Design of a Numerical Adaptive Relay Based on Memory Mapped Techniques

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Abstract - **This work describes the design of a DSP (Digital Signal Processor) based Adaptive Numerical Mho relay, to be used for distance protection schemes of long distance transmission lines. The relay settings will be automatically adjusted with the changes of power system parameters with the variation of frequency as well as with the variation of percentage compensation which may occur due to fault /damage in the compensating device itself for a series compensated line. The signal conditioning is oriented on the Inverse Discrete Fourier Transform (IDFT) and the relaying algorithm is based on Memory Mapped Targeting Technique (MMTT).**

Index Terms--**Adaptive Numerical Mho relay, Memory Mapped Technique (MMTT), Digital Signal Processor, Distance protection, Inverse Discrete Fourier Transform (IDFT).**

I. Introduction

ADAPTIVE relaying considers the fact that the status of a power system changes with the occurrence of the fault and with changing load patterns etc. This necessitates the changing of the on-line relay settings. The adaptive relaying technique therefore requires a DSP microcontroller for its accurate and reliable functioning.

A. A brief background of the problem:

Distance protection is a common practice for long transmission line protection. In a digital relaying scheme, voltage and current samples are taken at the relaying point and used to compute the apparent impedance of the line as seen by the relay. If the actual impedance lies inside a predetermined boundary, the decision is made to disconnect or trip the line. Adaptive relaying considers the fact that the status of a power system can change. Thus, the setting of relays will be changed on-line to accommodate these changes. Horowitz et a1 [1] defined adaptive relaying as a protection philosophy which permits and seeks to make adjustments to various protection functions in order to make them more attuned to prevailing power system conditions. M. S. Sachdev et al described about the Memory Mapped Targeting Techniques [2] i.e. how relay characteristics can be segmented on memory. The paper by Girgis [3] et al described the adaptive scheme for digital differential protection of power transformer by Kalman filtering taking account the adaptive percentage differential characteristics. An adaptive setting concept for two and three terminal lines, which can respond to changes in the network conditions, was proposed by Xia et a1 [4,5]. Sometimes the distance relay measure incorrect impedance to the fault for remote end infeed. Paper by Moore et al [6] & by Jamali [7] described the adaptive technique for measuring the correct impedance during fault. Papers by Sachdev et al [8] described the techniques of adaptive data windows. A recent paper by Hu et al [9] introduced the technique for graphical representation of digital relay.

B. Objective and Motivation

In this paper an adaptive numerical relay for protection of transmission lines has been developed using the DSP chip. Signal processing techniques evolve around the classical IDFT (Inverse Discrete Fourier Transform) techniques.

The relaying algorithm works on the Memory Mapped Targeting Technique. This is an interesting methods where the R and X values of the system trajectory are checked through look-up tables, one memory segment keeping the R values, the other the X values. A specific value of R in a memory location of a memory segment points to specific value of X in the corresponding location of another segment. A points on the relay locus is translated to the dual values of R and X, stored in two memory locations, indicated by the memory pointer. It is only to be checked whether the measured R & X (after translation) is within the relay locus. This method revolves the necessity of performing mathematical calculation in every supervisory loop of the relaying algorithm; Memory targeting and checking is a very trivial task for the DSP.

The relaying algorithm tracks the fundamental frequency in every cycle check. Change its sampling frequency accordingly (Adaptive Sampling) to find the updated impedance value. The relay settings with also correspondingly change for this, as a result of the adaptability feature. The time taken for the signal conditioning and relaying algorithm is within one and a half power cycles. The application of the developed numerical relay has been aimed mainly to solve a chronic ailment in one of the power utilities of India, the Damodar Valley Corporation. The series compensation failure in long lines is a common occurrence. Fault occurring during this time fails to trip the circuit breaker. This relay with its fast signal

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sensing capabilities takes care of this event by carefully changing its relay parameters, to accommodate the new value of the impedance. This is explained in detail in chapter IV.

II. The DSP based Numerical Adaptive Relay

A. Hardware Layout

The hardware of the relay is shown in Fig.1. The voltage signal from a PT and the current signal from a CT are sampled by an adaptive sampling rate controlled by the ADSP processor. The low pass filter (LPF) to be used as anti-aliasing filter (ALF). Then they are digitized. Then the processor calculates the apparent impedance from these signals and check that it is within the predetermined Mho boundary or not. A trip signal will generate if the impedance is outside the relay boundary.

