BUSBAR PROTECTION - BUSBAR DIFFERENTIAL: BEST PRACTICE AND RECOMMENDATIONS

04 December 2019

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Definitions

Busbar protection (BBP): Protection intended to detect and operate to clear faults on a busbar.

Circuit Breaker Failure (CBF) Protection: CBF protection is a backup protection in case the designated Circuit Breakers failed to open and clear a fault; it will avoid circuit breaker redundancy

Abbreviations

87- Differential principle of protection (ANSI code)
AFP - Arc Fault Protection
AIS – Air Insulated Substation
AR – Auto Reclose
BBP – Busbar Protection
BBTR - Busbar Protection Trip Relays
BFP – Breaker Failure Protection
BP – Bay Protection
BTTRTR - Back Trip Receive Trip Relays
BU – Bay Unit
CB – Circuit Breaker
CBF – Circuit Breaker Failure
CT – Current Transformer
DAR – Delayed Auto Reclose
DBI – “Don’t Believe It”, INVALID (1, 1 or 0, 0 for Double Points Status of CBs or Disconnectors)
DC – Direct Current
FAT – Factory Acceptance Test
GIS – Gas Insulated Substation
HVDC – High Voltage Direct Current
ICTR - Interlocked Current Trip Relay
IED –Intelligent Electronic Device
MSCDN - Mechanically Switched Capacitor with Damping Network
OHL – Overhead Line
RES – Renewable Energy Source
S/S – Substation
SGT – Super Grid Transformer, Power Transformer
SVC – Static VAR Compensator (for reactive-power control)
TSO – Transmission System Operator
VT – Voltage Transformer

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EXECUTIVE SUMMARY

This document has been developed by ENTSO-E and it is intended to present the fundamentals of the busbar protection and all stages of its engineering (design, settings, commissioning and maintenance). The report is based on responses received from European TSOs to a questionnaire on busbar protection. It presents the statistical findings of these responses and exploits the experience of TSOs in busbar protection.

The overall engineering and the management of busbar protection is of great importance to electrical utilities as busbar faults are of great importance to the safety and the stability of the transmission system. Busbar protection may simultaneously trip a number of bus segments or even an entire busbar of a substation and the fast elimination of busbar faults is critical to ensure that the transmission system does not suffer from severe shocks. The failure of protection operating or any unwanted tripping may also lead to severe consequences in a transmission system. Although busbar protection is quite expensive and complicated, its features may save equipment and even people's lives.

A busbar protection system should dynamically replicate the bus topology and contain design flexibility to protect all existing bus arrangements. In general, the main requirements for busbar protection include security, dependability, speed, sensitivity and selectivity. All these requirements are interrelated; therefore, it is not possible to satisfy one without affecting the other. The design solution should meet the requirements that correspond to the importance of the substation within the network and the layout of the substation.

The dominating protection principle of busbar protection is the differential principle. The main types of differential current protection relays are low-impedance and high-impedance differential protection. Low-impedance differential principle is mostly used, although, the high-impedance differential principle is still used by some system operators. Both types of differential current protection relays have advantages and disadvantages. The low-impedance deferential protection relays are frequently numeric and more flexible which allows to protect substations with complex schemes. Low-impedance deferential protection relays can stay in operation even during the reconstruction of substations when usually some temporary operation is needed. On the other hand, high-impedance relays can be more easily extended because there is no need to add new analogue inputs. They also need less mounting space and are less expensive. In addition, the hardware for low-impedance differential relays can be shared with breaker failure protection, so costs of these relays can be easily reduced. Each end user should evaluate the advantages and disadvantages and choose the best solution based on the intended application and installation.

Other busbar arrangements, reliability principles and tripping criteria which support the functionality of busbar protection (check zone logic, the directional principle, the saturation detection, voltage and current release criterion and built in circuit breaker failure) must be considered in the design and configuration of the breaker failure protection. Centralized or decentralized types are equivalently used depending on the local conditions. Aspects like the number of bays; integrated protection functions; distance between central unit and bay units; EMC problems; maintenance; function testing and design should also be considered. The redundancy level should be a function of the critical clearing time and if this is less than typical remote backup clearing times then busbar protection must installed. High penetration of power electronics at the connection interface and the existence of GIS or AIS substations should also be considered in the design and management of busbar protection.

Concerning planning great concern is devoted to the location of installation of busbar protection and there are a variety of tactics. Most companies try to install busbar protection as much as possible to

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avoid the clearance of the busbar faults by the second zone of the distance relays. However, double busbar protection is not the rule and its policy is managed and/or executed by the companies.

Under normal conditions, a switchgear cannot be switched off completely to check the busbar protection, making asset management issues critical for the BBP protection. As busbar protection is a system of the entire busbar, a suitable test strategy must be defined. A general recommendation of how to test a busbar protection is difficult to provide as it depends on the type of protection system, on the topology and on the risk or consequence of a false trip.

If the busbar protection must be replaced, the protection system usually must be switched off for a certain time. A parallel operation of the existing and the new busbar protection is very complex and involves many provisional steps (risks of false tripping). For this reason, the necessary deactivation of the busbar protection must be kept as short as possible. During the time when no busbar protection is in operation, the activation of a reverse zone in the distance protection can provisionally replace the busbar protection.

Components of the protection system (bay unit or central unit) may fail as with other protection devices. For this reason, it is advisable to have spares in case of failure, the spares must also be checked periodically. If applicable, spares for several substations can be stored centrally.

As a rule, the network operator provides a detailed technical specification for busbar protection. In addition to the protection-relevant requirements, the specification also contains additional requirements such as for the communication interface (e.g. IEC61850 Edition2) or quality management (ISO9001).

The life cycle of busbar protection systems is approximately 20 years and the number and rate of failures of hardware components is identical to that of numerical protection devices.

LIST OF FIGURES

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1 INTRODUCTION

Busbar faults are directly related and interlinked with the safety and the stability of the transmission systems. Their fast elimination assures the successful withstanding of the transmission system to severe shocks [3]. Busbar protection may simultaneously trip a number of bus segments or even an entire busbar of a substation which may then lead to the loss of important assets. If generation or big loads are connected to the busbar the energy balance of the system may be suddenly endangered. Consequently, the failure to tripping or any unwanted tripping may lead to severe consequences on the power system.

This document has been developed by ENTSO-E and it is intended to present the fundamentals of the busbar protection and all stages of its engineering (design, settings, commissioning and maintenance). The report is based on responses received from European TSOs to a questionnaire on busbar protection. It presents the statistical findings of these responses and exploits the experience of TSOs in busbar protection.

Chapter 2 presents a brief description of the principles of function of the busbar protection.

Chapter 3 documents the various configurations and architectures of busbar protections.

Chapter 4 analyses the protection of specific components of the buses (Eg. busbar couplers, segments between components, etc.) with the objective of covering all of the elements involved and even optimal overlapping regarding their protection.

Chapter 5 is exclusively devoted to a very important protection, usually interlinked with busbar differential protection, the circuit breaker failure protection.

Chapter 6 gives guidance concerning the setting and the parameterisation of the busbar differential protection.

Chapter 7 covers issues in relation to the asset management of the busbar differential protection, Eg. principles in relation to testing, maintenance, lifecycle and refurbishment.

Chapter 8 makes reference to Standards (CENELEC, IEC, ENTSO-E / EU regulations etc) concerning busbar (differential) protection as well as to brochures of related international organizations like CIGRE, IEEE etc.

Chapter 9 discusses a case concerning maloperation of busbar protection and the “lessons learned”.

Chapter 10 includes the statistical appraisal / presentation of the responses of the TSOs to the distributed survey about busbar protections.

Finally, Chapter 11 summarizes the conclusions and recommendations.

The report is accompanied by a related reference / bibliography list (Chapter 12) with books, papers, presentations, brochures etc. concerning busbar differential protection.

2 BUS BAR PROTECTION: PRINCIPLE OF OPERATION

2.1 FUNDAMENTALS

Busbar protection systems protect substation busbars and associated equipment from the consequences of short-circuits and earth faults. In the long ago early days of power system development no separate protection device was used for busbar protection. Remote end-line

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protections served as the main protection for busbar faults. As a result of increased network short-circuit capacity, dedicated differential relays for busbar protections have been applied to minimize the tripping time of the protection and to limit the damage caused by high fault currents. Today, busbar protection systems are used [7]. and even double busbar protections may be applied.

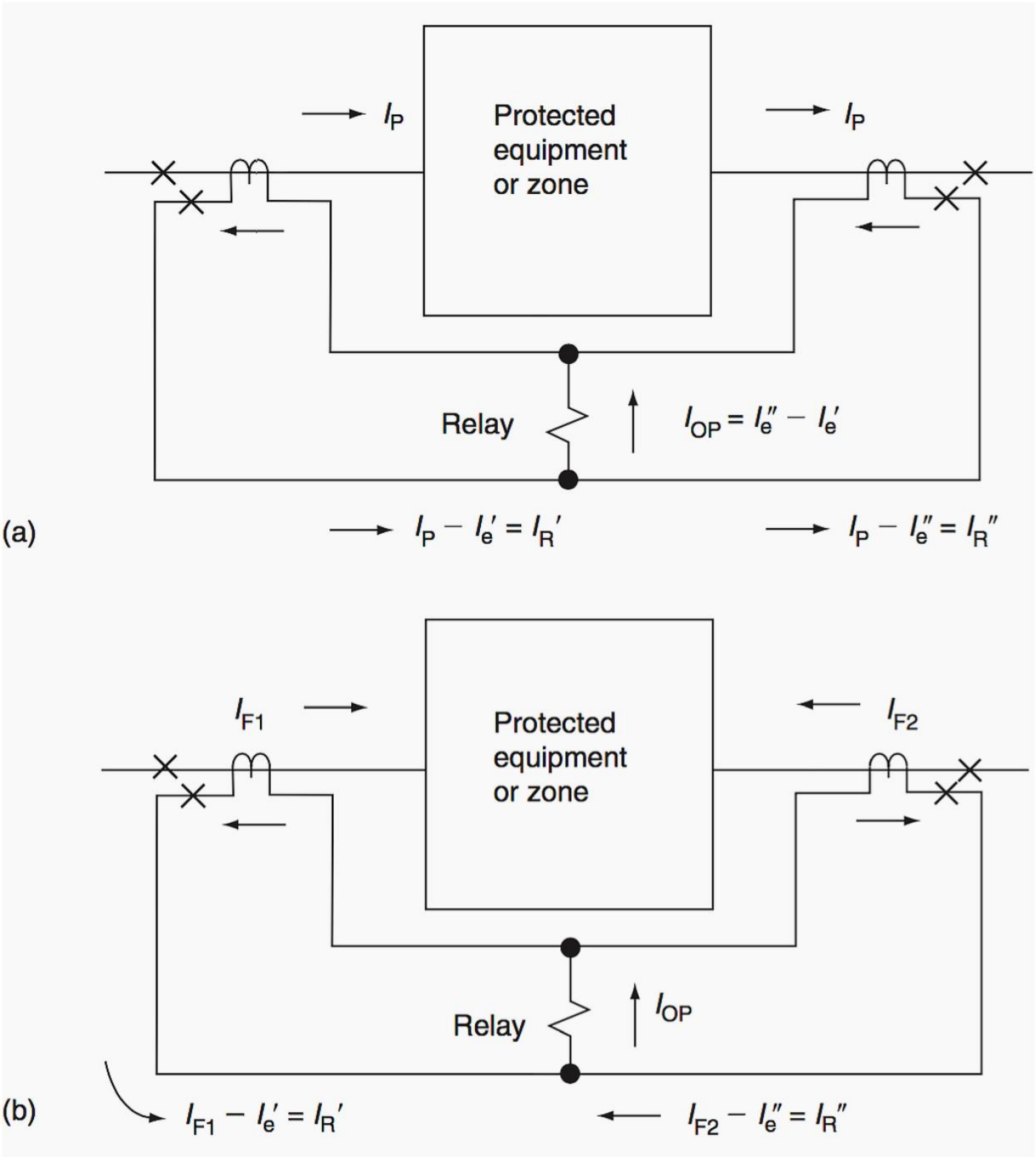
The generic transmission systems' key issues i.e. reliability, operability, maintainability and cost need to be addressed when designing a substation and selecting a busbar configuration and consequently a busbar protection scheme. At EHV/HV levels, solutions that provide a high degree of reliability can be justified. A busbar protection system should dynamically replicate the bus topology. It should also contain sufficient design flexibility to protect all existing bus arrangements. In general, the main requirements for busbar protection include:

- Security - probability of an unnecessary protection operation for through faults ("Out-of-Zone" faults) is low.
- Dependability - probability that the protection will not operate for a fault on the bus ("In-Zone faults") is low.
- Speed – high-speed operation is required to limit equipment damage, and to preserve system transient stability.
- Sensitivity – the ability to detect and clear high resistance faults.
- Selectivity – the ability to isolate only the faulty bus section.

All these requirements are interrelated; therefore, it is not possible to satisfy one without affecting the other. The design solution should meet the requirements that correspond to the Importance of the substation within the network and the layout of the substation.

The dominated protection principle of busbar protection is the differential principle. The fundamental general principle of differential protection of a "single object" is illustrated in FIGURE 1 bellow. In the place of "object" a generator, a transformer, a bus arrangement, a reactor, a line or a cable etc. can be considered. Of course the differential protection of each one of this type of components has additional specific peculiarities, but the fundamental principle is the same.

The affection of the measured and compared currents flowing "into" the protected object due to a fault is presented.



- **(a)** normal conditions, $I_{OP} = I_e'' + I_e'$;
- **(b)** internal fault $I_{OP} = I_{F1} + I_{F2} - (I_e' + I_e'')$

FIGURE 1: Differential (object oriented) protection principle

Concerning busbar differential and for simplicity a simple bus with four feeders in the protection zone are shown. Multiple circuits exist for the components connected to busbars, but the principle is the same. The sum of the currents flowing in essentially equals the sum off the currents flowing out during normal operation.

The protection concept for all bus differential relay schemes is based on Kirchhoff's First Law that the sum of all currents at the common point of connection, at any instant in time, is equal to zero. In particular, for bus differential protection this means that the sum of currents that flow from the source to the bus must be equal to the sum of all currents that flow from the bus to the load. If this is not satisfied, an internal fault ("In-Zone" fault) has occurred. However, in actual applications, bus differential relays could unintentionally operate when there is no fault on the protected bus. This might happen when faults in the power system cause high currents to flow through the protected bus causing saturation of some iron-cored CTs that provide information to the relay about the magnitude of the primary currents. Saturated CTs will provide false information, reporting smaller current magnitudes than there actually are. As a result, the relay will derive "differential" current that actually does not exist. To avoid unnecessary operation, manufacturers use different algorithms to achieve relay stability during CT saturation.

Kirchoff's current law states that the vectorial sum of all currents at a node or bus is equal to zero. This principle is applied to bus protection in power system networks. Current transformers (CTs) are installed to monitor all currents entering and leaving a bus through the normal circuits connected to the bus. A bus differential protection scheme, regardless of the type of relay used, simply compares the current entering the bus with the current leaving the bus. Any difference in the current entering and leaving the bus, above some predetermined threshold, is an indication of a bus fault that must be isolated quickly. Bus differential relays perform this function by detecting the differential current and tripping all breakers directly associated with the bus to isolate the fault. Unlike transformer differential relay schemes, the bus differential relay does not need to provide magnitude or phase angle compensation because of transformer winding ratios and connections. Likewise, bus differential schemes do not have to contend with magnetizing inrush currents that require transformer bus differential relay schemes to employ harmonic blocking, restraint, or other waveform recognition techniques. On the surface, bus differential schemes should be very simple to apply. A simple bus differential scheme can be implemented by paralleling CTs from all circuit breakers on the bus, in which case the sum of the current on each phase for all normal through-load and external through-fault conditions is zero, as shown in FIGURE 2. The first complication arises because all paralleled CTs must have the same ratio to ensure that all secondary currents are compared on the same base as the primary currents.

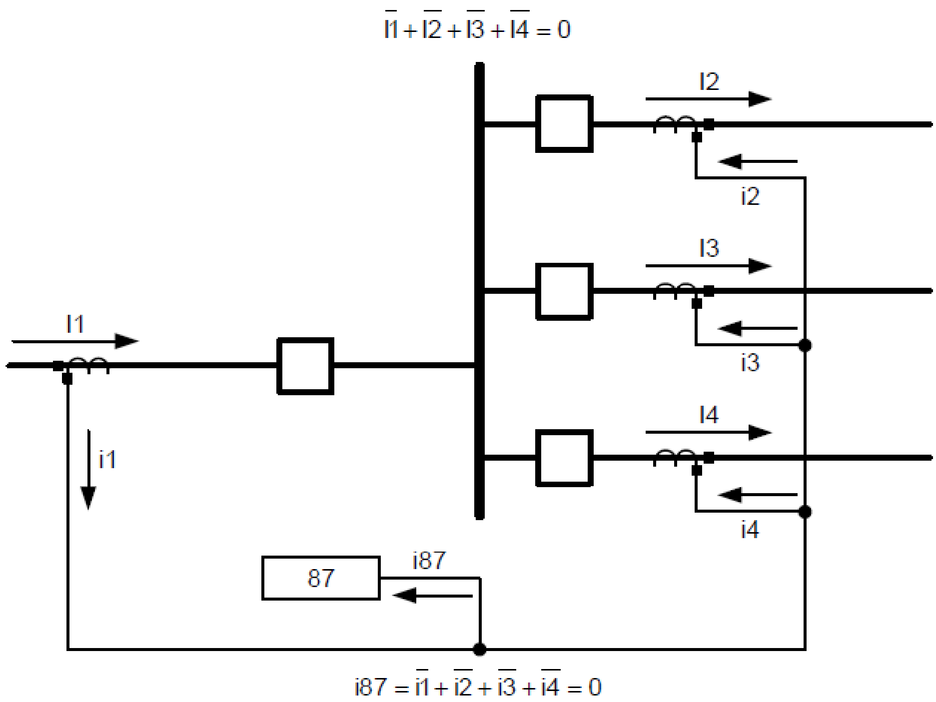


FIGURE 2: Simple current differential scheme with paralleled CTs

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The relay in this simple bus differential scheme could use a simple, instantaneous overcurrent element set with a very sensitive pickup, because ideally no current flows to the relay under normal through-load and through-fault conditions. This, of course, assumes that all paralleled CTs not only have the same ratio but that they also perform identically under all conditions, including external faults with heavy through current and asymmetrically offset waveforms caused by high source X/R ratios. The reality is that all conventional iron-core current transformers, regardless of ratio and accuracy class, are susceptible to saturation, during which time their secondary output current fails to accurately represent the primary current flowing in the bus. This causes a difference current that the differential relay may interpret as an internal fault. Bus differential relays, regardless of the design, must differentiate between true internal bus faults and false differential currents caused by CT saturation for a fault outside the bus differential zone of protection

2.2 NUMERIC CURRENT DIFFERENTIAL, HIGH IMPEDANCE, STABILIZED, ETC.

In the previous paragraph there was mentioned that the dominated principle of bus bar protection is the current differential principle. It is because of its great sensitivity. In this time mostly numeric current differential relays are used, because the microprocessor technology improves bus bar protection performance and economy. It is easy to change their settings in case of changing of either configuration of a substation or parameters of CTs. Using the modern technology allows to protect even substations with complex schemes and to let their protection stay in operation even during reconstruction of substations when usually some temporary operation is needed. An important feature of numerical relays is the in-built monitoring system so faults within the equipment can be detected and alarmed.

