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Multi-agent based coordinated protection systems for distribution feeder fault diagnosis and reconfiguration

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ABSTRACT

This paper presents an innovative peer-to-peer agent-based protection system for fault diagnosis and automatic power restoration in power distribution networks. In practice, modern digital relays play a vital role for handling faults by allowing different switching configurations of opening and closing the circuit breakers in power networks. An effective fault detection and diagnosis along with backup protection is essential in order to save the systems from collapse and reconfigure them properly after an outage. In the proposed agent-based protection scheme, a hierarchy of two categories of agents- (i) Relay agent and (ii) Configuration agent is designed where the agent communication plays an important role to effectively diagnose the fault conditions and thereby, restore the system through proper relay coordination. An open ring feeder distribution system is considered to evaluate the performance of the proposed protection scheme. Furthermore, the impacts of both communication failure and physical protection misoperation are also addressed in this paper through effective backup protection provided by the coordination of agents.

1. Introduction

Power distribution systems consist of numerous protection relays at different locations which are pre-programmed to protect the system from various faults and contingencies. The coordination of protection relays during faults is a tedious and time-consuming task as it is always desirable to minimize the number of switching operations to restore the power to unserved loads. Moreover, the traditional relays are not sufficiently intelligent to handle the rapidly changing conditions since the distribution systems exhibit random usage patterns due to the consumer demands. As a result, sometimes traditional relays fail to handle the faults quickly or falsely trip a healthy line from the system during a restoration process which may lead to a complete or partial blackout in power systems. Therefore, a better coordination among the protection devices is very important to detect faults and take corrective actions to preserve the system reliability and provide acceptable performance by maintaining a proper reconfiguration after service restoration.

A lot of effort has been made to design the protection automation infrastructure and computers are used at different levels of the power networks to provide assistance to that protection automation tools [1,2]. Recently, a number of knowledge-based intelligent fault diagnosis and reconfiguration techniques have been proposed for improving the automation of protection tools for restoration solution [3–8]. In [9], a new intelligent phase angle of positive-sequence integrated impedance (PAPSII)-based wide-area backup protection scheme is proposed to provide effective fault diagnosis in distribution systems. In [10], a frequency selectivity-based remedial action scheme (RAS) along with backup protection is proposed for overcurrent protection schemes in distribution networks. In [5,11], an optimized estimation-algorithm is proposed for adaptive backup protection scheme to diagnose faults in distribution feeders. However, most of the approaches discussed above are based on limited communication facilities which are susceptible to single point failures and obviously require high communication capability [12].

Currently there is a lack of application of knowledge-based artificial intelligence technique applications in power system protection design [13]. Recent research indicate that few agent-based technologies have been proposed for designing protection automation tools in power distribution networks [14]. In [15], a fuzzy clustering algorithm within a multi-agent framework is proposed where the information of the space relative distance between the on-line sample data and the cluster center are utilized to coordinate the relay operation during faults. In [16,17], an autonomous agent-based switching control algorithm is proposed for fault diagnosis and power restoration solution in distribution networks. In [18], a multi-agent based self-healing algorithm is proposed for distribution network automation to solve the service restoration problems. In [2], a group of decision support agents is proposed for distribution network fault diagnosis and restoration

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strategy where the unified data platform is built to manage the fault data, information and system models. In [19], an agent-based co-simulation platform is developed for fault diagnosis and reconfiguration of distribution networks where a high-level architecture (HLA) is used for managing the information exchange among agents. Although the aforementioned approaches are surely functional to solve relevant problems, still better coordination among the protection relays is necessary to handle the situation when there is a physical failure.

In [20], it is reported that an agent-based protection system can reduce the operating time of the backup protection systems to react when the primary relay fails as compared to the traditional protection systems. In [21,22], an adaptive multi-agent based protection system is proposed for distribution networks to provide a pair-to-pair relay agent coordination for backup protection. In [23], a multi-agent strategy along with programmable logic controller (PLC) and field bus technology is proposed to adopt the information interaction among multiple agents to improve the response time of the backup protection schemes. In [24], a communication assisted multi-agent based adaptive over-current protection scheme is proposed in which the reliable communication among agents increases the potential of the backup protection systems. Although the agent-based backup protection systems work well if any breaker fails to trip during faults, these methods are unable to handle the situations if there is a communication failure in the systems.

