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**AUTO-RECLOSING
LOCAL SYSTEM RESTAURATION**

**Working Group
B5.34.01**

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AUTO-RECLOSING AND LOCAL SYSTEM RESTORATION

CIGRE Study Committee B5 Working Group 34.01

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Preface

In 2000, CIGRE Study Committee 34 (Power System Protection and Local Control, SC 34) instigated the formation of a working group to look into the state of the art of autoreclosing and local system restoration.

The scope of work was defined as:

To determine the current state of the art of auto reclosing, examine how it may be further improved using new technologies and the role of automatic system restoration in “Making networks and plant work harder”.

1. Opportunities presented for the application of automatic reclosing using modern relays.
2. How should auto reclosing operate on power systems with FACTS and storage devices.
3. Influence of availability of modern communications.
4. Use of GPS time signals and phasor measurements.
5. Adaptive techniques.
6. New auto reclose characteristics.
7. Integration of auto reclosing with protection relays, switching station controllers and network control.
8. Setting and operator interface.
9. Testing.
10. Automatic system restoration functions, location, algorithms, testing and maintenance.
11. Automatic system restoration – integration with protection relays, switching station controllers and auto reclose.
12. Cooperation with Distribution networks with / without embedded generation.

The goal of the working group was to start work within the second half of 2000 and complete the work by year-end 2003.

The Working Group 01 (Auto reclosing and local system restoration), WG 34.01, met for the first time in October 2000. As part of this work a survey was prepared and sent to all Cigre members in October 2001. Returned surveys were accepted until July 2002. Analysis of the survey and preparation of the Draft Report was planned during 2003.

The Final Report is envisaged to be ready during 2004.

The following individuals have been regular members of WG 34.01 and participated in the preparation of the document: Ian Gardiner (UK, Convenor >2002, Secretary 2000 - 2002), Stephen James (UK, Convenor 2000 – 2002, retired 2002), Joe Monaghan (Ireland), Dan Hubinette (Sweden, Secretary >2002).

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General Introduction to Report

Auto-reclosing has been applied throughout the world in order to quickly restore supply after system faults or incidents.

This report details the information gathered by Cigre Working Group 34.01 (2000) Auto-reclosing and Local System Restoration. In order to appreciate the depth and differences to which auto-reclose is applied throughout the world the initial chapter of the report details current practice of auto-reclose. In order to gather information regarding current practice a survey was conducted to determine worldwide application.

Despite the efforts of those who responded, the survey was not well supported. A request was issued to some 73 organizations. Japan made an outstanding contribution supplying ten of the 32 responses. Scandinavia was also well represented. The majority of the other replies came from countries, organizations or individuals represented on the WG or strongly active in CIGRE. So in all, just fourteen countries responded. The Working Group had hoped for a better return of the survey, although the 32 responses did return an excellent coverage of adverse applications of auto-reclose, the other related topics provided far less information.

Following the information gathering stage it became apparent that there was little interest or returned data from a number of the initial proposed sections. This together with the limited human resource available to the Working Group and the difficulties experienced throughout the working period have entailed the report concentrating on areas of interest reported throughout the survey. The Working Group agreed to change the terms of reference to accommodate the chapters into better working areas. This has resulted in a number of proposed topics becoming combined into a common chapter.

This information is presented not as a definitive guide, but as an attempt to collate relevant facts and current experience that may be of interest to practitioners of power system protection, auto-reclose or system control. It is acknowledged that there are gaps in the coverage due to the nature of the survey returns and the knowledge of the working group. This applies in particular to areas where only limited information was made available to the Working Group, such as adaptive auto reclose, or use of communications in auto reclosure..

Topic 1. Opportunities presented for the application of automatic reclosing using modern IED's or functions.

1.1 Introduction

Statistically, the majority of system faults are of a transient nature so that once the fault has been cleared by the protection, the faulted circuit can be re-energized successfully with a likelihood of minimal disturbance to the rest of the system.

Auto-reclosing is commonly applied to transmission networks. The UK system currently experiences about 350 system faults during an average "good" year, but the number experienced in any given year depends heavily on weather conditions, with high fault rates of up to 1500 faults in a "bad" year of lightning, gales, snowstorms, icing, fog and pollution conditions. Similarly Japan averaged 3,437 faults per year between years 1986 - 1990, from which there was a reclose failure rate of 119 (3.5%). Statistics from Germany indicate 95% success rate at 400kV, 89% success rate at 220kV, and 85% success rate at 110kV. Ireland reports a 61% success rate at 110kV. Other utilities return success rates from 50 – 100%. This wide range results from different practices and success measurement criteria.

Particular severe weather conditions tend to result in exceptionally high fault rates over just a few hours or days. e.g. a severe lightning storm may result in several tens of faults per hour affecting large parts of the system as it moves across the country.

In an average year, approximately 80% of all system faults occur on overhead line and cable circuits, 7% on generator units, 6% on transformer and 2% on busbars, the remaining 2% on other plant. Clearly therefore, more than 95% of all system faults occur on the transmission system.

An important feature of overhead line faults is that since air is the main insulant a significant majority of flashovers cause no permanent damage to the circuits and the majority (about 88%) of fault clearances can be quickly followed by the circuit's return to service by operation of automatic switching and reclosing facilities.

1.2 Description of Autoreclose Operation

Operation of the autoreclose sequence is initiated from the Main protection's contact, which trips the circuit breaker and starts a Dead time timer. This timer will time out and issue a reclose signal to close the circuit breaker. This signal, in turn, initializes the Reclaim timer. The Reclaim timer will time out and if no further trip occurs during this time, the reclose sequence has been successful and the line is back in service.

Reclose will only proceed if the system is working satisfactory. This requires the circuit breaker to be closed and system voltage to be present prior to a trip signal being received.

The deadtime can start once the circuit breaker opens, (and possibly also the trip input resetting). System inputs are provided to stop or inhibit the reclose operation. If none of these are energized the reclose can proceed. At the end of the deadtime if the Check Reclosure conditions are met then reclosure can take place. The Check Reclosure conditions consist of Dead Line Charge, Dead Bar Charge, or Check Sync. Where it is utilized, Check Sync consists of Live Line, Live Bar, Under-voltage check, voltage differential check, slip frequency less than setting, phase angle less than setting, time delay expired: all of these parameters must be met. This logic is designed to proceed with reclosing only if everything is in order, which means - Autoreclosing errs on NOT closing. If there is a problem, then reclose will not proceed.

1.3 Deadtime

This is often defined as the time between the auto-reclose scheme being energized and the operation of the contacts which energize the circuit breaking closing circuit. On EHV schemes this time is the same as the circuit-breaker dead time.

The deadtime may also signify the conditions for charging a line are present, and have to be present for a time delay, before a reclose is attempted, i.e. Dead line charge timer, Dead Bar Charge timer. The Charging delay timers have a different function to that of the deadtime timer. Here, once the conditions for Dead Line Charging appear at the relay, i.e. Bar volts and no line volts, then the Dead line charge timer starts at the appropriate point in the autoreclose sequence. This could mean that the bar has been charged remotely, and this circuit breaker has been dead both sides of the circuit breaker; or that the faulted line has no voltage and the other side is live. In effect there could be a delay between the trip relay resetting and the start of the deadtime, this delay corresponding to the remote end deadtime charging the line first.

Note: Some utilities build in system restoration logic for dead line volts and dead bar volts at a circuit breaker. In order to preserve a network restoration procedure circuit breakers which are closed with no voltage either side are opened to aid system restoration.

1.4 Reclaim Time

The time following a closing operation, measured from the instant the auto-reclose relay closing contacts make, which must elapse before the auto-reclose relay will initiate a reclosing sequence in the event of a further fault.

Most utilities adopt logic where a trip occurring within the reclaim time causes the autoreclose sequence to stop; or alternatively to reclose if another shot is allowed; or to auto-isolate faulted equipment and then reclose. However this does not differentiate between closing onto the same fault and a second separate fault occurring near the end of the reclaim time. Some relays provide, in effect, two reclaim times, one that can signify a close onto fault, the other which can signify a second separate fault. It may be advantageous to allow the second separate fault to reclose especially if the circuit breaker

can handle this extra duty. Illustrating the difficulty of compiling comparable statistics, it may be asked: how many times does autoreclose fail during a storm; and has the possibility of two separate lightning strikes been considered? (for example, Japan can report: 2464 faults attributed to lightning, with 44 reclose failures). Depending on the approach, this might then be classified as an unsuccessful reclose when perhaps it may have closed successfully. On the other hand, some utilities may choose to block reclosing during a lightning storm to minimize equipment operation. This is only a viable option if alternative supplies are available, or if supply can remain off, which is not often.

Some utilities require separate single pole reclaim times and three-pole reclaim times. This is to differentiate between the fault current of single-phase and multi-phase faults, however the CB does not know which, so a common reclaim time is normally used.

1.5 Delayed Three Phase Auto-reclosing

This process of re-energisation is known as "Delayed Automatic Reclosure" (D.A.R.). This system is used as standard on the UK National Grid, where all three phases are opened on the occurrence of a fault, and all three phases are automatically reclosed. Synchronism may be lost using D.A.R. therefore the reclose relay must be fitted with synchronizing features. Following a fault, and coincident with the tripping of the circuit, the operated trip relays prepare the D.A.R. After a delay of about 15 seconds, when system power swinging may be assumed to have settled down, auto-reclosure is initiated and the D.A.R. equipment either recloses its breaker a) to "dead line charge" the circuit, or b) check for synchronism across the breaker and close if the voltages either side of it are within prescribed limits.

On a plain feeder, the D.A.R. will dead line charge from one end followed by a check-synchronize close from the other end. Dead line charging is usually employed at the end with the lowest fault level so as to minimize further disturbance to the system should the fault condition have persisted. Or alternatively, reclose at the highest fault level so as to maximize the protection detecting a fault. On attempting a reclosure onto a persistent fault, the protection at that end would operate for a second time, and because that happened within the reclaim time no further reclosure would be allowed.

At the check synchronizing end, typically after 25 seconds of the first trip, or a specified time, if successful line re-energisation has not been detected, all further attempts at D.A.R. are inhibited.

For certain items of plant, faults are likely to be persistent and D.A.R. is not permitted. These plant items are:

- transformers
- wound-type voltage transformers
- static compensation equipment
- cables
- generators and synchronous compensators
- busbar and mesh corners

Where such plant items trip on fault and otherwise "healthy" plant and/or sections of the system are also tripped to clear that fault, the D.A.R. adopted in the UK and some other utilities initiates appropriate automatic isolation of the faulted item before reclosing the remainder.

D.A.R. is "locked out" on receipt of a trip relay input that suggests that Main protection has failed e.g.:

- busbar backtripping
- circuit breaker fail
- system backup

Sophisticated systems exist where D.A.R. is inhibited for ferroresonance conditions and for a period of 2 seconds after manual closure of a circuit breaker. Where ferroresonance has been detected, automatic opening and closing of the associated transformer's HV disconnector is permitted to proceed. Or alternatively, if the transformer isolator is not rated to break the ferroresonance current, an earth switch may be closed then opened.

Typically:

deadtime 15 secs
 reclaim time 2 secs
 sequence time 25 secs

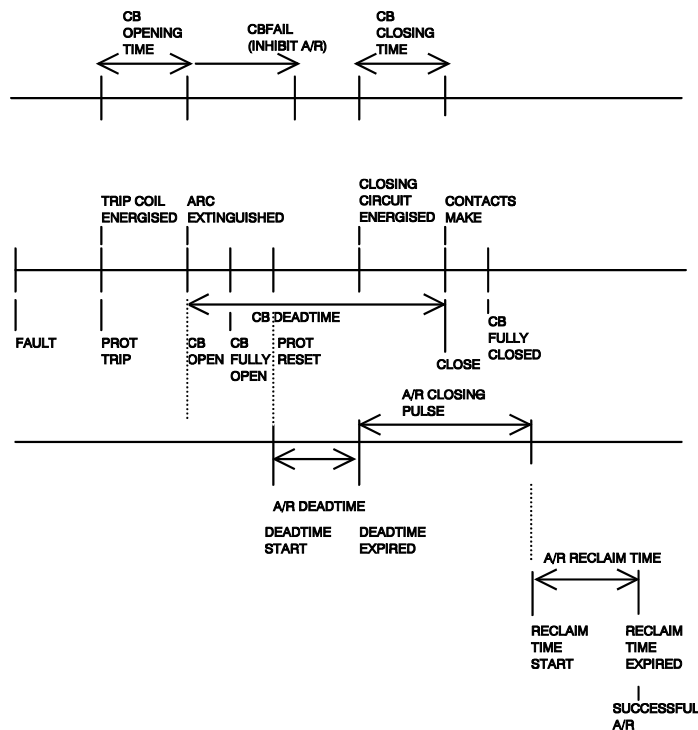


Figure 1: Delayed Autoreclose Scheme

1.6 Synchronising

If the circuit breakers control a line that is the only interconnection between two otherwise separate parts of a power system, or if the system is prone to synchronous instability, it is possible that the generators either side of the circuit breakers may fall out of step during the de-ionizing period. For example, when an inter-connector carrying a large power-transfer between two stations is interrupted, there is a sudden redistribution of the loading of the two sources. The generators of the two sources are acted on by accelerating or retarding torques, and since there is no path for the flow of synchronizing power between the two sources, they begin to fall out of step.

Reclosing is allowed when synchronism lies within prescribed limits i.e.

- phase angle typically 35° , but sometimes 20° close to major sources of generation; and can be as much as 60° for loosely tied networks.
- slip frequency 0.05 – 0.125 Hz (limit at 2Hz)
- voltage amplitude 80 - 90%
- time

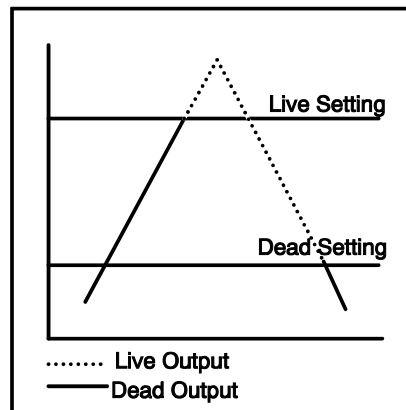


Figure 2: Check Sync Voltage Dead / Live Check limits

Voltage monitoring relays set to pick-up at 90%, drop-off at 20%.

Under voltage checking and Voltage Differential Checks.

1.6.1 Synchronisation Modes of Operation

The synchronisation function typically has three modes of operation, namely:-

- 1.6.2 Check synchronisation
- 1.6.3 System synchronisation
- 1.6.4 Close on zero phase

These are described below along with the conditions required to enter a particular mode. In all modes of operation the differential amplitude must be below a pre-set limit and both system amplitudes above a minimum value.

1.6.2 Check Synchronisation

This is the mode in which the relay initially operates. In this mode the relay will report the systems are synchronised providing the phase angle between the two systems is typically less than 20° (although it can be set between 1° and 90°) and the slip frequency is less than a typical value of 50mHz (it can be set between 0 and 2Hz). Figure 3 shows the region that is considered as synchronised in check synchronisation mode.

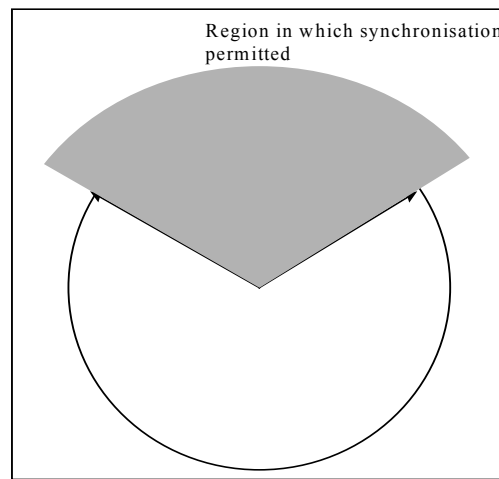


Figure 3: Region in which synchronisation permitted

The system will remain in check synchronisation mode unless a system split occurs. It is deemed a system split has occurred once the phase difference between the systems exceeds a set angle, this is typically 175° , however it can be set between 95° and 175° .

System split occurs only if the loss of a line results in the separation of the two power systems producing islands of generation. If there is at least one other connection between the power systems a phase difference will be introduced, however, the frequency of both systems will be the same and hence the slip frequency is zero. From equation (1) the rate of change of phase angle must also be zero, hence the phase difference is constant. If a system split occurs the Check Sync mode may change to lockout the autoreclose, or close with system synchronization settings.

Equation 1: Slip frequency = Rate of Change of Phase Angle / 360

1.6.3 System Synchronising

System Synchronising applies to a system that has drifted apart once the connected circuit breakers have opened. Depending on the system size, it may take up to twenty cycles for a drift to occur. In order to restore the system the two independent sources must again be brought into Sync. However since there is some difference in the movement between them, the frequencies of the two sides differ, and is measured as the frequency difference, called the Slip Frequency. Because there has been a drift between the two sources, the close limits allow for a greater slip frequency than for Check Synchronisation, typically 125mHz.

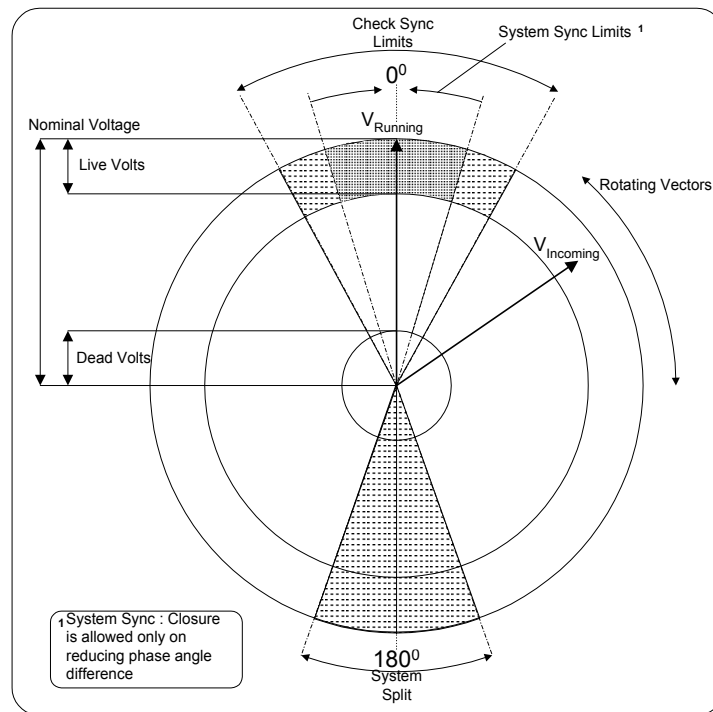


Figure 4: Check / System Synchronisation

Standard practice is to lockout the autoreclose sequence following a System Split detection; to alarm the system split to a control room operator; and then allow the operator to initiate closing with system synchronisation settings.

System synchronisation is the traditional response to a split system. Providing the phase angle is reducing and is typically less than 10° (a range of 1° to 90° is again required) and the slip frequency is less than a pre-set value, typically 250mHz (once again a range

from 0 to 2Hz is allowed) a synchronisation output may be given. Figure 5 shows the area where a synchronized output may be given.

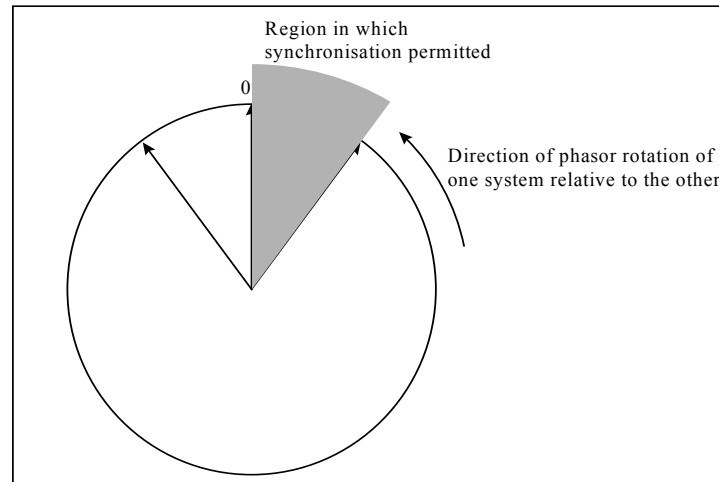


Figure 5: Region in which system synchronisation permitted

1.6.4 Close On Zero Phase Difference(COZ)

If the systems have split a better method of determining when to give a synchronised closure is to calculate when the systems have zero phase difference. This can be done using the slip frequency and the current phase angle, taking into account the direction of rotation. The time until the systems will have zero phase difference is given by:

$$\text{Time to zero} = \frac{\text{current phase angle}}{360 \times \text{slip frequency}}$$

When the calculated time to zero equals the circuit breaker closing time setting the function gives a synchronised output. In practice a window over which a synchronisation output can be given is used. This is necessary to prevent the systems moving past their zero phase difference point in the time it takes to measure the phase angle.

Close on Zero offers the advantage of minimization of power flow when re-connecting. Any difference in phase will result in power flow. In some situations care may be needed to ensure that a nearby generator is moving faster than the bus, otherwise it may trip on reverse power flow.

1.6.5 Choice of which end to close first?

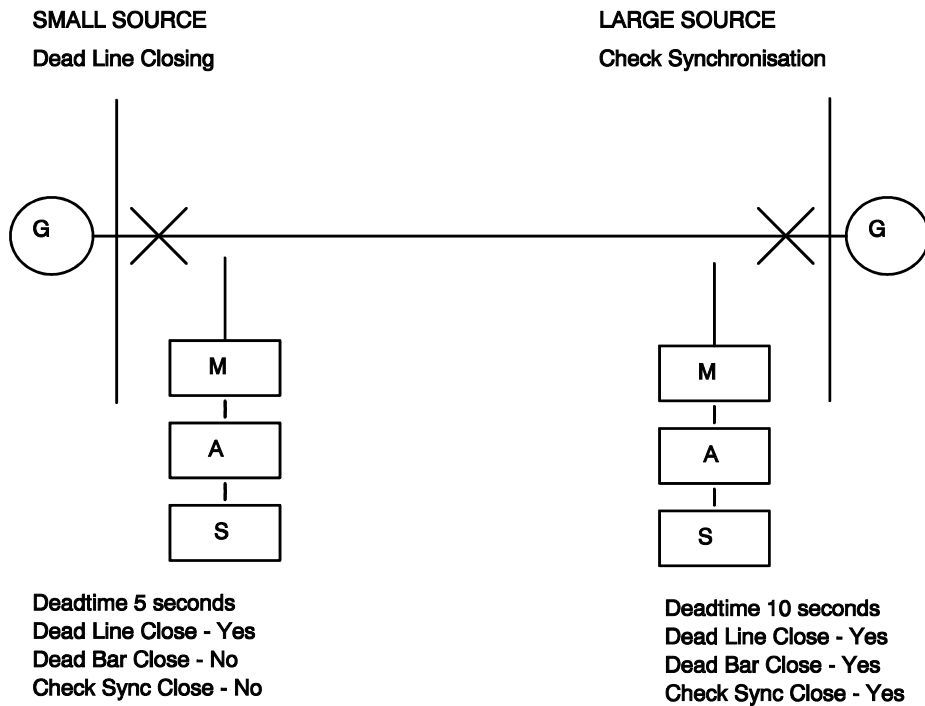


Figure 6: Transmission system

Small Source/Large Source:

Selection of end with local generation to charge line to reduce dip; or to detect fault? The practice varies between utilities. Some choose the large source to ensure that protection operates, others choose the small source to reduce voltage disturbance in the event of a close onto fault.

1.7 High Speed Three Phase Auto-reclosing

When a fault occurs on a circuit, the protection operates to open the circuit breakers, which may split the system at that point. The voltage vectors of the separated systems may commence to move apart. If the circuit breakers can be reclosed before the vectors have a chance to move too far apart, the systems again pull into synchronism. This is the principle of High Speed Auto-reclosing.

Typically:

deadtime 0.5 sec
reclaim time 2 sec
sequence time not reqd.

Due to the high speed of reclosing, the circuit breakers would be reclosed before the system settles down after the fault. Taking into account the time it takes for a generator to split, typically 20 cycles. If reclosing the circuit breakers re-applies the fault, the resulting shock to the still swinging system may cause widespread instability.

The circuit-breaker deadtime should not be too short, since otherwise the arc-path has not enough time to de-ionise completely, and the arc re-strikes on reclosure of the circuit breaker.

The application of high speed reclosing has mostly been successful although the inability to restore transformer and cable circuits after faults has proved ineffective where such circuits are directly tied onto another circuit.

UK experience showed a High Speed reclosing Effectiveness rate of approx. 70% against a D.A.R. Effectiveness rate of 80%.

1.8 Single Phase Auto-reclosing

Single Phase autoreclosing is applied where the tie connection between generating plant is paramount. Only the faulted phase is tripped and then reclosed.

The three phases of the circuit-breaker are arranged to operate independently, and only the faulty phase or phases are tripped and reclosed; if on reclosure it is found that the fault persists, the second trip opens all the three phases, and may isolate the line completely, or proceed with further three pole reclosing.

If only one phase of a transmission line is interrupted, some synchronising power can flow along the sound phases, and stability is improved. Thus, with single phase autoreclosing, there is less tendency for the two parts of the system to fall out of step, and so either a longer total time of disturbance can be tolerated, or, allowing the same total time of disturbance, more load can be transmitted without endangering the stability of the system. It may be advantageous, to have single phase auto-reclosing of tie-lines transmitting large amounts of power or operating at very high voltages, for which fault arc path de-ionising times are longer.

The possibility of using single phase auto-reclosing may be limited due to the capacitance current that flows from the sound phases to the faulty phases and then to earth through the fault arc; this helps to maintain the secondary arc and hence to increase the de-ionising time. Not only does single-phase auto-reclosing allow a longer deadtime, but it also requires it. When it is used for very long lines (300km at 132kV, or 100km at 1,000 kV) it may be found that the necessary increase in de-ionising time is greater than the increase in maximum allowable total time of disturbance for stability. In the limit, if the line is very long the arc may be maintained indefinitely by capacitance current, unless

special provision is made to extinguish it (normally neutral reactors are fitted to problem lines).

Typically:

deadtime	1.0 secs
reclaim time	3 secs
sequence time	250 secs

Japan reported some utilities where thermal or nuclear power lines have a problem with generator shaft torsional torque, high-speed single-phase reclosing is executed. In this case, taking into consideration the impact made on the generator, the circuit is first closed on the load side and then on the generator side. However most other utilities do not nominate an end to close first for single-pole reclose, generally there will be minimal scatter between ends.

1.8.1 Single Phase Autoreclose schemes:

Single-phase autoreclose schemes are generally one or two shots; either single or three phase, and are selected by a setting or via a switch termed Close Mode Selection.

The Close Mode Selection switch can determine the number and type of reclose to be allowed as follows: 1P, 3P, 1P/3P, 1P3P/3P, 1P1P, 1P1P/3P3P, 3P3P. This represents combinations of single-shot or two-shot, single-pole or three-pole reclose.

Single shot schemes are available to reclose for fault conditions that might be prevalent during a particular season; or are common on a particular transmission line.

Different schemes have become established to try and successfully restore the system. Experience gained from single shot single pole unsuccessful reclose operations determined that a majority of the faults could be reclosed successfully. Automatic reclosing schemes for single pole followed by three pole have been widely available.

Although relays exist which perform these single or three-phase multi shot autoreclose schemes, it is also common practice to apply a separate relay for the low speed action – “Whenever high-speed reclosing and medium-speed reclosing fail, low-speed three-phase reclosing is executed.”(Japan)

Different relays tend to exist which offer transmission autoreclose for single and three pole systems. Although single pole reclose relays may also perform three pole reclose, the type of three-pole reclose may not be suitable for all utilities. Some utilities, predominately those utilizing only three pole tripping, have requirements to start the autoreclose system which differ from the start requirement of single pole reclose. Some relays offer settings to select which method is employed. Other relays are specifically designed for one purpose. Each system has to be determined to be fit for purpose.

Two systems are in existence:
Start when CB opens.
Start when trip resets.

This difference may be overcome by the setting of different time delays. However the trip-reset method may also be used as an interlock to prevent reclose until isolation is complete. This necessitates that isolator/earth switch contacts are taken into account in the trip relay reset circuitry. However this might only be relevant for certain substation layouts where motorized items of plant are used for disconnection / sequencing. In simpler substation layouts i.e. single feeder single circuit breaker layouts the autoreclose logic for starting could be either. However an important feature of using start when CB opens is to detect another trip during the deadtime, so in effect the trip still has to reset before the sequence can proceed. Also, if the trip does not reset reclosure cannot take place due to the “trip free” action of the circuit breaker. That is, circuit breakers are normally designed to prevent repetitive trip / close actions when presented with contradictory signals, trip will always have priority. So, in conclusion, the different start schemes are both adequate for simpler substation layouts, but the trip-reset scheme is a necessity for interlocked switching schemes.

While practices differ, the following reasons favouring the first approach are taken from the RSA Eskom specification [24]:

The automatic reclosing cycle (deadtime) shall commence as soon as the circuit breaker is detected open, and not wait for the reset of the initiate signal for the following reasons:

- Waiting for the reset of the initiate signal is affected by the reset time of the initiating relay, which may not always be consistent and may also be slow;
- A delay in starting the deadtime increases the circuit breaker open time which, for single pole tripping, reduces the pole discrepancy margin (the pole discrepancy timer monitors the circuit breaker auxiliary contacts);
- The actual pole open deadtime for a circuit breaker which has opened successfully for a weak in-feed trip will be significantly lengthened if the initiate signal is also extended by the low current condition and the reclosing cycle is only begun when the initiate signal resets;
- If ‘fast’ automatic reclosing is selected, the start of the deadtime must not be delayed;
- If a circuit breaker failure to trip occurs and the fault is cleared by a bus strip operation, the automatic reclosing initiate signal will now reset and could start the automatic reclosing cycle for a closed circuit-breaker if this logic is used rather than circuit breaker open detection (this should be blocked anyway as a trip from the bus zone protection, routed via the external three pole trip input of the Tripping Systems should result in a block automatic reclosing signal being generated);
- The circuit breaker auxiliary contacts are input anyway to the Closing Control System to ensure no single pole automatic reclosing occurs for all three poles of the circuit breaker open;

- Eskom accepts this fact that circuit breaker auxiliary contacts are not reliable, but believes that for the Closing Control System the contacts offer the better solution, with cognizance taken of the following:
- If the contact/s fail to open with the circuit breaker, no automatic reclosing cycle can commence, and the Closing Control System must revert to the lockout state; and
- If the contact/s fail to close with the circuit breaker, no automatic reclosing is possible as successful initiation of an automatic reclosing cycle may only occur if it happens within a certain window following the circuit breaker pole/s detected open (circuit breaker pole/s open longer than the timing window, plus initiation, shall revert the Closing Control System to the lockout state)

Although the above specifies how the autoreclose is started from a trip signal followed by the circuit breaker open, it is also a requirement that the trip resets during the deadtime. If the trip does not reset during the deadtime then no reclose is allowed.

1.8.2 Three Pole Trip Select

A feature of single pole reclose schemes is the Three Pole Trip Select signal (3PTS). This may be an external output connection from a reclose relay that is connected to the protection device, or an internal logic connection within integrated relays. The purpose of this function is to only allow single pole tripping if single pole reclose can occur, otherwise the trip should be three pole.

