

# Bus Protection

## Introduction

Busbars in power systems are the location where transmission lines, generation sources, and distribution loads converge. Because of this convergence, short circuits located on or near the busbar tend to have very high magnitude currents. The high magnitude fault currents require high-speed operation of the busbar protection to limit equipment damage. However, this high-speed clearing must be balanced against the need for security. Tripping incorrectly for an external fault may cause large outages, and jeopardize power system stability. The high fault magnitudes increase the possibility of CT saturation during external faults close to the busbar, and CT saturation increases the possibility of an incorrect operation of the busbar protection.

Protection of the busbar may be complicated and varies with the topology of the bus. Many busbars connect all circuits to one common segment of busbar. The complication for these buses is simply the number of connected circuits. However, a specific busbar may have multiple bus segments, with individual circuits that connect to different bus segments depending on operating needs. For such complex buses, busbar protection must be able to protect each bus segment individually, and dynamically keep track of the circuits connected to a specific bus segment.

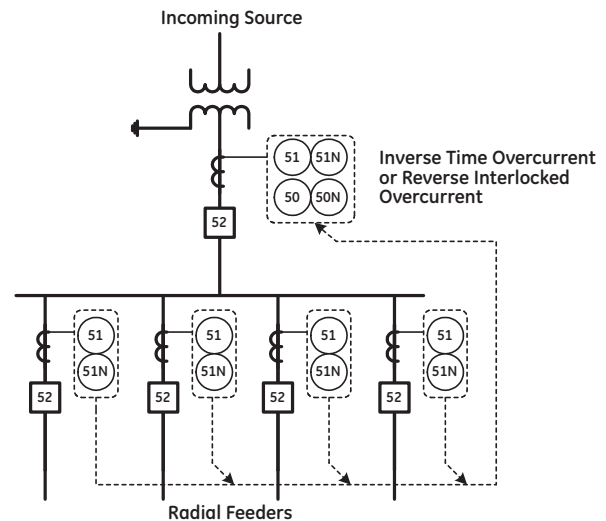
## Busbar Protection Techniques

The choice of protection technique used for a specific busbar depends on the protection requirements for speed and security, balanced against the cost of implementing a specific solution, and the operating requirements for a specific bus. Common methods of protecting busbars include overcurrent-based interlocking schemes, overcurrent-based differential protection, high-impedance differential protection, and percentage differential protection. Interlocking and overcurrent differential protection can be implemented with any suitable overcurrent relay from GE Multilin, and performance has to be balanced in terms of speed and security against the reduced cost of protection. These types of protection are typically applied on distribution busbars, where fault current magnitudes are lower and speed is generally less critical than with transmission busbars.

Differential protection provides high speed fault-clearing necessary for critical busbars such as transmission busbars, or distribution busbars where arc flash hazards are a concern. High-impedance differential protection or percentage differential protection may be the correct choice depending on the bus configuration and specifics of application. Both methods address loss of security for external faults due to CT saturation.

### Distribution Busbar Protection

Distribution busbars typically have a single incoming source supplying multiple radial distribution feeders. For these applications, the chief concerns for protecting the bus are normally meeting operating requirements and cost of protection. High speed clearing to maintain system stability is not normally necessary. Security



Overcurrent based interlocking schemes for simple Bus protection

is maintained by simple time coordination, or via hardwired communications in reverse interlocking protection schemes. The most significant factor in terms of operating speed is arc-flash hazards. The slow operating time of overcurrent-based bus protection can result in a larger arc-flash zone or in more restrictive hazard protection requirements. In these instances, high speed differential protection is appropriate.

