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Autonomous control strategy for fault management in distribution networks

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ABSTRACT

In this paper, the application of autonomous control on automatic switches in electric power distribution networks is proposed. The key feature for the proposed control strategy is based on a decentralized control aiming to automatically isolate the faulty section while reducing the overall dependency on the number of fault indicators and communication hops involved in the fault management process. In order to evaluate the performance of the proposed control strategy, its behavior is compared with the centralized and distributed agent-based decentralized switching control methods. Different aspects are considered in the evaluation such as the number of activated communication hops and the corresponding communication latency. A practical network configuration is utilized in order to verify the proposed decentralized control strategy for the fault management. The results corroborate the efficacy of the proposed autonomous decentralized algorithm for fault management in distribution networks.

1. Introduction

Reliable distribution of electric power is crucial to the development, progress and prosperity of communities around the world; therefore, it is important to guarantee the quality of service of electric power distribution in terms of reduced number of power disruptions and power-loss restoration time. Consequently, electric power distribution companies became more interested recently to equip their distribution networks with all kinds of automated systems in order to efficiently manage the process of power delivery to customers. A fault on distribution feeders disrupts electric power service, hence, reducing the power delivery reliability. Automated fault management is the process of using advance in fault detection and communication technologies to enhance the overall reliability of distribution systems [1–4]. Long periods of electric power disruption are annoying to public customers and increases outage costs to industrial customers for which regulations may impose financial penalties on distribution companies.

As distribution networks nowadays are becoming larger, dense and widespread over wider geographical areas extending to urban and rural areas to reach every customer, there are more chances of feeder lines to become faulty either intentionally or unintentionally. This is due to aging, weather conditions, tree branches, accident, natural disasters, etc. Power disruption occurs due to faults taking place on the power lines connecting primary and secondary substations of the distribution network. Generally, faults are more common on the overhead parts of the network than the underground cables. For the networks involved with underground cables, faulty section isolation is not recommended using trial switching [5].

Fault management is the process of detecting faults, identifying faulty lines or sections, and then isolating the faulty parts. Service can be restored by using the healthy parts of the network. In non-automated systems, switching action should be implemented by maintenance crew in order to restore electric power. For the current dense distribution networks, non-automated fault management costs money, time and manpower in order to rectify the faulty situations. Therefore, the latest trend is to apply automated fault management techniques to improve the quality of service and reduce the mentioned disadvantages of manual fault management. Automated fault management systems are an essential part of future smart grid operation. The fundamental steps for a successful fault management process are:

- Detect fault occurrence reliably and quickly.
- Locate the faulty section quickly.

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- Isolate the faulty section.
- Restore the power to the healthy part of the network.

A comprehensive fault management system should have the capability to identify different types of faults such as permanent and transient faults.

Several components should be inserted in the distribution network in order for the deployment of the automated fault management systems to be a success. First fault indicators must be employed to detect the existence of a fault by measuring voltages and currents on the feeder lines to identify an abnormal situation. Then remotely controlled switches (automatic switches) are used to open or close line feeders to complete the fault isolation and power restoration process. In order to remotely read the status and operate the previous components, communication nodes embedded with their protocols are needed to allow substations to communicate with each other [6]. The automatic switches are controlled remotely using messages exchanged over the communication network based on fault indicator measurements which are also sent over the communication network.

The remote control strategy of the automatic switches is broadly categorized into centralized or decentralized (distributed) control [7–9]. In centralized control all primary and secondary substation data and all feeder switch status are reported over the communication network to the centralized control system. The fault management system is considered here as a subsystem of the SCADA system. The main advantage of the centralized control is that all distribution network data is stored locally at the control center and updated on a real-time basis, hence the control system has a full view of the network condition before and after the fault. Therefore, load transfer can be done in optimal way either for planned or unplanned faulty feeder isolation. The major disadvantage is the excessive amount of data that should be communicated and stored in real-time even during the times when the network is working normally. On the other hand, decentralized control transfers the duties of managing the faults from the centralized control center to the shoulders of intelligent controller located at the feeders and substations [1,8–11]. The control center will be informed about the situation after the fault identification and the faulty feeder isolation process completed in order to start the power restoration process afterwards. There are two advantages of using distributed control methods: (1) their simplicity and fast operation, (2) they can be deployed locally to the less reliable zones of the network, and then the system can be gradually expanded to other feeder sections.

