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FAULT LOCATION ESTIMATION USING GAUSS-SEIDEL ITERATIVE ALGORITHM*

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ABSTRACT

In this paper, a method for determination of the fault location in a distribution power line is presented. This method can be applied for single-ended power line and double-ended power lines. It is capable to determine the fault location upon its occurrence, based on the voltage and the current measurements available from the measuring equipment. This method depends on an algorithm that uses Gauss-Seidel iterative technique for solving the fault equation to calculate the fault location and the fault resistance. The proposed method was tested through Matlab simulation and achieved suitable results to be applied. Thus, it can be used to build a stand-alone fault locating equipment that helps the maintenance team to determine the location of the fault.

KEY WORDS: Fault location, Gauss-Seidel, Distribution Power Line.

LOCALISATION DE DÉFAUT ESTIMATION PAR GAUSS-SEIDEL ITÉRATIF ALGORITHME *

RÉSUMÉ

Dans cet article, un procédé de détermination de la localisation de défaut sur une ligne d'alimentation de distribution est présentée. Cette méthode peut être appliquée à la ligne de puissance unipolaires et lignes électriques à double culot. Il est capable de déterminer la localisation de défaut lors de la survenance, en fonction de la tension et les mesures de courant disponible à partir de l'équipement de mesure. Cette méthode repose sur un algorithme qui utilise Gauss-Seidel technique itérative pour la résolution de l'équation d'erreur pour calculer l'emplacement du défaut et de la résistance de défaut. La méthode proposée a été examinée par la simulation Matlab et a obtenu des résultats appropriés à appliquer. Ainsi, il peut être utilisé pour construire un équipement de défaut de positionnement autonome qui permet à l'équipe de maintenance afin de déterminer l'emplacement du défaut.

MOTS CLÉS: localisation des défauts, Gauss-Seidel, de distribution d'alimentation de ligne.

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1- INTRODUCTION

Electrical distribution power lines are intended to process the transfer of electrical energy generated by the power plant to the beneficiaries. Configuration of these lines are classified as single ended line (radial) as shown in figure (1) and double ended through another parallel line as shown in figure (2).

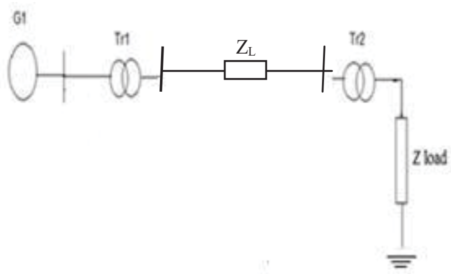

Fig.1: Single-Ended Line at the Steady Condition

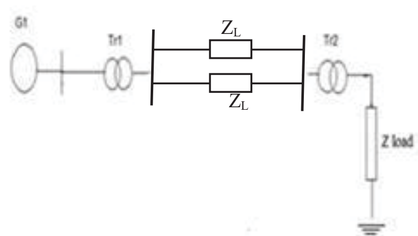

Fig.2: Double-Ended Line at the Steady Condition

Fault location is one of the main concerns for all electric utilities, as the accurate fault location can help to restore the power supply in the shortest possible time. Many researchers developed digital fault location techniques with a major emphasis on distribution systems. Y. Aslan and Aggarwalt (2) presented a technique for fault location on overhead distribution feeders using measurements of pre- and during-fault voltage and current phasors at the sending node of a substation during-fault. Pereira et al (14)presented a fault location algorithm based on extracting the superimposed voltage and current components from the measured signals Espaa et al (6) presented a strategy that only used the information contained in the single end measurements of the fundamental of current and voltage , based on the determination of the minimum fault reactance considering load uncertainties Yan and tian (7) and Dwivedi and yu (8) proposed two different methods for locating faults in a radial distribution lines using travelling waves

This paper describes a fault location and fault resistance determination method using Gauss-Seidel iterative technique that can be applied to both single-ended (Figure.1) and double-ended line through another parallel line (Figure.2), short and medium power lines. The inputs to the algorithm are the voltage and the current measurements at the relay point.

