A DIGITAL NEGATIVE SEQUENCE OVER-CURRENT RELAYING ALGORITHM FOR DETECTION OF UNSYMMETRICAL FAULTS ON 11 KV LINE

Dr. Mahmud H.Musa
Electrical and Electronic Eng. Dept.
Faculty of Engineering
Alfatah University

ABSTRACT

In this paper a new digital relaying algorithm for sensitive, and fast detection of unbalanced line faults on 11 kV distribution line is introduced. The method is based on instantaneous monitoring of the magnitude of the negative sequence current flowing in the concerned lines using high-resolution microprocessor. When the magnitude of the negative sequence current exceeds a pre-set value a trip signal is initiated. This new method proves to be very sensitive in detecting line to ground faults when the ground resistance is very high, and open conductor cases. Computer simulation results are presented in this paper, and compared with analog over-current relays usually applied in this kind of distribution networks

1-INTRODUCTION

Generally over-current protective devices are used to isolate only sections of the system affected by the fault [protected zone] so the remaining system can operate normally. The basic approach is that an abnormal fault current is clearly distinguishable from a normal load current, and protective devices are designed to respond to over-currents by opening the affected circuit rapidly.
Since faults can occur anywhere in the system, protective devices are located such that a single device operates to isolate the faulted area only, and the device nearest to the fault must operate first. Over-current devices have inverse time-current characteristics to clear the fault, which means the greater the fault current the shorter is the trip time [1,2,3].
Short circuit analysis are usually performed on the concerned power system under different loading, and layout conditions in order to [1,2]:

a- Determine the expected short circuit currents flowing throughout the system.
b- Determine the operating time of the protective devices needed to isolate the faulted area in a selective manner.

Digital computers are nowadays widely used to calculate short-circuit currents within the power system, and provide this information to the protection engineer for faster and more accurate relaying applications [4].
In rural distribution systems specially when the ground resistance is too high, it is usually found to be difficult for the normal over-current relays to distinguish between line

to ground faults at the end of the protected line, and the normally allowed over-loading currents. This situation may result in the flowing of fault current through the line, and interruption of service to the consumers without knowledge of the operating engineer or operation of the specific relaying unit. This problem becomes more pronounced when fuses are used as the protection equipments, since one or two of them may blow out resulting in an open-conductor operation.
In this study an attempt to introduce new method for sensitive, reliable, fast, and more accurate, digital over-current relay is investigated. The study utilizes the presence of an appreciable negative sequence current flowing in the line during asymmetrical faults, as well as during normal unbalanced loading operation [5,6,7]. Analyzing the instantaneous line currents into their symmetrical components, and comparing the results with pre-set values of these components one can make a judicious decision about the situation of the line [whether it is in faulty condition or normal operation].

2- SYMMETRICAL COMPONENTS

Symmetrical components method [5] can be used to analyze unbalanced faults, and loading conditions. Their idea is based on replacing the unbalanced network of the system by three new balanced circuits. The sequence components are defined by the following equation:

$$[x_{012}] = [s][x_{abc}] \qquad (1)$$

x_{012} = zero, positive, and negative sequence components.
x_{abc} = a, b, c phase quantities of the original unbalanced system.
S = Transformation matrix defined as:

$$[S]=\begin{bmatrix}1 & 1 & 1\\ 1 & a & a^2\\ 1 & a^2 & a\end{bmatrix} \qquad (2)$$

Where the elements a, a^2 are phase operators defined by:

$$a = e^{j\frac{2\pi}{3}}$$
$$a^2 = e^{-j\frac{2\pi}{3}} \qquad (3)$$

The inverse transformation matrix $[S]^{-1}$ is given by:

$$[S]^{-1}=\begin{bmatrix}1 & 1 & 1\\ 1 & a^2 & a\\ 1 & a & a^2\end{bmatrix} \qquad (4)$$

Transformation from symmetrical components into phase quantities can be found as:

$$[x_{abc}]=[S]^{-1}.[x_{012}] \qquad (5)$$

When dealing with digital relaying, sampled current and voltage signals are used., The symmetrical component currents in this case are found from sampled line currents $i_a(j)$, $i_b(j)$, $i_c(j)$, which are taken at specific sampling rate f_s given by:

$$f_s = N.f_o \qquad (6)$$

Where N is the number of samples per cycle, and f_o is the fundamental frequency of the system.

The fundamental components of the sampled line currents are found using Discrete Fourier Transform as [7,8]:

$$x(1)=\frac{2}{N}\sum_{k=0}^{k=N-1} x(k)e^{-j\frac{2\pi k}{N}} \qquad (7)$$

$x(k)$ is the value of the k^{th} sample, and $x(1)$ is the fundamental component of the sampled wave.
It is well known that for a sinusoidal wave of the form:

$$x(t)=\sqrt{2}|x|\sin(wt+\varphi) \qquad (8)$$

has a phasor form given by:

$$X=|x|e^{j\varphi}=|x|.(\cos\varphi+j\sin\varphi) \qquad (9)$$

For sampled current or voltage signals the phasor of each signal can be found from (4) as [7]:

$$X=\frac{1}{\sqrt{2}}jx(1)=\frac{j2}{N\sqrt{2}}\sum_{k=0}^{k=N-1} x(k)e^{-j\frac{2\pi k}{N}} \qquad (10)$$

For a 12 samples per cycle, which is usually used for digital protection devices, equation (10) can be re-written utilizing that:

$$w(k)=\frac{j}{6\sqrt{2}}e^{-j\frac{\pi k}{6}}=\frac{1}{6\sqrt{2}}\left(\sin\left(\frac{\pi k}{6}\right)+j\cos\left(\frac{\pi k}{6}\right)\right) \qquad (11)$$

