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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 Comp-onents, 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 off-line 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 one is the fault type detection. The decision making procedure can be managed by look-up tables saved in relays for online responses.

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.

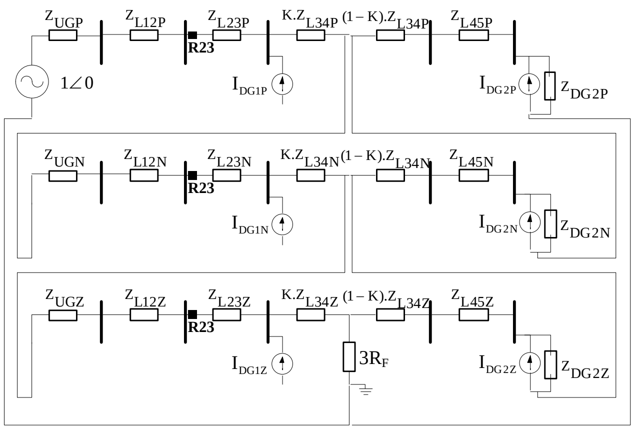

Fig. 1. Positive, negative and zero sequence circuits for AG fault.

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:

$$K.M + R_F.N = Q \tag{1}$$

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

$$M = Z_{34P}.(I_{R23P} + I_{DG1P}) + Z_{34N}.(I_{R23N} + ... \\ ... + I_{DG1N}) + Z_{34Z}.(I_{R23Z} + I_{DG1Z}) \tag{2}$$

$$N = 3(I_{R23Z} + I_{DG1Z} + I_{DG2Z}) \tag{3}$$

$$Q = 1\angle 0 - (Z_P.I_{R23P} + Z_N.I_{R23N} + Z_Z.I_{R23Z}) \tag{4}$$

$$Z = Z_{UG} + Z_{L12} + Z_{L23} \tag{5}$$

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:

$$K.Real(M) + R_F.Real(N) = Real(Q) \tag{6}$$

$$K.Imag(M) + R_F.Imag(N) = Imag(Q) \tag{7}$$

Thus, the *K* and R_F are obtained, as follows:

$$K = \frac{Im(N).Re(Q) - Re(N).Im(Q)}{Im(N).Re(M) - Re(N).Im(M)} \tag{8}$$

$$R_F = \frac{Im(Q).Re(M) - Re(Q).Im(M)}{Im(N).Re(M) - Re(N).Im(M)} \tag{9}$$

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.

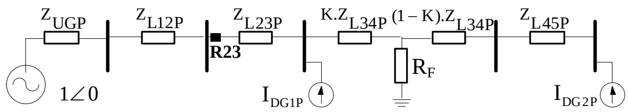

Fig. 2. Fault calculation circuit for ABCG fault.

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:

$$M = Z_{34P}(I_{R23P} + I_{DG1P}) \tag{10}$$

$$N = I_{R23P} + I_{DG1P} + I_{DG2P} \tag{11}$$

$$Q = 1\angle 0 - (Z_{UGP} + Z_{L12P} + Z_{L23P}).I_{R23P} \tag{12}$$

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-

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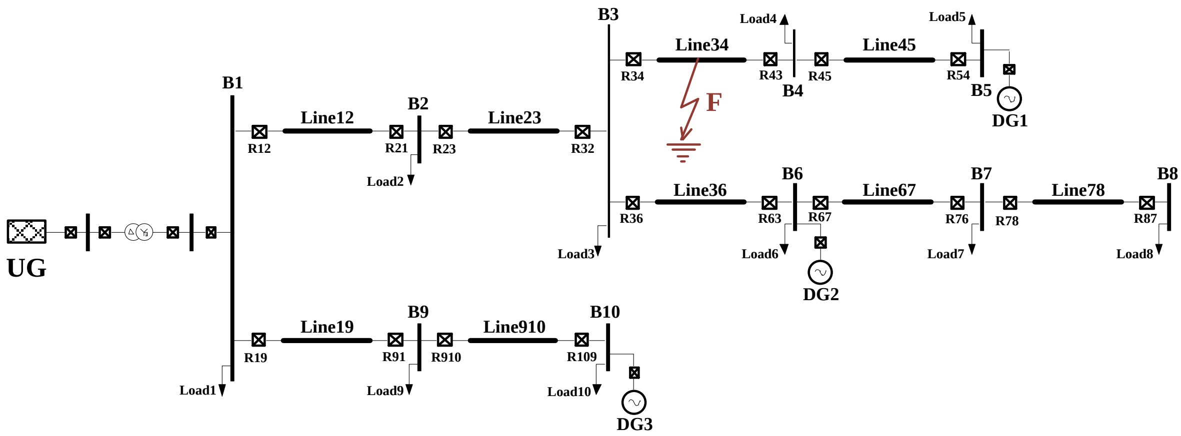

Fig. 3. Micro-Grid.

-grid through a 5%, 63/20 kV delta to grounded star transformer. The negative sequence impedance of each line section is equal to its positive one. In addition, the zero sequence impedance is approximately two times of the positive one. The total load of the MG is 31MVA.

In addition, DGs are able to supply 65% of the micro-grid total load. The short circuit capacity of each DG is three times greater than its full load condition. The micro-grid parameters are presented in Table I.

Table I - Micro-grid parameters

Micro-Grid Parameters	Value
Lines impedance per km (Positive and Negative Seq)	0.0673 + j0.045 Ohms
Lines impedance per km (Zero Sequence)	0.1346 + j0.090 Ohms
Lines length	2 km
Utility Grid Impedance	0.421 + 4.882 Ohms
Loads 2,4,5,6,7,8,9 & 10	1.424 MW + j0.623 MVAR
Loads 1 and 3	4.031 MW + j1.627 MVAR
DG1 and DG2	2.450 MVA
DG3	3.730 MVA

B. Faulted Condition Scenarios

In this section, a single phase to ground fault is simulated at the middle of the Line34 of the micro-grid presented in Figure 3. For each faulted condition, the relay R34 presented locates the fault for various conditions of the test system including traditional distribution system, which has no DG, micro-grid with only DG1 in service, micro-grid with both DG1 and DG2 in service and the islanded micro-grid with all of the DGs in service. This tries to show that the connection and disconnection of DGs that is known as uncertainty and the islanding problems can be solved in the proposed protection scheme. In addition, it can be concluded that the relay can detect faults that are not in their primary zone. Thus, the relays can back-up the forward relays after a time delay (i.e., 0.3sec). Therefore, another test for AG faulted condition has been tested.

The fault currents seen by R34 have been presented in Figure 4 for aforementioned scenarios. As shown, an increase can be detected in the currents seen by R34. 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.

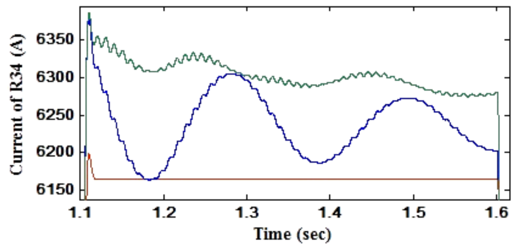

Fig. 4. Fault currents of R34. Red for traditional network without any DG, Green for micro-grid with DG2 in service, blue for micro-grid with DG1 and DG2 in service.

