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Busbar Protection

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Introduction

Busbar is a component connecting all infeed transformers, outgoing feeders, compensation devices and interconnectors. Once when a fault occurs in busbar, protection should detect and isolate the fault in a pre-designed time, i.e. **with security, speed, sensitivity and selectivity**. It should operate in minimum internal fault, and not operate in maximum external fault with a saturated CT, i.e. with distorted waveform. Once when there is circuit breaker (CB) failure, **back-tripping**, or even **re-tripping**, is implemented to open corres-ponding CB.

Busbar Protection Scheme

There are three main schemes with different philosophies implemented for busbar protection.

Frame To Earth / Leakage To Frame Protection (LTF)

LTF measures the fault current flowing from switchgear frame to earth. A CT is installed at the earthing cable connecting the frame and earthing point. A **check relay** is installed at the transformer earthing to observe any earth fault current returning. A **dummy bar** connecting with no infeed transformer may have fault and the fault is cleared by with feeder protection, ascheck relay does not see a fault and LTF does not operate.

However, this protection scheme is not with high reliability with the following reasons.

- **Low insulation** between switchgear frame and earth due to aged insulation or bad environment forming a shunt path for the earth fault can reduce the sensitivity with lower current flowing into the CT.
- This scheme is inoperative with three-phase-to-earth (i.e. **balanced**) fault with no current flowing through the CT.
- It is mal-operating with **cable end box fault**, with a cable end box with a poor insulation and leakage current flowing to the frame and CT.
- If there is **CB stuck** in the operation, the backup OCEF trips with a delay and clears the fault in-discriminatively if the LTF is designed without **insulation zoning** or **directional relay** to identify the faulty session or **busbar splitting** to separate healthy session[7].

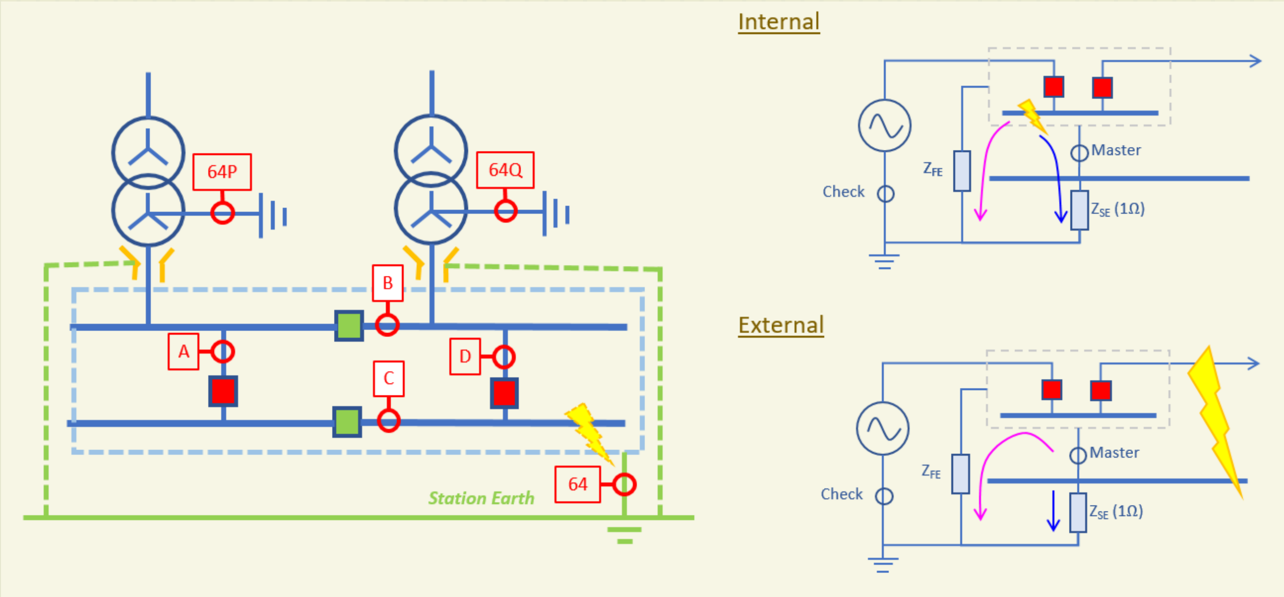

Figure 1
Leakage To Frame Protection and its Equivalent Circuit

High Impedance Busbar Protection (HZBBP)

This protection scheme simply adds up the current flowing into the busbar with parallel CT with matched ratio and burden. There is nearly zero current flowing through the relay with **external fault**, and the fault current, divided by a CT ratio, flowing into the relay during **internal fault**. Once there is **CT saturation**, the shunt path becomes low impedance and high voltage across the high impedance relay (87Z) branch can saturate the latter CT. In the high impedance relay, an **MOV** is implemented to clamp the voltage across the relay and absorb surge energy. To provide better protection to the relay, a **lockout relay** (86) can also be utilized so current can be diverted away from the high impedance relay path after the lockout relay is tripped.

