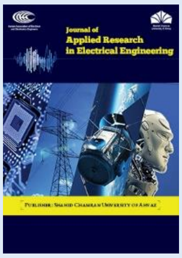
*J. Appl. Res. Electr. Eng.*, Vol. 1, No. 2, pp. 149-158, 2022 DOI: 10.22055/jaree.2021.38321.1034

Shahid Chamran University of Ahvaz

Iranian Association of Electrical and Electronics Engineers

**Journal of Applied Research in Electrical Engineering**

E-ISSN: 2783-2864
P-ISSN: 2717-414X
Homepage: https://jaree.scu.ac.ir/



**Research Article**

# Optimal Switch Placement in Radial Distribution Networks to Reduce Energy Loss and Improve Network Security in Khuzestan Province Conditions

**Ali Rouhipour, Elaheh Mashhour*, and Mohsen Saniei**

*Department of Electrical Engineering, Faculty of Engineering, Shahid Chamran University of Ahvaz, Ahvaz 6135785311, Iran*

** Corresponding Author: e.mashhour@scu.ac.ir*

**Abstract: This paper develops a new model for the optimal placement of switches (both manual and automatic ones) in distribution networks to simultaneously reduce energy loss and improve network security. Expected energy not supplied (EENS) is assumed as the security index, and a method is developed for more exact calculation of this index regarding drastic climatic changes along with global warming and the resultant effects on both power consumption patterns and power network occurrence. The objective function of the problem is minimizing investment and maintenance costs, the cost of energy loss, and EENS cost. The suggested model can locate optimal places for installing the switches and their seasonal closed and open states so that the total costs can be minimized. The model is implemented on two test networks and evaluated under different scenarios. According to the results, despite the higher costs of automatic switches, the application of automatic switches is more economical in low-security networks for improving network security.**

**Keywords:** Sectionalizing switch, tie switch, expected energy not supplied, seasonal network configuration, energy loss, investment cost.

**Article history**
Received 21 August 2021; Revised 28 December 2021; Accepted 31 December 2021; Published online 8 March 2022.

**How to cite this article**
A. Rouhipour, E. Mashhour, and M. Saniei, "Optimal switch placement in radial distribution networks to reduce energy loss and improve network security in Khuzestan province conditions," *J. Appl. Res. Electr. Eng.*, vol. 1, no. 2, pp. 149-158, 2022. DOI: 10.22055/jaree.2021.38321.1034


## 1. Introduction

Distribution network loss and security have always attracted the attention of distribution network operators. In some countries including Iran, the power industry is controlled with a wholesale competition model. In this model, distribution companies purchase the power required for consumers and network losses at an hourly price from a wholesale power market while receiving money only for energy delivered to the end-users at a regulatory price. Therefore, power loss reduction and security improvement of these networks are viable solutions for decreasing the costs of power purchase and increasing the revenue of distribution companies by the continuous sale of power to subscribers.

A review of the literature shows that reducing distribution network losses and increasing network security have always been the focus of scholarly attention. Methods proposed for reducing network losses include reactive power resources management [1], optimal conductor selection [2, 3], network reconfiguration (to reduce power or energy losses) [4, 5], or a combination of these methods [6]. In some cases, network reconfiguration has been proposed to reduce the loss and improve the security of the distribution network [7]. The solutions proposed for improving network security can be classified into three general classes. The first class, which involves a very limited number of works, seeks to improve network security through improving the security of different system components [8]. The second class contains studies that rely on other feed resources, such as distributed generations (DGs) [9]. The third class subsuming many works focuses on sectionalizing the placement of switches to improve distribution network security [10-15].In [10], an optimal sectionalizing switch placement problem in distribution networks is formulated to minimize the sum of investment cost, customer outage cost, and switch installation and maintenance cost. Then, it is solved using the Simulated Annealing (SA) algorithm. In [11], sectionalizing switch placement is done for manual and automatic switches in a distribution network to minimize the sum of investment cost and customer interruption cost using the immune algorithm. In [12], the problem of finding optimal number and places of sectionalizing switches is formulated to minimize the switch purchasing and maintenance costs and customer interruption cost, and the problem is then solved by a fuzzy optimization method. In [13], the problem of finding optimal number and places of automatic switches in distribution networks is modelled and solved to minimize the sum of customer interruption cost, investment cost, and maintenance cost in the form of a mixed-integer linear optimization problem. In [14], a method is presented for determining the optimal combination of sectionalizing and tie switches for the optimal design of the distribution automation system so as to minimize the losses and keep 100% of the reliability of service restoration. Moreover, an algorithm is provided to determine the optimal switch placement based on the pre-determined number for each kind of switch. In [15], the differential search algorithm is used to determine the optimal placement and number of remote-control switches in a radial distribution network so that the cost of expected energy not supplied and investment cost can be minimized. In [16], a model is developed for the optimal simultaneous allocation of fault indicators and sectionalizing switches in a complex distribution network based on reliability and cost-benefit analyses. The objective function is minimizing the sum of investment cost, maintenance cost, and customer interruption cost. In [17], a risk-based two-stage mixed-integer linear programming model is presented for the optimal placement of sectionalizing switches in active distribution networks considering the island mode operation of distributed energy resources.

Note that the third solution for reducing losses (i.e., network reconfiguration) and the third solution for improving network security (i.e., sectionalizing switch placement) are interrelated. In other words, optimal network reconfiguration to minimize energy losses is affected by the placement of the switches. Besides, network security depends not only on the place of the switches but also on the network configuration in normal conditions. Therefore, sectionalizing switch placement with the mere aim of improving network security and then using these switches in the reconfiguration process to reduce network loss is not necessarily the cost-effective and optimal solution. So, it is essential to pay attention to both roles of switches during the normal functioning of the network and during outages after a fault. In this regard, the drastic changes in climate and increased temperature of the earth and the resultant effects on power consumption patterns and power network occurrences should be taken into account. This increase in the earth's temperature is notable in some areas of the world such as parts of the Middle East. For example, in June and July of 2017, some parts of the Middle East experienced their maximum temperature compared to their previous patterns in a relatively long period of 4 weeks. In this context, on June 29th, 2017, Ahvaz city, the capital of Khuzestan province in Iran, was the warmest city in the world with a temperature of 54.29℃ [18]. The air temperature rises and subsequently the feeling temperature rise increase the use of the cooling electric devices, such as split air conditioners, which, in turn, affects the consumers' load patterns in the warm season of the year. In Iran, for example, although the demand-side management policies have been encouraged, the daily time of the load peak, which used to occur at night in the summertime, has changed to the afternoon (i.e., the hours of the maximum daily air temperature) since 2011. Furthermore, since 2011, the annual load peak, which belongs to the summer season, has experienced an average growth of 4.61% per year [19].

