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European Network of
Transmission System Operators
for Electricity

ENTSO-E CE Subgroup System Protection and Dynamics

Best Protection Practices
For HV and EHV Transmission Systems
of ENTSO-E CE Area Electrical Grids

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Contents

1 INTRODUCTION

The combination of increased renewable energy sources, simultaneous operation of different type of generating units (conventional, non conventional, renewables etc), power transmission over longer distances under limit load conditions and the influence of electricity markets have presented new challenges in maintaining and improving the quality of operation and security. It cannot be assumed that the transmission system will develop and expand at the same rate and there is a need to maximise the capacity of existing apparatus with reliability and safety, depending upon limit conditions.

Increased power flow requires advanced and secure methods of protecting transmission systems. In addition the change in system dynamics due to introduction of electronic converters in new generation technology can lead to a more stressed system. These new systems may cause difficulties or even incorrect operations under the new complex conditions.. Main specifications of the protection schemes are described in the national grid codes or in approved technical documents and standards

This document describes the best practices for protection schemes considering security of supply and safety of persons and equipment. The focus is on the protection application for equipment, at mainly extra high voltage or high voltage – and in special cases even other voltage levels.

The objective of this document –as being described in the «Terms of Reference» statement of the System Protection and Dynamics ENTSO-e Regional Group CE Sub Group, dated 19-03-2010- is to recommend common procedures and principles and to define common methods concerning protection engineering, as a supplement to operational handbook (O.H.) policy 3, guidelines.

This scope matches the overall mission of the tasks of the SPD SG that is the improved system operation and the provision of necessary background for new operational procedures. Technical solutions mentioned in this document are not considered mandatory. They are mentioned as mainly complying with the set of presumed protection principles.

Alternative technical solutions can be adopted following a thorough study provided they are technically and financially justified, lead to the same or better overall performance and comply with the national grid code, the ENTSO-e Operational Handbook or other ENTSO-e technical Standard or Guideline and the international Standards
Therefore present instructions may be specified and supported by specific solutions considering the local analyses of the various TSOs.

Note 1: The protection systems, described herein are designed for 110kV to 400 kV. If not clarified in each article, technical guidelines refer all voltage levels unless mentioned otherwise
Note 2: In present text protection systems are considered as integrated and include one or more protection equipments, instrument transformer(s), wiring, tripping circuit(s), auxiliary supply(s) and, where provided, communication system(s). Depending upon the principle(s) of the protection system, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment. The circuit-breaker(s) [CB] are basically excluded, except If otherwise mentioned.

2 PROTECTION PRINCIPLES

2.1 General issues

There are three main objectives which any protection system at EHV level (greater than 250 kV) has to perform.

Operational reliability - For this purpose there are two independent auxiliary direct current-supplies with separate circuit breaker's coils or main circuit breakers recommended. The main and backup protective functions should be separated with at least two independent devices, supplied from two different manufacturers or operating with different protection principles as far as possible. The relays may be connected at two different correctly rated current transformer cores, according to reliability assessment or imposed by operating condition of protection systems. The CB´s have two independent trip coils and two independent trip circuits. Each protection device should trip at least one of them by independent auxiliary DC-supplies. To allow maintenances while the EHV-circuit is in service the several protection devices should be equipped with appropriate slide clamps, test plugs etc.

For lower transmission voltages (i.e. less than 250 kV) it is the duty of each transmission system operator (TSO) shall respect certain principles that have been incorporated into documents for warranting operational reliability; e.g. two separate protection devices, one distance and one overcurrent may be installed or an optimum self monitoring with the immediate trouble shooting of any defected device must be assured, leading to maximum possible reliable availability of the protection function overall at the transmission System.

Dependability - The destructive power of a fault arc carrying a high current is very great. Power plants close to short circuits can loose synchronism. Therefore it is very important to clear any fault on EHV -circuits as fast as possible. For that, there are at least two different main protection schemes with instantaneous tripping recommended, usually double distance; or differential protection and distance protection especially of EHV over head lines-circuits additionally enhanced by teleprotection schemes. These different systems may have complementary qualities and features. Differential protection is faster and has a high detection capability, but it needs an efficient telecommunication system. In addition, it does not detect busbar faults, or faults between current transformer and CB, depending on the equipment configuration and connections. Distance protection is flexible to use and covers the bar bus area. Moreover distance function is necessary as back up protection and for coordination purposes in meshed grids. Appropriate protection schemes or suitable protection functions must at least ensure there are no unprotected zones along the whole path: busbars, CT, voltage transformers, CB, line trap, transmission line etc.

Also appropriate CBs with rapid tripping and arc quenching are recommended. Any fault should be cleared within less than150ms fault clearing time (i.e. including CB arc quenching) in EHV and HV voltage levels or as it is reasonably prescribed in the national grid code.

Additional functions, e.g. automatic reclosing (A/R), residual voltage / current protection and logical controls are common practice. In solidly earthed EHV networks single phase A/R should be generally implemented. After execution of necessary stability studies three phase fault A/R is also allowed, without endangering the system stability and security.

Security- The line protection shouldn't limit the maximum transmission capacity of the line. Distance protection in particular could cause spurious tripping due to specific grid conditions, in case of high load operation. Therefore any special topologies must be known and considered for protection parameterization. For parallel OHL´s it is necessary to consider the rapid increase of load current in the healthy line when the faulty line trips and the protection operation must allow re-dispatching (load transfer etc). In some cases it may be necessary to apply power swing blocking functions and then also out-of-step operations. Nevertheless, for dependable fault detection the distance protection setting needs a minimum of resistance reserve. This sets a limit of the

maximum load by using the distance protection. The load encroachment function must be used, whenever possible and it is strongly recommended for the cases when the highest distance zone resistance reach conflicts with the maximum transmitted load on the protected element. More details concerning issue of maximum load are cited in respective chapter here below.

2.2 Protection fundamentals for transmission lines, power transformers and substation busbars

EHV-overhead lines are generally protected by distance relays with teleprotection schemes (e.g. permissive underreach protection (PUP), permissive overreach protection (POP), accelerated underreach protection (AUP), and blocking overreach protection) and / or line differential relays, as specified elsewhere in this text.

EHV/HV-power transformers are protected by instantaneous and selective protection, such as differential relays; preferred with an outer and inner differential protection and back-up overcurrent relays with multiple stages. The outer differential protection is connected to the CT´s in the bays whereas the inner differential protection is connected to the CT´s in the bushings (if available). Additionally distance relays are provided on EHV and / or HV side of the transformer if the overcurrent (O/C) relays prove to be inadequate. The O/C-backup function in the differential relays may also be used. Buchholz alarms and tripping (tank and tap-changer) are used as standard. Other equivalent principles may be also adopted. Special attention must be paid in the proper setting of instant elements in order to avoid unwanted tripping due to inrush currents during initial energizing.

EHV-busbars (BB) are protected by BB-differential protection with a zone per each busbar section. An image of the disconnectors provides a selective tripping only of the faulty BB-section. Measurement has to be phase selective, summation transformers are not recommended. A circuit-breaker failure protection (CBFP) should be integrated in the BB-protection if necessary. The CBFP will be started from the protection in the circuits (OHL, transformer). The total tripping time in case of a CB failure should not exceed 250ms for HV and EHV levels.

BBP and CBFP in transmission s/s (220/400kV) should be supplied alone from an independent CT core in each substation (s/s) bay.

For level of even lower voltages (110 kV) other less demanding practices systematically adopted by the companies are also accepted. For example: a substation with 2 ÷ 3 110 kV OHL's and two power transformers 110kV/ medium voltage could have one DC supply; transformers could be protected by one overall differential protection and O/C back-up; common and not dedicated teleprotection channel for OHLs could be regarded as sufficient.

Protection of generators does not belong in the scope of this document. Though mainly aimed to protect the equipment of the power plants they play an important role in the objective of the transmission protection because they are normally energized for transmission faults, consequently they must at least perform selectivity with overhead lines protections and back up for external faults in the network they connect to.

