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Optimal procedure for remote-controlled switch devices siting in distribution systems using heuristic algorithms

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Abstract: The growing demand for improved quality of service increases the importance of network automation. This allows improving the fault isolation and reconfiguration time and therefore increasing the system quality of service. Since the investment in remote-controlled switch (RCS) devices comes at a cost, this study proposes a heuristic approach to solve the problem of optimal siting RCS devices in distribution systems. For doing that, RCS devices are located to improve the reliability of the system based on the optimal open ties deriving from the distribution network (DN) reconfiguration problem. A Genetic Algorithm has been developed to optimise the radial layout of the DN taking into account the reliability of the system. As a measure of the system reliability, the authors use a risk index which is expected to well estimate, based on the statistical data available, the system average interruption frequency index. The risk index is based on two parameters: the length of the feeders, which measures the failure probability, and the number of customers, which measures the failure impact. The solution approach has been tested on a real distribution subsystem of Milano.

1 Introduction

Power outages enforce costs on society by interrupting the flow of commerce and important services. One mode to improve the electrical service reliability is to adopt more suitable feeders planning procedure [1]. In this way, the distribution network (DN) is strengthened resulting in a more reliable system. A second way is acting on optimal maintenance scheduling by using an advanced asset management model [2]. Another approach for reducing the interruption costs is to shorten the outage time by investing in facilities such as remote-controlled switch (RCS) [3]. These devices allow improving the fault reconfiguration time when installed in normally open branches. By improving operation times RCS devices improve outage time increasing the overall system quality of service. Since the installation of these devices comes at a significant cost, the optimal siting of these devices is an important issue for distribution system operators. It is worth noting that, from a technical standpoint, this smart application requires a very good level of network observability and a high level of automation. Nowadays, observability is a major deficiency at the distribution level due to the lack of measurement devices (no redundancy) but this flaw is being mitigated [4]. On the other hand, distribution management systems, such as the one presented in the work of Arrigoni *et al.* [5], represents a mature solution for the supervision and control of the DNs and their contained devices.

Several papers addressed the problem of switch allocation in DNs. Ray et al. [6] present a differential search algorithm in order to solve the reliability optimisation problem of radial DN. Remote control switches are optimally allocated to improve reliability at a compromised cost. Alabdullah *et al.* [7] investigated the effect of number and location of the sectionalising switch in a real-distribution system which considers the costs associated with customer outages versus the switch capital investment, installation, as well as annual operation and maintenance costs. The problem has been formulated as a mixed-integer linear programming and solved with a commercial solver in a computationally efficient manner. Chehardeh and Hatziadoniu [8] proposed a two-level optimisation method to find the optimal number and location of conventional protective devices to be upgraded to RCS devices for a DN considering also the effect of distributed generation. In the work of Yari *et al.* [9] the same problem is faced using an approach for the minimisation of energy not supplied, the costs of installation, maintenance and operation of equipment, taking into account the practical parameters of the network.

The paper is organised as follows. In Section 2 the methodology is presented while in Section 3 the proposed approach is illustrated with an example from a real distribution subsystem of Milano. Some concluding remarks are given in Section 4.

2 Methodology

Most power distribution systems are designed to be radial, to have only one path between each customer and the high-/medium-voltage (HV/MV) substation. Those radial feeder systems are laid out and constructed as networks but operated radially by opening switches at certain points throughout the physical network configuration so that the resulting configuration is electrically radial (Fig. 1).

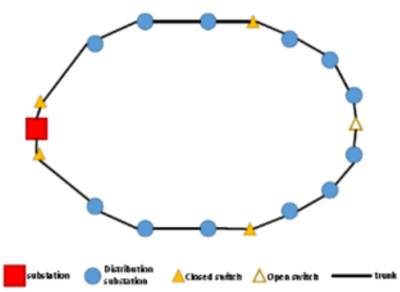

Fig. 1 *Example of radial designed*

Fig. 2 *Geospatial electrical diagram of the test network*

As load and power direction are easy to establish, voltage profile can be determined with a good degree of accuracy without using exotic calculation methods, equipment capacity requirements can be ascertained exactly, fault levels can be predicted with a reasonable degree of accuracy, protective devices can be coordinated in an absolutely assured manner, without using network methods of analysis. On the debit side, radial systems are less reliable than loop or meshed network systems because there is only one path between the HV/MV substation and the customer. Thus, if any element along this path fails, a loss of power delivery results.