For setting[1],

1. Maximum Through Fault
   $V_{SET} > V_{SAT} = K (R_{L2} + R_{CT2}) I_{Fmax} / N$
   I_{FMax} /N is all infeed current, i.e. maximum through fault, K is a safety factor
2. CT Saturation
   Check $V_{Knee} > 2 V_{SET}$
3. Minimum Pickup Current
   $I_{MIN} = N (nI_E + I_{MOV} + V_{SET}/Z_r)$,
   i.e. minimum pickup current = CT ratio* (n CT excitation current + MOV current respective to V_{SET} + V_{SET}/ relay impedance)
4. Minimum Internal Fault
   Check $I_{Fault, MIN} > I_{MIN}$
5. Sensitivity
   To increase sensitivity, a shunt resistor is added. $R = V_{SET} / ((I_{Goal} – I_{MIN})/N)$

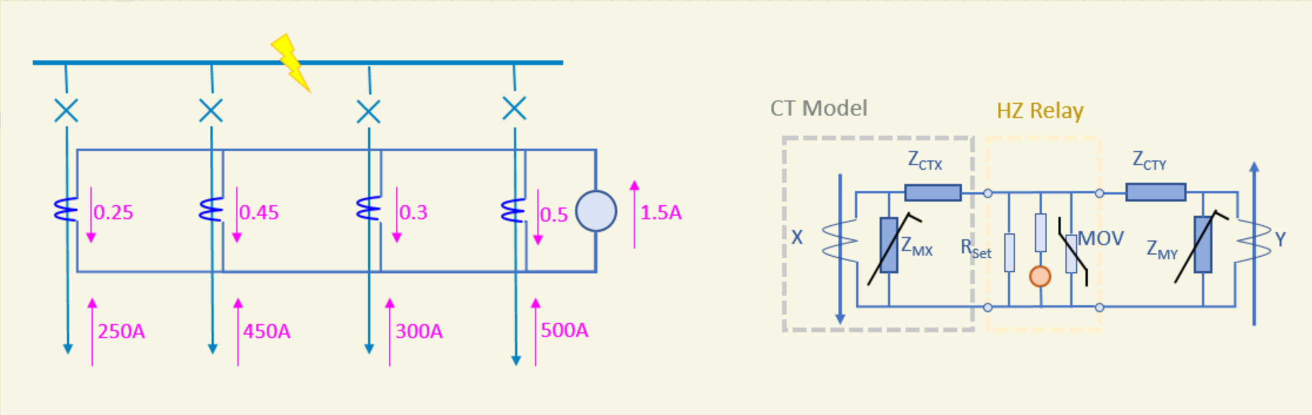

Figure 2
Philosophy of High Impedance Busbar Protection and its Equivalent Circuit

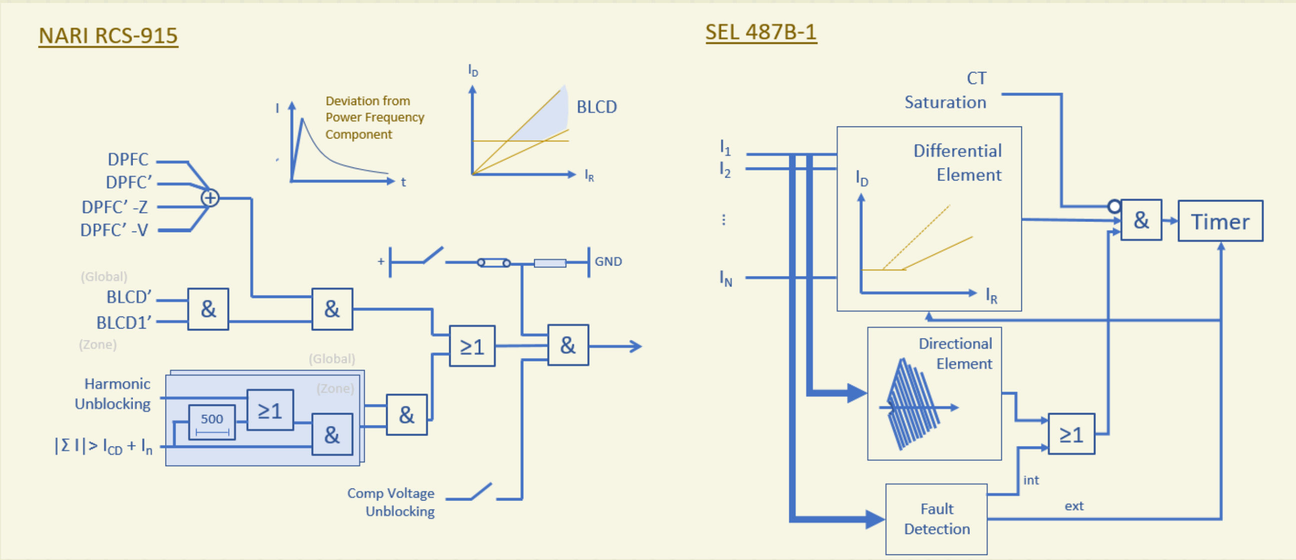

Figure 3
Logic Diagram of Busbar Differential Protection of NARI RCS915[2] & SEL 487B[3],[4]

