IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received June 29, 2021, accepted July 6, 2021, date of publication July 9, 2021, date of current version July 16, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3096128

Automated Distribution Networks Reliability Optimization in the Presence of DG Units Considering Probability Customer Interruption: A Practical Case Study

HASSAN KARIMI[1], TAHER NIKNAM[1], (Senior Member, IEEE), MOSLEM DEHGHANI[1], MOHAMMAD GHIASI[1], (Member, IEEE), MINA GHASEMIGARPACHI[1,2], SANJEEVIKUMAR PADMANABAN[3], (Senior Member, IEEE), SAJAD TABATABAEE[4], AND HAMDULAH ALIEV[5], (Member, IEEE)

[1]Department of Electrical and Electronic Engineering, Shiraz University of Technology, Shiraz 71557-13876, Iran
[2]Department of Electrical Engineering, Kazerun Branch, Islamic Azad University, Kazerun 73198-66451, Iran
[3]CTiF Global Capsule, Department of Business Development and Technology, Aarhus University, 7400 Herning, Denmark
[4]Department of Electrical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr 15847-43311, Iran
[5]Faculty of Energy, Tajik Technical University, Dushanbe 734042, Tajikistan

Corresponding authors: Hamdulah Aliev (hhuali334@gmail.com) and Taher Niknam (niknam@sutech.ac.ir)

ABSTRACT Automation in power distribution systems and supervisory control and data acquisition (SCADA), which perform network switching automatically and remotely, allows distribution companies to flexibly control distribution power grids. Cross-section switches also has a significant role in the automation in distribution systems, in that the operational optimization of these switches is able to enhance the supply power quality and reliability indicators, and can be a prosperous solution to increase the reliability, efficiency and overall service quality in services to customers. In this regard, in this work, the genetic optimization algorithm (GOA) approach which integrated the Steepest Descend Technique (SDT) is proposed and enhanced based on the features of the mentioned issue to sketch the optimal location and control of automatic and manual cross-section switches and protection relay systems in distribution power systems. The GOA is able to search globally that can prevent the result from locally convergence, also, GOA gives superior primary solutions for the SDT. Thus, the SDT can search locally with higher performance which increase the solutions' accuracy. Therefore, an optimization formulation is proposed to improve the value-based reliability of the suggested layout considering the cost of customer downtime and the costs related to segmentation of switches and relay protection devices. Also, a distributed generation (DG) system in distribution networks is considered based on the islanded state of generation units. The effectiveness of the optimal suggested procedure is evaluated and represented via performing a practical test system in the distribution network of Ahvaz city in Iran. The results show that using proposed method and by optimally allocating switches maneuver, energy losses without switches are reduced from 310.17 (MWh) to 254.2 (MWh), and also by using DG, losses are reduced from 554.01 to 533.61 which confirms the ability and higher accuracy of the proposed method to improve reliability indices.

INDEX TERMS Automated distribution networks, genetic algorithm, sectionalizing switch placement, reliability, distributed generation, customer interruption cost model.

I. INTRODUCTION

A. BACKGROUND

Today, assessing of power distribution systems in order to find new ways to improve reliability indicators in distribution networks using distribution automation systems (DASs) is one of the interests of experts in the electricity industry. The use of DAS in distribution power grids can be defined to monitor, control and operate the components and devices of the power distribution grid systems to restore and provide energy to customers in the event of an error. Actually, DAS not only remotely controls and operates distribution

The associate editor coordinating the review of this manuscript and approving it for publication was Siqi Bu.

substation equipment and feeders, but can also present a reliable, self-repairing power grid which is able to quickly and efficiently respond to events and react appropriately. Therefore, economic and technical analysis of DAS will be necessary due to the high cost of power grid investment [1]–[3].

In some researches, it has been estimated that almost 70% of interruptions and power outages are due to failures in the primary distribution networks [4], [5]. Hence, significant efforts have been made to decrease the negative impacts of failures using DAS with automatic protection devices like circuit breakers (CBs) or cross-sectional (sectionalizing) switches in the network. One important task of DASs can be optimally determining the location of remotely control switches to detect and separate faults and quickly mend customer service. Therefore, the appropriate number and location, as well as the type of such protective devices to minimize the effect of interruption, can play a pivotal role in improving the automation distribution systems' reliability [6].

In addition to this, the numeral and locational optimization of automatic and manual switches, and also the optimal type of protection devices and relays are highly effective to minimize overall costs and maximize customer yields [7], [8]. Sectionalizing switches have been mainly utilized to enhance service reliability in primary distribution networks. Research studies illustrated that a distribution system typically accounts for up to 40% of power supply costs and about 81% of customer reliability issues [9]. Also, reconfiguring distribution networks can be an efficient way and economical approach to enhance system reliability. Overall, one of the main purposes of evaluating the reliability indices in distribution power grids is to model any possible conditions for the occurrence of interruptions or errors in the system and to calculate the effect of reliability in any possible conditions. This process can be done through different approaches [10]–[13]. Considerable studies have been done in this area, for example, in the reference [14] an analytical technique according to the network assumptions and considering the statistical distribution of failure rate and repair time has been presented. They have proposed the related method, which was based on the error problem of all power grid devices and their results in interrupting load points. Reference [15] proposed an optimal practical method in which the reliability performance of the network can be estimated by directly evaluating the configuration of distribution power system. In this article, authors claimed that this method does not need historical data, and can identify specific places which require corrective action.

In the paper [16], a Markov hierarchical model for reliability analysis such as the impacts of various fault modes, failure separation strategy and load restoration according to the system configuration, integrity of control protection systems, and single protection component has been presented. Reference [17], also, presented an approach to reduce the complexity of radial distribution system using network equivalents to a set of general reliability of feeders. This method suggested a sequential and repetitive procedure for evaluating a person's reliability indicators from the point of load. Billinton and Wang, the authors of the paper [18], have proposed a sequential chronological simulation method using Monte Carlo to evaluate reliability and compare it with the analytical technique; where, they have resulted that the simulation method needs a longer computational time, however, they provided data on the point of load and system indicators which represented technical and analytical strategies.

Recently, heuristic algorithms like genetic optimization algorithm (GOA) [4], ant colony optimization (ACO) [19], simulated annealing optimization [20] and also immune algorithm optimization [21] have received more attention in the technical literature review as different techniques to address the problem of optimal sectionalizing switching allocation. For example, to specify the number and optimal placement of two different models of automatic switches (circuit breaker and sectionalizer) in distribution grids, the technique of the trinary particle swarm optimization algorithm (PSO) is used in reference [22]. In the paper [23], the problem of switch feeder displacement, with the aim of reducing customer power outage costs, has been solved using an innovative approach and simple numerical calculations. In the reference [24], a complex integer linear equation has been obtained to model the sectionalizing switch allocation issue, in that the switch cost and customer output power are also investigated. Also, in order to tackle the problem of optimal combination and location of switching placement in distribution automation grids, an analytical approach has been presented in article [25]. Other techniques including the decomposition method and the reference alliance algorithm were used in references [26] to specify the optimal placement of switches. Besides, in the reference [4], a framework and solution based on the concept of memetic method with a structured population has been proposed.

In these scientific works, several factors including switching cost, expenses of interruptions or outages of customer services and the desired number and the places of sectionalizing switches were considered to meliorate the reliability of electrical power grids. Nonetheless, considering information disparities such as the cost of disconnecting the customer are able to have a great impact on the precision of reliability assessments, which have not been taken into account in these articles.

One of the reasons that can directly affect the outage or interruption cost model of customer service is the accuracy of reliability analysis. In general, there are two models for modeling the cost of outages or interruptions in customer service. In the customer survey method, customer power outage or interruptions' cost data is usually provided, which can also be modeled as customer damage performance (CDF) [26], [27]. In this method, the total or average interrupt cost for every customer segment is determined as a duration function. The main drawback of this model is average cost model (ACM), which ignores the scattered nature of the information in a specific customer group. In this case, the scattered characteristic of customer disconnection costs during the specified fault period is determined as the probability distribution model (PDM). As the outcomes have been shown in articles [28], it was shown that PDM has a significant impact on forecasting the expected customer outage or interruptions' costs.

Another important issue that needs to be considered is the growth of distributed generation (DG) in the power grid, which is limited by economic reasons [29]–[31]. Issues such as increasing attention to the quality of electricity and its positive effects on grid-connected equipment, awareness of environmental issues arising from the use of renewable energy, regulation in the electricity market and attention to reducing the cost of photovoltaic and wind production can be defined as the reasons of increasing the integration of DGs in power grid systems. In the analysis of the issue of reliability in the power distribution network, DG units can improve the reliability of the network by reducing the downtime and repair time after a specific error. However, such improvements in network reliability depend on the performance of DG units, like islanding mode [32], [33], while protection needs are also met [34]. Therefore, when DG units are present in distribution networks and can produce a percentage of the network load, the problem of switching optimization and optimization of the location of protection devices and equipment becomes more complicated.

In this paper, GOA has been used to solve the switches placement in the real electrical distribution network. The aim is to minimize the whole objective functions with various constrains like technical and economical. The offered technique includes 3 various cost functions, consisting of maintenance and investment cost, the cost of expected undistributed power, and the cost of power losses.

B. MOTIVATION AND MAIN CONTRIBUTION

The principle contribution of this research work is to propose a GOA to address the optimal allocation issue of sectionalizing switches considering the effects of protection devices in the presence of DGs in power network. The suggested optimal approach provides a practical technique while limits the number of network switching and protection devices installed and minimizes the reliability costs. In the proposed cost model, the values contain the costs of maintenance and investment, costs of energy losses and undistributed energy, which simultaneously include costs related to switches and protection equipment like investment, installation, maintenance, and yearly operation costs have been considered. In addition, in this paper, the cost of interruptions and outage caused by temporary failures has been considered in the proposed equations. Generally, the main contributions of the paper are summarized as follow: 1) Optimal placement of different devices in an actual distribution system (Ahvaz distribution network) with 3 different cost functions; 2) Maneuver switches optimal configuration layout has been propelled to a real project in diverse case studies with or without DG and has been compared with classical mode (without maneuver switches); 3) This research work develops reliability of network with higher accuracy and efficient optimization technique in the GOA framework. Also, the presented algorithm integrates the steepest descent technique (SDT) to make up GOAs' drawbacks of rare performance in the local questing, and has been confirmed by an actual study case; 4) The branch line influence has been planned on the automatic device configuration in this study. The system reliability has been investigated significantly and avoiding manual planning. So, the electrical power grids reliability is meliorated.