Then equation (10) becomes:

$$X = \sum_{k=0}^{k=N-1} x(k).w(k) \qquad (12)$$

To obtain the phase shift of a, a^2 needed in the symmetrical component calculations only $w(k)$ is affected [7]. Then the *rms* values of the positive, and negative symmetrical components of the sampled current signals are obtained by:

$$x_1 = \frac{1}{3}\sum_{k=0}^{k=N-1}\left[\left(w(k)x_a(k) + w(k-4)x_b(k) + w(k+4)x_c(k)\right)\right] \qquad (13)$$

$$x_2 = \frac{1}{3}\sum_{k=0}^{k=N-1}\left[\left(w(k)x_a(k) + w(k+4)x_b(k) + w(k-4)x_c(k)\right)\right] \qquad (14)$$

These equations can be easily implemented in a digital computer utilizing fewer arithmetic operations.

3- HARDWARE CONSTRUCTION

The essential components of the hardware used in this relay are shown in figure 1. It consists of the following main components:

1- Input signal is taken via current and voltage transformers of suitable turns ratios. These signals are input to an analog low pass filter in order to remove high frequency signals, and noises.

2- Sample and Hold device [S/H]: This device is used to produce sampled signals of the input continuous line currents at specific rate. It holds signal in a Kew, [first come first service] for the period of time needed by the previous signal to be processed by the algorithm.

3- Analog to Digital Converter [ADC]: This device changes the sampled analog signals into numbers, which can be processed by the microprocessor.
4- Microprocessor Unit [MP]: This is the unit in which all relaying operations are performed. It represents the heart of the system. Relaying information such as setting values, delay time, and others are stored in ROM [read only memory], or PROM [programmable read only memory]. This gives the digital relay the advantage that its setting values can be changed according to the requirement of the system without any change in its algorithm.
5- Synchronizing Clock: This clock is used to synchronize the operations of the S/H, ADC, and MP components.
6- Output signals: These are the output signals of the relay. They could be in the form of digital or analog signals sent to the circuit breakers [in the form of open or close orders] or to the communication system where data can be stored or transmitted to control centers or other substations.

4- THE RELAYING ALGORITHM

The idea of the suggested relaying algorithm can be explained in the following steps:

1- Line currents are taken at a reduced level via current transformers of suitable turns ratio. These currents are changed into voltage signals using suitable potential dividers. These voltage signals are filtered using low pass analog filter to remove any unwanted high frequency signals, and noises.
2- Sampled current signals $ia(j)$, $ib(j)$, and $ic(j)$ at specific sampling rate f_s are taken. Then after they are changed into digital signals by the ADC. By using equations (13),

and (14) the *rms* phasors of the positive and negative sequence symmetrical components are obtained for each cycle of the sampled currents. Then the *rms* magnitude of these components can be easily obtained.

3- The magnitudes of the positive and negative sequence currents are continuously compared to a pre-set trip values. If the calculated magnitudes exceed these values within a specified delay time a trip signal is produced. Otherwise the counting interval is set back to zero, and the process is started again and again. The set value for the negative sequence current is taken as 20% of the full load current, which is a reasonable value as compared to the allowed negative sequence current during normal unbalanced loading operation

4- The relay must also provide protection in case of balanced three phase faults at any section of the line. The set value of the trip current for the positive sequence current is taken as 2.5 pu of the full load current [1,2,9]. This value is based on the fact that the minimum pick-up current usually used for inverse time over-current relays is not less than this value. The delay time used in this algorithm is taken to be 10 cycles, which is reasonable enough to allow any transients due to lightening or other switching operation to be by-passed, yet short enough to allow fast detection of internal faults, and tripping of affected line. The flow chart of this relaying algorithm is shown in figure 3.

5- COMPUTER SIMULATION STUDIES

Extensive computer simulation studies on this relaying algorithm were performed. The circuit used in this study is shown in figure 2. The 11kv distribution line of length 50 km, consists of three copper conductors hanged on either a wooden or concrete poles. The main characteristics of this line are given in table-1. The load supplied by this line is assumed normally unbalanced, with its characteristics given in table-1 also. Different faults and open conductors are applied at the end of this line. These faults are assumed to start after 0.05 sec of the normal loading operation, and lasts for about 5 seconds. The line currents are instantaneously sampled at the assumed sampling rate, filtered, converted into digital signals, and input to the microprocessor. The relaying algorithm produces its response in the form of trip signal to the concerned circuit breakers to clear the fault or in the form of normal operation, in which case the process is repeated again and again.

The results of this study are shown in the form of representative curves [Figures 4 -8] showing the sequence current components flowing during the concerned fault, and the response of the algorithm with the trip time shown on it.

In all cases studied the suggested algorithm manages to detect the faulty condition within a very short period of time, and issue a trip signal to clear that fault. It also manages to detect the open conductor cases, which were found impossible to be detected by the normal over-current relays. The trip time for analog over-current relays needed to detect a fault is greater than one second under all fault conditions, while for this relaying algorithm, it manages to detect the fault and issue a trip signal in less than one second in all cases studied. This characteristic together with the ability of the algorithm to detect line to ground faults, when the fault current is nearly equal to the normal over-load current gives this relaying algorithm superior advantages over the normal inverse time over-current relays.

Table-1: distribution line and load characteristics:

11kv line:

Resistance/km = 0.00242 Ω/km.

Inductive reactance at 50 Hz = 0.0242 Ω/km.

Ground resistivity = 10^5 Ω.m.

Loads:

Phase a = full load, 0.8 lagging power factor.

Phase b = full load, unity power factor.

Phase c = full load, 0.95 leading power factor.

