An Adaptive Protection Scheme based on Fault Location for Smart Micro-Grids

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Abstract. The traditional distribution systems are radial and have unidirectional power flow. The overcurrent protection system of these networks is negatively affected by Distributed Generation (DG) units. The time and current coordination of protection devices of these systems is the most important concern in the case of high DGs penetration. Actually, DGs connection and disconnection change the short circuit level of feeders and disturb the coordination of protection devices. So, new protection schemes should be proposed which must not to be affected by DGs and should work properly in both islanded and grid connected operation modes of the micro-grid. In this paper, an adaptive protection scheme, based on fault location, is proposed for smart micro-grids. The functionality of each protection device is adaptively selected based on detected network topology and fault type. The proposed solution is simulated in the SimPower software. The results show the efficiency of the proposed protection scheme which cannot be affected by DGs.

Keywords
Adaptive Protection, Fault Location, Sequential Components, Micro-Grid, Distributed Generation.

1. Introduction
The Distributed Generation (DG) units can be used in micro-grids, which are active distribution systems that contain distributed energy resources (DER) working under supervision of control system [1]. The protection system of traditional distribution systems is based on time and current coordination of overcurrent protection devices. This protection system contains inverse-time overcurrent protection devices including relays, reclosers and fuses. The coordination of these devices is the most important concern for active distribution systems. DGs adversely affect the operation of this protection system and cause maloperations as follows:
- Undesired DG outage [2]
- Relay overreach and underreach [3-5]
- Unwanted islanding [6]
- Miss-coordination

One of recently presented solutions for these problems is to install a Fault Current Limiter (FCL) in series with each DG [7]. In addition, as an acceptable and full flexible solution, the adaptive protection methods have introduced [8]. These methods are based on local or non-local information. The adaptive local protection system updates the settings of protection devices based on the local information, but the adaptive methods based on the non-local information gather necessary data from all regions of the smart micro-grid through communication infrastructures.

In this paper, a non-local information based adaptive protection scheme is proposed. Each relay has more than one function that adaptively selects the valid one based on reported topology of micro-grid (by the communication infrastructure) and detected fault type. In the next section, the analysis of the micro-grid for fault location functioning is presented. In section III, a distribution test system is simulated and the fault location and tripping are discussed. The efficiency of the proposed method is studied based on simulations carried out in SimPower software. Finally, the conclusion is drawn in section IV.

2. Principles of Protection Scheme
A. Principles of Adaptive Protection

The fault location is calculated using the short circuit analysis of the micro-grid in the presence of DGs in offline mode. Each relay detects the fault type by an available known method. The fault type detection is not a major problem. Also, the topology of the network and the state of circuit breakers of all feeders are sent to each relay through communication infrastructures. All the relays detect the location of the fault based on the reported topology and detected fault type. Thus all relays should select the fault locating function for the reported topology in the first step. On the other hand, for each topology, the occurred fault has variety of different types. Thus, each relay goes through a two level decision making procedure. The first level is the topology detection and the second
B. Fault Location Functions

In this section, two types of the most important faults are studied. The fault location is obtained for single phase to ground (AG) and three phase to ground (ABCG). However, the other fault types can be investigated using the same method.

First, a single phase to ground fault (AG) is discussed. Suppose that a faulted condition occurred at somewhere alongside a distribution feeder containing two DGs. The circuit of this scenario is presented in Figure 1.

The problem is to find the \( K \), i.e., the location of the fault. The currents of DGs are through the communication channel. In order to calculate the \( K \), the KVL is used as follows:

\[
K \cdot M + R_F \cdot N = Q
\]

where, the \( K \) is the fault location and \( R_F \) is the fault resistance. In addition, for \( M, N \) and \( Q \), we have:

\[
M = Z_{\text{sp}} \cdot (I_{\text{R}\cdot 21p} + I_{\text{DG1p}}) + Z_{\text{sn}} \cdot (I_{\text{R}\cdot 23n} + ...) + I_{\text{DG1n}} + \ldots + Z_{\text{sp}} \cdot (I_{\text{R}\cdot 21p} + I_{\text{DG1p}})
\]

(2)

\[
N = 3(I_{\text{R}\cdot 23l} + I_{\text{DG2l}} + I_{\text{DG2l}})
\]

(3)

\[
Q = 1\angle 0 - (Z_{\text{tep}} + Z_{\text{L12p}} + Z_{\text{L12p}} \cdot I_{\text{R}\cdot 21p})
\]

(4)

\[
Z = Z_{\text{L12}} + Z_{\text{L12}} + Z_{\text{L12}}
\]

(5)

In these equations, the equivalent impedance of lines and the utility grid are known. In addition, the currents injected by utility grid and DGs are known using communication channels. Therefore, the only unknown parameters are \( K \) and \( R_F \).

This equation has two unknowns and can be decomposed into two equations because of its complex coefficients.