Low Impedance Busbar Protection

Unlike high impedance relay principle, low impedance relays allow separated CT inputs and current sampling. It operates as a **percentage restraint relay**, which also enables shorted and open CT detection. It has a high flexibility in using different CTs with switched zone reconfiguration and selective end-zone protection. Yet, there are fixed number of CT inputs, i.e. fixed scalability.

This numerical relay has a different philosophy in busbar protection. As in Figure 3, CT saturation and double confirmation of internal fault are features in the relay. For example, **voltage sequence release** in NARI RCS-915 is to detect real fault instead of CT open or saturation, and current direction in SEL 487B is to double confirm its **internal fault characteristics**. Other common features are **check zone**, **phase under-voltage** and **extra overcurrent guard**[8]. In NARI RCS-

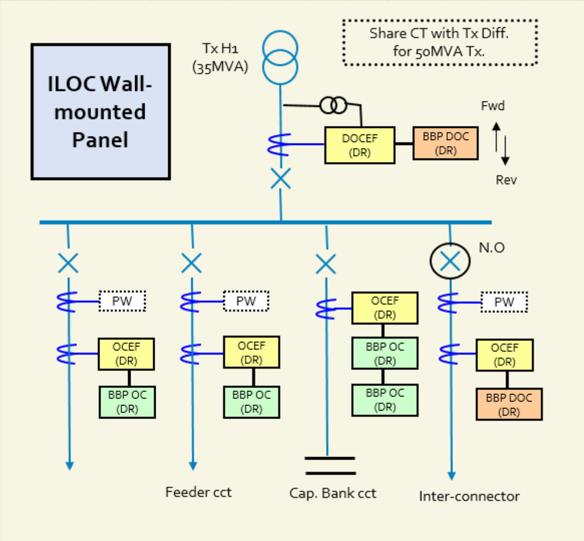

Figure 4
Interlocked Overcurrent (ILOC) Protection

915, it trips the CB only when the current reaches the operating region in differential and restraint current plane, and Deviation from Power Frequency Component (**DPFC**) after a bandpass filter has reached its limits. In SEL 487B, if it is no CT saturation with **abrupt change** of current[5], the fault detection logic, i.e. **current phase comparison** (>90° for external fault) and **rate of change of differential** (ROCOD)[6], determines if it is external fault, changes the differential element characteristics and delays the additional timer. If it is an internal fault, with characteristics lying in the operating region, the element will trip the CB after 2 half cycles.

Interlocked Overcurrent Protection (ILOC)

ILOC protects a busbar with a directional overcurrent (DOC) relay. It trips infeed transformer CBs if there is no blocking signal from following.

<u>Upstream fault (Forward Block)</u>: it caters for 35MVA transformer parallel operation, with current flowing from one source to another. The DOC seeing forward current sends a block signal to the others, as the fault should be isolated with other protection, e.g. duo bias (DB) current differential for transformer protection.

<u>Feeder fault (Reverse Block)</u>: ILOC is blocked by busbar protection OC. Breaker Failure Protection deblocks the tripping if the fault is over 300ms and not isolated with feeder protection (e.g. PW or OC) initiated.

<u>Capacitor bank fault (Reverse Block)</u>: similar to feeder fault.

This scheme can be implemented with shared CT from other protection. It does not require high performance and dedicated CT as needed from HZBBP. However, the DOC requires a **polarizing voltage** signal from a 11kV VT to determine fault current direction. VT with blown fuses may be a reason from DOC relay to trip unnecessarily if there is no VT failure (VTF) to block the relay from operation when an unhealthy voltage is detected[9].

Conclusion

Busbar Protection is a difficult topic as busbar serves as a node connecting many system components. Once it fails, it triggers headache of system operators and maintenance engineers as it requires power delivered from other paths. To much worse, it could lead to customer minutes loss if the protection is not operative in pre-designed time. Further case studies could be made in **evolving and simultaneous fault**, **different inception angle**s and **CT percentage remanence flux** [10] and **different busbar configurations**[11], [12], e.g. Ring Busbar.

Reference:

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[2] NR Electric (2012), RCS915AS Busbar Protection Instruction Manual

[3] Schweitzer Engineering Laboratories (2017), SEL 487B01 Bus Differential Relay - Datasheet, obtained from

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[5] Haji M. M. et al (2013), Current Transformer Saturation Detection Using Gaussian Mixture Model, Journal of Applied Research and Technology

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[12] IEEE std. C37.234 – 2009, IEEE Guide for Protective Relay Applications to Power System Buses