These changes in the consumption patterns have caused the load curves in warm and cold durations (seasons) to be significantly different in terms of both the shape and peak of the consumption. Therefore, optimal network configurations in the normal state of the network operation are different in warm and cold periods.

Moreover, in recent years, the volume of the atmospheric pollutants emitted from hydrocarbon sources and the dust hazes in the Middle East (owing to the water elimination policies and droughts) have increased. The frequent resting of these pollutants on the insulators of power distribution and transmission lines leads to insolation breakage of the insulators and consequently increases the line outage rate during the dense fogs or intermittent rains in cold seasons. For example, in spite of all preventive measures already taken, the rate of outages caused by dust hazes and air pollutant concentrations in the cold season is still notable in the southwest of Iran. As a result, the reasons behind fault occurrences and distribution of the number and time of interruptions in two warm and cold seasons are different. Evidently, using an average annual load, and indexes such as the number of annual feeder section interruptions and their average annual repair time as the basis for calculating the average out-of-service time of the load points and hence for the annual expected energy not supplied (as network security index) reduces the precision of calculations.

To solve the above-mentioned concerns in the operation of distribution networks in the south of Iran, a new and applied model is proposed here for optimal placement of switches in distribution networks in that the seasonal variations in load patterns that necessitate changes in network configurations are considered. Moreover, it simultaneously takes into account the considerations of both normal and post-fault conditions. In other words, the presented model takes account of the roles of switches in normal conditions and upon fault and outage occurrences and also determines the optimal seasonal configuration of the network. The objective function is to minimize the total costs of the network including the investment cost, maintenance cost, energy loss cost, and the cost of annual expected energy not supplied (as the network security index). For a more precise calculation of this index, the indices for the number of the feeder sections' interruptions and their average time of repair have been defined here seasonally rather than annually. By expanding the existing relations, the index for the annual expected energy not supplied has thus been calculated based on the aforesaid seasonal values and the average of the seasonal consumption of the loads. The suggested model can optimally determine the switch placement and seasonal configurations of the network in such a way that the total costs of the network are minimized. The remainder of the paper is organized as follows. Section II redefines the annual expected energy not supplied index for real networks considering climatic changes. Section III represents the formulation of the proposed model. Implementation results of the model on test networks are given in Section IV. Section V provides conclusions.

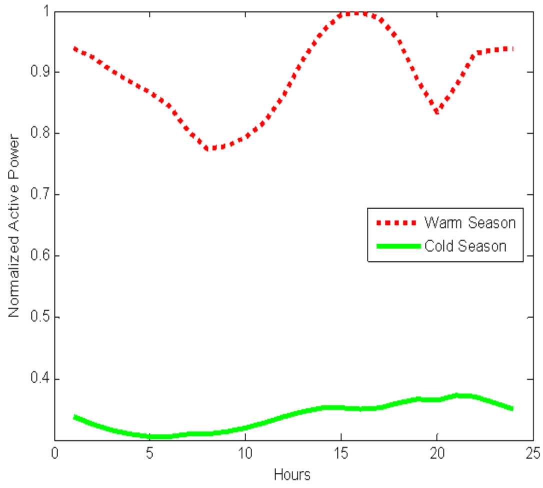



**Fig. 1:** The load curve of a sample feeder in Khuzestan province for two cold and warm seasons (normalized).

## 2. Redefinition Of Annual Expected Energy Not Supplied With Respect To The Changes In Climate

One geographical region that has negatively been affected by climatic changes, the rise of air temperature, and increased concentration of air pollutants (such as hydrocarbon pollutants and hazes from the droughts) is Khuzestan province, southwest of Iran. The power distribution network of Khuzestan is a network with a low annual load factor (about 50%). The load factor in the 8-month period of the warm season is around 70% and the load factor in the 4-month period of the cold season is about 25%. Moreover, the load peak of the warm season is about 3-4 times greater than that of the cold season (see Fig. 1), which can be attributed to the wide application of the split air conditioners in the warm season. This significant difference in the amounts of consumption and load behavior in warm and cold seasons besides the climatic conditions of the region would affect system operation, which entails avoiding the integrated view of the whole year in the system operation and instead the features of each season should be considered. One important problem in the operation of such systems is dissimilar reasons for faults and accordingly, for the number of interruptions and the time of repair and restoration of the system in cold and warm seasons, meaning that the distribution of the number and time of interruptions in these seasons are different. One index for estimating network security is expected energy not supplied generally defined in the literature as follows [10]:

$$EENS = \sum_{i=1}^{N_{lp}} L_{av,i} \times U_{lp,i} \quad (1)$$

$$U_{lp,i} = \sum_{j=1}^{n} \lambda_j \times r_j \quad (2)$$

where $EENS$ is expected energy not supplied in a year (in kWh), $L_{av,i}$ denotes annual average load at load point $I$ (kW), $U_{lp,i}$ is the annual average time of interruption for load point $i$ (minute), $\lambda_j$ is the number of failures of section $j$ of the feeder which is placed between substation and load point $i$ in a year, $r_j$ is the average repair time of section $j$ of the feeder that is placed between substation and load point $i$ in a year (minute), $N_{lp}$ is the number of load points, and $n$ denotes the number of feeder sections between substation and load point $i$.