The logic for this function determines to set the protection mode to three pole if the following occur:

OFF – the reclose function is switched OFF.

Inhibit – the circuit breaker is prevented from reclosing.

Lockout – the reclose function is stopped.

After first single pole reclose – second single pole reclose is not allowed.

If only 3P selected.

Some systems which have single pole tripping and integrated single pole reclose have a setting Internal/External/Off which effectively enables or disables single pole tripping depending on whether single pole reclose is allowed i.e. there is no point in performing a single pole trip if the single pole reclose cannot proceed – the trip may as well be three pole in the first instance.

1.8.3 Secondary Arc Voltage

Induced voltage is a phenomenon associated with single pole tripping, where after a faulted phase has opened, and the other two phases remain connected, the open power conductor will experience an induced voltage determined by the system voltage and local environmental conditions. Where the environmental fault conditions remain present after a fault has occurred, then an arc can be drawn between the faulted phase and ground. The voltage at which this arc occurs can vary. Typically when the air successfully de-

ionizes, the voltage cannot sustain the secondary arc, which disappears and is replaced with induced voltage. However for some environmental conditions i.e. fire, or fog around the line, the voltage required to re-strike the arc may not increase and the arc can continue indefinitely. When this occurs the reclose will fail. Analysis of voltage fault records can illustrate the states occurring during various autoreclose sequences. Long EHV lines require special precautions to prevent sustained secondary arcing. Single Pole deadtimes have to be set to take account of the secondary arc duration.

The following voltage fault records for a 275 kV line of 135km show the various stages of voltage associated with single pole tripping and reclose for:

1. Pre fault healthy voltage.
2. Primary arc – duration includes protection operate time and circuit breaker opening time.
3. Secondary arc.
4. Induced voltage.
5. Single Pole reclose.

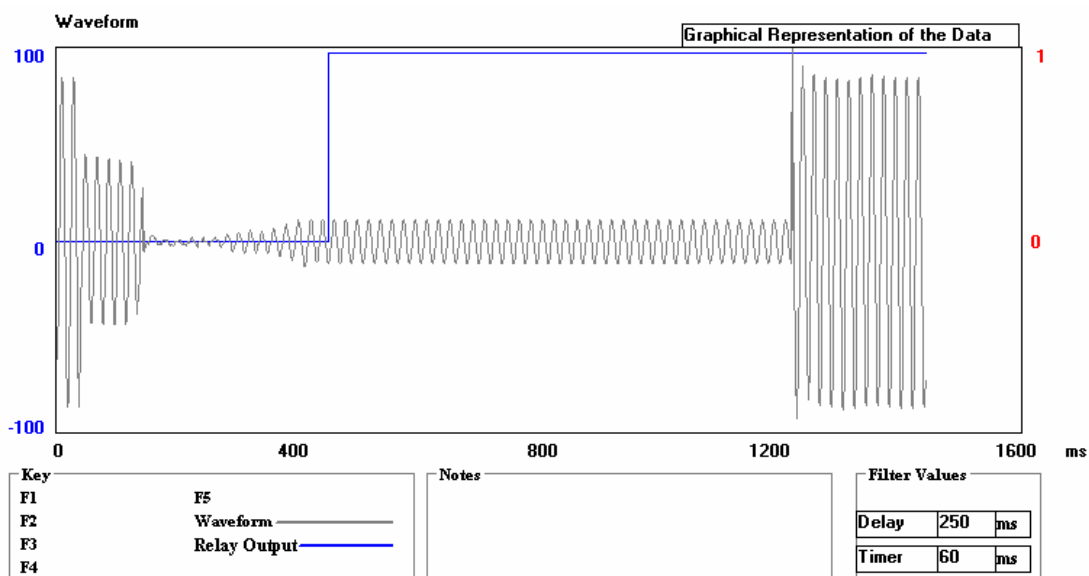


Figure 7: Conventional single pole reclose at 1s. Secondary arc extinction marked.

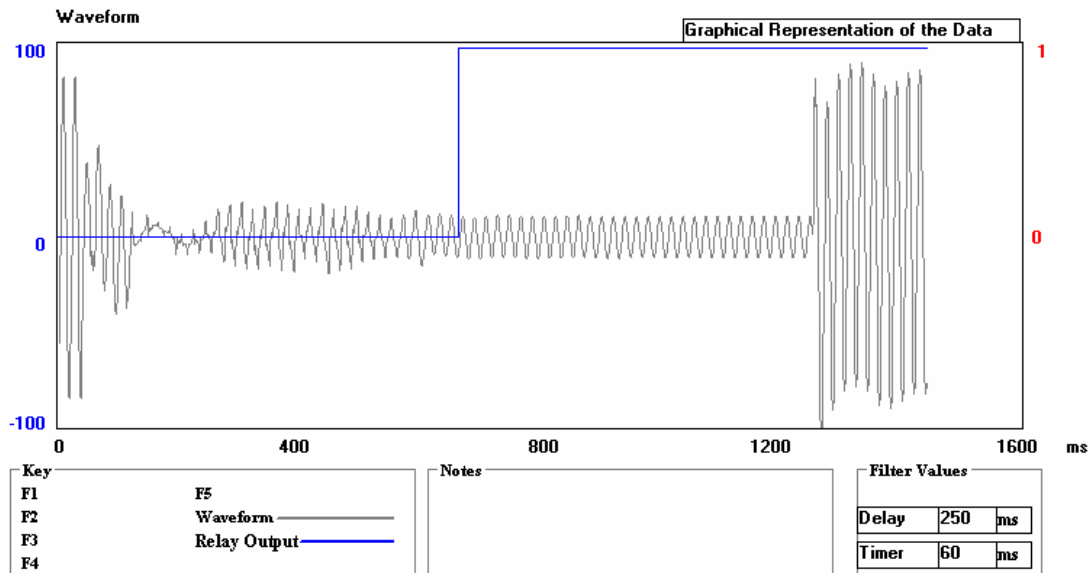


Figure 8: Conventional single pole reclose at 1s. Secondary arc extinction marked.

The next figure shows a reclose failure due to the secondary arc failing to extinguish.

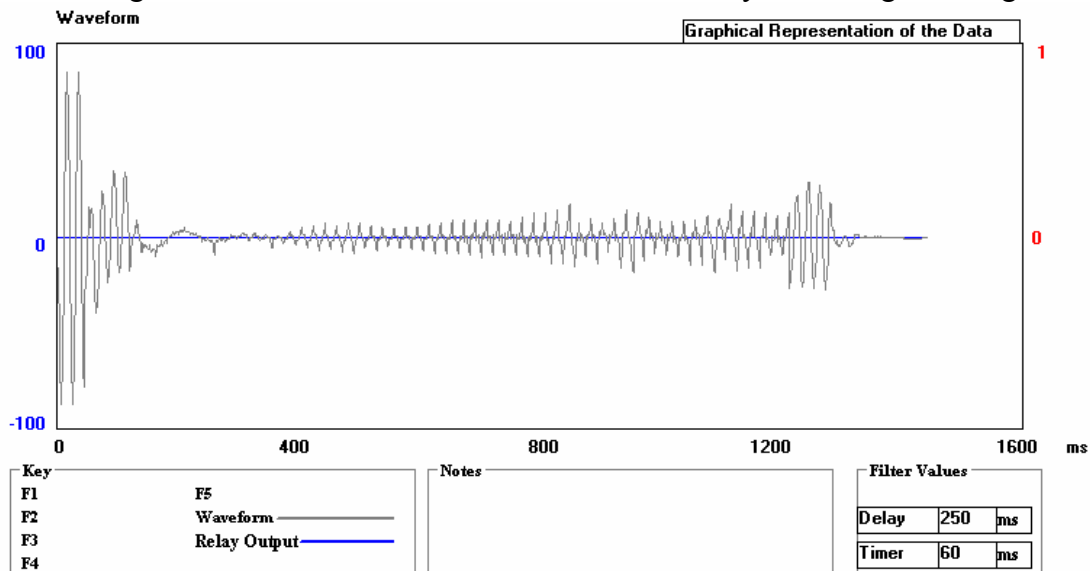


Figure 9: Continued secondary arc conventional single pole reclose failure.

Permanent faults tend towards a different waveform shape, which will vary depending upon the fault impedance. Generally the fault impedance will prevent secondary arcing due to the permanent earth connection. The following waveform indicates a low impedance permanent fault. For higher fault impedances the level of induced voltage will rise towards a level comparable to that of a transient fault.

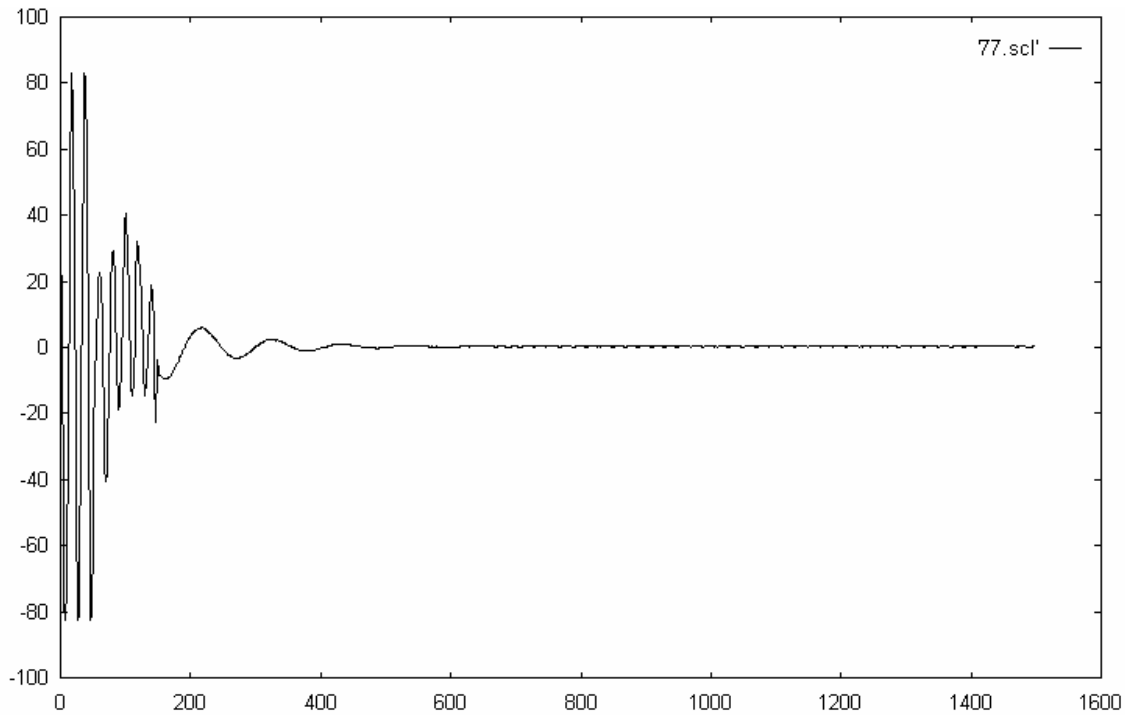


Figure 10: Permanent fault

The induced voltage level can be used to determine whether the secondary arc has extinguished. This must be performed at the fundamental frequency due to the high frequency components of the arc waveform. The induced voltage level will vary due to phase, line layout and configuration values. Using a voltage detector to determine whether induced voltage is present may give an indication of whether the arc has extinguished, but it will not work for all instances. Limitations exist in providing a setting, and it may fail to distinguish between the arc and induced voltage for a large portion of faults. Where there is excessive arcing, this can be misconstrued as induced voltage. However using a voltage check to prevent reclosing will offer some benefits. This problem is overcome by the neural network solution [1], which generalizes the wave shape of the secondary arc to detect the instance of arc extinction. In effect it detects the boundary between secondary arc and induced voltage, and therefore the period that arcing is present.

1.9 Multi Phase (Polyphase) Autoreclose schemes:

On double circuit lines, Japan's application of EHV high-speed polyphase reclosing with at least two different phases connected is used for all the systems to improve the ability to maintain system interconnection. Considering the impact by high-speed reclosing on the shaft torque of the generator, the following conditions are applied:

- a. On condition that at least two phases are connected in the two circuits, high-speed polyphase reclosing is executed for the faults in two phases or less in both circuits.

- b. For the double-circuit high-speed single-phase reclosing is executed in the circuit with a single-phase fault.
- c. For the double-circuit, medium-speed three-phase reclosing is executed in the circuit with two phases or more opened, after the remaining phases are opened.

1.10 High-speed Grounding Reclosing Protection:

At voltages approaching 1,000 kV the application of High-speed Grounding Reclosing Protection (HSGS) is applied to reduce the secondary arc duration to allow high-speed reclose.

Since the 1,000 kV transmission lines have high transmission voltage, the arc at a fault point on the transmission lines continues for a few seconds or longer due to electrostatic induced current from the adjacent phases even after the faulted phase is opened when high-speed reclosing is executed.

To solve this problem, for the 1,000 kV transmission lines, after the circuit breakers at both ends of the faulted phase are opened, both ends of the transmission line of the faulted phase are grounded by a high-speed grounding switch to forceably extinguish the arc. After that, the grounding is removed to reclose the circuit breakers. This allows reduction of the no voltage time to approximately one second to ensure stability. This procedure can shorten the deadtime by 3.5 seconds or more. [138].

Japan, Korea and Russia have applied this technology at EHV 765 kV – 1000 kV. [72]. It has also been considered in USA.

1.11 Loop Autoreclose schemes:

Feedback from the Japanese survey returns referred to Loop reclosing, which refers to the closing of circuit breakers in a specified order. The use of the remote circuit breaker's position is used to allow the local circuit breaker to continue to reclose. The use of numerical protection with digital communications channels allows the use of reserved bits in the protection information transmission format to transmit the required data. This allows addition of reclosing modes such as high and medium-speed loop reclosing, including different-voltage multiple loop interconnection, by means of both-end synchronism check method. Such reclosing modes have been difficult to realize on the conventional relays.

1.12 UK DAR Interlocking (Trip Relay Reset):

The UK system is predominately three pole tripping. The system is highly interconnected through transmission lines that are not of excessive length. The use of banked plant is prevalent, for example: mesh systems with single or double feeders and single or double transformers per corner of the mesh.

It is important to bear in mind the effect of the trip relay reset circuitry on the DAR sequence. This is especially important with banked plant and auto isolation features.

The trip relay is prevented from resetting while certain items of plant are in certain positions. This is an accepted interlock that prevents reclosing until those items of plant are back within their acceptable positions.

The following plant operations are prevented:

Prevent DAR if feeder isolation is incomplete?.

Prevent DAR if transformer isolation is incomplete?.

Prevent DAR if Earth Switch closed for F4 Ferroresonance Suppression is active?.

Prevent Transformer Isolation if F4 Ferroresonance Suppression is active?.

Prevent Feeder Isolation if F4 Ferroresonance Suppression is active?.

Prevent DAR if F3 Ferroresonance Suppression is active?.

Ferroresonance frequently occurs on parallel lines with items of banked plant. Two methods have been employed to suppress the phenomenon – F3: Open then close an isolator; F4: Close then open an earth switch.

The interlock requires both the position of the item of plant and the Bolt Interlock (BI) to confirm readiness. The Bolt Interlock is the auxiliary switch which indicates the plant is fully in position.

Another purpose of the Trip Relay Reset circuit is to prevent multiple reclosure onto persistent faults. For a three ended line these attempts at reverive [reverive – meaning from the remote end] dead line charge results in four successive primary faults to the system. The system utilizes the persistent intertrip timing circuit to prevent reclose. The intertrip channel signals the end to end tripping information and can be used to prevent reclose by maintaining the trip signal.

1.13 Multi shot Auto-reclosing

Multi-shot schemes are generally applied to Distribution networks. Programmable numbers of recloses are allowed i.e. 4 recloses and 5 trips. System co-ordination between other relay reclose sequences is important where rural feeders are concerned.

On HV distribution networks, multi-shot auto reclosing is applied mainly to radial feeders where problems of system stability do not arise, the main advantages are:

- reduction to a minimum of the interruptions of supply to the consumer.
- instantaneous fault clearance can be introduced, with the accompanying benefits of shorter fault duration, less fault damage, and fewer permanent faults.

With instantaneous tripping the duration of the power arc resulting from an overhead line fault is reduced to a minimum, thus lessening the chance of damage to the line, which might otherwise cause a transient fault to develop into a permanent fault.

Auto-reclosing allows the circuit-breakers to be reclosed within a few seconds; with transient faults the overall effect is loss of supply for a very short time, but affecting a larger number of customers. If time graded protection is used, a smaller number of customers might be affected, but for a considerable time and with less chance of a successful reclosure.

1.14 Fail to Reclose

Note that “fail to reclose” means that the circuit is opened due to the continuation of a fault or for some other reason, after reclosing.

“Fail to Close” could signify that the circuit breaker did not respond to a close command.

Reasons, which could be attributed to “Fail to Close”:

- Circuit breaker fails to open. Problem with trip coil or circuitry.
- Trip fails to reset. Problem with trip relay or trip relay reset timer or circuitry.
- Line does not go dead – remote circuit breaker fails to clear fault.
- Low Pressure alarm. Circuit breaker problem after clearing fault.
- Lockout input is energized.
- Evolving fault. 1PT – 3PT.
- Second trip picks-up during sequence. Fault during deadtime.
- Reclose not allowed i.e. set to 1PR but 3PT occurs.
- Incorrect sequence selected i.e. Dead bus charge disabled but required, etc.
- Fault type not suitable for reclosure e.g. DEF, Zone 2.
- CB Aux switch inconsistency, or other plant.
- A/R device Out of Service.
- A/R device faulty.
- Pole Discrepancy.
- Back up protection.
- Other Distance Protection zone operation.
- Interlocking scheme prevents closure.
- Other switching operations prevent closure.

This is not an exhaustive list, but attempts to show the complexity involved in Circuit Breaker closure.

1.15 Integration of Auto-reclose and associated functions

Manufacturers generally offer a range of equipment from single function relays to fully integrated relays including protection, autoreclose, check synch, and auto-isolation. The choice of application is dependent upon the utility’s standard. There are a number of standards, which vary by country and their particular chosen functionality. This will have been derived from experience and relay selection.

Autoreclose has benefited from the use of new technologies. One of the main advantages of numerical relays is their ability to perform negative checks, i.e. older schemes would provide a time delay relay for the close pulse – numeric relays provide a software setting for the close pulse and check to see that the circuit breaker does close during the close pulse. Similarly with double point inputs correct plant operation is checked.

Integrated numeric relays contain self-supervision logic, which caters for negative operation. Older type reclose schemes could constitute safety risks due to the fact that the reclose sequence could be primed indefinitely. Generally all operations are supervised i.e. circuit breaker close includes fail to close and position report conflict; Transformer Isolation includes Fail to open, fail to close and position report conflict.

The integration of functions within numeric relays has led to associated benefits to the system. The autoreclose device tends to be in a unique position within the system since it is connected to numerous items of plant. Manufacturers are offering functions that make use of this fact: Pole Discrepancy, CB Fail to Open, VT Failure, etc.

Check Sync / System Sync:

Historically electro-mechanical relays detected whether the system was synchronized by measuring the phase angle difference between two voltage signals; If the measured angle remains within a setting for a time delay this indicates that there is minimal movement between the two signals, and the system is assumed to be “In Sync”. Once a tripping action has occurred there may be the possibility that the system can move apart; again this was determined by checking to see whether the measured phase angle indicated that the two voltage signals were opposite (phase angle 180). With numerical relays there are a number of equivalent methods for detecting a system split. The most common is to compare when the phase angle has exceeded a setting; alternatively another technique is to detect a slip frequency, i.e. any difference in the two voltage signals frequencies indicating the system has parted. Numeric relays are able to directly calculate slip frequency.

A general advantage provided by numeric autoreclose and check sync relays is the improved setting ranges. A number of utilities indicate problems where the required settings were not available. However providing a wide range tends to obscure application.

With integration the interface between the functions is now internal and improvements to determine that this is correct can be implemented. Where previously the check sync relays were started from a trip relay autoreclose start or manual close signal the synchronizing functions to calculate frequency and phase can now run continuously and can be accessed when required.

Manual Closing system advantages:

System operators are now reducing their requirement to close the circuit breaker after system splits and are now allowing automatic reclosing to proceed with closing at different settings. Previously when a system split occurred the system would lockout,

Control would receive the system split alarm and take the appropriate action – manual intervention to select the system sync operation. This operation is now being carried out automatically and requires a number of settings to allow changes in operation: on occurrence of a system split during an autoreclose sequence the choice is either Lockout the reclose, or reclose by System Sync. Where the choice is selected to lockout, the manual close operation after a system split can be chosen to be a choice between Check Sync or System Sync; where the choice is reclose by System Sync the autoreclose sequence will close by system sync.

Voltage Selection Schemes - Ring voltage supply systems:

Mesh and Ring bus circuit breaker substations have required a complicated voltage selection scheme. This has been connected by an equivalent ring bus system that mimics the position of the primary plant in order to supply the correct voltage to the check sync relays. Replacement of the electro-mechanical schemes with logic has provided the associated benefits of supervision and reduction in cost.

VT Fail:

There is a requirement to prevent check sync when a VT fails. There are a number of methods to detect this: unbalance current and voltage, position of plant and voltage detection, or MCB's fitted instead of fuses.

Pole Discrepancy:

Pole Discrepancy can be included within the reclose relay since the circuit breaker auxiliary contacts are already connected. Primary function of Pole Discrepancy is to limit the amount of time a single (or dual) circuit breaker is open for a given length of time, whilst the other circuit breakers remain closed. Typical time delays of 1.6 seconds are set. Generally the setting is longer than the single pole deadtime, but shorter than Generator earth fault relays. Pole Discrepancy has a secondary benefit as a sort of Circuit Breaker Failure protection. Pole Discrepancy operation will prevent reclose and result in a three-pole trip. ['a' type contacts – normally open when breaker is open; 'b' closed when breaker open].

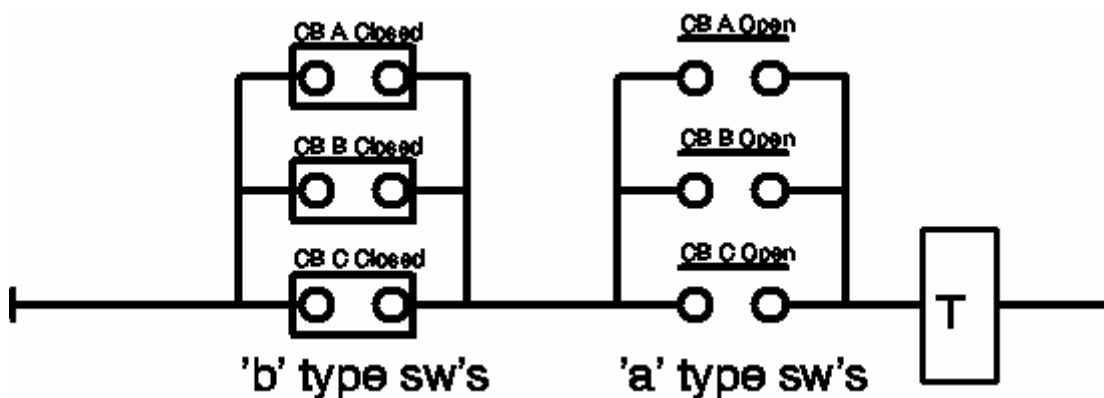


Figure 11: Pole Discrepancy

Associated benefits of modern equipment:

Reduction or elimination of auxiliary relays is made feasible by using numeric logic schemes. Typically older electro-mechanical schemes required more panel space and wiring. There is a case to show improved reliability is proportional to the reduction of hard wiring.

Communications:

Communications can improve the autoreclose sequence by including information from the remote CB. However, some schemes may be set to only proceed to close if the remote end charges the line.

There are two methods for assigning priority of closure: (a). stepped time delays; and (b). blocking schemes. Stepped time delays together with the selection that one end charges while the other performs check sync, is the standard way of assuring priority. However a disadvantage of this system is that if the charging end fails, the other end is normally unable to close. Blocking schemes offer a better way of coping with this dilemma, but require a communication channel. Modern feeder protection relays increasingly provide access to “bits” within their communications data frames to send dedicated information, such as the state of the circuit breaker. This can be used for the purposes of autoreclose prioritization.

1.16 Layout diagrams.

Examples of the following layouts are illustrated in Figures 12 to 20 below.

Autoreclose with Check Sync; Autoreclose without Check Sync; Single Feeder; Two main protections.

Separate Autoreclose and Check Sync relay. Two main protections. Possibly two separate autoreclose:

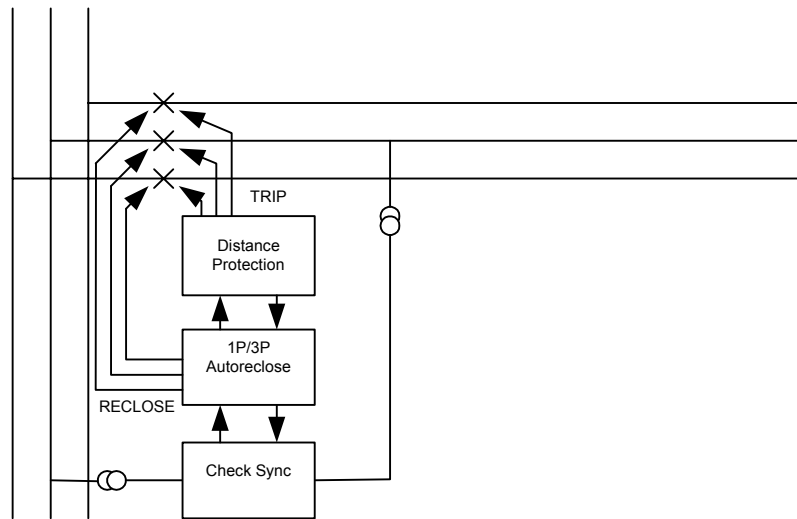


Figure 12: Separate Protection, autoreclose and check sync relays

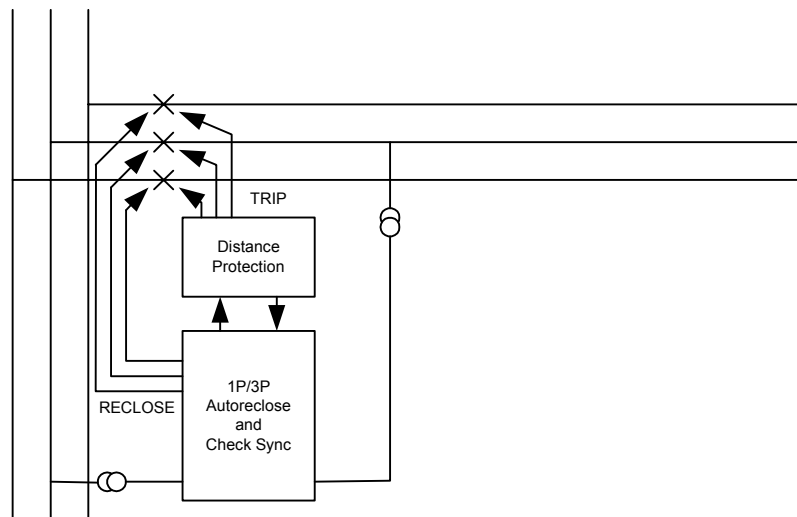


Figure 13: Integrated autoreclose and Check sync relays

Integrated relay. May be dual main protections both with integrated functions.
Two integrated main protections both with autoreclose. Single-pole auto-reclosers may require cross connection.

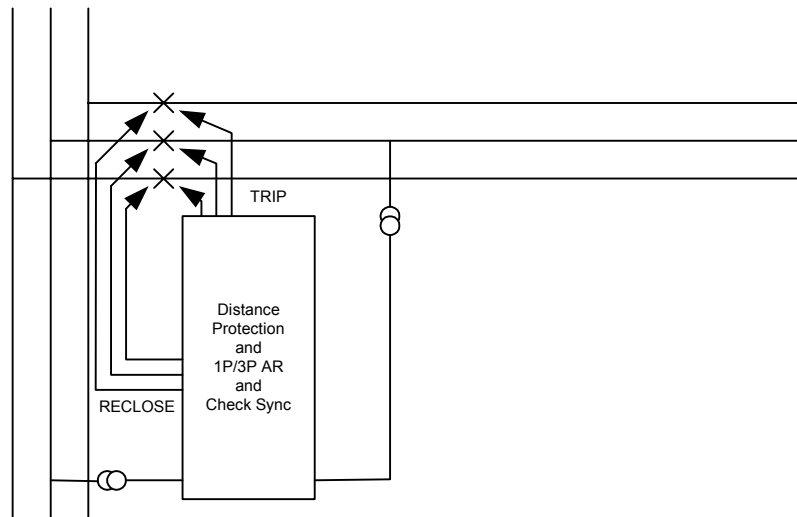


Figure 14: Fully integrated Protection and Autoreclose and Check sync relay

Three Pole tripping conventional system: Separate Protection, Autoreclose and Check Sync.

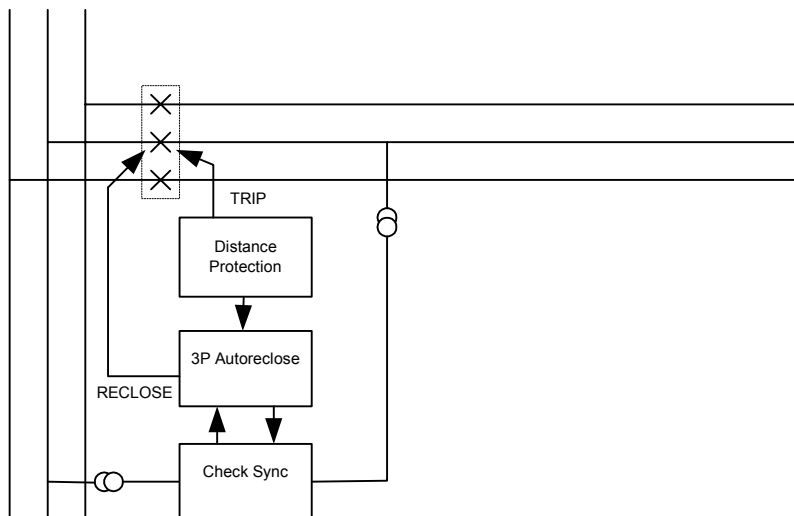


Figure 15: Three Pole Tripping and Reclose separate relay solution

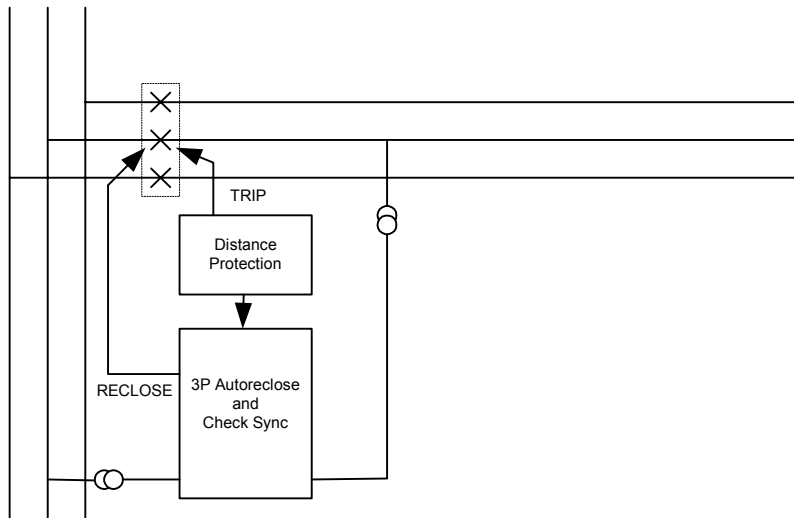


Figure 16: UK standard separate Protection relay, separate autoreclose with check sync relay

Switch and a Half: Breaker and a Half schemes.