C. PAPER STRUCTURE

The remainder of the research work is reported as follows. In Section II, the optimization method and problem formulation will be presented. Section III will present proposed algorithm and problem equations. In Section IV, also, assumed case studies will be investigated and simulation outcomes will be considered. Finally, the main conclusions of the suggested optimization technique will be stated in Section II.

II. PROPLEM FORMULATION

A. SWITCHES SECTIONALIZING AND PROTECTIVE COMPONENTS

Overall, in order to reduce the impacts of faults to an acceptable minimum rate, utilities usually have installed protective devices and components through the feeders of distribution grids. In this regards, in this paper, the protective components including CBs by overcurrent detection equipped with automatic reclosing relay protections at the substations, and also sectionalizing fuses and switches through the feeders are considered. After operating the upstream CB, automatic sectionalizing switches are able to isolate a faulted section. Fuses, which have lower protective costs, are able to sense the failure. We assume that they have the interruption capability, but they do not have the ability of reclosing automatically. In addition, in this article, fuses will be installed on the sides, and a limitation will be considered to prevent fuses from being placed on the main feeders.

B. BASIC OPERATIONAL CONCEPTS OF DISTRIBUTION SYSTEMS

Distribution systems typically use switches and protective components to increase network reliability and minimize the effects of customer errors which lead to minimizing the number of customers who are affected by protective components. Because of the inefficiency of equipping all feeders, only a finite number of protective components and switches could be set on the feeders. In addition, the type and location of these components should vary depending on the network configuration.

Since sectionalizing switches are able to locate on either side of each section of the line, the protection devices are generally placed at the inception of the line feeding sections and on the feeders. The performance of operation in distribution systems is generally considered based on the model, number and place of protective components and switches.

C. DISTRIBUTION NETWORKS RELIABILITY INDICES

In the event of a failure or outage in the distribution network, failure management processes try to return the network to normal operating conditions in the shortest possible time. Overall, a generic failure management procedures contains of 3 different parts: first, determining the location of failure, second, separating the failure location, and third, energy supply recovery. Failure indexes provide information to accelerate and identify the failure place finding and the energy supply restoration process. Switching segmentation can divide the failure section and reduce the number of outage for customers, and interruption time. In this way, assigning cross-section switches and failure signal indicators in power distribution networks can remarkably reduce interruption costs and improve reliability.

Cross-section switches can generally develop the rate of automation in distribution power grid and bring notable benefits to energy supply corporations. Furthermore, the cross-section switches divide areas from the faulty parts, whenever a failure is happened in the network. The upstream customer to the faulty area is reformed through the primary line, and the downstream customer to the faulty area is reformed via the alternative line linked with tie breaker switches. Additionally, the client's interruption and outage time in the faulty zone is the total of repair and failure periods. Overall, we can define two different modes of sectionalizing switching: one type is manual switch which has been performed the separation manually, and another type is remote-controlled switch that has been implemented the separation remotely. Therefore, the time of switching in remote-controlled switching mode is notably lower compared to manual switching mode that can reduce costs of outage and interruption time. Even though the remote-controlled switching mode executes with a higher performance in the failure management process, this type can be more expensive, so it is usually not preferred through energy supply corporations. As a result, manual switches, firstly, have been taken into account the first option in energy supply corporations. Whenever the located manual switch fails to meet the required reliability, remote control switching modes are selected. Briefly, reliability needs and component prices have a significant effect on the position of switches. In the electrical distributed sections, the most important characteristics of reliability are defined as follows:

- Medium interruption frequency index of the system (MIFIS);
- Medium interruption frequency index of the customer (MIFIC);
- Medium interruption duration index of the system (MIDIS);
- Medium interruption duration index of the customer (MIDIC):
- Medium service availability index (MSAI);

The formulas (1) to (5) are presented the mentioned specifications [35].

$$MIFIS = \frac{sum\ of\ customer\ interruption}{sum\ of\ customers\ that\ is\ serviced} = \frac{\sum \lambda_j N_j}{\sum N_j} \quad (1)$$

$$MIFIC = \frac{sum\ of\ customer\ interruption}{sum\ of\ customer\ interruption\ time} \quad (2)$$

$$MIDIS = \frac{sum\ of\ customer\ that\ is\ in\ electrical\ interruption}{sum\ of\ customers\ that\ is\ serviced} = \frac{\sum U_j N_j}{\sum N_j} \quad (3)$$

$$MIDIC = \frac{sum\ of\ time\ customer\ interruption}{sum\ of\ customer\ that\ is\ in\ electrical\ interruption} = \frac{\sum U_j N_j}{\sum \lambda_j N_j} \quad (4)$$

$$MSAI = \frac{sum\ of\ time\ that\ customers\ have\ electricity}{sum\ of\ time\ that\ customers\ must\ have\ electricity} = \frac{\sum N_j * 8760 - \sum U_j N_j}{\sum N_j * 8760} \quad (5)$$

where λ_j represents fault rate (number of fault based on *f/yr*); N_j represents the number of clients on spot j, and U_j indicates yearly egress period. In several research works, further indices have been suggested in the power distribution grids as follows:

- Average load

$$L_\alpha = L_\beta.f \quad (6)$$

where, L_α defines the medium of loads, L_β represents the maximum load, and f defines the load ratio.

- Energy not supplied (ENS)

$$ENS = \Sigma L_{\alpha(j)} U_j \quad (7)$$

where, $L_{\alpha(j)}$ represents the medium of loads that is connected with the grid at the spot j.

- Medium of not provided energy

$$MENS = \frac{sum\ of\ energy\ not\ generated}{sum\ of\ customers\ that\ is\ serviced} = \frac{\Sigma L_{\alpha(j)} U_j}{\Sigma N_j} \quad (8)$$

- Medium customer curtailment index (MCCI)

$$MCCI = \frac{sum\ of\ energy\ not\ generated}{sum\ of\ customers\ that\ contain\ interruption} \quad (9)$$

For active, passive, and transient failures which are happened accidentally, the amount of fault of the components on every off-grid section will be summed to the others, and an equivalent fault rate is achieved for the off-grid section.

$$\lambda_{total} = \sum \lambda \quad (10)$$

In equal blackout time of every island, it will be obtained using equation (11).

$$U_{total} = \sum (\lambda \times r) \quad (11)$$

1) DG MODELING

The DG operation in distribution power grids are able to be presented in a two conditions form in which the generator works in full/zero capacity that is displayed in Figure 1. Because the DGs are typically made as small generation units with the range of $< 15MW$, the incomplete capacity status has been relinquished in this research. The incomplete capacity status is normally utilized for 100MW production or more. In this work, we assume that the forced outage rate (FOR) is 0.01 and the maintenance time of DGs is 44h, that used in reference [28]. Another important point is that in face of existing active fault in the grid, the DG must be immediately decoupled. After isolating the faulted areas, the DG supplies the sound zones of the grid by working in islanded manner.

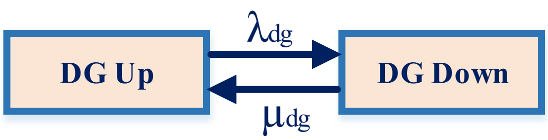


FIGURE 1. Two-state form for DG units.

Hence, we can define the probability of unavailability and availability of a double-mood form for DGs which are presented as follows:

$$P_{available} = \frac{\mu_{dg}}{\lambda_{dg} + \mu_{dg}} \tag{12}$$

$$P_{unavailable} = \frac{\lambda_{dg}}{\lambda_{dg} + \mu_{dg}} \tag{13}$$

where, λ_{dg} represents the expected fault rate and μ_{dg} gives the expected repair rate of a DG unit.

III. PROPOSED METHOD FORMULATION AND ALGORITHM

A. PROBLEM FORMULATION

The proposed method has 3 different cost functions, consisting of investment and maintenance cost, the cost of expected undistributed power, and the cost of power losses which are given in equations (14) to (16).

$$\begin{aligned} CF_1 &= (NS_{new}.C_{new}) + \left(NS_{plc}C_{plc}\right) \\ &\quad + \sum\nolimits_{m=1}^{T} \left(N_{total}C_{maint}PW^{m-1}\right) \\ N_{total} &= NS_{new} + N_c + N_{tie} \end{aligned} \tag{14}$$

Second cost function is presented in equation (15).

$$\begin{aligned} CEENS &= \sum\nolimits_{n=1}^{n} (U_{lp.j.n}P_{j.n} \times CE_{j.n} \\ &\quad + \sum\nolimits_{j=1}^{N_{i.n}} U_{p.j.n}P_{j.n} \times CE_{j.n}) \\ CF_2 &= \sum_{m=1}^{T} CEENS \times PW^m \left(1 + 0.01Lg_n\right)^{m-1} \end{aligned} \tag{15}$$

The third cost function is also provided in equation (16).

$$CF_3 = Loss - Cost_n = N_n \times \sum_{t=1}^{24} \xi_{t.n} \times Loss_{t.n} \tag{16}$$

where, N_n represents the number of period day; $\xi_{t.n}$ provides the average hourly energy market price, Lg_n defines the growth percentage of annual load corresponding to period n and $N_{i.n}$ represents the points load number which cannot be recovered; $CE_{j.n}$ expresses expected uninterruptible energy supply at point j and $Loss_{t.n}$ is the energy losses per hour t, for a typical day, in duration n, for the first project annual; NS_{new} represents the number of new switches, NS_{plc} is the number of switches moved to the other place; C_{new} defines the purchasing and installation cost for the new switches, C_{plc} represents the cost of moving the extant switches to the new place; and N_c gives the whole number of usual closed manner.

B. GENETIC ALGORITHM

Searching methods in some optimization algorithms like PSO, FA or DE include small-step random moving and heuristically directional moving, and may have difficulty to generate new answers which have been very away from the old cluster.

