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Accurate Fault Location Technique on Power Transmission Lines with use of Phasor Measurements

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***Abstract*— This paper presents a new approach to fault location on power transmission lines. This approach uses the phasor measurements at one end of the line and benefits from advantages of digital technology and numerical relaying, which are available today and can be applied for off-line analysis. This technique uses only end of data and accurate fault distance location is achieved after one cycle from the inception of fault. The analysis for fast identification of fault is evaluated based on the representation of the travelling waves through wavelet modulus maxima. The present criterion can detect the instant of fault, location of fault and kind of fault. MATLAB/ Simulink software was used to test the proposed approach. Various fault conditions were simulated by varying fault type, fault resistance, fault location and fault inception angle, on a given power system model. The simulation results demonstrate the validity of the proposed approach of faulted phase selection.**

Keywords—*Fault location, Current distribution factor, MATLAB, Fault impedance, Fault resistance, Fault inception angle.*

I. INTRODUCTION

Location of faults in power transmission lines is one of main concerns for all electric utilities as the accurate fault location can help to restore the power supply in the shortest possible time. Fault location methods for transmission lines are broadly classified as impedance based method which uses the steady state fundamental components of voltage and current values [1-3], travelling wave (TW) based method which uses incident and reflected TWs observed at measuring end(s) of the line [4,5], and knowledge based method which uses artificial neural network and/or pattern recognition techniques [6,7]. All the above methods use the measured data either from one end of transmission line or from all ends. The method which uses data from all ends requires synchronized measurement with time stamping and online communication of data to central location [8-13]. This paper describes a fault location determination method using fault current distribution factors on 400 KV transmission line.

II. PROPOSED FAULT LOCATION ALGORITHM

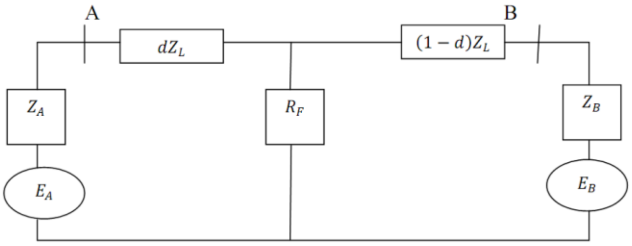

Fig.1 Fault network diagram

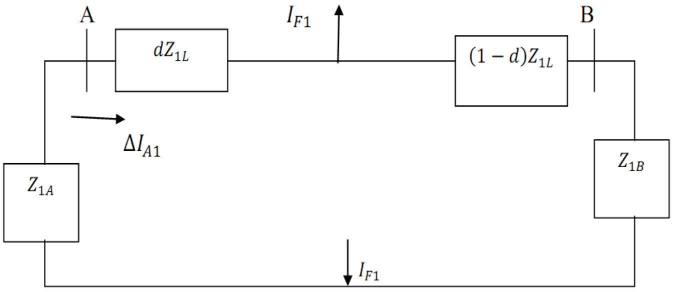

Fig.2. Incremental positive sequence network diagram

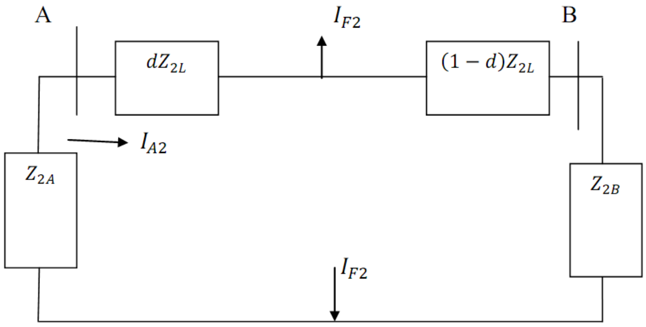

Fig.3.Negative sequence network diagram

d	Estimated distance to the fault (units: p.u)
V_{A_P}	Protective distance relay voltage at the line end A
I_{A_P}	Protective distance relay current at the line end A
I_F	Total fault current
Z_L	Total line impedance
V_F	Fault voltage
Z_A, Z_B	Source impedances at terminals A and B respectively
E_A, E_B	Source voltages at terminals A and B respectively
ΔI_{A1}	Incremental positive sequence current.
I_{A2}	Negative sequence current
Z_{1L}	Total positive sequence line impedance
Z_{2L}	Total negative sequence line impedance
Z_{1A} , Z_{1B}	Positive sequence source impedances at terminals A and B respectively
Z_{2A} , Z_{2B}	Negative sequence source impedances at terminals A and B respectively.

