Bus Protection Application Challenges

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Abstract – Bus protection is one of the most challenging applications because it requires the highest degree of security and dependability. Unforeseen during engineering and not detected during commissioning, potential problems can cause a blackout in the large geographical area. This paper will discuss several common problems and solutions for the low impedance bus differential protection to increase security and dependability for this protection. Specifically, paper will focus on the following:

- Increasing security by using supervising elements, such as external check zone or undervoltage.
- Detection of open CT at any feeder, connected to the bus—possible solutions will be presented.
- Monitoring isolators positions to ensure including/excluding in the zone without causing any potential misoperation.
- Ability to detect external fault and prevent bus differential misoperation when fault occurs on the feeder with a low CT ratio and feeder CT will saturate extremely fast.
- Experience with engineering of the bus protection for the configurable buses with several zones.
- End Fault protection to cover blind spots.

Paper will be illustrated with real-life examples of the application challenges and how these challenges can be addressed.

Index Terms — Busbar protection, CT Trouble, Bay identification, Intelligent electronic device (IED), Centralized busbar, CT secondary Open, blind spot, breaker failure, Bypass isolator, elimination of transfer bus, end fault, bus unification, directional principle, zones of protection, breaker re-trip, under voltage security

I. INTRODUCTION

Power systems used to have simple busbars with dedicated current transformers (CTs) and unidirectional current flow during load and fault conditions. These buses traditionally were protected by the high-impedance principle—a fast and reliable scheme with decades of dependable and secure field experience.

New power systems and substations are often designed to satisfy economic requirements rather than to keep protection schemes simple. At the distribution level, the addition of new power generation such as distributed energy resources (DER) complicates historically simple busbar arrangements and exposes existing CTs to saturation due to increased fault current levels which becomes bi-directional. This results in complex busbar arrangements. In transmission networks, quite often, the protection zones are required to adjust their boundaries based on changing busbar configuration (such as the double-bus single breaker arrangements in Figure 1). This requires the switching of secondary CT currents in high impedance schemes, however is easier and safer done in low impedance IED schemes in software. Bus protection hence has to evolve in more demanding bus configurations and applications.

Figure 1. Double Bus Single Breaker

With a low impedance bus differential protection in the digital relays, able to adapt to a re-configurable buses and able to provide additional means to achieve security and dependability in bus differential protection applications it is possible.

II. APPLICATION CHALLENGES

A. INCREASE SECURITY WITH SUPERVISING ELEMENTS

The low impedance bus protection IEDs on the market today have multiple additional security features to secure the Bus Protection (87B) from unwanted operations during external faults or switching conditions; such as CT saturation detection, directional (phase) comparison and bus zone breaker/isolator monitoring. However, these security means are still may not be enough for high-end transmission bus protection applications.
No matter how reliable or how high the mean time between failures (MTBF) of IEDs is, they are electronic devices which can fail, and the MTBF can never be high enough on high-end bus protection applications due to the severe impact of any incorrect operations.

Some contingencies that existing 87B are not always secured against are:
- CT problems and AC wiring problems
- Malfunctioning of the auxiliary 52/89 contacts for breakers and isolators
- DC wiring problems, involving the dynamic bus replica on reconfigurable busses

For these reasons, additional supervisory elements are recommended to enhance the security of the bus protection.

1. External Check Zone

The principle of the external check zone is to:
- Develop an independent copy of the differential current for the entire bus, regardless of the position of the primary switching devices, defining dynamic zones for each bus section
- Use this check zone to supervise the tripping of all bus zone(s)
- Use independent CTs/CT cores if possible, to guard against CT or wiring problems
- Use independent IED current inputs to guard against relay internal processing failures
- Early alarm on spurious differential

Using external check zone guards against contingencies listed above and Failure of IED current inputs.

The external check zone can utilize simply an overcurrent element, or a complete separate bus differential zone which can supervise one or more bus differential zones:

a. Overcurrent Check Zone

In this case, the external check zone can be configured as an unrestrained zone using separate CTs or CT cores. As an example, an Instantaneous Overcurrent (phase or ground) element can be configured to operate based on the externally summed currents, preferably in a separate IED, however all CTs to be summed up, must be of the same ratio and type.

The overcurrent can then supervise the bus differential as shown below.

b. External IED Check Zone

An external IED check zone can be configured as an equivalent bus differential zone, or as a larger zone overlapping multiple zones utilizing an external IED using separate CTs or CT cores as follows:

![Figure 2. External Overcurrent Check Zone](image)

![Figure 3. External IED Check Zone](image)
In this case, the B-phase IED supervises the A-phase IED, C-phase supervises B-phase and A-phase supervises C-phase. The fail-safe/critical fail output is used to ensure scheme operation in the event that one IED is out of service.