Therefore, this equation results in the following equations:

\[
K \cdot \text{Real}(M) + R_F \cdot \text{Real}(N) = \text{Real}(Q)
\]

(6)

\[
K \cdot \text{Imag}(M) + R_F \cdot \text{Imag}(N) = \text{Imag}(Q)
\]

(7)

Thus, the \( K \) and \( R_F \) are obtained, as follows:

\[
K = \frac{\text{Imag}(N) \cdot \text{Real}(Q) - \text{Real}(N) \cdot \text{Imag}(Q)}{\text{Imag}(N) \cdot \text{Real}(M) - \text{Real}(N) \cdot \text{Imag}(M)}
\]

(8)

\[
R_F = \frac{\text{Imag}(Q) \cdot \text{Real}(M) - \text{Real}(Q) \cdot \text{Imag}(M)}{\text{Imag}(N) \cdot \text{Real}(M) - \text{Real}(N) \cdot \text{Imag}(M)}
\]

(9)

These parameters now are determined and can be used for control or protection applications. The combination of these two parameters can be used to compensate the underreach and overreach phenomenon due to DGs as discussed in [9]. Using these parameters, the fault location can be determined. Thus, the relay R23 presented in Figure 1, is able to detect whether the fault is in its primary zone or not.

Furthermore, a three phase to ground fault (ABCG) is investigated in the same way as the previous case. Unlike the previous scenario, the negative and zero sequence currents and impedances are not involved. The circuit of this condition is presented in Figure 2.

The same as the previous scenario, the fault location function is obtained by a KVL along the feeder. In this case, only the positive sequence components are involved. In order to summarize the procedure, only the coefficients are presented as follows:

\[
M = Z_{\text{sp}} \cdot (I_{\text{R}\cdot 21p} + I_{\text{DG1p}})
\]

(10)

\[
N = I_{\text{R}\cdot 23l} + I_{\text{DG2p}} + I_{\text{DG2p}}
\]

(11)

\[
Q = 1\angle 0 - (Z_{\text{tep}} + Z_{\text{L12p}} + Z_{\text{L12p}} \cdot I_{\text{R}\cdot 21p})
\]

(12)

The unknown parameters can be determined in the same way as the first case, e.g., \( K \) using the equation (8) and \( R_F \) by using the equation (9).

3. Simulation Studies

A. Micro-Grid Model

The model of a 20kV test micro-grid, as a test system, is presented in Figure 3. The Utility Grid (UG) is a 63 kV sub-transmission network. The UG supplies the micro-
Thus, the overcurrent protection experiences the underreach phenomenon as discussed in [9]. This phenomenon has no effect on the proposed protection scheme because the amplitude of fault currents is not a major issue in this method and has no effect on it.

The AG faulted conditioned at the middle of the Line34 is simulated and \( K \) varies as presented in Figure 5.

![Fig. 5. \( K \) for fault located at 50% of Line34. Blue for traditional network with no DG, Red for micro-grid with DG1 in service and Green for micro-grid with DG1 and DG2 in service.](https://doi.org/10.24084/repqj12.366)

The AG faulted conditioned at the middle of the Line34 is simulated and \( K \) varies as presented in Figure 5.
As shown in this figure, the parameter $K$ is around 400 to 570 percentage of the Line34. This means that in normal operation condition, before the occurrence of the fault, the fault location is seen by R34 and this relay does not trip neither in its primary nor in any of its back-up protection zones. Thus, this relay does not see any fault prior to faulted condition.

As the AG fault occurs, the adaptive algorithm detects the fault type and selects the equation (8) for fault locating. As the fault occurs, the $K$ selects large values and shows fast swings. After 0.2sec, these swings are damped and $K$ remains on 50 percentage of the Line34 length or 0.5. In this condition, R34 sees the fault location at its primary protection zone and immediately trips the relevant circuit breaker.

In addition, this scenario is tested for another fault at the middle Line45, somewhere at 150% of Line34. The fault location is obtained as the previous scenario in the back up protection zone of the R34 as presented in Figure 6.

Furthermore, the micro-grid is islanded with the all of its DGs and its voltage and frequency are controlled in an off-line method. The above-mentioned scenario of the AG faulted condition at the middle of Line45 is tested and the R34 can relatively locate the fault somewhere at the 140 to 160% of the Line34 as presented in Figure 7.

The three phase to ground faulted condition is also investigated. In this case, the same scenarios for the ABCG fault as the previous tests are considered. The same as the previous case, prior to faulted condition the $K$ causes the R34 not to trip because the fault location is around 360 to 515 percentage of the Line34 length as presented in Figure 8.

In the case of the micro-grid with DG1 in service, the fault resistance is presented in Figure 10. As shown, in the normal operation condition the fault resistance is about 50ohms. This means that the fault is so far or the load impedance has the magnitude of 50ohms. Once the fault
occurs, this parameter falls to 1ohm which is exactly the fault resistance (set in the simulation software). This parameter is an alternative of the distance protection application in micro-grids. Because the fault resistance is one of the obstacles of using the distance protection in lines with the length less than 5km.

In this case, the micro-grid is islanded with all of the DGs in service and the proposed fault location scheme is tested for the ABCG fault at the middle of Line45. The voltage and frequency of the micro-grid are controlled. Once again the R34 detects the location of the fault with some small swing around the 150% of Line34 as presented in Figure 11.

4. Conclusion

An adaptive protection scheme based on fault location detection was proposed for smart micro-grids. The topology of the micro-grid and the currents and the operation condition of DGs were communicated to relays through the communication infrastructure. The fault location functions were discussed based on short circuit analysis. The most important faults, i.e., AG and ABCG, were simulated in various conditions. The simulation results show that the proposed scheme can detect whether the fault is in its primary zone or not even in islanded condition. It was shown that DGs has minimum effect on the proposed criteria.

References


https://doi.org/10.24084/repqj12.366