PROTECTION SCHEMES AND GROUNDING METHODS ON MV RENEWABLE SUBSTATIONS IN SPAIN

Carlos Aguilar, GE Grid Automation, Spain
Nemanja Vukobrat, GE Grid Solutions, Serbia

SUMMARY

This paper addresses renewables plants protection schemes and grounding methods used on MV interconnection substations in Spain. Several issues must be considered on the design of protection schemes and their setting calculation for these types of plants, where there is a contribution from both sides of the plant to short-circuit fault currents. Installed base in operation of Wind and Solar PV generation in Spain is 31,2 GW and there are already 102 GW granted but not in service. Despite of this, there is no national nor international guideline for the protection schemes to be used on these plants.

For multiphase faults, it will be explained phase overcurrent coordination and how it is affected by the contribution from the wind or solar PV side. Coordination with cable and transformer damage curve will be explained. Directional overcurrent schemes are also discussed and how they could be used for MV bus zone protection, implemented through 61850 Goose signalling.

Typical grounding schemes on MV substations are done through zig-zag grounding transformer to provide a low impedance earthing system and, in some cases, ungrounded systems are used. Phase to ground fault detection will be explained on both systems, at MV interconnection of power transformer that connects to the grid and at wind or solar PV feeders. Zig-zag grounding transformer protection and breaker failure implementation with 61850 goose signalling will be covered as well.

The paper continues with other protection elements dependent on voltage and frequency and how to reduce the implementation engineering time of breaker failure and MV bus zone protection schemes based on 61850 in case of installation of a new wind or solar PV circuit.

As conclusion, European Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators and New Spanish Grid Code proposal following European guidelines is explained and how they will affect to future protection systems.

Key words: Renewable Plants Protection, Regulations.

Carlos.aguilar@ge.com

RENEWABLE PLANTS TOPOLOGIES AND GROUNDING SCHEMES

Typical single line diagram topologies used in renewable plants are shown in FIGURE **1**. A medium voltage system with voltage levels that can vary from 12 kV to 34,5 kV is connected to national network at 66 kV or 220 kV voltage level through commonly one transmission line. Step-up transformer and total power capacity of renewable plants are generally in the range of 20 MVA to 60 MVA with an ungrounded delta winding connection on medium voltage level and solidly grounded wye winding connection at high voltage level. Medium voltage level circuits are limited to 4-6 circuits, which link to several photovoltaic transformer centers or wind turbine generators, depending on the type of plant. A Battery Storage System can also be installed at medium voltage level for storage of production during low consumption hours.

Grounding scheme most frequently used at medium voltage level is through zig zag grounding reactor with a resistor between the zig zag grounding transformer and the ground, obtaining a low impedance grounding scheme at medium level and limiting ground currents to 300 A to 600 A, depending on the project specifications. In rare cases, medium level is kept ungrounded.

