Microcontroller Based Numerical Mho Distance Relay For Transmission Line Protection

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***Abstract*:-The work described by in this paper related to the development and testing of microcontroller based mho relay suitable for the protection of EVH/UHV lines. The mho relay is most suited for long transmission lines where especially there are more chances of severe synchronizing power surge on the system. An interface has been designed and fabricated to obtain the samples of the voltage and current signals. The algorithms used for the calculation of line parameters have been based on the solution of the Cosine and sine transform representing the transmission line model. A generalized mathematical expression for the operating conditions of mho relays has been derived. Any desired mho or offset mho relay characteristics can be realized by changing the constants only. A program has been developed to obtain the mho and offset mho characteristic on the R-X diagram. The relay has been designed and successfully tested statically in the laboratory with a test signal. Microcontroller-based protective relays offer attractive compactness and flexibility.**

Keywords—
v, i = Voltage and current signals respectivily
Z = impedance seen by relay: , R = resistance seen by relay
X = wL= reactance seen by relay ; C_1 C_2 & C_3 are constants

I. Introduction

The increased growth of power system both in size and complexity has brought about the need for fast and reliable relays to protect major equipment and to maintain system stability. The concept of numerical protection employing which shows much promise in providing improved performance has evolved. With the development of economical, powerful and sophisticated Microcontroller,

The main features which have encouraged the design and development of Microcontroller based protective relays are their economy, compactness, reliability, flexibility and improved performance over conventional relays. A number of desired relaying characteristics, such as over current, directional, impedance, reactance, mho quadrilateral elliptical, etc. can be obtained using the same interface. Different programs are used to obtain different relaying characteristics using the same interfacing circuitry. This paper presents micro controller based mho relays for protection of extra high voltage long transmission lines. An interface using operational; amplifiers sample and hold, analog multiplexer, analog to digital converter (ADC), voltage comparator and passive circuit elements has been designed and fabricated (fig.1). To realize mho characteristics the resistance and reactance at the relay location are measured by micro-controller. A generalized mathematical expression for the operating conditions of mho relay has been derived. The constant involved in the expression depend on the desired mho relay on R-X diagram. Mho relays for zones 1and 2, and offset mho for zone 3 are desired for protection of transmission lines against phase faults are shown in fig 2. The desired characteristics for long transmission lines, to distinguish between loads and faults are shown in fig 3.

II. Theory

Figure 2 shows the characteristic of an offset Mho relay on the diagram. The radius of the circle is

$$r = \frac{Zr - Zo}{2}$$

The centre of the circle is displaced from the origin by

$$C = \frac{Zr + Zo}{2}$$

The operating condition for the offset Mho relay shown in Fig. 2 is given by

$$|Z - C| < |r|$$

or

$$\left|Z - \frac{(Zr + Zo)}{2}\right| < \left|\frac{Zr - Zo}{2}\right| \quad (1)$$

or

$$\left|Z - \frac{(Zr + Zo)}{2}\right| < \left|\frac{Zr - Zo}{2}\right|$$

or

$$\left|(R + jX) - \frac{(Rr + jXr + Ro + jXo)}{2}\right| < \left|\frac{(Rr + jXr) - (Ro + jXo)}{2}\right|$$

or

$$\left|\left\{R - \frac{(Rr + Ro)}{2}\right\} + j\left\{X - \frac{(Xr + Xo)}{2}\right\}\right| < \left|\frac{(Rr - Ro)}{2} + j\frac{(Xr - Xo)}{2}\right|$$

or

$$\left[\left\{R - \frac{(R_r + R_0)}{2}\right\}^2 + \left\{X - \frac{(Xr + Xo)}{2}\right\}^2\right] < \left[\left\{\frac{(Rr - Ro)}{2}\right\}^2 + \left\{\frac{(Xr - Xo)}{2}\right\}^2\right] \quad (2)$$

Rr, Xr, Ro and Xo are constants for a particular characteristic, and hence the above expression can be written as

$$[(R - C_1)^2 + (X - C_2)^2] < C_3 \qquad (3)$$

Where C_1, C_2 and C_3 are constants.

To realize an offset mho characteristic, as shown in Fig.3, the values of R_0 and X_0 are put negative in Equation.

