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Effect of Renewable Distributed Generators on the Fault Current Level of the Power Distribution Systems

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Abstract. The presence of renewable distributed generator (RDG) in a distribution system will have unfavorable impact on the operating system because the distribution system is no longer radial in nature and is not supplied by a single main power source. With RDGs in a distribution network, it brings about a change in the fault current level of the system and causes many problems in the protection system, such as false tripping of protective devices, protection blinding, an increase and decrease in short-circuit levels. This paper presents the effect of RDGs on the fault current level of the system. The operating protection issues particularly in cases where RDGs are added to a LV distribution feeder are also discussed.

Introduction

Typically, distribution systems are with radial configuration and have only one source from the main grid. In recent years, the installation renewable distributed generator (RDG) has increased significantly in the power distribution systems due to economic and technical benefits associated with RDGs such as higher efficiency, reduced system losses and enhanced system reliability [1]. The rating of the RDGs can vary between few *kw* to as high as 100 *mw*. Various new types of RDGs are such as solar and wind power systems [2]. Furthermore, biomass is another renewable energy source using biological materials from living organisms such as wood, waste and alcohol fuels. These new types of RDGs create new opportunities for the integration of diverse RDG unit to the utility. The interconnection of RDGs will offer a number of benefits for distribution networks such as reduction in distribution losses, deferral of distribution network reinforcement, emergency backup during sustained utility outages, voltage support, improvement of system security, reduced voltage sags, improved reliability, power quality, efficiency, alleviation of system constraints along with the environmental benefits [3]. However, The presence of RDGs in a distribution network will have unfavourable impact on the conventional protection schmes because the distribution system is no longer radial in nature and is not supplied by a single main power source [4]. With RDGs in a distribution network, it brings about a change in the fault current level of the system and causes many problems in the protection system, such as false tripping of protective devices, protection blinding, an increase and decrease in short-circuit levels, undesirable network islanding and out-of-synchronism reclosers [5, 6]. This paper presents the effect of RDGs on the fault current level of the system. The operating protection issues particularly in cases where RDGs are added to a *lv* distribution feeder are also discussed.

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Effect of Renewable Distributed Generators on Fault Current

To demonstrate the effect of a RDG unit on the fault current in a feeder, a generic feeder is given as a reference as shown in Figure 1. At distance, *d,* a RDG-unit is connected and at the end of the feeder, a three-phase fault is simulated. Therefore, a distance parameter to indicate the location of the RDG, which is relative to the total feeder length, is defined as:

$$l = \frac{d}{d_{tot}} \tag{1}$$

Where d is the distance to the RDG unit and d_{tot} is the total feeder length.

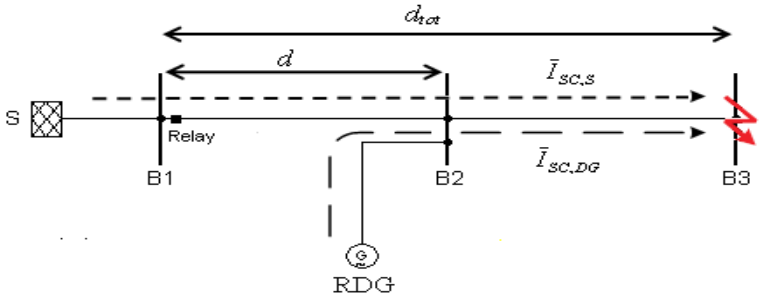

Fig. 1, Short-circuit current contribution of both main source and RDG unit

An electric equivalent of the feeder shown in Figure 1 is given in Figure 2. In this figure, $\bar{Z}_L$ is the total line-impedance, $\bar{Z}_{RDG}$ is the RDG impedance and $\bar{Z}_S$ is the source impedance. The voltages of the main source and RDG unit are denoted as $\bar{U}_S$ and $\bar{U}_{RDG}$, respectively.

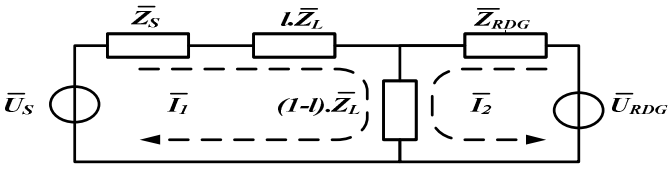

Fig. 2, Network equivalent circuit of Figure 1

Defining the mesh currents $\bar{I}_1$ and $\bar{I}_2$ and applying the Kirchhoff's voltage law for $\bar{U}_S$ and $\bar{U}_{RDG}$, we get,

$$\begin{bmatrix} \bar{U}_S \\ \bar{U}_{RDG} \end{bmatrix} = \begin{bmatrix} \bar{Z}_S + \bar{Z}_L & (1-l).\bar{Z}_L \\ (1-l).\bar{Z}_L & \bar{Z}_{RDG} + (1-l).\bar{Z}_L \end{bmatrix} \cdot \begin{bmatrix} \bar{I}_1 \\ \bar{I}_2 \end{bmatrix} \tag{2}$$

Where $\bar{I}_1$ is the grid contribution of the short circuit current, $\bar{I}_{SC,S}$, and $\bar{I}_2$ is the RDG-contribution of the short circuit current, $\bar{I}_{SC,RDG}$, to the total short circuit current.

