AN INNOVATIVE SOLUTION IN THE BUS PROTECTION FIELD

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SUMMARY

This paper introduces a new bus differential protection system. Besides the fundamental requirements for this type of protection, a set of complementary functions is added to the system. The high processing speed permits status monitoring of multiple breakers, disconnecting switches, and other protection devices in the lines connected to the bus.

Results obtained in type testing as well as experience in real working conditions proven that this protection system is accurate, secure and dependable.

KEYWORDS:
Protection, Digital Protection, Bus Protection, Distributed Protection, Commissioning, Testing

1.0 INTRODUCTION

Busses, as interconnection points in electric power systems, are subject to short circuits between phases and/or ground, usually caused by external elements, equipment failure or simply by contamination. Bus faults are infrequent but they can seriously damage the installation, and cause large disturbances to system stability, especially in HV and EHV bus faults. Therefore, application of bus protection capable clearing faults in few cycles is recommended for transmission systems.

The principle of operation for bus protection is based on Kirchoff's law, where the phasor sum of the currents of the same phase, in a network node, must equal zero during normal operating conditions. The largest problem implementing reliable protection with this principle is the fact that current transformer (CTs) secondary current is not linear during saturation conditions

Among the existing bus protection systems, two of the most commonly applied systems are High Impedance Differential Protection and Low Impedance Percentage Differential Protection.

High Impedance differential protection is based on the parallel connection of the different CTs to a common point in the switchyard. The resulting current in this junction is applied over a non-linear impedance element and a protection measuring element monitors the voltage across this impedance in each of the phases.

Percentage Differential Protection, the topic of this paper, is considered as a classic solution for the CTs saturation problem. This method was one of the earliest approaches for bus protection using analog technology. A variation of this approach introduces a stabilizing element in the differential circuit, known as "moderate high impedance". The earliest analog bus protection systems based on such method debuted in the field during the '70s. Today they still are viewed in high regard among professionals due to their reliability.

2.0 PREVIOUS EXPERIENCE

With a solid foundation on the application of digital technology in the protection field, ZIV defined the Bus Protection System development with the following goals in mind:

1. Digital technology with distributed architecture capable of expansion;
2. Secure for external faults at 20 times the rated current and CT saturation conditions;
3. Dependable for internal faults with total CT saturation conditions;
4. Capable of including CTs with different magnetic characteristics and different transformation ratios;
5. Low impedance with percentage restraint, and able to detect phase to phase, and phase to ground faults;
6. High operating speed independent on the number of lines connected to the bus;
7. Include selection logic for bus sections and to be adaptable to multiple bus schemes;
8. Include information functions easy to adapt into integrated protection and control systems.

After the conclusion of the bus protection project, with the completion of every test, including power testing, which enables the evaluation of performance in real operating conditions. The first units were commissioned in 1999. The two first units supplied to Brazil were installed in Itajai Substation of Electrosul. They have been in service since January 2002.

3.0 **PROTECTION FEATURES**

3.1 System Architecture

The protection system is based in a hardware platform comprised by the following units:

1. Central Unit: The protection algorithm resides in this module. The following functions are performed: calculation of the differential and restraint currents, and communication management with the different line units, with the SCADA system, and with the protection management and analysis systems.

2. Bay IED: The protection systems can include up to 32 bay IEDs (28 current units and 4 voltage units). The bay units are in charge of acquisition and synchronized sampling of the currents, monitoring the status of the bay breaker and associated disconnecting switches, and trip operations of the breaker. Bay IEDs also control the breaker failure function after differential protection operations or after activation of the external protection contact input. Overcurrent monitoring is also done at local level using the bay units.

3. Communications: The communications system between the central unit and the different bay IEDs is done over glass fiber optics with the required characteristics to cover the functions of the protection system.

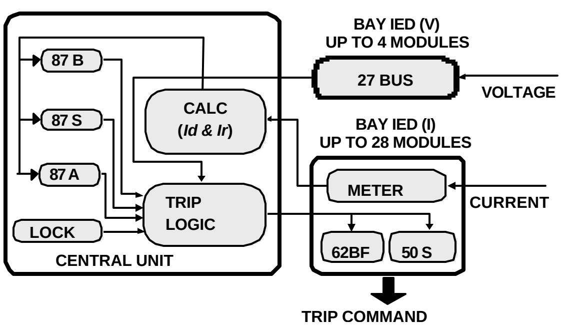

FIGURE 1 – DBN Protection Modules

3.2 Current Sampling

The current sampling rate is 48 samples per cycle, simultaneously for up to 84 currents (3 phases x 28 lines). This sampling rate allows for the calculation of the differential and restraints currents every 347µs. Both currents are independently calculated both per phase and per bus.

