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Operational Solution to Delayed Zero Crossings, Following a Short Circuit

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SUMMARY

Ensuring the availability of generators is critical to the continuity and stability of supply to an electrical system. As circuit breakers installed in transmission networks are generally designed to interrupt fault current within a few cycles, prolonged arcing within the breaker represents a significant failure risk and threatens availability of generators. This prolonged arcing can be caused by short circuit currents with significant dc component, as they may not experience a zero crossing for a large number of cycles. This is most likely to occur following a near generator short circuit. The issue of delayed zero crossings following a near generator short circuit has been outlined in [1-3, 10].

KEYWORDS

Zero Crossing, Short Circuit, Near Generator Faults, Circuit Breakers

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1 Introduction

1.1 Delayed Zero Crossings

Circuit breakers in electrical installations have to be rated to successfully make and break currents. Upon the occurrence of a fault, currents of large magnitudes will flow. Initially this current is a combination of alternating and direct current (AC and DC) components. This can be illustrated by considering the simple circuit shown in Figure 1.1, where R is the Thevenin resistance up to the fault point, L is the Thevenin inductance up to the fault point and E is the Thevenin source voltage. On closing the switch the current waveform represented by Equation 1.1 [3], is produced.

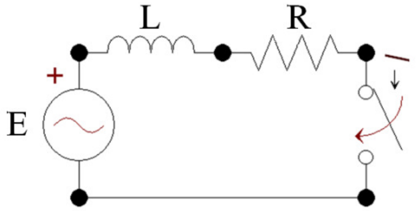

Figure 1.1 – Equivalent circuit representation

$$\underbrace{i(t) = e^{-(R/L)t}\left\{\frac{-E_{max}}{\sqrt{R^2+\omega^2L^2}}\sin\left[\varphi-\tan^{-1}\left(\frac{\omega L}{R}\right)\right]\right\}}_{\text{Part 1}} + \underbrace{\left\{\frac{-E_{max}}{\sqrt{R^2+\omega^2L^2}}\sin\left[\omega t+\varphi-\tan^{-1}\left(\frac{\omega L}{R}\right)\right]\right\}}_{\text{Part 2}}$$

Equation 1.1 – Current Waveform equation

The first part of Equation 1.1 describes how the DC component of the current, decays with time; the time constant of this decay is determined by the X/R ratio at the fault site described by the term. In the case of a high X/R ratio this decay time can be extremely large. The second part of the equation describes the AC component of the current. The combination of AC and DC components gives the asymmetrical current as shown in Figure 1.2. The AC current component decays from an initial large value for faults near to generators due to the influence of the transient and sub-transient reactances.

