Directional Relaying on Power Network Using DFT Algorithms in Simulink

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Abstract: The performance of a power network is frequently affected by the transmission line faults, which give rise to disruption in power flow. The fault diagnosis of Electric Power System is a process of discriminating the faulted system elements by protective relays and subsequent tripping by circuit breakers. Specially, as soon as some serious faults occur on a power system, a lot of alarm information is transmitted to the control centre. Under such situation, the operators are required to judge the cause, location, and the system elements with faults rapidly and accurately. Thus, good fault diagnosis methods can provide accurate and effective diagnostic information to dispatch operators and help them take necessary measures in fault situation so as to guarantee the secure and stable operation of the electric power system. This work investigated extensively the performances of various directional protection techniques for transmission lines. A comprehensive study is performed on different directional protection algorithms and relaying schemes in order to assess their performances in distribution systems; and a typical transmission line system was modeled using MATLAB/SIMULINK, which is able to offer many variations to cover all possible systems and fault conditions. Based on the comprehensive study and simulation, a novel and integrated directional relay and protection scheme were proposed, which combines a number of better performed directional relaying algorithms. The new directional relay and protection scheme could protect both symmetric fault and asymmetric fault.

Keywords: Directional relay, DFT, Positive Sequence Component, Negative Sequence Component.

I. INTRODUCTION

To prevent people and property from damage or injury, electrical faults in a power system must be cleared fast. In the early days of electrical power systems the fault clearing was administered by the maintenance staff, who visually detected the fault and manually operated a switch to clear the fault. As fault currents became larger and the operating requirements of the electric power system became more stringent, the need for automatic fault clearance became a necessity. A typical fault clearing system consists of a circuit breaker and a relay protection system. The relay protection system consists of transducers, wiring, relay, auxiliary power supply, and the operating coil of the circuit breaker. In the early days of automatic fault clearing, a fault was detected by electromechanical relays. The measured quantity, such as for example a voltage or a current, was transformed to a mechanical force which operated the relay when a preset threshold was exceeded. Following the advent of electronics such as transistors and operational amplifiers, solid-state relays were developed. The characteristic of such relays were implemented by circuit design. Today, new relays are normally numerical relays. They are built around a microprocessor in which the relay characteristic is digitally implemented. The analogue measurements are converted to digital signals for evaluation within the microprocessor. The recent development of fast microprocessors has led to the possibility to implement highly sophisticated relay characteristics within the microprocessor. Direction relaying is widely used for protection of this kind of faults. It improves the selectivity, sensitivity and reliability of the protection schemes. Directional of overcurrent relaying refers to relaying that uses the phase relationship of voltage and current to determine the direction of a fault. In directional relaying algorithm, the voltage and current phasor or the derived sequence components are applied to estimate the direction of fault with respect to relay location. Phasor based relays use either positive or negative or zero sequence components of voltage and current at fault for reliable estimation of direction of faults. In this work, positive sequence, negative sequence, positive sequence superimposed based directional relaying algorithm for power network has been provided. The negative sequence based directional element works only for unbalanced fault. The performance evaluation is being carried out using the data obtained from the three phase power system. The simulation has been performed in MATLAB. The phasors are computed through one-cycle Discrete Fourier transform (DFT) with 1 kHz sampling rate.

