International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 34 العدد
Part 1 المجلد
April 2024 ابريل

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ: 30/ 2024/3م وتم نشرها على الموقع بتاريخ: 27/ 2024/4م

Distance Protection Relay and effect MOV on zones of relay using MATLAB

www.doi.org/10.62341/mdmp2724

Mustafa Ali Esmaio[1], Mohamed Ali Eltaeb[2]
1. College of Technical Sciences. Misurata.
2. Misurata University
esmaiomustafa@gmail.com

Abstract:
Transmission lines are an important part of the power system. Transmission lines are used to transmit power and are prone to many breakdowns. Therefore, protection relays are used to protect transmission lines. The purpose of the protection system is to isolate the faulty part from the healthy part, because large currents generated by faults may cause damage to electrical equipment. One of the protection relays is the distance relay and is mainly used in the transmission line. Sometimes these relays are used for backup protection. Distance relays to determine impedance need voltage and current. Transmission lines are usually protected by a distance protection relay. Distance relays are of the high-speed class and can provide transmission lines.

Protection distance relays that use impedance measurements to determine the presence and location of faults, are "fooled" by a series capacitor mounted on the line, when the presence or absence of a capacitor in the fault circuit is not known in advance. This is because the capacitor cancels or compensates for some of the line inductance, so the relay may sense a fault in its first region when the fault is actually in the second or third region of the protection. Similarly, Zone one fault can be considered reverse faults. In fact, this can cause some costly operating errors.

Series compensated lines are protected from overvoltage by metal-oxide-varistors (MOVs) connected in parallel with the capacitor bank. The nonlinear characteristics of MOV devices add complexity to fault analysis and distance protection operation. During faults, the

تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

impedance of the line is modified by an equivalent impedance of the parallel MOV/capacitor circuit.

Worth noting is a method that determines the L and C string values of the font and the MOV effect at the time of the error. This is done by analyzing the synchronous and sub-synchronous content of the voltage and current signals separately which provides enough information to calculate the L and C series of the line.

In this paper, the transmission line impedance Z, Z(f) as a function of frequency has been calculated and plotted by the sequence characteristics and the studied MOV effect on line protection and fault location. Proper operation of the distance protection relay is also shown, and its effect on relay regions.

Keywords: Distance protection relay, transmission line, zones of relay, MOV.

مرحل حماية المسافة وتأثير MOV على مناطق المرحل بإستخدام الماتلاب

مصطفى علي اسميو
كلية العلوم التقنية مصراتة

محمد علي حسين
كلية الهندسة مصراتة

esmaiomustafa@gmail.com

الملخص

تشكل خطوط التحويل جزءاً هاماً من نظام الطاقة. وتُستخدم خطوط النقل لنقل الطاقة وهي عرضة للعديد من الأعطال. لذلك، تُستخدَم مرحلات الحماية لحماية خطوط النقل. والغرض من نظام الحماية هو عزل الجزءِ المعيب عن الجزءِ الصحيح، لأن التيارات الكبيرة التي تولدها الأخطاء قد تتسبب في تلف المعدات الكهربائية. وإحدى عمليات الحماية للنقل هو التتابع عن بعد ويستخدم أساساً في خط الإرسال. وفي بعض الأحيان تستخدم هذه المرحلات للحماية الاحتياطية. مرحلات المسافة لكي تحدد الإعاقة تحتاج إلى الجهد والتيارات. وعادة ما تكون خطوط النقل محمية عن طريق مرحّل للحماية عن

تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

بعد. ومرحلات المسافة هي من الدرجة العالية السرعة ويمكن أن توفر خطوط الإرسال ومرحلات المسافة الحماية التي تستخدم قياسات المعاوقة لتحديد وجود ومواقع العيوب، هي "مُحَلَّة" بواسطة مكثف سلسلة مركَّب على الخط، عندما لا يكون وجود أو عدم وجود فقدان عالي في دائرة الخطأ معروفاً مسبقاً. والسبب في ذلك هو أن المكثفات تقوم بإلغاء أو تعويض جزء من محاثة الخط، لذا فقد يستشعر المرحل وجود خطأ في منطقته الأولى عندما يكون الخطأ في الواقع في المنطقة الثانية أو الثالثة من الحماية. على نحو مماثل، المنطقة الأولى خطأ واحد يمكن اعتباره خطأ عكسي. وفي الواقع، يمكن أن يتسبب ذلك في بعض أخطاء التشغيل الباهظة التكلفة. والخطوط التعويضية في سلسلة خطوط محمية من الإفراط في الجهد من قِبَل معاملات ثاني أكسيد المعدن (MOVs) المرتبطة بموازاة مخزن المكثفات. والخصائص غير الخطية لأجهزة MOV تزيد من تعقيد عملية تحليل الأعطال والحماية عن بُعد. وأثناء الأخطاء، تعدل معاوقة الخط بعرقلة معادلة لدائرة MOV/capacitorالموازية.

الجدير بالملاحظة هو طريقة تحدد قيم L و C من الخط و تأثير MOV في وقت الخطأ. و يتم ذلك عن طريق تحليل المحتوى المتزامن والمتزامن الفرعي للمحتويات والإشارات الحالية بصورة منفصلة والتي توفر معلومات كافية لحساب سلسلة L و C من الخط و في هذه الورقة، حُسب خط الإرسال، معرقلةZ ، Z(f) كدالة للتردد، وحُدد بواسطة خصائص التسلسل وتأثير MOV المدروس على حماية الخط وموقع الخطأ. ويُبيَّن أيضاً التشغيل السليم لمرحلات حماية المسافة. وتأثيره على مناطق المرحل.

الكلمات الرئيسية: توفير الحماية عن بعد، وخطوط النقل، ومناطق المرحل، ووسائط النقل.

1. Introduction:

There are many different methods used to improve the stability of power systems. Some of these methods include reducing generator and transformer reactance, increasing the number of parallel lines used, using shunt compensation, or using series compensation.

"Series compensation is the use of capacitance in series on a transmission line. The addition of capacitance serves multiple purposes, the most important being the improvement in stability along the entire line. Another compensation method is shunt compensation, which is used to support voltage at a certain point on the line as opposed to the entire line [1].

"Sequential and shunt compensation were used at the beginning of the 20th century. The first implementation of shunt compensation was in 1914, and it has been used since it became the most common method of capacitive compensation. Sequential compensation was first used in the US for NY Power & Light in 1928, but it did not become popular until the 1950s when the voltage levels it could handle started to increase. By 1968 the 550 kV application was implemented and today there are applications approaching 800 kV" [2]. The conventional series compensation schemes have proven to be an important component in economical long distance power transmission. This is mainly because of the low cost of the series compensation compared to the cost of building a new transmission line. Series capacitors provide a direct mean of reducing the transmission inductive reactance and in turn increasing transfer capability, reducing the losses associated with transmission lines, controlling the load flow between parallel circuits and improving transient and steady state stability margins.

"For the reasons mentioned, series-compensated transmission lines have become rather common in locations where the distances between load centers is great and large transmission investments are required. Even though, the series compensation has been known to create problems in system protection and sub-synchronous resonance.

The addition of series capacitors in the transmission circuit increases the complexity of the protection design. The level of complexity depends on the size of the series capacitor, its location along the transmission line, and the method of bypassing the series capacitor." [3].

In this scenario, the transmission line network must be protected from breakdowns, because it is the most vulnerable to injuries, as it is exposed to a difficult operating environment such as lightning, snow, and rain, as well as malfunctions and improper operation. Where, short circuits and other distortions occur in the networks of power systems and because of these distortions, high currents flow in the equipment, which leads to its ruin and malfunction [4].

It is well known that one of the main considerations in the designing capacitor is over voltage protection of the capacitor itself. In recent years, the new metal oxide varistor (MOV), which has been widely used as the over voltage protection device for the series capacitor, has also been shown to improve stability in power systems. Because the MOV has a non-linear resistance characteristic and does not conduct symmetrically under unbalanced faults, this is in turn poses problem for conventional protection. Over the last decade, various techniques have been developed and published in the literature to solve the problem of protecting the series compensated lines.

