Multi-Objective Optimization using Microgenetic Algorithm Applied to the Placement of Remote and Manual Switches in Distribution Networks

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Abstract: This paper presents a new formulation for placement of switches in distribution of electric power. An approach for determination of the location of tie switches and section switches using a multi-objective microgenetic algorithm is proposed. In the procedure, load importance, reliability index, remote or manual controlled switch and investments costs are considered. The results are based on simulations in a 69-bus test system presented and the results are compared to the solution given by others search techniques. This comparison confirms the efficiency of the proposed method which makes it promising to solve complex problems of tie switches and section switches placement in distribution feeders.

1 INTRODUCTION

In order to increase the reliability in overhead radial electrical energy distribution systems, tie switches and section switches are normally installed. Section switches (SS) enable the isolation of failed components and tie switches (TS) are used for interconnection between feeders. In the planning process of distribution of electric power, the decision of the strategy to be adopted in the allocation of switching devices is an important aspect to be considered. Another important characteristic of these devices should be considered is their way of operation: manual controlled switch (MCS) or remote controlled switch (RCS). When MCS is used, a maintenance crew has to be dispatched to the switch site to perform the fault isolation and load restoration. RCS are usually initiated at a control room, where the operation crew performs the action of the switches. In this case, the switching time considerably decreases, performing the restoration of system capacity and reliability with minimum outage and least expenditure of manpower. Of course, RCS are more expensive and they need a communication system to be activated. However, the appearance of an increasing number of new automation equipment and communication technologies has provided economic viability to the application of RCS in distribution networks (Sperandio et. al., 2007). In last decades, the electric utilities have introduced remote control schemes in distribution networks to increase the reliability and to have faster responses in contingencies (Allan and Billinton, 1976), however, the cost involved in this process is very high and the amount of investment generally have budget constraints. So an alternative that has been considered by electric utilities is the gradual replacement at strategic points of MCS by RCS.

The selection of the number and location of the switches depends on factors such as reliability indices, cost of switches, maintenance and operation costs. Besides the cost and reliability, other factors connected to the system can be taken into account to define the allocation of switches, such as load importance. The solution of this problem is considered a very difficult task because it is a combinatorial constrained problem described by a nonlinear and nondifferential objective function. Several intelligent algorithms have been used to solve such a problem applying different heuristics. Simulated Annealing (Billinton and Jonnavithula, 1996), Genetic algorithms (Levitin, Mazal-Tov and Elmakis, 1995; Golestani and Tadayon, 2011; Dezaki et. al., 2012), Fuzzy Logic (Teng and Lu, 2002), Ant Colony (Falaghi, Haghifam and Singh,

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2009; Tippachon and Rerkpreedapong, 2009), Particle Swarm Optimization (Golestani and Tadayon, 2011; Moradi and Fotuhi-Firuzabad, 2008; Ziari et. al., 2009), Immune Algorithm (Chen et. al., 2006) and Tabu Search (Toune, 1998)

In this paper, a Multi-Objective Microgenetic Algorithm (MGA) is proposed and employed for the allocation of SS and TS, in order to assist the decision-taking during the planning of the distribution system. Investments costs, reliability, load importance and the use of MCS and/or RCS are considered in the solution.

2 PROBLEM FORMULATION

2.1 Expert Knowledge

In distribution networks planning, the decision of the strategy to be adopted in switch allocation is an important aspect to be considered. This decision is based on expert knowledge and influenced by several parameters that determine the importance of certain consumers and circuits. Technical and economic aspects must be considered, seeking a balance among: safe operation of the system, desired level of reliability and investments.

In general, from the point of view of reliability, the following criteria may be taken into account in the switches allocation:

- Minimizing the number of consumers affected by an outage in the distribution system;
- Restoration of service to critical loads;
- Preference must be given to the installation in:
  - circuits with high incidence of permanent faults;
  - points of interconnection between different feeders;
  - along the main section of the feeder, by dividing the load into blocks. It should be considered the voltage drop and maximum demand allowed in the restoration of each load block by a tie switch;
  - points near to the beginning of circuits with high loading;
  - before and after points where there are loads priority, with high continuity demanded;
  - places easily accessible.