The main types of differential current protection relays are:

- low-impedance differential protection
- high-impedance differential protection

Today mostly the low-impedance differential principle is used, although, the high-impedance differential principle is still used by some system operators.

Both types of differential current protection relays have some advantages and disadvantages. For example the advantages mentioned above are mostly true for low-impedance relays. On the other hand high-impedance relays can usually be more easily extended because there is no need to add new analogue inputs, they need less mounting space and they are less expensive. Nevertheless, the hardware for low-impedance differential relays can be shared with breaker failure protection, so costs of these relays can be easily reduced. Each end user has to evaluate them and choose the best solution based on the intended application and installation.

Because CTs can be prone to saturation during severe faults and because there are small differences in CT performance, it is recommended they should use some kind of stabilization or additional criteria for tripping. It is particularly possible if low-impedance relays are used.

The most common kind of stabilization of low-impedance differential relays compares the differential current which is a vector sum of currents from all CT inputs with arithmetical sum of these currents. The bigger the arithmetical sum of currents is the bigger differential current is needed for the relay to operate.

The other supplemental protection function, such as end-zone fault detection, breaker failure detection, and open or shorted CT detection are recommended.

If there is a fault between a CB and the CT associated witch the CB, the fault cannot be interrupted by opening all of breakers in the substation. The end-zone protection logic determines the breaker is open, but the current through the CT has not gone to zero. The logic sends a transfer trip to the breaker at the remote end to interrupt the last source of fault current. The other possibility is to send a teleprotection signal to distance relays on the remote end immediately when BBP operates. It will accelerate the operation of the distance relays.

An open or shorted CT in a low-impedance scheme produces a differential current, which is proportional to the load current on the circuit with the faulty CT. With low-impedance relays, the setting can eliminate differential current under normal load condition, so a current threshold can be set sensitively to detect an opened or shorted CT. This threshold can be used to alarm, disable the BBP or trip the bus. A more sophisticated method can detect the change in differential and restraint current. The loss of a CT output current results in an increase in differential current and a decrease in restraint current.

The additional tripping criteria are described in a chapter hereafter.

2.3 ARC PROTECTION (LIGHT SENSITIVE)

The arc fault protection technique employed for the fast clearance of arcing faults on busbar, circuit breaker compartments and associated cable boxes on the air insulated metal clad medium and low voltage switchgear.

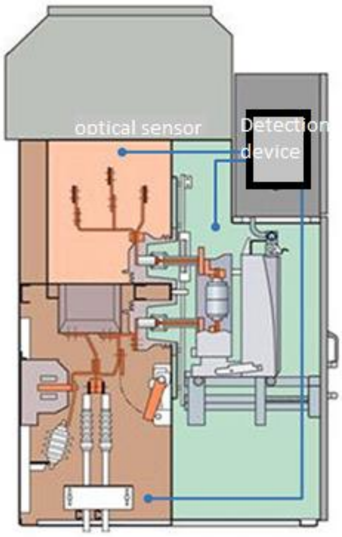

FIGURE 3: Cross-section of an air insulated switchgear unit within optical sensors

<u>Arc Flash Detection Methods</u> [4]

An arcing fault instantaneously releases large amounts of radiant energy, including both light and thermal energy. The light intensity resulting from an arc can be thousands of times higher than normal ambient light. An arc flash detection relay takes advantage of this phenomenon to achieve significantly faster response times—thereby affording significantly greater protection from damage—than the conventional relay.

Conventional current based protection techniques are at times challenged by the nature of arcing faults and can result in slow protection clearance times. Slow protection clearance times increase the risk to nearby personnel and increase the degree of damage to plant and equipment. By employing an optical detection technique, Arc Fault Protection (AFP) results in fast clearance of arcing faults. The AFP can detect arc-flash events and send a trip signal from 2 up 4 ms if using high speed output contacts or 15 ms for relay contacts.

Although detecting light is perhaps the easiest and fastest detection method, many systems detect two and sometimes a combination of three or more parameters (i.e. light, current and sound). The most efficient, cost effective, and therefore the most commonly used method combines the detection of light and current.

Arc Flash Detection System

The primary components of an arc flash detection system (light and current detector) are the arc monitor unit, control unit, optical detector, current detector and current transformer. The control unit receives signals from both a high-sensitivity light detector and the upstream current transformer, enabling it to determine whether to trigger the circuit breaker. Clearly, this signalling process must be both fast and reliable to minimize danger and damage. Fiber optics, with its inherent speed and EMI immunity, makes it a perfect medium for an arc flash detection system.

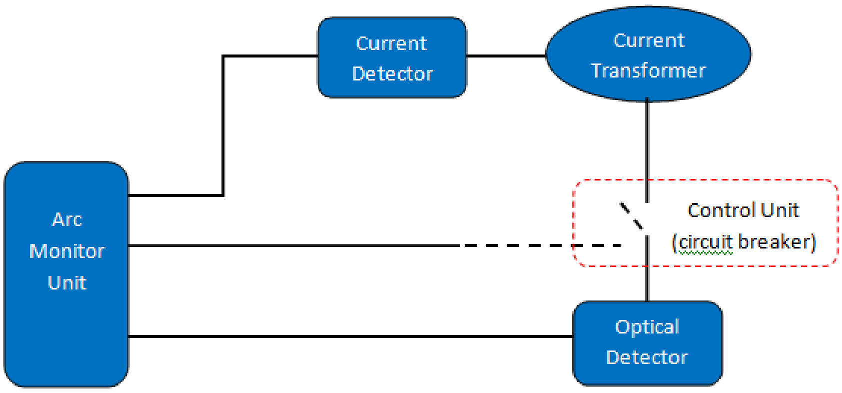

FIGURE 4: System diagram of a generic arc guard includes both optical and current detectors

The optical detector unit includes an optical emitter and receiver, an optical sensor in the form of a bare fiber loop, and fiber optic cable. The optical sensor collects the flash light and transfers it via fiber optic cable to the fiber optic receiver, which converts the optical signal to an electrical signal that informs the control system when an arc flash is occurring.

There are two types of optical sensors commonly used in such systems: the point sensor and the loop sensor. The point sensor approach uses a light sensor and an optical receiver to detect light in a given area, while the loop sensor uses a loop of bare fiber positioned strategically throughout the equipment.

2.4 Busbar Protection Blocking Scheme Supervision or Blocking Criteria

The unavailability of a differential busbar protection in a substation can be critical for the grid regarding the stability of the nearby power plant units. Operating reliability is also required in case of short circuit in the substation : it is forbidden to lose an entire substation in case of malfunction of the busbar protection.

It is therefore necessary to monitor in real time the proper functioning of the busbar protection. It is required to verify that the acquisition of the input quantities is correct and that the internal components of the protection are functional.

The main busbar protection fault supervision functions are mostly the following: faulty current measurement detection, faulty disconnector position detection and internal component failure detection.

For the reliable operation of busbar protection this supervision functions are continuously running and protect the busbar protection from false tripping. These supervision features are presented now.

First of all, current measurement supervision monitors in real time the following currents computed by the protection: the differential currents, the zone differential currents and the check zone differential current.

When a faulty current is detected, the actions can be:

- Alarm (possibly delayed),
- Full Busbar Protection blocking (full blocking or only for the phase concerned by the faulty differential current),
- Partially (Zone) Busbar Protection blocking (only for the zone concerned by the faulty differential current and only for the phase concerned).

Likewise, disconnector position supervision monitor in real time the faulty disconnector position replica and the wrong disconnector position detection (mistaken position).

Internal components failure supervision is also required as for any protection. This supervision monitor the following points: components failure (watchdog), link between bay failure (for decentralized arrangement), power supply failure…

When a faulty disconnector position or an internal component failure is detected, the actions can be the same: alarm (possibly delayed) or full (partially) busbar protection blocking

2.5 BUSBAR SPLITTING

A busbar differential protection is characterized by its protecting zones, which refer to bus segments being isolated by circuit breakers in case of busbar faults. Purpose is to isolate –after a fault- only the busbar part feeding the fault. When more than one protection zone at the busbar protection is applied, a busbar splitting strategy is used.

The positions of the CT are structuring to get the optimal splitting strategy. Indeed, in case of a busbar fault, the busbar protection performs the tripping of the CB only for the corresponding busbar section (the busbar section is boarded by CT with regard to measurement and by CB with regard to tripping).

The CBs and disconnector positions are also needed to apply the correct differential current computation and busbar splitting operation in case of fault. It is indeed useful to use several measuring zone to obtain the best selectivity.

Several busbar switching schemes are available and there are many variants of each scheme [2]

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Some examples:

Double Busbar with Transfer Bus

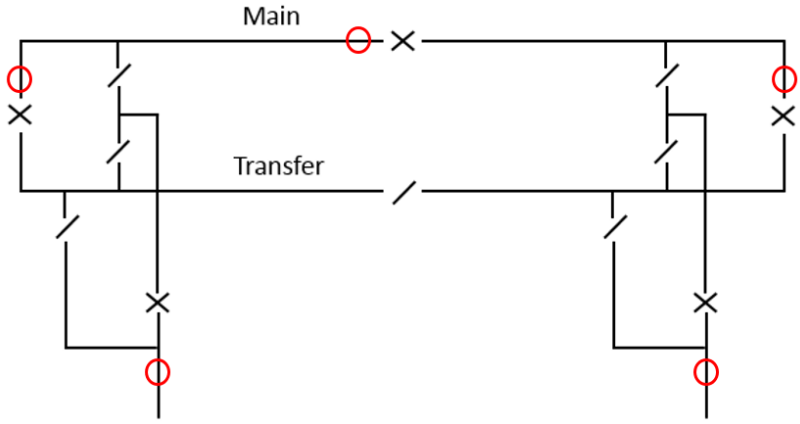

FIGURE 5: Double Busbar with Transfer Bus

To apply a selective busbar protection strategy, position inputs are required on each disconnector and circuit breaker to select the correct differential current measurements for the different zones and get the correct busbar splitting in case of fault.

Mesh busbar scheme

For mesh busbar scheme, the protection shown consists of a fully selective scheme with a busbar differential protection at each corner. A fault at any corner trips the two breakers associated with that corner and also initiates any intertripping necessary to open circuit breakers at opposite ends.

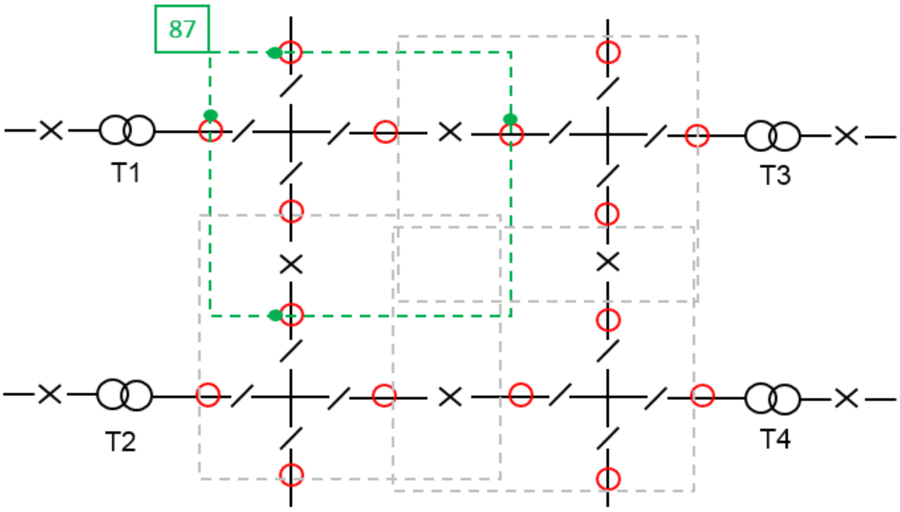

FIGURE 6: Mesh busbar scheme and BBP at Mesh scheme

One and a Half Breaker Scheme

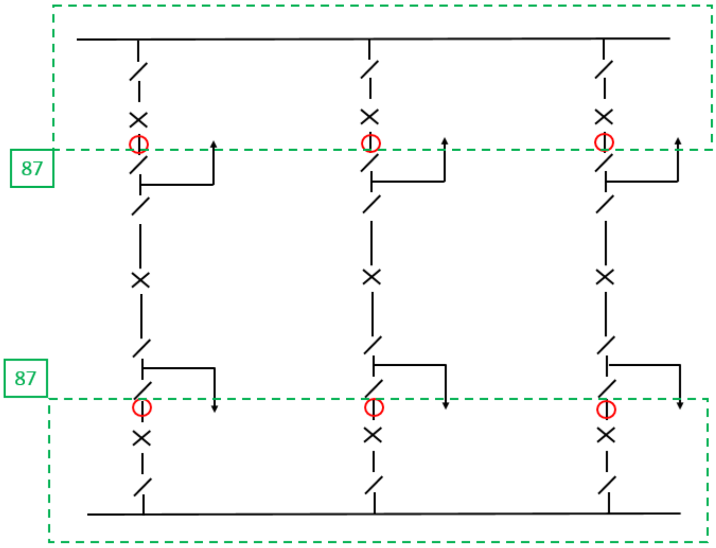

FIGURE 7: One and a Half Breaker Scheme

When busbar protection is required, then each busbar is considered individually and a single busbar scheme applied to each as shown.

It is possible to use more complex scheme that can protect the entire substation selectively:

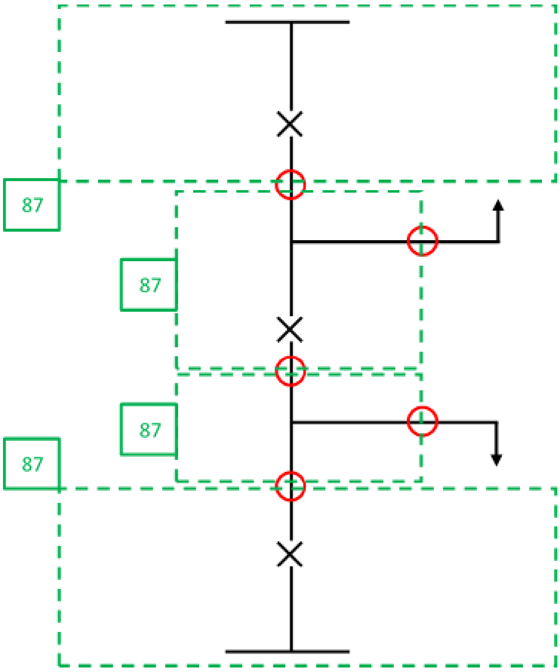

FIGURE 8: Protection scheme of busbar protection of a substation with the configuration of 1 ½ breaker

In that case it is necessary to install three more CTs with bay units of busbar protection in every branch of the substation. Further, direct trips to remote substations shall be sent. Faults in branches can be selectively detected and switched off.

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2.6 DISTANCE PROTECTION

Distance protection relays are mostly used for busbar protection backup (or during maintenance of the busbar differential protection).

Different choices are possible to use distance protection:

- Use of zone 2 of distance protection from the opposite end of the overhead lines or underground cables,
- Use of reverse zone (oriented towards the busbar) for the transformers distance protection or overhead lines distance protection,
- Use of distance protection to trip coupling circuit breaker (with blocking scheme between distance protection for the ring substation topology)

During maintenance period of busbar differential protection, it can be needed to modify distance protection settings (X-reaches, R-reaches or grading times).

These setting modifications are sometimes needed to ensure the stability of the generator in the area or to ensure the integrity of GIS busbar in case of fault during busbar differential protection maintenance.

2.7 ADDITIONAL TRIPPING CRITERIA FOR BBP DIFFERENTIAL

2.7.1 CHECK ZONE

To avoid maloperation resulting from disconnector auxiliary contact failures, substation configuration can require use of an additional trip criterion such as a check zones. The measuring system for the check zone detects a short circuit in the entire busbar. In this case, the disconnector positions are not considered. The disconnector positions must be considered in conjunction with the check zone only in special cases, for example, for transfer busbars or combined busbars.

Conceptually, an entire substation is treated as a single node, and the currents into the node are summed in accordance with Kirchhoff's current law. Regardless of the status of the disconnect switches, a fault is indicated if the check zone currents do not sum to zero. If the normal differential operating current is non-zero and the check zone operating current is zero, the most probable cause is a faulty disconnect status contact. Check zone supervision of the normal differential element significantly reduces the chance of a false trip.

2.7.2 CURRENT DIRECTION

There are several other options for a second trip criterion to supervise the differential element. In an advanced differential relay, a directional element can provide additional security during an external fault with CT saturation. During such an event, fault current contributions flow through each of the not faulted terminals and aggregate in the faulted terminal, causing the CT on the faulted terminal to saturate. This results in a false operating current. However, the current in the faulted terminal is out of phase with the other zone currents, indicating an external fault. The directional element chooses one of the currents as a reference quantity and calculates the phase angles of the other currents with respect to the reference. The element declares an internal fault only if all the currents are substantially in phase. This declaration can supervise the normal differential element.