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

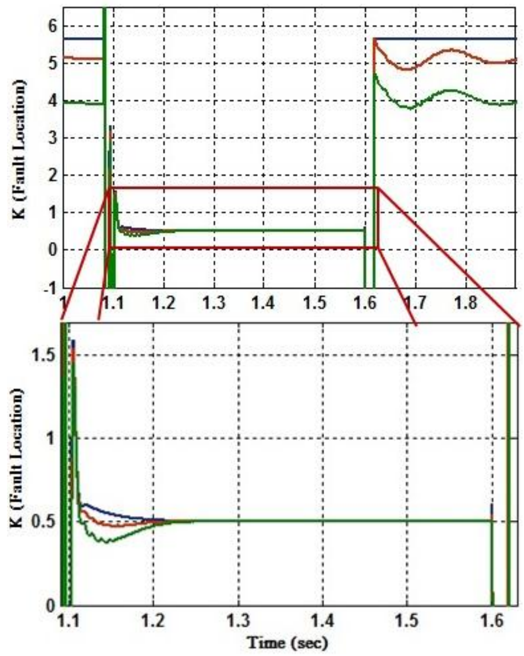

Fig. 5. *K* for fault located at 50% of Line34. Blue for traditional network with no DG, Red for micro-grid with DG1 in service and Green for micro-grid with DG1 and DG2 in service.

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.

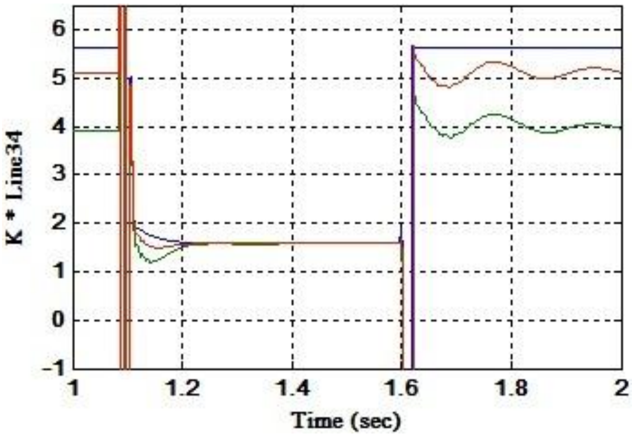

Fig. 6. K for fault located at 150% of Line34. Blue for traditional network with no DG, Red for micro-grid with DG1 in service and Green for micro-grid with DG1 and DG2 in service.

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.

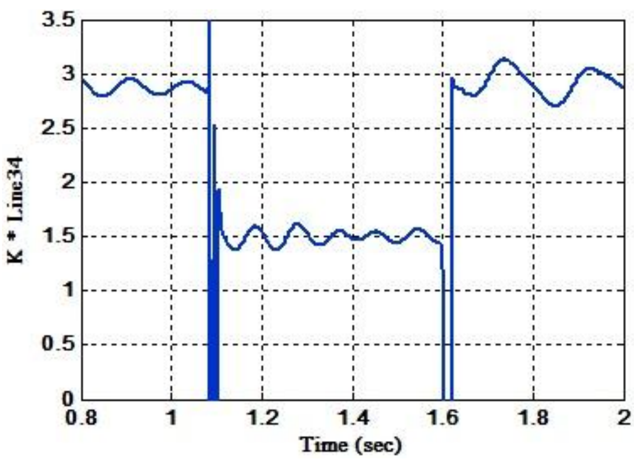

Fig. 6. *K* for fault located at 140-160% Line34.

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.

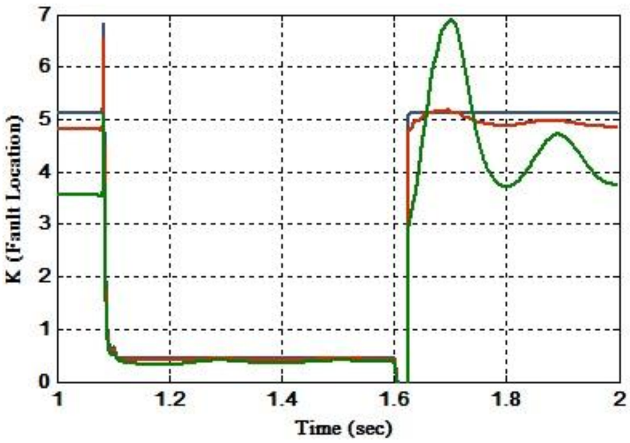

Fig. 8. *K* seen by R34 for ABCG. Blue for traditional network with no DG, Red for micro-grid with DG1 in service and Green for micro-grid with DG1 and DG2 in service.