To realize, the mho characteristic, as shown in Fig. 2, is reduced to zero. Consequently, the operating condition becomes

$$\left[\left(R - \frac{R_r}{2}\right)^2 + \left(X - \frac{X_r}{2}\right)^2\right] < \left[\left(\frac{R_r}{2}\right)^2 + \left(\frac{X_r}{2}\right)^2\right]$$

$$\left[(R - C_4)^2 + (X - C_5)^2\right] < C \qquad (4)$$

A generalized equation for mho and offset mho relays can be written as

$$\left[(R - K_1)^2 + (X - K_2)^2\right] < K_3 \qquad (5)$$

Where K_1, K_2 and K_3 are constants for a particular characteristics. Substituting the proper values of these constants a desired mho or offset mho characteristic can be realized.

III. Measurement Of Line Parameters Algorithm

In a numerical relaying scheme, the processor acquires the digitized samples of the relaying signals and processed them using numerical algorithm to extract the fault discriminates. The numerical filter based on different algorithms extract the fundamental frequency component.

The algorithm for extracting the fundamental frequency components from post fault current and voltage is based on Discrete Cosine & Sine Transforms. The algorithm is computationally simple and flexible to use with any sampling frequency. The post fault current signal contains fundamental frequency component as well as of D.C. offset and harmonic Components T he fundamental frequency component is extracted

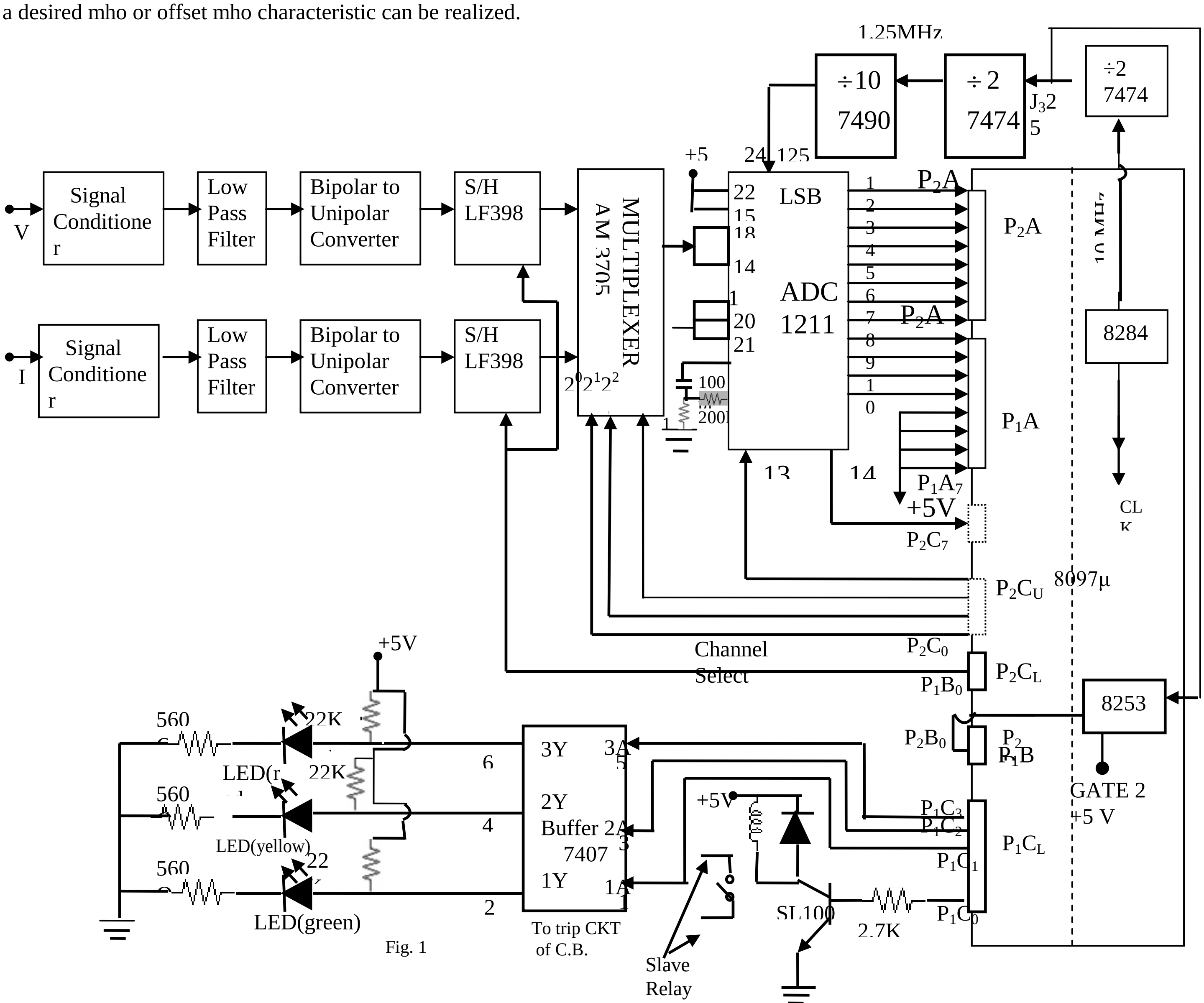
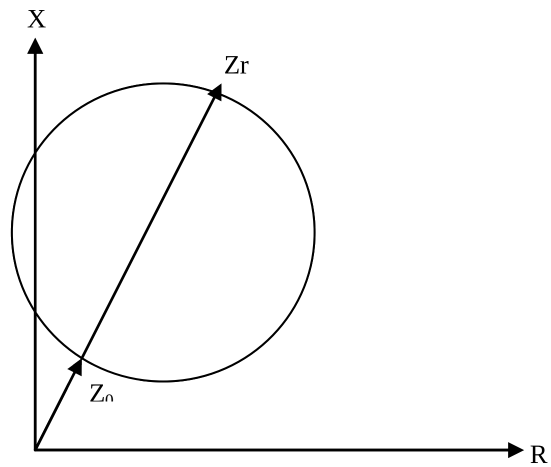