3.3 Differential Units – 87B

The protection system includes twelve single-phase differential units (three units per each of the four possible bus bars). The percentage restraint and the low impedance characteristic avoids the need for a dedicated CT winding. Due to the digital nature of the unit, it is possible to match via software different transformation ratios of the CTs for each of the lines, eliminating the need for external auxiliary elements.

3.4 Operation Magnitudes

The differential current (*Id*) is calculated by the phasor sum of the currents of the same phase. The restraint current (*r*) by the sum of the modules of the same currents.

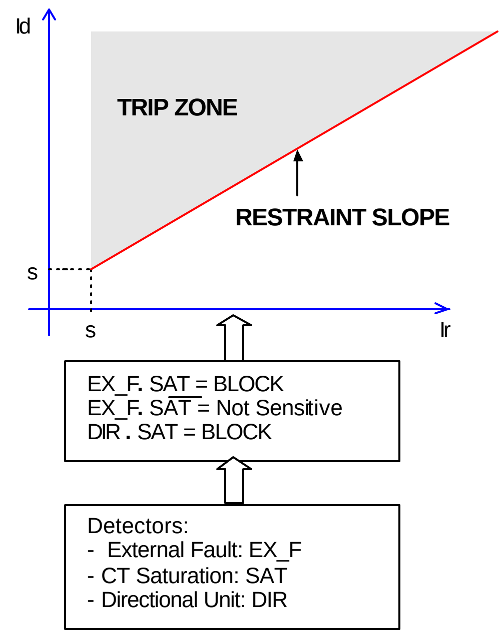

FIGURE 2 – Operation Characteristic.

The protection characteristic of operation is monitored by the following auxiliary detectors:

1. The saturation detector (SAT) is based on the calculation of the second derivative of the current wave and the comparison with a reference value defined by the saturation level of each CT. This accounts for each CT characteristic independently.
2. The external fault detector (EX_F) is activated when the differential current is 80% below the restraint current.
3. The directional detector (DIR) compares the current phasors and is considered only when the saturation detector is active.

3.5 Auxiliary Units to 87B

To increase reliability in the protection, the following auxiliary units supervise the trip:

1. Supervision differential unit 87S: a single unit monitors all busses and is designed to avoid false trips, mainly caused by failure of the disconnecting switch status monitoring. In many cases such failures are malfunctions of the disconnecting switch contacts when a breaker is isolated or transferred to another bus.

2. Differential alarm unit 87A: This unit blocks the protection under secondary CT circuit malfunctions. Such failures are most commonly caused by wiring breakdowns.

3. Undervoltage Unit 27B: As an option, a bay voltage unit can be installed in each bus. These units provide undervoltage functions to condition the protection trip to the voltage level of the fault.

3.6 Overcurrent Monitoring Units – 50Sup

The protection has three current units, one per phase, for every bay. When these units are in service, they disable the trips due to bus faults in those breakers without a source.

3.7 Breaker Failure Units

These units detect breaker failures and enable tripping of the other breakers in the bus. The breaker failure function is divided into three units: Single-phase fault unit with current supervision, three-phase fault unit with current supervision, and three-phase fault unit with breaker status supervision. By using programmable digital inputs it is possible to implement breaker failure schemes utilizing the trip signal generated by external protection devices. This functionality reduces wiring and the required external devices to implement the logic for association of breakers to the appropriate bus.

3.8 Operation Speed

The average operation speed is 9 ms. This time includes the trip contact closing time. This characteristic allows for fast clearance of high power short circuit bus faults, avoiding disturbances in the transmission systems or damage to the power apparatus.

3.9 Bus Topology Logic

The protection systems are provided with four differential units, allowing the protection of four busses either independently or combined in several schemes such as: single bus with bus tie breakers, main and transfer bus, double bus with four disconnecting switches per bay, double bus with double breaker, double bus with breaker and a half, ring bus, or triple bus schemes.

