AN INTEGRATED PROTECTION SCHEME FOR DISTRIBUTION SYSTEMS BASED ON OVERCURRENT RELAY PRINCIPLE

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ABSTRACT

This paper reports on the development of integrated protection for power system. The background of the development is firstly introduced, in which a centralized protection system (or relay) provides the protection of multiple power plant or a substation. A novel integrated protection scheme for distribution system based on overcurrent protection technique is described. In the proposed scheme, specially designed integrated protection relays are installed at each substation of a network and are responsible for the protection of every line sections connected to the substation busbar. The conventional directional overcurrent and the new adaptive accelerated protection algorithms are implemented into the relay with multiple overcurrent settings to cover all the protected line sections. The paper includes studies of a typical multi section distribution network to demonstrate the principle of the scheme. Studies show that the new scheme not only offers the new protection features for individual power line, but also provides the characteristics of integrated protection.

INTRODUCTION

In the late 1960's, Rockefeller [1] proposed the application of a centralized substation protection system based on a centralized computer system. The proposal fits well with the concept of an overall integrated protection where the protection package would not only oversee individual units of 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 the communication technology were not available to support such an idea. Since then, relay technology has enjoyed successful development based on the application of digital techniques for power system protection. 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. Limited integrated protection was provided in the form of back-up protection and as such has remained a secondary function. In recent years, there has been the further development in both microprocessor and transducer technologies. The dramatic growth in signal processing power of relay platforms, and the availability of suitable communications schemes, has provided a new opportunity to revisit the concept of integrated protection. Research shows that information obtained from multiple power plants and components can be used to derive new protection principles and schemes, which could have significant advantages over the existing protection techniques based on individual plant or component.

This paper reports a novel integrated protection scheme for distribution system based on overcurrent (OC) protection technique. In the proposed scheme, the specially designed integrated protection relay installed at each substation of a network and interfaced to every line through the CTs and busbar VT is responsible for the protection of every line sections connected to the substation busbar. The conventional directional OC and new adaptive accelerated protection algorithms are implemented into the relay with multiple OC settings to cover all the protected line sections. The relay is also interfaced to the substation communication network which is communicated with all neighboring stations and a central protection and control system. The paper includes studies of a typical multi section distribution network to demonstrate the principle of the scheme. Studies of the IEC61850 communication standard for substation Ethernet communications supporting the protection schemes are also included in the paper.

INTEGRATED PROTECTION SCHEME BASED ON OVERCURRENT RELAY

The integrated protection scheme is mainly based on the well established overcurrent (OC) protection technique, the basic principle of which is well known and will not to be described here.

Basic Principle of the Protection Scheme

A typical distribution network together with the proposed relay units as shown in Fig.1 is used to demonstrate the proposed protection scheme. As shown, the integrated overcurrent relays (IORs) are installed at each substation busbars, and are interfaced to every CT on the lines connected to this busbar. The relays are also interfaced to the busbar VT for the purpose of directional measurement. The IORs are equipped with a number of conventional and new protection functions operating in serial/parallel, which can be classified as 3 operating stages.

The first stage is the directional OC based instant tripping stage, each relay is equipped with multiple overcurrent settings to cover all its associated line sections. The relay will instantly trip the circuit breaker associated with the faulted line section for a fault over its predefined OC setting threshold. At the same time, the relay will send the direction information to the remote relays if the communication channels are available and to the Integrated Network Protection (INP) unit.

The second stage of protection function will apply if the relay can not instantly operate based on OC settings. There are two protection functions in this stage, the application of which will depend on whether a communication channel is available between the relays at both ends of the protected line section. The directional comparison technique specially designed for distribution systems [4] will apply when the communication channel for inter-tripping is available, otherwise, the accelerated non-communication protection techniques for distribution systems [2-3] will be applied for accelerated tripping. The details about the techniques are well documented in the references and will not be described here.

In the third stage, the Integrated Network Protection unit (INP) will received the faulted information, particular the directional information from all IOR relays within the network. A comparison between the directional information obtained will decide the faulted line section. The INP will send a direct trip command to the relays associated with the faulted line section based on the information obtained from IORs within the network [5].

Operation of the Protection Scheme

When a fault occurs on the system, for example, at F1 on line section Line2 as shown in Fig.1, the IOR relays, such as IOR1, IOR2 and IOR3, in the system will detect the fault. In this case, the IOR1 will not respond immediately to this fault location since it is outside the setting of its instant operation range. The IOR2 will instantly trip if the magnitude of the fault current reaches over its predefined setting for the line section Line2, or delay the tripping if it is not. After the IOR2 trips the faulted line section, the fault is removed for IOR1, which will restrain from operation.

At the same time, IOR2 will send its faulted directional information to the INP. It will also send the directional information to its associated other relays if the communication channels are available. When the communication channel is available between IOR2 and IOR3, the IOR3 will compare the directional information obtained derived locally with that sent over from IOR2 and trip its associated faulted line section Line2.

