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Reliability based Switch Placement In Distribution Systems

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A B S T R A C T

Background: The main objective of the planning and operation of electric power distribution systems is to satisfy the system load and energy requirements continuously and without any interruption. To achieve this goal improving reliability is the most concerned issue at distribution system. The System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) are two most widely used indices that measures reliability. Improving reliability means decreasing outage. **Objective:** In this paper the optimization problem is solved by genetic algorithm GA to minimize installation cost of sectionalizers, simultaneously improving reliability indices and Expected customer interruption Cost (ECOST). **Results:** Compared with conventional techniques, the proposed strategy reduces system outage and Improves network reliability. **Conclusion:** Outage plan is the optimization of voluntary disconnection, aiming to minimize interruptions for preventive maintenance in a distribution utility. Hence, installations of switching devices like sectionalizers along the network could manage outage. In this paper the optimization problem is solved by genetic algorithm GA to minimize installation cost of sectionalizers, simultaneously improving reliability indices and Expected customer interruption Cost (ECOST).

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INTRODUCTION

Electric power distribution systems constitute the greatest risk to the interruption of power supply (Billinton, R. and R.N. Allan, 1996; Bertling, L., 2002; Brown, R.E., 2002). Faults in distribution system may cause interruption of power supply to customers.

Currently the improvement in distribution performance is hampered by four major defects: a) lack of data. Beside voltage and current measurement at substations, few monitoring devices for measurements are installed in a distribution system; b) aging of equipment. Most of the primary equipment installed in distribution systems is pretty old, in some instances over 30-40 years. c) Ineffective processing of faults and maintenance scheduling caused by the lack of data. The fault location is currently based on trouble calls and manual switching (James Northcote-Green, Robert Wilson, 2006) while maintenance is performed either with a run-to-failure strategy or with a fixed ahead-of-the-time planned schedule (IEEE/PES, 2001), which does not require operational data; d) independent planning and operation of asset and outage management. Those two functions are planned independently even though the equipment that may record and collect relevant data from the field maybe common to both applications.

Since distribution systems in general encounter high frequency of faults, the need to reduce outage time caused by faults is required for several reasons. a) Better service to customers. Customers' requirement on the quality of service is constantly growing. As an example, sensitive loads in modern industry such as oil pumping complex and ore smelter are very sensitive to interruptions in power supply. The consequence of failure is more severe nowadays than a decade before; b) Return on investment for utility shareholders. The most direct impact of faults on the profit is the loss in customer billing, as well as maintenance expense. The optimal maintenance strategy should also provide support for finding the optimal level of outsourcing of maintenance measures since this affects the maintenance strategy.

Outage plan is the optimization of voluntary disconnection, aiming to minimize interruptions for preventive maintenance in a distribution utility. It deals with several databases on equipment and consumers information and past interruptions and may also include a load flow program to verify the possibility of transferring load. Although some services can be executed without disconnection, generally maintenance is executed on

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equipment without voltage, and due to the radial topology of distribution systems, this usually causes interruptions, which will be later computed for the continuity indices. Reliability indices defined in IEEE Standard 1366 are used to evaluate the impact of faults on power distribution performance ("IEEE 2004). SAIFI and SAIDI are two most widely used indices. The lower the value of SAIDI and SAIFI, the better the performance in terms of reliability.

