

Better short circuit protection in distribution and sub-transmission networks

Considerable improvements in sensitivity, functionality and selectivity can be obtained for protection systems in town networks, meshed networks and long/short line combinations if the traditional long-differential protection is replaced with uncomplicated impedance protections with communication.



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Most distribution networks are initially built as radials with overcurrent protection, but with several stations after each other the trip delays often turn out to be unacceptably long. Many distribution networks have expanded into interconnected systems that are no longer properly protected with overcurrent relays. The more advanced 66kV and 132 kV systems usually had impedance protection without communication. Short lines or unfavourable short/long line combinations were however not properly protected with acceptable selectivity. Unit protection was therefore introduced, improving selectivity and reducing trip delays.

Unit protection

Unit protection for power lines usually consists of one measuring system in each end of the line, with communication between the line ends. The different solutions have different properties that are analyzed in this document.

Line-differential relays are often considered uncomplicated and reliable, but the measuring principle includes major weaknesses. In the traditional relay models, the measured currents are transformed and continuously circulated on copper cables between the stations. There are clear limits to the length of the lines that can be protected like this. Step voltages between the stations may create serious trouble for the relays. The sensitivity of line-differential relays depends on which primary phase that has a fault, and most of the trip levels are quite high. Some of these problems are solved in numerical relays that communicate via fiber cables or other networks, but several basic problems are still unsolved.

One problem is faults on the signal channel between the stations, causing unwanted or missing functionality. Another problem is missing primary or backup protection outside the range covered by the diff relay. Therefore another local protection is always used as a backup for line-differential systems.

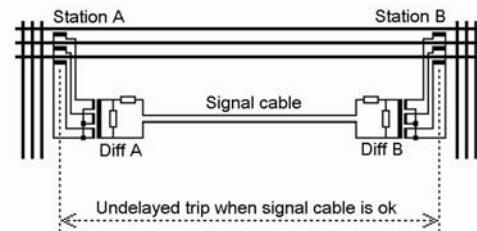


Fig. 1. Traditional line-differential protection

Under impedance relays measure local currents and voltages and calculate impedances (distance) to the fault location. This principle has some weaknesses during side-infeed and by high arc resistances.

When impedance relays are configured as unit protection then one relay is placed at each end of the power line (see fig. 2 below). If one relay can “see” a fault towards another relay, then the fault must be located between the relays and they can both trip undelayed. This logic requires a brief communication between the relays during the fault. If the communication fails then the relays will still operate as normal impedance protective units. The trip delays will then increase and full selectivity is probably not obtained.

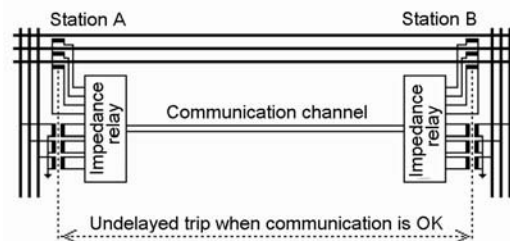


Fig. 2. Impedance based unit protection

Typical properties	Traditional longitudinal-differential relay	Numerical longitudinal-differential relay	Impedance relay with communication
Main trip level	0.2-1.7xIn	0.1-2.0xIn	0.1xIn
Measuring system	Currents	Currents	Currents/voltages
Double earth faults in isolated systems	Tripping two lines	Tripping two lines	Tripping one line (phase priority)
Backup type	Overcurrent (OC)	OC or impedance	Impedance
Backup trip level	I > 1.2xIn (max load) t > 1-3.5 sec	I > 1.2xIn (max load) t > 1-3.5 sec	Z < 0.1xIn Z < 0-0.6 s (zone 2)
Communication medium	Fixed copper cable	Fixed fiber/network	Pulse transfer
Communication activity	Always active	Always active	Active only by trip
Communication distance	Max step voltage 5kV (15 kV possible)	Unlimited	Unlimited
Test procedures	Staff in both stations during complete test	Staff in both stations during complete test	Stations can be tested one by one

Figure 3 Properties of different unit protection schemes

Comparison

Some time ago line-differential relays were the preferred unit protection at 11-132kV. This was caused by high cost, high complexity and complicated maintenance of electromechanical impedance relays. In those days differential relays were less expensive and a lot easier to maintain. Typical properties of protective systems are compared in figure 3.

