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A mixed integer linear programming based approach for optimal placement of different types of automation devices in distribution networks

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ABSTRACT

This paper presents a mixed integer linear programming (MILP) based approach for determining the optimal number, type and location of automation devices to be installed in the network by considering different types of devices simultaneously (remotely controlled circuit breakers/reclosers, sectionalizing switches, remotely supervised fault passage indicators). Simultaneously, it determines the new (optimal) locations of the automation devices that already exist in the network. In determining the most effective network automation scenario, the proposed approach takes into account the outage cost of consumers/producers due to momentary, short-term, and long-term interruptions, the commonly used network reliability indices (SAIFI, SAIDI, MAIFI, and ASIDI) as well as the cost of automation devices and the cost of crews. It provides the best network automation scenario in distribution systems if the network reliability indices are used for measuring the distribution system reliability, if cost of interruptions is defined to all consumers/producers, and if both aforementioned approaches (criteria) are used.

1. Introduction

The improvement of network reliability is one of the main drivers of various enhancements in distribution networks. One of the most effective strategies to increase reliability is network automation. In an automated distribution network, remotely controlled switches (RCSc) and remotely supervised fault passage indicators (FPIs) are used to reduce the duration of the interruptions and the number of the affected consumers/producers. The selection of the optimal number, type, and location of the automation devices (ADs) to be installed in the distribution networks is a complex combinatorial optimization problem with a long history of contributions for improved solutions [1–21]. However, only a few of the proposed approaches [13–21], consider using different types of ADs simultaneously in order to obtain a more effective automation scenario. The MILP approach proposed in [13] takes into account the cost of long-term interruptions and the total cost of automation devices. This approach uses heuristic rules, which are dependent on the feeder layout, for the automation devices placement. In [14] a reactive tabu search algorithm based on the set of heuristic rules for determining the best location of the automation devices is proposed. This approach considers the cost of short-term and long-term interruptions and the investment and maintenance cost of the automation devices. A modified version of the discrete particle swarm optimization is presented in [15] to determine the optimal number and locations of two types of switches (sectionalizing switches and reclosers) in radial distribution networks taking into account the cost of long-term interruptions and the cost of automation devices. The heuristic combinatory search algorithm proposed in [16] employs the decomposition of the overall automation problem with multiple types of automation devices into a number of simple sub-problems with one type of device. It defines a set of heuristic rules to determine the location of individual devices along the feeders. The long-term interruption cost and the cost of automation devices are considered. In [17] a genetic algorithm is used to obtain the optimal number and location of sectionalizing switches and reclosers in radial networks. This approach optimizes the reliability indices (SAIFI, SAIDI, DGUI (Distributed Generation Unavailability Index)) taking into account the cost of automation devices. A multi-objective approach

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proposed in [18] employs a set of heuristic rules to divide the considered a radial distribution network into smaller parts (service zones) in order to decrease the complexity of network automation planning problem. This approach takes into consideration reliability indices (SAIFI and SAIDI), total cost of different types of automation devices and cost of long-term interruptions. In [19] a MILP approach is used to determine optimal network automation scenario taking into consideration different types of automation devices (reclores, sectionalizing switches, fault passage indicators). It takes into account total cost of devices along with the cost due to long-term and momentary interruptions. The MILP approach proposed in [20] considers radial distribution networks in which island operation of DGs along with the load shedding is allowed. It considers various types of automation devices simultaneously along with the momentary and long-term interruptions. A mixed integer nonlinear programing approach is presented in [21] to determine the optimal number and locations of sectionalizing switches and fuses in radial distribution networks with island operation of DGs. It takes into account the cost of long-term and short-term interruptions and the cost of automation devices. Because the majority of the proposed approaches are based on heuristic and metaheuristic algorithms or employ heuristic rules they do not guarantee the global optimality of the obtained solutions, i.e. the quality of the obtained solutions is uncertain. Furthermore, the proposed approaches do not consider the possibility of relocating the automation devices that already exist in the network, which is addressed as an effective alternative for improving reliability in distribution networks [3]. Finally, they do not address the possibility of using the cost of interruptions and the reliability indices simultaneously in determining the best network automation scenario/solution.