Generally, when such a failure occurs, in order to minimise the period of outage, a repair crew is dispatched to re-switch temporarily the radial pattern network, transferring the interrupted customers onto another feeder, until the damaged element can be repaired. Great advantages can be achieved by using RCS devices to faster the restoration process. From here there is the need of optimal siting RCS devices whose location can be derived by solving the DN reconfiguration problem. In fact, finding the optimal DN layout gives information about open ties and consequently the optimal location of RCS devices.

The problem of optimal RCS devices siting has been faced in this paper by using a genetic algorithm (GA). The GA was first proposed by [10]. In a GA, a population of candidate solutions (called chromosomes) is iteratively evolved toward better solutions. Each chromosome has a set of properties (called genes) that can be mutated and altered. Traditionally, solutions are represented in binary as strings of 1 and 0 s. In this paper, we coded the chromosomes by labelling each gene with the open branch number that makes the DN radial.

After selecting the best genetic representation, the fitness function has to be defined. The fitness function is usually the value of the objective function of the optimisation problem. In this paper, we use a risk index which is expected to measure, based on the statistical data available, the system average interruption frequency index. On one hand, we suppose that the MV feeders failure probability is proportional to their length. On the other hand, the failure impact could be associated with the number of customers potentially interrupted in case of fault. Hence, for each MV feeder, we can define a feeder risk (F_R) as in (1), where L is the length of the feeder and N_{CUS} is the number of customers supplied by the feeder itself.

$$F_R = L \cdot N_{CUS} \qquad (1)$$

Assuming that F_{Ri} is the risk index of the ith feeder, the fitness function used to evaluate the chromosomes, to which we can refer as the network reliability index, is as in (2) where N_F is the number of feeders.

$$\text{Fitness function} = \sum_{i=1}^{N_F} F_{Ri} \qquad (2)$$

Once the genetic representation and the fitness function are defined, the GA improves the solution through three operators, i.e. selection, crossover, and mutation.

2.1 Creation of the initial population

The initial population size depends on the nature of the problem, but typically contains hundreds or thousands of possible chromosomes. Often, the initial population is generated randomly, to investigate the whole search space.

2.2 Selection

During each successive generation, several chromosomes are selected, through a fitness-based process, to breed a new generation. Fitter solutions (as measured by a fitness function) are typically more likely to be selected. In this paper, the selection is made by a mixed roulette wheel-elitism approach. The elitism method selects a predefined number of best chromosomes while the roulette wheel method randomly selects some chromosomes considering a probability associated with the fitness function of each solution.

2.3 Crossover

For each of the population created, pairs of chromosomes, called parents, are selected and some of the genes exchange to create a

Table 1 Feeders reliability index

Feeder	Current	After GA	Variation
F1	1601	1601	—
F2	4438	4438	—
F3	4418	2897	—
F4	0	0	—
F5	0	2623	—
F6	4198	1621	—
F7	2342	2342	—
F8	0	0	—
F9	2353	1099	—
Tot	**19,351**	**16,623**	**−14%**
Ave	**3870**	**3324**	**−14%**
St. Dev	**1898**	**1421**	**−25%**

Bold is to highlight total and statistical values.

