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Auto-reclosing

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The prerequisites for auto-reclosing are discussed and a general survey is given of the factors influencing the choice of single-phase or three-phase auto-reclosing, dead time, number of reclosing shots, etc.

The auto-reclosing of power lines has become a generally accepted practice. Reports from different parts of the world show that in certain networks in regions subject to a high lightning intensity only about 5 per cent of the faults are permanent. Auto-reclosing therefore provides significant advantages. Outage times will be short compared with systems where station personnel have to turn out and re-energise the lines after a fault. Such emergency visits often entail long trips at inconvenient hours and in bad weather, which will have as consequence a long outage time. Personnel can be saved if several substations can be unmanned. It is also possible to reduce the number of emergency visits to unmanned substations provided merely with alarm transmitters, if they are equipped with an auto-reclosing system.

In other words, auto-reclosing reduces operating costs and improves the reliability of service of the network. In the case of transmission lines between network sections with their own generating facilities auto-reclosing is generally justified with respect to the network stability.

The choice of one or more reclosing shots, high-speed or delayed (low-speed) auto-reclosing, single-phase or three-phase auto-reclosing depends on many factors. Some of these will be discussed in the following.

Fault types

Transient faults

A characteristic feature of transient faults is that they either disappear after a short dead time or that they disappear quickly without any action being taken.

Lightning is the most usual cause of this type of fault. The overvoltages induced in the lines generally cause flashovers across the insulator strings. The arc seldom extinguishes on its own. This means that the line must be tripped for de-ionisation of the fault path and can then be re-energised, without the fault recurring.

In this context it can be mentioned that double circuit lines on common towers are sensitive to lightning faults, since roughly every other lightning stroke affects both lines.

Other transient faults may be caused by swinging conductors contacting each other due to high winds or the shedding of ice. Unfortunately, conductor swinging due to ice shedding has the characteristic that the conductors of different phases may contact each other several times in succession and the fault can then be interpreted as a permanent fault.

Birds, temporary contact with foreign objects such as trees, etc., can also cause transient faults.

Differences in climate, lightning intensity, ground conditions, voltage level, line design, etc., have the consequence that the number of transient faults varies considerably. On an average it is estimated that about 80 to 85 per cent of all line faults are transient and that successful reclosure is obtained with the first shot.

Semi-permanent faults

A semi-permanent fault requires more than one de-energised interval, in the following called dead time, before it disappears.

A fault of this type may be caused by, for example, a tree branch falling on the line. It is burnt up by the arc when the line is re-energised.

A further 10 per cent or so of all reclosures are consequently successful with the second shot. If a third shot is made, only a further 1 to 2 per cent of the reclosures are successful. More than two shots are therefore generally rather meaningless and only subject the breaker to unnecessary wear.

Permanent faults

Permanent faults, such as a broken conductor, the collapse of a line tower, a tree leaning against the line, a fault in any cable included in the transmission, must first be traced, before the cause of the fault can be removed and the damage repaired. This often entails time-consuming work and therefore imposes great demands on the ability of the network to cope with the load on the healthy section during this period.

Fault statistics

Single-phase earth faults are the predominating fault type for all lines. This predominance is most pronounced for high-voltage lines, because the large conductor spacings prevent some two-phase and three-phase faults.

The following statistics reported by Bonneville Power Administration (BPA) for faults on their 500 kV network during the period 9th December, 1967 to

30th June, 1973 and by the Swedish State Power Board for faults on the 400 kV and 200 kV grids during 1951 to 1975 confirm this.

	BPA	*Swedish State Power Board*	
	500 kV	400 kV	200 kV
Single-phase earth faults	93 %	70 %	56 %
Two-phase faults	4 %	23 %	27 %
Two-phase faults with earthing	2 %		
Three-phase faults	1 %	7 %	17 %

The number of successful reclosures on the State Power Board's 400 kV and 200 kV grids during 1970 to 1974 can be seen from the following statistics, which do not differ for the two voltages:

Total number of line faults	238	
Successful reclosures	179	75.2 %
Definitive trippings	32	13.5 %
Equipment out of service or defective	27	11.3 %

De-ionising

The time required for the de-ionising of the fault path depends on several factors including the arcing time (fault duration), fault current, wind conditions, air humidity, air pressure, circuit voltage, capacitive coupling to adjacent conductors, etc. The circuit voltage is the factor having the predominating influence on the de-ionising time.