As is seen, this index is affected by the average annual consumption and the average annual interruption time. Concerning the nonhomogeneous distribution of the number and time of interruptions and different consumption levels in cold and warm seasons, (1) and (2) are not precise enough to be utilized for calculating expected energy not supplied index in the studied distribution networks that are situated in warm and polluted areas. Therefore, indexes $\lambda_j$ and $r_j$, based on which the average time of out-of-service for load points is computed (see (2)), need to be defined and calculated separately for warm and cold durations. Note that the method for seasonal calculation of these indexes is similar to their annual calculations considering seasonal information. However, such calculations are beyond the scope of the present study. In this work, having the said indexes as seasonal, the expected energy not supplied is calculated seasonally and annual expected energy not supplied is obtained from the sum of the expected energy not supplied indexes of the two seasons:

$$EENS_k = \sum_{i=1}^{N_{lp}} L_{av,i,k} \times U_{lp,i,k} \quad (3)$$

$$U_{lp,i,k} = \sum_{j=1}^{n} \lambda_{j,k} \times r_{j,k} \quad (4)$$

$$EENS = \sum_{k}^{K} EENS_k \quad (5)$$

where $EENS_k$ denotes the expected energy not supplied in season k (kWh), $L_{av,i,k}$ is the seasonal average load at load point $i$ (kW), $U_{lp,i,k}$ refers to the seasonal average time of interruption for load point $i$ (minute), $\lambda_{j,k}$ is the number of failures of section $j$ of the feeder that is placed between substation and load point $i$ in season $k$, $r_{j,k}$ denotes the average repair time of section $j$ of the feeder that is placed between substation and load point $i$ in season $k$ (minute), and $k$ is an index for time durations of a year, $k \in \{1: \text{warm}, 2: \text{cold}\}$.

To confirm this, a real case is exampled. The annual number of interruptions of a sample feeder section of a feeder in the distribution network of Ahvaz in 2015 was 21 (with 6 and 15 for warm and cold seasons, respectively). Besides, the average interruption time per year was 34.17 minutes where 9.6 and 44 minutes were observed for warm and cold seasons, respectively. The same was also true for most of the other feeder sections. Moreover, the average consumptions in the warm season, cold season, and total year for most of the load points were significantly different (e.g., 75.44 kW, 24.29 kW, and 37.43 kW, respectively for a sample load point). The annual expected energy not supplied of the abovementioned sample network is calculated using (1) as to be 69.68 MWh. Moreover, the expected energy not supplied in the cold season and that in the warm season is calculated using (2) at 7.419 and 26.68 MWh, respectively. Accordingly, the annual expected energy not supplied from (5) is 34.099, which is different from the value obtained from (1). Besides, based on the real information from the record system of the network events, the real value of the energy not supplied for this network is equal to 34.55 MWh. This finding well corroborates the authenticity of our suggested modified model for the calculation of the expected energy not supplied.

## 3. Problem Formulation

### 3.1. Objective Function

The objective function of the presented model has three components, as follows:

*3.1.1. The first component– minimization of energy loss cost for normal conditions of the network*

This study considers energy loss corresponding to Joule loss affected by network configuration and consumption pattern of loads in cold and warm seasons. Generally, the energy loss cost for season $k$ is calculated as follows:

$$Loss - Cost_k = N_k \times \sum_{t=1}^{24} \rho_{t,k} \times Loss_{t,k} \tag{6}$$

where $Loss_{t,k}$ is power loss at hour $t$ for a typical day of season $k$ (warm or cold) in the first year of the project which can be obtained from load flow calculations considering the network configuration and load patterns of different consumers, $N_k$ is the number of days of season $k$, and $\rho_{t,k}$ denotes the price of the energy market at hour $t$ of the day corresponding to season $k$ ($/kWh). Note that the costs of the first year are calculable based on the existing load and market prices. However, for the next years, both the amount of loss (influenced by load growth) and energy prices (influenced by economic factors) change. Since Joule loss is proportional to the second power of load current, having the annual load growth rate, network losses in the project lifetime can be estimated. Also, by applying interest and inflation rates to the unit price of energy in the first year, costs of energy loss for the project lifetime can be calculated. Hence, the first component of the objective function is:

$$OF_1 = \sum_{y=1}^{T} \sum_{k=1}^{K} Loss - Cost_k \times PW^{(y-1)}.(1 + 0.01 \times Lg_k)^{2(y-1)} \tag{7}$$

$$PW = \frac{1 + Infr}{1 + Intr} \tag{8}$$

where $T$ is the lifetime of the project, $Lg_k$ denotes the percentage of load growth corresponding to season $k$, $Infr$ is the inflation rate and $Intr$ is the interest rate.

Note that practically in each season, the annual growth rate of the base load and that of the load peak are not similar. Although this point can be entered into problem formulation, it is here disregarded for the simplicity of calculations while keeping the problem generality.

*3.1.2. The second component– minimization of cost of expected energy not supplied (CEENS)*

Expected energy not supplied is an energy amount that could have been consumed by users if no fault had occurred in the system but has become inaccessible after the fault occurrence. Note that when a fault occurs, a number of loads are restored by the switching process and some other ones remain without electricity until the complete removal of the fault. Therefore, by expanding (3) and considering the cost of load interruptions, the cost of expected energy not supplied (CEENS) for the first year of the project is:

$$\text{CEENS} = \sum_{k=1}^{K} \left( \sum_{i=1}^{N_{s,k}} L_{av,i,k} \times U_{lp,i,k} \times CE_{i,k} + \sum_{i=1}^{N_{n,k}} L_{av,i,k} \times U_{lp,i,k} \times CE_{i,k} \right) \tag{9}$$

where $N_{s,k}$ is the number of restored load points after a fault (based on network configuration in season $k$), $N_{n,k}$ is the number of unrestored load points after a fault (based on network configuration in season $k$), and $CE_{i,k}$ is the cost of energy not supplied at load point $i$ based on the tariff of season $k$ ($/kWh).

