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Cost/worth assessment of reliability improvement in distribution networks by means of artificial intelligence

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ABSTRACT

A major challenge for the power utilities today is to ensure a high level of reliability of supply to customers. Two main factors determine the feasibility of a project that improves the reliability of supply: the project cost (investment and operational) and the benefits that result from the implementation of the project. This paper examines the implementation of an Artificial Intelligence System in an urban distribution network, capable to locate and isolate short circuit faults in the feeder, thus accomplishing immediate restoration of electric supply to the customers. The paper describes the benefits of the project, which are supply reliability improvement and distribution network loss reduction through network reconfigurations. By comparison of the project benefits and costs the economic feasibility of such a project for an underground distribution feeder in Greece is demonstrated.

1. Introduction

Distribution system protection and restoration along with loss reduction are some of the most important topics concerning contemporary power engineering research. Two main parameters lead power utilities nowadays to redefine their policies regarding investments on power networks. The first parameter is the demand for increased reliability considering the fact that the way of living today (both at personal and professional level) tends to become fully dependent on electricity. On the other hand the energy problem and its consequences to the environmental pollution render the need for energy saving more imperative than ever. It is estimated that the largest proportion of losses in power networks corresponds to distribution networks; for a typical system in a developing country, distribution losses account for approximately 8% of the total electrical energy produced [1]. Considerable research has been accomplished so far for systems and methods that contribute in loss reduction across distribution networks and reliability improvement.

Automation has been applied to the distribution network in order to achieve significant service reliability improvement for electricity customers [2–4]. Other approaches investigate reliability improvement and interruption cost minimization based on appropriate switch location or relocation across a distribution feeder [5,6]. Finally, significant research has been conducted on loss reduction in distribution systems via network reconfiguration. These applications are based on the development of algorithms for switching operations utilizing heuristic, fuzzy logic and other approaches [7–9].

The undertaking of investments in such novel systems from the utility's perspective constitutes a complex procedure which depends on many factors. The investment decisions are based on project economic feasibility studies through which the most beneficial investment alternative is determined. For an investment to be economically viable, utility's cost to improve reliability should be less that the customer's cost.

In this paper, the implementation of a Multiagent System (MAS) [10–12] in urban distribution networks is examined as an investment proposal. The MAS is capable of locating and isolating sustained faults to the shortest possible segment of the feeder, and of achieving restoration of supply to the maximum possible number of consumers (within approximately 0.5 min). Additionally, the system deals with the loss reduction problem by transferring loads to adjacent buses.

The problem of fault detection and power restoration is a multi-objective dynamic combinatorial problem with topology constraints [13]. In practice considering that the complexity of the problem has been classified as NP-complete it becomes obvious that for real time fault restoration the problem cannot be solved exactly. The proposed MAS on the other hand implements heuristic approaches in order to deal with the problem, thus it becomes suitable for online implementation. Modifying the implementation approach of the proposed MAS, either a centralized management of the network or local supervision and control of adjacent topologies, the required time for optimal or near-optimal solution could also be improved. Furthermore, once the ontology of the software

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agents is constructed, additional functionalities for the MAS, such as network reconfiguration for loss reduction or real time management of distributed generators during peak demand periods, only require upgrade of the MASs software. Considering that most of the aforementioned functionalities are based on heuristic approaches, since such algorithms seem to be more suitable for real applications, upgrading MASs software would demand disproportional effort.

A case study is presented, in which two investment alternatives for the MAS implementation on a specific feeder are examined and the benefits during the lifetime of the investment are analyzed. Useful conclusions are derived about conditions under which the project is profitable. Finally, the effects on reliability improvement are discussed and an approach concerning real time loss reduction is demonstrated.

2. System implementation

2.1. Network and feeder description

Distribution systems in Greece consist of groups of interconnected radial circuits, as shown in Fig. 1. Both underground cables and overhead lines are used. Network reconfiguration may be accomplished by switching operations aiming to transfer loads among feeders. However, the infrastructure of these networks does not allow frequent switching operations. Basic prerequisite for this is the existence of remote controlled switches that permit centralized management of the distribution system. Distribution automation depends greatly on remote control capability concerning the switches, and power utilities today invest ever more often toward this direction.