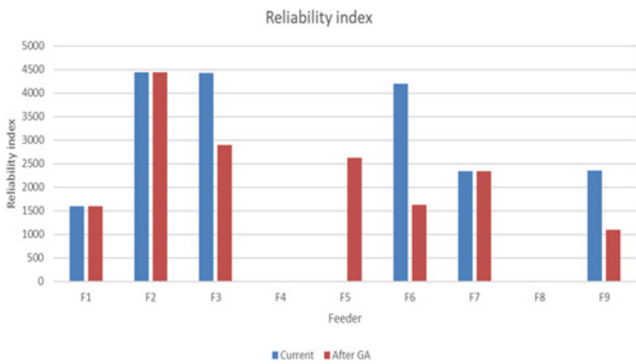

Fig. 3 *Feeders reliability index – Current vs. optimised*

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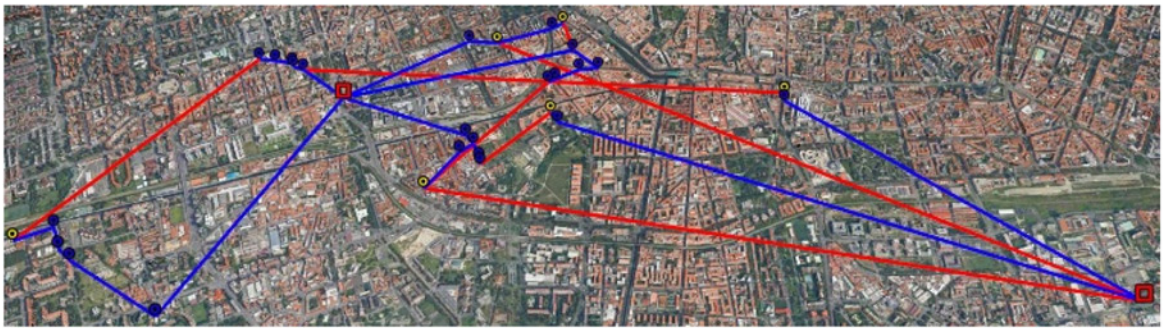

Fig. 4 *Layout with open branches in red*

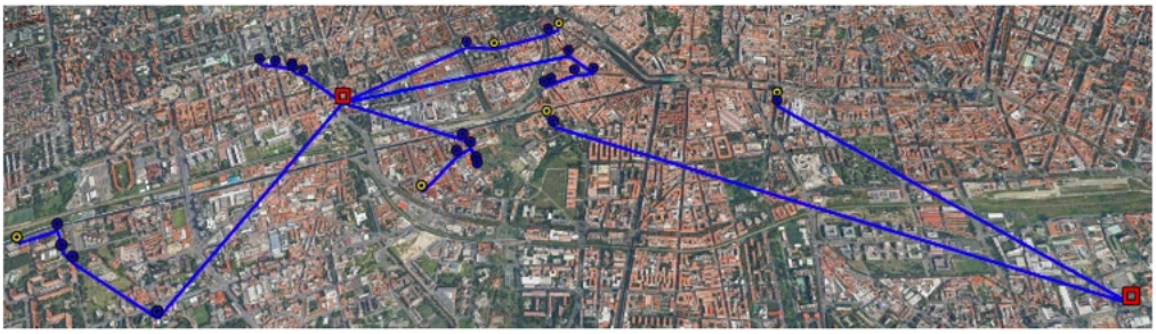

Fig. 5 *Radial layout with remote-controlled secondary substations in yellow*

new chromosome, called the child. New parents are selected for each new child, and the process continues until a new population of chromosomes of appropriate size is generated. This process results in a new population of chromosomes, which typically shares many of the characteristics of their parents, that is different from the initial one. Generally, the average fitness of the children is increased since the selection always keeps the best parents.

2.4 Mutation

The mutation, which is applied occasionally according to a predefined probability, randomly changes single genes of the chromosomes in order to maintain genetic diversity from a generation to the following one. The mutation is used to avoid local minima by preventing the population of chromosomes from becoming too similar to each other, thus slowing the convergence to the global optimum.

3 Results

In this section, the proposed procedure is implemented on a real 6.4 kV primary distribution system, whose geospatial electrical diagram is shown in Fig. 2. The system comprises 2 primary substations, represent as red squares, 9 feeders and 29 secondary substations, represent as blue circles. To guarantee the radiality of the system, seven tie switches are open. For each secondary substations, the number of customers and the power demand is known as well as the extension and all the electrical parameters of the lines.

Table 1 reports, for each feeder, the current value of the reliability index and the one deriving from the GA optimisation. As shown in Fig. 3, four feeders are reconfigured to share, more evenly, the extension and customers supplied, resulting in a more uniform reliability index. In particular, Feeder 5, which was de-energised, is now in service and contributes to level the network reliability index. As shown in Table 1, the total, average, and standard deviation are reduced.

Fig. 4 shows in red the seven open branches proposed by the GA. Based on the current layout, three open branches are reconfigured to reduce the network reliability index. Fig. 5 highlights in yellow, based on the results of open branches reconfiguration, the secondary substations that should participate in the switch upgrade plan. By upgrading those substations to RCS devices, the fault reconfiguration time is improved, increasing the overall system reliability.

4 Conclusion

The paper presents a GA to solve the problem of siting RCS devices in distribution systems. RCS devices are located to improve the reliability of the system based on the optimal open ties deriving from the DN reconfiguration problem. The proposed approach, tested on a real DN, demonstrates to be a valuable tool for RCS devices siting. On one hand, optimal siting can improve system reliability. On the other hand, by using this methodology planners can obtain useful information for prioritising their investments.

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