6- CONCLUSIONS

A digital relaying algorithm utilizing very simple arithmetic operations, and produces valuable information for protection as well as data exchange and/or storage has been studied. This relaying technique utilizes the very rapid development in computer industry, the continuous decrease in its cost, and rapid increase in its processing speed and memory. This relaying algorithm can be integrated with a larger relaying algorithm that can perform all the relaying operation of the distribution line, and perform continuous measurements of all the necessary network variables with no extra extension of the algorithm, and at no additional cost.

REFERENCES

[1] **Westinghouse Electric Corporation**, "distribution systems", "book", Volume 3.

[2] **Paul Anderson**, " Analysis of Faulted Power Systems", "book", Iowa State University Press, Ames 1973.

[3] **IEEE Committee report** "Computer representation of over-current relay characteristics", IEEE Transaction on Power Delivery, Vol.4, No.3, July 1989].

[4] **William D.Stevenson, Jr.**, "Elements of power system analysis", "book", 3^{ed} Edition, McGraw-Hill 1975.

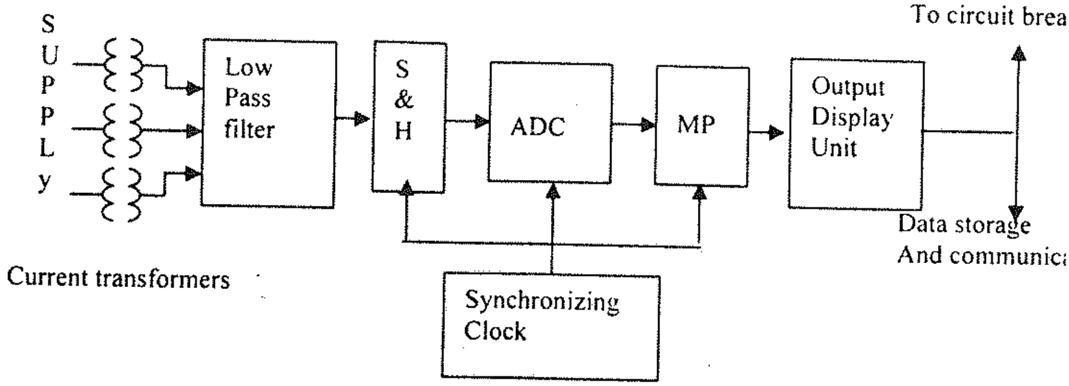
[5] **E.O.Schweitzer, Antenor Aliaga**, "Digital Programmable Time-Parameter Relay Offers Versatility and Accuracy", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No.1 Jan/Feb. 1980.

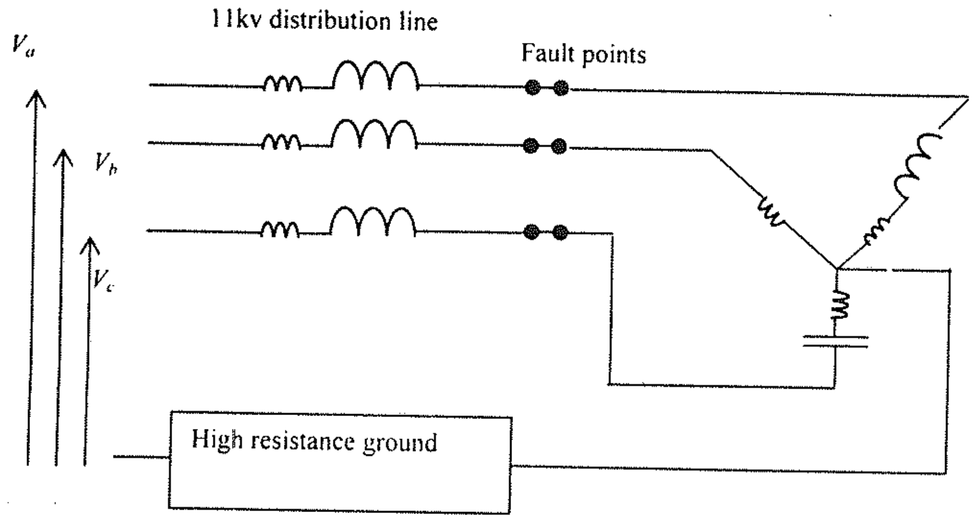
[6] **L.A.Pipes**, " Transient Analysis of Symmetrical Networks by the Method of Symmetrical Components", IEEE Transactions Vol.59, pp 457-9, 1940.

[7] **A.G.Phadke, M.Ibrahim, T.Hlibka,** "Fundamental Basis for Distance Relaying With Symmetrical Components", IEEE Transaction on power apparatus and systems, Vol. PAS-96, No.2, March/April 1977.

[8] **Sachdev, M.S.** "Computer relaying and protection systems", IEEE Tutorial course text, Publication No. 88EH0269)-1-PWR, New York, USA, January 1988.

[9] **Westinghouse Electric Corporation,** " Transmission and Distribution", "reference book", Fourth edition.