2- THE STUDIED MODEL

The studied model shows a 13.8 kV, 25 MVA generator with step up transformer Δ / Y_g 13.8/66 kV, 25 MVA and a power line with length 100 Km and step down transformer 66/13.8 kV ,25 MVA [3]. The line with sufficient accuracy can be modeled by series impedance Z_L, and neglecting the mutual effect. The model data can be found in the appendix. To induce a fault in the modeled power line, a point in the line has to be connected to ground through a resistance (fault resistance R_f) as shown in figure (3) for single ended line at the fault condition and figure (4) for double ended line at the fault condition. At that point, the line is represented with two sections, the first one with a distance equal to the distance from the relay point upto the fault location (X), and the second one with a distance equal to the total length of the line minus the fault distance (L-X). The two models have been simulated using MatlabR2010b environment [5].

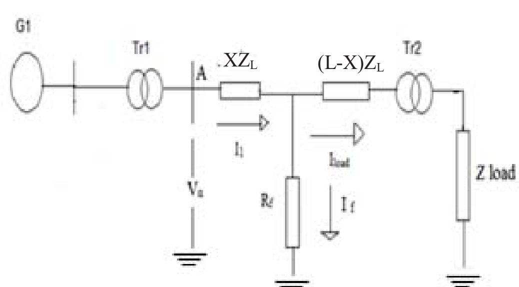

Fig.3: Single-Ended Line at the Fault Condition

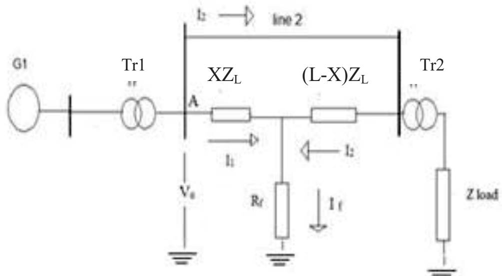

Fig. 4: Double-Ended Line at the Fault Condition

3- THE DEVELOPED FAULT LOCATION ALGORITHM

3.1 Case (1) Single-Ended Power Line

For single-ended power line at the fault condition, shown in Figure (3) the relation between the measured voltage, the measured fault current and the line impedance at the relay point for the phase-to-earth loop can be written as in equation (1)

$V_\alpha = I_1.X.Z_L + I_f.R_f$ (1)

Where

$I_1 = (I_\alpha + k_0 . 3I_0)$ (2)

The symbol α refers to any one phase such as A, B or C and k_0 is the residual compensation factor [1], which can be calculated from the line positive Z_{L1} and zero sequences impedances Z_{L0} parameters of the chosen line as in equation (3)

$K_0 = (Z_{L0} - Z_{L1}) / (3. Z_{L1})$ (3)

$I_1 = I_f + I_{load}$

Because $I_f >>> I_{load}$, therefore I_{load} can be neglected in mathematical calculation of fault current equation ($I_f = I_1 - I_{load}$), but (I_{load}) has very small value with compared to I_f through simulation process.

The fault current is approximated as the current seen at the relay point as in (4)

$I_f = I_1$ (4)

So equation (1) can be re-written as in equation (5)

$V_\alpha = Z_L . X. (I_\alpha + k_0 . 3I_0) + R_f . (I_\alpha + k_0 . 3I_0)$ (5)

From equation (5), the fault location X and the fault resistance R_f can be estimated

$X = (V_\alpha - R_f .(I_\alpha + k_0 . 3I_0)) / (Z_L. (I_\alpha + K_0 .3I_0))$ (6)

$R_f = (V_\alpha - Z_L . X .(I_\alpha + K_0 .3I_0)) / (I_\alpha + K_0 .3I_0)$ (7)

The same process can be repeated for the phase to phase fault loops

$V_{\alpha\beta} = I_{\alpha\beta} .X.Z_L + I_f.R_f$ (8)

The symbol αβ refers to any two phases such as AB, AC or BC

$I_f = I_{\alpha\beta}$ (9)

By substitute equation (9) in equation (8),

the measured voltage at the relay point for the phase-to-phase loop can be written as in equation (10)

$V_{\alpha\beta} = I_{\alpha\beta} .X.Z_L + I_{\alpha\beta} .R_f$ (10)

Where

$V_{\alpha\beta} = - (V_\alpha - V_\beta)$ and $I_{\alpha\beta} = - (I_\alpha - I_\beta)$

$(V_\alpha - V_\beta) = (I_\alpha - I_\beta) .X. Z_L + (I_\alpha - I_\beta). R_f$ (11)

From equation (11), the fault location X and the fault resistance R_f can be calculated as following:

$X = (V_\alpha - V_\beta) - (I_\alpha - I_\beta) .R_f / (I_\alpha - I_\beta) . Z_L$ (12)

$R_f = (V_\alpha - V_\beta) - (I_\alpha - I_\beta) .X. Z_L / (I_\alpha - I_\beta)$ (13)

By using Gauss-Seidel iterative method [9] with zero initial condition for (X & R_f), equations (6,7) for single phase to ground faults and equations (12,13) for double phases faults ; can be solved to calculate the values of fault location X and fault resistance R_f can be estimated.

