RE-SYNCHRONIZATION OF MEASUREMENT SIGNALS FROM TWO ENDS FOR FAULT LOCATION ON TRANSMISSION LINES

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Abstract - This paper presents an approach to synchronize fault records from two-ends of a power transmission line, which is used for fault location identification. The proposed method allows synchronizing both voltage and current signals of fault records from both line ends without using the parameters of line length and line parameters. The proposal utilizes two-step synchronization algorithm: phase angle synchronization and timing or sample synchronization. The algorithm is simple and uses only positive symmetric components of measurement signals; therefore, it can be applied to synchronize measurement signals and identify fault locations for all fault types. The accuracy and effectiveness of the proposed algorithm is validated through simulation using MATLAB software.

Key words - fault location; unsynchronized measurement; phase angle synchronization; timing synchronization; transmission lines; line parameters estimation.

1. Introduction

Most of the faults occuring in electric power system are on transmission lines. Knowing exactly the fault location on power transmission lines will decrease time of outage and human effort to locate the fault, which allows repairing the faulted component of line as soon as possible to increase power system reliability.

Nowadays, distance protective relay is one of the main protections for transmission lines; however fault location reported by distance relay usually incurs large errors. This inherent error is due to the fact that distance relay uses only one-end terminal measurement signals for locating the fault.

Recently, many studies have focused on fault location on transmission line and reported some very effective algorithms for improving accuracy of fault location. Algorithm as in [2] presents a new approach to fault location on power transmission lines. This approach uses two-end unsynchronised measurements of the line and benefits from the advantages of digital technology and numerical relaying, which are available today and can easily be applied for off-line analysis. The approach is to modify the apparent impedance method using a very simple first-order formula. The new method is independent of fault resistance, source impedances and pre-fault currents. Algorithm as in [3] presents a new numerical algorithm forfault location on transmission lines. It does not require line parameter, so the algorithm can be considered as a settings-free algorithm. Line parameters are only approximately constant; they differ in loading and weather conditions. Thus, an approach which does not require them would be more robust, accurate and flexible than those approaches that do require line parameter information to determine the location to the fault. Algorithm as in [4] explores iterative and non-iterative methods in order to locate the transmission line fault without the use of line parameters. Firstly, the simulation is carried out in Matlab to obtain the fault voltages and currents at both ends of a transmission line. Then, with the help of enhanced Newton-Raphson based iterative method,simulated data is used for estimating the location of unbalanced and balanced faults on line. Algorithm as in [6] presents a new setting free approach to synchronization of two-end current and voltage unsynchronized measurements. Authors propose new non-iterative algorithm processing three-phase currents and voltages measured under normal steady state load condition of overhead line. Using such synchronization line parameters can be estimated and then precise fault location can be performed.

All algorithms stated above determine fault location with the asumption that unsynchronized signals from both line ends are re-synchronized by angle component only. Another difficulty with time synchronization is that fault records of both line’s are often not the same size, one record may have pre-fault, post fault intevals longer than those of others. If the recorded signals deviates away from each other more than one cycle of industrial frequency (50Hz or 60Hz) then the re-synchonizing algorithms which base only on angle component will result in large error in computing fault location.

In order to overcome the drawback of those previous algorithms, this paper introduces an improved algorithm for re-synchronizing fault records from both line ends with higher accuracy. The proposed algorithm consists of two-stage synchronization processes: firstly, all records are roughtly re-synchronized by time then applying phase angle as re-synchronization step.

2. Proposed algorithm

2.1. Flowchart

The proposed algorithm is shown in the Figure 1 below:

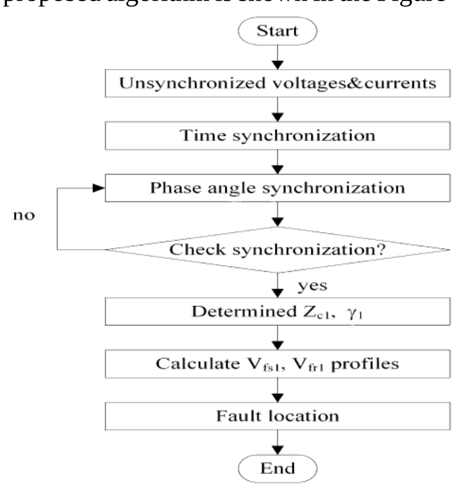

Figure 1. *Pre-synchronize algorithm*

Where:

Z_{c1}: Surge impedance;

γ_1: Propagation constant;

V_{fs1}; V_{fr1}: positive sequence voltage components at fault point when calculated from voltages and currents of terminal S and R.

