Some Basics of System Grounding

Part II – Distribution Grounding

The previous article discussed some of the basics of grounding in substations and transmission systems. This article will conclude with an examination of similar considerations as they apply to distribution grounding.

The purpose of grounding in ac distribution systems is much the same as for substations (refer to previous article), with safety of persons being the highest priority. The distribution system, of course, brings electric service to the end users and hence presents a protection challenge encompassing the general public and accordingly different from that of utility workers in substations. The challenge includes:

- Stabilization of service potentials to ground against overpotentials.
- Safety from electrical fires.
- Safe grounding of fixtures and exposed noncurrent-carrying elements of electrical systems.

Distribution primary circuits are grounded to avoid overstressing insulation and to provide a path for ground fault clearance in order to insure prompt disconnection. The lower voltages of distribution systems mean that insulation is inherently less robust in comparison to the electrical system upstream, and lightning protection is appreciably different than that for transmission lines. The principle goal is to prevent insulation failure in transformers and other valuable equipment. Beyond that, a certain amount of line tripouts from lightning and high magnitude surges is accepted and dealt with by other means than those described previously. These measures include automatic reclosers, circuit duplication, and similar adaptations intended to minimize the effects of tripouts rather than totally preventing them.

Early practice was to ground each function separately, and, unfortunately, some of that thinking can still be found. But accepted practice now is to parallel all grounds together. This serves the dual purpose of achieving the lowest ground resistance and equalizing potentials between various grounded circuits for added safety. Secondary-circuit neutrals are typically grounded at transformers and service entrances, interconnected through the neutral. Supplementary grounds may exist, forming a multigrounded secondary neutral.

Multigrounded primary neutrals are found on 2400 to 4160 four-wire, grounded-neutral systems. Multigrounded common primary and secondary neutrals have the advantage of requiring only one neutral wire. As the electrical system developed, heightened load densities and greater distribution distances through expansion into rural areas resulted in higher distribution primary voltages (e.g., 11 and 13 kV four-wire grounded neutral). Again, the common primary and secondary multigrounded neutral scheme has been successfully applied.

In urban areas, interconnection of multigrounded systems may involve hundreds of thousands of individual grounds. But in rural areas, grounds are less dense and spaced more widely. The absence of a concentrated water pipe system to use as a supplementary ground and the reduced frequency of secondary mains where many customers are served by individual transformers makes the establishment of an effective ground more challenging in these areas. At one time, there was some fear that primary and secondary systems should not be interconnected
except in situations that provided the lowest possible resistance; that is to say, urban areas with their high concentration of grounds. It was realized, however, that occasional problems could not be completely extinguished; therefore, the more effective the grounding system, the greater the safety. Such occurrences as breakdown between primary and secondary winding of transformers, bushing flashovers, and accidental crosses of primary and secondary conductors were recognized as not totally preventable.

Pole-butt grounds can be an effective supplement to driven rods in such systems. A spiral of wire around the butt with perhaps a metal pancake can serve as an effective enhancement. More of them must be installed than driven rods, but their lower cost can be a sufficient offset. Extremes of poor grounding soil, however, can render them less effective than deep-driven rods.

Current-carrying neutrals can be rendered more efficient by a multigrounded system. Impedance can be reduced and improved voltage regulation achieved. As an example, an overhead neutral grounded at regular intervals with approximately the same ground resistance will have current from the source flowing entirely in the neutral only as far as the first ground. There it will divide by parallel resistance. This process will repeat at each ground until, if the line is long enough, a stable condition will be reached between current flowing in the neutral and in the grounding system.

Electromagnetic effects determine a level of stability. At the load end, this process is repeated in reverse. Plotting current against distance along the neutral conductor would produce a hyperbola at each end. The total effective impedance, then, is comprised of two elements: this hyperbolic decay and a uniform point-to-point current that corresponds to the division of current at the point of stabilization.

A further example of how the pooling of grounding facilities enhances effectiveness can be illustrated by lightning protection devices on the primary side of distribution transformers. If the grounding conductor of the lightning protection device is connected to the secondary neutral or a common primary-secondary neutral, the quality of protection is greatly increased. In this scheme, the protective device thereby bridges the insulation intended to be protected, which is the insulation of the transformer windings. Additionally, the lightning arrester ground has now been paralleled in with the common grounding system. In an alternative scheme, spill gaps can be used in place of direct connection. The figures illustrate several schematics. Figure 1 shows the lightning arrester grounded solidly to the transformer tank and common ground; Figure 2 shows the tank offset by a spark gap with primary and secondary grounded solidly to the protective ground; and finally, Figure 3 shows the protective ground completely offset by spark gaps.
It can be seen, then, that distribution systems are grounded at transformers and sometimes other pieces of equipment, at poles with and without transformers, and at service entrances. The electrodes can be the water-pipe system, driven rods, and pole-butt grounds. The effective principle is to employ as many grounds as possible while insuring that all are interconnected in parallel. An effective system limits overpotentials, prevents potential differences between pieces of equipment or surfaces where a person might bridge the gap, and includes conductors adequate to carry all ground currents without excessive heating or burning open.

Summarizing the three principle sections of a grounded system from substation through transmission to distribution:

The substation ground must facilitate operation of fault clearance and protect utility workers as well as the general public who may be passing by in proximity. Grounding is extremely complex, with all equipment and metallic elements tied together in a Faraday cage. There is a considerable below-grade structure that may consist of different elements such as meshes, grids, and rods, all tightly and thoroughly bonded. Adequate step and touch potentials must be defined and maintained.

Transmission lines are grounded primarily for lightning protection. Flashovers and their resultant tripouts are to be prevented, and formulae exist whereby cost can be balanced against necessity to effectively limit such occurrences. Grounding takes some specialized forms with tower legs and the extensive use of counterpoise.

Finally, distribution grounding requires the same attention to fault clearance and safety as does substation grounding, with the safety aspect more diverse in that it must address the infinite variety of equipment being powered at the user end as well as operation by personnel lacking the expertise of utility workers in substations. Lightning protection is essential here too, but is focused more on the protection of valuable equipment than the prevention of occasional tripouts.

Ground testing, which is especially challenging for transmission lines, will be examined in the next edition.

Source of information: W. R. Bullard, System Grounding, AIEE (now IEEE).

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