ISSUES AND SOLUTIONS FOR THE PROTECTION OF SUBSTATIONS WITH SINGLE BATTERY

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1. INTRODUCTION

Short circuits and other abnormal power system conditions are very rear, but may result in heavy losses if not detected and cleared as designed. Because of that power system protection systems are designed as shown in Figure 1, with primary and backup relays, in most cases with independent CT/PT/Trip circuitry, different operating principles (e.g. 21 and 87L) and/or different relay manufacturers to avoid potential common mode of software and hardware failure.

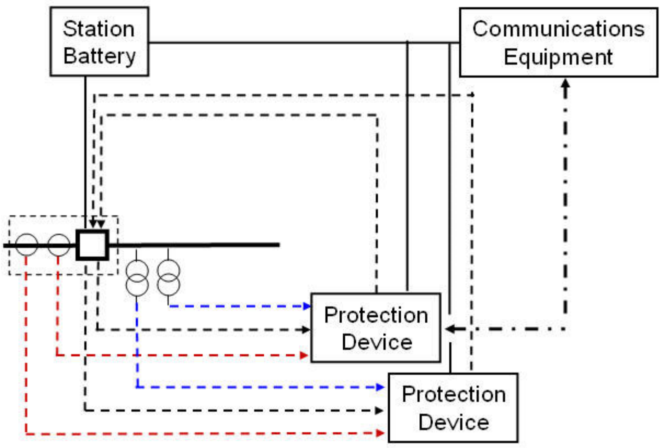

Fig. 1: Redundant fault clearing system

The challenge for electrical design engineers is to design system in such a way as to prevent dangerous failures or to control them when they arise. Dangerous failures may arise from:

- Incorrect specifications of the system, hardware or software;
- Omissions in the safety requirements specification (e.g. failure to develop all relevant safety functions during different modes of operation or commissioning),
- Random hardware failure mechanisms,
- Systematic hardware failure mechanisms,
- Software errors,
- Common cause failures,
- Human error,

- Environmental influences (e.g. electromagnetic, temperature, mechanical phenomena);
- Supply system voltage disturbances (e.g. loss of supply, reduced voltages, re-connection of supply).

Relays are also only one of the components of a fault clearing system. As can be seen from Figure 1, a simple protection system consists of:

- Protection relay
- Instrument transformers – voltage and current as required by the application
- Circuit breaker
- Auxiliary power supply
- Wiring between all the components of the system

Main and backup protection are normally fully independent with physical separation, independent AC and DC circuits, dual breaker trip coils, different operating principal or hardware or algorithm design, etc. The practice of using devices from different manufacturers for redundant or backup functions is existing for many years in our industry.

Even that protective relays are designed to be extremely reliable, they still may fail as a result of component failure, operating principle, measuring transformer failure, DC supply failure, etc. Backup protection is required to provide fault clearance by local or remote relays. Local backup relays can be primary (if they protect the same substation equipment or transmission/distribution line), or secondary (located in the same substation). Remote backup relays are located in other substations (remote end).

To determine the failure rate of the fault clearing system in Figure 1, we can use an example [1] of a "fault tree analysis" based on the failure rate of the individual components of the system. The result is shown in Figure 2. Failure of any of the components will result in the failure of the fault clearing system to operate as designed.

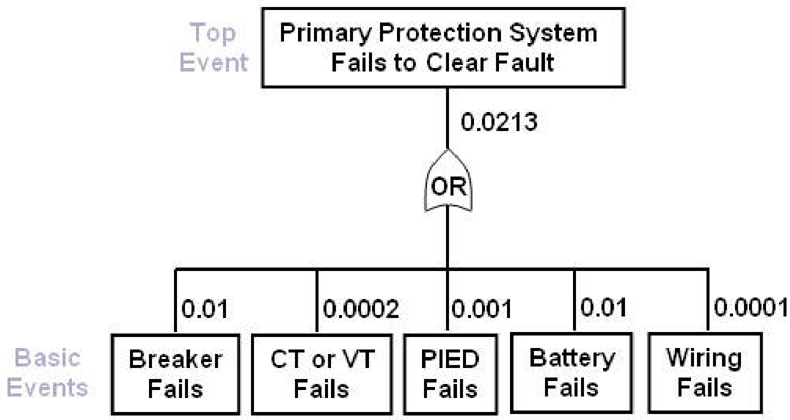

Fig. 2: Fault tree of a fault clearing system

If we analyze the numbers in Figure 2, we will notice the significant impact of the failure of a breaker or a battery. Even if we provide local backup protection in a substation with a single battery, the failure of the battery can not be overcome. Remote backup protection is required in such case to provide fault clearance by remote relays. Unfortunately, remote backup protection can not be always applied without any challenges.

Power system protection obviously requires a very reliable DC power supply in order to ensure the availability of protective relays when a fault occurs. Because of that the utilities pay a lot of attention to the design, commissioning and maintenance of the DC system in the substations. To provide an uninterrupted power supply, energy storage devises like battery are used. In very critical substations the utilities install two battery systems and separate the primary and backup protection systems completely by adding also two trip coils to the breakers.

The paper discusses such fault and operating conditions and proposes some existing solutions that will reduce the probability for a complete loss of DC in the substation or even if such an event occurs, it will ensure adequate fault clearing for any fault condition in the substation.

2. SUBSTATION BATTERY

Batteries are used in the substation control house as a backup to power the control systems in case of a power blackout. Banks of batteries as shown in Figure 3 are installed for breaker control, relay protection and tripping circuits, etc.

