Generator Protection

An Online Continuing Education Course for Engineers

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Generator Protection

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Introduction

This course covers generator protection concepts and theory. Protective devices that are described in this course can be used in multiple generator protection configurations. There are various protection relays and those are used for protection against a wide variety of conditions. Protection relays protect the generator, prime mover, external power system or the processes it supplies. The fundamental principles that are covered in this course are equally applicable to individual relays and to multifunction numeric relays. The protection engineer has to balance the expense of using a particular protection relay against the consequences of losing a generator. The total loss of a generator may not be that bad especially in situations when it represents a small portion of the investment in an installation. However, the effect on service reliability and upset to loads has to be considered. Damage and product loss in continuous processes can represent the major concern rather than the generator unit. Hence, there is no universal protection solution based on the MW rating. However, it is expected that a 500kW, 480V, standby reciprocating engine will have fewer protection elements and simpler protection arrangement than a 400MW base load steam turbine unit. One typical dividing point is that the extra CTs required for current differential protection are less commonly encountered on generators less than 2MVA, generators rated less than 600V, and generators that never work in parallel with other generation.

This course explains protection relay selection process by detailing how to protect against each fault type or abnormal condition. Also, recommendations are made for what is considered to be a minimum protection as a baseline. After making the baseline, extra protection relays may be introduced. (Note that numbers shown in parenthesis throughout this course refer to protective device function numbering per ANSI/IEEE C37.2 "Electrical Power System Device Function Numbers, Acronyms, and Contact Designations.") The topics included in this course are as follows:

- Earth Fault (50/51-G/N, 27/59, 59N, 27-3N, 87N)
- Phase Fault (51, 51V, 87G)
- Backup Remote Fault Detection (51V, 21)
- Reverse Power (32)
- Loss of Field (40)
- Thermal (49)
- Fuse Loss (60)
- Overexcitation and Over/Undervoltage (24, 27/59)
- Inadvertent Energization (50IE, 67)
- Negative Sequence (46, 47)
- Off-Frequency Operation (81O/U)
- Sync Check (25) and Auto Synchronizing (25A)
- Out of Step (78)
- Selective and Sequential Tripping

Ground Fault Protection

The following cases describe three grounding impedance levels: low, medium, and high.

A low impedance grounded generator relates to a generator that has zero or minimal impedance at the Wye neutral point. In that case during an earth fault at the generator HV terminals, earth current from the generator is roughly equal to 3 phase fault current.

A medium impedance grounded generator relates to a generator that has a substantial impedance at the Wye neutral point. In that case during an earth fault, a decreased but detectable level of earth current, commonly in the 100-500A range, flows.

A high impedance earthed generator refers to a generator with big earthing impedance. In that case during an earth fault, a nearly undetectable level of fault current flows, requiring earth fault monitoring with voltage based (for example, 3rd harmonic voltage monitoring and fundamental frequency neutral voltage shift monitoring) protection relays. The location of the earthing, generator neutral(s) or transformer also affects the protection scheme.

The position of an earth fault within the generator winding, as well as the grounding impedance, affects the level of short-circuit current. Assuming that the generated voltage along each winding portion is uniform, the pre-fault line-ground voltage level is proportional to the percent of winding between the fault location and the generator neutral as shown in V_{FG} in Figure 1. Assuming an impedance earthed generator where ($Z_{0,SOURCE}$ and Z_N)>>$Z_{WINDING}$, the current level is directly proportional to the distance of the point from the generator neutral (please refer to Figure 1(a)), so a short circuit 10% from neutral creates 10% of the current that flows for a fault on the generator terminals. While the current level decreases to zero as the neutral is getting closer, the insulation stress also decreases, tending to decrease the chance of a fault near the neutral. If a generator earthing impedance is low relative to the generator winding impedance or the system earthing impedance is low, the fault current decay will be non-linear. For I_1 in Figure 1, lower fault voltage is offset by lower generator winding resistance. A typical example is presented in Figure 1(b). The generator differential relay (87G) should be sufficiently sensitive to sense winding earth faults with low-impedance grounding as shown in Figure 2. In this situation, a solid generator-terminal fault creates roughly 100% of rated current. The differential relay minimum pickup setting need to be adjusted to detect faults on as much of the winding as possible. Nevertheless, settings below 10% of full load current introduce increased risk of misoperation due to transient CT saturation during external faults or during step-up transformer energization. Lower pickup settings are advised only with high-quality CTs and a good CT match (for example, same accuracy class and same burden).