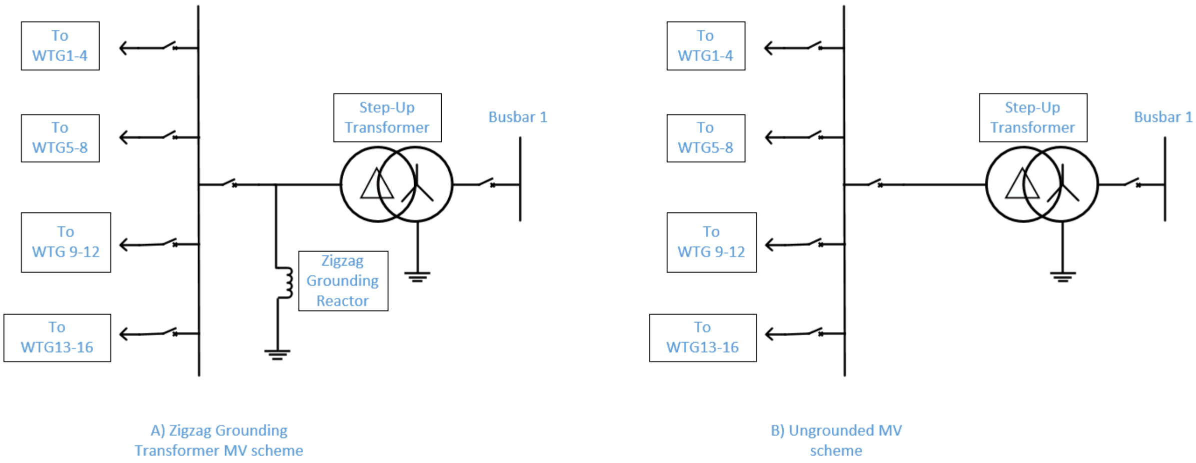

FIGURE 1 – TYPICAL TOPOLOGIES OF RENEWABLE PLANTS

MULTIPHASE FAULTS PROTECTION

Due to low contribution of wind turbine generators or photovoltaic plant in comparison to short-circuit power and current faults provided by high voltage network, multiphase faults at medium voltage level on renewable plants can be generally covered through standard phase overcurrent elements. This consideration allows us to consider the renewable plant as a radial system and coordination will be followed considering the renewable generation as the downstream point.

Phase time overcurrent protection on circuits to renewable generation must be coordinated with protection elements included on each Wind Turbine Generator or each transformer center connected to the photovoltaic systems. Pickup of phase time overcurrent must cover the lowest cable ampacity on the circuit and it must obviously allow nominal current of the whole circuit, as well as coordinated with renewable generator step-up transformer protection. This could not be achievable at some point due to cable sections on circuits decrease as far as you are from the supplying circuit, as less load is expected at the end of the circuit, where only one remaining Wind Turbine Generator or Photovoltaic system remains to be connected. This can be shown in FIGURE 2. Directional overcurrent with higher sensitivity could be added in these cases looking into the collector feeder to improve coordination, but special care must be taken as directional elements can maloperate during external faults as specified in MIGRATE Project Working Package 4 (1).

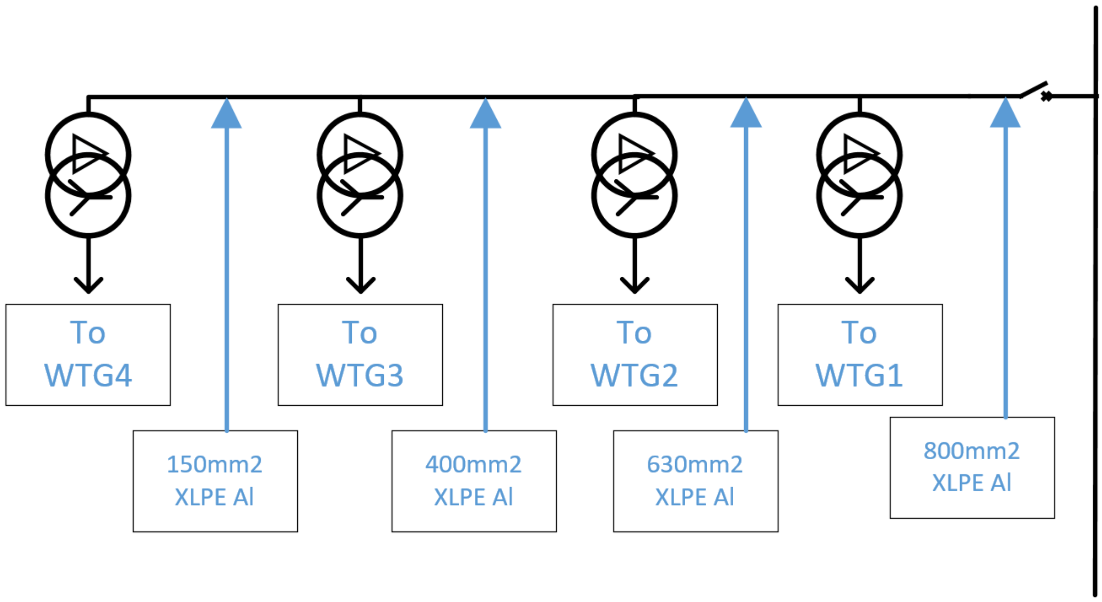

FIGURE 2 – CIRCUIT TOPOLOGY AND CABLE SECTION DECREASE

Medium voltage incomer phase time overcurrent will be coordinated with cable thermal capability of the incomer itself, transformer damage curve and downstream protections on circuits to renewable generation.