The first term in (9) shows the load points restored by switching after the fault occurrence. The second sentence is related to the loads remaining without electricity during the faulty section repair. Obviously, in the first term, the average interruption time equals the average restoration time, and in the second term, the average interruption time equals the average repair time. Applying the annual load growth and interest and inflation rates to the first year costs, the net present value of CEENS of the project lifetime is calculated. So, the second component of the objective function is expressed by (10):

$$OF_2 = \sum_{y=1}^{T} \text{CEENS} \times PW^{(y-1)}.(1 + 0.01Lg_k)^{(y-1)} \tag{10}$$

*3.1.3. The third component–minimization of investment and maintenance costs*

This has three parts. The first part is related to the cost of establishing any new switch including the cost of purchase and installation of switches. The second part is due to the cost of moving the existing switches to new positions, and the third one is related to maintenance costs. Purchase, installation, and replacement costs are for the first year, but maintenance costs are for the project lifetime. So, the third component of the objective function is:

$$O.F_3 = (NS_{new}.C_{new}) + (NS_{plc}.C_{plc}) + \sum_{y=1}^{T} (\mathrm{N}_{total}.C_{maint}.PW^{y-1}) \tag{11}$$

$$N_{total} = NS_{new} + N_C + N_{tie} \tag{12}$$

where $NS_{new}$ is the number of new switches, $C_{new}$ is the cost of purchase and installation of new switches ($), $NS_{plc}$ denotes the number of existing switches that are placed in new positions, $C_{plc}$ is the cost of replacement of existing switches in the new position ($), $N_C$ is the number of sectionalizing (normally closed) switches in the original network, $N_{tie}$ denotes the number of tie-switches (normally open switches) in the original network, and $C_{maint}$ denotes the maintenance cost of a switch ($).

*3.1.4. General objective function of the problem*

Since each component of the objective function considers the net present value of the related costs for the whole project lifetime, all three components are of the same economic value. Therefore, the general objective function of the problem is defined by (13) and minimized in the trend of problem-solving.

$$O.F = O.F_1 + O.F_2 + O.F_3 \quad (13)$$

### 3.2. Constraints

1. Maximum number of purchased switches:

This constraint is considered with respect to the budget limitations of the distribution company:

$$NS_{new} \leq N_{sw,max} \quad (14)$$

where $N_{sw,max}$ is maximum number of new switches which can be purchased.

2. Power capacity of lines:

$$S_{ij}(\mathrm{t}) = \left(\sum_{j=1}^{N_{node}} |Y_{ij}V_iV_j| < (\theta_{ij} + \delta_j(\mathrm{t}) - \delta_i(\mathrm{t}))\right)^* \quad (15)$$

$$|S_{ij}(t)| \leq S_{ij,max} \quad \forall\, i,j = 1{:}N_{node} \;, i \neq j \qquad \forall\, t = 1{:}24 \quad (16)$$

where $S_{ij}(t)$ is the apparent power passing through the line connected between node $i$ and node $j$, $Y_{ij} = |Y_{ij}| < \theta_{ij}$ is component $(i,j)$ of nodal admittance matrix, $V_i(t) = |V_{i(t)}| < \delta_i(t)$ denotes the voltage of node $i$, $N_{node}$ *is* the number of nodes, and $S_{ij,max}$ is the capacity of the line connected between node $i$ and node $j$.

3. Voltage limits of buses:

$$V_{i,min} \leq |V_i(t)| \leq V_{i,max} \quad \forall t = 1{:}24 \quad (17)$$

4. Keeping radial structure and feeding all loads:

This constraint is necessary for the feasibility of the proposed configurations for cold and warm seasons. According to graph theory, for a radial network, the number of graph branches equals the number of nodes minus 1. Also, there exists one and only one path between every two nodes of a continuous graph corresponding to a radial network. Therefore, this constraint is formulated as:

$$N_{br} = N_{node} - 1 \quad (18)$$

$$Np_{ij} = 1 \quad \forall\, i,j = 1{:}N_{node} \;, i \neq j \quad (19)$$

where $N_{br}$ denotes the number of branches and $Np_{ij}$ is the number of paths between node $i$ and node $j$.

### 3.3. Solving the Problem

The presented optimization model is a mixed-integer nonlinear programming problem. Among the existing algorithms for optimization problems, the evolutionary algorithms (EA) simulate natural evolution principles to find optimal solutions. These algorithms are population-based and free-derivative that easily model the constraints. Although they do not determine the condition for reaching absolute optimum, they take advantage of some operators that reduce their chance of involving in local optimum, so they have a good chance for reaching the optimal solution. Due to its wide applicability, straightforwardness, and versatility, the genetic algorithm is one of the best evolutionary algorithms [20, 21]. Here, the optimization problem is solved by a genetic algorithm.