“Usually, high-level faults are tested in sequential compensating transmission lines, and faults must be quickly eliminated, as they cause system instability as well as damage and hazards to equipment and people. Therefore, proper classification of transmission line faults is essential for the proper operation of power systems, and Identification of the type of fault is an essential protective relay feature because it has a significant impact on enhancing the operation of the relay scheme. Correct operation of the main protection relays sometimes depends on the identification of the fault. " [6].

"Faulted phase selection is as important as fault detection. It would lead to increase the system stability and system availability by allowing single pole tripping. Single pole tripping has many benefits like improving the transient stability and reliability of the power system, reducing the switching over voltages and shaft tensional oscillations of large thermal units" [7].

Ghassemi and Johns [8] Checking the effect of the residual compensation factor affects the accuracy of measuring distance protection when an earth fault occurs on a series compensation line.

تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

A method is described in [9] that enhance the accuracy of digital distance relays applied on series compensated lines where the series capacitors are protected against over voltages by MOV. The technique is applicable to systems where the relaying voltage is taken from the bus bar side of the series capacitor. The basis of the technique is a method known as voltage compensation. The voltage across the series capacitor and over voltage protective device is calculated in the relay. Thus, the over-reach or under-reach of distance relays as a result of MOV operation is eliminated.

Aggarwal and Johns [10]"The use of one of the high-speed numerical methods, based on the principle of directional comparison of chain-compensated transmission systems. What distinguishes their proposed method is the use of communication channels to extract information about voltage and current waveforms from both ends of the protected area. algorithm"

This information is analyzed and the fault is located, as string compensation is the most commonly used, to be used to improve system stability. As it greatly improves additional stability with how the network handles the error. When stability is uncertain in certain regions, sequential compensation is a viable method used today to improve its stability.

The previously mentioned applications are just a few of the uses offered by series compensation devices. These and other applications are widely used to improve the system as a whole. One common location where series compensation devices are used heavily is long transmission lines fed from hydroelectric power plants. Many lines use series compensation devices to improve voltage regulation because the main load area is usually more than 100 km away from the generating station, which allows significant voltage erosion.[10]

2. Materials and Methods:

In this paper a simulated network use MATLAB Simulink system as shown in figure (1), study this simulated network without series capacitor compensation (SCC), then add SCC, Distance relay and MOV then record the results.

تم استلام الورقة بتاريخ: 30/ 2024/3م وتم نشرها على الموقع بتاريخ: 27/ 2024/4م

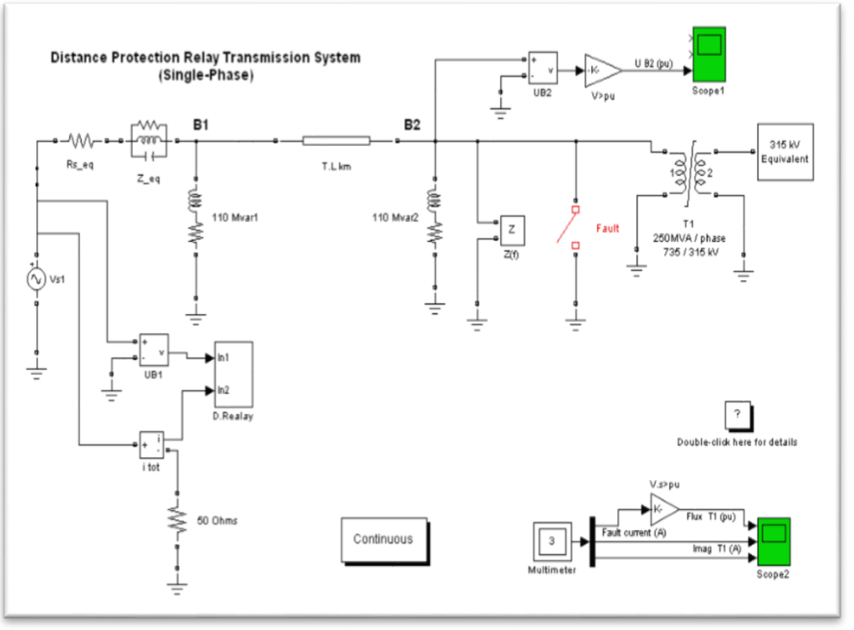

Figure 1. Simulated network transmission line (single phase)

3. Theory and Calculation

3.1 .Simulated network Description:

Generator 735 kV, 300 km transmission line is used to transmit power from bus B1 (735 kV (equivalent system) to bus B2 (315 kV equivalent). In order to simplify, only one phase of the system has been represented.