When the communication channel is not available, the IOR3 will detect a under voltage directional fault and is able to produce an accelerated trip decision [2-3] after the IOR2 instantly trips the line section. In both cases, the fault is removed from both ends of the faulted line section, while for the conventional protection schemes the fault is only removed from source side of the line. As mentioned, all the relays which detect the fault will record the faulted direction and send to the INP Unit, which can easily determine the faulted line section and issue direct trip command to open the circuit breakers at both ends of the faulted line section, if they have not been opened by its associated IORs. In this case, the INP will compare the directional information obtained from IOR1, IOR2, IOR3, IOR4 and IOR5, which will clearly pointed out that the faulted line section is Line2, as a result, INP will send the trip command to both IOR2 and IOR3 if they have not operated yet.

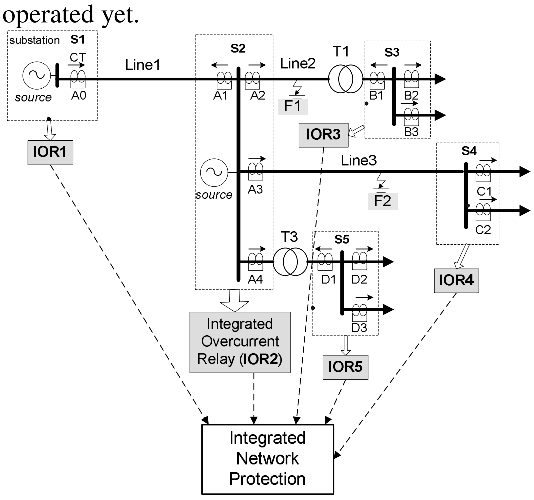

Fig.1 Integrated Network Protection Scheme

RELAY SYSTEM DESIGN

The proposed relay is based on a substation communication network, which mainly consists of three major redundant components in the system:

Interface Unit (IU)

An interface unit (IU), interfaces to power lines through different types of transducers available, such as the conventional and optical CT's and VT's. The analogue and digital signals measured are converted into optical format and sent to the central protection relay through the redundant optical network. The IU unit also receives and executes control signals from the relay through the control circuit to determine whether to trip the faulty line. Moreover, this unit also incorporates relevant algorithms for converting the instantaneous value of the data samples to required format by the relay and other equipments. As a result, not only the overhead on data transmission can be reduced, but also the communication capacity of the network can be improved.

Relay Unit

By comparing the measured signals from various locations within the substation, the relay can perform all the necessary calculations to determine whether there is a fault within the substation or on its associated line

section. Then, the relay will issue a trip command speedily through the Ethernet to open the associated circuit breaker if a fault is detected.
Fig.2 shows the block diagram of the proposed relay unit. This consists of the faulted line selection, Instant trip based on OC setting, Channel inter-tripping, Non-communication accelerated tripping and INP direct tripping unit. It also contains two communication channels.

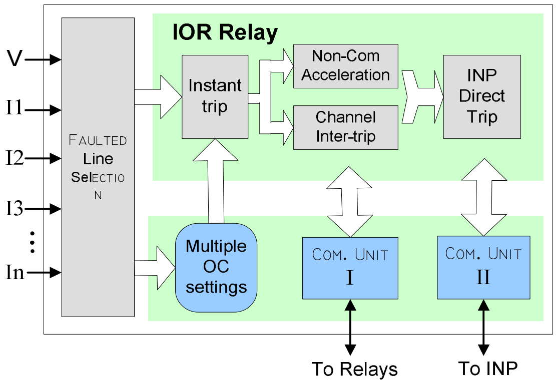

Fig.2 The proposed relay unit

The "Faulted Line Selection" determines the faulted line associated with the busbar where the IOR is installed. Here the technique used can be the conventional directional element or the new transient based protection technique [5]. Once the faulted line or direction is selected, the "Instant Trip" will pick up the settings associated with the faulted line from the "Multiple OC settings" to instantly trip the line section for a fault over the predefined settings. Those settings are typical settings widely used in overcurrent protection, such as phase and earth fault overcurrent settings.
The "Channel Inter-tripping" is based on the directional comparison technique specially designed for distribution system which is able to adaptively respond to real time changes in system source, fault and various conditions. Once a fault is detected, the relay will send the directional information locally derived over to the remote IOR associated with the faulted line section through Communication Channel I while waiting for the direction information from the remote IOR. The relay will trip once the local direction match the remote one. The basic principle of the directional comparison technique is well known and not to be described here. The Communication channel I is a multi channel communication unit which is responsible for sending and receiving signals from all remote IORs on the associated line sections if the communication links are available. Only 'on' and 'off' signals, which represent inter-trip commands, are required for communication by the scheme.
The "Non-Com Acceleration" (NCA), which means the accelerated operation without the need for communication link, will start action after an instant trip decision fails to operate, in another words, the fault is not within the instant trip zone. There are a number of associated techniques available for the accelerated overcurrent protection depending on the system configurations, the principles of which are based on the detection of remote circuit breaker operation. The NCA has two new features, firstly instead of waiting for fixed time delayed trip, the NCA will accelerate trip the faulted line section; secondly the NCA is able to trip from the load side of the faulted line section for a single source supply system, thereby removing the fault from both ends of the faulted line section.
The "INP Direct Trip" will send the directional information of a fault to the INP unit and receive a direct trip command from it through Communication Channel II. The INP can easily determine the faulted line section by comparison between the directional information from all the IORs in the network it protects. It is obvious that the INP unit could coordinate with the wide area control and protection system for the purpose of maintaining system stability.

