New protection scheme based on IEC61850

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1. Abstract

The new International standard for communication networks and systems in substation, IEC61850 protocol, is expected to bring a profound evolution in electrical power systems. The new functionalities supported by an intelligent application of IEC61850 must result in a significant improvement of stability and reliability of power system.

Protection systems play a leading role in power system stability and reliability, since those depend on correct, rapid and selective disturbances elimination. IEC61850 opens the possibility of developing new protection schemes with these aims. In this paper is presented a new protection scheme performed by new IEDs based on the new features brought by IEC61850.

Key words: IEC61850, IED, Protection scheme, Reliability.

2. Introduction

IEC61850, the new International standard for substation communications, is going to involve a significant impact on the development of new devices, systems and communications schemes for power systems. In an advanced application phase of IEC61850, all devices in the substation and from remote substations, if needed from different vendors, will interchange information, such as remote sampled analogue measurements or digital signals.

Having local and remote analogue inputs available allows IEDs (Intelligent Electronic Devices) to carry out complete and precise calculations. In the same way, new algorithms and logical schemes will be developed using these measurements and digital inputs from devices of different locations of the system. This all new advantages should be used to expand the protection system solutions, resulting in a more reliable power system.

In this paper, a new protection scheme, based on IEC61850 communications is presented. The proposed scheme uses the interchange of analogue measurements and digital signals between different IEDs of a meshed network, with the aim of increasing the protection redundancy and reliability of the system.

3. Proposed scheme

In order to illustrate the new protection scheme proposed, the network area presented in Figure 1 is used as representative example of a meshed network.

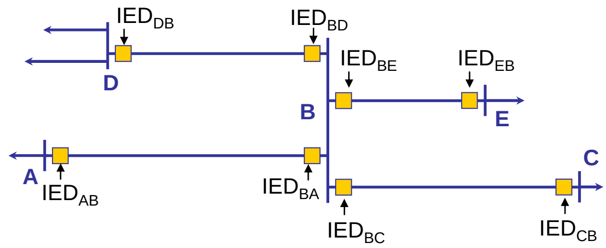

Figure 1. Meshed network scheme

Each bay of the proposed scheme is equipped with IEDs, with several protective functions implemented, such as differential (87) and distance protection (21) functions.

Taking full advantage of the new possibilities provided by IEC61850, every IED could take any information involved in the Substation Automation System, whether they are measured in local or remote substations.

In the proposed solution, each IED is informed of the following analogue values:

1) Local current and voltage.
2) Current and voltage measured at the remote end of the protected line.
3) Current and voltage measured at both ends of adjacent lines to the remote bus of the line where the IED is installed.

Using as particular example the IED_{AB} shown in Figure 1, its available analogue values are the following:

1) IAB, VAB.
2) IBA, VBA.
3) IBC, VBC; ICB, VCB; IDB, VDB; IBD, VBD; IBE, VBE; IEB, VEB.

Analogously, the rest of IEDs are informed of the current and voltage values of their adjacent forward lines, besides the local measurements, obviously.
In the presented scheme, every IED uses the information described above to evaluate fault conditions in its local line and, simultaneously, in the adjacent forward lines. This is called the protected area. In case of fault in any of the lines of the protected area, each IED can determine which of those lines is the faulted. In the example shown in Figure 1, if a fault occurs in line *BC*, all the IEDs looking at *B* substation (IED_{AB}, IED_{DB} and IED_{EB}) apart from local IED_{BC}, know that a fault has occurred in line *BC*.

In the proposed scheme, two different protective algorithms (differential and distance protection) work in parallel in every IED to evaluate fault conditions in the protected area:

1) Differential protection: Using local and adjacent forward lines measurements each IED executes differential calculations for each line of the protected area.
2) Distance protection: Using local measurements, each IED carries out fault impedance calculations and forward distance zone detection. Remote measurements from each end of the adjacent forward lines are used to execute directional comparison calculations. An overreaching zone detection combined with the directional comparison result determines which is the faulted line.

