A Review on Applications of PMUs in Impedance-Based Fault Location in Transmission Lines

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Abstract

This paper presents an extensive review of algorithms for location of faults on transmission lines. Each algorithm operates with some assumptions and certain inputs that include measurements as well as system data. Selection of the suitable algorithm demands a detailed knowledge of the available methods and principle behind. This paper summarize works associated with fault location algorithms based on measurements received from single end and both ends of faulted transmission line and also methods available to locate faults in three- and multi-terminal lines.

Key Words: Fault location, impedance-measurement, intelligent electronic devices (IED), power system.
faults, Phasor Measurement Unit, transmission line measurements.

1 Introduction

With high progression in the multifaceted network of generation, transmission and utilization by loads, continuous observation of the network through sophisticated sensor technology is imperative. Any fault on transmission line results in abnormal condition of the power system. Flow of a current more than rated is called a fault. It might lead to power interruption, damage to equipment insulation in case of over voltages or equipment failure in case of low voltage. Reasons for the occurrence of a fault can be natural such as heavy winds, falling of a tree, an ice storm or physical such as failure of equipment in the system. Fast and accurate fault diagnosis – fault detection, classification and location, is crucial to restore power system operation. Thereby, power system security and reliability of the Grid are improved.

Fault location methods require voltage and current of the transmission lines and are classified into impedance-based [1, 2] and traveling-wave based fault-location methods based on fundamental frequency components and high-frequency components respectively. Based on the availability of voltage and current waveforms collected, methods are further divided into single-ended [3]–[18], two-ended [19, 20] or multi-ended, in case of tapping points available on the line. Accuracy of output of the algorithm is obtained when electrical waves accrued from both or multiple ends and are synchronized. Such synchronized real-time measurements are acquired from measuring device, Phasor Measurement Unit (PMU).

PMUs are the dedicated devices used in the power system monitoring and control built at Virginia Tech in 1992. Unlike the conventional measuring instruments, PMUs measure the analog waveforms and provide digitized output, with GPS reference source and accuracy of 1 microsecond. These high precision synchrophasor data composed of both magnitudes and phase angle, are transmitted to the remote servers, local substations. This drastically improves visibility and expedites truthful fault diagnosis.
Types of faults

Faults on any transmission line can be categorized into balanced fault (symmetrical) and unbalanced fault (asymmetrical) or as shunt faults and series faults. Series faults do not involve neutral or ground, interconnection between the phases. They lead to increase in voltage, frequency and decrease in current in the faulted phases. Shunt faults are due to the unbalance between ground and phases or between phases. They lead to increase in current and decrease in frequency and voltage in the faulted phases. Since an unbalanced system do not have three phase symmetry, fault analysis is performed by transforming fault currents and fault voltages into their symmetrical components and obtaining a sequence network for each phase [2].

2 Impedance-based fault location algorithms

Impedance based method are devised to operate with the fundamental frequency components of voltage and current phasors sampled from one end or both ends of the faulted line. When data is realized from multiple locations, it may be synchronized or unsynchronized. In case of unsynchronized data, synchronization error is computed to obtain the fault location. Data synchronized data is achieved by using communication devices such as GPS, PMU. Thus, it is more expensive.