2.2 Distribution Feeder Model

In general, the distribution feeder model is represented by sections with its respectively length, cable type, origin node, end node and active and reactive load. In order to evaluate the switches placement problem is needed that the feeder model also contains line's failure rate, mean time for restoring by switching and mean outage time of a fault in the feeder. Every possible solution defined by proposed algorithm, identify a group of sections where the SS are allocated at their beginning. Besides that, it was considered that a TS is somewhere allocated downstream of the line section containing a SS. It can happen that the same TS is downstream of more than one SS. This occurs when the sections that contain SS belong to the same set of line sections that start at the substation and end on a terminal node. In the Fig. 1 is showed an example with 5 SS allocated but only 2 TS are necessary to be allocated downstream of SS.

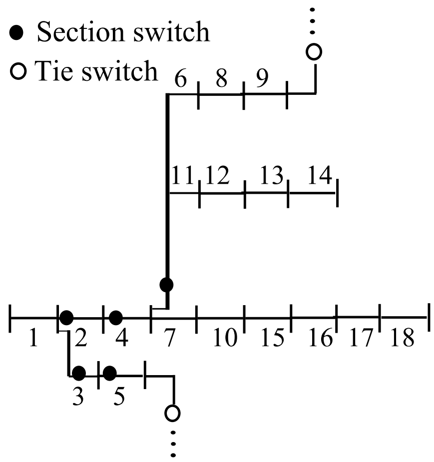

Figure 1: Example of tie switches allocated downstream of section switches.

2.3 Expected Unsupplied Energy Due to Power Outages and Costs Considering MCS and RCS Simultaneous Placement

Switches Placement in distribution networks can reduce down time by isolating the faulted part of the circuit after protection operation. Hence, the upstream and downstream sections of the faulted section can be restored. In this case, the outage time and the expected unsupplied energy due to power outages are reduced.

Manual and remote switches perform the same function, changing only the operation form. Outage time could be reduced by replacing manual by remote switches. This reduction is caused to increase reliability and reduce outage cost in network. Moreover, most devices in automation system resulting in more cost to the system..Simultaneously placement of manual and remote controlled switches decreases the total cost in life time. Due to these facts, it is essential to develop appropriate strategies to consider the gains and costs produced with the use of remote switches.

Expected unsupplied energy due to power outages can be calculated using Eq. (1). The first part of Eq. (1) is the unsupplied energy up to detection of the fault and switching and the last part is the unsupplied energy after switching.

$$EUE(S) = L_{tot}T_{switch}\sum_{i=1}^{Ns}(\lambda_i) + \\ +(T_{outage} - T_{switch})\sum_{i=1}^{Ns}(L_i(S)\lambda_i) \quad (1)$$

where, EUE(S) is the expected unsupplied energy due to power outages considering switches installed according S [kWh]; S is the set of section switches and tie switches installed; Ns is the number of sections in the feeder; Ltot is the total load in the feeder [kW]; Li(S) is the load interrupted in the feeder by a fault in section i after service restoration performed with the operation of switches installed according S [kW]; λi is the annual failure rate of section i; Tswitch is the mean time for restoring by switching (hours); and Toutage is the mean outage time of a fault in the feeder.

When all switches installed in the feeder are MCS, the time Tswitch(MCS) is considered in the calculation of EUE. Likewise, when all switches installed in the feeder are RCS, the time Tswitch(RCS) is considered in the calculation of EUE. When MCS and RCS are simultaneous placement, the calculation of EUE will depend on the procedures used for operation and maintenance teams. In this case, in order to define EUE, the following switches are identified considering a fault in line section i:

- CLU(*i*): the closest upstream SS of the line section *i* that isolate the fault from main source (Fig. 2 - SS_1);
- CLD(*i*): the closest downstream SS of the line section *i* that isolate the fault from an alternative source. There may be more than one CLD triggered to isolate distinct alternative sources (Fig. 2 - SS_4, SS_2 and SS_5);
- TST(*i*): TS triggered to restore part of the feeder load through alternative source considering a fault in line section *i*. There may be more than one TST triggered for interconnection with distinct alternative sources (Fig. 2 - TS_4, TS_3 and TS_2);
- CLD&TST(*i*): CLD(*i*) and TST(*i*) triggered to restore part of the feeder load through alternative source (Fig. 2 -SS_4&TS_4, SS_2&TS_3 and SS_5&TS_2). If both CLD(*i*) and TST(*i*) are RCS, CLD&TST(*i*) is considered RCS, otherwise CLD&TST(*i*) is considered MCS.