An intelligent algorithm determines, via disconnecting switch status monitoring, whether a bay is connected to or disconnected from a given bus. This logic enables the protection to automatically supervise the status of each bay, to properly associate each current to the appropriate bus section. This algorithm contemplates every possible combination of the digital inputs monitoring breaker and sectionalizer contacts. It also includes a sectionalizer operation timer setting. The system features the possibility of generating an external indication when inconsistencies are founded. This signal can be sent to an optical LED target, to a digital contact output, or via communication protocol.

3.10 Faults between CTs and Breakers

In schemes with tie breakers, the protection system enables the isolation of the faulted bus section without interruption of service to the rest of the sections. The systems are designed to clear faults in the so-called “blind spot” of tie bays, which is the section between the CT and the breaker. The following two techniques are available:

1. With the use of a single CT in the tie, the current circulating in this bay is accounted, with opposite polarities, to calculate the differential current in each bus section.

   Faults in the section between the CT and the tie breaker initially causes a trip in every breaker on bus 1, which does not clear the fault. In these cases, the protection algorithm in charge of the Tie bay locates the fault in the blind spot with a few additional milliseconds to the normal operating time, generating a trip command for bus 2 breakers. Refer to figure 3.

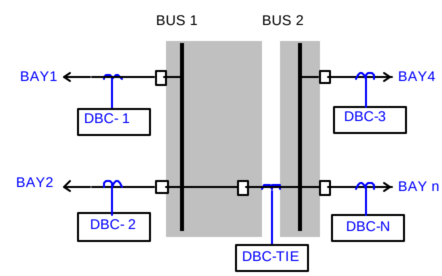

FIGURE 3 – Tie Bay with one CT.

2. Measuring the current circulating through the Tie breaker, independently in each bus section, via two transposed CTs, located to each side of the breaker. In this scheme the protection zones overlap, measuring the current circulating through the bus tie breaker on the other side of such breaker.

   This solution is less economical as it requires two sets of CTs and two bays IEDs, one per bus section. The benefit of this scheme is a higher selectivity with reduced time for fault clearing.

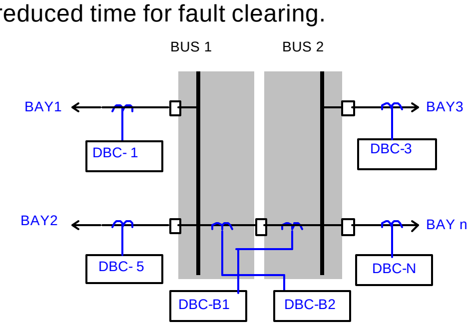

FIGURE 4 – Tie Bay with two CTs.

3.11 Faults between CT and line breaker

The protection system can detect a fault in the line end, the section between the CT and the breaker, and transmit a teleprotection signal to the remote end protection to speed fault isolation by opening the remote end breaker.

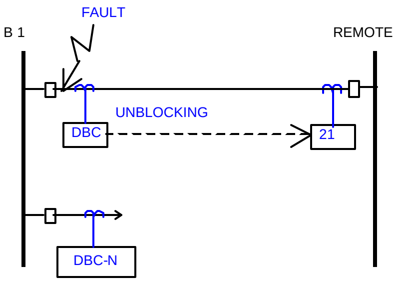

FIGURE 5 – Line end-point protection.

3.12 Communications

The central unit is provided with three communication ports: one front RS232C port and two rear fiber optic ports. The settings software package is provided with the protection system and usually installed on a portable PC. It enables simultaneous communication with the different bay IEDs. This feature enables multiple users to access the relay information at the same time.

3.13 Graphical Interface

Locally, via the keypad and display in the central unit, it is possible to input protection settings, or display phase currents in each bay, differential currents, and restraint currents. It is possible to input both locally or remotely the following setting groups via the communications software:

- Setting values;
- Central unit general settings;
- Central unit logic settings;
- Central unit protection settings;
- Bay unit general settings;
- CT parameter settings;
- Bay unit logic settings;
- Bay unit protection settings.

Input and output programming is only permitted locally. This type of programming is usually done only during commissioning, and requires verifying the wiring before changes are made.

3.14 Records

The following data is stored in non-volatile memory: the chronological sequence for the last 100 events; all the information pertaining to the last protection trip operation; last two oscillographic recordings containing 41 cycles (2 pre-fault cycles) of every phase current, differential and restraint currents, as well as status of 175 digital signals for each of the oscillographs.

