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Expert system for protection coordination of distribution system with distributed generators

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ABSTRACT

Distributed or dispersed generation may cause various complexities to the operation of distribution system. Therefore, it is of interest to propose an expert system for protection coordination of distribution system under the presence of distributed generators. The expert system employs knowledge base and inference process to improve coordination settings of protective devices in order to accommodate the penetration of distributed generators. The expert system feeds input data by using graphical user interface and develops coordination settings based on power flow and short-circuit analyses. The expert system has been developed and successfully tested with a 22-kV distribution system with multiple distributed generations.

1. Introduction

It is a common practice worldwide to connect distributed generators (DG) by means of solar, wind, biomass, and other sources to distribution systems. The DGs could provide supply diversity, redundancy, and security. Meanwhile, they could also cause reliability and power quality problems too. Given significant level of integration; it is essential to revise the operation, protection, and control of distribution systems in accordance to the emergence of distributed generation. The previous studies [1–7] have shown that distributed generation caused several challenges to the protection of distribution networks such as false tripping in feeders, nuisance tripping of production units, protection blinding, changes of fault levels, unintended islanding, and prohibition of automatic reclosing. The appearance and impact of these problems depend on both the characteristics of DGs and distribution network [1]. In general, the impact depends on penetration level of DGs and connection point in distribution network, as well as generation technology. Regardless of the impact, it is necessary for electric utility to revise protection coordination to maintain standard of connection [8]. The good standard may be measured in terms of accurate and on-time detection, reliability and dependability, as well as equipment costs.

There are several software tools available for coordinating protective devices of distribution system. The main tasks of coordination are to (a) perform power flow analysis, (b) calculate fault levels, and (c) select proper protective devices [9]. Artificial Neural Network (ANN) has been used in protection coordination [10,11]. ANN may be helpful in calculating power flow and fault levels; but coordination settings may be too complicated for ANN to deal with because they depend primarily on expertise of grid operator.

The principle of expert systems, which is essentially a mimic of human experts, is to solve complicated problems by using "knowledge" and "inference process" while other approaches use "data" and "program" [12–14]. The expert systems have been applied to solve various power system problems [15–17] including feeder network planning [18], back-up protection of distribution system [19], configuration of distance relay [20], wide area protection [21], and determination of the characteristics of power system components failures [22]. Although the expert system has already been applied to the protection problem of distribution system [12–14], but those works have not properly considered the impacts of DG connection. It is essential to design protective devices to prevent adverse effects introduced by either the grid or the DGs.

The remaining parts of this paper are organized as follows. The structure of expert systems for protection coordination is described in Section 2. Then, the solution procedure is explained in Section 3. Next, implementation and results are provided and discussed in Section 4. Finally, this work is concluded in Section 5.

2. Protection coordination of distribution system

The coordination of protection devices is necessary to maintain the selectivity among protective devices involved with several fault conditions as well as to assure reliable operation of distribution

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system. When a fault occurs, it should be cleared as fast as possible and the effected area in the distribution system must be minimal. In addition, time coordination among protective devices are also essential. Primary devices, which are closed to the fault point, should take action before backup devices which are located farther. Fault analysis may be divided into two steps: (a) determination of the maximum currents that components must endure and switching devices must interrupt and (b) coordination of circuit protection. By far, the fault characteristics of DGs are not well represented by existing tools and methodologies used by the industry. For example, after a connection of DG, a fault current may backflow from load to source side so that a fuse may see the fault current in both downstream and upstream. Consequently, setting point of minimum trip current may be altered. These characteristics are little understood by the utility engineers, who must design the distribution system to be secure and reliable.

Generally speaking, expert systems are algorithms for functioning similar to human experts. They could be represented in terms of knowledge, inference ability, and explanation. Expert systems are valuable because, theoretically, they allows any one to think and then make a decision like an expert. The knowledge base of expert system is basically a set of rules. For instance, those rules may be stated as "if-then" conditions. Given that thousands of rules may associate with the same consequences, the abilities to infer and explain are necessary to overcome such ambiguities. The expert systems are thus suitable for solving a large or complex problem.

A conventional expert systems solve a problem by using information available from knowledge base and then improving knowledge from inference procedure. An expert system provides an explanation of how and why it reached its decision. This can be seen by the users to check the validity of the decision as well as the knowledge and inference procedures associated with it [19]. This feature is crucial because it allows the users to update the knowledge base and repeatedly improve the inference.

