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Transmission line fault detection and location using Wide Area Measurements

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ABSTRACT

Knowledge of both voltage and current data is conventionally entailed for locating fault on transmission network. However, owing to the non-linearity of the system, the process becomes iterative and cumbersome. In order to address this issue, a new technique for fault location on transmission lines using only voltage measurements obtained from Wide Area Measurement Systems (WAMS) and the network bus admittance matrix has been reported in this paper. It is based on the fundamental law of electrical networks. It delineates a single step method to find out the faulted line and the exact location of fault. The decision is based on change in injected current at various buses following the line fault. The method has been tested on IEEE 14 bus and New England 39 bus system. Applicability of the proposed algorithm is independent of fault type, location of fault and fault resistance. This method not only proves to be accurate but also furnishes quick results with reduced computational burden. Besides, the faulted phase as well as fault type detection has been suggested in this paper using same measurements.

1. Introduction

Occurrence of short circuit faults is inevitable in transmission lines. Damage to the system depends on severity and location of fault. Sometimes, it may initially cause voltage dip, and ultimately would cause system blackout if not cleared in the stipulated time. Continuous and reliable availability of electric power at the customer end is highly dependent on the proper operation of the transmission network. That is why it is very necessary to locate the fault and segregate the faulted section from the rest of the network. Traditionally, data from the protective relays and circuit breakers were used for protection of the transmission lines. However, some unforeseen events may cause mal operation of the protective relays and circuit breakers, which becomes the root reason of many blackouts.

Occurrence of various blackouts in leading countries in past few years speaks volumes about the inefficiency of our existing protection schemes. Early fault location can speed up the process of restoration and can thus make the system more reliable. Traditionally fault location techniques have been broadly classified as (1) techniques involving high frequency components (travelling wave based, wavelet based) and (2) techniques using power frequency components (impedance based).

In travelling wave based methods, the time taken by the waves to travel between the fault point to one of the terminal buses is used as a means to calculate the fault distance and hence locate the fault. This has been studied intricately in Refs. [1–7]. However, travelling waves suffer from many shortcomings. It offers errors when fault is close to the bus or at zero incidence angle [8]. Moreover, it is a time taking process as there is a time loss in obtaining the receiving wave and calculating the distance. The alteration of magnitude of the returning wave might confuse the operator in detection of the expected wave. Wavelet based approach has also been incorporated in fault location and classification in Refs. [9–13]. However, they fail to detect faults with over damped transients and are highly influenced by the choice of the mother wavelet presenting time delay in the real time analysis [14]. With the increasing intersts in smart grid concept, a machine learning method combined with wavelet approach has been explained in [15].

Strategies involving impedance of the line as the criteria for fault location has been suggested in Refs. [16–18]. Decision of fault location based on reactance seen by relay has been reported in Ref. [16]. However, this method suffers from the problem of inaccuracy during the presence of fault resistance. The Takagi based approach overcomes the above restrictions as discussed in Ref. [17]. It uses voltage and current data of one end of the line. A number of unsyn-

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Nomenclature

B_{pq}	Line charging susceptance of line pq
f_p, f_q	Calculated distance of fault from bus p and q respectively, expressed as a fraction of the length of faulty transmission line p-q
ΔI	Post fault change in bus injecting current vector
I and I′	Pre fault and post fault bus injecting current vector
I_a, I_b, I_c	Currents in phase A, B and C
L_{pq}	Length of faulty transmission line between buses p and q
l_p, l_q	Calculated distance of fault point from bus p and q in percentage of line length
ΔV	Post fault change in bus voltage vector
V and V′	Pre fault and post fault bus voltage vector
x	Fault location
Y_{BUS}	Positive sequence bus admittance matrix
Y_{pq} andY'_{pq}	Pre fault and post fault admittance of line pq

chronized fault location calculated on the basis of reactance has also been reported in Ref. [18]. However most of the impedance based methods need voltage or current measurements at both end of the lines.

From the last two decades fault location techniques employ Artificial Neural Networks for faster and more efficient fault location. Application of artificial neural network (ANN) on fault location in transmission lines have been well explored in which both voltage and current measurements are used as inputs as reported in Refs. [19,20]. A supervised learning algorithm, Levenberg-Marquardt Neural Network (LMNN) has been applied in Ref. [17] while Ref. [18] have used Radial Basis Function (RBF) network. RBF is a hybrid network inheriting the features of both supervised and unsupervised learning. Owing to this additional feature RBF is faster than LMNN. However, ANN based methods require large number of training cases and the accuracy of the result is highly dependent on the technique used to obtain the training patterns.