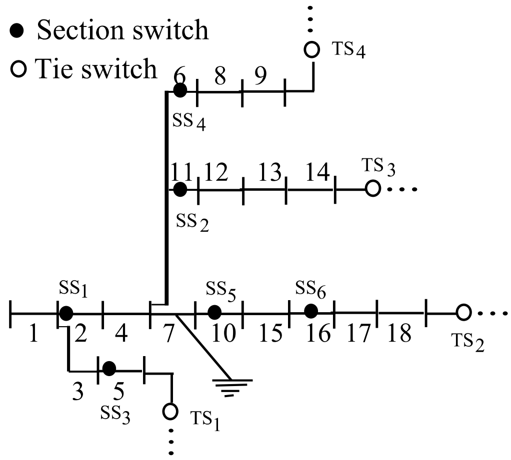

Figure 2: Feeder with switches installed considering a fault in line section 7.

Considering the possible situations that can occur for the simultaneous operation of manual and remote controlled switches, the expected unsupplied power can assume the following values during switches operation:

- Case 1: CLU(*i*) and/or some CLD&TST(*i*) are RCS
  - During time $T_{switch(\mathrm{RCS})}$, L_{tot} will be disconnected by main breaker. In $T_{switch(\mathrm{RCS})}$ the RCS switches are triggered to restore L_x through main source and/or alternative source.
  - Between $T_{switch(\mathrm{RCS})}$ and $T_{switch(\mathrm{MCS})}$ (when MCS switches are triggered) the load $L_{1,i} = L_{tot}$-L_x will be disconnected for time $T_{switch(\mathrm{MCS})}$-$T_{switch(\mathrm{RCS})}$. In $T_{switch(\mathrm{MCS})}$ the MCS switches are triggered to restore L_y.
  - Between $T_{switch(\mathrm{MCS})}$ and $T_{outage}$the load $L_{2,i} = L_{1,\mathrm{i}} - L_y$ will be disconnected for time T_{outage} - $T_{switch(\mathrm{MCS})}$.
- Case 2: CLU(*i*) and all CLD&TST(*i*) are MCS
  - During time $T_{switch(\mathrm{MCS})}$, L_{tot} will be disconnected by main breaker. In $T_{switch(\mathrm{MCS})}$ theMCS switches are triggered to restore L_y through main source and/or alternative source.
  - Between $T_{switch(\mathrm{MCS})}$ and T_{outage} the load $L_{2,i} = L_{tot}$-L_y will be disconnected for time T_{outage} - $T_{switch(\mathrm{MCS})}$.

- Case 3: CLU(i) and all CLD&TST(i) are RCS
  - During time $T_{switch(\mathrm{RCS})}$, L_{tot} will be disconnected by main breaker. In $T_{switch(\mathrm{RCS})}$ the RCS switches are triggered to restore L_x through main source and/or alternative source.
  - Between $T_{switch(\mathrm{RCS})}$ and $T_{outage}$the load $L_{1,i}$ = L_{tot}- L_x will be disconnected for time T_{outage} - $T_{switch(\mathrm{RCS})}$.

