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### **Ground Fault Neutralizer for Wildfire Mitigation in California**

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#### **SUMMARY**

As the devastating 2020 fire season demonstrated in the western USA, climate-driven wildfire risks are increasing annually, and focused and sustained mitigation efforts are needed to reduce the threat and impact of wildfires. The U.S. Forest Service estimates that 147 million trees died in California from drought and invasive beetles from 2010-2018, which is just one of the factors that has contributed to the growing wildfire risk [1]. New technologies are being evaluated to reduce the risk of ignition from electric facilities operating in high fire risk areas. One approach is to compensate electric distribution networks through resonant grounding instead of solid grounding.

Many types of distribution faults and equipment failures have the potential to cause outages and even ignite wildfires. Ground faults such as transformer failure, insulator failure, vegetation contact, and downed power lines make up over 65% of the faults on electric distribution in high fire threat districts (HFTD). With the power system solidly grounded as is the prevalent practice in the USA, the ground fault current is in hundreds or thousands of Amps, well above the ignition threshold in many cases. In other parts of the world, resonant grounding is used to limit the fault current, mostly to limit damage to equipment.

One technology which is an extension of resonant grounding is known as a Ground Fault Neutralizer (GFN). The modern GFN uses power electronics to rapidly reduce the voltage of the faulted phase and thus limit the fault current below the fire ignition threshold. Through California's Electric Program Investment Charge (EPIC), Pacific Gas and Electric Company (PG&E) is demonstrating the GFN to protect two distribution circuits in Napa Valley, California. The GFN is also referred to as a Rapid Earth Fault Current Limiter (REFCL) in other parts of the world.

#### **KEYWORDS**

REFCL, GFN, wildfire, resonant grounding, California

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When a ground fault occurs, such as a powerline breaking and hitting the ground, it can create an arc, potentially starting a fire. A common practice in the USA is to solidly ground the neutral of the distribution substation transformer bank secondary. While this has a reliability benefit, the fault duty is typically in the hundreds or thousands of amps, potentially resulting in a fire ignition in high fire risk areas.

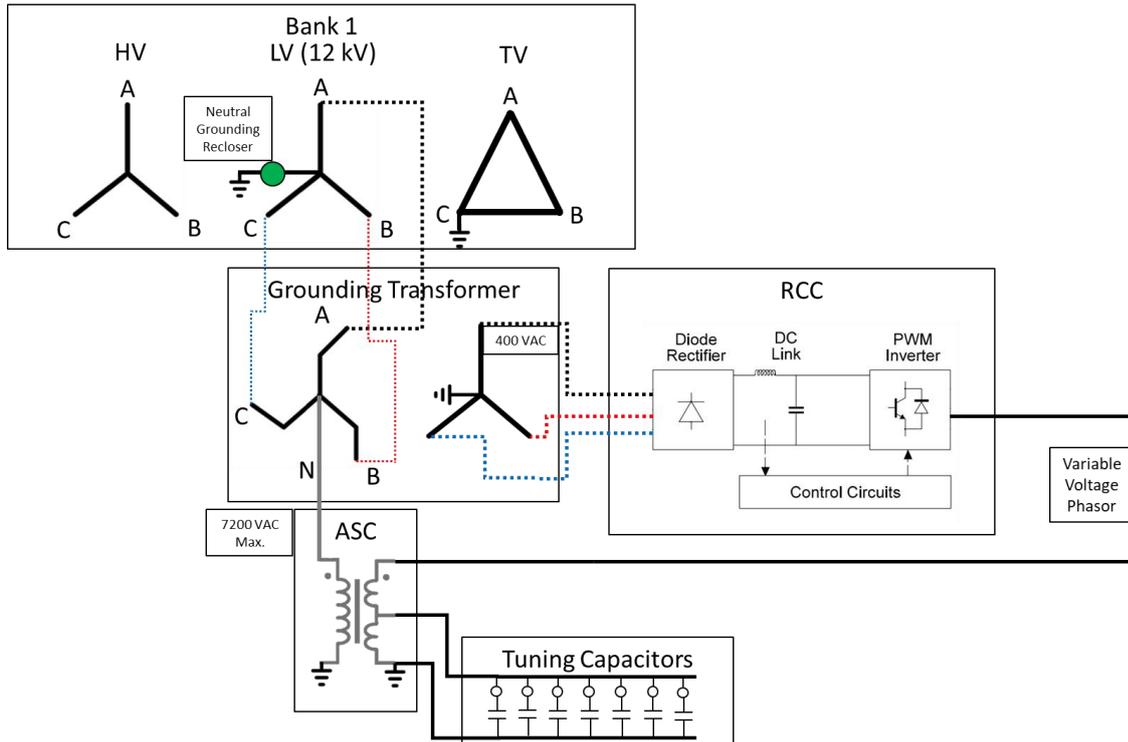
The Ground Fault Neutralizer (GFN) is an extension of resonant grounding and installed in the distribution substation to protect the outgoing distribution circuits. The GFN rapidly limits the fault current for single line to ground faults to less than 1 Amp, reducing the likelihood of fire ignition by 90% [2]. A GFN is only applicable for uni-grounded (3-wire) circuits with a single neutral point in the substation. Converting Multi-grounded (4-wire) circuits to uni-ground to support a GFN installation is very expensive and difficult. Multi-grounded electric distribution is very widely applied in the USA, but in California within PG&E’s service territory, over 80% of the distribution circuit mileage in high fire threat areas are uni-grounded 3-wire.