S
U
P
P
L
y
Current transformers
Low Pass filter
S & H
ADC
MP
Output Display Unit
Synchronizing Clock
To circuit brea
Data storage
And communica


11kv distribution line
Fault points
V_a
V_b
V_c
High resistance ground

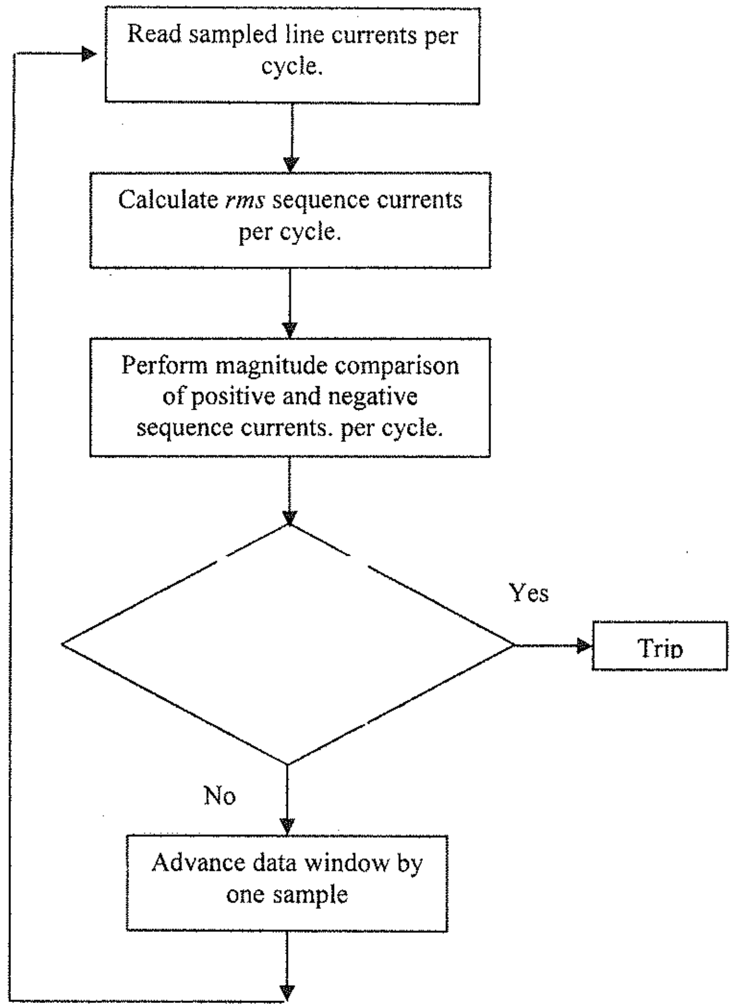
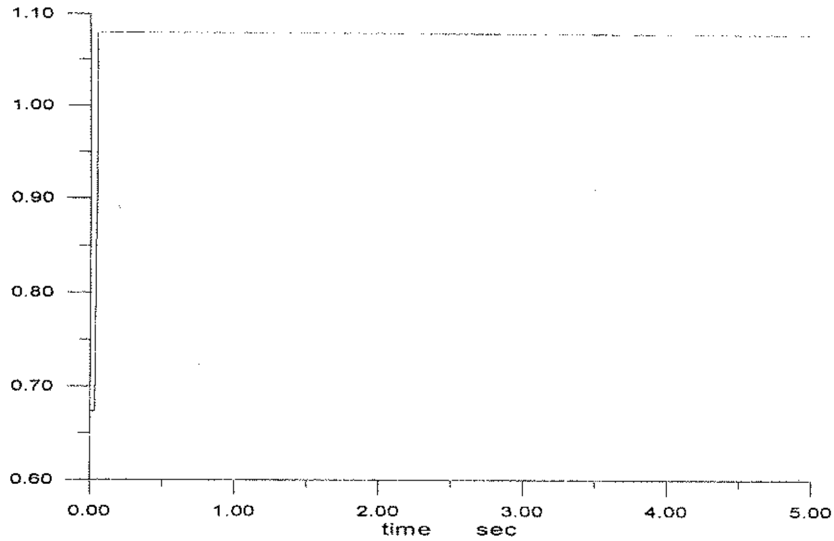
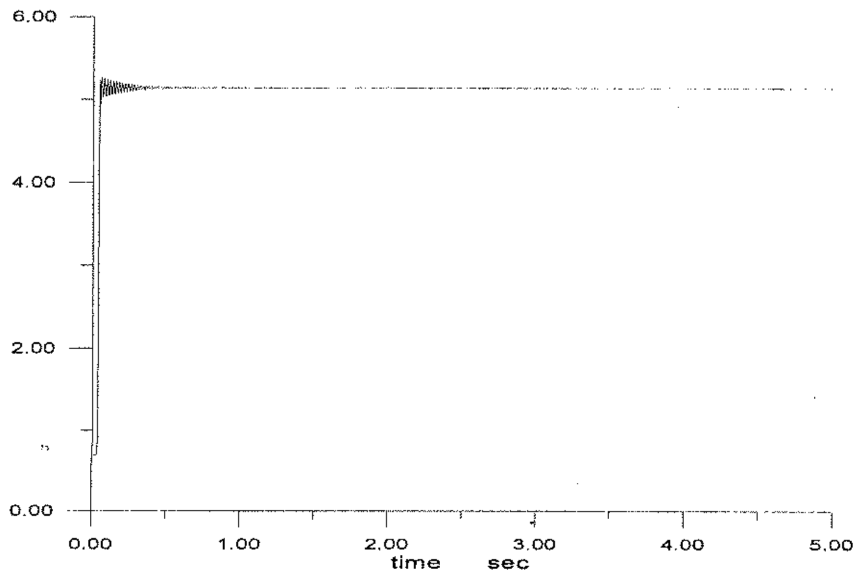


Figure 3: Flow chart for the relaying algorithm based on positive and negative sequence currents