Phase instantaneous overcurrent pickup on medium voltage circuits to renewable generation must be below the minimum multiphase fault on the furthest renewable generation in each circuit. It must be time coordinated with individual protection of each renewable generator with at least 200 ms of coordination time. In the same way, at medium voltage incomer, phase instantaneous overcurrent can be considered as the main protection against busbar faults and it must have a time coordination of at least 200 ms to avoid tripping on medium voltage circuit faults.

An example of phase time overcurrent and phase instantaneous overcurrent curves coordination at medium voltage is shown in FIGURE 3.

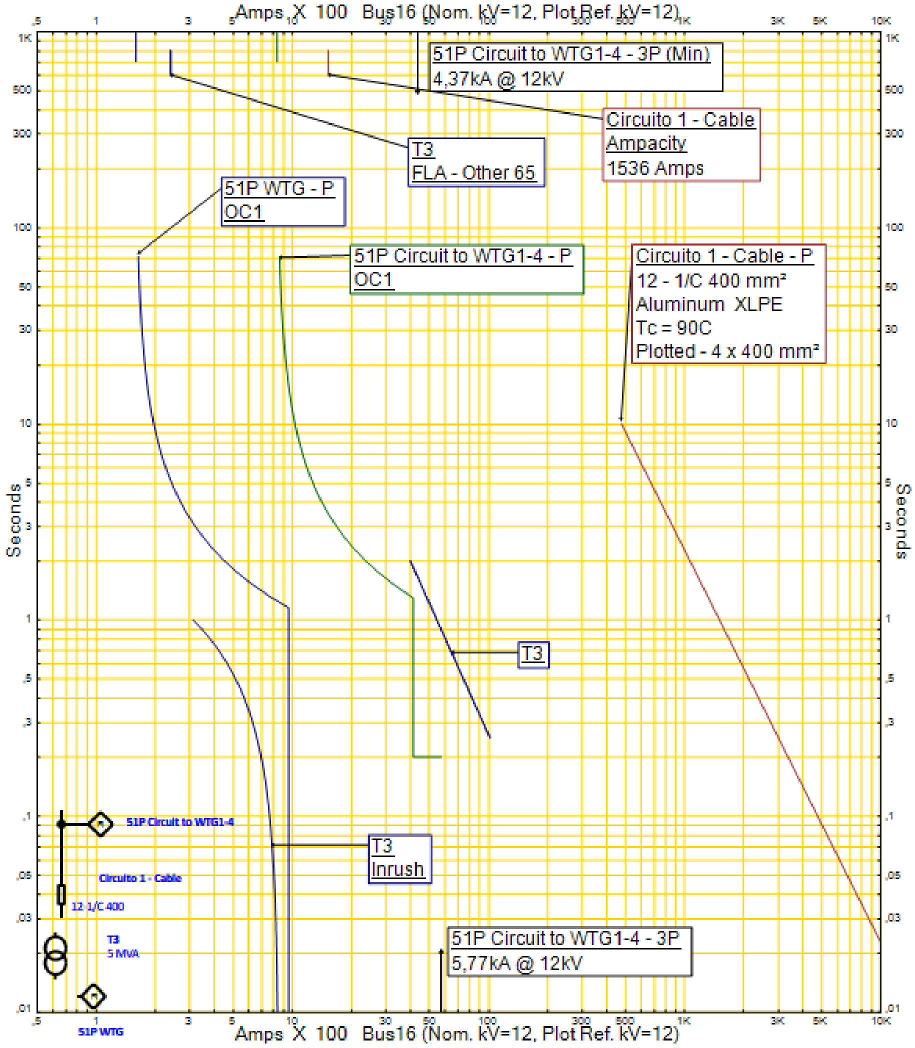

FIGURE 3 – COORDINATION CURVES ON MEDIUM VOLTAGE LEVEL OF RENEWABLE PLANT

One of the main issues during coordination is to properly model transformer damage curves and cable damage curves. Transformer damage curves can be modelled as defined in (2). For cable thermal damage capability, it must be considered the cable manufacturer datasheets. Main characteristics that affects to the cable thermal capacity as well as short-circuit current through capability are section cross (mm2) and conductor material (Aluminum or copper). Conductor disposition (opened air installation or underground cables) and number of conductors per phase are also important factors. In FIGURE 4 is shown a comparison on short-circuit current capability considering adiabatic and non-adiabatic model for cables as specified in (3). It is seen that thermal dissipation factors are less important for high short-circuit current levels. There are several electrical insulation material developments which also affects to thermal dissipation on the conductors, but this is not critical as it can be seen in FIGURE 5. In FIGURE 6 a comparison of cross section is shown and it is shown that the higher the cross section, the bigger the short-circuit current capability.

