S1-3: New and re-discovered theories and practices in relay protection

Practical experience from multiterminal line differential protection installations

Z. GAJIĆ, I. BRNČIĆ, T. EINARSSON, B. LUDQVIST
ABB AB, Substation Automation Products
Sweden
zoran.gajic@se.abb.com

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Introduction

Multi-terminal lines are more often used in modern power systems than before. They are becoming particularly popular in sub-transmission networks (i.e. in networks with rated voltages between 60kV - 160kV). Such lines pose big challenges for an utility protection engineer. Traditionally a lot of skills are needed in order to properly apply stepped distance relays to protect the line. For protection of such lines the multi-terminal differential protection is a much better solution. However even for the differential protection such applications might pose special operating conditions which need to be investigated.

Trial Installations

In order to get some practical experience in such applications ABB has installed two trial installations of such nature since 2003. The first installation is a differential protection for a five-end 132kV overhead line as shown in Figure 1.
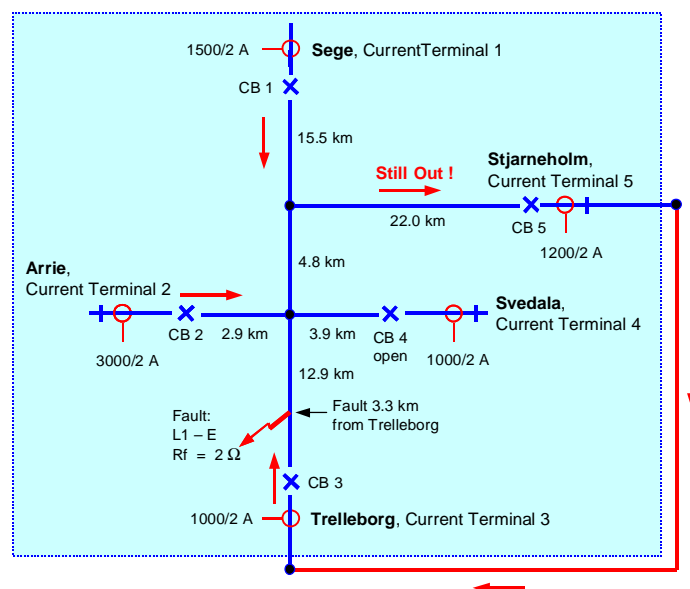

Figure 1: Five-end, 132kV OHL used for first trial installation

For this installation master-master differential protection principle was used (i.e. every differential relay had all five currents available and were able to perform the differential protection algorithm). The special application problem with this installation was a possibility for a current out-feed for internal faults as shown in Figure 1. Such faults were simulated by use of ATP [2] and proper operation of the multi-terminal line differential protection for such special fault cases was verified. One such case will be presented in the paper.

The second installation is a differential protection for a three-end 132kV overhead line as shown in Figure 2.
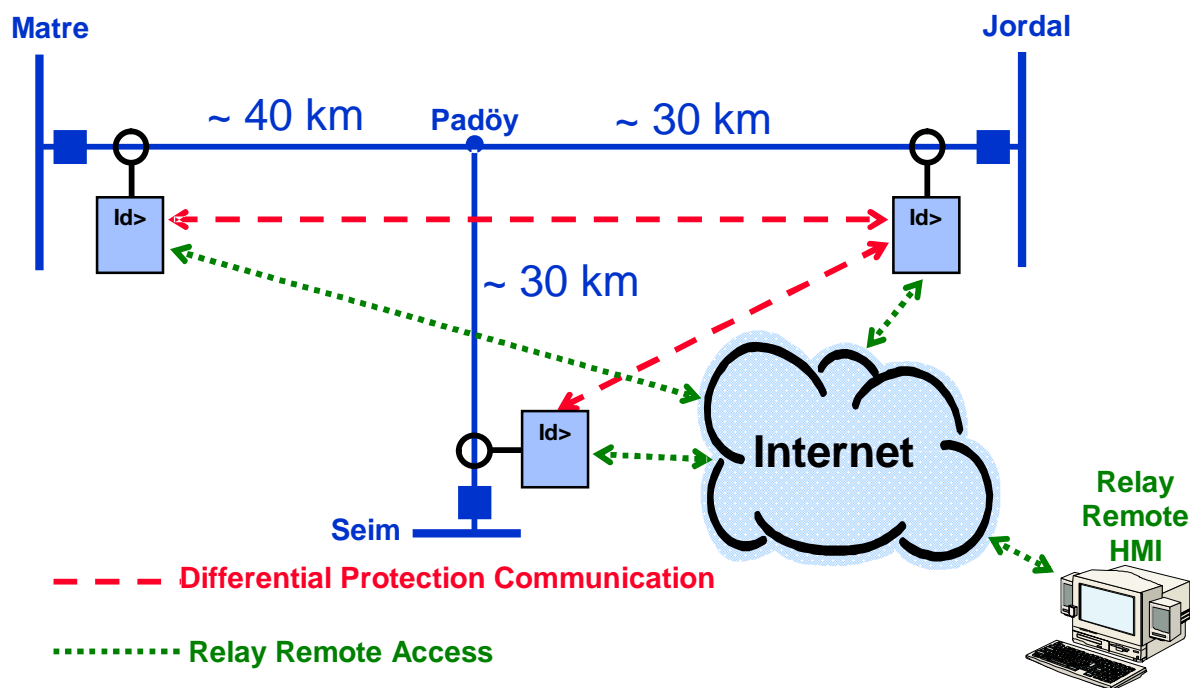

