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Integrated Protection Unit Design for Power Networks

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Abstract

This paper presents an hardware design solution for integrated protection of distribution systems (Network Protection Unit) by combining transient polarity comparison technique, which is based on the detection and processing of fault generated transient current signals. The integrated protection relays installed at each substation of a distribution network are communicated with the Network Protection Unit through specially designed Packet Transport Network (PTN) for fast and reliable transmission of transient polarity current signals. The relay detects the faulted generated super-imposed current signals. The transient polarity identification algorithm is then applied to the super-imposed signals to identify the polarity of the signal detected. The Network Protection Unit can collect all the transient polarity current signals under its protection area. Then The direction of a fault is determined by comparison of the polarity of the signals derived from all the line sections connected to the substation. The actual faulted section is identified by the Network Protection Unit through comparing the directional information from various stations. Simulation results presented in the paper demonstrate the feasibility of the scheme.

Keywords*: Integrated Protection, Transient Based Protection, Packet Transport Network. Network Protection Unit*

1. Introduction

The application of an integrated substation protection system based on a centralized computer system was proposed at the start of the digital protection age in the late 1960's [1]. The idea fits well with the concept of an overall integrated protection where the protection package would not only oversee individual units of a plant but also a section of the network. However, the idea has not been put into practice thus far since the computer hardware/software and more importantly the communication technology were not available to support such an idea.

The introduction of microprocessors into protection in the 1980's generally followed the conventional approach with the implementation of distributed processing platforms that concentrated on protecting individual units of the system. The fast development in both microprocessor and transducer technologies in recent years has enabled fault detection techniques to be considered which were impractical in the past and encouraged interest in the utilization of fault generated transients for protection. Studies have found that the fault generated high frequency transients can be detected and quantified and open the possibility for developing new protection principles and techniques[2-6]. At the same time, the dramatic growth in signal processing power of relay platforms, and the availability of suitable communication schemes, has provided a new opportunity to revisit the concept of integrated protection [7]. Research shows that information obtained from multiple power plants and components can be used to derive new protection principles and schemes, for example the wide area protection[8], which could have significant

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advantages over the existing protection techniques based on individual plant or component.

A new integrated protection scheme for the protection of substation as well as distribution network as a whole based on advanced communication network is presented in the paper. The concept of Integrated Protection is firstly introduced, followed by a description of the proposed new integrated protection scheme based on the detection of fault generated transient current signals from all locations of the protected network. In this, a centralized protection relay is installed at a substation and interfaced to every line, through the CTs. The fault generated transient signals are captured by the relay and the transient polarity identification algorithm is then applied to the transient signals to identify the polarity of the signal detected. The polarities and levels of the signals are then compared, from which the direction of the fault can be derived. The directional decision is then forwarded to relevant substation relays and the integrated network protection unit through specially designed PTN communication network, the faulted line section can be isolated by local protection and network protection. A typical power network is modeled using EMTP and extensive simulation studies with respect to various system and fault conditions are conducted. Results show that the relay is able to give correct responses for all tested cases.

2. Basic Principle of the Scheme

A typical distribution network as shown in Figure.1 is used to demonstrate the proposed scheme.

A fault occurring on any part of the network will generate transient currents in the system. The signals will travel to different part of the network and in time will be detected by relays at all of the various locations. The magnitudes of the transient currents detected at each CT will be different depending on the position of the CT related to the fault, the location of the sources and the line loading condition, *etc*. However, the most important of all is that the polarities of these signals follow a defined pattern. This enables the faulted section to be identified. For example, a fault point at 'F1' in Figure.1 will generate transient current signals on the faulted phases that flow through all the CTs. The polarities of the transient signals detected consist of two groups of opposite polarity. The polarities of the signals detected by the CTs of group 1, which point to the fault position, will be same. This will be either positive or negative depending on the polarity of the faulted phase voltage signal at the time of fault inception. The polarities of signals detected by the CTs of group 2, which point away from the faulted point, will be also the same but will be the opposite to that of group 1.

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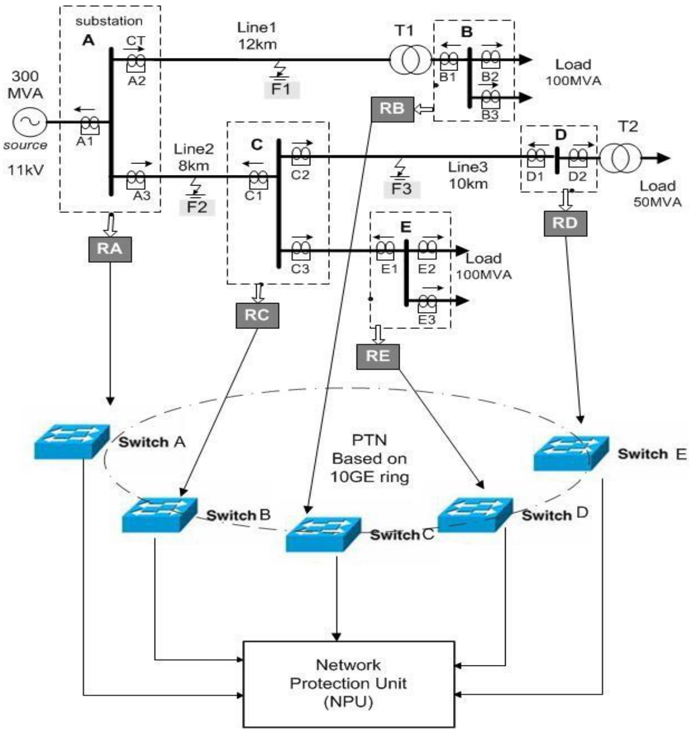