2.3 Protection studies, wide areas settings, alternative setting groups

Protection studies must have high quality, must guarantee   the reliable operation and security of the system. Procedures and validation requirements are very important and must be observed

according to the practice of each TSOs. Every proposed new piece of transmission equipment and every topology change must have as a precondition the execution of a study, with the checking of the settings and their revision if necessary. Other possible reasons for settings revision could be lack of telecommunication between opposite breakers, the periodical checking of wide grid area, defects of primary schemes or special substation bus configuration due to works or maintenance.

In meshed transmission networks, the coordination is especially difficult because of the short-circuit power variability and because of the intermediate infeed. This can lead to problems with coordination and reliability.

A wide area coordination study should consist of simulating thousands of faults in the system using computer aided protection simulation software. The correct and coordinated relays response is checked when each fault occurs.

Two network study cases should be considered: PEAK CASE, with all available generation connected, and OFF-PEAK CASE that considers the same topology, generation disconnected for power balancing and overhead lines outage («N-1» criterion) according to the common dispatching practices. Both cases contain the real time double busbar configuration where available, in order to check the bus coupler relays response. The cases should include the whole generation and transmission electrical system modelled down to low voltage transformers distribution and generation levels. Models must be the suitable (e.g. transient or subtransient, saturated or non, whatever applicable) for the scope of each study. Special concern is recommended for the proper simulation of the non-conventional generating sources.

For checking coordination only «non-unit» protections (i.e. those not directly related only to the «protected object», i.e. all protections except differential) should be included in the study network model. Bus-bars, lines and transformer differential protections, are absolute selective and non-time-delayed protection and they are not checked concerning coordination. The communication failure for transfer trip distance protections is also modelled. These assumptions are equivalent to consider an N-1 situation of the protection system. Therefore, only overcurrent and distance relays are considered as responsible for clearing the faults.

In the study three phase and single phase to ground faults should be simulated. At least for the «intermediate» in-line faults also faults with a reasonable fault resistance should be examined. These faults are applied to all elements included in the coordination area. It also would be a good practice to consider different (more crucial) network topologies for simulating faults, such as N situation and N situation with minimum infeed. The first one with all network components in service; and the second one considering the overhead line only contributing fault current for a three phase fault and the studied fault must be cleared.

Day by day the society has come to depend on the reliability of the power system. This dependence makes the coordination of the relay settings with those of the surrounding area mandatory and quality demanding.

2.4 Coordination of tie-lines, generator- transmission-distribution

Although probably belonging to different companies the complete path: generation-transmission-distribution must be considered as an interlinked entity and faults passing through different voltage levels must be cleared coordinated and with selectivity. The selectivity is not required in the case of radial feeders. A safe margin between primary and next back-up stage and zone is considered between 0.2(digital relays) and 0.3 to 0.5 sec (older generations of relays). Less margin –but not less than 0.15 sec- could be accepted for protection schemes of devices like bus tie circuit breakers (couplers), wherever selectivity is required. It is advised the standardization of the

stepping times overall the regional system and for the same voltage level. Standardization of the zone delays is not necessary concerning tie-line between neighbouring TSOs, because in those cases selectivity is based on the trip time discrimination strategy of the interconnected systems. Nevertheless the safe margin must be respected in these cases as well.

3   FAULT CLEARANCE TIMES

3.1 Faults according to the concept

The maximum fault clearing time consistent with best practice in the CE transmission system should be less than the critical fault clearance time. By using modern protection relays and circuit breakers (two-cycle-cb), fault clearing times less than 100ms are generally possible. Shorter fault clearing times will cause better system stability in case of faults, but shortening the time margins should not jeopardize the overall protection system security. Also the maximum protection time delay for zero impedance faults –by convention- and for the whole protections of the system must be a concern. This time delay can be either the delay time of the highest back-up distance relay zone or of the highest overcurrent stage. This is suggested to be kept as low as possible and coordinated with grid automatic and special protections schemes. A value between 0.6 and 5 sec, depending on the available zones is recorded currently for the regional grids and hence it is acceptable.

3.2 Busbar faults

A busbar (BB) fault may endanger the whole system stability due to the loss of many transmission lines and generating units.
Busbar faults should be cleared within critical fault clearance time. All buses of voltage level greater or equal to 250 kV should principally have busbar differential protections. For buses less than 250 kV the decision to use busbar differential lies with each TSO depending on issues of stability, reliability, availability and security. If, for some reason busbar protection fails to operate, the fault clearing times of the opposite feeders of the nearby substations have to be kept as small as possible or reverse zone at each feeder should be implemented as backup for BB-protection.
The duration of non-availability of the busbar protection has to be kept as short as possible because of endangering the system stability.
There could be EHV substations not equipped with differential protection, but only after carrying out stability studies or if this is argued and foreseen by official national technical standards (e.g. at locations remote from generation or in cases of special substation configuration –e.g. ring type buses etc-). For this voltage level and these cases generally it must be ensured that instant tripping takes place where there is a bus fault.

4   REDUNDANCY OF PROTECTION SYSTEMS

For a reliable and safe electrical power supply, the protection relays have to operate *fast*, *selectively* and *reliable*.

4.1 Redundancy

The level of redundancy depends on the critical fault clearing time of the protected element for a three phase fault as this is the most severe system fault, and it is the result of stability studies. Most important are the conditions for critical time calculation. Three -phase fault followed by three pole circuit breaker CB failure or CB single pole failure. It is very severe condition especially for 220 kV and 400 kV voltage level. In some locations of the system one can receive times around 100 ms which can not be covered by the existing primary and secondary equipment, keeping the selectivity.

The level of redundancy is defined taking into consideration all lines and bays with typical remote backup tripping time according to the following table.

Tc_L (ms)	Tc_R (ms)	Tc_{LZI} (ms)	Redundancy
< 350	< 350	------	2SP/2C
	> 350	< 350	2SP/2C
		> 350 (**)	2SP/1C
> 350	> 350	-----	2SP/1C

Tc_L Critical clearing time a local end
Tc_R Critical clearing time at remote end
Tc_{LZI} Critical clearing time at Z1 distance protection reach
Redundancy: Degree of redundancy:
      2SP/2C double system protection with double communications channels
      2SP/1C double system protection without communication redundancy
(**) In this case it is required to comply with the critical clearing time for 3phase faults in the 20% from the local end in less than 350 ms and Z2 typical clearing times for the remote end (sequential clearing of the fault it is assumed)

If there is no teleprotection redundancy, a blocking overreach protection scheme ensures guaranteed performance of tripping time.

For short circuit protection of a system element with a 2SP requirement the principle of dependability should be valid, as analyzed in chapter 2.1. In terms of object's protection and for EHV level, we should have:

- **Primary protection system,** which is the scheme that detects the faults in the power system tripping the element. The relay associated with the system is considered the main or primary relay.

- **Main backup protection,** which is the protection system redundant to the primary protection system that ensures that a failure of any element of the primary protection system is covered. This protection is called secondary or backup protection,

- For EHV in particular there is no defined hierarchy between the two schemes. We can have two main protections, and they can include complementary principles.

The maximum possible reliability, redundancy and availability of the measuring transformer, of the DC supply are required. Protection standby power supply must be available for between 4 and 24 hours and can be provided by battery until restoration of auxiliary AC supply (Diesel generator).

Both schemes are not fully redundant, as some elements as the VT transformers or circuit breakers not need to be duplicated. However both system should use independent CT cores and the voltage supply and tripping circuit have redundancy (two trip coils). In order to cover the failure

of the not redundant elements remote or local back up protection should be used. The communication system should also be fully redundant where it is needed. The figure below shows the ideal redundancy case for demonstration purposes mainly. As much as possible redundancy of devices´ coils and communication paths can be applied according to each TSO´s written Standards and practice.
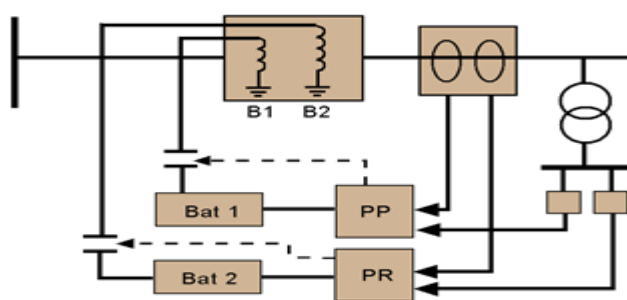

Figure 1 Full redundancy scheme for a protection system

Key note: Bat: Battery, PP: main Protection PR: Secondary protection

The protection scheme should be based on two different measuring and operating principles or on devices made by different manufacturers, except for the case of short lines (mixed or not), multi-end lines and transformer plus feeder circuit and cables, where line differential is preferable (see section hereafter). Especially for short lines a blocking overreach protection principle is also acceptable.