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2.7.3 PHASE UNDER-VOLTAGE RELEASE CRITERION

The busbar protection tripping command is released by under-voltage function. The under-voltage function senses voltage collapse during short circuit on a busbar. In case of current transformer circuit failure in a bay the missing current will cause differential current in the measuring element and it can cause unwanted trip of this busbar section. In order to avoid this faulty trip the measuring element can trip the busbar section, if the under-voltage release criterion is fulfilled.

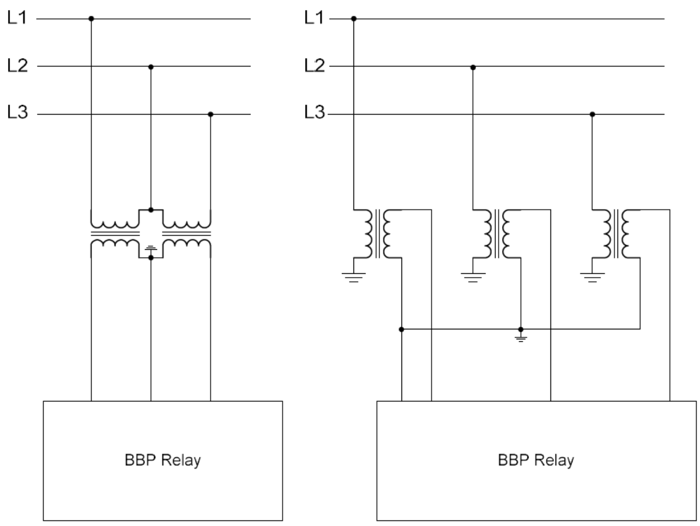

FIGURE 9: Under-voltage release criterion

The evaluation of the busbar can be accomplished by two different methods (see above Figure).

Version 1: With the VT. 'V (delta)- Arrangement', the phase-to-phase voltages can be evaluated. The busbar system measures the values of the phase voltages UL1-L2, UL1-L3 and UL3-L1.

Version 2: With the VT. 'Y (star)- Arrangement', the phase-to-phase voltages and the phase to ground voltages can be evaluated.

2.7.4 VOLTAGE SEQUENCE COMPONENTS RELEASE CRITERION

Voltage elements can be used to indicate whether a fault has occurred near a protected bus. A fault generally reduces the positive-sequence voltage magnitude (balanced and unbalanced faults) and increases the zero sequence and negative-sequence voltage magnitudes (unbalanced faults). These signatures can be used to supervise a differential element, but they are not as selective as a check zone or a directional element because they cannot distinguish between faults that are internal or external to the protection zone.

2.7.5 NEUTRAL OVER VOLTAGE RELEASE CRITERION

A 'neutral over voltage release criterion' should be considered for impedance grounded networks. Under normal operation, or during a phase-to-phase fault condition, without ground connection, the neutral voltage (sum of the phase to ground voltages) is almost zero. A ground fault in an impedance grounded network is characterized by the fact that the neutral voltage reaches a certain value very quickly. The amplitude of the voltage value depends on the relationship between the fault resistance and the grounding impedance.

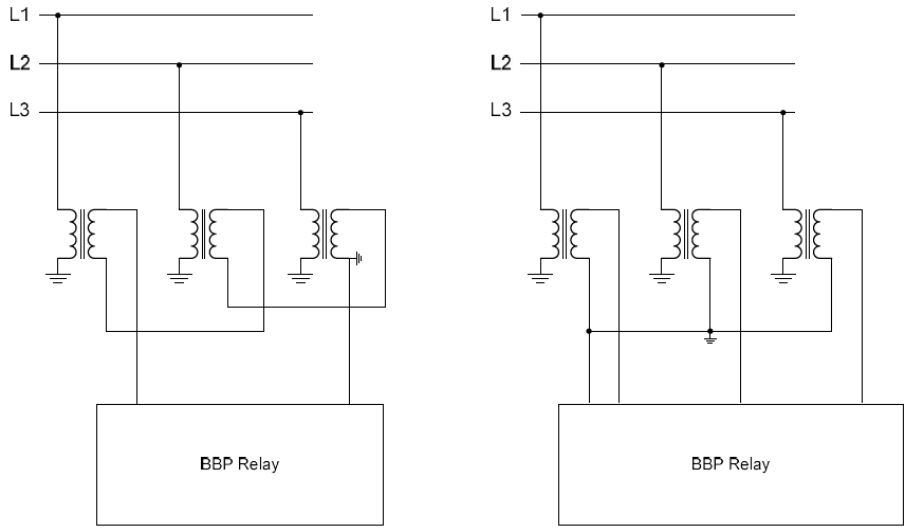

FIGURE 10: Neutral over-voltage release criterion

2.7.6 NEUTRAL OVER CURRENT RELEASE CRITERION

A 'neutral over current release criterion' only has to be considered for impedance grounded networks. Under normal operation, or during a phase-to-phase fault condition without ground connection, the neutral current is zero. A ground fault in an impedance grounded network is characterized by the fact that a current will exist in the transformer neutral. The amplitude of the current value depends on the relationship between the fault resistance and the grounding impedance.

2.7.7 OVERCURRENT RELEASE OF THE TRIP COMMAND

In order to ensure that the BBP acts during faults, the net overcurrent flowing through the feeders is assessed (active feeders), in order to distinguish if an internal fault has occurred while passive feeders are left un-tripped. So, this criterion must be simultaneously truth additionally to the differential current.

2.7.8 OTHER TRIPPING CRITERIA

2.7.8.1 BUILD IN CIRCUIT BREAKER FAILURE PROTECTION

The advantages of integrating the BF function with the distance relays are double.

First, cost saving at the construction phase; saving panel space by eliminating some panels and reducing requirements for the size of the control house; eliminating wiring, drafting, construction and commissioning labour; and saving in period of maintenance by supervising less equipment.

Second, by reducing wiring and maloperations, increasing reliability and increasing availability of BFP, also reducing the total fault clearing time under BF conditions.

With security taking precedence over dependability for BF protection, two key aspects need to be considered when designing a BF scheme. Because it is a backup function for the breaker (including its tripping path), some may prefer for the BF protection to use hardware and firmware independent from the zone relay and a separate tripping path. This preference is naturally met when using a standalone BF relay.

Integrating the BF function in multiple zone relays allows biasing the scheme for more security or more dependability compared with standalone BF protection, depending on the specific architecture selected and willingness to accept extra inter-relay signalling and associated complexity.

3 BUSBAR DIFFERENTIAL PROTECTION CONFIGURATION

3.1 CENTRALIZED ARRANGEMENT

Numerical centralized busbar protection can be found in new substations as well as where retrofit of old conventional BBP was made and the cables were still in good condition. In a numerical centralized arrangement the amount of cabling is approximately the same as it was in conventional arrangements. A reduction can only be made, if additional protection functions are gathered in the busbar protection relay (e.g. busbar- and circuit breaker failure protection). The advantage of using numerical protection equipment is the easy adoption of functionality and simple arrangements of I/O. Furthermore, the numerical technique allows fast and easy connection with substation automation systems which allow fast fault analysis and monitoring.

3.2 DECENTRALIZED ARRANGEMENT

In the past, before numerical de-centralized busbar protection was available, busbar protections were constructed centrally. All process data, such as CT currents, isolator positions and tripping channels had to be wired back towards the central position of the busbar protection panel.

Considerable interconnection (such as start circuit breaker failure protection, block autoreclosure, etc.) between the other protection panels had to be made. In those conventional arrangements, many cables had to be used, the engineering, commissioning and maintenance was quite time consuming and costly.

A vertical comparison of centralized vs. decentralized is shown in TABLE 1.

Subject	**CENTRALIZED**		**DECENTRALIZED**	
	Pros	Cons	Pros	Cons
Number of bays		limited, less than 10	over 20 bays	
Other integrated protection functions		BFP, Pole discordance	BFP, Pole discordance, I>, U<, Z<, etc.	
Distance between Central unit and the bay		limited in some 100 m	at list 1 km	
EMC problem		Yes, because of copper wires	No, because of fiber optic connection, bay units are located in relay houses	
Maintenance, function test	Simple, all function in the central unit			More complicated because of the decentralised location
Design	Simple, one unit			More units, power supply, etc.

TABLE 1: vertical comparison between BBP Centralized and Decentralized arrangements

To apply the centralised or decentralised arrangement, these aspects have to take into account.

4 SPECIAL BUSBAR ARRANGEMENTS/ COMPONENTS AND THEIR PROTECTION

4.1 THE 'END FAULT' PROTECTION

4.1.1 DEAD ZONE (BLIND SPOT) - A FAULT BETWEEN A CIRCUIT BREAKER AND A CURRENT TRANSFORMER

To cater for a fault in a bay between a circuit breaker and a current transformer ("small zone" fault), the 'end fault' protection functionality should be provided for all bays except bus sections/couplers/shunt equipment to protect the zone located between the CT and the circuit breaker, when the CB is open.

The Small-zone faults between CTs and circuit breakers are normally detected by the busbar protection but tripping of the circuit breaker will not clear the fault. This is addressed by the application of CB Fail or an interlocked overcurrent relay depending on the voltage.

Circuits using "end fault" protection shall prevent busbar zone tripping for small-zone faults and only intertrip the respective remote infeed end to clear the fault.

There is normally no requirement to provide 'end fault' protection on shunt equipment which includes shunt reactors, MSCDNs, SVCs, HVDC convertor transformers and HVDC harmonic filters.

The measuring range of a BBP is limited by the CT location. The section between the CT and CB is called the dead zone (blind spot). By using the end-fault protection in the bus coupler, improved behaviour of the protection is achieved with an open CB. The protection range may be extended by the dead zone between the CT and CB.

End-fault protection is active only when the CB is open. When the CB closed, the protection doesn't activate end-fault protection function. Depending on the installation location of the CT, the end-fault protection prevents undesired tripping of the busbar section or it causes a fast fault clarification.

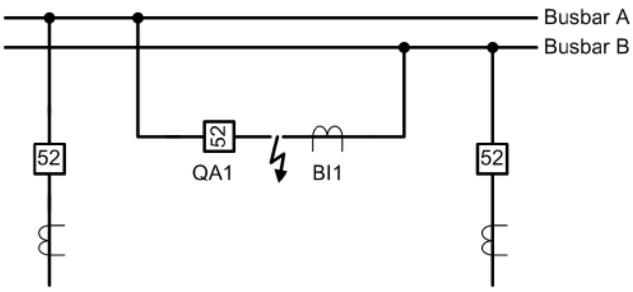

FIGURE 11: Fault in the dead zone

The CB position is detected by the CB auxiliary contacts and not by the current-flow criterion. The end-fault protection sets the currents of the assigned CT for the BBP to 0. Consequently, the busbar differential protection can detect a fault when current transformers are ranged on the busbar side or in the case of a busbar coupler with 1 or 2 current transformers. The calculated current results in disconnection of the faulty busbar by the busbar differential protection. In the case of current transformers arranged on the line side, the fault must be disconnected by the circuit breaker at the opposite end.

4.1.2 A FAULT IN A BUS COUPLER OR A SWITCHED BUSBAR

Low impedance busbar protection schemes where bus section and couplers with CTs on either side are used to provide overlapping zones, should take due cognisance of "small" zone faults with associated disconnector combinations in open and/or closed states. The scheme shall achieve correct discrimination to prevent nuisance or unwanted tripping following a busbar fault.

Where a fault occurs in the overlap between two zones, e.g. at a Bus-section or Bus-coupler, with the circuit breaker closed, both zones shall be tripped simultaneously.

The fault will be switched off immediately, but not selectively. Protected zones look like this:

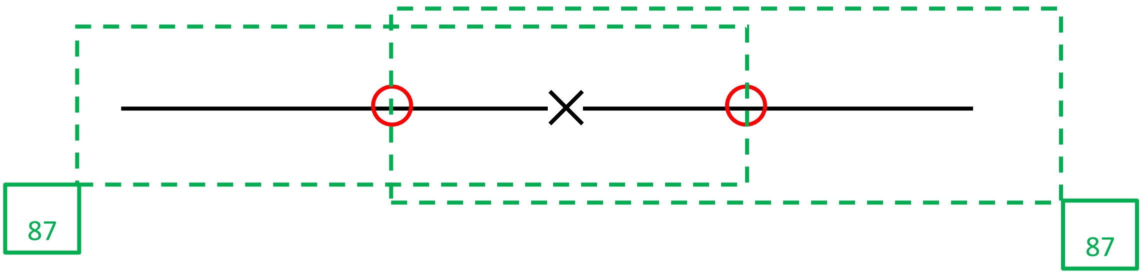

FIGURE 12: Fast but not selective protection of bus couplers and switched busbars

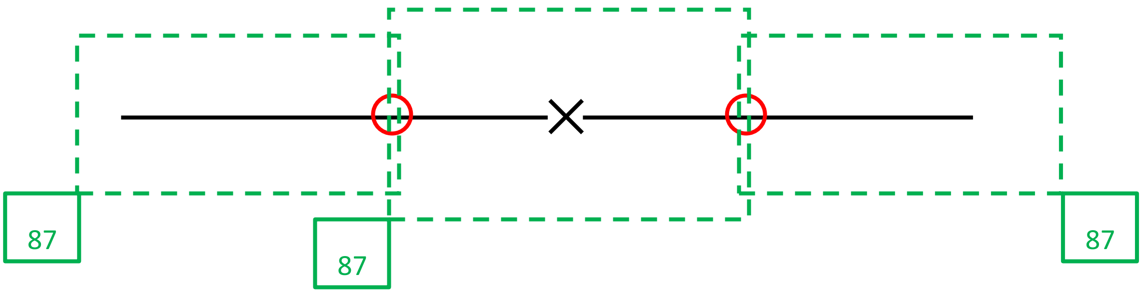

FIGURE 13: Selective but delayed protection of bus couplers and switched busbars

There are two other possible ways how to protect these bays.

The first one is selective but the switching of the fault is delayed. It can be used if we prefer selectivity to speed.

If there is a fault between CTs, only the CB in the bus coupler or bus section is tripped. After that these two CTs are with different zones of the BBP, so only the faulted bus can be switched off. A small delay about 100ms is necessary in this case to let CB in the bus coupler or bus section to open and the BBP to change configuration of the S/S. The state of the CB must be signalized to the BBP.

The second one is cheaper and easier but is both unselective and delayed. It can be used if there is not problem with stability and power outage. It is described in the chapter 4.1.1 (dead zone) in detail.

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4.2 On-load Busbar Changeover

The busbar protection should be able to correctly detect a fault condition occurring during an on-load busbar changeover and issue trip commands to the connected bays. The selected disconnector auxiliary switches must ensure correct zone selection for all fault conditions. In the closing cycle the correct zone must be selected prior to the primary contacts being able to carry current.

4.3 Bus Coupler Time Delay

For substation The time delay should be shorter than delay of Zone 2 of distance protection from this substation. The shortest possible delay is determined by trip of BFP so it has to be within the range 0,15÷0,3 s.

4.4 Policy for isolator alarm or Auxiliary contact

Switchgear positional information should be used to determine the primary arrangement of each busbar section using busbar disconnectors and/or circuit breakers, and to determine the selection of end fault protection.

The selected disconnector auxiliary switches must ensure correct zone selection for all fault conditions including on-load busbar changeover.

Where circuit breaker positional information affects the selection of CT's to the algorithm a means of ensuring advance selection prior to circuit breaker closure shall be provided. Pre-close repeat relay contacts can be used to give advance information of circuit breaker closing to cover for slow circuit breaker auxiliary switches.

Where a discrepancy (DBI) in switchgear positional information occurs, the busbar protection shall have user selectable options either to remain in service using the last verified switchgear position or to block protection operation for the affected zone. Unaffected zones shall remain in operation

5 CIRCUIT BREAKER FAILURE PROTECTION (BFP) OPERATING PRINCIPLES

The Circuit Breaker Failure Protection function, CBF protection, is a local back-up protection function which will operate selectively in the event of an unsuccessful attempt by a circuit breaker to interrupt fault current in bay or bays despite tripping impulse from its protection [1]. Selectivity means tripping the least possible number of bays (i.e. bays from specified busbar section or busbar system)

Several types of CBF protection schemes exist and are explained in IEEE Std C37.119-2016.

The simplest scheme relies upon the occurrence of two signals during a specified time: an external start and an overcurrent condition or a CB contact information or both. The external start is typically triggered by a trip command to the circuit breaker from any protection function. For example in a line feeder this can be the trip from a distance relay, in a power transformer feeder this can be a trip command from a differential relay and for any feeder connected to a special busbar this can be from a BBP relay.

The overcurrent relay confirmation is used as the main criteria for the extinction of the circuit breaker through current. It can also be used for security in case an unwanted start signal appears, normally in testing procedures. For feeders with weak infeed it is common to use the circuit breaker auxiliary open contact 52a instead of current base confirmation.

The time delay is established according to stability network demands and is an important factor when coordinating with remote back-up protections.

Different consequences can result from the output of this scheme: a re-trip function, a back-up trip function and intertripping.

The FIGURE 14 scheme uses the inputs (CT, wiring, relay input circuitry, and firmware) to issue the trip and to determine if the breaker actually failed. This combined with multiple operational copies of the BF function can potentially erode security of the BF protection. Some multi-input relays reduce this concern to a degree by allowing different CT, wiring, and relay inputs for the BF function, as shown in the next picture.

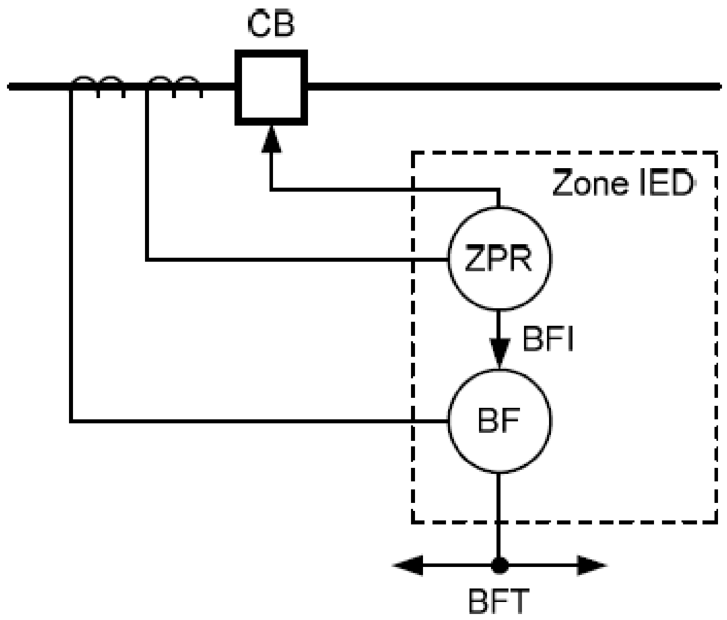

FIGURE 14: Breaker Failure Protection

Re-trip function idea often occurs from two independent tripping circuits. In bay there are protection devices which are tripping on 1st tripping circuit and after short period of time t1 (approx. less than 100ms) BFP sends repeated trip signal to circuit breaker on both coils (i.e using two tripping circuit). If retrip is unsuccessful than its working second stage of BFP with time delay t2 (around 250ms) opens circuit-breakers connected to the same busbar section.