Advantage of this method of external check zone has a strong 2-out-of-2 security, preventing undesired operation in the case of the single CT or IED input failure, but disadvantage is that each IED requires large number of CT inputs in each phase IED.

c. Undervoltage Supervision

Undervoltage Supervision consisting of 3 undervoltage elements per phase (e.g., AG, AB, and CA to supervise A-phase differential), can be configured as an external check zone, supervising the bus differential on a per-phase basis. This Undervoltage can be set high (0.85 – 0.90pu) to allow high speed operation, and would still allow alarming of spurious differential operation that could occur due to CT problems, AC wiring problems, current input failures, breaker or isolators auxiliary contact or DC wiring problems.

Voltage measurements should preferably be in a different IED, i.e. B-phase IED supervises the A-phase IED, C-phase supervises B-phase and A-phase supervises C-phase.

Similar to the External Bus Check Zone, this scheme would also utilize the fail-safe/critical fail output to ensure scheme operation in the event that one IED is out of service.

These security features prevent the IEDs from unexpected operation during CT failure [3]; however, exact identification of the faulted CT is equally important, as a secondary open CT may result in a hazardous overvoltages which may lead to blasting of the CT, thereby creating danger to life and damaging switchyard equipment.

To prevent such occurrences, the concept of symmetrical components can be used to detect a faulty CT or its circuit. If a CT/circuit becomes faulty, an unbalance current will be measured by the IED, which results in the negative sequence current in that particular bay which in turn will be utilized by the IED to annunciace or trip the faulted bay. Such concept cannot be always implemented in centralized bus bar protection, as this architecture dictates the concept of phase segregated protection.

To adhere to this concept, in some busbar architectures each phase will be connected to a separate IED, thus the calculation of symmetrical component is defeated, without which the above solution cannot be employed. Hence the necessity for alternate solution is required, which should be capable of addressing other challenges thrown by dynamic bus replica. Such a solution is shown in Figure 5. Figure 1 below where the combination of circuit breaker close position, CT trouble differential measurement and the current supervision feature are utilized to identify the faulty bay.

The solution presented above has been engineered in a centralized low impedance IED and implemented in 220kV Bus (double bus arrangement) and 400kV Bus (1½ breaker arrangement) at Tamil Nadu Electricity Board 400/230kV Karamadai Sub Station located in Tamil Nadu, India.

C. Monitoring Isolator Positions

In many cases a feeder or line need to be transferred from one bus to another bus for maintenance and serviceability. The reconfiguration of the bus [6] such as the one shown in Figure 6 is performed by switching on/off the disconnect switches (isolators) connecting the primary circuit to one of the two buses.
Another advantage of using dual isolator auxiliary contacts status is ability to monitor disagreement between 89a and 89b contacts for alarm purposes and also to define an action in case of such disagreement.

### D. DETECTION OF EXTERNAL FAULTS

Some bus protection configurations are facing with the challenge that some outgoing feeders would have lower CT ratios compared to power supply feeders, hence would be exposed to severe and fast CT saturation conditions [5] during external faults on these outgoing feeders, as highlighted below:

![Figure 8. Fast CT Saturation on outgoing feeder](image)

In this example, the problem is that the fault current I2 on the outgoing feeder, which occurs when a power supply feeders would feed fault F2, is much larger than fault current I1 for a fault at F1 on the bus through the same outgoing feeder.

The outgoing feeders CTs are typically sized for line load and not for the system fault conditions, hence significant CT saturation may occur on the outgoing feeder.

The low impedance bus differential element would expect the differential-vs-restraining currents trajectory to move from t0 to t1 and then to t2 as below:

![Figure 9. CT Saturation Detection on External Faults](image)
In some cases the CT saturation might be in less than 2.5ms at 50Hz as shown below:

![Figure 10. Extremely saturated CT secondary waveform](image)

This CT saturation is too fast to guarantee secure CT saturation detection in most low impedance bus protection IEDs that uses trajectory of differential element to detect CT saturation.

In general the recommendation would be to change the CT ratio, however in the high voltage substation this is not always economical and feasible. Also increasing CT ratio will impact sensitivity for the outgoing feeder protection.

Typically, the internal fault current supplied by these feeders with low CT ratios, would be much less than the external bus fault currents. Hence, a very fast current magnitude detection, faster than the bus differential protection, be required to secure differential element. Conventional overcurrent functions utilize discrete Fourier transformation (DFT) that converts sinusoidal waveforms to phasor to allow calculation of the RMS magnitude, which is typically used as parameter to determine a high current. The operating time of this algorithm with a non-saturated waveform is in the order of 16ms at 3-times Pickup at 60Hz, which is much slower than the differential algorithm.

A better approach is to use a time domain sample-based overcurrent algorithm that can react much quicker on the order of 3 to 5 ms.

Below is a comparison between the traditional full cycle Fourier and the Fast OC Magnitude algorithm performance during severe CT saturation occurring in 2.7ms: (Blue represents CT secondary current, Green is full cycle Fourier and Red is the Fast Magnitude sample-based overcurrent algorithm)

![Figure 11. Fast OC Magnitude Estimator](image)

This new overcurrent element can thus easily be used to supervise the bus differential on external faults since the required pickup setting will be significantly above load current levels. Such approach also helps with a CT selection for the outgoing feeders without any impact to feeder protection sensitivity.