Fig. 3: Banks of batteries

Tripping/DC supply is one of the most important components in power transmission and distribution networks. A highly reliable tripping/DC supply is required to ensure correct protection and equipment operation especially when a power system or equipment fault occurs. Loss of the critical function of the battery system can be devastating for a switchgear breaker unit and inability to trip a faulted circuit can be a disaster for the primary equipment, personal as well as the power system stability.

Battery monitoring is normally used based on low voltage limits that alarm instantly the SCADA or remote center, warns the maintenance personnel who can respond quickly and avert a major problem in case of battery discharge. Redundancy could be provided, so that no single point alarm system failure will lead to a battery plant outage.

A few years ago, Newton-Evans completed a research study concerning substation battery management and monitoring. In the U.S., larger and mid-size substations most often have batteries used as primary (or secondary, backup) power sources. Many small substations do not have battery power. Newton Evans estimated percentage of substations equipped with such batteries is more than 90% of transmission substations and about 55% of distribution substations.

Remote monitoring of substation batteries is being done for many utilities, and is normally being done via SCADA. However, there are also sub-system level battery monitoring units available, including systems that monitor the battery chargers, and perhaps not the batteries themselves.

3. REMOTE BACKUP PROTECTION SETTINGS AND COORDINATION

Power system protection coordination is an extremely complex process that depending on the system configuration can reach a stage when it goes from science to art. The reason for this is that in a complex network there are numerous combinations of operating, maintenance and fault conditions, post-fault outages, etc. that make it practically impossible to ensure appropriate coordination for all existing conditions.

Modern microprocessor based relays have multiple setting groups that allow different modes of adaptive protection based on monitoring of breaker status in the substation or remote control signals from SCADA. This results in significant improvement in the relay coordination. However, there are other factors that create problems for the coordination or the backup protection functions of distance and overcurrent relays. They are usually related to the maximum load conditions and the infeed fault current in the remote substation. These are two conflicting requirements that have to be very carefully considered during the settings calculation process.

The encroachment of the load impedance into the distance characteristic becomes the limiting factor for the reach settings of a mho distance characteristic. At the same time the zone has to be set to reach faults at the low side of the transformer at the remote end of the substation, in order to ensure transformer protection in the case of loss of DC at the same time when a fault occurs. The probability for such an event is very small; however, it may have very destructive effect. The presence of a fault for a long time may not only lead to the complete loss of very expensive substation equipment such as a power transformer. It also presents a significant power quality problem, because of the low voltage, that may affect a large area of the distribution power system.

Improvement of the settings and coordination of remote backup relays is one of the ways to avoid the potential problem of remote relays not operating under such system conditions. In some cases utilities try to set the relays based on normal or “N-1” (one line or transformer out-of-service) conditions.

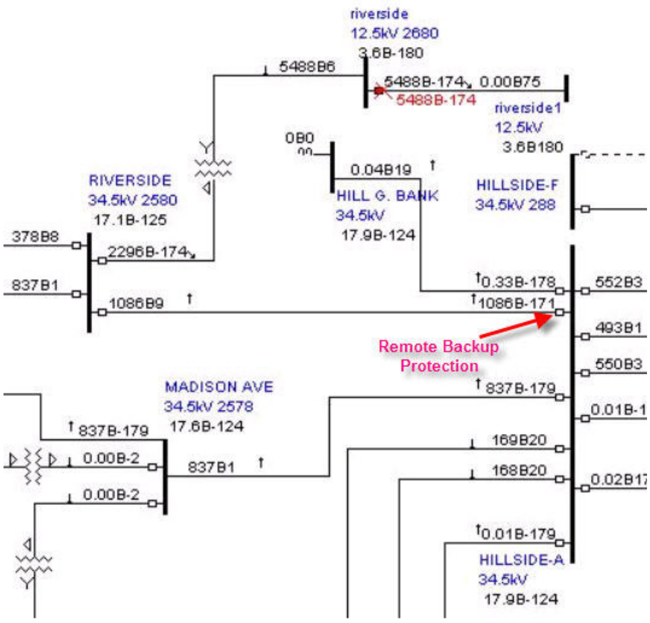

Fig. 4: Remote backup protection operation

Figure 4 shows the power system configuration of a real power system. A phase-to-phase fault is applied at the low side of a 34.5/12.5 kV transformer in Riverside substation. Remote backup for phase to phase faults is provided by distance relays at each substation connected to the substation with the fault.

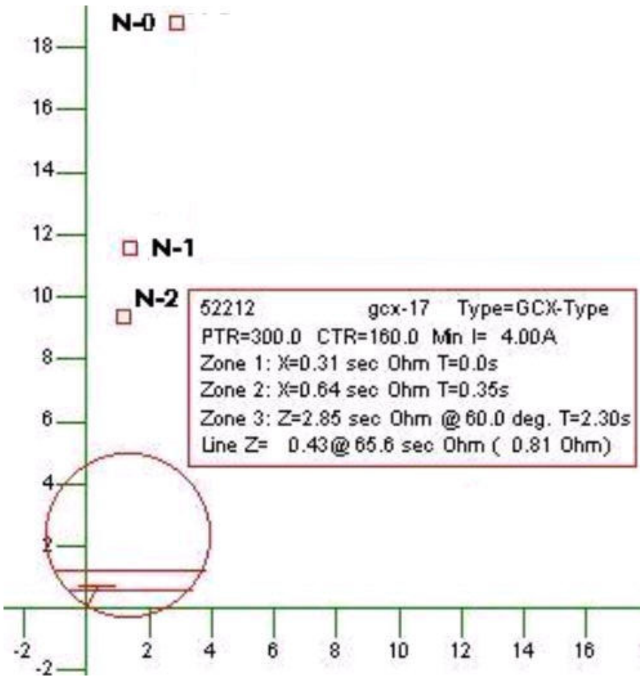

Fig. 5: Phase distance relay – apparent impedance

Figure 5 shows the characteristic of the phase distance relay in the impedance plain. The relay operation (apparent impedance seen by the distance relay) is displayed for the same fault with three different power system configurations:

- All lines in service
- N-1 (one line at Riverside out-of-service)
- N-2 (two lines at Riverside out-of-service)

As expected, the apparent impedance measured by the relay in Hillside for the fault with all lines in service is much larger than the impedance with two or even one line out of service. It is obvious that the Zone 3 (mho) characteristic reach has to be increased in order for the relay at Hillside to see the fault. However, the characteristic selected for the case with all lines in service will be to large and may result in relay operation for heavy load conditions or miscoordination with other protective relay under N-1 or N-2 conditions.

If the distance reach of Zone 3 is restricted by the apparent impedance of the maximum load conditions, the relay can not be set to provide the remote backup protection for the fault case under consideration.

The problem with overreach and miscoordination under N-1 and N-2 conditions should be resolved by applying adaptive protection with changing Zone 2 and Zone 3 impedance reach based on control signals received from the SCADA master, indicating the changes in the system configuration. However, this can not be done with electro-mechanical relays, that are still a large percentage of the protective relays in service.

All of the above demonstrates the need for other solutions that will eliminate the requirements for remote backup for all fault conditions in another substation.

4. BUSBAR PROTECTION

Introduction

DC supply is one of the key aspects of a busbar protection scheme to be looked at by the Protection Design Engineer. The design should take account the required dependability and selectivity to be adapted to bus relay (depending of a centralized or decentralized architecture is used). In many cases, modern bus relays are equipped with much more functions than just a bus differential protection.

Several situations can arise, where the risk of losing the busbar protection due to DC supply loss might occur:

- Maintenance of a station battery
- Damage to one station battery
- Discharge of a station battery
- Short circuit of DC supply
- Interruption of DC circuit
- Failure of the power supply module within the protective relay

CIGRE WG B5.16 [2] has listed some suggestions to be used by Protection Design Engineers when implementing a distributed or centralized busbar protection scheme.

Centralized busbar protection

In a centralized busbar scheme, the protection relay is concentrated in one location within the substation. All the substation currents are wired to the centralized bus relay (which computes both differential and bias currents) as well as all the switchgear position status (to give the correct current balance to feed the tripping zone logic). In case of a busbar fault or breaker failure, the general trip to all the substation circuit breakers will be issued from this location.

In power substations where only one busbar scheme is used, the dependability of the system is achieved by the remote Zone 2 / 3 tripping which can be unwanted since the fault clearance time is longer, increasing the risk of substation and personnel damage, causing transient stability problems and reducing the protection system selectivity. The busbar protection scheme DC supply failure is one cause which requires the action of a back-up protection.

The probability of losing the busbar scheme due to DC supply failure can be reduced by using a battery back-up system. In this case, the protection system is supplied by two batteries and, an auxiliary relay commutes between batteries in case of a battery failure as shown in Figure 6. To have a busbar scheme out of service due to DC supply failure, both batteries have to fail which is more unlikely to occur, consequently the need of remote zone 2 operations are reduced.

If the required system dependability asks to duplicate the busbar protection scheme, it should be accomplished with the use of two independent batteries as shown above. If one battery fails, the corresponding busbar scheme will be out of service but the second bus protection will remain in service. If a duplicated battery system is unavailable then no duplication of the power supply exists and there is no advantage of having two busbar protection schemes in case of a DC supply failure; both bus relays will be switched off and remote Zones 2 will have to operate in case of a busbar fault.

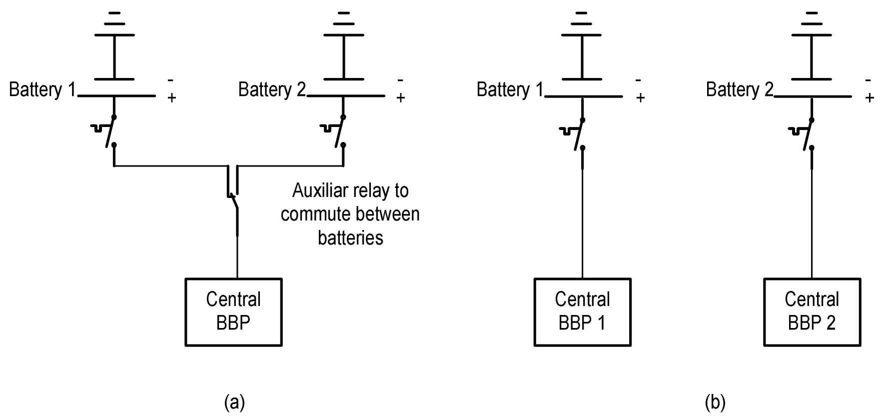

Fig. 6: Centralized bus relay using two batteries and a full redundant systems

Decentralized busbar protection

In a decentralized busbar protection scheme there are two DC supplies that need to be considered:

- The central unit's DC supply. The considerations for the DC supply of the central unit are similar to the centralized busbar DC supply; for example it can have back-up with a second battery if there is no second busbar relay.