5.1 CONTINGENCY ARRANGEMENT IN CASE OF FAILURE OF BBP

Historically busbar protection systems have been installed with check and discriminating zones whereby both zones must operate to initiate tripping. This is generally referred to as 2 out of 2 systems. With the move to installing numerical busbar protections due to the increased reliability and self-monitoring facilities available within modern systems this requirement has been relaxed to allow single units to be installed on a single CT per Circuit.

However a consequence of this is that if one of the distributed units or the central unit of the numerical protection fails the entire busbar protection for one or more busbar sections is lost. The result is that a substantial number of circuit may have to be taken out of service until a repair is completed.

Two options are possible as contingency arrangement to allow the busbar sections to remain in service:

1) Provision of a second central unit and associated fibre optic connections so that in the event of failure of the first unit the busbar protection can be manually connected to the second unit to enable it to remain in service.
2) Adjust the protection arrangement on the infeeding circuits (feeders) to provide limited protection for the busbars to allow them to remain in operational service.

The option 2 contingency plan can be implemented by using feeder distance protection fast discriminative reverse Zone 3. The reverse Zone 3 can be selectable via Group settings, when used to provide busbar contingency plan, it shoul trip not only the local circuit breaker/s of the feeders but also other circuit breakers of connected bays to the busbar(s) (such as Transformers and other shunt plants etc.) by a separate cross tripping scheme. The time setting for the reverse Zone 3 should be properly graded with the all the distance protections of the feeders connected to the busbar to ensure that a busbar fault is cleared as quickly as possible but not tripped by the faults within Zone 1 of the feeder protections.

5.2 DIRECT AND SELECTIVE TRIPPING

Direct Tripping - The immediate tripping of the remote end of a feeder connected to a double busbar substation in the event of the operation of busbar protection at the double busbar substation. Tripping of the remote end is achieved by DTT and/or un-stabilization of the circuit protection by the Busbar Protection Trip Relays (BBTR) or Back Trip Receive Trip Relays (BTRTR) when selectable links are inserted. The Interlocked Current Trip Relay (ICTR) links should also be inserted.

Note that un-stabilization of the circuit protection may be no longer used on modern protection systems, however, there exist some legacy installations with un-stabilization of the circuit protection as a means of tripping the remote end/s.

Selective Tripping - The tripping of the remote end of a feeder connected to a double busbar substation initiated by the Interlocked Current Trip Relay (ICTR) after a time delay (such time delay being determined by the Circuit Breaker Fail timer). In this case tripping of the remote end is achieved by intertripping and/or protection un-stabilization. To achieve this selective tripping, the links associated with the BBTR and BTRTR must be removed and the links associated with the ICTR relay must be inserted.

Note that in some cases the ICTR relay may also operate for “End Fault” protection in order to intertrip the remote end circuit breaker/s as ICTR links are always in-service regardless of the link selection for Direct or Selective Tripping.

Direct and Selective tripping initiated by the busbar protection trip relay(s) and circuit breaker fail function shall be selectable by means of removable links. The requirements for Direct and Selective tripping are given below.

Where nuclear generation is connected locally and/or remotely, the requirements for direct and selective tripping usually are obtained from the competent authority or are described at the

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appropriate safety or operational Codes / guidelines or they are according to the utility's specific policy.

Direct tripping from busbar protection trip relay shall be selected as follows:

(i) Where the remote end of a two-ended feeder is connected to a double busbar substation

(ii) Where the remote end of a three-ended feeder is connected to a double busbar substation and fault clearance from the remote substation in CB Fail time is unacceptable from a system operation perspective.

(iii) Where the local substation is indoors with CTs on the line side only i.e. possibility of a 'Small zone' fault indoors except where (viii) and (ix) apply.

(iv) Where the outgoing feeder is a transformer feeder with LV-side circuit breaker connected to LV-level kV at the remote end

(v) Where the local SGT LV circuit breaker is connected to LV-side kV at the local end i.e. for the LV circuit breaker of a HV/LV kV SGT.

(vi) In all those cases where the additional time delay associated with CB Fail protection would adversely affect the transient stability of generators or where continued energisation from the remote end only is unacceptable,

(vii) There is no requirement to affect direct tripping from bus sections or couplers.

Selective tripping of the remote ends of feeders shall be selected where:

(viii) The feeder is a 'teed' feeder, including feeders whose remote termination is a double busbar or a mesh corner to which is also connected an interconnecting transformer.

(ix) The feeder's remote termination is a mesh corner with or without a connection to a supply transformer.

(x) However, if the delayed tripping of the remote ends in (viii) to (ix) will cause instability problems, direct tripping should be adopted.

6 PRINCIPLES OF SETTING/PARAMETERIZATION FOR BBP AND BFP

As mentioned in chapter 2.1, BBP is based on the principle of Kirchhoff's Current Law, which states that in the case of unfaulty operations all currents flowing into and out of the object must be zero [4]. The BBP protection calculates the sum of all currents flowing into and out of the busbar. The differential current $\boldsymbol{I_{Diff}}$ is equal to the phasor sum of all feeder currents, belong to particular section – $\boldsymbol{I_{Diff}} = |\boldsymbol{\bar{I}_1} + \boldsymbol{\bar{I}_2} + \boldsymbol{\bar{I}_3} + \cdots + \boldsymbol{\bar{I}_N}|$. The restraint current $\boldsymbol{I_{Res}}$ corresponds to the arithmetic sum of all feeder currents (sum of their absolute values) belong to particular section - $\boldsymbol{I_{Res}} = |\boldsymbol{\bar{I}_1}| + |\boldsymbol{\bar{I}_2}| + |\boldsymbol{\bar{I}_3}| + \cdots + |\boldsymbol{\bar{I}_N}|$. The tripping characteristic of numerical low impedance biased BBP is shown in the FIGURE 15 [6].

The tripping characteristic is determined by the two settable parameters – differential current limit $\boldsymbol{I_B}$ and stabilizing factor $\boldsymbol{k}$. BBP operates when two criteria are met – $\boldsymbol{I_{Diff}} > \boldsymbol{I_B}$ and $\boldsymbol{I_{Diff}} > \boldsymbol{k} \times \boldsymbol{I_{Res}}$.

- The current threshold I_B must be 20% lower than minimum calculated short circuit and should be 25-30% greater than maximum operational current, commonly nominal current of CT with the highest primary current

$$1,25 \times I_{MaxCT} < I_B < 0,8 \times I_{MinSC}.$$

  Sometimes, in the case of a single phase to earth fault, 80% of the minimum calculated short circuit may be lower than 125% of the maximum operational current (mostly when considering energizing a substation by one transmission or distribution line). The setting must be then done appropriately to this situation. Some vendors offer controllable (by binary input) sensitive setting of the current threshold – I_{B-Sens} , some offer separate setting for neutral current – I_{NB}, which would be suitable for this situation.

- The stabilizing factor k must provide stability against external faults (faults outside protected zone) and, on the other hand, should be sensitive to detect busbar faults. In the case of a busbar fault, when each feeder either feed the fault or doesn't flow any current through, the operating current is equal to the restraint current. The operating current lies on the fault characteristic with stabilizing factor $k = 1$ i.e. $I_{Op} = I_{Res}$. As a fault resistance on the substation used to be low and short circuit current is high, compare to the operational current, this the most likely situation, that can happen in transmission and distribution system. To determine the value of k the saturation time of CTs should be taken into account. This factor can be calculated according following equation [6]

$$k > \frac{K_B}{\left(4 \times \sqrt{K_B - 1}\right)} \quad for\ \ K_B \geq 2 \qquad while\ \ K_B = \frac{I_{MaxSC}}{I_{SatCT}} = \frac{I_{MaxSC}}{I_{NCT} \times n'}$$

  Where I_{MaxSC} is the maximum continuous short circuit, I_{Sat} is the saturation current of a particular CT, I_{NCT} is the nominal current of the CT and n' is the effective overcurrent factor of that CT. Since the K_B factor in transmission and distribution system is usually lower than 2, and very often lower than 1, the setting, with safety margin, $k = 0,6$ is sufficient. The practice is set the stabilizing factor between 0,6 and 0,8 – $k \in \langle 0,6 - 0,8 \rangle$.

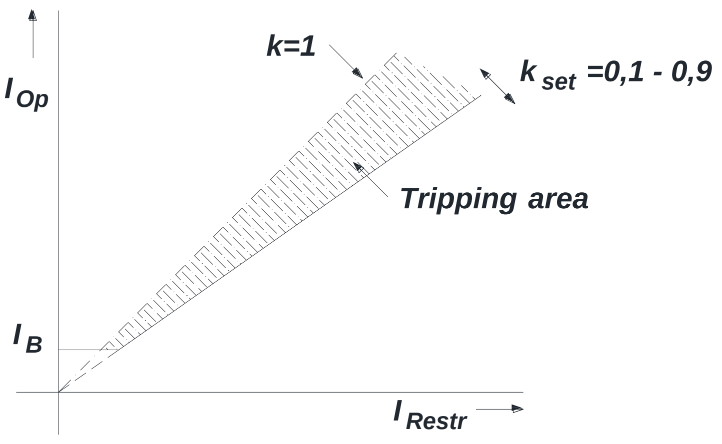

FIGURE 15: BBP Tripping characteristic

In the case of electromechanical low impedance BBP, the protection trips according to the equation$I_{Op} > I_B + k \times I_{Res}$.

Regardless to vendor, common BBP practice is that the setting is valid for all zones of the protected object (when there are more than one zone)

The same rules should be applied also on check zone's setting. Some vendor's BBP doesn't allow separate setting of the check zone and it is the same as particular (bus) zones

The time delay of BBP should be set to zero

BFP – Breaker Failure Protection

As mentioned in chapter 5, two stages of BFP can be set by default. First stage re-trips the same circuit breaker as feeder protection. Second step trips all neighboring circuit breakers. To trip, the feeder current level must be above threshold and external start by feeder protection (e.g. by binary signal) must be performed. In the case of possible single-phase tripping of the circuit breaker (almost all line's operation), there must be separate start signals for each phase to avoid false and spurious tripping of circuit breaker

Concerning to current level, both stages have usually the same setting. The current threshold $\boldsymbol{I_{BF}}$ should be lower than minimum expected short circuit current of the corresponding feeder.

$$\boldsymbol{I_{BF} < 0,8 \times I_{MinSC-F}}.$$

The time of first stage $\boldsymbol{t_{1BFP}}$ should take into account the operating time of circuit breaker $\boldsymbol{t_{CB}}$, the reset time of overcurrent element/function a $\boldsymbol{t_{rOC}}$ and safety margin $\boldsymbol{t_{marg}}$

$$\boldsymbol{t_{1BFP} > t_{CB} + t_{rOC} + t_{marg}}$$

In practice, this time can be set between 50 and 100 milliseconds. On the other hand, to set this time to zero $\boldsymbol{t_{1BFP} = 0}$ doesn't endanger the operation of system. First stage always trips the same phase(s) as feeder protection.

The time of second stage $\boldsymbol{t_{2BFP}}$ should take into consideration the dynamic state's calculation of CCT for particular substation and should be set according to this calculation. The minimum time, if there is no use of first stage, may be set in the same way as first stage. With regard to reliability of the system, it shouldn't be set lower. The maximum set time should take into account the first stage setting and moreover it may take into account the processing time $\boldsymbol{t_{PrTiBFP}}$ of both BBP stages.

$$\boldsymbol{t_{2BFP} > t_{1BFP} + t_{CB} + t_{rOC} + t_{PrTiBFP} + t_{marg}}$$

The second stage's time $\boldsymbol{t_{2BFP}}$ should be set lower than the time of backup zones/functions of the feeder protection.

If a one and half breaker substation is on opposite side of the feeder object, a BFP start signal from remote end should be transferred and connected to the BFP.

6.1 BBP Settings and Coordination for 1 ½ Configuration

In the case of 1 and half breaker substation, there are the same rules for BBP settings as to typical 2 or 3 main busbar's substation, but number of zones. There can be more zones in the protected object; it depends on the number and position of CTs.

Concerning BFP, two side circuit breakers should be set according to the same rules as a circuit breaker of standard substation. In the case of middle breaker, the BFP start signal of one feeder's protection should be also sent to remote end of second feeder object's BFP. It solves the middle circuit breaker's failure.

7 ASSET MANAGEMENT ISSUES

7.1 BUSBAR PROTECTION INSPECTION

Under normal conditions a switchgear cannot be switched off completely to check the busbar protection. Normally, one feeder after the other is taken out of service to test the protection devices on the corresponding feeder. However, because the busbar protection is a system of the entire busbar, a suitable test strategy must be defined.

Possible test sequences:

1. Short-circuit and disconnect the current transformer circuits for busbar protection. Opening all tripping circuits on the bays which are still in operation. Testing the BBP function by secondary injection. Check at the tripping contacts whether the protection scheme has given a tripping command at the corresponding bay. However, this variant carries the risk, since manipulation must be carried out at switched-on feeders (short-circuiting of current transformer circuits and opening of tripping circuits).
2. If an empty busbar is available, the bays to be tested can be connected to this empty busbar. In this way, the entire functionality for the corresponding feeders can be checked by inject of secondary current. This variant also carries a certain risk of incorrect tripping of the busbar which is in service.
3. A numerical busbar protection has a very deep self-monitoring. For this reason, the test sequence for these modern protection systems must be adapted accordingly. Problems with current measurement or failure of the busbar topology are detected by the internal monitoring system and the corresponding alarm is generated (e.g. measured value monitoring, differential current alarm or faulty isolator image). If necessary, the protection system is blocked immediately to prevent false tripping.

7.2 BUSBAR PROTECTION TESTING

A general recommendation how to test an busbar protection is difficult to given. This depends on the type of protection system (numerical or static), on the topology of the SS (single SS or multiple SS) and on the risk or consequence of a false trip [5]. Spare parts for busbar protection devices

Components of the protection system (bay unit or central unit) may fail as with other protection devices. For this reason, it is advisable to purchase reserve material in case of failure. Ideally, a bay unit and a central unit (tested and with identical firmware) is stored for each substation. This spare material must also be checked periodically.

If applicable, reserve material for several substations can be stored centrally. It should be noted that hardware and firmware are suitable for the corresponding systems.

7.3 REPLACEMENT OF BUSBAR PROTECTION

If the busbar protection has to replaced, the protection system usually has to be switched off for a certain time. A parallel operation of the existing and the new busbar protection is very complex and involves many provisional steps (risks of false tripping). For this reason, the necessary deactivation of the busbar protection must be kept as short as possible. During the time when no busbar protection is in operation, the activation of a reverse zone in the distance protection can provisionally replace the busbar protection.

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7.4 Additional protection functions in the busbar protection

Some numerical busbar protection systems offer additional protection functions in the bay units. It is possible to activate a distance protection function, autoreclosing, synchrocheck etc. in the bay units. This certainly offers interesting possibilities in medium-voltage systems, but these additional functions are hardly used in extra-high voltage systems.

7.5 Certification

As a general rule, the network operator provides a detailed technical specification for busbar protection. In addition to the protection-relevant requirements, the specification also contains additional requirements such as for the communication interface (e.g. IEC61850 Edition2) or quality management (ISO9001).

The vendor must prove compliance with the requirements by means of tests or certificates. The tests can be carried out either in the manufacturer's laboratory or in the network operator's own laboratory.

7.6 Factory Acceptance Test (FAT)

In order to keep the commissioning time as short as possible or if not all functions/configurations can be tested during commissioning, a FAT certainly makes sense. If all functions can be tested during the phase of a new voltage-free switchgear, a FAT can be dispensed with under certain conditions.

7.7 Commissioning

As a rule, all functions of the busbar protection together with the process (from the auxiliary contacts of the isolators, trips to the circuit-breakers, current transformers and signalisation of the alarms/events) are tested during the commissioning by protection specialists (own or from the manufacturer). Since the busbar protection is not in operation, the complete protection functions can be tested. Whether a test with primary current must be carried out is decided on a case-by-case basis. It is essential that the stability control of the differential function (with operating current or with primary feed-in) is carried out.

7.8 Life cycle

The life cycle of busbar protection systems is approximately 20 years as for numerical protection devices. The number and rate of failures of hardware components is identical to that of numerical protection devices.

8 Reference of Standards CIGRE and related technical brochures

Hereafter some important related technical documents are cited:

IEEE Std C37.234/2009 - Guide for Protective Relay Applications to Power System Buses

Concepts of power bus protection are discussed in this guide. Consideration is given to availability and location of breakers, current transformers, and disconnectors as well as bus-switching scenarios, and their impact on the selection and application of bus protection. A number of bus protection schemes are presented; their adequacy, complexity, strengths, and limitations with respect to a variety of bus arrangements are discussed; specific application guidelines are provided. Breaker failure protection is discussed as pertaining to bus protection. Means of securing bus protection schemes against corrupted relay input signals are also included.

IEEE Std C37.119-2016 - Guide for Breaker Failure Protection of Power Circuit Breakers

This guide compiles information on the application considerations for breaker failure protection. The reasons for local backup protection are described. Breaker failure schemes are discussed. Issues relating to the settings of current detectors and timers are discussed for various applications.

ENTSO-E 181010 SOC TOP 09.2 - Best protection practices for HV and EHAV AC Transmission Systems of ENTSO-E Electrical Grids

This document describes the best practices for protection schemes with considerations of security of supply and safety of personnel and equipment. The focus is on the protection application of equipment, at mainly extra high voltage (EHV) AC, i.e. 400 kV, or high voltage (HV) AC, i.e. less than or equal to 220 kV, and in some special cases other voltage levels as well.

