IEC 61850 BASED ADAPTIVE DISTRIBUTION PROTECTION

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ABSTRACT

This paper describes the implementation of adaptive distribution protection systems based on IEC 61850 that allow improvements in the performance of the system and reduction of the impact of abnormal system conditions on sensitive loads.

INTRODUCTION

Requirements for reduction in the duration of short circuit faults on distribution feeders and substation equipment are based on significant increase in the numbers of customers with loads sensitive to voltage variations. High-speed fault clearing for different faults on distribution feeders and substation can be achieved by advanced communications based protection schemes. However, they have the disadvantage that they require the availability of communications between devices, which in many cases are not available.

Significant improvement in the performance of non-communications based distribution protection solutions can be achieved by the implementation of adaptive protection at the distribution level of the system. The grounding of transformers and their state, state of distributed generators, the configuration of the system and the dynamic behavior of the system are analyzed from the point of view of the performance of distribution feeders' and substation protection relays.

Special attention is paid to the cases of substations with multiple transformers and their grounding. The effect of transformer state and grounding is analyzed.

The performance of relays under dynamic loading conditions is later described in order to discuss the challenges of detecting of faults occurring under such conditions.

Sympathetic Trip logic is used as an example of adaptive distribution system protection.

Selective backup tripping is a second detailed example of adaptive behavior of distribution protection IEDs.

The paper describes the methods for detection of changes in the different factors that affect the operation of the relays. Features in the distribution feeders and substation protection relays that allow them to adapt to the changes in the system condition are described later in the paper. Monitoring of the state of breakers or switches, interface with the substation automation system, detection of faults under dynamic system conditions, changing of setting groups or use of the programmable scheme logic are discussed.

DISTRIBUTED PROTECTION FUNCTIONS

Peer-to-peer communications are used to perform protection, control, monitoring and recording functions. Any function can be divided into sub-functions and functional elements.

The functional elements are the smallest parts of a function that can exchange data. These functional elements in IEC 61850 are called Logical Nodes. When a function is executed based on the exchange of communications messages between two or more devices, it is called “distributed function”.

The exchange of data is not only between functional elements, but also between different levels of the substation functional hierarchy. It should be kept in mind that functions at different levels of the functional hierarchy can be located in the same physical device, and at the same time different physical devices can be exchanging data at the same functional level.

Figure 1 shows Logical Connections (LC) - the communication links between functional elements - in this case logical nodes of the P and R groups. IEC 61850 also defines interfaces that may use dedicated or shared physical connections - the communication links between physical devices.

The allocation of functions between different physical devices defines the requirements for the physical interfaces, and in some cases may be implemented into more than one physical LANs.

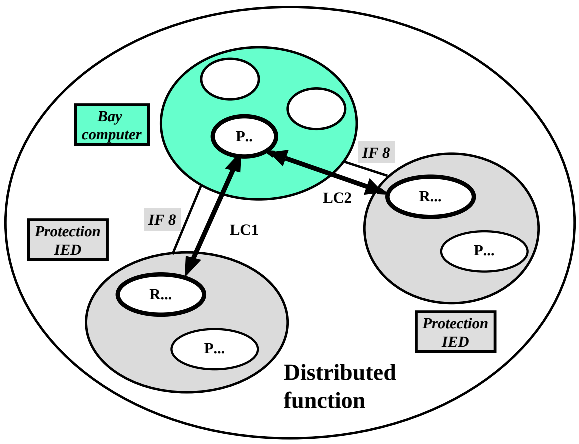

Fig. 1 Distributed Function definition in IEC 61850

The functions in the substation can be distributed between IEDs on the same, or on different levels of the substation functional hierarchy. IEC 61850 defines three such levels:

- Station
- Bay/Unit
- Process

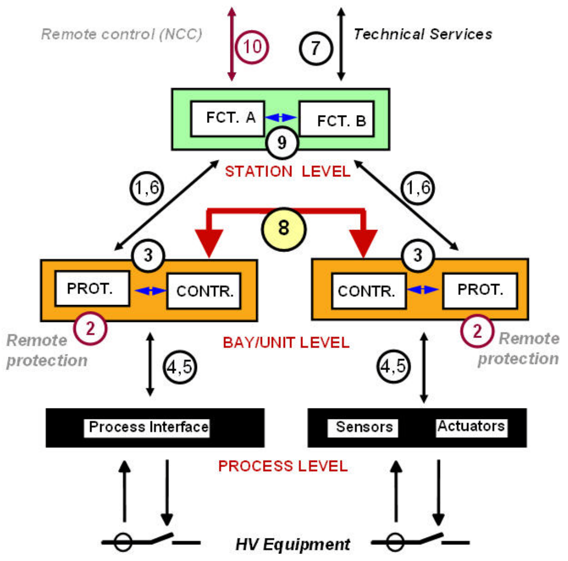

Fig. 2 Logical interfaces in Substation Automation Systems

These levels and the logical interfaces are shown by the logical interpretation of Figure 2. IEC 61850 focuses on a subset of the interfaces shown in Figure 4 with Interface 8 (shown in red) being used for high-speed peer-to-peer communications.

The logical interfaces IF8 is defined as direct data exchange between the bays especially for fast functions like interlocking.

ADAPTING TO CHANGES IN SUBSTATION CONFIGURATION

There are many cases when the performance of the protection and control IED is affected by the substation or power system configuration. With conventional relay, for example, it is very difficult to adjust to changes in the grounding at the relay location.

If the relay (Feeder PIED in Figure 3) is located in a substation with two transformers, one grounded on the high side and the other on the low side, taking one of the transformers out of service will significantly affect the levels of zero sequence current seen by the ground overcurrent relays. If this is the transformer grounded on the distribution side, the distribution system will change from solidly grounded to isolated, which will require significant changes in the protection. The change of state is delivered as a GOOSE message by the IED monitoring the status of the breaker.

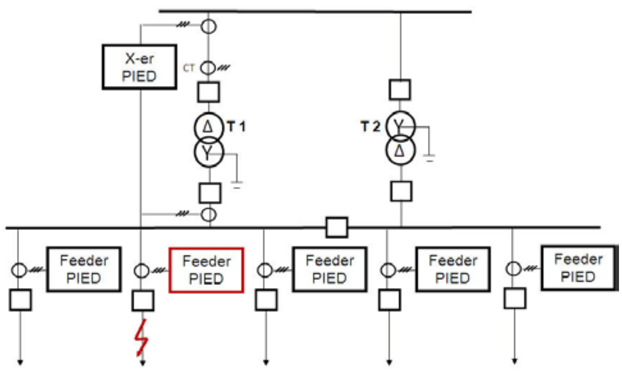

Fig. 3 Protection IED with transformers with Δ/Y and Y/ Δ transformers behind it

The levels of fault currents for phase faults will also change with one of the transformers out of service. This requires monitoring of the state of the transformers and adapting to the new conditions as soon as one of the transformers is taken out of service. The changes will be different as a function of which transformer has been taken out of service.

Multiple Setting Groups

The typical solution in the case of microprocessor based relays is by changing to a new setting group that will provide settings based on the current configuration of the substation or power system. Multiple opto-isolator inputs may be used for changing between setting groups.

In the example above, the relay will switch to a different setting group depending on which of the transformers is taken out of service or if the sectionalizing breaker is opened or a transformer is taken out of service.

Programmable Scheme Logic

The programmable scheme logic in modern multifunctional protective relays is an extremely powerful tool that allows the user to adapt the relay logic to very different applications or to changing system conditions.

Considering the fact that the relays have multiple instances of the same protection function, for example definite or inverse time overcurrent elements, the user can enable or disable individual elements as a function of dynamic changes of the substation or power system configuration.

The advantage of this approach is that it is instantaneous and it affects only a very limited part of the relay logic. It also provides additional flexibility, especially in the case of limited number of setting groups.

If we consider the example with change of the grounding conditions in the substation (Figure 3) or at the remote end of a protected distribution feeder, instead of changing the setting group in order to adapt to the new configuration, we can just enable a more or less sensitive

ground overcurrent element.
Another factor that can determine the need to use the programmable scheme logic instead of changes in the setting groups is the availability of relay opto inputs. Multiple setting groups require the operation of a combination of multiple inputs in case of a change in a single status point, for example a transformer breaker. If the programmable scheme logic is used, a single input is sufficient.