3.2 Case (2) Double -Ended Power Line

For double-ended power line at the fault condition, shown in Figure (4) the relation between the measured voltage, the measured fault current and the line impedance at the relay point for the phase-to-earth loop can be written as in equation (14)

$V_\alpha = I_1.X.Z_L + I_f.R_f$ (14)

Where

$I_f = I_1 + I_2$ (15)

By substituting equation (15) into equation (14), the measured voltage at the relay point can be rewritten as following:

$V_\alpha = I_1.X.Z_L + (I_1 + I_2). R_f$ (16)

$V_\alpha = I_1.X.Z_L + I_1 R_f + I_2.R_f$ (17)

Equation (17) can be presented an equation that contains on three variables the fault location (X), the fault resistance (R_f) and the infeed current (I_2). If repeated the same procedures previous of Gauss-Seidel iterative method that used in single ended power line to solve this equation, then it is found that the solution will not be converge i.e. it diverges because the initial conditions for (R_f) that supposed with different values between (0 – 0.1) as shown in equation (18). So, it is suggested that the infeed current (I_2) can be neglected in mathematical calculation of equation (17) because of divergence solution of I_2 as indicated above, and so $I_2 <<< I_1$ in fault current equation ($I_f = I_1 + I_2$), but (I_2) has very small value with compared to I_1 through simulation process.The value of measured (I_2) is not constant on length of line, but it is changing which it depends on fault location and fault type occurrence on length of line.

∴The fault current (I_f) is approximated as the current seen at the relay point (I_1) and so the equation (17) will tends to equation (1), or another suggestion (I_2) can be measured by measurement elements that are connected on health parallel line (line 2) as shown in figure (4) .As the infeed current (I_2) can be measured, then the fault location (X) and the fault resistance (R_f) can be estimated accurately by using Gauss-Seidel iterative method as shown in equations (19) and (20).

$$I_2 = (V_\alpha - (I_\alpha + K_0 .3I_0)(X.Z_L + R_f)) / R_f \quad (18)$$

$$X=(V_\alpha - R_f .(I_\alpha + K_0 .3I_0 + I_2))/(Z_L. (I_\alpha + K_0.3I_0)) \quad (19)$$

$$R_f = (V_\alpha - Z_L .X. (I_\alpha + K_0 .3I_0))/(I_\alpha + K_0 .3I_0 + I_2) \quad (20)$$

The same process can be repeated for the phase to phase fault loops as shown in equations (21), (22) and (23) respectively as following:

$$I_2 = (V_{\alpha\beta} - I_{\alpha\beta} (X.Z_L + R_f)) / R_f \quad (21)$$

$$X = V_{\alpha\beta} - (I_{\alpha\beta} + I_2) .R_f / (I_{\alpha\beta} . Z_L) \quad (22)$$

$$R_f = (V_{\alpha\beta} - I_{\alpha\beta}.X. Z_L) / (I_{\alpha\beta} + I_2) \quad (23)$$

4- RESULTS AND COMMENTS

Many test cases are carried out to examine the developed fault location and fault resistance algorithm using the models shown in figures (1) and (2), 66 kV medium line with length of about 100 Km is chosen to be under study. The test cases were simulated taking into account the following features:

- Changing the fault location along the line.
- Changing the types of fault.
- Changing the value of fault resistance (R_f).
- Changing the pre-fault conditions, by applying the method for different loads (11.6 MVA at 0.85 lagging p.f and 23.3 MVA at 0.85 lagging p.f)
- Changing configuration of the network (single ended line and double ended line through another parallel line).
-

The tables (1, 2, 3 and 4) show the results of the fault location and fault resistance in case of single ended line with two different load conditions (11.6 MVA, 0.85 lagging P.F) and (23.3 MVA, 0.85 lagging P.F), for various type of faults at different fault locations and different fault resistances. Number of the required iterations to estimate correct values for fault location and fault resistance with tolerance (10^{-4}) is found among (5-8) iteration.