Figure 2: Three-end, 132kV OHL used for first trial installation

For this installation master-slave differential protection principle was used (i.e. only one differential relay had all three currents available and was able to perform the differential protection algorithm). In addition, remote access via public internet network was arranged for ABB in order to make easier disturbance file downloading. In this installation very interesting primary fault which evolved all three phases in a special way has happened during the trial. The captured disturbance file will be used in the paper to evaluate the differential protection scheme operation for such special fault.

In both trial installations the differential relay trip output contact was only used for alarming (i.e. the differential relays were not connected to the trip the protected line circuit breakers).

Description of the line differential function

The installed protection was a newly developed multi-terminal line differential relay [1] consisting of a traditional unrestrained/restrained differential function in combination with an internal/external fault discriminator. The restrained differential function has a dual biased slope characteristic according to Figure 3. The function is phase segregated except for the case when a power transformer is included in the protected zone. The differential current (Operate current) is the vectorial sum of all measured currents taken separately for each phase and the bias current (Restrain current) is considered as the greatest phase current in any line end and is common for all three phases.
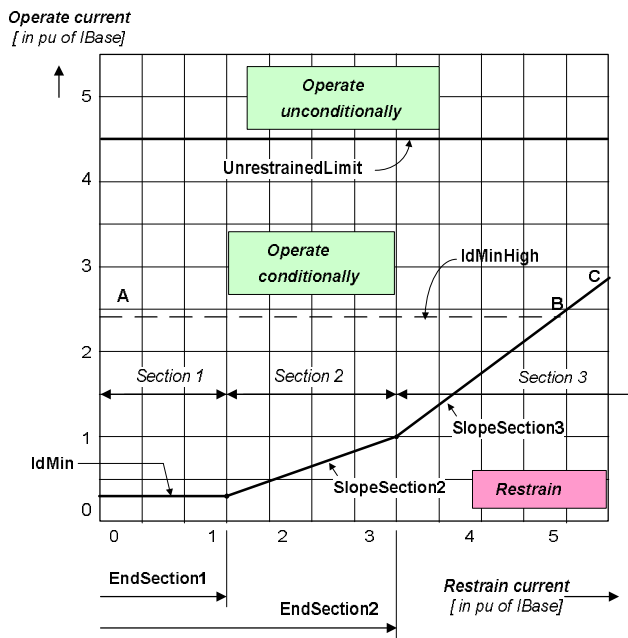
Figure 3.   Line differential protection characteristic

If a fundamental frequency differential current is above the restrain characteristic a start signal is issued for that phase. The instantaneous differential current of the phase is analyzed regarding the 2nd and 5th harmonics. If the function has started and the content of these harmonics are below defined levels the function will trip. In other case the function will be blocked as long as the harmonics are above the defined levels. The blocking affects the phase where a high level of harmonics has been detected. However with the cross-blocking feature the 2nd and 5th harmonic blocking in one phase will also block the differential function of the other phases. There is also an unrestrained differential function without any stabilization from the 2nd and 5th harmonics.