ADAPTING TO CHANGES IN ANALOG CIRCUITS

The performance of different protection functions in a distribution system is based on the assumption that the currents and voltages seen by the protection elements correctly represent the primary currents and voltages in the system. However, there are different possibilities for degradation in the accuracy of the instrument transformers or failure in the wiring between the secondary of an instrument transformer and the analog input of a protection device.
Monitoring of the analog circuits allows the multifunctional distribution protection IEDs to detect such problems and adjust their behavior in such a way that will still maintain acceptable levels of protection while eliminating undesired operations. When such condition is detected, a GOOSE message is sent to all IEDs that may be affected.

Voltage Transformer Supervision (VTS)

The voltage transformer supervision (VTS) feature is used to detect failure of the ac voltage inputs to the relay. This may be caused by internal voltage transformer faults, overloading or faults on the interconnecting wiring to relays, as well as fuse failure. Another cause may be human error during maintenance or VT circuit switching.
Following a failure of the ac voltage input there would be a misrepresentation of the phase voltages on the power system, as measured by the relay, which may result in incorrect operation.

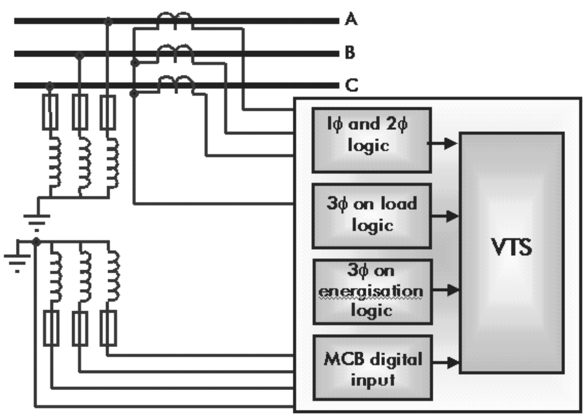

Fig. 4 Voltage transformer supervision logic

The VTS logic in the relays is designed to detect the voltage failure, and automatically adjust the configuration of protection elements whose stability would otherwise be compromised. There are three main aspects to consider regarding the failure of the VT supply:

- Loss of one or two phase voltages
- Loss of all three phase voltages under load conditions
- Absence of three phase voltages upon line energization

Any operation of the Voltage Transformer Supervision logic will indicate the need for maintenance of the voltage circuit of the relay.

Current Transformer Supervision (CTS)

The current transformer supervision feature is used to detect failure of one or more of the ac phase current inputs to the relay. Failure of a phase CT or an open circuit of the interconnecting wiring can result in incorrect operation of any current operated element. Additionally, interruption in the ac current circuits risks dangerous CT secondary voltages being generated.
The CT supervision feature operates on detection of derived zero sequence current, in the absence of corresponding derived zero sequence voltage that would normally accompany it. The voltage transformer connection must be able to refer zero sequence voltages from the primary to the secondary side.
Operation of the element will produce a time-delayed alarm and instantaneous block for inhibition of protection elements. Protection elements operating from derived quantities (Broken Conductor, Ground Fault or Negative Sequence overcurrent should always be blocked on operation of the CT supervision element.

ADAPTING TO CHANGES IN LOAD

The load on distribution feeders can change significantly depending on:

- type of load
- season
- day of the week
- time of the day
- special events
- other

Since a fault condition is characterized not only by increase in phase or zero sequence currents, but also by a change in voltage as a function of the type of fault and the grounding of the system, multifunctional protection relays can use this fact to block the tripping by overcurrent protection relays in case of unbalanced changes of the currents on the protected distribution feeder. Information regarding the amount of load on each feeder is made available to the relays using analog values in the a GOOSE message data set, sent when the load changes outside of the user defines range.

ADAPTING TO FAULTS ON ADJACENT FEEDERS

The changes of fault conditions in the distribution system impact not only the sensitive loads, but also depending on the load may lead to the operation of protection elements of multifunctional relays on healthy feeders.

