HABITUAL PRACTICES USED BY SPANISH ELECTRICAL COMPANIES TO DEAL WITH HIGH IMPEDANCE FAULTS

SUMMARY

Electrical power systems are planned and designed to supply energy dealing with all security and reliability requirements. Conventional protection schemes, based on measuring currents or impedances cannot successfully achieve high-impedance phase to ground faults detection and clearance. This situation generates a very high risk situation for person’s security.

This paper presents the protection practices used by Spanish utilities to detect and clear high-impedance faults in their networks. For this purpose, electrical networks have been classified in three types: Transmission network, meshed Distribution network and radial Distribution network. Conclusions drawn from operating experience are presented and opportunities for improving sensitivity for the detection of high impedance faults are identified.

INTRODUCTION

Most of disturbances registered in power systems have their origin in low impedance faults and consequently produce substantial increases in currents flowing towards fault location. Currents magnitude can reach several times the nominal rates of lines and transformers, so, protection against this kind of faults is successfully achieved by means of conventional protection schemes based on measuring currents or impedances.

However, it is not unusual, especially in Distribution networks, to register faults with currents magnitude around or below nominal rates, and even below the sensibility limit of conventional protection relays. As a result, these relays are unable to detect and clear such faults. This situation is mostly observed in high-impedance phase to ground faults and generates risk situation for person’s security. Main factors contributing to this phenomenon are:

High impedance fault. This type of failures happens when a high impedance object (like a tree) contacts a phase conductor or when a broken conductor falls on to a very resistive ground. Eventually, resistance in the contact to earth point increases reducing fault current significantly, even to zero.

System grounding. It is usually different in Transmission and Distribution networks and relays both on technical and legal aspects, what justifies that its historical evolution differs from one country to other and even from one utility to other.

Isolated neutral result in low phase to ground fault currents even in case of low impedance faults. Neutral in Spanish Transmission and Distribution networks with voltages over 30 kV is solidly grounded. However, the most extended grounding practices in Distribution networks from 1 to 30 kV in Spain are both isolated neutral and reactance grounding.

TRANSMISSION NETWORK

The Spanish transmission network is a solidly grounded 3-wire network at the 400 and 220 kV voltage levels, with all transformer and autotransformer neutrals directly connected to earth.

The usual protection equipment for detecting phase to ground faults in line bays consists of:

87L – Line bays are equipped with line differential protection. With the sensitivity settings which are usually carried out for the line differential protection and the transformation ratios applicable to the supply current transformer (CT), faults to ground of a few hundred A can be detected. The faults detected by these protection systems are cleared instantly.

21G – As secondary protection, line bays are equipped with distance relays measuring the phase to ground loop. These relays are provided with a teleprotection scheme (the permissive scheme is mainly used although there are exceptions). Single pole tripping and reclosing is implemented. Relays are set to detect faults to earth with a typical resistance value between 30 and 40 ohms.

67N – It is usual for the main (87L) and reserve (21G) protection relays to include a directional ground overcurrent unit with a very inverse or inverse current-time characteristic and three phase tripping. This protection system is typically set to detect faults to ground with a resistance of 40 ohms, which usually oscillate between 15% and 30% of the transmission capacity of the line to be protected, and to withstand open pole operation during single phase reclosing. It is usual to have ground current settings in the 200-350 A range. When the residual current values are quite low (appreciably resistive faults), the operation times which are achieved with the 67N function are usually s or even in excess of one minute.
MESSED DISTRIBUTION NETWORK
In this section we consider all voltage networks below 220 and over 1 kV in meshed operation.

In Spain, the meshed distribution networks are 3-wire networks at voltages of 132, 110, 66, 50, 45 and 30kV. These are solidly earthed systems, with the exception of the 30 kV networks, which are earthed by means of a zigzag reactance. It is usual not all the neutrals to be grounded in order to limit ground short-circuit currents.

Solidly grounded network

These networks are connected to the transmission network by means of Y-y transformation solidly grounded. The connection between meshed distribution networks with different voltage levels is carried out also by means of Y-y transformation (transformers or autotransformers) solidly grounded. Generation is connected to the network with Y-d transformation, with delta on the generation side and the star with the neutral grounded on the distribution side.

Transformation to the radial distribution network is carried out by means of Y-d or Y-y transformers, with the neutral of the primary solidly grounded or ungrounded according to the criterion of the company.