In the case, 87G relaying is installed as shown in Figure 2; relay 51N backs up the 87G, as well as external relays. In the case, 87G is not installed or is not sufficiently sensitive for earth faults then the 51N gives the primary generator protection. The benefit of the 87G is that it does not require to be delayed to coordinate with external protection. Nevertheless, delay is needed for the 51N. Engineers need to be aware of the effects of transient DC offset induced saturation on CTs during transformer or load energization with respect to the high-speed operation of 87G protection relays.

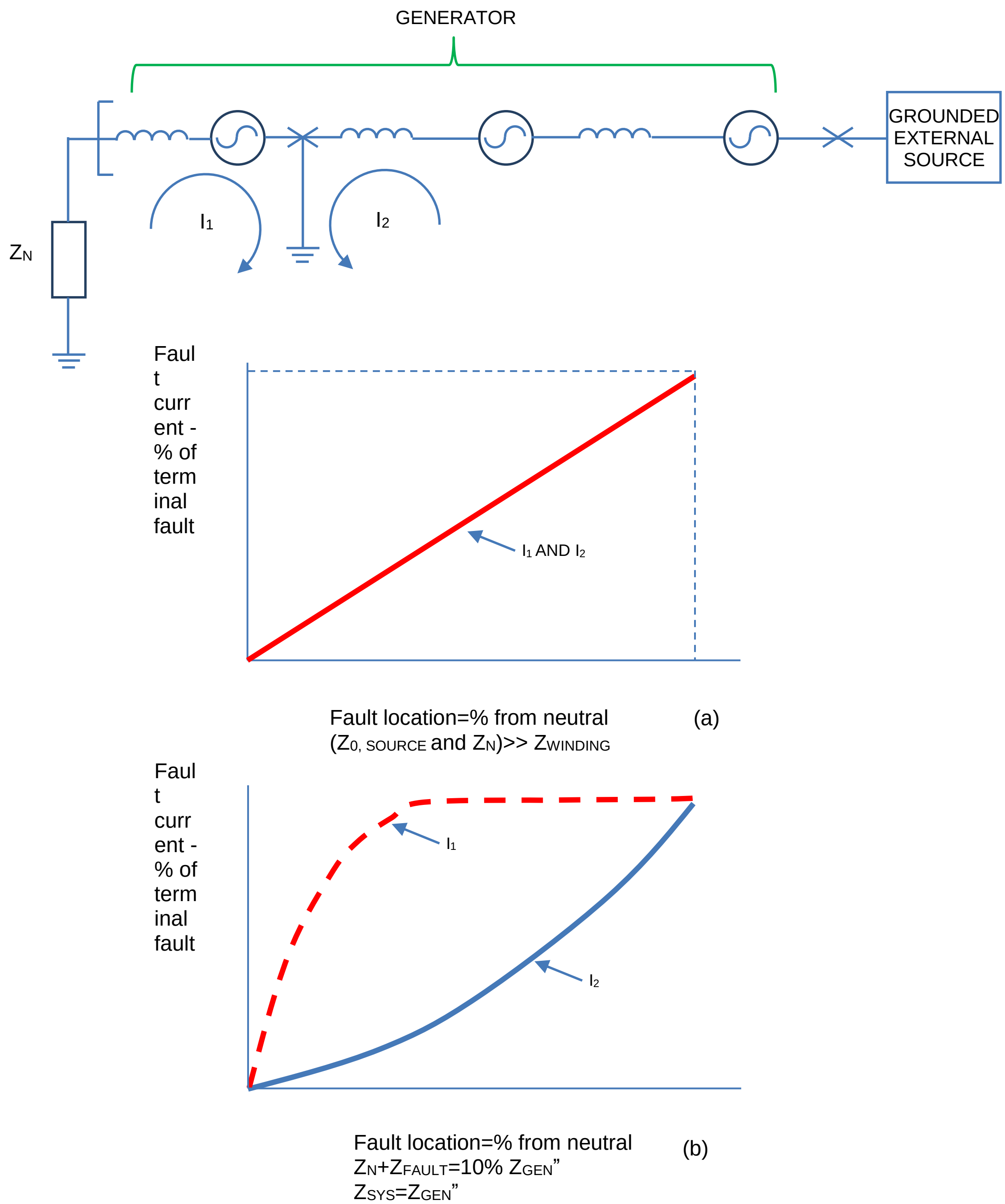


Figure 1. Effects of fault position within generator on current level

Transient DC offset may create CT saturation for many cycles (most probably not more than 10), which may start 87G relay false operation. This may be addressed by not block loading the generator, avoiding large transformers sudden energization, installing overrated CTs, putting insignificant time delay to the 87G trip circuit, or insensitively setting the protection relay.