1.10
1.00
0.90
0.80
0.70
0.60
0.00
1.00
2.00
3.00
4.00
5.00
time sec


6.00
4.00
2.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
time sec

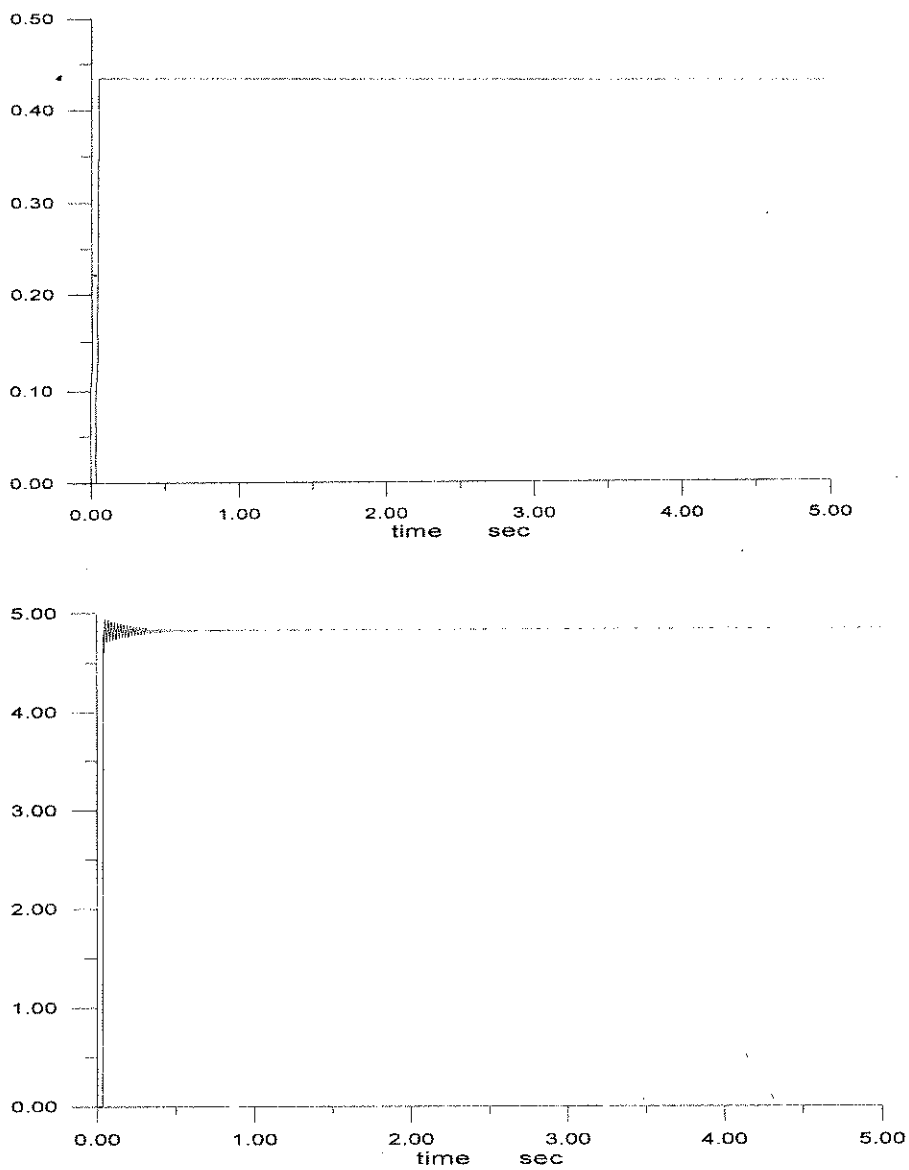