Due to unsynchronized measurement signals, the proposed algorithm includes 2 steps: applying time synchronization algorithm as in [5] and algorithm as stated in [6] to calculate precise synchronized angle for currents and voltage signals. After that, line parameters are calculated, also fault location is determined from those already synchronized quantities.

2.2. First step: Time synchronization

The purpose of this step is to determine the peaks of signal at each cycle and then determine instant when fault occurs. After that fault records are shifted based on time alignment. To determine the peak of a signal, derivative calculation is used. The peak is determined if the derivation of signal changes its signs.

Instant of fault inception is recognized by comparing three consecutive peaks of signal. If the magnitude of last peak is greater than those of two previous peaks, then it can be concluded that fault occurs at the last peak instant.

After the signal peak and the fault inception instance are determined, time alignment of records are implemented by shifted signals until time instants of records are exactly aligned.

The detailed implementation of time synchronization procedures are as follows: Using algorithm as in [5] to calculate time when fault occur: compare value of $P\left(t\right)$ at instant t to signal values $P\left(t-2T\right)$ and $P\left(t-T\right)$ recorded in relay memory before instant t. If $P\left(t\right) > P\left(t-2T\right)$ and $P\left(t\right) > P\left(t-T\right)$ then t is instant when fault occur (Figure 2).

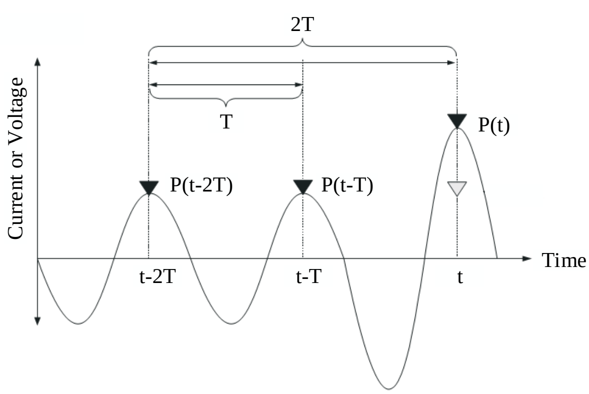

Figure 2. *Abrupt change detection*

After the determination instant t, measurement signals from two-end transmission lines are shifted so that they can have alignment with the instant t.

After this step is finished, the recorded samples from two line ends are approximately time-synchronized, with error likely to be within one cycle. In the next step, accurate time synchronization will be implemented to align the two records more precisely.

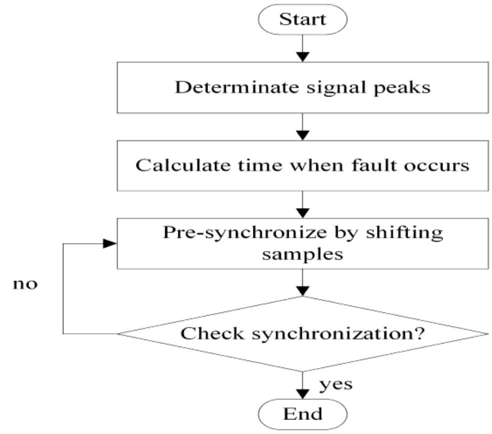

Figure 3. *Pre-synchronize algorithm*

2.3. Second step: Precise synchronization and line parameter determination

The main philosophy of precise synchronization algorithm is based on a simple rule: The measured voltage and current values at one line's end must equal to values if calculated from voltage and current from other end. The algorithm as in [6] to calculate synchronization angle:

$$B_2 tan^2(\frac{\delta}{2}) + B_1 tan^2(\frac{\delta}{2}) + B_0 = 0 \qquad (1)$$