To determine expressions for $\bar{I}_{SC,S}$ and $\bar{I}_{SC,RDG}$, the Thevenin equivalent circuit of the above network is derived as shown in Figure 3.

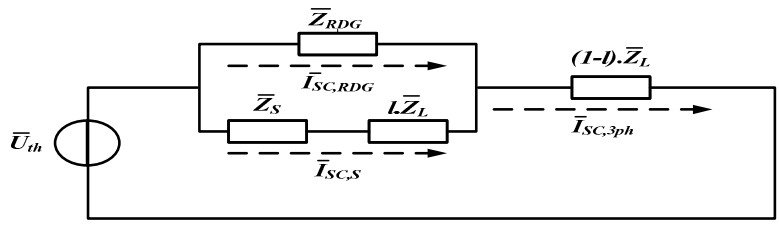

Fig. 3, Thevenin equivalent circuit

From this figure, the Thevenin impedance is derived and given as,

$$\overline{Z}_{th} = \frac{(\overline{Z}_S + l.\overline{Z}_L).\overline{Z}_{RDG}}{\overline{Z}_S + l.\overline{Z}_L + \overline{Z}_{RDG}} + (1 - l).\overline{Z}_L \tag{3}$$

Where, $\overline{Z}_S = R_S + jX_S$ is the grid impedance, $\overline{Z}_{RDG} = R_{DG} + jX_{RDG}$ is the generator impedance and $\overline{Z}_L = R_L + jX_L$ is the total line impedance. l is the relative generator location as defined in Eq. 1. It should be noted that R_S and R_{RDG} are too small and negligible.

The total three-phase short-circuit current can be calculated by:

$$\overline{I}_{SC,3ph} = \frac{\overline{U}_{th}}{\overline{Z}_{th}} \tag{4}$$

Substituting Eq. 3 into Eq. 4 yields:

$$\overline{I}_{SC,3ph} = \frac{\overline{U}_{th}.(\overline{Z}_{RDG} + l.\overline{Z}_L + \overline{Z}_S)}{\left[(\overline{Z}_L.\overline{Z}_{RDG} + \overline{Z}_S.\overline{Z}_{RDG} + \overline{Z}_S.\overline{Z}_L) + l.\overline{Z}_L(\overline{Z}_L - \overline{Z}_S) - l^2\overline{Z}_L^2\right]} \tag{5}$$

For the RDG unit contribution holds:

$$\overline{I}_{SC,RDG} = \frac{\overline{Z}_{RDG}}{(\overline{Z}_{RDG} + l.\overline{Z}_L + \overline{Z}_S)} \times \overline{I}_{SC,3ph} \tag{6}$$

Substituting Eq. 5 into Eq. 6 gives the RDG contribution of the short circuit current,

$$\overline{I}_{SC,RDG} = \frac{\overline{U}_{th}.\overline{Z}_{RDG}}{\left[(\overline{Z}_L.\overline{Z}_{RDG} + \overline{Z}_S.\overline{Z}_{RDG} + \overline{Z}_S.\overline{Z}_L) + l.\overline{Z}_L(\overline{Z}_L - \overline{Z}_S) - l^2\overline{Z}_L^2\right]} \tag{7}$$

The total short-circuit current, $\overline{I}_{SC,3ph}$, which is given by Eq. 5 is a non-linear current. $\overline{I}_{SC,RDG}$ is also non-linear as given by Eq. 7. In case of a weak grid, $\overline{Z}_S$ can be as large as $\overline{Z}_{RDG}$ and due to the contribution of the generator, the DG unit contribution to the short-circuit current decreases [7].

Operating Protection Issues in the Presence of RDGs

Conflicts between RDG and protection schemes are typically due to unforeseen increases in short-circuit currents, lack of coordination in the protection system, ineffectiveness of line reclosing after a fault, undesired islanding and untimely tripping of generator interface protection. Conflicts between RDG and protection schemes have been discussed in the literature, but effective and practical methods to solve protection malfunction due to the presence of RDGs must be further investigated. Some practical cases related to these issues in a typical distribution network will be discussed in the following sections.

Increase in short-circuit currents. The fault contribution from a single small RDG unit is not large, but the aggregated contributions from many small RDG units, or a few large units, can significantly increase the short-circuit levels and cause fuse-relay or fuse-fuse miscoordination, which could affect the reliability and safety of distribution systems [8]. The incorporation of RDGs may result in the mal-operation of existing distribution networks by providing the flow of fault currents, which are not expected when protection systems are originally designed. Generally, an increase in fault current largely depends on a number of factors, such as capacity, penetration, technology, interface and the connection point of a RDG, in addition to other parameters such as system voltage prior to the fault [9].