### E. ENGINEERING EXPERIENCE OF COMPLEX BUS PROTECTION SCHEMES

In some power stations, by the use of special operational procedures; any two or more of the main bus bars is utilized as a transfer bus bar to facilitate maintenance of circuit breakers and current transformers (in each section) without shutting down the bay(s) [2]. Owing to this fact, the complications in operational philosophy have thrown challenges for the bus bar protection implementation.

The bus topology allows will be designed such that any one of the main busses available in the station to be used as an auxiliary bus. In such systems, pre-defined precautions and procedures are made as guidelines, which are followed before assigning any bus as an auxiliary bus. The procedure involves, shifting of links, changing rotary switches, insertion of test block and so on thereby causing unreliable operation. This kind of unreliable operations or inadvertent procedural lapse may result in a load disconnection from the grid due to unpredictable operation of bus bar protection relay which is a frequently occurring phenomenon.

With the sophisticated configuration and implementation, the cumbersome procedures are totally eliminated and the operator is free to choose the transfer arrangement without compromising the protection need of a bus differential system for a reliable operation. This paper deals with the security logics for such special scenarios, implemented in bus bar protection relay to ensure system stability and eliminate all the special operational precautions / procedure.

In addition to these scenarios, it’s been a custom to provide current transformers on either side of bus section and bus coupler to eliminate blind spots. Sophisticated logics have been implemented with single current transformers, to eliminate blind spot resulting in huge cost savings and switch yard spacing, to facilitate space for additional bay. These complications are well addressed by IED working on a low impedance principle with the internal logic capability. Such complications along with suitable logics were engineered and implemented in Sharavathy 1035 MW Hydroelectric generation station located near Jog falls, Karnataka, India.
**F. End Fault Protection Schemes**

In typical bus protection scheme arrangements, an over-trip spot between the circuit breaker (CB) and current transformer (CT) develops when the CB is opened of a bus feeder. In this scenario, currents measured by the CT, must be removed from the bus differential calculation to ensure a secure differential zone, which means the zone contracts to end at the open CD and excludes to portion between the CB and CT, as seen below:

![Diagram](image)

**Figure 12. Eliminating over-trip when CB opened**

This spot is thus a blind spot not covered by the differential, since tripping the differential zone with the bus feeder CB already open, will not clear the fault.

![Diagram](image)

**Figure 13. End Fault Protection**

The protection function needed to clear this type of fault is so-called End Fault Protection [4].

End fault protection consists of an instantaneous overcurrent, enabled only if the CB is open, has a pickup delay of at least 1.3 cycles to allow for adequate current ramp down after the CB opened, and must be blocked by the manual close command.

Typically end fault protection would send a transfer trip to the remote end of the bus feeder or power system component it is covering.

Most modern low impedance bus protection IEDs do include end fault protection and typically one per bus zone feeder.

**III. Conclusions**

As power systems have evolved, their associated busbar schemes have become much larger and more complex. Reconfigurable buses are essential, and low impedance bus protection schemes have had to evolve to ensure all bus configurations can be covered allowing for bidirectional current flow on all feeders.

As busbar schemes keep on changing based on application needs, the bus protection must follow these new requirements and still deliver very dependable and secure protection under all circumstances including load and abnormal load conditions, internal and external faults.

This paper covered 6 applications where traditional bus protection schemes fell short and highlighted advancements and changes needed to ensure additional new requirements on the bus protection are met.

**IV. References**


**V. Authors Information**

**JC (Jacobus) Theron** is Srn Product Manager for Grid Automation division of GE Digital Energy. He received the degree of Electrical and Electronic Engineer from the University of Johannesburg, South Africa in 1991. Mr. Theron has 24 years of engineering experience; 6 years with Eskom (South Africa) as Protection / Control and Metering Engineer, 11 years with GE Multilin (Canada) as Product / Technical support / Protective Relaying Consultant/Protection and Systems Engineer leading the Project and Consulting Engineering team and as Product Manager, 2 years with Alstom T&D (USA) as Senior Systems Engineer and 5 years with Hydro One as Operations Assessment Engineer / P&C Technical Services Manager. He specializes in transmission, distribution, bus and rotating machines protection applications support, system designs and transient system testing. He is a member of IEEE.
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K N Dinesh Babu is a professional power system protection engineer in India with extensive experience in HV / EHV sub stations and industries. His work background includes experience in working for Alstom, ABB, GE and Megger in various roles like testing; commissioning; design and application engineering. A major portion of this experience has been in the area of protective relaying with a major focus on the application and coordination of protective facilities on electrical power systems. His experience includes the development of protection philosophies, implementation of new technologies in the field; control logic requirements for protective systems; development of specifications for protective relay settings; and analysis of disturbances and faults in electric power systems. He also provides training to protection / field / O&M engineers on IEDs, SCADA, power system protection and synchrophasors for major utilities and industries in India and Abroad. He holds a doctorate in electrical engineering and is a DFSS certified six sigma green belt. He is a senior member of IEEE and member of Cigre. His areas of contribution are electric traction, power system protection and renewable energy utilization and have published several articles in international journals and conferences.