4.0 **TESTING**

4.1 Power Test

Tests simulating real operating conditions were performed to analyze the protection performance under severe fault conditions for both internal and external faults. Testing was performed at LABEIN High Voltage Laboratories [4].

4.2 Type Testing

The independent laboratory LABEIN, also performed the electromagnetic compatibility, environmental, and mechanical tests as per corresponding IEC standards:

1. Electromagnetic Compatibility Testing
2. Environmental Testing
3. Mechanical Testing

4.3 Model Testing

Model testing was performed by the laboratories at KEMA – Arnhem, The Netherlands [5]. The purpose of the test was to check the performance of the protection system during every possible extreme condition for both internal and external faults. The short circuit cases of the dynamic testing were simulated by the EMTP software package for transient analysis. The following conditions were tested:

Dynamic Testing for Accuracy:

1. Current injection in a Bay IED, with and without DC offset for different inception angles of fault;
2. Current injection in two Bay IEDs, with and without DC offset for inception angles of fault of 180^o;
3. Current injection with CT saturation in two bay IEDs, with and without DC offset for inception angles of fault of 180^o;
4. Current injection in two Bay IEDs, with and without DC offset for values of the inception angles of fault different than 180^o;

Dynamic Testing for Operation Times without CT saturation:

1. Current injection in a Bay IED;
2. Current injection in two Bay IEDs for inception angles of fault of 180^o;
3. Current injection in two Bay IEDs for inception angles of fault of 0^o;

Dynamic Testing for Operation Times with CT saturation:

1. Current injection in a Bay IED with a CT-5P20;
2. Current injection in a Bay IED with a CT-5P20 under conditions of +80% remanent;
3. Current injection in two Bay IEDs, one of them with a CT-5P20 and the second one with an ideal CT, for inception angles of fault of 180^o and 0^o;
4. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with an ideal CT, for inception angles of fault of 180^o and 0^o;
5. Current injection in two Bay IEDs, one of them with a CT-5P20 without remanent and the second one with an ideal CT, for inception angles of fault of 180^o and 0^o;
6. Current injection in two Bay IEDs, one of them with a CT-5P20 without remanent and the second one with a CT-5P20 without remanent, for inception angles of fault of 180^o and 0^o;
7. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with a CT-5P20 under conditions of +80% remanent, for inception angles of fault of 180^o and 0^o;

8. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with a CT-5P20 under conditions of -80% remanent, for inception angles of fault of 180^o and 0^o;
9. Current injection in two Bay IEDs, one of them with an ideal CT and the second one with an ideal CT, for inception angles of fault of 180^o and 0^o.

Dynamic Testing for Security during external faults without CT saturation:

- Current injection in two Bay IEDs, one of them with an ideal CT and the second one with an ideal CT, for inception angles of fault of 180^o.

Dynamic Testing for Security during external faults with CT saturation:

1. Current injection in two Bay IEDs, one of them with a CT-5P20 and the second one with an ideal CT, for inception angles of fault of 180^o;
2. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with an ideal CT, for inception angles of fault of 180^o;
3. Current injection in two Bay IEDs, one of them with a CT-5P20 without remanent and the second one with a CT-5P20 without remanent, for inception angles of fault of 180^o;
4. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with a CT-5P20 under conditions of +80% remanent, for inception angles of fault of 180^o;
5. Current injection in two Bay IEDs, one of them with a CT-5P20 under conditions of +80% remanent and the second one with a CT-5P20 under conditions of -80% remanent, for inception angles of fault of 180^o;
6. Current injection in two Bay IEDs, one of them with an ideal CT and the second one with an ideal CT, for inception angles of fault of 180^o.

5.0 **ITAJAI SUBSTATION BUS PROTECTION**

Itajaí Substation of ELETROSUL, which was commissioned in January 2002, has 138kV and 230kV sections utilizing a double bus scheme with four disconnecting switches per bay, as shown in figures 6 and 7:

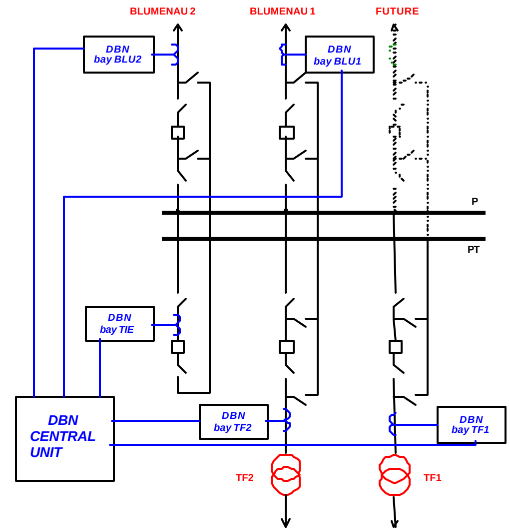

FIGURE 6 –Itajai Substation – 230kV Bus.