IEC61850 BASED COMMUNICATION SYSTEM

In the proposed protection scheme as shown in Fig.3, the IU and communication units etc. are interfaced with the central protection relay through the Ethernet using one communication standard, the IEC61850. The network interfaces not only to critical IUs and the relay, but also to a number of other equipment, such as communication gateway, Human machine interface, etc. The network comprises an optical fiber ring with comprehensive monitoring functions, the failures of components can be detected within a few milliseconds and indicated to the operator within a fraction of a second. If a device fails, the normal communication among the other devices can be restored in a few milliseconds after the network has been reconfigured.

Structure of Communication Network

Based on 100 Mbit/s optical Ethernet ring, the information can be transmitted with a high-speed between the interface unit and the central protection relay through Ethernet, which is the foundation for implementing data communication in the integrated protection scheme. With high-speed and reliable communication capacity of Ethernet, the central integrated protection unit can record fault information at a high rate to determine the faulted line and then take the protective measures necessary to isolate it within the required operating speed.
Equipments in the station level include the central integrated protection unit or relay with protection algorithms, Human Machine Interface (HMI), relevant controller and gateway and so on. The gateway is used to communicate between Ethernet and networks at other substations, through which the transmission of data

information and control information between interior and exterior of the network is achieved. Collection and processing of information from all substations will be undertaken, then the control command from station level is sent to the interface unit. Among them, the central integrated protection unit, which can also work as a backup protection if the local protection is available. It receives measurement from all locations in the substation through Ethernet and information from other related substations through the communication gateway, and then act to isolate the fault line.

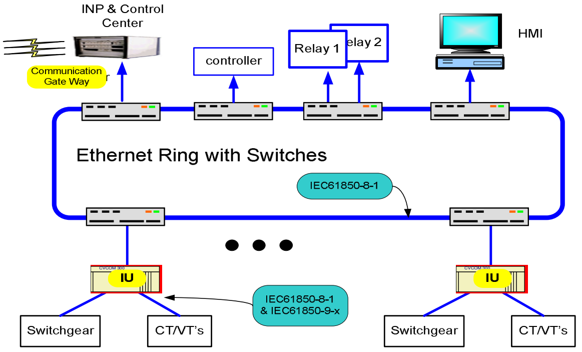

Fig.3 New communication network scheme

Feasibility analysis of the network with IEC61850

Based on the IEC61850 standard, the output data from sensors is sent to IUs for A/D conversion, to implement synchronous sampling of the fault information including voltage signal and current signal, then these signals will be transmitted to the network in the form of framing according to requirements of the standard. In addition, the frame also includes some status messages and synchronizing information.

Ethernet bandwidth relates to the length of message and sampling rate, baud rate of data transmission D_R is given:

$$D_R \geq S_R N_{mu} L_T$$

Where the S_R is the sampling rate, the product of sampling points and signal frequency in a period; N_{mu} is the number of the IU unit; L_T is the maximum length of message, if the clearance distance between Ethernet frames is regarded as 96bits and the frame will have a length of 111 bytes, thus, the length of the message will be 984 bits (111*8+96=984).

For the power frequency of 50 Hz, a typical number of sampling points in a period will be 48. In the limit,

$$D_R \geq 2.3616 Mbit/s$$

（48×50×984×1×10^{-6}=2.3616）

Considering a few uncertain factors, then add 10% redundancy

$$D_R \geq 2.3616 Mbit/s \times 1.1 = 2.59776 Mbit/s$$

To make the data transmission feasible, the baud rate of data transmission must be above 2.59776Mbit/s based on aforementioned analysis for one IU in the network. It can be derived that for network with 10 to 20 IUs in a moderate size of substation, the requirement for data transmission will be well within the 100Mbit/s, therefore the 100Mbit/s Ethernet will meet the requirement of the data transmissions in such a network.

CONCLUSIONS

A new integrated protection scheme for the protection of distribution line system as well as distribution network as a whole based on overcurrent protection technique is described in the paper. The scheme, which combines the conventional overcurrent protection technique and the latest developments in distribution system protection, has a number of protection operating stages for instant, accelerated inter-tripping and direct tripping respectively. The scheme offers not only fast protection for individual line section, but also integrated network protection. With the continue advances in measurement, communication and signal processing technologies, the proposed scheme could have a bright future for practical application. Overall improved performance of protection can be expected from the proposed scheme, but for it to become useful in power system application, it is equally important that its practical implementation be readily manageable or user friendly and cost effective. The authors consider that, to achieve these goals, the centralized totally integrated relay proposed offers an attractive way forward.

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