Current transformers assure the appropriate accuracy, they must follow standardized specification and class, they must be adequate for the maximum rated current without suffering due to permanent flow of the anticipated maximum permanent and temporarily load.

4.2 Backup-Protection

Main protection relays will trip for all faults on the dedicated transmission line or equipment without delay. By time grading of the zones, faults on the remote busbar or line will be cleared in case the main protection fails to operate. In case of such an incorrect operation, the adjacent relay(s) will clear the fault with a time delay.

The backup-function of the distance zones has to be ensured for all busbar faults in adjacent substation(s). In case of the failure of busbar protection, reverse zones of distance relays, with delay time between Z1 and Z2 could «cover» the equipment.

4.3 Breaker failure protection

A three-phase fault in the transmission system combined with a breaker failure will endanger the system stability in many places of the grid. The fault clearing time for a three-phase breaker failure has to be kept as short as possible even if the probability for such a fault is very small.
Single-phase faults are the most frequent type of faults in the transmission grid. Even though these single-phase faults are less critical regarding the system stability, they could endanger the system

and should therefore be cleared in a short time. So any breaker failure has to be cleared by a breaker failure protection as fast as possible.

Fault clearing times should be within 300ms for all types of faults and under all N-1 conditions at levels higher or equals of 250 kV, while in lower voltages the limit figure is considered 500 ms.

4.4 Loss of Potential

The loss of potential must be considered by the design of the protection scheme. In this case distance elements could be blocked and the emergency non-directional overcurrent (O/C) automatically operates. In case the experience of the company is not favourable and a loss of selectivity is possible, then instead of allowing the O/C to operate unselective, they could be blocked as well and let the «next» circuit breakers operate on the surrounding lines. Other countermeasures against the loss of measuring voltage or the auxiliary voltage can be either:
- installing two protection relays with separate voltage transformer (VT) windings, separate batteries, switching two emergency-overcurrent relays, directional earth fault protection (taking voltage from open delta connection of voltage transformer)
- switch the line on to the bypass busbar or differential and distance protection relays as main1- and-main2- concept (differential schemes are not affected by the loss of measuring voltage).

4.5 Open transmission conductor

This situation is very important first because of worsening the quality of supply and secondly because it can rapidly evolve to short circuits and/or contact of live conductor with ground. This condition must be permanently monitored and alarmed either with Energy Management Systems-SCADA tools or with built-in functions of intelligent electronic devices (IEDs). Following the experience of each grid operator, considering the construction of the OHL etc it is also possible that tripping -with this condition- will be adopted by a utility.

5 SETTING OF DISTANCE PROTECTION IN CONTEXT WITH NORMAL OPERATION PHENOMENA

5.1 General

All CE TSOs will do the settings of the protection system in such way that short circuits in the grid will be detected and cleared selectively. Therefore the settings depend directly from the technical conditions in the grid. As a general rule special (dedicated) overload protection should not be installed on OHLs at least; therefore the grid control centre has to identify and to remedy overload conditions.
The «protection limiting current» is defined as the value of the current which can be transferred safely – i.e. without picking-up of starter elements and/or tripping of the protection system. Thereby the settings of starter elements, reset ratios, measuring tolerances and additional safety factors have to be considered by protection engineers.
The indication of the protection limiting current has to be done under pre-defined conditions (minimum operating voltage, load area). Relevant lists for all c.b. must be issued, updated and available to the dispatching personnel, indicating the normal and emergency operating limits of the transmission circuits and allows them to be included in the EMS on line operating data.
The protection should be set not to trip under system transient conditions, which are not short circuits. Conversely where the short circuit current is low due to local grid conditions (weak network) or due to high resistance of the arc, this must be taken into consideration to trip the relay by using the most appropriate criterion , without jeopardising the unwanted tripping during heavy

load conditions (e.g. by lengthening the resistive blinder, by setting trip angle (as a ± angle area on both sides of torque vector of overcurrent setting, by combining with load encroachment, by using «relay trip logic» etc; see also next chapter),

5.2 Load encroachment

Protection relays must allow the maximum possible loadability of the protected equipment, without diminishing the clearing of anticipated faults according the simulation studies. Special care must be taken to avoid unwanted tripping of certain distance relays or avoidance of decreasing the loadability due to the transient enlargement of the dynamic mho characteristic, in case this type of characteristic is applied. This must be checked by the protection engineers from the relay application manual and the algorithm of operation. Load encroachment feature of distance relays and –if possible- the setting of torque angle and trip angle of directional overcurrent relays must be applied.
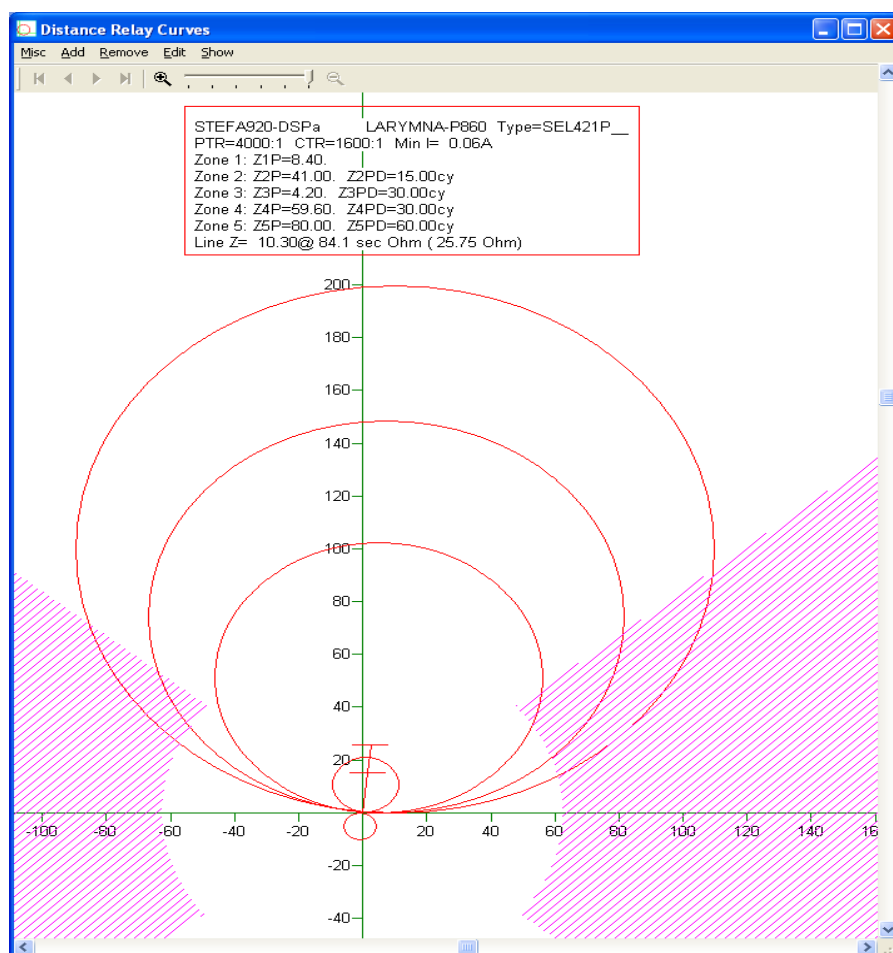

Figure 2: Load encroachment characteristic

5.3 Interconnecting lines

Following conditions may be considered for the protection limiting current on interconnecting lines to other TSOs for standardization purposes:
-   voltage > 90% * U_n (U_n = 400kV) and

- current in load area, i.e. cos(φ) > 0,8

Neighbouring TSO (Transmission System Operators) may mutually agree on other conditions in special cases (e.g. lower voltage). Normally the settings related to the maximum possible loadability of the protected equipment are specified after a dedicated load flow study and contingency analysis.