Such techniques usually lessen universal efficiency, even though help too much to convergence performance. As a result, this work expands the enhanced GOA that has a more suitable template questing with major-scale questing capabilities. In addition, it has been incorporated with SDT for enhancing the convergence accuracy and performance. Fig. 2 displays the diagram of the proposed optimization method. Aa can be seen, it includes three different parts: 1) Additional migration operator in comparison to the simple GOA owing to the recruitment of parallel GOAs [35] as its template; 2) The member part which calculates the optimization objective; 3) The SDT which takes the great members within the improvement and questing further from them for raising the accuracy of the solution. The GOA can effectively and universally control the optimization process which evaluates every member (solution). Whenever an excellent member generates, it sends to the SDT questing as a primary solution. The optimally universal solution has been opted from the quested solutions of SDT.

Not only that GOA techniques are generally global searching approaches for avoiding from local convergence, but also they are very useful owing to the parallel calculation process. GOAs quest to find the optimum solution with simulating the inherent choice and genetic strategy in the evolution view of Darwin [36]. This optimization method is started with a population which provides the potential solutions area for the problem. This population contains a group of members by having encoded genes. Therefore, every member is the feature of special chromosomes. As the genetic materials carrier, the chromosome characterizes inherently with a compound of genotype/genes, and has been specified the outer statement of one member. As a result, a direction between the phenotype and the genotype is established at the beginning in the type of genuine/binary coding to simplify. Within the subsequent evolution, the members are opted based on the basic of fittest surveillance, and then, a new population has been

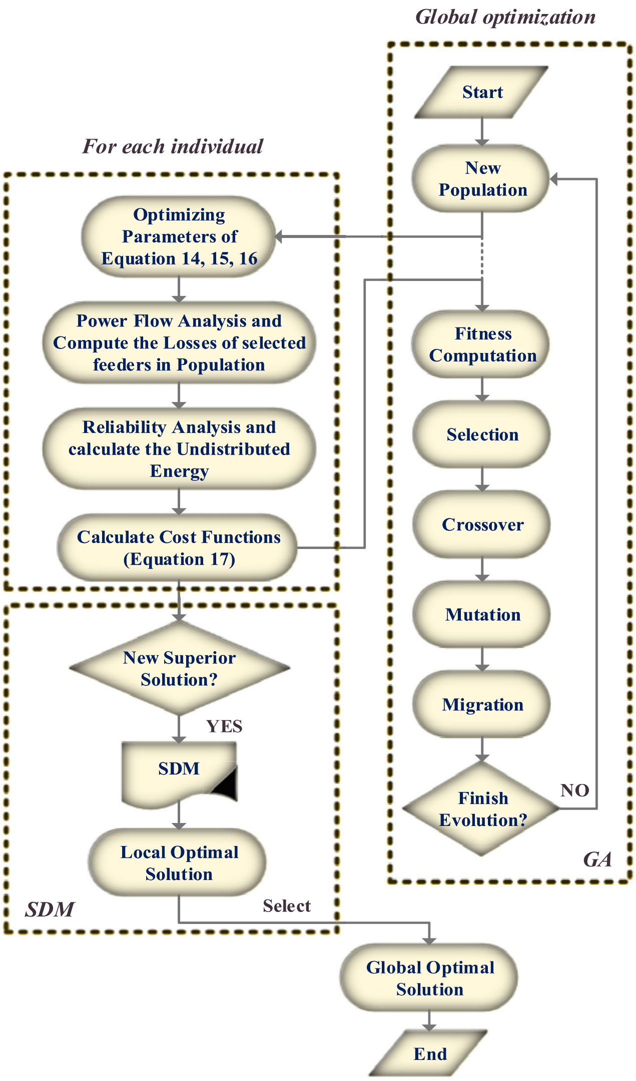


FIGURE 2. **Suggested optimization algorithm flowchart.**

produced with genetic factors, mutation and crossover. As new descendants are rather environmentally adaptive compared to the previous ones, the population is acceding optimal. The desired conclusive solution is able to be achieved through decoding the optimal members in the previous descendant. Various enhancements were developed in the recent years, including fluid GOA [37], Niched GOA (NGOA) [38], messy GOA [39] and Adaptive GOA (AGOA) [40]. As efficient universal heuristic questing approaches, they are successfully utilized in energy management optimization problems to optimally allocate switches [41].

The GOA must forbid local converging of solutions, provide primary solutions accessible to SDT, and consider computational proficiency. Therefore, the consequent enhancements have been executed accordingly.

GOA should prevent local convergence of solutions and provide the initial solutions available to SDT that take into account computational efficiency. Therefore, some improvements can be made accordingly as follows:

1) **Initiation**. To use all of the advantages of computational resources, a parallel GOA has been employed [35]. The global population have been separated to the N sub-populations, where every of them includes μ members and evolves independently. All members have been randomly generated at the first generation. Genes have been encoded based on binary coding.
2) **Termination status**. In overall, the GOA has been terminated whenever the number of production (n_p) has been reached to the determinate maximum (N_p). An extensive amount of N_p, that is difficult to estimate, may give rise to vast calculations cost. As a result, the other end estimator (n_{pnb}) has been defined. It is specified as the generations number when better member has not appeared. Whenever either n_p or n_{pnb} attains to their defined maximum of N_p or N_{pnb}, the iteration will be terminated.
3) **Preselection**. Here, the crowding method in the NGOA has been applied to form members in the 1^{th} various productions uniformly spread in the solution area [38]. It adjusts the crowding factor (CF) where chooses randomly $^1/_{CF}$ of entire members to crowd to omit and reproduce to those very alike to them. Therefore, members have been divided from each other, and the population diversity have been increased. The likeness among 2 members are able to be tested based on the specified threshold of hamming distance (d_{m0}) [42]. The Subroutine CROWD pseudocode has been presented as below:

CROWD (CF)
1 $n_{\text{CROWD}} = [\mu/\text{CF}]$
2 $c_k = \text{RANDOM}_{ARRAY}(1,\mu)[1 : n_{\text{CROWD}}+1]$
3 for $k = 1$: μ *and* k not in c_k
4 for l in c_k
5 If d_h(Members [k], Members [l]) $< d_{m0}$
6 Members [l]. PRODUCTION()

Where the Subroutine $\text{RANDOM}_{ARRAY}(\alpha, \beta)$ will generate a range of random-sorted sequence from $\alpha to \beta$; *Line_2* also will select random indexes of the crowding members via producing a random area/domain of array from 1 *to* μ and cutting out the prime n_{CROWD} elements. Figure 2 displays the diagram of the proposed optimization method.

4) **Fitness function**. For every member, the fitness will be calculated using the optimization objective, where the objective will be calculated via the Equations. 14 to 16. As the objective should be minimize (OF), the basic fitness will be given as:

$$\text{OF} = \sum\nolimits_{k=1}^{3} \omega_k CF_k; \quad \sum\nolimits_{i=1}^{3} \omega_k = 1 \qquad (17)$$

According to ref [38], a niching method has been used in NGOA with the aim of preventing local convergence via a sharing function:

$$S(x_k, x_l) = \begin{cases} 1 - \frac{d_1(x_k,x_l)}{\xi_1}, \textit{if } d_1(x_k,x_l) < \xi_1, d_1(x_k,x_l) \geq \xi_2; \\ 1 - \frac{d_2(x_k,x_l)}{\xi_2}, \textit{if } d_1(x_k,x_l) \geq \xi_1, d_2(x_k,x_l) < \xi_2; \\ 1 - \frac{d_1(x_k,x_l) d_2(x_k,x_l)}{\xi_1 \xi_2}, \textit{if } d_1(x_k,x_l) < \xi_1, \xi_1(x_k,x_l) < \xi_2; \\ 0, \quad \textit{otherwise}. \end{cases} \tag{18}$$

Here $S(x_k, x_l)$ refers to the share functional amount of members x_k and x_l; $d_1(x_k, x_l)$ and $d_2(x_k, x_l)$ donate their hamming distance (d_h) [29], [30] and major fitness interval;, respectively; nich radius ξ_1 and ξ_2 refer to the determined maximums of $d_1(x_k, x_l)$ and $d_2(x_k, x_l)$. Fitness function have been adjusted like below:

$$OF'(x_k) = OF(x_k) \Big/ \sum_{l=1}^{M} S(x_k, x_l) \tag{19}$$

Afterward, the equation tenses the fitness. A member who is more like other ones is in lower fitness at present.

Selection. The members have been chosen on the basis of the classical roulette technique. Any member in a sub-population has been chosen in a possibility of $OF'(x_k) \Big/ \sum_{k=1}^{M} OF'(x_k)$ Crossover and mutation. For avoiding problems in determining the probability of crossover and mutation, the adaptive technique in AGOA [40] has been used in this part. These have been formulated like below:

$$cp = \begin{cases} cp_1 - \frac{(cp_1 - cp_2)(OF - OF_{avg})}{OF_{max} - OF_{avg}}, \\ \qquad OF \geq OF_{avg}; \\ cp_1, \qquad OF < OF_{avg} \end{cases} \tag{20}$$

$$amp = \begin{cases} amp_1 - \frac{(amp_1 - amp_2)(OF - OF_{avg})}{OF_{max} - OF_{avg}}, \\ \qquad OF \geq OF_{avg}; \\ amp_1, \qquad OF < OF_{avg} \end{cases} \tag{21}$$

Here cp refers to adaptive crossover possibility; cp_1 and cp_2 donate its determined max and min, respectively; amp refers to adaptive mutation possibility; amp_1 and amp_2 show its determined max and min, respectively; OF_{max} and OF_{avg} donate the max and average amounts of population fitness, respectively. For the mutating member, OF refers to only its major fitness.

OF is larger for two crossovers. A constant crossover technique and a bit inversion technique have been utilized to the crossover and mutation procedures, respectively. The relations among adaptive possibilities and member fitness are illustrated in Figure 3. Members who have lower fitness have been broken through crossover and operators of mutation more easily, however, members who have higher fitness have been broken harder. The technique has the capability of increasing the global search feature and GOA convergence efficiency.

