IMPROVEMENTS IN DISTRIBUTION FEEDER PROTECTIVE RELAYING

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Introduction

Historically, electromechanical disk-type overcurrent relays have been used to protect distribution feeders against faults or overload conditions. These relays have provided adequate and reliable protection at a low cost and with low maintenance requirements. The need to replace or supplement these relays is now being considered due to many advanced features available with microprocessor-based technology. This paper describes some of the features of a new line of microprocessor-based overcurrent relays with built-in communications ports to allow remote access.

These new microprocessor-based relays offer improvements in protection, operation, and maintenance. A design that minimizes hardware and relies on software for most functions will result in high reliability, long service life, and low maintenance support requirements. Increased flexibility due to modular design allows uses ranging from stand alone protection to completely integrated protection, control, and monitoring. Additional capabilities within the relays offer features not normally available with electromechanical relays. These features include automatic detection of a cold load pick-up condition with changes made to accommodate this condition, internal logic to provide breaker failure relaying, and inter-relay logic to allow improved distribution bus protection. Advanced communication facilities provided in the relay allow a number of remote access options. Programmable logic for multiple relay inputs and outputs, along with the communication interface to substation computers or to remote computers, provide the user with options to develop his own solutions and improvements.

The paper also discusses some of the barriers that must be overcome to effectively use the full value of this new technology. Some of these barriers are internal to company organizations. Few companies are structured to easily allow protection, monitoring, control, and some metering and communications functions to be specified and selected by a single group. Also, few companies have the infra-structure in place to effectively access, distribute, and then use the greatly increased information that will become available from these relays and from the many other "smart" devices now available. Another internal company barrier to be faced is the always possible resistance to change which may come from field operations and maintenance personnel.

Besides the internal company barriers, the industry as a whole must work to resolve the confusion surrounding communications. A myriad of protocols and special requirements unnecessarily complicate the process of accessing the new type devices.

Present Practices

Present practices for distribution protection, operation, and maintenance, while certainly not standardized among companies, follow a few recurrent patterns. The vast majority of companies use single phase electromechanical disk-type overcurrent relays. These relays typically have an instantaneous element and either a very inverse or extremely inverse time unit. Most companies use three phase relays and a ground relay, although quite a few use only the three phase relays, and some use two phase relays and a ground relay. Many companies have either disabled the instantaneous units or have schemes to remove this unit after the initial trip.

Distribution systems almost universally have downstream fuses, mostly just on laterals. Some systems also have additional feeder protection and sectionalizing provided by circuit reclosers, either electronic or hydraulic. These fuses and reclosers, along with load levels, the type of load served, feeder unbalanced currents, conductor ampacities, and cold load pick-up, determine feeder overcurrent relaying requirements and settings.

Most utility companies also use some form of automatic reclosing, with variations from one shot to as many as four. Two shot and three shot reclosing schemes are most common. Companies are just beginning to apply automatic reclosing systems with logic added to provide some adaptive features. Some companies selectively adapt reclosing to weather conditions or to certain system conditions. Companies also adjust reclosing based on fault type or current levels or other criteria. Industrial distribution systems and systems that are comprised largely of underground cables do not typically use automatic reclosing.

Many companies now use SCADA systems to control the distribution breakers and to obtain information about the distribution system. Most of these companies only monitor breaker position, current level (usually only one phase), and transformer watt and var levels. More detailed information, such as current levels on each phase or unbalanced current levels, can only be obtained by sending personnel to the substation. Instantaneous and maximum demand ammeters are typically available on each feeder. Unbalanced current and feeder watt and var data normally could only be obtained by connecting portable instrumentation at the substation. Feeder load trend data is sometimes obtained by connecting a special recorder.

Following faults, whether temporary or permanent, relay target data is retrieved by sending personnel to the substation. Fault current levels are seldom available. Breaker preventive maintenance is performed based on a set time interval or, at best, based on total number of breaker operations. Relay maintenance is also usually based on a fixed time interval. The availability of the relay is not generally known during the period between maintenance tests, except by demonstrated performance for faults.

Substation distribution bus protection is typically provided by overcurrent relays set to coordinate with feeder overcurrent relays. These same relays provide back-up protection for feeder relaying failures or for a failure of a feeder breaker. Some companies also have tie breakers, which have overcurrent relays that must be coordinated with the main breaker overcurrent relays and with the feeder breaker overcurrent relays. In addition, the main breaker overcurrent relays or a separate set of overcurrent relays, applied with the transformer, must be set to provide the thermal protection for the transformer which is not provided by the differential relaying.

