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Applying modern communication technology to loss-of-mains protection

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The protection of distribution networks is facing new challenges from an increasing amount of distributed generation (DG). Even though current technology provides satisfactory solutions to manage this new situation, loss-of-mains protection (LOM) is still considered problematic.

The solution proposed in this paper focuses on the use of a line differential protection relay. It inherently contains a suitable communication channel and provides absolutely selective protection for the feeder. Furthermore, it prevents the feeder relays from false tripping for faults on the neighboring feeder.

The present trend in protection communication points towards the use of fibre optics. For line differential protection, this means a fast and high-capacity communication link which enables the implementation of many advanced protection functions. In addition, a solid foundation for such a communication link is offered by the new IEC 61850 standard and Ethernet technologies.

The basic functionality of the line differential protection enables the operation of both the feeder protection and the DG protection for any fault on the feeder. Furthermore, basic LOM protection methods can be applied as backup protection for failures on the communication link.

INTRODUCTION

The share of distributed generation (DG) is expected to grow rapidly in the near future. Besides the environmental aspects, a shorter construction period is considered as a key driver in accelerating its development. Around the world, huge R&D resources are currently used for developing a variety of new distributed energy generation technologies. Typically these technologies have brought about modular and relatively small production units in the output range of 10 kW to about 10-20 MW located near the energy consumer. In practice this means the power distribution network has to accept and be able to manage distributed generation.

Traditionally, it has never been common practice to connect generation directly to distribution networks and thus the industry is facing new challenges. One of the areas requiring special consideration is system protection. If adequate protection is to be achieved, all possible faults and operating conditions must be considered and this is not as straightforward as it might seem. To handle this new situation many new approaches and technologies have been developed and introduced. For loss-of-mains (LOM) protection, however, a good general solution is simply not available. In this paper a new approach, based on a modern line differential relay, is proposed. At first a general overview of DG is given together with various protection related problems, and this is followed by an introduction of and an example using the new approach.

DISTRIBUTED GENERATION

Technologies

Among the various forms of DG wind power has been the fastest growing power technology [1]. Wind power technology is rapidly developing and the size of the units has been increasing from below 1 kW units to over 5 MW. In the power range below 1 MW a typical design has been the fixed-speed stall regulated wind turbine with a asynchronous generator. In order to withstand mechanical stress, most wind turbines above 1.0 MW are equipped with a variable-speed system incorporating power electronics in combination with pitch control.

Other widely applied DG technologies are photovoltaic (PV), reciprocating engines and combined heat and power (CHP) plants. Of these the reciprocating engines and CHP represent conventional technology applying a synchronous generator. PV represents modern technology in which power electronics are applied in the grid connection. PV panel outputs direct current that is directly proportional to the solar radiation. Before the generated current is fed into the grid, it is first fed to a DC/DC converter to achieve the desired voltage level and then to a DC/AC converter to obtain the desired AC output. A similar approach is adopted in other technologies that are still in their early development stages, such as the fuel cells.

From a grid or distribution network point of view, the DG units can be considered as power sources with various characteristics. According to these characteristics three basic types of DG units can be categorized according to the type of interconnection device:

– Asynchronous generator
– Synchronous generator
– Inverter

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Of these the first two represent traditional technology.However, due to DG the use of asynchronous machines as generators is increasing. When compared to synchronous generators, asynchronous generators have only limited capability when it comes to providing short-circuit current in fault situations. This must be taken into account in network protection. DG incorporating inverters represent a new technology that has consequently led to re-assessment of the protection system design. One major disadvantage with these types of

DG units is that they are typically not capable of producing any significant short-circuit current. IEC standards [2] assume that the short-circuit current delivered by an inverter is three times the rated current. However, in many cases the maximum fault current is limited to about twice the rated current in order not to damage the sensitive power electronic components.

Protection of power systems containing DG

From a technical point of view, the connection of DG units to a distribution network is a challenging task. The basic reason for this is that distribution networks are typically not designed for hosting generation. For example, the traditional relay protection system of a medium voltage (MV) network relies on the fact that the fault current is fed from one direction only. An increasing proportion of DG means the network topology is now evolving towards a ring or even a meshed system. When DG is added to a typical distribution network, potential problems may arise for main two reasons:

- In the management of the network voltage level the effects of DG must be taken into account.
- Detailed studies and even some advanced solutions are necessary to achieve properly functioning protection arrangements.