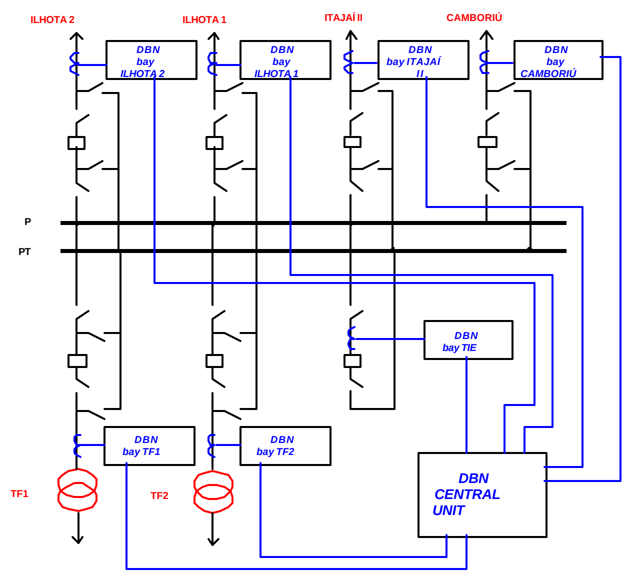

FIGURE 7 –Itajai Substation – 138kV Bus.

Despite the distributed architecture of the system, at Itajai the IEDs were mounted in dedicated racks to enable the addition of future bays with an expected final configuration of 10 bays at 230kV and 20 bays at 138kV.

5.1 Model Testing for Electrosul Application

Utilizing the EMTP transient analysis software, KEMA simulated abnormal system conditions during fault conditions and during system control operations. To devise the test plan the following information was provided:

1. Equivalent System for every possible topology;
2. Faults to perform;
3. Nominal characteristics for the equipment in the installation;

Every case generated by the EMTP software, for a total of 255 cases, was reproduced from COMTRADE files.

The results obtained were:

1. Trip time: 9 to 14 ms;
2. Reset time: less than 25ms;
3. Secure: No trips were experienced for external faults.

5.2 Commissioning Testing

On top of the routine factory testing, during the commissioning of the protection system, the following tests were performed after definitive protection settings were uploaded:

1. Current injection in every phase to check metering accuracy, CT ratio settings and proper external wiring;
2. Current injection at several bay units to simulate both internal and external faults;
3. Verification of the differential unit characteristic;
4. Verification of the supervision differential unit characteristic;
5. Verification of the alarm differential unit characteristic;
6. Breaker failure simulation to evaluate selectivity of the tripped bays depending on the bus topology;
7. Fiber optic link breakdown simulation between central and bay modules to verify protection lockout;
8. Test of the alarm differential unit, to check protection lockout;
9. Simulation of the activation of the Supervision differential unit without the activation of the bus differential unit to check the protection lockout;
10. Simulation of sectionalizer status contacts to verify proper signaling of unknown status;
11. Simulation of incorrect sectionalizer status indication, where sectionalizer signals of adjacent bays were connected to the IED, to verify protection lockout;
12. Current injection in a Bay unit isolated from the bus by open sectionalizers, to verify that the test current is not included in the differential current calculations.

6.0 **CONCLUSIONS**

Test results and the observed performance of the different protection units are proof of the high reliability of the protection system.

Having all the measured and calculated currents in the system available at every IED, reduces the required time for testing during commissioning.

The low impedance characteristic avoids the use of a dedicated CT winding. The distributed architecture enables the central units to be mounted either in the primary or secondary protection cabinets of the bay. These two features make the protection system an economically feasible alternative for existing installations that require bus protection, where the existing CTs do not provide a dedicated winding for such function.

7.0 **BIBLIOGRAPHY**

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