Review on Multiterminal Transmission Line Protection Techniques

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***Abstract*—The protection of multiterminal transmission lines is a challenging task due to possible infeed or outfeed currents contributed from the taped lines. As a result, the first zone reach of a non-communication-based scheme (e.g., impedance-based distance relays) usually cannot be extended more than a small portion beyond the tap point. This paper presents a various protection technique for multiterminal transmission line.**

***Keywords*— Multiterminal transmission line, protection.**

I. INTRODUCTION

The North American power system consists of thousands of high voltage transmission lines (TL) transmitting electrical power between generators and load centers which represent the foundation of the power system. The majority of transmission line construction is of overhead type and therefore, is easily susceptible to various transient and permanent faults. These faults can lead to damage of the line itself and can cause power system instability. It is of the utmost importance that protective relay systems are capable of clearing all faults within the designed operating time, and have a high degree of dependability and security.

Typically, there are three types of line configurations used within the industry. These line configurations include radial configuration that are (a) one-terminal, (b) two-terminal, and (c) multi-terminal of which three-terminal is possibly the most prominent multi-terminal type. It should be noted that "terminals" in this context, refers to source terminals and not-tapped transformer terminals or stations. The two-terminal line configuration is the most dominant type followed by radial, and the three-terminal lines are the exceptions.

Three-terminal and other multiterminal line construction projects are generally a trade-off of planning economics and protection complexities, and can lead to compromises in reliability. Two-terminal lines with long tap(s) supplying remote load from the main line may display many of the same protection and loadability issues as three-terminal lines. These types of configurations and those with multiple tapped transformer stations (low voltage tie breaker closed) are beyond the scope of this discussion. However, it should be noted that some of the same types of complexities may be experienced with these types of configurations as three-terminal lines. The complexity of protecting these line configurations increases from the relatively simple radial, to the more difficult two-terminal, and to the still more difficult three-terminal. Relaying three-terminal lines has been and continues to be a challenge for protection engineers.

There are a number of factors that influence the decision to configure a transmission line with three terminals, such as economics, constrained lead time, regulatory approvals, right-of-way (RoW) availability, line overloads, and system performance requirements.

- There is an economic benefit in the construction of three terminals because it avoids the expense of all or a portion of a substation and typically reduces the transmission line miles.
- Use of three-terminal lines may be more expeditious in Add-ressing system needs.
- Right-of-way may be limited or not obtainable for new lines and stations.
- Regulatory approvals may be problematic. There may be opposition to the construction of new facilities and the construction of a three-terminal line may reduce the over-all project impact.
- Three-terminal line configuration may mitigate the possibility of transmission line overloads due to single contingency events. However, this is very dependent on system topology.

The differential relaying scheme using a communication link between the TL ends could provide a secure protection for multiterminal TLs [1]–[3]. However, the reliability of such a protection scheme depends upon the reliability of the communication link. Moreover, the measurement infrastructure of the tapping lines could be poor or there could be no communication channel for sending measurements from the far end of the tapping lines [4]. Therefore, a protection algorithm, which is based only on the local information obtained at the relay bus, is greatly useful for the protection of multiterminal TLs. Even when a quite reliable communication-based technique is employed for the protection of a TL, a second relay, which makes the decision only based on the local information, would be helpful to increase the reliability of the protection scheme.

The conventional TL protection schemes (e.g., distance relays) are based on the fundamental frequency components of the fault signals. It is well known that the fundamental frequency components of the local signals do not provide the sufficient information required for discriminating between the internal and external faults for a multiterminal TL. This is due to the fact that the infeed or outfeed currents contributed from the tap points could affect the fault-loop impedance estimated by a distance relay. As a result, the distance relay may under-reach or overreach depending on the transmission system configuration and parameters [5].

The fault-induced high-frequency (HF) transients contain extensive information about the fault by which the fault direction and location could be identified in a few milliseconds [6]–[9]. The traveling-wave positional protection technique uses polarities and time intervals between arriving waves at the relay bus to estimate the fault location [8], [9]. Nevertheless, this technique cannot be easily employed for protection of multiterminal lines due to the reflections of traveling waves at the tap points.

Recently, some non-communication-based techniques for the protection of two-terminal lines have been introduced which use the HF components of the fault signals measured at the relay bus to discriminate between the internal and external faults [10]–[14]. These algorithms rely on the fact that the substation equipment affects the characteristics of the HF transients generated by the faults. The bus stray capacitances have a low-pass filtering effect on the fault-generated transients. As a result, in the case of external faults beyond the TL ends, the HF components involved in the fault signals are attenuated when passing through the remote substation bus, whereas in the case of internal faults, the fault signals measured at the TL ends contain a higher amount of HF components. When the bus equivalent capacitance is sufficiently large, these algorithms could provide a satisfactory response. Nevertheless, for small values of the capacitance, discrimination between the internal and external faults might become difficult due to the small difference between the characteristic features of these two cases. In addition, variation of the power system parameters (e.g., due to the disconnection of a transformer or a transmission line) could affect the performance of these algorithms.