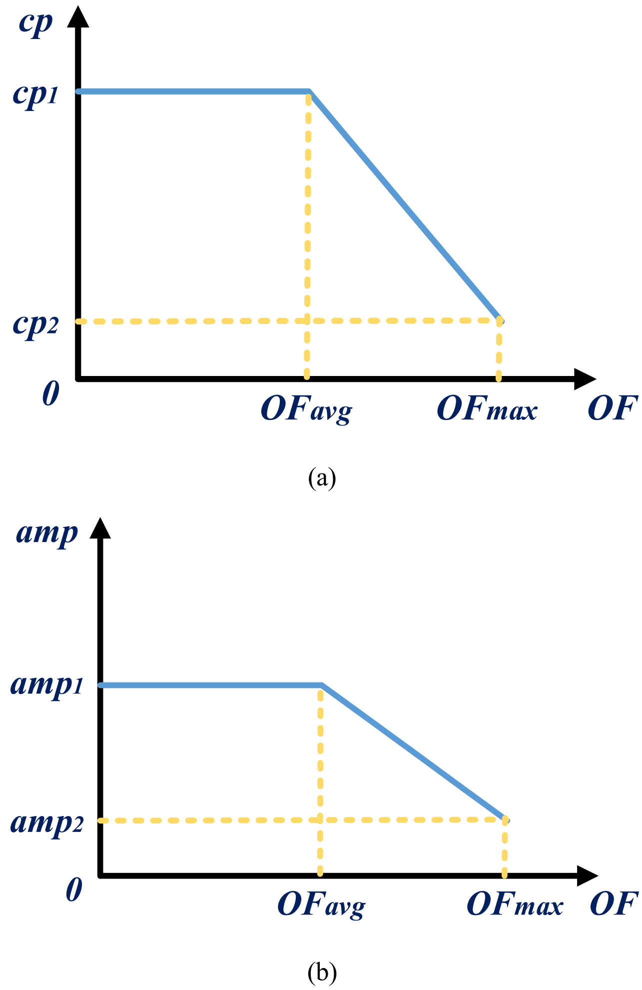


FIGURE 3. Adaptive possibilities: (a) possibility of adaptive crossover, (b) probability of adaptive mutation.

Migration. An operator of migration in the Multi-island GOA (MIGOA) [35] has been entered with the aim of helping to keep subpopulation variety. MIGOA is one of the finest gained GOA schemes. Any subpopulation has evolved into discrete islands, and several members on any island have migrated to other particular numbers of productions, p_m, in a migration possibility, mp_p. In general, MIGOA subpopulations eventually has converged to various local optimal solutions; global optimum is one of them. The Subroutine MIGOARATE pseudocode is like below:

Here *Line_2* produces a random sequence, r_s, in order to choose migrating islands (*Line_5 to Line_6*); Subroutine RANDOM (α, β) has returned a random float area from α *to* β; Subroutine $RANDOM_{INT}(\alpha, \beta)$ has returned a random integer area from α *to* β; *Line_6* shows the continuance of *Line_5*.

Generally, the optimization algorithm pseudocode is given like below:

```
MIGOARATE()
1   if Production % p_m == 0
2     r_s = RANDOM_ARRAY(1, N)
3     for k=1: N/2
4       if RANDOM (0, 1)<mp_p
5           interchange
      Islands [r_s [2 * k − 1]] .Members
                [RANDOM_INT(1, μ)]
6       With Islands [r_s [2k]].
          Members [RANDOM_INT(1, μ)]
```

```
Optimization Mehod
1    input Global_Constants//,
     containingallabovementioned
2    // constants in the GOA and constants in the SDT.
3    INITIATE()
4    for n_p = 1toN_p
5      Parallel for k=1 to N
6        Islands [k [.CROWD(C_p) //Preselection.
7        parallel for l=1 to μ
8          f=Islands[k]. Members [l].FITNESS() //
   Calculate fundamental fitness (Eq. 17).
9          if OF > OF_o
10
         Excellent_Members.APPEND(Islands
                 [k] .Members [l])
11         Islands[k].NICHE D_ FITNESS() // Calculate
   niched fitness by Eqs. 18, 19
12         Islands[k].SELECTED() // by roulette way.
13         Islands[k].PROBABILITIES()  //  Calculate
   adaptive probalities by Eqs. 20, 21
14         Islands[k].CROSSOVER()
15         Islands[k].MUTATE()
16       MIGOARATE()
17       if n_pnb ≥ N_pnb// End checking.
18         break
19   Put Optimal be a Member and Optimal.
       Basic_Fitness = 0
20   parallel for every in Excellen t_ Members
21         ind=SDT_SEARCH_FROM (Member, inc,
           tolerance)
22         if ind.Basi c_ Fitness > Optimal.Basi c_ Fitness
23           Optimal =ind
24       Output Optimal
```

The repetition of GOA has been described by the initial 18 lines. A parallel calculation layout that considerably aids the performance of the algorithm, has been used at this part. The parallel keyword refers to that the loop contents are parallel. FITNESS member function in line 8 calculates the major fitness equation.17. Great members who own finer fitness in comparison to fitness threshold, OF_0, are chosen by lines 9 and 10 for the next SDT searching (Lines 19–23). Part C would examine the SDT. Because the mutation, crossover and selection procedures are like the ones in classic GOA, the comprehensive description of the MUTATE, CROSSOVER and SELECT subroutines have been eliminated at this part.

C. STEEPEST DESCENT METHOD

The above advance in GOA's global search capability may unavoidably cause the destruction of its local search feature around optima. Meantime, the result of GOA has been considerably affected via the size of the population [43], however, the scale of the population of this paper has been limited via bounded computational sources. Afterward, for improving the solution accuracy, an SDT [44], [45] has been used. A superb member may be buried throughout the evolution in the GOA. However, this member may be near to the optimal solution. Therefore, SDT has been used for all superb members throughout the history of GOA.

The process of SDT starts at a possible solution, $x^{(0)}$. At any stage, it has searched from the solution of the ultimate stage, $x^{(j)}$, and along the gradient, $\nabla OF(x^{(0)})$:

$$\mathrm{OF}\left(x^{(j)} + t_j \nabla OF\left(x^{(j)}\right)\right) = max(x^{(j)} + t\nabla OF\left(x^{(j)}\right)) \tag{22}$$

$\nabla OF\left(x^{(j)}\right)$ has been calculated via the diversity process at this part (separate variables, n_k, (k= 1, ..., 4) have not not involved):

$$\begin{aligned}\nabla OF\left(x^{(j)}\right) &= (0, 0, 0, 0, \\ &\frac{OF\left(n_1, \ldots, n_4, \varphi_1 + \nabla\varphi_1, \varphi_2, \ldots, \vartheta_4\right) - OF\left(x^{(j)}\right)}{\nabla\varphi_1}, \\ &\frac{OF\left(n_1, \ldots, n_4, \varphi_1, \varphi_2 + \nabla\varphi_2, \ldots, \vartheta_4\right) - OF\left(x^{(j)}\right)}{\nabla\varphi_2}, \ldots, \\ &\frac{OF\left(n_1, n_2, \ldots, \vartheta_4 + \nabla\vartheta_4\right) - OF\left(x^{(j)}\right)}{\nabla\vartheta_4})\end{aligned} \tag{23}$$

t_j refers to the length of the step to be calculated. The following paper utilizes an adaptivebisection process to calculate t_j. The pseudocode is like below:

Subroutine SDT _NEXT (member, inc, tolerance) seeks from the member in a first stage length increase of inc and finishes based on the tolerance threshold. Member function OFFSET (ρ, t) of the member who has the relating solution is x, returns a novel member who has the relating answer is $x + \rho t$. In the following process, the length of the step alters via an increase, inc. Firstly, inc reduplicated till the gradient goes down (Lines 4–6). Afterward, the searching keeps on. Throughout any repetition in *Line*_7 to *Line*_12, the spot with max fitness has been stored via the further, and 2 adjoining spots have been sought at a halved stage length increase. The repetitions finish at the time of satisfying the determined accuracy and tolerance. The subroutine has returned the novel questing spot of the further stage of the SDT. The adaptive process prevents the large calculation costs resulting from a very small increase in the first stage length.