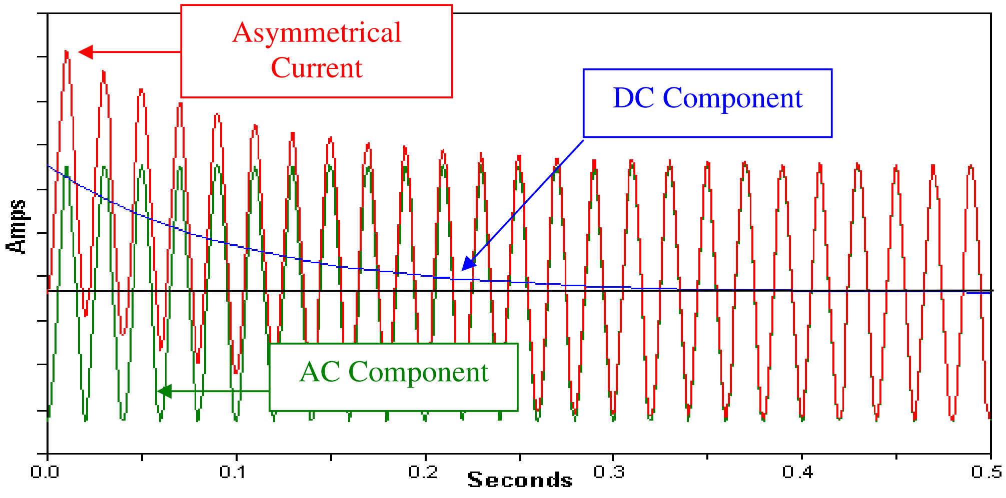

Figure 1.2 – Current Waveform

In cases where the generator is operating in the under-excited mode it is possible that the DC component of the fault current is larger than the AC component. This DC component will decay as a result of the term $e^{-(R/L)t}I_0$, where I_0 is determined by the load, shown in Figure 1.3. The longest decay time will result due to capacitive loads [3]. As a result, the current wave form may not cross the zero axis for a long period of time as shown in Figure 1.4. This has implications for the ability of circuit breakers to break this fault current. The problem with delayed zero crossings is becoming more pronounced as the losses in generators and transformers reduce, thus increasing the X/R ratio.

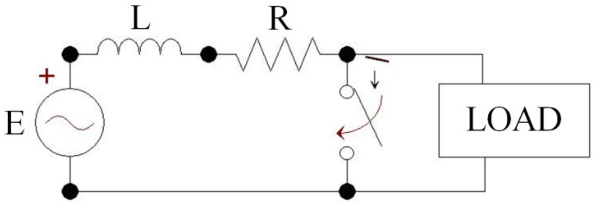

Figure 1.3 – Equivalent Circuit with load

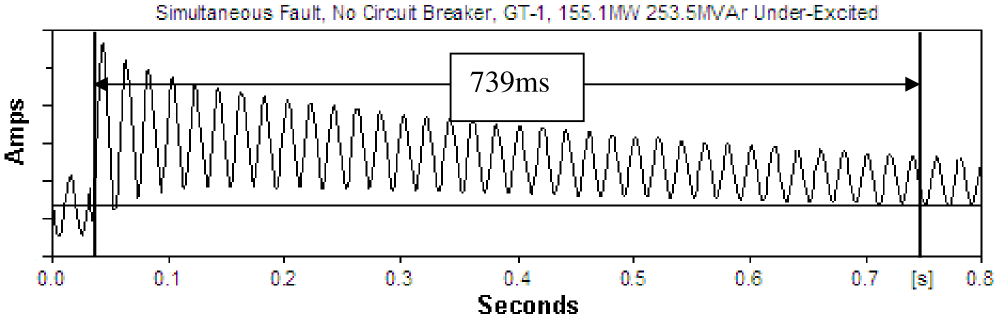

Figure 1.4 - Delayed Zero Crossing

If a circuit breaker attempts to break a current that does not cross zero, the resulting arc may not be broken and may damage the circuit breaker, endanger the lives of people, equipment and property in the vicinity, as well as risking the stability of the whole electrical system. There is no straightforward solution to this issue. This phenomenon is not new but is becoming more of a problem due to the advent of low(er) loss generators and transformers. A detailed examination of this subject is given in [1] and [2].

The matter of delayed zero crossings as a result of faults on high voltage systems is an issue that is not adequately dealt with by international standards [11], [12], [13] & [14]. It is the authors understanding that there is no standard available to which HV manufacturers can design and test their equipment adequately, with respect to the issue of delayed zero crossings. An overview of this subject is given in [4]-[8], which give examples of where this may occur such as ITAIPU in Brazil.

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

The provision of adequate solutions to the impact of the delayed current zeros crossings on successful fault current interruption is not comprehensively addressed by international standards. It is nevertheless incumbent on system designers to ensure that the risks associated with the failure of a breaker to interrupt fault currents are minimised.

2 Proposed Solution

As discussed in [1], 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.

In the event of a fault on Feeder A, the following is proposed in order to mitigate the effect of a delayed zero crossing, it is proposed that if there is a fault on Feeder A, the following will happen:

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

If after 100 ms 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.

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 with a delayed time after the generator circuit breaker CB 4.

This is illustrated below:

1) The local protection will send a trip command to the circuit breaker CB 1.

