A New Method for Fault Detection during Power Swing in Distance Protection

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***Abstract*- During a power swing, currents and voltages behave such as a fault. Therefore, Power swing blocking function in distance relays is necessary to discriminate between a power swing and a fault. Otherwise power swings can be considered as a fault and causes relay trip. The main problem happens when during power sings a fault occurs. In this case, distance relays should be unblocked. In this paper, a new method based on the DC component of fault currents will be proposed to detect a fault during power swing blocking. The proposed method can detect single-phase to ground, two-phase to ground and three-phase fault. Applying the new method on a sample network reveals the features of the method.**

***Keywords*- DC component, Distance relay, FFT analysis, Power swing, Symmetrical fault, single-phase fault.**

I. Introduction

Power swing occurs when the rotor angle between two generators or more generators varies. This phenomenon causes large fluctuation power in a power system. Rotor angle variation happens when the system is recovering from a disturbance like a fault or a load rejection. If the swing is stable, the fluctuations damp. However, unstable swings result into progressive separation of angle between two areas of the power system (each area represents a group of generators), causing large swings of power flows, large fluctuations of voltages and currents and eventual loss of synchronism between such areas [1]. When two areas are in phase, the voltages are maximum and currents are minimum, and when the two areas are out of phase by 180°, currents are at peak and voltage are close to zero [1]. During a power swing for some time intervals the current increases and voltage drops. So a situation like fault situation occurs which can cause the distance relay to trip. In order to prevent the distance protection from tripping during such conditions, a power swing blocking is utilized.

Power swing blocking function is included in distance relays to detect a power swing and block the operation of a distance relay due to the power swing. However, if a fault occurs during power swing, the power swing function should be able to detect the fault and let the relay trip.

The most popular method to detect a power swing is to measure the rate of change of impedance as it travels into the protection zones of the relay [2]. This is known as "decrease impedance" method. However this method has a major defect. In this method the relay is not able to detect a fault occurring during a power swing. So if a fault occurs the relay will not trip and the fault remains in the system. Now one question arises. Is there a method for discriminating a symmetrical or asymmetrical fault during a power swing? Several methods are proposed to overcome this problem. A fault identification scheme based on the orthgonoal wavelet transform algorithm is proposed in Reference [3]. In reference [4] the authors propose a method to detect a fault during power swing based on waveform of swing center's voltage. In reference [5] fault identification during power swing is proposed with symmetrical component. The decreasing impedance, the Vcosφ and the superimposed currents methods are conventional algorithms for power swing detection [6-8]. Power swing is occurred with different slip frequency from less than 1Hz to greater than 5Hz. Based on the slip frequency, some methods have been invented. Some of them can only detect low slip frequency power swings.

It is very important to detect the asymmetrical or symmetrical fault reliably and fast during power swing. In this paper a simple but reliable approach is used to detect a fault during power swing. The method is based on DC component of current achieved from FFT analysis to detect a fault quickly and reliably during a power swing. To evaluate the proposed method, different fault conditions are simulated with MATLAB® software on a sample network. The obtained results show that the method can detect asymmetrical and symmetrical faults on different locations with various fault resistance.

II. Power Swing Calculation

Consider a single-machine connected to an infinite bus system. When a power swing occurs, the voltage and current of generator are in out of phase of voltage and current of infinite bus. So voltages and currents have two different frequencies as follows (for phase a):

Equation (1)-(3):

$$i_a = i_{m1}\sin(\omega_1 t + \theta_1) + i_{m2}\sin(\omega_2 t + \theta_2)$$

$$i_b = i_{m1}\sin(\omega_1 t + \theta_1 - 2\pi/3) + i_{m2}\sin(\omega_2 t + \theta_2 - 2\pi/3)$$

$$i_c = i_{m1}\sin(\omega_1 t + \theta_1 + 2\pi/3) + i_{m2}\sin(\omega_2 t + \theta_2 + 2\pi/3)$$

