INTERNATIONAL

Operational Solution to Delayed Zero Crossings, Following a Short Circuit

Anthony Chabrol, James Dooley, John Doyle

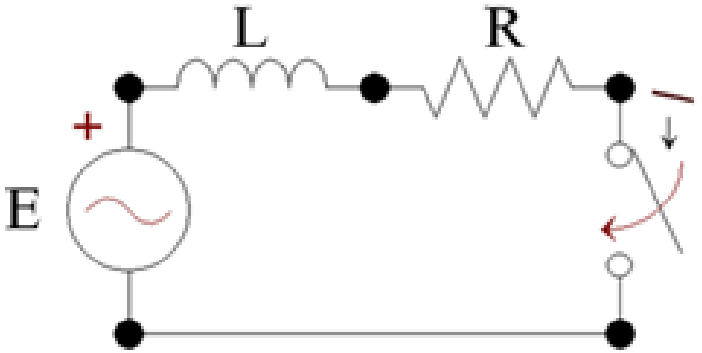
ESB International, Ireland

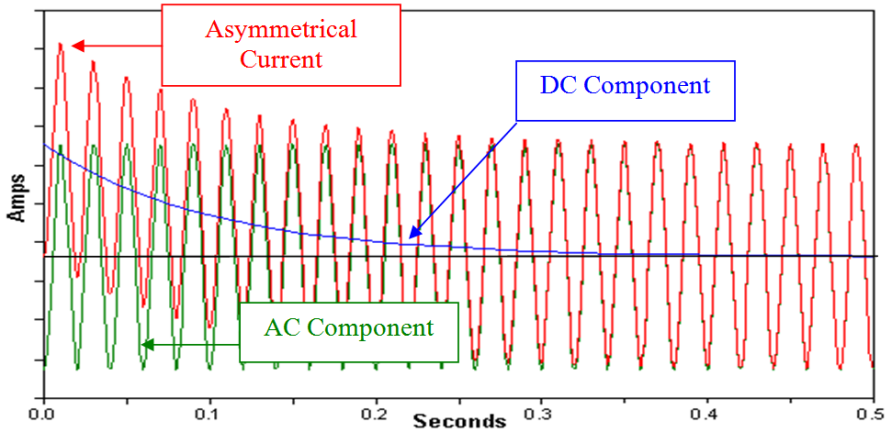
Agenda

- **Issue of Delayed Zero Crossings**
- **How Does This Effect Generation of Stations**
- **Mitigation Options**
- **Option Chosen and How It Was Implemented**

Issue of Delayed Zero Crossings

- The occurrence of a fault leads to a large current magnitude
- Fault current comprises of both AC and DC components
- The DC Component Decays over time.