Microprocessor-Based Distribution Relaying

Modern microprocessor-based distribution relays provide the capabilities to not just replace, but to also enhance, the protection, control, and monitoring functions described in the previous section. These relays also make possible the implementation of protection and logic schemes not feasible with the electromechanical relaying. In addition, the application of these new relays lays the foundation for the future--for distribution automation, for applications of expert systems and artificial intelligence, and for many other high-tech solutions still on the horizon.

The line of relays described in this paper are available in many models from a single element ground version through a three phase and ground version with directional supervision. Physically, the three phase and ground directional version measures only six inches by seven inches. This package includes the communication interface, eight optically isolated inputs, and eight programmable output relays.

Three Separate Overcurrent Stages

The protection provided by this new relay begins with an emulation of the techniques familiar to protection engineers. All versions of the relay will provide **two instantaneous overcurrent functions,** available with or without a fixed time delay, and a **separate inverse time function.** The inverse time unit will have the full range of American and IEC curves available for user selection. Reclosing will be provided by a separate four inch by seven inch relay package that can be physically and electrically interconnected with the overcurrent relay to act as a single unit. This reclosing relay has the capabilities of a programmable logic controller with multiple inputs and outputs. Standard reclosing programs can be selected or special requirements can be met with customized programming.

Cold Load Pick-up Solutions

These new microprocessor-based relays are capable of solving problems that have faced the distribution protection engineer for years. One of these problems is **cold load pick-up.** These relays are capable of recognizing a cold load pick-up condition and providing solutions such as disabling instantaneous tripping or changing settings to higher values. Improvements can also be made in the coordination with downstream circuit reclosers. The elimination of disk over-travel and the ability to reset the relay with no time delay or with a selectable time delay allows the overcurrent relay to more closely and consistently coordinate with all types of circuit reclosers.

Alternate Setting Groups

Another feature offered by this relay is the ability to switch between **alternate setting groups.** The first setting group would be the group used for normal system conditions. The second group may be used to allow for unusual conditions on the feeder. During these unusual conditions, these settings would protect the conductor from damage but may not be required to fully coordinate with other upstream or downstream devices. The unusual conditions could be a cold load pick-up situation or any of the many possible emergency conditions in which the full thermal capability of the feeder may be needed. The alternate setting may also be applied to provide fast tripping and to block reclosing when line maintenance work is taking place.

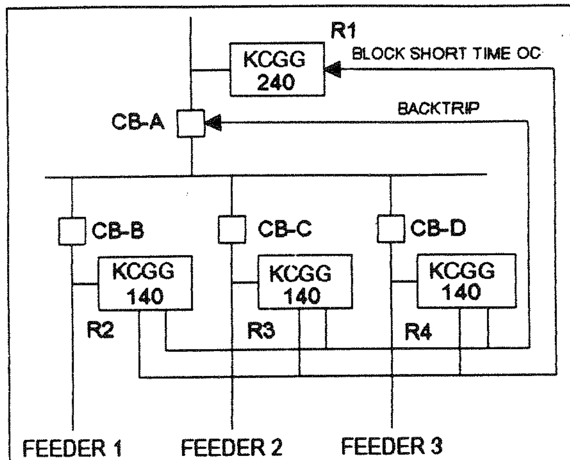
Breaker Failure Protection

The relays also offer many other useful features, such as **built-in breaker failure protection.** Since the sensitivity of feeder relaying is often much greater than that of the relays in the main breaker which serve to provide the protection back-up, it is important to provide breaker failure protection. Many faults on the distribution system would not be detected by the main breaker relays. For these faults, a trip coil problem or other similar feeder breaker failure condition could result in an uncleared fault.

Enhanced Bus Protection

The relays provide considerable flexibility for various applications by the use of **programmable optically isolated inputs and programmable relay outputs.** These inputs and outputs allow the user to create special protection schemes. One such scheme would be **distribution bus protection.** If these relays are applied on each breaker on a bus, a contact from the relays on the load breakers can be used to block the fast operation of the relays on the source breakers. This blocking would be take place for faults out on a feeder. If the fault were on the bus, the fast operation of the source breaker relays would not be blocked, thus allowing bus clearing in as little as 3 - 4 cycles plus breaker time.

The figure below illustrates both the breaker failure protection and the high speed bus protection which can be achieved using these relays. If there is a fault on feeder 1, the trip signal is sent by relay R2 to circuit breaker CB-B to perform normal breaker tripping. If circuit breaker CB-B fails to trip, the relay R2 will identify the breaker failure condition by allowing an adjustable time delay and then checking to see if current is present. Relay R2 then sends a trip signal to circuit breaker CB-A. For this same feeder 1 fault, Relay R2 also provides a contact input to block the short time overcurrent unit of Relay R1. Each feeder on this bus would provide similar inputs for feeder faults. If, however, the fault is on the bus, no feeder relay input blocks R1 and fast bus protection is achieved. The short time delay of about 50 ms. is required to allow reception of the inputs from the feeders.