This paper considers only the protection related problems, and the most commonly mentioned ones are:

- False tripping of feeders (sympathetic tripping)
- Nuisance tripping of production units
- Blinding of protection
- Increased or decreased fault levels
- Unwanted islanding
- Prohibition of automatic reclosing
- Unsynchronized reclosing

The appearance of these types of problems depends on the characteristics of the network and on DG. In short-circuit faults a DG unit generates a fault current that depends heavily on both the generator type and the network configuration. Current protection technology offers satisfactory solutions in most cases, but LOM protection is still considered problematic.

Since the distributed generators owned by independent power producers are usually not designed for island operation, LOM protection is a necessary part of the system protection. It is also considered necessary from a personnel safety point of view. LOM protection is usually required either in the grid codes or utility specific interconnection rules.

The codes and guidelines vary from country to country but requirements similar to the following are often given [5]:

- DG should be disconnected from the network in case of abnormalities in voltage or frequency
- If one or more phases are disconnected from the grid supply all DG units should be rapidly disconnected from the network
- If auto-reclosing is applied, the DG units must be disconnected well before reclosing to allow enough time for the fault arc to extinguish.

DG seems to be incompatible with current reclosing practices. Under certain conditions DG may prevent arc extinction, which means that a temporary fault becomes permanent. During the reclosing sequence dead time, the generators in the network usually tend to drift out of synchronism with the grid. However, reconnecting without synchronizing, which is common practice, may seriously damage the generators and introduce high currents and voltages into the neighboring network.

During the past years, many methods for detecting island operation have been proposed and developed. Two commonly used methods are the rate of change of frequency (ROCOF) method and the vector shift method [3]. In practice, these methods have turned out to be too sensitive and to cause false trips, for example, due to major faults in a neighboring part of the network.

LOM detection techniques can be divided into three categories:

- Passive methods
- Active methods
- Communication-based methods

In the first one protection is accomplished by relying solely on the available measurements. However, a major drawback of the passive methods is the so-called non-detection zone. In other words, passive methods are unable to detect islanding if the power mismatch at the tie-breaker creating the island is small.

Active methods “actively” induce disturbances in the voltage. These methods are especially suitable for generating units which are based on grid inverters. A good overview of different methods, especially methods used in PV systems, is given in [4].

The third category of LOM detection methods consists of communication-based methods. In the transfer trip scheme, the feeder relay located at the substation sends a trip signal to the DG units located along the feeder. For this purpose, a suitable communication channel is needed.

The latest solution proposed in this paper is the use of a line differential protection relay. It inherently contains a suitable communication channel, and provides absolutely selective protection for the feeder. Furthermore, it prevents the feeder relays from false tripping in case of faults on the neighboring feeder.

LINE DIFFERENTIAL PROTECTION

By nature, the line differential protection scheme offers unit protection functionality for the feeder in question. This type of totally selective protection provides ideal basic protection for the interconnecting feeder between the DG unit and the MV distribution network. Depending on the applied system earthing principle, the line differential protection system has to be supplemented with suitable earth-fault protection functions to achieve the necessary sensitivity for earth faults. In case the interconnecting feeder is an overhead line type, the need for auto-reclosing will also be considered.

Protection communication channel

The line differential protection scheme has developed from the plain pilot-wire relay to a modern, communicating, numerical, phase-segregated multifunctional protection and control IED. Also the requirements on the protection communication channel have changed from that of a galvanic connection, - carrying purely analogue signals - to an optical link transferring information between the line ends in digital format. Since the bandwidth of an optical link is considerably higher than that of a galvanic link, it is also possible to use the optical link to transfer information other than that from the line differential protection point of view.

Binary signal transfer (BST) is a feature whereby a number of binary signals can be transferred from the local to the remote end of a feeder and vice versa. This functionality utilizes the communication channel of the line differential protection. The binary signals originate from either the relay's internal logics or from an external source, and they can be utilized in the internal logics of the relay at the opposite line end or they can be routed out of the relay to an external device. Typical application areas for the BST functionality include transfer trip, blocking or permissive protection schemes, interlocking of the control of primary devices and co-ordination of auto reclosing.

As a critical link in a unit protection scheme, the protection communication channel is constantly supervised. Any breakdown in communication, irrespective of duration, is immediately noted by the relays and acted on.

HORIZONTAL SUBSTATION COMMUNICATION

The IEC 61850 standard is rapidly gaining a significant foothold in electric power utilities. IEC 61850-8-1 specifies the so-called GOOSE (Generic Object Oriented Substation Event) functionality, while certain performance classes for the GOOSE messages for different applications are specified in IEC 61850-5. Modern protection relays with a "native" implementation of IEC 61850 have opened up possibilities for extending the new approach in the engineering of station wide protection schemes. A native implementation refers to a design where no internal or external adapters are used and the data modelling of the relay is based solely on the IEC 61850 standard. The publisher/subscriber method used in GOOSE messaging provides an efficient and fast means of sharing information between all relays in a substation. The inherent quality validation of GOOSE messages and the condition monitoring of the physical communication link increase reliability and provide a means of alerting the operator (or even of automatically changing the system parameters) in case any abnormalities are detected.