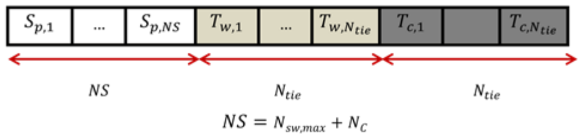



**Fig. 2:** The chromosome structure.

Each chromosome comprises the selected places of sectionalizing switches and places of tie-switches (normally open) in warm- and cold-season configurations. A typical chromosome structure is given in Fig. 2. Each gene actually shows the number of network branches on which the switch is installed. In the chromosome shown in Fig. 2, $S_{p,i}$ shows the location of the sectionalizers. Also, $T_{w,i}$ and $T_{c,i}$ show the location of tie-switches in warm and cold seasons, respectively. The number of nonzero values in the first part of each chromosome (white-color part) represents the total number of the sectionalizes in the structure. By comparing the number and place of all the switches (sectionalizes and tie-switches) in each chromosome to the number and place of the existing switches in the original configuration, the number of new switches purchased ($NS_{new}$) and the number of the existing switches in the present structure that must be replaced ($NS_{plc}$) are determined. From the second (light grey) and the third (dark grey) parts of each chromosome, the configurations of warm and cold seasons are obtained, respectively. By the method in [4], the constraint of keeping radial structure and feeding all loads is checked. If this constraint is violated in a given chromosome, a very large value is assigned as the objective function to this chromosome and the next chromosome is examined. If this constraint is satisfied, the objective function is calculated. Recall that the first and second components of the objective function depend on the proposed configurations for the two seasons. In this respect, for each proposed configuration of the warm and cold seasons, 24 load flow programs are run and the first component is calculated using (7). For load flow calculations, the backward-forward algorithm is used as in [22]. Other problem constraints are checked based on the load flow results and for each constraint violation, a penalty is applied. The imposed penalty is a variable value as a function of the distance of the violated constraint from the feasible area. Next, for each infeasible chromosome, a coefficient of the penalty values is subtracted from the value of the objective function of the worst feasible chromosome in the present population. The obtained value is assumed to be the objective function of the infeasible chromosome. By doing so, the infeasible chromosomes that do not violate the constraint of keeping radial structure and feeding all loads are not discarded and their information can be used for the algorithm search procedure. In the reproduction process, the roulette-wheel selection is used for a new generation. Using a test and set method, a two-point crossover with a rate of 0.8 is selected. Besides, the mutation rate is determined using a test and set of 0.05. If the objective function does not improve after a certain number of consecutive iterations, the algorithm will stop. In this work, these iterations are determined for each network by the test and set method. The general problem-solving algorithm is shown in Fig. 3.

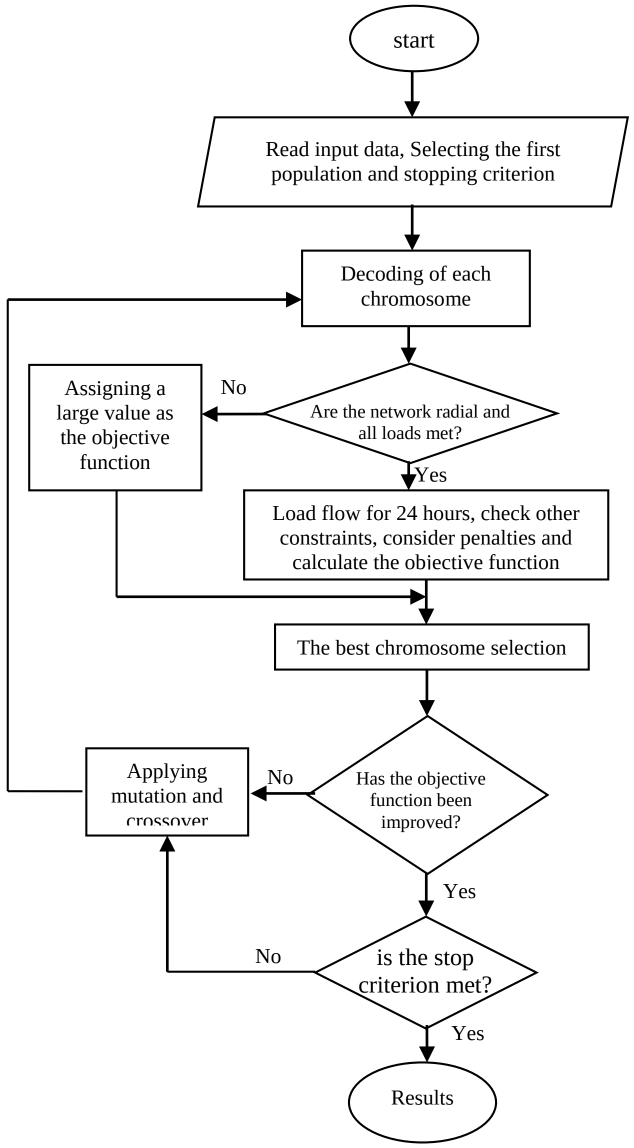



**Fig. 3:** The solving algorithm.

## 4. Numerical Results

### 4.1. Assumptions

The project lifetime is 5 years, the inflation rate is 11%, and the interest rate is 15%. The costs of purchase and installation of any new automatic and manual switches are US$ 5000 and 3000, respectively. The cost of replacing any existing switch and its installation in a new place is 0.1 of the purchase and installation cost of a new switch. The cost of annual maintenance for any switch is 0.02 of its purchase and installation cost. The annual load growth rates in warm and cold seasons are 3% and 0.5%, respectively. The cost of expected energy not supplied for different types of users is calculated as the average tariffs of the Power Ministry of Iran for different types of subscribers in warm regions and is assumed to be 0.03 US$/kWh. Energy market prices are similar to the energy market prices in Iran. Service restoration times for automatic and manual switches are 1 minute and 30 minutes, respectively.

### 4.2. Test Systems

To evaluate the proposed model, two test systems are used. The first one is a 33-bus system with characteristics in [4]. To have a real network's conditions, the system is modified and three types of loads as residential, commercial, and administrative and teaching centres are considered. Fig. 4 shows the single-line diagram of the modified 33-bus system. The load pattern for different consumers of this system is presumed to be similar to the load behavior of the consumers in Khuzestan, Iran [4]. Also, the distribution of the number and the time of interruptions in cold and warm seasons are assumed to be similar to the ruling conditions in studied real networks. Since the present study has introduced a novel model, the validity of the results cannot be investigated through the literature. Therefore, the validity of the suggested model is confirmed by analyzing the results obtained for different scenarios of the 33-bus system. The second test system has two 33-kV feeders from the power distribution network of Ahvaz city, the center of Khuzestan, with 332 buses to show the efficiency of the proposed model in real systems. This system has three normally closed switches and two normally open switches with residential and commercial subscribers. The details of this system are available in [23].

### 4.3. Results for Modified 33-Bus Test System

Section I of Table 1 shows the original system conditions, i.e., the location of the switches, normally open switches, the cost of seasonal energy loss, and the cost of seasonal expected energy not supplied considering the load and prices in the first year. The maximum number of new switches is assumed to be four and sectionalizing switch placement results for this system are given under five scenarios in section II of Table 1.