Outdated

The old electromechanical line-differential systems with copper cables between stations have critical flaws. The trip levels are very high, test and maintenance is quite demanding and the signalling cable between line ends is hard to keep in service. This solution is technically obsolete, but may still be useful if already installed and in operation today.

Limited backup

Line-differential relays only protect the high-voltage unit between the current measuring circuits in both stations, and only if the communication between the stations is intact. Built in overcurrent (OC) or impedance functions can form a backup for both the line and other high voltage components nearby. Busbar faults are usually not covered by the differential function. OC backup trip levels are set above max load current, and OC trip delays are usually very long. Selectivity is not really obtained. It is an interesting thought that the differential protection was installed because the OC protection was deemed useless. Still the OC needs to be re-introduced to handle critical protective functions in this case.

Useful backup

Impedance relays used as unit protection can trip undelayed on unit faults. By communication failure the impedance relays will still protect all components in the system however with a slightly increased trip delay. The backup protection is still functional although reduced selectivity may be expected.

The impedance relay is not perfect, but probably the best option available unless a large number of relays and breakers are duplicated.

Trip levels and measuring principles

Experience indicates that differential relays are frequently unstable. This is caused by the main principle of continuously comparing several measuring values both in amplitude and angle. Faults in measuring circuits usually lead to trip and not to a stable condition, and through faults in the protected primary system easily provoke saturation on one side unless the Ct's are properly matched on both line ends. The need for accurate information from both line ends also put strain on the communication systems between two or more line-ends. When the sensitivity for a differential relay is increased these problems appear even more frequent. Common practise is therefore to reduce sensitivity of line-differential relays to 30-120% of rated current. Impedance relays have a different measuring principle that appears to be much more stable by a sensitivity of 10%-20% of rated current. This is particularly important in systems where fault currents are low.

Communication

The line-differential relays must continuously exchange measuring values between both line ends, and then compare them in real-time. Small failures in the transfer of measured values may result in unwanted trips. The communication between line ends therefore becomes critical:

- High bandwidth / transfer capacity
- Availability / “live time”
- Synchronization of transferred data
- Strict demands on transfer times by multiplexing

These needs can of course be handled, but requires relatively complicated equipment and competence. To obtain proper communication a number of additional parameters in the relays must be evaluated and set.

The impedance relays for unit protection do not communicate continuously, but must transfer a single pulse to the other line end during a fault on the line. The consequences of transfer delays up to 50ms are insignificant and therefore dramatically easier to obtain and less expensive in purchasing, installation and maintenance.

Measuring requirements

The differential relays must have CT's in both line ends, and 3-phase measurement is a must today even if 2-phase measurement can be applied in some cases.

Impedance relays need both voltage and current in all three phases to operate properly, something that may be an issue in old stations without complete measuring systems available. A common VT on the bus is however usually sufficient for the measurements needed.

Double earth-faults

During double earth faults in isolated or weakly grounded systems it is desirable to trip one line only.

When using line-differential relays both lines will trip simultaneously during a double earth faults.

When impedance relays are set in “Phase selection” mode, then double earth faults may trip one line but not the other unless it is programmed to do so. This reduces the short circuit currents to short periods of time, and only one unit is being tripped.

Maintenance

Complete testing of differential unit protection requires staff and test equipment present in both (all) line ends at the same time. This becomes extremely complicated on lines with more than two ends, and results in costly and complicated tests. Undesired connections in the measuring circuits may immediately result in tripping because of differences in the compared currents. The problem can be overcome by introducing a current starting criterion on the relays, but in that case the trip current must always be higher than the load current.

Impedance relays with Permissive Overreach communication (POR) are easily tested by an engineer that moves from station to station testing the individual relays one by one, even if the line has more than two ends. This limits the danger of unwanted trips during testing, reduces the need for qualified staff and reduces the need for detailed work coordination.

Choice without difficulties

The difference in price between communicating impedance relays and line-differential units is insignificant today. A line-differential solution is critically dependent on the communication between both (all) line ends.

Experience and common sense indicates that local functions are easier to operate, maintain and understand than systems that require continuous and accurate information from somewhere else.

Today impedance relays are easier to handle, have higher sensitivity, offers far better backup and have very low requirements to available communication.

It therefore seems obvious that impedance protection combined with uncomplicated communication is a better choice than longitude-differential relays for selective unit protection in meshed networks, city networks and long/short line combinations.

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