6 PERFORMANCE OF LINE PROTECTION DURING SYSTEM STRESSED CONDITIONS

6.1 Definitions

Power Swing Detection — - function inside the distance protection which detects power swings by the travelling of the impedance vector and which induces specific measures (tripping of the tie-lines, etc)

Power Swing Blocking — - (PSB) blocking of one or several zones of the distance protection during stable power swing

Out of Step Protection — - (OOS) Tripping during unstable power swing if specific conditions, exist fulfilled, Out of step, excess a specified number of power swings, etc

Frequency excursion — - underfrequency, over frequency

Tie line: — - a line connecting two grids

System protection schemes must support the detection of abnormal system conditions, like: large load / generation imbalance, voltage instability, rotor angle instability. They must contribute in taking predetermined, corrective action (other than the isolation of faulted elements), with a quick time response. They must preserve system integrity and to provide acceptable system performance. They must be able to assist in the separation of system in order to mitigate against instability and on the other hand they must keep running the installations in case of stable oscillations or disturbances. These functions could be achieved by the out-of-step (or pole slip) feature and the power swing blocking feature of the multifunctional distance relays.

6.2 Requirements of automatic protection schemes during power swings

Following items describe the requirements for the line protection schemes regarding the behaviour during power swings. They are related to power swings only that reach the starting and/or tripping zones of distance protection functions.

1. All type of faults or short circuits, low impendence or high impedance, single phase - ground or multiple phases, temporary or permanent must trip instantaneously the relays in both ends of the faulted equipment.
2. Stable i.e. damped (decreasing) power swings shouldn't cause any automatic trip of transmission line
3. Increasing power swings shall cause a trip at the nearest electrical node of the power oscillations based on specific criteria (e.g. minimum impedance), and being returned to operation only after an attentive stability study.
4. Slowly drifting grids (phase angles), could cause grid separations based on specific criteria to avoid the loss of power stations, only if this is proved be happened after an attentive stability study.

5. Asynchronous operation (out-of-step or pole slip) shall cause a trip at the nearest appropriate electrical node.
6. Any faults occurring during a power swing have to be cleared selectively and in the respective zone of the distance protection.
7. Voltage collapse should be addressed by using under voltage relays taking account of of related loads as e.g. large induction motors etc. Special attention should be paid to corresponding automatic restarting schemes after voltage recovery in order to avoid a subsequent voltage collapse due to too high reactive power demand during parallel restarting of too many machines at the same time. In radial connected feeders equipped with transformers with automatic under load tap changer control a blocking scheme for the tap changer should be made accessible to the system operator, so that during high voltage gradients in direction of a collapse the transformer taps can be blocked either automatically or by the system operator.

An impedance measuring criterion is a stringent condition for the items above to specify a trip in tie lines or nearby the electrical node at a beginning grid collapse, this criterion must be available in all distance protection schemes. Protection schemes not using such a criterion are therefore not acceptable as a stand-alone scheme at the tie lines.
Certain companies prefer the application of the power swing detection and protection function, to be executed by separate dedicated devices.
Other automation schemes (example given: angle automations etc) are also acceptable if they are the result of stability studies.
 The absence of above functions is acceptable provided stability studies for all sound and realistic operational scenarios show otherwise.

As a general requirement a minimum safety-margin of 20% to the maximum operating current is considered for the setting of distance protection relays for load flow conditions (see other relevant chapter in present document as well). The margin of safety must be detailed considering the current transformer, the asymmetry of lines, the transients, the measurement tolerances. This shall prevent that transients in the grid causing a pick–up of starter elements of the distance relays. If there is any assumption that this margin might not be sufficient, a dynamic grid´s analysis should be performed. With these results of this study, it's possible to choose the required method against incorrect operation in case of transients (power swing) in the grid. As a basic principle the method with the smallest influence on the distance protection scheme shall be chosen.

6.3 General protection measures at dynamic transients

Dynamic transients which may lead to starting of protection schemes (under consideration of settings above) have to be analysed particularly.

Power Swing Blocking function or Out of Step tripping must be used only if this is proved to be necessary after a detailed stability study.

The following measures are possible:

6.3.1 Appropriate settings of tripping zones

Unwanted starting and tripping of protection schemes may happen should damped synchronous power swings arise where the impedance vector crosses the limits of starting and tripping zones.

A short pick-up of the starter elements of the protection scheme is not critical, as long as no tripping zone is reached and the starter elements reset clearly before the time setting of the final zone is reached. A less sensitive setting may be chosen if these conditions can't be fulfilled. However the following limits of fault resistance have to be considered to ensure the distance protection detecting short circuits in all cases.

Minimum reserve for fault resistance:
If there is an overhead earth wire, following values are recommended. If not, these values could be increased:.

Zone 1	≥ 10 Ω_{prim}
Zone 2	≥ 12 Ω_{prim}
Z1 extension	≥ 12 Ω_{prim}
Zone 3	≥ 14 Ω_{prim}
Starting	≥ 20-30 Ω_{prim}

Keynote: Above specified arc reserve is sufficient for most single- and three-phase faults. Under extreme conditions (low conductive and dry area), the distance protection scheme may be supplemented with a directional sensitive earth fault protection scheme (U0/I0). In this case it is not necessary to increase the fault resistance of the distance zones.

Generally speaking the values for fault resistance are matter of calculation (depending on tripping time, magnitude of short circuit current, wind speed, isolation distances and the fact of different manufacturers suggest different settings related to X and R settings (R1/X1 ≤ 3 for example is proposed by certain manufacturers.

Concerning the minimum resistive reserve for arc depending on the inductive reach of the Zone, a method is proposed that provides rules for the setting of the fault resistance based on the value of the corresponding step; it is shown in the tables (Tab. 1 and Tab. 2) included in Annex I:

It may be assumed that distance protection schemes without power swing detection fulfil following requirements of previously mentioned list:

1. All type of faults or short circuits, low impendence or high impendence, single phase or multiple phases, temporary or permanent must trip instantaneously the relays in both ends of the faulted equipment by distance relays.
2. Not fulfilled, see below [1]
3. Increasing power swings shall cause a trip nearest appropriate electrical node (minimum impedance)
4. Slowly drifting grids (phase angles), could cause grid separations
5. Asynchronous operation (out-of-step or pole slip) shall cause a trip nearest node.
6. Any faults have to be cleared selectively and in the respective zone of the distance protection.
7. Voltage collapse should be addressed by under voltage relays taking account of related loads as e.g. large induction motors etc. Special attention should be paid to corresponding automatic restarting schemes after voltage recovery in order to avoid a subsequent voltage collapse due to too high reactive power demand during parallel restarting of too many machines at the same time. In radial connected feeders equipped with transformers with automatic under load tap changer control a blocking scheme for the tap changer should be made available to the system operator, so that during high voltage gradients in direction of a collapse the transformer taps should be blocked either automatically or by the system operator.

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[1] Requirement 2 (Stable i.e. damped (decreasing) power swings shouldn't cause any automatic trip of transmission line) shall be tested by grid dynamic studies and simulations.

6.3.2 Application of power swing blocking (PSB) for distance functions

PSB (and OOS) shall be used after a detailed analysis of the grid's dynamic and if the other measures cannot avoid incorrect operation of the distance protection schemes. This could happen for instance in case of power swings with long cycle durations (inter area oscillations), if the impedance vector remains too long in the starting and/or tripping zones.

The application of PSB should require provisions for tripping where necessary of unstable power swings.

The active blocking time of the PSB will be limited and set accordingly to the expected cycle duration of the power swing; e.g. 5 seconds. In case of a decreasing voltage, caused by slowly drifting grids (phase angles), it is suggested the PSB to be inactive and so the distance protection will trip the nearest appropriate electrical node.