Relay manufacturers were the first to develop relay models for evaluating the performance of their designs. Those models implemented the processes by substituting the values of inputs in equations representing the relays to check if the outcomes were acceptable. The characteristics of over current relays were the first to be modeled. Mathematical models [11], [12] were developed in the form of algebraic equations for representing time-current characteristics of over current relays. The first transient model of a distance relay was presented in [13], where the ninth-order state space mathematical model of a mho element was developed. MATLAB integrates mathematical computing, visualization, and a powerful language to provide a flexible environment for technical computing [14]. MATLAB possesses a flexible software structure comprising libraries, models and programs that enable integration of different model components in a single package. SIMULINK is a package in MATLAB for obtaining time domain solutions. This package shows an open system where new libraries and models can be added with relative ease [15]. The Power System Block Set enables transient modeling of basic components of power systems [16]. The combination of MATLAB, SIMULINK and the POWER SYSTEM BLOCK SET permits users to model and simulate real-time power and related protection systems with high accuracy. The works presented in the past on modeling of digital and numerical relays have used two different approaches: The first approach has modeled the power system and the relay in the same electromagnetic transient program ([21], [17], [19], [18], [20]), while the second approach has modeled the power system in the electromagnetic transient program and the relay in an external program [22]. In the second approach, the interface between the electromagnetic transient program and relay models is crucial. The following is a description of the works developed in the past on modeling of digital and numerical relays.

One of the earliest works on modeling relay algorithms was presented in 1990 by M. S. Sachdev, M. Nagpal, and T. Adu [23]. The authors introduced an interactive software programmed in APL for evaluating algorithms of digital relays. The software included signal processing and protection modules used in typical digital relays. The data for testing the performance of digital relay designs could be generated either by facilities included in the software, recorded from a power system location or generated by other software. In 1994, A. K. S. Chaudhary, Kwa-Sur Tam and A. G. Phadke developed specific models of relays for line protection and transformer differential protection and models of current and capacitor voltage transformers for the EPRI/DCG EMTP version 2.0 [24]. The authors made several changes to the main subroutine of EMTP to link it with user defined FORTRAN subroutines that simulate relay algorithms. The elements modeled permitted the user to simulate dynamic interactions between the power system and the protection system. K.S. Prakash *et al* [1] presented a high speed directional comparison relay based on the evaluation of the locally measured deviations of the voltage and the phase shifted current from their prefault values is described in this paper. The operation of the relay depends on the power frequency components of the voltage and phase shifted current deviation signals. The direction to a fault is determined by an amplitude comparator technique which compares a discriminate value with a positive or negative threshold. Simulation studies on a three-phase power system model show that the direction to a fault is determined within the first few milliseconds following the inception of a fault. Studies over a wide range of faults and source impedance angle show that the proposed amplitude comparator technique performs better than an analogous phase comparator technique. P.G. M'Laren *et al.* outlines the principle of operation of the new element[2], describes the integration of the element into a distance relay, then gives results of tests on the relay. The relay was tested first of all on the RTDS (Real Time Digital Simulator), then on-line in two different locations in the Manitoba Hydro network. P.G. McLaren *et al.* [3] outlines the principle of operation of the new element, describes the integration of the element into a distance relay, then gives results of tests on the relay. The relay was tested first of all on the RTDS, then on-line in two different locations in the Manitoba Hydro network. Finally an off-line model of the relay was tested in a complex series compensation application.

One of the important aspects that this paper concentrates on is the analysis of the transmission line's phase voltages and currents during various fault conditions and how they can be effectively utilized in the design of an efficient fault locator. The present work also focuses on how a numeric directional relay uses the phase relationship of sequence components such as positive sequence (V_1 vs. I_1) , negative sequence (V_2 vs. I_2) and Positive sequence superimposed voltage and current.(ΔV and ΔI) with 0.001ohm fault resistance to sense fault direction.

II. SYSTEM DESCRIPTION

The model network shown in Fig1 has been simulated using MATLAB/SIMULINK package. A common property for model algorithms are that the protected power system object is modeled by differential equations. A transmission line can for example be modeled by an RL-link or a pi-link. Sampled values of voltage and current measured in the power system are then fitted to the differential equations. The result from the algorithm estimates the impedance of the protected power system objects. Phadke and Thorpe describe an algorithm for estimation of apparent impedance to a fault based on three consecutive samples. The algorithm fits the samples by solving a differential equation that models the protected object as a resistance in series with an inductance.

