A New High Impedance Fault Detection and Location for Distribution Systems

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ABSTRACT

In this research, a new approach for detection and localization of High Impedance Fault (HIF) is proposed. This approach is designed based upon the reflection of the traveling waves on transmission lines. The form and reflection of the traveling wave in the transmission lines depend on the line parameters and the conjunctions locations. The shape of the reflecting wave and the reflection time provide information which can be used to determine the occurrence of the HIF in the transmission line. Moreover, by analyzing the provided data we can identify the location of the existing disorder in the power grid network.

1. INTRODUCTION

High impedance faults detection and identification are two challenging topics in both transmission and distribution sections in power systems. In general, it is difficult to detect HIFs occurrence through conventional protection methods due to the low current flow. Most of the times, this current is as low as normal load current and even HIFs relays cannot detect them in 50-60% of occurrence [1]. These faults normally occur when a high impedance object like a tree contacts the conductor or conductor breaks and touch the earth. HIFs nevertheless, must be accurately detected and removed. This is utmost important not only because these faults are threatening the reliability of electric power system but also, these faults pose a risk of fires and endanger life through potential electric shocks. Failure in detecting HIF faults leads potential hazards for publics [2].

Various modeling methodologies for HIFs has been proposed and utilized for fault detection purposes. HIFs are modeled as voltage source in [3]. Nam et al. proposed a model for HIFs based on two series time varying resistances (TVRs) in the EMPT software. These two series are controlled by Transient Analysis of Control Systems (TACS) [1]. Furthermore, a model consisting of a nonlinear resistor and diodes is presented in [1], and [4] to capture the behaviors of HIFs in the power system. Also, an experimental setup is used to establish a high impedance fault of a leaning tree type in [5]. These models of HIFs can be used in fault diagnosis approaches to detect the occurrence of disorders in the power system.

There are different approaches for high impedance fault detection in the existing literature. For example, HIFs detection is done by using wavelet transform [2]. In [6], a detection method is proposed by utilizing the high frequency current components based on the fact that arcing would happen in case of high impedance fault occurrence. Moreover, Kwon et al. developed a method by utilizing incremental variance of normalized even order harmonic power to detect the HIFs [7].

Apart from detection of the HIF, the location process of HIF is also very challenging task. In spite of enormous efforts for HIF detection, there are very few studies on high impedance fault location. For example, [8], proposed an algorithm based on Artificial Neural Network (ANN) to identify the location of HIF. However, the exact localization of the HIFs is not explored in detail by control oriented approaches. In this research we propose a novel methodology to detect and identify the location of HIFs in a power system. In this method, we use the advantages of a traveling wave and its reflection in the transmission line. The shape and reflection time of the traveling wave in the transmission line provides necessary information to identify the faulty line as well as the location of fault occurrence.

2. PROBLEM STATEMENT

Fault location using travelling wave has been applied in high voltage systems for several years successfully. To detect fault corresponding to the lightning in the power system, an arcing wave will be developed which makes the occurrence of lighting noticeable [9]. However, in the distribution system numerous switching and low voltage levels make the detection and location of the HIFs more challenging. In this research, we attempt to identify the location of the HIFs in the power system using traveling wave. We know that there is a strict proportionality between voltage waves on transmission lines and their associated current waves and this proportionality is a factor of the line characteristic impedance Z_0. The reflection of the wave will change in case of any change in Z_0 due to the change in network topology for any reason like fault occurrence.

Implementing suitable equipment in specific locations in distributed network leads us to detect and locate changes in the topology of the network by sending and receiving the waves. To pursue this idea, we first need to model our power system and next, apply the traveling wave approach on it.

2.1 System modeling

Our case study is a sample micro-grid consisting of a 5 MW synchronous generator equipped with excitation and governor control systems. The generator may represent either a diesel-generator or a gas-turbine-generator unit. Also, the microgrid includes a 2.5 MW converter based source supplying a distribution network which can be a photovoltaic source or a large battery pack. Furthermore, the distribution network consists of three radial feeders connecting to some linear and nonlinear loads. The schematic of the whole microgrid that we developed in PSCAD software with all its components is shown in Fig.1.

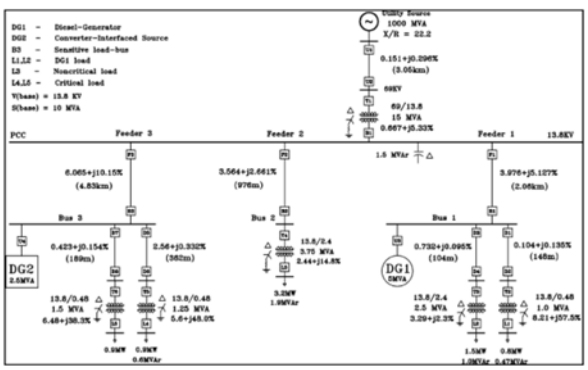

Fig.1. Single-line diagram of the study system [10]

3. EXPECTED CONTRIBUTIONS

As it is mentioned before, traveling wave has been used for fault location in case of lightning in transmission and distribution systems. In this project, we will use traveling wave and its reflected portion for detection and location of HIF in distribution network. Also, an optimal configuration of device implementation will be proposed to reduce the redundancy and diagnosis costs. Hence, apart from developing and evaluating a detailed model of microgird in PSCAD software, the contributions of this research are as follows

3.1 High Impedance Fault Detection and Location

The proportionality between voltage and current in a travelling wave in a transmission line depends on the line characteristic impedance, Z_0. When a wave arrives at a discontinuity in a line, where the characteristic impedance of the line changes, some adjustment must occur. This adjustment is presented as a combination of two new waves, reflection and refraction waves. The reflection wave travel back down the line and the refraction wave travels through the discontinuity. Any changes in reflection wave means changes in the network topology.