Dead time

Auto-reclosing requires a dead time (see Fig. 1), which exceeds the de-ionising time. In Sweden a dead time of 0.4 s has been successfully used for voltages up to 400 kV, when both ends of the line are tripped simultaneously. Shorter dead times may be employed for lower voltages, if a suitable breaker is used. If there is no communication link available between the protective relays, it may be necessary to wait for the second step of the distance protection, which means that a dead time of 0.8 to 1.2 s is frequently used.

Long transmission lines with single-phase tripping and single-phase auto-reclosing require a slightly longer dead time than for three-phase tripping, because the capacitive coupling from the healthy phases results in a longer de-ionising time.

Three levels of the dead time normally occur:

1. High-speed auto-reclosing, dead time <0.8 s. This is used for single-phase and three-phase auto-reclosing. It requires a communication link between the protective relays for the simultaneous tripping of the two ends of the line. Instead of a communication link between the relays, the instantaneous steps of the distance protections may be set in certain cases for overreach. When one reclosure has taken place, the reach is automatically changed over to 80 to 90 per cent of the line length and then selective tripping is obtained for a permanent fault. There is no checking of the phase angle and voltage difference.
2. High-speed auto-reclosing, dead time 0.8 to 2 s. This is used for single-phase and three-phase auto-reclosing, when there is no communication link available between the protective relays or when the overreach of the instantaneous step of the distance protections is not applied. It may then be necessary to wait for the second time step of the distance protection, if the line is fed from both ends. The phase angle and voltage difference are not normally checked, but it may be necessary in certain cases, e.g., at an interconnector. Watch the co-ordination of back-up inverse earth-fault relays when one pole is open.
3. Delayed (low-speed) auto-reclosing, dead time 2 s to 3 min. This is normally used only for three-phase auto-reclosing, mainly in distribution networks. When the line can be fed from both ends, it is necessary to check the phase angle, voltage and, in certain cases, also the frequency difference.

Fault duration

Short tripping times for protective relays and high-speed circuit-breakers have a positive influence on the probability of a successful reclosure. If a fault is cleared more rapidly, there will be less damage and less ionisation in the fault path. The stresses on the network in other respects will decrease and there will be a greater probability of a successful reclosure.

Blocking

The reclaim time is the time during which a new start of the auto-reclosing equipment is blocked, see Fig. 1. If all reclosing shots have been carried out and the line is energised and a new fault occurs before the reclaim time has elapsed, the auto-reclosing equipment is blocked and a signal for definite tripping of the breaker is obtained. After the reclaim time has elapsed, the auto-reclosing equipment returns to the starting position and a new reclosing sequence can occur. The reclaim time must not be set to such a low value that the intended operating cycle of the breaker is exceeded, when two fault incidents occur close together. If the

Fig. 1. Definitions of times. The reclaim time may also start when the closing impulse is obtained. In the case of a line fed from both ends the communication time between the protective relays is included in the relay operating time. If no such communication is available, the second time step of the distance schemes must be taken into account.