Figure 4: Response of algorithm to a line to ground fault at the end of the line

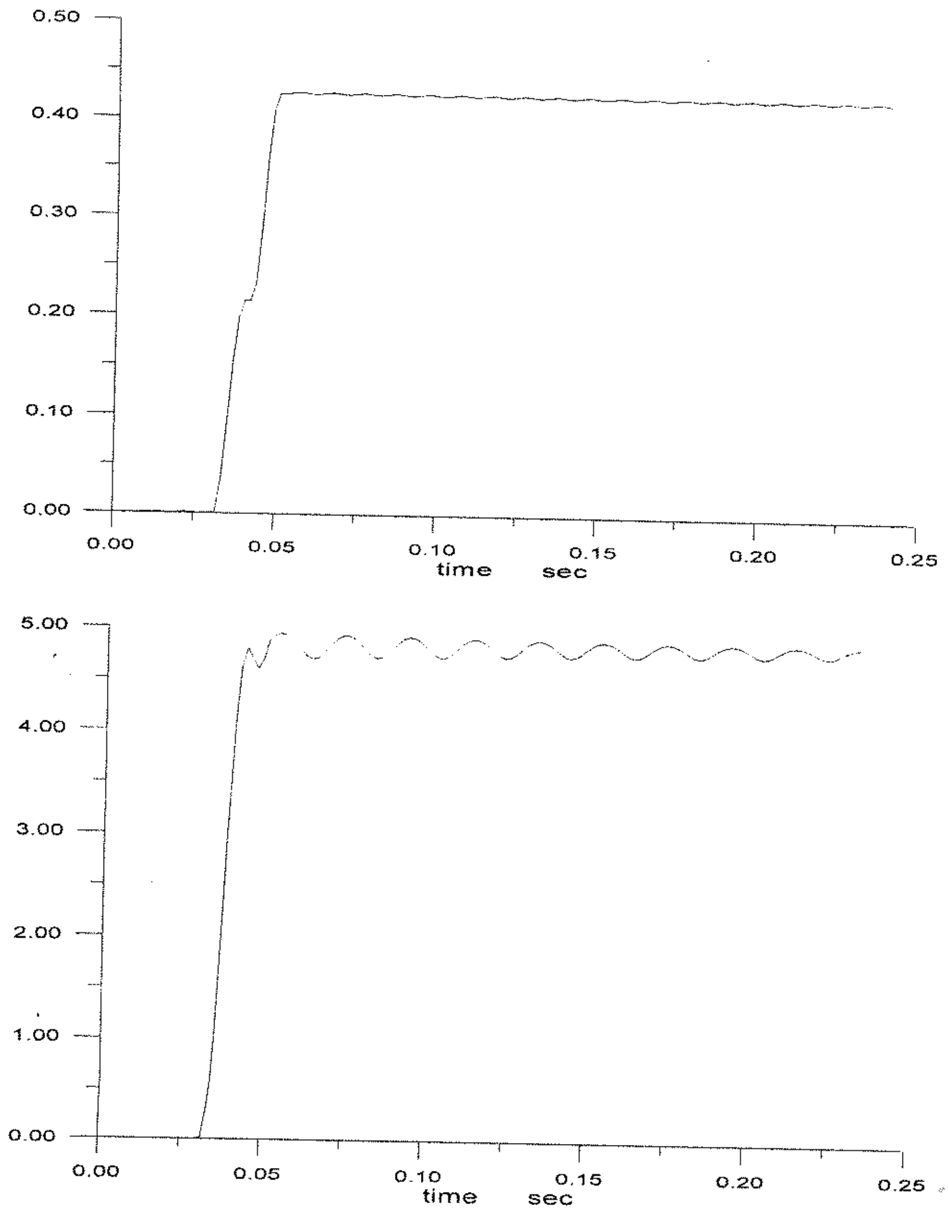
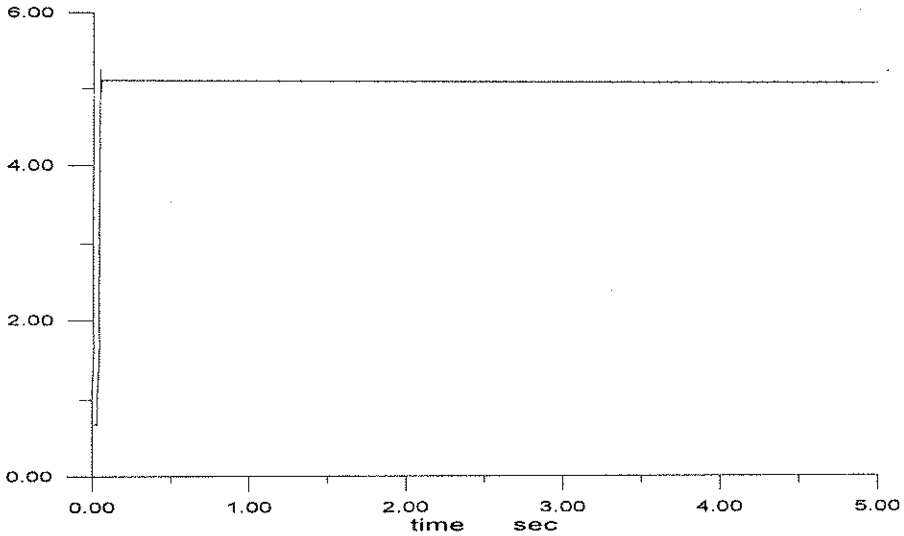
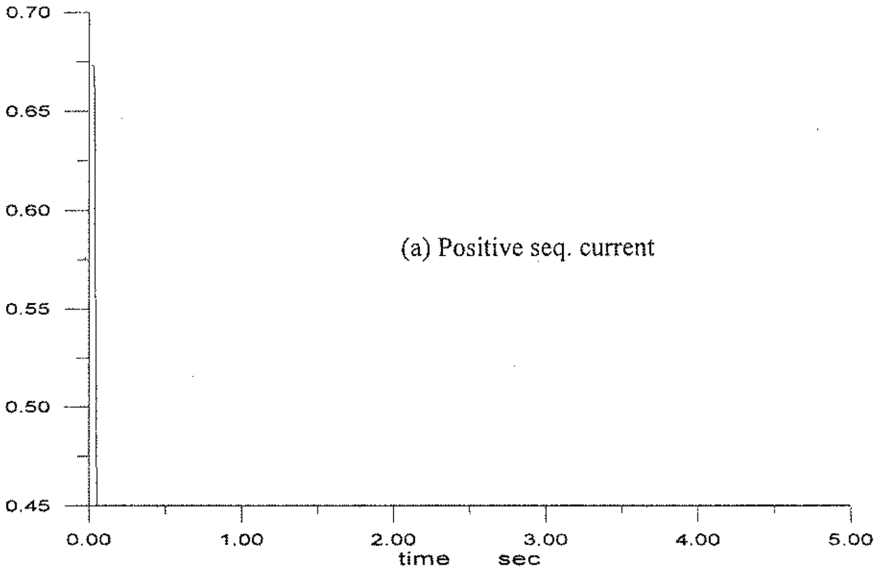
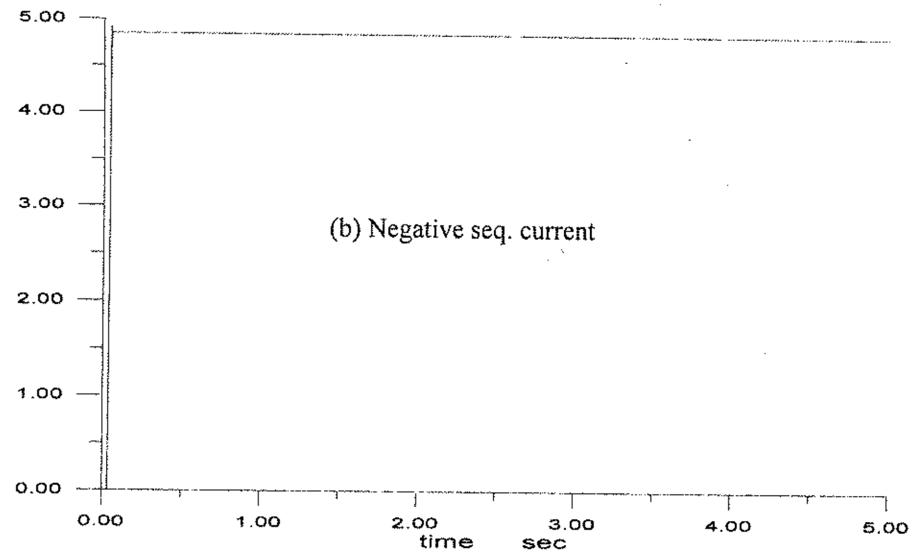


