New Fault Location Detection Method on Three Phase Micro Grid Systems

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Abstract—

This paper presents a novel fault detection system in a three phase micro grid systems. It is done through the observation of damping oscillations caused in the transient voltage magnitude when the fault occurs. Our theoretical study and extensive simulations demonstrate that there is an approximated linear relationship between the maximum magnitude of the transient signal observed by a sensor, and the distance between the sensor and the fault location. Based on the discovered relationship, microgrid topology and sensor location information, we have designed an algorithm capable of locating the fault in the single-phase microgrids. The proposed fault location method has been implemented and validated through simulations in MATLAB Simulink software and the results are shown with different fault location on the micro grid.

I. INTRODUCTION

Electric power distribution feeders are susceptible to faults caused by a variety of situations such as adverse weather conditions, animal contacts, equipment failure, accidents, etc. Distribution circuit faults result in a number of problems related to the reliability of service and customer power quality. In the past, the permanent interruption of customer service resulting from a blown fuse or a recloser lockout was the only factor which was used to determine service reliability. However with the introduction of sensitive customer loads, such as adjustable-speed motor drives, which are sensitive to the voltage sags caused by faults, even temporary self-clearing faults have become an item of concern. To maintain a high-quality of electric service, it is essential for utilities to determine the locations and causes of faults and take effective measures to minimize the occurrence of future interruptions in service.

Power companies normally perform fault location and diagnosis based on the customers' outage reports. Upon receiving the trouble calls from the customers, the dispatchers look at the feeder configuration map and the protection design manual to determine the outage area. Then a crew has to be sent to patrol the outage area. The location and diagnosis of the fault in this manner can be a rigorous and time-consuming task. Temporary faults are especially difficult to identify since these do not often result in a blown fuse and evidence leading to the fault cause and location is unavailable.

Various fault location and diagnosis techniques have been proposed in the literature. However, a survey of previous work has revealed that most of the fault location algorithms were developed for transmission systems and are not suitable for radial distribution networks [1-3]. The literature describing algorithms that can be used for distribution networks has not as yet addressed the problem of how to rank the multiple calculated fault location possibilities or how to deal with modeling errors [4-6], Other recent efforts have focused on developing fault diagnosis systems using knowledge- based approaches [7-9]. Knowledge-based techniques often rely on external information such as SCADA alarms, substation and feeder switch status, feeder measurements, load voltage sensors, etc. In many distribution systems, knowledge-based approaches may not be feasible since measurements are usually only available at the substation and information about the operation of feeder protective devices is normally unknown.

This paper describes an automated distribution system fault location and diagnosis system, as shown in Figure 1. This system integrates information available from a substation digital transient recording device with knowledge of the feeder configuration and protective coordination contained in a distribution database. One of the benefits of such a system is that it will speed up the service restoration process by giving repair crews a more accurate indication of the fault location. The developed fault location and diagnosis system can also be applied to identify, the location of temporary faults and thus serves as a tool for fault prevention. Fault location in transmission networks generally assumes a long transmission line with sensors deployed at either one or both ends of the line. The travelling wave (TW) method utilizes the time difference between the incidence wave and the reflection wave of transient voltage/current signals caused by disturbance to identify the fault location [6], [7]. The TW method is also the key method suggested by the IEEE guide for fault location on ac transmission and distribution lines [8]. Jafarian and Sanaye-Pasand [6] proposed a solution to detect small-voltage-magnitude faults that happen very close to the sensors or when a single phase is grounded.

Fault location in distribution networks is usually accomplished based on the information collected by one main sensor. Distribution networks often have relatively smaller scales and more complicated topologies compared to transmission networks. The typical topology of distribution networks is a tree with the main sensor installed at the root of the tree, namely the distribution substation. The wavelet transform (WT) method in [9] is introduced to find the fault branch. Its theoretical foundation depends on the high frequency components of transient signals which may have different performances with respect to the different paths they pass through. Based on this idea, Borghetti et al. [10] considered that there is a characteristic frequency corresponding to a certain location of distribution networks. The fault location can be determined by comparing the theoretical frequency with the frequency identified by the WT. However, the characteristic frequency is related to many other factors in practice which can be easily disturbed. In [11], high frequency components (103 − 109 Hz) are first extracted by the WT. Then the fault distance is calculated by the TW method which increases the noise immunity. There still exist other methods (see [12]), which require a precise simulation to calculate the fault location.

