



by Damien Tholomier., AREVA T&D Automation, Canada

Dual Power Protection

Single Battery – What if it Fails?

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 with primary and backup relays, in most cases with different operating principles and different manufacturers.

Even that protective relays are designed to be extremely reliable, they still may fail.

Biographical Sketch

Damien Tholomier received a B. Eng. in Electrical and Automation Engineering in 1992 from the University of Marseilles, France (Ecole Polytechnique Universitaire de Marseille). Damien joined ALSTOM T&D GmbH in Stuttgart, Germany where he worked for 5 years in the Protection & Control department as Power System Application Engineer. In 1997 Damien moved as Marketing Manager High Voltage Protection Business Unit with Alstom T&D Protection & Control in Lattes, France where he worked on full scheme distance protection algorithms. From 1999-2001 he was Sales & Service Director for Mediterranean Countries and Africa. From 2002-2006 he was Marketing Protection Relays Director for ALSTOM and later AREVA T&D Automation where he worked on new busbar relay (application of universal topology and CT saturation detection algorithms). Damien is currently Managing Director in Canada, and he is also responsible for Substation Automation Solutions in North America. Damien is CIGRE, IEEE, IEC TC95 and GIMELEC member, and Convener of CIGRE WG B5.36 "Applications for protection schemes based on IEC 68150."

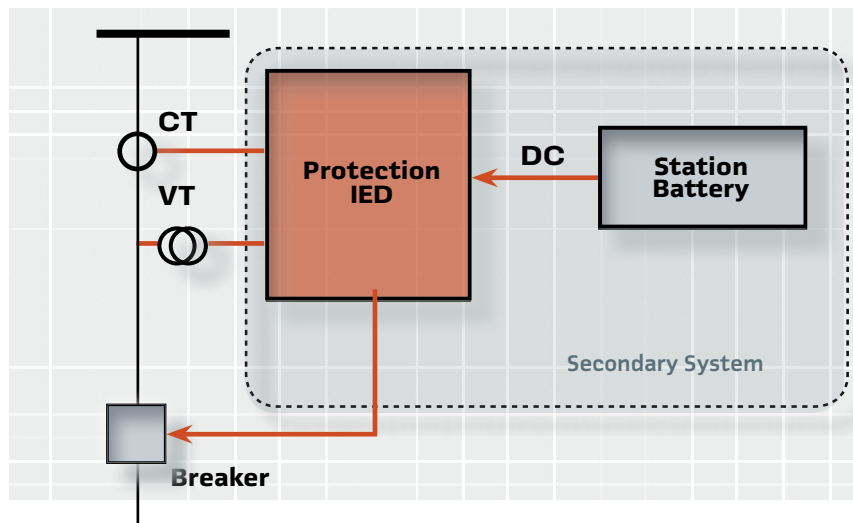
Introduction

Protection relay failure may be the result of component failure, operating principle, measuring transformer failure, etc. 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

Failure of any of the components will result in the failure of the

1 Fault clearing system components



fault clearing system to operate as designed. To determine the failure rate of the fault clearing system in Figure 1, we can use an example of a “*fault tree analysis*” based on the assumed failure rate of the individual components of the system. The result is shown in Figure 2.

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 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. 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. However, the large number of substations have a single battery subjected to different fault and operating conditions. There are 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.