The same faults conditions have been repeated for double ended line with neglecting the infeed current (I_2), the results are shown in tables (5, 6 , 7 and 8). It is clear that, for single ended line, the algorithm succeeded in estimating the fault location with maximum percentage error is (1.3%) and fault resistance with maximum percentage error is (5.7%) approximately. With respect to results of double ended line, the algorithm calculates the fault resistance with maximum percentage error about (60%) due to neglecting of the infeed current that represents the worst case error for fault resistance through fault (B-C),fault (A-C-N) and fault (A-B-C) under R_f = 10 Ω, X_f = 77 km with load (11.6 MVA, 0.85 lagging P.F) for Case Neglecting (I_2) at table (6). Although the fault resistance is not accurate, it improves the results of fault location, where the percentage error of fault location will not exceed about (2.5%).

All worst fault conditions have been repeated for double ended line will be improved with taking into account the infeed current (I_2) measurement in the fault equation, and the results are shown in tables (9& 10). It is found, When the algorithm does not neglect the infeed current (I_2), the maximum percentage error of fault resistance will decrease (1.6%).

. So, the proposed algorithm achieves the following benefits; it is an accurate and a simple algorithm to calculate the fault resistance and the fault location, which is the main concern, for different fault conditions with changing the line configuration.

Also it is important to mention that, the fault type must be detected before starting the algorithm.

Table (1): The Results of the Single Ended Line Faults at 33 Km from the Relay Point with Load (11.6 MVA, 0.85 lagging P.F)

Fault type	Actual Fault Location = 33 Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	33.0327	0.5342	32.8946	3.5224	32.6873	9.9815
B-C	33.1313	0.5201	33.1794	3.4887	33.5074	9.8153
A-C-N	33.1133	0.5064	33.1690	3.4839	33.5069	9.8150
A-B-C	33.1419	0.5025	33.1888	3.4835	33.5081	9.8150

Table (2): The Results of the Single Ended Line Faults at 77 Km from the Relay Point with Load (11.6 MVA, 0.85 lagging P.F)

Fault type	Actual Fault Location = 77 Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	77.2093	0.5342	76.9920	3.7045	76.7079	10.4776
B-C	77.4535	0.5201	77.4972	3.5147	77.8271	9.8674
A-C-N	77.4107	0.5064	77.4655	3.5017	77.8234	9.8654
A-B-C	77.4759	0.5025	77.5212	3.4998	77.8314	9.8654

Table (3): The Results of the Single Ended Line Faults at 33 Km from the Relay Point with Load (23.3 MVA, 0.85 lagging P.F)

Fault type	Actual Fault Location = 33 Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	33.0220	0.5049	32.8344	3.4612	32.6467	9.7532
B-C	33.1347	0.5096	33.2454	3.4696	34.0055	9.6648
A-C-N	33.1169	0.5042	33.2349	3.4653	34.0050	9.6645
A-B-C	33.1432	0.5024	33.2533	3.4647	34.0063	9.6645

Table (4): The Results of the Single Ended Line Faults at 77 Km from the Relay Point with Load (23.3 MVA, 0.85 lagging P.F)

Fault type	Actual Fault Location = 77 Km From the relay point					
	R_f = 0.5 Ω		R_f = 3.5 Ω		R_f = 10 Ω	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	78.0792	0.57496	76.8716	3.6197	76.6120	10.1511
B-C	77.4609	0.5180	77.5663	3.4921	78.3185	9.6976
A-C-N	77.4188	0.5063	77.5346	3.4809	78.3144	9.6956
A-B-C	77.4771	0.5016	77.5849	3.4781	78.3225	9.6955

Table (5): The Results of the Double Ended Line Faults at 33 Km from the Relay Point with Load (11.6 MVA, 0.85 lagging P.F), (With Neglecting (I_2))

Fault type	Actual Fault Location = 33 Km From the relay point					
	R_f = 0.5 Ω		R_f = 3.5 Ω		R_f = 10 Ω	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	33.0598	0.4609	33.1513	3.2022	33.3708	9.0955
B-C	33.1218	0.6087	33.0901	4.1786	33.1148	11.8149
A-C-N	33.1030	0.6022	33.0799	4.1740	33.1145	11.8146
A-B-C	33.1328	0.6007	33.0992	4.1735	33.1154	11.8146

Table (6): The Results of the Double Ended Line Faults at 77 Km from the Relay Point with Load (11.6 MVA, 0.85 lagging P.F), (With Neglecting (I_2)).