CIGRE 2010 Technical Brochure – Modern Techniques for Protecting Busbars in HV Networks, ISBN 978-2-85873-119-0

This Technical Brochure is intended to assist the relay application engineer in the correct selection and application of busbar protection. It provides relevant information about their performance, operation, testing, and maintenance. Two main designs used for HV busbar protection today are high impedance and low impedance differential protection systems. Features of modern low impedance differential protection are described in details.

9 Events / Maloperations / Case Studies

Events of operation of BBP and CBF might be different. Quite common event is human failure in preparing working place on AIS substation. For instance leaving earthing switch close while substation voltage testing.

9.1 CEPS's event

On 7.10.2014 in a double bus substation 400kV a BBP did not operate during a busbar fault. It was not caused by the BBP itself but by special conditions before the fault.

The BBP contains a current measurement blocking function that is described in the chapter 2.4. In case that the BBP measures only a small differential current it is suspected that the measurement of the relay is not correct. If the situation takes longer than 5s the function of the relay is selectively blocked – tripping in zones with the spurious measurement is blocked.

The fault occurred during an on-load busbar changeover. It means the bus coupler was switched on and all bays were changing to a one bus. In changed bays, one bus disconnector was gradually switched on and the second one switched off.

In one bay, there was a drawbar of one phase of the disconnector Q1 broken. It meant that the motor was working but the contact in one phase did not move. Therefore, the disconnector Q1 was closed only in two phases, but signalization to the control system and to the BBP was that it was connected in all three phases.

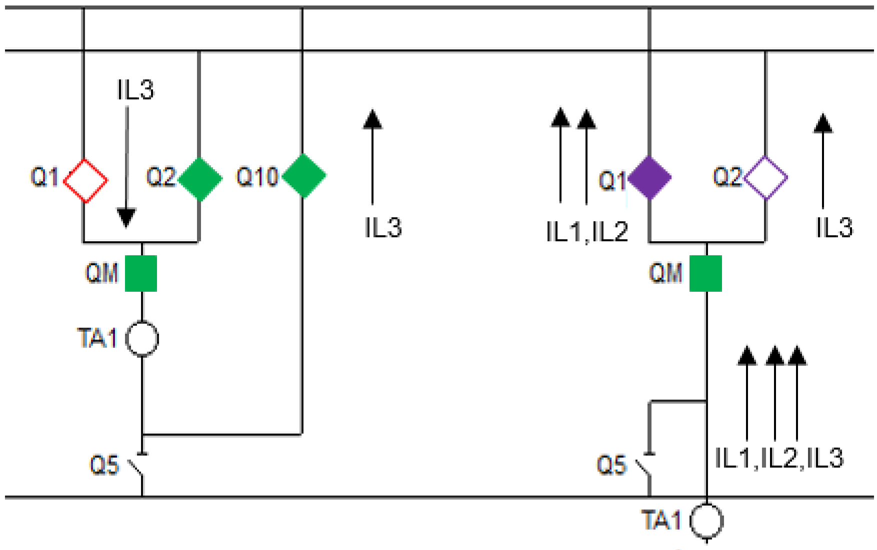

FIGURE 16: The situation just before the busbar fault

The disconnector Q2 had to open all operational current which was still flowing through its third phase. It caused an arc in the phase. The arc approached to an earthed construction and caused a short circuit in 11 seconds after the BBP had already been blocked by small differential current. The fault was cleared by distance relays at remote ends of lines and transformers.

10 TSO's QUESTIONNAIRE

A questionnaire was addressed for filling in by TSOs represented within or being corresponding with Protection Equipment subgroup, in order to gather information about busbar protection, about the adopted practice and the problems faced.

The TABLE 2 shows –in alphabetic order- the TSOs of ENTSO-E that responded to the questionnaire (24 companies responded, coming from all ENTSO-E regions).

TSO's NAME	COUNTRY
AMPRION	GERMANY
AST	LATVIA
CEPS	CZECH REPUBLIC
EIRGRID	IRELAND
ELERING	ESTONIA
ELES	SLOVENJIA
ELIA	BELGIUM
EMS	SERBIA
ENERGINET	DENMARK
ESO EAD	BULGARIA
FINNGRIG	FINLAND
IPTO	GREECE
LITGRID	LITHUANIA
MAVIR	HUNGARY
NG	UNITED KINGDOM
PSE	POLAND
RTE	FRANCE
REN	PORTUGAL
SEPS	SLOVAKIA
SVENSKA KRAFTNAT	SWEEDEN
SWISSGRID	SWITZERLAND
TENNET (DE)	GERMANY
TENNET (NL)	NETHERLANDS
TERNA	ITALY

TABLE 2: TSOs that responded to the questionnaire

Hereafter the main findings from the received responses are cited.

10.1 Q.1 [QUESTION 1] SUBSTATION DESIGN ISSUES

From the 24 TSO-s that answered the question, almost each TSO use a few bus bar design configuration. The most of them use single (66%) , double bus bar with single breaker (83%) and double bus bar with transfer bus coupler (83%) and triple bus bar design. There are 6 TSO who has some special bus bar design configuration (answers mark on *other configuration).*

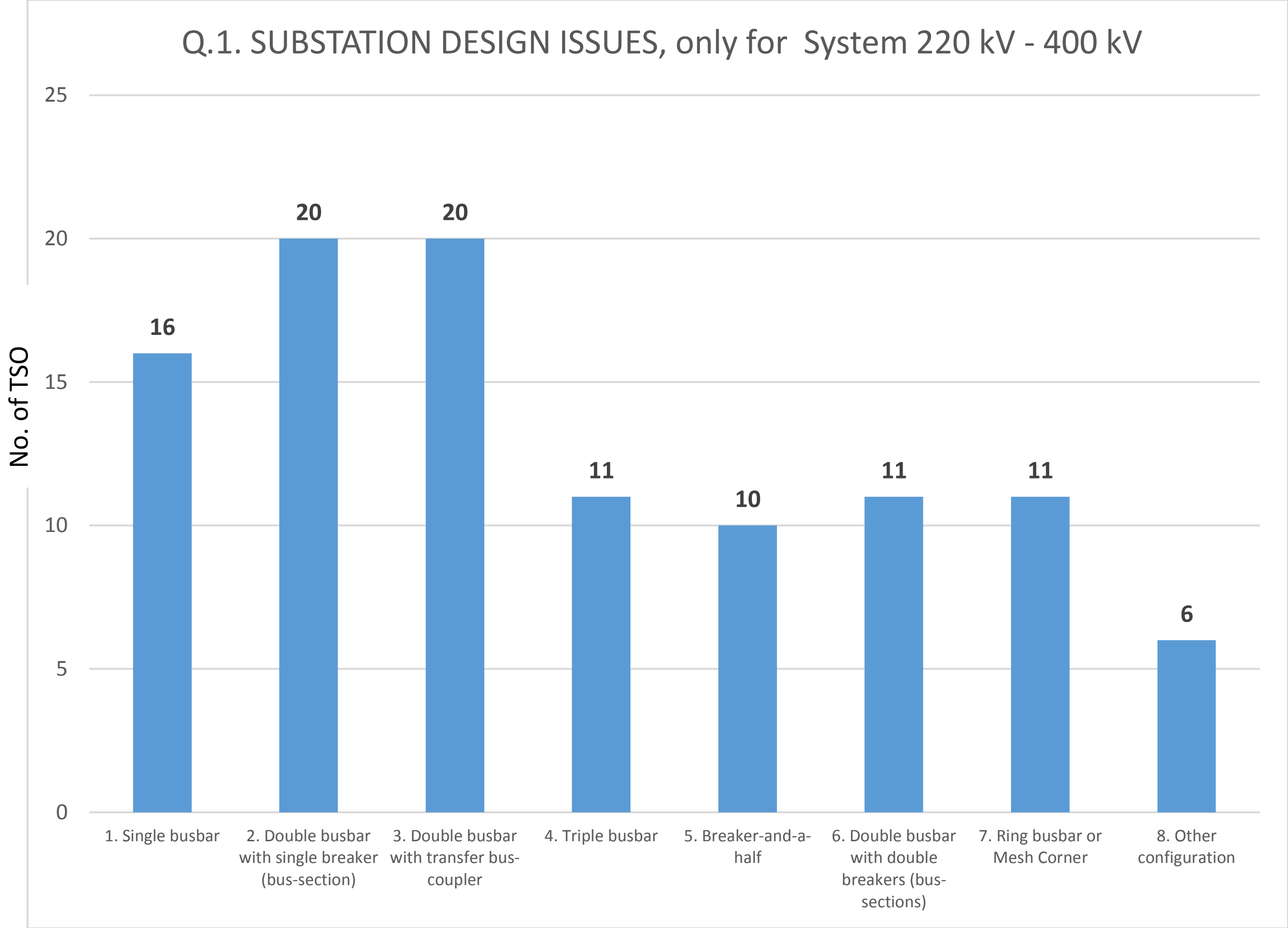

FIGURE 17: Chart - Substation Design Configuration

10.2 Q2 DIFFERENTIAL BBP BASED POLICY

Differential busbar protection is important transmission system element against all probable types of faults. The BBP can be found BBP in all type substations, an open air (AIS) or a gas insulated substations (GIS) without reference to voltage level (FIGURE 18, FIGURE 19).

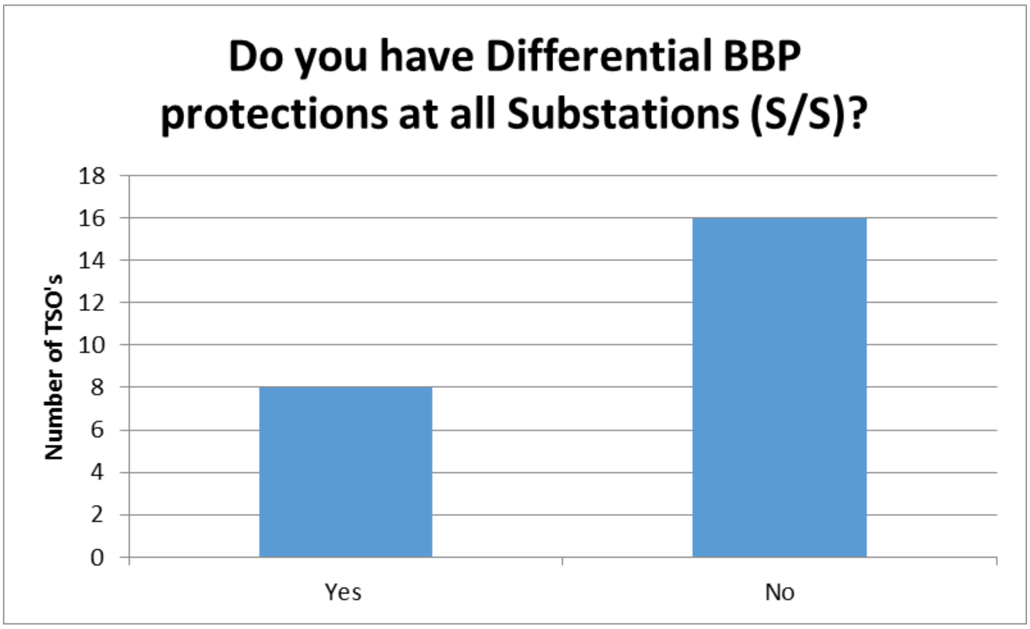

FIGURE 18*: Do you have Differential BBP protections at all Substations (S/S)?*

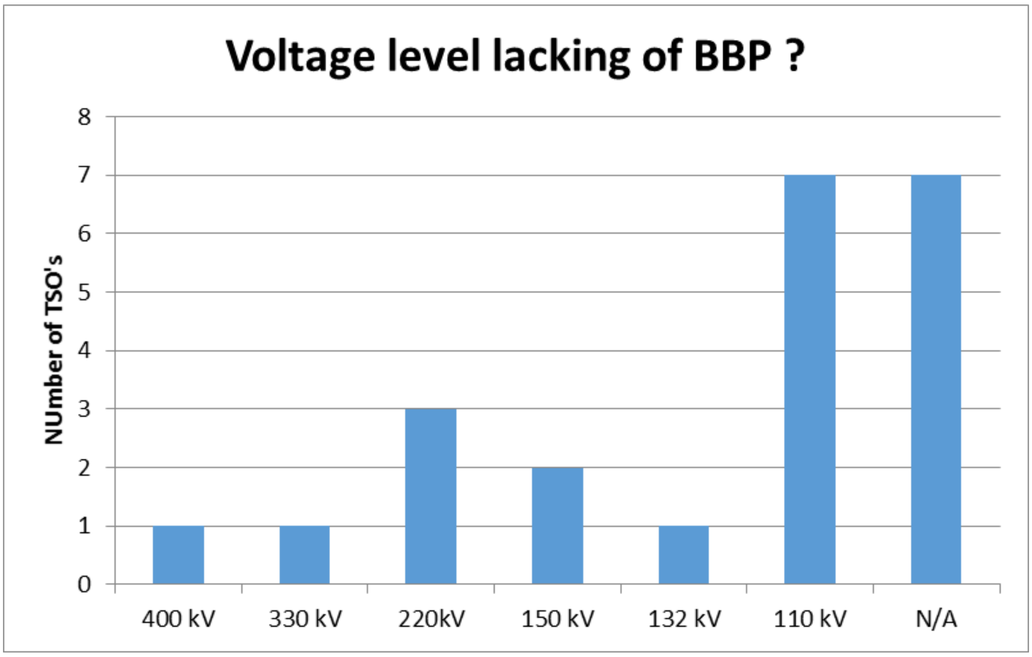

FIGURE 19: Voltage level lacking BBP?

The main reason of not having BBP is the configuration of older-design substations with an electromechanical relay or according each TSO's requirements, depends mainly on technical and economical evaluation: substation have few feeding lines, importance for transmission system, critical fault clearing time, lower power consumption or quality requirements (FIGURE 20). In giving time the prevailing tendency is to install BBP in all new or reconstructed substations.

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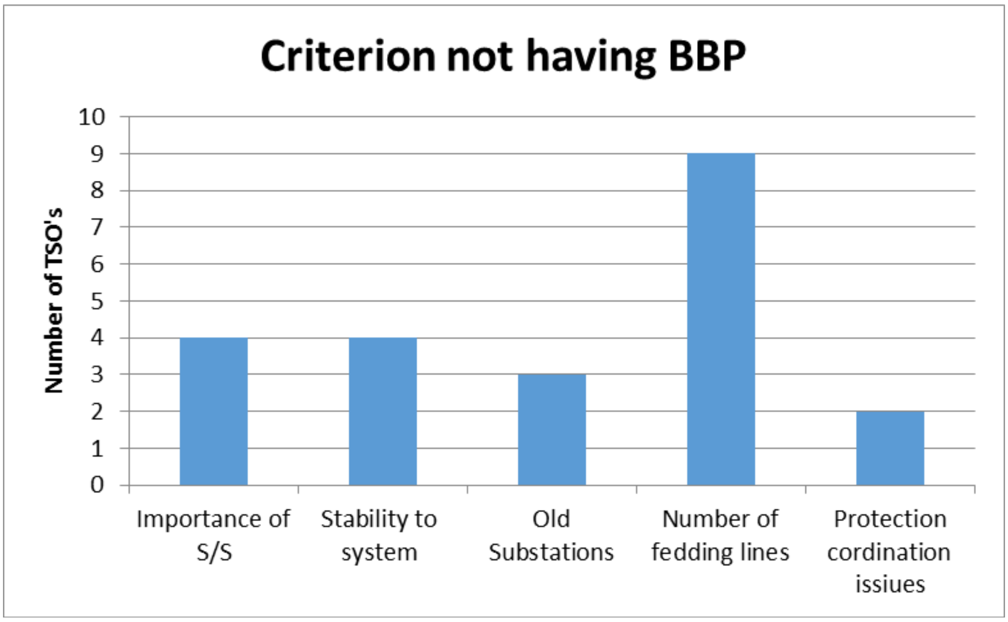

FIGURE 20: Criterion not having BBP in S/S

BBP protection usually doesn't differ in the S/S at different voltage levels; the difference emerges mostly in exceptional cases like S/S near nuclear power plants, nevertheless without specific requirements.

The protection philosophy is applied evenly in AIS and GIS. The use of single BBP is prefer by most TSO's with few exceptions in some cases. The double BBP are used in off-shore S/S to ensure protection redundancy due to possible difficulties to reach off-shore platforms or to maintain redundancy in important substations where fast clearing time and transient stability are important.

For double BBP independency are achievable by separating CT cores, auxiliary contact and tripping circuits (for both tripping coils) and using redundant power supply. Both BBP IED's can be from different manufacturers and work independently, including independent operating principles to reach a better independency.

A back-up protection of BBP, TSO's use line distance protection reversal zone(-s) oriented towards the BB, autotransformer or bus coupler distance protection zones and over current protection. A long-distance reservation of BBP also can be achieved with distance protection zones (zone 2, 3) from the opposite end of OHL/Cables of another S/S.

Requirements for BBP schemes in S/S feeding RES doesn't differ from other S/S according TSO's, except for higher requirements for the off-shore S/S connected to WG plants (FIGURE 21).

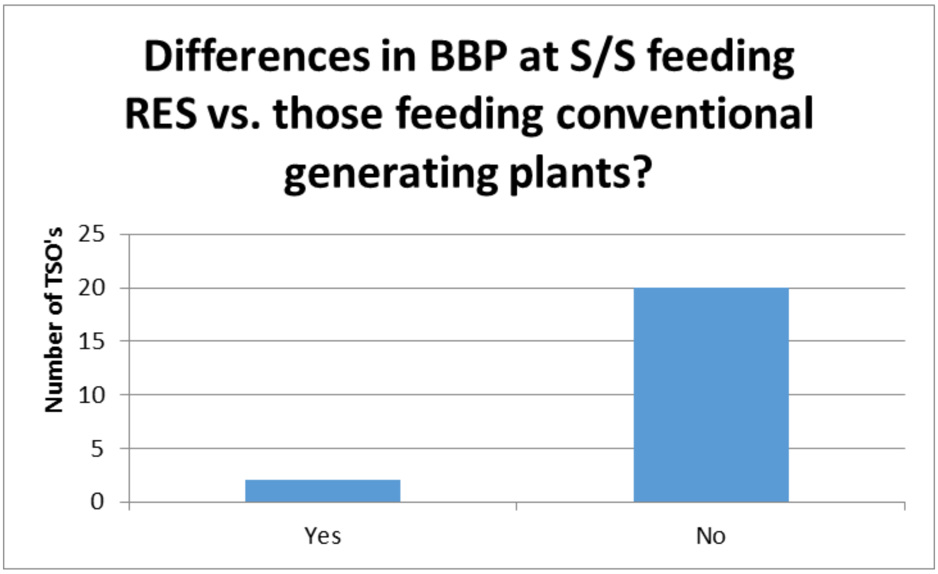

FIGURE 21*:* **Differences in BBP at S/S feeding RES vs. those feeding conventional generating plants?**

10.3 Q3. BUSBAR PROTECTION CONFIGURATION

First the BBD configurations centralized and decentralized are investigated.