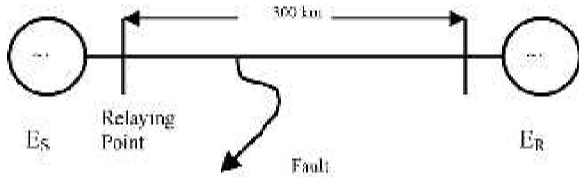


Figure 1 System structure

I. SEQUENCE COMPONENT BASED DIRECTIONAL RELAYING

In this section a comparative assessment of different sequence based directional relaying algorithms for power networks is provided. The evaluation is carried out using data obtained from the three-phase power system simulated through MATLAB/SIMULINK, with a sampling rate of 1 kHz one-cycle. Performance of each algorithm is also provided to access the consistency and correctness.

Directional elements determine the fault direction. They are used to control over current elements, supervise distance elements for increased security, and form quadrilateral distance characteristics. Generally, directional elements are not applied alone, although they can be in unique applications. Directional elements respond to the phase shift between a polarizing quantity and an operate quantity. In Fig. 2, the faulted phase voltage, V, is the polarizing quantity, and the faulted phase current, I, is the operate quantity. Because lines are predominantly inductive, I lag V by the fault loop impedance angle, φ_F, for forward line faults. For reverse faults on the adjacent line, I lead V by approximately 180 degrees minus the fault loop impedance angle, φ_R. The polarizing quantity may be called the reference quantity, which reinforces the need for it to be a stable and reliable signal, no matter where the fault is located. The options for selecting polarizing and operate signals vary and include voltage or current signals or phase (V_A or I_A), phase pairs (V_{AB} or I_{AB}), or symmetrical component quantities (I_1, I_2, or I_0). When determining which signals to choose, designers and application engineers must consider ease of implementation, cost, security, and sensitivity.

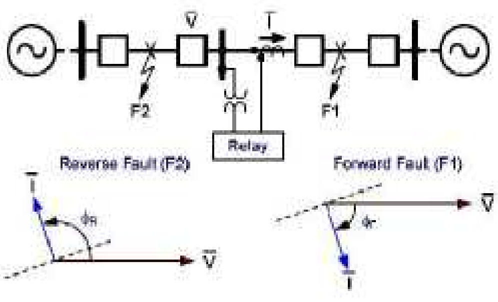


Fig. 2 Basic directional element principle

A. The Sequence component based Directional Relaying Algorithms

Three positive and negative sequence components based algorithms are considered for comparative assessment. The first algorithm is based on the angle between the positive sequence fault voltage and current. The second one uses the angle between the negative sequence fault voltage and current. The angle between the positive sequence superimposed component of voltage and current based algorithm is the third one. The performance of each algorithm is evaluated for situations like unbalanced fault, high resistance fault, balanced fault, close-in fault, current transformer (CT) saturation and for variation in fault location. A two source system as shown in Fig. 3 is considered for the analysis.

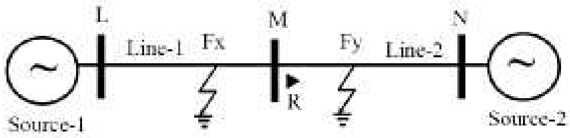
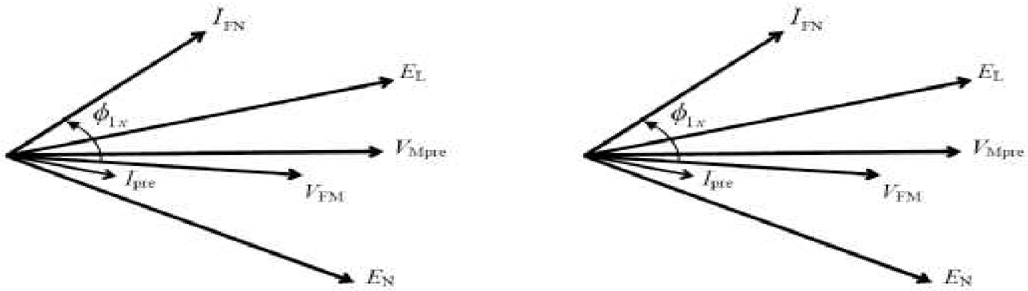


