Fault Location and Fault Section Identification in Multi Section Lines using Single Ended Information

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***Abstract* —The objective of a protective device is to detect and clear the faults occurring on the transmission lines with reliability and also, the accurate location of a fault is essential for those involved in operation and maintenance. This paper presents the fault location and fault section identification techniques for a multi section transmission line using single ended information. If a transmission line is composed of more than one line section between two substations, the transmission line parameters are different for each section and the fault location estimation is challenging in these conditions. The proposed method considers the transmission line parameters of each section in estimating the fault location. Simulation studies are carried out using MATLAB/SIMULINK and hardware-in-loop testing is also carried out using RelaySim simulator for a 2 – phase, 16.7 Hz transmission system. The results show accuracy of the proposed method for significant fault resistance.**

Keywords— Fault location, Fault section identification, Multi section, Single end

I. INTRODUCTION

The fault locator in a protective device is used to estimate the distance to a fault occurring on the transmission lines. An accurate fault location helps in fast restoration of the power supply. The fault location algorithms will be available along with the numerical distance relays. There are various methods of fault location algorithms are described in [1–4], viz.

- Single ended
- Double ended
- Multi ended voltages and currents

In all above methods, the transmission lines are made up of a single conductor. If the transmission line is composed of different line sections due to geographical constraints, the transmission line parameters are different for each section. It cannot be considered as a single line model in fault location algorithm, which will otherwise produces the erroneous results.

In [4], a negative sequence based method was proposed for the estimation of a fault location in case of multi section lines using both end phasor information.

In this paper, a method for fault location estimation and fault section identification for a multi section transmission line is proposed by considering the sequence impedances of each section of a transmission line. Fig. 1 depicts the transmission line composed of three different line sections between Source A and Source B.

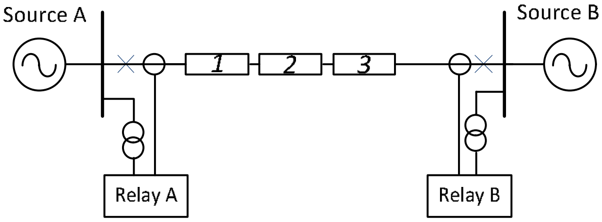

Fig. 1. Power transmission system with three line sections

Fig. 2 indicates the errors in measurement of fault location if the three line sections are considered as single transmission line in estimating the fault location for a fault occurred in the power system in comparison with combined transmission line.

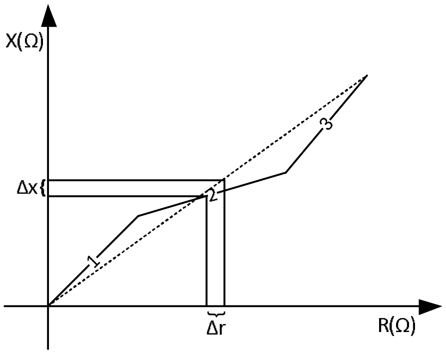

Fig. 2. R – X diagram indicating the error

In the case of phase to ground faults, the difference in the zero sequence parameters further degrades the accuracy of the fault location algorithm. Hence, it is important to consider each section parameter in the fault location algorithm for a multi section transmission line.

The proposed method uses only the local end voltage and current information to estimate the distance to a fault in multi section transmission lines.

II. THE PROPOSED METHOD

As described in section I, the proposed algorithm is derived for a typical power system shown in Fig. 1.

The algorithm consists of the following steps:

- Selection of fault phasors based on fault loop
- Fault section detection
- Voltage compensation
- Fault location algorithm considering only single faulted line section

A. *Selection of fault phasors*

Based on the fault loop detected in a protective device, the voltage and current phasors can be selected as shown in Table I and Table II for 3-phase and 2-phase transmission systems respectively.