- The bay unit's DC supply. The bay units, which are located in each bay panel, can be powered from the local panel DC supply system.

In a typical transmission feeder protection system as shown in Figure 7, is composed of two main protections. There are normally supplied by separate batteries for reasons of redundancy. In this case, the bus bay unit can be supplied by one of the batteries without compromising its dependability. With the above example, special attention should be also taken during maintenance of bay panels as the operation and availability of the bus relay can be affected.

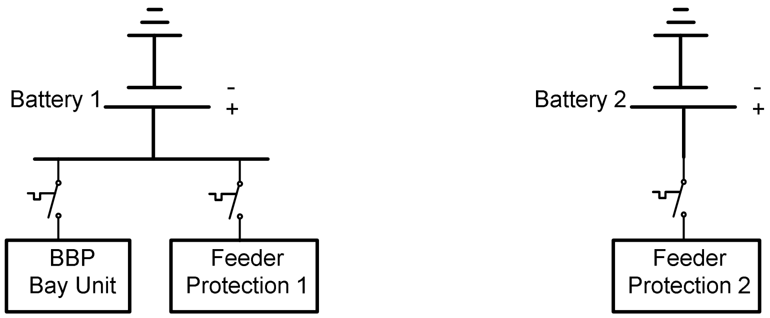

Fig. 7: Busbar bay unit sharing the same battery with one feeder relay

An alternative solution could be to supply each bay unit with the same DC supply as the central unit to have a fully independent DC circuit for the bus relay. The dependability of this scheme could be also affected in case of DC supply failure.

Another alternative is to have a redundant power supply within the central and each bay units of the decentralized bus relay as shown in Figure 8.

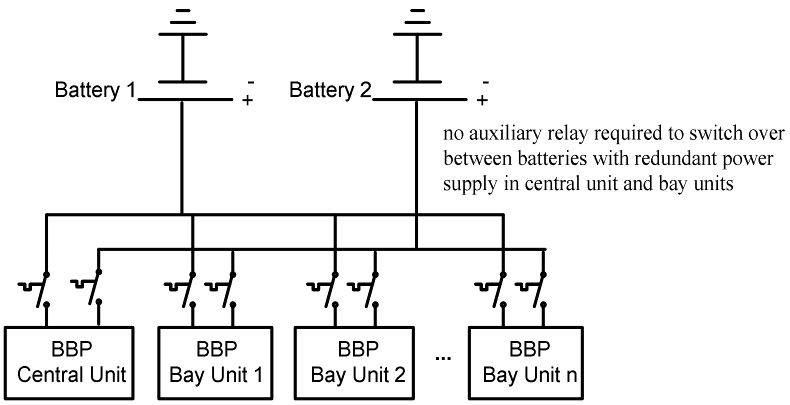

Fig. 8: Central and Bay Units with integrated Redundant Power Supply module

5. BATTERY MONITORING

As we discussed above, the worst case scenario is the battery failure in the substation with the fault, that results in the loss of all primary, redundant or local backup protection. On way of solving this problem is to add a second battery and completely separate the DC circuits of the primary and backup protection. However, this is very expansive and is difficult to justify for substations at the sub-transmission level.

A significant improvement can be achieved by reducing the chances for battery failure by continuously monitoring the battery and the DC circuits in the substation. Substation battery installations are required to provide not only dc auxiliary supplies for protection and control equipment, but also to supply trip and close currents to breakers under tripping conditions. Monitoring of the performance of the dc system is therefore fundamental to the efficient operation of the substation.

For substations it is important that the security of the supply is maintained at all times. This means not only that the battery voltage is within required limits, but that earth leakage and any latent faults in the battery and connections will not result in failure to initiate tripping when a heavy current is demanded.

In order to reduce potential outage times, the battery alarm device should provide continuous battery monitoring and give local and remote indication of alarm conditions, including an impedance alarm. This alarm monitors the ability of the battery to supply a large current for trip/close requirements, failure of which could result in extensive damage. Early detection of such problems allows effective maintenance to be scheduled to help maintain the integrity of the dc system and avoid potential battery failure.

By monitoring the ability of the substation battery to supply load current, it ensures dc powered equipment such as critical protection relays and SCADA systems remain operative during different fault conditions. Continuous in-service monitoring of the battery eliminates the need for time consuming and costly site visits and battery servicing by maintenance engineers is minimized. Another benefit is that the batteries may remain safely in service after their expected useful life has expired, thus reducing replacement costs.

A modern state-of-the-art battery monitoring device is multifunctional and contains elements that will detect different problems in the battery or other components of the DC system in the substation:

- Over and Under voltage alarms ensure that the battery charge is sufficient to support the required voltage level and indicates that the battery charger is performing correctly
- High Impedance alarm guards against high battery circuit impedance, caused by corroded terminals or internal build-up of plate deposits, which would prevent the battery from supplying the required load current.
- Ground Fault alarm protects against earth leakage which could prevent the battery supplying sufficient load current and would also result in increased charging costs
- Fault indication LEDs and relay contacts provide local and remote alarms to facilitate fast and efficient fault diagnosis
- Loss of supply volts indicated via drop-off of normally battery alarm does not require expensive energized relay, providing self checking maintenance
- Self-powered with minimal burden easily retrofitted to existing installations

6. SELF- AND DUAL POWERED PROTECTION RELAYS

Introduction

Self-powered relays are energized directly from the power taken from the line currents provided by the CTs (a minimum load current on at least one phase current will be needed to energize the relay). Self-powered relays can be energized from 3 phase CTs + core balance CT, 2 phase CTs and core balance CTs or 3 phase CTs as shown in Figure 9.