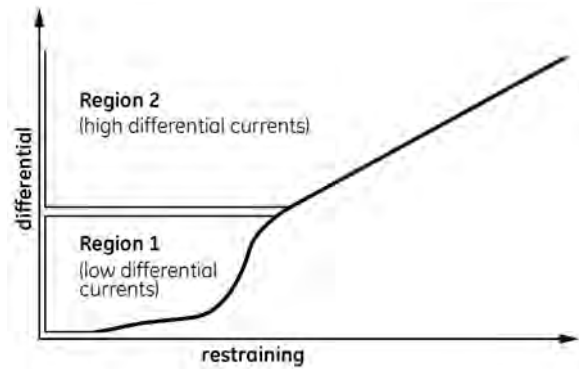
### Transmission Busbar Protection

The predominant requirements for protecting transmission busbars is the speed and security of the protection scheme. These requirements are built around the need to minimize equipment damage and maintain system stability during fault events. If these are the only two considerations for transmission busbar protection, then high-impedance differential protection may be appropriate. High-impedance voltage differential protection is a solution to the challenge of CT saturation during external faults, as the high impedance of the relay forces the error current due to the saturated CT back through the CTs instead of the relay operating coil. The relay uses a setpoint to differentiate between the maximum error voltage due to CT saturation, and the full voltage of an internal fault.

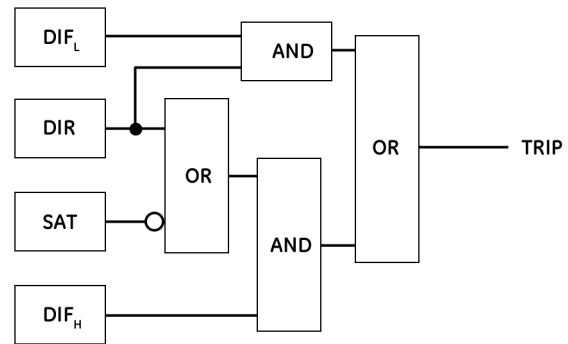
When also considering the requirements for operating a specific bus, and the cost of installation, high-impedance differential protection schemes have some limitations. The major limitation is the strict requirements on the CT circuits necessary for the high-impedance scheme. All CTs used in the scheme must have the identical performance class and turns ratio, must be tapped at full ratio, and must be dedicated to the bus protection scheme. Additionally, the secondary lead burden from the each CT to the relay should also be identical. These requirements are necessary to keep the level of error voltage as low as possible to prevent maloperation of the relay. Making modifications to an existing bus protection scheme, such as adding an additional circuit, may be very challenging in engineering and installation.

In addition, high-impedance differential relays also have some limitations in terms of normal operations and maintenance. The relay sees only the voltage from the differential junction point, and therefore cannot provide any auxiliary protection functions such as breaker failure, or record the individual currents from each CT connected to the relay. Data to analyze fault events must therefore come from additional sources. Another operating limitation of high-impedance differential is the ability to handle routine bus switching, such as removing a circuit breaker for maintenance. Typical, the differential relay must be blocked during such switching operations. While this type of switching is uncommon with the typical single segment busbar, it is a routine occurrence with multiple segment busbars, making high-impedance differential schemes difficult to apply on such multiple segment busbars.

Percentage differential relays, also known as low-impedance differential relays, provide similar operating speed, and can provide a similar level of security, as high-impedance differential relays. In addition, low-impedance relays are simple to apply, as there are no special requirements for CT performance class, turns ratio, or secondary lead burden other than good performance practice. A microprocessor-based low-impedance differential relay measures input currents from each set of CT, and therefore can provide auxiliary functions such as breaker failure for every circuit, and measure and record all currents during a fault event. In addition, switching events can be routinely handled in the relay, and low-impedance differential relays can be specifically designed for multiple segment busbars.



Differential characteristic region



Adaptive Trip logic

## GE Multilin Busbar Protection

GE Multilin provides protective relays that support all busbar protection techniques, including overcurrent, high-impedance differential, and percentage (low-impedance) differential. The protection techniques for overcurrent and high-impedance differential protection are well known. GE Multilin low-impedance differential relays are designed to provide specific performance advantages on applications for all busbars, from single segment busbars with up to 24 connected circuits, or large multiple segment busbar configurations. These include the correct restraint while facing CT saturation during a fault event, detecting the failure of a CT secondary circuit connected to the relay, protection of multiple segment busbars, and providing enough digital inputs and outputs for proper bus protection.