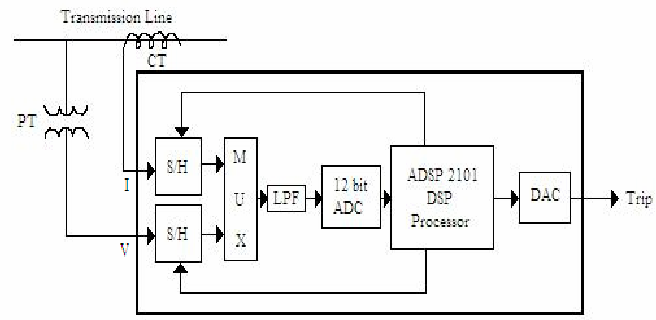

Fig.1. Hardware layouts of the relay.

B. Relaying algorithm

The relaying algorithm is executed after the signal processing, which is done in this work by Inverse Discrete Fourier Transform (IDFT). After IDFT the relaying algorithm is done on the sampled signals, to get the value of R & X at fundamental frequency with the sampling rate of 12 samples/cycle. The values of R & X are made independent of frequency changes by tracking the nominal frequency.

1) Determination and translation of R-X to memory plane

In a system if V_m and the I_m is the peak value of line voltage and line current respectively then the impedance,

$$Z = \frac{V_m}{I_m} \quad (1)$$

the resistance $R = \dfrac{V_m \cos\theta}{I_m}$ and, (2)

the reactance $X = \dfrac{V_m \sin\theta}{I_m}$; (3)

Where Θ is the power factor angle. If the current & voltage signals are described as $i=I_m \sin \omega t$ and $v=V_m \sin(\omega t+\Theta)$ respectively, sampling at $\omega t = 90^0$ will give $i=I_m$, and $v=V_m \cos \Theta$

Therefore, $$R = \frac{V_m \cos\theta}{I_m} = \frac{v}{i};\ when\ \omega t = 90^0 \quad (4)$$

So when the current samples reach the maximum value, the corresponding voltage samples divided by this maximum current sample give us the R value.

At $\omega t = 0^0$, $i=0$, and $v=V_m \sin \Theta$

Therefore, $$X = \frac{V_m \sin\theta}{I_m} \quad (5)$$

So when the current samples reaches the zero value (or positive zero crossing), the corresponding voltage samples divided by the maximum current samples give us the X value. In this way using equation (4) and (5), find out the values of R and X for every cycle and stored it in some memory location.

2) Memory Mapped Targeting Techniques

Memory Mapped Targeting Techniques (MMTT), which consists of segmenting the characteristics of the relay, can be used to model a Mho relay characteristic. (Fig.2.) Here it required three parameters to plot the relay characteristic in the impedance plane. One is the R value for the centre, another is the X value for the center and the last one is the radius of the circle. All these quantities are in terms of memory segment. There is a conversion factor which converts the real time value to memory segment.

First calculate the radius of the Mho circle then find out the coordinates of its periphery (R_i, X_i). So there are two column matrix one for R value, another for X value. The elements of these two matrix ore assigned a one-to-one correlation with each other. i.e. element one of the R matrix relates element one of the X matrix.

An apparent impedance Z_L, of a transmission line is also changed to integer coordinates by dividing its real and imaginary components (R_L, X_L). Linear transformation is then applied to eliminate the negative coordinates. This procedure allows the impedance to be checked against the coordinates of the elements and to ascertain whether the impedance lies in the relay operating region or not. A linear transformation applied to any point solves 75% of memory location reserved for R & X.

a) Advantage of MMTT over circular relay techniques

- Very simple algorithm for obtaining the circular locus.
- Draw the circle for positive R and positive X axis only, it save 75% memory location.
- Once plot the circle, it is very easy to check a point is inside the circle or not. It is not require to solve any equation of circle for this purpose, i.e. it save the time for calculation.
- It can be reduce or increase the radius of the circle as required, i.e. the reach of the relay can be change automatically.
- The center of the circle can be shifted in any quadrants as required.
- Determination of R & X is completely independent of frequency. Also the relay locus changes with change of X (as frequency change). Adjustments are necessary to set the relay locus at the new frequency. With the changes of frequency, the sampling rate also changes known as adapting sampling.