Based on these considerations, the expected unsupplied energy due to power outages is calculated in this work using Eq. (2):

$$EUE(S) = L_{tot} \sum_{i=1}^{Ns} (t_1 * \lambda_i) + \sum_{i=1}^{Ns} \left(L_{A,i}(S) * (t_2 - t_1) * \lambda_i\right) + \sum_{i=1}^{Ns} (L_{B,i}(S) * (T_{outage} - t_2) * \lambda_i) \quad (2)$$

Case 1: t1=Tswitch(RCS); LA,i= L1,i; LB,i= L2,i; t2=Tswitch(MCS);

Case 2: t1=Tswitch(MCS); LA,i= 0; LB,i=L2,i; t2=Tswitch(MCS);

Case 3: t1=Tswitch(RCS); LA,i=0; LB,i=L1,i; t2=Tswitch(RCS);

where, Li(S) is the load interrupted in the feeder by a fault in section i after service restoration performed with the operation of switches installed according S [kW]; Lx is the part of Ltot restored after RCS switches are triggered; L1,i(S) is the load interrupted in the feeder by a fault in section i after service restoration performed with the operation of RCS installed according S [kW]; Ly is the part of Ltot restored after MCS switches are triggered; L2,i(S) is the load interrupted in the feeder by a fault in section i after service restoration performed with the operation of MCS installed according S [kW]; Tswitch(MCS) is the mean time for restoring by manual controlled switching (hours). It is considered the same time for all line sections; and Tswitch(RCS) is the mean time for restoring by remote controlled switching (hours). It is considered the same time for all line sections;

Costs associated with system expected outage to customers due to supply outages and switches placement can be calculated using Eq. (3).

$$COST(S) = k_e EUE(S) \sum_{i=1}^{A} \left(1 + i_{cres}\right)^{i-1} + COST_{RCS}(S) + COST_{MCS}(S) \quad (3)$$

where, k_e is the energy cost (\$/kWh); A is the planning horizon (years); i_{cres} is the annual load growth; $COST_{RCS}(S)$ and $COST_{MCS}(S)$ are the costs of RCS and MCS installed according S, respectively, all installed in the first year of planning. It includes capital cost, installation cost and maintenance cost.

Many works only consider switches' absolute value in the cost evaluation (Assis et. al.,2012; Ziari et. al., 2009; Villasanti et. al., 2008), although utilities are already having costs with unsupplied energy, so it should be included in cost equation. Another difference on this formulation is related to switch placement as a planning process, including the planning horizon. This index is used as object function in MGA in order to evaluate the costs.

2.4 Reliability Assessment

According to Billinton and Jonnavithula (1995), reliability evaluation includes all the segments of an electric power system in an overall assessment of actual consumer load point reliability. The primary reliability indices are the expected failure rate, the average duration of failure and the annual unavailability, at the customer load points. Individual customer indices can also be aggregated with the number of customers at each load point to obtain system reliability indices. These indices are the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), the customer average interruption duration index (CAIDI) and the average service availability index (ASAI). The most common reliability indices used by electric utilities are SAIFI and SAIDI. They are used to measure the impact of power outages in terms of the number of interruptions and interruption durations respectively (Allan and Billinton, 1993). These indices can be calculated for the overall system or for subsets of the system depending on requirements for the performance measures. These indices depend on the circuit topology and location of switches. In order to compare different switches allocation, is used SAIDI, as follows:

$$SAIDI(S) = \frac{EUE(S)}{L_{tot}} \quad (4)$$

where, $SAIDI(S)$ is the system average interruption duration index according S.

It's common that researchers use SAIDI as a portion of the EUE, however most of them, like Ziari et. al., (2009), Billinton and Jonnavithula (1996) and Chen et. al. (2006) don't evaluate the unsupplied energy before switch's triggered to simplify the analysis. So this work performed a more realistic reliability analysis, using this index as objective function of the MGA.

2.5 Load Importance

Generally, the electric utilities need to prioritize the service to some consumers due to its special characteristics, such as: critical loads, big power consumers, loads with high continuity demanded, etc. The proposed algorithm has defined a new variable called load importance (LI), which defines the importance for the electric utility of each consumer connected to the feeder. It establishes a ranking between 0 and 1 (inclusive) for consumers defined by the electric utility

In order to give preference to the switches installation in sections situated before and after priority loads is defined the priority index as follows:

$$PRIORI(S) = \frac{\sum_{i=1}^{Ns} LI_i(S)}{LI_{tot}} \tag{5}$$

where, LI_{tot} is the sum of all *LI* defined to the feeder; $LI_i(S)$ is the sum of *LI* of all consumers not interrupted by a fault in section *i* after service restoration performed with the operation of switches installed according *S*; and *PRIORI*(*S*) is the priority index considering the set *S* of section switches and tie switches installed.