### CT Saturation

Saturation of a CT connected to a low-impedance differential relay during an external fault produces an incorrect differential current that may cause the relay to operate. GE Multilin relays use adaptive trip logic to prevent an operation due to CT saturation during external faults.

The adaptive trip logic is designed around the differential characteristic. The restraint current of the differential element is based on the maximum measured current, as opposed to the traditional magnitude sum of the currents. This ensures ideal restraint for the actual fault condition, balancing sensitivity and security. The differential element uses a dual slope-dual

breakpoint characteristic matching the differential characteristic to the saturation performance of the CT ensuring security, while maintaining sensitivity.

The differential characteristic can correctly restrain for many external faults when CT saturation occurs. However, the differential element itself is not enough to ensure correct restraint to external faults when severe CT saturation occurs. The differential protection is always supervised by a directional element. The directional element compares the angle of the measured fault currents. If at least one current is away from the sum of the remaining currents by an angle greater than 90°, the fault is considered an external fault. If all fault currents are within 90° of each other, the fault is considered internal.

During low magnitude fault events, the differential element must assert and the directional element must declare an internal fault for the relay to trip. A low magnitude fault event occurs when the differential current is less than the breakpoint for the second slope of the element characteristic. During high magnitude faults a CT saturation detector additionally supervises the differential protection. During such a fault, the differential protection may operate only if the differential element asserts while no CT saturation is present, or when the directional element declares an internal fault when CT saturation is present. The CT saturation detector simply sets a logic flag when the restraint current exceeds the setting for the second breakpoint of the differential characteristic, and the differential current remains below the first slope of the characteristic.

**CT Trouble**

Any differential protection scheme depends on the correctness of the CT secondary circuits connected to the relay. In addition to CT saturation and linear CT measurement error, broken or shorted CT connections cause the relay to see a false differential current. During normal operations, the false differential current due to an broken or shorted CT secondary circuit is typically too small to cause a relay operation. However, during external faults or high load periods, this false differential current can result in an incorrect relay operation. The CT Trouble function in the B30 and B90 relays detects this condition by using a low-set differential element, typically set around 10% of the least heavily loaded circuit connected to the bus, that asserts after a settable time delay. The CT Trouble alarm can be sent via SCADA to operating personnel, or it may be used to block the differential element.

**Multiple segment busbar protection**

Multiple segment busbars, such as double busbar and triple busbar arrangements, are used to balance loads between various transmission circuits, minimize the physical space required for a substation, and provide simpler operating procedures when performing breaker maintenance. The protection challenge for these busbar configurations actually lies in operations. The busbar protection must recognize which segment is faulted, and clear only that segment. Additionally, the busbar protection must not operate when breakers are transferred between busbar segments. The figure shows a typical double busbar configuration. For an internal fault, the busbar protection must identify the faulted bus segment, and trip the circuit breakers attached to that bus segment. This requires the busbar protection to use a dynamic bus replica to track which circuit breakers are connected to the bus segment.