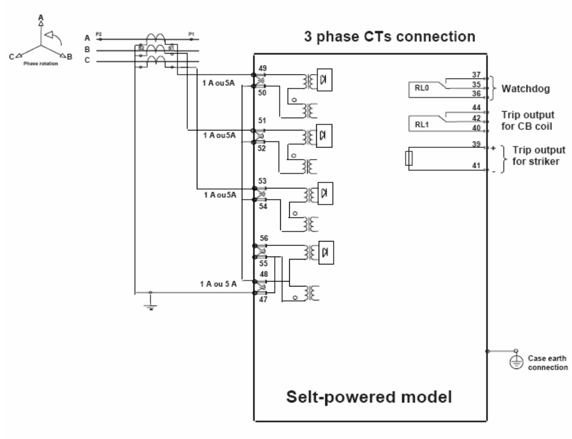

Fig. 9: Self-powered relay energized from a 3 phase CTs connection

Dual-powered relays as shown in Figure 10 are normally powered from an AC or an external DC auxiliary supply through a high capacity internal transformer which protects the relays against short interruptions (<50ms). In case of auxiliary DC power loss, the relay is powered by the line CTs (downgraded mode) and performs the same functions as the self-powered model.

Self and dual-powered overcurrent relays have been designed to protect both industrial installations and power distribution networks and substations, without having to resort to an external auxiliary power supply. They can also be used as backup for HV protections of power transmission networks.

The protection relays self-powered by the load or fault current offer the specific feature of non-conventional current inputs. Accordingly, special attention will be given to the choice of the current transformers supplying these relays.

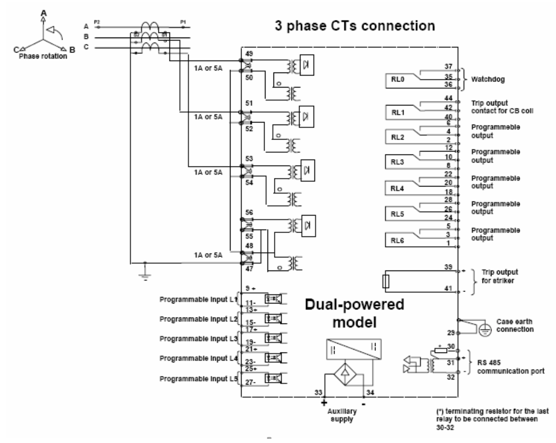

Fig. 10: Dual-powered relay energized from a 3 phase CTs connection or an external auxiliary voltage (DC or AC)

The following sections discuss different options for powering a protection relay and methods for tripping the breaker in the absence of DC power.

Powered From Current Transformers Alone

Self and dual-powered relays (with identical ac burden at their current inputs) require for a minimum level of current flowing through at least one phase of the current transformer to enable the relay to be correctly self-powered ensuring the full capability of its protection functions.

Lowering the design value of this parameter increases the burden on the current transformers and the power dissipated within the relay case. A combined three phase and ground fault relay will operate with low ground fault current settings when the load current in the protected circuit is sufficient to power the relay as listed bellows:

- Minimum starting current to power the relay with only one phase current = 0.2 **x** I_N
- Minimum starting current to power the relay with 3 phases = 0.1 **x** I_N
- Minimum current threshold for phase and ground fault = 0.1 **x** I_N

The figure 11 indicates for example, the voltage (average value of signal for 10ms) on each phase or on ground current input depending of the current injected.

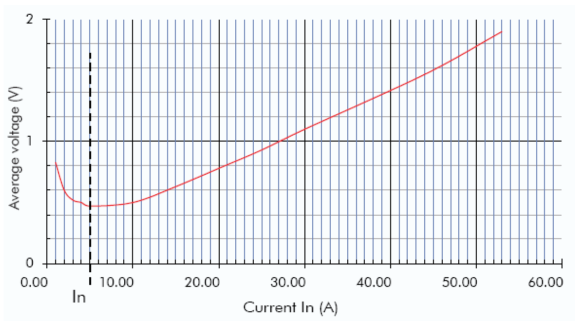

Fig. 11: Current input burden, rated current 5A

The worst case scenario is when switching onto a fault with no auxiliary power available. In this case the relay is not powered and will be delayed in operation by the start-up time. This delay will need to be taken into account in any relay coordination exercise.

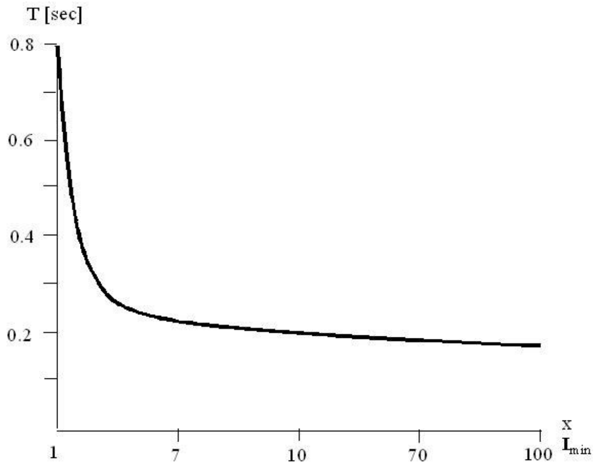

Fig. 12: Start-up delay

The delay is the total time required for:

- the processor to initialize its registers
- read in settings from non-volatile memory
- perform self-checks

There will be an additional delay while the power supply builds up, but this will be less significant when using an inverse time/current characteristic as the power supply delay similarly varies with current. The start-up time is not reduced by lowering the time-multiplier setting and it needs to be considered in the coordination time of the remote backup protection.