Where:

$$B_0 = A_3 + A_2, B_1 = 2A_1, B_2 = A_3 - A_2$$

$$A_1 = Re(I_{S1}^{pre})Im(V_{R1}^{pre}) - Im(I_{S1}^{pre})Re(V_{R1}^{pre})$$
$$- Re(I_{R1}^{pre})Im(V_{S1}^{pre}) + Im(I_{R1}^{pre})Re(V_{S1}^{pre})$$

$$A_2 = Re(I_{S1}^{pre})Re(V_{R1}^{pre}) + Im(I_{S1}^{pre})Im(V_{R1}^{pre})$$
$$+ Re(I_{R1}^{pre})Re(V_{S1}^{pre}) + Im(I_{R1}^{pre})Im(V_{S1}^{pre})$$

$$A_3 = Re(I_{S1}^{pre})Re(V_{S1}^{pre}) + Im(I_{S1}^{pre})Im(V_{S1}^{pre})$$
$$+ Re(I_{R1}^{pre})Re(V_{R1}^{pre}) + Im(I_{R1}^{pre})Im(V_{R1}^{pre})$$

Equation (1) will have two solutions $\{\delta_{(1)}; \delta_{(2)}\}$. At this point, one can use the criteria stated in [6] to eliminate the undesired solution and retain the correct synchronization phase angle δ:

$$\text{If} \left| \frac{I_{S1}^{pre} e^{j\delta(1)} + I_{R1}^{pre}}{V_{S1}^{pre} e^{j\delta(1)} + V_{R1}^{pre}} \right| \le \left| \frac{I_{S1}^{pre} e^{j\delta(2)} + I_{R1}^{pre}}{V_{S1}^{pre} e^{j\delta(2)} + V_{R1}^{pre}} \right| \rightarrow \delta = \delta_{(1)}$$

$$\text{If} \left| \frac{I_{S1}^{pre} e^{j\delta(1)} + I_{R1}^{pre}}{V_{S1}^{pre} e^{j\delta(1)} + V_{R1}^{pre}} \right| > \left| \frac{I_{S1}^{pre} e^{j\delta(2)} + I_{R1}^{pre}}{V_{S1}^{pre} e^{j\delta(2)} + V_{R1}^{pre}} \right| \rightarrow \delta = \delta_{(2)}$$

The line parameter is calculated as:

$$Y_{1L} = \frac{2(I_{S1}^{pre} e^{j\delta} + I_{R1}^{pre})}{(V_{S1}^{pre} e^{j\delta} + V_{R1}^{pre})}$$

$$Z_{1L} = \frac{(V_{S1}^{pre})^2 e^{j\delta} - (V_{R1}^{pre})^2 e^{-j\delta}}{I_{S1}^{pre} V_{R1}^{pre} - I_{R1}^{pre} V_{S1}^{pre}}$$

With line impedance calculated, the surge impedance and propagation constant can be determined:

Surge impedance: $Z_{c1} = \sqrt{Z_{1L} / Y_{1L}}$

Propagation constant: $\gamma_1 = \sqrt{Z_{1L} Y_{1L}}$

2.4. Fault location algorithm

Figure 4 shows the diagram of transmission line used for testing proposed algorithm.

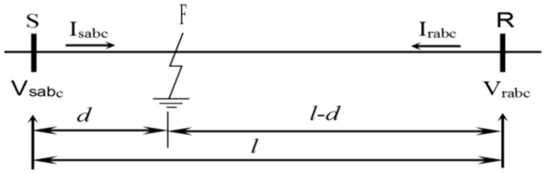

Figure 4. *Faulted tranmission line*

When the fault records from both line ends are perfectly synchronized, we can apply algorithms proposed in [1], [7]-[9] and use synchronized signals, line parameters Z_{c1}, γ_1 to calculate voltage at faulted point:

Voltage at fault point when is calculated from local end (S):

$$V_{fs1} = cosh(\gamma_1 d)V_{rf1} + Z_{c1} sinh(\gamma_{d1} d)I_{rf1}$$

Voltage at fault point when is calculated from remote end (R):

$$V_{fr1} = cosh(\gamma_1 (l-d))V_{sf1} + Z_{c1} sinh(\gamma_1 (l-d))I_{sf1}$$

Where:

V_{sabc}, V_{rabc}, I_{sabc}, I_{rabc} are the pre-fault voltages and currents:

V_{sfabc}, V_{rfabc}, I_{sfabc}, I_{rfabc} are the fault voltages and currents.