This index is used as object function in MGA in order to evaluate the load importance. Most of the paper in this field, e. g. Assis et. al. (2012) Falaghi, Haghifam and Singh (2009) Tippachon and Rerkpreedapong (2009), Golestani and Tadayon, (2011) and Ziari et. al., (2009), don't include this evaluation on it solution.

3 SOLUTION

In order to find an optimal allocation of switching devices in distribution networks based on load priority, reliability, costs, and considering the simultaneous allocation of MCS and RCS, a multi-objective algorithm is proposed. MGA is used in the solution. The simultaneous allocation of MCS and RCS is considered to calculate reliability index and costs. Load importance is defined by electric utility. A weight function based on reliability index, costs and load importance is used as object function.

3.1 Microgenetic Algorithms

Genetic algorithms are simple, robust, flexible, and able to find the global optimal solution. They are especially useful in finding solution to problems for which other optimization techniques encounter difficulties (Goldberg, 1989). A basic genetic algorithm is constituted by a random creation of an initial population and a cycle of three stages, namely:

1. evaluation of each chromosome;
2. chromosomes selection for reproduction;
3. genetic manipulation to create a new population, which includes crossover and mutation.

Each time, this cycle is completed, it is said that a generation has occurred.

The disadvantage of genetic algorithms is the high processing time associated. That is due to their evolutionary concept, based on random processes that make the algorithm quite slow. However, different methods for reducing processing time have already been proposed, such as more appropriate choice of solution coding and reduction of search space using the specialist knowledge. One alternative method known as microgenetic algorithms, whose processing time is considerably smaller, is shown in (Delfanti et. al., 2000; Chakravarty, Mittra and William, 2001).
According to Souza, Alves and Ferreira (2004), most of the genetic algorithms produce poor results when populations are small, because insufficient information is processed about the problem and, as a consequence, premature convergence to a local optimum occurs. Population size generally varies from 30 to 300 individuals. In contrast, microgenetic algorithms explore the possibility to work with small populations (from five to 20 individuals usually) in order to reduce the processing time. From a genetic point of view, it is known that frequent reproductions inside a small population may disseminate hereditary diseases rarely found in large populations. Therefore, small populations can act as natural laboratories where desirable genetic characteristics quickly can emerge. In microgenetic algorithms, mutations are unnecessary because after a certain number of generations, the best chromosome is maintained and the rest are substituted by randomly generated ones. On the other hand, it requires adoption of some preventive strategy against loss of diversity in population.

Basically, two mechanisms are used to prevent loss of diversity in population (Ongsakul and Tippayachai, 2002). First, the individuals are selected (only once) for a binary tournament. In this way, not only do the most developed individuals have an opportunity to participate in the reproduction but all of them do. The second mechanism is to insert new individuals each time the population becomes homogeneous. The best individual is kept and inserted into a new population randomly created. When it occurs, a migration has occurred. If the same individual is the best one along a certain number of migrations, the algorithm stops and this individual represents the solution.

3.2 Multi-Objective Algorithm

Multi-objective formulations are realistic models for many complex engineering optimization problems. In many real-life problems, there are typically multiple conflicting objectives that need to be evaluated in making decisions. Optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to the other objectives. A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution. Typically, there is not a unique optimal solution for such problems and it is necessary to use decision maker's preferences to differentiate between solutions.

There are two general approaches to multiple-objective optimization (Deb, 2001). One is to combine the individual objective functions into a single composite function. Determination of a single objective is possible with methods such as utility theory and weighted sum method. The second general approach is to determine an entire Pareto optimal solution set or a representative subset. A Pareto optimal set is a set of solutions that are nondominated with respect to each other. In this paper is used the weighted sum method due to its simplicity and its characteristic of being a priori approach since the user is expected to provide the weighting factors. Assign weighting factors for each criterion used will reflect its relative importance to the decision. The weighted sum method combines the weighting factors and scores for each criterion to derive an overall value.