In this paper, network automation planning problem is defined in terms of mixed integer linear programming, which guarantees the global optimality of the obtained solution. Besides that, the advantages of the proposed approach are the following:

- It simultaneously determines the optimal number, type and location of the new automation devices and the optimal (re)location of the existing devices.
- In addition to the commonly considered costs related to distribution companies (DSOs) (cost of new automation devices, relocation cost of the existing devices), the proposed approach takes into account the cost of the crews engaged in the fault localization, isolation, and service restoration. Along with the usually considered cost related to consumers/producers (short-term and long-term interruption cost), the proposed approach takes into account the cost of interruptions due to transient faults (momentary interruptions). These are of particular interest in the case of large industrial and commercial consumers (e.g., interruptions due to equipment damage in the cases of large motor loads and damage to electronic equipment [22]).
- Besides the cost of interruptions, the proposed approach considers different groups of reliability indices. Along with the usually considered sustained interruption indices (SAIFI, SAIDI) [2,17], the momentary index (MAIFI) and the load based index (ASIDI) are taken into consideration [22,23].
- Proposed approach enables determining the best automation scenario if the reliability goal is expressed in monetary units, if the reliability goal is expressed through the target values of various reliability indices and in the case where a combination of those goals is used. This last possibility enables the use of interruption cost to the consumers/producers with the easily identified direct costs for given interruption conditions and the reliability indices to other customers (e.g., residential customers) [22].

The effectiveness of the proposed approach is tested on Bus 4 of the RBTS [24].

2. Problem formulation

The goal of network automation planning can be stated as follows: determine the number, type and location of new automation devices and the new locations of the existing devices so that the decision maker's goals are fulfilled in the considered planning period. This paper considers the goal expressed in monetary units as well as in terms of target values of the reliability indices. Hence, the goals of the static automation planning problem can be expressed as follows:

$$\begin{aligned} &\mathrm{F1} = C^{\mathrm{AD}} + C^{\mathrm{RL}} + \sum_{t=1}^{\mathrm{T}} \frac{1}{(1+\mathrm{d})^t} \cdot (CINT_t + CCREW_t) \ \wedge \\ &\mathrm{F2} = ReliabilityIndices \end{aligned} \tag{1}$$

The monetary goal is defined by F1 in (1) while the goal related to reliability indices is defined by F2.

In F1 (1), the investment cost of remotely controlled and supervised automation devices (reclosers, fault passage indicators (FPIs), sectionalizing switches (switches)) is represented by C^{AD}. This cost consists of the purchase cost, installation cost, and maintenance cost. The cost of the other necessary equipment (e.g., communication equipment, remote terminal units) could also be associated with the investment cost. The cost of the relocation of the existing automation devices, C^{RL}, consists of de-installation cost and installation cost of an automation device. The annual expected outage cost of consumers and distributed generators (DGs) due to momentary (e.g., up to 1 s), short-term (e.g., from 1 s to 3 min), and long-term interruptions, taking into account the forecasted load/production growth, is denoted by $CINT_t$. The annual cost of crew (men, vehicles, and other equipment) engaged in the localization, isolation and restoration process is denoted by $CCREW_t$ while discount rate is denoted by d.

Reliability indices (*ReliabilityIndices*) considered in this paper within F2 are the following: MAIFI, SAIDI, SAIFI, and ASIDI [23]. While MAIFI index takes into account momentary and short-term interruptions, SAIFI and SAIDI take into account long-term interruptions in the network. Those indices are based on the number of customers affected. For measuring reliability in the areas with relatively few consumers/producers that have relatively large concentrations of load/production (industrial and commercial customers and DGs) the load/production based indices are used. In this paper, ASIDI is considered as the load/production based index.

The approach proposed in this paper provides optimal network automation in distribution systems if reliability is measured in the following way:

1) If reliability is measured using only the reliability indices, the goal of the network automation planning is expressed as follows:

$$\begin{aligned} &\min \ \{C^{\mathrm{AD}} + C^{\mathrm{RL}} + \sum_{t=1}^{\mathrm{T}} \frac{1}{(1+\mathrm{d})^t} \cdot CCREW_t\} \\ &\text{subject to :} \\ &SAIFI \le \mathrm{SAIFI_T} \\ &SAIDI \le \mathrm{SAIDI_T} \\ &MAIFI \le \mathrm{MAIFI_T} \\ &ASIDI \le \mathrm{ASIDI_T} \end{aligned} \tag{2}$$

Objective function and constraints (2) defines the network automation scenario which ensures fulfilling of the target values