The main methods for improvement in reliability of distribution systems are installation of switching devices such as sectionalizing switches (Brown, R., 2002). By the use of sectionalizing switches, the faulted sections are isolated from the other parts of system to continue energizing the unfaulted parts. Determination of optimal numbers of switches and their locations is in general a combinatorial optimization algorithm. As a result, several optimization algorithms for solving this problem have been used in the references (Billinton, R., S. Jonnavithula, 1996; Levitin, G., *et al*., 1994; Celli, G. and F. Pilo, 1999; Adel Moradi and M. Fotuhi-Firuzabad, 2008; Chen, C.S.h., *et al*., 2006; Amir Abiri-Jahromi, *et al*., 2012; Kumar, Y., *et al*., 2008; Falaghi, H., *et al*., 2009). The simulated annealing in (Billinton, R., S. Jonnavithula, 1996), GS in (Levitin, G., *et al*., 1994) and in (Celli, G. and F. Pilo, 1999) Bellman's optimality principle method is used to locate the Sectionalizing switches. Improve reliability and reduce costs in this papers is based on an economic objective function based on this work has been based studies. The main goal of authors in (Adel Moradi and M. Fotuhi-Firuzabad, 2008) is minimizing the Customers' Expected Outage Cost (ECOST), which has been presented as the function of average outage time, average failure rate, and its related cost. To solve the problem, a novel multistate version of a discrete structure has been suggested for particle swarm optimization (PSO). In order to increase the economic efficiency of distribution automation system, immune algorithm (IA) is employed in (Chen, C.S.h., *et al*., 2006) for switch placement aiming at reducing total cost of customer service outage and switch investment cost. The proposed function in (Amir Abiri-Jahromi, *et al*., 2012) considers customer outage costs in conjunction with sectionalizing switch capital investment, and it is modeled as a Mixed-Integer Linear Programming (MILP). The function is solved by large-scale commercial solvers in a computationally efficient manner, and then tested on a reliability test system as well as on a typical real size system. Kumar *et al*. presented NSGA-II algorithm to solve the power restoration problem in distribution network. In this study, many practical aspects of distribution system operation such as priority for loads along with remote and manual controlled switches mechanism have been considered (Kumar, Y., *et al*., 2008). Using a fuzzy based multi-objective function, Falaghi *et al*. proposed a methodology for placement of sectionalizing switches in the presence of distributed generation. They used ant colony optimization algorithm to find the best solutions taking operational and electrical constraints into account (Falaghi, H., *et al*., 2009).

In this paper a genetic optimization algorithm is proposed to determine the optimal location of sectionalizing switches in distribution networks. Using a simple objective function because of competing and non-commensurable nature of objectives including reliability improvement and cost minimization, makes the calculations unrealistic and impractical. In other words, taking benefit from multi-objective approach makes it possible to compromise between involved factors; it means that a proper scheme according to technical and economic requirements of the network is provided. After feeder configuration and presence of distributed generation, the location of switches may deviate from its optimum point. Hence, relocation of existing switches which can significantly improve the reliability indices and reduce costs, has been taken into account.

Switching placement problem for large networks is a complex and difficult task. Therefore, genetic algorithm as a non-classical and direct search optimization technique is used. It starts from several points in set of candidate solutions and keeps searching the variables of objective function point by point. Finally, to demonstrate the practical implementation and robustness of algorithm, simulation applied to the sample network.

This paper is organized as follows: After the introduction, the concept of problem formulation is briefly described in section II. Section III discusses the application and realization of GA based installing sectionalizers problem. Section IV explores the application of the proposed strategy to case studied and result of simulation. A sample 30 bus distribution system is employed for applying proposed strategy. Section V discusses the results and the conclusions of this paper.

Problem formulation:

In order to formulate the problem, two objectives have been considered. First objective is reliability improvement for which various indices have been already defined. System average interruption duration index (SAIDI) and annual expected energy not supplied index (EENS) are two of them. Second objective is minimization of switches cost which can be realized by reducing the number of new sectionalizing switches. Objectives are stated in the form of functions which their values vary from zero (lower satisfaction) to unity (greater satisfaction). Therefore, this function is expressed as follow:

$$\begin{cases} F = \{Max\,[\beta_1 \mu \frac{1}{EENS} + \beta_2 \mu \frac{1}{SSC}]\} \\ \beta_1 + \beta_2 = 1 \end{cases} \quad (1)$$

Where $\mu_{\frac{1}{EENS}}$, $\mu_{\frac{1}{SSC}}$ is the value of membership function EENS and switches cost, respectively. β_1, β_2 are weighting factors that indicate the importance and priority of EENS and switches cost. Weighting coefficients are supposed to be changed according to decision maker's preference to provide various planning strategies which are economically and technically practical.