III. Algorithm for Developing the Program

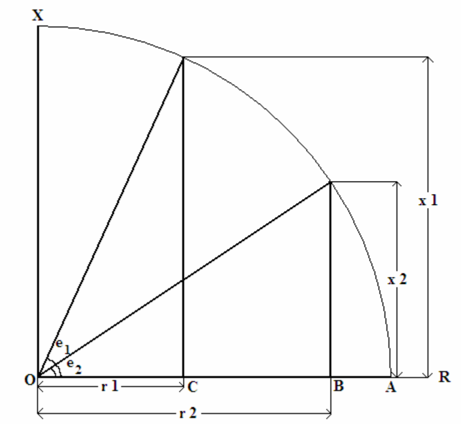

Fig.2. Translation from R-X plane to memory plane

At point 'A',

$R \cos \Theta = r_A = R;$

$\cos \Theta = R/R = 1;$

$\sin \Theta = \sqrt{1-(\cos\theta)^2} = 0;$

$x_A = R \sin \Theta = 0.$

At point 'B',

$R \cos \Theta_2 = r2;$

$\cos \Theta_2 = r2/R;$

$\sin\Theta_2 = \sqrt{1-(\cos\theta_2)^2}$

$x2 = R \sin \Theta_2.$

Similarly at point 'C',

$x1 = R \sin \Theta_1.$

So starting from point A to point O we get two columns. One for R and another for X. there is one to one mapping relation between these two columns, i.e. element n in R column correspond to element n in X column. The elements of this R and X column indicate the point situated at the perimeter of the circle.

IV. Adaptive Relaying

Adaptive relaying considers the fact that the status of a power system can change. Thus, the setting of relays will be changed on-line to accommodate these changes. The schematic layout is shown in the Fig.3. The data has been adopted for a 400 km long 100 MVA base line. First the mho characteristic is drawn from that preset data.

Here, for the signal processing technique (IDFT) it requires 12 samples/cycle and it should be independent of frequency. So it requires an adaptive sampling block which determines the line frequency and set a sampling frequency 12*f*. After determining the frequency compare it with 50 Hz, if it is found that the frequency is change then modifies the X value and redraw the characteristics.

There is a series compensation of the line. It actually compensates the X of the line. If sometime the calculated X is greater than the compensated X value then there must be some problem regarding the series compensation. Then also update the relay characteristics, by increasing the radius.