The fault discriminator distinguishes between internal and external faults and is based on an analysis of the negative sequence current component at the ends of the protected circuit. It works such that the phase angle of the negative sequence current component from the local end is compared with the phase angle of the sum of the negative sequence current components from the remote ends. The characteristic for this fault discriminator is shown in Figure 4, where the directional characteristic is defined by the two setting parameters *IminNegSeq* and *NegSeqROA*.
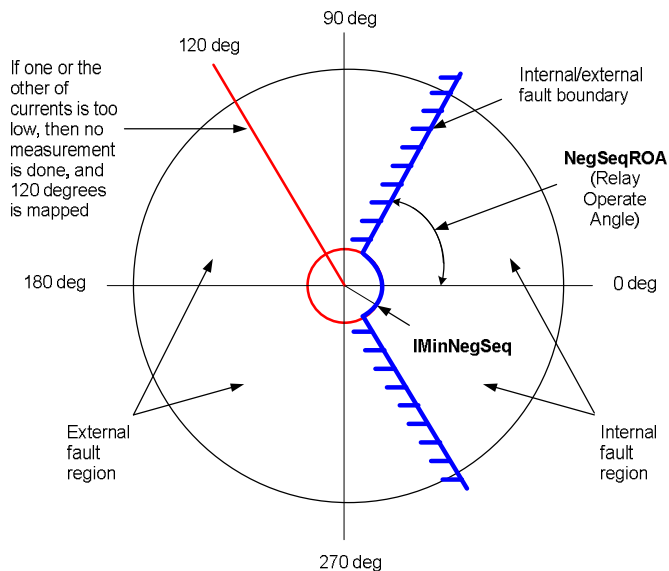

Figure 4.   Operating characteristic of the internal/external fault discriminator

The reference direction of currents is considered to be towards the line. Thus, when both currents to be compared have this direction, the phase difference between them will ideally be close to zero and an internal fault can be suspected. In the opposite case, when one current is entering and the other is leaving the protected object, the phase difference will ideally be 180 degree and an external fault can be expected. In case either the local or the sum of the remote negative sequence currents, or

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both, is below the set minimum current level, *IminNegSeq*, the fault discriminator will not make any fault classification and the value 120 degree is set. This value is an indication that negative sequence directional comparison has not been possible to do and the classification is neither internal fault nor external fault.

When a fault is classified as internal, a trip is issued under the condition that the dual slope restrained function has started. In most cases the harmonic blocking is overridden. A classification as external fault results in an increase of the restrained characteristic trip values from *IdMin* to *IdMinHigh*.

Current Out-feed Possibility during Internal Faults

One of the specialties with multi-terminal line differential protection is the possibility for current out-feed during internal fault. Namely, depending on the external connections around the protected circuit, current can flow out of the protected zone during internal fault. Such conditions can happen for the application shown in Figure 1 when the circuit breaker at Svedala substation (i.e. Terminal 4 in Figure 1 and Figure 5) is open and at the same time a fault happens close to Trelleborg Substation (i.e. Terminal 3 in Figure 1 and Figure 5). One such fault at distance of 3,3km (i.e. critical distance) from the Trelleborg Substation has been simulated in ATP [2]. L1-to-ground fault was simulated with 2Ω fault resistance, as shown in Figure 1. For such a fault current will flow out of the protected zone at Stjarneholm Substation (i.e. Terminal 5 in Figure 1 and Figure 5), as shown by red line in Figure 1. Current waveforms for such fault scenario are given in Figure 5. Currents obtained from this ATP simulation were fed to multi-terminal line differential protection algorithm. The new line differential protection [1] can easily cope with such faults and it will trip the protected circuit irrespective of out-feed currents at one terminal end of the protected line.
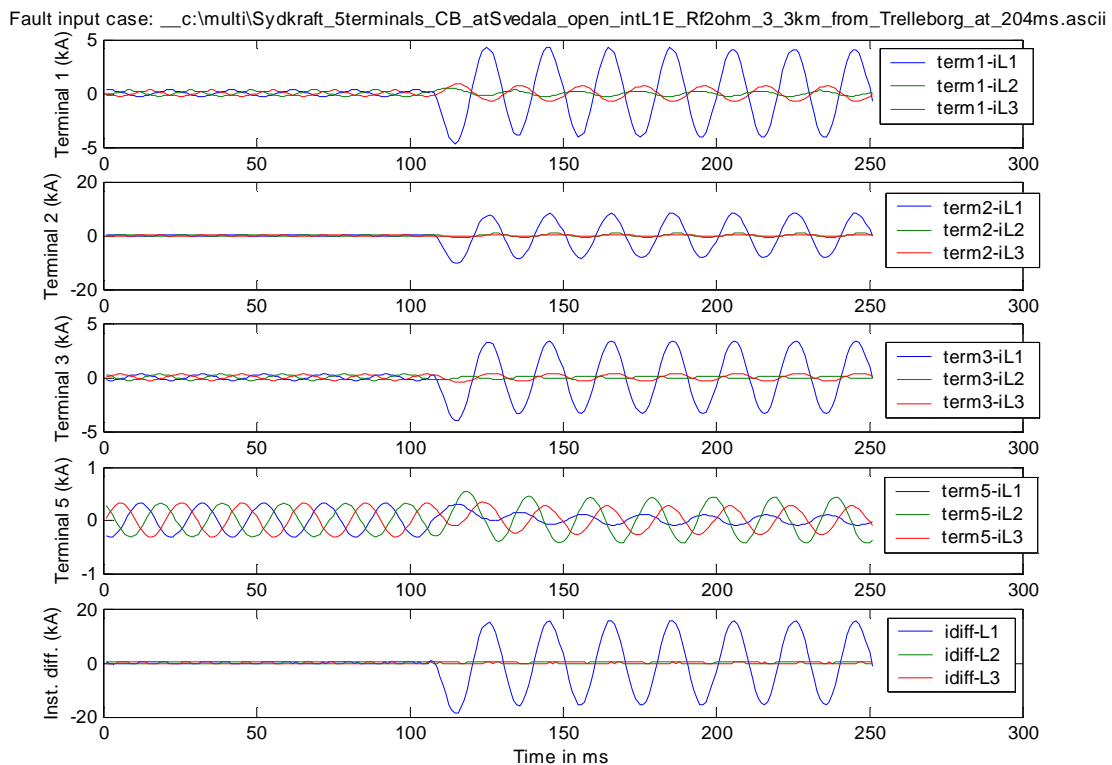