The usual equipment for detecting phase to ground insulation defects in lines consists of:

21G – Lines are equipped with an impedance protection system using measurement of the phase-ground loop set to detect phase to ground faults with a resistance of 20-30 ohms. The polygonal feature is preferred to detect ground faults with resistance. In those relay which so permit, differentiated zero-sequence balancing factors ($K_0$) are incorporated for each step. Occasionally the protection system is provided with a teleprotection scheme, which might be accompanied by a directional comparison scheme (67L) for ground faults. Where directional comparison is not used, the resistive sensitivity of the 21G function is limited by the length of the line to be protected. In those 132 kV installations with critical clearing times of less than 500 ms, two impedance protection systems with teleprotection are fitted.

67N – Lines are equipped with directional ground overcurrent units with current-time feature of the inverse type, set to detect ground faults with a resistance of 40 ohms. These relays usually include an instantaneous ground overcurrent unit.

67L – In cables or overhead lines with a length of cable in excess of 20% of the total line length or otherwise in overhead lines with a length of less than 4 km, a line differential protection system is frequently installed.

Zigzag reactance grounded network

The 30 kV network is connected to the transmission network by means of Y-d transformation. On the 30 kV side, the transformer is grounded referred by means of a zigzag reactance. It is a 3-wire network grounded in the head substations by means of the zigzag reactance. All the lower voltage level transformers towards the radial distribution network are D-y.

The usual equipment for detecting phase to ground insulation defects in lines consists of:

51N – Lines are equipped with non-directional ground overcurrent units with current-time feature of the inverse type, set to detect ground faults with a resistance of 40 ohms. These relays usually include an instantaneous ground overcurrent unit.

Providing back-up in the case of phase to ground faults in lines the following protection equipment is installed in power transformers:

51N – At each of the transformer voltage levels, non-directional ground overcurrent relays with current-time feature of the inverse type are fitted and operate as back-up in case of line faults.

Solidly grounded 45 kV network

One part of the 45 kV network is operated radially, and is connected to the transmission network or to the 132 kV meshed network by means of Y-y transformation with neutral solidly grounded. It is a 3-wire network in which the transformers connected to the 45 kV lines of the network are MV transformers and have a D-y or D-z connection set, so that they are ungrounded on the 45 kV side.

The usual equipment for detecting phase to ground insulation defects in lines consists of:

51N – Lines are equipped with non-directional ground overcurrent units with current-time feature of the inverse type, set to detect ground faults with a resistance of 40 ohms. These relays usually include an instantaneous ground overcurrent unit.

Providing back-up in the case of phase to ground faults in lines the following protection equipment is installed in power transformers:

51N – At each of the transformer voltage levels, non-directional ground overcurrent relays with current-time feature of the inverse type are fitted and operate as back-up in case of line faults.

Solidly grounded MV network

This is a 3-wire MV distribution network (<30 kV) supplied by D-y transformation in which the only grounding is carried out by grounding the transformer neutral, either solidly or by means of a limiting reactance of 4 ohms (depending on the power rating of the transformer). Transformers connected to the MV lines of the network have a D-y or D-z connection, so that they are earth insulated on the MV side. Networks of this type have voltage ratings of 20, 15, 13 and 11 kV.

The following protection systems are fitted to detect
insulation defects between phase and earth in lines:

51N - Lines are equipped with protection systems with non-directional ground overcurrent units with a current-time characteristic of the inverse type, set between 20 and 40 A and connected on the neutral of star-connected CTs. These protection systems include an instantaneous ground overcurrent unit set at 300 A primary or according to the length of the lines.

50NS - The protection systems which are currently installed at the line outputs are digital and are equipped with a sensitive non-directional ground overcurrent unit connected, either on the neutral of the secondary protection CT, or on measuring CT, or on a toroid CT and set in the range of 4-10 A primary (depending on the ratio of the CT) and time delay timed at 50 s.

Providing back-up in the case of phase to ground faults in lines the following protection equipment is installed in power transformers:

51N – A non-directional overcurrent protection system with an current-time characteristic of the inverse type is installed in the transformer position of the head substation and acts as back-up protection in case of failures in the MV network and is set to a start value of between 75 and 120 A primary according to the type of grounding.

51G – It is usual to install a toroid CT in the connection of neutral to ground. A non-directional overcurrent relay with current-time characteristic of the inverse type is connected to the toroid CT. This relay acts as back-up protection for faults in the MV network and it is set to a starting value between 85 and 150 A primary according to the type of grounding. Some utilities do not install this relay.

