

Verification of Utility Requirements on Modern Numerical Busbar Protection by Dynamic Simulation

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Summary

Power utilities are aware of the specific characteristics and requirements for their network. For this reason, they may require additional functionalities from the protective devices and secondary systems included in their power network. Therefore State Grid Cooperation of China (SG) requires a number of specific tests to be conducted on the protection system proposed for a particular application to prove the suitability of the proposed protection system for the specific application. Only when all of these tests are successfully passed, the protection system is certified for use in State Grid's network which has 70% of total installed capacity of China. China Electric Power Research Institute (CEPRI) is given the tasks for carrying on this type of dynamic tests to check if the protection system can fulfil SG's requirement by using the power system dynamic simulator in CEPRI's test centre.

Keywords

Relay Protection, Busbar Protection, Differential Protection

1 Introduction

The 500kV busbars are extremely important nodes in State Grid's transmission network. Thus, busbar protections for these stations have to fulfil very strict requirements, which are set down by the China national testing standards. Two typical station layouts are used in the busbar protection tests, mainly one-and-a-half breaker station and double-bus single-breaker station with a bus coupler bay [1].

The numerical busbar protection has been tested on an analogue power system simulator in order to verify that it can handle both station configurations. Different operating conditions for the busbar protections have been tested as listed below:

- Internal and external metallic faults (i.e. without fault resistance)
- Internal faults with fault resistance
- Evolving faults
- Circuit Breaker Failure
- Faults during a power swing in a network
- Internal and external faults during active load-transfer for double-bus single-breaker station layout
- CT saturation for external faults
- Open CT secondary circuits
- Line and power transformer energization
- Internal and external faults during off-nominal power system frequency condition

- Special test for one-and-a-half breaker station (internal faults with out-feed currents)
- DC power switching (off/on) while relay is in service and busbar is loaded

Altogether 1528 test cases on an analogue power system simulator were performed [1]. The behaviour of the numerical busbar differential protection IED [2] during these operating conditions will be presented. Some of the results will be presented by using the captured disturbance files.

2 Relay Operating Principles

The basic concept for any bus differential relay is practically a direct use of Kirchoff's first law that the sum of all currents connected to one differential protection zone shall be zero. If that is not the case, an internal fault has occurred.

In other words, as seen by the busbar differential protection the sum of all currents which flow into the protection zone (i.e. currents with positive value) must be equal to the sum of all currents that flow out of the protection zone (i.e. currents with negative value), at any instant of time. Such interpretation enables quite efficient implementation of a numerical bus differential relay algorithm, because any differential zone can be represented by just three quantities, as shown in Figure 1, regardless the number of actually connected feeders.

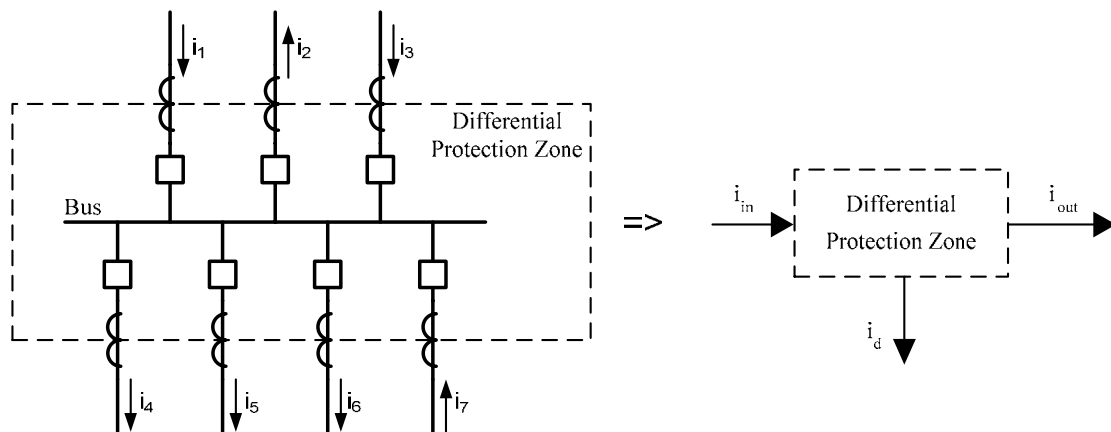


Figure 1: Representation of the bus differential protection zone

Here:

- i_{in} is total instantaneous incoming current flowing into the bus
- i_{out} is total instantaneous outgoing current flowing from the bus
- i_d is instantaneous differential current

By looking into the property of only three quantities it is possible to make a numerical busbar differential protection relay which can:

- Operate quickly for internal faults due to the fact that i_{in} becomes much larger than i_{out} during an internal fault (i.e. current flows into the faulty bus but it doesn't flow out from the faulty bus)
- Remain stable for external faults followed by CT saturation due to a fact that for short period of time, immediately after the fault current zero crossing, i_{in} will be equal to i_{out} (i.e. before any CT goes into saturation)
- Detect an open CT secondary circuit in any one of the connected feeder CTs when one of i_{in} or i_{out} remain unchanged while the other experiences a sudden drop in magnitude

These are actually the very similar methods used by analogue, moderate impedance bus differential relay which has been successfully used in practice for many years [3]. For more information regarding numerical implementation please refer to [2].

3 Relay Test Setup

3.1 Double-bus single-breaker station layout

For the double-bus single-breaker station layout four feeder bays and one bus-coupler bay were used during the testing. Only the disconnectors auxiliary contacts and CT input (three of them with ratio 2500/1 and one with ratio 1250/1) were available from each feeder bay. From the bus-coupler bay only one CT set (with ratio 2500/1) and auxiliary contacts of the CB were available to the busbar protection during the testing. The five fault positions were used:

- Internal fault on Busbar I
- Internal fault on Busbar II
- Internal fault in Dead-zone between bus-coupler CB and between bus-coupler CT
- External fault on Feeder 1
- External fault on Feeder 3

3.2 One-and-a-half breaker station layout

For the one-and-a-half breaker station layout two full diameters (e.g. altogether four feeders) were used during the testing. Only four CT inputs, all with ratio 2500/1 A, were connected to the busbar protection. The four fault positions were available as follows:

- Internal fault on Busbar I
- Internal fault on Busbar II
- External fault on Feeder 1 (locates as upper feeder in the first diameter)
- External fault on Feeder 3 (locates as upper feeder in the second diameter)

Additional fifth feeder, with CT ratio 2500/1 was connected to the lower busbars in order to test internal faults with out-feed conditions. During all tests busbar differential protection operated as required. Table 1 provides overview about all test results.

3.3 Busbar Protection Settings

Only the most important setting parameters will be presented here. During all tests the differential protection minimum pickup level was set to 800A primary. The differential protection slope is fixed to 0.53 and can not be changed by the end user. The built-in open CT detection feature was set to 200A primary. Same settings were used for both differential zones. Pickup for built in breaker failure protection was set to 250A primary with time delay $t_2=0,15s$.

4 Testing Results

During all tests busbar differential protection operated as required. Table 1 provides short overview about all tests:

TABLE I: Summary of test results

Test Point	Test Description	Relay Performance
Internal and external metallic faults	All types of internal and external faults without fault resistance were simulated.	Protection remained stable for all external faults. Protection operated selectively for all internal faults. Operating time was from 11.2ms to 19.0ms*
Internal resistive faults	Internal single-phase-to-ground fault with fault resistance of 100Ω and phase-to-phase fault with fault resistance of 25Ω.	Protection operated correctly for all fault types. For single-phase-to-ground faults operating time was from 15ms to 27.5ms and for phase-to-phase fault operating time was from 12ms to 20ms*
Evolving faults	External fault evolves into internal fault with different evolving time (i.e. 10-200ms). Internal fault in one section evolves into internal fault on the other section with different evolving time (i.e. 10-200ms). Simultaneous double internal faults in both busbar sections.	Protection remained stable for all external faults. Protection operated selectively when fault evolves into internal.
External faults with CT saturation	Simulate all types of external faults followed by a CT saturation in the faulty feeder.	Protection remained stable for all test cases. Fastest time to saturation achieved during testing was 2.8ms
Faults during active load-transfer	Internal and external faults were applied while one feeder bay was simultaneously connected to both busbar sections	Protection correctly tripped both busbar sections for all internal faults. Protection remained stable for all external faults.
Power swing and faults during power swing	Cause dynamic power system instability in the tested system with the centre of a power swing close to the protected busbar. Apply internal and external faults during the swing.	Protection remained stable for all external faults. Protection operated selectively for all internal faults.
Open secondary CT circuits	Open one phase of a loaded CT on its secondary side. Apply internal and external faults after that.	Protection could detect the open CT circuit in all test cases. Behaviour for consecutive internal/external faults was in accordance with the relay setting.
Energising of a bus-section, line and transformer	Energise a healthy bus-section via bus-section CB. Energise a line. Energise a transformer. Energise a fault bus-section via bus-section CB.	Protection behaved as expected during these tests (e.g. remained stable and only tripped when energising a faulty bus-section)
Faults during off-nominal frequency conditions	Apply internal and external faults during off-nominal frequency conditions (e.g. 48Hz & 52Hz)	Protection remained stable for all external faults. Protection operated selectively for all internal faults.
Special test for one-and-a-half breaker station layout	Internal fault situation in which current flow out from the faulty busbar.	Protection operated selectively for such special internal faults.
Circuit breaker failure	Bus-coupler CB failed to trip for internal busbar fault. Feeder CB failed to trip for external fault.	Protection correctly tripped all adjacent breakers for all CB failure test cases.
DC supply power off/on test	During normal through-load condition DC power supply to the relay was switched off and on.	Protection behaved as expected during these tests (e.g. remained stable)

* Operating time measured by external recorder (include relay trip output contact time)

Three selected test cases are presented. Disturbance files captured by busbar protection relay are used in the following figures. In Figure 2 external fault followed by faulty feeder CT saturation is presented. The relay remained fully stable for this external fault. In Figure 3 internal fault is presented. The relay operated quickly in less than half-a-cycle. In Figure 4 evolving fault is presented. The relay operated quickly once the fault becomes internal.