Decentralized agent based control has been applied to achieve different goals such as state estimation, system monitoring, fault management and power systems restoration [9–15]. Associated with these applications, local and remote control functions have been performed using distributed agents like: feeder terminal unit agents, transformer agents, circuit breaker agents, etc. [12]. Distributed agent fault management control strategy has been reported in [1] by applying a token passing policy from the primary substation till the secondary substation to which the faulty feeder is connected. The total number of communication hops has been substantially reduced by the proposed method in [1] as compared to the centralized control. However, total reliability due to communication links and fault indicator components is not given. Also the number of communication hops can be reduced more as aimed in this paper. Furthermore, since a token is exchanged starting from the primary substation and passed downstream to consecutive secondary substations then it cannot be regarded as fully decentralized local fault management approach as all previous healthy sections are dependently involved in the process of fault management.

In this paper, a new decentralized control strategy is introduced for fault management in distribution networks. The proposed method is developed such that the number of communication hops is reduced to a minimum and only involving the affected faulty section. In Section 2 the proposed method is introduced. Then Sections 3 and 4 detail the delay and reliability evaluations, respectively, including comparison with previous techniques. Finally conclusions are drawn at end of the paper.

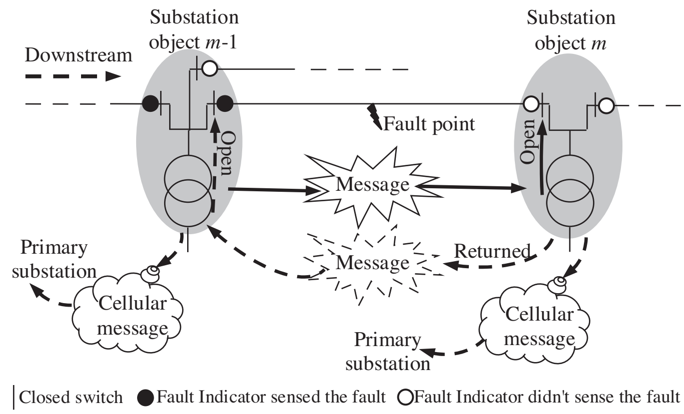

Fig. 1. Schematic of autonomous agent-based control.

2. Proposed autonomous agent-based control

The proposed fault management is suggested to be implemented using the basic decentralized control system. The decentralized control is mainly implemented on the secondary substations level, where these substations can control switches locally. This significantly reduces the required communication infrastructure, simplifies its performance, and reduces the time delays. The system description of such a control strategy is summarized in Appendix A.1. Fig. 1 illustrates the basic core of autonomous agent-based control, where each two neighboring secondary substations $m-1$ and m communicate together. Then, both substations are allowed to raise their own decision when a fault occurred between them. All substations are independently initiated for the fault management process. However, the substation activation to participate in the fault management is restricted by two conditions; the voltage has disappeared and its fault indicator detects the fault. These two conditions are going to be attained for the secondary substations that are located before the fault point. Then, each agent of these substations is going to simultaneously and independently send a fault message to the neighbor downstream substation in the direction of the fault. For example at substation $m-1$ shown in Fig. 1, the message is going in the direction of substation m as its branch indicator detects the fault. In other words, for substation $m-1$, there are three branches while two fault indicators detect the fault; one is upstream of the substation and the other is downstream at the fault direction. However, the third one does not sense the fault occurrence because the fault is not at its downstream direction. Accordingly, the message is going to substation m.

Each substation, which is before the fault, generally receives this message and consequently the faulty section is not identified as long as its fault indicator detects the fault. Another case arises when the substation received a message while its fault indicator does not detect the fault as shown in Fig. 1 for the substation m. This means that the faulty section is identified and the action to isolate the fault is to be activated with the aid of a return message. After the fault isolation, a message from each secondary substation at the faulty section terminals is directly sent to the primary substation in order to reclose the breaker and restore the healthy parts. This requires a direct communication between the secondary substations and the higher level stations. This has been subjected, as an example, in Feeder Terminal Unit (FTU) applications as addressed in