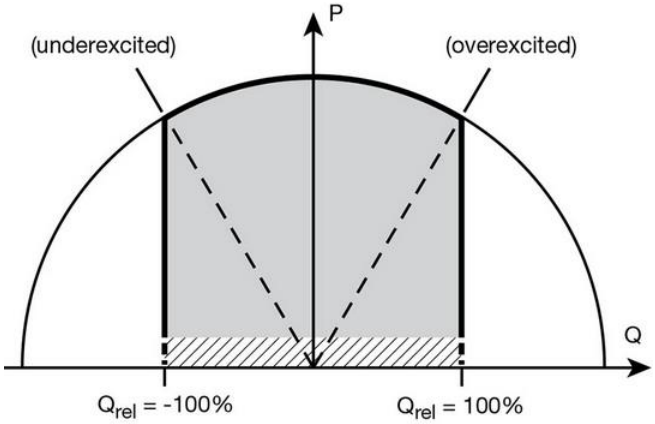


Issue of Delayed Zero Crossings

- **The time constant of this decay is determined by**

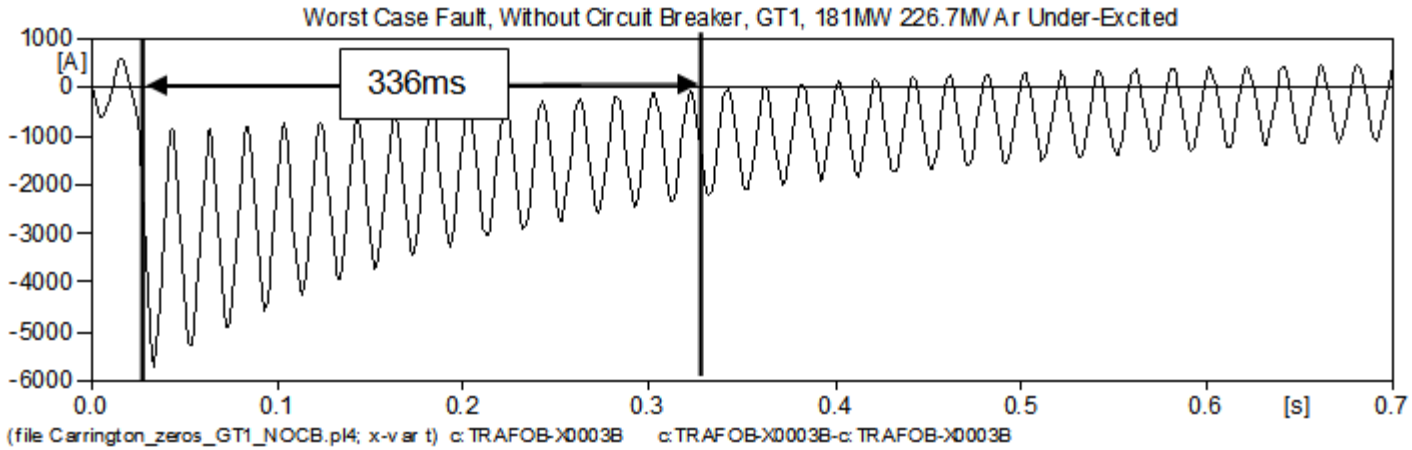
$$\frac{1}{2\pi f} \cdot \left(\frac{X}{R}\right)$$

- **Essentially the X/R ratio of the fault determines the rate of decay of the DC Component**
- **For generators operating in the under-excited mode, the DC component may be larger than the AC component**
- **This can lead to the fault current not crossing the zero axis for a long period of time**



Issue of Delayed Zero Crossings

- **This has implications for the ability of the circuit breaker to interrupt the fault current**
- **If a circuit breaker attempts to interrupt a fault current that does not cross the zero axis, it risks forming an arc that will not be broken**



- **This may destroy the circuit breaker, endanger the lives of people in the vicinity, items of plant connected to the system and the stability of the whole system**

Issue of Delayed Zero Crossings

- **The worst case faults arise in the scenario where there is a two phase fault that develops into a three phase fault, while the generator is operating in an under-excited condition**

- **This fault will start as a line to line fault, which then develops into a three phase fault 5ms later**

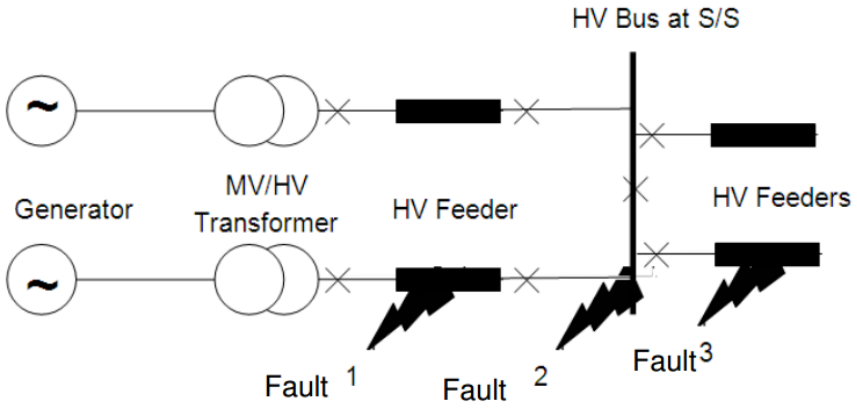
- **It is important that there is negligible resistance in the fault path, so ideally this would be a bolted fault. This worst case scenario is improbable but still possible**