TABLE I. FAULT PHASOR SELECTION BASED ON FAULT LOOP IN 3-PHASE TRANSMISSION SYSTEM

Fault Loop	**U_f**	**I_f**	**I_N**
L1E	*UL1N*	*IL1*	*IN*
L2E	*UL2N*	*IL2*	*IN*
L3E	*UL3N*	*IL3*	*IN*
L1L2/L1L2E	*UL1L2*	*IL1L2*	*0*
L2L3/L2L3E	*UL2L3*	*IL2L3*	*0*
L3L1/L3L1E	*UL3L1*	*IL3L1*	*0*
L1L2L3/L1L2L3E	*UL1L2*	*IL1L2*	*0*

TABLE II. FAULT PHASOR SELECTION BASED ON FAULT LOOP IN 2-PHASE TRANSMISSION SYSTEM

Fault Loop	**U_f**	**I_f**	**I_N**
L1E	*UL1N*	*IL1*	*IN*
L2E	*UL2N*	*IL2*	*IN*
L1L2	*UL1L2*	*IL1L2*	*0*

where,

U_f: The fault loop voltage

I_f: The fault loop current

I_N: Neutral current

B. *Fault section detection*

The fault section detection algorithm is a close approximate of fault location by considering that the fault resistance is negligible.

The algorithm to detect the fault section at the fault point is

V – IZ = 0 (if fault resistance = 0)

For each section, the fault factor x_i, where i = section number, is evaluated. If the fault factor calculated from the remote end to the local end is positive, the corresponding section is identified as faulty section.

The fault factors are calculated for each section as:

In the case of section 1,

$$x_1 = real\left(\frac{U_f}{(I_f * Z_{11} + I_N * Z_{N1})}\right) \quad \text{... (1)}$$

In the case of section 2,

$$x_2 = real\left\{\frac{(U_f - I_f * Z_{11} - I_N * Z_{N1})}{(I_f * Z_{12} + I_N * Z_{N2})}\right\} \quad \text{... (2)}$$

where,

Z_{11}, Z_{12}: Positive sequence impedance of section 1 and 2 respectively.

The neutral impedances of section 1 & 2 are

$$Z_{N1} = \frac{(Z_{01} - Z_{11})}{KFact} \quad \& \quad Z_{N2} = \frac{(Z_{02} - Z_{12})}{KFact}$$

Where, $KFact = \begin{cases} \text{2 for 2 phase system} \\ \text{3 for 3 phase system} \end{cases}$

Thus, the generalized equation to find the fault factor x_i for the i^{th} section as

$$x_i = real\left\{\frac{U_f - U_{drop}(i-1)}{(I_f * Z_{1i} + I_N * Z_{Ni})}\right\} \quad \text{... (3)}$$

where,

$$U_{drop}(i-1) = \begin{cases} 0 & if \ \ i = 1 \\ I_f * \sum_{k=1}^{i-1} Z_{1k} + I_N * \dfrac{\sum_{k=1}^{i-1}(Z_{0k} - Z_{1k})}{KFact} & \end{cases}$$

Z_{1i}: Positive sequence impedance of section *i*

Z_{0i}: Zero sequence impedance of section *i*

Z_{1k}: Positive sequence impedance of section *k*

Z_{0k}: Zero sequence impedance of section *k*

Following gives the basis for identifying the correct fault sections based on “x_i “factors

i) Case 1 : Fault is in section 1

$\underline{x_1 >= 0.0}$; x_2 < 0.0; x_3 < 0.0

ii) Case 2 : Fault is in section 2

x_1 > 1.0; **$\underline{x_2 >= 0.0}$**; x_3 < 0.0

iii) Case 3 : Fault is in section 3

x_1 > 1.0; x_2 >1.0; **$\underline{x_3 >= 0.0}$**

Instead of comparing with zero, it can be compared with some factors based on test results in-order to avoid the in-accuracies caused due to wrong fault section detections at the junctions.

C. *Voltage compensation*

In order to reduce the errors due to non-homogeneity of the transmission line, the estimation of voltage and the fault location for a faulted section can be evaluated by the corresponding line section parameters as a single section.

The calculation of voltage until the beginning of the estimated faulty line section is given as:

$$U_{Comp} = U_f - U_{drop}(i-1) \quad \text{... (4)}$$

where,

U_{Comp}: Compensated voltage

U_f: Fault loop voltage

D. *Fault location algorithm considering as a single section*

After estimating the fault section and evaluating the compensated voltage, the system can be modelled as a single section transmission line. The simplified equivalent network to estimate the fault location is depicted in Fig. 3.