Fig. 1



Fig, 2 Offset Mho relay with +ve offset

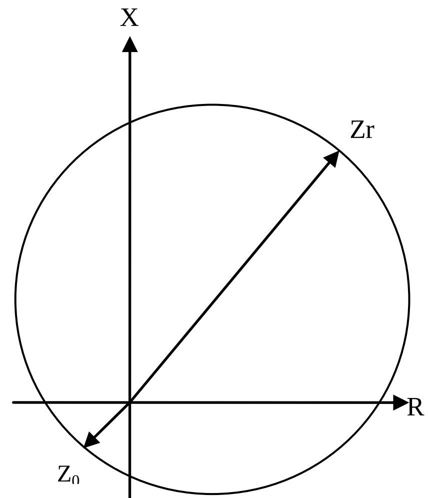


Fig.3 Offset Mho relay with -ve offset

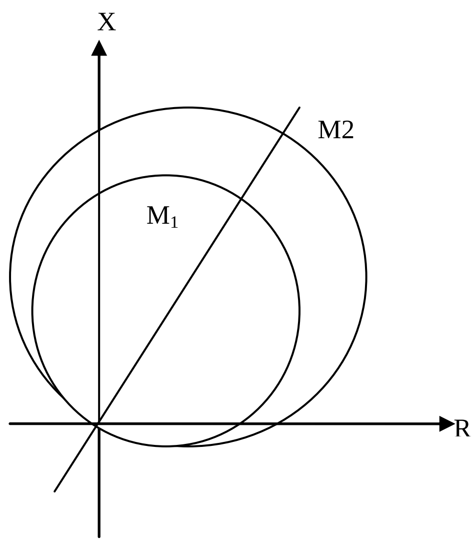


Fig. 4 mho relays

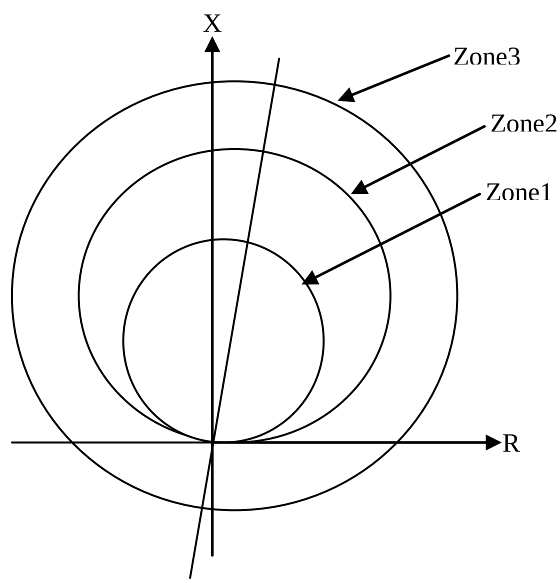


Fig. 5 mho & offset mho relays

by using this algorithm and operating conditions of relay is decided according to the value of this frequency component. The current samples acquired over a full cycle data window at the sampling rate of 16 samples per cycle. The Discrete cosine & sine transform coefficients are obtained by merely calculating the values of current samples. Computation based on this algorithm requires less memory space and hence less time consuming, that is why, it is better than other algorithms.