***Scenario 1:*** All switches are assumed to be manual and the switch placement is intended to minimize energy not supplied and investment and maintenance costs. After that, optimal seasonal configuration for minimizing energy loss cost is attained by reconfiguration. Two new switches are purchased and four of the existing switches are replaced. The normally open switches in the cold season are 7, 33, 34, 35, and 37. Also, the normally open switches in the warm season are 14, 27, 33, 35, and 36. The comparison of the results with the original network conditions shows that in the first year, energy loss costs in the cold and warm seasons have been reduced from US$ 803.2 and 15021 to US$ 670 and 11941 (16.58% and 20.5%), respectively, and total year decrease is 20.3%. Also, the costs of expected energy not supplied in the cold and warm seasons have been reduced from US$ 818 and 3088.5 to US$ 813.9 and 2707.6 (5% and 12.33%), respectively, and the total annual reduction is 9.8%. Besides, the total cost in the project lifetime is US$ 89425.

***Scenario 2:*** All switches are assumed to be manual and the switch placement is done by the proposed model. In the first year of the project, energy loss costs in the cold and warm seasons have been reduced by 20.56% and 22.1%, respectively and by 22% in the total year. Expected energy

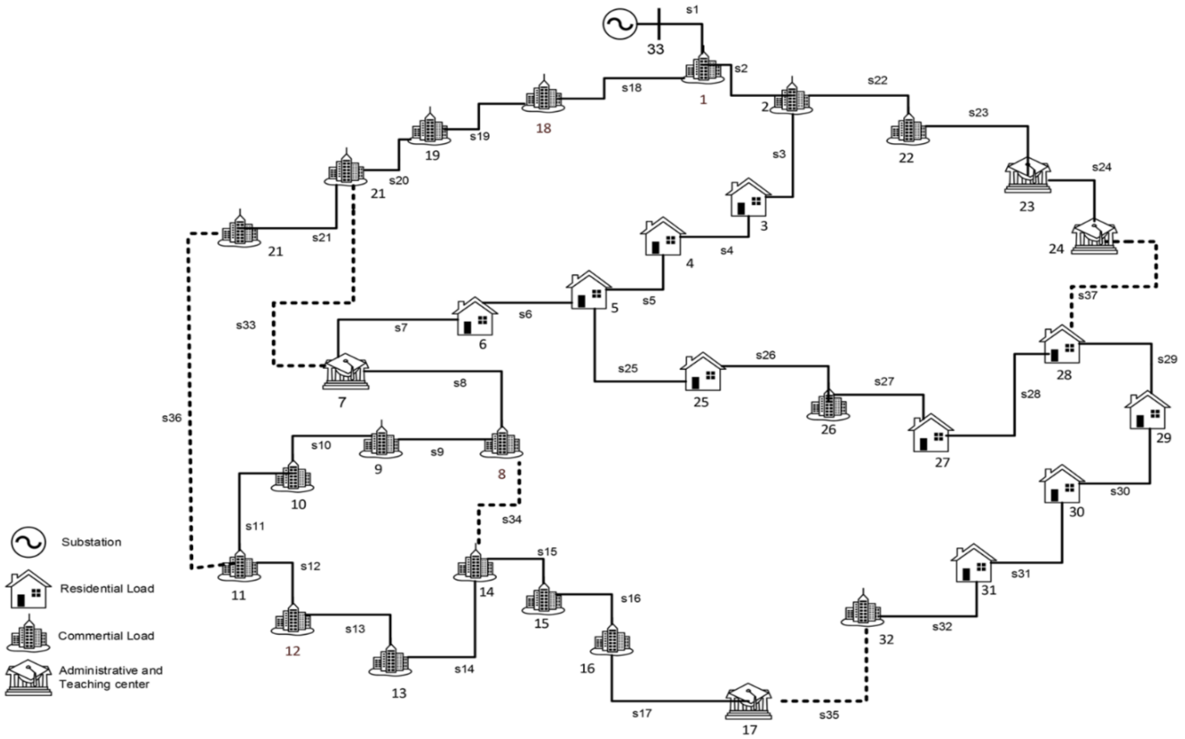



**Fig. 4:** The modified 33-bus test network.

**Table 1:** The results of sectionalizing switch placement for modified 33-bus test system.

**Part 1: Initial condition**

| Switches Position | Tie-Switches | Cost of Energy Loss ($) | | Cost of EENS ($) | | | |
|---|---|---|---|---|---|---|---|
| | | | | When all switches are manual | | When all switches are automatic | |
| | | Cold Season | Warm Season | Cold Season | Warm Season | Cold Season | Warm Season |
| 9-14-33-34-35-36-37 | 33-34-35-36-37 | 803.2 | 15021 | 818 | 3088.5 | 738 | 2596 |

**Part 2: Optimization Results**

| | | | Scenario No. | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 |
| Number of New Switches | | | 2 | 2 | 2 | 2 | 2 |
| Number of Replaced Switches | | | 4 | 3 | 3 | 3 | 3 |
| Tie-Switches | | Cold Season | 7-33-34-35-37 | 7-9-14-32-37 | 7-9-14-32-37 | 7-9-14-32-37 | 7-9-14-32-37 |
| | | Warm Season | 14-27-33-35-36 | 7-33-34-35-37 | 9-33-34-35-37 | 7-33-34-35-37 | 7-33-34-35-37 |
| First Year | Cost of Energy Loss ($) | Cold Season | 670 | 638 | 638 | 638 | 638 |
| | | Warm Season | 11941 | 11700 | 11761 | 11700 | 11700 |
| | Cost of EENS ($) | Cold Season | 813.9 | 795.5 | 654 | 1591.2 | 1262 |
| | | Warm Season | 2707.6 | 2831 | 1800 | 5583 | 3788 |
| Lifetime of Project | Total Cost of Energy Loss ($) | | 63491 | 62128 | 62440 | 62128 | 62128 |
| | Total Cost of EENS ($) | | 16604 | 17110 | 11553 | 33844 | 23564 |
| | Total Investment Cost | | 9329 | 8729 | 15048 | 8729 | 14548 |
| | Total Cost ($) | | 89425 | 87969 | 89043 | 104701 | 100240 |

not supplied costs in the cold and warm seasons have been reduced by 2.75% and 8.33%, respectively and by 7.16% in the total year. The total cost in the project lifetime equals US$ 87969. As is seen, the cost of energy not supplied in scenario 1 is low, compared to scenario 2, since switch placement in scenario 1 is focused on minimizing energy not supplied and investment and maintenance costs, and thus the places determined for installing the switches are optimal only from the said aspects. So, the application of these switches for finding optimal seasonal configuration to minimize energy loss cost cannot necessarily yield the best response. However, in scenario 2, switch placement is done by focusing on minimizing energy not supplied and energy loss costs besides investment and maintenance costs. As observed, in this scenario, reductions in the costs of energy loss in the cold and warm seasons and in the total year are more than the reductions in scenario 1. Although in scenario 2, the reduction in the cost of energy not supplied is smaller than this reduction in scenario 1, the total costs of scenario 2 in the project lifetime have been reduced by 1.6%, compared to scenario 1. This result supports the proposed model in the present study.