In this paper, in order to explain the system reliability, EENS index has been used. Calculation strategy of this index has been explained in appendix (A). The main purpose of this membership function is to improve service reliability by reducing EENS. Minimum value of EENS can be obtained by installation of sectionalizing switches in all candidate locations which leads to the highest degree of satisfaction. As the EENS becomes greater, the degree of satisfaction will decrease. As a result, $EENS_{max}$ represents the minimum satisfaction. According to reference (Falaghi, H., *et al*., 2009), the exponential function can be an appropriate option to represent the membership function.

$$\mu_{\frac{1}{EENS}} = \begin{cases} 1, & EENS \leq EENS_{min} \\ exp\left(\frac{EENS_{min} - EENS}{EENS_{min}}\right), & otherwise \end{cases} \quad (2)$$

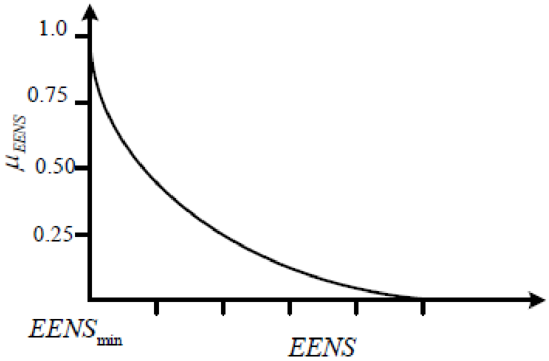

Fig. 1: Membership functions of the EENS index.

If the number of selected switches to be installed (new switches) becomes greater, required expenditures for purchasing and installing new switches will increase. It should be noted that there always are some existing switches in the network for which a negligible placement cost is considered. Investment costs including both new switches and existing switches relocation costs can be calculated as follow:

$$SSC = (NS_{new} - NS_{old}).SNC + \Sigma\alpha_i.RES_i \quad (3)$$

SSC is total cost of switches, *SNC* is investment cost of new switches, RES_i is relocation cost of existing switches, NS_{new} is Number of selected switches, NS_{old} is Number of existing switches, α_i is set to zero if location of the existing switch is selected for switch installation, otherwise, it is equal to 1.

Even though a greater number of switches can guarantee a higher level of reliability and make benefit, required investment cost for purchasing new switches will increase. According to Fig. 2, existing equipments are more likely to be considered than new ones. In other words, our top priority is to determine the location of existing switches. Therefore, new switches are used as a secondary option. As a result, membership value of investment cost of sectionalizing switches is maximum as long as the selected equipments investment cost is less than the existing switches cost. Membership function for cost of switches is defined as follow:

$$\mu_{\frac{1}{SSC}} = \begin{cases} 1 & SSC \leq 0 \\ \frac{SSC_{max} - SSC}{SSC_{max}} & 0 \leq SSC \leq SSC_{max} \\ 0 & SSC_{max} \leq SSC \end{cases} \quad (4)$$

Where SSC_{max} is the maximum value of cost of sectionalizing switches which can be expressed as follow:

$$SSC_{max} = (NS_{max} - NS_{old}).SNC \quad (5)$$

NS_{max} is the maximum number of switches which can be installed taking a predefined criterion such as available budget into account. In this case, the membership function value is its lowest value. Fig. 2 depicts the membership function for the cost of switches.

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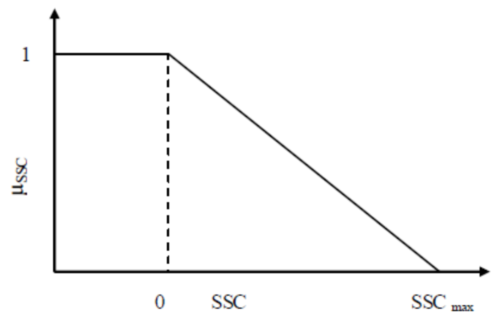

Fig. 2: Membership function of the switch cost.