Fault type	Actual Fault Location = 77 Km From the relay point					
	R_f = 0.5 Ω		R_f = 3.5 Ω		R_f = 10 Ω	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	77.1503	0.4658	77.5508	3.3286	78.4676	9.4447
B-C	77.4366	0.8332	77.3933	5.6967	77.4691	16.0462
A-C-N	77.3939	0.8194	77.3653	5.6846	77.4674	16.0451
A-B-C	77.4596	0.8156	77.4162	5.6832	77.4715	16.0452

Table (7): The Results of the Double Ended Line Faults at 33 Km from the Relay Point with Load (23.3 MVA, 0.85 lagging P.F), (With Neglecting (I_2)).

Fault type	Actual Fault Location = 33 Km From the relay point					
	R_f = 0.5 Ω		R_f = 3.5 Ω		R_f = 10 Ω	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	33.0715	0.4705	33.2240	3.2636	33.6223	9.2186
B-C	33.1166	0.6058	33.0793	4.1476	33.3001	11.6324
A-C-N	33.0978	0.6003	33.0687	4.1435	33.2996	11.6322
A-B-C	33.1247	0.5983	33.0868	4.1427	33.3007	11.6322

Table (8): The Results of the Double Ended Line Faults at 77 Km from the Relay Point with Load (23.3 MVA, 0.85 lagging P.F), (With Neglecting (I_2)).

Fault type	Actual Fault Location = 77Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	77.2202	0.4837	77.8994	3.4713	79.4875	9.7529
B-C	77.4341	0.8290	77.3881	5.6423	77.8234	15.7128
A-C-N	77.3885	0.8165	77.3589	5.6318	77.8212	15.7117
A-B-C	77.4512	0.8113	77.4058	5.6293	77.8256	15.7116

Table (9): The Results of the Double Ended Line Faults at 77 Km from the Relay Point with Load (11.6 MVA, 0.85 lagging P.F), (Without Neglecting (I_2)).

Fault type	Actual Fault Location = 77 Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	77.1257	0.5028	76.7863	3.5136	76.1990	9.9629
B-C	77.4346	0.5126	77.3929	3.5020	77.5362	9.8473
A-C-N	77.3929	0.5041	77.3654	3.4945	77.5345	9.8467
A-B-C	77.4581	0.5019	77.4161	3.4937	77.5386	9.8467

Table (10): The Results of the Double Ended Line Faults at 77 Km from the Relay Point with Load (23.3 MVA, 0.85 lagging P.F), (Without Neglecting (I_2)).

Fault type	Actual Fault Location = 77Km From the relay point					
	$R_f = 0.5\ \Omega$		$R_f = 3.5\ \Omega$		$R_f = 10\ \Omega$	
	Calculated location	Calculated resistance	Calculated location	Calculated resistance	Calculated location	Calculated resistance
A-N	77.0910	0.4925	76.5923	3.4320	75.9789	9.6521
B-C	77.4316	0.5095	77.4202	3.4658	78.1203	9.6392
A-C-N	77.3889	0.5018	77.3923	3.4593	78.1183	9.6385
A-B-C	77.4501	0.4990	77.4391	3.4580	78.1226	9.6385

5- CONLUSIONS

For distribution lines, this paper presented an accurate and a simple algorithm to calculate the fault location and fault resistance using Gauss-Seidel iterative technique. Various test cases of Matlab simulations have been done, and the results show that, the method can estimate accurately the fault location and fault resistance in single ended distribution power lines. With respect to the results of double ended distribution power lines, the method do not succeed in calculating the value of fault resistance accurately due to neglecting of the infeed current, but calculation of the fault resistance help to improve the results of fault location which is the main concern. It is worth saying that the method will be accurated in estimation the fault resistance due to measuring the infeed current (I_2) by measurement elements are connected on another parallel line (line 2) and applied it in developed algorithm, therefore it will succeed in calculating the value of fault resistance accurately due to calculating of the infeed current (I_2) in fault equation.

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APPENDIX

The parameters of the distribution power line used in the simulation for the two models shown in figures (1&2) can be found in the following table:

Table: The Parameters of the Distribution Power Line

PARAMETER	VALUE
Line Length	100km
Resistance Per Unit Length	R1= 0.0127Ω R0= 0.0386Ω
Inductance Per Unit Length	L1= $0.93*10^{-3}$ H L0= $4.12*10^{-3}$ H
Capacitance Per Unit Length	C1= $12.7*10^{-9}$ F C0= $9.75*10^{-9}$ F