To derive the Fault location algorithm, the fault loop composed according to the fault classified type is considered. This loop contains the faulted line segment (between points AA and F) and the fault path itself. A generalized model for the fault loop is stated as fallows

$$V_{A\ P} - dZ_{1L} * I_{A\ P} - I_F * R_F = 0 \quad (1)$$

Where

$$I_F = a_{F1} * I_{F1} + a_{F2} * I_{F2} + a_{F0} * I_{F0} \quad (2)$$

Fault loop voltages and current can be expressed interns of the local measurements and with using coefficients gathered in Table 1

$$V_{A\ P} = a_1 V_{A1} + a_2 V_{A2} + a_0 V_{A0} \quad (3)$$

$$I_{A\_P} = a_1 I_{A1} + a_2 I_{A2} + a_0 \frac{Z_{0L}}{Z_{1L}} I_{A0} \quad (4)$$

Table1. Coefficients for determining signals defined in Equations (3) and (4)

$Fault\ Type$	a_1	a_2	a_0
AG	1	1	1
BG	a^2	a	1
CG	a	a^2	1
$AB, ABG, ABC, ABCG$	$1-a^2$	$1-a$	0
BC, BCG	a^2-a	$a-a^2$	0
CA, CAG	$a-1$	a^2-1	0
$a = exp(j2\pi/3)$			

Voltage drop across the fault path (as shown in the third term in Equation (1)) is expressed using sequence components of total fault current (I_{F0}, I_{F1}, I_{F2}). Determining this voltage drop requires establishing the weighting coefficients. These coefficients can accordingly be determined by taking the boundary conditions for particular fault type. However, there is some freedom for that. Thus, it is proposed firstly to utilize this freedom for avoiding zero sequence quantities. This is well known that the zero sequence impedance of a line is considered as unreliable parameter. This is so due to dependence of this impedance upon the resistivity of a soil, which is changeable and influenced by weather conditions. Moreover, as a result of influence of overhead ground wires, the zero sequence impedance is not constant along the line length. Thus, it is highly desirable to avoid completely the usage of zero sequence quantities when determining the voltage drop across the fault path. This can be accomplished by setting $I_{F0} = 0$ as shown in Table 2**,** where the alternative sets of the weighting coefficients are gathered. Secondly, the freedom in establishing the weighting coefficients can be utilized for determining the preference for using particular quantities. The negative sequence (Table 2) or the positive sequence (Table 2**)** can be preferred

For example, considering AG fault one has:

$$\begin{vmatrix} I_{F0} \\ I_{F1} \\ I_{F2} \end{vmatrix} = \frac{1}{3} * \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} * \begin{vmatrix} I_{FA} \\ 0 \\ 0 \end{vmatrix} \quad (4)$$

Thus, symmetrical components of a fault current are:

$$I_{F0} = I_{F1} = I_{F2} = \frac{1}{3} * I_{FA} = I_F \quad (5)$$

It follows from Equation (5) that the total faults current ($I_F = I_{Fa}$) can be expressed in the following alternative ways, depending on which symmetrical component is preferred:

$$I_F = 3 * I_{F1} \quad (6)$$

$$I_F = 3 * I_{F2} \quad (7)$$

$$I_F = 3 * I_{F0} \quad (8)$$

$$I_F = 1.5 * I_{F1} + 1.5 * I_{F2} \quad (9)$$

The total fault current (I_F) is expressed as weighted sum of its symmetrical components (I_{F1}, I_{F2}, I_{F0}) , which can be determined with use of fault current distribution factors:

$$I_{F1} = \frac{\Delta I_{A1}}{k_{F1}} \tag{10}$$

$$I_{F2} = \frac{I_{A2}}{k_{F2}} \tag{11}$$

$$I_{F0} = \frac{I_{A0}}{k_{F0}} \tag{12}$$

Taking into account a set of weighting coefficients that for zero sequence:$a_{F0} = 0$ and expressing the symmetrical components of total fault current with use of fault current distribution factors and one obtains:

$$I_F = a_{F1}\frac{\Delta I_{A1}}{k_{F1}} + a_{F2}\frac{I_{A2}}{k_{F2}} \tag{13}$$

Considering that for the fault current distribution factors for positive- and negative-sequence, with respect to their magnitude and angle, we have

$$k_{F1} = k_{F2} = |k_F|e^{j\gamma} \tag{14}$$

$$\gamma = angle(k_{F1}) = angle(k_{F2}) \tag{15}$$

The Equation (13) can be rewritten as

$$I_F = \frac{a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2}}{|k_F|e^{j\gamma}} \tag{16}$$

Substitute Equation (16) in the basic Equation (1)

$$V_{A\_P} - dZ_{1L} * I_{A\_P} - \frac{a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2}}{|k_F|e^{j\gamma}} * R_F = 0 \tag{17}$$

Multiplying the Equation (17) by the term$\left(e^{j\gamma}(a_{F1}\Delta I_{A1} + a_{F2}I_{A2})^*\right)$ yields

$$V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma} - dZ_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma} - \frac{R_F}{|k_F|} = 0 \tag{18}$$

Eliminating the term $\frac{R_F}{|k_F|}$ by taking imaginary parts of the Equation (18) and then rearranging, the resultant formula for the sought distance to fault (*d* (p.u.)) is obtained as follows:

$$d = \frac{Im\left(V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma}\right)}{Im\left(Z_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma}\right)} \tag{19}$$

$$d = \frac{Im\left(V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^*\right)}{Im\left(Z_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^*\right)} \tag{20}$$

In formula (19), the angle of the current distribution factor (for the positive or negative-sequence) is involved. It is proposed to assume that this angle equals zero (γ = 0), i.e., that the fault current distribution factor is a real number. In practice, this assumption is not completely fulfilled and thus there is a certain error due to this.