The other objective function of the optimum switch relocation problem is to minimize the interruption costs for distribution feeders by rearranging the existing switches. In a distribution feeder, the group of line segments between adjacent switches or circuit breakers is defined as a *section.* Each *section* will have several load points and the equivalent load of a *section* is obtained by summing individual loads within the *section* (Jen-Hao Teng, *et al*., 2003). System expected outage cost to costumers due to supply outages (ECOST) is used as an objective function that should be minimized by Genetic algorithm. ECOST is used as the objective function because it responds to the effects of system topology, interruption duration, load variations, random failures and also recognizes the various costumer types and their non linear customer damage functions (Billinton, R., S. Jonnavithula, 1996). The system ECOST can be expressed as follows:

$$ECOST = \sum_{j=1}^{nj} \sum_{k=1}^{nk} L_k . C_{jk}\left(r_j\right) . \lambda_j \qquad (\$/yr) \tag{6}$$

Where *nk* is the number of load points that are isolated due to contingency *j*, *nj* number of contingencies, L_k curtailed load at load point *k*, r_j average outage time of contingency *j*, λ_j average failure rate of contingency *j* and C_{jk} outage cost($/KW) of customer class *k* due to outage *j* with an outage duration of r_j. Optimal locations of ***n*** number of switches are determined using Genetic algorithm process such that ECOST is minimized; it is clear that, system reliability increases as the number of switches is increased. However, factors such as capital investment cost, installation and maintenance costs of switches must be considered in conjunction with the benefit derived by implementing additional switches.

In each step, EENS and IEAR are, calculated for a given number of switches. The EENS due to all contingencies that lead to load curtailment is given by this equation.

$$EENS = \sum_{j=1}^{nj} \sum_{k=1}^{nk} L_k . r_j . \lambda_j \qquad (KWh/yr) \tag{7}$$

Interrupted energy assessment rate (IEAR) of each system can be expressed by the following equation [17]

$$IEAR = \frac{ECOST}{EENS} \qquad (\$/KWh) \tag{8}$$

Genetic Algorithm:

In the proposed approach, for a given number of ***n*** switches after relocating switches in the best positions by multi objective Genetic algorithm, optimum number of switches is determined by algorithm given in Fig.3.

Simulation results:

The main purpose of this test is to investigate the impacts of relocation of existing switches and installing new switches in the network on the problem. The first experiment has been carried out without considering any existing sectionalizing switches. Three selected sectionalizing switches offer a 30% reduction in EENS value. The aim of performing this experiment is to investigate the effect of weighting factors on the objectives of the problem and additionally, explore its adaptation to these conditions. Different values have been assigned to weighting factors. The lowest value of EENS shows the network high reliability. The lowest and highest value of switch cost is proportional with lowest and highest value of β_2. The results show that β_1 and β_2 that determine the degree of priority and importance of reliability and switch cost have significant impact on objectives of the problem. For β_1=0.2, because of a lower degree of priority and importance of reliability, a fewer number of switches has been selected. Due to a higher degree of importance of switches cost, slight cost changes can significantly affect the satisfaction of the design. By increasing β_1 from 0.2 to 0.8, in each step, reliability indices (EENS, SAIDI) is improved and related costs of switches are increased. For a lower value of β_2, which

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represents the degree of priority of the switches cost, the number of selected switches is increased and simultaneously, the EENS value is reduced.

