IDENTIFYING DISTRIBUTION PROTECTION SYSTEM VULNERABILITIES PROMPTED BY THE ADDITION OF DISTRIBUTED GENERATION

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Introduction

The reliability of a power system is closely dependent on the performance of its protection system. For distribution systems overcurrent is the most economical, reliable and dependable protection scheme, thus it is the most widely used. The addition of distributed generation (DG) to the power distribution system imposes a challenging and unconsidered fault condition to the traditional distribution overcurrent protection scheme. DG short-circuit contribution may cause erroneous operation of protective devices located downstream to the fault. These distribution protection system vulnerabilities prompted by DG have been extensibility studied but no methodology to spot them through the distribution system has been proposed.

This paper proposes an innovative tool to asses the impact of distributed generation (DG) on protective device coordination in distribution power system. The assessment is focused on the identification of vulnerabilities of the distribution protection system prompted by the addition of distributed generation. The fundamental principle of the vulnerability assessment is the comparison of maximum and minimum short circuit levels before and after the distributed generation is added.

Radial feeder short circuit calculation

For radial feeders the symmetrical short circuit current is calculated as the ration between voltage and the total impedance from the source to the fault location. This methodology implies that the short circuit current decreases as the fault location moves away from the source. Additionally in a pure radial system, without Distributed Generation (DG) connected down stream to the fault, there is no contribution to the fault other than the one coming from the source. Under these premises the coordination of protective devices is necessary only for upstream protective devices neglecting any other down stream devices. Figure 1 shows the short circuit calculation and current contribution for a pure radial system.

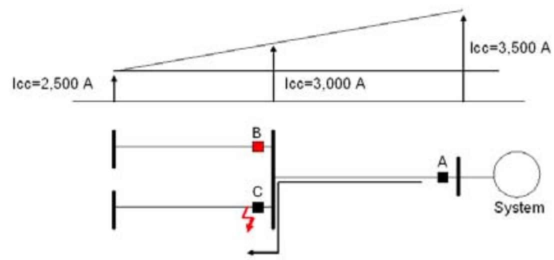

Figure 1: Radial system short circuit current

When DG is connected to the system a secondary short circuit current contribution coming from the DG to the fault takes place. This contribution is similarly calculated as the ratio between the voltage and the total impedance from the DG to the fault. This short circuit current contribution coming from the DG adds to the main source contribution current at the fault location increasing the total short circuit level of the fault. Figure 2 shows the short circuit current contributions for a radial feeder with DG.

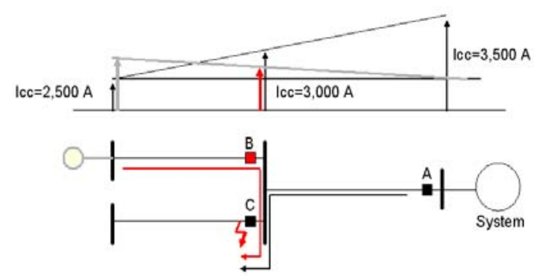

Figure 2: Radial system short circuit current with DG

For the case of several DG units connected at different spots of the distribution feeder the total DG short circuit contribution is calculated by superposition. The individual contribution of every DG is given by the ratio between the voltage and the total impedance to the fault location. The total DG contribution is the sum of all individual contributions. This same methodology is valid to calculate the magnitude of the short circuit currents that flow through every branch of the distribution system. Figure 3 shows the short circuit calculation with multiple DG and the short circuit contribution flowing through every branch of the system.

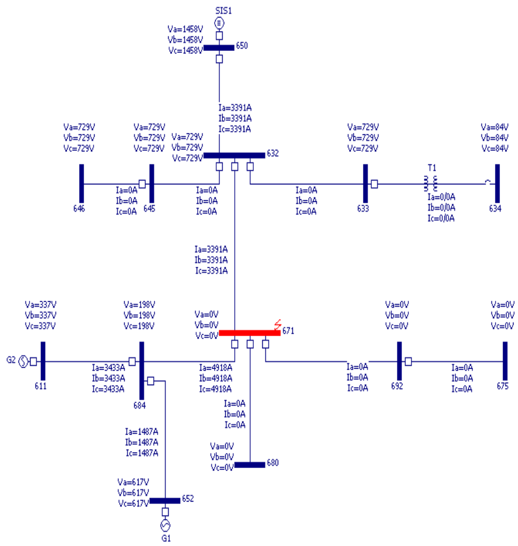

Figure 3: Short circuit current contributions with multiple DG

Protective device coordination

The protective device coordination for radial distribution feeders is done based on the decreasing patter shown by the short circuit current with respect to the fault location. The coverage of the area of protection for every device is defined using the maximum short circuit current possible at the closest downstream bus (lower limit of the protection area). Setting the pick up setting of the protective device at the maximum short circuit current at the location of the closest downstream device assures it will not operate for fault taking place out of the protected feeder. Any fault located out of the protected area has a short circuit current level below the pickup setting blocking the operation of the protective device. Figure 4 shows that setting the pick up setting of the protective devices A and B at 3 and 2.5 kA guaranties a coordinated operation of the protection system upon any fault location.