Many methods have been suggested for transmission line fault classification [21–26]. Artificial neural network (ANN) along with fuzzy set theory have been proposed for this purpose in Ref. [21]. Taking advantage of the transient phenomena of faults, techniques using discrete wavelet transform (DWT) have been used for fault classification [22,23]. These technologies employ a threshold value for fault classification. Other methods combining ANN with DWT have also been suggested [24]. Sign of instantaneous power flow [25] and sign of reactive power [26] from the buses (containing the fault) has been used for fault classification. These methods do not require any threshold.

Advent of WAMS technology has proved its application beneficial in power system protection [27]. Owing to this fact, number of researches have been carried out for transmission line protection using this technology [28–36]. Work reported in Ref. [28] requires current measurements for fault location. Voltage and current measurements from PMU as well as SCADA data have been used for fault detection and classification in Refs. [29,32]. This might be an issue if complete replacement of existing monitoring systems with PMU is aimed. They are iterative methods and are prone to C.T. errors. Moreover, Refs. [28–32] offer heavy computational burden. Technique suggested in Ref. [33] employing electromechanical wave oscillations, uses a similar concept for fault location as used for travelling waves. Thus the investigation of a straightforward method which can guide the operator in detecting the fault easily and reliably is imperative.

An optimization based technique is proposed in Ref. [30] which uses a PMU placement scheme devised for the sole purpose of fault location. Method reported in Ref. [34] uses only voltage measurements but considers only bus faults. However technique proposed in Ref. [35] is more practicable but it assumes that faulted line has already been identified. Work reported in [28,31,36] employ iterative solutions using optimization tools or simple trial and error while in Ref. [36], a lot of restrictions in placement of the PMUs need to be considered as it uses voltage and current phasors at atleast one of the terminals of the faulted line.

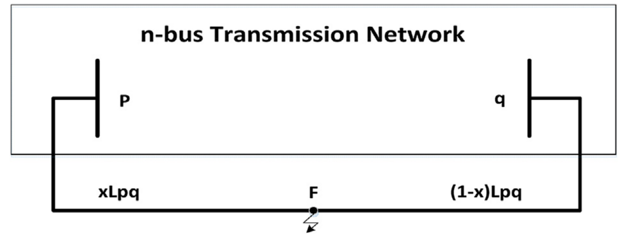

Fig. 1. n-bus transmission network.

This paper aims at development of a method which works on sole measurement of voltage at various buses. It furnishes deviation in the current injected at the buses. The instant decision is taken by the operator based on these observations without resorting to any further calculations. These deviations in bus injected current information are further utilized to find out the location of fault on the transmission line also. The associated methodology has been delineated in Section 2. A single step non iterative method has been derived that would not only identify the faulty line but also locate the faulted point. Pre fault and post fault voltage measurements at every bus are utilized to obtain the change in bus injected current. This deviation in the bus injected current at every bus is used for the faulty line identification and fault location. Section 3 presents the proposed method for fault location in algorithmic form. A brief idea about fault type identification has been demonstrated in Section 4. In an attempt to present the underlying principle without complications, the fault classification has been accomplished by only using the current signals. Simulation results have been discussed in Section 5. The outcome of the investigations have been summarized in Section 6.

2. Proposed method of fault identification and location

Let us consider an n-bus system shown in Fig. 1. The bus voltages are V_1, V_2......V_n and injected currents at various buses are I_1, I_2......... I_n.

The injected nodal currents I, can be expressed as,

$$[I] = [Y_{BUS}][V] \tag{1}$$

Alternatively,

$$\begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & \dots & Y_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ Y_{n1} & Y_{n2} & \dots & \dots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \dots \\ V_n \end{bmatrix} \tag{2}$$

where Y_{ij} represents the positive sequence admittance between terminal buses i and j. Y_{ij} includes the resistance, reactance and shunt capacitance (half line charging) across the lines. Let us assume a short circuit fault in line p-q connecting nodes p and q with length L_{pq} as shown in Fig. 1. The fault occurs at a point F at a distance of x km from node p. For further analysis, the fault point can be considered to be an additional node, say node F. Total num-