Considering Characteristics of Arc on Travelling Wave Fault Location Algorithm for the Transmission Lines without Using Line Parameters

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Abstract: **A realistic simulation of fault arc is required in proper design of transmission system equipment such as fault locators. Usually, in the travelling wave-based fault location algorithms, the effect of the arc of the fault is neglected. The influence of fault arc characteristics on the accuracy of fault locator which is based on the travelling wave theorem, is studied in this paper. Proposed algorithm uses samples taken from two terminals and shows that it is possible to calculate the accurate location of fault by measuring voltage transients caused by the fault. The travelling wave-based algorithm does not use the line parameters. Therefore, the accuracy of algorithm is not affected by aging, change of climate and temperature, which change wave speed. In addition, the effect of fault conditions such as arcing fault resistance, fault inception angle and fault distance are studied on the accuracy of the proposed algorithm. Simulations carried out by SimPowerSystem toolbox of MATLAB software confirm that mentioned parameters do not affect the accuracy of the method.**

Keywords: Arcing faults, Fault location, Travelling wave-based algorithm.

1. INTRODUCTION

THE complexity of power network and their lower stability margins have increased the possibility of failure in power system. The economic penalties associated with such events have become more important since society relies on the availability and quality of an uninterrupted power supply.

In order to improve the power reliability, a variety of protection devices are developed such as fault locator which is proposed in literatures. Accurate fault location reduces time and costs related to the dispatched crews searching to find the fault location. Also, provides customers and consumers feeding with minimal interruption and improves the performance of the power system [1]. Fault location methods that are used to find location of fault in the transmission lines are classified into two general categories [2]:

1- Impedance-based methods [3]
2- Travelling waves-based methods [4, 5]

The accuracy of the impedance-based methods depends on this fact that how accurately the fundamental components are extracted. The process of estimating fundamental frequency requires filtering, which incorporates an inherent delay [6].

Use of travelling wave theory in the fault location algorithms is expanding. When a fault occurs on a transmission line, travelling waves are generated and propagated in both directions of the line and lead to generation of high frequency transients.

The sign, magnitude and timing between various waves arrived to the line terminals contain information about the fault location. Using travelling wave theorem, it is possible to calculate the accurate location of the fault within a few milliseconds after the fault initiation.

The use of travelling wave theory for fault detection was initially proposed in 1978 [7]. Since then a lot of work has been down. In [8] it is suggested to calculate fault location using voltage travelling waves which are taken from one terminal. This algorithm is dependent to the line parameters. Algorithm presented in [9] proposes new method for accurate calculating of fault location in transmission lines using traveling wave theorem. Proposed method uses voltage and current samples which are taken from both ends of the line. Proposed algorithm in [10] calculates accurate location of the fault using voltage traveling waves taken from one terminal of the cable lines independent of line parameters. Usually, in all travelling wave-based fault location algorithms, it is neglected from arc characteristics.

The influence of arc characteristics on the travelling wave fault location algorithms in the case of permanent faults is studied in this paper. Proposed method utilizes two terminal data. Samples are taken from voltage transients generated by fault occurrence. Using wavelet transform, it is possible to detect the first and second inceptions of the voltage travelling waves to the both terminals of the transmission line. Then, actual propagation speed of the travelling wave in the transmission line is obtained without using line parameters and finally accurate fault location is calculated. Because of sampling only from voltage signal, proposed algorithm is more economic compare to algorithms which take sample from both voltage and current signals. Presented method needs to Global Positioning System (GPS), communication systems and data synchronization.

Simulations were carried out in MATLAB software and the effect of fault conditions such as arcing fault resistance, fault inception angle and fault distance are

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studied. Simulation results confirm that mentioned parameters do not affect the accuracy of the proposed method.

2. DYNAMIC CHARACTRISTIC OF ARC

2.1. Arc model

It is probable that insulation strength between one conductor of transmission line and its tower be reduced. In this condition, a short circuit is happened and because of high voltage and low impedance, large quantity of current will flow through this path. According to design of power system, the amplitude of this current will vary from 1400A to 24000A [11]. Studies have shown that the voltage drop on the column of arc only depends on the weather location of the arc place. In addition, it is almost independent of amplitude of the current and the physical profile curve. The voltage drop is constant and about 12-15 Volt per centimetre. Different equations for arcing fault model are presented constant coefficients.