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

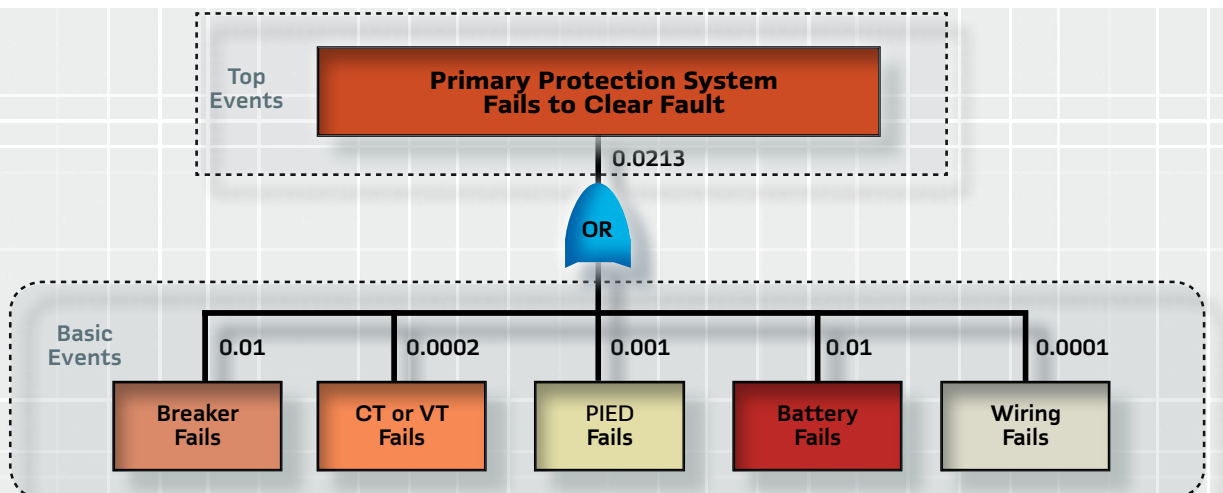
Failure of a circuit breaker or the substation battery has a significant impact on the reliability of the fault clearing system.

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

Achieving optimal performance of an electromechanical or solid state protection relay under all system conditions is practically impossible.

2 Fault tree of a fault clearing system



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.

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.

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.

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 expensive 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. It 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 ensure 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 fault conditions.

Dual powered protection relays

Dual powered relays (as the name indicates) are normally 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 current from the current transformer circuit in the absence of the auxiliary supply.

In a conventionally designed substation with a single battery, loss of DC will not only affect the operation of the protective relays. It will also make impossible the tripping of any breakers, required for the clearing of the fault. As can

Battery failure can be prevented through continuous monitoring.

Adding a second substation battery is very expensive and in many cases difficult to justify.

Dual-power relays can be powered by auxilliary supply, as well as load or fault current.

be seen from Figure 1, a single mode failure of the battery leads to a failure of the otherwise redundant fault clearing system.

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

In self-powered mode the relay is powered from the current transformer circuit alone. There is a requirement for a minimum level of current flowing through at least one phase of the current transformer in order for the relay to operate. Lowering the design value of this parameter increases the burden on the current transformers and the power dissipated within the relay case. The limits should therefore be a compromise based on these factors:

- Minimum current to power the relay for phase faults = $0.4 I_n$
- Minimum current to power the relay for ground faults = $0.2 I_n$

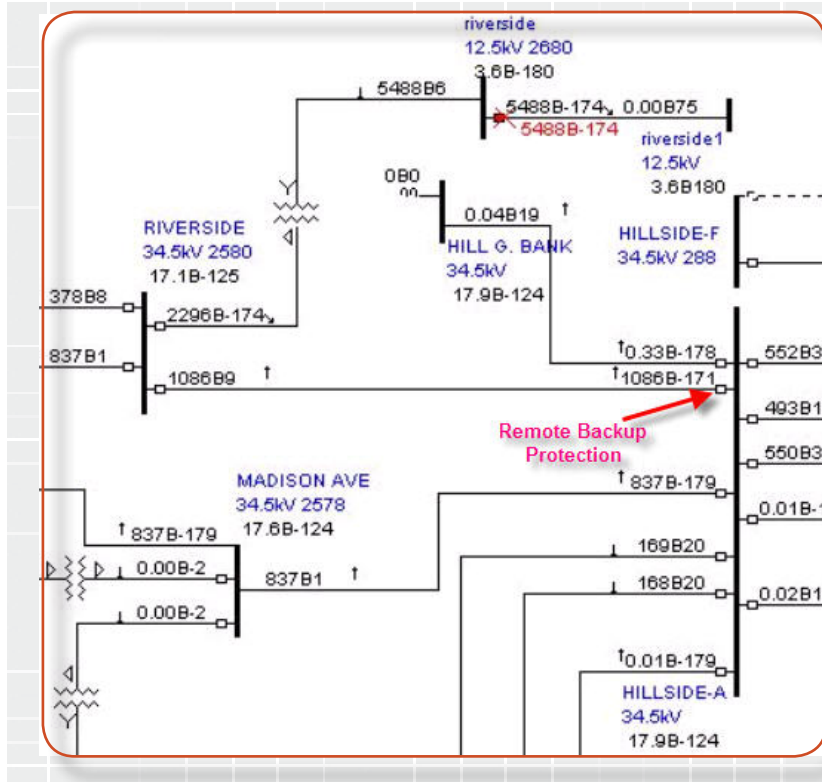
However, a combined three phase and ground fault relay will operate with lower ground fault current settings when the load current in the protected circuit is sufficient