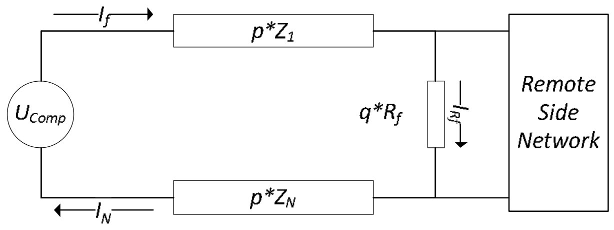

Fig. 3. Simplified equivalent network for fault location estimation

By applying Kirchhoff's Voltage Law for the network shown in Fig. 3,

$$U_{Comp} = I_f * p * Z_1 + I_{Rf} * q * R_f + I_N * p * Z_N \quad \text{... (5)}$$

By separating real and imaginary components from Eqn. 5, p and q are calculated.

Therefore, the distance to a fault in multi section transmission line is:

$$FLTDIST = \sum_{k=1}^{k=i-1} LineLength_k + p * LineLength_{FaultSection} \quad \text{… (6)}$$

where,

$FLTDIST$: Distance to a fault

$\sum_{k=1}^{k=i-1} LineLength_k$: Sum of line lengths of all sections up to the identified fault section

p: Fault distance in per unit

$LineLength_{FaultSection}$: Length of faulty section

III. RESULTS AND DISCUSSIONS

Simulation studies are carried out using MATLAB/SIMULINK to evaluate the performance of the proposed method. Following two systems are considered for evaluating the performance of the method mentioned in section II.

- 110 kV, 2 – phase, 16.7 Hz network with 3 line sections
- 110 kV, 3 – phase, 50.0 Hz network with 3 line sections

A. 2 – phase, 16.7 Hz *double bus system*

The single line diagram of a network considered is shown in Fig. 1 and the transmission line parameters are provided in the Appendix.

The measured voltages and currents at Source A are fed to the proposed method. Results obtained are plotted in Fig. 4 and Fig. 5 for L1N and L1L2 faults created at various positions on each line section.

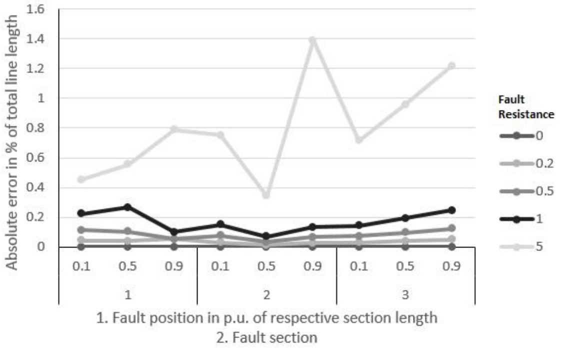

Fig. 4. 2 – phase L1N fault with varying fault resistance

From the Fig. 4, it can be observed that error is within 2% for faults with fault resistance up to 5.0 Ω. Also, the error is increased with the increasing fault resistance and the fault position is moved towards the remote end.

Results for a 2 – phase system with L1L2 faults is shown in Fig. 5.

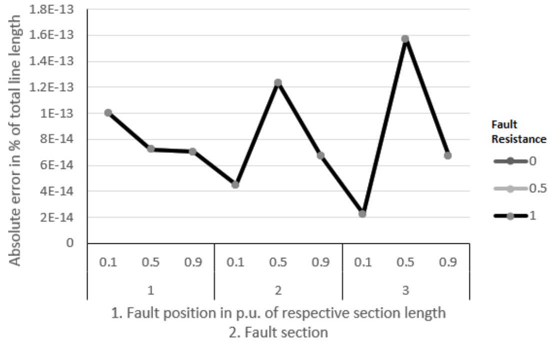

Fig. 5. 2 – phase L1L2 fault with varying fault resistance

From the Fig 5, no error is observed for L1L2 fault with fault resistance up to 1.0 Ω. As the L1L2 fault is a symmetrical fault for 2 – phase systems, there is no effect of fault resistance on the fault location estimation.

B. 3 – phase, 50.0 Hz *double bus system*

The single line diagram of a network considered is shown in Fig. 1 and the transmission line parameters are provided in the Appendix.

Results obtained are plotted in Fig. 6 and Fig. 7 for L1N and L1L2 faults created at various positions on each line section.