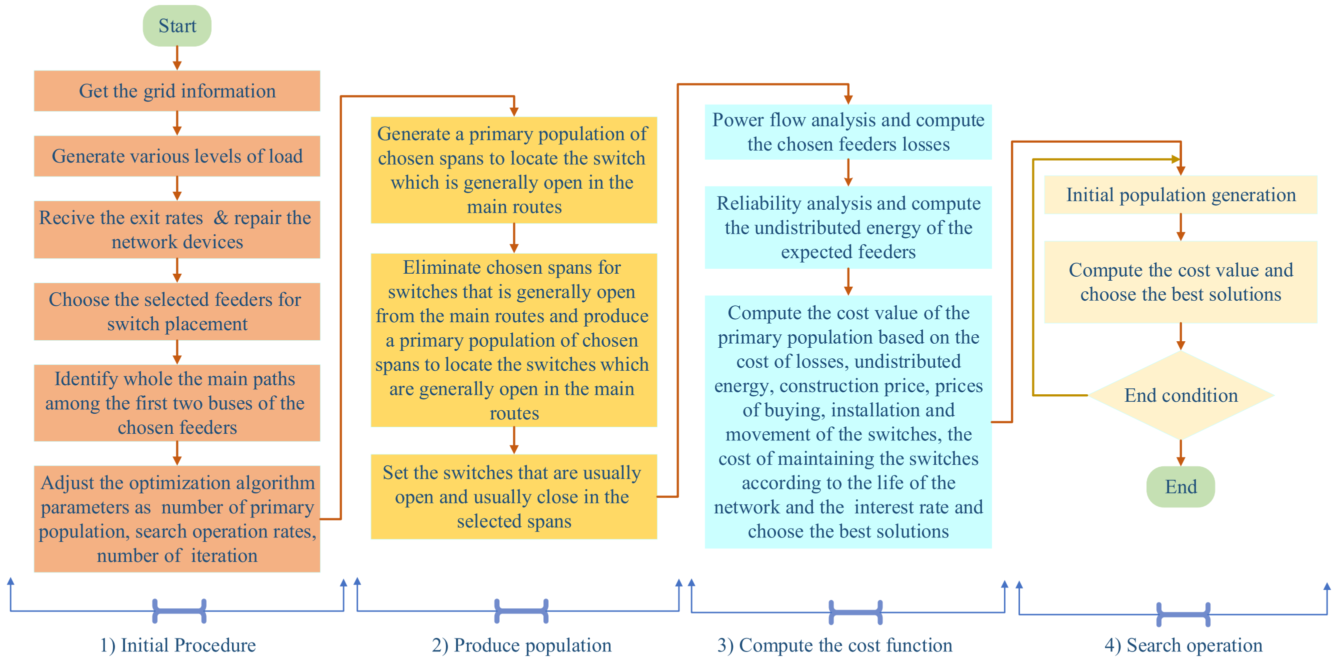


FIGURE 4. **The flowchart of the suggested placement algorithm.**

```
SDT_NEXT (Member, inc, tolerance)
  ρ = Member.GRADIENT() // By Eq. 23.
  subsequent= Member.OFFSET(ρ, inc)
  subsequent.FITNESS() // Update subsequent.
   fundamental_Fitness for the 1th iteration.
  while subsequent.OFFSET(ρ, inc).FITNESS() >
   = subsequent. fundamental _Fitness
       subsequent=subsequent.OFFSET(ρ, inc)
       inc=inc * 2
  while inc > tolerance
       inc=inc/2
       if subsequent.OFFSET(ρ, inc) > subsequent. fun-
damental_Fitness
          subsequent= subsequent.OFFSET(ρ, inc)
        else if subsequent.OFFSET(ρ, - inc) > subse-
quent. fundamental_Fitness
          subsequent= subsequent.OFFSET(ρ, - inc)
     return subsequent
```

When length of step, t_j, has been sought, the search keeps on from the novel point

$$x^{(j+1)} = x^{(j)} + t_j \nabla OF\left(x^{(j)}\right) \tag{24}$$

After a series of repetitions, the SDT is able to be finished on situation that $x^{(j+1)} - x^{(j)} \leq \Delta x_0$, in which Δx_0 shows the determined step threshold. The SDT pseudocode shows like below:

SDT is a local search process and its effects are considerably dependent on the first solution. Therefore, GOA solutions are used in the form of the primary searching

```
SDT _QUEST_FROM (Member, inc, tolerance)
  OF=0 // To store the fundamental fitness of the
 solution in the final stage.
  ind= Member. fundamental_Fitness
  while ind - OF> tolerance
  OF=ind. fundamental_Fitness
  ind= SDT _ subsequent(Member, inc, tolerance)
  return ind
```

points with the aim of avoiding useless search costs and local convergence.

D. PROPOSED ALGORITHM

The flowchart of our suggested algorithm for switch allocation is depicted in Figure 4. In some cases, the available data to feeders might not have adequate reliability information. Hence, this is vital to first receive and sufficient grid data. Then, the essential data is completed with computing the diverse parts of load and the exit and entrance level of fault and maintenance.

In this regard, we first determine the optimal allocation of selected feeders. After selecting the adequate optimization method for the network, the candidate feeders could be analyzed in reliability and normal conditions. In fact, the status should be evaluated for optimal distribution of load. Besides, computational information including initial values of reliability and losses are determined in the feeders. Then, according to the desired limitations including undistributed power and losses, the objective functions (OFs) are analyzed with equations (19) to (21), and the outcomes of the performance in the grid are considered. In this research work, in the first step, all the data of faults and repair of switches, feeders load values, blackout information and distribution transformers are investigated. Considering the suggested algorithm, the characteristics of the system including the operational switching mode in normal condition, failure occurrence and load restoration values are depicted in Figure 5.

As can be seen, the separated and intended islanding modes are displayed in the Figure 5 (a). These smart islands are protected by devices like fuses, relays and power switches, and the load of them is determined. Figure 5 (b) depicts the fault event in the assumed grid. In addition, the operational switches for isolating the failure place are indicated in the Figure 5 (c). As shown in the Figure 5 (c), two of down switches have been opened and the faulty location is decoupled from the main grid system. Consequently, about 1 MW of transmitted power is lost as the quantity of load loss till it has been restored. However, as can be seen from the Figure 5 (d), about 0.5 MW of a MW is covered from another transmission line, where the same operation is performed with the proposed optimal algorithm. Assuming that an error occurs in multiple zones of the power grid, the amount of load lost in the islanded mode will be determined, and then, the best mode will be selected with the least lost, and the switches are placed in those locations. As a result, the amount of energy supplied will be minimal.

Considering all the above mentioned issues, we model the reliability analysis in the assumed power grid with the suggested algorithm. Because reliability is often used for power grid equipment such as feeders and lines, and here the whole system is considered, two essential power system parameters including λ and r have been computed for every chosen off-grid zones. The amount of the parameter λ in the entire network has been displayed in equation (10), and the amount of energy is calculated using equation (11).

In the suggested algorithm, the number of failures is made taken into account various failure models that are given as follows:

- Active failure
- Passive failure
- Preventive repair failure
- Transient failure

The happening of every failure state has a various impact on the reliability indices. So, according to this issue, by applying each of the failure states in the power network system, the impact of this failure on the performance of every switch is calculated one by one based on the protection approach in each area, hence the loads which affected by the operation of every switch have been specified.

IV. SIMULATION RESULTS

A. CASE STUDY

In order to implement the offered approach in this project, we use a real case study and 34 feeders in medium voltage power network are selected in the Ahvaz city, Iran.

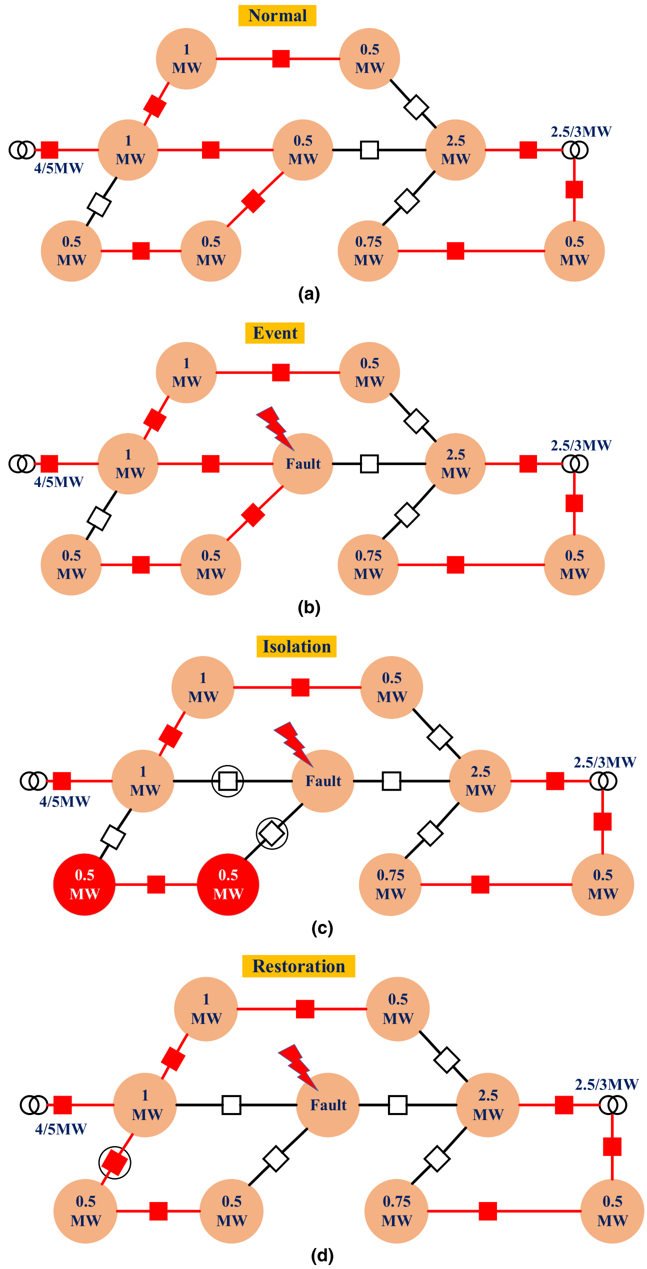
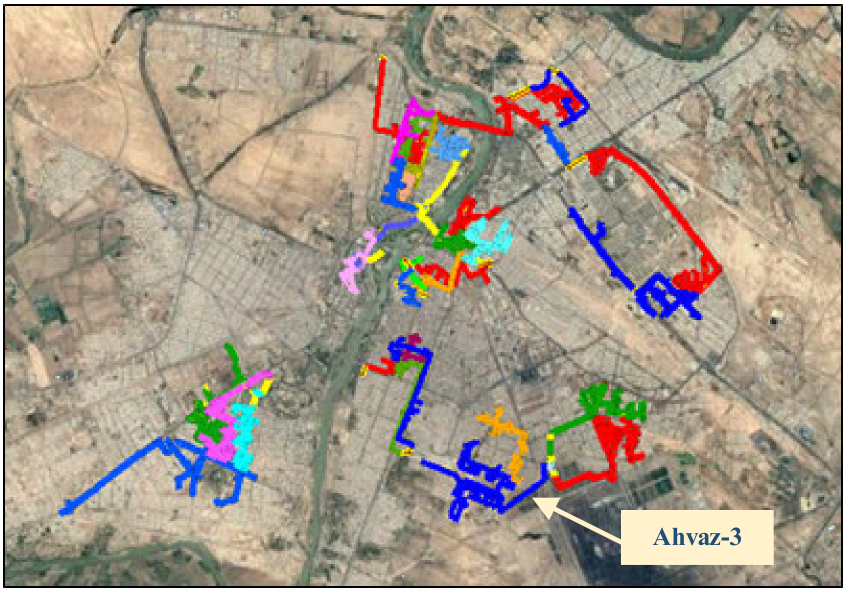


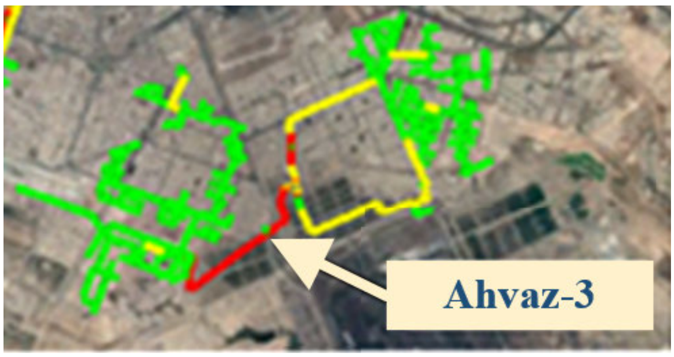
FIGURE 5. The operational switches and loads restoration lines in the power network.