V_{s1}, V_{r1}, I_{s1}, I_{r1}, V_{sf1}, V_{rf1}, I_{sf1}, I_{rf1} are positive sequence components of pre-fault and fault voltages, currents.

Voltage of faulted point calculate from local end and remote end must equal to each other:

$$V_{fs1} = V_{fr1}$$

$$\Rightarrow \begin{array}{l} cosh(\gamma_1 d)V_{rf1} + Z_{c1} sinh(\gamma_{d1} d)I_{rf1} \\ = cosh(\gamma_1 (l-d))V_{sf1} + Z_{c1} sinh(\gamma_1 (l-d))I_{sf1} \end{array} \quad (2)$$

In order to sovle equaltion (2), some research [7]-[9] proposed using the "trial and error" method: The position of the fault is assummed to move from the begining of line ($d = 0$) toward the end. The calculation will stop if equation (2) is satisfied with allowed tolerance.

In this paper, a new approach is presented to solve d. In stead of using "trial and error" method, equation (2) will be solved by applying an optimum algorithm to find the root. The variable is d (fault location) and with constraint $0 \le d \le l$. With this approach, the solution d can be achieved with better accuracy, and the inherent error due to the step size of the trial and error approach can be avoided.

3. Results

A transmission line with $l = 100km$ is simulated in Simulink/Matlab. The simulation model is shown in Figure 5. Because measurement signals from Matlab are synchronized;so after extracting signals from local and remote end, R signals are intentionally shifted to simulate unsynchronized measurement signals. In this simulation, signal at R termnial will be time shifted referred to S signal then implementing phase angle shift with angle of δ.

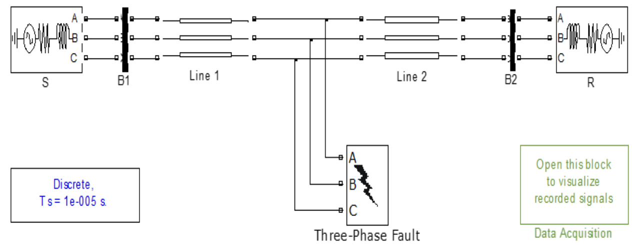

Figure 5. *Transmission line model in Simulink*

The line parameters and voltage source parameters are shown in the Table 1 and 2, respectively.

Table 1. *Line parameters*

Parameter	Positive	Zero
R (Ω/km)	0.01143	0.24665
L (H/km)	0.00086839	0.003088
C (F/km)	1.342e-008	8.58e-009

Table 2. *Soure parameters*

Source	Voltage (KV)	X/R	Phase
S	505	10	5
R	500	10	0

The proposed algorithm will be tested with following conditions:

- Fault type: single to ground (most common fault in transmission line system);

- Fault location is varied (0 to 37km);

- The synchronization angle is varied (0 to 90 degrees).

The fault location results of the proposed algorithm is shown in the Table 3.

Table 3. *Results of the present algorithm*

Actual values		Results of the present algorithm	
$d(km)$	δ^0	$d(km)$	δ^0
11	10	11.3042	10.0754
17	15	17.2697	15.0754
19	17	19.2611	17.0752
21	21	21.2390	21.0753
22	35	22.2426	35.0754
55	75	55.0176	75.0754
65	90	64.9515	90.0754
77	110	76.8674	110.0753
85	135	84.8250	135.0752
89	145	88.7894	145.0754

From Table 3, it can be seen that all calculated qualities are very close to simulated values. The error in synchronization angle calculation is less than 0,7534%, error in calculating fault location is less than 0,4675%.

4. Conclusions

This paper presents an improved algorithm for re-sychronizing measured records for relay at both sides of a transmission line. The synchronized records are used to determine both line parameter as well as fault location. The proposed algorithm allows precisely re-synchronizing all signals using two-step synchronizations.

The algorithm in determining fault location is also improved: an optimal algorithm is used to compute fault position d, instead of using “trial and error” method as in [8], [9].

In our future work, the proposed approach will be tested with real transmission line fault records obtained from two line-ends.

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(The Board of Editors received the paper on 29/03/2015, its review was completed on 14/04/2015)