IV. Discrete Fourier Transform

If the periodic function x(t) is sampled N times per period at the sampling interval of T_S, the N samples represent the period t, so T= NT_s. These N samples of X(t) from the data sequence X_m m=0,1,2,3----- (N-1). Therefore, the DFT of a data sequence X_m

$$C_{fk} = \frac{1}{N}\sum_{m=0}^{N-1} X_m \exp(-j2\pi km / N) \qquad (6)$$

m=0, 1, 2, and 3------- (N-1) is defined as:

And K=0, 1, 2-------- (N-1)

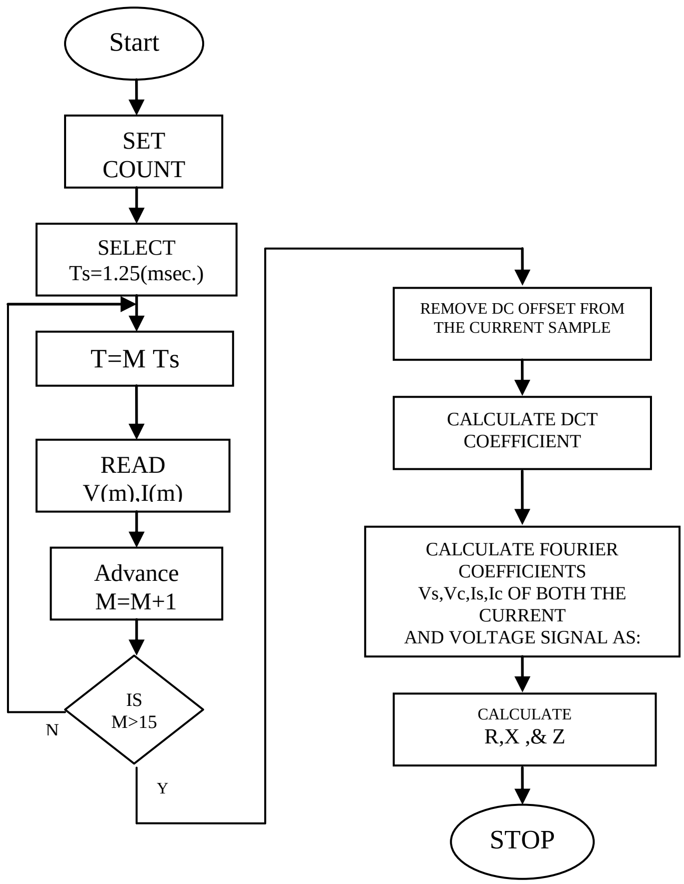


Fig. 6 Flow chart for computation of R & X

The computation of Fourier coefficients by using Equation (6) involves complex arithmetic that makes the computation difficult with a microprocessor. Therefore, for microprocessor implementation of the DFT, separate equations for real and imaginary parts are used. The real and imaginary components of the fundamental frequency signal are respectively:

$$F_1 = \frac{a_1}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{m=0}^{N-1} X_m \cos(2\pi m / N) \qquad (7)$$

$$F_2 = \frac{b_1}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{m=0}^{N-1} X_m \sin(2\pi m / N) \qquad (8)$$

A. *Discrete Cosine Transform (DCT)*

In this algorithm, only two components are needed to evaluate among the four. Here only reactive fundamental frequency components of voltage and current are extracted to calculate the impedance for the distance relaying. The real components are extracted from the already calculated values in the real time of distance protection. For DCT full cycle data window algorithm is used.

a) *DCT With Full Cycle Data Window*

The incoming sample for voltage and current are correlated over one cycle with complex value of the fundamental component in rectangular form. Reactive components are given by:-

$$F_{ckv} = \frac{2}{N}\sum_{i=1}^{N} V_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (9)$$

$$F_{cki} = \frac{2}{N}\sum_{i=1}^{N} I_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (10)$$

Where,

N = Number of samples taken per cycle.