Hence, assumed feeders in the power network are fed from 19 substations. In our case study, the results and data of 2 feeders are illustrated in the following as Ahvaz 3-5132 and Ahvaz 3-5052. In order to have a reliable research, it is vital to define with the configuration of the power gird including place and the number of components. Therfore, the configuration data, type of failure and the number of components have been used from the piror authors' research in reference [46].

Figure 6 displays the overall geographical map showing the location of lines and feeders from power distribution system of Ahvaz city.



(a)



(b)

FIGURE 6. a) Geographical map showing the location of lines and feeders in the power distribution system of Ahvaz city; b) Grid power flow results is color design according to the load sharing of feeders where green less than 50 %; Yellow from 50% to 80 %; Red more than 80 %.

TABLE 1. Obtained outcomes of power flow and loss analysis, Reliability assessment of main feeders from Ahvaz 3-5132 and Ahvaz 3-5052 in fundamental state.

Feeder name	Peak input current (A)	Peak input active power (MW)	Peak input power factor (%)	Peak load maximum (%)	Peak voltage minimum (pu)	Energy losses (MWh)
Ahvaz3-5052	254.2	13.62	91.77	100	1.01	99.91
Ahvaz3-5132	231.1	12.36	91.68	92	1.008	210.26
Simultaneous sum	458.3	25.98	-	-	-	310.17

B. POWER FLOW AND RELIABILITY ANALYSIS

In this part of the research, the two studied feeders including Ahvaz3-5132 and Ahvaz3-5052 in five different modes consisting of without maneuver, with the presented maneuver, three switches, four switches, three switches with DG and four switches with DG are studied and evaluated. The GOA has been utilized to address the presented approach.

1) WITHOUT SWITCHING MANEUVER

In the first mode, the power distribution network of the case study is tested and evaluated without taking into account maneuvers and switches. The obtained outcomes including the power flow and loss analysis, reliability assessment of main feeders in Ahvaz3-5132 and Ahvaz3-5052 in the basic mode are presented in Table 1. Figure 7 also

TABLE 2. Obtained outcomes of power flow and loss analysis, and reliability assessment of main feeders from Ahvaz3-5132 and Ahvaz3-5052 in the suggested manner of utilization (three different switches allocation).

Feeder name	Peak input current (A)	Peak input active power (MW)	Peak input power factor (%)	Peak load maximum (%)	Peak voltage minimum (pu)	Energy losses (MWh)
Ahvaz3-5052	254.2	13.62	91.77	100	1.01	84.18
Ahvaz3-5132	231.1	12.36	91.68	92	1.008	170.02
Simultaneous sum	458.3	25.98	-	-	-	254.2

TABLE 3. Simulation results of reliability assessment for Ahvaz3-5132 and Ahvaz3-5052 feeders in the proposed approach by island areas based on the Figure 8.

Region	Zone	ENS (MWh)
1	Red	115.1
2	Yellow	52.5
3	Blue	86.6
Total	-	254.2

TABLE 4. Simulation results of reliability assessment for Ahvaz3-5132 and Ahvaz3-5052 feeders in the proposed approach by island areas based on the Figure 9.

Region	Zone	ENS (MWh)
1	Red	115.1
2	Yellow	19.72
3	Green	24.08
4	Blue	86.6
Total	-	245.5

displays the maneuver switches positions in the main feeders of Ahvaz3-5132 and Ahvaz3-5052 in the basic mode.

2) POWER DISTRIBUTION GRID WITH PROPOSED MANEUVER APPROACH (3 SWITCHES)

In the second mode, the assumed power distribution grid is studied and assessed with three different proposed maneuver switches. The obtained results of placement in the proposed three switches for the power flow and loss analysis, reliability assessment of the main feeders from Ahvaz3-5132 and Ahvaz3-5052 are presented in Tables 2 and 3. The obtained reliability simulation results for the main feeders of Ahvaz3-5132 and Ahvaz3-5052 in the separately operational proposed mode for the island zones are depicted in Figure 8. As shown in Figure 8, the positioning of the maneuvering switches in the feeder Ahvaz3-5132 and Ahvaz3-5052 are displayed in the fundamental state.

3) POWER DISTRIBUTION GRID WITH PROPOSED MANEUVER APPROACH (4 SWITCHES)

In the third mode, the assumed power distribution grid is studied and evaluated with four different proposed maneuver switches. The obtained results of placement in the proposed four switches for the power flow, and loss analysis, reliability assessment of the main feeders from Ahvaz3-5132 and Ahvaz3-5052 are presented in Table 4. The obtained reliability simulation results for the feeders Ahvaz3-5132 and Ahvaz3-5052 in the separately operational proposed mode for the island zones are displayed in Figure 9. As can be seen from this Figure, the positioning of the maneuvering switches in the feeder Ahvaz3-5132 and Ahvaz3-5052 are displayed in the basic mode. Figure 10 also displays the cost function diagram of the suggested allocation method in several iterations.

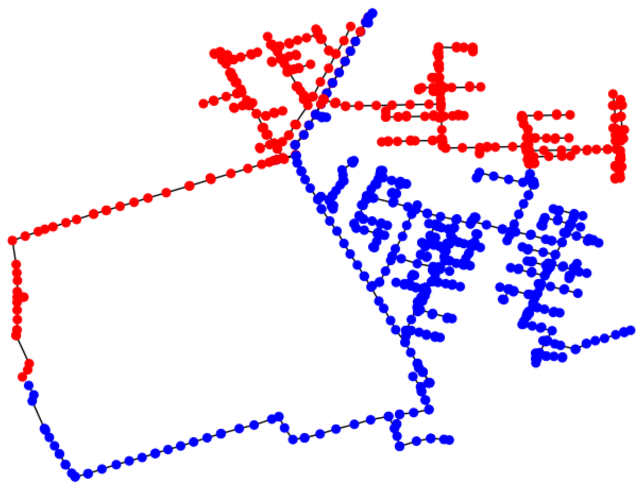


FIGURE 7. The positioning of the maneuver switches in the main feeders of Ahvaz3-5132 and Ahvaz3-5052 in the basic mode.

4) POWER DISTRIBUTION GRID WITH THE PROPOSED MANEUVER LOCATED (3 SWITCHES) IN DG CONNECTION MODE

In the fourth mode, the assumed power distribution network is studied and assessed with three different proposed maneuver switches in presence of DG. The obtained results of placement of the four switches for the power flow and loss analysis, reliability assessment of the feeders from Ahvaz3-5132 and Ahvaz3-5052 with and without

TABLE 5. Simulation results of the reliability assessment of Ahvaz3-5132 and Ahvaz3-5052 feeders in the proposed approach with and without the presence of DG.

Zone	Losses without DG connected	Losses in presence of DG	ENS (MWh) without DG connected	ENS (MWh) in presence of DG
1	136.76	136.76	115.1	115.1
2	218.12	197.72	52.5	52.5
3	199.13	199.13	86.6	86.6
Total	554.01	533.61	254.2	254.2

TABLE 6. Simulation results of the reliability assessment of Ahvaz3-5132 and Ahvaz3-5052 feeders in the proposed approach (three switches) in the presence of DG.

Zone	Losses in presence of DG	ENS (MWh) in presence of DG
1	136.76	115.1
2	60.5	19.72
3	96.44	24.08
4	199.13	86.6
Total	492.79	245.5

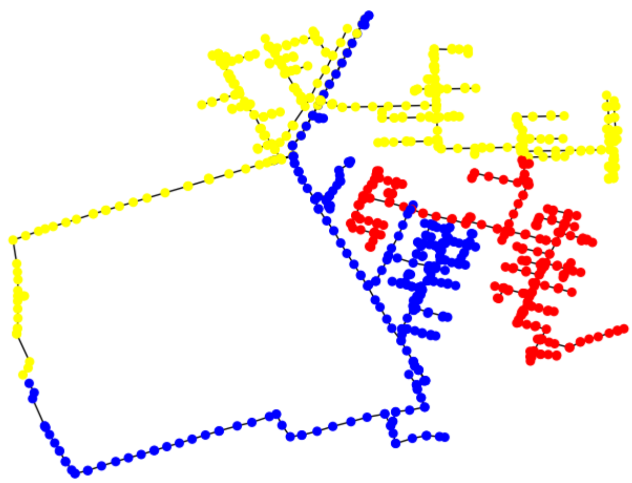


FIGURE 8. Position of maneuver switches in Ahvaz3-5132 and Ahvaz 3-5052 feeders in the recommended mode state.

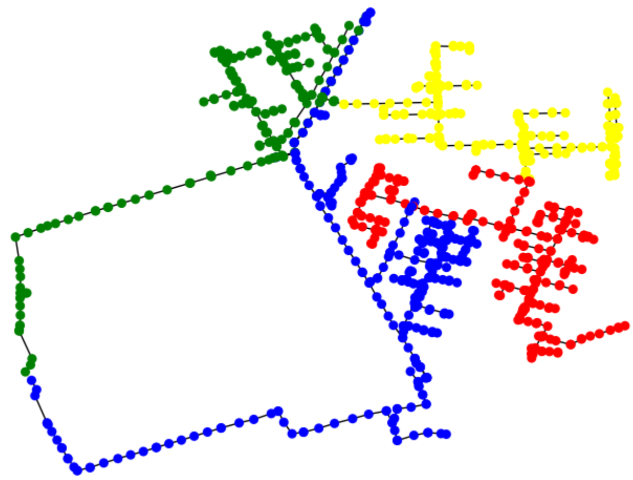


FIGURE 9. Location of the suggested switches.