III. POWER SYSTEM MODEL

The SimPowerSystem which is an extension to the Simulink of MATLAB software was used to simulate the double end fed power system. The 100 km, 400 kV transmission line was modeled using distributed parameter model as shown in Fig.4

Table:2 Alternative sets of weighting coefficients

Fault type	*Set I*			*Set II*		
	a_{F1}	a_{F2}	a_{F0}	a_{F1}	a_{F2}	a_{F0}
AG	0	3	0	3	0	0
BG	0	$-1.5 + j1.5\sqrt{3}$	0	$-1.5 - j1.5\sqrt{3}$	0	0
CG	0	$-1.5 - j1.5\sqrt{3}$	0	$-1.5 + j1.5\sqrt{3}$	0	0
AB	0	$1.5 - j0.5\sqrt{3}$	0	$1.5 + j0.5\sqrt{3}$	0	0
BC	0	$j\sqrt{3}$	0	$-j\sqrt{3}$	0	0
CA	0	$-1.5 - j0.5\sqrt{3}$	0	$-1.5 + 0.5\sqrt{3}$	0	0
ABG	$1.5 + j0.5\sqrt{3}$	$1.5 - j0.5\sqrt{3}$	0	$1.5 + j0.5\sqrt{3}$	$1.5 - j0.5\sqrt{3}$	0
BCG	$-j\sqrt{3}$	$j\sqrt{3}$	0	$-j\sqrt{3}$	$j\sqrt{3}$	0
CAG	$1.5 - j0.5\sqrt{3}$	$1.5 + j0.5\sqrt{3}$	0	$1.5 - j0.5\sqrt{3}$	$1.5 + j0.5\sqrt{3}$	0
$ABC, ABCG$	$1.5 + j0.5\sqrt{3}$	$1.5 - j0.5\sqrt{3}$	0	$1.5 + j0.5\sqrt{3}$	$1.5 - j0.5\sqrt{3}$	0

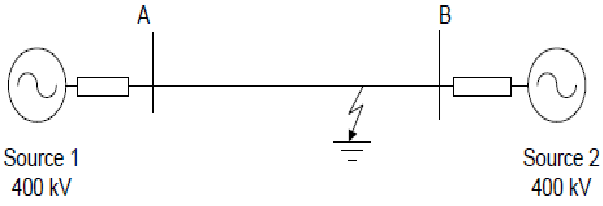

Fig.4 Power System model

The transmission line parameters are as follows:
Positive Sequence Resistance, R_1 : 0.0275 Ω / km
Zero Sequence Resistance, R_0 : 0. 275 Ω/km
Zero Sequence Mutual Resistance, R_{0m} : 0.21 Ω/km
Positive Sequence Inductance, L_1 : 0.00102 H/km
Zero Sequence Inductance, L_0 : 0.003268 H/km
Positive Sequence Capacitance,C_1 : 13 $e^{-0.009}$ F/km

IV. SIMULATION RESULTS

The fault location error is calculated as

$$Error(\%) = \frac{|Calculated\ Fault\ Location - Actual\ Fault\ Location|}{Total\ Line\ Length} * 100 \quad (21)$$

V.CONCLUSION

In this paper, the new accurate algorithm for locating faults on power transmission line with use of the phasor measurements of voltages and currents at one end of the line has been presented. Since numerical relays often store oscillographic and phasor information following the occurrence of a fault, the algorithm can be implemented using information which should be readily available. The complexity of all ten types of faults, fault locations (0-100km), fault inception angles (0-90^0), fault resistance (0-100 Ω) are considered. The simulation results show that all ten types of faults are correctly located with fault location error less than 1%.

Table 4: Results for all 11 types of faults

Fault Type	Fault Resistance	Actual Fault Location	Estimated Fault Location	Error (%)
LG	84	18	17.1766	0.8234%
LG	194	36	35.4792	0.5208%
LG	106	54	53.1764	0.8236%
LG	55	75	74.1868	0.8132%
LG	25	86	85.2781	0.7219%
LLG	100	12	12.3849	0.3849%
LLG	166	64	64.2147	0.2147%
LLG	128	48	48.1589	0.1589%
LLG	74	8	8.1988	0.1988%
LL	6	44	44.0529	0.0529%
LL	14	94	95.5680	1.5680%
LLL	2	26	25.3589	0.6411%
LLL	16	56	56.1358	0.1358%

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