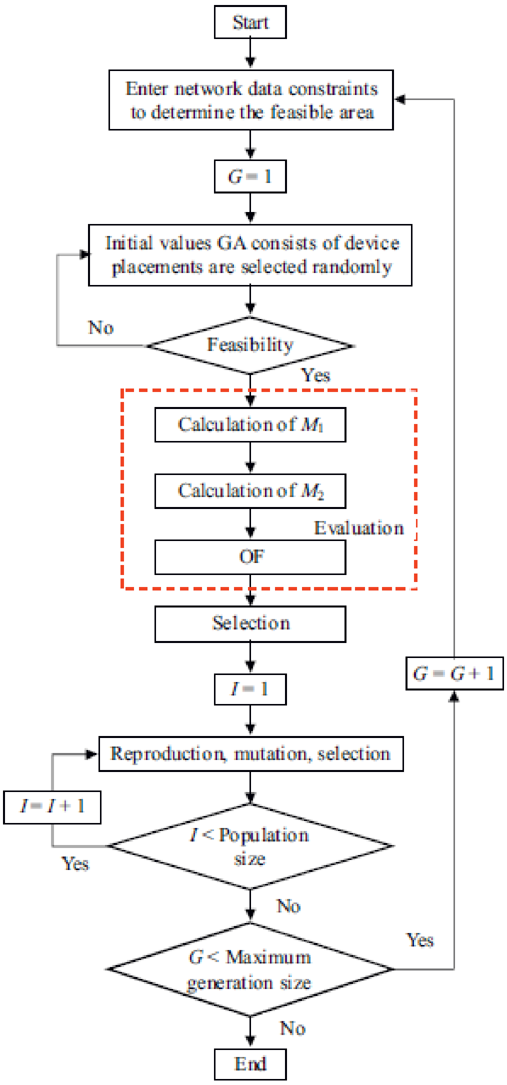

Fig. 3: Flow chart of the optimization by multi objective GA

Simulation is done on 30 bus sample distribution system and results illustrated in table 1 and figure 4.

Table 1: best solution obtained after simulation.

Optimal Branches for Inserting Switches	24-25, 5-6, 22-23, 5-21, 11-12, 2-3, 18-19, 14-15, 7-8, 28-29, 13-30

Length axis is IC index in terms of dollar. Width axis is ECOST in terms of dollar and height axis is SAIDI in terms of outage hours for consumers for a year. These solutions are in fact a set of best solutions for optimization problem that can simultaneously minimize three objective functions.

Results shows that after installing and relocating switches reliability indices improved and cost of unsupplied energy decreased.

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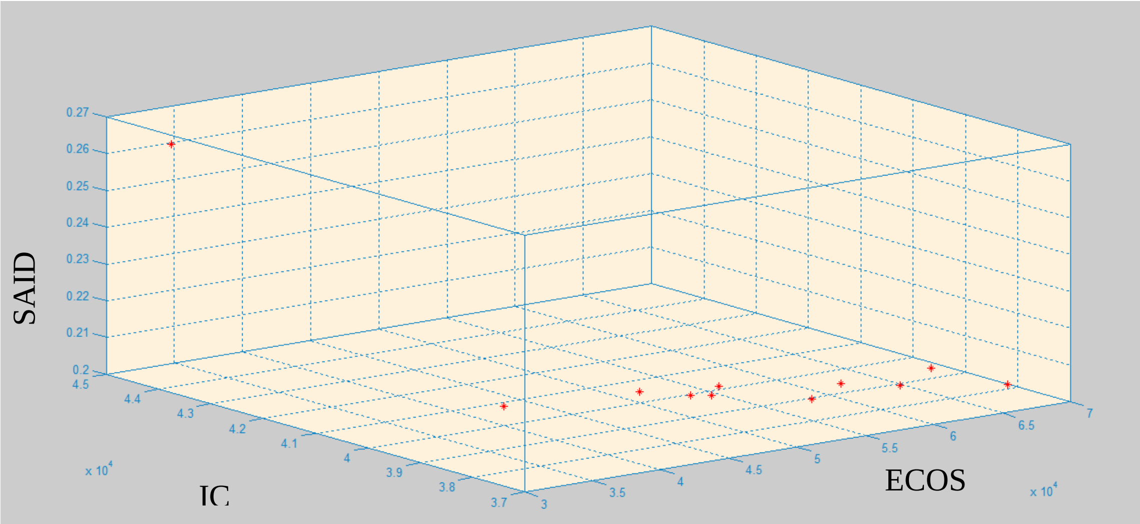

Fig. 4: Simulation result on sample network.

Conclusion:

In this paper a multi-objective optimization algorithm is used for optimal placement of sectionalizing switches in distribution network. Objective functions used for optimization are SAIDI, ECOST, IC and EENS. Multi-objective genetic algorithm is used to optimize objective functions and simultaneously to find optimal places for switches applied in the system. Employing multi-objective approach along with using a switch relocation strategy makes it possible to have a high level of reliability and acceptable investment cost simultaneously. It can also make it possible for different scenarios to be presented taking economic and technical requirements into account. The results indicated a considerable effect of weighting coefficients on the problem objectives so that the variation of EENS and switches cost was significant. In the simulation the crucial role of existing switches relocation in order to improve reliability and reduce the cost of switches and objective function was highlighted. Acquired results showed complete adaptation of algorithm to the problem variations in order to make high level of satisfaction.

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