Once the faulted line is precisely located, the proposed protection scheme isolates it in a totally coordinated way ordering locally and remotely the trip of the line breakers. Each IED of the presented scheme detects when an adjacent line is faulted, as it's described above and, again using the means provided by IEC61850, sends remotely a trip signal to the corresponding breaker. In the example shown in Figure 1, if a fault occurs in line *BC*, all the IEDs looking at *B* substation detect that line *BC* is faulted and, instantaneously, cause *BC* breaker in *B* substation to trip. Analogously, all IEDs looking at *C* substation, which are not represented in Figure 1, trip *CB* breaker in *C* substation.

As can be deduced from the scheme description, each line is not only protected by local equipment, but actually it is protected remotely by a significant number of IEDs, so back-up protection support is clearly increased respect nowadays conventional protection schemes. At present, no more than two different protective devices are installed at each end of the best protected lines.

As a particular case of example, the failure of IED_{BC} is supposed when a fault occurs in line *BC* of the meshed network shown in Figure 1. With the proposed scheme implemented the fault would be correctly and selectively isolated by IED_{AB}, IED_{DB} and IED_{EB}, as it is shown in Figure 2.

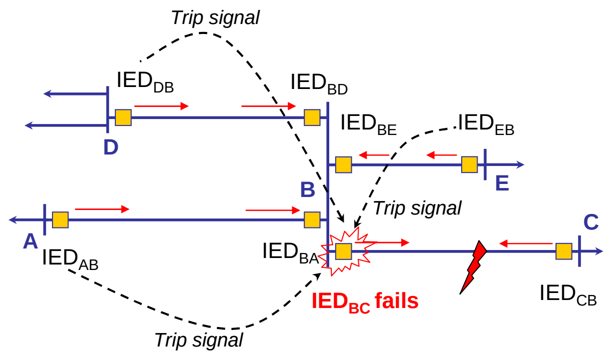

Figure 2. Scheme behaviour against fault and IED failure

In this example, each IED has three remote back-up devices, so three IEDs failures could happen and faults still would be isolated; moreover only the affected line would be isolated, which improves significantly the protection system. Another important feature of the scheme is that, under a total communication failure, the protective system would still preserve the nowadays behaviour, since distance protection functions implemented in IEDs would maintain their functionality (except communications aided schemes, obviously).

4. System modelling

The proposed scheme has been modelled and implemented in a protection simulation software. Having the system modelled in detail provides the performance of simulations which permit to evaluate the correct response of the scheme under different situations and eventual incidents.

The used tool, CAPE (Computer-Aided Protection Engineering), has the characteristic of being designed for relay settings coordination and having good and complete calculation modules for short-circuits and power flow. Furthermore, CAPE permits the analysis of the proposed scheme, contemplating diverse situations and incidents, such as failures of functions, devices, communications, etc.

CAPE has a large library of relays which includes realistic models of most of the commercial existing devices, and also offers the user the option of creating new relay models. Due to the originality of the proposed system, a new relay model has been developed in CAPE. This model, which has been called *IED_61850*, includes all the distance and differential protection functions detailed in the scheme described above. Figure 3 shows the CAPE chart with the elements which perform all the functionalities of the IED.