Figure 5: Algorithm response to a line-line-ground fault at end of the line





(a) Positive seq. current



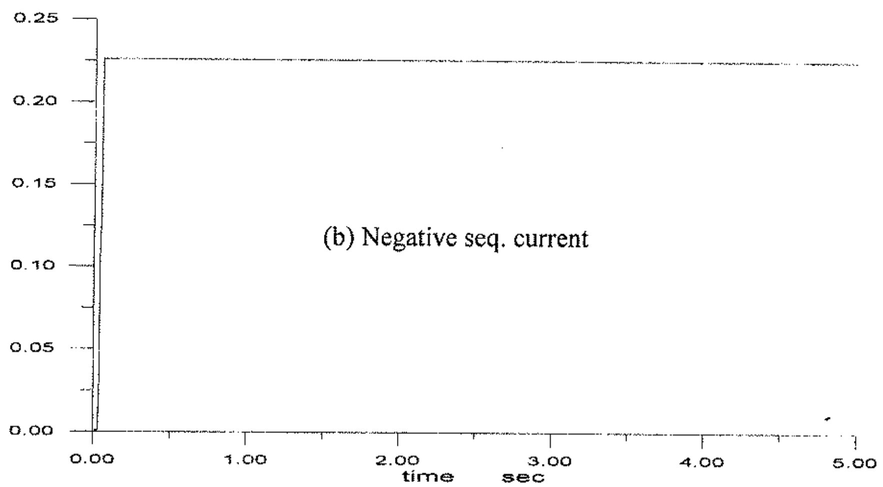


Figure 6: Algorithm response to a line-line fault at end of the line

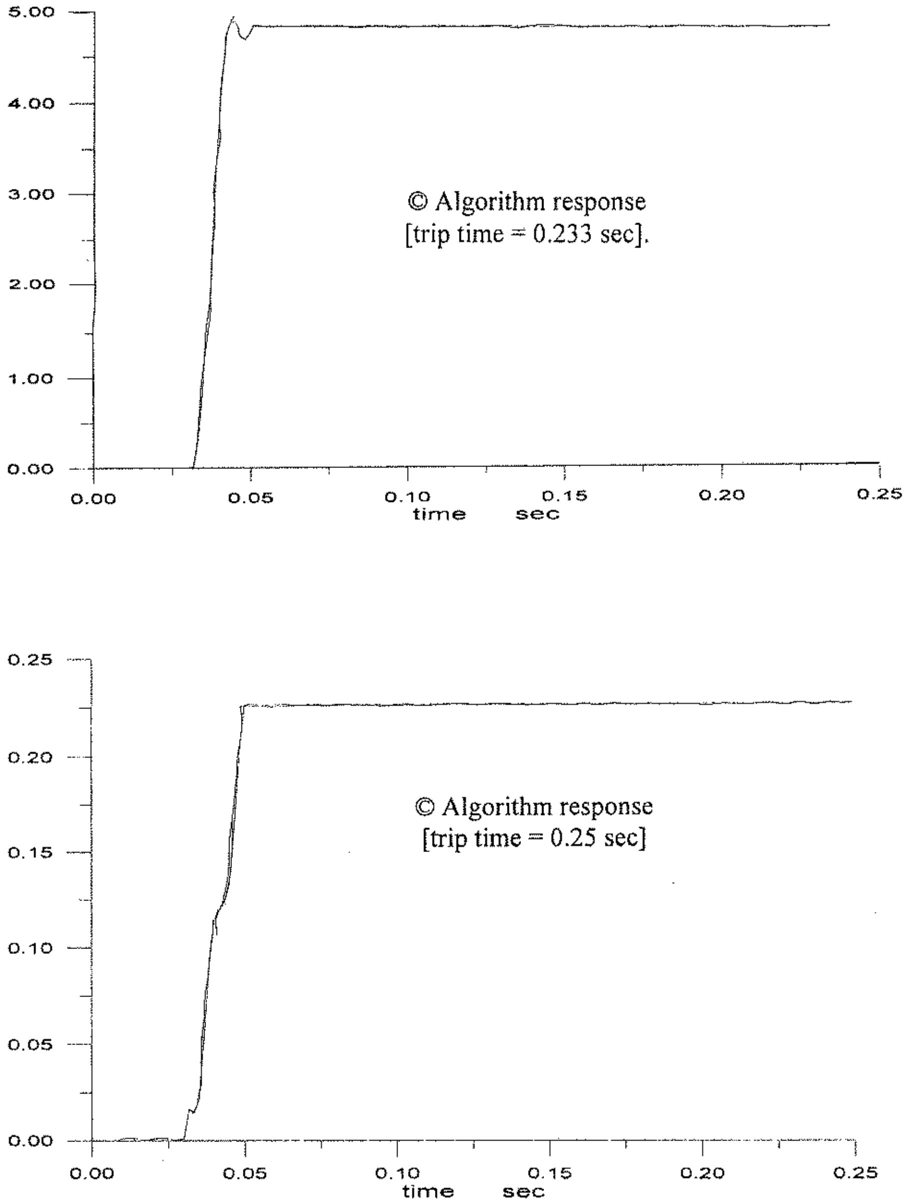
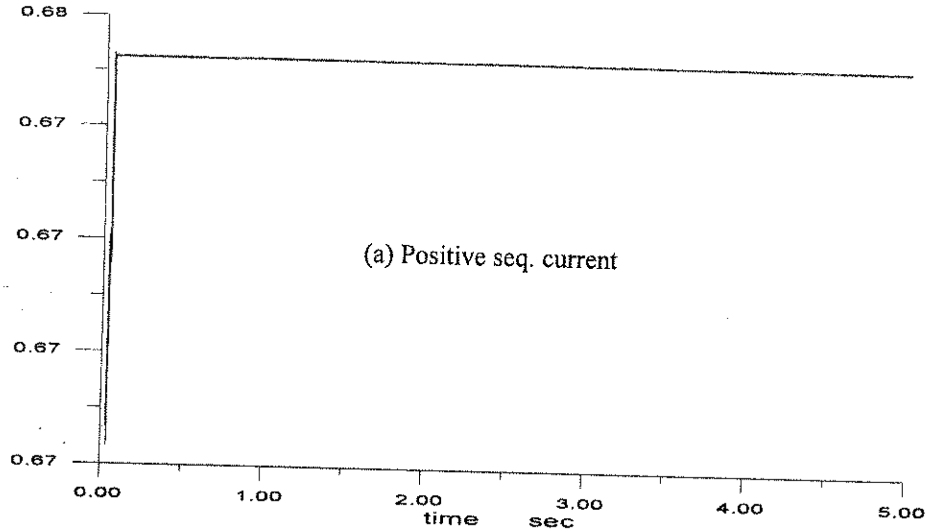