II. MULTITERMINAL LINE PROTECTION TECHNIQUES

A. *Using synchronized phasor measurements*

The method [15] uses synchronized voltage and current measurements from all terminals. Using positive-sequence components of the prefault and postfault waveforms, positive-sequence source impedances are estimated. Using these source impedances and the line data, the positive-sequence bus impedance matrix (bus) is formed. Using the properties of bus, an iterative algorithm is proposed. The algorithm first identifies the faulted section and then locates the fault on this section. This algorithm is applied to the data obtained from the Electromagnetic Transients Program simulation of a multiterminal transmission line. Though the method uses source impedances at line terminals, it does not depend on the system data for their values. It calculates the source impedances at the time of a fault from the prefault and the postfault voltage and current data recorded in a digital fault recorder. Using these calculated values, a method based on properties of the bus impedance matrix is proposed and test results are reported from applying the method on data obtained from the EMTP simulation of a multiterminal transmission line. The reported results indicate that all components of the method, namely, the estimation of source impedances, identifying the faulted section, and locating the fault on this section give very satisfactory results. The distinctive features of this method are that it performs with very high accuracy for all types of faults at different fault locations and is practically immune to fault resistance.

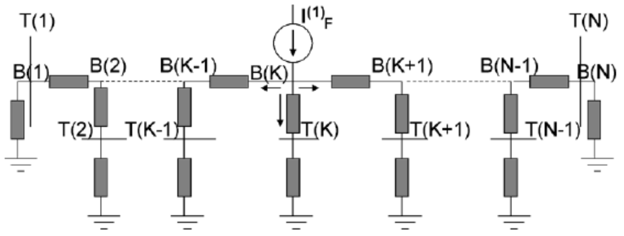


Figure 1. Positive sequence network for a multiterminal line.

B. *Using current differential relay*

Estimation of a distance to fault and indication of a faulted section is performed using three-phase current from all three terminals and additionally three-phase voltage from the terminal at which a fault locator is installed. Such a set of synchronized measurements has been taken into consideration with the aim of developing a fault-location algorithm for applications with current differential relays of three-terminal lines. The delivered fault-location algorithm [16] consists of three subroutines designated for locating faults within particular line sections and a procedure for indicating the faulted line section. Testing and evaluation of the algorithm has been performed with fault data obtained from versatile Alternate Transients Program–Electromagnetic Transients Program simulations.

The specific set of the fault-locator input signals has been assumed with the aim of developing the fault-location algorithm for applying current differential relays protecting a three-terminal line. It has been shown that it can be accomplished using phasors of three-phase current from all line terminals—exchanged by the current differential relays, and additionally, the locally measured three-phase voltage phasor. The developed fault-location algorithm consists of three subroutines, designated for locating faults within the respective line sections, and a multi criteria procedure for selecting the valid subroutine. The subroutines are formulated with the use of generalized fault-loop models. For this purpose, information on the fault type is required. It has been shown that the applied set of the fault-locator input signals allows for accurate determination of the total fault current, flowing through a fault path resistance.

Direct summing of currents from all line terminals for particular phases, which is a natural way of determining the total fault current, has not been used in the proposed approach. This is so because since performing direct summing, the positive-sequence currents, for which the shunt capacitances effect is the most distinct, are contained in the summed phase currents. As a result, the accuracy of the total fault current determination deteriorates. Therefore, it has been proposed to determine the total fault current as the weighted sum of particular sequence components, by applying such a set of the weighted coefficients so that the use of postfault positive-sequence components of currents is avoided. Three subroutines of the fault-location algorithm have been formulated using the lumped model of the fault loop while neglecting shunt capacitances. The distributed parameter line model was utilized only for the analytical transfer of signals across the healthy line sections toward the tap point. In order to ensure high accuracy of the fault location in case of considerable length of the line sections, the distributed parameter line model has to be fully incorporated to the algorithm.

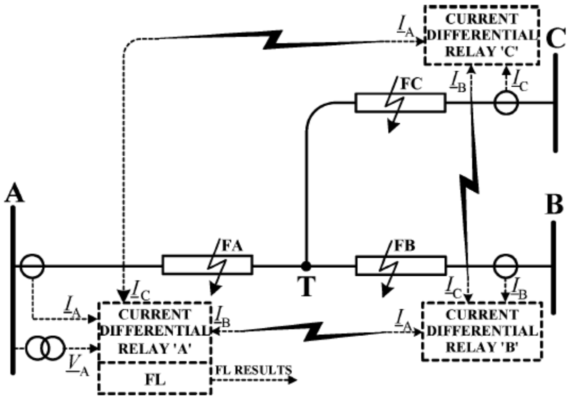


Figure 2. Fault location on a three-terminal line associated with current differential relays.

A multi criteria procedure for selecting the valid sub-routine has been introduced. First, the subroutine, which yields the distance to fault indicating the considered fault as occurring outside the section range, and/or the calculated fault resistance of a negative value is rejected. Second, the impedances of the remote sources are calculated according to different subroutines. The placement of a given calculated source impedance outside the 1st quadrant on the impedance plane results in rejecting the considered subroutine. In case this is not sufficient, the comparison of the calculated source impedances with the actual values has to be performed.