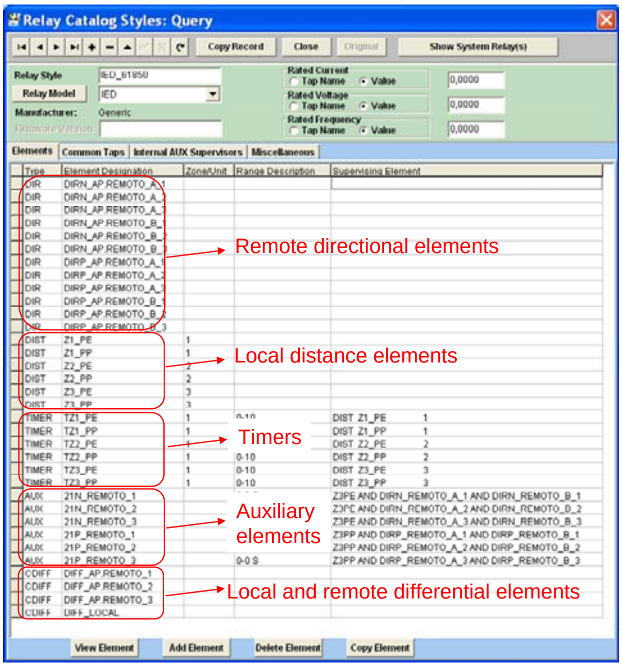

Figure 3. CAPE IED model elements

The description of the different functionalities of the model elements is the following:

1. Differential elements (CDIFF):

These elements perform current differential calculations using information provided by local and remote current transformers. The developed model has four current differential elements. One of them is the classic differential protection function, which receives information from the local current transformer and from the one at the remote end of the same line. The other three differential elements are used to protect three different lines. For this purpose, each element is informed by the current transformers of both ends of its protected line. In the example network, the four differential elements of the IED_{AB} protect lines *AB*, *BC*, *BE* and *BD*. Figure 4 shows that one of the differential elements takes information from both current transformers of line *BC*, which is its protected line.

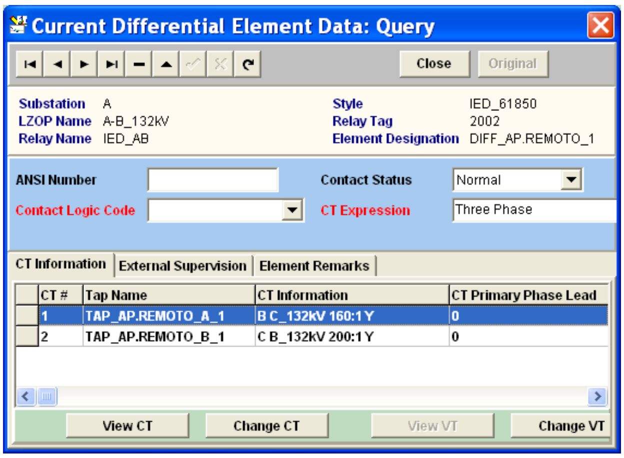

Figure 4. CT assignation to differential element

2. Distance elements (DIST):

The developed model contains six distance elements, which are used for three distance zones and two measurement loops for each zone (phase-phase and phase-earth). Figure 5 illustrates the six distance elements representation.

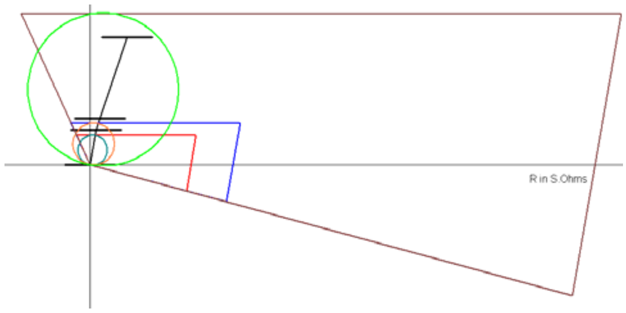

Figure 5. Distance protection zones

Each distance element carries out fault impedance calculations using measurements from local voltage and current transformers. Typically, each distance zone has a different time delay associated, which is executed in the CAPE model by the timer elements (TIMER).

3. Remote directional elements (DIR):

Each of these elements executes directional calculations using voltage and current information from the end of one of the forward adjacent lines. The object of these elements is to perform directional comparisons of the adjacent forward lines. The model uses twelve DIR elements, which consist of two elements that determine the phase-phase and phase-earth faults directionality for each end of the three forward adjacent lines (2 fault types, 2 line ends, 3 lines).

4. Auxiliary elements (AUX):

Auxiliary elements are used to define the remote trip logic based on distance and directional functions described above. For example, to remotely trip the *BC* breaker (in *B* substation), the logic implemented in the IED_{AB} is the one shown in Figure 6.