K = Number of sample at the instant.

F_{ckv} =Reactive component of voltage at the k^{th} instant.

F_{cki} = Reactive component of current at the k^{th} instant.

V_{k-N+I} and I_{k-N+I} are the sampled values of voltage and current at the $(k-N+i)^{th}$ instant.

$$F_{2V} = \frac{a_1}{\sqrt{2}} = \frac{F_{ckv}}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} V_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (11)$$

$$F_{2i} = \frac{a_1}{\sqrt{2}} = \frac{F_{cki}}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} I_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (12)$$

Therefore,

$$V_c = F_{2V} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} V_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (13)$$

$$and$$

$$I_c = F_{2i} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} I_{K-N+i} COS(\frac{2\Pi i}{N}) \qquad (14)$$

b) *Extraction Of Real Components Of Voltage And Current Signals*

At the k^{th} instant the fundamental frequency cosine (reactive) components of voltage and current are given by

$$V_k = V_c = VSin\phi_v$$
$$I_k = I_c = ISin\phi_i$$

Where V & I are the rms values of the filtered voltage and current respectively, Φ_v and Φ_I are their phase angles at the K^{th} sampling instant. Since the sampling interval for N = 16 is $\frac{\Pi}{8}$ the filtering values of voltage and current at $(k-4)^{th}$ instant are

$$V_{k-4} = V\ Sin\left(\phi_v - \frac{\Pi}{2}\right) = -VCOS\phi_v \qquad (15)$$

$$I_{k-4} = I\ ISin\left(\phi_i - \frac{\Pi}{2}\right) = -ICOS\phi_i \qquad (16)$$

Knowing Vs ,Is, Vc and Ic, R and X are computed by DST

B. *Discrete Sine Transform (DST)*

In this algorithm, only two components are needed to evaluate among the four. Here only real fundamental frequency components of voltage and current are extracted to calculate the impedance for the distance relaying. The reactive components are extracted from the already calculated values in the real time of distance protection. For DST full cycle data window algorithm is used

a) DST With Full Cycle Data Window

The incoming samples for voltage and current are correlated over one cycle with complex value of the fundamental component in rectangular form. Real components are given by:-

$$F_{skv} = \frac{2}{N}\sum_{i=1}^{N} V_{K-N+i} SIn(\frac{2\prod i}{N}) \quad (17)$$

$$F_{ski} = \frac{2}{N}\sum_{i=1}^{N} I_{K-N+i} Sin(\frac{2\prod i}{N}) \quad (18)$$

Where,

N = Number of samples taken per cycle.

K = Number of sample at the instant.

F_{skv} =Reactive component of voltage at the k^{th} instant.

F_{ski} = Reactive component of current at the k^{th} instant.

V_{k-N+I} and I_{k-N+I} are the sampled values of voltage and current at the $(k-N+i)^{th}$ instant.

$$F_{2V} = \frac{b_1}{\sqrt{2}} = \frac{F_{1kv}}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} V_{K-N+i} Sin(\frac{2\prod i}{N}) \quad (19)$$

$$F_{2i} = \frac{b_1}{\sqrt{2}} = \frac{F_{1ki}}{\sqrt{2}} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} I_{K-N+i} Sin(\frac{2\prod i}{N}) \quad (20)$$

Therefore,

$$V_s = F_{2V} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} V_{K-N+i} Sin(\frac{2\prod i}{N}) \quad (21)$$

and

$$I_s = F_{1i} = \frac{\sqrt{2}}{N}\sum_{i=1}^{N} I_{K-N+i} Sin(\frac{2\prod i}{N}) \quad (22)$$

V. Hardware And Interfacing Circuit

The block schematic diagram of the proposed microcontroller based mho and offset mho relay is shown in Fig.1. The levels of voltage and current signals are stepped down to the electronic level by using auxiliary voltage and current transformers. The current signal derived from the current transformer is converted into proportional voltage signal. As the sampling frequency (fs) used for the data acquisition is 800 Hz, an active low pass filter of cut-off frequency 400Hz is used to avoid aliasing error .The data acquisition system (DAS) consists of signal conditioner, active low pass filter, bipolar to unipolar converter, sample and hold circuit (LF398), analog multiplexer (M3705) and 12-bit A/D converter (ADC 1211). ADC 1211 has been used in single supply (+5V) operating configuration. A clock of 125 KHz for ADC1211is obtained by dividing 2.5 MHz peripheral clock7490