Detecting the operation of a relay on adjacent feeder can be use to adjust the sensitive settings of the relays on the healthy feeders for the duration of an inrush condition following the clearing of a fault in a distribution system with a significant number of motor loads.

This is known as a Sympathetic Trip scheme. As soon as a relay detects a fault on the feeder that it is protecting, it sends a GOOSE message to all other relays informing them to expect an inrush as a result of the voltage recovery following the clearing of the fault.

Each of the relays on the healthy feeders then adapts its settings for the period of time that the expected inrush condition is going to last. Two options are usually available:

- block the sensitive overcurrent setting
- reduce the sensitivity by increasing the pickup setting for the duration of the inrush

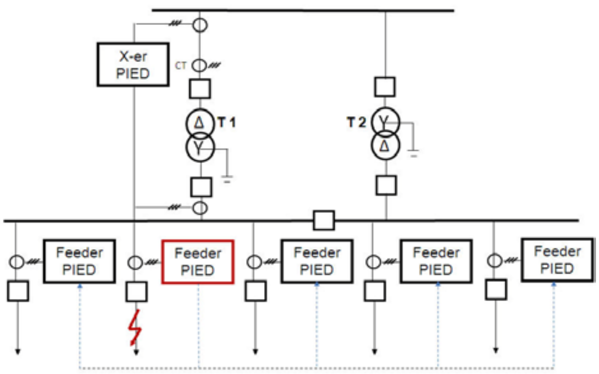

Fig. 5 Sympathetic trip protection

ADAPTING TO LOSS OF PROTECTION IED

The common approach that many utilities have taken is to use a single protection IED on a feeder. In case of failure of this relay, faults on the line are cleared by the backup overcurrent protection on the transformer or sectionalizing breaker.

The problem with this approach is the long fault clearing time that may affect sensitive loads fed by the distribution substation. A solution that significantly reduces the duration of the fault is based on the adjustment that the backup relay can make in its decision to trip based on the knowledge that a specific IED has failed.

This adaptive form of protection uses the normally closed contacts of the feeder relays that close when the relay is not healthy. When the transformer of sectionalizing breaker relay sees a fault and does not get any blocking signal from any of the feeder relays, it knows that there are two possible cases:

- The fault is on the feeder with the failed relay
- The fault is on the distribution bus

The operation of this adaptive protection scheme is show in Figure 6. Since the probability for a fault on a distribution feeder is much higher that the probability for a distribution bus fault, the relay first sends a GOOSE message (1) to trip the breaker of the failed relay. If this does not clear the fault, then it is clear that the fault is on the bus and it is cleared by tripping the source breakers using signal (2).

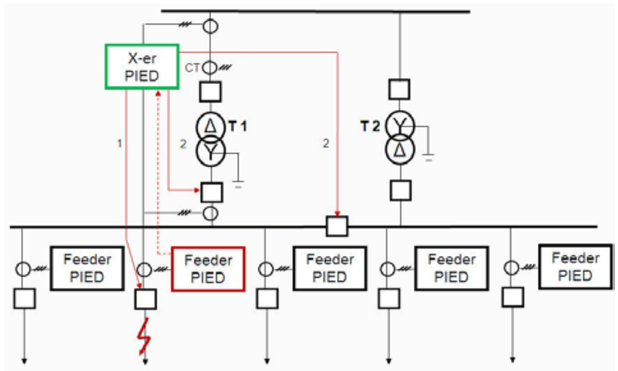

Fig. 6 Selective backup tripping

CONCLUSIONS

Modern microprocessor based distribution protection relays are designed to provide high speed protection under different power system conditions and configuration.

The relays have numerous features that allow them to adapt to a new system configuration and optimize the protection performance. Frequency tracking is used to adapt the sampling rate of the relay.

Multiple setting groups and programmable scheme logic allow easy adaptation to changes in the substation or power system configuration.

Analog circuit supervision adapts the relay operation to failure in the voltage or current circuits.

Voltage supervision of overcurrent functions allows them to avoid undesired operation caused by changing load conditions.

Sympathetic trip schemes can be used to adapt the relay to the inrush condition caused by the fault on an adjacent distribution feeder.

Selective backup tripping significantly improves the performance of the protection of a distribution feeder in case of failure of the relay that normally protects it.