Figure 12 shows the start-up time delay of a self-powered relay as a function of the current through the CTs. With pre-fault load current above the minimum level required, there will be no start-up time delay and the relays will operate within their normal time settings.

In cases where the start-up delay cannot be tolerated it is recommended that the relay is also powered from an auxiliary AC voltage supply so that it can be up and running before a fault occurs. It will also make stored disturbance and event records more accurate, because the recording will start only after the relay powers up and initializes, i.e. the record will not include the pre-fault condition.

That is why dual-powered relays were selected instead of self-powered relays. This ensures faster operation in the cases when:

- Auxiliary power supply is available at the time when a fault occurs
- Auxiliary power supply has failed, but the load current is above the required minimum to power the relay

A battery in the relay is used to support the existing records in case of loss of auxiliary power supply and load current below the minimum level.

The start-up time delay will then only apply to the cases when there is a loss of AC power and load current below the minimum level at the time when a fault occurs. But even in that worse case the additional time delay for the fault clearing time will typically be in the range of about 200 milliseconds.

Dual-powered relays are equipped with multiple opto-isolated inputs and relay outputs. Their operation must be considered in the analysis of the relay performance, since at the claimed minimum operating current they cannot all be energized at the same time. If they have to be simultaneously operated, then the minimum operation current will have to be increased. However, in applications requiring a dual powered relay it is unlikely that more than two output relays will be energized at any one time.

Powered From an Auxiliary AC Voltage and From Current Transformers

The addition of an auxiliary AC or DC voltage supply to power the relay will:

- Enable the settings to be changed when the protected circuit is de-energized.
- Enable records to be retrieved and control functions to be carried out over the communication link.
- Reduce the burden on the line CTs.

When using an auxiliary AC voltage, it may be lost during a fault, but power will be drawn from the current transformer circuit to maintain the relay in a fully operational state. However, if the source of the auxiliary voltage is carefully chosen it is unlikely to be lost completely during ground faults but it may collapse to 50% of its rated value. Provided the voltage is still above the minimum required to power the relay, very low ground fault settings can be successfully applied. In the absence of the auxiliary voltage the relay is not guaranteed to operate for ground fault currents less than 0.2 **x** I_N.

No alarm is given for loss of the ac auxiliary voltage, unless it is externally monitored by a separate supervision relay.

Breaker Tripping Concepts

The successful clearing of a fault requires a protection relay to detect the fault condition and issue a trip signal and a breaker to operate and clear the fault. Dual-powered relays may use different methods for tripping of the breaker to clear the fault. The method selected for each specific application depends on the specifics of the breaker used and the auxiliary voltage available at the breaker location. Some of the more commonly used methods for breaker tripping by self-powered or dual-powered relays are described in the following sections.

<u>Breaker Tripping Using Striker</u>

Whatever the version (dual or self-powered), a dual or self-powered relay can trip the circuit breaker via a striker output or a C/O contact.

Dual or self-powered relay can trip the circuit breaker by performing a capacitance discharge through a heavy-duty output capable of putting out sufficient power (20mJ at 12V) to a striker that releases the actuating mechanism of the circuit breaker.

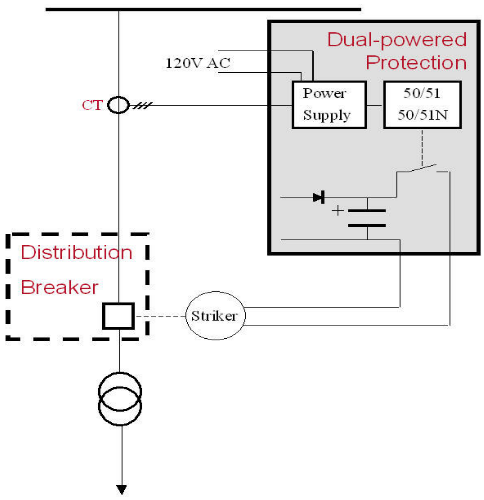

Fig. 13: Tripping scheme using a striker

This tripping output is completely independent from any auxiliary supply.