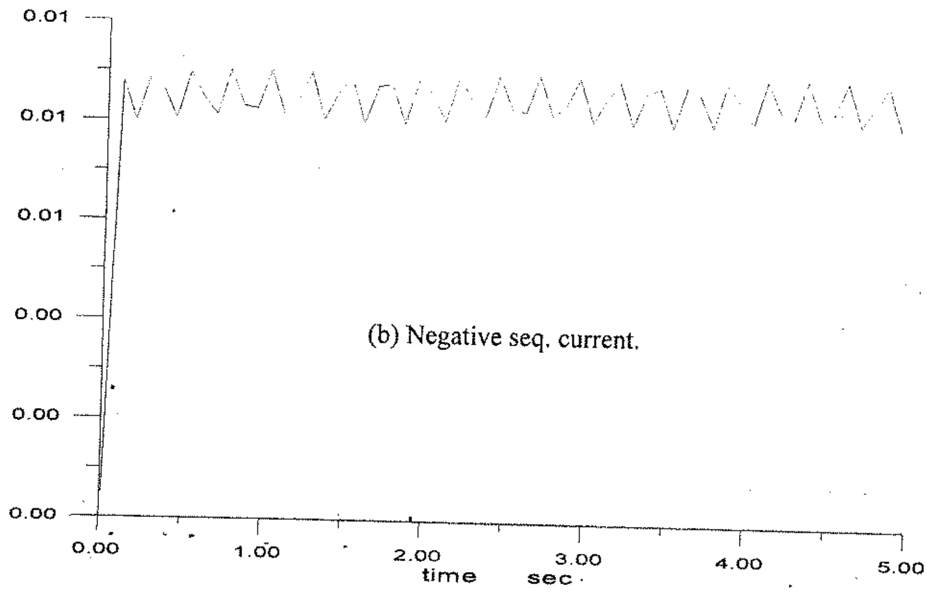


Figure 7: Algorithm response to an open conductor condition at end of the line



(a) Positive seq. current



(b) Negative seq. current.

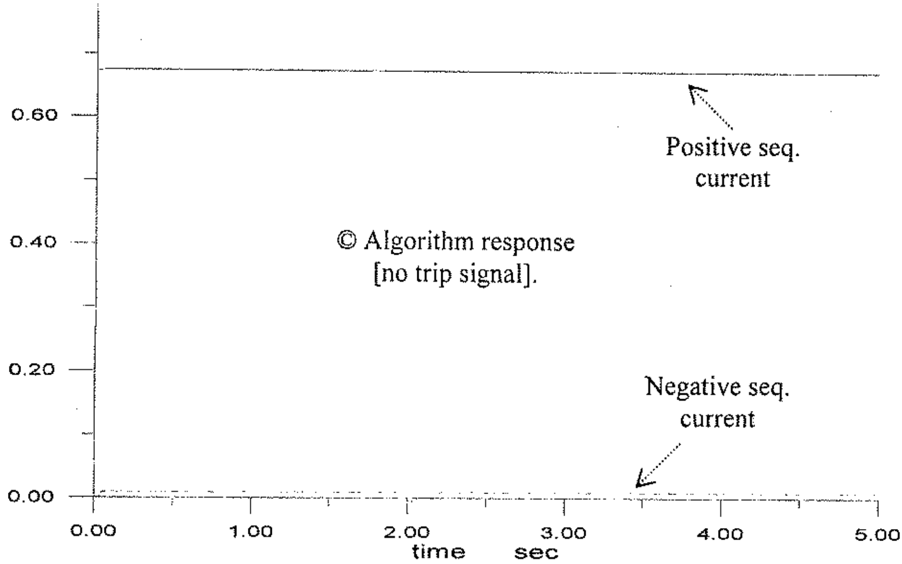


Figure 8: Algorithm response to a normal unbalanced operation