Zigzag reactance grounded MV network

This is a 3-wire MV distribution network (<30 kV) supplied by a Y-d power transformer in which grounding is carried out connecting to ground, either directly or using a resistor, the neutral of a three phase reactance with a zigzag connection that limits the fault current to 300, 500, 575 or 1000 A. Load transformers connected to the MV lines of the network have a D-y or D-z connection group, so that they are earth insulated on the MV side. Networks of this type have voltage ratings of 25, 20, 15 and 11 kV.

If they are overhead or mixed MV line feeders, the limitation is to 300 or 500 A. If they are underground MV line outputs, the limitation is to 1000 A.

The following protection systems are fitted to detect insulation defects between phase and earth:

51N - Lines are equipped with a non-directional ground overcurrent relay with a current-time characteristic of the inverse or very inverse type. The relay is set to 30 A primary, or to 6% of the rated current of the CT, or to the scale minimum (10% of the rated current of the CT in the electromechanical relays). The relay is connected on the neutral of the star-connected secondary of CTs, or on the secondary of a toroid CT. These relay include an instantaneous neutral overcurrent unit, set at 300 A primary or at 8 times the starting current (or 5 times if the start-up is 0.5 A).

87L – Line differential protection systems are installed at both ends of underground feeders without taps.

50NS - The protection relays which are currently installed at the line outputs are digital and are equipped with a sensitive non-directional ground overcurrent unit. This unit is connected either on the neutral of the star-connected secondaries of protection CTs, or on the neutral of the star-connected secondaries of measuring CTs, or on the secondary of a toroid CT. It is set in the range of 2 to 10 A primary and is delayed between 7 and 50 s.

Providing back-up in the case of phase to ground faults in lines the following protection equipment is installed in power transformers:

51N - A non-directional overcurrent protection system with current-time characteristic of the inverse or very inverse type is installed in the MV position of the HV/MV transformer of the head substation and acts as back-up protection in case of failures in the MV network and is set to a start value of between 75 and 120 A primary according to the type of grounding or to 10% of the rated current of the CT.

51G - A toroid CT is installed in the neutral of the zigzag reactance and a non-directional overcurrent protection relay with current-time characteristic of the inverse or very inverse type is connected and This relay acts as back-up protection in case of failures in the MV network and is set to a starting value between 18 and 200 A primary according to the type of system grounding. Some utilities install a second non-directional overcurrent independent-time measuring relay set to 3 and 10 A primary and time delay between 15 and 20 s that only cause alarm at the control centre, without tripping any circuit breaker.

49 – A thermal replica relay is fitted in the toroid CT of the grounding element.

59N – In addition, in installations earthed by means of a three phase reactance with a zigzag connection, a three VT set is installed in MV bus bars with a secondary connected in an open triangle in which an overvoltage relay is fitted that measures the neutral point displacement voltage (voltage between neutral and earth). This relay is set to detect the neutral point displacement voltage that causes a 15 A ground fault current, and generates an alarm after 30 s so that the Control Centre begins switching in order to locate it. In facilities in which there are no digital relays equipped non-directional sensitive ground overcurrent units at the line outputs, tripping of the transformer MV switch takes place 30 minutes after the alarm is raised. Some companies use this option because this protection system only generates an alarm to the control centre, without causing tripping.

Resistance grounded MV network

This is a 20-25 kV network powered by Y-y transformers and single grounding in the substation with a 6 ohms resistor and current limitation to 310=1000 A.

To detect phase to ground faults, the protection and criteria of
zigzag reactance grounded networks are also applied.

**Ungrounded MV network**

Some Spanish utilities are using this type of grounding for distribution networks with voltages of 10, 15, 20 and 25 kV. These are three wire distribution networks powered by Y-y-d, Y-d or Y-y transformers whose secondary windings are ungrounded. Load transformers are D-y or D-z, so network is isolated from ground. The following protection systems are fitted to detect insulation defects between phase and earth in lines:

**67N** - Lines are equipped with a directional overcurrent relay with definitive time settings connected to a toroid CT with a ratio of 20/1 or 60/1 or CT in residual current connection (primary current below 200A). Sensitivity setting is adjusted between 0.12 and 1 A, primary side, taking into account the number of lines, length and type of line: overhead or underground cable. Studies shows that a phase to ground fault supply 4 A per 100 km of overhead line and 20 A per 100 km of cable. To define settings, a simultaneity factor is considered regarding network topology -lines out of service- when the fault occurs. The polarization voltage is taken from voltage transformers of 110:√3 or 110:3 ratios with starting setting of 58 V and 30 V (secondary) respectively.