Figure.1 Typical Transmission Network

The information about the polarity of the fault generated transient current signals detected by each relay is sent to its associated relay at the far end of the protected section through the PTN communication network [9]. The polarity comparison at each end will determine whether a fault is inside the protected zone or not. In the case of fault at 'F1', the relay at two ends of Line1, stations A and B, will detect a signal of the same polarity. As a result, signals detected by the relays at both ends of Line1 will indicate that the fault is on the line section between station A and B.

For network protection, the polarity signals derived from each relay location will be sent to Network Protection Unit (NPU) through PTN. The NPU will be able to determine the faulted zone through the comparison between the polarities of the signals obtained from all locations within the network. Due to space limit, the specially designed PTN technology could be discussed in a separated paper.

3. Relay System Design Principle

3.1 Relay Platform Design

Figure.2 shows the block diagram of the proposed relay system. As shown in Figure.2, an interface unit (IU) interfaces to power lines through different types of transducers available. The analogue and digital signals measured are converted into optical format and sent to the central protection relay through the redundant communication network. The IU also receives control signals from the relay through the network and issues control commend to the circuit breakers.

The IU and communication unit *etc*. are interfaced with the central protection relay through the Ethernet using one communication standard, such as IEC61850 [10-11]. The network interfaces not only to critical IUs and the relay, but also to a number of other equipment, such as communication unit, Human machine interface, *etc*.

The communication unit interfaced to the PTN network is responsible for sending information to and receiving information from remote relays at far ends of the associated

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line sections for the protection of the line sections associated with the substation. It also can be used to communicate to the network protection unit (NPU) through PTN network for the backup protection of entire network. Only 'on' and 'off' signals, which represents positive or negative polarity, are required for communication by the scheme.

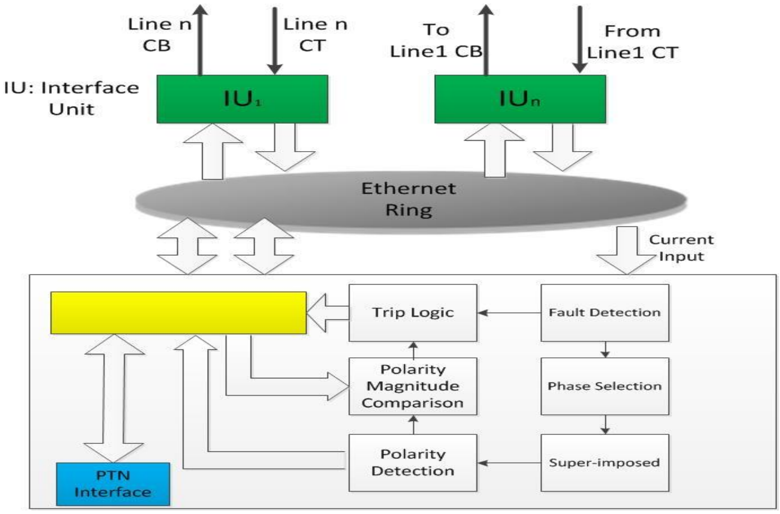

Figure 2. The Proposed Relay Unit

3.2 Protection Algorithm Design

As shown in Figure.2, this relay unit consists of fault detection, phase selection, super-imposed (S-I) signal extraction, digital counter, polarity detection, and polarity and level comparitor circuitry. It also contains two communication channels and a decision-making unit.

The use of phase selection in the design, instead of the modal transformation technique normally used for transient detection, is that this design can be implemented using hardware that is currently available.

Extraction of Super-Imposed Component: The S-I current is derived from the sampled current values that are delayed in memory for one cycle. The S-I current is then formed by subtracting the delayed sample from the most recent sample. The arrangement assumes that the sampling frequency is an integer multiple of the power system frequency, so there will be a whole number of samples taken per power cycle. If this is so, then the one cycle delay can be implemented by delaying the samples in a fixed number of memory locations [12].

Polarity Detection and Comparison: The centre part of the relay is the Polarity Detection and Comparison units. Once a fault signal is detected by using the S-I unit, a digital counter incorporating an adaptive algorithm is then applied to the signal detected. If the level of the faulted S-I signal has a magnitude greater than the adaptive threshold level, for a period of time exceeding the restrain time determined by the counter stage, then the polarity of the fault generated signal can be determined. The polarity information is then passed to the next stage for comparison with polarity detected at the other end(s) of the protected unit. Only when a relay has received signals of the same polarity as its sent signal will a final trip decision be made. At the same time, the polarity signal will be also sent to the NPU through PTN for network protection.