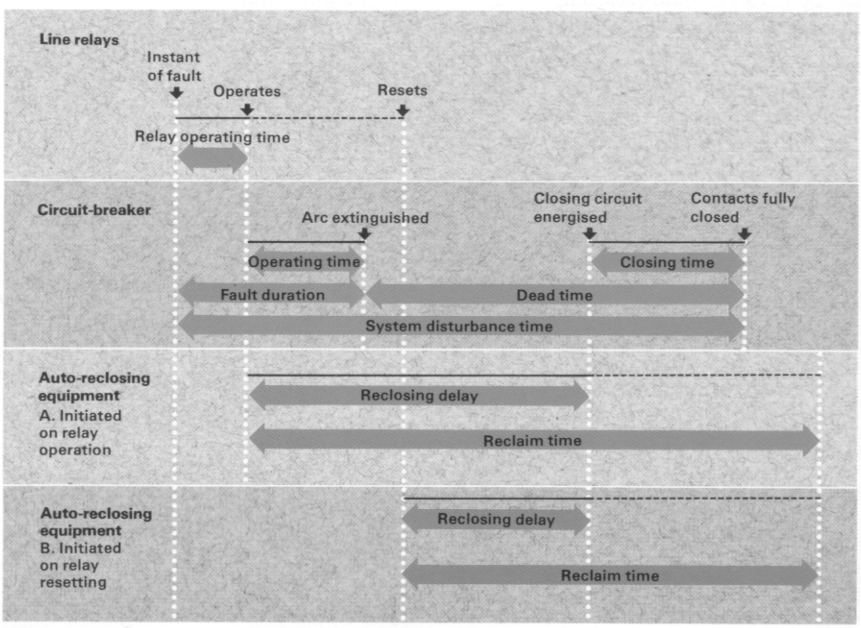

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Fig. 2. ASEA oil-minimum circuit-breakers type HLR 300/2504 B with a rating of 300 kV, 25 kA.

breaker is closed manually, the auto-reclosing equipment is blocked and cannot start again until the reclaim time has elapsed.

Another form of blocking also occurs. If, for example, the breaker is not prepared for reclosing or if, for example, a high-frequency link for co-ordinating the line protections is inoperative, the auto-reclosing is blocked.

Circuit-breakers

Breaking capacity and operating time characteristics

If a breaker is to be used for auto-reclosing, it is above all essential that it has the operating mechanism and breaking capacity necessary for it to be able to perform the auto-reclosing sequences required.

The breaker should be able to close after a dead time of about 0.3 s, if it is to be suitable for high-speed auto-reclosing. If multi-shot reclosing is used, the time between the shots must be long enough to ensure that the breaker operating mechanism always has time to store the necessary energy for a subsequent tripping.

The breaker must be able to withstand reclosing on to permanent faults, without its breaking capacity deteriorating and without it being damaged.

The operating (break) time of a breaker should be short to ensure as little ionisation as possible in the fault path and thus improve the probability of a successful reclosure.

Modern oil-minimum and SF_6 breakers retain their full rated breaking capacity on closing after a dead time of about 0.3 s. This applies in general also to air-blast breakers.

If more than one reclosing shot is made, due regard must be paid to the influence of the operating cycle on the breaking capacity. According to IEC Publication 56-2, a breaker must be capable of withstanding the following operating cycle with full rated breaking current:

O + 0.3 s + CO + 3 min + CO

If the breaker is not intended for high-speed auto-reclosing, the first delay is 3 min. This means that a breaker must not be operated at shorter intervals, unless approved by the manufacturer.

In the United States ANSI C37.04-1964 specifies the rated breaking capacity for another operating cycle:

CO + 15 s +CO

If the circuit-breaker has to operate more frequently or at shorter intervals than 15 s, the standards state that the rated breaking current of the breaker may be reduced, if the breaker does not cope with the new operating cycle.

When the reclaim time for the reclosing is being selected, it is therefore necessary to take into account the operating cycle which would occur if a new fault incident is experienced immediately after the reclaim time has elapsed.

Maintenance requirements

When selecting the type of breaker, one has to take into account its maintenance requirements. The maintenance intervals depend on the ratio between the breaking capacity of the breaker and the system fault level. Depending on the type, a modern breaker (see Fig. 2) can cope with 5 to 20 interruptions at full MVA breaking capacity or 30 to 100 interruptions at 30 per cent of its full breaking capacity. The trend is therefore towards a fewer number of reclosing shots in order to limit the maintenance costs.

Auto-reclosing and other equipment

Different types of auto-reclosing equipment have been developed to meet the varying requirements on the dead time and number of reclosing shots:

1. One high-speed reclosing shot.
2. One high-speed reclosing shot followed by one or more delayed reclosing shots.
3. One delayed reclosing shot.
4. Several delayed reclosing shots.

