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Improvement of Protection Coordination for a Distribution System Connected to a Microgrid using Unidirectional Fault Current Limiter

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Abstract The presence of distributed generation (DG) units in distribution systems increases the fault current level, which disrupts the existing coordination time interval of the protective overcurrent relays. One of the ways for decreasing DG effects on the coordination of protective devices is re-coordination of the relays by installing unidirectional fault current limiter (UFCL) between the main grid (upstream network) and the microgrid (downstream network). The UFCL does not limit fault current contribution of the upstream network when fault occurs in downstream but limits fault current contribution of the downstream network when fault occurs in the upstream. Moreover, it preserves the coordination between all of the relays. Several case studies are carried out for illustrating the performance of the UFCL in maintaining the relay coordination.

1. Introduction

Due to the increase of electricity demand and the change of concerning environments, the capacities of renewable energy generation systems, which are mainly connected to a distribution system, are being expanded [1]. The penetration level of DGs being small in size [2] is expected to be higher in many countries to accelerate development of renewable technologies. The DGs based on renewable energy sources such as photovoltaic systems, wind turbines, and fuel cells will help in reducing greenhouse gas emissions. Moreover, these DGs can provide benefits for both utilities and consumers since they can reduce power loss, improve voltage profile and reduce transmission and distribution costs as their location will be close to customers [3]. The penetration level of DGs in radial distribution network has a significant impact on power flow, harmonics, voltage regulation and short circuit levels of the Network [4].

The level of fault current increases when DGs are connected with distribution network with a subsequent serious effect on the existing coordination of the protective devices. DG interface may be either a transformer or a power electronics device, which is another important factor affecting overall short-circuit level [5,6]. Since the coordination time interval

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(CTI), as shown in Fig. 1, cannot be guaranteed if the fault current flowing through any protective device is changed, protective coordination could be lost. As a result, the DGs may need to be disconnected from the distribution network at fault condition in order to restore relay coordination on the expense of loss of DG power [7,8]. In order to solve the miss-coordination between protective relays resulting from the connection of DGs to a distribution system, several studies have been implemented [5,9–12].

Fault current limiters (FCLs) with fast action can limit the instantaneous magnitude of the short-circuit current during fault conditions at a predefined value [13]. When a microgrid (MG) in a downstream network is connected to the main upstream network, a FCL can be installed in the tie feeder, which connects upstream and downstream networks. Conventional FCLs generally have a bidirectional behavior that limits the short-circuit current in two directions. For faults in upstream network, the operation of the FCLs is desirable to limit fault current contribution of the MG and preserve the coordination of upstream over current relays, but during a fault in downstream, current limitation by the FCL may decrease operational flexibility and reliability of the downstream network. Loss of coordination between the upstream and downstream protective relays is one the of arisen problems [14]. In order to overcome the problems resulting from fault occurrence downstream, a unidirectional fault current limiter (UFCL) specially designed for microgrid is recommended. The proposed UFCL presents a low resistance value in normal and downstream fault conditions and a high resistance value during the upstream fault conditions [15].

The objective of this paper is to estimate the optimal value of UFCL resistance which achieves proper relay coordination time interval in order to avoid miss-coordination between overcurrent relays in distribution systems. Such miss-coordination is expected due to the connection of DG units into the distribution system. The procedure to obtain the optimal resistance of UFCL is iterative in nature. The optimal UFCL-resistance value is determined for the following four scenarios:

- Scenario A: The rating of the main grid rating is increased from 1000 MVA to 1500 MVA for the same rating and type of DG_1 unit.
- Scenario B: Different types of the DG_1 unit include induction generator (IG) or doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) keeping the same rating of both the DG_1 unit and the main grid.
- Scenario C: A new synchronous generator DG_2 as a DG unit is added to the MG side. This scenario is the only one which was investigated before [14].

2. Method of analysis

2.1. Configuration of distribution system

A power distribution network with the DG unit is shown in Fig. 2 which consists of upstream and downstream networks connected by a unidirectional fault current limiter (UFCL). The upstream network consists of 1000 MVA substation connected through a 50 MVA transformer to a transmission system with four OCRs, each follows a bus and a non-rotating load (L_1 to L_4). The UFCL is connected to the downstream network through bus 5. A synchronous generator representing DG_1 and non-rotating load L_5 is connected to bus DG_1 through a 2 MVA transformer. A non-rotating load L_7 is connected to bus 5 through a 1.5 MVA transformer. A DG_2 and non-rotating load L_6 are added and connected to bus DG_2 through a 2 MVA transformer. Buses DG_1 and DG_2 are connected to bus 5 through underground cables Z_{DG1} and Z_{DG2}, respectively. Parameter values related to the upstream and downstream networks are shown in Table 1.

2.2. Calculation of short-circuit impedances according to IEC 60909 Standard

In this paper, the IEC Standard 60909 [16–20] is utilized for fault level calculations. The fault level calculations are performed on the 20-kV distribution network as shown in Fig. 2. Based on the network data shown in Table 1, the short circuit impedances of the main substation, transformers, DG unit (synchronous generator) and non-rotating loads are calculated as described in Appendix A. Table 2 presents the values of the short circuit impedances of the system.

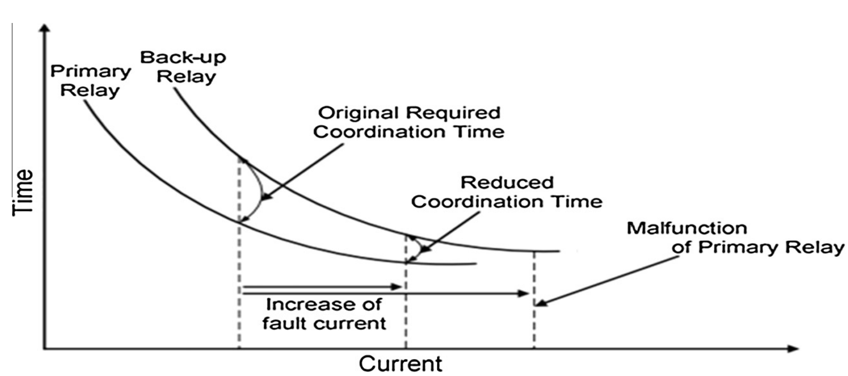

Figure 1 Protective coordination characteristics between primary and back-up relays.