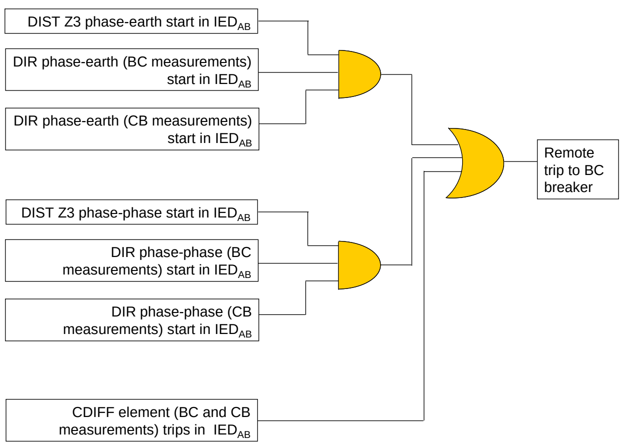

Figure 6. Remote trip logic based in differential, distance and directional elements

The elements used to implement this logic are the auxiliary elements. The developed CAPE model uses six AUX elements: two elements to trip each of the three forward adjacent protected lines (one element protects against phase-earth fault and the other one against phase-phase faults).

Once the new IED is modelled, the whole proposed scheme is implemented in CAPE. A network area like the presented in Figure 1 is used to simulate the scheme. Each line of the network area is protected by IEDs like the one described above.

Each breaker has a logical expression associated that, when it is asserted, causes the breaker to open. This expression, called trip logic, includes all the element actuations, taken from local IEDs or from remote ones, which may trip the breaker. By associating local and remote elements used in CAPE, are emulated the real trip signals with the IEC61850 features proposed in the scheme. As an example, the trip logic expression implemented in CAPE for breaker *BC* in substation *B* (in the example network area shown in Figure 1) consist of the surveillance of local IED trip and the remote IEDs ones. Each of these trip signals can be generated by the following elements actuations:

- Local IED trip:
  - -CDIFF element with BC and CB measurements.
  - -Zone 1, Zone 2 or Zone 3 of DIST element.

- Remote IEDs trip:
  - - IED_{AB} elements actuations.
  - - IED_{DB} elements actuations.
  - - IED_{EB} elements actuations.

Each of these remote trip signals contains a logic expression equivalent to the one exposed in Figure 6.

5. System simulations

Once the IED, the scheme and the network are modelled in CAPE as described above, simulations contemplating four relevant cases have been carried out in the program.

These four cases are:

1) Three-phase fault in line BC with all the protections and communications available.
2) Three-phase fault in line BC without differential functions.
3) Three-phase fault in line BC without local protections.
4) Three-phase fault in line BC without communications.

A three-phase fault in line *BC* is simulated in CAPE. The result is shown in Figure 7.

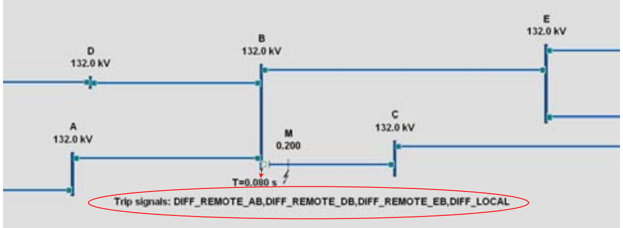

Figure 7. Result of the simulation in CAPE

As can be observed, *BC* breaker in *B* substation is tripped virtually instantaneously and without miscoordinations. The simulation result presents the trip expressions which have ordered the trip of the breaker. These orders are DIFF_LOCAL, DIFF_REMOTE_AB, DIFF_REMOTE_DB and DIFF_REMOTE_EB, which means that all the IEDs whose adjacent forward line is line *BC*, detect the fault and send the trip signal to the correct breaker. Note that no distance protection trip appears because differential algorithm is faster.

If we inhibit differential elements, which could simulate an element failure, the result is the presented in Figure 8.