***Scenario 3:*** All switches are assumed to be automatic and switch placement is conducted by our model. Two new switches are purchased and three of the existing switches are replaced. Here, the normally open switches of the cold season are similar to that of scenario 2. The normally open switches in the warm seasons are 9, 33, 34, 35, and 37. In the first year, energy loss costs in the cold and warm seasons are US$ 638 and 11761 and the expected energy not supplied costs are US$ 654 and 1800, respectively. In the cold seasons of the first year, the energy loss costs are similar to those in scenarios 2 and 3 due to similar configurations of cold seasons. However, due to different configurations of the warm seasons, the energy loss cost in the warm season of the first year in scenario 3 shows a 61-dollar (0.52%) increase compared to scenario 2, and in annual bases, a 0.49% increase is seen. Besides, due to the very short restoration time with automatic switches compared to manual ones, the costs of expected energy not supplied for the cold and warm seasons in the first year in scenario 3 have had US$ 141.5 (17.78%) and US$ 1031 (36%) reductions, respectively, compared to scenario 2. Nonetheless, due to the higher investment costs in automatic switches, the total cost of scenario 3 is 1.2% greater than that of scenario 2. In a network with a low level of security, the decrease in the cost of expected energy not supplied due to automatic switches is expected to go beyond the increase in the original investment costs for these switches. This is shown in scenarios 4 and 5.

***Scenario 4:*** In this scenario, the number of occurrences and the repair time for each feeder section are assumed to be double and manual switch placement is done by the proposed model.

***Scenario 5:*** This scenario is similar to scenario 4, except that the switches are here automatic.

In scenario 4, the costs of energy not supplied in the cold and warm seasons in the first year are US$ 1591.2 and 5583, respectively. In scenario 5, they are US$ 1262 and 3788, showing 20.68% and 32% reductions compared to scenario 4. In scenario 5, a 4.2% decrease in total cost in the project lifetime is observed compared to scenario 4. As it is seen, despite the higher investment cost of automatic switches, in the low-security networks, they can be more economic for improving network security.

### 4.4. Results for the Real System

The costs of energy loss and expected energy not supplied per year (considering the load and prices in the first year) are US$ 28850 and 4189.9, respectively. The maximum number of new automatic switches is assumed to be two and switch placement is done by the proposed model. No new switch is purchased and four of the existing ones are replaced. Therefore, the existing switches are not in proper places in the original network structure, and replacement of these switches can reduce the costs of energy loss and energy not supplied without installing new switches and spending investment costs. Due to these replacements and network reconfigurations, the costs of energy loss and energy not supplied in the first year decrease to US$ 24330.9 and 3331.1 (i.e., 15.56% and 20.5% reductions), respectively, and the total cost in the whole project lifetime equals US$ 142882.4. The detail of the results is provided in [23].

## 5. Conclusions

This study introduces a novel and applied model for switch placement in radial distribution networks in which both roles of switches in normal operating conditions and in the presence of fault are taken into consideration. Moreover, the conditions of Khuzestan's distribution networks in both warm and cold seasons are incorporated in the model. The objective function is to minimize investment and maintenance costs, the cost of energy loss, and the cost of expected energy not supplied. The cost of energy loss in each season is calculated based on the network configuration of the normal condition in that season. The expected energy not supplied is also calculated seasonally and the annual expected energy not supplied is obtained by the sum of expected energy not supplied in the cold and warm seasons. This model can determine optimal places for installing sectionalizing switches and optimal network's configurations for minimizing the total costs. The model is confirmed through a 33-bus network under the first and the second scenarios. The total costs of scenario 2, which is corresponding to the presented model, are decreased by 1.6% compared to scenario 1, which is like the common cases in previous papers. The comparison of scenarios 2, 3, 4, and 5 shows that in low-security networks, the application of automatic switches for improving network security can be more economic. The results of implementation on a real network in Ahvaz show that the existing switches in the original network structure are not properly positioned and the costs of energy loss and energy not supplied significantly decrease by replacing these switches and without purchasing new ones.

## Credit Authorship Contribution Statement

**Ali Rouhipour:** Data curation, Methodology, Resources, Roles/Writing - original draft. **Elaheh Mashhour:** Project administration, Supervision, Validation. **Mohsen Saniei:** Validation, Writing - review & editing.

### Declaration Of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy has been completely observed by the authors.

## References


[1] A.A. El-Fergany, "Optimal capacitor allocations using evolutionary algorithms, " *IET Gen. Trans. & Dist.*, vol. 7, no. 6, pp. 593-601, 2013.

[2] Z. Wang, H. Liu, D. C. Yu, X. Wang, and H. Song "A practical approach to the conductor size selection in planning radial distribution systems, " *IEEE Trans. Power Del*, vol. 15, no. 1, pp. 350-354, 2000.

[3] J. F. Franco, M. J. Rider, M. Lavorato, and R. Romero "Optimal conductor size selection and reconductoring in radial distribution systems using a mixed-integer LP approach, " *IEEE Trans. Power Del.*, vol. 28, no. 1, pp. 10-20, 2013.