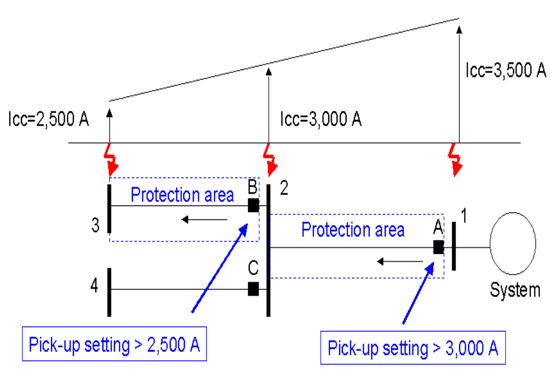

Figure 4: Protective device coordination in radial feeders

The above described protective device coordination methodology is conceptually correct; however, in the field the protection engineer should consider other factors such as accuracy in the estimation of the feeder impedance, measurement errors, pick up setting precision and operating voltage. All these issues, if not considered, introduce errors that may jeopardize the coordinated operation of the protective devices. In order to avoid miss-coordination in the operation of protective devices security factor must be included in the protective device coordination assessment. The pick up setting is usually set at 90-80% of desired value.

Another important feature of the radial feeder protection system is that the over-current relays are not directional. Since the short circuit current always flows from the source to the fault location, there is not need to discriminate based on the direction of the current flow. The protective devices only sense the current magnitude and operate if the threshold is exceeded. This particular condition of the radial feeder protection system introduces a strong limitation for the interconnection of distributed generation. As it was explained in the previous section DG may introduce a short circuit current contribution in a direction which is opposite to the one coming from the source. This DG contribution may prompt the uncoordinated operation of devices located downstream to the fault location unveiling a potential vulnerability of the protection system.

Vulnerabilities identification

The identification of vulnerabilities of the protection system prompted by the interconnection of DG to the distribution feeder is proposed to be done by comparing the total DG short circuit contribution passing through a specific protection device with its pick up setting. Figure 5 shows the effect of DG in the coordination of protection devices. In the cases where the DG short circuit contribution for faults at bus 2 is greater than the pick up setting of the protective device B there will be a miss-operation of unit B and its connected load will unnecessarily be disconnected.

The describe vulnerabilities identification methodology may be easily applied to small distribution networks such the one shown in Figure 5. However, for large network a recursive methodology is proposed. For every bus the aggregated DG short circuit contribution is calculated and compared to the pick up setting of the device inconsideration. The algorithm then moves to the next bus and repeats the vulnerabilities identification procedure. This recursive methodology is repeated for every feeder of the distribution system. For every step the system calculated the aggregated DG contribution using the superposition methodology previously described. Figure 6 schematized this recursive methodology.

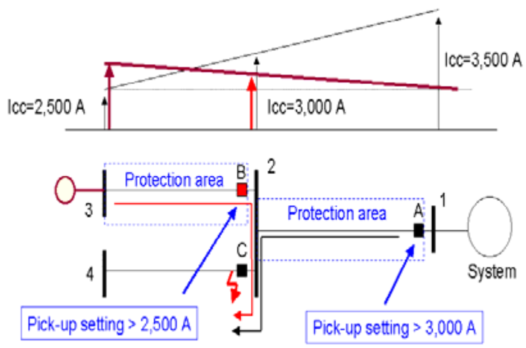

Figure 5: Effect of DG in the coordination of protective devices.

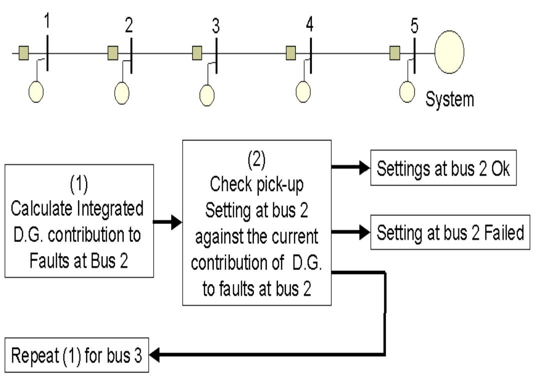

Figure 6: Recursive methodology for the identification of DG prompted vulnerabilities of the protection system.

The general output of the assessment is the identification of vulnerabilities in the protection system for particular topology of the network and penetration of DG. Additionally the assessment could be used to identify maximum levels of DG penetration at certain buses of the system without modifying the protection system. This features make the DG prompted vulnerability assessment a very useful tool for operation and planning of the distribution network.

Conclusions

The addition of distributed generation (DG) to the power distribution system imposes a challenging and unconsidered fault condition to the traditional distribution overcurrent protection scheme. DG short-circuit contribution may cause erroneous operation of protective devices located downstream to the fault. The fundamental principle of the vulnerability assessment is the comparison of maximum and minimum short circuit levels before and after the distributed generation is added. Those protective devices installed at buses where the DG short-circuit contribution exceed the pre-DG minimum short circuit level are the most likely to miss-operate under fault conditions.

This vulnerability assessment can also be used as a planning tool to identify the maximum allowable DG penetration without modifying the distribution protection system. On the other hand, if DG is to be installed, the technique discussed in this paper provides a method to identify the protective devices, already installed in the network, that require modification in settings or protective characteristics. Today's relays and other Intelligent Electronic Devices (IEDs) have the possibility to store and use several families of settings which may be selected dependant upon operating conditions or topologies. These devices may prove very valuable on the protection of feeders where DG is used.

References

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