Simple Busbar Protection Diagram

Improved Measurements

In addition to the these protection features, these new relays will have built-in **capabilities to measure and perform calculations on input quantities.** This capability will result in the availability of information generally beyond what is currently available to operations personnel. This information could include the currents for each phase, the unbalanced current, phase voltages, maximum demand currents, and such calculated quantities as watts, vars, and power factor. These quantities can also be periodically sampled and stored for trend observations or to develop load profile data.

Maintenance Aids

The relay will have the capability to store fault current data and to provide **sequence of events** data relating to internal relay logic and status of the external contact inputs and the output relays. The relays will also provide **maintenance related data,** such as the number of faults detected and the **accumulated total fault current interrupted on a per phase basis.** The time, in milliseconds, from the relay's trip output until the breaker current is interrupted is also provided by the relay for each fault operation. All of this information greatly improves the capability of operations personnel to respond to system problems and provides additional tools for engineering personnel to analyze relaying operations, to plan system changes and to establish maintenance criterion.

Fault Diagnostic Aids

Fault analysis can also be supplemented by **oscillography** data available in the relay for the last fault seen by the relay. This oscillographic data must be loaded onto a PC for display. The full capabilities provided are 8 analog channels and 2 digital channels with sufficient pre-fault, fault and post-fault data to cover most fault conditions.

Self-Checking

Another feature of this technology is **internal self-checking.** This process provides increased levels of confidence in the availability of the protection and may reduce the required redundancy necessary to maintain current levels of reliability. As confidence is gained by the users, self-checking and remote communications access may eventually allow them to postpone, or reduce, preventive maintenance checks. At the very least, the time-consuming calibration checking and related adjustments are eliminated.

Remote Communication Access

Most relaying engineers would agree the biggest difference between these relays and their predecessors is **the ability to remotely communicate with the relay** from an engineering office or a control center or from any PC location. All that is required to add the communication access is a shielded twisted pair cable. This communication link provides several important new capabilities: to change settings remotely, to access fault data, to access system measurements, to enable or disable instantaneous tripping, to change or control automatic reclosing, and to trip or close the circuit breaker.

This feature, when effectively employed by a user, has the potential to significantly reduce O&M expenses by reducing the number of times personnel have to be dispatched to the substations and by identifying potential problems or actual problems earlier and faster. Personnel can be dispatched more intelligently following a permanent fault by knowing current levels and phases involved. Recurring temporary faults involving the same phase and current levels may indicate a problem that could be corrected, such as a tree which should be trimmed. Knowledge of high phase unbalanced currents may allow re-distribution of loading on a feeder. Significant differences in phase power factors may indicate line capacitors with blown fuses.

These and many other such solutions provided by these microprocessor-based relays have real value that, in time, will not only justify their use on new feeders, but may well justify the retrofitting of this technology to older feeders.

Retrofit Applications

The ability to apply the relay in a **retrofit** situation is critical to the effective utilization of this new technology. It will make little sense in the long run to have scattered feeders connected to communications and providing information and control. To be an effective operations tool, the operations people need to have this capability available to them at most locations so that they are accustomed to having these tools available and to using them.

This new relay has the physical dimensions to allow a very practical retrofit option. The user would simply replace one of the existing electromechanical phase relays with a three phase and ground version of the microprocessor- based relay. With a very little panel work and minimal rewiring, the feeder acquires all the advanced features of the new relays along with full redundancy provided by the remaining electromechanical relays, normally two phases and a ground.

Expected Benefits

The list of expected or potential benefits of the use of microprocessor-based relays is both long and impressive. The most important of these expected benefits is the **improvements of the distribution system** and the **higher levels of reliability** that the protection offers. These improvements will result because the relays have greater capabilities and greater flexibility. Trip times can be reduced, coordination can be improved, redundancy levels can be greater, and added protective schemes, such as bus differential and breaker failure protection, can be provided. Persistent problems, such as cold load pick-up, can be more easily handled. Self-checking and other advanced monitoring techniques will enhance reliability. In addition, conventional reliability enhancement techniques, such as duplication of protection, can be achieved using new back-up concepts that take advantage of improved capabilities within these relays to share logic and information.

Another benefit that will manifest itself as users learn to integrate these systems into their operations is the **improved response to distribution faults.** Knowledge of phases involved and fault current levels can allow more efficient dispatch of personnel, can identify certain types of problems, and can improve the restoration process.

Improvements in day to day operations of the distribution system can be expected with increased feeder information available. Remote access to three phase currents and to unbalanced current information, as well as the ability to change settings based on these conditions, can reduce load related outages. Remote setting changes will also reduce the need to dispatch personnel to the substation when operating conditions change due to failures or to maintenance.

