollars); X_{ij}, element of the *i*th row and *j*th column of the decision matrix in the TOPSIS method; α, β, γ, weight coefficients related to λ, U, ENS in the reliability improvement index; λ_i, annual failure rate of the *i*th component (in interruption per year); $\lambda_i^{base}, U_i^{base}, ENS_i^{base}$, λ, U, ENS of the *i*th component for allocating a PM budget equally to all the critical components; $\lambda_i^{\max}$, maximum annual failure rate of the *i*th component (in interruption per year); $\lambda_i^{\min}$, minimum annual failure rate of the *i*th component (in interruption per year);

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