Distributed Energy Resource Ground Fault Overvoltage Impacts to Rural Sub-Transmission Systems

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RLC ENGINEERING

BACKGROUND

Interconnections of Distributed Energy Resources (**DER**) have increased to a point where power may flow upstream through utility distribution substation transformers into the regional power grid. Many utilities rely on a lower voltage transmission system, a.k.a. sub-transmission system, to interconnect and distribute power to customers throughout rural areas of their service territory. Many of the DERs are located in these rural areas and are attempting to interconnect to the sub-transmission connected substations. Why is this a concern? Before answering, here's some background:

- First, DERs are small generators (compared to 'conventional' power plants), typically less than 5,000 kW, such as solar photovoltaic arrays (whether small rooftop or larger fields with rows of solar panels), or battery storage systems, connected to the roadside utility distribution system traditionally used to serve homes and businesses.
- Second, for over 100 years, utility roadside **distribution systems** have been designed to carry electrical energy downstream to homes and businesses from large power plants connected to the high-voltage power grid. The power was typically delivered along medium and low-voltage distribution lines to individual service connections at each customer's meter. Unlike the high-voltage power grid, the distribution system was designed for downstream power flow – **from** the high-voltage power grid through distribution substation transformers along the streets and on **to** individual customers.
- Third, without DER, distribution systems are guaranteed to collapse following a power outage because the utility source is removed. With DER and specifically when the generation exceeds the load, the distribution system is **not** guaranteed to collapse immediately because the DER is supporting the load even though the utility source has been removed.

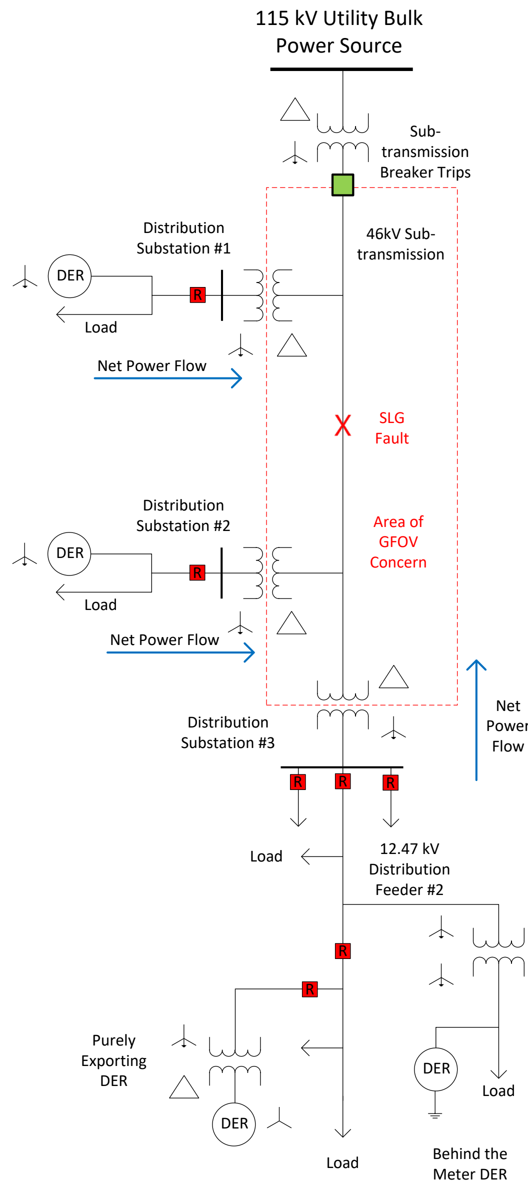
THE CONCERN:

All electrical systems are exposed to power outages caused by many different reasons. Some causes of power outages are contact between bare wires and adjacent trees and limbs, or failure of electrical equipment (i.e. poles, cross-arms, or insulators) on the power delivery system, and sub-transmission or distribution lines. These power outages may cause large current flow into the earth, also known as a Single Line-to-Ground (**SLG**) short-circuit events, or "**faults**". Fuses or circuit breakers, much like those in our home electrical panel, quickly interrupt the fault current by opening the utility source to disconnect the power from feeding the fault current.

When a SLG fault occurs on the grid supply of the rural sub-transmission system, the voltage may rise to damaging levels. This situation is known as Ground Fault Over-Voltage (**GFOV**), and can cause serious damage to customer and electric utility equipment if not addressed by various grounding methods. As mentioned previously, when significant DER additions exceed the load demand of customers, the distribution system may not collapse and instead may remain energized by the connected DER, which can prolong the exposure of customers' and the utility's equipment to high GFOV.

IEEE, the "Institute of Electrical and Electronics Engineers, Inc.", develops international standards for electrical equipment and processes ranging from electric power to transportation to space to communications and computing. IEEE Standard 1547-2018 was recently adopted to address potential adverse impacts of DER on utility distribution systems. This international Standard states:

> *"The DER shall not cause the fundamental frequency line-to-ground voltage on any portion of the Area EPS [Electric Power System] that is designed to operate effectively grounded, as defined by IEEE Std C62.92.1, to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period."*



This means that voltages above 138% of their normal rating are not acceptable, even for a fraction (one-sixtieth) of a second. Either fast-acting overvoltage protection or grounding system changes are needed to solve this problem.