Whereas stable power swings shall not cause trips, unstable power swings shall be detected and tripped in time. Each crossing of the PSB polygon may be counted during PSB application. Several crossings (starts) of the PSB polygon may indicate low damped or even increasing power swings. In this case the PSB may be unblocked after a given number of power swings. (Figure 4, trajectory 3; Proposal: Three times PSB permitted, then unblocking or alternatively blocking if the speed of crossing the characteristic is related with a stable swing). A detection of increasing power swings, e.g. by tracking the reversal point, would be preferable. The exact selection of the power swing detecting and acting mode will be decided by each TSO. As the more conservative possible solution for stable power swings would be considered not to block the first zone and/or to trip after a given number of (unstable) power swings[2]. In next two paragraphs the two options of Z1 blocking or not is presented.

For PSB feature, like OOS feature, it can be achieved in a specific dedicated device, outside the distance protection

Non symmetrical faults have to unblock the PSB immediately (item 5 of requirements), to permit tripping in all cases. Criteria may be zero sequence currents or negative sequence currents. A detection of symmetrical faults during power swings is a stringent condition.

6.3.2.1 Application of power swing blocking without blocking first zone

The basic application will be a setting of the arc reserve of the first zone to $10\,\Omega_{prim}$ and will not be blocked by the PSB. All other zones (also starting zone) will be blocked during power swings by PSB. In this case, the non-blocked first zone ensures tripping of the distance protection scheme at the nearest appropriate node during extreme power swings and separating of the grid. The non-blocking of the first zone extension (Z1X) secures protection for the whole line (100%) even during power swings and three phase faults. It has to be considered however that permissive overreach transfer protection tripping schemes (POP) may lead to incorrect operations. By application of a POP scheme, the signal sent from zone 2 has to be blocked by PSB in any case. In addition the historical scheme used on the 400 kV network (acceleration by Z2), includes a release functionality of power swing blocking in the case of reception of the acceleration signal. This function has been very useful for the protection of the network during an incident near a 400 kV power plant, in the 1980's.

All faults in the close-up range will be tripped by the non-blocked zone 1.

6.3.2.2 Application of power swing blocking with blocking first zone

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[2] It has to be ensured that the PSB may block all zones including the final zone. The PSB shall start preferably with the starting of the protection scheme

In certain cases it may also be necessary to block zone 1. Precautionary measures have to be made to ensure grid separation in the case of asynchronous operation (out-of-step) at the nearest appropriate electrical node. This may be realised e.g. by a non-sensitive out-of-step protection (Figure 3, trajectory 1). This non-sensitive out-of-step protection trips, if the impedance vector enters the dark-blue area at one side and leaves this area at the opposite side (out-of-step).
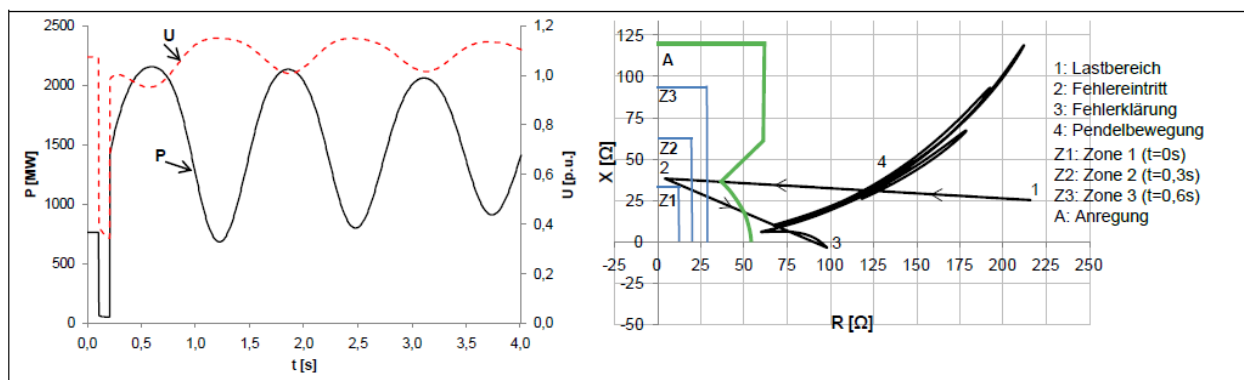

Fig 3. Typical PSB characteristic in Z level (Source: Power Swing Blocking – Solution for all oscillatory problems, Martin Lösing, Klaus Vennemann, Rainer Krebs, VDE Conference, March 2011, Munich)

The trip of symmetrical faults during power swings may be realised by detecting the fast change of the impedance („leap") and subsequent unblocking of the PSB.

6.3.3   Out-of-step protection

The out-of-step protection trips if the impedance vector enters the out-of-step area on one side and leaves this area on the opposite side. An example of application is given in Figure 4. The <u>non-sensitive</u> out-of-step protection is represented by the blue area in Figure 4 (trajectory 1). The reactance of the out-of-step area is set according to the length of the protected line (e.g. 115% of line length).
For the <u>sensitive</u> out-of-step protection, the reactance is set to a higher value (e.g. up to the starting of PSB-polygon); see trajectory 2 in Figure 4. A sensitive out-of-step protection will be used only in exceptional cases at selected stations.
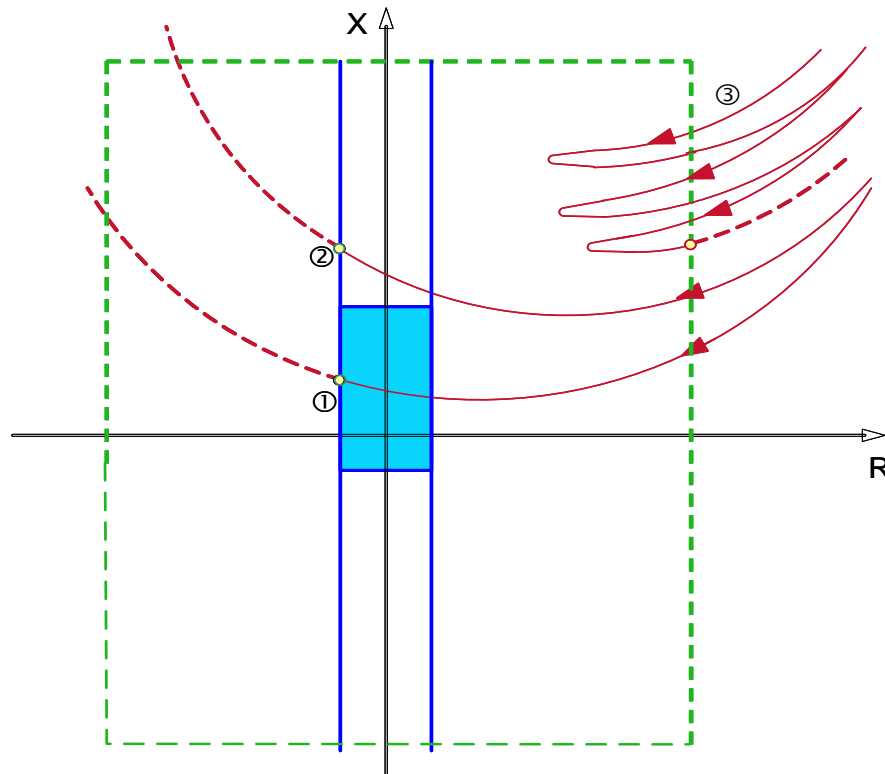
Figure 4 – Out-of-step protection (source: "Requirements for Protection schemes in EHV Transmission Systems, PG Systems Stability, Amprion-EnBW-transpower-50HeRTZ; original title: Anforderungen an Netzschutzeinrichtungen im Übertragungsnetz- PG Systemstabilität, 20-05-2010")

7 TELEPROTECTION

Telecommunication aided protection must be established assuring the safe and reliable clearing of faults in any point of the line. For 2SP/2C and 2SP/1C schemes the following teleprotencion schemes could be alternatively used:

- ♦ Distance protection with accelerated underreach protection (AUP) or permissive overreach protection (POP)

- ♦ Directional Comparison Protection (blocking and permissive schemes or hybrid)

- ♦ Phase Comparison

- ♦ Load Comparison

- ♦ Line Differential

For aided communication distance schemes the preferred scheme should the accelerated underreach protection (AUP) scheme. In case this preferred scheme is not possible, then the alternative should be a permissive overreach protection (POP) scheme, with the zone 2 as pilot zone. For this last alternative, special care should be taken (e.g. the current inversion logic could be included in the distance protection) for the case of multiple circuit lines to avoid unwanted tripping due to current reversal phenomenon.