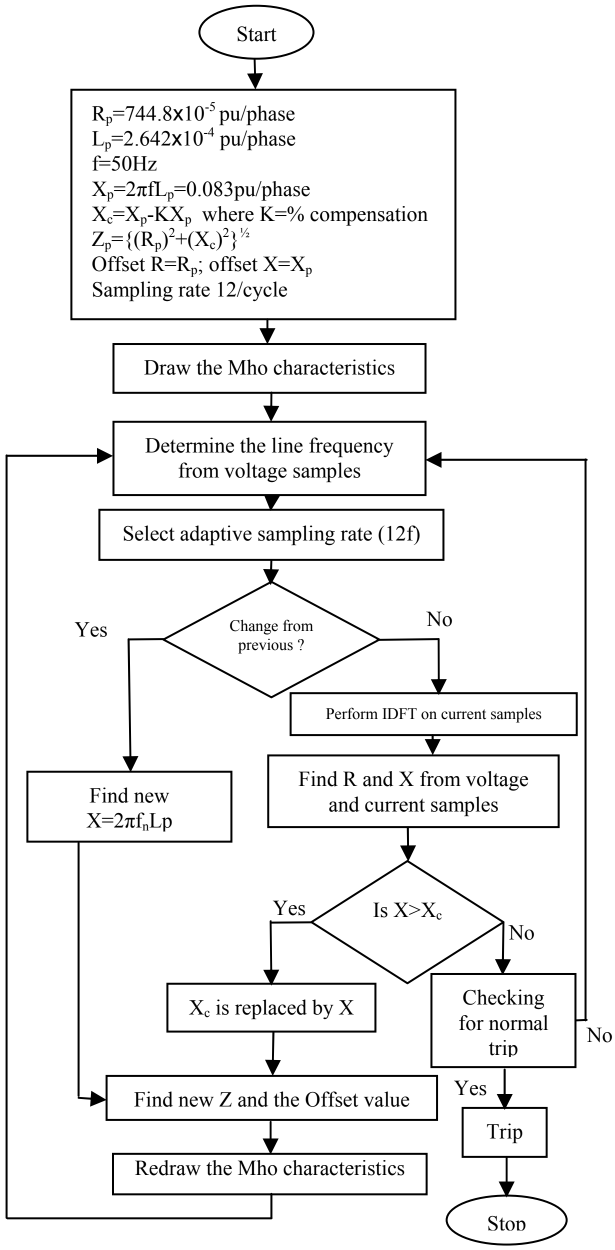

Fig:3 A complete Flow Chart of the Adaptive Relay

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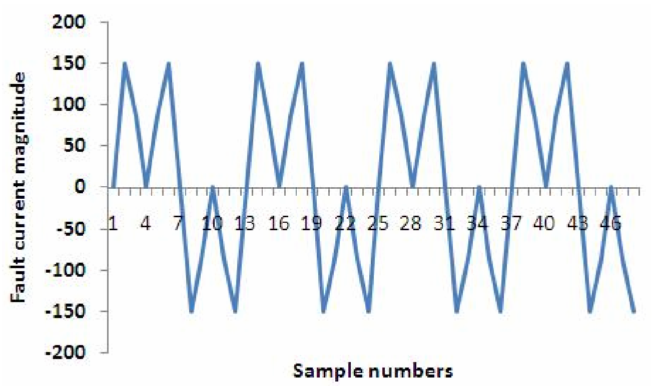
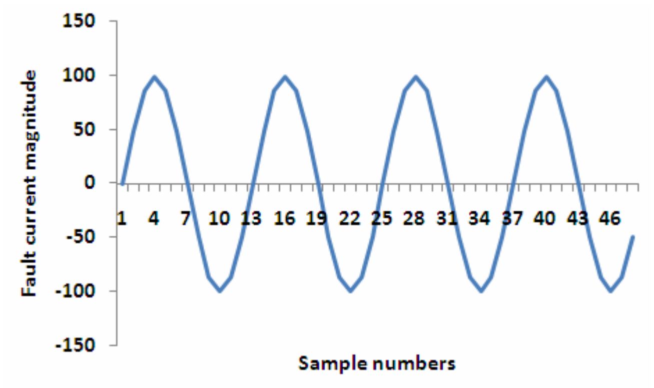
V. Test Result and Analysis

A. *Filtering of the signal:*

At the time of fault the fault current is not a fundamental frequency signal. Some harmonics may present in the fault current. Here some assumption is made that odd harmonics are superimposed with the fundamental frequency signal. A simulated signal is generated with the help of MATLAB which is the superimpose waveform of a 50 Hz fundamental signal plus its 3^{rd}, 5^{th} and 7^{th} harmonics as shown in Fig.4 (a). After that sampled the signal at the rate of 12 samples/cycle. Then apply IDFT filtering technique on these sampled data of this superimpose waveform. At last get the fundamental frequency signal from ADSP 2101 DSP processor, which is shown in Fig.4 (b).

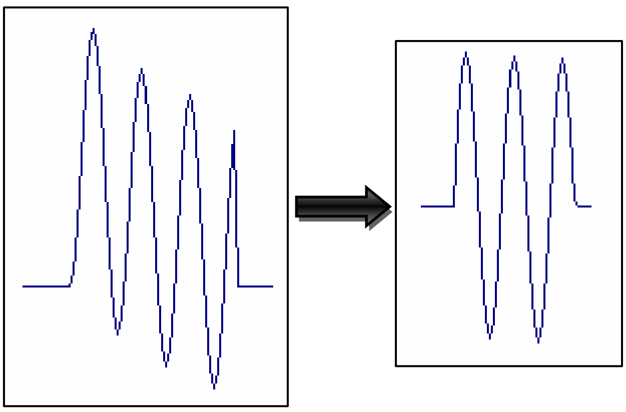


(a)



(b)

Fig. 4.(a) Waveform for fundamental plus 3rd, 5th and 7th harmonics (b) After the IDFT process we get the fundamental frequency waveform



(a) (b)

Fig.5(a) Fault current with a decaying dc component (b) after IDFT the dc component is partially removed

In the time of fault, some decaying dc component is also present with the fault current. After IDFT it partially removes this unwanted dc component. Fig.5 (a) shows the fault current waveform with a decaying dc component, Fig.5 (b) shows after IDFT the decaying dc component is partially removed.

B. *Calculation of R & X:*

Two data files are taken, one for current samples and another for voltage samples. These two data files are the input of our program. First finds the maximum current sample value and its position also the corresponding voltage sample value. To find R, divide the voltage sample by current sample. After that it finds the position of positive zero crossing of current sample and the corresponding voltage sample. Dividing this voltage sample by maximum current sample gives the value of X. Table 1 shows the voltage and corresponding current samples.

TABLE. 1: VOLTAGE AND CURRENT SAMPLES

Sl No	Current Samples After(IDFT)	Voltage samples
1	24	134.1236
2	85	149.7359
3	130	125.2267
4	144	67.1631
5	124	-8.8968
6	73	-82.5728
7	5	-134.123
8	-63	-149.735
9	-113	-125.226
10	-132	-67.1632
11	-114	8.8967
12	-66	82.5727
13	1	134.1234
14	67	149.7359
15	116	125.2269
16	133	67.1634
17	115	-8.8965
18	66	-82.5725
19	0	-134.1233
20	-67	-149.735
21	-116	-125.227
22	-134	-67.1635
23	-116	8.8963
24	-67	82.5724

The current samples are multiplied by 100, voltage samples are in original value.