Next Figure illustrates the applied categories.

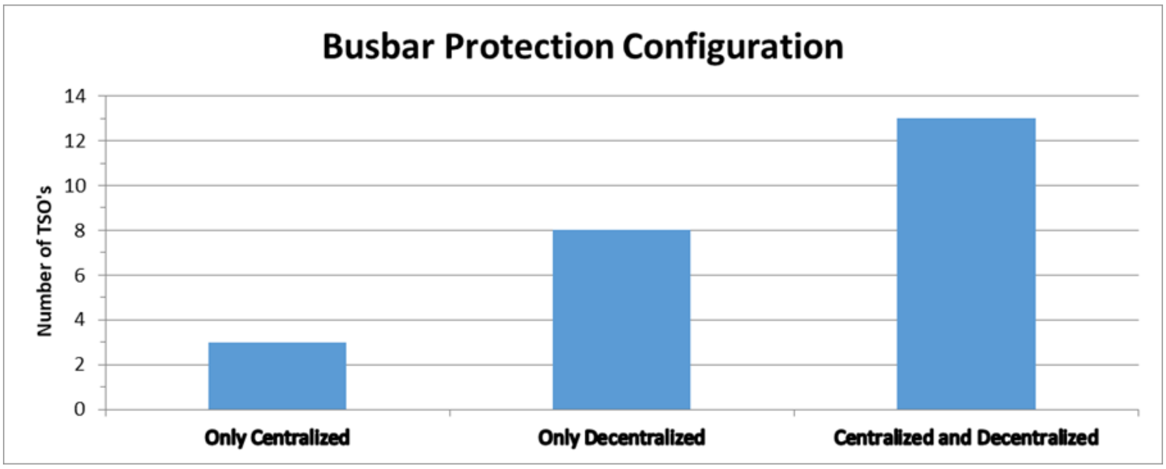

FIGURE 22: Busbar Protection Configuration

Some TSOs are using both arrangements, made following clarifications, concerning the reasons for installing each type of BBD:

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No.	Centralized arrangement	Decentralized arrangement
1	only a few	
2	110 kV	330 kV
3	smaller installations	Main principle
4	Old substations in 400 kV grid	Used in 400 kV substation built after 2005.
5	Yes: a lot of centralized busbars of old technologies has been installed. When a replacement has to be done, a centralized busbar can be installed at the same place of the old one only to simplify the engineering constraints	Yes : for all new substations, Decentralized busbar are installed. If the protection system of the substation is changed and an old centralized busbar is installed: a decentralized is installed.
6		Mostly
7	old BBP or 3-feeder substations	mostly

TABLE 3: Centralized arrangement vs Decentralized arrangement

As a summary of this Table above, why TSO's are using both arrangement, the main reasons are of using :

- centralized BBP:
  - old or small substations
  - 110 kV voltage level
- decentralized BBP:
  - new substations
  - higher voltage level (330 kV or above)

Q. 3.1. POWER SUPPLY TYPE FOR SINGLE BUSBAR PROTECTION

The design criteria of the power supply were questioned. Responses are summarized in next chart.

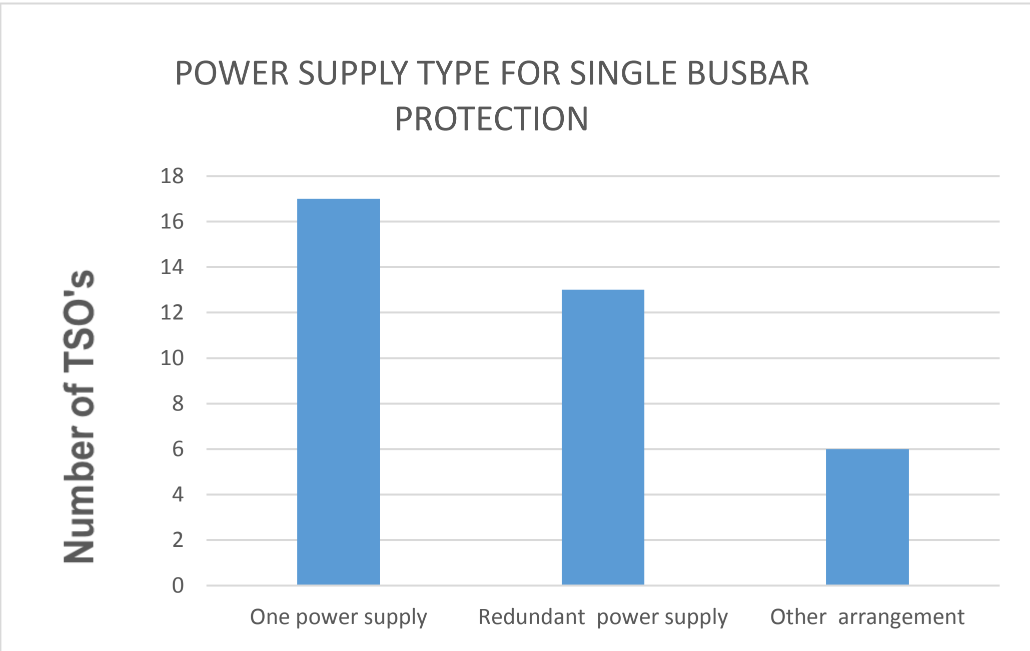

FIGURE 23: Power supply type for single busbar Protection

One power supply use 17 TSO. Redundant power supplies use 13 TSO. Both, one and redundant power supply use 6 TSO. About 45 % of the TSO' use one power supply, 30 % of them use redundant PS and about 25 % use both type.

No.	One power supply	Redundant power supply	Other arrangement
1	In some existing BBP	Standard for new substations.	
2	There is a manual possibility to switch power to another battery	Redundant power supply from another power source (dc battery)	
3	One polarity is used for the power supply. This polarity uses a backup from batteries.		For the distributed relay room applications, the each of Numeric BBP Bay Unit is powered by the DC first tripping supply for the bay, For the common relay room applications, duplicated SC supplies with automatic changeover are deployed. - Two independent DC power suppliers for duplicated High Impedance schemes.
4	Bay unit	Central unit	

TABLE 4: Power Supply Type for Single Busbar Protection

10.4 Q4. BUSBAR PROTECTION OPERATING PRINIPLES (DIFFERENTIAL ETC.)

The applied protection principles for protecting high voltage busbars were examined. The registered methods are put in next chart.

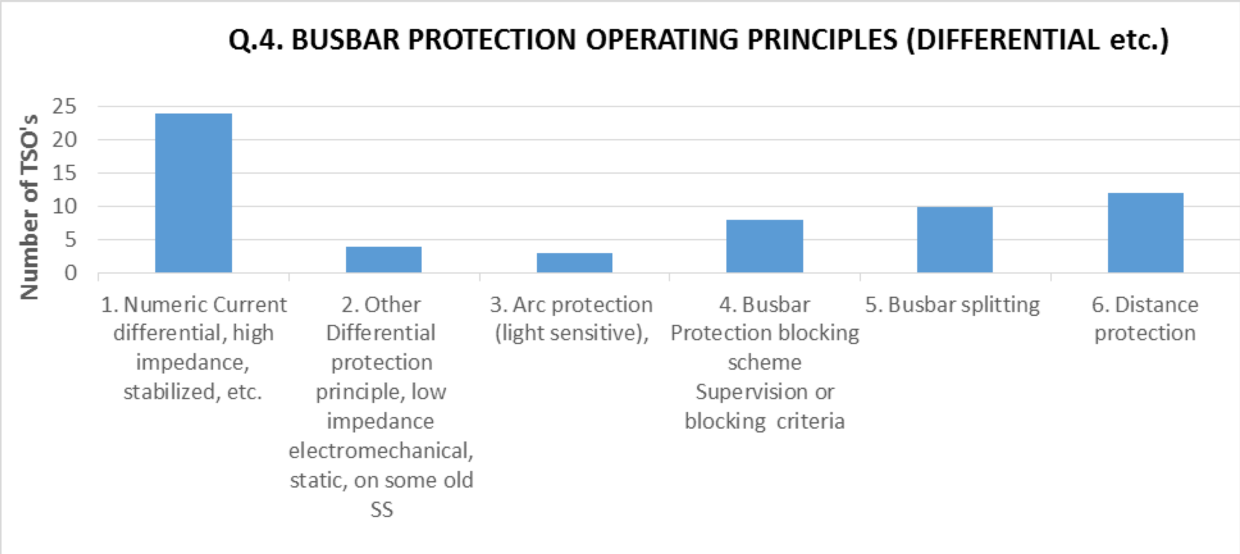

FIGURE 24*:* Busbar Protection Operating Principles

10.4.1 Q4.1. ADDITIONAL TRIPPING CRITERIA FOR BBP DIFFERENTIAL

Additional to the main criterion of the differential current, for reliability and security purposes, other criteria in an AND logic are applied. This depends on the devices features and capabilities and on the utility practice. The received responses are shown in chart of Figure 25.

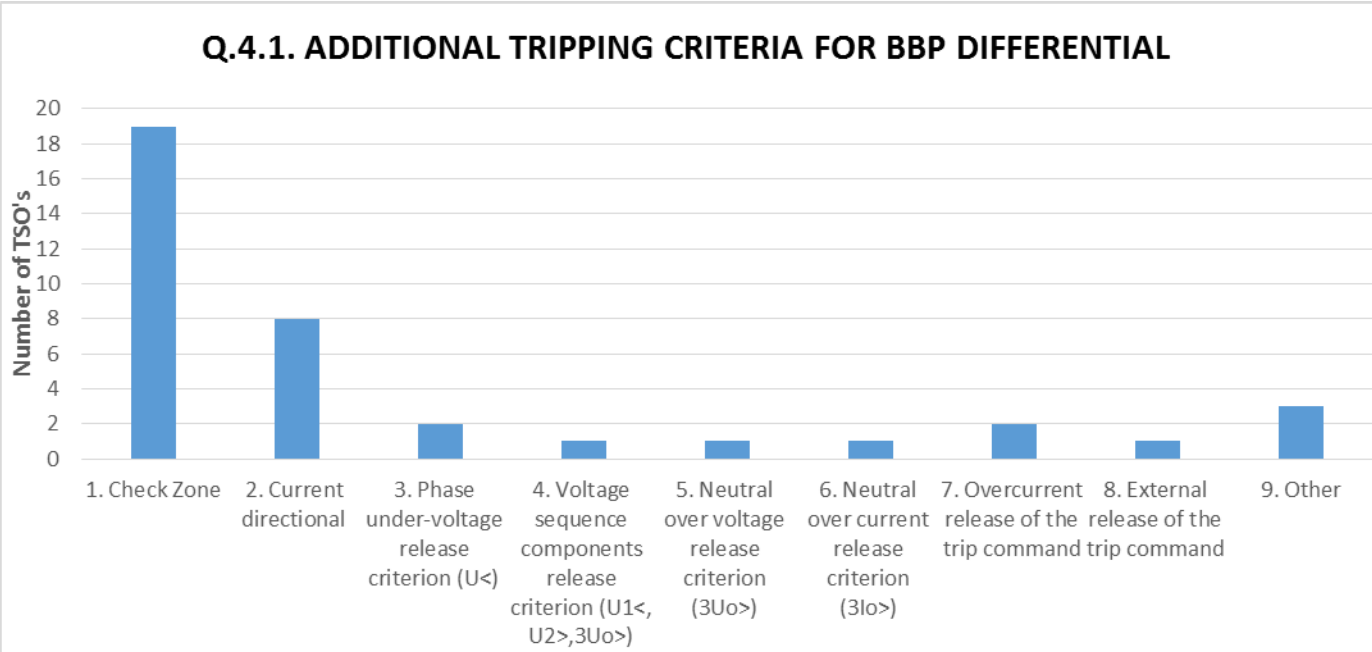

FIGURE 25: Additional Tripping Criteria for BBP Differential

The justification of each additional criterion is briefly as it follows:

- Check Zone

It's used to increase stability of BBP, The check zone calculates the diff. current and restrain current for the all s/s (all bays, except bus-coupler) without taking into account the position of the BB disconnectors. A trip order is issued only in case a fault is detected simultaneously in both the BBP zone and in the check. It is also used in smaller 110kV substations

- Current directional
  Currents in all bays must have the same direction – into the protected zone. Generally it's not common upon responders.
- Phase under-voltage release criterion (U<)
  It is not used among responders.
- Voltage sequence components release criterion (U1<, U2>,3Uo>)
  It is not used among responders.
- Neutral over voltage release criterion (3Uo>)
  It is not used among responders.
- Neutral over current release criterion (3Io>)
  It is not used among responders.
- Overcurrent release of the trip command
  It is not used among responders.
- External release of the trip command
  It is not used among responders.
- Other
  Check Zone + Discrimination Zone -Two independent algorithms (e.g. angler differential + current differential), dead zone function

10.5 Q5. SPECIAL BBP ARRANGMENTS/COMPONENTS

Next the mehod of protection of various busbar segments, parts, equipment is examined. Purpose is to cover with security all related to high voltage buses equipment.

10.5.1 Q5.1. A FAULT IN A BAY BETWEEN A CB AND A CT

In all cases the CT is located towards the line (according TSO's answers), between the CB and feeder (line, transformer). The fault between the CB and the CT fall in busbar protection zone and makes BBP to trip. If fault after BBP operation persists and the CB in faulted bay is open, the remaining fault is then eliminated with help of "end fault" protection, where BBP protection sends a trip signal to line distance protection of the remote end. After signal was received the CB of an opposite side trips and eliminates the remaining fault.

The other options to eliminate Fault in the dead zone are by tripping fault from other end of the line by distance protection or using BFP function. The "end fault" function is used in cases where tripping speed is more important factor, as example in important S/S (FIGURE 26).

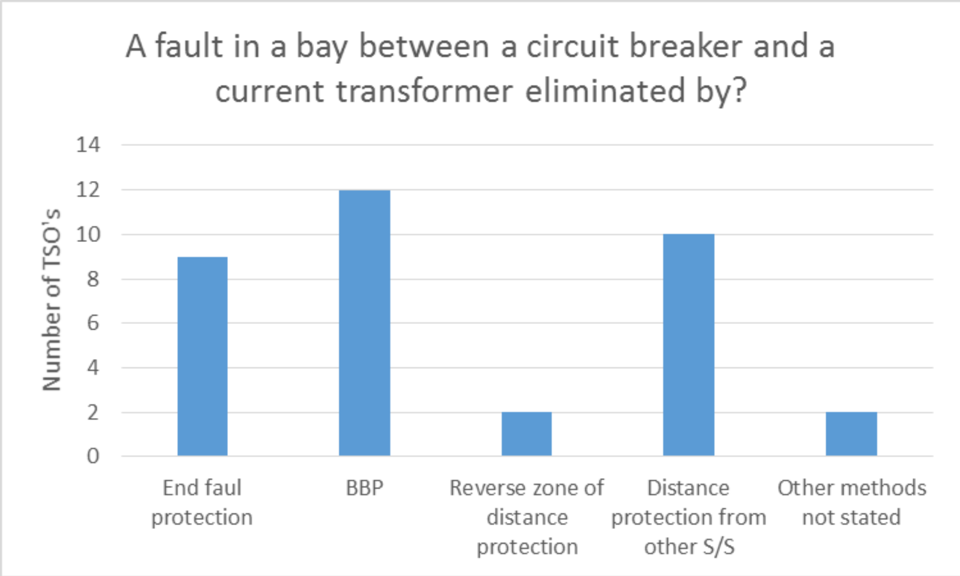

FIGURE 26: A fault in a bay between a circuit breaker and a current transformer eliminated by?

10.5.2 Q5.2. A FAULT IN BUS COUPLER BETWEEN CB AND CT

Each TSO choose differently how many CT's use on bus section and in which S/S. The one CT installed always in one side of bus coupler side and faults in that case are eliminated by tripping two buses. The two CT's are installed in two sides of the bus coupler and eliminate faults selectively by tripping only one bus. Usually two CT's are used in GIS or in important AIS where fast and selective fault elimination is vital.

10.5.3 Q5.3. BUS COUPLER

Faults on busbar or near S/S can also be eliminated by bus coupler protection, using distance, overcurrent or sensitive earth fault relays (FIGURE 27).

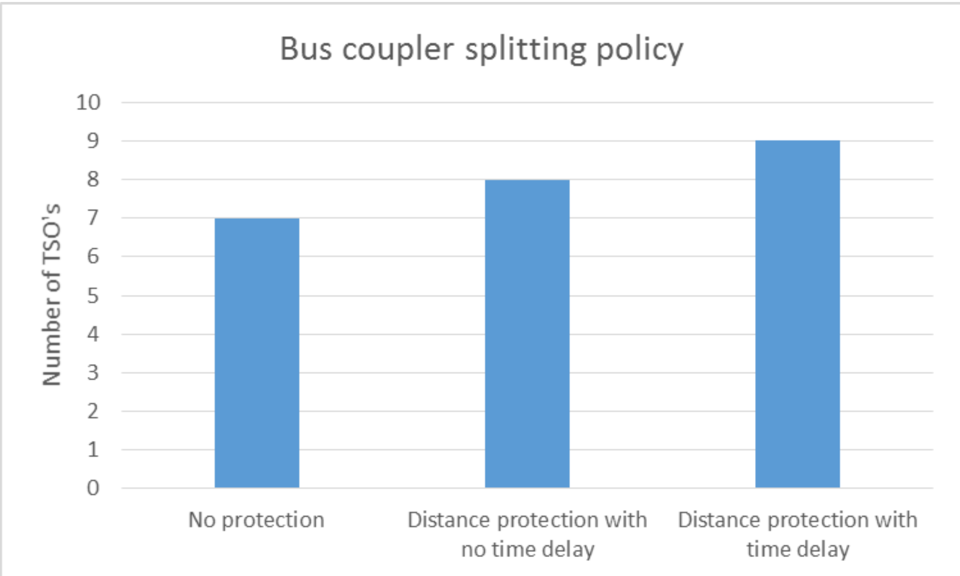

FIGURE 27: Bus coupler splitting policy

A bus coupler distance protection zone reach is calculated by estimating shortest line reactance reach with additional margin (0,72 x shortest line). Time delay is between 150 ms and 300 ms with consideration of other protection time delays (line distance protection zone 2, BFP, line distance reversal zone). The similar setting selection principles apply to overcurrent protection relays. Protection must trip before line distance remote end protection and/or before reversal line distance protection zone.