Time graded or Blocking scheme (possibly blocking by CB aux. contacts).

Fault results in triple split.

Some utilities use single pole, others three pole at Switch and half substations.

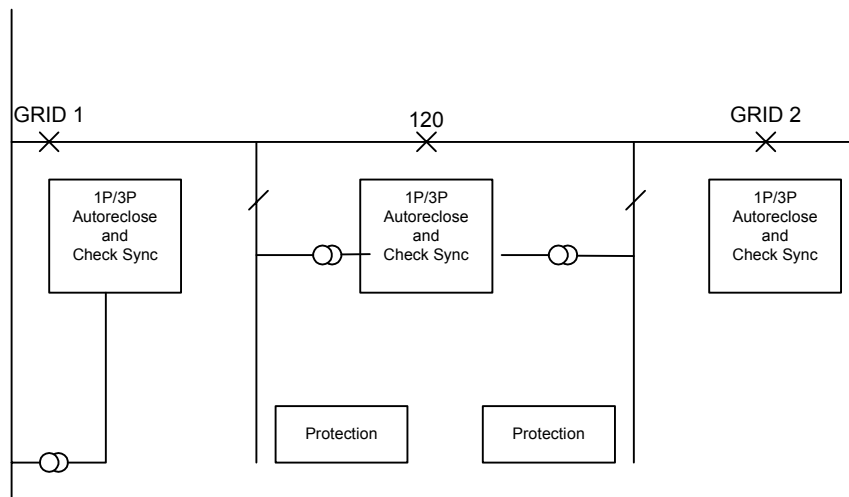


Figure 17: Switch and a Half

Or integrated distance relay Double CB recloser for switch and a half.

Double Busbar:

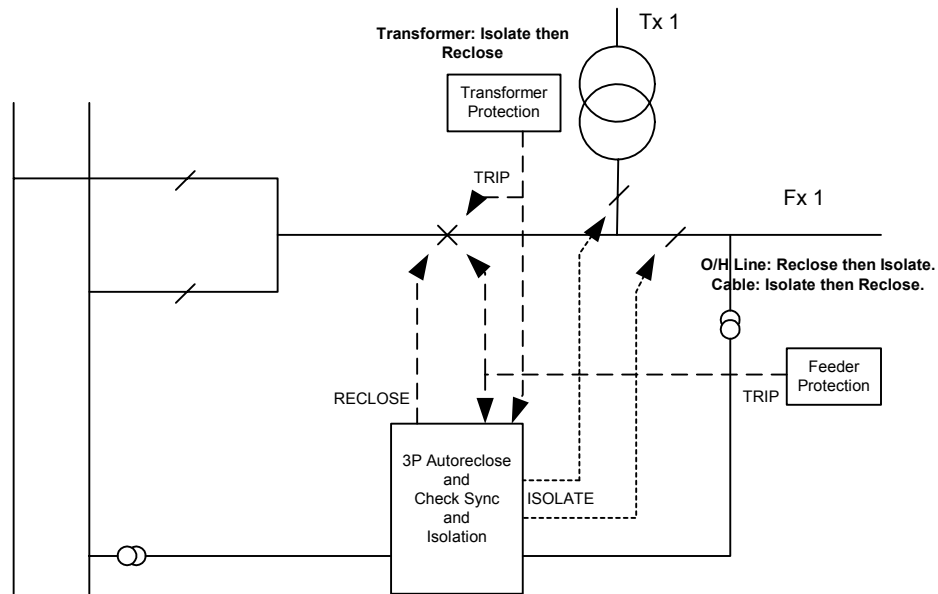


Figure 18: Double Busbar T'd

Mesh: Banked Plant:

Where fault type might not generally initiate reclosing, i.e. Zone 2 Protection Operation, for banked plant, the particular section that has tripped may be isolated and the rest of the connected equipment may be reclosed.

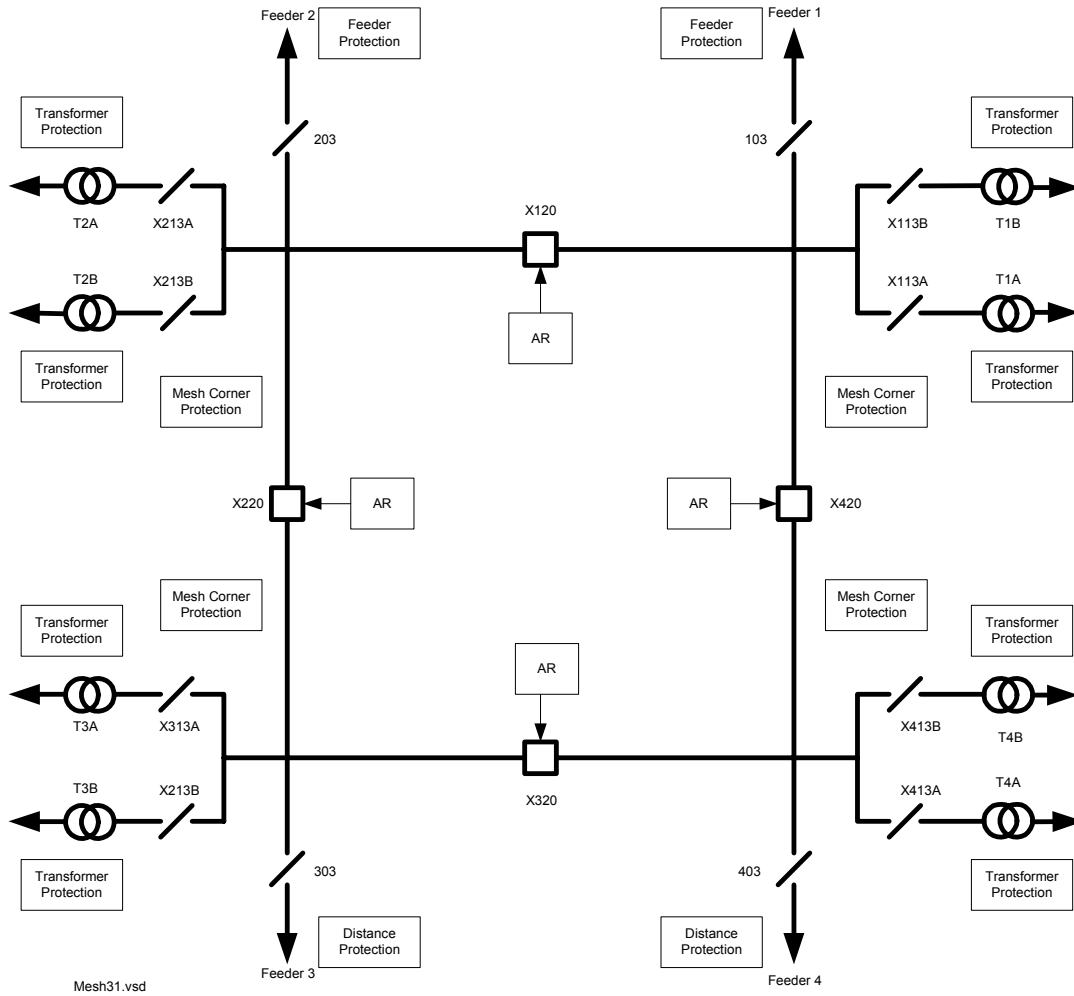


Figure 19: Four Switch Mesh Substation

T'd Feeders:

Generally the Teed feeder will be provided with an HV circuit breaker. However if this is substituted with an HV isolator, then the reclose sequence may be designed to cope with transformer isolation before reclose.

Where transmission systems are installed within built-up areas or cities, cables are used. Purpose-built auto-reclose equipment has been designed to provide the required functionality to control three isolators: Cable fault – open feeder isolator reclose other ends. Transformer fault – open transformer isolator reclose cable.

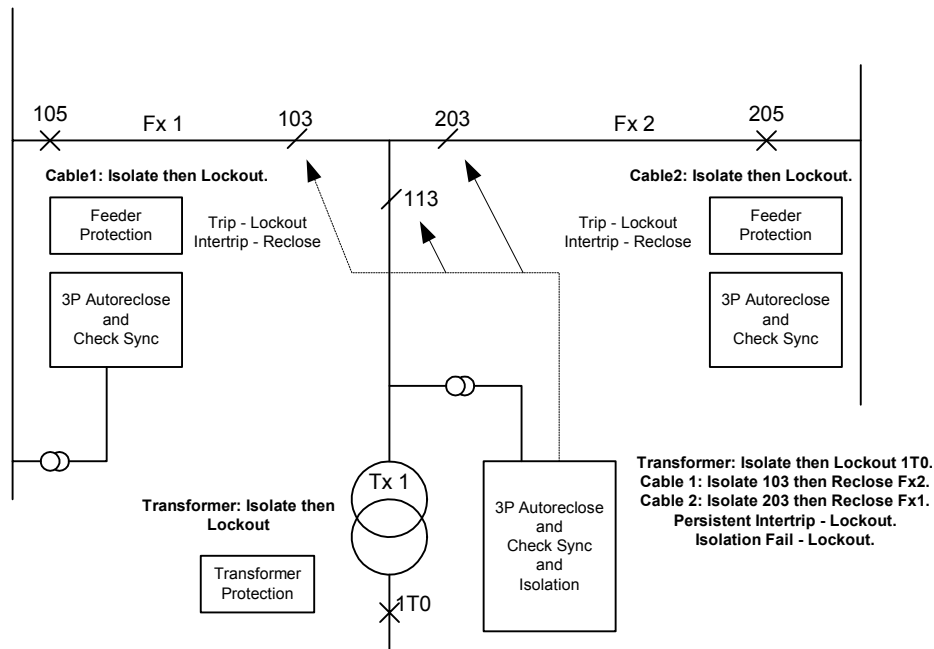


Figure 20: T'd cable circuits

1.17 Problems/Deficiencies with current equipment, application and performance.

1.17.1 Trip in deadtime:

Autoreclose may be designed to fit Single breaker transmission lines where a trip originates only from one side; or to be applied at interconnected circuit breakers where trips may originate from either side of that circuit breaker. This means that whilst performing the autoreclose sequence for a trip on one side, a trip on the other side occurs. The autoreclose logic may be designed to cater for this in the following way:

Single Pole Tripping systems:

Generally applied to transmission feeders.

A single pole trip that evolves to a three-pole trip can change from a single pole reclose to a three-pole reclose if allowed. A further trip within the three pole reclose will result in the reclose being locked out.

Three Pole Tripping systems:

A further trip within the deadtime will reset and restart the deadtime. This is due to Meshed systems where trips may come from either side of a circuit breaker. Example: Mesh corner recloses onto fault – Trip Reclose Trip – remote end sees two trips, second trip would become persistent intertrip to indicate to remote end that a persistent trip has occurred. Appropriate action would be taken: Open isolator or/and lockout/reclose.

This difference to the logic for single pole reclose and three pole reclose requires either a setting and logic to cater for the two modes of operation, or as is practiced in the UK, different autoreclose schemes for the two distinct systems.

Distribution type reclose systems may differ further from the above in that, a trip in the deadtime may proceed with the next shot if allowed.

1.17.2 Differences between Single Pole Reclose Relays and Three Pole Reclose Relays:

The following list highlights some differences between single pole reclose and three pole reclose logic.

1. single and three pole two shot schemes; and selection
2. Three-pole trip logic
3. deadtime initiation
4. CB aux sw's per phase
5. trip inputs for all phases
6. trip logic to determine type of trip
7. trip within the deadtime: evolving fault or another circuit?
8. high speed deadtimes

The implementation for the single or three-pole deadtime start may also differ between two methods:

1. Two signals: Single pole initiate and Three pole initiate.
2. Trip inputs for all phases L1, L2, L3.

The first method requires the protection device to discriminate between trips that can start single or three-pole reclose. Extra logic is required in the protection relay.

The second method requires the reclose relay to continuously monitor and latch inputs until the required operation is complete, and detect evolving faults; though the advantage is the direct connection to the protection.

1.18 Application of Autoreclose to Generating Plant.

The assessment of which autoreclose sequence to apply near generating plant is dependent primarily upon the generation's connection to the transmission system, the length of line of the transmission system, and the amount of interconnection. If the generation is a long way from the load center then keeping the connection intact becomes an issue. Single pole tripping and single pole reclose are commonly applied to retain this connection.

Where the system is strongly interconnected, with a design criterion that no single line failure should result in loss of a generator i.e. UK, Germany, the generation may be disconnected from the faulty line and then reconnected for any fault. Differences between these two countries practice concern whether to apply high speed or delayed reclosure. Delayed reclose requires check sync equipment, but the delay determines that most power swing problems have ceased. High speed is applied due to the nature of the majority of faults, and the fact that synchronism is not lost.

In developing countries, where the system does not yet have the benefit of the single line failure criteria, the system dictates that single shot single pole reclose is the only option to apply.

Embedded generation is commonly designed to trip off for a system fault to avoid out of sync closing. This means the trip must occur before the autoreclose deadtime expires. German experience with embedded generation records that synchronous generators need to be separated before reclosing to avoid torque stress and to prevent current in-feed to the fault location. However, under-voltage and under-frequency relays may be too slow in the case of fast AR and remote tripping of the embedded generation may be necessary. Vector jump relays are not considered reliable enough. No stress problems have been reported with relatively small asynchronous motors or generators. However, at sizes above 100 kW manufacturers should be consulted about permissible stress. A special problem may occur with extensive wind farms in Germany (5,000 MW now and 10,000 MW anticipated by year 2005). The plan is to decouple these by large area under-voltage

protection if a severe HV system fault occurs. But if this generation cannot be fast decoupled then a serious problem will exist for AR.

The problem of generator shaft torque stress was a high profile subject over the last few decades. Autoreclose practices have attempted to deal with this and generally there is less concern with this issue now. Where there is a problem site, delayed reclose with check sync at the generator end is the most common solution.

Various research papers [88] have highlighted different practices in an effort to minimize this stress resulting from multi-phase faults. A proposal had been made to utilize high-speed non-simultaneous 3 pole auto reclosure, the first pole to close tests the system, and if the fault is cleared the next two phases are reclosed on a time staggered basis. There are no known applications of this at present.

Concerns were raised as to the unnecessary shortening of the shaft life, and because of this, restrictive forms of autoreclose have been applied.

High speed auto-reclosing electrically close to a generating station - particularly unsuccessful reclosing onto a permanent three-phase fault - can damage the machines, apart from the heightened risk of system instability. More restrictive auto-reclosing strategies are therefore often considered for these locations. These methods include delayed reclosing (10 – 15 s, to allow the transient torques decay), remote-end reclosing with near-end synch-check (only worthwhile if electrically remote), high-speed 3-pole reclosing only for single-phase faults but delayed reclosure for all other fault types, selective reclosing based on fault magnitude, and lastly, 1-pole tripping for single-phase faults.

Extensive classic studies have been performed [128] on the impact of auto-reclosing on turbine-generator shaft torques. One of the more pertinent conclusions concerns the situation where a generator is connected to the system by a single circuit, for example under maintenance conditions. In this circumstance it can be shown that successful 3-pole reclosure for a single-phase fault can be almost as severe for a turbine-generator as unsuccessful reclosure of a three-phase fault on one of multiple circuits. This can be roughly explained on the basis that opening all three poles amounts to load rejection, causing the generator pole axis to advance ahead of the system phasors; so the reclosure constitutes a mal-synchronisation and this excites torsional oscillations. As might be expected therefore, 1-pole auto-reclosure for single-phase faults is much less severe and is more acceptable.

The above remarks apply to single-phase faults. It can likewise be shown that unsuccessful reclosure onto a three-phase fault under adverse conditions (multiple connections are worst here) can be severely damaging. For three-phase faults the analysis indicates that each turbine generator possesses its own inherently favourable fault clearance times from the point of view of shaft stresses. These favourable times depend on the natural torsional frequency of the shaft system. This can be estimated for any given machine design. In an example illustrated, the most favourable fault clearance

times occur at 3, 6, 9 and 12 cycles after fault inception, while the most unfavourable times occur roughly 1 cycle earlier. In a practical sense it may or may not be feasible to take advantage of this knowledge because the margins are quite close, and different machines in the same station may not be identical. In any event these remarks apply to tripping, not reclosing. It appears to be much less feasible to attempt to predict a suitable delay for auto-reclosing from this class of study.

However, another case is put for the defence of 3-pole high-speed (0.5 s) auto-reclosure on the system, which is made to rebut the shaft torsional study conclusions.[129]. Such 3-pole high-speed reclosing rapidly restores the system to its pre-fault condition, minimising the probability of multiple contingencies and re-establishing margins upon which system integrity is based. The practice of 3-pole high-speed reclosure is regarded as particularly beneficial on lines near generating stations. In this regard it is argued that during severe weather conditions it may prevent the isolation of a generating station.

In summary, in the Working Group's opinion the benefits of 3-pole high-speed auto-reclosing are so overwhelming, particularly near generating plants, that it should not be eliminated unless it can be shown that the risk of shaft damage is significant. Yet despite this, it is conceded that unsuccessful 3-pole high-speed reclosing onto a three-phase fault at or electrically close to a machine can result in significant loss of shaft life. To put this in perspective, the AEP researchers concluded that no significant shaft damage could be simulated for any successfully reclosed fault, or for any single-phase fault with unsuccessful reclosure – in all cases based on 3-pole high-speed reclosure.

The topic of generator stress is still open to debate. Practices of autoreclose near generating stations are well established and look unlikely to change. One area that may cause change is the public liability risk, litigation may be a potential issue if best practice is not assured. Likewise, as power utilities cease to be vertically integrated, damage to generator shafts caused by AR may possibly become a litigation issue. At some point it may be necessary for utilities to address these concerns.

Topic 1 Survey Results

Section 1 of the survey contained the majority of questions of the survey and concerns current practice of Autoreclose. It is apparent from the results that each country has their own autoreclose policy and separate requirements. Utilities have often developed autoreclose equipment with their own suppliers.

This section does not attempt to list all answers from every survey respondent, only to highlight differences and important points that have been raised, some of the answers are summarised. The points have been reported for the benefit of all, they are not intended as the definitive answer, only so that the reader can use them to make their own engineering judgement. Where a consensus of opinion has arisen this represents typically all utilities that have replied.

There follows a comprehensive review of the survey returns regarding current practice and trends in autoreclose.

Q.1 Are your circuits predominately single or double circuit?

Single circuit and double circuit transmission systems are commonly applied throughout the world. Each type will have a protection system designed for that particular layout. This predetermines which type of automatic reclose system is applied. Experience gained from these types of systems has resulted in different requirements. Autoreclose is applied at all system voltages, with the primary effect of fast restoration of supply after transient faults. Generally the survey highlighted that only a single reclose shot is allowed; and this may be single pole (typically India) or three pole (typically UK). Although in a few instances a separate low speed reclose is followed after an unsuccessful high speed reclose. Generally those countries that have disallowed single pole reclose have done so because of a number of reasons: tightly meshed systems, cost, or practicality.

Q.2 Do you apply Single Pole Reclosing or/and Three Pole Reclosing to the Transmission system?

Single pole reclose is only applied to systems that possess phase segregated circuit breakers. This tends to be at EHV levels due to cost. Protection for these systems must be selected to only trip for the faulted phase. In the case of generator interconnectors, the requirement for selecting single pole tripping and reclose systems is determined by the connection of such plant, the length of the transmission line and the possibility of loss of supply. With a complete disconnection of the line, system stability can become an issue. Time taken to reconnect the generating plant – often considerable - also needs to be taken into account.

A prerequisite for single pole reclose is that a single pole trip can open a single circuit breaker and that the circuit breaker can successfully attempt to close. There is no benefit

in allowing a single pole trip if the single pole reclose is not allowed. The single pole reclose may not be allowed for various reasons, such as circuit breaker low pressure. For this example the system may revert to three pole reclose, if allowed. Complex logic is required to implement the required functionality for single pole reclose.

Single pole reclose can fail if the secondary arc is maintained by the two healthy un-tripped phases.

In general it is the transmission system that dictates what type of reclose system can be applied. At low transmission voltage levels (i.e. 132 kV), single pole reclose and three pole reclose are applied, but it is predominately three pole.

Three pole reclose may be high speed or delayed, typically settings are 3P delayed 3 – 60sec. High Speed minimum 0.3 sec or 18 cycles (Korea), – 0.4 sec - 0.8 sec (Finland).

Although three pole reclosing may be high-speed, single pole reclose must be high-speed. This is to avoid excessive ground currents for prolonged periods generated when operating with a pole open.

Typical settings e.g. Ireland:

Single pole reclose delay, first shot, 400 kV = 1s

Single pole reclose delay, first shot, 220 kV = 600 ms

Three utilities use two shot reclosing which entails single pole followed by three pole. It is known that other utilities including the Philippines and Malaysia apply this method, although these are not covered by the responses..

One utility (UK) recloses after persistently faulted plant is isolated, reclose – isolate – reclose, on Mesh type substations.

India applies single shot, single pole only. “In our organization, we have breaker dedicated auto-reclose relays i.e. every breaker (line breaker, center breaker, transfer breaker) schemes. We are not using protective relay based auto-reclose relay. This minimizes cabling during change from main to transfer breakers for line bays.”

Sweden - Three Pole single shot: Delayed or High Speed. An interesting facet of this comprises the selection between performing high speed or delayed three-pole which is determined by the speed of the trip signal. The reclose logic is required to measure the time difference between a Starter and the Trip signal, if the measured time difference is within a window then high speed reclose is allowed, otherwise the delayed reclose is initiated.

On systems that are tightly connected, where alternative routes of supply are provided delayed three pole reclose is commonly applied. This system dictates that all three phase circuit breakers open for all types of fault. Where avoidance of closing during a power swing is preferred, delayed three pole reclose is applied.

Q3. Why do you choose to have a) one pole b) three pole or c) multi-pole automatic reclosing?:

One pole reclosing is generally applied to long lines in countries where generation may be a long distance from load, and where synchronizing between ends may cause difficulties.

Three-pole reclosing is used for multi-pole faults. Three pole reclosing is used where breakage of the tie between generation is not critical. It is generally applied in countries with meshed or closely tied transmission systems. Delayed three pole reclose allows any power swings or abnormalities to die down before reclosing.

Some interesting observations are made:

Multi pole reclosing is beneficial where the system can deliver power through only one phase, provided the reclose delay is high speed e.g. Japan, Eastern Europe.

Within the UK, due to extensive use of banked plant and ganged circuit breakers it is not possible to apply single or multi-pole reclosure.

Where a system is weak, as in India, with few redundant or parallel lines, only 'one pole' and 'one shot' auto-reclosing is applied.

Australia applies single pole reclosing in only two situations on the 220kV network:

- On radial lines to generation plant to maintain synchronism and limit disruption.
- On critical inter-connector lines within the 220kV network.

Most other 220 kV lines have three- pole slow speed reclosing applied. Three pole reclosing is done in all other areas. The rest of the system is fairly well interconnected and loss of a line causes minimal disruption. Reclosing by the operators is considered satisfactory. Auto reclose is used in lightning prone areas with limited interconnection. They also have autoreclose on some 330kV lines. This is done because of the relatively high charging current of these lines; restoring the VAR support provided by the line limits the system disturbance and avoids possible voltage problems.

The argument for Sweden's application of three pole autoreclose is lower cost for protection and control equipment compared to one pole reclosing.

Denmark and Spain utilize single pole reclosing on 400 kV for stability reasons; longer dead-times are possible (and necessary partly due to capacitive influence from parallel systems); but the simpler layout for three pole reclosing is favoured on 132 kV.

Belgium highlights the fact that there is less disturbance for customers on the secondary side of transformers when using single pole; and three pole reclose deals with all multi phase faults.

Finland applies single-pole AR only on two 420 kV lines connecting a big nuclear power station and on one long 245 kV line connecting Finland with Norway. Otherwise, they tend to agree that three-pole AR is enough even for stability reasons.

Germany only applies high speed reclosing single or three pole without check sync at 400 kV and 220 kV. This is justified at 400 and 220 kV because multiple-phase fault are rare, the networks are heavily meshed and a single line outage does not cause problems. However, at 110 kV only three-pole reclosing is adopted because the largest part of the network is Petersen-coil earthed and circuit breakers do not have phase segregated tripping and reclosing circuits.

Ireland states that single and three pole high speed auto-reclose is adequate for network requirements – system stability is not usually an issue.. At 400kV one pole AR is applied because the particular lines (small network) connect to a major generating station.

Stability and synch-check would be issues for three pole AR.

At 220kV technically they prefer one pole, but for a practical reason they had utilized only three-pole in the period 1976 to 2002. The reason here is that one pole generates zero sequence quantities and there was a concern that in some circumstances these might impinge on the sensitive directional comparison EF protection schemes installed on most 220kV lines. These sensitive schemes are required because 220kV lines are not equipped with ground wires and single-phase faults with high fault resistance are not unusual. In year 2002 the AR policy was reviewed for the, by now, more robust 220 kV network, and high-speed single-pole AR was re-adopted as the norm for all new and refurbished 220 kV lines. At 110kV the circuit breaker mechanisms are not phase segregated so only three pole AR can be adopted. This is partly historical because this network was equipped with Petersen coils until c. 1976. But in addition most 110 kV feeders are equipped with sensitive directional comparison EF protection, so the comments made for 220kV also apply. At 110 kV the cost and complexity of single pole CB's is an issue.

Korea are introducing multi pole reclosing on a new transmission network at 765kV. On 154 kV lines the existing 3-pole schemes do not significantly improve system reliability as compared with 345kV lines, and old type 154 kV circuit breakers are for 3 pole operation.

765kV(multi-pole), 135 kV(1+3pole) will enhance the availability and reliability for power supply.

The Republic of South Africa (RSA) adopts single pole reclose because 90 % of transmission line faults are single-phase to ground.

Three pole reclose occurs where effectively earthed networks trip three pole for all multi-phase faults, or where single phase faults recur within the reclaim time.

India restrict their reclosing philosophy to single shot single pole autoreclose, chosen because most of the faults on transmission lines are single phase to ground faults. For the single pole reclosing applied on the 400 kV system, the criterion is to have successful reclosing through the use of the Knudson/Kimbark connection of 4 reactors on the line.

No three pole or multiple automatic reclosing is envisaged. The transmission planning criteria are based on this premise.

Japan's combined comments:

They use autoreclose in order to maintain the reliability of the utility system, to reduce labour for restoration operations, and to shorten restoration time. They also select and use optimal autoreclose methods based on the importance of a system and the fault detection performance of relays.

The basic policy is to utilize multi-pole reclosing because this proves to be highly successful. Multi pole reclosing is only applicable to double circuit lines. However, where the protection consists of a distance directional comparison scheme, one-pole and three-pole delayed reclosing is adopted in order not to restrict protection performance.

Q4. With / Without Check Sync:

a) With Check Sync.

This is applied at CBs where there is a need to close and where there is a risk of closing out of sync. Some utilities use Check Sync as standard, others only at specific points.

Some utilities apply check sync on lines where there is a weak interconnection and hence a higher chance of loss of synchronism. It provides controlled autoreclosing. Other utilities install the check sync equipment at every circuit breaker. In Australia check synch is used where they have only limited interconnection, which increases the possibility of systems running islanded. Ireland apply to generation.

General comments reported long interconnecting lines between generation sources and to international customers requires autoreclosing with sync check. Also, to enable synchronizing of islanded sub-networks. Check Sync applied as a standard on all EHV schemes. Check Sync is also used to detect system splits.

Japan highlights the damage which would be caused if both power sources are connected while out of synch, the large inrush current would result in various system breakdowns, such as damage to switching and electrical devices due to relay operations, and the loss of synchronism if relays do not operate.

b) Without Check Sync.

The typical instances are as follows. Where one of the lines is always dead. Or where no possibility of out of sync conditions is possible, such as sufficient back-feed. Or where only single pole reclosing is used.

Old equipment in the Swedish system does not provide check sync. Also it is too expensive to exchange all old equipment. Denmark's application of single pole

autoreclose on 400 kV eliminates the need for check sync. On 132 kV, the grid is sufficiently meshed to avoid problems with angle differences. Furthermore, omission of Check Sync provides a simpler layout.

Finland have autoreclose with check synch in all 420 kV and new 245 kV installations. They have long distances and feel more secure, when they use check synch. In the 123 kV network, they only use check synch when there can be situations with power plants connected to the line or when a generator is connected to the network with only one or two lines.

Check synchronism is not used in Germany because only 1-pole or fast 3-pole reclosure is practiced.

The network is heavily meshed in Ireland and their experience is that check synch is not needed because the dead interval is only 0.4 s, and in general parallel paths exist on the network. They do not install or favour busbar VT's for security reasons, so a check synch system would necessitate a complex reference voltage selection scheme.

If generating stations are fed from less than two circuits, three pole reclosing is switched off.

In general, check sync is omitted where there is no risk to generation.

The Netherlands confirm that check sync is not needed with single pole autoreclose. Three pole autoreclose is permitted on one side of the circuit only. The AR terminal is located as far as possible from generators; AR only takes place when the position of the CB on the other side is "OPEN".

Q5. Why do you choose to have a) single-shot or b) multiple-shot?

No reclosing onto permanent faults allowed.

Some utilities use single shot on the basis that if the first reclose attempt fails then the probability that a subsequent attempt will also fail is high. For other utilities, multi-shot is limited to situations where single pole reclose is followed by three pole reclose if single pole reclose is unsuccessful. A different approach allows a reclose after a second fault if that fault is transient.

India add that "every shot, after the fault is interrupted by line breaker, will impose a severe jerk / vibration on the generator at power station. Therefore, only one shot is attempted to restore the line, in case of transient fault, after deadtime of 1.0 seconds". Also that single shot autoreclose is chosen, as a fault persisting even after dead time of 1st shot is considered unlikely to clear itself even subsequently. Single shot high speed auto reclosing is chosen to achieve system stability under majority of single phase faults. Multiple shot reclosing is not envisaged at all to contain the stress due to repeated or permanent faults.

Australia adopt single shot because the success rate of single shot is fairly good, and it does not infringe limiting the duty cycle of the circuit breakers to trip – close – trip.

Single shot is also seen as a compromise between restoring supply and limiting safety issues relating to downed conductors.

Sweden have single shot without check sync combined with a delayed (90 seconds) shot with check sync. This solution aims to speed up restoration after local as well as widespread disturbance.

Statistics in Denmark show that 80 – 90 % of all single-shot autoreclose operations are carried out successfully. Further attempts are likely to fail, giving larger impact on system stability and presenting a risk to conductor damage in case of a persistent fault.

Spain applies multiple shots to overhead lines. Experience with single pole reclose in Belgium is good; and multiple shots are not permitted because of cranes regularly getting into contact with the lines.

Finland use double-shot AR because the 1st AR (rapid AR) usually clears more than 87 % of the line faults, the 2nd AR (delayed AR) clears about 8% of the line faults, and thus they have only about 5 % of the line faults as persistent ones.