Issue of Delayed Zero Crossings

- **The two instances where this worst case scenario may happen is a lighting strike or switching onto a line or bus where the earths are applied**
- **In the case of switching onto a fault, the two poles of the circuit breaker must be closed in unison at the zero point of the phase to phase voltage between the two phases and the remaining poles closing 5ms later**
- **This results in the largest DC offset and the longest delayed zero crossing**
- **Similarly if there is a three phase fault with the generator also operating in the under-excited position it will result in with significant delayed zero crossings but with a reduced delay**
- **Assuming all HV feeders and busbars are adequately shielded, the possibility of a three phase fault as a result of lightning is remote, and will not be discussed further.**

Operational Considerations

- There are three scenarios that will be discussed in relation to three phase faults as a result of earths being left on lines or busbars:
- High voltage line between generator step-up transformer and high voltage substation - Fault 1
- High voltage busbar in main substation - Fault 2
- High voltage lines feeding substation - Fault 3



Operational Considerations

- **However in case of fault 3, in the event of only one out-going feeder being in service when the three phase fault occurs then there is a risk that significant DC current offset will result in delayed current zeros and failure of the line circuit breaker to clear the fault**
- **The following is a list of possible mitigating actions that may be employed to reduce or remove the impact of delayed zero crossings:**
- **Decrease the X/R ratio in the path feeding the fault**
- **Provide appropriate protection coordination**
- **Limit the operating range of the generator**
- **Insert series resistor to the generator**

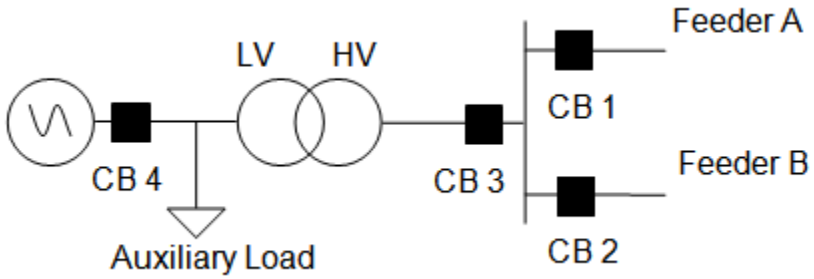
Operational Considerations

- **The generator side of the transformer has a relatively low voltage and the resistance of the interrupting arc reduces the X/R ratio and DC decay time**

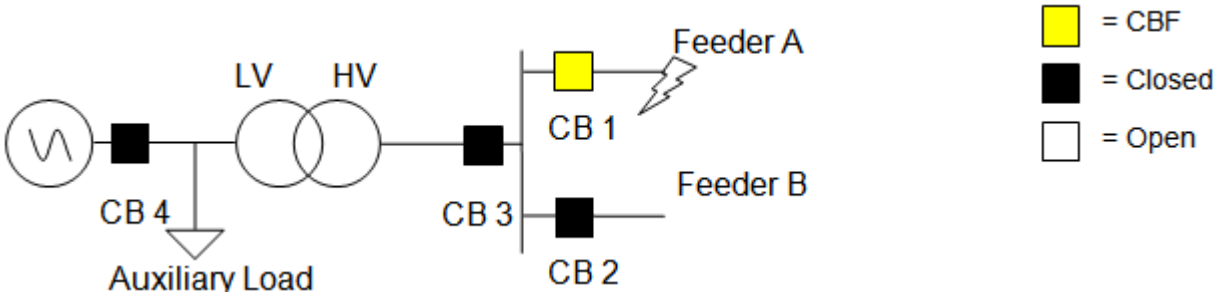
- **For generation stations with circuit breakers on the generator side of the transformer this means there is a solution to the issue of delayed zero crossings**

- **This paper proposes a solution based on the coordination of the generator circuit breaker with other protective equipment in the generating station**

