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A cost-effective fault management system for distribution systems with distributed generators

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ABSTRACT

Fault Management System (FMS) is one of the main functions in Distribution Automation System (DAS); however, the conventional FMS cannot be used in distribution systems with Distributed Generators (DGs) due to the lack of directional function. The directional fault detection device is expensive due to the expensive directional module used. In a wide-ranging distribution system, the investment cost will be very high if the fault detecting devices are expensive. Therefore, the design and implementation of a cost-effective FMS for distribution system with DGs is necessary. A Multi-Level Fault-Current Indicator (MLFCI) having a plurality of reed switches used to detect different current levels is proposed in this paper. The hardware prototype is designed and implemented. An algorithm used to locate fault based on the different fault current levels is derived. A MLFCI-based FMS for distribution systems with DGs is then realized. Experimental results demonstrate the feasibility of the proposed MLFCI. Simulation results are then used to demonstrate the validity of the proposed MLFCI-based FMS for distribution systems with DGs.

Introduction

Distribution system provides the final link between the bulk transmission system and the customers. Research reveals that most of customer service interruptions are due to failures in distribution systems. Therefore, many power companies have implemented the concepts of Distribution Automation System (DAS) and Smart Grid (SG) to enhance the reliability, power quality, power efficiency and service to the customers. The functions of DAS generally include data gathering and correcting, contingency analysis, optimal volt/var control, Fault Management System (FMS), and feeder reconfiguration, etc. These functions are performed through interfaces with different databases and systems and then integrated into substation automation, feeder automation, advanced metering infrastructure and so on. FMS, especially the procedures of Fault Detection, Isolation and Restoration (FDIR), is one of the main functions in DAS to reduce outage times and improve service reliability immediately. Different devices and functions for fault indication and location have been designed, implemented and broadly installed in FMS. The fault indicating devices used in FMS generally include Circuit Breakers (CBs), Feeder Terminal Units (FTUs) and Fault Current Indicators (FCIs), etc. Some of those devices are embedded with communication interfaces and thus can be integrated into distribution SCADA systems [1–6].

Among them, FCIs mounted on distribution line sections are used to indicate the short-circuit fault current flowing through the line sections and have been widely installed in distribution systems due to their lower cost [4–11]. FCIs can reduce operation costs and service interruptions by identifying the faulted line section. Moreover, FCIs can increase safety and reduce equipment damage by decreasing the need for hazardous fault chasing procedures. FCI can use reed switch for fault detection. The magnetic field around a conductor induced by the fault current flowing through will trigger the reed switch in the FCI and produce signs such as the change of mechanical flag and/or the flash of LED for short-circuit fault indication [6–9]. Although the conventional FCIs are useful, maintenance staffs need to walk along the distribution feeder to check the FCIs' signs for fault location. The procedure is time-consuming and sometimes difficult; especially when the FCIs have been muddied and are not cleaned periodically. Therefore, FCIs embedded with communication interfaces were proposed in [7–9] to enhance the performance of the conventional FCIs. Even then, the FCIs can only be used to detect whether a fault current occurs, it cannot provide other useful information such as the approximate magnitude of the fault current. Some fault detecting

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devices with an expensive current sensor and a high performance microprocessor can acquire accurate fault current magnitude; however, it is not cost-effective to use many such devices in distribution systems. Besides, the major restriction of conventional FMS is the lack of directional function; thus, cannot be used in distribution systems with Distributed Generators (DGs) [6,10–16]. The directional module commonly used in a fault detection device needs voltage measurement. The inductive voltage transformer typically used to measure voltage is heavy and expensive; therefore, the directional fault detection device is also expensive. In a wide-ranging distribution system, the investment cost will be very high if the fault detecting devices are expensive. Therefore, the design and implementation of a cost-effective FMS for distribution system with DGs is necessary.

The procedures of FDIR are started after the protection and coordination system activated by a fault. Fault location is an important step for fault isolation and restoration. A Multi-Level Fault-Current Indicator (MLFCI) having a plurality of reed switches used to detect different current levels is designed in this paper. The approximate magnitude of the fault current can be acquired by using the proposed MLFCI. The proposed MLFCI can be used for fault detection for distribution systems with DGs by using a fault current difference calculation algorithm derived in this paper. After fault detection and location, the commonly-used restoration procedure can be used for the faulted distribution system. Since the reed switches used in the proposed MLFCI are cheap, the proposed MLFCI-based FMS is more cost-effective than conventional ones to be used on distribution systems with DGs.