Since these new relays will also provide information needed to determine when manufacturer's recommended maintenance levels are reached for circuit breakers, **preventive maintenance of these breakers can be optimized.** Similarly, the relays themselves may require less preventive maintenance and certainly less of the time consuming calibration type testing. These benefits, along with the operations benefits mentioned above, should eventually show up as reduced support requirements for the distribution system as a whole.

As substation communications are improved and integrated more effectively, these relays will easily evolve into part of a system that integrates protection with the monitoring and control devices. Stand alone SCADA, stand alone fault recorders and sequence of event recorders, and stand alone protective relays will all become a part of an integrated system incorporating expert system technology and other modern techniques to improve performance while reducing total costs.

Another benefit to be expected is **improvements in protection for distribution busses, the main and tie breakers, and for the power transformers.** The relays will allow faster clearing for bus faults, breaker failures, and, through improved coordination, for most feeder faults. All of these improvements reduce the through-fault exposure to the transformers, which should result in a reduction in transformer failures.

Logic within the relays can be used to work with underfrequency relays or with directed load shedding systems to improve the effectiveness of **load shedding.** The amount of load to be shed can be more accurately determined in order to better match the situation.

Transitional Difficulties

The introduction of new technologies usually requires several obstacles to be overcome within an organization. One of the greatest of these obstacles is usually the organization itself. These new microprocessor-based relays continue the trend toward integration of protection with control and monitoring. They also continue the trend of making available more extensive and more diverse information.

In order for utility companies or other users of this new technology to effectively specify, purchase, implement, and then utilize a fully integrated system, these users should review their organizational structure to determine what barriers might exist. As the technologies of protection, control, and monitoring merge, it is logical to also create a closer association among the groups supporting these technologies.

In addition to organizational adjustments, the transitions to this new technology will be hindered by the large number of communication protocols being provided by the various suppliers of protection, control, metering, or monitoring equipment. In the short term, protocol conversion will be the solution most often used. Putting an intelligent terminal at the substation to interface with the various "smart" devices may provide a single access point for the remote communications and could also provide all necessary protocol conversion. This intelligent terminal could work through the SCADA system, but will more likely be operated in parallel with the SCADA.

This system would scan the various devices within the substation, process and store the required information, provide the necessary protocol conversions to allow direct access to the remote devices, and also provide a single point to interface the substation devices to the external communication circuit. An advantage of this on-demand system could be the unloading of the existing SCADA systems to minimize the information deluge that often occurs for major system faults or other disturbances.

The modern SCADA systems have the capability to provide large quantities of system data. The limiting factor has become the ability of the operations personnel to process the data automatically presented to him during these major events. An on-demand system could pre-process and, to some extent, filter or condense this information, assign a priority to the data, provide this priority level through the SCADA system, and then make the data available when the operator determines he is ready to handle it.

Perhaps the most difficult of the transitional barriers to the full acceptance of this new technology is the issue of personnel acceptance. Whenever change is proposed, the proponents of change must recognize the need to provide the information, training, documentation, and support to those personnel who will be affected by the changes. Relay maintenance personnel and those who direct them must be made aware of what maintenance is expected and what maintenance procedures are appropriate. Most important of all is the effective indoctrination of all the personnel who should take advantage of the enhanced capabilities-- operations personnel, system planning personnel, and the various other engineering groups.

Summary

The era of microprocessor-based distribution relaying has arrived. All major relay suppliers are offering some version of this technology. The relay described in this paper provides enhanced protection capabilities, offers increased measurement and fault analysis capabilities, is remotely accessible, and comes in a physical package suitable for retrofit where one electromechanical overcurrent relay has been installed.

The expected benefits of the widespread use of these relays may be fewer or shorter distribution outages, more effective use of distribution support personnel, reduced maintenance requirements, less fault exposure to power transformers, better information available to engineering and planning personnel, and improved ability to fully use the thermal capabilities of feeder circuits during emergencies or maintenance conditions.

The barriers to be overcome have also been described. Company organizations must be adjusted to optimize implementation and utilization of this technology. Proper indoctrination of personnel must take place to help overcome reluctance to change. Suppliers of these types of devices, as well as the users, must deal with some of the technical issues, such as creating a standard communications protocol and determining proper use of the large volumes of data now available.

The microprocessor-based overcurrent relay, with all the advantages of remote access, is likely to quickly become the new standard for application on distribution feeders, mains, and ties. Since hardware is minimized with this technology and since software can be perfected and standardized, it is reasonable to expect this new distribution protection to become as reliable, long-lasting, and as popular as its predecessor. Considering the history of its predecessor, that is a powerful endorsement.