In order to overcome the aforementioned limitations and technical challenges, a new agent-based protection coordination model is proposed without changing the basic decision making logic of the actual digital relays. In this paper, two types of agents are designed such as- (i) relay agent (RA) and (ii) configuration agent (CA) to improve the performance of the digital relay operation and their interactions with power systems via multi-agent communication. The communication of pair-to-pair agent facilitates the information exchange between the RAs and the CA which enables the relays to respond quickly to the changing system conditions by adopting new prevailing conditions. In the designed scheme, the agents interact with each other through local as well as neighboring information exchange. Moreover, the information sharing can also reduce the frequent false tripping and prevent cascading failures. The proposed scheme also provides an effective platform for backup protection to reduce the fault clearance time in case of any failure in physical breakers or communication links.

In this paper, an open ring distribution feeder is considered for simulation purposes and several case studies are demonstrated to evaluate the effectiveness of the proposed method. The simulation results show that the agents can determine their activity to flexibly manage the network reconfiguration process through proper fault diagnosis. Also, a comparative study with an existing method is also presented to justify the effectiveness of the proposed approach. However, the major contributions of this paper are outlined below which indicate the novelty of the proposed method:

(1) The multi-agent interaction allows to determine the relay control operation to precisely identify the faults as well as to take proper actions to restore the power system with minimal impact to the rest of the system.
(2) The appropriate information exchange among the agents requires only a minimal number of switching operation which improves the resiliency and reliability of the distribution systems.
(3) Each set of agents uses local as well as neighboring information which in turn primarily reduces the computational burdens and also makes the breaker operation highly efficient and accurate to diagnose the fault conditions.

2. Agent-based protection systems

In recent years, a number of intelligent protection analysis tools have been developed by the research community to meet the requirements of comprehensive and automated protection relay coordination for the utility companies. A multi-agent system (MAS) is widely recognized as an effective real-time platform which adds an extra value to the automation of protection systems [12]. The modular architecture of the MAS provides agents to interact with each other through neighboring information exchange to achieve a global goal while satisfying the local objectives.

In the designed protection framework, the RAs are designed to coordinate the relay operation and control the corresponding circuit breakers. It is assumed that, each RA has complete access to the phasor measurement unit (PMU) information where the synchrophasor current information provide an accurate detection of faults in the system. The RAs simultaneously send and accept requests and share information to the neighboring RAs via information exchange to rapidly determine the fault

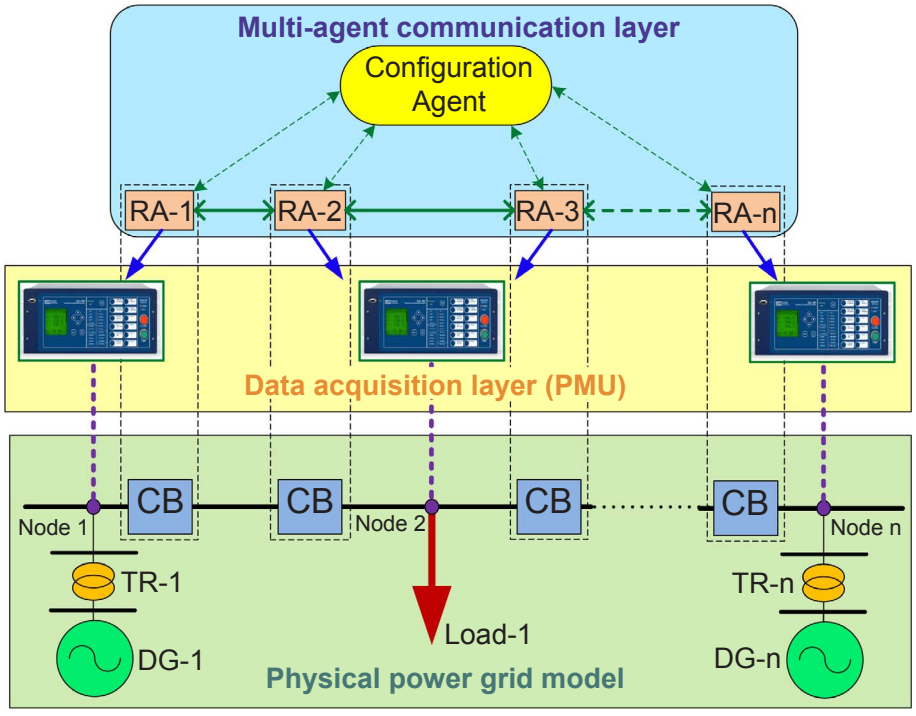

Fig. 1. Interaction between multi-agent system and power system.