Figure 5: Current waveforms for fault shown in Figure 1

During this trial installation no real internal faults has happened on the protected circuit.

Faults Captured in Second Trial Installation

The second trial installation is shown in Figure 2. In this installation a very interesting primary fault, which involved all three phases in a special way, happened during the trial period. The captured disturbance file by the differential relay installed in the Jordal Substation is used here in order to evaluate the differential protection scheme operation for such special fault. At the moment of the disturbance the 132kV circuit breaker in the Seim Substation was open. The captured current waveforms from all three line ends and resulting differential currents waveforms, captured by relay installed in Jordal Substation, during this fault are given in Figure 6.
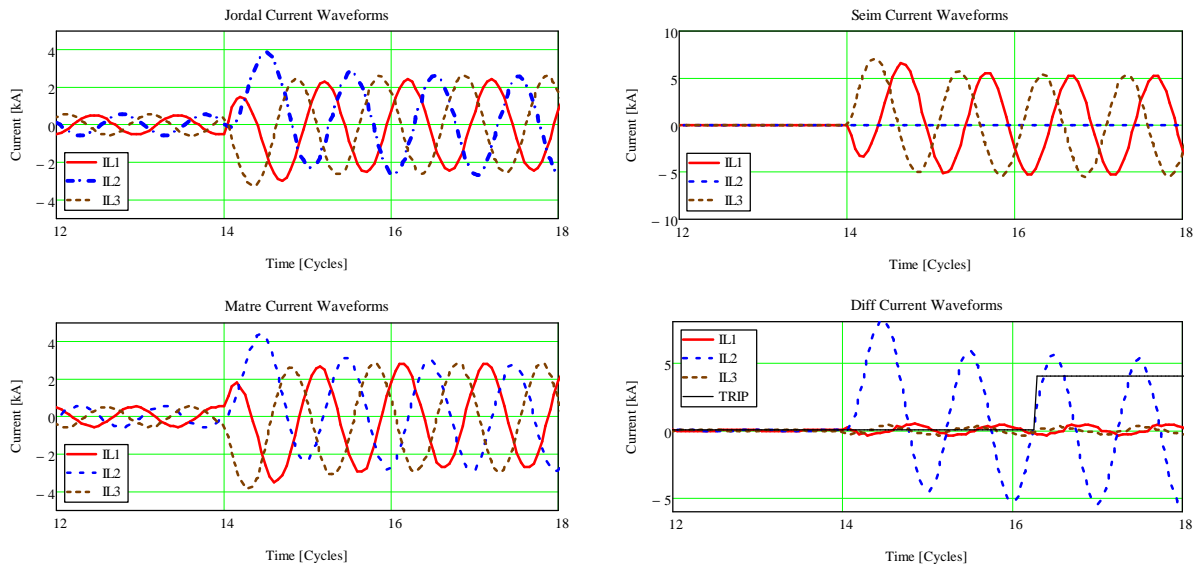