Once the fault occurs, the *K* decreases to around 50 percentage of the Line34 length after some fast swings. This means that the fault is in primary zone of R34 and this relay should trip as soon as possible.

The backup protection operation of the R34 is also tested for the same fault at the middle of the Line45. This relay detects the exact location of the fault somewhere in 150% of Line34. Thus, the backup protection zone should wait for its downward relay, R45, to trip as soon as possible. If this fault is not cleared after 0.3 sec, then the R34 will trip the fault as the backup protection. The fault location is illustrated in Figure 9.

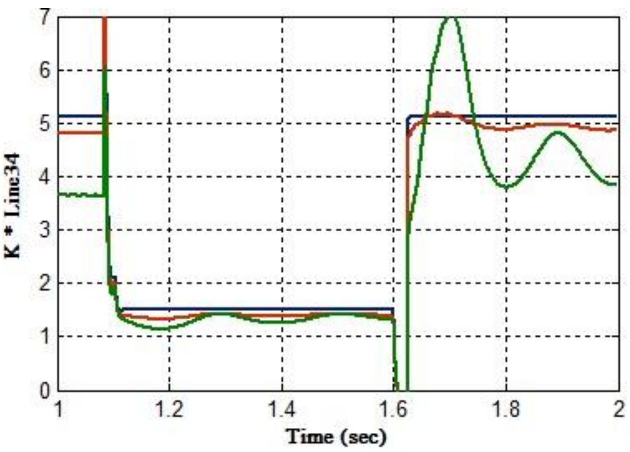

Fig. 9. *K* seen by R34 for ABCG. Blue for traditional network with no DG, Red for micro-grid with DG1 in service and Green for micro-grid with DG1 and DG2 in service.

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

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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.

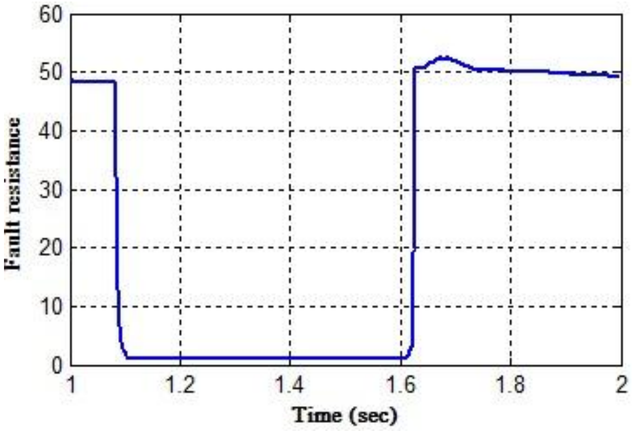

Fig. 10. Fault resistance for ABCG fault at middle of Line45 with 1ohm .

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.

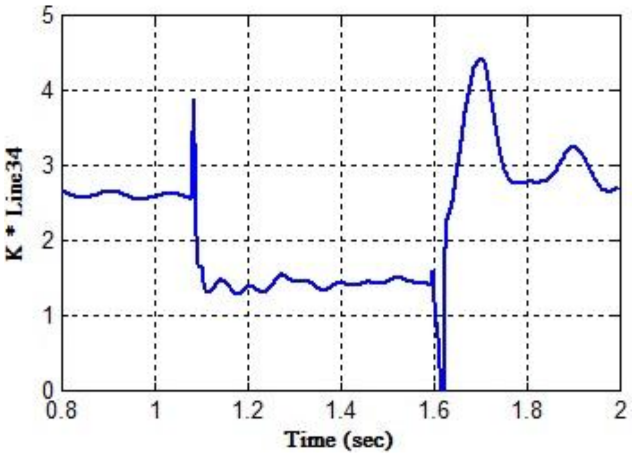

Fig. 11. *K* for fault located at 130-155% of Line34.

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.

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