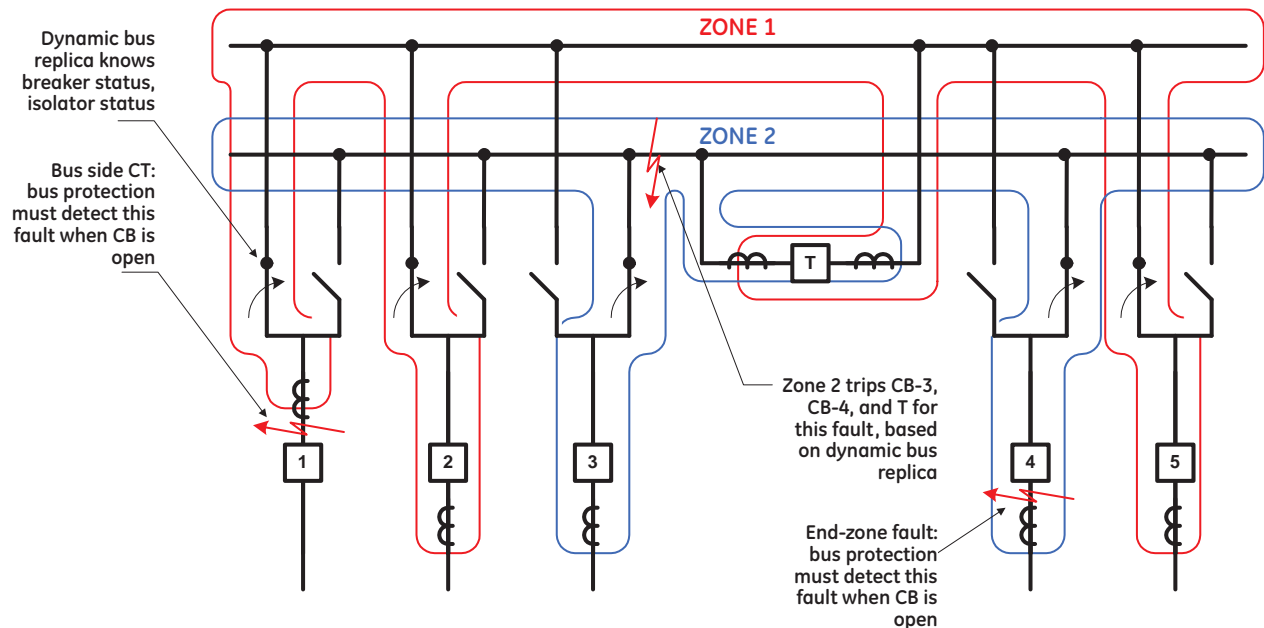
The B90 Bus Differential Relay provides protection of multiple segment busbars, using a phase-segregated, centralized protection scheme. The B90 is phase-segregated to simplify the design of the system. One B90 is used for each phase, and processes only the AC signals for that phase, eliminating the need for data transfer and synchronized sampling between the devices. The B90 uses a centralized protection scheme to also simplify the design of the system. The relays are in the substation control house, and all current circuits and control wiring are brought to the control house as per typical relay installations. No special equipment needs to be mounted in the substation yard or circuit breaker control cabinets.

**Dynamic bus replica**

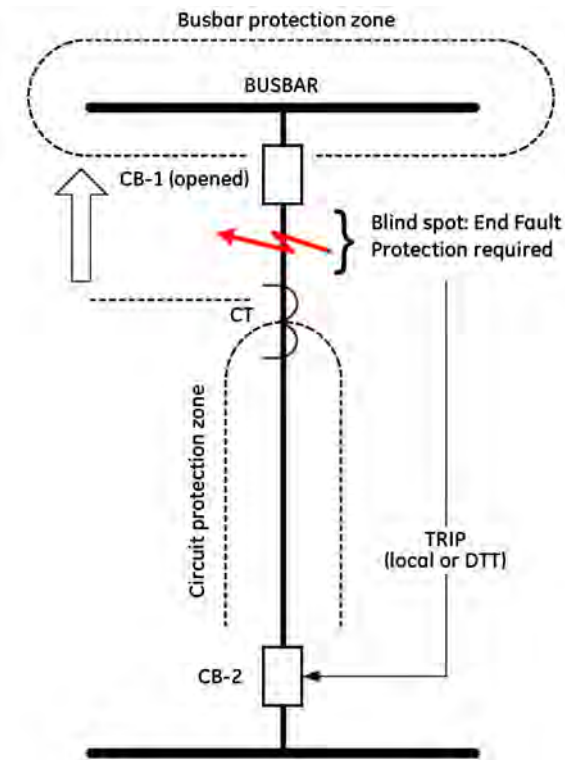
The objective for protecting complex busbar arrangements is to provide for optimum protection by avoiding blind spots or unnecessary bus outages. As a rule, this task calls for dynamic adjustments of boundaries of differential zones of protection, and can be safely accomplished when using numerical relays. Dynamic bus replica and CT switching were initially done outside the relay and as such complicated the bus protection schemes. The B90 and B30 relays provide user programmable logic to create a dynamic bus replica inside the system, catering for dynamic switching schemes necessary to make the bus protection scheme secure and reliable.