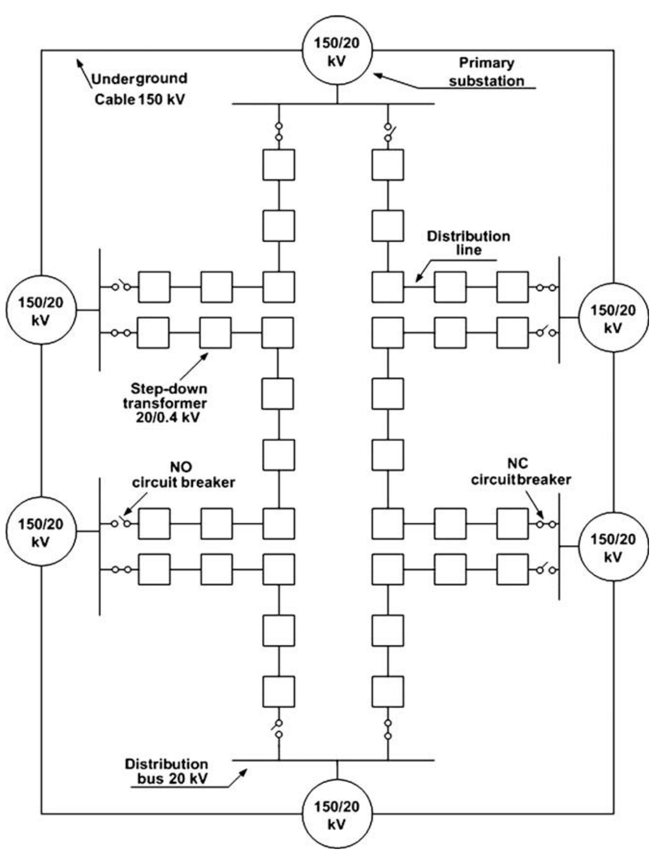

Fig. 1. Typical topology of distribution networks.

The analysis in this paper focuses on a distribution feeder that consists of an underground cable protected by a circuit breaker (CB) at the sending end of the High Voltage (HV 150 kV)/Medium Voltage (MV 20 kV) substation. A second path for alternative feeding is also considered at the end of the feeder from an adjacent bus (20 kV).

For the analysis 18 load points, shown in (Fig. 2), are assumed across an urban distribution feeder (part of distribution network in Fig. 1); each one supplied by a step-down transformer 1MVA, 20/0.4 kV.

A line fault will cause the tripping of the NC 20 kV circuit breaker, and as a result the entire line will undergo a power outage. Control engineers hereupon have to perform a search over the line, in cooperation with the technical support crew. The crew, under the guidance of the control center, manually operates the load switches of the line locally, while the control center is trying to locate the fault by operating the breaker and deciding by its behavior. This procedure may last up to several hours. Based on information provided by the Public Power Company (PPC) the average time needed for this procedure is 2 h, as the crew has to move sequentially among a number of substations, often during rush hours.

The MAS architecture proposed in [10–12] implements similar groups of collaborating software agents which are expected to join decisions and actions to achieve a common goal. The goal is to autonomously perform effective fault management on MV power distribution lines. The system is capable of locating and isolating simultaneous or even cascading line faults.

Two basic states describe the system's operation; the steady-state and the fault isolating state. The MAS will not change to fault isolation state unless it realizes fault detection followed by total voltage and current loss across all phases.

As soon as the CB tripped to clear the fault, the MAS will change to a new state. The adjacent MAS installations, hosted in adjacent substations, exchange messages containing their corresponding fault detection status. The result is that the MAS installations of substations adjacent to the fault will realize that a fault occurred between them. Thereafter, these systems proceed to fault isolation by opening the load switches located at both sides of the fault. Finally power restoration is achieved by closing the circuit breakers at the terminals of the line.

2.2. MAS hardware requirements

A set of required apparatus must be installed on each step-down transformer for the proposed MAS implementation. This set consists of the following devices:

- One embedded computer, powered by Uninterruptible Power Supply (UPS), for hosting and implementing the agent's ontology.
- Two motor driven MV (20 kV) load switches. The local agent (hosted in the embedded computer) is responsible for the operation of these switches. The open–close operations are executed via an appropriate signal between the computer and the motor of the switch.

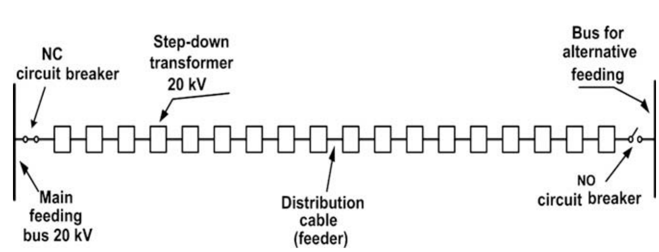

Fig. 2. Typical layout of urban distribution feeder.