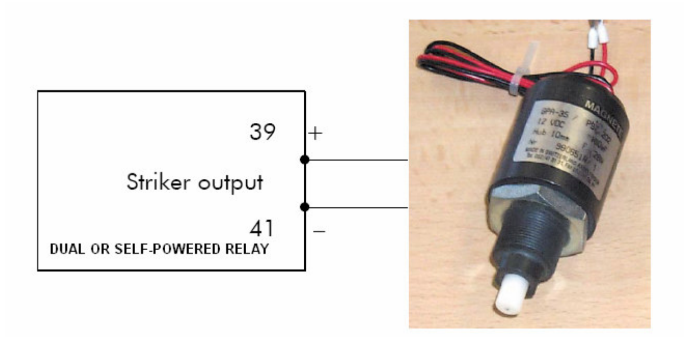

Fig. 14: Relay connection to Striker

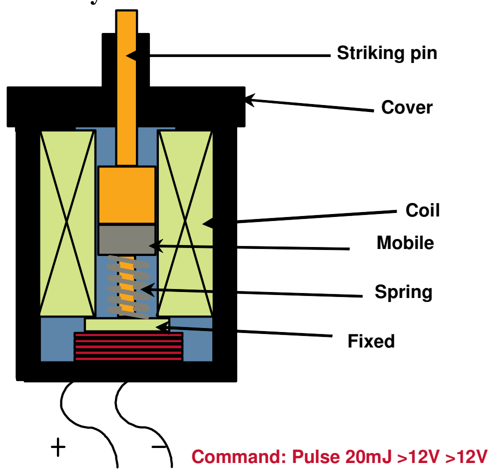

Fig. 15: Mechanical principle of a striker

Figure 13 shows a simplified block diagram of this breaker tripping method, Figure 14 gives an example of a striker connected to a dual or self-powered relay and Figure 15 shows the mechanical principle of the striker.

Capacitor Discharge Tripping

Dual powered relays may use either of the above methods. In addition, these particular relays charge an internal capacitor from the current circuit and also from the auxiliary voltage circuit (Figure 16). This capacitor module has such storage capacity that, in case of loss of auxiliary supply, it can supply sufficient energy to excite a standard trip coil for two consecutive tripping orders without recharge. It may be discharged directly into a suitably sensitive trip coil via one of the programmable output relays. The minimum energy fed to the trip coil is that from the capacitor, but in most cases it will be supplemented by a current from the auxiliary voltage circuit and/or the current circuit.

When energized from current alone, the lowest current for which the relay will operate will be that necessary to start up the power supply. To be able to use lower fault settings an auxiliary supply will be required.

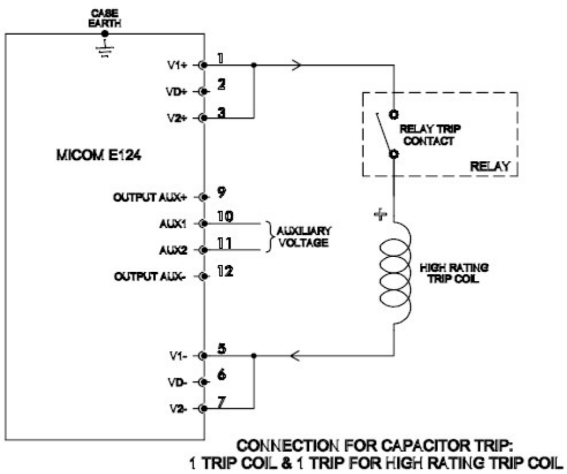

Fig. 16: Capacitance discharge wired to CB trip coil

The capacitance discharge circuit is not isolated from the auxiliary supply and to prevent the relay from being damaged, no external ground connection should be made to this circuit.

Figure 17 shows a capacitor module with such storage capacity that, in the case of loss of auxiliary supply, it can supply sufficient energy to operate a standard trip coil for two consecutive breaker trips without recharge.

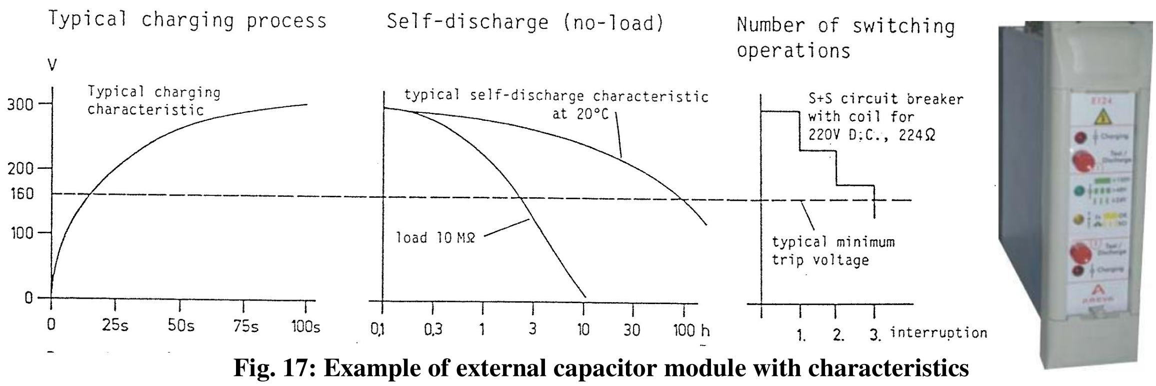

Fig. 17: Example of external capacitor module with characteristics

Special attention should be taken that the output voltage is not subjected to permanent loads, otherwise this would lead to rapid discharge of the storage capacitor and thus tripping of the circuit breaker would not be warranted. The tripping capacitor is charged up to approximately 300 V from the low voltage supply or from a voltage transformer. If there is a failure of voltage supply the capacitor maintains its charge for quite a long period (up to several days).

Some devices are able to provide two consecutive trips at maximum power (300V / 59J) without having to be recharged (multiple trips of lower voltage and lower energy). The trip contact of the protective relay is serially connected to the external trip coil as shown in the figure 16.
At the end of a first trip, an internal bi-stable relay automatically switches from the first bank of capacitors to the other. It is thus possible to get two successive trips without recharging of the capacitor banks.