Typical Configuration

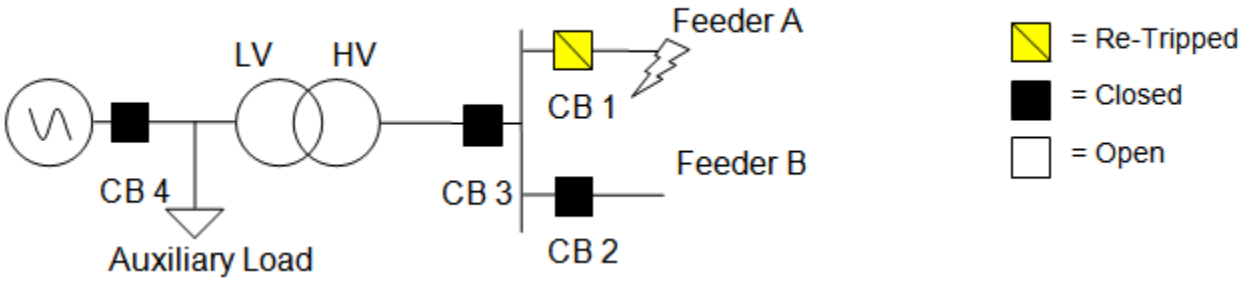


- **For the typical generator feeding arrangement shown the protection scheme on CB 1 as currently configured will operate as follows in the event of a fault on feeder A**
- **The local protection will send a trip command to the circuit breaker CB 1**
- **The circuit breaker fail monitor will start**

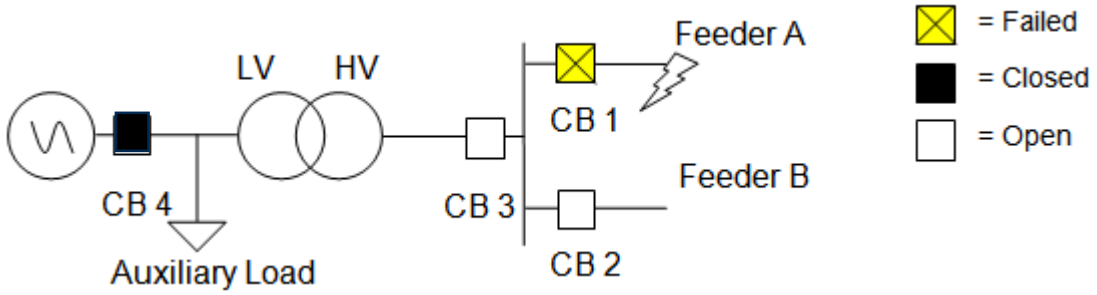


Typical Configuration

- **If after 100ms the circuit breaker fail condition is still detected a re-trip command is sent to the monitored breaker (CB 1)**



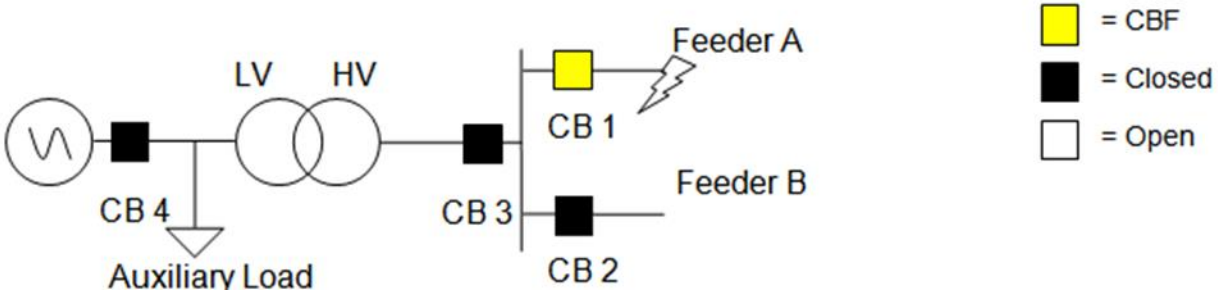
- **If after another 100ms the circuit breaker fail condition is still detected a trip command is sent to all adjacent breakers**



- **However, if the failure of CB 1 was caused by a delayed zero crossing, it is likely that CB 3 will also fail, resulting in damage to the circuit breaker**