In this paper, differential equations are used to model the arcing faults. It is shown that the dynamic arc characteristics can be exactly simulated by the following equation [12]:

$$\frac{dg_p}{dt} = \frac{1}{T_p}\left(G_p - g_p\right) \tag{1}$$

In this equation g_p is conductivity of arc, T_p is primary arc time constant and G_p is conductivity of primary arc which can be evaluated by:

$$G_p = \frac{|i|}{V_p L_p} \tag{2}$$

In equation (2), L_p is length of arc, V_p is the average constant arc voltage gradient which is about 12-15 V/cm and i is the current of primary arc. Time constant T_p can be obtained using experimental curve as [11]:

$$T_p = \frac{\alpha I_p}{L_p} \tag{3}$$

where the coefficient α is about 2.85×10^{-5} for heavy current arcs, which is empirically obtained by fitting (1) with (2) and (3) to match the experimental cyclograms of the arc currents ranging from 1.4 kA to 24 kA. In this paper, to obtain the normalizing arc peak current I_p, it is used from this fact that, for heavy current primary arcs, the arc voltage drop will be very small. Consequently, in order to estimate I_p, the fault is assumed as a solid fault, and fault analysis is then carried out to determine the fault current I_p, for the latter condition.

2.2. Solving the arc model equation

In order to model the primary arc, the differential equation should be replaced with difference equation as:

$$\frac{dg_p}{dt} = \frac{1}{T_p}\left(G_p - g_p\right) \rightarrow \frac{\Delta g_p}{\Delta t} = \frac{1}{T_p}\left(G_p - g_p\right) \tag{4}$$

Now, it is possible to obtain the conductivity of arc with:

$$g_{p1} = \left(g_{p0} + \frac{|i|\Delta t}{\alpha V_p I_p}\right)\left(1 + \frac{L_p \Delta t}{\alpha I_p}\right)^{-1} \tag{5}$$

where, g_{p0} is initial value of arc conductivity. This value changes in each iteration of solution procedure.

The characteristic of voltage and resistance of the arc in a 230 kV and 50 Hz power system is shown in Fig 1. It is seen that the resistance of the arc varies from 3-280 Ω and the voltage signal does not have a sinusoidal form.

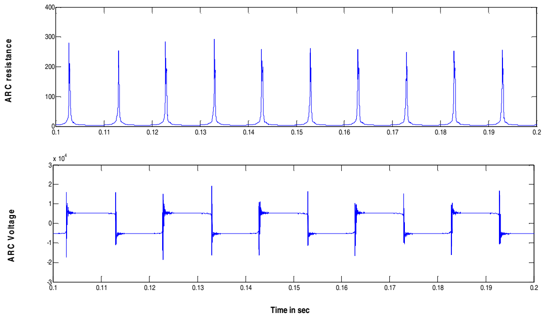

Fig.1 : Arc characteristic; resistance and voltage

3. THEORY OF TRAVELLING WAVE

Any sudden change in such as fault occurrence generates voltage and current traveling waves, which propagate in both directions of the transmission. These waves travel along the line to reach to the discontinuities such as fault point and terminals. In these points some part of wave will be reflected and reminder refracts [1]. The principle of travelling wave theorem can be illustrated by the lattice diagram shown in Fig 2.

Voltage and current signals at any point of the transmission line can be expressed using backward and forward travelling waves illustrated with f_1 and f_2, respectively. The voltage and current waves at a distance x and time t can be expressed as:

$$u(x,t) = f_1(x - vt) + f_2(x + vt) \tag{6}$$

$$i(x,t) = \frac{1}{Z_0}\left(f_1(x - vt) + f_2(x + vt)\right) \tag{7}$$

where, v is the propagation speed of the wave in the transmission line and Z_0 is the characteristic impedance of the line, which can be obtained as:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{8}$$

$$v = \frac{1}{\sqrt{LC}} = \frac{Z_0}{L} \tag{9}$$

Here L and C are inductance and capacitance of the line per unit length, respectively [10].

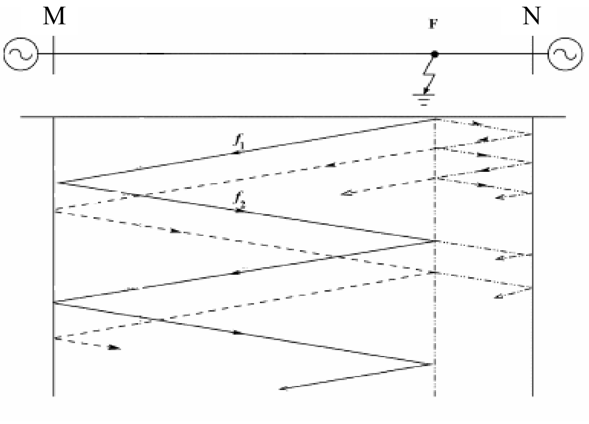

Fig. 2: Lattice diagram for a fault

4. TWO-TERMINAL FAULT LOCATION ALGORITHM BASED ON TRAVELLING WAVE

This paper presents a fault location algorithm based on two terminal travelling waves, which does not require the line parameters. Proposed algorithm takes samples from transient voltage signals in both terminals, which are generated by fault occurrence. Using modal decomposition, three phase voltages are decomposed into modal components. Then, wavelet is applied to the alpha mode signal, which is obtained by modal decomposition. Using details of first level of wavelet results, first and second inceptions of voltage travelling wave to the fault locator are detected. Thereupon, actual propagation speed of the travelling wave can be calculated and precise fault location will be calculated independent of line parameters.