One of the main problems when trying to use aforementioned methods in a microgrid is that these methods need data acquisition devices with fairly high sampling rates to achieve the high resolution in fault location needed for the microgrid. For example, in the traveling wave approach [9], it needs to detect the time difference between the first transient wave and the second transient wave arriving at the sensor; in the transmission line case the time difference is in a magnitude of seconds corresponding to a wave traveling distance of about 100 km while in a microgrid the time difference would be in a magnitude of 10−6−10−7 s if such concept would still apply.

Thus, as further explained in Section II-B, it is infeasible to perform accurate fault location for typical microgrid deployment based on the traveling wave approach. Related research for three-phase microgrids only addresses fault detection problems. The difference between fault location and fault detection is that solving the fault location problem needs to identify the accurate location of the fault while solving the fault detection problem only needs to detect whether a fault has happened on certain line or not. For instance, new methods of fault detection for three-phase microgrids include frequency shift [13], phase shift [14], high impedance detection [15], and harmonic current injection [16]. These methods take three-phase symmetric components as their basic features and are capable of working in both transmission networks and distribution networks. Other fault detection methods use data mining and d–q WT approach, respectively [17], [18], which are both specifically designed for three-phase microgrids. These methods can only achieve the wide area protection while the realization of accurate fault location in microgrids is still absent.

II. TEST SYSTEM CONSIDERATION

Generally, the protective relays are installed at distributed generators (DGs) and important loads and there is no protection device for each transmission line in such microgrids. Therefore, it may be labor-intensive and time-consuming to locate a fault that has happened in a transmission line spanning hundreds of meters that may be hard to inspect. As shown in Fig. 1, we also assume that each DG in the microgrid has a data acquisition device, and there is also a data acquisition device installed at the interface between the microgrid and the external grid. In Fig. 1, dotted lines denote information flows sent from sensors to the central controller and dashed lines represent the control signal flows from the central controller to the DGs. Each circuit line is marked as Ti. As mentioned in [15], centralized control performs well in microgrids and is not difficult to realize while there also exist microgrids adopting decentralized control. In this paper, we focus on microgrids with centralized control and the decentralized control scenarios will be our future research work.

In general, for the problem of fault location in single-phase microgrids, the following prerequisites are used.

1) The microgrid topology is known.

2) The basic system parameters are known. For instance, the accurate line length and approximately the equivalent impedances of circuits.

3) The basic circuit principles and theorems are applicable, such as Ohm's law, Kirchhoff's law, and Thevenin's theorem.

4) The electrical signals can be sampled by multiple sensors in the microgrid at the same time.

The fault location problem in single-phase micrgrids is to estimate the fault position based on the aforementioned information and the error between the estimated fault location and the actual fault location should be within an engineering tolerance margin. For example, assume that a short circuit has occurred at the midpoint of transmission line 4 (T4) in the microgrid shown in Fig. 1. The transient voltage signal caused by the short circuit has been sensed by sensors 1–4. Using the sensor data along with the known topology and system parameter information, a fault location solution should be able to estimate that the fault has happened at somewhere close to the midpoint of T4. The error between the estimated fault location and the actual fault location should be within an engineering tolerance margin.

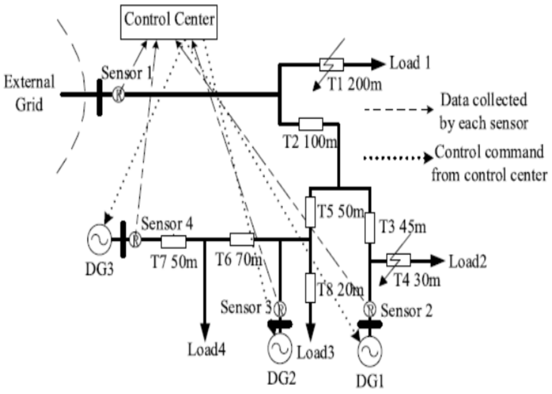

Fig. 1: Test system with DGs

III. SFCL CONFIGURATION

Fig. 2 shows the SFCL model developed in Simulink/Sim-PowerSystem [16]. The SFCL model works as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic table. Second, if a passing current is larger than the triggering current level, SFCL's resistance increases to maximum impedance level in a pre-defined response time. Finally, when the current level [17] falls below the triggering current level the system waits until the recovery time and then goes into normal state. Verification test of SFCL model conducted on power network model depicted in Fig. 1. SFCL has been located at substation (Location 1) and for a distribution grid fault (Fault 1), various SFCL impedance values [18] versus its fault current reduction operation has been plotted. Maximum fault current (No SFCL case) is 140 A at 110V for this arrangement.