The expert systems have been applied to the protection coordination problem of distribution system [12–14]. The main advantage of expert systems is simplicity such as the implementation of rule base by using structured query language (SQL) [12,13]. However, when the rule base has been modified, the computation process must be done again which essentially turn the advantage into disadvantage. So, it is proposed in this work to apply the expert system to solve the protection coordination problem. The proposed expert system is improved to avoid unnecessary computational time and be able to accommodate the connection of DGs in distribution system. The proposed expert system is implemented by using Delphi under Microsoft windows operating system.

2.1. Proposed structure of expert system

The proposed structure of expert system, as shown in Fig. 1, has four modules: graphical user interface (GUI), engineering analysis, knowledge base, and inference engine. Initially, configuration data of distribution system and DGs are fed into the expert system via GUI. The engineering analysis module then perform power flow and short-circuit analyses. Next, the analytical results are kept in the knowledge base module and passed to the inference engine for protection coordination settings. Finally, the preliminary settings are shown via GUI for approval or revision by the user. The details of all four modules can be described as follows.

2.1.1. Graphical user interface

The GUI provides interaction between user and the expert system. The user can feed input data to the expert system via GUI. The expert system can process and ask for revision or decision from the user. When the process is completed, the coordination settings are shown via the GUI. In this work, the time–current characteristic (TCC) curves are illustrated on a log–log graph along with a coordination tree view of each protective device so that the coordination settings can be easily verified. Fig. 2 illustrates the TCC curve upon completion of protection coordination settings.

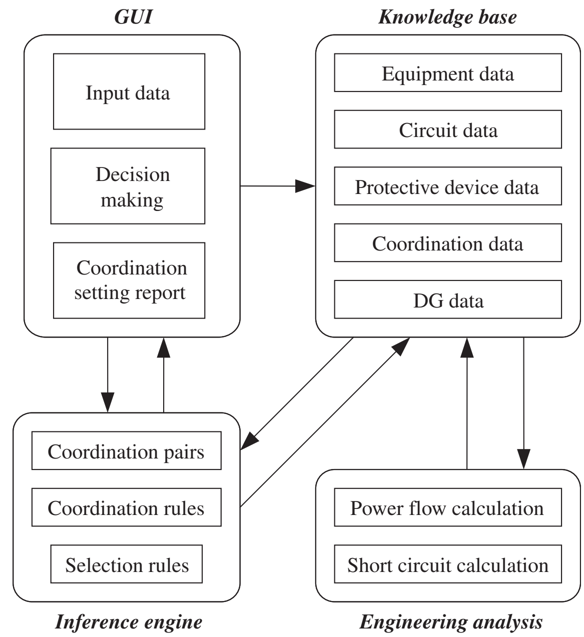

Fig. 1. Proposed structure of expert system for protection coordination.

2.1.2. Engineering analysis

The engineering analysis module receive information from the user via GUI and also retrieve information from the knowledge base module. The main tasks of the engineering analysis module are to perform power flow and short-circuit calculations. Note that the power flow algorithm used in this work is based on the Gauss–Seidel method. A computation of the bus impedance matrix is carried out to calculate the fault currents, post-fault bus voltages, and line flows. There are six types of short-circuit currents being computed, i.e. 3-phase to ground, 3-phase ungrounded, single line to ground, single line to ground with fault impedance, double line to ground, and line to line.

2.1.3. Knowledge base

The knowledge base module comprises equipment data, circuit data, protective device data, coordination data, and DG data. Equipment data contain line and switching data. Protective device data contain data of relays, reclosers, and fuses. These data were stored as a database in Microsoft Access and can be accessed via Open Database of Connectivity (ODBC). Circuit data contain single line diagram, bus data, network data, device location, and DG location. DG parameters are stored in DG data.

The heart of this module is a set of rule bases. These rule bases include coordination rules and selection rules as shown in Tables 1 and 2, respectively. The 12 coordination rules are processed by the inference engine to generate satisfactory coordinate settings. The 11 selection rules are then employed to identify the proper coordination pair. The user can also make a decision in case of a conflict in selection.

2.1.4. Inference engine

The inference engine of the proposed expert system is based on the *forward chaining* inference. The inference structure consists of