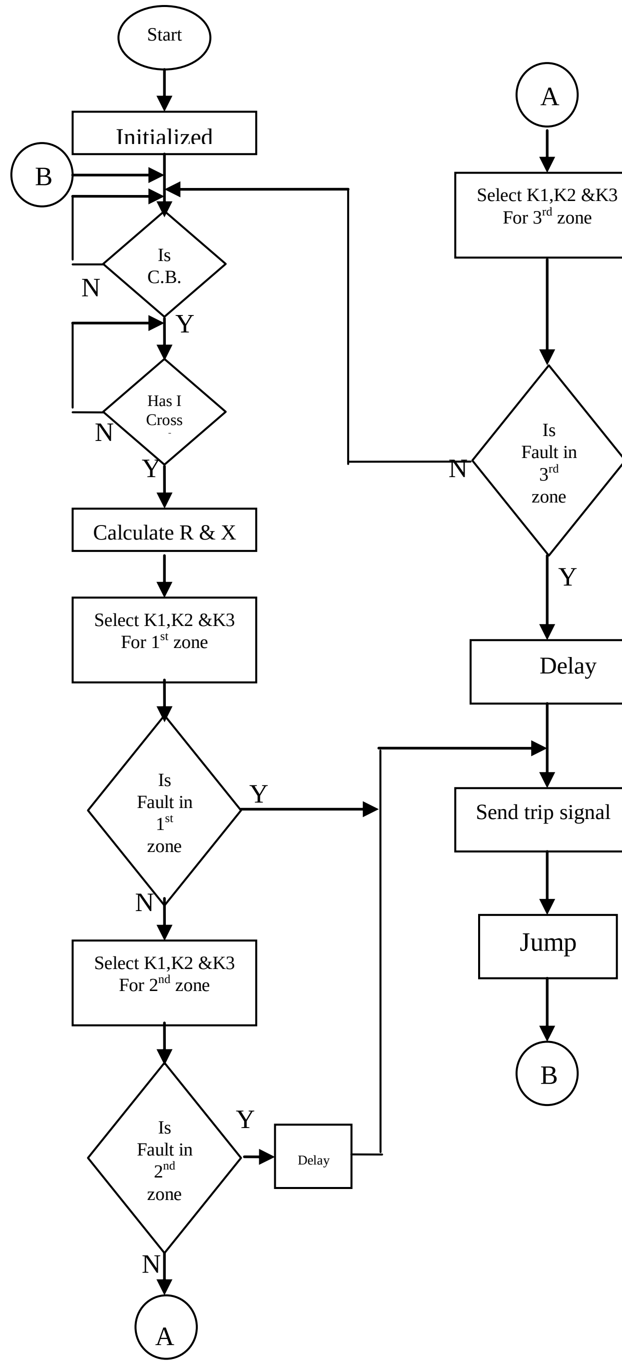


Fig. 7 flow chart for mho & offset mho relay

The DAS is interfaced to microprocessor using 8255 a
(CLK0) from J3 pin 25 by using IC using package 7474 and programmable peripheral interface. The 8253 programmable timer / counter have been used to generate a square wave of 1.25ms period, i.e. 800 Hz for sampling of signals. The controls for S/H circuit, the analog multiplexer and ADC are all generated by the microcontroller under program control. Three LEDs of different color are used for Visual indication of occurrence of faults in three protective zones of mho Distance relay. A slave relay whose contacts are connected in series with the trip circuit of circuit breaker is used to actuate the trip circuit after receiving the trip signal output by the microprocessor through an I/O port line on occurrence of fault in any one of three protective zones of the relay.