Fig. 3 Three phase power system

B. Algorithm-1: Phase angle between positive sequence fault current and voltage

Angle between positive sequence fault current and voltage is widely applied for directional relaying. Fig 4(a) & 4(b) show the different positive sequence phasor positions during faults in Fx and Fy sides of the relay respectively for the three phase power system. E_L and E_N represent the source voltages at two ends. Φ_1x is the angle between I_{FN} and V_{FM} during the fault in the system. From the figure, the relay fault current I_{FN} leads the relay fault voltage V_{FM}. So Φ_1y becomes positive for fault in F_X side (up-stream). For the fault in F_Y side (down-stream), the relay fault current I_{FM} lags the relay fault voltage V_{FM}. So Φ_1y is negative. The rule of decision with such an algorithm will be, positive angle corresponds to fault in upstream and negative angle for downstream fault.



(a) (b)

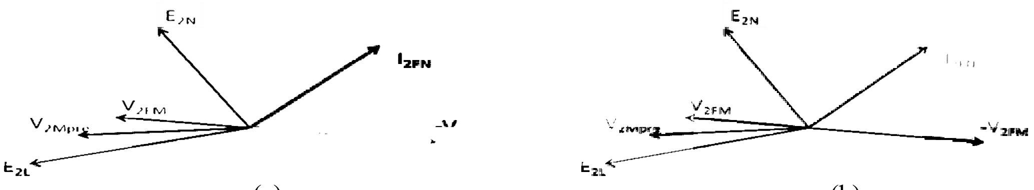
Fig.4 Phasor diagram for Algorithm-1

(a) For fault in Fx side

(b) For fault in Fy side

C. Algorithm-2: Phase angle between negative sequence fault current and voltage

The second algorithm uses the angle between the negative sequence relay fault current and voltage to obtain the direction of fault. Fig5. shows the different negative sequence phasor positions during unbalanced fault in the system. Φ_2 is the angle between the negative sequence fault current and voltage. E_{2L} and E_{2N} in the diagrams represent the negative sequence voltages at the two ends. It is seen from Fig. 5 (a) that for fault in Fx side, the negative sequence relay fault current I_{2FN} leads the negative sequence relay fault voltage ($-V_{2FM}$) resulting proper fault direction ($\Phi_2$xbeing positive). On the other hand, for fault in Fy side as shown in Fig. 5(b), the negative sequence relay fault current I_{2FL} lags the negative sequence relay fault voltage ($-V_{2FM}$)which leads to proper fault direction (Φ_2y being negative). The rule of decision with such an angle should be : positive angle corresponds to fault in upstream and negative angle for downstream fault.



(a) (b)

Fig.5 Phasor diagram for Algorithm-2

(a) For fault in Fx side

(b) For fault in Fy side

D. Algorithm-3: Phase Angle between Positive Sequence Superimposed Voltage and Current

The third algorithm uses the angle between superimposed relay voltage and current. The superimposed components are obtained as,

$\Delta V_M = V_{FM} - V_M pre$

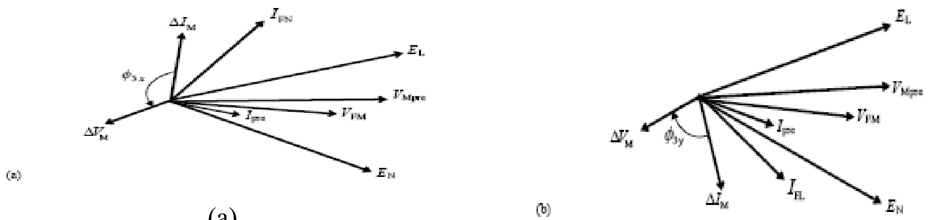
$\Delta I_M = I_{FM} - I_M pre$

Φ_3 = angle(ΔV_M)-angle(ΔI_M)

Where, V_{FM} and V_{Mpre} are the fault and pre fault voltages

I_{FM} and I_{Mpre} are the fault and pre fault currents at the relay point.