The equipment is supplied as separate units or incorporated in the line protections. It can be easily supplemented and adapted for different breaker schemes, e.g., the 1 1/2 breaker scheme.

In addition, other, more sophisticated types of equipment have been developed for automatic system restoration after a disturbance. Such equipment may sometimes work together with synchro-check and synchronising equipment to restore the network.

Automatic equipment has also been developed for automatic load restoration after load shedding.

System restoration, load shedding and load restoration will not be discussed in this article.

Distribution networks with radial feeders

Problems of system stability or synchronising requirements do not occur with radial feeders with load only and therefore they can easily be provided with three-phase auto-reclosing equipment. This gives certain benefits such as short outage times and the possibility to save personnel. If instantaneous tripping and high-speed auto-reclosing are utilised, damage to the line in connection with a transient fault can be limited.

When feeders consist partly of underground cables, the suitability of auto-reclosing should be considered, since the faults occurring in a cable are generally permanent. If there is only a small risk of the cable being damaged by excavators, auto-reclosing may nevertheless be justified, since cable faults do not arise so frequently as faults on overhead lines.

Auto-reclosing equipment starting principles

Distribution lines are normally protected by time-lag overcurrent relays with instantaneous and delayed tripping functions. It seldom happens that instantaneous tripping of more than the circuit-breaker located furthest away can be utilised. If instantaneous tripping of breakers in series is introduced, non-selective tripping is generally obtained, since the fault level differences in various parts of the network are too small for current selectivity to be obtained for a short circuit.

Instantaneous tripping of the breakers when short circuits occur improves the possibilities of a successful reclosure owing to the reduced ionisation of the fault path. At the same time, damage to, and stresses on, the network are reduced. It is therefore desirable always to be able to trip the breakers instantaneously.

Modern time-lag overcurrent relays (see Fig. 3) are therefore provided with an additional contact function, a starting contact. This closes instantaneously, when the current exceeds the set value for delayed operation. It is then possible to utilise the starting contact, instead of the instantaneous contact, to trip the breaker instantaneously, also for a current not exceeding the instantaneous setting, and to start the auto-reclosing equipment.

Instantaneous tripping of several breakers in series, irrespective of whether this is initiated by the instantaneous contact or the starting contact, generally means that all breakers trip for a disturbance on the line situated furthest away. More consumers than necessary will then be affected. If high-speed auto-reclosing is introduced, however, the loss of supply will be limited and the disadvantage of non-selective tripping can be tolerated in many cases. If the high-speed reclosing fails, the breaker is tripped by the delayed operation of the protection. The reclosing is started again, if several shots are to be made.

Non-selective tripping of breakers in series combined with high-speed auto-reclosing cannot be tolerated in all networks. This is the case with, for example, networks feeding certain industries having electronic equipment, which is too sensitive to brief interruptions and would then be unnecessarily disturbed. In such cases instantaneous tripping and starting of the auto-reclosing can be applied to the breaker located furthest away. Other breakers are tripped selectively by the delayed operation of the protective relays, which at the same time start the auto-reclosing equipment.

Another philosophy has been developed for certain networks such as those containing a large proportion of cable feeders. If instantaneous tripping is obtained for a high current, the auto-reclosing is not started. In such circumstances it is considered that the fault is of such a serious nature that the reclosing will not be successful but would only aggravate the damage. If, on the other hand, delayed tripping is obtained, this is assumed to be caused by an overload or a fault that has not fully developed. The line is therefore reclosed after a certain delay.

As far as earth faults in solidly (effectively) earthed networks are concerned, the auto-reclosing is started by the earth-fault protection according to the same principles as those applying to the short-circuit protections. In the case of isolated networks or resonant-earthed networks, the reclosing is started by the delayed operation of the earth-fault protections.

Number of reclosing shots

One or two shots are generally used in distribution networks, sometimes three shots and very seldom more shots. This depends on the frequency of the different types of fault occurring (see under the heading "Fault types") and on the likelihood of a successful reclosure with more than two shots being so small.