From table.1 it is seen that maximum current value is 144 and its position is 4, the corresponding voltage value is 67.1631. So using equation (4),

$$R=\frac{67.1631}{144}\times 100=46.64\approx 46\Omega$$

Also from table.1it is find that at position 13 the current samples just crosses zero value (positive zero crossing). And the corresponding voltage samples value is 134.1234. So using equation (5),

$$X=\frac{134.1234}{144}\times 100=93.14\approx 93\Omega$$

Table.2 shows the reactance X_i values corresponding to resistance R_i.

TABLE.2: RESISTANCE (RI) AND CORRESPONDING REACTANCE (XI) VALUES

R_i	X_i	R_i	X_i	R_i	X_i	R_i	X_i
1	128	33	122	65	110	97	84
2	126	34	122	66	110	98	83
3	126	35	122	67	108	99	80
4	126	36	122	68	107	100	79
5	126	37	122	69	107	101	79
6	126	38	121	70	107	102	78
7	126	39	121	71	106	103	76
8	126	40	121	72	104	104	74
9	126	41	120	73	104	105	72
10	126	42	120	74	104	106	72
11	126	43	120	75	103	107	70
12	126	44	120	76	102	108	69
13	126	45	119	77	102	109	66
14	126	46	119	78	101	110	66
15	126	47	119	79	101	111	65
16	126	48	117	80	99	112	62
17	126	49	117	81	98	113	60
18	126	50	117	82	97	114	57
19	126	51	117	83	97	115	57
20	125	52	116	84	96	116	55
21	125	53	116	85	96	117	52
22	125	54	115	86	94	118	49
23	125	55	115	87	94	119	49
24	125	56	115	88	93	120	46
25	125	57	113	89	92	121	43
26	124	58	113	90	90	122	39
27	124	59	112	91	89	123	35
28	124	60	112	92	89	124	35
29	124	61	112	93	88	125	30
30	124	62	111	94	87	126	24
31	124	63	111	95	85	127	17
32	122	64	110	96	84	128	0

Here R=128 indicates that there are 128 memory segment in the 'r_buffer' and the values of X_i indicates the 'x' value corresponding to each 'r' value in the first quadrant, i.e. for r= 128 x=0, r=127 x=17, r=126 x=24…r=1 x=128.

C. Relay characteristics

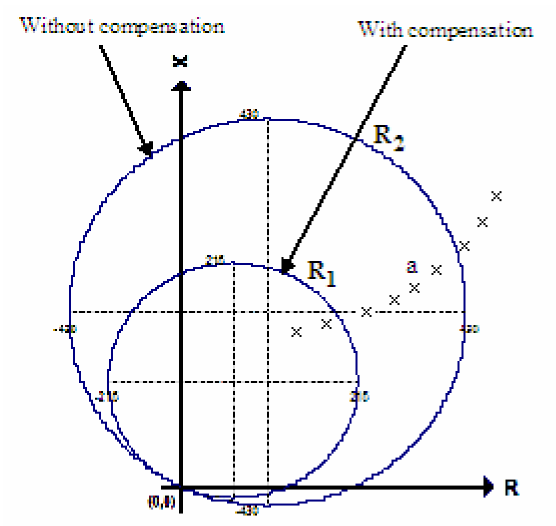


Fig.5. Relay characteristics with and without series compensation

Fig.5 shows the mho relay characteristics. The small circle R1 represents the characteristics of the relay with series compensation and the bigger one R2 is without compensation. Fault point 'a' does not receive trip signal with R1 characteristics but within the new relay boundary R2, it receives trip signal.

During Change of compensation of the line due to operation of protective devices placed across the compensating devices the relay will adjust the setting automatically as needed.

VI. CONCLUSION

Adaptive relaying is a new philosophy in protecting electric power systems. Adaptive relaying utilizes the continuous changing status of the power system as the basis for on-line adjustment of the power system relay settings. Consequently, it provides the required flexibility for obtaining very high levels of system reliability. Digital relays with adequate software and communication capability make these devices ideal for implementing adaptive relaying concepts. Incorporation of this concept can be done for other complicated cases like protection of compensated lines with series capacitors by Phase Comparison Relaying and also for lines with series reactors.

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