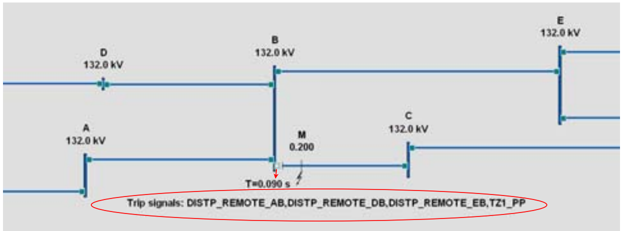

Figure 8. Result of the simulation in CAPE without differential elements

In this simulation the faulted line breaker is also tripped without miscoordinations. The trip expressions are DISTP_REMOTE_AB, DISTP_REMOTE_DB, DIST_REMOTE_EB and TZ1_PP (local zone 1 distance protection). The scheme operates correctly to clear the fault as can be observed in the two simulations shown above.

Another simulation has been performed in CAPE to verify the response of the proposed system in case no local protections were available in line *BC*, due to a failure or maintenance works. With this aim, local IED_{BC} is inhibited and a fault in line *BC* is simulated. Figure 9 shows the results.

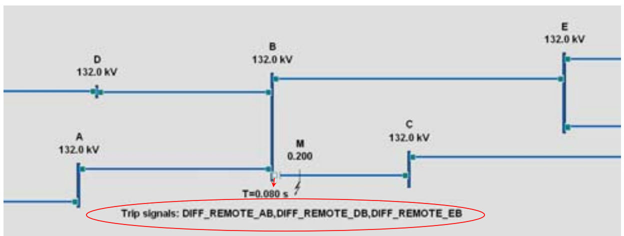

Figure 9. Result of the simulation in CAPE without local protections

Again, the fault is correctly cleared. In this case, all the trip signals have been sent by remote IEDs. The trip expressions are DIFF_REMOTE_AB, DIFF_REMOTE_DB and DIFF_REMOTE_EB. Three different IEDs are ready send a trip signal in order to clear the fault, so actually, IED_{BC} has three backup protections, which are $IED_{AB,}$ IED_{DB} and IED_{EB}.

The last simulation carried out emulates the failure of the communication system, which disables all remote trips and the differential function in the local IED. This case is simulated inhibiting these elements in the trip logic. The result is shown in Figure 10.

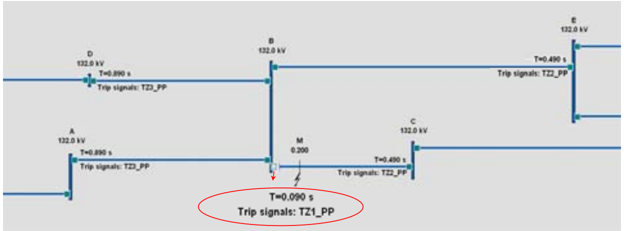

Figure 10. Result of the simulation in CAPE without communications

As can be observed, the protective system behaviour is the expected for a current one without communication schemes. Local distance protection detects the fault in zone 1 and orders the trip signal instantaneously, according to its settings. Remote devices detect the fault in overreaching zone (zone 2 or zone 3) and wait their set time delay after which, in case fault would not have been cleared, they would send a trip signal to their correspondent local breaker.

The simulations performed confirm the advantages of the proposed scheme presented in this paper.

6. Conclusion

A new protection scheme using the new features brought by IEC61850 is proposed. The main characteristics of the proposed system are the following:

1) As the number of redundant protective functions has increased, the reliability of the system must be improved. A deeper analysis of the reliability with precise data should be performed in order to quantify an exact result of this improvement.
2) The medium fault isolation time is decreased since under a correct operation of the scheme, all faults are tripped instantaneously.
3) The isolated area in case of a failure of local protections is lower than the required in current schemes.
4) The scheme complete functionality uses IEC61850 communications features, but if a total communications failure happens, the network would not be left unprotected: ordinary distance protection function implemented in proposed IEDs would keep active.

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