The German success rate of 1-shot AR is considered sufficient to ensure system availability; and multi-shot AR is only practiced on distribution level (1 fast, 1 delayed shot).

Ireland has chosen single shot because if the fault not cleared, it is undesirable to switch on to fault. Historically they tend to regard multi shot as more appropriate for lower voltage levels and have a perception that multi shot would not increase the success rate. In general they favour scheme simplicity.

Within South Africa the philosophy was originally to ‘close at all costs’ hence multiple-shot reclosing was applied. An increasing focus on quality of supply (dips) has lead to reduction to single shot on most transmission lines (but a few selected lines still operate with multiple-shot reclosing to sustain supply).

The UK system uses single shot because the majority of faults are transient. The system is designed to withstand the loss of a circuit due to a persistent fault – there is no loss of demand for the loss of a double circuit. All persistently faulted plant is isolated before reclosing other banked sections.

Other utilities have a philosophy that one shot reclosing can discriminate between persistent fault and transient fault; and when applying single shot reclosing, unsuccessful reclose is judged to be permanent.

Q7. Are there any specific automatic reclosing problems associated with your scheme arrangements?

A UK manufacturer states that equipment has been designed to cater for different utilities needs. Settings have been provided to allow flexible schemes to be engineered. Programmable logic is provided to customize designs. Generally separate relays have been provided for three pole reclose, single pole reclose, mesh reclose, with or without internal check sync.

India state automatic reclosing does not take place due to:

- i) Delayed resetting of line protection relay at one end for '1PG' fault, after opening of CB Pole, due to presence of residual current to the relay earth fault element and remnant voltage of 400KV line having line (shunt) reactor.
- ii) Breaker low pressure 'alarm' at one end of line, leading to three phase tripping and lockout.
- iii) Failure to discriminate '1PG' fault and 'P-P' fault by distance relays at one end, causing three-phase tripping.
- iv) Middle CB, associated with switch and half schemes is provided with exclusive auto-reclose relay. Deadtime setting of this relay is set as 1.0second with one shot, one pole mode. However, when main CB of line is also in service, autoreclosing of main CB is initiated first and middle CB is closed after closing of main CB.

India (second utility) add that it is their practice to utilise a phase-segregated trip even for the tie breaker in one and a half breaker scheme. They also use priority logic to first close the main breaker and if the same is successfully reclosed, then only auto reclose the middle breaker.

For switch and a half scheme, generally at 400kV, the success rate for HSAR is quite high. The dead time provided is between 1 and 1.2 second. The middle breaker could also be tripped on this phase and reclosed after the bus breaker is reclosed automatically. In some cases sequential tripping and reclosing have been adapted.

It has been felt that the middle breaker has the mode of 3 phase tripping and 1- phase tripping, twice as much as the bus breakers. The risk of failure of the middle breakers could then be higher.

Australia apply end to end signaling in conjunction with the single pole schemes on radial lines to power stations to ensure that the network end closes first. This is done to limit transient overvoltages on the generator transformer. They add that they have experienced a lot of problems trying to use autoreclose functions which are integral to protection relays in breaker and a half applications. The logic is difficult to program, and hence it is difficult to get the appropriate coordination between the circuit breakers. "Our lesson learnt is to buy and use dedicated reclose relays designed for the purpose".

Australia (second utility) - The only issue relates to restoring supply that may have its own generation. This area may also have no generation running and totally rely on the rest of the system. In this case we set up the autoreclose to allow dead line and dead bus

closing as well as check synch closing. To ensure both ends do not close in on a dead line at the same time and result in connection of two systems out of synch, there are timing differences between the closing of each end.

Finland add that the double breaker scheme needs an AR relay for each CB. In bypassing lines with single-phase tripping and AR, three-phase AR is to be used. The switchover from the bus coupler gets otherwise too complicated.

In Germany, in cases where a transfer bus is used, the protection of the bus coupler takes on the protection task. The distance zone reach has therefore to be adapted to the line length at least in coarse steps, because a special zone switching scheme together with AR is used. Many of the lines, even in EHV, do not have signaling links for protection due to the former shortage of PLC and microwave channels. (Only recently have channels become available via digital communication networks and optic fibers).

A special zone switching logic is still practiced on lines without protection signaling. In the healthy line state, the instantaneously operating zone overreaches the line by about 20% to ensure fast fault clearance on 100% line length. During the dead time, the zone is switched back to 85% so that reclosing on a persistent fault will result in a coordinated zone/time graded tripping. That means that all transient faults are cleared without delay, a persistent fault near the line end however would only be tripped by the back-up zone (0.4 s). There is of course a certain probability that the overreaching zone could trip on faults directly behind the next substation. This probability however is rather low due to the intermediate in-feeds at the next substation. In the worst case the circuit breakers of some additional lines could trip (sympathetic tripping) and perform AR. In the normally heavily mesh systems, this is no problem. The zone overreaching shall only be effective for fault types where AR is allowed, that means, with 1-pole AR only for single phase to earth faults and for 3-pole AR for all kind of faults. The logic for this procedure is assigned to the AR relay, which controls the zone reach of the distance relay. With digital relays it is of course a part of one integrated protection device.

For CB and a Half system, different practice occurs, with the use of priority schemes, and single / three pole tripping applied. For example, Korea define the leader CB and follower CB. When double circuit is located at the same side (#1 or #2 bus side). To enhance availability of circuit, they cross the leader CB selection with each other. Adding it is also difficult to define the time difference between leader CB operation and follower CB operation. However the Netherlands add that they apply single pole tripping to the middle breaker as well.

The extensive use of mesh stations within the UK requires complex autoreclose equipment that needs to be designed specifically.

Q8. Choosing autoreclose time delay settings:

There are a variety of deadtime ranges applied. Some utilities standardize on set times, others vary this according to voltage level: typically shorter deadtimes at lower voltages:

1P: 0.3sec at 100 kV, 0.6 – 1.0sec at 220 kV+, 1.0sec+ at 500 kV+

System voltage directly affects the delay settings. Some utilities have specific delay settings for different voltage levels.

Country	100 – 220kV		220 -400kV		500kV		Reclaim
	1P	3P	1P	3P	1P	3P	
Australia	0.7	3					20
Australia(2)	0.7	5 - 15					5
Denmark			1.2	0.3			10+
Denmark(2)	0.8	0.3					5
Finland	1	0.4 – 0.6					15
Germany		0.3 – 0.5	0.4 – 1.2				10
India	0.6		1.0				25
India(2)	1						25
Ireland		0.4	0.6 - 1	0.4			
Japan (1)	0.4	0.3 - 5			0.8		60
Japan(2)	0.3 - 1						5
Japan(3)	1	7					2 - 3
Japan(4)		0.9 - 60			0.9	60	120
Korea	0.8	0.4 – 0.4			1	1	10
Netherlands	0.7	3 - 10					10
South Africa	1	3 - 4					180
Spain	1 – 1.2	1 - 2					10
Sweden(1)		0.4 – 1.0					10
Sweden(2)		0.4					60
UK		10 - 30					2

Figure 21: Table of Deadtime settings (seconds)

Other interesting deadtime and application settings noted were:

Sweden(1):

Three Pole First Shot: 0.4 sec

Three Pole Delayed: 70 sec

Reclaim 60 sec

Sweden(2):

200kV: Three Pole: First shot 0.4 – 1.0sec. Second shot 60sec.
Reclaim 10sec

Spain:
220kV Single Pole 1 – 1.2sec
220kV Three Pole first shot 1 – 2 sec
220kV Three Pole second shot 20 sec
Reclaim 10 sec

Finland:
220kV+ Single Pole 1sec
220kV First shot Three Pole 0.4 – 0.6 sec, Second Shot 25 – 35 sec
Reclaim 15 sec

South Africa:
Single Pole 1 sec
Three Pole 3 – 4 sec (26 to 30 sec at power stations)
Reclaim 180 sec

Japan (1):
500kV+ Single Pole 50 cycles @ 60Hz
220kV Single Pole 25 cycles @ 60Hz
Three Pole Moderate 5 seconds; High speed 20 cycles @ 60Hz
Reclaim 60 sec

Japan(4):
500 kV+
First shot multi pole 0.9 sec
Second shot multi pole 60 sec
100 - 220 kV
First shot HSAR 0.9 sec
Second shot DAR 60 sec
Reclaim 120 sec

Q9. Are there any particular factors taken into consideration when setting these timers?:

The general consensus was that the type of fault, secondary arc extinction time, system restoration considerations, CB duty cycle, maintenance of system stability, previous experience, CB capabilities and shaft stress are all considered when selecting the reclose delays. The arc extinction time is based on approximate line de-ionization time, including factor of safety period, and tower geometry; feedback of actual behaviour is also reviewed. Shunt reactor back up protection operating time and breaker pole discrepancy time are coordinated with the dead time. The existing surrounding lines are evaluated.

The UK system is required to prevent simultaneous closure where multi-line faults may occur, by the sequence of reclosing on double circuit teed lines. This necessitates that each line is reclosed successfully. The deadtimes are consecutive – 5s, 10s, 15s, 20s, 25s, 30s. Therefore the sixth end may only close at 30 seconds, and for a fault only involving that line the line is effectively reclosed much later than would be liked.

Australia add that for SPAR, the dead time is chosen to give a small chance of re-strike, yet not initiate pole discrepancy protection, which on some older air operated CBs, cannot be very accurately set; and the dead time for three pole reclosing is chosen as three seconds for public safety reasons.

Sweden's dead-time depends whether the line is equipped with relay-communication for fast fault clearance. 60 second is the minimum reclaim time for circuit breakers.

All lines in Finland are set so that one end (usually the “feeding” end) has a marginally shorter time setting than the opposite end, in 1st shot about 0.2 s and in 2nd shot about 5s.

The average line length in Germany is about 50 km and there are no stability problems. The dead times listed in Figure 21 above have proved effective in practice. Very long lines above 100 km that would require special consideration no longer exist. Compensation coils to reduce the arc current are also not used.

Where duplicate feeder protection is utilized in Ireland these will each have in-built AR's. Almost invariably they will be from two different manufacturers. In general, auto-reclosers tend to have some important conceptual design differences, and the Type A recloser differs somewhat from Type B devices. The interfacing arrangement takes into account the differences between these specific relays. Note that the Type A recloser needs to be started by an external trip command (for *this input* no distinction is made between single-phase or three-phase trip), and it also requires activation of a second binary input if the tripping is three-phase (so it can modify the dead time). In contrast, the Type B devices need both an external starting command and an external trip command; where appropriate the latter is phase-selective (in order to modify the dead time). Furthermore, when setting duplicate auto-reclosers it is important to recognize that the dead time may begin at different instants. Thus, for Type A it commences when a trip command is issued by the relay, while for Type B it only begins when the circuit breaker opens and the distance relay resets. Compared with Type B relays the Type A therefore needs a correspondingly longer dead time setting. Experience indicates that reclosing with deadtimes exceeding 0.5 seconds was not very successful.

In the Japanese / Korean application of multi-pole reclosing, consideration is given to the coordination with HSGS (high speed grounding switch) operation.

In the Netherlands, the reclose time (single pole) is set to 700 ms.. It has been calculated that a normal arc becomes extinct in that time.

Reclose time (three pole) is set to 3 sec or 10 sec depending on the line length. Due to capacitive in-feed from the parallel line an arc will extinguish slowly..

Application experience in South Africa between two power stations and at power stations connected to the network, requires that the 'weaker' source be closed first. On the other hand, between two transmission substations, the 'stronger' source is closed first. These remarks apply to 3-pole slow reclosing only.

Setting of the Reclaim time has more of a bearing to CB duty. If the reclose sequence is limited to single shot then any fault within the reclaim period will lockout; however if the reclose sequence is double shot further recloses will proceed. The international specification IEC 56 defines the permitted sequence as O – 300ms – CO – 3mins – CO, therefore to comply with the specification the 3 mins period must correspond with an appropriate dead period. However most circuit breakers will be designed to exceed this specification, and judgment needs to be taken as to whether to reduce the actual relay times. Setting a short reclaim period may have an adverse effect due to consecutive reclose sequences.

Q10. Do you experience any applications with automatic reclosing, which do not have standard numerical relay solutions?

One manufacturer is of the opinion that generally, mature developments exist for most applications. Relays provide flexible logic, which can improve application. However, additional auxiliary relays may be required to engineer the appropriate scheme. All functions needed by the utilities are implemented in the digital relay software and can be activated by parameter setting.

However, in Denmark, some numerical relay schemes require a logic preventing AR on multi-phase faults to be implemented using binary inputs and outputs. Australia state that in the past they did have non-standard issues, but with the increased flexibility of current schemes they no longer have concerns in this regard. The Netherlands reports an application concerning two 400 kV lines equipped with a tapped transformer. During a single phase fault the line trips single pole (and recloses automatically) but the transformer trips three pole and is not reclosed automatically.

The UK experience some problems with Mesh Stations.

In India, on some long double circuit lines the secondary current has had an impact on the choice of dead time.

Q11. Are there any public safety issues affecting the reclose settings?

Generally the deadtimes are kept short, the number of shots and the time between the shots are considered. In Sweden the second shot has to be completed before 90 seconds according to the law. Spain state that on double circuits they use definitive trip when people are working in the other line. Finland usually try only with two shots (rapid and delayed AR). However, in city areas they use only one shot (rapid AR). Germany does

not experience public safety issues at HV and EHV, but add that this subject is more related to distribution networks. But there is some uncertainty as to whether delayed AR or later manual test reclosing is allowed in particular cases, e.g. crowded residential areas. However no strict rules exist in Germany at this time. Ireland keep the dead time short, but observe that longer times (e.g. 1 minute +) clearly increase the risk to any members of the public attracted to the fault vicinity. The Netherlands report that where lines are not re-energized (on one side) after a three pole trip then the line has to be inspected visually for safety purposes. Cables tend to increase the safety risk and are dealt with separately, depending upon length of cable and where the cable is situated.

Q12. What are the overriding factors when selecting the Reclose Delay Setting?

The secondary arc extinction time for single pole reclosing is the main consideration. Other factors include CB duty cycle, maximum reclosing cycle may be governed by legislation, public safety, risk of instability with three pole AR, shaft torque near big nuclear power plants, backup protection operate times, minimization of disturbance to generation.

Korea adds they are going to apply a variable dead-time auto-reclosing scheme controlled by power system stability margin. If the margin is high, deadtime may be longer otherwise the margin is low, applied with the provision that they can get higher rate of successful auto-reclosing than fixed deadtime.

Q13. Do currently available automatic reclosing /Check Sync relays provide enough setting flexibility or accuracy?

Most manufacturers have worked closely with utilities to perfect relay solutions. Australia comment that the dedicated relays are satisfactory, however reclose functions built into protection relays tend to be only suitable for single circuit breaker feeders. They have had some issues in being able to independently select combinations of dead line, dead bus, live line, live bus or check synch. Some relays limit the combinations, which has proven difficult. Denmark add that the AR feature is included in the distance and longitudinal differential protections, and the available features are sufficient.

In Finland the relays are generally satisfactorily. However, line VTs do not usually exist on their 123 kV network. Therefore, they need a special voltage measuring input in the check sync relay in order to manage with the low burden requirement (max. 50 mVA) when connecting it to the capacitive taps on the bay CT's. Germany reports that in particular the digital relays have all necessary features implemented. These allow even single pole tripping (leading or lagging phase) with a phase-to-phase fault (some times practiced where conductor galloping is a problem). Most utilities now recognize that should unforeseen special functions be necessary, they can be implemented by the programmable logic now available with digital relays. Korea highlight that some relays do not satisfy the setting range of synch-check time; they have either a narrow range or

no time setting. South Africa reports that numerical technology provides sufficient setting flexibility; but electromechanical and solid state relays have limitations.

Q14. If No what improvements could be made?

Many respondents suggested that setting flexibility and ease of commissioning are the two areas most needing attention.

Additionally, India indicate that there is scope for improvement in the area of:

- i) better co-ordination with bus switching scheme and relay i.e. 1½ breaker scheme.
- ii) Double circuit lines application, for three pole reclosing application.

A second Indian comment recognises that if repeated unsuccessful reclosure take place, then the issue of dead time duration and fault evolution from single to multi-phase would have to be checked, or tests carried out. There could be a problem with HSAR for a single-phase fault on one circuit of a double circuit line. The secondary arc current and re-ignition voltage may need to be re-evaluated.

Australia add that easier application of logic is a requirement.

Q15. What smart additional functionality, if any, should automatic reclosing relays offer?

Please specify:

Particular suggestions included the following topics. Fault type recognition, including recognition of permanent faults and secondary arcing. Ability to reclose at the optimum moment. Ability to avoid reclose where it would prove to be unsuccessful. Specific problems to be considered included fires under lines with single pole reclose. Also, the adaptive matching of number of shots/delay times to specific CB duty cycles

India:

- Numerically controlled relay output interface with stand alone AR relay for discrimination of type of faults (1PG, 2PG, transient, high resistance arcing).
- Prevent or inhibit closing on line, in case of failure of remote line CB.

Denmark do not see a need for smart additional functionality, adding that present numerical relays include the needed functionality (no AR after manual close, breaker reclaim time, different AR programs, blocking of AR in case of evolving faults, etc.)

Germany suggest that monitoring arc extinction, adapted dead times (practiced in some countries with very long lines, e.g. Russia), and recognition of a persistent fault would be appreciated. A simple feature is already integrated in some digital relays. Here, the dead time can be interrupted and reclosure can immediately be released if full voltage returns on the line. This allows fast reclosure in case of a relay over-function (for example overreach).

Apart from the above suggestions, Germany concludes that no other essential features can be formulated.. Rather, the adopted strategy is to keep it simple and use standardized settings. (Reduced staff and expertise in all utilities due to deregulation!) Selective fault tripping and reclosing is important to prevent unnecessary line outages. For example cross county faults on double circuit lines (e.g. L1-E on one line and L2-E on the parallel line) should result in single pole tripping and reclosing each of the affected phase only. However, phase segregated line differential and distance directional comparison protection are now increasingly available with digital relays and digital communication at a reasonable cost, and this is a real improvement.

Q16. Are there any faults, which do not initiate reclosing?

This generally depends upon the reclose scheme employed. So each utility will have their own types of fault which do not initiate reclosing. For example, India only use single shot single pole reclose therefore any other types of fault will not initiate reclosing.

A general summary of situations that inhibit AR is as follows:

Zone 2 or Zone 3 or backup protection trips.

Underground cable faults.

Where three pole reclosing is allowed this can be disabled for a three phase fault, and only proceeds for single phase or phase to phase faults.

Manual close of CB (blocks AR for 5 s).

Repetitive faults (AR blocked for 5 s after first fault).

All faults in case IED is faulty.

CB not ready.

Failure in the voltage circuits feeding the distance relay.

Switch onto fault.

Further details are as follows for different utilities:

Australia:

On lines with SPAR, multiple phase faults initiate a three-pole trip and lock out. The lines that have single pole reclosing do not reclose for multiple phase faults. Backup protection does not initiate reclosing. All others the trip initiates the reclose. On lines with three pole reclosing, reclose is only initiated for in zone faults, i.e. Zone 1 or signal aided trips.

Finland:

For 400 kV faults near generators 1-phase rapid AR is applied without check synch, but in case of unsuccessful AR, the delayed AR is conditional (AR only, if the line is energized from the other end).

In 400 kV network when there is a high impedance fault, AR is allowed only, if the line does not lose voltage at all, i.e. when there has been a non-selective tripping only on one end of the line.

Rapid AR is used only in case of fast tripping (zone 1 of distance relay).

Any slower tripping (zone 2 or 3 of distance relay, backup relay) leads only to delayed AR.

AR is not allowed for any tripping by:

- Transformer protection
- Backup earth fault protection (U_0 -relay, $t_d=5$ s)
- Busbar and breaker failure protection

Germany:

In Germany, reclosing is only practiced with fast fault clearance.

Traditional AR relays had a timer started by the fault detection zone (about 0,2 s to 0.4 s) which blocked AR on time-out.

In case of 1-pole AR, reclosing is blocked on detection of a multi-phase fault.

Manual CB closing also blocks AR.

On lines consisting of an overhead line section and a cable section, AR is only desirable for faults on the overhead line section. Some digital distance relays can now distinguish between both sections by using two graded zones and a small logic.

Ireland:

Only faults that issue a trip within an AR Action Time of 0.5 s (equal to distance relay Zone 1 time) initiate AR. Consequently Zone 2, Zone 3, and any other backup protection cannot initiate AR. AR is retained for high impedance faults provided the trip occurs during the Action Time. A bus-zone protection trip command will block all adjacent AR's. A fault near a generator is not arranged to automatically block an AR, but in some operational circumstances (e.g. outage of parallel feeder) an AR may be manually turned off. High current faults, or phase-to-phase faults, do not inhibit AR. Transformer and cable faults block AR.

South Africa:

Any delayed zone tripping.

IDMT earth fault.

Over-voltage.

Line reactor inter-trip.

Trip during power swing.

UK:

Breaker Fail protection.

Busbar protection.

Manual Close.

Q17. Would you apply smart automatic reclosing relays?

There is much negative sentiment towards the technological ideas outlined.

India - Yes. Primary feature should include:

- i) Availability of parallel line at own station and remote stations.
- ii) Fault current threshold setting to determine permanent fault versus transient.
- iii) Discriminate availability of line reactor having separate breaker.
- iv) Detection of breaker failure during fault, without waiting for time delay.

However, cost is generally a deciding factor. Advantage of smart reclosing would be more effective. Selective phase relaying, end zone fault measurement accuracy, correct evaluation of mutual coupling on the same tower or in the same ROW.

Australia and Denmark believe that smart automatic reclosing relays would not be generally applied.

Spain would like to see better discrimination of persistent faults. Germany add that the success of 1-pole AR strongly depends on reliable single phase fault recognition in particular on heavily loaded long lines. Digital relays provide improved algorithms using for example superimposed quantities or pattern recognition based on symmetrical components. Ireland would in principle apply smart ARs. But since they already utilize ARs integrated into sophisticated relays, they would be unlikely to introduce additional smart stand-alone devices. South Africa would like to see low cost smart AR technology integrated within standard reclosing IEDs. The UK would accept them provided they improved the success rate for reclosure. Information such as fault types i.e. high impedance, earth fault, phase to phase, distance to fault and other information would be helpful in developing more advanced reclosure strategies.

Q18. Do you use integrated automatic reclosing and Main Protection?

There was no huge consensus among those who responded. Utilities that apply relatively simple busbar arrangements (e.g. double busbars rather than 1½-breaker schemes) are more likely to adopt integrated systems. It is conceded that complex busbar arrangements do not lend themselves to integrated ARs.. Newer relays are now being applied with integrated functions. Some utilities are quoted as saying functionality is now too complicated. Some manufacturers' schemes differ from others. This can cause problems if using common engineering drawings. India do not apply integrated ARs for 400 kV lines. For a few 220 kV lines, they were used without any difficulty, where only one 'main' distance relay is used. Denmark accepts integrated ARs in Main 1 protection. In newer stations, AR is also integrated in Main 2 (typically a longitudinal differential relay). Germany accepts them, Normally Main1 and Main2 have their own integrated AR, which operate in parallel. Some co-ordination between both is necessary, for example the other AR must be blocked if one AR is blocked or, in the case of 1-pole AR, if one relay detects a multi-phase fault. South Africa apply them only on single main protection schemes (typically less than 132 kV).

Q19. Level of integration of closing system – with protection IED(s) and/or with control IED?

One manufacturer reports that both separate relays and integrated relays are available. Generally more specific relays have more functions whereas integrated relays have basic

functionality. This may mean that there are more alarms, events etc. in the stand-alone device.

India has no integrated systems – separate relays are utilized for the EHV system. Australia, Denmark, and Spain integrate reclosing with protection. South Africa integrates it with control. The UK integrates reclosing with control and backup protection. In Finland integration depends upon the system voltage i.e. separate relays (420 kV), integrated with protection (123 kV and 245 kV), and check synch integrated with AR relay (any voltage level).

Q20. It is generally a requirement of automatic reclosing to use Check Synchronisation. Do systems use integrated automatic reclosing and Check Sync functions or is there some reason why integrated relays are not specified?

Manufacturers are tending to offer solutions to utilities. These can vary as to what is offered i.e. relays provided such as distance + SPAR + DAR + CS + PNT. Also standard relays with DAR + CS. Where PNT = Pole Discrepancy.

However the position of system VT's may require complicated voltage selection schemes.

Sweden use integrated A/R and Check Sync relay for reliability and safety. Check Sync is applied at each circuit breaker dedicated auto-reclose relay. Finland at 420 kV and 245 kV voltage levels use Check Sync at each transmission line circuit breaker, at 123 kV level only those circuits that need it are provided with Check synch function. In Belgium, Check synch is used when reclosure is chosen slower than 0,3 s (depends on the historic installations on the surrounding grid) in the cause of multiphase faults. On the newer installations synch check and reclosure are integrated. In Australia, where check synch is used it tends to be a separate relay. The requirement for a check synch relay is determined by the degree of meshing in the network, and hence the chance of loss of synchronism.

In Ireland, If check sync is employed it would typically not be integrated with the recloser. On new installations the recloser is an integral part of the main protection relay, while these relays typically also have a check sync function, using this function may require that a voltage input normally used for measurement of residual voltage would have to be used for the reference voltage. Also there may be insufficient binary I/O available on the relay to implement the required scheme.

Japan use both a system of synchronized relays and a system that sync checks whether CBs are ON or OFF.

- Single-pole reclosing: CB is ON
- Multipole reclosing: CBs of at least 2 different phases are ON, on a total of 2 lines (i.e. one double circuit).
- Three-pole reclosing: (front end): CB on the next line is ON + no voltage in the line for this terminal.

(rear end): CB on the next line is ON + voltage in the line for this terminal absent at first, and then present

If the relay system prevents the transmission of the ON/OFF status of the CBs at each terminal, the required conditions are for the CB on the next line to be ON and for there to be a current variation in the next line.

Q23. Statistics of successful automatic reclosing in percentage?

Country	400kV	220kV	110kV
Australia		60%	70%
Belgium		85%	
Denmark	85%		
Finland		86%	
Germany	95%	89%	85%
India	65%	75%	
Ireland	61%		
Japan	100%	91%	
Korea		63%	
Netherlands		100%	
South Africa	76%		
Spain		88%	94%
Sweden		75%	
UK	88%		

Figure 22: Statistics of Successful Reclose

Additionally provided by Eltra (Denmark):

	Faults 1991-2000 400 kV			Faults 1991-2000 220 kV			Faults 1991-2000 150 kV		
	O-C	O-CO	TRIP*	O-C	O-CO	TRIP	O-C	O-CO	TRIP
F0	34	3	6	6		1	224	24	51
FF0							20	3	7
FF	2	2	2**				69	8	35
3F		1					10	5	3

* AR mostly blocked in case of new failures in the reclaim time.

** AR blocked in case of new failure in the reclaim time.

Ireland:

The percentage of successful auto-recloses is calculated as follows:

61% of Q23 reply is derived as follows, based on year 2000 data.

Number of successful AR both ends = 59 (118 ends).

Failed to AR both ends = 36 (72 ends).

Failed to AR at one end = 25 (25 ends).

Successful AR at one end as programmed = 10 (10 ends).

Spain:

220kV Single Pole 88%, 110kV Single Pole 85%

220kV DAR 90%, 110kV DAR 94%

Finland:

86% first shot followed by 9% second shot, leaves 5% unsuccessful.

Koori – Tohoku Electric Power Co. (Japan):

Multi-phase 500kV+ 100%; 220 kV+ 91%

Nakauchi (Japan):

Multi phase 100%

Sato, Hokkaido Electric Power Co. (Japan):

100% (but based on closing at one end).

It is clear however that the results may not always be directly comparable, since some utilities compute 'success' based on a single feeder, while others (e.g. Japan) base 'success' on a double-circuit feeder equipped with multi-pole reclosing. In the first case, a permanent fault on one phase leads to unsuccessful AR; but in the second case, it may take a permanent fault on four of the six phases to result in unsuccessful AR. A 100% success rate needs to be viewed in this context.

Q24. Where the statistics of automatic reclosing indicate a low success rate, can you indicate what measures would be necessary to improve them?

The following points may improve the success rate:

Review of relay settings.

Prevent closing onto faults.

Examine the type & cause of faults.

Reduction in fault clearance times.

Improved equipment reliability.

Better discrimination of persistent faults.

Where the success rate is low for transient faults then a longer dead time may be more appropriate, for example to avoid reclosing until after arc extinction. Adjustment of reclosing relay settings using the result of individual power system simulation may be necessary i.e. Check Sync phase angle setting may be insufficient to cover the line operating conditions.

Indicate the nature of the fault so that the correct action can be taken. i.e. if a feeder tripped three pole because the secondary arc did not extinguish then it may be valuable to indicate that closure is permitted after the arc extinguishes. However if tripped three poles, because there exists the possibility that reclose will be unsuccessful, then it would be useful to indicate to 'control' that further closing should be prevented. Without this

type of indication 'control' can issue too many closures after reclose fail. One utility reported 29 such closures.

In India, unsuccessful auto reclosing is sometimes attributed to human factors. These include

- i) Maintenance of switchgear or breakers.
- ii) Mis-co-ordination between end stations.
- iii) Poor discrimination by relays at two ends.

Improvement is possible by way of training, recognizing the importance of line availability, and documentation of procedures.

Reasons for failure of reclose are generally as follows:

- Close up single phase fault seen as multiphase fault by distance relays of older generation.
- Fault actually of multiphase type whereas single pole recloser is actuated
- Persistent fault
- Trouble with breaker

In Australia lines with a low success rate tend to be due to the line design in difficult areas, i.e. snow loading and broken earth wires. Sweden would review the deadtime settings in the event of poor AR performance. Denmark add that on 132 kV lines they would check the PLC (or other) signal transmission and relay / AR operating times. Delays will shorten the deadtime, thus reducing the chances of arc extinction. Belgium add that maintenance would normally rectify the situation.

Ireland puts forward several issues that may help explain its low success rate:

1. A defective autoreclose response from modern numerical relays is believed to contribute to the low success rate. Thus, the priority assigned by the relay to the processing of certain binary inputs relevant to AR has caused important signals to be delayed. This issue has since been recognized and corrected by the manufacturer in the current product release.
2. Better maintenance and in particular more sophisticated GPS-based end-to-end injection testing may be useful to identify actual deficiencies (e.g. non-simultaneous closing at both ends, possibly reducing the actual dead interval).
3. When a failure to reclose occurs it is often only at one end.
4. Since high resistance faults can be expected at 220 kV and 110 kV, the tripping time may exceed the AR Action Time. In theory installation of ground wires would improve this; in practice retro-fitting is not feasible. In the past, ground wires were omitted for reasons of cost, and because the isokeraunic level is low. Other measures like reducing tower footing resistance may give an improvement but such improvement is likely to be limited.
5. The apparent fault resistance may be high at only one end (the end contributing least current to the fault).

For reasons such as these, smart AR's would be attractive.

In Korea one particular case, was due to the narrow synch check angle setting.