Definitive time settings are applied. According to the utility, values of 250 ms or 3 s for overhead lines and 2 s for cables are applied. Because of the starting relay characteristics, higher polarization is need for low current faults. In most of networks, sensitivity of 2000 ohms is obtained. This time setting and tripping characteristics are intended to allow self extinction of arc fault. Typical fault levels are between 30 and 100 A. As network grows, fault current increase and self-extinction ratio reduces. Some faults are very difficult to be located because of the small thermal effect. As the damage is not visible, fault location could be very difficult for maintenance crews.

**59N** - In addition, a zero sequence voltage relay is installed connected to the open delta secondary of bus bar voltage transformers. Relay is set to 64 V for 110:√3 V secondary VT or between 30 and 35 V for 110:3 V secondary VT. Time setting is adjusted between 4 and 10 s. When a fault is detected, an alarm is send to the control centre and a process, manual or automatic, starts opening and closing lines sequentially to locate the faulty line. Other practice is to trip the transformer after a time since the alarm appeared, being possible to disconnect the relay trip from control centre. In substations with only two or three very short lines, faults could not be detected because of the low current contribution from healthy lines.

**CONCLUSIONS**

The following conclusions can be highlighted:

**Transmission network**

The protection systems and setting criteria used in transmission network are effective in detecting high impedance faults. Faults of current below line differential and ground overcurrent protection sensitivity levels are very rare, due to it is solidly grounded.

**Meshed Distribution network**

All of the distribution utilities in Spain are applying the same protection functions for ground faults in the meshed distribution network (mainly distance and directional ground overcurrent protections for overhead lines, line differential protection for cables and non-directional overcurrent relays as back-up protection in transformers), with the setting criteria of reaching enough sensitivity to detect faults of 20 to 30 ohms of resistance.

There is a tendency to commonly use teleprotection systems in meshed distribution networks of higher voltage, such as 110-132 kV, although they are only required if critical fault-clearing time is under 500 ms.

**Radial Distribution network**

The following difficulties have been observed in networks with insulated neutral:

- When a ground fault occurs, healthy phase voltages increase, so the probability of a second ground fault increases, this causing a two-phase to ground fault. The reclosing trials considerably increase the probability that this phenomena will happen.

- Ferro resonance phenomena can be present. They are generally avoided by means of installing resistances in the open delta connection of VT secondary

- The protection system is more complex as voltage polarization is required.

- Although high impedance fault detection sensibility is considerably higher than that of solidly earthed networks (in the range of some mA), however, sometimes fault location is very difficult because damage is reduced.

- In substations in which there are few lines of very different length, if there is a trip of the longest line, the fault current in the rest of the lines is reduced, even below protection sensitivity levels.

The following difficulties have been observed in solidly grounded networks:
Ground fault currents are comparable to phase fault currents and therefore more destructive, so it is advisable to install current limiting resistances at grounding connection.

Although modern digital technology has permitted to increase protection sensitivity, difficulties have been observed to detect high impedance faults, because fault currents are in cases still below protection sensitivity levels.

Current limit to protect human life is estimated in 0.5 A. The sensitivity that can be reached by protections (even considering digital protections) is far from that value, so that they cannot preserve human life.

It has been identified that in all radial distribution networks, with any kind of grounding system, there is a serious difficulty to detect and isolate ground faults caused by an open conductor with contact to ground, under voltage from load side. The neutral-to-ground voltage displacement and the fault current are so weak that they cannot be detected by conventional protections based on overcurrent or overvoltage measurement, and the detection by negative sequence current is complicated because it depends on the load amount that is “beside” the defect. In this situation, for networks with insulated neutral, the 59N protection installed in the bus bar that supplies the feeder under fault, can helps in its detection and location.

Technology and future

In Spain, there is little experience in the use of high impedance fault detection systems based on harmonic analysis, arc detection algorithms, and expert systems. However, in distribution networks, conventional protection systems have proved to lack enough sensitivity to detect all high impedance faults, and difficulties have been observed to locate defects of low current. Considering also the increasing importance of securities issues, in the future it will be necessary a considerable effort in technology research between manufacturers and utilities in this area.

In this task, it can be foreseen that the research will mainly focus on the improvement of today current measurement sensitivity, which can be achieved by the estate of the art technology.