Blocking schemes should not be used except when it is not possible to use permissive schemes or if it is directed by other reasonable technical reasons.

In addition the choice criterion may be related to the quality of telecommunication.

For weak infeed end cases a week infeed logic should also be used for teleprotection aided distance schemes (e.g. echo function with weak infeed end). The weak infeed end will be one whose short circuit current (or impedance equivalent) is less than the minimum setting value of the distance protection to be used to protect the line. The week infeed end logic will alternatively operate if the following two conditions happen: the existence of an undervoltage or the absence of distance protection start. This logic is activated if in a substation there are less than three active feeders connected. SIR (source impedance ratio) should be also considered, when deciding a week infeed end. The week infeed end could be defined as the end whose short circuit current contribution transferred in impedance is less than the minimum setting value of the distance protection. Additionally, in order to consider a line end as a weak infeed it should have this condition (with the above mentioned criteria) for at least 10% of the yearly hours annually.

7.1 Requirements of the communication system for teleprotection schemes

The communication system should be designed to work, when there is short circuit in the protected line, and it should comply with the IEC 60834. The availability of the communication system should be as high as possible, in the order of 99.9%.

From the protection point of view, the pick up time should be the adequate for the correct operation of the relays and the scheme. In general, this time should be less than 20 ms. For the different protection schemes the following typical times are recommended:

- Distance protection with zone acceleration
    - Command pick-up time 20 ms
    - Command drop-out time 500ms
- Directional comparison with permissive over-reaching scheme:
    - Pick-up and drop-out time 10 ms
- Directional comparison blocking scheme:
    - Pick-up and drop-out time less 5 ms

In the case of the use of direct transfer trip, when there is no local condition supervising of the received order, the security should be more important than other factors, and therefore the pick-up time should be at leas 40 ms.

7.2 Redundancy requirements of teleprotection systems

For 2SP/2C protection systems, the teleprotection system should be fully redundant. That means:

double communication physical channels and cables or fibres, with low probability of common mode failure; redundancy of the teleprotection equipment, one of the equipment associated to the Main-1 protection and another one associated to the Main-2 protection. Voltage supply from redundant sources is preferred.

When requirements are 2SP/1C type protection schemes both protection systems may use the same communication and teleprotection devices without complete redundancy

It is possible in lower voltages (e.g. less than or equal 150 kV), in radial feeding OHL, in substations far away from generating centres or if otherwise (e.g. due to company's practice or in accordance with national grid code) teleprotection system not to be an obligation. In any case the fault clearing time all OHL along must be kept as low as possible for both ends´ protections.

Teleprotection might not be existent in case of maintenance or other transmission works.

8 AUTOMATIC RECLOSING

Automatic reclosing (A/R) is applied at all overhead lines.

Automatic reclosing is suspended for cable faults, transformer faults, bus faults, generator faults. In mixed circuits (combination of overhead and underground or undersea circuit) controlled autoreclosing allowed providing the fault has not occurred on the cable and that reenergizing will be effected after cable's discharging.

There are some configurations of combined link (OHL+ cable) treated as an overhead line according the successful practice of certain TSO; (Automatic reclosing is permitted, even if the fault occurs on the cable) and that is valid for the following cases:
•   The length of the cable is less than 1km (for all possible configurations: transformer in radial feeder, interconnection transformer, tapped transformer or a cable as part of a mixed circuit - «siphon link»)
•   Client Transformer in radial feeder: if the cable belongs to the client, it's the client's responsibility to choose if an automatic reclosing is permitted on the link or not (the client has to consider his link as a cable or as an OHL)
•   TSO´s transformer in radial feeder with underground cable where the length of the cable is less than 40% of the total length of the link; this link is considered as an OHL.

In lower voltages (e.g. less or equal than 150 kV) A/R could not always applied due to safety, depending on the construction of the line and the tradition / practice of the electricity company. Lines that are placed in more crowded environment where the chance of touching the line with a machine is greater, lines running within urban areas etc or transmission circuits connecting manned substations with fast restoration can be excluded from the application of A/R.

All possible A/R modes (fast, delayed, voltage or synchrocheck) are allowed with safety and respecting the stability issues and the equipment withstanding capabilities. A/R for three phase faults is applied only after assuring that due to system configuration and S/S arrangement, there is not the possibility of jeopardising system security and stability. The ranges, where limit values for synchrocheck are included, are: ΔU=10-20%, Δf=0.030-0.5 Hz, Δa=10° - 35°, and in exceptional cases -and always only after study- the upper limit could be 55°, dead bus or line: U< = 20 – 40% pu, Live bus or line: U> = 70 – 80%.

9 FAULT-LOCATOR

They are intended for use either as a start point for locating fault or for permanent faults. Emphasis must be given on certain theoretical aspects related with FLOC, when their accuracy is reduced; for example mixed circuits, earth faults in double circuits, earth faults in next lines with

simultaneous multiple substation feeders etc. For special transmission circuits or fault cases or for peculiarities of the relays measuring methods auxiliary tables -in the form of spread sheets- for conversion of the FLOC indication to actual fault location are recommended.

10 LINE DIFFERENTIAL (87L)

10.1 Differential protection application

The current line differential protection, associated with distance protection is considered a preferable protection technique for HV and EHV lines. A precondition is the reliable availability of reliable telecommunication links. This principle of protection should always be used for multi-terminal lines, where other protection principles, e.g. distance, cannot guarantee selectivity with protection of other elements of the system, or when and where instantaneous clearing time need to be guaranteed. Additionally it can be used for lines with tapped transformers.

Due to the fact that short lines and/or cables do not have enough electrical length, the current differential relay should be always be used. When redundancy is needed, double current line differential protection could be used.. Whilst a short line maybe considered to be those less that 10km as a general rule. The limit may be shortened depending on the voltage level, the source impedance behind the relay or the characteristics of the voltage and current transformers.

Cables should always use at least a differential line protection in order to guarantee fast fault clearing while maintaining security. The reason being that there are many sources of errors associated to other protection principles, especially for ground faults in cables. For short cables, as for short lines, where redundancy is required double current differential protection could be used.

Where double current differential protection is decided to be used, for very specific and sound reasons, it must have as back-up at least overcurrent protections, especially for radial feeders. For meshed networks –in all cases- they must be accompanied by distance functions serving as back-up zones and for the coordination with the transmission system.

The use of differential line protection guarantees under normal conditions a resistive coverage of 150 Ohm or more. For this reason it should be the main protection in redundant systems.

10.2 Differential protection requirements

The current differential protection should a reliable type (preferably digital). The protection should be of the segregate phase type, i.e. it should be able to detect the phase in fault and therefore for the case of single line-ground (SLG) faults to trip only the phase in fault (also to establish single phase A/R). The synchronization of the measured values is done via a communication system.

The differential protection used should be preferably a biased current differential protection type and take into consideration the measuring errors from CTs, communication errors, and frequency deviation. The requirements for CTs should be according with the relay manufacturer specification but in any case CTs should not saturate within the first 5 ms for pass through faults to prevent unwanted tripping. The CTs´ class should be at least 5P30, 30VA as a starting point and it must be checked by calculation if the CT core fulfils the relay requirements for the protection functions included in the relay.

The differential relays used on 400 kV must operate in less than 20ms.

For protection of lines with tapped transformers, the differential protection should include some special features as:
- Ratio and vector group adaptation
- Inrush blocking

For this type of application the maximum feeder-transformer protection distance should be 1 km taking into consideration the burden that in this case may be introduced on the secondary winding of the CTs which in turn can make the differential protection unstable using direct fibre optic as communication media.

10.3 Communication requirements for differential protection

The communication system for differential line protection should be based on fibre optic and any equipment should comply with the IEC 60834. In general not more than 20 ms should be the activation time for the communication between the protections of the differential scheme. A TDM (Time Division Multiplexing) network is also acceptable for 87L.