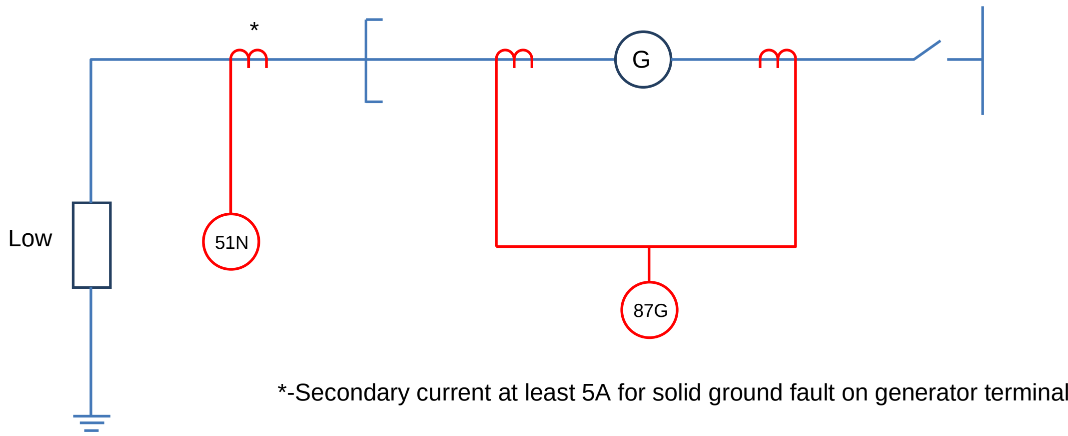
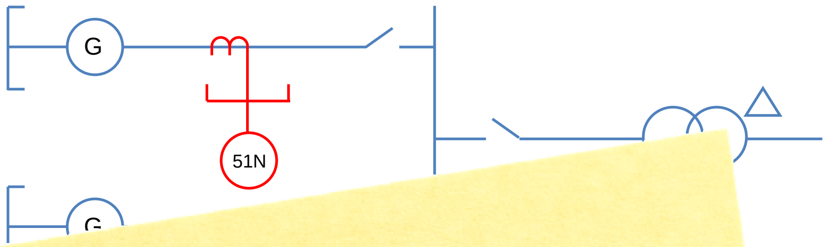
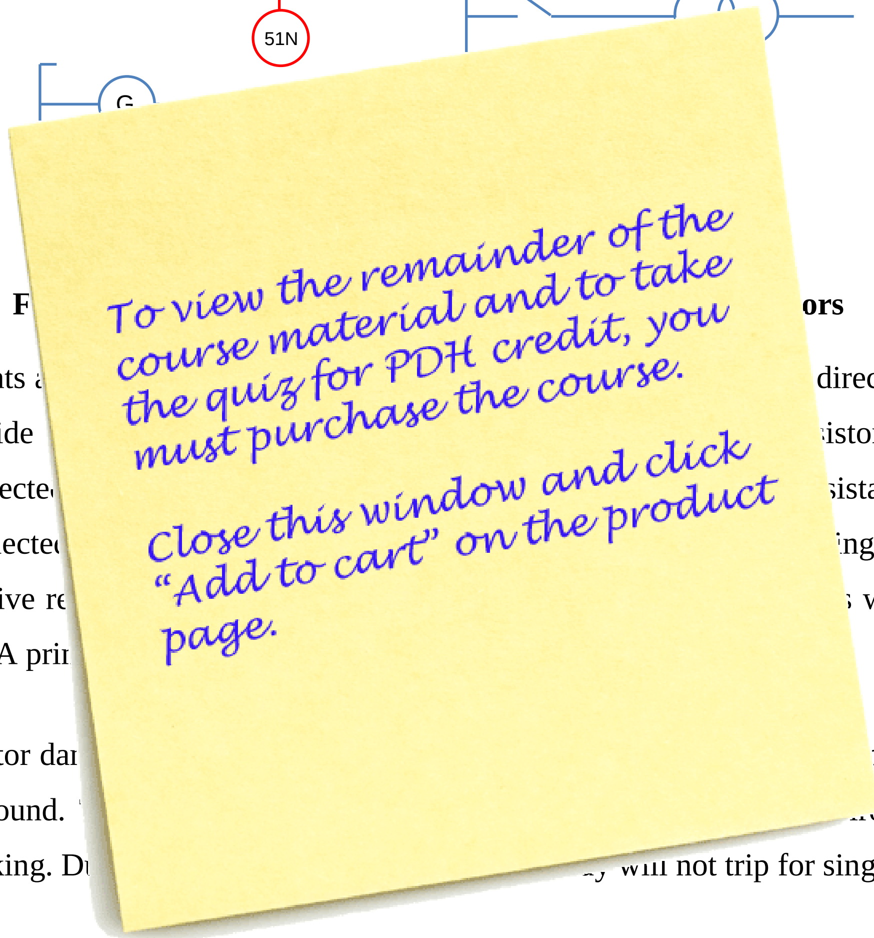


Figure 2. Earth fault relaying generator low-impedance earthing

The neutral CT has to be chosen to create a secondary current of at least 5A for a solid generator terminal fault, giving sufficient current for a fault near the generator neutral. For instance, if a terminal fault creates 1000A in the generator neutral, the neutral CT ratio must not exceed 1000/5. For a fault 10% from the neutral and assuming I_1 is proportional to percent winding from the neutral, the 51N current will be 0.5A, with a 1000/5 CT.

Figure 3 presents multiple generators with the transformer that provides the system earthing. This scheme is applicable if the generators will not be operated with the transformer out of service. The arrangement will lack earth fault protection before generator breakers are closed. The transformer could serve as a step-up as well as an earthing transformer. An overcurrent relay 51N or a differential relay 87G gives the protection for each generator. The transformer needs to generate a ground current of at least 50% of generator rated current to provide about 95% or more winding coverage.





F [illegible] ors

Figure 4 presents a [illegible] directly connected with no low-side [illegible] istor and voltage relays are connecte [illegible] sistance is chosen so that the reflecte [illegible] ingle-phase line-ground capacitive re [illegible] will limit fault current to 5-10A prin [illegible]

Adequate resistor dar [illegible] presence of an intermittent ground. [illegible] on damage to require re-stacking. Du [illegible] will not trip for single phase earth faults.