Also, there are some cases without additional time delays in bus coupler protection to consider.

10.5.4 Q5.4. 1 1/2 BREAKER CONFIGURATION SUBSTATIONS

In 1 ½ configuration BBP principle almost has no difference from other types of S/S configurations. Zones between two CB and line are also protected by BBP. When the BBP operates teleprotection signal is send to other ends of the line. If line is out of operation, zone without branch is still protected with BBP.

10.5.5 Q5.5. SPECIAL PROTECTION SCHEMES SUPPORTING BBP OPERATION

Special protection schemes supporting BBP:

- Teleprotection schemes;
- BFP function.

10.5.6 Q5.6. ISOLATOR ALARM OR AUXILIARY CONTACT

TSO’s using several policies for isolator alarm treatment:

- Alarm and take no action;
- Alarm and block BBP.

In case the isolator alarm is issued, the BBP remain in service by using last valid switchgear position into account or the BBP operation is blocked for the affected zone.

10.6 Q6. CIRCUIT BREAKER FAILURE PROTECTION OPERATING PRINCIPLES.

The different approaches to BFP by TSO are gathered in chart FIGURE 28.

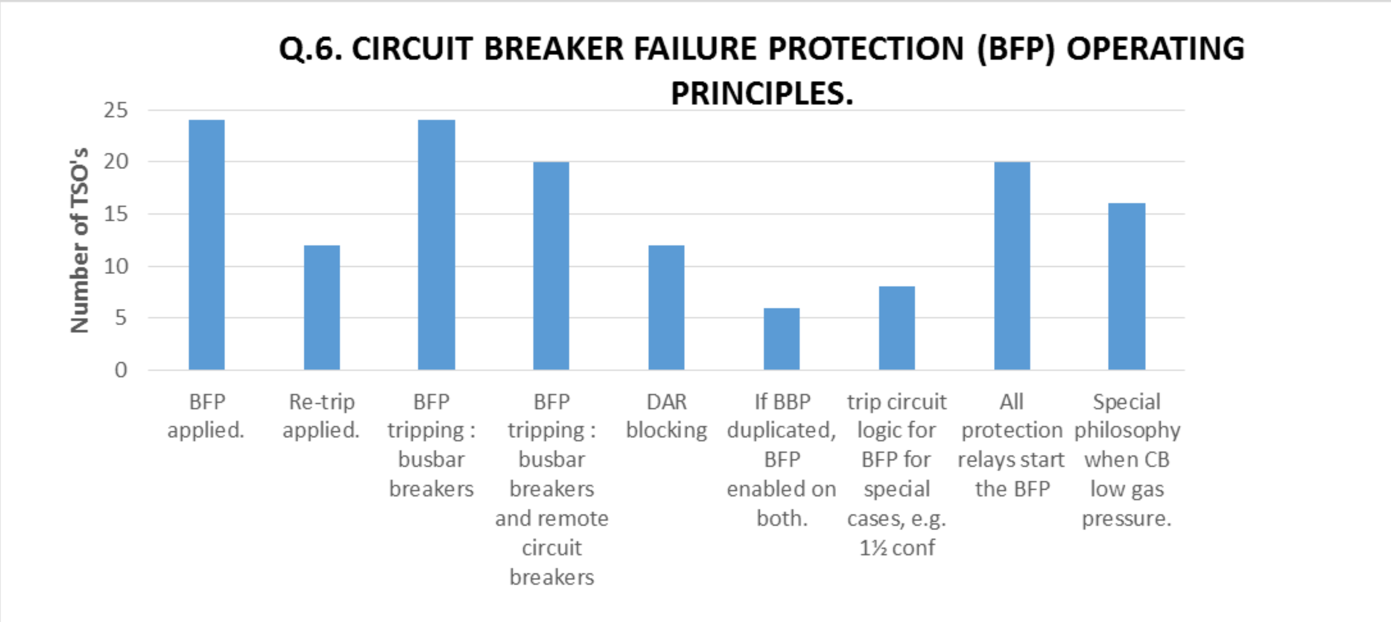

FIGURE 28: Circuit Breaker Failure Protection (BFP) Operating Principles

10.7 Q7. PRINCIPLES OF SETTING/PARAMETERIZATION FOR BBP AND BFP

Present session summarizes the followed tactic for the busbar protection studies.

10.7.1 Q7.1. BBP SETTINGS

The TSO's choose settings for the BBP by their in-house resources, taking under consideration the BBP manufacturer settings (FIGURE 29) recommendations as well, nevertheless the calculation of setting varies among TSO's due to inherited legacy and requirement differences.

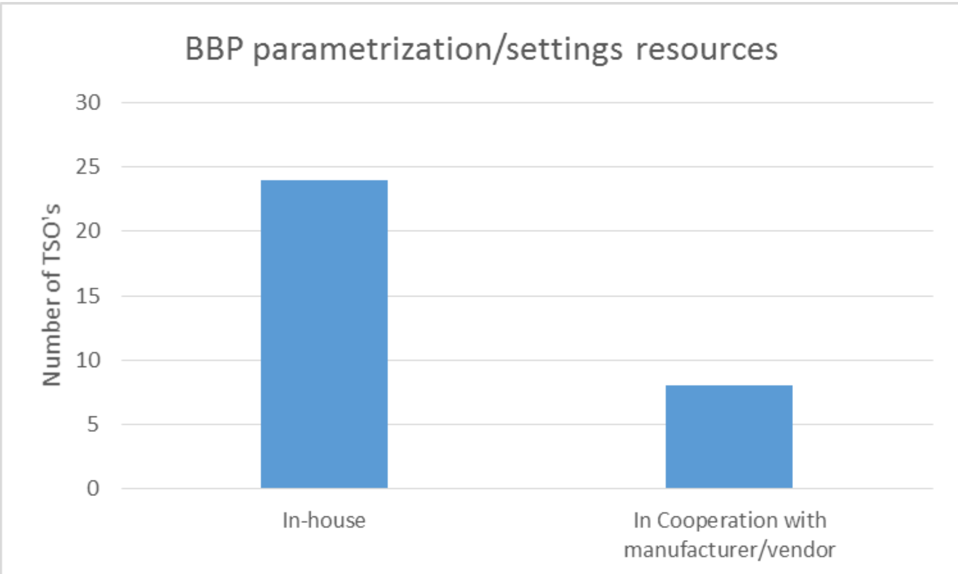

FIGURE 29: BBP parametrization/settings resources

As example can be a criterion for the settings of the minimum differential current of busbar protection (FIGURE 30). The setting can be chosen by taking into consideration:

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- The protection sensitivity;
- A safety margin (at least 20 percent or more) of minimum fault current on busbar in different scenarios (N-1 or N-2) and with different fault types;
- The fault resistance on bus;
- Highest CT of the line (not to trip BBP when one of the CT's are faulted) with or without additional safety margin for the setting as well;
- Operating time

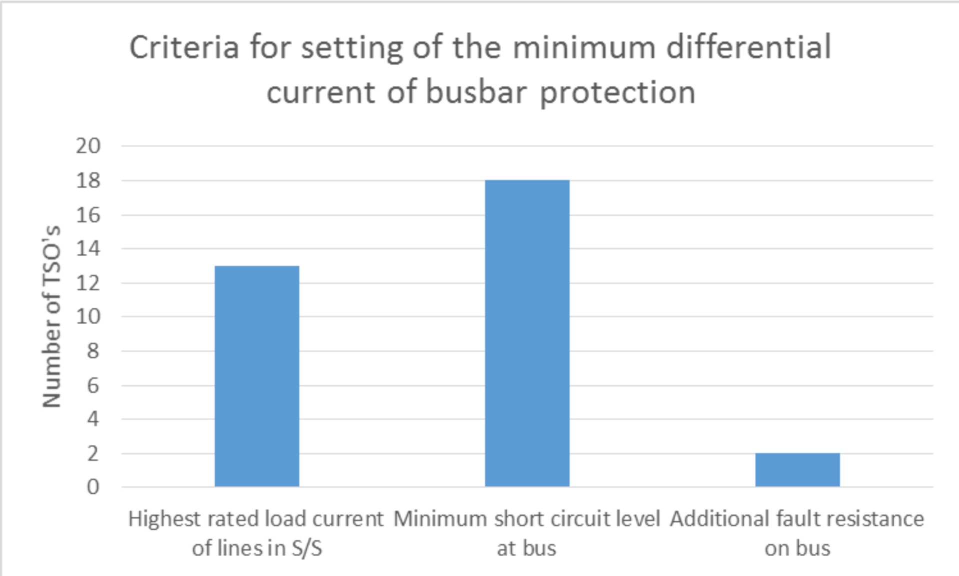

FIGURE 30*: Criteria for Setting Of The Minimum Differential Current Of Busbar Protection*

10.7.2 Q7.2. BFP SETTINGS

Breaker failure protection (BFP) is important back-up function for breaker redundancy. The BFP can detect that a CB has failed to interrupt by those criterions (FIGURE 31):

- Measuring current flow through the CB;
- The CB position criteria;
- Combination of the two criteria.

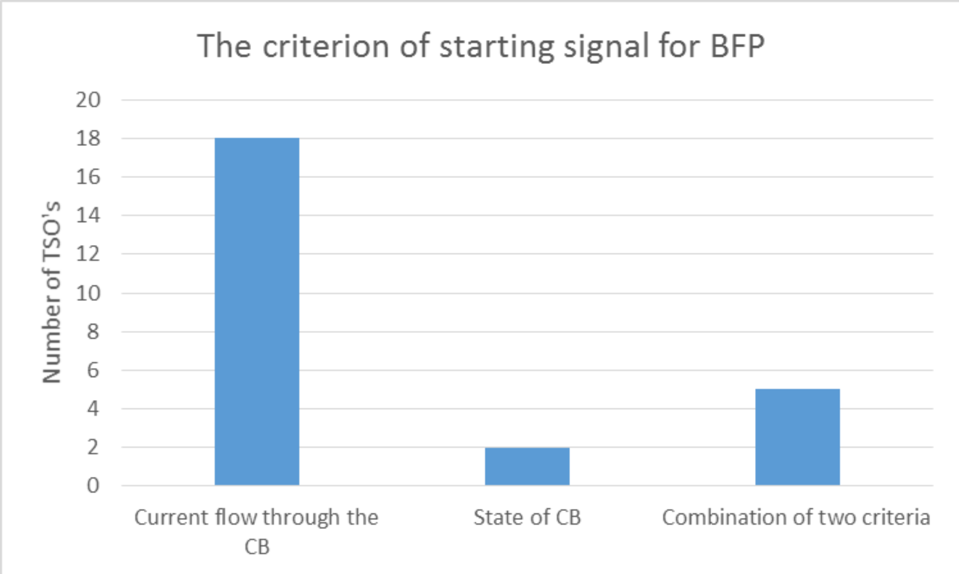

FIGURE 31*: The criterion of starting signal for BFP*

The minimum current for BF detection can be set for each of three phase detections (FIGURE 32). The current limit can be fixed value or can vary in correspond to S/S CT's currents.

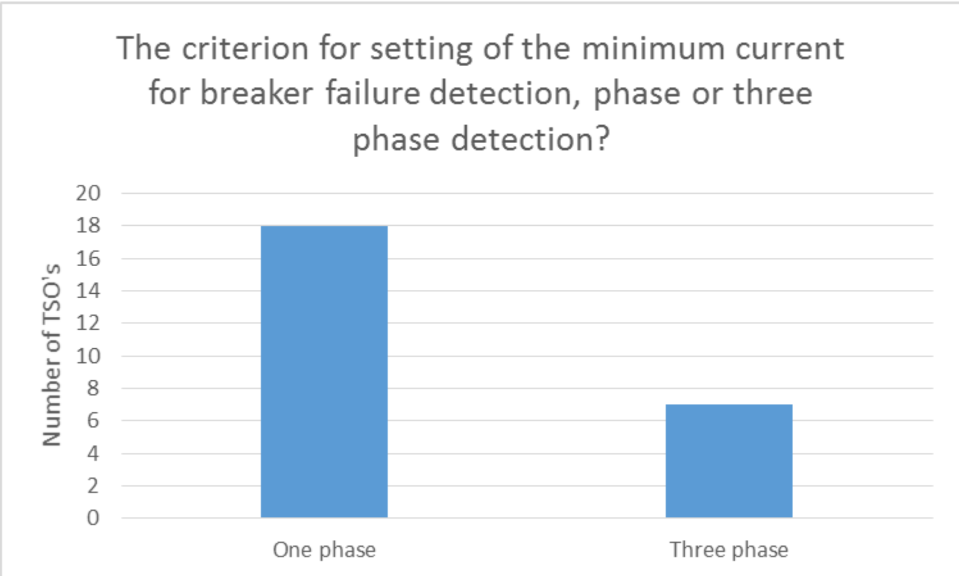

FIGURE 32*: The criterion for setting of the minimum current for breaker failure detection, phase or three phase detection?*

The BFP tripping time is crucial factor for transmission system operation stability and must fulfil critical clearing time conditions. The setting for the time delay varies among TSO's from 120 ms to 300 ms. The time delay is calculated by evaluating protection response time, CB contact tripping time, action time of auxiliary relays, safety time margin and selectivity in relation with the fault clearance time by the main protection.

10.7.3 Q7.3. OTHER SETTING PARAMETER OF BBP AND BFP

Other BBP and BFP functions and settings to take upon consideration:

- The current circuit supervision with an operating time delay;

- The stabilization factor in case of external faults or external errors;
- BB auto-reclosure;
- BFP clearing time reduction in special cases.

The current circuit (differential current) supervision function is part of BBP. Current circuit supervision picks up if differential current exceeds setting value for a set time. Settings values are determined by maximum CT primary current or by certain level of operational current. Function can block BBP entirely or alarm about current circuit malfunction due to incorrectly connected CT, open wire or CT defects.

The stabilization factor (k-factor) for BB zones determines the stabilization in case of external faults. A higher stabilization factor has a positive influence on the stabilization for external errors, while the sensitivity to internal faults diminishes.

BB auto-reclosure solution is initiated only for one time when BBP trips faulty busbar section and if BFP permits to do it. BB auto-reclosure is initiated by one of the dedicated CB's, after successful busbar auto-reclosure remaining busbar CB are connected automatically.

Special solution BFP applicable to reduce short circuit clearing time in S/S with connected extra-large units (app. 1GW). Aim is to speed up reaction of BFP when failure of CB occurs during clearing multiphase short circuit on line. For detection such short circuit additional zone must be set (shorter to zone 1) in line distance protection. Activation signal of this zone is sent to BFP. If this zone is still active after time of proper reaction on short circuit in base protection zone, re-trip is omitted and BFP is operating according to scheme.

10.8 Q8. BBP - Asset management issues

The questionnaire includes 12 asset management issues. The answers are quite different and therefore some tendencies can only be summarized.

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10.8.1 Q.8.1. Maintenance of BBP – how is it implemented? For the entire substation, one after the other bay?

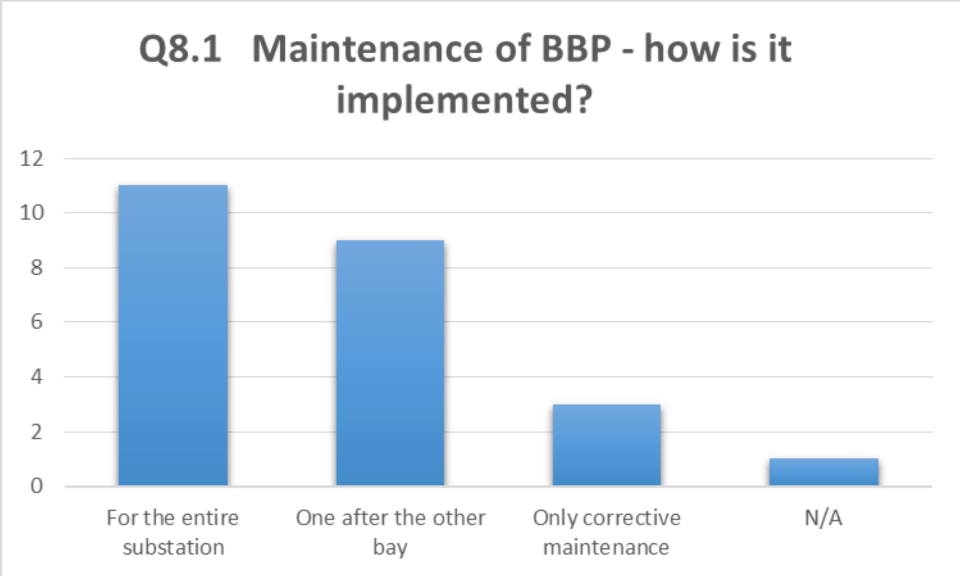

FIGURE 33*: Maintenance of BBP – how is it implemented?*

It is remarkable that three TSOs do not do preventive maintenance at all. Only corrective maintenance is done.

Two TSOs have stated that S/S is in operation during maintenance.

- One TSO has stated that maintenance of BBP for the entire substation requires out-of-service of full S/S.
- As an example to do maintenance of BBP one after the other bay/for single bay the following example describe. One TSO do often the maintenance of BBP on bay unit level when a feeder is in maintenance. S/S is in operation doing the work. In the tested bay, the disconnector to the "free" busbar (busbar out of operation) is closed, the rest of BBP's tripping circuits (tripping from other bay units) are unplugged and there is forbidden to work in the area of S/S (nobody must be in area of S/S).