Combined comments from Japanese utilities -

Chugoku (Japan):

They do not use automatic reclosing with 100-220kV for double circuit simultaneous faults or faults that occur during the countdown for reclosing standby. This is because there have been some instances where automatic reclosing did not occur because the required condition of a current surge in the next line for Check Sync failed (the CB was ON but the current surge was below the value set for the relay). They believe it is possible to improve the success rate for automatic reclosing by changing the Check Sync to another method..

Kodama (Japan):

A low AR success rate results when the fault recurs within the reclaim time.

Koori – Tohoku Electric Power Co. (Japan):

They experience a low success rate by snow damage. To improve it, they have adjusted the sequence and a deadtime.

Mizukami, Hokuriku Electric Power Co (Japan):

- Improvement of design facilities to prevent permanent fault
- Change of reclose delay etc
- They apply High Speed Multi Pole automatic reclosing and don't use Single Pole automatic reclosing.

Nakauchi (Japan):

- The total success rate for 15 years is 85 %
 - but this rate include condition failure of automatic reclosing about the next thing
 - Success rate of remove the next thing is 95 %
 - (1) on reclaim time
 - (2) fault at low current (don't move the current relay for judge of connection phase)
- (1) shortening of reclaim time considered circuit breaker efficiency is effective
- (2) judge method of connection phase is use to information of circuit breaker condition for improvement of success rate

Q25. How is successful reclose measured?

Generally successful reclose is determined when all CBs have closed. However, some utilities indicate that 'success' is deemed to occur when at least one end has closed.

So 'success' means different things depending on whether the interest is with the circuit breaker or the reclose policy.

Q26 Is there any specific damage caused by automatic reclosing?

Generally autoreclose is applied to overhead lines and no particular damage occurs for transient faults. However permanent faults are a different matter; and so are faults involving other items of plant i.e. transformers, generators.

In rare cases, noted by a utility in Denmark, older CB's (hydraulically operated) are damaged. Other consequences are voltage dips in large parts of the supply area. Belgium records that when unsuccessful reclosure occurs, sometimes load, which is branched in a tee configuration on the line, is lost. Costs are very limited. Yet in the open market, costs will rise. A topic which is gaining prominence in Ireland and South Africa is power quality, which has become a major issue for sensitive industrial loads and is clearly exacerbated by unsuccessful AR. It may be difficult to coordinate eventual transformer damage with specific instances of unsuccessful AR. Breakers (unless over-duty) should be expected to withstand such duty (if not, specifications are dubious even if internationally agreed). Unsuccessful AR will also produce additional instances of touch and step voltage problems in the vicinity of the fault and perhaps in the feeding stations, with implications for persons, animals, telecommunications equipment, etc. Korea have some experiences that distribution transformers sustain damage due to high speed reclosing with high current. The UK have no quantifiable damage due to reclosure. The system is interlocked to prevent reclosure where damage to plant could occur if reclosure took place. India comment that there have been a few cases where the unsuccessful reclosure has triggered a major grid failure through cascading. The weak end system with voltage depression is also a concern.

Q27. What benefits would more successful automatic reclosing bring?

The obvious benefits include improved quality of supply, less action for CB's therefore more life expectancy, unmanned stations, fewer call outs as a line inspection is only necessary following an unsuccessful reclose, faster restoration and reduced workload on control center staff especially in storm prone areas, fewer customer outages, and fewer voltage dips. These are the most significant benefits particularly when storms are sweeping through an area causing multiple line faults. Korea highlight the enhanced availability of circuits and the improved power system stability. Moreover the effects of the fault do not propagate onto customer side.

Ireland cites several further advantages. These include better utilization of HV plant investments and reduced risk of widespread outages caused by the tripping of a second or third line (e.g. weakened system during line maintenance season; or multiple tripping during thunderstorm activity). It reduces the risk of system split or collapse. Furthermore, in certain locations it improves the dependability of access to generation plant. It minimizes the impact of unwanted tripping caused by relay defects or maintenance personnel mistakes. It facilitates better regulation of system voltage. It reduces system losses. Finally, unsuccessful AR produces troublesome voltage dips that clearly ought to be eliminated as soon as the technology allows. Philosophically, more successful autoreclose raises network operating standards, which in turn should have a knock-on effect

elsewhere; thus, everything should be measured against a 100% yardstick and all shortcomings should be scrutinized.

The benefits of successful reclosure in India include improved continuity of supply and prevention of blackouts. The Indian network though quite large is still weak, as the system planning criteria are based on 1-phase successful auto reclosure instead of 3 phase. Fewer lines are therefore required compared with criteria applied elsewhere. These criteria are under review.

Japan cites the advantage of rapid removal of overload from lines and devices. Other advantages include:

- Avoidance of voltage dips , avoidance of instability risk
- Lower customer outages
- Lower generation hindrances

Q28. Do you inspect the line when the automatic reclosing has been unsuccessful?

Most utilities inspect the line after every unsuccessful close. A further manual close attempt may be permitted after a certain time, especially where thunderstorms seem to be the obvious reason. Australia also manually close from the control center after reclose failure, but the line is inspected even if the manual attempt is successful. An unsuccessful AR indicates a permanent fault, this is the reason for inspection. The UK would inspect unless the reason for the fault is known, such as lightning activity. In Belgium, lines are always inspected after an incident when reclosure fails; where possible inspection is started immediately. In Germany inspection is normally performed within the next 24 hours, using the information of fault recorders. In Ireland, lines are always inspected after unsuccessful AR.

Q29. What types of fault cause unsuccessful automatic reclosing?

The following causes of unsuccessful auto-reclose have been highlighted:

Permanent faults.

Fires under the lines, especially cane fires.

Lightning storms.

During bad weather (fog / rain) 1 pole faults may evolve to multi phase faults during the deadtime.

Physical damage to the line, i.e. fallen earth wire or insulator string damaged by gun shot

Broken insulators or fallen conductors (failure of mid-span joint).

Contact with fast growing vegetation.

Trees falling on conductors.

Surge damage to voltage arresters.

Vehicles or truck-mounted cranes touching the line.

Switching onto permanent faults.

Extensive frost or snow on the conductors.

Collapsed line tower.

Exploding CT or VT parts

High resistance slow-clearing fault
Dead time reduced by non-simultaneous tripping or reclosing at both ends.
Failure of arc to extinguish in time available, especially for one-phase faults.
Insulator pollution.
Conductor galloping.
Faults occurring repeatedly at same location during heavy fog.
Multi phase faults (single phase reclose is chosen).
Problem with Circuit breaker.
Protection relay misbehaviour or defect.

Q30. Would an indication to fault type be useful?

It is generally accepted that some such information is usually obtainable from the protection device and the fault locator.

However, other useful information might include recognition of permanent fault, transient fault, secondary arc present, secondary arc extinguished etc.

Germany state more data would be useful, for analysis of the AR performance particularly in case of unsuccessful AR; also to recognize weaknesses in the power system and plan countermeasures.

Q31. Do you use dual or single automatic reclosing functions? i.e. If 2 main protections would both be fitted with automatic reclosing? Q32. If Yes how would priority be given?

Some relays provide a master /slave arrangement within the scheme to allow multi AR functions to operate in parallel. Generally this is only applied for single pole reclose. Each relay is designated either the master or slave. Generally the master has priority over the slave. If the slave sees it's slave input active then it will not proceed with reclosing and will allow the master relay to control the sequence.

In India one auto reclose relay per line breaker is used; this is interfaced with two line main protection relays. Some times AR relay and Distance Protection relay of separate manufacturer are integrated. No problem is experienced in this.

In general, only one reclose relay per circuit breaker is installed. Australia apply automatic reclosing only on one protection. It is installed on the protection using the same battery as the manual close command.

In Sweden only 1 out of 2 main protections is fitted with automatic reclosing. The protection that does not have autoreclose starts the autoreclose function in the other protection. Spain has a similar arrangement; where 2 main protections exist, only one is fitted with automatic reclosing.

Finland also mostly use a single AR device. The 1st and 2nd Main protections start the same AR relay. Backup relays start only DAR, but here again they use just one AR relay. Dual AR functions (relays) are used only in substations with double breaker schemes. There is one AR relay per circuit-breaker, so in bays with two breakers the two systems operate together. By time delay settings it is assured, that only one CB recloses in persistent faults, i.e. if the AR of the 1st CB is unsuccessful, the AR of the 2nd CB is blocked. A so-called master-slave AR function is used between the two CB's.

Where Denmark use two auto-reclosers there is no interconnection between them. They view this as acceptable since they only apply AR on single-phase faults.

In older installations in Ireland, duplicate protections shared a single separate recloser. Modern schemes have reclosers integrated in the protection and interconnection ensures coordinated response. Both reclosers are always active. They are interconnected to ensure they respond the same way. The main protection systems are invariably different and almost always come from different manufacturers. Regarding the justification of duplicate AR's, this is made easier because they are integrated, so extensive external wiring or space is not required. Also even if the AR feature is optionally priced it is likely to be less expensive than a stand-alone device. The only argument against dual AR's is the increased complexity.

Other comments concern the application of duplicate single pole reclosers. If AR is carried out on single- and multiphase faults with different deadtimes, an interconnection is imperative. This is to avoid situations where Main 1 detects a single-phase fault and Main 2 a multi-phase fault. Differences in definitions of dead-time and protection device drop-off-times may have to be taken into account, however. This is explained clearly by Ireland – “It is usual to interconnect duplicate auto-reclosers in some fashion to ensure that they respond identically to a system fault condition. This is especially the case where single-pole auto-reclosing is practiced. It also makes some sense where Main 1 and Main 2 protection schemes differ in design or manufacture, because in some circumstances they may respond differently to a HV fault condition. However, when applying duplicate auto-reclosers that are non-identical - for example both may be integrated into distance relays from different manufacturers - special concerns may arise. For example, if one relay incorporates dynamic blocking of the auto-recloser, and if all the conditions that actuate this feature are not understood and fully explored by the user (relay technical manual descriptions may be incomplete), there may be circumstances where this auto-recloser would communicate an unwanted blocking signal to the second auto-recloser. In such a circumstance, despite the investment, auto-reclosing would not occur. Secondly, when interconnecting single-pole auto-reclosers for the purpose of guaranteeing that both systems respond identically to a HV fault that may be ‘seen’ differently (e.g. Main 1 trips phase L1 and Main 2 trips phase L2), it is important to ensure that a two-phase pickup results in three-pole tripping. Specifically this means that each protection relay should ideally have the intelligence to take into consideration not only internally generated phase-selection decisions but also external phase-selections. If this intelligence is not a feature of the relay design then some form of external coupling equipment is necessary. A third consideration is the method of handling evolving faults,

and whether or not choices are available, ideally both relays should behave identically in order to avoid conflicts. In the interests of development progress the 'external' attributes of auto-reclosers cannot yet be fully standardised, so it is clear that special attention will always need to be given to optimise the design and /or configuration of dissimilar duplicate auto-reclosers. Where duplicate auto-reclosers are three-pole rather than single-pole, there is clearly no need to interconnect the phase pickup signals, but it may still be beneficial to exchange well-designed blocking signals”.

Germany provides relevant comments about digital relays, where each relay has its own integrated AR. In most cases these are used in parallel. On the other hand, with traditional relays, single AR or dual AR has been used.

Dual AR provides redundancy and allows testing of the complete protection with AR while the parallel scheme remains in operation. Dual single-pole AR however requires coordination and some inter-wiring. Coordination is necessary in particular for single pole AR. Reclosing commands however can be connected in parallel and operate according to the principle that “who comes first will control first”. Exchange of fault detection and/or phase segregated tripping signals and the “AR blocked internally” signal is necessary however to ensure that the CB is not tripped 3-pole by one protection and reclosed by the parallel single pole AR. In this case a 3-pole reclosure would take place after the longer single-pole dead time. To prevent this by all means, state indication signals of the CB poles can be used additionally to block AR when more than one pole is open

Korea generally use a single automatic reclosing function. But they have recently installed unit differential relays with AR function. In this situation they install separate AR and also use the internal AR function in the differential relay. The separate AR has higher priority than the other one. In the case where a separate AR is not available, the internal function is active. There is no problem encountered where dual AR functions are fitted.

There are several lines equipped with two numerical relays in the Netherlands, and both have AR functions incorporated. However, only one is used. South Africa specify a single reclose unit (separate from the main IED's). India have both the main protections interfaced to a single autoreclosing scheme. As one common auto-reclose relay is used and interfaced with both main protections no coordination problems are experienced. The auto-reclose relay and main protections can be of different make and no problems are encountered on this account.

In Japan:

- If a fault occurs in a line equipped with dual automatic reclosing functions, automatic reclosing is triggered in both and a command to close the CB is output simultaneously from both devices.
- Where protection relays of different vintage issue non-identical trip commands, they use the information with the greatest effect on the system.
- If the reclosing device of another system outputs a final trip command, the reclose signal output of the first system is blocked.

Q33. For high resistance faults what do you do? Autoreclose or Block?

The general consensus is not to reclose. In fact most utilities do not initiate reclosing from earth fault relays. Although reclosing onto high impedance faults is generally not a problem, so long as the protection can detect the fault, due to the fact that the fault current is low.

In Finland, every transmission line fault starts the AR function. If the tripping is a delayed one, then no rapid AR is performed, but only a delayed AR. In the 420 kV network AR is not allowed when high impedance earth-fault relays trip the circuit-breakers on both line ends. No such measure is taken at 245 kV or 123 kV.

German philosophy shows AR is started by protection tripping (distance or line differential relays) independent of the fault resistance. At very high resistances, these protections will not operate and the fault will have to be tripped by sensitive earth fault relays. These are all time delayed in Germany and do not initiate AR. High fault resistance (flash over to trees) will progress, as experience shows, in a very fast time to low resistance and the short-circuit protection can trip and initiate AR in most cases.

Ireland generally state that no special precautions for reclosing are taken – note: if high resistance causes a fault to clear in zones 2 or higher then autoreclose is blocked. An interesting insight as to reasons behind this is given “Originally, several years ago, our opinion was that we should block, on the basis that it is hard enough to guarantee the first trip without running the risk of failing to trip the second time. But this was probably too pessimistic. These particular networks are a special case because of the absence of ground wires”.

Ireland adds that where technically feasible, it might be interesting to adapt the AR to increase the Action Time from say 0.5 s to 2 s in the case of high fault resistance. The usual thinking behind the choice of a fast action time is that after a longer time too much damage may be done to ensure successful AR; this reason may be less well founded for high resistance faults. At present, reclosing is blocked only if the fault resistance causes the fault duration to exceed 0.3 seconds.

The UK are one of the few utilities that initiate reclosing for high resistance faults. However they would generally isolate the faulted line and reclose the remainder of banked plant on mesh type substations. They recognize that it may be useful to take account of fault resistance if this improved the success of reclosure.

Q34. What level of fault resistance would you choose to block automatic reclosing and why? This will be different for each network?

Australia state that as they do not initiate reclose from the high impedance earth fault relay, the boundary is that of the main protections, which tends to be somewhere between 20 and 50 ohm. Sweden blocks auto-reclose by means of broken conductor protection or

impedance zones that are beyond zone 2 (normally more than 25 Ohm). In Finland, on the 420 kV network, only the distance relay starts AR, when an earth-fault with some tens of ohms fault resistance is seen by that relay. In case of higher fault impedance, the high-impedance earth-fault relay does not start AR, unless the circuit-breaker on the other end of the line has not tripped.

The German reply indicates that the question has not been discussed in Germany of “How to differentiate between transient tree fault and downed conductor? They believe one will allow reclose hoping that the fault resistance will be burned-out due to the high released energy or disappear for other reasons, and the line can be restored again, in particular considering the increased loading of the lines in future.”

Ireland add to this thought - rather than choose a specific resistance value, they would approach it a different way by increasing the Action Time. This is because the maximum tolerable fault resistance will vary for each feeder (it depends on feeder rated kV, feeder length, CT primary rating, relay settings, position of fault from line end, source impedances at both line ends, etc.). Depending on circumstances, a downed conductor will possibly not trip in the first place. On networks that are not equipped with earth wires it may be impossible to distinguish between a downed conductor and high tower footing resistance fault.

Chugoku (Japan):

For systems of 220kV or greater, they use a standard of a low resistance of a few hundred ohms (a primary fault current of 200 to 300A), such as faults caused by contact with trees during dry seasons.

Q35. Would a feature that blocks automatic reclosing if the next fault is at the same distance to fault as the previous fault be useful?

Conflicting replies as to the usefulness to this method were raised, some referring to the accuracy of distance relays while others considered the superior accuracy of fault locators.

One response from India recognized that it would be of little value because distance measurement is subject to a 15% error anyway. Another response believed that it would be useful as it gives the indication of weakness of insulation or external interferences due to trees or vegetable faults.

Denmark commented that it is not relevant, since only one shot is allowed adding that distance to fault from an integrated fault locator in the relay is sent to control centre to speed up line inspection. While Australia state that it would be useful they would be reluctant to pay for such refinement. Logically, they would be more interested in a system that allows additional reclosing if the fault is in a different position during the reclaim time. The German reply doubts whether it would be useful for blocking. However, this could for example indicate that a tree is growing close to a line or wind blowing a tree onto a line. While this would be a valuable hint for line maintenance people to check the

line, it is dubious if such information would be used on-line to block AR. Only with crowded residential areas might there be an application case.

Ireland agree in principle that it would be useful, but only for shorter lines. The accuracy of fault location under real conditions would be crucial to successful application. Ideally it would be possible to declare that the fault is at the same tower; but with span lengths of say 300m this would be almost impossible to achieve. Assume the best fault locator accuracy under real condition is $\pm 3\%$ (not easy – this includes CT and VT errors, line parameter errors, fault resistance errors, double-in feed effects, source impedance effects, etc.) then the optimum feeder length would be ≤ 10 km. This is considered rather too short. So for a line of length 80 km it may be impractical to distinguish between a fault at any one of 16 towers – and this would not be good enough.

Korea do not see a usefulness for this. They just block the reclosing if the next fault is within the resetting time.

Chugoku (Japan) would rather reclose than block if this indicated a local thunderstorm. Since faults at the same distance as a previous fault could occur at times of multiple lightning strikes, it is considered a disadvantage to block automatic reclosing.

Q36. When the automatic reclosing sequence goes to Lockout would a feature, which told the user why that relay had gone to Lockout be useful? And Q37. Lockout Indicators?

It is considered that most utilities provide this information in Scada format, e.g. an AR blocked / lockout annunciation. Some utilities indicate that this would be duplicating information, whilst others indicate it may be useful but only for equipment failure diagnosis. Again, the opinion is expressed that digital fault recorders on EHV lines already provide a very clear picture. .

But others point out that a disadvantage of the Scada information is that it needs to be deciphered from all the recorded data. Modern techniques can specifically name problems, with the benefit that quicker restoration actions can be undertaken.. Some examples of useful information are as follows:

- Close onto fault
- Second fault
- Persistent inter-trip
- Pole discrepancy
- CB fail to open
- CB fail to close
- Permanent fault

Q38. Do you investigate when the automatic reclosing sequence goes to Lockout? Please specify

Lockout can be programmed to latch or reset if required. A minimum Lockout timer is normally provided to allow a signal to be present for a sufficient period

Different approaches are encountered – in India, the conditions leading to lockout are examined. Elsewhere the lockout relay is reset, manually to charge the EHV line after tripping of line CB. Several responses indicate that the lockout relay does not reset automatically. However in Denmark the lockout resets after 5 s (unless blocked by CB, in which case the AR awaits the blocking signal to drop off). In Australia the line is normally patrolled before being restored to service after going to lockout. The lockout does however reset automatically so that the operators have the option of closing the line in. The German response notes that it is important to differentiate between “internal blocking” of the AR (e.g. multi-phase fault in case of 1-pole AR, no reset of trip signal or back-up zone tripping) and “external lockout” (switch-off of AR, or CB not ready). In each case the reason for the non-operation of AR needs to be checked.

Q39. How is the automatic reclosing sequence started? Please also specify Single Pole, Delayed or High Speed?

Generally there are three methods employed: Trip, Trip and CB Open, Trip Reset. Each may have additional logic or interlocks associated with it. Obvious choices include the circuit breaker positions prior and after the fault, system voltage levels etc.

India’s application of EHV single shot single pole reclose has the following sequence:

- i) ‘1PG’ fault of distance relay trips one CB pole, by 1 pole trip relay.
- ii) Trip relay contact initiates ‘start AR’ sequence.
- iii) Breaker pressure for AR is checked;
- iv) Deadtime count starts.
- v) Fault in other phase converts 1 pole trip to 3 pole during deadtime.
- vi) In normal transient faults, CB closes after deadtime and reclaim time starts.

For three pole reclose the reclose is initiated by the circuit trip relay from first and second main protections. For single pole reclose it is initiated by the trip relay for one phase. If more than one phase trip relay operates or the three phase trip relay operates reclose does not occur.

Where different manufacturers equipment has been used the operation may vary or be settable. Some on trip reset, others on trip & CB open. AR deadtimes may have to be adapted during commissioning to achieve the desired deadtime (line de-energized).

The response from Finland shows the differences between rapid autoreclose (RAR) and delayed autoreclose (DAR). The AR logic is started by a circuit-breaker tripping command from a line protection relay. However, if the AR relay is not constructed to

measure the time between the starting and tripping of the protection relay (in order to distinguish between cases when rapid AR and delayed AR shall be used), then the logic starts by the starting of the protection relay, but the AR starts only in case there is a tripping after the starting signal.

In Germany the approach is for the dead time to start with reset of the trip command.

Ireland indicate the difficulties encountered when applying two relays with different logic sequences. They install AR's from two manufacturers and they differ somewhat. All are high-speed. The 400 kV ones are single pole while 220 kV and 110 kV are three pole.

For Type A the reclosing sequence is started by a trip command. For this starting no distinction is made between a single-pole and three-pole trip. However, in the case of a three-pole trip a further input is provided to allow the dead time to be reduced. The dead time commences when the trip command is issued by the protection relay.

For Type B the reclosing sequence is started by a protection start and it also needs a protection trip command. Where appropriate the latter is phase-selective (in order to modify the dead time). The dead time commences when the circuit breaker opens and when the protection relay resets.

South Africa highlight their preference: trip plus CB open within a prescribed time window. Closing in Progress is from start of any dead time until end of reclaim time. Reclaim time commences at end of dead time(s).

The application of delayed three pole reclose in the UK uses trip plus CB closed and live at time of trip; CB must open; voltage must go dead; trip must reset. The trip reset is an accepted interlock system that prevents closing if items of plant are not in their required position.

Japan add that the automatic reclosing sequence starts with a trip command from the main protection relay. If reclosing conditions are satisfied after the deadtime has passed, a command to close the CB is given. In the case of a double circuit line, the trip phase information of the relay on the second line is introduced to the relay on the first line and combined with the trip phase information of that line to determine whether to respond by a single-pole reclosing or a delayed reclosing. When the CB closes or the reclosing conditions are not satisfied even after the set time has passed, the sequence to reset the automatic reclosing begins.

Q41. Would you duplicate the Manual Close wiring to close the CB directly as well as through the automatic reclosing relay?

Generally all closing is controlled by a Closing IED. This may be part of the reclosing device or separate. However, some utilities including Ireland route the close command directly to the circuit breaker in the interest of dependability.

Q42. If the automatic reclosing equipment is switched out, do you want the Manual Close feature to still be active?

Manual control will always be active if required.

Q43. Where a feeder consists of part overhead line and part underground cable, what approach do you take to automatic reclosing? Have you utilised or considered distance relays that attempt to discriminate between faults on the two types of feeder, with a view to determining whether automatic reclosing should be released? Alternatively, do you equip the cable section with feeder differential protection (CTs at both ends of the cable), not so much to trip, but to block the automatic reclosing relays?

Australia generally apply no autoreclosing to cables, but where it is employed there is also a differential protection to detect cable faults in order to block reclosing. This is a similar strategy as to that employed in most other utilities Sweden, Denmark, Germany, UK.

Sweden explain that discrimination between faults using distance relays could be used if the overhead line is long enough. If the overhead line section is short they would not use autoreclose at all. This is repeated in Denmark where for short underground cable parts they use AR; and for longer underground cables they have used distance relays attempting to discriminate between faults on the two types of feeder, with a view to determining whether AR should be released. So, AR is applied for overhead line faults and AR is avoided for underground cable faults. Also, Depending on the importance of the combined line (which may vary according to network operation conditions), AR may be set active or inactive.

Discrimination by other means has been considered, but not implemented. In one specific case, AR is normally inactive, so the benefit would be marginal. In another case, the line consists of 2 overhead line sections & 1 cable section, so the discrimination scheme cannot be implemented (too few zones). Blocking by differential protection is not feasible because CT's are not available at the connection points.

Ireland's approach is to use auto-reclose where the cable is less than 15% of the total circuit length.

They do not use blocking differential relays. Instances of composite feeders rarely arise on their networks, except for quite short cable sections on overhead lines – in which case they choose to ignore the cable. But recently they had to consider a high profile proposal to introduce an underground section because of environmental pressure, and sought some views from suppliers. These are summarized below.

Reply 1: Most users of mixed lines (cable /OHL) ignore the cable and apply AR. The reasoning is that the probability of OHL faults is higher. However, a minority of users apply distance relays that attempt to discriminate between cable and OHL faults; AR is then blocked for cable faults.. It would be implemented as follows. Both distance relays would be set to 85% in the usual way. In addition, the relay 'A' nearest the cable would

have a Zone 1B set to cover just the cable (3 km in this specific case, quite a low impedance); the relay 'B' at the other end would have a Zone 1B set to cover the OHL but not the cable (easier said than done!). If relay 'A' sees the fault within its Z1B it blocks AR. If relay 'B' sees the fault outside its Z1B it blocks AR.

Reply 2: For cables up to 300 m connected to an OHL, AR is utilized and the cables are thermally dimensioned for this application (it is economic for short cable lengths). Where the cable is longer, the cable thermal rating determines whether AR is feasible.

Sometimes the cable section is equipped with differential protection to block AR. It may be that the differential protection uses just one relay (like transformer differential protection) fed from CT's at the cable /OHL junction; this avoids the need for a battery, etc. at the junction. Sometimes distance relays are utilized as for Reply 1 above.

Reply 3: A consideration is that the probability of faults on OHL's almost invariably exceeds that on cables (including cable bushings, the weak point). This favors the use of AR on composite circuits. Regarding other possible approaches, fault locator accuracy is reckoned to be '< 5%'. AR on composite circuits can also be justified by the fact that if AR does not exist, an operator will almost invariably try to manually close the circuit at least once.

Another response states that where a small amount of XLPE insulated cable is part of a feeder it would be ignored and reclosing would be employed. If the cable is a significant length or is oil filled, reclosing would be released if distance protection determines that the fault is on the line section.

Korea omit AR where the proportion of underground cable exceeds 30%. But generally for underground cable, they equip it with current differential protection and block the AR.

UK state that safety issues are a deciding factor. If the cable is short and there is no risk of injury due to reclosure and there is no separate protection on the cable then they reclose. If there is a risk of injury and the fault is in the cable zone then they do not reclose.

Q44. In the case of HV lines with an intermediate tapped load (e.g. a directly connected transformer, with no local circuit breaker), is automatic reclosing permitted? Is it allowed only for transformers below a certain rating (state rating)? If automatic reclosing is permitted, confirm that it is invariably three-pole?

Where applied in the Netherlands, they always incorporate a breaker near the tapped transformer. The main function of the line is transmission of energy so AR is needed. The tapped transformer is switched off three pole without AR.

In the UK, it is common to have teed off transformers with isolators instead of circuit breakers. This requires a three-way trip for every fault. Different strategies are employed for different faults for example: feeder fault – reclose; persistent feeder fault – isolate then reclose; transformer fault – isolate then reclose.

Q45. In the case of series compensated lines, do you allow automatic reclosing? Single-pole or Three? Depending on whether the capacitor protective airgap is likely to flashover, are coordinating measures necessary at the series capacitor control circuit?

South Africa allow single and three pole AR, taking the precaution that the bypass CB opens well before reclosing.

India are presently installing series compensation on their 400kv lines. They intend to use single phase auto reclose. The 400kV system has HSAR together with Knudson/Kimbark connection of shunt reactors that keeps the secondary arc current to well within the 12-15 amps considered safe for all purposes.

In contrast, Japan responded that only three pole reclose is implemented with series compensated lines.

Q46. With single pole automatic reclosing, during the time that the conductor is open ground currents circulate in the network and potentially these may react with ground fault relaying. What precautions do you take to avoid problems?

One response indicates that although the system may be designed to work indefinitely with one pole open, the effect of unbalance is normally restricted by the use of pole discrepancy (1.6s) normally set to longer than the single pole deadtime (1s).

Another response states that generally settings are coordinated so as not to interfere; the ground fault relays associated with underlying system of EHV lines are of 'Idmtl' type, And they have not experienced operation of these during the deadtime with the adopted settings. But directional comparison ground fault protection, integrated in distance relays are automatically blocked during AR.

German reply that fast earth fault relays are blocked during the single pole AR cycle. Digital relays which contain directional earth fault protection have this transient blocking feature integrated.

Ireland give some detail about coordination of this feature and problems raised. High speed ground fault relays employ directional comparison criteria and therefore remain stable. Simpler ground relays are time delayed. Because they need quite sensitive EF protection ($3I_0 = 10\%$ or 20% rated; $3V_0 = 1.0$ volt) at 220 kV and 110 kV, they reverted some years ago from single-pole to three-pole AR at 220 kV (AR at 110 kV was already three-pole because the breakers do not have single-pole actuation). They introduced this as a blanket solution (rather than trying to fully investigate all the issues) because at the time the operations personnel did not raise strong objections to losing the single-pole facility. One proposal considered and rejected at that time was to block the EF protection during single-pole AR on the same line. They have recently reviewed this policy and are in the process of changing back to single-pole tripping at 220 kV. An issue to consider (and perhaps a common inconsistency) is whether to block the EF relay only on the

feeder that has auto-reclosed, or also to block EF relays on adjacent feeders in the two stations concerned.

Q47. Where you apply single pole auto-reclosing, to what extent do you take the tower footing resistance into consideration? Or are you satisfied that if earth wires are installed this effectively alleviates the problem of the occasional few ‘bad’ towers in a line of adjacent towers? Have you ever decided not to install single pole tripping/reclosing because of a concern about tower footing resistance?

Australia:

They do have lines with SPAR applied and high footing resistances (up to 600 ohm) without earth wires. They handle this by not initiating reclose from the high impedance earth fault protection.

Denmark do not take footing resistance into consideration but it is normally low; also they have installed earth wires.

In Ireland,

Where earth wires are installed, they assume that no resistance problem exists.

Nevertheless, it must be recognized that ‘bad’ towers may also exist in groups in rocky terrain, partly challenging this assumption.

In practice, most lines do not have earth wires; resistance is relatively high and sensitive directional comparison earth fault protection relays are installed.

Where they have a concern about tower footing resistance (almost always), they take whatever measures they can to improve the EF protection, and then implement AR, hoping that an EF will trip within the AR action time. Other than this, tower footing resistance is not taken into consideration for AR.

Single pole reclosing feeders (two of at 400 KV) have shield wires thus tower footing resistance is not a problem. Single pole tripping and reclosing was abandoned on the 220 kV system some years ago because of tower footing resistance concerns. The bulk of 220 kV lines do not have earth wires. However, they are now in the process of restoring 220 kV single-pole tripping to selected lines as distance relays have improved sufficiently to deal with single phase to ground faults which include significant tower foot resistance.