The circuit breaker fail (CBF) monitor will start

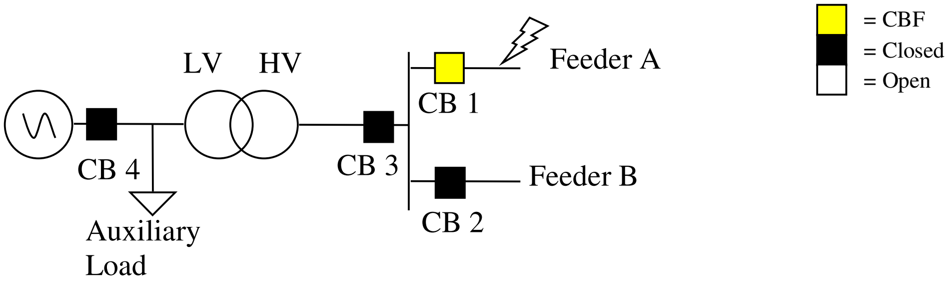

Figure 2.1 – Local protection trip signal

2) If after 100 ms 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).

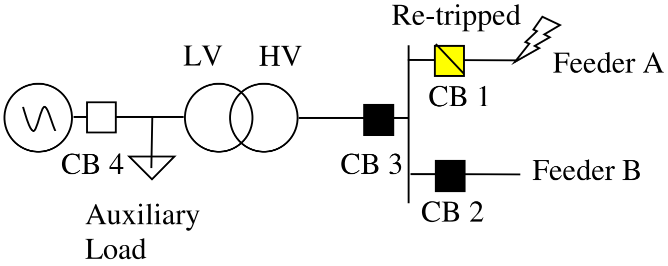

Figure 2.2 – re trip signal sent

3) After a delayed time a trip command is sent to all adjacent breakers.

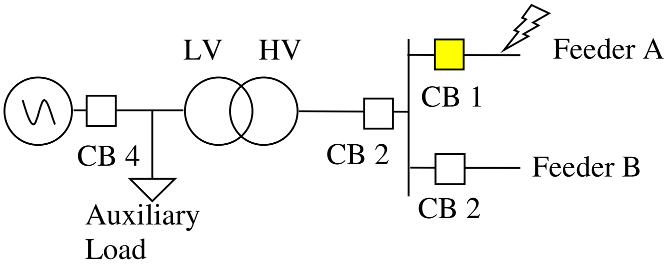

Figure 2.3 – Trip adjacent to all CB

This solution is shown in the circuit breaker fail logic diagram in **Figure 2.4**.

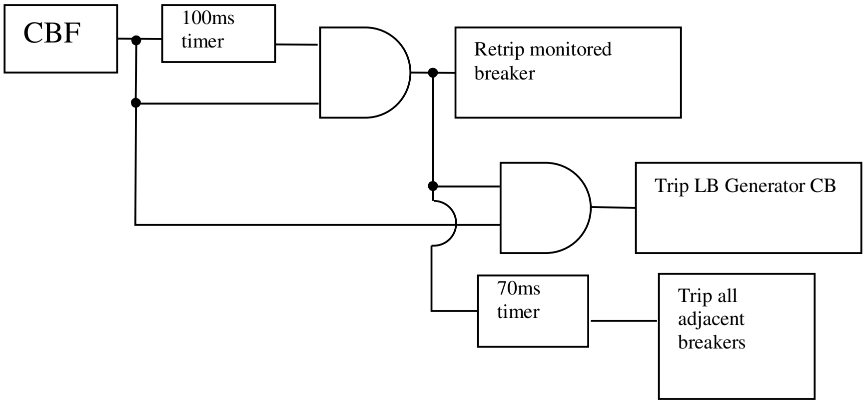

Figure 2.4 Proposed Protection Scheme

3 Generator CB and HV CB Break Times

In order to decide what the delay period between the generator circuit breaker trip and the HV circuit breaker trip should be, the break times for both the generator CB and the HV CB should be analysed.

Generator LV circuit breakers typically have a break time of approximately 30-60 ms. HV circuit breakers typically have break times of approximately 60-90 ms [14].

In order to ensure that the LV generator circuit breaker trips first and to avoid damaging the HV circuit breaker, the HV circuit breaker should not start to open until 70 ms after the LV generator circuit breaker 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.

4 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.

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