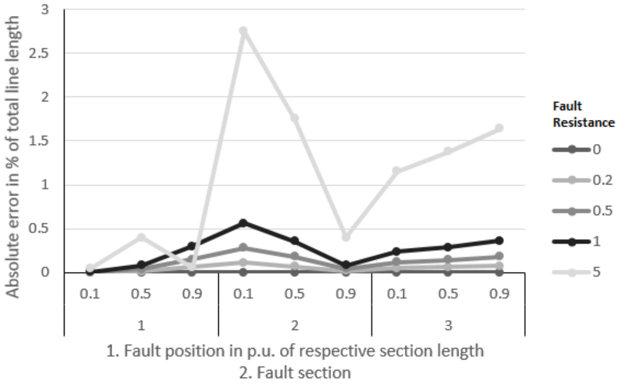

Fig. 6. 3 – phase L1N fault with varying fault resistance

From the Fig 6, it can be observed that error is below 3.0% for a L1N fault with fault resistance up to 5.0 Ω. The effect of remote end in-feed on the accuracy of fault location can be seen when fault position is created towards remote end.

Results for a 3 – phase system with L1L2 faults is shown in Fig. 7.

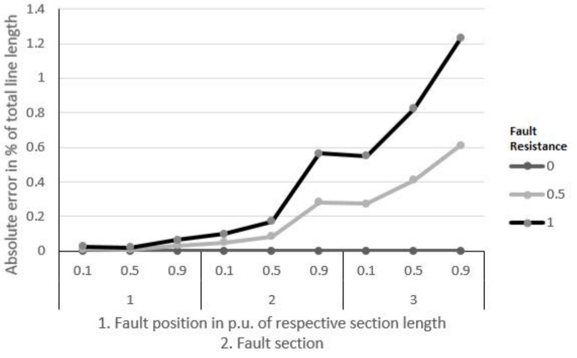

Fig. 7. 3 – phase L1L2 fault with varying fault resistance

From the Fig. 7, it can be observed that error is below 2.0% for a L1L2 fault with fault resistance up to 5.0 Ω. As the phase to phase fault is an unsymmetrical fault, the effect of remote end in-feed can be seen on the accuracy of fault location.

A comparison is performed with the results obtained from the same algorithm considering the whole transmission line as single section and providing the line parameters as the sum of three sections. The faults considered are with very low fault resistances. It can be observed from the Fig. 8 that the error is significantly more than the error obtained by considering the three sections separately.

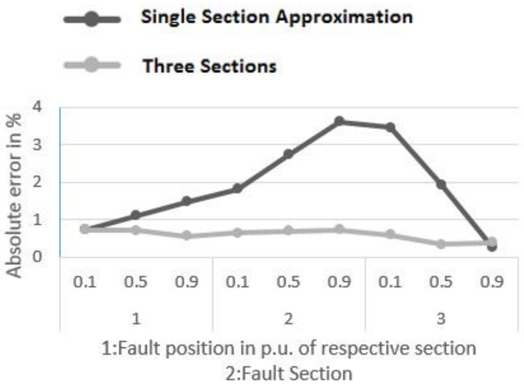

Fig. 8. Error due to the single section approximation

C. Hardware-In-Loop (HIL) testing

The proposed method is implemented in a numerical relay to evaluate the performance of an algorithm and the testing is carried out using Omicron's RelaySim simulator on a 2 – phase, 16.7 Hz radial power system. The test set-up is shown in the Fig. 9.

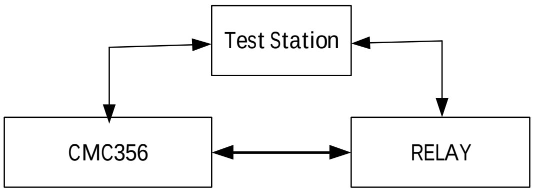

Fig. 9. Test set-up with RelaySim for HIL testing

The test station is connected to Omicron's CMC356 and RELAY. The analog channel connection exists between the CMC 356 and the RELAY. A view of single line diagram of the network considered using RelaySim simulator is shown in the Fig. 10. The voltage and current signals generated by RelaySim simulator are shown in Fig. 11.