The Netherlands do not take tower footing resistance into consideration. They always install two earth wires (not segmented) that connect all towers. Apart from that all tower footing impedances are measured and where necessary a low value is achieved, for instance by inserting earthing conductors.

Consensus: generally accepted that the earth wires cope with this.

Q48. Multi pole Reclosing

Japan and Korea apply this as standard to double circuit lines.

Q49. Transposed lines?

One respondent is of the opinion that transposed lines in general offer little benefit. However certain layouts may benefit from the balancing effect of the induced voltages. The use of HSGS (high speed grounding switches) in 765kV transmission lines eliminates the requirement. The Netherlands use un-transposed multi circuit lines, and they never observed any problems (the longest line in the Netherlands is approx. 130 km).

India have mostly single circuit 400kV lines provided with 1phase autoreclosing. They also have double circuit lines or two single circuit line on the same right of way. All these lines are transposed once and this gives a negative sequence unbalance factor less than 4%. For an 800kV system presently operated at 400kV, they have two single circuit lines in the same ROW, and also an 800kV single circuit line. These lines have a 4 reactor scheme to facilitate single phase HSAR. These lines are transposed. So far, they have not faced any problems although the AR success rate is only about 40 – 50 %.

One utility in Japan provide details about an unsuccessful autoreclose caused by reclosing before the secondary arc extinguished. This was a 500kV, 150km, untransposed line with a single phase earth fault.. It is believed that the presence of a number of conditions that were disadvantageous to arc extinction, such as a 2 line fault, a fault location near the end of the line, and a long line length, caused a long extinction time for this fault. As a measure against this, they are studying a method for extending the reclosing dead time without transposing the conductor or temporarily grounding the fault conductor. The reclosing dead time in this instance was 830ms.

Q50. For breaker-and-a-half schemes, the tripping of two breakers for a line fault causes a triple split at that station end, and precautions are necessary to prevent inadvertent coupling of non-synchronous systems. One solution (Evans, 1980) is to reclose the first breaker via a dead line check interlock, and then to reclose the second breaker via a synch-check device. But recognising that the first breaker may be temporarily unavailable, it is essential to also give the second breaker an opportunity to reclose via a dead line check interlock. The trick is to slightly increase the dead time on the second breaker in order to avoid contention. But any such delay slightly extends the dead time. Do you implement these design features? Or have you a different strategy?

Utilities responded that this is the strategy they predominately use. Although a few reported the use of single pole tripping throughout. The solution to the breaker and a half problem depends upon whether there is generation at each end.

Auxiliary logic is employed by India to act as a blocking scheme. Initiation of AR start commences at the line breaker on the bus side. On successful closing of same, the centre breaker starts its deadtime. In case the line breaker is 'out of service' for any reason, the AR start is routed to the center breaker through an auxiliary contact of the line breaker(N/C when breaker is open).

Q51. Do you use such logic, or do you see a need for using such logic?

Some manufacturers have designed their autoreclose sequences in software, whilst others have implemented their schemes using logic. Differences are minimal and preference rests with the user. Flexibility is the key in order to be able to provide the required solution. The drive to modernize substations is to minimize hard wiring. Utilities accept differences and first off engineered schemes, "If provision is made within the relay, logic can be developed by the user and applied in the field". Utilities need the flexibility to apply the relays to all circuit breaker configurations. Trends show that integrated devices offer limited functions. Cost reduction and ease of taking into service are important.

Topic 1 Review

Current state of technology:

It is a credit to engineering that so many different operational autoreclose practices are employed. Each system must be viewed on its own merits. The application of all types of autoreclose practice have been seen throughout the world, for example, single shot single pole in India, high speed single shot in Germany, three pole delayed in the UK, single or three pole two shot schemes in South Africa, etc. Local engineering requirements are also prevalent, for example, how the autoreclose sequence is started - trip, trip reset, starter to trip time. Manufacturers have provided solutions around these requirements. These solutions tend to be a mix of common software modules and/or logic, which offer flexibility.

Some interesting logic functions have been implemented by different utilities in their reclose operation to enhance reliability of the reclose function. These may or may not be suitable for other utilities. The global practice of reclosing is unlikely to become standardized; only local standardization is likely to happen.

Most utilities accept the performance of their reclose functions. No real effort has been centered on trying to improve the success rate of reclosing. However although the success rate is a measurable figure this may not be the determining factor. For example using multi-shot reclosing rather than single shot reclosing may improve the success rate. But this approach may introduce other problems associated with voltage dips that are unacceptable. Analysis of faults, types and success rates appears to offer the opportunities for determining whether reclose could proceed after an unsuccessful reclose. For example, Japan produced a comprehensive list of faults and their causes [129]. In this list from a total number of 3406 faults, 3.5% were failure. However these failures included 15 attributed to “wind and rain”, and 44 attributed to “lightning”. Since these types of fault are predominantly transient in nature, an improvement in the success rate could be achieved by introducing multi-shot reclosing. However while the success rate would reduce this would not be acceptable due to the number of recloses onto real permanent faults. Identification of the type of fault is the key to changing to safe multi-shot reclosing. There are not many utilities that can lay claim to a comprehensive analysis of faults and their cause. To many, the effort required for this purpose is restricted to examining only the events that are unsuccessful, and limited data is available. Most utilities state that damage due to unsuccessful reclosing is minimal, and therefore there is no incentive to change.

Another criteria could be to block reclosing during a lightning storm to minimize equipment operation. Each utility will decide their philosophy based on their preferred operation. The logic for one decision can have an opposite logic that is also true – in this sense the choice is to whether to allow reclose or prevent reclose – each decision can be viewed as correct dependent upon the philosophy chosen.

It is interesting to note that some of the faults which were attributed to failures of reclose, were attributed to transient type faults i.e. faults which could be closed later. Some logic functions can result in immediate improvements for this case by effectively using two consecutive reclaim times and changing to two shots. This approach can be used to not allow reclose if the fault is during the first reclaim (close onto fault), and allow reclosing if the fault is during the second reclaim. The two reclaim times run consecutively. It is general practice to set a reclaim time in seconds; however reducing the reclaim time can have the same effect, but would not prevent the permanent fault from reclosing. Other views for this condition indicate that instead of a separate fault it could be a slow trip and should be dealt with separately, possibly by delayed reclose; and there are further concerns about reclosing for faults that were marginally detected in the first place.

Utilities vary as to the setting of the reclaim time. The setting of a long reclaim time will result in more unsuccessful recloses than a shorter reclaim time. The reclaim time should be sufficient to allow the circuit breaker to recover for successive trip – close operations. The standard for recommending the time between operations (IEC 56) states a 300ms between trip and close; to 3mins for next shot. Therefore if single shot reclosing is being performed setting a reclaim time of 180 seconds prevents further transient faults from being reclosed successfully. Circuit breaker mechanisms will have to be taken into account. It is noted that most utilities that apply multi-shot, break the IEC recommendations and set a minimal reclaim time. This indicates that circuit breaker manufacturers data is more relevant than the IEC specification when it comes to allowable breaker duty and reclaim time setting.

Deficiencies in current technologies:

Designs of reclose functions have now matured. Although there are differences in how utilities apply the reclose function; and differences in reclose relays that manufacturers provide, these can usually be overcome with correct engineering. The global market place now sees relays that were once designed for one utility now being applied in another utility's system; this can cause problems, especially where perceived interfaces are different.

Some utilities are introducing specifications that establish the reclose interface. This interface consists of start, inhibit and lockout features. Each constituent part of this interface then includes a list of connections and sense required. For example lockout may be connected to circuit breaker fail and pressure fail. The sense of operation for each input needs to be specified in case one is Normally Open and the other is Normally Closed. If the two signals are different then the lockout interface to the reclose relay would require two lockout inputs operating on different senses.

Impact of new technologies:

The application of numeric relays with integrated functions such as autoreclose and check sync has been the main focus for all utilities. This has been driven by a desire to reduce costs for protection equipment. There has not been any significant application of new

autoreclose functions to increase the reclose success rate. Some manufacturers have reported research and offered relays that can be used to detect certain faults which have caused the reclose to fail, but which are in effect transient, with the aim of allowing reclose. These have not been taken up by utilities.

The development of communications has heralded the access to information the relays offer for all decisions that are made. Events are now used to determine exact cause of operation and failure.

Logic within the relay allows customization of the reclose process. Relays now act as re-configurable IED's, allowing the user to specify the reclose operation, modify operation instantly, include new logic blocks easily, and allow upgrade potential. This tool provides flexibility, which is essential, especially during the commissioning stage.

Integration of functions has made reclose technology a part of most protection devices. It is important to realize that an integrated reclose function may not provide the same functionality as a stand-alone device. The I/O or events may be limited, or the check sync algorithm may be slower, these criteria must be viewed to see whether the relay is acceptable for application. Certain applications may, for instance, require a fast check sync decision, while others accept a delayed response. Integrated reclose logic may be single-shot or multi-shot depending upon manufacturer.

What is apparent is that utilities are using these functions if they are provided. Where dual main protections are both fitted with reclose then the trend is for both reclosers to operate.

Opportunities presented by new technologies for making plant and networks work harder:

With the introduction of numeric relays and event lists available by communications the philosophy as to what to do after an unsuccessful reclose could be changed. At present there are the facilities to view fault recorder data, but generally the information would need to be analysed to ascertain exactly what happened, and this may take time. With independent events correct action can proceed at a faster rate, reducing outage downtime.

Typical SCADA events: Autoreclose In Progress – Autoreclose Lockout. New events could indicate exact reason for lockout, and action can be adapted to suit exact cause for the following:

Lockout due to CB fail.

Lockout due to check sync angle out of limits.

Lockout due to voltage out of limits.

Lockout due to block reclose input.

Lockout due to remote CB problem.

The problem here is one of too much information. At the time of fault, numerous relays will set and reset a number of output contacts, operate for various reasons, plant will change state, etc. Experience to date shows that SCADA data, and fault recorder data is

used instead of the newly emerging IEC communications data. This information, although not as specific as relay event lists, shows limited application.

The usefulness of some of the events is primarily more for commissioning work and determining relay problems than for in-service application. For example, “lockout due to check sync angle out of limits” should be found during live testing prior to circuit breaker closure.

There does not appear to be a demand for improved reclose performance. The effect of utility rationalization has focused resources away from improvement towards a more pragmatic approach.

Schemes exist for single pole reclosing where a second three pole reclose is allowed after the first single pole reclose has failed. This has been provided to counter the failure being instigated by secondary arcing. The action of the second trip being three pole removes the possibility of arc re-strike and therefore the second three pole attempt has a better chance of success. This is only an advantage for a system that is prone to single pole reclose failures. This is likely to be countries that employ single pole reclose and suffer from areas that encounter fires. Either bush, forest, sugar cane, veld fires; or atmospheric conditions conducive to a similar effect to that of a fire such as fog, sea mist etc.

Role of Automatic System Restoration in “Making Networks and Plant Work Harder”:

How can automatic system restoration make systems work harder? – by improved reliability and dependability; reduced plant stress; fewer reclosures onto persistent faults; reduced need for operator intervention; improved AR success rates.

Examining the returns from the survey suggests that practically all of the utilities are content with their autoreclose schemes. They accept the functionality offered; are happy with the operation and expect reclosing to successfully close about 80% of the time.

There is a level of complacency that has been introduced by using autoreclose schemes that, although evolving from electro-mechanical to numeric, have not changed their function. With resources becoming limited and ‘network control’ more active, how can a utility be content with a success rate of 60 or 75%? Would a success rate of 95 or 100% not be better? Can this be achieved? And with less stress to the system?

A visionary concept would be the following:

Fast protection to detect faults and trip the correct associated circuit breaker.
Circuit breaker to reclose successfully when check sync limits are met exactly.
Autoreclose equipment to switch to System Synchronising automatically and allow circuit breaker to close at zero phase difference if systems moving.
Circuit breaker to close at optimum point on wave.
Permanent faults to be indicated and correct ‘network control’ action to be initiated.

Circuit breaker monitoring for condition based maintenance: time to open; time to close; CB close / open counts.

Circuit breaker fail alarms – open and close.

If however the reclose attempt fails, then to classify why the failure occurred, to indicate whether it was the same fault as the first, or whether it was a second separate fault, which type of permanent fault such as secondary arcing or solid mechanical fault, and to proceed with an appropriate action depending upon the importance of the transmission line. Where single pole reclose is avoided due to continued secondary arcing, three pole tripping can be instigated, followed by three pole reclose with an increased chance of success. This avoids the voltage dip to the system. These functions are available or are becoming available now and can improve the success rate.

Topic 1 Conclusion

The questionnaire found a wide variety of interesting practices and opinions that are considered worth recording. An unexpected measure of conservatism is also evident particularly with regard to smart AR relays and also the attitude to expenditure on additional equipment. A particular concern is the issue of increasing the complexity of systems with the consequent risk of lower reliability. This applies both to improvement of stand-alone relays and to more extensive communication systems. Every response to the questionnaire evoked some interesting information. The permutations of AR practices are considerable and there is little consensus as different strategies evolved in different geographical locations. Thus, there is support for single-pole, three-pole, multi-pole, high-speed, delayed (by various amounts), one-shot, multi-shot, with or without synch check, time-graded or not at both ends, single or duplicate hardware, and various configurations depending on the bus layout, attitude to high impedance earth faults, etc. Mostly the parameters are determined by utilities but in a few instances regulatory authorities impose constraints based on public safety issues.

Practically all the emphasis is on AR. Very few utilities practice local automatic system restoration. Reclosing equipment tends to be more sophisticated in the Far East compared with other world regions, a comment that particularly applies to multi-pole AR.

Utilities, generally, are satisfied with their existing systems. The prime function of autoreclose equipment is to close the circuit breaker after a fault, and this is achieved. However reclose success rates vary between 60 - 100% restoration. These rates have remained unchanged since autoreclose was first applied.

Single pole deadtime settings are getting shorter, the trend appears to be to set this at the minimum possible. Is this really required? Some utilities advocate different deadtimes for different transmission voltages, again intent on driving the deadtime setting down at lower voltages. Systems are generally designed to work indefinitely with a single circuit breaker open. If it is not necessary to restore the system at the minimum time, then it would be better to take account of the maximum single pole deadtime. This would then reclose after all secondary arcing has extinguished. By its nature, secondary arcing may

remain indefinitely, therefore it is impractical to set a minimum or maximum deadtime, and some engineering judgment will need to be taken in order to arrive at a suitable setting. Although measures are taken to reduce the secondary arc, with reactors and transposed lines, the duration may extend indefinitely due to atmospheric conditions, and this will result in reclose failure.

The exception to this high reclose failure rate is Japan which return failure rates of 3.5%. However this figure covers their entire system, and the rate increases to 10% for EHV systems, which employ conventional type reclose relays. Where they have applied poly-phase high-speed reclosing and high speed earth switches at 1000 kV they have experienced a 100% success rate. This is evident from a limited study of 32 faults, although initial results are promising. However the application of high speed earth switches may be cost prohibitive for most types of network. Although this approach is ideal in clearing the line of any capacitance or arcing it will have no effect for permanent mechanical faults such as broken conductor.

Similarly, high success rates can be achieved with highly interconnected transmission systems by employing high-speed autoreclose and single pole reclose. Correct engineering and limiting the number of shots can also improve matters. Though certain utilities are fortunate to have considerable interconnected lines available.

An alternative to high-speed earth switching which detects the secondary arc rather than removes it, is to apply an adaptive autoreclose algorithm, which recognizes the secondary arc voltage waveform. An advantage of devices that recognize the arc is that they can also recognize permanent faults. Using high-speed earth switching with permanent faults does not provide a means to successful reclose. The application of adaptive autoreclose or high speed earth switching can minimize single pole reclose attempts, which have failed due to continued secondary arcing.

Some benefits to operation can be gained by applying modern numeric technology. Being able to differentiate between closing onto the same fault and closing with a second separate fault occurring near the end of the reclaim time, and allowing recloses for second separate faults within the reclaim can improve the success rate. Numeric algorithms for slip frequency calculation allow the use of Close on Zero facilities, and this reduces the energy transfer when re-connecting plant. The position of the autoreclose equipment provides the advantage that it is connected to numerous pieces of plant. Secondary functions within numeric autoreclose equipment can now take into account monitoring for CB fail to open/close; VT failure; CB alarms; isolation and ferroresonance suppression logic, etc.

Autoreclose is a complex and essential part of the protection requirement. However there is a reluctance to change existing systems. It is probable to expect that if the AR failure rate (10%) applied for protection then more would be done to alleviate the problem. The system statistics will remain unchanged unless more effort is concentrated on trying to improve the success rate of reclosing.

Regulation authorities to electricity providers are introducing limits to power outages and voltage dips which are forcing some utilities to change their autoreclose practice to take account of power quality issues.

Topic 1 Recommendations

The topic “making systems and plant work harder” can only be achieved if all advances to autoreclose logic and associated functions are used to their full advantage.

There are a number of advances in technology that can help to alleviate problems associated with autoreclose. Making the best use of the facilities now provided within numeric relays can help the diagnosis of problems, pinpointing exact causes of failure.

To increase the success rate of reclose requires the utilities to critically reexamine the historical operation of the reclose function and to review the available options for possible benefits.

Benefits can only be proved with the study of system statistics. These statistics of number of faults, successful reclose and fault type are invaluable to the application of reclosing.

Topic 2 FACTS

The survey did not return any information regarding problems with autoreclose regarding this type of equipment. A number of utilities reported applying SVRs, but generally on the busbar side of the system and did not report any application problems. The particular application of FACT equipment and autoreclose will need to be more widely applied before any interesting areas appear.

Topic 3 Communications

This topic has been integrated within Topic 1.

Topic 4 – Use of GPS Time Signals and Phasor Measurements

Topic 4 Introduction

In principle, a GPS timing receiver located anywhere in the world can deliver a timed output pulse accurate to UTC (USNO¹) $\pm 1 \mu\text{s}$ or better (actually, up to recently $\pm 0.34 \mu\text{s}$ for 95% of the time; and now even $0.1 \mu\text{s}$ for 95% of the time since Selective Availability was eliminated in 05 /2000). In practice the accuracy will be degraded by the receiver design, and this is clearly cost related; a representative figure cannot be found in the technical references, but it is still believed to be more than adequate for most requirements. A typically receiver will deliver such a pulse once per second, and the rising edge of the pulse marks the start of the UTC second. This pulse is simultaneously available right across a network of any size and can be utilised to synchronise external equipment. Since a $1 \mu\text{s}$ error is equivalent to an angular error of only 0.018° in a 50 Hz system, it is clear that errors larger by an order of magnitude are still of relatively little consequence. Typically such a receiver will, in addition to the pulse, also deliver a serial message giving the year², day, hour, minute and second of the previous pulse. Note that once a GPS receiver has established its own position (latitude, longitude, elevation) using four satellites, it only requires a minimum of one satellite to continue the time calculation to $\pm 1 \mu\text{s}$ accuracy. Apart from the basic task of keeping the real-time clocks of secondary equipment synchronised, GPS can additionally facilitate the synchronous sampling of voltages and currents.

Topic 4 Survey Results

GPS is not utilised within the context of AR (Q.67) by respondents from the following countries /regions: UK, Sweden, Ireland, Germany, South Africa, Denmark, Western Australia, Finland, Tasmania, Belgium, Netherlands, India, Sweden, Korea, Japan, Spain.

One response from Japan states that time scheduling of automatic switching would not be useful (Q.68); and while time stamped events are useful, another data recording device already performs the function (Q.69); for double-circuit faults system restoration is completed by low speed AR, circuit by circuit (Q.70), and this is satisfactory (Q.71). For EHV double-circuit lines TEPCO has applied multi-pole AR, and it succeeds in almost all the double-circuit faults (Q.70). India reports that a double-circuit line fault is accepted as a calculated risk that may lead to island formation or grid collapse (Q.70).

GPS time controlled AR is judged to be of little benefit in improving performance (Q.72) by respondents from the following countries /regions: UK, Sweden, Germany, South Africa, Denmark, Finland, Tasmania, Belgium, Netherlands, India, Japan. Ireland believes it may have useful potential. No reply made by Western Australia, Korea, Spain.

GPS-synchronised phasor measurements enable phase-angle differences to be derived between line ends, etc. (Q.74). UK believes this may support a voltage collapse predictor

¹ United States Naval Observatory. There are over 70 national variants of UTC, all co-ordinated by BIPM, Paris where an attempt is made to keep them all within $1 \mu\text{s}$.

² However if the receiver outputs the message in the IRIG-B format, it does not include the year.

that could be used to adapt AR behaviour. No applications for this can be foreseen by Sweden, South Africa, Denmark, Western Australia, Tasmania, Belgium. Ireland suggests it might have benefits for difficult faults (multi-ended circuits or high resistance faults), Germany cannot see an application for AR purposes but recognises its usefulness for system instability detection and control (Special Protection Schemes). Netherlands points out that information for AR is obtained on one side of the line only, that is locally, so GPS is not required. India and Korea consider the idea attractive but have no plans to apply it yet. Japan uses GPS to synchronise times for ‘waveform transmission devices’ (i.e. feeder differential protection) and fault locator systems, but not for AR; while GPS would improve the precision of simultaneous closing at each line end, they do not require that technology. Japan believes it would make it feasible to perform AR during power swings when traditional constraints would otherwise apply, and this would improve system stability. Japan can also foresee an application – at present they use out-of-step protection to exchange phase of voltage between terminals, it uses high-speed communications, but not GPS. Ireland points out that its synch check capability would be useful to permit /block AR. Ireland also states that it has significant potential for Wide Area Protection or System Protection Schemes (SPS).

Out-of-step relays based on GPS have been described (Q.75), but the following respondents either have no such systems installed or are unable to report any in-service experience: UK, Sweden, Ireland, Germany, South Africa, Denmark, Western Australia, Finland, Tasmania, Belgium, Netherlands, India (in India out-of-step relaying and power swing blocking is a major problem, and no satisfactory solution is in sight), Japan. No response from Korea, Spain.

Voltage phase-angle differences, also real and reactive power can be measured in real time from GPS-synchronised phasors and could be considered for adaptive ARs and check sync relays (Q.76). UK believes that the benefits are not clear, and that any benefits would need to be balanced against additional cost, complexity, and possible reliability reduction. Ireland believes it would be useful to derive acceptable phase-angle settings for synch check relays, but for cost reasons this would be applicable only for special cases. Germany advocates simplicity and independent local operation for protection and AR activities in the interest of reliability. Most of the mentioned possibilities would be assigned instead to power system control. The following respondents expressed no views on this question, or are non-committal: Sweden, Finland, Denmark, Korea, Spain. The following respondents see no value in this sophistication, at least at the moment: South Africa, Denmark, Tasmania, Belgium, Japan. Western Australia anticipates it could be of value in the future to limit shock on closing, and could give benefits from point-on-wave switching. India has conflicting opinions, one believing that the listed functions can be achieved with available devices, the other stating that it would definitely be helpful and will have to be introduced on their system sooner or later. Japan classifies the proposal as a concentrated surveillance protection system as opposed to the present decentralised approach, but is otherwise non-committal. Another response from Japan sees it as valuable, but for a power system stabilising system rather than AR.

GPS-synchronised phasor measurements can assist accurate fault location and this can assist adaptive AR (Q.77). UK believes that the benefits are not clear, and that any benefits would need to be balanced against additional cost, complexity, and possible

reliability reduction. Ireland believes that combining AR with fault location has merits, but fault locator accuracy is an issue. Germany sees some merit in the proposal provided the exchange of fault location information is included in the protection end-to-end communications without involving extra communications. South Africa does not favour this and comments instead that a better decision is based on source impedance. Korea and Spain expressed no views on this. Denmark provided the clarification that for the proposal to work, unsuccessful AR at the first end to close would need to block AR at the second end. But the necessary discrimination could be achieved with sufficient accuracy by a built-in fault locator rather than a GPS system. While Western Australia would favour the idea they would not be prepared to pay extra for it. Finland would possibly see merit in it provided it is economical and standardised for the stations. Tasmania would see a possible future application when stability is closer to the edge. Belgium, Netherlands, Japan are not in favour of such sophistication. India believes the sophistication is hardly merited because fault current is already reduced if the fault is only a few km away from the busbar; on the other hand another expert in India favours the idea. Sweden states that only the dead time is important, not which breaker recloses first. Utilities in Japan have different perspectives on this – one sees little need for this idea; three others favour the idea, two of these pointing out that while they have not integrated the fault locating function with AR, they have used GPS for fault locators. Another utility suggests that if the fault locator could accurately detect the fault location on part overhead line and part underground cable they would consider adopting such sophistication. Ireland favours the idea unless the added sophistication degrades the functionality (Q.77).

High-speed real-time voltage phase-angle measurements can be used to prevent the accidental reconnection of unsynchronised parts of a system (Q.78): This is not of interest to utilities that apply only delayed AR, such as UK. But Germany, Sweden, and Ireland regard this as more of interest for power system control. It is regarded as unnecessary by South Africa. The following respondents have no particular views on this, or have not given it thought: Finland, Belgium, Korea, Spain. Denmark suggests that a check synch relay would be just as effective; for this purpose they use check synch on 400 /132 kV transformers and 400 kV bus couplers. Western Australia, Tasmania, and Belgium also believe that synch check relays are adequate. India believes it would definitely be helpful; they have four large regional networks each of about 25,000 MW connected through weak (<500 /1000 MW) asynchronous links, and within a region islands can form. Replies from Japan highlight different aspects: one utility remarks that cost /benefit would be an issue because it would rarely be called into play. Another notes that it would be effective to measure the phase angle to know the stability limit of the power system. A third reply clarifies that TEPCO already applies real time voltage measurements to detect system separation, but it is not based on GPS synchronised phasors. Ireland comments that AR is not used if island creation could occur for an n-2 event; but the possibility presented here would hardly be cost effective. On the other hand, Ireland suggests that phase angle measurements have great potential for control and protection (Q.78).

With GPS applied for protection relaying purposes, issues of availability, coverage, accuracy, jamming, and weather related problems may be important (Q.79). The following respondents did not experience problems, although this may be due in part to

insufficient experience with such systems: UK, Germany, Western Australia, Tasmania, Belgium. The following respondents expressed no views on this: South Africa, Spain. The following replies reported problems: Denmark (but commented that it is superior to DCF-77), India (and would therefore be hesitant to apply GPS for protection functionality). Ireland reported that coax cable should be unjointed to prevent moisture ingress at connectors; component failure can suddenly occur in active antenna; but satellite coverage is unlikely to be an issue as only one satellite is required after the initial position fixing. Finland reported only minor availability problems. Belgium does not yet use GPS but still use DCF77 clocks. Sweden offered the opinion that as GPS is not 100% reliable it would only be used for time synchronisation. Korea comments that the cost of investment for the uncertain technology is an overriding consideration. Two utilities in Japan report that GPS is not utilised for protection relays, monitoring or control; one comments that geographical features may prevent reception; a third reports that a weather related obstruction has been experienced with a fault locator that needs GPS for synchronisation.

Four questions (Q.68 – Q.71 inclusive) did not elicit any information that would be useful in the context of drawing any conclusions on the present topic of GPS time signals and phasor measurements. This remark is true for the following respondents: UK, Sweden, Ireland, Germany, South Africa, Denmark, Western Australia, Finland, Tasmania, Belgium, Netherlands, India, Korea, Japan (exception Q.70), Spain.

Topic 4 Review

Not only has GPS superb time accuracy, but this accuracy is available at relatively low cost right across a transmission or distribution network regardless of its geographical extent. All that is required is a suitable receiver at each location where precise time is required. From such a solid foundation all manner of elaborate tools can be created to process HV network variables such as voltage and current phasors. GPS is a new tool for system designers, little more than ten years in existence. In parallel with this development, HV network communication techniques have improved enormously in recent years, especially high speed techniques based on optical fibre.

Despite these exciting twin developments it is clear from the submitted replies that there is little or no enthusiasm among utilities to introduce the advanced concepts of GPS for the several tentative uses related to auto reclosing and system restoration as outlined in the questionnaire. Not even one utility applies GPS, directly or indirectly, for any task associated with auto reclosing. The reasons are various, and stem from a number of considerations. First of these is perhaps the undeclared view that GPS may well be a solution in search of a problem, and at the present time those problems do not justify the cost, or increased sophistication and complexity of GPS. There is a concern here that complexity, especially of communications based systems, may lead to reduced reliability. The other important insight offered by the replies is that the traditional established methods of supply restoration are perfectly adequate in many cases and that GPS would confer no technical advantage.

With the exception of feeder differential protection systems, it is clear that the 1 ms time-stamping accuracy of traditional protection systems is considered to be sufficiently

adequate for most purposes, and there is little demand for the vastly superior accuracy of GPS *per se*. That said, GPS is often preferred as a time stamp source because it is becoming increasingly commonplace worldwide, and costs are falling. Used intelligently with suitably designed protection relays (IRIG-B inputs are becoming the norm on modern relays), GPS can also circumvent the in-built time error variations characteristic of systems utilised for time distribution such as IEC 60870-5-101, IEC 60870-5-103. These observations are intended to be quite general and are not specific to the narrow field of interest here, namely reclosing and restoration.

Perhaps the most powerful aspect of GPS is the ability it provides to create voltage or current phasors, and to determine the angular difference between such phasors at two or more ends of a protected line. Present indications are that utilities are unlikely to apply this for auto reclosing or system restoration, and will instead reserve it for more elaborate system-wide applications, or some specific uses such as instability containment or improved fault location (perhaps first for composite OHL /cable feeders). Utility managers are more than ever conscious of value for money considerations. Utilities have a strong perception of what costs can validly be allocated to feeder and plant protection, and any attempt to increase such investments without an identifiable cost-effective return will meet insurmountable resistance. A consideration here is that feeder protection is perhaps historically at an all-time low cost (when recognition is given to the fact that a typical numerical relay incorporates numerous features that once required a complete cubicle to house them). That being so, each additional item (e.g. a GPS based refinement) adds a disproportionate cost increase to the overall protection scheme.

Having said all that, considerable surprise can be expressed here that GPS has not penetrated deeper into the power utility market, not so much for auto reclose or restoration functions, but for miscellaneous purposes and especially for system-wide protection. This is evident from the general lack of GPS experience reported. It has not been said directly but there would appear to be an underlying reluctance by utilities to invest heavily in mission-critical projects that depend so heavily on what may prove to be a politically sensitive, if freely available, asset that has been created and is maintained at high cost, primarily to meet military objectives.

Topic 4 Discussion /Conclusions

It has to be concluded that GPS has no place in auto reclosing or system restoration strategy except for synchronised end-to-end testing where a powerful case is made later in this report.

Topic 4 Recommendations

The conclusions reached regarding GPS are unlikely to change within the next few years, and no further examination is proposed for the time being. But it is expected that GPS and modern communications will slowly infiltrate all aspects of protection relays, including the topics of direct concern here, at its own pace.

Topic 5: Adaptive Relays - New Developments

Topic 5 Introduction

Auto-reclosing has up to the present proved successful at retaining continuity of supply. In general, at least 90% of auto-recloses attempts are successful, but the remaining unsuccessful attempts have caused voltage dips and loss of quality to the supply whilst closing onto permanent faults; and in some cases expensive damage to equipment with a second or subsequent shock to the system. Further developments are continuing in the areas of recognizing the difference between transient and permanent faults and whether it is safe to reclose.