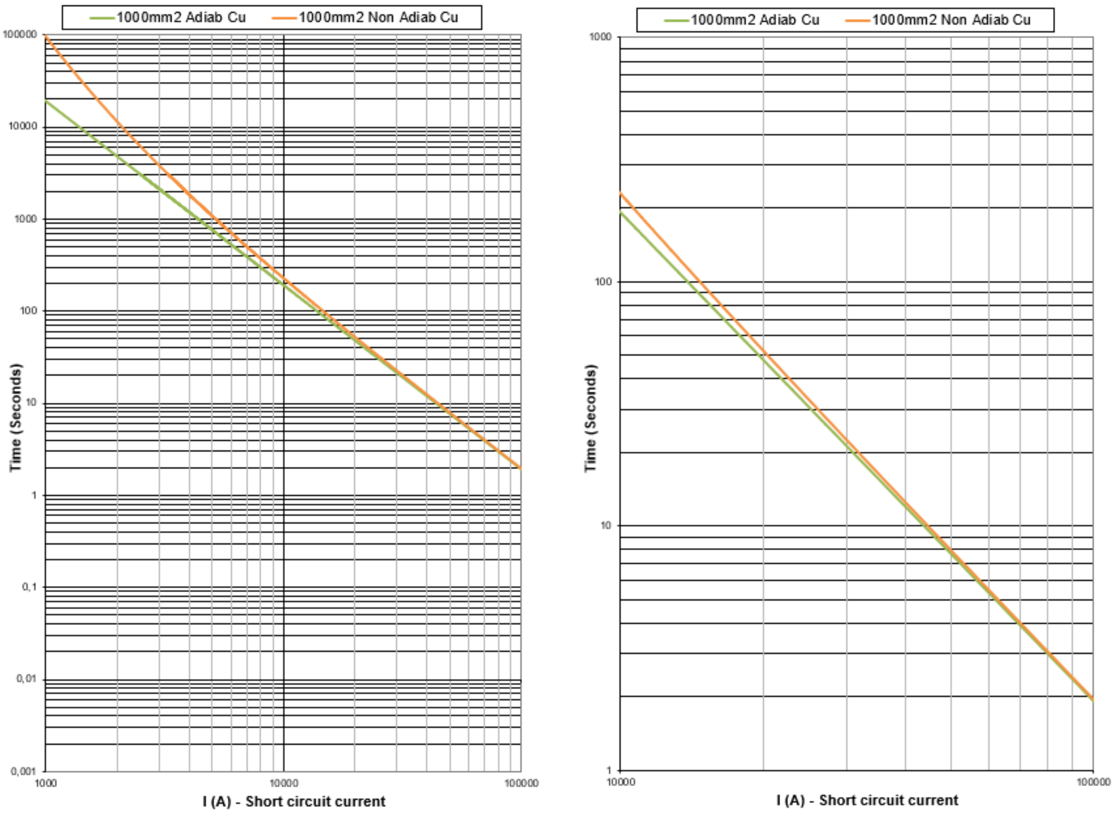

FIGURE 4 - SHORT-CIRCUIT CAPABILITY CONSIDERING ADIABATIC AND NON-ADIABATIC EFFECTS

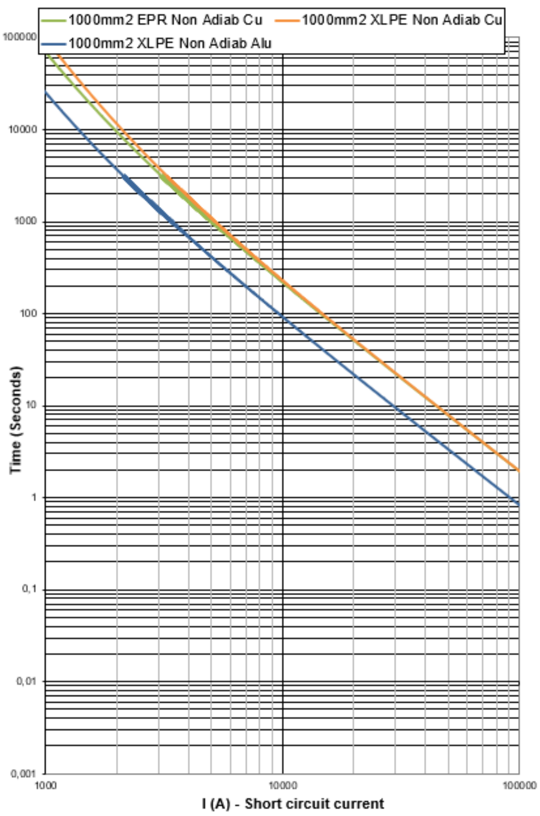

FIGURE 5 – SHORT-CIRCUIT CAPABILITY AL VS CU

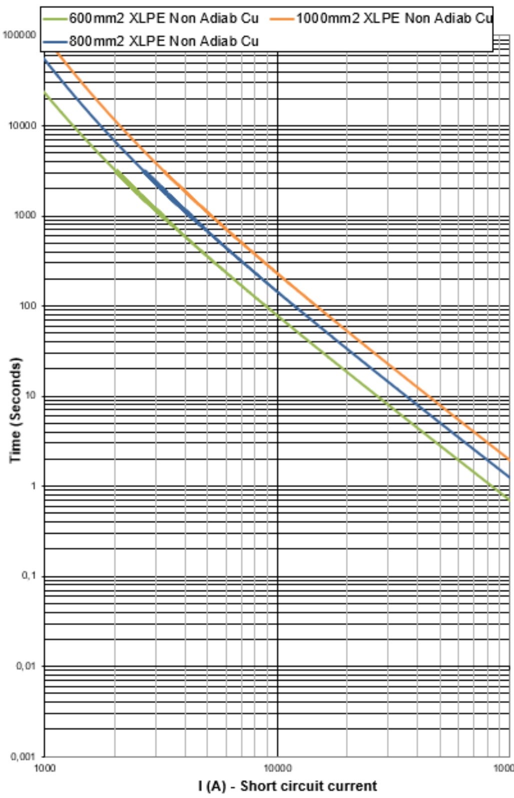

FIGURE 6 – SHORT-CIRCUIT CAPABILITY ON DIFFERENT CROSS SECTIONS

GROUND FAULT AND REACTOR PROTECTION

Ground fault protection will depend on grounding scheme. As specified in Renewables plant topologies and grounding schemes, most frequent grounding scheme is zig-zag grounding transformer with impedance between neutral side of grounding transformer and ground. This limits the ground fault current to 200-600 A, depending on the impedance used, and providing a ground fault current source for phase to ground fault detection on all the medium voltage level, from the step-up transformer to the transformer connecting to each individual renewable generation system.

In the same way as for phase time overcurrent protection, protection will be set from the downstream elements to the upstream elements. In this case, downstream elements are the residual current protection on the circuits, then the incomer residual current protection and at last the ground overcurrent protection from the measurements of the zig-zag grounding transformer itself through ground current transformer on the neutral side of zig-zag grounding transformer. A deeper detailed on zig-zag grounding transformer connections is shown in FIGURE 7. It is seen that current transformer on neutral side of the zig-zag grounding transformer will provide the same level of current for external and internal faults on the zig-zag grounding transformers. Nevertheless, phase current transformers connected on the primary side of the zig-zag grounding transformers can be used for internal fault detection of the zig-zag grounding transformer itself, as it is shown in FIGURE 7c . For internal fault detection, phase current transformer must be connected through delta connection to provide sensitivity against internal fault on the grounding transformer and avoid misoperation during external faults.