3 Striker

Can be used for breaker tripping



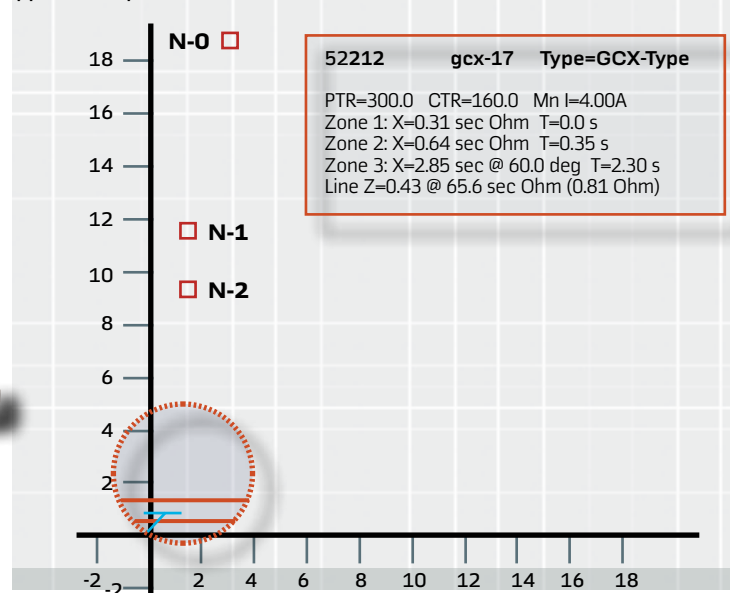
4 Remote backup protection operation



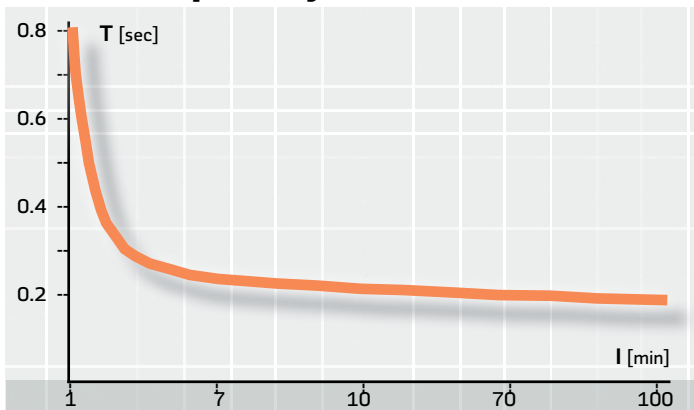
If Zone 3 of a distance relay can not see a fault on the low side of a remote end transformer, it will not provide remote backup for such a fault in case of single battery failure.

5 Phase distance relay -

Apparent impedance



6 Startup delay



to power the relay i.e. greater than 0.4 In. Settings less than 0.2 In are provided for ground faults, but they must be used with discretion.

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.

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 6 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 are usually 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

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 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 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 In.

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

Capacitors can be used to

store energy to trip the breaker

directly or through a striker.

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.

Breaker Tripping Using Striker

A dual-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. (Figure 3, Figure 7)

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 7).

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.

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 8 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.

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. 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.

Different methods for tripping the circuit breaker can be used to clear the fault.

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.

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. ■

7 Tripping scheme using a striker 8 Capacitor discharge trip