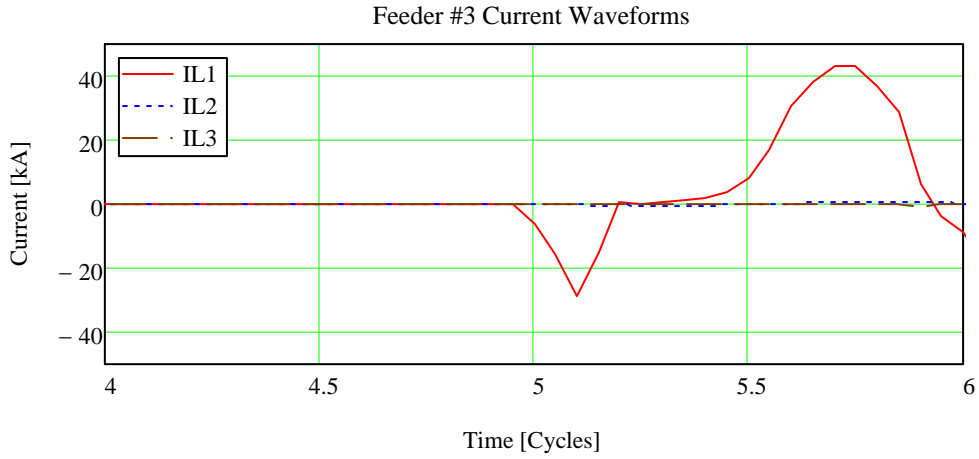


Figure 2: Faulty feeder CT saturation for external fault

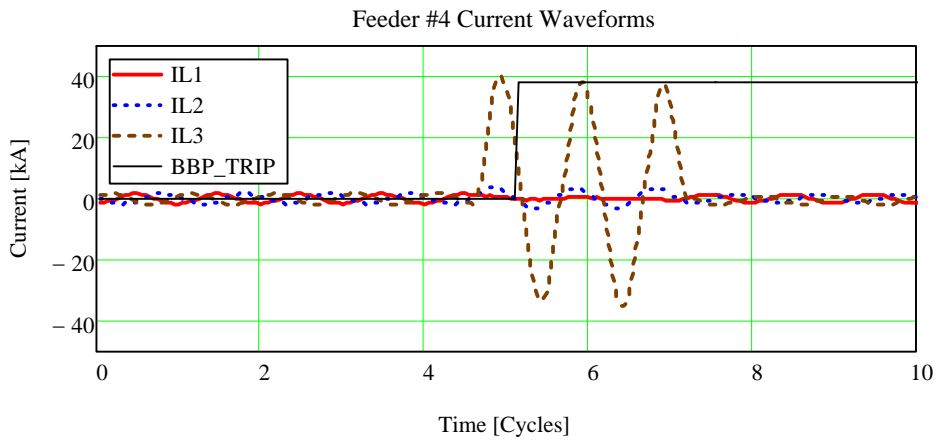


Figure 3: Internal L3-to-ground fault

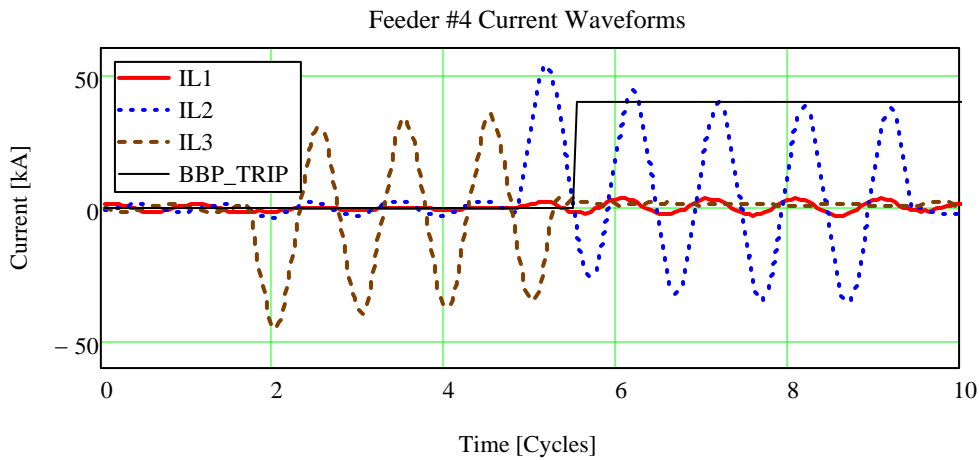


Figure 4: External L3-to-ground fault evolves into internal L2-to-ground fault

5 Conclusion

After all these tests, the protection relay [2] was officially approved by CEPRI to be used for busbar protection applications in China for all voltage levels up to and including 500kV.

References

- [1] CEPRI "Inspection and Test Report", Document No: 2006008
- [2] ABB Document 1MRK 505 178-UEN, "Technical reference manual, Busbar Protection IED REB 670", Product version: 1.1, ABB Power Technologies AB, Västerås, Sweden, Issued: March 2007
- [3] T. Forford and J.R. Linders, "A Half Cycle Bus Differential Relay and its Application", IEEE Transaction on Power Apparatus and Systems, Vol.PAS-93, July/Aug. 1974.