The GFN consists of an arc suppression coil (ASC), residual current compensator (RCC), and controllers (Figure 1) [3]. To package the GFN components more easily in a standard shipping container, a grounding transformer is connected to the substation 12 kV bus, creating an easily accessible neutral point for the ASC.



**Figure 1 From left to right : ASC, RCC, Control Cabinet (Swedish Neutral AB)**

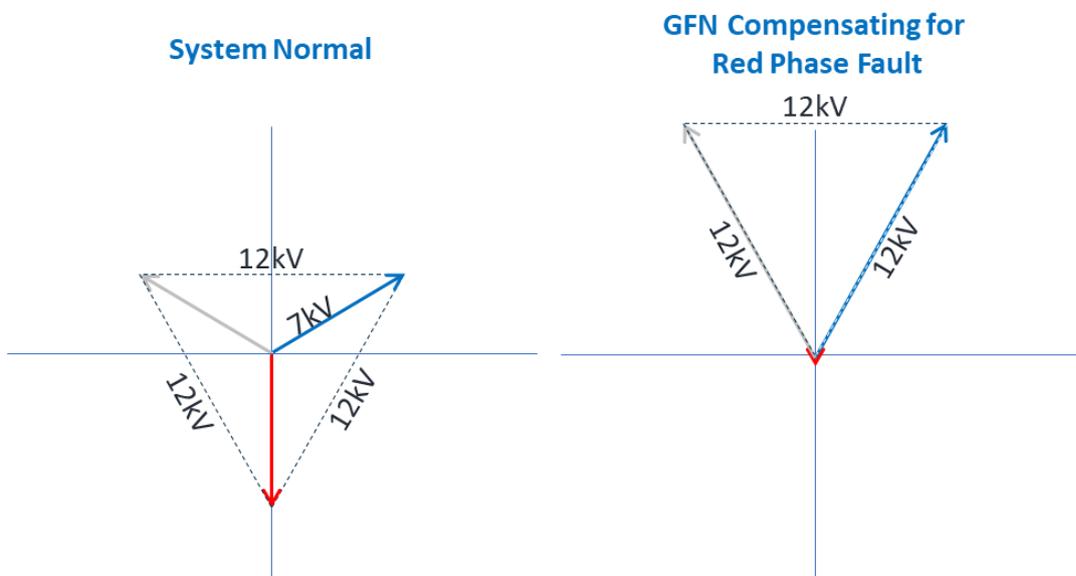
Through California’s Electric Program Investment Charge (EPIC), PG&E is demonstrating the GFN to protect two 12 kV distribution circuits in Napa Valley, California. Figure 2 shows the electrical connections between the substation bank and the GFN components.



**Figure 2 Substation connections to GFN components**

The substation bank is changed from solid grounding to resonant grounding based on the position of the Neutral Grounding Recloser, which operates as a switch. With the GFN cut-in, it protects 100% of the primary distribution networks connected to the substation transformer bank secondary.

When a ground fault occurs with the GFN in service, the neutral voltage passively increases and the GFN detects the fault once the voltage rises above the threshold setting. Within about 50 ms, the RCC actively outputs voltage to further increase the neutral voltage, which brings the faulted phase voltage typically below 250V primary. A side effect of this neutral shift is that the line to ground voltage of the two healthy phases increases to line to line magnitude as shown in Figure 3. The fault current follows Ohm's Law and is rapidly reduced as the faulted phase to ground voltage drops. Note that the phase to phase voltage is maintained, so no immediate service interruption is encountered. Customer service voltages remain the same as the service transformers are all connected Phase to Phase.