In the two terminal fault location algorithm applied in this paper, the fault point is determined by measuring the time difference between the time of incident of travelling wave to both ends of the transmission line [13]. Because of using both terminals data, presented method requires to GPS, communication systems and data synchronization.

Suppose L_{line} is the line length and a fault occurs at point F. The travelling waves propagate in both directions of the line. The transmission line and lattice diagram of the travelling waves are shown in Fig. 3.

In Fig. 3, t_1 and t_2 are the time of first incepted travelling wave to the remote and near terminals, respectively.

L_l is distance between fault point and near terminal. The travelling wave propagation speed is v which can be calculated as:

$$v = \frac{L_{line}}{t_3 - t_2} \qquad (10)$$

Using wave speed obtained by (10) L_l can be calculated by:

$$L_l = \frac{L_{line} - ((t_1 - t_2)v)}{2} \qquad (11)$$

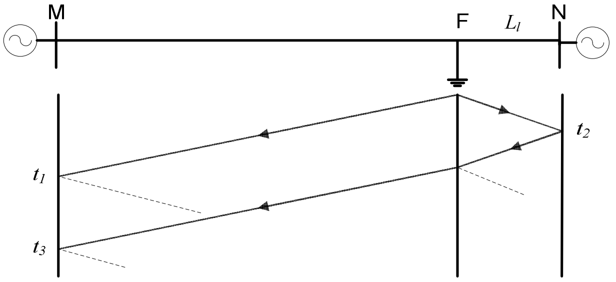

Fig. 3: The transmission line and lattice diagram of the traveling waves

5. SIMULATION RESULTS

To analyze the effect of arcing characteristics on the operation of double ended travelling wave fault locator which is based on travelling wave theorem, a simple power system such as shown in Fig. 4 is selected.

The 230kV transmission line with parameters presented in Table 1 operates in frequency of 50 Hz.

Table 1: Line data(100km length)

	Positive Sequence	Zero Sequence
R(Ω/km)	0.01165	0.2676
L(mH/km)	0.8679	3.008
C(nF/km)	13.41	8.57

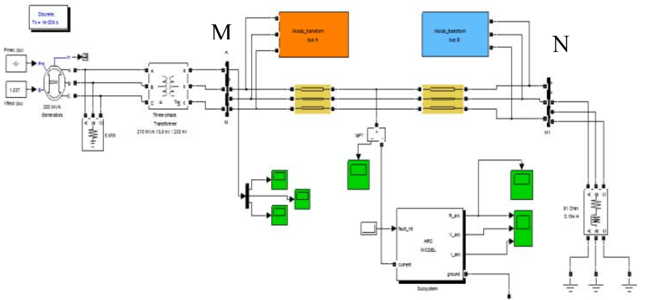

Fig. 4: Three phase diagram of test system

Arc parameters for test system are shown in Table 2.

Table 2 : Arc characteristic data

V_p (V/cm)	15	α	2.85*10^-6
L_p (cm)	350	Δt(sample time)	50*10^-6
G_{p0} (1/Ω)	0.05		

In order to determine I_p, the fault is assumed as a solid fault then peak value of current measured and use as I_p. Single phase to ground fault is considered because of 80% of transmission line faults are single phase fault to ground. To consider the influence of arc on the fault location algorithm, extent simulations are done.

To have a comparison between the faults with and without arc characteristics, two cases are considered.

In the first case single phase to ground fault is considered with a constant 5 Ω resistance and in the second one the fault is considered with an arc which its described model is in part 2 of this paper. Different conditions such as different fault inception angles and fault distances are tested for both mentioned cases and are compared with each other. Computational error for the distance calculated as fault location is obtained by equation (12):

$$\%error = \frac{x_{calculated} - x_{actual}}{L_{line}} * 100 \qquad (12)$$

where x_{actual} is actual distance of the fault point from the locator and $x_{calculated}$ is calculated fault location.

As an example, if a single phase to ground fault at phase A with the arc and zero fault inception angle occurs at distance 40 km far from bus M. Wavelet transform of alpha component of the decomposed signal at bus as M and N are shown in Fig. 5 and 6, respectively.