The adaptive technique for local automatic system restoration can be defined as follows: “Adaptive technique is a technique which permits and seeks to make adjustments to various local automatic system restoration functions in order to make them more attuned to prevailing power system conditions”.

The primary objective of automatic reclosing of circuit breakers, following a fault, is to return the transmission system to its normal configuration with a minimum outage time of the effected equipment and the least expenditure of manpower.

Adaptive reclosing logic offers many significant opportunities to enhance power system restoration. Below, some of these opportunities are briefly described:

- Discrimination between transient and permanent fault (minimize unsuccessful reclosing leading to stress on generator shaft, system stress i.e. stability, overvoltage, reducing breaker wear) [29].
- Detection of incorrect (sympathy) trip, minimize outage time.
- Detection of secondary arc extinction (adapt deadtime to minimize outage impact) [4].
- Measurement of fault resistance (block reclosing for high resistive mid-span faults with low probability for successful reclosing).
- Adapt control of breaker poles during single pole energisation depending on fault type – soft breaker closing (minimize transients, breaker maintenance).
- Adjust number of reclosing shots depending on fault current magnitude (for over-dutied breakers) [30].
- Minimize CT saturation problem at reclosure on permanent fault (prevent protection maloperation).
- Discriminate between line charging inrush current and fault current (prevent incorrect closing) [31].
- Adaptive control of breaker switching in ring bus arrangement) minimize breaker wear).
- Various research with simulated data concerning wavelet transforms and neural networks [107, 108].

Topic 5 Survey Results

UK, Sweden, Ireland, Denmark, Finland, Korea, Japan, Spain, report that adaptive techniques are not utilized at present, but they would be considered where beneficial. To the same question, Germany reports that adaptive techniques are not offered and have not yet been considered. South Africa states that a trial relay was evaluated, and the only reason for not applying it was cost. Western Australia, Tasmania, would only consider them if the benefit was significant and the cost minimal. India supports the idea in principle but points out that the cost/benefit and attendant risk are complicated. Japan do use adaptive techniques for the sequential clearance and AR of two simultaneous faults on a double circuit line, and for multi-pole AR. UK mention the Adspar function that recognizes secondary arc extinction by means of a neural network.

Current Application:

In the survey section regarding adaptive technique the respondents were asked to answer following questions:

Q1: Do you employ/offer adaptive control techniques? If yes, which adaptive technique do you use?

- One UK manufacturer offers a relay that can give advantages to systems which apply single pole reclose. The relay recognizes secondary arc extinction on the faulted phase by means of a neural network based algorithm on post fault voltage measurements. The relay will adapt deadtime and thereby increase the rate of successful reclosing and minimize outage time. One utility from South Africa have had a test installation of the adaptive function from this manufacturer. They were satisfied with the technical performance “but didn’t buy it, only due to cost”; they will review the situation in the future as soon as integrated device is ready.
- A document called “Automatic reclosing in Japan” based on an autoreclosing study among Japanese utilities has been provided from one respondent [138]. According to the document high-speed multi-phase reclosing with at least two phases connected in both circuits (i.e. two of the six conductors) is applied to all the systems as a basic reclosing protection because the reclosing protection has the greatest ability to maintain system interconnection.
- One Japanese utility described how their adaptive autoreclosing operates on 154 kV double-circuit lines : “One side distinguishes the faulted phase and the fault type twice in the event of a simultaneous line fault; and where the first fault is a short circuit , and the other is a ground fault, it processes the short circuit fault’s line, trips the fault on a priority basis, and performs automatic reclosing; the ground fault on the other line is removed afterwards, and its automatic reclosing is executed”.

Interest:

Q2: Would you consider using adaptive control techniques?

Many utilities, more than 50%, expressed their interest to employ adaptive technique. A few utilities said they will consider using adaptive technique when the relationship between cost and functionality is favourable.

Topic 5 Survey Conclusion

There are many opportunities for adaptive technique to improve the performance of local system restoration. But few applications are available on the market and commercially implemented according to answers from the survey.

A majority of utilities in the survey have a positive attitude towards installing adaptive techniques. In Japan the utilities have implemented adaptive solutions for multi-pole autoreclosing on double circuit lines.

One utility in South Africa had a test installation of the adaptive deadtime autoreclosing function.

Various establishments are continuing with research into the area of secondary arc detection employing various non-linear methods such as neural networks; and wavelet transforms.

The application of numeric technology to autoreclose schemes provides clear benefits in allowing a standard relay to be applied to a variety of different schemes. The ability to calculate slip frequency and phase within a few cycles allows the circuit breaker to be closed when there is zero phase difference between the systems. Adaptive Single Pole Reclosing functionality using Artificial Intelligence techniques offers several advantages over conventional autoreclose. The major advantage is the ability to prevent reclose onto many types of permanent faults. The advantages of CB close on zero and adaptive autoreclose both contribute to reducing damage to system equipment and improving quality of supply.

Topic 5 Recommendations

Improvements to the success rate of autoreclose can only be seen when fault types can be recognized. Adaptive techniques that recognize permanent faults and then allow reclosers and 'network control' to apply the correct action offer the chance of all reclosing being successful. Prototype relays have gone from research to development, but have yet to be applied by utilities. The next step is for utilities to apply these types of relays.

Addendum to Topic 5 -Adaptive Autoreclose

Adaptive autoreclose prevents closing onto solid permanent faults. It also has the ability to adapt the dead time allowing the mean time to reclosure to be reduced and resulting in a greater number of successful reclosures. In this respect, Adaptive Single Pole Autoreclose (ADSPAR) offers many advantages such as increased rate of successful reclosure, improved stability and a reduction in system and equipment shock for a permanent fault,[1].

The numeric autoreclose relay provides a selectable function for adaptive autoreclosing. At the heart of the ADSPAR is an Artificial Intelligence algorithm based on a Neural Network (NN) which has been trained to recognize secondary arc extinction from the frequency signatures of the line voltage,[2,4]. A feed forward type NN is used in this relay with the error back-propagation training algorithm.

Adaptive autoreclose addresses the problem of closing when it is clear to do so. Conventional autoreclose schemes have been applied to provide fast restoration of supply. This was originally intended to keep as much of the system in service as is possible. After analysis of the types of faults which occur on the system, the majority of faults have been determined to be transient in nature, and since air has been the main insulant, reclosing after a set time delay has restored the supply. As systems become older and more established it is worth reviewing whether this policy is still valid. Where deregulation has occurred one of the prime concerns to the customer has been with quality of supply. This issue is a measurable quantity and is being used by progressive utilities and system regulators as a target to provide improvement across the system [3]. One area of quality of supply which causes major concern to users is the occurrence of voltage dips on the system. This effect can cause major problems to industrial users with continuous motorized processes. Deregulation is tackling this problem by introducing reduced voltage dip targets. How can these targets be met?

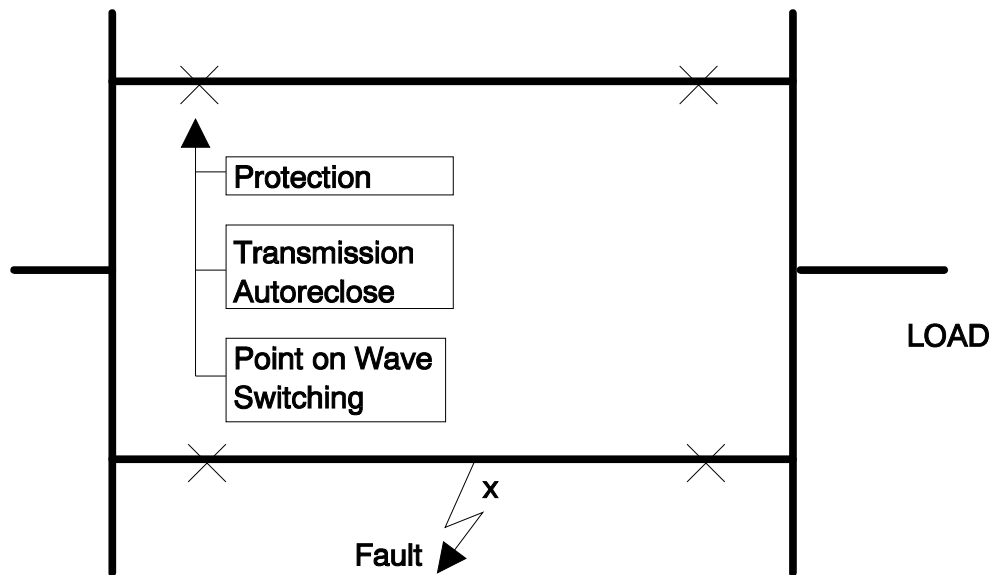


Figure 23 Double bus connection to heavy load

Figure 23 shows a dual bus connection to a continuous process customer. A fault at point x although remote from the customer's plant causes a voltage dip on their bus. The effect of this can be to slow the motors and cause the process to crash. This is dependent on the length and depth of the dip. In many cases the process can ride through this first voltage dip. Where the dip is severe a Dynamic Voltage Restorer (DVR) can be provided to replace the lost energy and restore the waveform. This is only a short term action and is an expensive solution. These devices are fairly new in service and have a finite operating duration. The application of conventional automatic reclose has an adverse impact in connection with reclosing onto a permanent fault. A second voltage dip following closely after the first causes significant problems. Usually the process is just recovering from the first dip when the second dip occurs causing the process to fail. This second dip can be avoided by the application of adaptive autoreclose which closes only when safe to do so. Thus providing a cost effective solution which supplements the DVR and if fitted independently provides its own benefits.

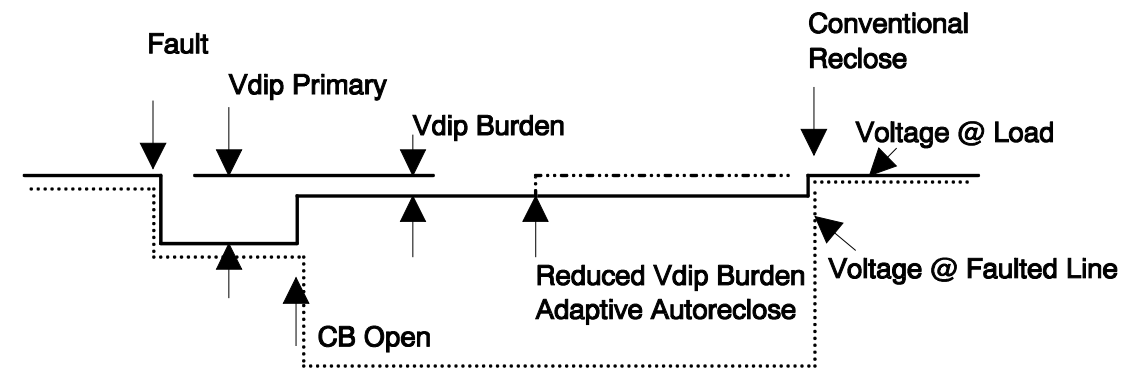


Figure 24 Voltage Dip Profile associated with Heavy Load and a single Transient Fault

Figure 24 illustrates the case where a heavy load is connected through a double bus to provide a secure supply, the loss of one of the lines due to a fault can result in a voltage

dip on the other line for the whole period that the line is out of service. This is associated to the increased burden. In cases where this dip is onerous for a DVR to compensate? over this longer time or there is no DVR available the adaptive autoreclose can reduce the secondary dip period. In this case it is an advantage to close when it is safe, as soon as possible, and not wait for a pre-determined time. This is an operation of adaptive autoreclose which closes at the optimum point.

Up to now different manufacturers of autoreclose relays have used autoreclose schemes based on logic and timers. Typically 80-90% of faults are transient, reclose philosophy based on this technology will only be successful for this type of fault. The optimum solution for an autoreclose relay is to only reclose when conditions permit a successful reclosure. Using this adaptive approach coupled to a user-configurable action matrix will significantly increase the effectiveness of autoreclose on the EHV system.

Different sequences of autoreclose operation using autoreclose logic have been used to try to overcome problems associated with single pole operation. Reclosing can be unsuccessful for a number of reasons, some common only to single pole operation. These are either due to permanent faults of varying impedance; or the continued secondary arc maintained by the two healthy phases. Sequences of autoreclose logic have been developed in the past to try to overcome these problems. The most successful to date has been the 1P then 3P sequence. This will effectively remove the secondary arc by tripping three phases prior to the 3P reclose attempt and therefore improves the effectiveness of single pole reclose. The first 1P reclose attempt would have been unsuccessful resulting in a shock to the system and the associated CB problems and wear. For solid permanent faults this scheme results in two shocks to the system since the 3P reclose attempt will also fail.

By being able to determine this fault type, progression of the autoreclose scheme can be made once a "do not reclose" waveform has been detected. There are two possibilities as to why the autoreclose has been inhibited. For the first case where the air has not de-ionised sufficiently in order to allow secondary arc extinction i.e. fire under the line, instead of reclosing, the adaptive autoreclose relay selects three phase tripping, then proceeds with a reclose signal after a settable time delay. In this case the priority returns to restoring the system, but now with an increased likelihood of success because by tripping the line all secondary arcing will be removed. The advantage is that the second voltage dip has been avoided. For the second case where a solid permanent fault has occurred i.e. collapsed tower, the adaptive autoreclose selects three phase tripping, drives the scheme to lockout and instructs 'network control' to stop further manual close attempts. Operational experience has shown operators continually close lines trying to restore supply, as many as 26 unsuccessful manual close attempts during a one hour period have been recorded.

The autoreclose cycle determines the action of the CB. By improving this cycle the lifetime of the CB can be improved, maintenance periods reduced and the break-make-break cycle reduced to break-make. Where utilities apply their CB's to duty cycles

exceeding IEC 56 which states the CB should operate O - 300ms - CO - 3 sec - CO, the application of adaptive autoreclose can allow this specification to be met.

Supplementing these two improvements with point on wave switching [6], the following advantages to the system and to the CB can now be illustrated by the following sequence:

1. On fault occurrence, the relays accurately detect the fault, and location, and instruct tripping of selected CB's within the nominal clearance time.
2. The adaptive auto-reclose relay recognizes that the fault is transient, determines when the fault path has de-energized and instructs the CB's to reclose at the earliest time taking into account air de-ionization.
3. Synchronous operation is checked across the open CB and reclosing is permitted to restore the line on load.
4. The point on wave controller permits the CB to close at the precise instant ($\pm 1\text{ms}$) to ensure minimum system transients.
5. All operating parameters for the protection, reclosing events and fault waveforms are available for analysis.

Topic 6 Integration

This topic has been included within Topic 1.

Topic 7. Setting and Operator Interface

Topic 7 Introduction

Extensive settings are required to competently set autoreclose relays. Historically, electromechanical relays would provide deadtime, close pulse, reclaim and lockout timers. Systems were designed for simplicity to close the circuit breaker. Facilities to indicate failure were not provided. Logic systems were designed to close, not to prevent closing. With the logic for autoreclose now firmly embedded within numerical relays there is emphasis on the system carrying out the autoreclose task to perform this safely.

Autoreclose sequences have evolved for each utility. Generally three pole reclose schemes are fairly simple. A single trip input, CB position indication, a setting for number of shots and some control logic are all that is required to perform an autoreclose sequence. However things become more difficult due to legacy systems and interconnection to other pieces of equipment. Utilities operational requirements also require certain engineered schemes. Single pole tripping and reclose schemes need further examination to explore the required operation for different types of fault.

Where in the past an autoreclose sequence could be left primed ready to issue a close pulse indefinitely, the facility to stop the sequence after a selectable time is now provided. Some utilities use an Overall timer, others a Sequence Fail timer. In each case either can be selected to OFF so that the system still operates in the electro-mechanical method. The question arises - Is it safe to allow an autoreclose system to be primed indefinitely? The answer to this is, yes, so long as it has been selected appropriately. Some utilities standard practice instructs engineers that if the Autoreclose In Progress light is lit, then the sequence is primed and may issue a close pulse if the right conditions occur. A common problem with this is if the trip relay fails to reset, here the autoreclose sequence may start but fails to proceed, waiting for the trip relay to reset. If the Sequence Fail / Overall timer is set then the system will lockout at the end of the timer, if the Sequence Fail / Overall timer is not set then the system will remain primed indefinitely.

Ergonomic factors for setting and operator interfaces concern the correct labeling and positioning to prevent incorrect operation. Settings tend to be named for function, or alternatively some manufacturers use numbered functions that require the understanding of the relevant technical manual.

Setting changes can normally be provided locally through a keypad interface, or remotely via communications. Commissioning of equipment is generally performed with laptop computers for convenience. From the survey results a high proportion of respondents indicate that settings are changed via remote communications.

Operator requirements determine whether the autoreclose process is to have any manual intervention. Manual closing facilities are usually provided. Equipment is required to be flexible enough to allow manual closing or to perform the task automatically. Certain utilities determine that the reclose process must be cancelled if system split occurs. The

operator then completes restoration of the system. However reclosing relays can now automatically restore the system under the correct synchronisation checks after a system split. This may be check sync, system sync or close on zero.

Other signals to prevent control (reclose, or isolation) are being provided. Switches for various functions - Inhibit Isolation, Local and Remote switching, Function In/Out switching, A/R Out switching mounted on panel, Mesh Corner In/Out switching disables any autoreclose for two or more circuit breakers, high speed / delayed 3P A/R switch, Scheme selection. 1P/3P etc., Blocking, Manual Closing set and reset, Line check – start autoreclose reclaim timer – prevent autoreclosing after the CB is closed.

A number of utilities provide a trip relay reset override, which requires special note. With electrically reset trip relays the scheme wiring prevents resetting whilst any isolator switching is taking place. Two timers are provided: one for initiating isolation such as persistent faults; the other during non-isolating sequences such as reclose for transient faults. The timers have separate settings typically 10sec and 70sec. The DAR equipment may see a second trip during the deadtime; in this case, the sequence waits for the second trip to reset before proceeding with the next action. If the trip resets before the 70sec timer then autoreclose can proceed. If the trip exceeds the 70sec timer then the reclose may be prevented, or only proceed after the faulted line has been isolated. The override switch should only be used with care, since reclose may then proceed, and the reason why the trip has not reset, say Earth Switch is closed, could still be closed, therefore getting the trip relay to reset may allow reclose onto a closed earth switch.

Certain indication features are provided within various schemes: AR In Progress, Successful Close / DAR Complete, Lockout. Condition monitoring indication directed at the reclosing facility can highlight specific problem areas, for example number of closes, or Fail indication, which can then be met with the appropriate maintenance response. Change settings, Read settings and Configuration are easily performed within modern numeric relays. Operator requirements, which have a bearing on autoreclose, are mainly the Manual Close or Override or Emergency Close controls. However switching AR Out during an autoreclose sequence should stop the sequence.

Although standards purport to show the required functionality, they do not lend themselves to the application of increased functionality. The area of autoreclose is changing rapidly and standards must cope with this.

For example UK standards have evolved from System Split causes AR Lockout, ‘network control’ to issue close command and Start System Sync; to an automated approach where the relay automatically recloses after system split with System Sync settings and CB close time. Settings within the IED are provided to cope with this.

System split has been the historical method of detecting a drift in the phase angles between a connection, an equivalent method is to detect a slip frequency greater than a setting. Either method is satisfactory, but what is more important is the closing limits when the phase angles have completed a full rotation.

Topic 7 Setting and Operator Interface Survey Results

Questions Q.89 – 92 were specifically about the Setting and Operator Interface.

Sweden indicated the required relays response to a change between two or more predefined settings via external signals. If the relay has several lists of settings, indication is needed as to which setting is active. Some utilities make use of Setting Group functions. These allow relays to be set with a number of groups during the commissioning phase. Selection between different groups can be performed during service to adapt for circuit conditions i.e. change from 1 pole to 3 pole reclose during certain weather seasons. Denmark noted the usefulness of IEC events (i.e. AR blocked, IEC 60870 130) and AR command issued (IEC 60870 128) in case of two parallel AR-devices to determine if both have performed correctly. Most utilities responded that manual closing may be initiated through the SCADA system. Finland were only interested in the unsuccessful AR (persistent fault) indication, and no other indication is required.

Ireland pointed out that for high speed / delayed three pole reclose certain options would be potentially useful. Block reclose via binary inputs is considered essential. In the interest of dependability, manual closing ought to be direct, not via the auto-recloser. Lockout indication for unsuccessful reclose is also considered useful. Signals for CB failed to open, close onto fault and VT fail are all part of the protection relay and hardly need to be duplicated. Close mode selection would be advantageous only on selected feeders.

Japan required selection for preceding / succeeding terminal; indication of final CB trip; event list giving reasons for final CB trip; indication of fault type and fault phase.. They also required indications for recloser not ready and conditions for reclose not satisfied .

Similarly Korea required station selector switch (leader or follower), circuit breaker selector switch (leader or follower), synchronism checking selector switch, remaining phase condition selector switch. They also required indications for autoreclose not ready, three or one pole trip, and relay fail.

South Africa apply a two shot single and three pole reclose scheme which requires a specific blocking of the second shot. They also require indication of Main 1 initiation, Main 2 initiation, and Main 1 + Main 2 initiation.

The UK required options for reclosure mode selection (Dead line/Dead bar/Check sync/Unconditional close). They also required an event list for lockout, fault alarms, AR In, AR Out, and closure mode (conditions under which closure took place).

The tables below are intended to summarise the various requirements. The left hand column was included in the questionnaire, and the right hand column lists the various responses.

Autoreclose Selection Switches / Settings	Survey Response
Autoreclose In/Out switching.	Generally used by all utilities.
High speed / Delayed three pole reclose.	Delayed only. High speed only?? Many application where single pole reclose is used.
Close Mode Selection. Scheme selection i.e. 1P, 3P, 1P3P etc.	Some utilities switch from single pole reclose to three pole reclose during different seasons. Finland: always 3P (or 1P rapid + 3P delayed).
Settings change via communications.	High proportion of respondents use communications within the autoreclose process.
Blocking.	Generally used by all utilities. Block second Shot.
Lockout.	
Manual closing.	Some utilities have adopted this as internal to the autoreclose relay, while others perform this function independently. SCADA only through relay.
Trip relay reset override.	
Other please specify	Reclosure mode selection (Dead Line/Bar/Check sync/unconditional close. Station Selector Switch (leader or follower). Circuit Breaker Selector Switch (leader or follower). Synchronism Checking Selector Switch. Remaining phase Condition Selector Switch. Main 1, Main2, Main 1+2 initiation.

Figure 25: Autoreclose Selection Switches / Settings

Indications	
Autoreclose In Progress.	
Successful Close.	Only some utilities use this.
Lockout.	
Other please specify	CB position. In/Out of service. Unsuccessful AR. AR blocked. Final CB trip' Fault type Fault phase Recloser not ready. Conditions for reclose not satisfied. Failure of close. Relay failure. Three/One pole trip. 1 pole and 3 pole start.

Figure 26: Indications

Public Events [i.e. part of IEC 60870-5-103]	
AR In Progress	
CB 'on' by AR	
CB 'on' by long time AR	IEC 60870-5-103.
AR blocked	IEC 60870-5-103.

Public Events [i.e. part of IEC 60870-5-103]	
Other please specify	Lockout Fault alarms AR In AR Out Closure mode (conditions under which closure took place). Reasons for final CB trip' Recloser not ready Conditions for reclose not satisfied. AR failed.

Figure 27: Events

Private Events [provided as part of relay]
Lockout
Successful Close
CB Failed To Close
CB Failed To Open
Close Onto Fault
VT Failure Alarm
CB Close Count Alarm
Sync In Progress
Sync Override
Dead Line Close
Dead Bus Close
System Split
Check Sync Start
External AR Start
Manual Close
AR Out
AR In
In Sync
Live Bus
Live Line
Dead line, dead busbar detected
Pole Discrepancy
Reclaim time expired
Isolator Open
Isolation Complete
AR is blocked

Private Events [provided as part of relay]
AR is not ready
AR is dynamically blocked
Circuit breaker not ready
Circuit breaker supervision time expired
1-pole deadtime for RAR is running
3-pole deadtime for RAR is running
Evolving fault recognition
3-pole deadtime for DAR is running
Close command from AR
Close command after 1-pole RAR cycle
Close command after 3-pole RAR cycle
Close command after 3-pole DAR cycle
Trip during 1-pole AR cycle
Synch-check is switched off
Synch-check is blocked
Synch-check is faulty
Synch-check supervision time expired
Voltage difference exceeds limit
Frequency difference exceeds limit
Angle difference exceeds limit
Synchronism release
Close command from synch-check

Figure 28: Private Events

Topic 7 Review

Generally autoreclose systems provide the facilities that the utilities require. However it is obvious that each utility has a different requirement, and this imposes upon manufacturers the necessity to design bespoke systems to those requirements.

There are no standard autoreclose interfaces, settings or events. The best that can be provided is for a list of choices that can be selected if required. This is generally achieved by a manufacturer offering, for example, an output relay menu, to which the utility will program their required selections, or a provision to load different logic schemes. This menu or logic may contain numerous other elements that may not be relevant?. This is a problem that utilities and manufacturers have yet to resolve. Some utilities are willing to accept redundant functionality others are not. This leads to a large number of relay variants for manufacturers to design. The Working Group have noted numerous different autoreclose relay variants obviously manufactured for individual customers. Standardisation would reduce costs and increase competition.

Different relays tend to exist which offer transmission autoreclose for single and three pole operation. Although single pole reclose relays may also perform three pole reclose, the type of three pole reclose may not be suitable for all utilities. Some utilities, predominately those utilizing only three pole tripping, have requirements to start the autoreclose system which differ from the start requirement of single pole reclose. Some relays offer settings to select which method is employed. Other relays are specifically designed for one purpose. Each system has to be proven to be fit for purpose.

Autoreclose systems are now being designed with communication facilities and comprehensive event details. This now allows successful interpretation of system switching operations and failures, and indicates the precise nature of the failures.

Factors used to determine settings:

Type of system.

Operational experience.

Legislation in certain countries states that reclose must be completed within a time window.

Public safety issues.

Autoreclose Settings	Range (typical)
Autoreclose In/Out switching.	In / Out
Single Pole Deadtime	0s – 10s
Three Pole Deadtime	0s – 45mins
Close Pulse	0.1s – 20s

Autoreclose Settings	Range (typical)
Reclaim time	0 – 600s
Pole Discrepancy trip	0.1 – 10s
Persistent Intertrip	1 – 600s
Overall Timer	0 – 600s
Sync Timer	0 – 600s
Block Timer	0 – 600s

Figure 29: Autoreclose Settings

Check Sync Settings	Range (typical)
Voltage Nominal	0 – 200V
Dead Line	0 – 100%
Live Line	0 – 100%
Dead Bus	0 – 100%
Live Bus	0 – 100%
Voltage	63.5 – 110 [perhaps 100/ $\sqrt{3}$ – 120] Utilities use VTs rated 100/ $\sqrt{3}$, 110/ $\sqrt{3}$, 120/ $\sqrt{3}$, and may use star or delta connections]
Line Undervoltage	0 – 100%
Bus Undervoltage	0 – 100%
Voltage Differential	0 – 100%
Split Angle	0 - 180°
Manual Close Split Action	Close On Zero, System Sync, Check Sync
Autoreclose Split Action	Lockout, Close On Zero, System Sync

Check Sync Settings	Range (typical)
Check Sync Angle	5 - 90°
Check Sync Slip	10 – 2000mHz
Check Sync Timer	0, 0.1 – 100s
System Sync Angle	5 - 90°
System Sync and COZ Slip Frequency	10 – 2000mHz
System Sync Timer	0, 0.1 – 100s
CB Close Time	5 – 200ms

Figure 30: Check Sync settings

Topic 7 Conclusion

Utilities have applied engineered systems to autoreclose that have included the required Setting and Operator interface. Switches can be provided to select various operating selections, for example close mode 1P or 3P; or high speed or delayed. Other functions can be enabled or disabled as required, such as AR In / Out. Relay settings can now be changed via the front keypad or communications. Different practices are evident from the survey returns and relays cope with this by providing flexible setting ranges, I/O and programmable logic. Generally manufacturers provide the type of settings and operator interface that is required by the utility.

Topic 7 Recommendations

Setting and Operator interfaces are allowing communications to cope with the autoreclose sequence. Advantages provided by the relays will only change operating procedure if they are encompassed by utilities.

Topic 8 Testing

Topic 8 Introduction

Auto reclose and protection relay testing is necessary to assure the user that the equipment will perform in the intended manner during a system short-circuit, with no surprises. Testing is performed at the commissioning stage, and later at periodic intervals. The extent and timing of testing is primarily governed by the nature of the tested object and the existence or otherwise of in-built self-monitoring features. The more comprehensive tests encompass not just the relay device itself, but its connections to the HV plant, and in many cases the connections to the communications equipment. Since fully comprehensive testing can only be achieved during a circuit outage, and since prearranged outages often need to be cancelled for operational reasons at short notice, there is a tendency to perform less searching tests. Allied to this, HV testing can tend to be a very special and socially unfriendly activity, limited as it often is to off-peak load valley periods, often in remote locations. It follows that testers are invariably under pressure to work faster, mechanise tasks, minimise wasted time, and complete the task within the allocated feeder outage.

There is very little margin of error for HV tests, and no place for careless practices that may place the HV system in jeopardy. It can also be said that the frequency of testing can directly contribute to the quantity of unwanted trippings. For all these reasons utilities may want to minimise the invasive aspect of testing, but in any event it is mostly categorised as a necessary evil, and something to be entrusted to a few highly experienced practitioners.

GPS-synchronised end-to-end testing is a powerful tool to prove the viability of (almost) complete systems including communications links, and also to permit reconstruction of fault sequences based on stored fault recordings. The task of the GPS device is merely to initiate the test sequence simultaneously ($\pm 1 \mu\text{s}$) at all ends. The great value of such tests lies in the repeatability. Of course such tests do not include the primary side of instrument transformers.

Topic 8 Survey Results

Whether GPS is applied for testing AR sequences (Q.73):

GPS is not applied for this purpose by the following countries /regions: UK, Sweden, Denmark, Western Australia, Finland, Tasmania, Belgium, Netherlands, India, Spain. But it is used by Germany, South Africa, Ireland. Japan uses GPS to create simultaneous faults during equipment operation testing, but they do not use it for AR.

Whether problems are associated with testing AR (Q.93):

The UK experiences problems because of the complexity of the AR system and the difficulty of obtaining operation clearance to perform a test. Problems are not experienced by Sweden, South Africa, Denmark, Western Australia, Finland, Tasmania, Belgium, Netherlands, India, Japan, Spain, Ireland. Ireland states that testing each end independently presents no problem, but such tests are not fully realistic.

Germany indicates that there is no testing problem, only a problem of getting the line out to test the AR with the circuit breaker. Japan comments that they need test equipment to test the AR sequence – it is implied that availability of this is a problem.

Whether specialist test equipment is required to test the AR sequence (Q.94):

Not used by Denmark, Western Australia, Finland, Tasmania, Netherlands, India, Japan (most utilities), Spain. Germany reports that modern test sets (e.g. Omicron) provide all facilities for detailed testing; Denmark and Belgium comment similarly. Specialist test equipment (sequence programmable test set) is utilised by Ireland (same equipment as for relay testing; requires knowledgeable test persons!), South Africa, Sweden, Japan (one utility). UK reports that specialist equipment is supplied for testing mesh type systems (Q.94). India uses an experienced test engineer, sometimes with help from the manufacturer's test department. No response made by Korea. One utility in Japan comments that specialist equipment is not required for performing an AR sequence test on the local end; another comments that a model of the circuit breaker is required.