EXAMPLE OF LOM IMPLEMEMTATION

To speed up LOM protection and to enhance its reliable operation, GOOSE and BST signaling can be employed. At substation "A", the positions of breakers 1Q0 and 2Q0 are checked, and if either one is opened the information is transmitted to the generator control and protection system of substation "B", so that an immediate disconnection can be made. The conventional, passive, LOM protection system remains as back-up in case of a communication failure between the substations. The transfer to the back-up system is automatically performed based on the supervision of both the horizontal (i.e. bay-to-bay) and the vertical (in this context station-to-station) communication.

To illustrate such an LOM protection situation let's assume circuit-breaker 2Q0 is opened by mistake. The change in the breaker position is noticed by the REF615 relay via a binary input. This information is transmitted using GOOSE to the RED615 relay at substation "A". The information is further transferred to the RED615 relay in substation "B" using BST signalling. At substation "B" the information is taken out of the RED615 relay via a binary output and transferred to the generator control and protection systems. In such an example, the total signal transfer time delay would be below 30 ms.

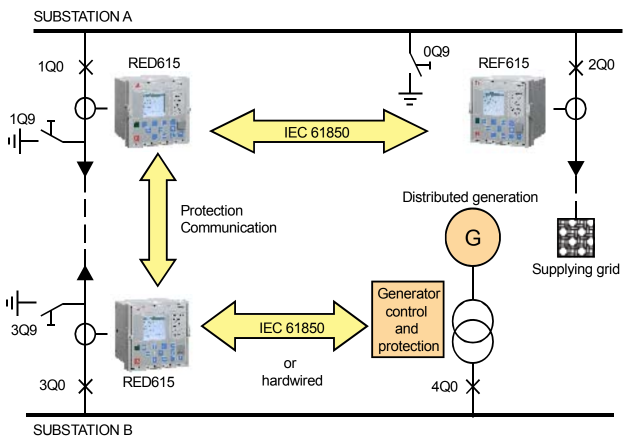

Figure 1. RED615 Line differential protection and REF615 feeder protection relays utilizing GOOSE and BST signalling in a power system with distributed generation (DG).

Signal transfer times for the above described application using RED615 and REF615 relays are shown in Table 1. The total signal transfer times seen in the test results include the physical binary input activation delay (typical impact on test results 10 ms), GOOSE message transfer delay, BST signalling delay and the physical output contact delay (typical impact on test results 10 ms).

Total Signal Transfer Time	Number of Test Cycles
24 ms	143
25 ms	416
25 ms	1352
27 ms	1274
28 ms	1079
29 ms	637
30 ms	99
	Σ 5000

Table 1. Distribution of signal transfer times obtained at a LOM protection scheme test with out-of-the-box relays.

CONCLUSION

In applications where the communication infrastructure and primary circuit lay-out support the use of line differential protection of the interconnecting feeder, LOM protection can be realised in a fast, reliable and selective way by utilizing the communication link of the line differential protection scheme for BST signalling. Combining the vertical inter-substation BST signalling with horizontal GOOSE messaging at the substation level, further enhances the operation and the reliability of the protection. As Table 1 shows the total operating speed of a modern LOM protection system can be up to a decade faster than that of a traditional LOM protection system, without compromising sensitivity and selectivity. The conventional passive techniques for LOM protection can be utilized as back-up or stand-by protection should any abnormalities be detected in the communication chain.

REFERENCES

[1] Ackermann T. (ed.), 2005, Wind Power in Power Systems, John Wiley & Sons

[2] IEC 60909-0, 2001, "Short-circuit currents in threephase a.c. systems - Part 0: Calculation of currents", International Electrotechnical Commission

[3] Jenkins, N., Allan, R., Crossley, P., Kirschen, D., Strbac, G. 2000: Embedded generation. IEE Power and Energy Series 31, IEE

[4] Bower, W., Ropp, M., 2002, Evaluation of Islanding Detection Methods for Photovoltaic Utility-Interactive Power Systems, Report IEA PVPS T5-09: 2002

[5] K. Kauhaniemi, L. Kumpulainen, 2004, "Impact of distributed generation on the protection of distribution networks", Eighth IEE International Conference on Developments in Power System Protection, Amsterdam, Netherlands, 5-8 April 2004, pp. 315 – 318

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