In order to increase the transmission capacity, the line is series compensated at its centre by a capacitor representing 40% of the line reactance. The line is also shunt compensated at both ends by $330 Mvar$shunt reactance (110 Mvar /phase). Open the Series Compensation subsystem. Notice that the series capacitor is protected by a metal oxide varistor (MOV), simulated By the Surge Arrester block. The 250 MVA, 735 kV / 315 kV transformers are a Saturable Transformer block simulating one phase of the three-phase 750 MVA transformer. A Multi-meter block is used to monitor the fault current as well as the flux and magnetizing current of the transformer [11].

International Science and Technology Journal
المجلة الدولية للعلوم والتقنية
Volume 34 العدد
Part 1 المجلد
April 2024 ابريل
المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ
تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

3.2 .Demonstration :

Studied the transient performance of this circuit when a 6- cycle fault is applied at node B2, fault is simulated by the Breaker block. Switching times are defined in the Breaker block menu (closing at t = 3 cycles and opening at t = 6 cycles) and distance protection relay.

3.3. Frequency Analysis:

In order to understand the transient behaviour of this series-compensated network, a frequency analysis is first performed by measuring the Impedance at node B2. This measurement is performed by the Impedance Measurement block connected at node B2. Open the block in the Tools as shown in figure (2), menu select 'Impedance vs. Frequency Measurement'. Display to compute and display the impedance for the 0 - 50 Hz range.[11], then MALLAB program draw Z(f) measurement and relay characteristic (zones) .

3.4. Time Domain Simulation - Fault at Bus B2

Start the simulation and observe waveforms on the two scopes at t = 3 cycles, a line-to-ground fault is applied and the fault current reaches 10 kA. During the fault, the MOV conducts at every half cycle and the voltage across the capacitor is limited to 263 kV.

t = 6 cycles, the fault is cleared. During fault the flux in the transformer is trapped to around 1 pu. At fault clearing the flux offset producing magnetizing current pulses.

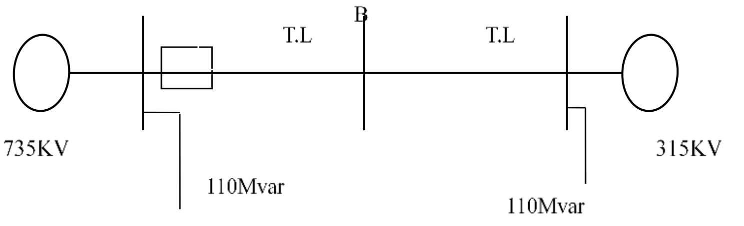

Figure 2 single line diagram

3.5. Content of simulated network:

1- Power supply ideal sinusoidal AC voltage source 735 KV, 50 Hz.

2- Implement a parallel RLC element:

-Resistance R 180.1 Ohms.

International Science and Technology Journal
المجلة الدولية للعلوم والتقنية
Volume 34 العدد
Part 1 المجلد
April 2024 ابريل
تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

-Inductance L 0.026525 H.
-Capacitor C 117.84e-6 F.
3- Two parallel load 110Mvar at Bus (B1), Bus(B2):
-inductive reactive power QL (positive var)
$-V_n 735kv/\sqrt{3}$
4- Two implements one phase distributed parameters line model the R, L and C line parameters are specified by$[N * N]$matrixconnected between B1 and B2:

-Resistance per unit length$[R1\ R0\ R0m]$0.011
-Inductance per unit length$[L1\ L0\ L0m]0.867e-3\ (\frac{H}{Km})$
-Capacitor per unit length $[C1\ C0\ C0m]13.41e^{-9}$ (F/Km)
- Transmission Line length (changeable) Km.