Whether end-to-end tests are specified for AR (Q.95):

This question is strongly related to Q.73 as presented above. Such tests are specified by UK, India (one utility), Japan (three or four utilities). They are not specified by Sweden, South Africa, Denmark, Western Australia, Finland, Tasmania, Belgium, Spain. Ireland uses them for special investigations but may consider them at a future date for more routine application. They are used only when commissioning critical lines by Germany. Netherlands specify such tests for commissioning and after refurbishment. India (a second utility) reports just one demonstration trial, but as such tests require special equipment they were not subsequently introduced; omitting the tests has not given any known disadvantage. No response made by Korea. Such tests are apparently not applied by most utilities in Japan.

Whether AR tests are performed periodically (Q.96):

Periodic tests at an unspecified interval are performed by UK. Tests are performed every fourth year by Germany. South Africa performs maintenance test every two years and a commissioning-grade test every five years. Ireland tests every two years for 400 kV and 220 kV but every five years for 110 kV. Ireland clarifies that AR is tested when testing protection relays provided the breaker can be made available. Denmark (one utility) tests mechanical relays every second year and numerical relays every fourth year. Denmark (second utility) tests electromechanical relays every fifth year, static relays every third year, and expects to test numerical relays thoroughly every eight to ten years. Western Australia tests every five years. Finland tests older 400 kV installations every year, and modern 123 kV installations every three years. Tasmania tests relays every six years. Netherlands tests relays every year. Sweden (one utility) performs tests every three to four years. Sweden (second utility) tests modern numerical protection with integrated AR and synch check every eight years. India tests once a year or sometimes twice a year depending on the relay behaviour during a fault. Korea tests once per two years in general, once per year for older relays, and once per year for numerical relays. Ten utilities in Japan test relays every six years more particularly the numerical designs, but at least one of these utilities test analogue relays every three years. Spain does not test periodically, instead they do corrective maintenance.

Topic 8 Review

The questionnaire requested specific information about the testing of auto reclosing sequences, but most of the responses did not adequately distinguish between general relay testing and auto reclosure testing.

In general, most users claim not to experience problems with the testing of relatively simple auto reclosing sequences, but rather the problem is simply the difficulty of getting feeder outages for the necessary testing work. Having said that, some auto reclosing schemes are so complex that there appears to be a natural reluctance to make the effort to periodically test them, relying instead on actual HV system faults to pinpoint weaknesses.

The impression is formed from the replies that the effectiveness of auto reclosing is, in two out of three cases, routinely verified by testing each end independently rather than as a scheme. It can be argued that such tests, while useful to detect many defects, are limited in their capability to test the complete scheme, and in particular the all-critical actual dead time. The actual dead time is of course dependent on equipment performance at both (or all) line ends, and any encroachment on dead time may inhibit arc extinction and result in unsuccessful reclosure. According to the responses, only one in three users conduct end-to-end tests of auto reclosing. However, such a simple statement grossly misrepresents the true situation, because it fails to distinguish between commissioning tests, special investigation tests, and routine tests. It seems fair to conjecture here that few if any users apply end-to-end tests for routine maintenance purposes, despite the technical advantages, preferring instead to reserve them for special investigations and the more challenging commissioning tasks.

Remarkably, only a handful of utilities testing auto reclose sequences appear to supplement end-to-end testing with GPS synchronisation of secondary injection tests. While relatively costly in manpower and resources to test protection in this manner, it adds a level of realism – especially for auto reclosure - that cannot be approached by more traditional testing techniques. It may be argued that it is chiefly relevant for once-off commissioning tests, or for special protection schemes, but the opinion is expressed here that unless auto reclosing is known to have a reliability comparable with protection tripping, then a valid case can be made for the more routine application of synchronised end-to-end testing. The benefits accrue not just to auto reclosure, but to the complete protection and communications systems. In the view of at least some utilities, the performance of auto reclosing falls short of requirements. Various reasons can be put forward for this situation, but the more interesting observation to make here is that numerical relays may contribute to the phenomenon because of processing delays at binary inputs under HV fault conditions. An example might be where a relay consigns a lower priority to the processing of binary inputs during a processing-intensive HV fault sequence, and where a binary input provides information on a circuit breaker status or readiness to reclose.

The definition of what constitutes a ‘special’ test set is open to interpretation, and little distinction is made between relay testing and auto recloser testing. But it is clear that the commonly available test equipment is generally satisfactory, consisting mostly of sophisticated programmable sequence test sets - in the hands of very experienced users. Or alternatively, at least with test sequences created originally by very knowledgeable

individuals, and implemented in the field by experts thoroughly familiar with the test tools and the expected system responses to the test stimuli. So in a sense, a given test set can be applied at different levels of sophistication depending on the expertise of the user. A highly experienced user will set up test sequences that can search out those equipment and timing anomalies that result in unexpected failure of auto reclosing. Apart from periodic routine testing, such equipment and expertise is more particularly applied for detailed investigation of unsuccessful reclosure sequences.

Periodic routine tests are performed for auto reclosing, with little or no distinction made between testing the auto reclosing itself and testing the rest of the protection equipment. The chosen test intervals vary widely depending on the philosophy and experiences of the individual utilities, the voltage levels involved, the circuit importance, the age or condition of the installed protection, and the mix of protection designs between numerical, static and electro-mechanical. With such a large number of variables for consideration, no consensus can be discerned. But test intervals stretch from twice a year at one extreme to eight years at the other extreme. In an intelligent compromise, two-tier testing is performed by just one utility, with regular tests at two years and in-depth tests at five years. One utility does not perform routine testing at all, relying instead on corrective maintenance. Again, especially if the occurrence frequency of HV faults is high, this philosophy can be a perfectly valid response.

Topic 8 Discussion /Conclusions

GPS synchronised end-to-end testing is the ultimate tool to determine weaknesses in auto reclosing systems, and indeed in the total protection system. The pressure on feeder outages, the scarcity of experienced test personnel, the determination of utilities to reduce maintenance costs, and the inherent risks in testing, may together form a strong disincentive that discourages utilities from investing resources in more advanced testing. It is to be hoped that this trend will reverse and that the merits of this powerful tool will cause it to be applied on a more routine and systematic basis for the elimination of hidden defects, more especially those that give rise directly to critical second contingency situations.

Topic 8 Recommendations

Utilities are encouraged to commit to more advanced mechanized testing of auto reclosing sequences and protection relays generally, unless the performance of such systems is already demonstrably at the highest level.

Topic 9: Local System Restoration

Topic 9 Introduction

There was a limited response to this topic, indicating a scarcity of information about system restoration.

Local system can be defined as: A local system comprises a limited number of substation or a limited area, or parts of those structures. Where local system restoration is part of global grid restoration system, it is not possible to express an absolute distinction between the systems.

Restoration can, in this respect, be defined as: Restoration means to return the system back to an acceptable, healthy, operating condition as quickly as possible, excluding circuits or items of plant with permanent faults.

The automatic restoration of a power system to an operating condition following a power system fault may be a relatively simple or complicated process depending on the complexity of the power system and the severity of the system disturbance, which may result from the fault condition. The actions required, additional to what may be performed by automatic reclosing, may include the following:

- The automatic restoration to service of healthy circuits or items of plant which, due to economy in the provision of circuit breakers, may become disconnected from the system by the tripping required to effect the disconnection of faulted circuits or items of plant. Such automatic restoration action is coupled with action required to effect the automatic isolation of faulted circuits and plant through operation of associated isolators.
- Some countries introduce zero-voltage tripping of feeder, bus coupler and bus section circuit breakers as a means of facilitating the rapid restoration of the healthy part of the system. The circuit breakers are automatically tripped if the system voltage remains below a pre defined voltage for longer than a specified time, which must be chosen to be longer than the automatic reclosing time. Having thus ensured that all affected circuit breakers are open, the affected parts of the network are automatically restored in a pre-programmed manner with appropriate voltage and synchronizing checks.
- The automatic switching of standby circuits or plant following loss of a circuit or item of plant due to fault.

Topic 9 Review

Current application:

- 50% of utilities in the survey reported the use of local restoration equipment.
- Among the respondent utilities, restoration is most commonly achieved by means of local control actions, rather than by centralized intelligence.
- Restoration normally starts automatically when automatic reclosing fails.

- No problems are reported.

Automatic reclosing improvements will reduce the requirement of restoration when dealing with larger scale disturbances. Optimization of reclose characteristics to improve system performance include automatic reclosing after islanded fault, flexible time graded schemes, adaptive recognition of types of fault, indication of fault type, and slow CB detection. Check sync deadtime override facilities allow the circuit breaker to close without waiting the required time setting when the system is determined to be in synchronism.

System restoration facilities exist to time grade reinstating items of plant. This could simply be achieved by closing a circuit breaker a certain time after one side of that breaker becomes live, thereby allowing each item of plant to be consecutively energized in turn. Other procedures exist to help restoration, such as by opening Dead Line Dead Bar circuit breakers after set time, as practiced by EDF.

Where restoration has failed due to excessive phase angles or inadequate time windows, modern equipment can cope better. Manual closing through common equipment that includes the reclosing and check sync functions can save expense and provide benefits to the closing sequence..

Mesh auto reclose and auto-isolation of persistently faulted plant is intended to reclose after persistently faulted items of plant have been identified and isolated. Operational experience in the UK is excellent.

Low Speed Reclose (Japan) is intended for automatic system restoration. The low speed reclosing device uses different hardware from that for the high speed reclosing device. Organisationally, low speed reclose is a distinct responsibility that does not fall within the protection sphere. The no-voltage time is set for 60 seconds to allow for the circuit breaker operating duty.

Reference is made to [Cigre TF 38.06.04] which referred to at least 20 Centralised Restoration systems that were either at the development state or in operation.

What follows is a brief description of a novel frequency dependent automatic load restoration scheme, primarily intended for islanded networks³, and extensively installed in Ireland.

The scheme is intended to reclose all distribution feeders that had earlier been tripped by load shedding relays as a consequence of a generation deficit. The design is such that it will not reclose feeders opened for any other reason. The frequency based restoration scheme is entirely separate from the frequency based load shedding scheme, although some essential information is exchanged between both. For example, when a load shedding trip occurs, the restoration scheme becomes fully armed, with the result that all

³ System response during frequency dependent automatic load restoration. T. D. Brosnan et al. Cigre General Session, 1984, Paper No. 34-11.

feeders which trip are identified, and this identification is retained in storage until reclosure is eventually achieved, automatically or manually. Such storage is one of the mandatory conditions for initiation of automatic frequency based restoration.

This automatic reclosure is achieved right across the network in the optimum time, that is, as soon as the system can re-support the shed load. It is designed as a distributed system, with the restoration equipment in each station physically independent of all other stations, but of course with settings co-ordinated system-wide. In any given station the restoration scheme is centralised, in its own cubicle. The concept is simple: system frequency is the measured parameter, and when frequency recovers to 49.8 Hz restoration begins. Time co-ordination between the eighty or so independent and geographically distributed HV stations that participate in the restoration process is simply achieved – the common time reference datum is recovery of frequency to 49.8 Hz.

Each feeder that can be potentially tripped by load shedding is pre-allocated a restoration time on its Sequence Delay Timer. These time settings are staggered at 5 s intervals in an overall range 0 – 360 s, providing over 70 steps system-wide in the restoration process. Regardless of geographical location, these timers all begin to time-out at the same instant, that is, the instant at which frequency first recovers to 49.8 Hz.

The scheme has several refinements. A variety of frequency and time based features are incorporated to ensure that the scheme will only respond to meaningful and sustained frequency excursions. For example, it is not enough for the frequency to recover to 49.8 Hz, but it must remain above that value for a defined Initial Delay Time (9 s). Ideally the rate of restoration of system load should match the rate of increase of generation. Excessive load restoration forces system frequency below 49.8 Hz, the restoration point. Then restoration is suspended and does not re-commence until additional generation has restored the frequency above 49.8 Hz. During this restoration pause the Sequence Delay Timers - these are integrating timers - do not reset to zero. The timers pause, and when frequency recovers they continue to time the sequential delay. Thus the restoration queue pauses, and moves forward, in an orderly manner. The use of integrating timers ensures that the Sequence Delay Timers only summate those time intervals where the frequency exceeds 49.8 Hz; this feature considerably enhances the scheme design and gives the settings a clearer focus.

When the rate of load restoration exceeds the rate of generation increase, a load restoration pause on its own may not be sufficient for smooth restoration. If the system frequency is forced down to 49.0 Hz, a significant frequency drop, the 9 s Initial Delay Time is re-introduced before restoration is permitted to continue. The Sequence Delay Timers continue to hold their position and do not reset.

The scheme has an Action Time and a Cycle Time. The Action Time (setting 29 minutes) is the period allowed for completion of a restoration sequence, once started. The Cycle Time (setting 30 minutes) is intended to define the point at which the scheme fully resets, whereupon it is once more available should further restoration be demanded. The distinction between these two timers is chiefly related to the practical issue of achieving an orderly reset. The Action Time and Cycle Time are started by the Initial Delay Timer, and so are not prematurely eroded before the network is ready to accept load.

Considering the original experimental nature of the concept when it was first implemented in 1982, all settings have wide setting ranges. But in fact performance has been so good that this flexibility has not been invoked.

The concept has been so successful that in year 2001 the original electro-mechanical design was translated verbatim into PLC logic, where it is integrated into bay level numerical protection /control devices as part of a standardised substation control system for the next generation of substations.

Topic 9 Recommendations

The functions available in individual relays have been provided because they are deemed useful. For example, the lockout alarm signal is driven from several deficiencies. The SCS (substation control system) local restoration system should make use of all the reasons to effectively pinpoint problems, in contrast to the old SCADA system which gave minimal common alarms. SCADA was limited by hardwired contacts.

If the SCS systems mimic the older SCADA information then only minimal information about system failures will be provided. Modern autoreclose relays provide detailed information as to why systems fail, and it would be useful to use this data to quickly restore systems. With traditional methods it may take a significant effort to resolve the underlying problems. It is possible that the events from individual relays can be accessed and utilized in the restoration process.

If the Operator has the information to hand e.g. CB problem Feeder X, or Earth Switch Failed Feeder X, then the appropriate action can be implemented to avoid closing Feeder X. If this information is not known subsequent restoration attempts may fail, whereas choosing another approach may allow the system to be restored, or alternative actions taken to retain supply. In short, the indication of the exact problem can result in quicker restoration.

General Report Conclusion

The report has highlighted the complex nature and variety of autoreclose practice throughout the world.

Practically all the emphasis within the industry is on automatic reclosing. At present, very few utilities practice local automatic system restoration. Reclosing practices tend to be more sophisticated and complex in countries that minimize the installation of expensive EHV circuit breakers (meshed busbars, UK) or 1½-breaker schemes (widespread). High-merit systems are also very successfully applied to double-circuit feeders (multipole AR, Japan and Korea), and could usefully be exploited in many other world regions..

There are no International Standards for Autoreclose. Agreement would be difficult to achieve, so there are only local specifications and working practices. Due to the application of autoreclose around the world being driven by local opinion, there have been different operational logic sequences developed. Generally manufacturers have been able to provide standard relays which can be engineered or set to accommodate these differences. This might entail a bespoke designed logic scheme or settings within a relay to select the required operation.

Numerical methods in measuring frequency can assess the slip frequency between two voltage sources. This provides the ability to adjust the system synchronising close signal to take into account the circuit breaker close time resulting in an effective close at zero phase difference.

System operators are now reducing their requirements to close the circuit breaker after system splits and are now allowing automatic reclosing to proceed with closing at different settings. Previously when a system split occurred the system would lockout, Control would receive the system split alarm and take the appropriate action – manual intervention to select the system sync operation. This operation is now being carried out automatically and requires a number of settings to allow changes in operation: on occurrence of a system split during an autoreclose sequence the choice is either Lockout the reclose, or reclose by System Sync. Where the choice is selected to lockout, the manual close operation after a system split can be chosen to be Check Sync or System Sync; where the choice is reclose by System Sync the autoreclose sequence will close by system sync. Additional features can automatically revert back to Check Sync after a System Sync attempt.

Constraints to operating practice include tripping schemes, Safety and Litigation issues. The type of tripping scheme dictates the application of which type of reclose scheme to choose. Further aspects to consider are the safety issues and electrical possibilities. Utilities have reported the environmental position and proximity to people will have a bearing on the reclose sequence, with the priority given to safety issues. Standards of circuit breaker duty need to be upheld in line with manufacturers recommendations.

Litigation issues are becoming a concern, especially with the de-regulation of electricity providers. Legislation in some countries applies restrictions to the reclose delays and number of shots. Preventing voltage dips is seen as a means of reducing a measurable quantity by Regulatory bodies. Reducing system outages and duration is a direct improvement for system quality. Autoreclose can play a significant part in this.

Adaptive relays have shown the capabilities to correctly distinguish types of fault which would cause unsuccessful reclose. These reported algorithms are emerging from research into the substation environment and can improve the autoreclose success rate.

Differentiating between the types of permanent fault has been proved possible, allowing different control strategies for solid mechanical faults and continued secondary arcing. Here, single pole reclose would be inhibited if the secondary arc does not extinguish, the line would be tripped three pole and reclosed, eliminating the single pole reclose; whereas for solid faults no reclose will be allowed. Other possibilities for Adaptive algorithms include detection of incorrect trips, which can help to minimize outage time; Adapt control of breaker poles during single pole energisation to minimize transients; Adjust number of reclosing shots depending on fault current magnitude.

Setting and Operator interface requirements for reclose systems can benefit from modern communication mediums. Traditional alarm panels are being replicated within the communications interface. Additional information is available to help diagnosis.

Although a number of utilities reported a reluctance to expand on the alarms provided, indicating there is no reason to complicate matters. The additional alarms can give exact cause of failure i.e. Check Sync Phase out of limits; or Lockout due to Evolving Fault.

Standard testing practises for reclose systems generally involve some type of end to end testing, which may involve final live testing. It is envisaged that end to end testing will become commonplace in the testing of autoreclose schemes, possibly with the use of GPS equipment.

Local System Restoration systems are applied throughout the industry and normally start automatically when automatic reclosing fails. Some applications of automated systems came to light, but a limited response indicated this as an area which is still to be deployed with modern systems. Substation restoration schemes are prevalent but total system schemes are not. Zero-voltage tripping of feeders in order to facilitate restoration is practiced to rapidly restore healthy parts of the system. Isolation of faulted plant in Mesh and Teed circuits before auto-reclose is widespread. Automatic switching of standby circuits or plant following loss of a circuit is also used.

Reclosing practice at generator stations has raised the concern of generator shaft torque stress, which has been a high profile subject over the last few decades. Autoreclose practices have attempted to deal with this and generally there is less concern with this issue now. Concerns were raised as to the unnecessary shortening of the shaft life, and because of this, restrictive forms of autoreclose have been applied.

The Report has shown that Utilities are content with their auto-reclose schemes, and accept success rates that are not totally successful. A number of new techniques have emerged: Changes to Autoreclose schemes and Logic; Check/System Sync Improvements; Frequency measuring algorithms; High Speed Grounding; Poly Phase Reclosing; Adaptive Autoreclose, and combinations of these can make a significant benefit in increasing the level of successful reclose. Additional failure information can provide the guide as to the type of Control strategy to deploy. There is a complacent acceptance of the efficiency of autoreclose due to the belief that there is no way to tackle permanent and unsuccessful reclose. To further improve the efficiency, Utilities must adopt these newer technologies and review their existing working practices. This is where statistics of relay operation can help to persuade Utilities of the need to improve. The goal should be not to close unless the restoration is going to be successful.

Appendix A: Survey Questions

- Q.1 Are your circuits predominately single or double circuit?
- Q.2 Do you apply Single Pole Reclosing or/and Three Pole Reclosing to the Transmission system?
- Q.3 Why do you choose to have a) one pole b) three pole or c) multi-pole automatic reclosing?:
- Q.4 With / Without Check Sync:
- Q.5 Why do you choose to have a) single-shot or b) multiple-shot?
- Q.6 Station bus arrangement(s) used?
- Q.7 Are there any specific automatic reclosing problems associated with your scheme arrangements?
- Q.8 Please state typical settings applied?
- Q.9 Are there any particular factors taken into consideration when setting these timers?:
- Q.10 Do you experience any applications with automatic reclosing, which do not have standard numerical relay solutions?
- Q.11 Are there any public safety issues affecting the reclose settings?:
- Q.12 What are the overriding factors when selecting the Reclose Delay Setting?
- Q.13 Do currently available automatic reclosing /Check Sync relays provide enough setting flexibility or accuracy?
- Q.14 If No what improvements could be made?
- Q.15 What smart additional functionality, if any, should automatic reclosing relays offer?
- Q.16 Are there any faults, which do not initiate reclosing?
- Q.17 Would you apply smart automatic reclosing relays?
- Q.18 Do you use integrated automatic reclosing and Main Protection?
- Q.19 Level of integration of closing system – with protection IED(s) and/or with control IED?
- Q.20 It is generally a requirement of automatic reclosing to use Check Synchronisation. Do systems use integrated automatic reclosing and Check Sync functions or is there some reason why integrated relays are not specified?
- Q.21 Do you apply Check Sync at each Circuit Breaker, or do you select a automatic reclosing strategy to reduce the number of Check Sync relays?
- Q.22 Integration of automatic reclosing and Check Sync?
- Q.23 Statistics of successful automatic reclosing in percentage?
- Q.24 Where the statistics of automatic reclosing indicate a low success rate, can you indicate what measures would be necessary to improve them?
- Q.27 What benefits would more successful automatic reclosing bring?
- Q.28 Do you inspect the line when the automatic reclosing has been unsuccessful?
- Q.29 What types of fault cause unsuccessful automatic reclosing?
- Q.30 Would an indication to fault type be useful?
- Q.31 Do you use dual or single automatic reclosing functions? i.e. If 2 main protections would both be fitted with automatic reclosing?
- Q.32 If Yes how would priority be given?
- Q.33 For high resistance faults what do you do? Autoreclose or Block?

- Q.34 What level of fault resistance would you choose to block automatic reclosing and why? This will be different for each network?
- Q.35 Would a feature that blocks automatic reclosing if the next fault is at the same distance to fault as the previous fault be useful?
- Q.36 When the automatic reclosing sequence goes to Lockout would a feature, which told the user why that relay had gone to Lockout be useful?
- Q.37 Would you find the following Lockout indicators useful?
- Q.38 Do you investigate when the automatic reclosing sequence goes to Lockout? Please specify
- Q.39 How is the automatic reclosing sequence started? Please also specify Single Pole, Delayed or High Speed?
- Q.40 Manufacturers are offering relays which incorporate automatic reclosing, Check Sync and Manual Closing facilities, thereby offering a complete Closing solution. These offer a number of advantages over older schemes, which used interconnected relays. Would you be willing to use these schemes?
- Q.41 Would you duplicate the Manual Close wiring to close the CB directly as well as through the automatic reclosing relay?
- Q.42 If the automatic reclosing equipment is switched out, do you want the Manual Close feature to still be active?
- Q.43 Where a feeder consists of part overhead line and part underground cable, what approach do you take to automatic reclosing? Have you utilised or considered distance relays that attempt to discriminate between faults on the two types of feeder, with a view to determining whether automatic reclosing should be released? Alternatively, do you equip the cable section with feeder differential protection (CTs at both ends of the cable), not so much to trip, but to block the automatic reclosing relays?
- Q.44 In the case of HV lines with an intermediate tapped load (e.g. a directly connected transformer, with no local circuit breaker), is automatic reclosing permitted? Is it allowed only for transformers below a certain rating (state rating)? If automatic reclosing is permitted, confirm that it is invariably three-pole?
- Q.45 In the case of series compensated lines, do you allow automatic reclosing? Single-pole or Three? Depending on whether the capacitor protective air gap is likely to flashover, are coordinating measures necessary at the series capacitor control circuit?
- Q.46 With single pole automatic reclosing, during the time that the conductor is open ground currents circulate in the network and potentially these may react with ground fault relaying. What precautions do you take to avoid problems?
- Q.47 Where you apply single pole auto-reclosing, to what extent do you take the tower footing resistance into consideration? Or are you satisfied that if earth wires are installed this effectively alleviates the problem of the occasional few 'bad' towers in a line of adjacent towers? Have you ever decided not to install single pole tripping/reclosing because of a concern about tower footing resistance?
- Q.48 Have you successfully applied this form of automatic reclosing?
- Q.49 Do you have practical experience of these issues at HV, EHV or UHV? Have you experience that would indicate that these concerns only apply at UHV, and /or for extremely long lines? Have you intentionally avoided the issue by installing only

single-circuit lines? Or have you intentionally avoided the problem by transposing the conductors? For untransposed double-circuit lines of a voltage level where the above conclusions are valid, have you solved the problem by temporarily grounding the faulted conductors?

- Q.50 For breaker-and-a-half schemes, the tripping of two breakers for a line fault causes a triple split at that station end, and precautions are necessary to prevent inadvertent coupling of non-synchronous systems. One solution (Evans, 1980) is to reclose the first breaker via a dead line check interlock, and then to reclose the second breaker via a synch-check device. But recognising that the first breaker may be temporarily unavailable, it is essential to also give the second breaker an opportunity to reclose via a dead line check interlock. The trick is to slightly increase the dead time on the second breaker in order to avoid contention. But any such delay slightly extends the dead time. Do you implement these design features? Or have you a different strategy?
- Q.51 Do you use such logic, or do you see a need for using such logic?
Included as standard within relays.
- Q.52 Do you consider cost versus benefit when using automatic reclosing equipment?
- Q.53 Do you use FACT devices?
- Q.54 Does the use of FACT devices impact on the use and/or performance requirements of automatic reclosing?
- Q.55 If yes, How?
- Q.56 Does the use of FACT devices ease the requirements of automatic reclosing?
- Q.57 Will the availability and functionality of modern communications affect your automatic reclosing philosophy?
- Q.58 Are there opportunities to adapt deadtime and lockout settings using LAN/WAN networks technology?
- Q.59 Do you use time graded automatic reclosing?
- Q.60 Is simultaneous closure of circuit-breakers after a fault a problem? If yes do you use communication systems to avoid this?
- Q.61 Possibly still time graded if LAN/WAN out of service?
- Q.62 Can using LAN/WAN accelerate the automatic reclosing sequence?
- Q.63 Is a priority blocking scheme required when using LAN/WAN automatic reclosing control?
- Q.64 Is synchronization information provided over LAN/WAN?
- Q.65 Would Autoreclose control be exercised over the LAN/WAN?
- Q.66 Are you willing to use modern communications to provide automatic reclosing control?
- Q.67 Do you use GPS within the context of automatic reclosing?
- Q.68 Would time scheduling of automatic switching activities be useful?
- Q.69 Would time-stamped events be useful?
- Q.70 How is system restoration completed for Double Circuit faults?
- Q.71 Does this cause a problem?
- Q.72 Would GPS time controlled automatic reclosing help to improve your system?
- Q.73 Do you use GPS testing of automatic reclosing sequences?
- Q.74 GPS receivers can be applied - in conjunction with appropriate algorithms - to measure the phasors at all ends of a feeder, in real time, and in this way the phase

angles are measured on a common reference, and phase angle differences can be derived. This can just as easily be applied to derive the positive sequence quantities rather than the phase quantities. Can you foresee any applications for this new technique in the area of auto-reclosing?

- Q.75 GPS based adaptive out-of-step relays have been promoted as research projects in recent years (V. Centeno et al, 1993), and the stated objective is to block tripping, to cause tripping, or to confirm that successful automatic reclosing would be effective in achieving a stable swing. Are there any practical applications of this principle in service on your networks?
- Q.76 GPS receivers allow synchronised sampling across a network, and this in turn allows voltage phase angle differences, real and reactive power, and other parameters to be measured in real time across system components such as transmission lines (R. J. Murphy et al). Would there be value in allowing any such measurements to be taken into account by a smart automatic reclosing relay? For example, following a trip, the measurement of a phase angle difference exceeding the setting of a synch-check relay would suggest that automatic reclosing should not be attempted as it would be unsuccessful. Or if the phase angle difference is very large, the shock to the system might not be acceptable at that time, depending on other measured system data. Or if the load is light the advantage of automatic reclosing may be minimal. Or again, the direction of power flow may be worth considering. Can you see any value for such sophistication on your networks?
- Q.77 One possibility for adaptive automatic reclosing may be to apply it in conjunction with a fault locator. While not essential, the fault locator design could be based on GPS-synchronised phasor measurements. In such a system the circuit breaker furthest from the fault would be directed to reclose first. Would you be in favour of such sophistication?
- Q.78 High-speed real-time voltage phase angle measurements are mentioned (Cigre 38-104 /1994) as a possible means of detecting islanded sections of a network, and could be applied to prevent the accidental reconnection of unsynchronised parts of a system. Have you any views on such a possible application?
- Q.79 Have you at any time experienced problems with GPS (e.g. availability, coverage, accuracy, jamming, weather related obstruction, etc.) that might cause you to be hesitant in placing greater reliance on that technology for protection relaying purposes?
- Q.80 Do you employ/offer adaptive control techniques?
- Q.81 Would you consider using adaptive control techniques?
- Q.82 Which adaptive techniques do you use?
- Q.83 Is automatic reclosing integrated within the protection or substation control equipment?
- Q.84 Do you use integrated systems?
- Q.85 Do the integrated schemes replicate exactly how the previous schemes performed?
- Q.86 Do they perform as effectively as stand alone relays?
- Q.87 Are there any disadvantages of integration?
- Q.88 What do you perceive to be the advantage of integrated systems?
- Q.89 Which of the following selection options/switches do you require?
- Q.90 Which of the following indications do you require?

- Q.91 Which of the following events do you require?
- Q.92 Private events?
- Q.93 Do you experience problems associated with testing automatic reclosing?
- Q.94 Do you require specialist test equipment to test the automatic reclosing sequence?
- Q.95 Do you specify the use of end to end tests on your automatic reclosing equipment?
- Q.96 Do you test periodically, or at all, how often?
- Q.97 Do you use Local Automatic System Restoration?
- Q.98 Do you use any automated features of system restoration?
- Q.99 Are existing restoration systems successful?
- Q.100 Do you start/stop the restoration sequence?
- Q.101 Is the restoration sequence controlled locally or from a central control point?
- Q.102 Is local system restoration started after an automatic reclosing attempt has failed?
Or how?
- Q.103 What is the behavior of embedded generation systems with respect to automatic reclosing functionality?
- Q.104 Are any problems encountered?
- Q.105 Are there any particular faults which cause automatic reclosing problems in context to power quality issues?
- Q.106 Automatic reclosing onto faults causes voltage dips/sags on the system. How disruptive do you view these dips/sags?
- Q.107 Is there a voltage quality issue with your automatic reclosing sequence?
- Q.108 Do you think that automatic reclosing has an effect on power quality? Is this dip duration or occurrence of dip?
- Q.109 Do you consider power quality requirements when setting the automatic reclosing equipment? number of shots, deadtime etc.
- Q.110 Have you been forced to change your automatic reclosing practice to take account of power quality issues?
- Q.111 Do you experience any problems with automatic reclosing not covered in any of the above questions?

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