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Equations (4)-(6):

$$v_a = v_{m1}\sin(\omega_1 t + \beta_1) + v_{m2}\sin(\omega_2 t + \beta_2)$$
$$v_b = v_{m1}\sin(\omega_1 t + \beta_1 - 2\pi/3) v_{m2}\sin(\omega_2 t + \beta_2 - 2\pi/3)$$
$$v_c = v_{m1}\sin(\omega_1 t + \beta_1 + 2\pi/3) + v_{m2}\sin(\omega_2 t + \beta_2 + 2\pi/3)$$

By using trigonometric calculations, the voltage and current of phase a can be written as equation (7) and (8).

$$i_a = i_m \sin\left(\frac{\omega_1 + \omega_2}{2} t + \theta_3\right) \cdot \sin\left(\frac{\omega_1 - \omega_2}{2} t + \theta_4\right) \qquad (7)$$
$$v_a = v_m \sin\left(\frac{\omega_1 + \omega_2}{2} t + \beta_3\right) \cdot \sin\left(\frac{\omega_1 - \omega_2}{2} t + \beta_4\right) \qquad (8)$$

In this case, the power equation will be:

$$P = P_0 + P_1 \sin\big((\omega_1 - \omega_2)t + \varphi\big) \qquad (9)$$

It is important to know under power swing condition ω_1 is close to ω_2 and hence $\omega_1 - \omega_2$ is a low frequency angular velocity. This term is called slip frequency and power swing is identified by it. The typical current and power during power swing are shown in Fig.1 and Fig. 2, respectively.

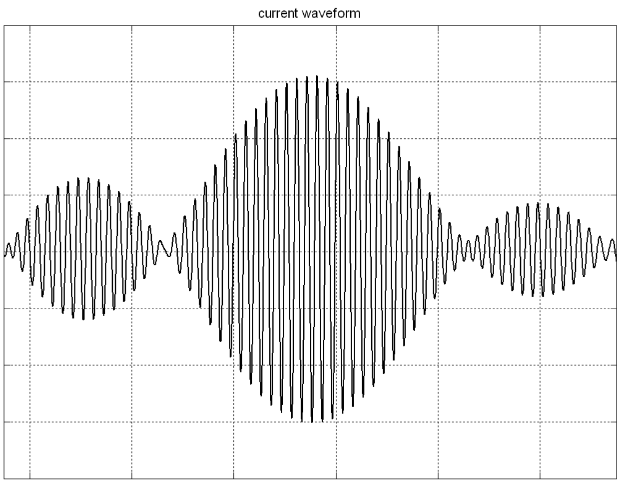

Figure 1. Typical current waveform during power swing

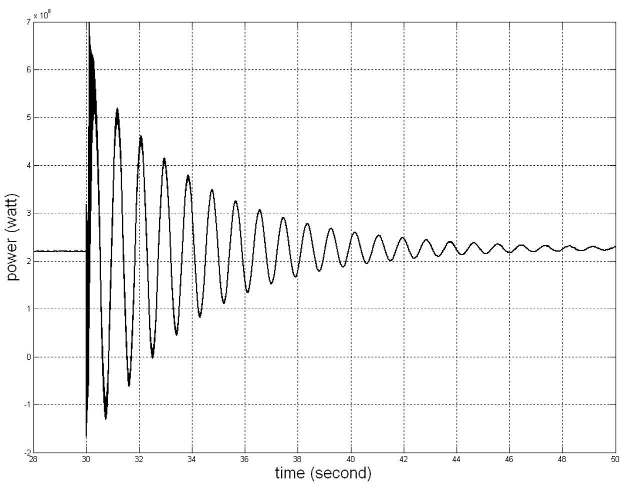

Figure 2. Typical power waveform during power swing

III. Problem Statement and Proposed Method

Consider the single-machine power system shown in Fig. 3. Consider Fault 1 is occurred on line AB at time t1 and is cleared at time t2 by opening circuit breakers A and B. After disconnecting line AB, the power is transferred through line CD and a power swing happens. Power swing blocking of distance relay operates and blocks the relay. In this case, if a fault like Fault 2is occurred on line CD, then the relay does not operate and stability of the power system get into trouble.