Proposed Solution

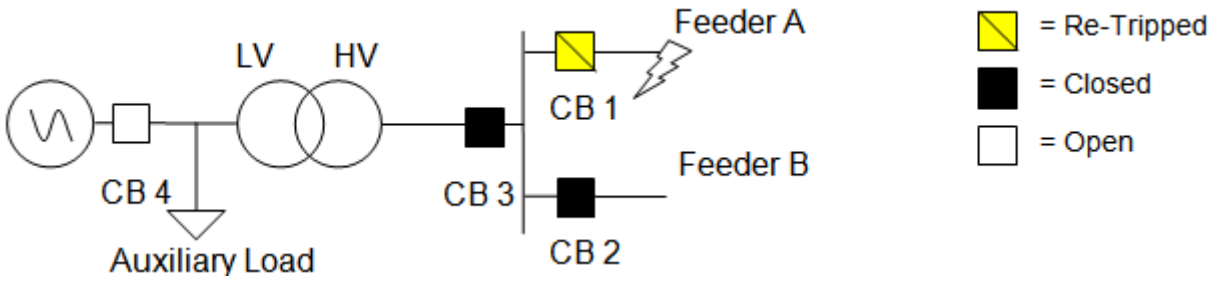
- **The local protection will send a trip command to the circuit breaker CB 1**
- **The circuit breaker fail monitor will start**



- **If after 100ms the circuit breaker fail condition is still detected a re-trip command is sent to the monitored breaker. Simultaneously a trip command is sent to all adjacent breakers, including the LV generator circuit breaker, i.e. both the HV circuit breaker CB 3 and the LV circuit breaker CB 4 are issued a trip command at the same time**

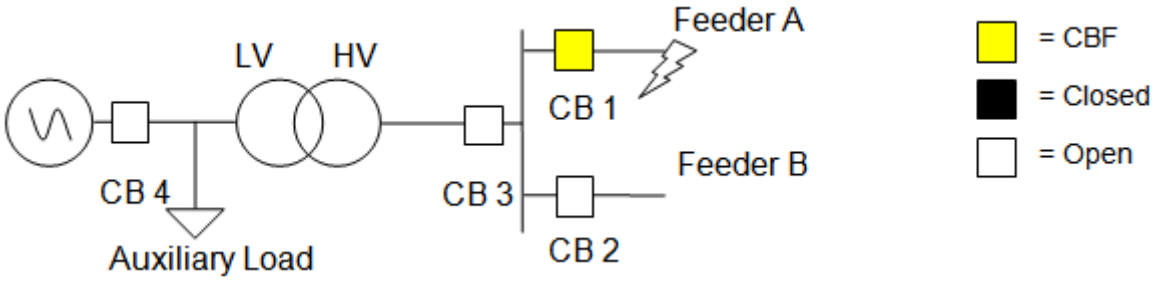
Proposed Solution

- **However, both breakers may open at the same time, or one may open slightly earlier than the other. In order to save CB 3 in the event of a delayed zero crossing, CB 4 should trip before CB 3**
- **To ensure that CB 4 trips before CB 3, it is proposed that in the event of a stage two Circuit Breaker Failure, the HV circuit breaker CB 3 will trip a delayed time after the LV generator circuit breaker CB 4**
- **If after 100ms the circuit breaker fail condition is still detected a re-trip command is sent to the monitored breaker (CB 1) and the LV generator circuit breaker (to ensure that the LV generator CB 4 trips before the generator circuit breaker CB 3)**



Proposed Solution

- **After a delayed time a trip command is sent to all adjacent breakers**



- **Generator circuit breakers typically have a break time of approximately 70ms**
- **HV circuit breakers typically have break times of approximately 40ms**
- **In order to ensure that the generator circuit breaker trips first and to avoid damaging the HV circuit breaker, the HV CB should not start to open until 70ms after the generator CB has started to open**
- **It may be possible to trip the HV CB earlier and avoid damaging the CB, to confirm this would require further investigation**

Conclusion

This solution minimises the risk of multiple failure of the high voltage circuit breakers when attempting to clear the generator contribution to close-up system faults

A consequence of the proposed solution is that supply to the unit auxiliaries is lost when CB 4 is tripped, resulting in unit shutdown

However, once CB 1 has been isolated and the necessary reconfiguration of the HV feeders has been completed, the generator can be run and resynchronised via feeder B, thus keeping the required outage to a minimum

This solution has been adopted for all stations built by ESB International, as there is an LV generator CB available