Three or more shots consequently do not imply any significant improvement but only substantially increase the stresses on the breaker and other network apparatus. If one takes into account the fact that yet a further reclosing attempt is often made, via remote control or manually, when personnel reach the substation, it can easily be seen that the breaker may be overstressed in conjunction with permanent faults. The number of reclosing shots should therefore be limited.

Auto-reclosing with respect to the load etc.

When delayed auto-reclosing is applied, it is important that the dead time should be sufficiently long to ensure that all motor drives have time to be disconnected from the supply by their undervoltage protections. The voltage fed out by the motors to the network during their retardation must also have time to disappear. A delay of 10 s normally suffices. There is otherwise a risk that the voltage from the motors will be completely out of phase with the network voltage when the reclosing takes place.

If street lighting is influenced in conjunction with the reclosing of a line, this requires special attention in areas with dense and fast traffic. The shortest possible dead time is desirable from the traffic safety viewpoint.

A brief outage does not cause too much inconvenience to domestic consumers. To avoid telephone calls from consumers, it is in the interest of the utility to keep the outages as short as possible to ensure that the consumers will not have time to get to the telephone in order to complain.

In areas subject to icing risks, overhead lines may contact each other several times when the ice is suddenly shed. They

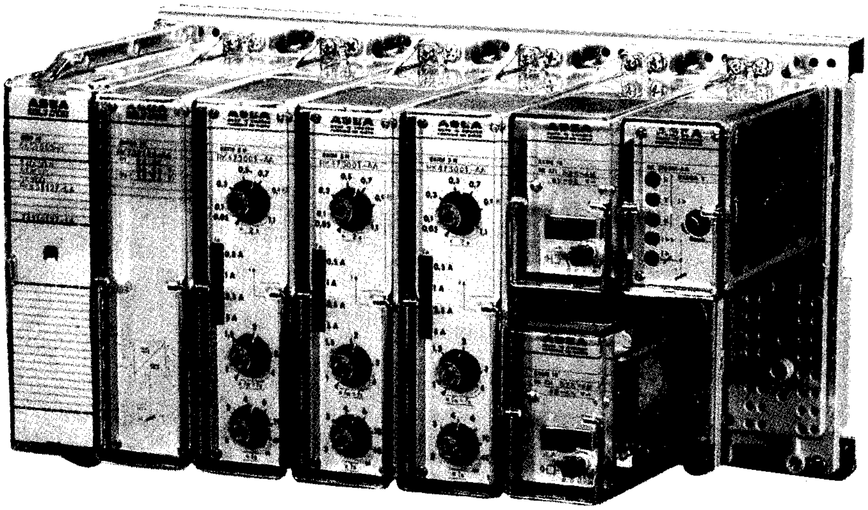

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Fig. 3. Three-phase overcurrent protection with time-lag overcurrent relays type RXIDF 2 H.

must be given time to stabilise so that they do not contact each other again after a reclosure. The reclosing is therefore delayed 1 minute or longer to ensure that no contacting of the conductors will occur after the reclosure and be interpreted as a permanent fault.

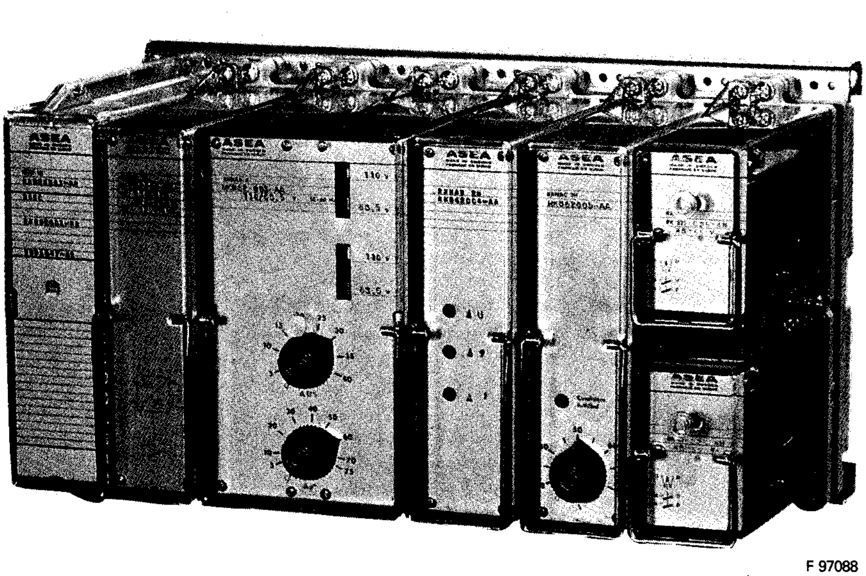
When selecting the auto-reclosing method, one must take into account above all the network configuration, the nature of the load and the suitability of the breaker. It is not therefore possible to give any general recommendations.