**End-zone fault protection**

End fault protection is one use of a dynamic bus replica. When using line-side CTs, the circuit breaker is included in the bus zone of protection. When the relay determines the circuit breaker is open through the use of breaker status contacts, the circuit breaker is removed from the bus zone. In this case, a fault between the CT location and the circuit breaker is in a protection blind spot. Since



Re-configurable busbar with zone boundaries

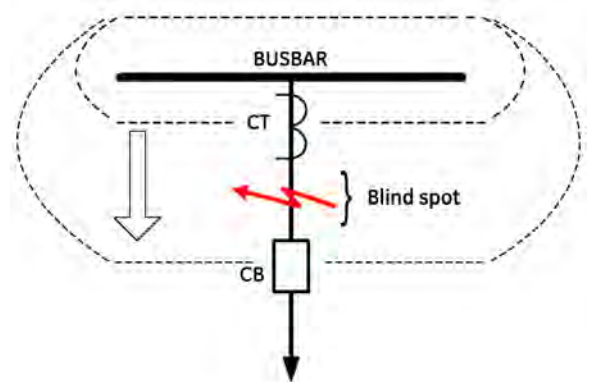


End Zone Fault - Line side CTs

the B90 is still measuring the current, a simple overcurrent function, can be used to determine the fault exists, and send a direct transfer trip signal to the circuit breaker on the other end of the transmission line. Without the use of a dynamic bus replica, this fault would cause an operation of the bus protection for what is essentially an external fault.

**Bus side CTS**

Bus side CTs provide another illustration of the use of a dynamic bus replica. Similar situation occurs for bus-side CTs. A fault between the circuit breaker and the CT is in a blind spot of the bus protection. To clear the fault the busbar must be tripped, but the differential zone will not see this fault. Similar to the end-zone fault, this situation requires using breaker position as a connection status for the associated current. The fault is cleared sequentially. First, protection of the circuit, fed from the CT, responds to the fault and opens the breaker. When the breaker opens, the CT current is removed from the differential zone by the dynamic bus replica. As a result, the zone expands to the bus-side pole of the opened breaker, the fault becomes internal, and the bus protection clears the busbar.



End Zone Fault - Bus side CTs

**Flexible input and output options**

Traditional busbar protection and control schemes typically use a lockout relay to open the connected circuit breakers when a bus fault is detected. For simple busbars, this is the most effective way to open the circuit breakers. GE Multilin relays can replace the separate lockout relay with mechanically latched output contacts. Once asserted, these contacts latch closed until manually reset via contact input, pushbutton control from the relay HMI, or SCADA command.

For applications where the bus protection relay will be used for control and status information, or the relay is protecting a complex busbar where the status of circuit breakers and isolator switches is vital, the number of inputs and outputs is quite large. Taking a double busbar example with 5 feeders and a tie breaker, the relay requires 12 output contacts (trip and close for each circuit breaker), and 16 to 32 contact inputs (1 or 2 status inputs for each circuit breaker and isolator switch). This many inputs and outputs may be beyond the physical limits of an individual relay. For this reason, GE Multilin provides an additional B90 to add a combination of up to 96 additional inputs and 84 additional outputs for a bus protection system. The relays can communicate via Direct I/O communications to pass digital input status and control output contacts. Direct I/O is a robust communications protocol that uses copper or fiber optic communications. The protocol is very reliable, and includes 32-bit CRC error checking, and may integrate up to 16 different relays on one communications circuit.