5- Implement a circuit breaker, breaker resistance R on (0,01ohm) Switching time$[3/50\ \ 6/50]\ (s)$
6- Impedance measurement: to calculate and measure the impedance between two nodes of circuit as function of frequency $Z(f)$.
7- Saturable transformer: implement a three windings saturable transformer. *250*MVA/phase,735/315KV.
8- Model of Distance Protection Relay [12]. Output of distance protection relay (zones of relay) as shown in figure (3).
9- MOV equivalent circuit is shown in figure (4).
10-

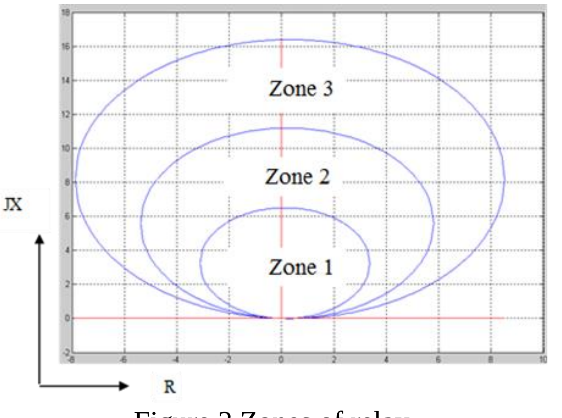

Figure.3 Zones of relay

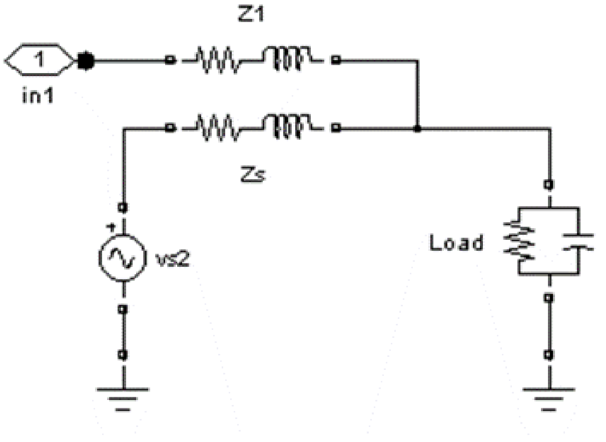

Figure.4 MOV equivalent circuit

4. Results and Discussion

1- Case 1: T.L. length 300 km, fault at end of T.L, simulation stop time 0.2 second.

Table 1: Explain T.L with compare with SCC and without SCC

T.L. length (km)	**Without SCC**		**With $SCC(C = 67.6e^{-3}F$**	
	Z_f	**Zone of relay**	Z_f	**Zone of relay**
5	$0.0571 + J0.3819$	1	$-0.1908 + J2.3416$	Out of zones
10	$0.1114 + j0.4347$	1	$-0.2516 + j2.3024$	Out of zones
50	$0.5361 + j0.8509$	1	$-0.7225 + j1.99$	Out of zones
100	$1.0439 + j1.3556$	1	$-1.2755 + j1.6028$	Out of zones
200	$1.9886 + j2.3159$	1	$-2.2737 + j0.8443$	Out of zones
300	$2.7539 + j1.7788$	1	$-3.1463 + j0.1123$	Out of zones

2- Case 2:
Effect SCC (value of capacitor) on Z impedance and zones of relay.

Table .2 explain capacitor values on Z impedance and zones of relay

T. L 5 km		
C value (F)	Z_f	**Zone of relay**
$1-e^{-6}$	13.874 + j21.9026	Out of zones overreach
$1-e^{-3}$	18.4773 + j 23.4958	Zone 2 under reach
$1-e^{-2}$	15.8365 − j 19.6645	Zone 3 under reach
$1-e^{-1}$	1.1492 − j1.3305	Zone 3 under reach
1	1.013 + j0.0922	Zone 3 under reach
$67.6e^{-3}$	1.2674 − j 2.1379	Out of zones under reach
T.L 150 km		
$1-e^{6}$	13.874 + j21.9026i	Out of zones overreach
$1-e^{3}$	18.5167 + j 23.4464	Out of zones overreach
$1-e^{2}$	15.3979 -j 15.5559	Out of zones under reach
$1-e^{1}$	2.5747 − j0.3177	Out of zones under reach
1	2.3757 + j0.9368	Zone 1undr reach
$67.6e^{-3}$	2.7223 − j1.0236	Out of zones under reach

3- Breakdown MOV:

Table.3 explain some results when breakdown MOV and effect it on Z_f

T.L. length (km)	MOV		Breakdown MOV	
	Z_f	Zone of relay	Z_f	Zone of relay
50	1.746 − j1.7866	O.O.Z under reach	1.4468 + j0.5007	1
100	2.2485 − j1.4019	O.O.Z under reach	1.9149 + j0.7864	1
200	3.1693 − j0.6521	O.O.Z under reach	2.7812 + j1.3527	2
300	3.9901 + j0.0693	O.O.Z under reach	3.5631 + j1.9087	2

Z.O.O = *Out of zones*

In the case of a single phase to ground fault, the method for calculating the fault impedance is to use the formula:

$$Z_{fault} = \frac{V_{phase}}{I_{phase} + (mI_0)}$$

Where I_0 is the zero-sequence current equal to one third of the sum of I_a, I_b, and I_c or:

$$I_0 = \frac{1}{3} * (I_a + I_b + I_c)$$

And m is a factor given by:

$$m = \frac{Z_0 - Z_1}{Z_1}$$

This is however the expression describing m in a line that does not include series capacitance. The value of m in that case is independent of distance to the fault. However, when considering a line with series capacitors installed, it can be concluded that the value of m when the capacitor is switched into the line is given by:

$$m = \frac{Z_0 - Z_1}{Z_1 - Z_c}$$

Thus, the value of m depends on the location of the fault.

5- Conclusions

In this work, the transmission line impedance Z, Z (f) as a function of frequency is calculated and plotted by the relay characteristic and the study effect of the series compensation capacitor for line protection. Proper operation of the distance protection relay has also been demonstrated.

In the event of a fault within the zone protection, the measured impedance of the transmission line function as a function of frequency is within the specified limits of the characteristic.

The series compensation capacitor causes a change in the value of **Z** because the addition of **R** to the line then changes the relay areas as the value of the capacitor.

Series compensation is caused overreach or under reach as values of capacitor.

The presence of **MOV** in the network affects the fault zone determination of the distance protection relay, as the results showed.

References

[1]ABB Power Systems. "Series Capacitors for Enhanced Power Transmission."

[2]Jancke, G., et al. "Experience with Series- Compensated Systems." IEEE Transactions on Power Apparatus and Systems, May/Jun 1975, pp. 915-925.

[3]Iliceto, F., et al. "Comparison of Series Capacitor Compensation with Shunt Reactor Compensation." IEEE Transactions on Power Apparatus and Systems, Nov/Dec..

[4]M.H. Idrisa, S. Hardia, M.Z. Hasana, "Teaching Distance Relay Using Matlab/Simulink Graphical User Interface", Malaysian Technical Universities Conference on Engineering & Technology 2012, MUCET2012.

[5]A.G.Phodke, J.S.Thorp, Computer Relaying for Power Systems, John Willey & Sons Inc,1988.

[6]S.H. Horowitz, A.G. Phadke, Power System Relaying, RSPLD, Engeland,1992.

تم استلام الورقة بتاريخ: 30/ 3/2024م وتم نشرها على الموقع بتاريخ: 27/ 4/2024م

[7]IEEE,Working group –power system relaying committee, Single Phase tripping and auto reclosing of transmission lines, IEEE tranc Power Deliv. 7(Junuary(1))(1992)182-192.

[8]F.Ghassemi,A.T.Johns Investigation of alternative residual current compensation for improving series compensated line distance protection, IEEE Trans. Power Deliv. 5(April (2))(1990)567-574.

[9]F.Ghassemi, J. Goodarzi, A.T.Johns,Method to improve digital distance relay impedance measurement when used series compensated line protected by a metal oxide varistor, IEEE Proc. Generation Transm.distrib. 145(July (4)) (1998)403-408.

[10] R.K. Aggar, A.T. Johns, D.S. Tripp, the development and application of directional comparison protection for seriescompensated transmission systems, IEEE transactions on power delivery, vol2, No4 October 1987, pp.1037-1045.

[11] MATLAB R2007a, User guide, Simulink and help.

[12] Abdlmnam A. Abdlrahem, "Modeling of distance power system protection', Master thesis in EEES, El-Fath University, September 2007