For a fault in Fx side as shown in Fig. 6(a), the superimposed component ΔI_M lags the superimposed component ΔV_M providing proper fault direction (the angle Φ_3x being positive). On the other hand for fault in Fy side, the superimposed component ΔI_M leads the superimposed component ΔV_M as shown in Fig. 6(b) and provides correct direction of fault as the angle Φ_3y is negative. The rule for directional relaying decision with such an angle will be: if the angle is positive then the fault is in Fx side (upstream) and if it is negative then the fault is in Fy side (downstream). There is no effect of fault resistance to this algorithm but is affected by change in load.



(a) (b)

Fig.6 Phasor diagram for Algorithm-3
(a) For fault in Fx side
(b) For fault in Fy side

III. Comparative Assessment

A Two source system of 400kV, 50Hz with 100km of line segment on both sides of the relay is considered as shown in fig 7 to evaluate the comparative assessment of the protection algorithm. The DFT algorithm is formulated to estimate the fundamental component. At each phasor computation, window of 1 cycle data samples were considered. In the results, the performance (angle vs. time) is provided to access the algorithm. The data sampling rate is maintained at 1 kHz. Positive and negative sequence components are estimated with phase-a as reference. The phase angle of fault phasors is limited to -π to π. In some cases this angle calculated by this way will exceed the mentioned limit. In that case 2π should be subtracted or added to the difference if it exceeds π or – π limit respectively. This is performed as the approach is based on the principle of whether the fault phasor leads or lags the pre-fault phasor.

A. Line-to-Ground Fault

Line-to-ground faults of ag-type are simulated in Fx and Fy sides at t=0.04 s with a fault resistance of .001Ω. The results are provided in Table 1&2.. The angle for algorithm-1 in Fx side fault is .6135 rad and that for fault in Fy is -2.7445 rad. The angles for other two algorithms are positive for Fx side and negative for Fy side (2.8194 and - .7096 rad by algoritm-2, 1.2574 and -1.7807 rad by algorithm-3 respectively). The results are in agreement to the theory presented; positive angle for upstream case and negative angle for downstream case. Corresponding phasor plots for features for upstream and downstream faults are shown in Fig.4. Fig.5, Fig.6 which clearly demonstrate the performance of the three algorithms. From the plots it is to be noted that all the three algorithms work well such faults but the angle Φ1 is low as compared to other two angles.

IV. FAULT MODEL

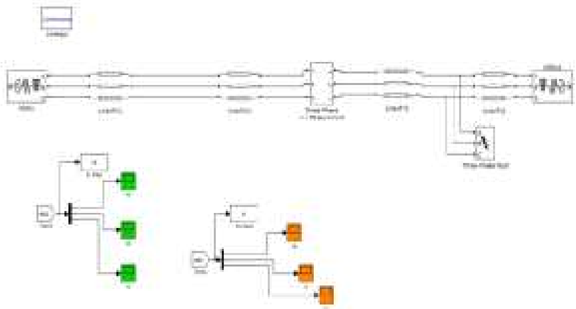
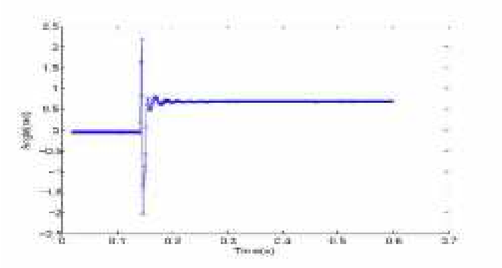