Figure 6: Current waveforms for fault captured in second trial installation (shown in Figure 2)

Fault started as external L1-L3-to-ground fault in between open CB and the CT in Seim substation. Within three to five milliseconds it evolved the L2 phase as well but on the line side of the CT in the Seim substation as shown in Figure 7. Thus, the fault finally became the three-phase-fault from the power system point of view, but for the differential protection it was an external fault in phases L1 and L3 and an internal fault in phase L2! Such fault behavior was confirmed by site inspection in the Seim substation where it was concluded that it was simultaneous phase-to-ground fault in all three phases. Differential protection tripped correctly for this internal fault as shown in Figure 6.
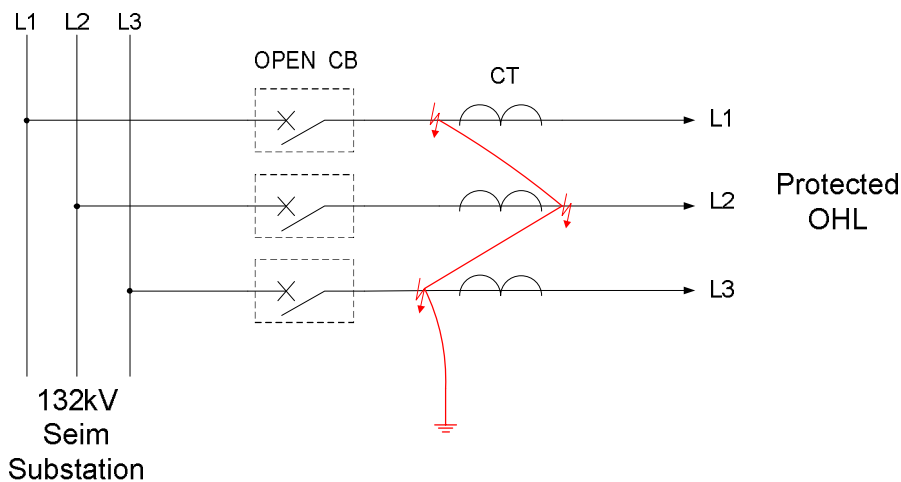

Figure 7: Exact fault location in every phase for presented fault in Seim substation

In the same trial installation another internal three-phase fault has happened. By evaluating the captured disturbance file it was confirmed that the internal/external fault discriminator (Figure 4), based on negative sequence current components, can properly identify this fault as internal, despite of the fact that this was a "symmetrical" three phase fault!

Communication Issues

Communication is a one of the most critical parts of a multi-terminal current differential protection scheme. There are two main types of telecommunication networks used for the multi-terminal current differential protection:

1) Telecommunication networks with fixed or symmetric routes, where echo timing can be used
2) Telecommunication networks with unspecified route switching, where the accurate global time such is GPS (Global Positioning System) is required

In both trial installations digital communication network via multiplexer has been used to provide communication media between differential protection relays. In one of the two trial installations even a commercial broadband telecommunication network was used as communication media for the differential protection. Practical experience from this installation proved that such solution works well.

For ABB it was good experience to fine-tune all details of the differential relay remote end communication software in order to insure proper operation of the differential protection scheme under periods of time when communication errors occur or a setting change is applied in one of the differential relays.

Conclusion

In this paper it has been shown that the multi-terminal line differential protection is a good solution for protection of lines with more than two ends. Multi-terminal lines are more and more often used in modern power systems. They are becoming particularly popular in the sub-transmission networks (i.e. in networks with rated voltages between 60kV - 160kV). By applying multi-terminal line differential protection scheme on such lines very good protection solution is achieved. If required, optional distance protection can be included in each differential relay in order to provide reserve protection for the line. Alternatively distance protection can be used as main protection in case of communication failure.

Presently the first trial installation is discontinued while the second one is still in service.

Acknowledgement

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References

[1] ABB Document 1MRK 505 186-UEN, "*Application manual, Line differential protection IED RED 670*", Product version: 1.1, ABB Power Technologies AB, Västerås, Sweden, Issued: March 2007
[2] ATP is the royalty-free version of the Electromagnetic Transients Program (EMTP). For more info please visit one of the following web sites: http://www.eeug.de/ or http://www.ee.mtu.edu/atp/