Multi-Level Fault Current Indicator

Basic concepts of reed-switch-based FCI

Reed switch as illustrated in Fig. 1 [17] has been widely used in test and measurement equipment including fault detecting device in power engineering. A reed switch generally consists of iron and nickel ferromagnetic blades hermetically sealed in a glass capsule. The blades overlap internally with a gap between them, and make contact with each other when the polarity induced by magnetic field exceeds the spring force of the blades. As a result, this type of reed switch can be treated as a normally open switch. Due to its very simple structure, reed switch has high reliability and a long life, and generally can be operated well into the billions of times without wearing parts. Reed switch can also be used in FCI for short-circuit fault indication [17]. The main concept is illustrated in Fig. 2. From Fig. 2, it can be observed that the magnetic force induced by the fault current flowing through a conductor will cause the reed switch in FCI to be magnetized. If adequate magnetic force was induced, the reed switch would be triggered (blades is magnetized and contacts are closed) and produce signs for short-circuit fault indication.

Design concepts of the proposed MLFCI

Obviously, the advantages of the FCI as illustrated in Fig. 2 includes the low cost and high reliability. However, the FCI can only be used to detect whether a fault current occurs. It cannot provide other useful information such as approximate magnitude of the fault current. The approximate magnitude of the fault current can be used for fault type identification, fault distance estimation and even fault location for distribution systems with DGs. Therefore, a MLFCI having a plurality of reed switches used to detect different current levels is proposed in this paper. Fig. 3 shows the architecture of the proposed MLFCI. It can be seen that the proposed MLFCI consists of a multiple-level fault-current detection circuit, a sampling-and-hold circuit, a microprocessor module, and communication interfaces. When a short-circuit fault was detected by the proposed MLFCI, a wake-up signal would be transmitted to an interrupt register (IRQ as shown in Fig. 3) of the microprocessor to wake up the microprocessor. The multiple-level fault-current detection circuit is used to detect the fault current level. The sampling-and-hold circuit will then sample and hold the fault current level and the result is transmitted to the I/O pin of microprocessor. All the fault information can be reported to control center by the communication interfaces.

The multiple-level fault-current detection circuit is composed of multiple reed switches. Two methods are used to design the proposed multiple-level fault-current detection circuit. The first method is to adjust the distances between cable and reed switches. The contacts of reed switch are closed when the polarity induced by magnetic field exceeds the spring force of the reed blades. The magnetic field generated by the current flowing through an infinite line as illustrated in Fig. 4 can be calculated by Biot–Savart law [18] and be expressed as

$$B = \frac{\mu_0}{2\pi}\frac{i}{r} \tag{1}$$

where B is the magnetic field and i is the current flowing through the cable. μ_0 is the magnetic constant. r is the distance.

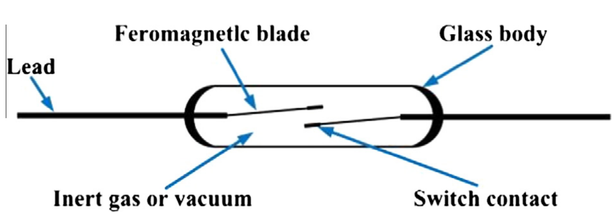

Fig. 1. Structure of normally open hermetically sealed reed switch.

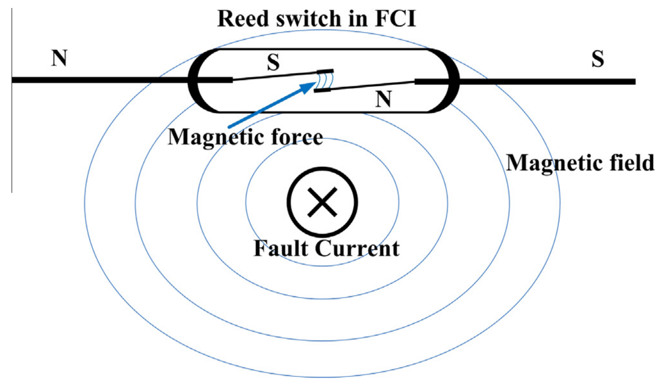

Fig. 2. Concepts of reed-switch-based FCI.

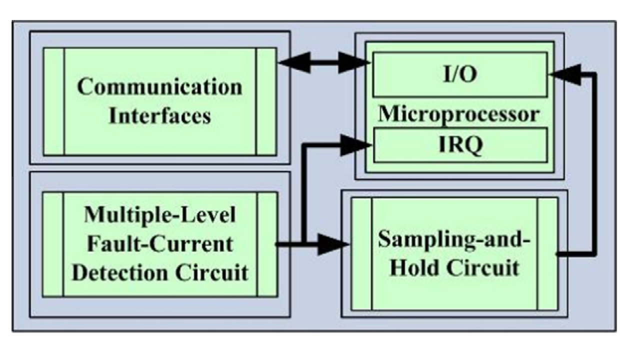

Fig. 3. Architecture of the proposed MLFCI.