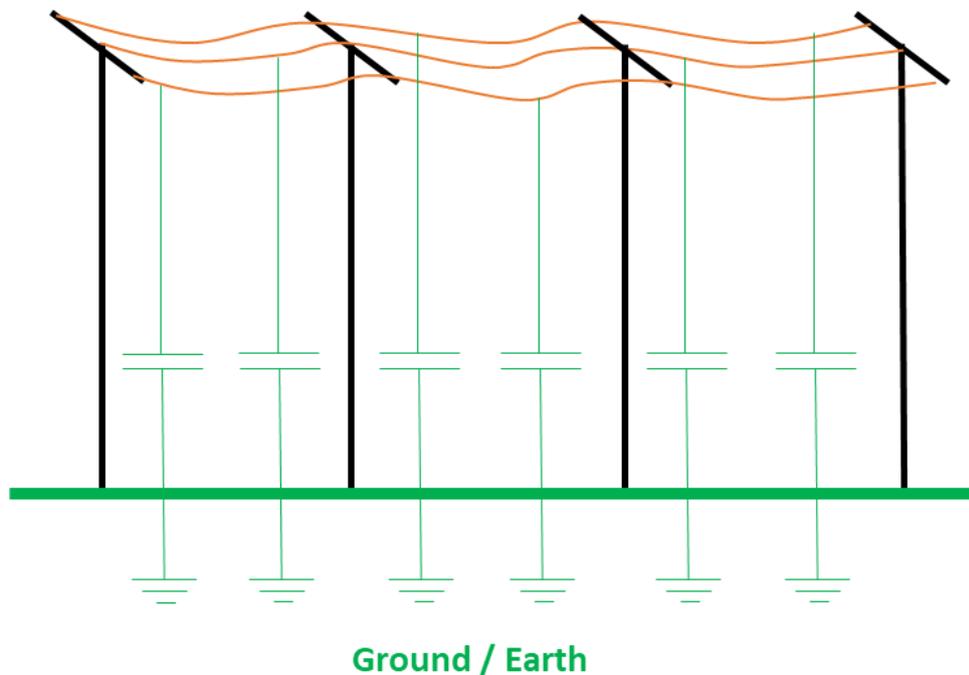


**Figure 3 The GFN shifts the neutral, reducing the line to ground voltage of the faulted phase**

After fully compensating the fault, the GFN performs a soft confirmation to locate which circuit the fault is on. The GFN does this by making small adjustments to the neutral voltage phasor via angle or magnitude and measuring the change in zero sequence admittance for each circuit. The circuit with the largest change in admittance is identified as the faulted circuit. The faulted circuit breaker is then tripped to isolate the fault.

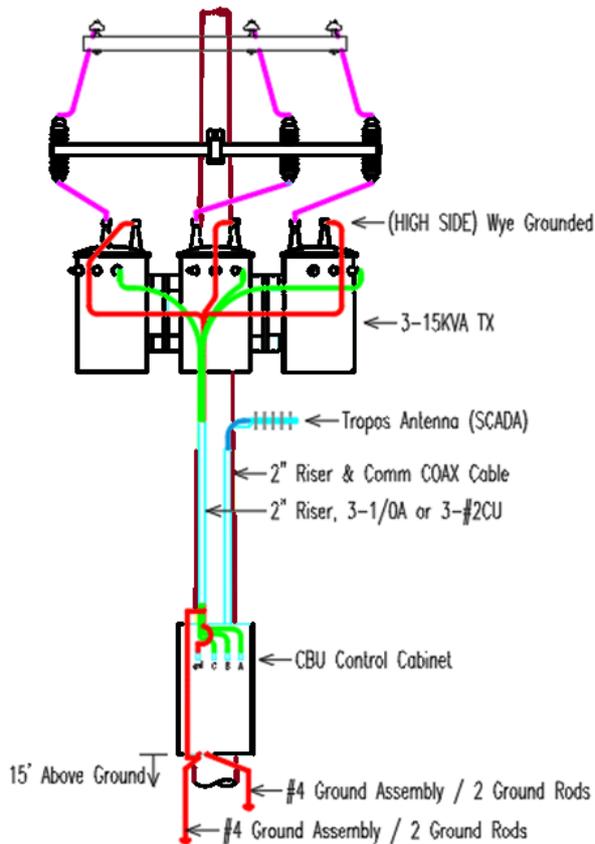
Before commissioning a GFN, supporting changes are needed. The main areas of concern are the following:

1. Insulation review of all primary connected equipment to withstand 1.73 times nominal line to ground voltage for 10 minutes. Underground cable and surge arrestors are the largest insulation challenges.
2. Closed delta voltage regulation (replace open delta banks)
3. Group tapping of all three phases of voltage regulators banks
4. Balanced zero sequence charging currents to minimize the standing neutral voltage on the bank [4]. The charging currents are the result of the unbalanced line to ground capacitances



**Figure 4 Line to ground capacitance of the lines results in zero sequence charging currents**

Balancing the charging currents to minimize the standing neutral voltage and maintain it is not a trivial task. In the USA, two phase taps (laterals) are commonly used on distribution circuits, especially more rural circuits. Phase swaps are performed for coarse balancing and a new type of equipment called a Capacitive Balancing Unit (CBU) is installed at major protection zones on the circuits to remotely inject ground current from each phase in 0.03 Amp increments, up to 0.5A maximum per phase. Single phase transformers or 5-limb three-phase transformers are to be used for the CBU so that the excitation of each phase is nearly identical [4]. To maintain balance, some single phase fuse locations need to be replaced with three-phase ganged protection to prevent false operation of the GFN in case of line-line faults [4].