Cyclic auto-reclosing

Cyclic auto-reclosing can be used to trace a defective part of a network, when there is no selective protection available. In a non-solidly earthed network a substation, for example, with radial feeders may be equipped with only one neutral-voltage relay as earth-fault protection.

The substation may then be equipped with automatic equipment for cyclic tripping of the feeders. If an earth fault occurs, the neutral-voltage protection starts the automatic equipment, which trips one feeder after another until the neutral voltage disappears. The automatic equipment then returns to the starting position. The feeders are re-energised by the auto-reclosing equipment of their associated breaker. When short circuits occur, the auto-reclosing equipment of each breaker operates in the normal manner.

Fig. 4. Synchro-check relay type RASC with voltage check unit.



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Cyclic auto-reclosing leads to loss of supply on several feeders and increased breaker wear. In addition, there is an increased risk of double earth faults owing to repeated voltage rises on the healthy phases. This method is therefore not used so frequently. Preference is given to selective auto-reclosing and selective earth-fault protections.

Distribution networks with power source at each end

Meshed distribution networks or networks with a small power station connected at one end and with a power source at the other end require voltage and phase angle difference checking, which blocks the auto-reclosing equipment until the conditions are fulfilled. If there is, for example, a counter voltage during the checking before the first shot, the reclosing is blocked by the voltage checking. If the counter voltage disappears before the next reclosing shot, the reclosing can be carried out. In other respects roughly the same conditions apply here as those mentioned in the previous section.

Single-phase auto-reclosing in weak high-voltage networks

A network with inadequate transmission capacity can be defined as a weak network. In such a weak, meshed high-voltage network it is necessary to use high-speed auto-reclosing so as not to jeopardise the network stability. The loss of a line in a weak network may lead to the collapse of the network. To ensure that the high-speed reclosing of a tie-line will be successful, it is important to have as short a dead time as possible. This presupposes the use of high-speed protective relays and approximately simultaneous tripping of both ends of the line to ensure that the de-ionising time will be as short as possible.

If the line in question constitutes the only link between different sections of the network having their own power production, or if those sections of the network operating in parallel are very weak, it may be necessary to use single-phase tripping for earth faults and single-phase high-speed auto-reclosing. There is otherwise the risk that the network sections may drift apart, thus jeopardising the stability and synchronism. If a two- or three-phase fault occurs, it is preferable in many cases to trip the line definitively and block the reclosing. Knowledge of the load angle change/time relationship, when a disturbance arises, makes it easier to assess the possibilities of using three-phase high-speed auto-reclosing. The risk of stability disturbances increases, when high-speed auto-reclosing on to a permanent fault takes place. This must be weighed against the possibilities of a successful reclosure for a transient fault. Delayed three-phase auto-reclosing requires a strong network, see the next section.

The advantages of single-phase high-speed auto-reclosing can be summarised as a negligible influence on the line transfer capability, which means that synchronism and stability can be maintained. The high-speed auto-reclosing equipment may be of relatively simple design. No checking of the voltage, phase angle or frequency difference is necessary.

Among the disadvantages can be mentioned the longer de-ionising time owing to the capacitive coupling between the healthy phases, which may lead to disturbances on telecommunication lines and earth-fault schemes for double circuit lines. Single-phase high-speed auto-reclosing may fail on long shunt-compensated EHV lines owing to the capacitive coupling. A neutral-point reactor can then substantially improve the conditions [1]. The protective relays must be able to determine in which phase the fault occurs. Further, each phase of the breakers must be segregated and provided with its own operating mechanism, which may entail extra costs at voltages below 220 kV.