The traveling wave current and voltage equations for a single line are as follows:

$$I(x,t) = f_1\left(\frac{x}{v} - t\right) + f_2\left(\frac{x}{v} + t\right) \quad (1)$$

$$V(x,t) = Z_0 f_1\left(\frac{x}{v} - t\right) - Z_0 f_2\left(\frac{x}{v} + t\right) \quad (2)$$

Where Z_0 denotes the characteristic impedance for the transmission line. These equations allow us to observe any changes in voltage and current as a function of time and its distance from the source.

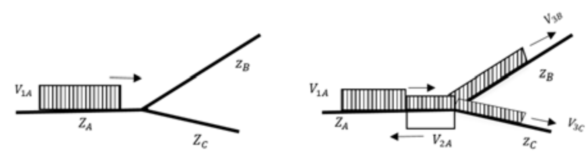

Fig. Traveling wave of voltage encountering a line bifurcation

If we assume the characteristic impedance of the lines shown in Fig.2, Z_A, Z_B, and Z_c, by considering following equations for junction:

$$V_{1A} + V_{2A} = V_{3B} = V_{3C} \quad (3)$$

$$I_{1A} + I_{2A} = I_{3B} + I_{3C} \quad (4)$$

And applying equations below:

$$I_{2A} = -\frac{V_{2A}}{Z_A},\ I_{1A} = \frac{V_{1A}}{Z_A},\ I_{3B} = \frac{V_{3B}}{Z_B},\ \text{and } I_{3C} = \frac{V_{3C}}{Z_C}$$

We can derive voltage and current equations for the line. Based on the sending wave, its reflection characteristics and time delay, the distance of the junction can be calculated.

It is worth mentioning that the equation for multi conductor system, which we need to use in this project, is more complex but still follows the same rules.

High impedance fault defines a new junction in the grid which changes the topology of the grid. Observing the normal situation in specific time intervals allows us to follow any changes in the grid. Unexpected changes in the grid means fault and it can be located base on the equations above.

3.2 Optimal Configuration

By defining HIF and injecting high frequency voltage wave with small amplitude in different stations, and based on sending and receiving time we can detect the existence and distance of the junction in the line. For fault detection we need to implement a wave sending and receiving devices in optimum places to have best coverage for accurate fault detection and location and reduce the diagnosis costs. To achieve this goal, all possible configuration, and a cost function based on accuracy of the model and the number of the devices should be defined.

4. RESEARCH PLAN

The aims of this research are (i) develop a new method of high impedance fault detection and location based on high frequency traveling wave in a sample distribution network and (ii) design an optimal configuration of device implementation. To achieve the aforementioned research objectives, we develop the research plan coordinately.

4.1 Work Performed

In the current project, a simple microgrid has been modeled in PSCAD as shown in Fig.1. We have considered accurate load description to model the switching and time varying load in the system which makes the microgrid model close to real scenario. There are two important load curves used for power system study: (i) load duration curve and (ii) load curve. The former is used for load forecasting and long term planning purposes that is needed to investigate peak load duration or lowest load consumption in the network. The latter, shows load consumption for a typical day in different seasons. Load curve is used for studying short time (hourly) forecasting and hourly grid planning. A general load curve for summer season has been used in this project, since we expect to see the same results for HIF and load variation in voltage and current.

4.1.1 Fault Analysis

After validating the developed model of the power systems in the PSCAD simulation environment, we study the faults into the system. To analyze the effect of HIFs in power system and validate the behavior of the model in occurrence of the HIFs, different fault scenarios are studied. These HIF scenarios contains solid and high impedance single phase, and three phase faults applied to the model. As it has been expected for high impedance faults, the voltages and currents in the entire grid did not show any specific changes. HIF results are close to the load variation results which make the detection and location processes of these faults very challenging tasks.

4.2 Remaining Work

For future work different combination of travelling waves with different frequencies according to the length of the transmission lines and their characteristics will be defined. The wave frequency should be determined such that fault locating accuracy meets required margins. Then, different HIF will be applied in different points of the distribution feeders. Based upon the characteristics of the reflected wave including shape and returning time, we can identify the faulty feeder as well as the location of the HIF in the feeder. Next, we will define a cost function for optimal implementation of detection and location devices according to the desired accuracy level and implementation costs. Finally base on the final configuration appropriate filters for filtering the high frequency current injected to the grid will be designed to maintain power quality of the network at standard level.

5. CONCLUSION

In this research, a microgrid as a benchmark has been modeled. A novel HIFs diagnosis approach based on traveling wave is proposed to detect the HIFs as well as identifying their location. Furthermore, different places for implementation of the equipment will be evaluated to find an optimal configuration for high impedance fault detection and location in a sample distribution system. The outcome of this project not only can help health monitoring of the distribution system but also is helpful to avoid potential hazards for human lives.

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