 The synchronization method for relays of the protected elements could be any except the GPS (Geographical Positioning System) signal due the lack of control of that signal. The bit error rate (BER) of the communication system should be 99% of the time less than 10-6 and 0,99% of the time less than 10-3 when this reduction BER it is not directly associated with a line fault.

When redundancy is a requirement and double differential scheme is needed the communication channels will be fully and physically redundant, and therefore will no share the same physical path/cable.

For differential protection (current or others), in order to synchronize the analogue measurement, the maximum delay of the transmission system should be less than 10ms and the asymmetry in the pick-up times should be less than 1 ms.

11 PROTECTING CABLES

In general the principles described in chapter "Protection Principles" should be applied.
EHV- and HV-cables are protected by differential relays and necessarily also by distance relays as backup also for remote cables and OHL´s. The two protection schemes could be supplied by two different DC-supplies and two different CT-cores. The CB´s could have two separate trip coils which are used separately by the two protection schemes.
If for reliability purposes the practice of the company is different, it is also acceptable, provided that a detailed examination and justification of the high reliability level is carried out.
Additional functions, e.g. U0 (residual voltage), Directional O/C, Directional Earth Fault, U> (overvoltage), CBF (circuit breaker failure) and others may be required.
For routine testing, the protection schemes should be equipped with test plugs or similar. For heavily loaded cables it should be possible to test one protection scheme with the cable in service using the other protection.

12 PROTECTING REACTORS

Reactors are an important element of the transmission grid. They are used for reactive power offset of transmission cables, as passive element in the tertiary (MV) of tie transformers or autotransformers, they can be shunt reactors or switched reactors and are usually grounded. They can be found in 400, 150, 30 kV voltage level. They are in effect, radial loads that do not perform selectivity with other transmission networks; therefore they are not mentioned in other places in the present text as transformers are.

For their protection and switching IEEE Standards C37.015, C37.109, or equivalent IEC are valid. Permissible permanent current overloading are clearly described and specified.
Protection functions that are used are phase overcurrent, earth overcurrent, neutral overcurrent, overvoltage and residual voltage. High and low impedance current differential protection, restricted earth fault protection and distance protection can also be used. In some cases automatic schemes are applied for the optimum switching of the reactors.

13 PROTECTING CAPACITORS

Capacitors are an important element of the transmission grid. They are used for reactive power offsetting element. They are installed either in the MV level of the substations or in the HV level. They are mentioned here because they serve mainly the power transmission. Their protection is designed according to the Standard IEC 60871 or equivalent. Permitted safe overloading etc are clearly described. They can be single star/wye ungrounded, double-star/wyes ungrounded etc. They are in effect radial loads that do not perform selectivity with other transmission networks; therefore they are not mentioned in other places in the present text, like transformers are.
Protection functions that are used are phase overcurrent, earth overcurrent and neutral imbalance overcurrent.
Important issues are the necessity of a controlled switched mechanism of the main circuit breaker in order to avoid switching overvoltages, the necessity of delayed re-energizing (re-energize inhibit function) in order to assure the discharge of the capacitor bank before re-energizing.
Where capacitor banks are connected in common medium voltage busbars the inrush current during neighbouring capacitor switching in must be calculated, in order not to lead to unwanted tripping of the instant overcurrent protection of the live bank.
Where they are directly connected to the high voltage busbars, attention must be paid in the automatic reclosing of the CB opposite to the substation of the high voltage capacitors; automatic reclosing is allowed with dead time sufficient, as the maker of the capacitor recommends.

14 PROTECTING RENEWABLES (W/P, P/V)

The main issue of the protection in grids with non-conventional generating plants, like a wind farm (W/P), photovoltaic farms (P/V) etc, is their behaviour in case of short circuits. With an increase amount of renewable infeed a proper modelling of the behaviour of these according to symmetric and asymmetric faults will become more important. Existing standards of the short circuit calculation (IEC60909-0) have to be adjusted to the controlled and not linear characteristic of the power electronic connected power plants. New standards must be developed. The contribution of the plants to system faults must be clearly known. Therefore information on power plant transient performance during system faults must be available from manufacturers.
Plants with fault ride through capability must have high voltage nodes connected to the existing transmission grid via circuit breaker(s) equipped at least with distance protection. In many cases the renewables are mounted at an EHV or HV line by a radial feeder. A possible protection scheme is shown in Annex II (This configuration must be considered as an example only.

Differential protection is used with the solid grounded neutral of the infeed transformer for distance protection). Autoreclosing of the lines feeding the busbars of the farm is allowed. In any case the connection of new plant to the system must consider and respect the operation specifications and conditions mentioned in the grid code or other valid technical document. In any case the owner of the generator must guarantee that all faults will be cleared by its systems and that these systems are reliable and dependable and have built in redundancy.. It is not the task of the transmission system protection schemes in the meshed grids to detect and clear (as back-up function) all faults occurring in the equipment of the renewables substation (i.e. between the main step up transformer and the generators).

On the other hand the protection of the renewables must respect the protection principles and the operating tolerances of the transmission system and they must guarantee that they –at no time- are cut off unselectively or without coordination with the system protection.

15 THREE-END LINES, SPECIAL TOPOLOGIES

These topologies are not forbidden. Special teleprotection schemes or multi-end differential protection are applied. However, this kind of configuration should not be encouraged from the protection and system operation point of view as the absence of sufficient selectivity is obvious on the one hand as is the reliability of the communication paths on the other. If necessary, for cost efficiency and environmental purposes (saving of transmission paths etc), then the appropriate protection scheme should be fully agreed and applied.

16 FAULT RECORDING, ANALYSIS, EVENTS STATISTICS

EMS-SCADA are mainly used by the TSOs for event recording. Fault and event files are available in the modern multifunctional relays. Separate fault recorders are often found in selected older substations. Disturbances data are continuously gathered and they can be analyzed. All faults must be systematically traced and statistically assessed. Technical information for the assessment of the system and protection performance can be considered and continuously tracked.

17 FACTORY ACCEPTANCE TESTS (FAT), SITE ACCEPTANCE TESTS (SAT), MAINTENANCE

All TSOs must have written procedures for quality acceptance and/or control (QA/QC),- FAT/SAT and commissioning. Their procedures shall specify who is doing what. FAT is done by manufacturer/ supplier according to plans approved and supervised by the TSO.
SAT and commissioning is carried out mostly by in house personnel.
Maintenance policy may range from annual testing or every several years depending on technology (electromechanical, static, digital) or to NO preventive maintenance. This policy accepts different approaches due to legislation differences. The use of official company web sites for maintenance programme and specifications is encouraged.

18 ANNEX I Resistance values of the zones of distance protections related to the lines

Tab. 1 - Resistance values of the zones of distance protections related to the lines HV with distribution function

$X_{ZONE\ 1\div3}$ [Ω/phase]	Measurement phase-earth (φ-N) R/X	Measurement phase-phase (φ-φ) R/X
1.5 ÷ 3	5 ÷ 3	4 ÷ 3
3 ÷ 6	3 ÷ 2.5	3 ÷ 2
6 ÷ 9	2.5 ÷ 2	2 ÷1.5
9 ÷ 12	2 ÷ 1.8	1.5 ÷ 1.2
12 ÷ 24	1.8 ÷1.5	1.2 ÷ 1
24 ÷ 36	1.5 ÷ 1.2	1 ÷ 0.8
36 ÷ 48	1.2 ÷ 1	0.8 ÷ 0.7
48 ÷ 60	1 ÷ 0.7	0.7 ÷ 0.6
NOTE: values of the resistance phase-earth $R_{φ-N}$ are valid for the coefficients of earth K_T with value in the range 0.85-1. For lower values they must be proportionately increased.		

Tab. 2 - Resistance values of the zones of distance protections related to the lines HV with transmission function

$X_{ZONE\ 1\div3}$ [Ω/phase]	Measurement phase-earth (φ-N) R/X	Measurement phase-phase (φ-φ) R/X
2 ÷ 4	4 ÷ 3	3 ÷ 2.5
4 ÷ 8	3 ÷ 2	2.5 ÷ 1.5
8 ÷ 12	2 ÷ 1.5	1.5 ÷1.2
12 ÷ 24	1.5 ÷ 1.2	1.2 ÷ 1
24 ÷ 36	1.2 ÷1	1 ÷ 0.8
36 ÷ 48	1 ÷ 0.9	0.8 ÷ 0.6
48 ÷ 100	0.9 ÷ 0.5	0.6 ÷ 0.3
NOTE: values of the resistance phase-earth $R_{φ-N}$ are valid for the coefficients of earth K_T with value close to 1. For lower values they must be proportionately increased.		