In this paper, the solution method will find an alternative for locating switches devices based on a set of criteria, in which load importance, reliability, costs and simultaneous manual and remote controlled switches are considered. Regarding the criteria adopted in this paper can be affirmed:

- High values of PRIORI(S) increase the chances of S to be chosen for allocation.
- High values of SAIDI(S) decrease the chances of S to be chosen for allocation.
- High values of COST(S) decrease the chances of S to be chosen for allocation.

For all criteria have the same behavior and the objective function to be minimized, the portion of the objective function relative to PRIORI(S) is calculated as shown in (6).This formulation ensures that the lowest value of PRIORI(S) corresponds to the value 1 and other values of PRIORI(S) correspond to values less than 1.The values for the weighting factors employed are defined according to (7) and they reflect the relative importance for each criterion. The proposed algorithm normalizes each criterion by its maximum value at a given population. This procedure is performed for each new generation.

$$OF(S) = w_1\left(1 - \frac{PRIORI(S) - Min(PRIORI)}{Max(PRIORI)}\right) + w_2\frac{SAIDI(S)}{Max(SAIDI)} + w_3\frac{COST(S)}{Max(COST)} \quad (6)$$

$$w_1 + w_2 + w_3 = 1 \quad (7)$$

where, w_1 is weighting factor for *PRIORI*; w_2 is weighting factor for *SAIDI*; w_3 is weighting factor for *COST*; and OF is the objective function.

3.3 Proposed Algorithm

From studies and experiments with several methods reported in the literature, a MGA is proposed for solving the tie switches and section switches placement problem. The MGA uses load importance, costs and a reliability index as criteria to find the optimal solution. In order to calculate costs and reliability index is considered the simultaneous allocation of MCS and RCS. The proposed algorithm consists of the following steps:

1) Define the number of section switches (*ns*) and maximum number of tie switches (*nt*) that can be used to allocation;
2) Define the number of RCS (*nr*) used to allocation;
3) Define the weighting factorfor each criterion;
4) Load importance (LI) variable is defined by the system manager for each consumer connected to the feeder;
5) Adopt OF expressed in Eq. (6) as objective function. The MGA is applied to minimize OF;

6) Randomly create a initial population *p* with *ns* sectionalizers allocated in each cromosome and go to step 8;
7) Randomly create an population *p*-1 and add to it the best chromosome from the last migration;
8) Determine the objective function of each chromosome;
9) Choose chromosomes from the present population using the tournament method based on crossover rate *c*. Make crossover operation using pairs of chromosomes from this subgroup, determining new chromosomes;
10) Calculate the objective function value of the new chromosomes;
11) Replace the present population for a *p* size new population compost of the best chromosomes from the present population and the new chromosomes;
12) Repeat steps 9 to 11 until the population reaches an homogeneous degree *h* previously chosen or for *g* generations;
13) Find the best chromosome, keep it, and discard the others.
14) Repeat steps 7 to 13 until the best individual does not change for *m* migrations.

The homogeneous degree may be adjusted between 90% and 99%. For instance, if this highest degree is chosen, it means that the population is considered homogeneous when all individuals have at least 99% of their genes identical to the genes of the most adapted individual.

Numbers *c*, *g*, *h*, *m* and *p* are previously specified. The tournament method is a process in which a population subgroup is randomly formed and from which the most well-adapted individual is elected for crossover.

In this work, the chromosome is a vector divided in two parts:

1. Section Switches Group (SSG): the first *ns* positions are the sections in the feeder where SS are installed. Each position is associated to one of the sections in the feeder.
2. Tie Switch Group (TSG): The last *nt* positions are the sections where tie switches are installed. These sections are somewhere downstream of the sections appointed by first *nt* positions. They are defined based on SSG.

For instance, considering a feeder with *Ns* sections, *ns*=4 and *nt*=2, a possible chromosome is shown in Fig. 3. The sections *i*, *j*, *k* and *l* are randomly chosen to receive SS, and the section *m* and *n* are defined based on sections *i*, *j*, *k* and *l* to receive TS. Only the genes from SSG are randomly chosen and copied from parents to their offspring. TSG is always defined based on SSG.