Reverse Power Flow. Radial distribution networks are usually designed for unidirectional power flow, forming the in-feed downstream to the loads. This assumption is reflected in standard protection schemes with directional overcurrent relays. With a RDG in the distribution feeder, the

power flow situation may change. If the local production exceeds the local consumption, the power flow will change direction. Reverse power flow is problematic if it is not considered in the protection system design [10].

Overcurrent Protection. Overcurrent protection schemes for radial distribution systems are designed based on the available short-circuit ratios, maximum load currents, system voltage and insulation levels. The addition of generation on the feeder results in altered current flows in various parts of the feeder for faults at different points on the feeder. The primary concerns for RDG interconnection are typically sympathetic tripping issues, failure of fuse-saving schemes, and the reduction of station breaker reach, potentially resulting in undetected faults. These issues are briefly addressed separately in the next section.

Sympathetic tripping. Sympathetic tripping is a concern due to the connection of RDGs, which alters the flow of fault currents. This tripping occurs when a protective device operates unnecessarily for faults in other protection zones. Such tripping could be caused by the additional fault currents contributed by the RDGs that were are included in the original feeder protection design calculations for typical radial systems [11].

Fuse-Saving Disruption. Many distribution companies employ fuse-saving schemes for their line reclosers that are installed at urban/rural boundaries. Fuse saving is the practice of coordinating the feeder breaker or recloser to operate quickly relative to the lateral fuses. It can be accomplished by setting the first one or two recloser operations on "fast" curves, followed by two or three "delayed" operations. The fast operations are designed to beat the fuse melting time so that temporary faults caused by lightning, conductor slaps, or tree branches can be cleared without blowing a fuse. The presence of RDGs downstream from the fuse will obviously contribute to fault current during breaker or recloser operation; hence, fuse-saving may not be possible [11].

Reduction of station breaker reach. Another potential overcurrent protection disruption is the de-sensitization of the feeder overcurrent protection, also referred to as the reduction of reach of feeder protective devices. “Reach” refers to the distance downstream of the protective device at which the device can detect a fault. Without a RDG, only the utility source feeds a fault, and the currents flowing into the fault in a radial circuit are easily calculated. Utility protection engineers typically coordinate protective devices by setting the pickup current such that the device will operate for the selected smallest minimum fault current expected, which correlates to the highest impedance fault to be detected. The sensitivity of the feeder protection is reduced by inclusion of a RDG between the protective device and the fault, as shown in Figure 4, because the RDG unit will hold up the voltage profile across the up-line portion of the feeder. The presence of RDG reduces the current seen by the protective device and reduces its sensitivity to the fault such that the fault must be closer to the protective device to be detectable. Another way of visualizing this situation is to picture the fault farther away as a result of the RDG [12].

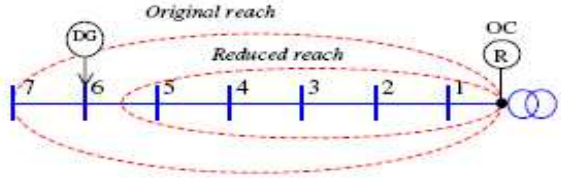

Fig. 4, Overcurrent relay reach with and without RDG.

Temporary faults. In radial systems, fault clearing requires the opening of only one device because there is only one source contributing to the fault current. In contrast, meshed transmission systems require breakers at both ends of a faulted line to open. Obviously, when a RDG is present, there are multiple power sources and opening only the utility breaker does not guarantee that the fault will clear quickly. Therefore, a RDG is required to disconnect from the system when a fault is suspected and before the fast reclosing time has elapsed so that the system reverts to a true radial system, and the normal fault clearing process may proceed. In actuality, there is the possibility that a RDG will disconnect either too quickly or too slowly, producing a detrimental impact on the distribution system, which creates numerous potential operating conflicts with respect to overcurrent protection and voltage restrictions. In this view, renewable distributed generators seem

to be rather incompatible, especially with fast reclosing during temporary faults. This procedure may not allow the RDG units to have enough time to be disconnected from the network. In this case, RDG units may sustain the voltage and fault arc, preventing successful reclosing in case of temporary faults [12].

Conclusion

With deregulation, advancement in technologies and concern about the environmental impacts, competition is particularly fostered in the generation side thus allowing increased interconnection of generating units to the utility networks. There are many benefits to be gained from the installation of RDG, but the presence of RDG in a distribution system would lead to conflicts with the current protection procedures operated in the present networks. In this paper, the effect of RDGs on the fault current level of the system presented. Furthermore, several protection issues have been identified for situations in which RDGs are connected in a distribution system.

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