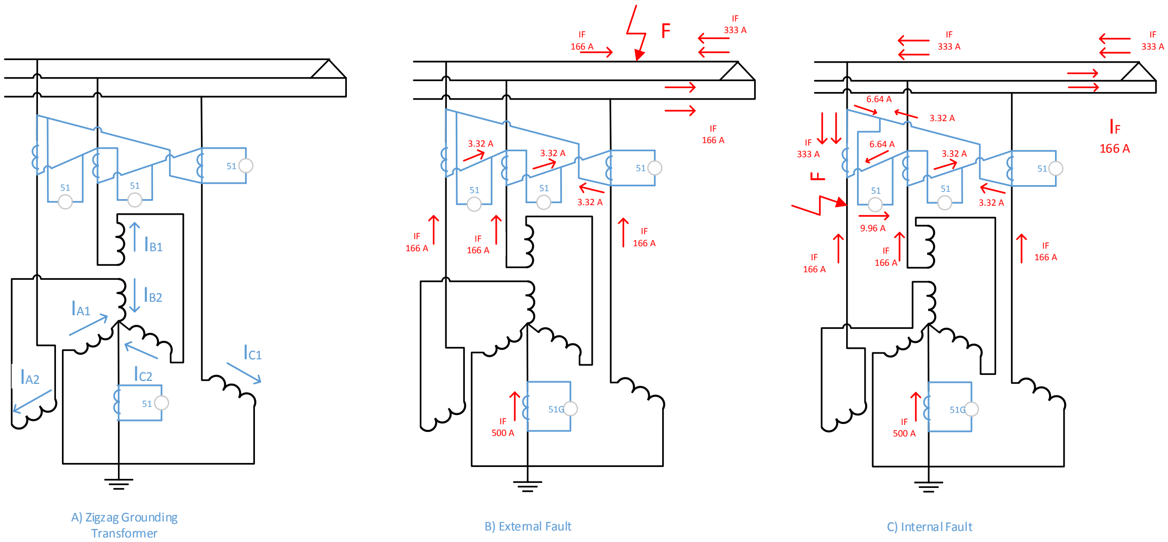

FIGURE 7 – ZIG-ZAG GROUNDING TRANSFORMER CURRENT DISTRIBUTION FOR EXTERNAL (B) AND INTERNAL FAULTS (C).

For ungrounded grounding schemes, a toroidal current transformer on each circuit must be installed to provide enough sensitivity to detect the capacitive ground currents expected during phase to ground faults.

VOLTAGE AND FREQUENCY PROTECTION ELEMENTS

Voltage protection measures from the busbar voltage transformer on the medium voltage busbar. In FIGURE 8 is shown the voltage curve versus time that must be supported in the connection point based on (4).

In (5), it is also specified FIGURE 9, where U_{ret} is the residual voltage in the connection point during a fault. T_{clear} is the time to clear the fault and U_{rec1}, U_{rec2}, t_{rec1}, t_{rec2} and t_{rec3} are specific below limit times of compliance after recovering from a fault.

Based on (4), two levels of undervoltage is recommended to be set with one at 85 % of voltage and 15 seconds for disconnection and another level at 70 % and 1 second.