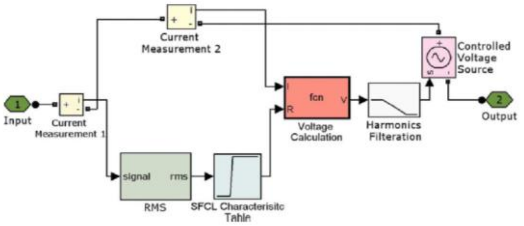

Fig. 2: SFCL Simulink modelling

IV. SIMULINK MODELING AND RESULTS

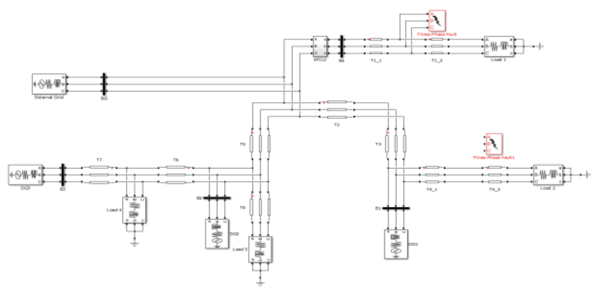

Fig. 3: Test system Simulink modelling with SFCL

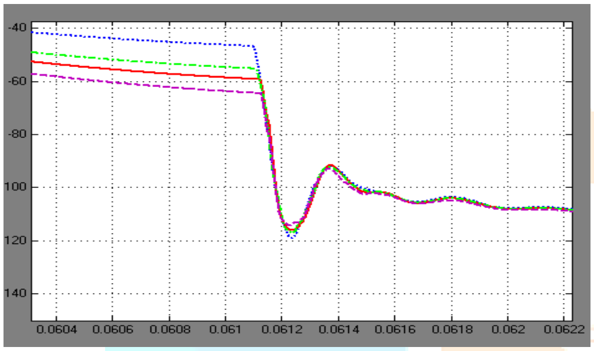

Fig. 4: Bus voltages during fault on first transmission line without SFCL

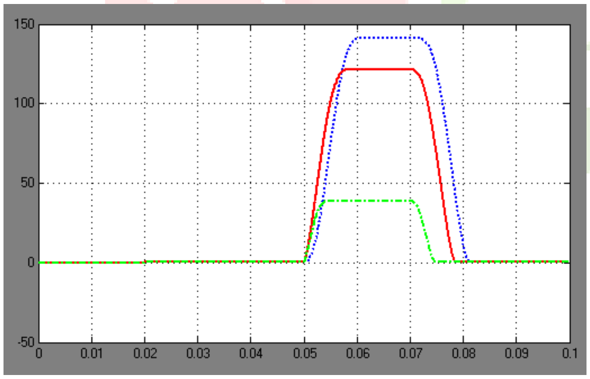

Fig. 5: Bus currents during fault on first transmission line without SFCL

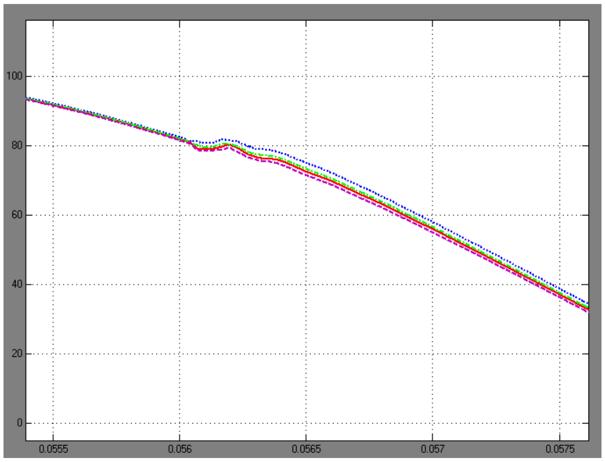

Fig. 6: Bus voltages during fault on first transmission line with SFCL

Fig. 7: Bus currents during fault on first transmission line with SFCL

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V. CONCLUSION

As it can be seen with the analysis of the test system the currents in the bus system are reduce by 70% with SFCL compared to the test the system without SFCL. A fault is introduced with specific time and impedance on the first transmission line. The drop in the voltages is also suppressed with SFCL and continuity of supply is maintained to the loads without disturbance to the DGs.

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