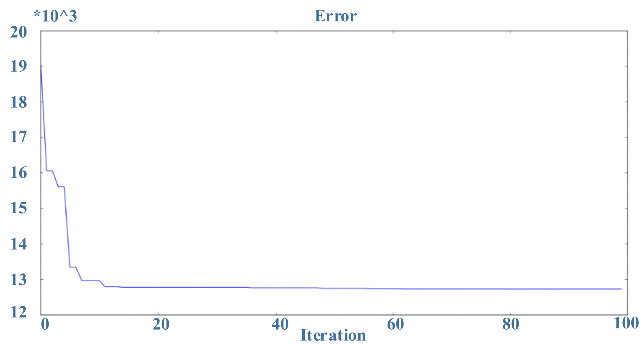


FIGURE 10. Diagram of the objective function of suggested allocation algorithm in various iterations.

the presence of DG are presented in the proposed mode in Table 5.

5) POWER DISTRIBUTION GRID WITH THE PROPOSED MANEUVER LOCATED (4 SWITCHES) IN DG CONNECTION MODE

In the fifth mode, the assumed power distribution network is studied and assessed with four different proposed maneuver switches in presence of DG. The obtained results of placement of the four switches for the power flow and loss analysis, reliability assessment of the feeders from Ahvaz3-5132 and Ahvaz3-5052 with and without the presence of DG are presented in the proposed mode in Table 6.

DG connection in zone 2 has reduced the losses of this section; it does not have a positive effect on the ENS rate, but by increasing the number of switches and converting the desired area into 4 zones, the presence of DG makes it possible to create an independent island to be fed by DG. In this case, the total ENS and total losses are reduced (see Table 5).

V. CONCLUSION

Overall, the most important benefit of optimal placing and operating switches in the power distribution grid during their utilizable lifetime is achieving compatibility between increasing the reliability of the network and the costs depended on the purchase, installation and repair of switches. In this research work, we have proposed an optimal solution to specify the number, type and place of protection devices and cross-section switches in power distribution networks without and with the presence of DG units, taking into account the possibility of clients' interruption. The proposed placement method is accomplished on a real power distribution grid of Ahvaz city. A genetic algorithm optimization technique has been utilized to analyze the effects of distribution automation systems to meliorate the reliability indices of a power distribution grid. The significant purposes of the paper are to optimally minimize the three overall cost functions comprising the cost of investing and maintaining network equipment, the cost of undistributed energy, and the cost of losses of energy. Overall, the suggested optimization approach combined the benefits of GOAs and SDT. The GOA searched for the optimal universally, that prevented the outcome from locally converging, and provided great primary solutions for the SDT. The SDT also searched locally with the excellent performance for improving the accuracy of the optimum solution. The optimal placements of switches under several study test cases in the actual distribution grid of Ahvaz city have been considered. The reliability simulation outcomes confirmed the effectiveness of the presented optimal placement of automatic switches mechanism including auto-cross-section switches and re-closers. In general, the great advantage of placing and operating switches in the network over their useful life is to achieve a conciliation among network reliability and costs associated with the procurement, installation, and repair of switches. Additionally, by applying DGs, the impacts of using DAS on the optimal placement of protection devices and switches have been analyzed.

REFERENCES

[1] M. Ghiasi, N. Ghadimi, and E. Ahmadinia, "An analytical methodology for reliability assessment and failure analysis in distributed power system," *Social Netw. Appl. Sci.*, vol. 1, no. 1, p. 44, Jan. 2019.

[2] I. G. 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 Gener., Transmiss. Distrib.*, vol. 6, no. 6, pp. 493–502, Jun. 2012.

[3] M. Ghiasi, T. Niknam, M. Dehghani, P. Siano, H. H. Alhelou, and A. Al-Hinai, "Optimal multi-operation energy management in smart microgrids in the presence of RESs based on multi-objective improved DE algorithm: Cost-emission based optimization," *Appl. Sci.*, vol. 11, no. 8, p. 3661, Apr. 2021.

[4] L. S. de Assis, J. F. V. Gonzalez, F. L. Usberti, C. Lyra, C. Cavellucci, and F. J. Von Zuben, "Switch allocation problems in power distribution systems," *IEEE Trans. Power Syst.*, vol. 30, no. 1, pp. 246–253, Jan. 2015.

[5] H. Shirazi, M. Ghiasi, M. Dehghani, T. Niknam, M. G. Garpachi, and A. Ramezani, "Cost-emission control based physical-resilience oriented strategy for optimal allocation of distributed generation in smart microgrid," in *Proc. 7th Int. Conf. Control, Instrum. Autom. (ICCIA)*, Feb. 2021, pp. 1–6.

[6] M. Ghiasi, M. Dehghani, T. Niknam, H. R. Baghaee, S. Padmanaban, G. B. Gharehpetian, and H. Aliev, "Resiliency/cost-based optimal design of distribution network to maintain power system stability against physical attacks: A practical study case," *IEEE Access*, vol. 9, pp. 43862–43875, 2021.

[7] H. R. Baghaee, M. Mirsalim, G. B. Gharehpetian, and H. A. Talebi, "Reliability/cost-based multi-objective Pareto optimal design of stand-alone wind/PV/FC generation microgrid system," *Energy*, vol. 115, pp. 1022–1041, Nov. 2016.

[8] M. R. Esmaili, A. Khodabakhshian, R.-A. Hooshmand, and P. Siano, "A new coordinated design of sectionalizing scheme and load restoration process considering reliability of transmission system," *Int. J. Electr. Power Energy Syst.*, vol. 102, pp. 23–37, Nov. 2018.

[9] S. Moghaddam, M. Bigdeli, M. Moradlou, and P. Siano, "Designing of stand-alone hybrid PV/wind/battery system using improved crow search algorithm considering reliability index," *Int. J. Energy Environ. Eng.*, vol. 10, no. 4, pp. 429–449, Dec. 2019.

[10] M. Ghiasi, "Detailed study, multi-objective optimization, and design of an AC-DC smart microgrid with hybrid renewable energy resources," *Energy*, vol. 169, pp. 496–507, Feb. 2019.

[11] M. E. Honarmand, M. S. Ghazizadeh, V. Hosseinnezhad, and P. Siano, "Reliability modeling of process-oriented smart monitoring in the distribution systems," *Int. J. Electr. Power Energy Syst.*, vol. 109, pp. 20–28, Jul. 2019.

[12] B. Khan, H. H. Alhelou, and F. Mebrahtu, "A holistic analysis of distribution system reliability assessment methods with conventional and renewable energy sources," *AIMS Energy*, vol. 7, no. 4, pp. 413–429, 2019.

[13] H. C. Nejad, S. Tavakoli, N. Ghadimi, S. Korjani, S. Nojavan, and H. Pashaei-Didani, "Reliability based optimal allocation of distributed generations in transmission systems under demand response program," *Electr. Power Syst. Res.*, vol. 176, Nov. 2019, Art. no. 105952.

[14] G. Kjolle and K. Sand, "RELRAD—An analytical approach for distribution system reliability assessment," *IEEE Trans. Power Del.*, vol. 7, no. 2, pp. 809–814, Apr. 1992.

[15] W. Xu, J. Li, M. Dehghani, and M. Ghasemigarpachi, "Blockchain-based secure energy policy and management of renewable-based smart microgrids," *Sustain. Cities Soc.*, vol. 72, Sep. 2021, Art. no. 103010.

[16] R. E. Brown, S. Gupta, R. D. Christie, S. S. Venkata, and R. Fletcher, "Distribution system reliability assessment using hierarchical Markov modeling," *IEEE Trans. Power Del.*, vol. 11, no. 4, pp. 1929–1934, Oct. 1996.

[17] E. Eslami and M. Ahmadi Kamarposhti, "Optimal design of solar–wind hybrid system-connected to the network with cost-saving approach and improved network reliability index," *Social Netw. Appl. Sci.*, vol. 1, no. 12, p. 1742, Dec. 2019.

[18] R. Billinton and P. Wang, "Teaching distribution system reliability evaluation using Monte Carlo simulation," *IEEE Trans. Power Syst.*, vol. 14, no. 2, pp. 397–403, May 1999.

[19] H. Falaghi, M. R. Haghifam, and C. Singh, "Ant colony optimization-based method for placement of sectionalizing switches in distribution networks using a fuzzy multiobjective approach," *IEEE Trans. Power Del.*, vol. 24, no. 1, pp. 268–276, Jan. 2009.

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

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

[22] A. Moradi and M. Fotuhi-Firuzabad, "Optimal switch placement in distribution systems using trinary particle swarm optimization algorithm," *IEEE Trans. Power Del.*, vol. 23, no. 1, pp. 271–279, Jan. 2007.

[23] J.-H. Teng and C.-N. Lu, "Feeder-switch relocation for customer interruption cost minimization," *IEEE Trans. Power Del.*, vol. 17, no. 1, pp. 254–259, Jan. 2002.

[24] A. Abiri-Jahromi, M. Fotuhi-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, Jan. 2012.

[25] I. Lim, T. S. Sidhu, M. S. Choi, S. J. Lee, and B. N. Ha, "An optimal composition and placement of automatic switches in DAS," *IEEE Trans. Power Del.*, vol. 28, no. 3, pp. 1474–1482, Jul. 2013.

[26] P. M. S. Carvalho, L. A. F. M. Ferreira, and A. J. C. D. Silva, "A decomposition approach to optimal remote controlled switch allocation in distribution systems," *IEEE Trans. Power Del.*, vol. 20, no. 2, pp. 1031–1036, Apr. 2005.

[27] V. Calderaro, V. Lattarulo, A. Piccolo, and P. Siano, "Optimal switch placement by alliance algorithm for improving microgrids reliability," *IEEE Trans. Ind. Informat.*, vol. 8, no. 4, pp. 925–934, Nov. 2012.