10.8.2 Q.8.2. Is tripping test applied – which is the policy/methodology?

Two tendencies seem to apply for The TSOs doing preventive maintenance:

- Trip test without circuit breaker (trippings are tested to the terminal blocks in relay cubicle)
- Trip test including circuit breaker (tripping is executed on CB).

The two tendencies appear with some percentages.

10.8.3 Q.8.3 BBP MAINTENANCE STRATEGY/HOW OFTEN IS THE DEVICE TESTED AND WHAT IS TESTED?

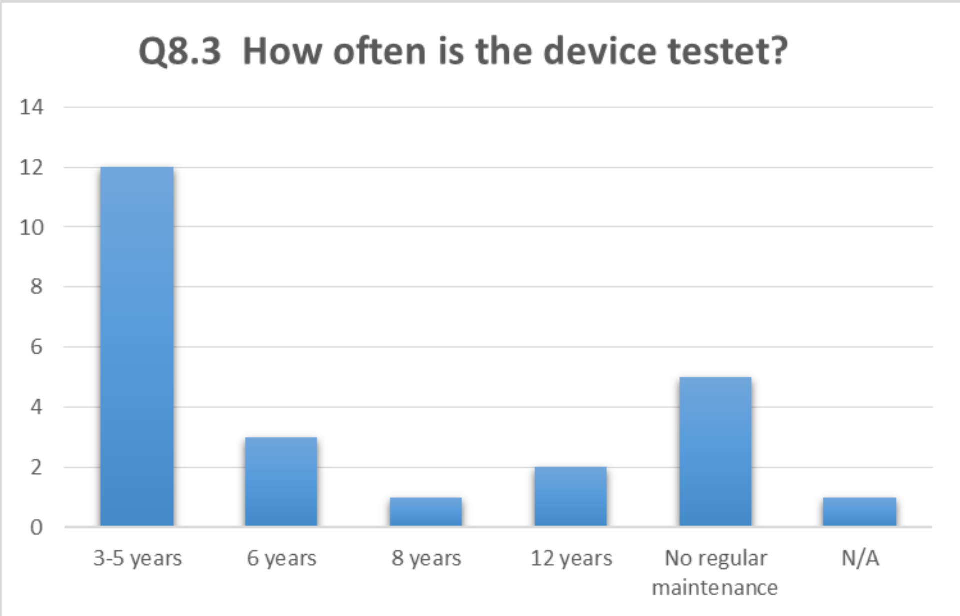

FIGURE 34: BBP maintenance strategy/How often is the device tested?

The answer "no regular maintenance" includes the following answers: No regular maintenance, no strategy yet and condition based maintenance.

Some TSO do a test of the BBP one year after commissioning and afterwards ordinary maintenance tests.

As seen from FIGURE 34 the majority of the TSOs do maintenance test of BBP every 3-6 years. A few TSOs have another strategy.

There are variations in what is included in a test doing maintenance. Some TSO focus on tripping functions, other visual inspections and other again do a full test or partly a full test. Full test including: power control, control of settings, control of protection functions and characteristics by secondary test equipment, control of analogue and binary inputs, control of binary output, control of signalisation and tripping test.

10.8.4 Q.8.4 SPARE PARTS MANAGEMENT STRATEGY?

Four different strategies are used by the TSOs. Some TSOs use a combination of the strategies. The strategies are:

- Maintenance agreement. The manufacturer holds all need spare parts.
- Spare parts on stock by TSOs
- Only bay units and important cards on stock by TSOs.
- Reliance on vendors combined whit in some cases equipped spare bays and holding of decommissioned equipment.

Half of the TSO have spare parts on stock.

10.8.5 Q.8.5 REPLACEMENTS OF ALL PROTECTION RELAYS THROUGHOUT A SUBSTATION WITH THE DECENTRALIZED BBP DESIGN. IS BBP OUT OF OPERATION OR IS THERE

SOM TEMPORARY OPERATIONS? DESCRIBE BRIEFLY THE OPERATION OF BBP DURING SUCH A RECONSTRUCTION.

The majority of TSOs have BBP in service as much as possible under such a reconstruction.

If the BBP itself has to be replaced than different strategies are used depending on the circumstances:

- BBP out of service
- BBP out of service – backup protection from distance protection relays in reverse direction with 300 ms time delay or distance protection from remote ends are used as backup protection (sometimes time delays of zone 2 are shorten).
- Old BBP remains provisionally in operation until the last bay is replace if there is work on the primary equipment.
- BBP may be in operation for one bus or for one bus section during works on the other bus or bus section.

One TSO do not have any decentralized BBP design.

10.8.6 Q.8.6 ADDITIONAL BAY PROTECTION (BP) RELATED FUNCTION ON BAY UNITS (BU)

The "district" options / combinations are:

- Overall protection sytem (BBP+BP in same devices).
- Distance protection on BU
- Overcurrent on BU
- Autoreclosing (AR)?
- Disturbance protection (starting?)

The majority of TSOs use the BU for BBP only.

Five TSOs use BU for BBP and BFP only. Some of the TSOs have additional bay protection in already running BBP.

Four exceptions occur:

- BU contains BBP, BFP and Pole discordance function
- Two TSOs use overcurrent protection on BU. One only for 110 kV overhead lines.
- One TSO use Distance Protection on BU in a few S/S.

10.8.7 Q.8.7 IS THERE A CERTIFICATION PROCESS FOR THE BBP? (TENDER REQUIREMENT)

Nearly all TSOs have a certification process. The certification processes are very different, but tree different strategies seam to occur:

- Tender specification: All requirements are detailed described including technical data, manufacturer quality management system, list of clients/users, etc.
- Type test in laboratory owned by TSO (Done by either TSO itself or the vendor).
- Type approval process for protection relays and functional requirements.

One TSO requires reference list of the clients/users.

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10.8.8 Q.8.8 Are Factory Acceptance Test required? Why?

13 of the TSOs require Factory Acceptance Test (FAT). The outage time during the installation on site can be shorter while errors in configuration of the protection relay can be retrieved in advance.

Some TSO do not require FAT because the vendors already are qualified/certified doing frame agreements (tender requirements).

10.8.9 Q.8.9 What is your Qualification of the process for commissioning?

The answers to this question are quite different and therefore some tendencies are summarized. 5 TSOs do not answer this question.

Insourcing:

- 7 TSO do the commissioning themselves with own engineers with full qualification. A few TSO also do engineering themselves.

Outsourcing is done in different ways:

- The manufacturer is responsible for commissioning – with/without with validation with own employees.
- Commissioning is done by contractor together with manufacturer. Validation with own employees.

10.8.10 Q.8.10 What tests are performed during commissioning? Are the done when the substation is in operation or when it is out of service?

The answers to this question are quite different and therefore some tendencies are summarized.

For new substations the tests of BBP during commissioning are done when the S/S are out of service.

In case of commissioning of BBP in existing substation 7 TSO have stated that S/S is out of service during commissioning of BBP. One TSO states that this is the best case. If not the bays are out of service one after one other.

Different tendencies are:

- Due to extensive FAT (Q8.8) performed test are related to the interfaces: CBs, isolators positions, CTs, telealarms going to the SCADA system, local alarms.
- Full test concerning both functional test and tests to the interfaces. Following test are usually performed: power control, control of setting, control of protection functions and characteristics bye test equipment, control of analogue and binary inputs, control of binary output, control of signalization, tripping test, signalization of CBs and disconnectors, polarity check of CTs by a primary power source.

A commissioning test includes some of or all of the following statements:

- Power control
- Control of settings
- Control of protection functions and characteristics by test equipment
- Test of breaker failure scheme on each bay
- Control of analogue and binary inputs
- Control of signalizations
- Tripping test
- Signalizations of CBs and disconnectors

- Polarity check of CTs by a primary power Source
- Tele alarms going to the SCADA system
- Local alarms

10.8.11 Q.8.11 DO YOU DO PRIMARY CURRENT INJECTION TESTS? IF YES THEN HOW? BY AN OPERATION CURRENT OR BY A TEST EQUIPMENT?

It is remarkable that for the first commissioning for a new S/S or a new bay more than the half of the TSO uses primary current injection tests done by test equipment before energizing. Some TSO use primary current injection by a test equipment only for advanced protection schemes but mostly as a part of standard commissioning.

10.8.12 Q.8.12 WHAT IS EXPECTED LIFETIME FOR DIFFERENT TECHNOLOGIES/WHAT ARE THE FAILURE RATES OF THE EQUIPMENT/MAIN FAILURE MODES FOR DIFFERENT TYPE OF BUSBAR PROTECTIONS? PLEASE GIVE SOME FIGURES IN CASE THEY ARE AVAILABLE.

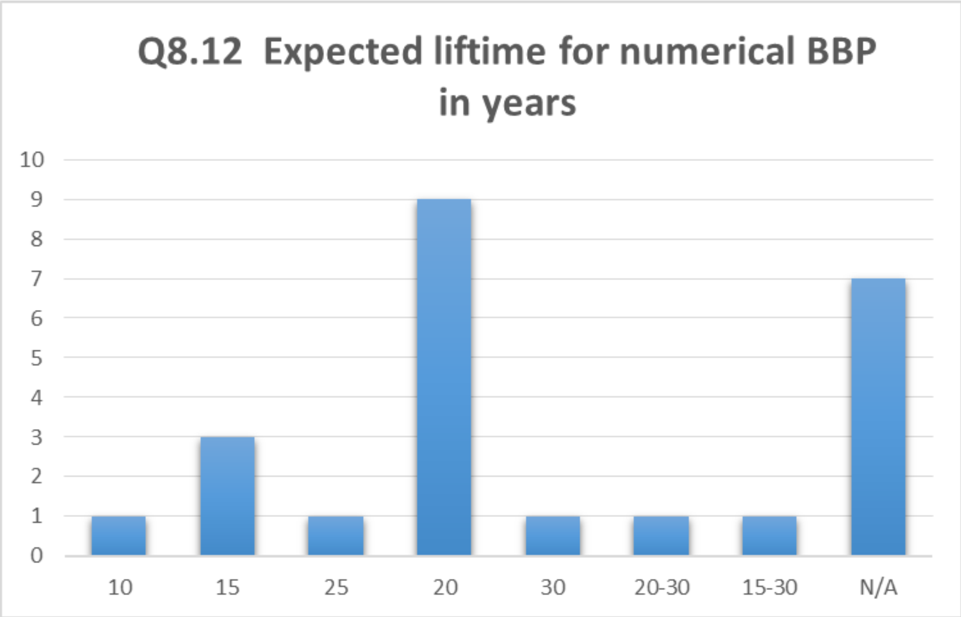

FIGURE 35: Expected lifetime for numerical BBP in years

As seen from FIGURE 35 the expected lifetime for the numerical BBP is assumed from 15-30 years, where majority says 20 years. Failure rates vary from products to products.

A few TSO have assumed lifetime for electromechanical to 40 to more than 50 years.

The reported failures for the numerical BBP are: communication failure, I/O modules, modules for optical connection between BU and CU, bay units, power supply.

10.8.13 Q8.13. STATISTICS ABOUT NUMBER OF BUSBAR FAULT (PER SUBSTATION AND PER YEAR)/ NUMBER OF UNWANTED TRIPS/AVAILABILITY

Please note that answers not are given in an uniform format:

- Some TSOs report numbers of substation for each voltage level others “x substations with highest voltage 110 kV and y substations with highest voltage 400 kV” . In Question 4.1 TSOs are asked for substation design issues but only for system 220 kV-400 kV. The problem is to distinguish on this when statistics are made.
- Some TSOs use unit “number of busbar fault per substation” others “number of busbar fault per substation”.
- Some TSOs have answered number of busbar faults per year and per substation, others number of unwanted trips and others have answered both questions. It seems to some TSOs only have statistics on unwanted trips.

In Figure 36 is shown years to busbar faults. Faulty trips (over-reaction) from busbar protection are not included in this figure.

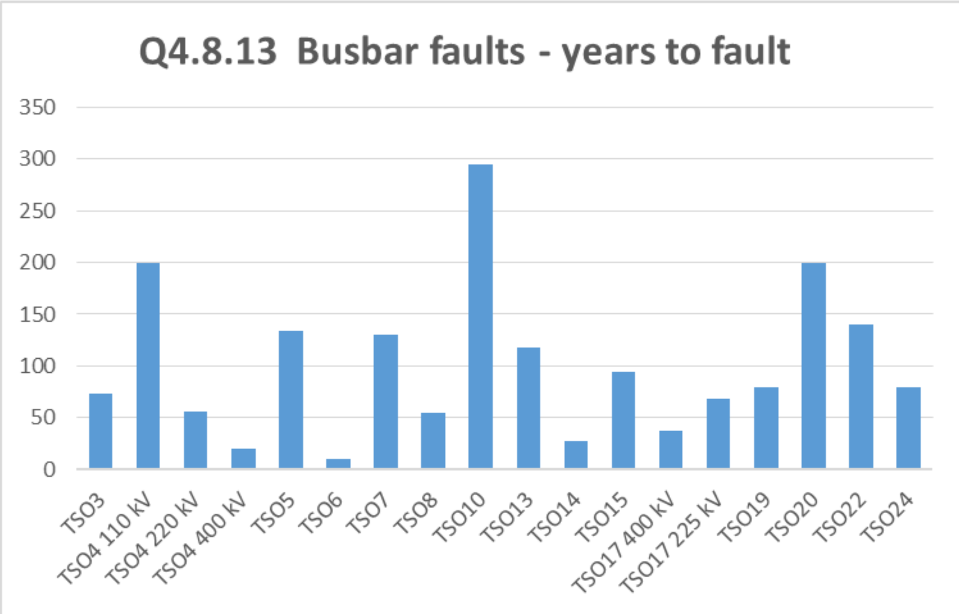

Figure 36: Number of busbar faults - Years to Busbar Fault. Faulty trips are not included

Figure 37 shows Number of unwanted trips from busbar protections.

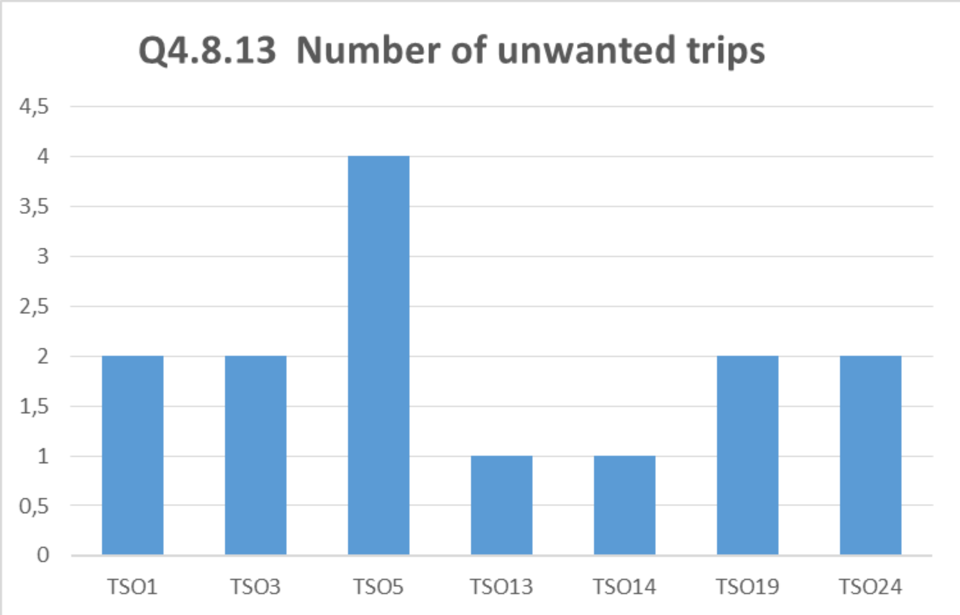

Figure 37: Number of unwanted trips from busbar protections

10.9 Q9. OTHER ISSUES

Finally a section was included in the survey for notifying any possible important factor related with BBP that deserves future investigation, that consist the state of the art of BBP or the long –term trend. For this case two questions were proposed and were put:

- **Fiber optic or copper wiring for connection to central unit?**

All TSOs uses fiber optics between bay units and centralized BBP unit.

- **Do you apply at any S/S BBP functionality with reversely oriented and interlocked distance zones using IEC61850**

Only one TSO has applied the BBP functionality in one S/S, but it's not in operation yet.

11 Conclusions

BBP is one of the most important protection devices which is installed on substations. It is the most critical protection system due to its big impact for the system. The most important key factors related with the correct function of BBP is the large amount of the affected elements that trip and the necessity of the instantaneous tripping of the bus faults.

HV and EHV (220 kV and above) bars must be equipped with busbar protection phase segregated.

BBP realizes fast and selective tripping. Although BBP is quite expensive and complicated device, its features may save equipment and even peoples live. Using BBP and CBF is also a necessity to assure system stability.

The redundancy level should be a function to the critical clearing time: If this is less than typical remote backup clearing times then busbar protection must installed.

The BBP protection should not trip for external faults. Check zone logic that covers the whole busbar arrangement is recommended. Other reliability principles that support the functionality of BBP are: the directional principle, the saturation detection, voltage and current release criterion, etc.

The protection should only trip the bar faulted section (selectivity). The protection should include dynamic bus replica mechanism. When bad arrangement is detected the protection should alarm and block.

Low impedance differential protection systems are preferred.

Centralized or decentralized types are equivalently used depending on the local conditions. The pros and cons were given as they frame the design decision.

Local back-up protection (breaker failure protection) needed for busbar protection. When the busbar protection is unavailable, if the critical clearing time of the substation is small, local back-up with reverse zones of the line protection should be used.

Concerning planning great concern is devoted to the places of installation of BBP. There is a variety of tactics. Most companies try to install as much as possible BBP and to avoid the clearance of the busbar faults by the second zone of the distance relays.

Double busbar protection is not the rule. Setting procedure is managed and/or executed by the companies. Commissioning and maintenance is made in a manner not to jeopardise the security of the system.

High penetration of power electronics at the connection interface and the existence of GIS or AIS substations are taken into consideration to the even more detailed and sound management of the BBP.

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