The most severe case of maximum GFOV occurs when a portion of the rural sub-transmission system is separated from the power grid as shown in the red dashed line in the adjacent diagram. In this islanded mode, the presence of DER may result in sustain and potentially damaging GFOV on the rural sub-transmission system until the distribution feeders are tripped. Substations that are equipped with 3V0 sensing can trip feeders by detecting unbalanced voltages during the SLG fault.

EVALUATING THE RISK OF GFOV

Utilities must determine if there is a risk of damaging their own or their customers' equipment, and if there is an issue, they must solve it. The risk of GFOV is significantly higher in rural sub-transmission systems, because rural systems tend to have more radial lines supplying distribution substations. Those distribution substations tend to have transformers which can affect grounding in a way that increases the potential for GFOV issues. Evaluating this risk can be performed in steps, ranging from quick and simple techniques to more complex and time-consuming analyses. In this order, the steps are:

1. One of the simplest and quickest methods of evaluating GFOV is to screen for reverse power flow at the distribution substation transformer. The following formula is evaluated such that:

   [Minimum **Load**] – [Connected **DER capacity**] =
   [lowest net Load if **positive**, or possible reverse flow if **negative**]

   The maximum output of all DER is subtracted from the minimum load served by the distribution substation transformer. A negative value represents the capability for reverse power flow through that transformer, and the possibility of dangerous over-voltages. However, screens such as this only indicate a possible GFOV concern and, without further analysis, may lead to unnecessary and costly upgrades.
2. If the Step 1 screen fails (a negative number above), then studying the effect of GFOV takes more effort as the local distribution system must be modeled. The next step is to use the well-established Coefficient of Grounding (COG) analysis, detailed in another IEEE standard, C62.92.1-2000. With this simplified method, all the DERs are modeled as classical rotating generators, and a SLG fault is then tested. This screening method also provides a conservative estimate on whether GFOV may be a concern.
3. If the Step 2 analysis fails (showing a high GFOV above 138% with the COG method), then the DER interconnections that are Inverter Based Resources (**IBR**) must be modeled and simulated more accurately. An IBR responds to a fault in a unique manner based on its programing, and its physics are fundamentally described as a "Voltage Controlled Current Source", which is different than a classical rotating generator. With this added detail, this analysis method tends to demonstrate harmful GFOV less often.
4. Lastly, the most accurate method of analyzing potential GFOV is a time-domain analysis, i.e. PSCAD studies (simulating the SLG fault, the unique IBR responses, and operation of the interrupting circuit breakers over time). This method requires modeling the local distribution system and the connected grid, including actual manufacturer IBR PSCAD models and DER protection and control schemes, and region operator ride-through set-points and parameters. This is the most complex and accurate of all methods to simulate and evaluate the true impact of DER on GFOV.

SOLVING GFOV ISSUES, IF A PROBLEM IS FOUND

The most-effective mitigation of GFOV is adequate grounding provided through an alternate means such as a special transformer or transformer connections. These automatically limit GFOV instantaneously during the SLG without additional intervention or protection schemes.

A 3V0 relay sensing scheme, as discussed previously, is the next most common mitigation when GFOV is unacceptable. Depending on the substation, this method can be costly as a relay and voltage transformers need to be added to the distribution substation high-voltage bus where space is often a challenge.

Protection and communication schemes may be added to the sub-transmission system ensuring that both local and remote circuit breakers trip at the same time (if there is a local distribution substation breaker).

CONCLUSION

GFOV must be considered based on international standards, and is a common concern as more DER is added to the distribution system that is served by the rural sub-transmission system. Comprehensive evaluation of potential GFOV up front, starting with simple screening methods, but followed by more accurate and complex modeling if necessary, can potentially avoid costly infrastructure upgrades.

REFERENCES

[1] IEEE Standard 1547-2018 “IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces”, 15 February 2018

[2] IEEE Standard C62.92.1-2000“IEEE Guide for Application of Neutral Grounding in Electrical Utility Systems, Part I—Introduction”, 21 September 2000

[3] IEEE Standard C62.92.6-2017 “IEEE Guide for Application of Neutral Grounding in Electrical Utility Systems, Part VI—Systems Supplied by Current-Regulated Sources”, 23 September 2017

[4] Electric Power Research Institute (EPRI) Presentation, “Seminar on Neutral-Grounding of Inverter-Connected DER”, 10 December 2020, Presented to the NY Interconnection Technical Working Group (ITWG)

BIOGRAPHIES

Jonathan Gay, P.E. is a Principal Power System Engineer at RLC Engineering. He has an AS in Electrical & Mechanical Technology from the Community College of the Air Force and a BS in Electrical Engineering Technology at the University of Maine. Jon has over 14 years of experience in the electrical industry and holds a Master Electrician license in the State of Maine. Over the past six years he has directed over 300 DER Impact Studies with multiple utilities in the Northeastern US and continues to participate in IEEE 1547 related working groups.

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