[4] S. H. Alemohammad, E. Mashhour, and M. Saniei, "A market-based method for reconfiguration of distribution network, " *Electr. Power Syst. Res.*, vol. 125, pp. 15-22, 2015.

[5] A.Y. Abdelaziz, F.M. Mohamed, S.F. Mekhamer, and M.A.L. Badr, "Distribution system reconfiguration using a modified tabu search algorithm, " *Electr. Power Syst. Res*., vol. 80, no. 8, pp. 943-953, 2010.

[6] V. Farahani, B. Vahidi, and H. A. Abyaneh, "Reconfiguration and capacitor placement simultaneously for energy loss reduction based on an improved reconfiguration method, " *IEEE Trans. Power Syst*., vol. 27, no. 2, pp. 587-595, 2012.

[7] B. Amanulla, S. Chakrabarti, and S. N. Singh, "Reconfiguration of power distribution systems considering reliability and power loss," *IEEE Trans. Power Del.*, vol. 27, no. 2, pp. 918-926, 2012.

[8] G. A. Hamoud and L. Lee, "Criticality assessment of distribution feeder sections, " *IEEE Trans. Power Syst*, vol. 27, no. 1, pp. 298-304, 2012.

[9] N. Khalesi, N. Rezaei, and M. Haghifam, "DG allocation with application of dynamic programming for loss reduction and reliability improvement," *Journal of Electrical Power & Energy Syst.*, vol. 33, no. 2, pp. 288–290, 2011.

[10] R. Billinton and S. Jonnavithula, "Optimal switching device placement in radial distribution systems, " *IEEE Trans. Power Del.*, vol. 11, no. 3, pp. 1646-1651, 1996.

[11] C.-S. Chen, C.-H. Lin, H.-J. Chuang, C.-S. Li, M.-Y. Huang, and C.-W. Huangl, "Optimal placement of line switches for distribution automation systems using immune algorithm, " *IEEE Trans. Power Syst.*, vol. 21, no. 3, pp. 1209–1217, 2006.

[12] I. Goroohi Sardou, M. Banejad, R. Hooshmand, and A. Dastfan, "Modified shuffled frog leaping algorithm for optimal switch placement in distribution automation system using a multi-objective fuzzy approach," *IET Gen. Trans. Dist.*, vol. 6, no. 6, pp. 493-502, 2012.

[13] A.A. Jahromi, M.F. Firuzabad, M. Parvania, and M. Mosleh, "Optimized sectionalizing switch placement strategy in distribution systems, " *IEEE Trans. Power Del.*, vol. 27, no. 1, pp. 362–370, 2012.

[14] S. I. Lim, T. S. Sidhu, M. S. Choi, S. J. Lee, and B. N. Ha, "A optimal composition and placement of automatic switches in DAS, " *IEEE Trans. Power Del.*, vol. 28, no. 3, pp.1474-1483, 2013.

[15] S. Ray, A. Bhattacharya, and S. Bhattacharjee, "Optimal placement of switches in a radial distribution network for reliability improvement, " *International Journal of Electrical Power & Energy Sys.*, vol. 76, no. 6, pp. 53-68, 2016.

[16] L. Wang, J. Lin, G. Liu, G. Wang, Q. Zhong, and Y. Zhao, "An MIP-based model for the deployment of fault indicators and sectionalizing switches in distribution networks, " *Electr. Power Syst. Res*., vol. 179, 106076, 2020.

[17] M, Moradijoz, S. Moradijoz, M. Parsa Moghaddam, and M.-R. Haghifam, "Flexibility enhancement in active distribution networks through a risk-based optimal placement of sectionalizing switches, " *Reliability Engineering & System Safety*, Vol. 201, 106985, 2020.

[18] AccuWeather, (June 29, 2017). [Online]. Available: https://www.accuweather.com/en/ir/ahvaz/210047/month/210047?monyr=6/01/2017

[19] "Monthly information of simultaneous load peak of the whole network," *Tavanir specialized parent company, Deputy of Research and Human Resources, Office of Information Technology, Communication and Statistics*, 2016.

[20] K. Deb, "Multiobjective optimization using evolutionary algorithms," *Wiley, Chichester*, 2002.

[21] M. Gen and R. Cheng, "Genetic algorithm and engineering optimization, " *John Wiley & Sons*, 2000.

[22] S.M. Moghaddas-Tafreshi and E. Mashhour, "Distributed generation modeling for power flow studies and a three-phase unbalanced power flow solution for radial distribution systems considering distributed generation," *Electr. Power Syst. Res.*, vol. 79, no. 4, pp. 680-686, 2009.

[23] E. Mashhour, " Optimal placement of line switches for pilot feeders of Ahvaz distribution network to improve the security indices," *Research Project Report, Shahid Chamran University of Ahvaz*, June 2016.


## Biography

**Ali Rouhipour** was born in Behbahan, Khuzestan, Iran in 1992.He received the B.Sc. and M.Sc. degrees in Electrical Power Engineering from Shahid Chamran University of Ahvaz, Ahvaz, Iran in 2014 and 2016 respectively. His interest topics include reliability, rearrangement and restructuring of power networks.

**Elaheh Mashhour** (M'08) was born in Tehran, Iran, in 1974. She received the Ph.D. degree in Electrical Engineer-ing from K. N. Toosi University of Technology, Tehran, Iran, in 2010. She worked in Khouzestan Electric Power Distribution Company for 15 years as the manager of network and load control office, the manager of power market office and head of DG participation unit. From 2011, she has been an Assistant Professor and a Faculty Member with the Electrical Engineering Department, Shahid Chamran University of Ahvaz, Ahvaz, Iran. Her research interests are distribution system automation and planning, power market, network resiliency and deep learning.

**Mohsen Saniei** was born in Dezful, Iran, 1966. He received B.Sc. in Electrical Power Engineering from Ferdowsi University of Mashhad, in 1989, and received M.Sc. in Electrical Power Engineering from Tarbiat Modarres University, in 1992. He completed his Ph.D. in Electrical Engineering from Strathclyde University, Glasgow, UK, in 2004. His interest is in power system dynamics, microgrid and power system operation.