Auto-reclosing in strong high-voltage networks

The same need for fast, simultaneous tripping of the breakers at both ends of a faulty line applies to strong networks as to other networks, if there are to be as good chances as possible of a successful reclosure of the line and limiting of the damage.

An ultra-high-speed relaying (UHSR) system is now available for lines requiring fast tripping. The operating principle is based on the detection of the direction of the travelling wave generated at the location of the fault. The UHSR system operates within times down to 1 to 4 ms. Its operation is not influenced by the presence of series capacitors in the network [2].

The advantages and disadvantages applying to single-phase high-speed auto-reclosing in weak networks (see the previous section) are valid also for strong networks.

If the network is sufficiently strong, three-phase high-speed auto-reclosing can be utilised without the synchronism or stability being disturbed. Simple equipment without facilities for checking the voltage, phase angle and frequency difference can then be used. Protective relays, breakers, etc., will be simpler than for single-phase auto-reclosing and no zero-sequence and negative-sequence currents are obtained during the dead time.

In networks with series compensation the series capacitors are protected by spark gaps. These generally spark over at the same time as a fault occurs on a line. The reduction in the power transfer capability of the network then obtained in many cases can exceed that occurring when a line is tripped. It is therefore important to provide the capacitors with equipment, which as quickly as possible extinguishes the spark gap in order to bring back the capacitors into operation again and restore the power transfer capability [3]. Auto-reclosing can generally be applied also in series-compensated networks. In exceptional cases there may be a risk of subsynchronous resonance (SSR). Under unfavourable conditions SSR may give rise to severe stresses in the shafts of large steam turbine-generators [4].

The possibilities of utilising three-phase delayed auto-reclosing depend on the load angle change/time relationship, when a disturbance occurs. No stability problems should arise in a strong network, but it is impossible to guarantee that synchronism can always be maintained between different sections of a network when a major disturbance occurs. Under unfortunate circumstances incorrect synchronising may therefore take place with delayed reclosing. If this happens in a section of the network where there is a large line impedance between the systems, no damage as a rule occurs. If, on the other hand, incorrect synchronising takes place in the vicinity of large thermal power plants, this may lead to a generator breakdown with disastrous consequences.

It is possible to provide protection against incorrect synchronising by adding equipment for phase angle difference checking, voltage checking, etc. (see Fig. 4). However, this still does not provide protection against the severe stresses which under unfavourable circumstances may develop in the large turbine-generators, when a reclosing attempt is made on to a permanent fault. It is therefore doubtful whether high-speed auto-reclosing should even be used in certain networks where thermal power predominates.

When only three-phase delayed auto-reclosing is utilised, no problems are experienced with the de-ionising time and breaker operating time. If oscillations occur in the network, they generally have time to become stabilised before a reclosure. There are somewhat greater chances of a successful reclosure with three-phase delayed auto-reclosing than with only high-speed auto-reclosing.

When a line has been tripped, the voltage in the network increases or decreases owing to the change in the load. Transformer tap changers may then start to operate with the risk of being damaged, if reclosing on to a short circuit occurs during the switching process. The delay of the voltage regulation equipment should therefore be checked. This delay should be longer than the system disturbance time, see Fig. 1.

Several reclosing shots may be justified in the case of, for example, radial lines. However, the advantages of the increased probability of a successful reclosure must be weighed against the disadvantages in the form of greater damage at the site of the fault and higher breaker maintenance costs.

Conclusion

The network configuration and type of load vary from case to case. Many of the requirements and factors discussed here must therefore be assessed on the basis of their importance in each individual case. It is therefore impossible to give any general rules for the application of auto-reclosing. However, a trend towards a wider acceptance of single-phase reclosing due to its advantages in many applications has been noticed.

The intention of this article has been to throw light on the parameters influencing the choice of a suitable auto-reclosing system.

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