4. The Hardware Design of Network Protection Unit

Hardware design solution uses multi-core CPU plug-in architecture, in which the Data Processing Module and Logical Operation Module both use multi-core processor (P2020 processor), Communication Module is realized by power-PC processor (MPC8377). The

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hardware block diagram is shown in Figure.3. As the bus processing unit, Data Processing Module provides a redundant Gigabit Ethernet process bus interface, completes reception and transmission of SV, GOOSE and other important electrical quantities. On the other hand, the Logic Operation Module as a main control unit will receive SV and GOOSE data from Data Processing Module through Gigabit Ethernet interface. It can realize action logic judgment by combining different protection principles. The logic processing results obtained from Logic Operation Module will be sent to intelligent primary equipment such as intelligent circuit breaker. At the same time, the logic processing results will also be sent to Data Processing Module through internal GE interface. Then the Data Processing Module will send these results to Communication network of regional power grid. As for Communication Module, it can realize the management of entire device, Human Machine Interface(HMI) and the communication with regulation layer [13]. The Communication Module will receive data from logic processing results through internal FE interface and communicate with display panel of device through parallel bus. Besides, Redundancy is the most simple and practical means to improve system reliability. This device uses two independent power supplies to supply different loads respectively so that the load conditions of two independent power supplies are closer (Less than 50% of rated output). In the case of one power supply failure, another one can seamlessly access to another set of load.

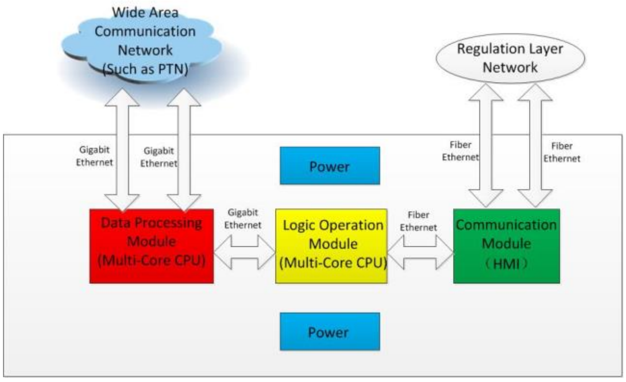

Figure 3. The Hardware Design Diagram of Network Protection Unit

5. System Response Evaluation

The response of the system is evaluated by digitally modelling the distribution network together with the relay units. As shown in Figure.1, the circuit system is based on an 11 kV distribution system. The parameters are shown in the figure. The simulation of the faulted power system was implemented using the EMTP software. A sampling frequency 36 samples per cycle is used here in the simulation studies. For explanation purpose, only the faulted phase signal at the outputs of S-I unit is used in the following demonstration. The fault direction estimation principle and trip logic will be presented in a separated paper.

Figure.4 shows the corresponding outputs of the faulted phase S-I signals detected by the relays at various locations; where (a) shows the responses at substation ‘A’ and (b) shows that at substation ‘B’. As expected, the S-I signals are of zero value before the fault inception at Tf. After fault inception, there are significant increases of S-I signals from all locations except A3.

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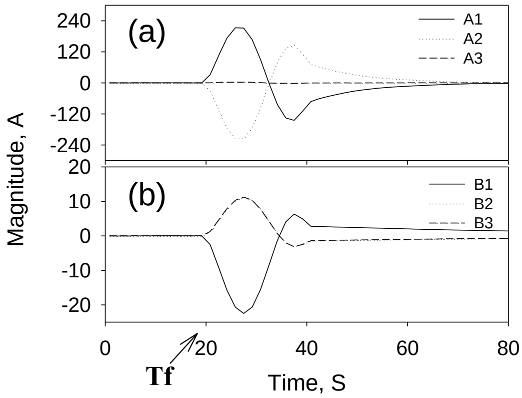

(a) Substation A; (b) Substation B

Figure 4. An 'a' – 'b' Fault on Line1 on F1

The responses of substation 'A' can be seen from Figure.4(a), the A1 signal is the same magnitude and opposite polarity to that of A2, and the magnitude of signal A3 is very low since there is no fault current follow in the branch. As a result, there is no clear indication as the faulted direction as can be seen from substation 'A'. The response of substation 'B', the signal B1 is significantly higher than and opposite polarity to that of B2 and B3, which indicates that the fault is from the direction of Line1. Comparison between the signals obtained at substations 'A' and 'B' through communication link shows that the polarities of A2 and B1 are the same, which clearly points out that the fault is on section Line1.

6. Conclusions

This paper presents a hardware design solution for Network Protection Unit. Its working principle and architecture are introduced in detail. Besides, the paper presents a entire network protection scheme based on PTN technology. By this network, the complicated IP routing process and MAC address learning process can be effectively avoided [14-15]. Therefore, it is able to save processing time, improve the forwarding speed and reduce information delivery delay. As a result, the entire network protection scheme can realise fast and accurate comparison of the transient polarity current to determine the fault section. Finally, simulation studies also show that the proposed protection scheme is able to produce desired performance.

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