Single-Ended Impedance-Based Fault Location Algorithms

M.T. Sant et al. introduced single ended reactance based fault location method. This employs an intelligent electronic device (IED) at one end of the line to calculate the reactance between the device and location of the fault. This method doesn’t require any communication channel. Thus it is simple to use but didn’t consider the effect of fault resistance. Thus it fails to estimate the fault location under heavily loaded conditions. In improvised reactance calculation by phase shift between current at one end of the line and current flowing through fault resistance. T. Takagi et al. highlighted in that the effect of fault resistance on the fault location is reduced by using pre-fault load flow. This takes care of the system grounding effects. But this method is limited to a homogeneous
transmission network where the fault resistance is a real value. To overcome this non-homogeneity, proposed the system load to be represented with its zero-sequence current during a single line-to-ground fault. ERIKSSON estimated the value of fault resistance to overcome the reactance error caused by all the above reasons. This method was developed and tested for short-circuit model of a transmission network alone. In 1998, Novosel et al. modified ERIKSSON algorithm to be applied to radial, short transmission lines or any line where the in-feed from the remote end is comparatively less. Compared the popular single-ended methods to demonstrate the sensitivity of the method to fault characteristics and inaccuracy in transmission line parameters. In fault location was determined from the current data from single end of the line. D.J. Zhang et al. proposed a mathematical morphology based on signal processing technique to improve accuracy of fault location. Power frequency phasors from one end of the line were utilized to obtain the fault location by least square matrix pencil method. Single-ended algorithms found predominantly in most of the numerical relays due to the requirement of simple equipment and algorithm at one end [18].

Two-Ended Impedance-Based Fault Location Algorithms

These algorithms calculate the fault location by using the phasor voltage and current waveforms from both ends of the transmission lines. For this, a communication channel is dedicated to transfer data from one end to the other. Also, this data is collected and analyzed at a central location. Advantages of the two-ended algorithms are accuracy, as it is not affected by fault resistance and reactance.

Two-Ended Synchronized Method

Synchronization between the measurements from both ends of a transmission line is obtained via a global positioning system (GPS) or a Phasor Measurement Unit (PMU). A PMU enables real-time calculation with the phase angle data synchronized to an arbitrary but common reference, other than the magnitudes of voltage and currents. GPS-synchronized phasor data provided by PMUs have many applications in real-time monitoring, operation and control of the electric power system including fault locations. Algorithms to locate
faults with synchronized PMU data from both the ends can be iterative or non-iterative. Non-iterative methods are employed in case of unsynchronized measurements. Either of the positive, negative or zero-sequence components may be used for determination of the fault location. But use of the negative sequence components is more advantageous as it is affected by zero-sequence mutual coupling, loads, and uncertainty in line impedance or in-feed from tapped loads. It also eliminates the need to know the type of fault since negative-sequence components do not exist for three phase balanced faults. Thus, they are used to detect the faulted phases, to discriminate internal and external faults in generator and in over current relay.

Two-Ended Unsynchronized Method
In 1988, Sachdev et.al calculated fault location using unsynchronized post fault data from the two ends. Sometimes, three-phase voltage and current measurements received from the two ends of a faulted transmission may be unsynchronized. This may be due to malfunctioning of GPS, mismatch between the sampling rates of the fault recorders at both the ends, phase shift introduced by the communication channel over which the data is transferred. Measurements are synchronized by the calculation of a synchronizing operator from the phase-sequence components. In mutual coupling effect is analyzed on determination of fault location in space crossed transmission line. Simulations were performed in PSCAD with voltage samples from both the ends of the line.

Fault Location Algorithms For Three And Multi-Terminal Lines
Multi-terminal lines have three or more terminals. These terminals are equipped with certain generation. Taps provided on the transmission lines to feed the loads form tapped line. These tapped lines are also three or more terminal lines. A fault beyond the tap point changes the overall line impedance. Thus, algorithms discussed in the previous sections are applicable till two-terminal lines only.

Several algorithms are discussed in literature to estimate fault locations in three-terminal lines using synchronized data from all terminals and data obtained from two terminals only. Tziouvaras et al. unsynchronized currents from two were used to determine the fault location after network reduction to
its equivalent two-terminal model.

3 Conclusion

Fast and accurate fault diagnosis – fault detection, classification and location, is crucial to restore power system operation. This lowers the risk of power interruption, damage to equipment insulation and equipment failure. Several algorithms are developed to estimate the fault location. High precision synchrophasor data expedites this process. This paper discussed comprehensive works in the field of Impedance-based fault location algorithms utilizing PMU data.

References

Location Algorithms and the Potential of Using Intelligent Electronic Device Data for Protection.