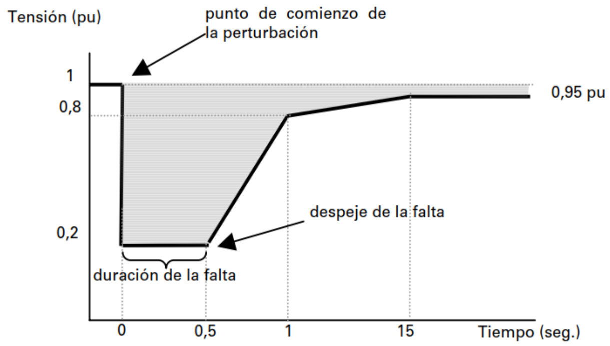

FIGURE 8 – VOLTAGE GAP THROUGH FAULT CURVE AT GRID CONNECTION AS PER SPANISH REGULATION

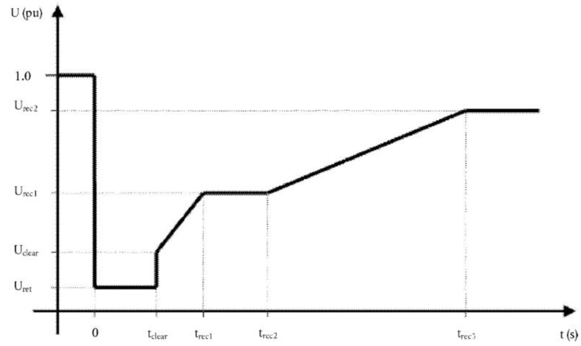

FIGURE 9 - VOLTAGE GAP THROUGH FAULT CURVE AT GRID CONNECTION AS PER EUROPEAN UNION

Under and over frequency protection elements are also set at each circuit of medium voltage as a backup of individual renewable generation frequency protections. Based on (5), minimum period of withstand time for generation systems must be as per TABLE 1.

TABLE 1 – FREQUENCY REQUIREMENTS FOR GENERATION SYSTEMS

Frequency range (Hz)	Período de tiempo de funcionamiento
47,5 – 48,5	To be specified by each TSO, but not lower than 30 minutes
48,5 – 49	To be specified by each TSO, but not lower than period of time in 47,5 Hz-48,5 Hz
49 – 51	Unlimited
51 – 51,5	30 minutes

As per (4), minimum frequency protection must be coordinated with the load shedding scheme, disconnecting only if frequency comes below 48 Hz for more than 3 seconds as minimum.

61850 PROTECTION SCHEME IMPLEMENTATIONS

61850 protection scheme implementations can help to improve coordination and accelerate the tripping times in case of enough contribution short-circuit current from renewable generation. As well, signal exchange between circuits can be implemented through 61850, allowing an easier implementation of future circuits and saving wiring costs on new projects.

Breaker failure initiation scheme is shown in FIGURE 10, where a failure on breaker of circuit 1 will send a GOOSE signal to adjacent circuits and incomer for tripping to isolate the fault on circuit 1.

Directional Schemes as shown in FIGURE 11 will allow acceleration of tripping times in case of fault in a circuit through permissive or blocking signals exchange between circuits. A differential scheme for medium voltage busbar can also be implemented based on 67N reverse or 52 open signals of relay circuits and 67N Forward or 52 open from Incomer. Blocking scheme vs permissive scheme have increased dependability by reducing security, as any failure on communication could result on an over-trip. If default-status of received signals is defined in case of communication failure, blocking and permissive schemes have similar characteristics and they can be used indistinctively. In case of communication failure, considering received signal as ON in blocking scheme or OFF in permissive schemes will improve security against unwanted commands, while considering received signal as OFF in blocking scheme or ON in permissive scheme will increase dependability against missing commands.