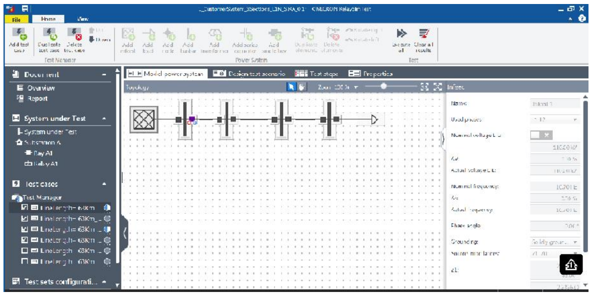

Fig. 10. RelaySim Omicron software tool

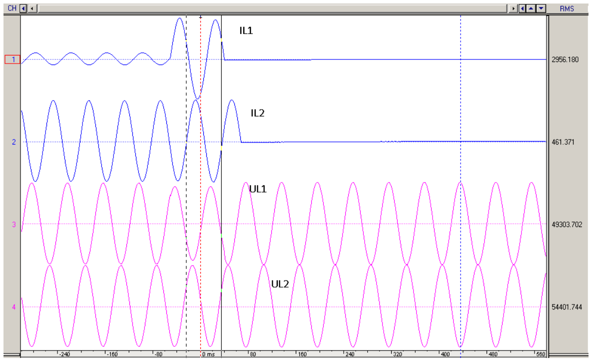

Fig. 11. Analog signal waveforms for a 2 – phase system generated by RelaySim simulator

The single line diagram of system considered is shown in Fig. 12.

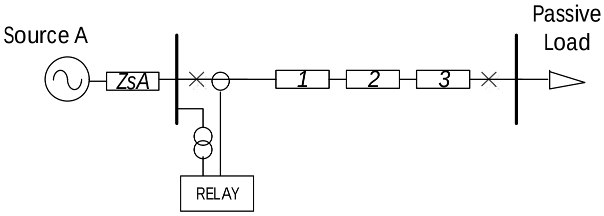

Fig. 12. single line diagram of a network considered for testing

Both the L1N and L1L2 faults are considered for different fault positions in a transmission line. Fig. 13 indicates the error for a fault resistances of 0.0 and 10.0 Ω. The maximum error reported in these cases is close to 2.0%.

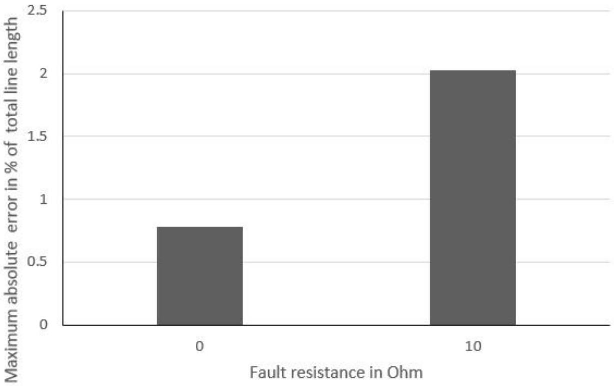

Fig. 13. Absolute error percentage for fault resitance 0, 10 Ohm

CONCLUSION

A fault location technique and a method to identify the faulted section in a multi section transmission line configuration is described. A comparison is made between the results obtained by considering the transmission line as a single section and three different sections. The results show accuracy of the proposed method for significant fault resistance.

APPENDIX

TRANSMISSION LINE PARAMETERS FOR 2-PHASE 16.67HZ SYSTEM

Section	Section 1	Section 2	Section 3	Total
Distance[Km]	4.8	40.3	18.200	63.300
R1[ohm]	0.575	11.1	5.609	17.306
X1[ohm]	1.206	10	4.765	16.005
R0[ohm]	0.543	8.29	3.752	12.588
X0[ohm]	1.284	12.4	6.858	20.571

TRANSMISSION LINE PARAMETERS FOR 3-PHASE 50HZ SYSTEM

Section	1	2	3	SUM
Distance[Km]	80	30	50	160
R1[ohm]	2.8776	6.1518	2.8437	11.8731
X1[ohm]	23.0208	6.1518	14.2184	43.391
R0[ohm]	8.6328	15.9948	6.2561	30.8837
X0[ohm]	69.0625	15.9948	31.2805	116.3378

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