This external capacitor module can be also used to supply power to an external device from an auxiliary AC/DC supply (even in case of voltage dips) or from a voltage transformer (VT) connected on the busbar as shown in Figure 18. In normal condition, the relay uses the DC version of the auxiliary voltage provided by an auxiliary AC/DC supply or from a voltage transformer (VT). In case this auxiliary voltage is lost (voltage dip), the two sets of internal capacitor banks will provide voltage to the relays. The duration for this depends on the power consumption of the relays and on its voltage range.

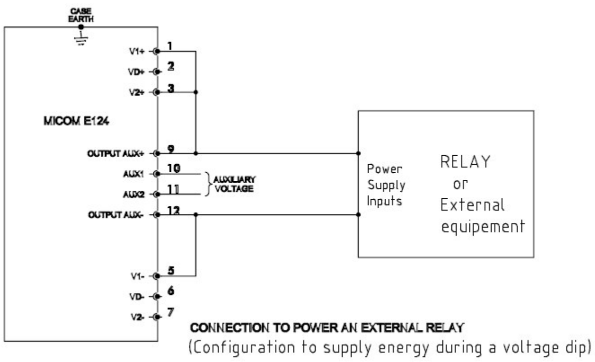

Fig. 18: Capacitor module used to Supply Power

AC Series Tripping

As an alternative the trip capacitor in the dual powered relays may be discharged into an auxiliary relay. This relay will be de-energized in the quiescent state, with its break contacts short circuiting the trip coils of the circuit breaker (shown in Figure 19).

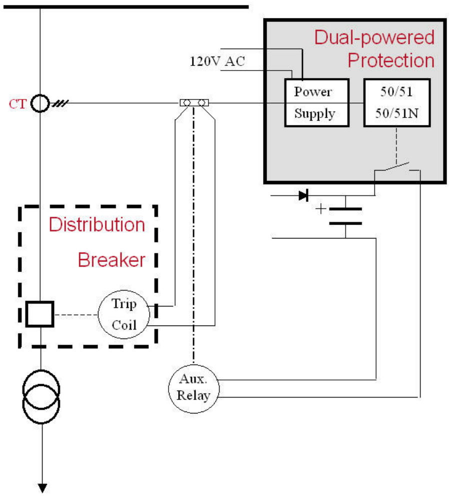

Fig. 19: AC series trip arrangement scheme

The operation of the changeover contact is completely independent from any auxiliary supply. On the other hand, an auxiliary supply will be necessary for the supply of the CB coil.

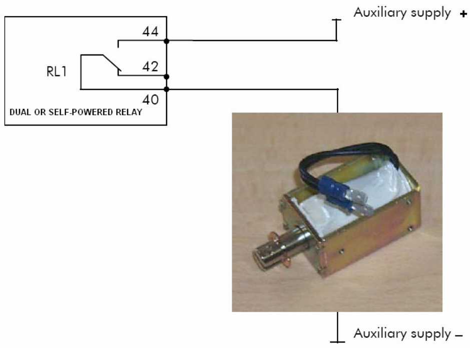

Fig. 20: Trip of the CB coil via a C/O contact

The trip coils are connected in series with the current transformer secondary circuit so that, when the auxiliary relay is operated, the full secondary current is diverted through the trip coils. To cover all fault conditions, three trip coils are required and may be necessary to limit the maximum energy that can be fed to each coil, by means of saturating shunt reactors.

7. TESTING OF DUAL-POWERED RELAYS

The testing of dual-powered relays in general is similar to the testing of relays with similar functionality. The only difference is that the tests require the addition of several modes of operation discussed previously in the paper. The tests of relay performance and characteristics should be performed under the following test conditions:

- Relay powered by AC
- Relay powered by load current above the required threshold
- Relay powered by load current below the required threshold

The threshold of the load current required to power the relay also needs to be tested.

8. CONCLUSIONS

Local and remote backup protection is intended to provide fault clearing in the case of complete failure of the primary and redundant backup protection in the substation affected by the fault. Such a failure can be related to loss of DC power that will eliminate all protective relays, i.e. there will be no device to detect the fault and issue a trip signal.

Remote backup protection reach settings are determined based on the careful consideration of multiple factors such as apparent load impedance and different level of infeed fault current under varying power system configuration. The problem with overreach and miscoordination under N-1 and N-2 conditions should be resolved by applying adaptive protection with changing Zone 2 and Zone 3 impedance reach based on control signals received from the SCADA master, indicating the changes in the system configuration. However, this can not be done with electromechanical relays, that are still a large percentage of the protective relays in service.

All of the above demonstrates the need for other solutions that will eliminate the requirements for remote backup for all fault conditions in another substation. A significant improvement can be achieved by reducing the chances for battery failure by continuously monitoring the battery and the DC circuits in the substation. For substations it is important that the security of the supply is maintained at all times. This means not only that the battery voltage is within required limits, but that earth leakage and any latent faults in the battery and connections will not result in failure to initiate tripping when a heavy current is demanded.

Another level of reliability that can be considered as a good insurance against complete local primary and backup protection failure is the application of dual powered relays. They are powered from an AC, or DC auxiliary supply. However, even both of these power supplies need not be secure because the relay can be powered by the load or fault current from the current transformer circuit in the absence of the auxiliary supply.

Applying one of these relays on the incoming feeder of a small distribution substation will ensure that the substation is still protected in the event of complete failure of the auxiliary supplies. In the case of larger substations with multiple transformers it is recommended that a dual-powered relay is installed on the high (or source) side of each transformer in order to provide selective tripping of the faulted power equipment only.

9. REFERENCES

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