The starting resistance can be set with the following tables, which are the typical values of the fault resistance, depending on the value of X_{START}, respectively, for HV lines that carry out distribution function (Tab. 3) and EHV lines that carry out transmission (Tab. 4):

Tab. 3 - Typical starting values for distance protection lines with distribution function

$X_{STARTING}$ [Ω/phase]	$R_{STARTING}$ (φ-N) Characteristic of starting A (Fig.1) $R_{START\ φN}$ [Ω/phase]	$R_{STARTING}$ (φ-N) Characteristic of starting B and C (Fig.1) $R_{START1\ φN}$ [Ω/phase]	$R_{START2\ φN}$ [Ω/phase]	Angle $\Psi_{φN}$	$R_{STARTING}$ (φ-φ) Characteristic of starting A (Fig.1) $R_{START\ φN}$ [Ω/phase]	$R_{STARTING}$ (φ-φ) Characteristic of starting B and C (Fig.1) $R_{START1\ φφ}$ [Ω/phase]	$R_{START2\ φφ}$ [Ω/phase]	Angle $\Psi_{φφ}$
20	25 ÷ 35	25 ÷ 35	25 ÷ 35	0°	20 ÷ 30	20 ÷ 30	20 ÷ 30	0°
35			25 ÷ 35	0°			20 ÷ 30	0°

50			30 ÷ 45	45°			25 ÷ 40	45°
65			30 ÷ 45	45°			25 ÷ 40	45°
NOTE: values of the resistance phase-earth $R_{START\,\phi N}$ are valid for the coefficients of earth K_T with value in the range 0.85-1. For lower values they must be proportionately increased.								

Tab. 4 - Typical starting values for distance protection lines with transmission function

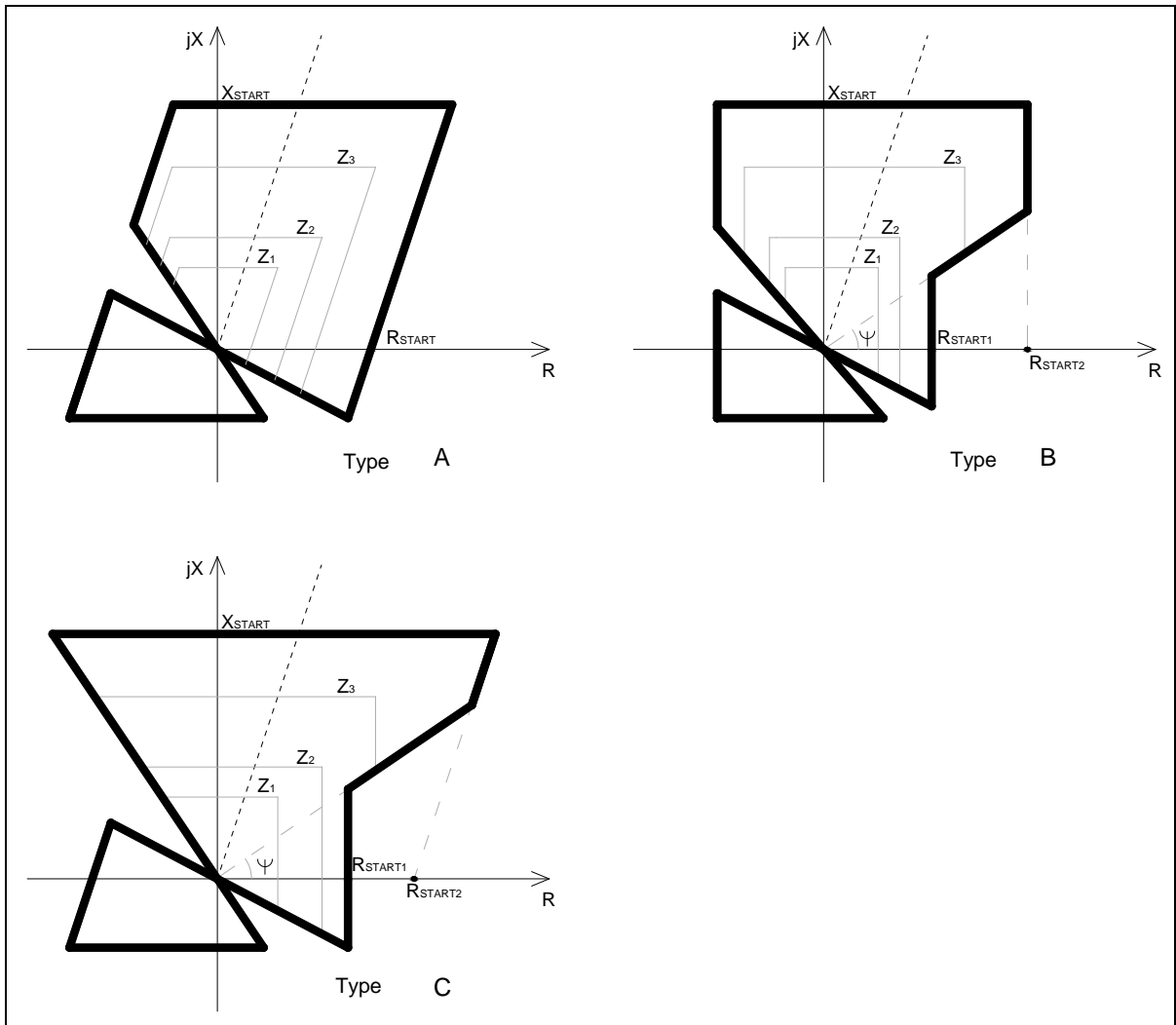| $X_{STARTING}$ [Ω/phase]	$R_{STARTING}$ (φ-N)				$R_{STARTING}$ (φ-φ)			
	Characteristic of starting A (Fig.3)	Characteristic of starting B and C (Fig.3)			Characteristic of starting A (Fig.3)	Characteristic of starting B and C (Fig.3)		
	$R_{START\,\phi N}$ [Ω/phase]	$R_{START1\,\phi N}$ [Ω/phase]	$R_{START2\,\phi N}$ [Ω/phase]	Angle $\Psi_{\phi N}$	$R_{START\,\phi N}$ [Ω/phase]	$R_{START1\,\phi\phi}$ [Ω/phase]	$R_{START2\,\phi\phi}$ [Ω/phase]	Angle $\Psi_{\phi\phi}$
40	25 ÷ 35	20 ÷ 30	35 ÷ 45	45°	20 ÷ 30	15 ÷ 30	25 ÷ 35	45°
50								
60								
75								
100								
125								
NOTE: values of the resistance phase-earth $R_{START\,\phi N}$ are valid for the coefficients of earth K_T with value close to 1. For lower values they must be proportionately increased.								

Fig. 1 - Main features of starting distance protection

19 Annex II: Protection Schema for connection of renewables (Example – indicative; figures are also indicative)

1) Lineprotection: Distance protection with impedance starting and differential protection
   - Protect the **EHV / HV line** without delay
   - The distance protection is additional backup protection for 2), 3) und 4)
   Two separate trip commands are recommended
2) Buchholzrelay
   - transformer protection
3) Differentialprotection
   - transformer protection
4) Time over-current
   - protect the busbar with 0,5s delay
   - backup protection for 6).
5) Directional earth fault detection (needs cable type current transfomer)
   - to detect the residual resistive current in huge compensated grids or the capacitive earth fault current in small insulated grids
   - earth fault detection for the machine connected cable
6) Time over-current
   - protect the machine connected cable with 0,1s delay
7) Starting comparison and circuit breaker failure protection
   - Trip in case of starting of 4) and no starting of 6)
   - Switch off the 30 kV breaker at the end of the first tripping time and the EHV breaker at the end of the second tripping time
8) Earth fault monitoring

protection scheme
windfarm-substation