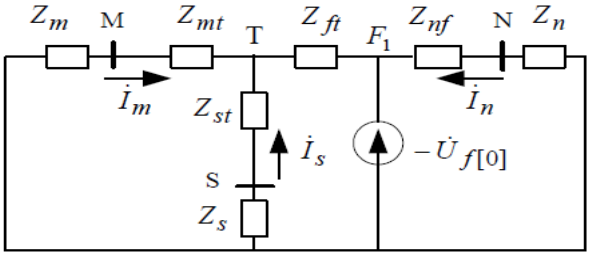
C. Current differential protection scheme

Based on the characteristics [17] of the superimposed currents in Teed feeders, a unique differential criteria was proposed and analyzed under different operating conditions.

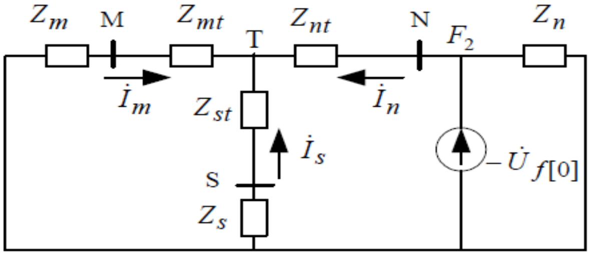
This criteria inherently has sufficient sensitivity for internal faults and stability for external faults. Particularly, it copes well with both the internal high resistance faults on a heavily loaded feeder and the out-feeder problem.

Aiming at the two stubborn problems encountered by the traditional line differential protections, this technique provided a effective solution without increasing any other quantities, such as voltage, zero sequence current or impedance. Firstly, it has inherent immunity to the effect of load condition on differential protection, which builds a base to be able to detect high resistance faults. Secondly, the unique design for the criteria assures the maximum sensitivity for internal faults, maximum stability for external faults and adequate sensitivity for the unusual internal faults with out-feeder at one of the three terminals.

Finally, the response time of the proposed algorithm based on full-cycle DFT is less than half a cycle for most fault cases. This indicates that the operating time of the proposed differential scheme could be less than one cycle even if considering the data transmission delay.



(a) Internal fault



(b) External fault

Figure 3. Superimposed networks

D. superimposed component impedance relay

The relay design [18] is immune from false tripping owing to power swings or prefault load conditions. This has been achieved by extracting and using prefault and superimposed components of relaying voltages and currents. Relay trip time is typically in the range 11 to 20ms and is plotted as a surface against prefault power angle and fault point on wave angle.

The new relay principle improves on the performance of conventional distance relays under abnormal system conditions.

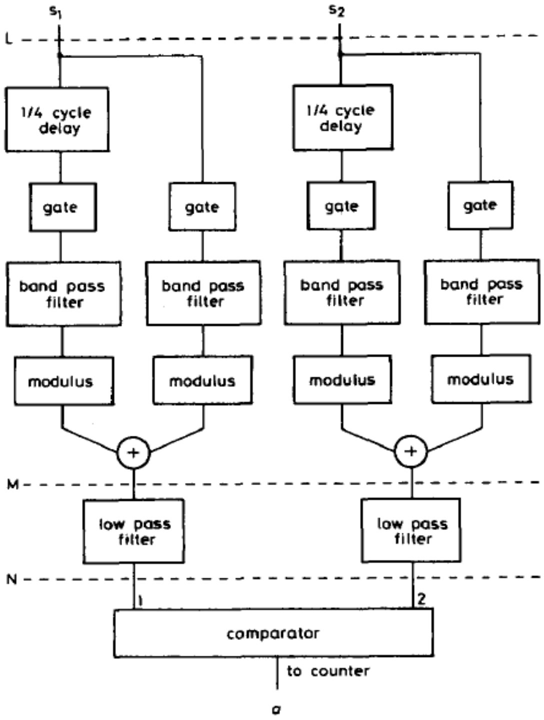


Figure 4. Superimposed component impedance relay algorithm

This is achieved by extracting additional information from the relaying signals (i.e. effectively the phase angle of the prefault voltage at the fault point). Two assumptions are made in the theory:- (i) that fault reistance is zero; (ii) that the power system is homogeneous. Additional advantages of the design are: (i) Good fault resistance coverage; (ii) The reach characteristic is relatively insensitive to fault point on wave and prefault system conditions; (iii) A relatively low sampling rate (2 kHz) is required. The disadvantages are: (i) It requires triggering by a directional relay; (ii) The operating time is not fast (11- 22ms on a 50Hz system); (iii) The design is more complex than a conventional distance relay.

III. CONCLUSION

This paper is an effort to review the most recent techniques which are used for protection of multiterminal transmission line using various protection scheme. So, for this there is a need for new algorithms that have high efficiency and suitable for real time usage. All these techniques have their own features and researches are still going on to obtain lesser operating time of relay at high speed.

IV FUTURE SCOPE

This work can be extended for protection of double circuit transmission line and normal two terminal transmission line.

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