**Figure 5 Capacitive Balancing Unit**

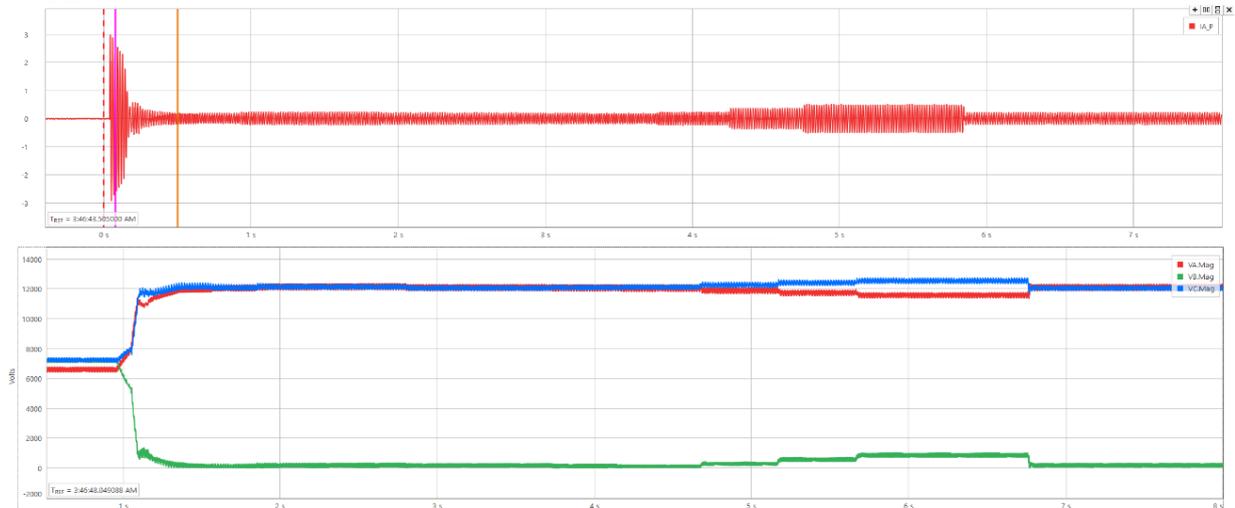
After commissioning, the GFN is field tested to verify performance. The Powerline Bushfire Safety Program in Victoria, Australia developed a performance benchmark based on ignition testing [2][4]. The State of Victoria has made this performance benchmark a regulatory requirement.

1. For a high-impedance fault:
  - a. GFN must detect the fault within 1.5 seconds of its occurrence
  - b. Within two seconds of fault occurrence, GFN must limit the voltage on the faulted conductor to less than 250 volts except during diagnostic tests
  - c. During diagnostic tests to confirm if the fault is sustained or not or to identify which powerline it is on, the GFN must:
    - i. Limit the fault current to less than 0.5 amps
    - ii. Limit the  $I^2t$  to less than 0.1 A<sup>2</sup>s
2. For a low impedance fault:
  - a. Within 85 milliseconds (ms) of fault occurrence the GFN must limit the voltage on the faulted conductor to less than 1,900 volts
  - b. Within 500ms of fault occurrence the GFN must further limit the voltage on the faulted conductor to less than 750 volts
  - c. Within two seconds of fault occurrence the GFN must further limit the voltage on the faulted conductor to less than 250 volts except during diagnostic tests.

The definitions of high-impedance fault and low-impedance fault should be:

- High impedance fault: a resistance from any high voltage powerline conductor to earth of value equal in ohms to twice the nominal phase-to-earth voltage in volts (13,800 Ohms in a 12kV network); and
- Low impedance fault: a resistance from any high voltage powerline conductor to earth of value equal in ohms to the nominal phase-to-earth voltage in volts divided by 31.75 (200 Ohms in a 12kV network).

The first real-world staged fault test on one of PG&E’s distribution circuits met the performance benchmark (Figure 6). The fault resistance was 3200 ohms and the faulted circuit was correctly identified.



**Figure 6 3200 Ohm fault current (top) and bus voltage (bottom)**

Ferro-resonance issues resulted in the failure of a voltage regulator internal potential transformer (PT) and contributed to the failure of a grounding transformer used in the GFN. The equipment failures caused the integration of the GFN into daily operations to be unsuccessful as of July 2021. PG&E is continuing the demonstration and testing of this technology.

**End of text**

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