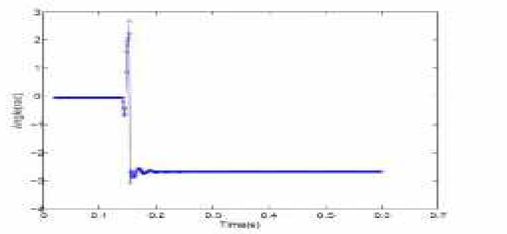
Fig.7. Simulink Model

VI. SIMULATION RESULTS

A. *For algorithm-1*



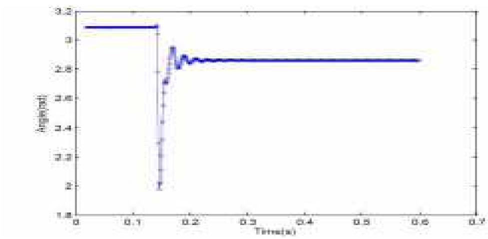
(a)



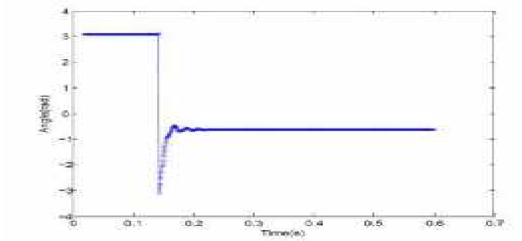
(b)

Fig.8 Performance for ag-fault with 0.001Ω fault resistance (a) In Fx side (b) In Fy side

B. *For algorithm-2*



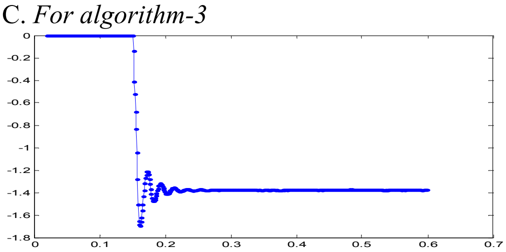
(a)



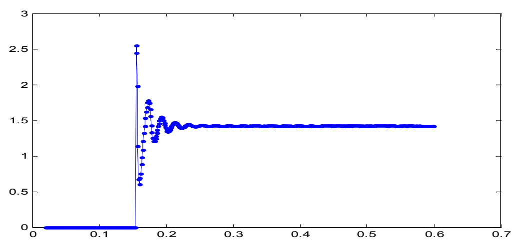
(b)

Fig.9 Performance for ag-fault with 0.001Ω fault resistance (a) In Fx side (b) In Fy side

C. *For algorithm-3*



(a)



(b)

Fig10 Performance of ag-fault with 0.001Ω resistance (a) In Fx side (b)In Fy side

TABLE-1

Results for fault resistance of 0.001Ω of Algorithm-1& 2

Fault position	Positive sequence fault current angle(rad)	Positive sequence fault voltage angle(rad)	Negative sequence fault current angle(rad)	Negative sequence fault voltage angle(rad)	Angle difference(rad) Φ_1	Angle difference(rad) Φ_2
Fx	0.2013	-0.4122	0.3351	-2.4844	0.6135	2.8194
Fy	-3.0018	-0.2573	3.0995	-2.4730	-2.7445	-0.7096

TABLE-2

Results for fault resistance of 0.001Ω of Algorithm-3

Fault position	Positive sequence pre fault current angle(rad)	Positive sequence fault current angle(rad)	Positive sequence pre fault voltage angle(rad)	Positive sequence fault voltage angle(rad)	Angle difference (rad) Φ_3
Fx	1.7979	-0.4138	1.7433	0.2013	1.2574
Fy	1.7973	-0.2580	1.7440	-3.0024	-1.7807

VII. CONCLUSION

In this paper a comparative assessment of three sequence component based directional relaying algorithms is provided. Such algorithms are commonly used in relaying. The performances of the directional relaying algorithms are evaluated for 0.001fault resistance.

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