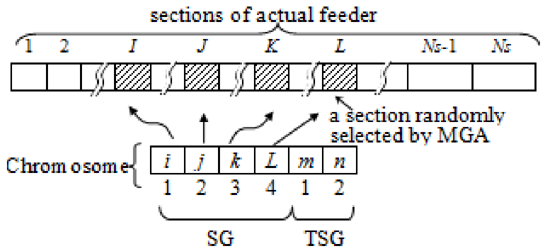

Figure 3: Genetics information stored in chromosome is pointed to section array.

The sections represented in a chromosome that contain remote controlled switch are identified by negative sign. For instance, considering the example shown in Fig. 3 and *nr*=2 (number of RCS), any of the chromosomes below represent one possible solution.

Chromosome1	-i	j	k	-l	m	n
Chromosome2	I	-j	k	L	-m	n
Chromosome3	I	j	k	-l	m	-n

Figure 4: Example of 3 different chromosomes with the same sections.

4 APPLICATION

The proposed algorithm is implemented using MATLAB® on a 1GHz AMD Dual core personal computer. In this paper, the test system selected to illustrate the performance of the algorithm is a 69-node radial distribution system which includes one main feeder and seven laterals as shown in Fig. 4. The system and load data can be referred to Baran and Wu (1989). The line voltage in substation is 12.66 kV. The mean time for restoring by RCS used is 3 minutes and by MCS is 48.8 minutes. The mean outage time of a fault in the feeder is 153 minutes. It is considered the cost of $ 5,000.00 for MCS and $ 10,000.00 for RCS. The annual load growth used is 5% for a ten-year planning horizon. The cost of energy considered is $ 0.14 / kWh. In the proposed algorithm, PRIORI is calculated based on LI established by the system manager. In order to evaluate the effect of this variable in the solution, it is considered that all consumers have LI = 0.1, except a consumer randomly chosen with LI = 1.0 (section 20 is chosen). Table 1 shows the annual failure rate per section adopted in this application. The weighting factor of each criteria used in this application is defined to four different groups: equal weighting factor for each criteria (group 1 - w1=w2= w3=1/3), a greater weighting factor for PRIORI (group 2 - w1=0.8,w2=0.1 and w3=0.1), a greater weighting factor for SAIDI (group 3 - w1=0.1, w2=0.8 and w3=0.1) and a greater weighting factor for COSTS (group 4 - w1=0.1, w2=0.1 and w3=0.8).

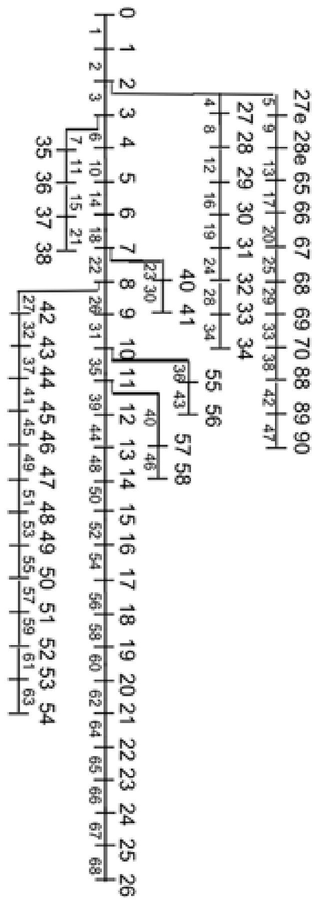

Figure 5: The diagram of a 69-bus test system array.

The MGA uses p=20, c=80%, g=200, m=5 and h=95%. It is considered the allocation of 10-sectionalizers (ns) and a maximum of 10 tie switches (nt). Regarding the amount of remote controlled switching allocated are considered three configurations: all switches allocated are MCS (C1), at least 50% of the switches allocated are RCS (C2) and all switches allocated are RCS (C3).