VI. Software Details

Among the various distances relay operating characteristics available, the microcontroller based mho relay suitable for the protection of long transmission lines. An interface have been designed and fabricated to obtain the voltage and current signals. The algorithm used for the calculation of line parameters has been on the solution the discrete cosine & sine transforms representing the transmission line model. A generalized mathematical expression for the operating conditions of mho and offset mho relays are derived. Any desired mho or offset mho characteristic can be realized by changing the constants only. A program has been developed to obtain the mho or offset mho characteristic on the R-X diagram. An interfacing using operational amplifiers, sample and hold circuit, analog multiplexer, analog to digital converter (ADC), voltage comparator have been designed. To realize a mho relay characteristic, the resistance and reactance at the relay location are measured by the microcontroller. A generalized mathematical expression for the operating conditions of mho and offset mho relays has been derived. The constants involved in the expression depend on the desired mho or offset mho characteristic on the R-X diagram. Mho relays for zones 1 and 2, and offset mho for zone 3 is desired for protection of transmission lines against phase faults. The constants for all the three zones of protection are predetermined and stored in the memory. The microcontroller examines whether the measured values of R and X lie within the protective zones of the relay. In case of no fault in the protective section, the microcontroller goes back to the starting point for the measurement of R and X repeats the entire process

VII. Mho And Offset Mho Characteristics

For the protection of transmission lines against phase faults mho relays for zones 1 and 2offset mho for zone 3 as shown in Fig. 3, are used. For long transmission lines mho and offset mho characteristics are used to discriminate between load and faults. The various values of constants K_1, K_2, and K_3 for different zones of protection are pre-determined and stored in memory. The microcontroller measures R and X at the relay location. Thereafter, it makes calculations for different terms of equation and checks whether the operating condition for the first zone of protection is satisfied. If the fault point lies within the first zone of protection, a tripping signal is sent instantaneously. If the point does not lies in the zone 1 of protection, the microcontroller takes the values of K_1, K_2, and K_3 for the zone 2 protection and makes the desired calculations and comparison. If the fault point lies in the zone 2, the trip signal is sent after a certain predetermined delay. A delay subroutine is used for the purpose. The delay is calculated from stability point of view. If the fault point does not lie in the zone 2, the microcontroller takes the values of K_1, K_2, and K_3 for the zone 3, and makes calculations for offset mho characteristic. If the fault point falls within the zone 3, a trip signal is sent after greater delay as shown in program flowchart of Fig 7.If the microcontroller goes to the starting point and measures R and X, and repeats the whole process. No directional unit is required for these relays as they are inherently directional.

VIII. Laboratory Testing Of The Relay

The proposed microcontroller based mho distance relay has been tested statically in the laboratory with the simulated fault data generated by a transmission line model. A single phase series R-L model of the transmission line was achieved by using three modules of variable inductance and resistance connected in series. The capacitance of the transmission line has been neglected for the test purpose. Faults at different points of the transmission line were created by closing the switches connected at those points. The bus voltage of the model was 220 volts. The level of fault signal was stepped down to the electronic level by using potential and current transformers. The current signal derived from the current transformer was converted into proportional voltage signal. The realized relay test result shown in the table 1 & 2.

A. *Offset Mho Relay With Positive Offset*

Zr =3+j30, Zo = 1+j10

K_1=2, K_2 = 20, K_3 = 101

Operating condition is:

$[(R-2)^2 + (X-20)^2]<101$

TABLE 1:

LINE IMPEDANCE Z (Ω)	RELAY OPERATION
0 + j10	no
0 + j12	yes
5 + j30	no
5 + j28	yes
10 +j30	no
0 + j25	yes
0 +j30	no
0 +j28	yes

B. *Offset Mho Relay With Negative Offset*

Zr = 6 +j60, Zo =-2 –j20
K_1=2, K_2 = 20, K_3 = 1616
Operating condition is:
$[(R-2)^2 + (X-20)^2]<1616$

TABLE 2:

LINE IMPEDANCE Z (Ω)	RELAY OPERATION
10 + j63	no
10 + j59	yes
20 + j57	no
20 + j55	yes
40 + j0	no
36 + j0	yes
40 + j35	no
40 + j32	yes

IX. CONCLUSIONS

The microcontroller based mho relay have been successfully developed and tested in the laboratory. Their performance is quite satisfactory. The 16 bit 8097 microcontroller based relays are fast, accurate and reliable. They operate within one cycle period (1.25msec.). Any desired mho relay can be realized using the same interface and program; only constants are to be changed. Restricted mho characteristic is least affected by power surges and is quite suitable for the protection of very long lines. This characteristic has also been obtained using the same interface. Microcontroller based protective relays offer attractive compactness and flexibility. The present downward trend in cost of large scale integrated circuits will encourage wide applications of microcontroller based protective schemes to meet the requirements of modern power system in near future.

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