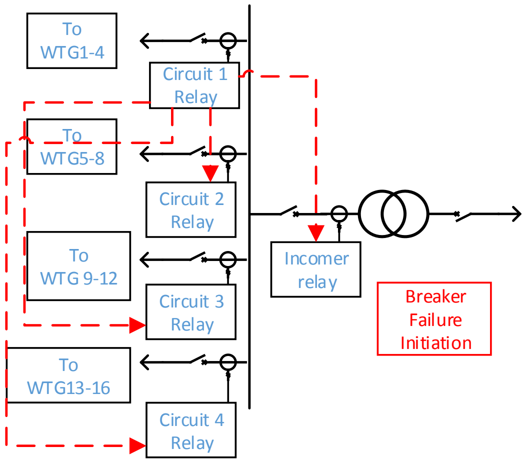

FIGURE 10 – BREAKER FAILURE GOOSE IMPLEMENTATION

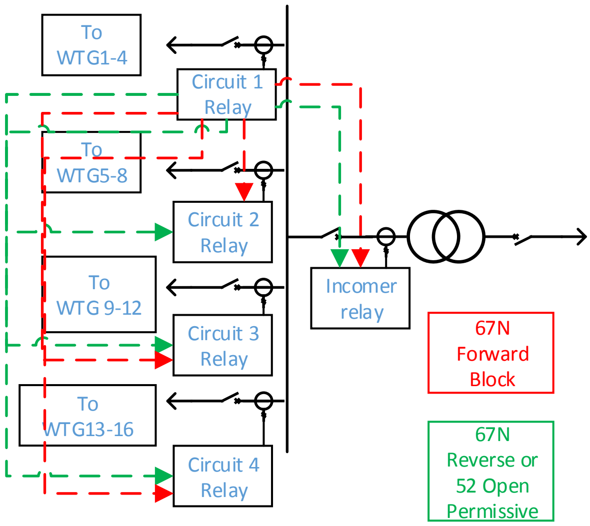

FIGURE 11 – DIRECTIONAL SCHEME ACCELERATION

NEW REGULATIONS

Network code on requirements for grid connection of generators from European Union of 14 April 2016 (5) establishes a first step to regulation of voltage ride through requirements including also to inverter based generation on renewable plants. On (5) Article 20 for requirements for type B power park modules (between 1 MW to 50 MW capacity), the following additional requirements in relation to voltage stability are defined: "(a) with regard to reactive power capability, the relevant system operator shall have the right to specify the capability of a power park module to provide reactive power;"; "(b) the relevant system operator in coordination with the relevant TSO shall have the right to specify that a power park module be capable of providing fast fault current at the connection point in case of symmetrical (3-phase) faults"; "(c) with regard to the supply of fast fault current in case of asymmetrical (1-phase or 2-phase) faults, the relevant system operator in coordination with the relevant TSO shall have the right to specify a requirement for asymmetrical current injection."

Spanish regulation operation procedure PO12.3 (4) specifies the performance of renewable generation against the voltage gap and reactive consumption. Deeply influenced by (5), non-peninsular operation procedure has already been updated (6) to request reactive power generation and fault current injection on renewable generation plants.

This implies a new concept of inverter-based generation control which has been started to call Grid Forming Control, instead of the existing Grid Following Control technology. This new Grid Forming Control enables renewable generation to generate reactive power and inject fault current, providing a higher short-circuit capability that could affect to the way that renewable generation plants are protected with simple overcurrent due to the difference in short-circuit power between the grid and the renewable plant.

Spanish Grid Code proposal P.O.3.7 for renewable plants production also gives the TSO the right to limit the renewable production based on the minimum short-circuit power requirements based on security criteria in insular areas. A comparison of other European Grid Codes with fast fault injection current has been established in Deliverable D1.6 of MIGRATE Project (7). This will limit the new installation of grid following inverter-based generation and promotes the grid forming ones and gives us the tendency on the way the future regulation will evolve.

CONCLUSION

Protection schemes and grounding methods used in MV substations have been explained. Key points and future challenges are summarized below:

- Multiphase fault coordination on MV may be limited to phase overcurrent elements on feeders connected to collector bus. Coordination with cable damage curves within the collector feeder can be compromised due to smallest size of cable at the furthest renewable generation. Sensitivity can be improved with phase directional elements looking into the collector.
- Typical ground scheme used is a zig zag grounding transformer with impedance for ground current limiting purposes, where there are phase current transformers for internal fault protection at the grounding transformer and a neutral current transformer for ground fault backup protection of renewable medium voltage level
- Voltage and frequency requirements are established as Spanish Grid Code (4)
- 61850 protection schemes for breaker failure initiation have been implemented, and additional directional schemes for faster tripping at collector bus are proposed.
- New regulations could vary the way protection schemes are implemented on renewable collector bus substations, without applying directionality due to low short-circuit current of renewable plants. Fast fault current injection requirements during grid faults on new Grid codes will affect to collector bus protection schemes, as renewable plant short-circuit capability will increase and directional schemes for fault direction identification will need to be applied.

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