The 30 executions' means of the proposed algorithm are presented in Table 2. The execution time of MGA is about five minutes. In solutions 1, 2 and 3 the weighting factors used are identical (group 1) but the number of RCS installed is modified (configurations C1, C2 and C3) in order to analyze the effect on some parameters related to the feeder when these changes occur. In solutions 3, 4, 5 and 6 all switches installed are RCS (C3) but the weighting factors used are different in order to analyze the effect on some parameters related to the feeder when these changes occur.

Comparing the results of solutions 1, 2 and 3 verify that the set of sections selected by MGA differs in all them. This shows that the type of switch used (RCS or MCS) influences the choice of the section for allocation. As expected, the larger the number of RCS installed, the better are the values obtained for SAIDI. Comparing solutions 1 and 3 (all MCS and all RCS respectively) the costs are close for a ten-year planning horizon although the investment cost for RCS is double of investment cost adopted in this work for MCS. This occurs because the larger the number of RCS installed, the lower is the value of EUE. Solution 2 has the lowest cost because it has 7-RCS installed which reduces the value of EUE compared to solution 1 and 8-MCS installed which reduces the investment cost compared to solution 3.

Comparing solutions 3, 4, 5 and 6 verify that the set of sections selected by MGA differs in all them. This is due to the different weighting factors adopted. Only solution 3(in sections 9 and 47) and solution 4 (in sections 13, 25 and 47) allocate switches in the lateral that is section 20 (the highest LI in the feeder). This is due to the considerable value of w1used in these solutions in relation to the others weighting factors. Solution 4 (the highest value of w1) allocates SS before and after section 20 (sections 13 and 25) where there are loads priority,

Table 1: Switches allocated by the proposed algorithm.

No.	Configuration	Section Switches	Tie Switches
1	Group 1 – C_1	3;4;15;18;27; 31;39;53;59;60	21;34;63;68
2	Group 1 – C_2	-3;-6;-26;-27; 50;51;53;-54; 55;-57	-63;68
3	Group 1 – C_3	-6;-9;-11;-26; -35;-37;-39;-55; -56;-57	21;-47;-63;-68
4	Group 2 – C_3	-3;-6;-13;-25; -27;-31;-39;-54; -55;-57	-47;-63;-68
5	Group 3 – C_3	-9;-11;-14;-21; -31;-32;-39;-55; -56;-57	21;-45;-63;-68
6	Group 4 – C_3	-3;-10;-26;-32; -35;-44;-54; -55;-57;-62	-63;-68

demanding high continuity. As expected, solution 5 (the highest value of w2) shows the best value for SAIDI and solution 6 (the highest value of w3) the best value for the costs.

These results confirm that the multi-objective algorithm proposed achieves efficient solutions considering simultaneously a different number of RCS for allocation and different weighting factors for criteria adopted.

Table 2: Reliability and Costs' results.

No.	Configuration	SAIDI (h)	EUE (MWh)	COSTS (10^6\$)
1	Group 1 – C_1	12.78	48.59	0.15
2	Group 1 – C_2	4.51	17.14	0.13
3	Group 1 – C_3	2.79	10.61	0.16
4	Group 2 – C_3	3.27	12.44	0.15
5	Group 3 – C_3	2.69	10.24	0.16
6	Group 4 – C_3	3.36	12.77	0.14

5 CONCLUSIONS

This study presented a method for allocating of section switches and tie switches in radial distribution networks based on a multi-objective microgenetic algorithm. This algorithm is applied to determine the advantage of having a switch installed in a particular section or not considering load importance, reliability index, remote or manual controlled switch and investments costs. The main stages and characteristics of MGA and its application in the proposed problem were described. In order to illustrate the performance of the algorithm, several experiments using a real distribution system were conducted. This work did not consider the possible additional costs for the electric utility associated with the interruption of an important load. Solutions 1, 2 and 3 indicated a considerable effect of number of RCS installed on reliability index and investments costs. Solutions 3, 4, 5 and 6 indicated a considerable effect of weighting factors on the problem objectives. These results showed complete adaptation of algorithm to different requirements that are determined by the planner who can adapt the value of weighting factors according to the technical and economic conditions. The proposed algorithm has shown excellent results making this tool a great potential to assist in planning of distribution networks and also to make improvements in existing networks.

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