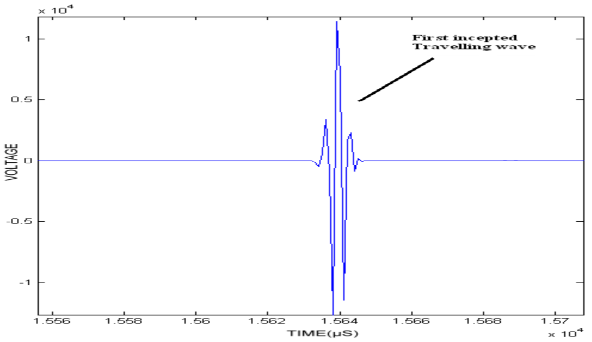

Fig. 5: Wavelet transform of alpha mode signal and detection of first inceptions of traveling wave at the bus M(near terminal to fault)

In this example t_1=15700 µsec, t_2=15631 µsec and t_3=15972 µsec. The wave speed is calculated equation (10) which is equal to v=293255132$\frac{m}{s}$. Location of fault is calculated with equation (11) and it is equal to 39882.69m.

The error for calculation of fault is equal to 0.117%. Almost all the travelling wave fault location algorithms are influenced by parameters such as fault distance and fault inception angle. Therefore, next subsections are devoted to investigate the effect of these parameters on the accuracy of proposed method.

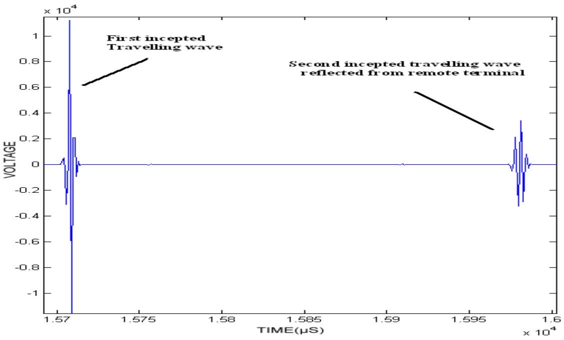

Fig. 6: Wavelet transform of alpha mode signal and detection of first and second inceptions of traveling wave at the bus N(far terminal to fault)

5.1. Influence of fault distance

Some of fault location algorithms are influenced by fault distance. So in this subsection it is aimed to investigate the effect of fault distance on the accuracy of the algorithm. Simulations are done for both situations including single-phase to ground fault with constant resistance 5 Ω and another case for single phase to ground fault with arc.

Simulation results for single phase to ground fault occurred at distance 13, 24, 31 km from terminal M and distance 49km from terminal N with a zero fault inception angle are presented in Table 3.

Table 3: Effect of location of fault on the accuracy of proposed algorithm

single fault	Resistance 5 Ω		ARC	
Distance(m)	Calculated fault distance(m)	Error%	Calculated fault distance(km)	Error%
13000	12941.17	0.0588	12886.59	0.1134
24000	23883.52	0.1164	23808.12	0.1918
31000	30882.35	0.1176	30803.3	0.1966
49000	49135.44	0.1176	49135.44	0.1354

From provided results of Table 3, it is obvious that the considering arc characteristic in fault, reduces the accuracy of method but reduction of accuracy is not significant.

5.2. Influence of fault inception angle

In this subsection the influence of fault inception angle on the accuracy of the algorithm is investigated. Similar to past subsection, simulations are repeated for single phase to ground faults with constant resistance 5 Ω and single phase to ground faults occurs with arc.

Simulation results for single phase to ground fault occurred at distance 20 km from terminal M with 30°, 45°,60° and 90° fault inception angle are presented in Table 4.

Table 4: Effect of fault inception angle on the accuracy of proposed algorithm

single fault	Resistance 5 Ω		ARC	
angle(deg)	Calculated fault distance(m)	Error%	Calculated fault distance(km)	Error%
30	19994	0.006	19956	0.044
45	19991.17	0.0088	19955.81	0.0441
60	19991.3	0.0087	19951.4	0.0486
90	19990.29	0.0097	19951.39	0.0486

Similarly, it is obvious results presented in Tables 4, that considering arc characteristics, will reduce the accuracy of travelling wave fault location method to some extent.

6. CONCLUSION

Almost in the all travelling wave fault location algorithms, the effect of fault arc characteristics on the calculation of fault location is neglected. In this paper a new challenge is discussed for fault location algorithms which are based on travelling wave theorem. So, the effect of arc characteristics on the travelling wave fault location algorithms is investigated. For this purpose, a double ended travelling wave-based fault location algorithm is considered. Applied algorithm is independent of line parameters and voltage samples taken from both terminals are used to calculate fault location. Simulation results indicate that arc characteristics will affect the accuracy of algorithm to some extent. This paper indicates the importance of studies to investigate the effect of arc characteristics on the accuracy of other travelling wave-based fault location algorithms such as single ended algorithms and algorithms which use current samples and etc. Therefore, additional studies are directed and results will be presented in the future.

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