[28] A. Heidari, V. G. Agelidis, and H. Zayandehroodi, "Reliability worth analysis of distributed generation enhanced distribution system considering the customer cost model based on optimal radial basis function neural network," in *Proc. IEEE 7th Int. Power Eng. Optim. Conf. (PEOCO)*, Jun. 2013, pp. 641–646.

[29] P. Duan, H. Soleimani, A. Ghazanfari, and M. Dehghani, ''Distributed energy management in smart grids based on cloud-fog layer architecture considering PHEVs,'' *IEEE Trans. Ind. Appl.*, early access, Jul. 21, 2020, doi: 10.1109/TIA.2020.3010899.

[30] M. Dehghani, M. Ghiasi, T. Niknam, A. Kavousi-Fard, M. Shasadeghi, N. Ghadimi, and F. Taghizadeh-Hesary, ''Blockchain-based securing of data exchange in a power transmission system considering congestion management and social welfare,'' *Sustainability*, vol. 13, no. 1, p. 90, Dec. 2020.

[31] M. Ghiasi, ''A comparative study on common power flow techniques in the power distribution system of the tehran metro,'' *Tehnički Glasnik*, vol. 12, no. 4, pp. 244–250, Dec. 2018.

[32] M. Dehghani, A. Kavousi-Fard, T. Niknam, and O. Avatefipour, ''A robust voltage and current controller of parallel inverters in smart island: A novel approach,'' *Energy*, vol. 214, Jan. 2021, Art. no. 118879.

[33] M. Fathi and M. Ghiasi, ''Optimal DG placement to find optimal voltage profile considering minimum DG investment cost in smart neighborhood,'' *Smart Cities*, vol. 2, no. 2, pp. 328–344, Jun. 2019.

[34] M. Dehghani, M. H. Khooban, and T. Niknam, ''Fast fault detection and classification based on a combination of wavelet singular entropy theory and fuzzy logic in distribution lines in the presence of distributed generations,'' *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 455–462, Jun. 2016.

[35] E. Cantú-Paz, ''A summary of research on parallel genetic algorithms,'' Tech. Rep., 1995.

[36] D. E. Goldberg, ''Genetic algorithms in search,'' in *Optimization, and Machine Learning*. 1989.

[37] R. Jafari-Marandi and B. K. Smith, ''Fluid genetic algorithm (FGA),'' *J. Comput. Design Eng.*, vol. 4, no. 2, pp. 158–167, Apr. 2017.

[38] J. Horn, N. Nafpliotis, and D. E. Goldberg, ''A niched Pareto genetic algorithm for multiobjective optimization,'' in *Proc. 1st IEEE Conf. Evol. Comput., IEEE World Congr. Comput. Intell.*, Jun. 1994, pp. 82–87.

[39] J. R. Beveridge, K. Balasubramaniam, and D. Whitley, ''Matching horizon features using a messy genetic algorithm,'' *Comput. Methods Appl. Mech. Eng.*, vol. 186, nos. 2–4, pp. 499–516, Jun. 2000.

[40] M. Srinivas and L. M. Patnaik, ''Adaptive probabilities of crossover and mutation in genetic algorithms,'' *IEEE Trans. Syst., Man, Cybern.*, vol. 24, no. 4, pp. 656–667, Apr. 1994.

[41] R. Gholami, M. Shahabi, and M.-R. Haghifam, ''An efficient optimal capacitor allocation in DG embedded distribution networks with islanding operation capability of micro-grid using a new genetic based algorithm,'' *Int. J. Electr. Power Energy Syst.*, vol. 71, pp. 335–343, Oct. 2015.

[42] D. Zhai, X. Liu, H. Chang, Y. Zhen, X. Chen, M. Guo, and W. Gao, ''Parametric local multiview Hamming distance metric learning,'' *Pattern Recognit.*, vol. 75, pp. 250–262, Mar. 2018.

[43] D. E. Goldberg, K. Deb, and J. H. Clark, ''Genetic algorithms, noise, and the sizing of populations,'' *Complex Syst. J.*, vol. 6, pp. 333–362, Aug. 1992.

[44] J. Janeček and P. Paricaud, ''A new optimization method for the determination of classical force fields. Application to the united atom force field of short alkanes,'' *Fluid Phase Equilibria*, vol. 429, pp. 27–36, Dec. 2016.

[45] M. Natali, M. Attene, and G. Ottonello, ''Steepest descent paths on simplicial meshes of arbitrary dimensions,'' *Comput. Graph.*, vol. 37, no. 6, pp. 687–696, Oct. 2013.

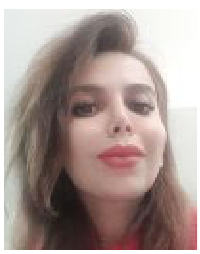
[46] H. Karimi, T. Niknam, J. Aghaei, M. Ghasemigarpachi, and M. Dehghani, ''Switches optimal placement of automated distribution networks with probability customer interruption cost model: A case study,'' *Int. J. Electr. Power Energy Syst.*, vol. 127, May 2021, Art. no. 106708.

TAHER NIKNAM (Senior Member, IEEE) was born in Shiraz, Iran. He received the B.S. degree in power electrical engineering from Shiraz University, Shiraz, in 1998, and the M.S. and Ph.D. degrees in power electrical engineering from the Sharif University of Technology, Tehran, Iran, in 2000 and 2005, respectively. He is currently a Faculty Member with the Electrical Engineering Department, Shiraz University of Technology. His research interests include power system restructuring, impact of distributed generations on power systems, optimization methods, and evolutionary algorithms.

MOSLEM DEHGHANI was born in Shiraz, Iran, in 1990. He received the B.S. and M.S. degrees in electrical engineering from Islamic Azad University-Kazerun Branch, in 2012 and 2014, respectively. He is currently pursuing the Ph.D. degree in electrical engineering with the Shiraz University of Technology, Shiraz. His current research interests include power electronic, control, optimization algorithms and cyber security analysis of smart grids, microgrids, smart cities, HVDC systems and protection of power systems, fuzzy logic, and signal processing.

MOHAMMAD GHIASI (Member, IEEE) received the B.S. degree in electrical power engineering, in 2012, and the M.S. degree in electrical power engineering, in 2016. He is currently a Research Assistant with the Shiraz University of Technology, Shiraz, Iran. He has authored over 30 scientific articles in ISI ranked journals and one chapter book. He has two hot articles and one highly-cited article based on SciVal and Web of science statistics. His research interests include modeling, simulation and optimization of power systems, integration and control of hybrid and distributed renewable energy resources, smart grids, and cyber-physical resilience in power systems has led to multiple publications in these fields. He is also an Active Reviewer for several IEEE, IET, Elsevier, Springer, Wiley, Sage, and Taylor and Francis journals and conferences.

HASSAN KARIMI received the B.S. degree in electrical engineering from Mazandaran University, the M.S. degree in electrical engineering from Shiraz University, Iran, and the Ph.D. degree in electrical engineering from the Shiraz University of Technology, Shiraz, Iran, in 2021. His current research interests include reliability, distributed generation, and optimization.



MINA GHASEMIGARPACHI is currently pursuing the M.Sc. degree in electrical power engineering with Islamic Azad University-Karerun Branch, Kazerun, Iran. Her current research interests include optimization algorithms, cyber security analysis of smart grid, microgrid, smart city, HVDC systems and protection of power systems, fuzzy logic, and signal processing.

SANJEEVIKUMAR PADMANABAN (Senior Member, IEEE) received the Ph.D. degree in electrical engineering from the University of Bologna, Bologna, Italy, in 2012.

He was an Associate Professor with VIT University, from 2012 to 2013. In 2013, he joined as a Faculty Member with the National Institute of Technology, India. In 2014, he was invited as a Visiting Researcher with the Department of Electrical Engineering, Qatar University, Doha, Qatar, funded by the Qatar National Research Foundation (Government of Qatar). He has authored over 300 scientific articles. He continued his research activities with the Dublin Institute of Technology, Dublin, Ireland, in 2014. Further, he served as an Associate Professor for the Department of Electrical and Electronics Engineering, University of Johannesburg, Johannesburg, South Africa, from 2016 to 2018. Since 2018, he has been a Faculty Member with the Department of Energy Technology, Aalborg University, Esbjerg, Denmark. He was a recipient of the Best Paper cum Most Excellence Research Paper Award from IET-SEISCON'13, IET-CEAT'16, IEEE-EECSI'19, IEEE-CENCON'19, and five best paper awards from ETAEERE'16 sponsored *Lecture Notes in Electrical Engineering*, (Springer). He is a fellow of the Institution of Engineers, India, the Institution of Electronics and Telecommunication Engineers, India, and the Institution of Engineering and Technology, U.K. He is an Editor/Associate Editor/Editorial Board for refereed journals, in particular the IEEE SYSTEMS JOURNAL, IEEE TRANSACTION ON INDUSTRY APPLICATIONS, IEEE ACCESS, *IET Power Electronics*, *IET Electronics Letters*, and *Wiley-International Transactions on Electrical Energy Systems*, the Subject Editorial Board Member for *Energy Sources*, *Energies* Journal, and *MDPI*, and the Subject Editor for the *IET Renewable Power Generation*, *IET Generation, Transmission and Distribution*, and *FACTS Journal*, Canada.

SAJAD TABATABAEE received the B.S. degree in electrical engineering from Sharif University, Iran, in 1996, the M.S. degree in electrical engineering from Tarbiat Modarres University, in 2001, and the Ph.D. degree in electrical engineering from the Shahid Chamran University of Ahvaz, Iran, in 2018. He is currently working as an Assistant Professor of electrical engineering with the College of Electrical and Computer Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran. His teaching and research interests include power system operation, optimization, microgrids and renewable energy systems.

HAMDULAH ALIEV (Member, IEEE) received the B.Sc. and M.Sc. degrees, in 2008 and 2010, respectively, and the Ph.D. degree in electrical and electronics engineering from The University of Texas, USA, in 2014. He is currently a Researcher with Tajik Technical University, Dushanbe, Tajikistan. His research interests include renewable energy resources, power system analysis, stability, protection, cyber-physical systems, and energy conversion. He is a Reviewer for several IEEE, IET, and Elsevier journals.