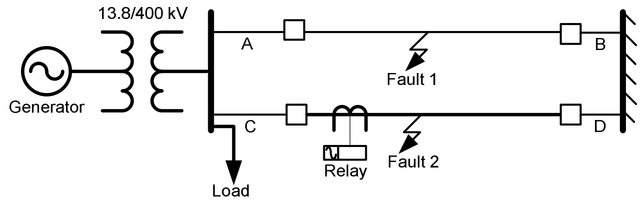

Figure 3. Single machine system

In this paper, a new method based on the phase current Dc component will be proposed. It is possible to simulate the power system by an L-R AC network as shown in Fig. 4.

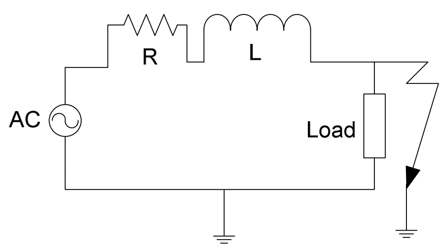

Figure 4. Simple RL circuit

Given at t=t_0 a short circuit occurs and the load is bypassed. By utilizing circuit analysis methods for $t > t_0$ we can write:

$$i(t) = ke^{-\frac{R}{L}(t-t_0)} + i_m \cdot \sin(\omega(t - t_0) + \varphi) \qquad (10)$$

The first part of equation (10) indicates a DC component. This DC component has a maximum value at t=t_0 and then damped to zero. Therefore at the inception of fault a DC component has occurs. This criterion is used to detect a fault during a power swing. For this purpose, whenever a power swing blocking relay blocks the relay distance, each phase current measured and analyzed by Short Fourier Transform (SFT) and their DC component will be obtained. The obtained values will be comparing by thresholds and if they were bigger then the fault will be detected.

IV. Simulation Results

To test the methodology a system shown in Fig. 5 was chosen. The system parameters are given in appendix. Consider Fault 1 is occurred on line AB at t=20 [s] and is cleared after 0.1 seconds. After disconnecting line AB, the line CD experiences a power swing. Now suppose Fault 2is occurred at t=22 [s] on line CD, which could be either three-phase or single-phase.

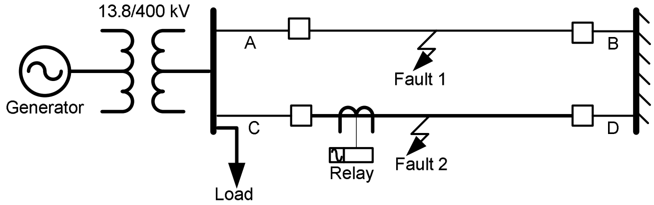

Figure 5. Simulated system

Different fault conditions shown in TABLE I are simulated by using MATLAB® software. As shown in this table, different fault resistance is also considered that varies from 0.1 to 100 ohms.

TABLE I
THREE-PHASE FAULT DETAILS CONDITIONS

CASE	FAULT RESISTANCE (Ω)	FAULT DURATION (second)
1	0.1	0.05
2	1	0.05
3	10	0.05
4	100	0.05

Fig. 6 shows the current waveform of phase A during power swing. As shown in this figure, at t= 20 [s] a three-phase fault occurs. In this figure at t=22 [s] another fault (fault 2 in Fig. 5) with case 3 specification (fault resistance=10Ω) occurs at 50km of the line. At this time, the relay decides to unblock itself by using DC component of the current. It is important to know that the DC component of the different phases differs from each other. FFT analysis is done at t=21.9 [s] and t=22 [s] for 1-cycle duration. The result is shown in Table II to Table IV for a three-phase fault and fault location at 5km, 50km and 95km, respectively.

Also a single-phase fault at distance 50km is simulated and the result is shown in Table V. As shown in these table, AT t=21.9[s] to 21.92 [s] (1-cycle duration) DC component is negligible whereas for t=22 to 22.02 [s] this is considerable. For each case the maximum DC component among the current of phase A, B and C is considered. For example at 50km of line for a symmetrical fault with resistance 1Ω, phase A has the maximum DC component 76.33%. For this case according to table V if a single phase fault occurs during power swing, the maximum DC component would be 105.88%. Therefore in single phase fault this method works better. According to Table V, if a DC component threshold of 20% is set to unblock the relay, this method is able to detect single phase fault with resistance 100Ω.

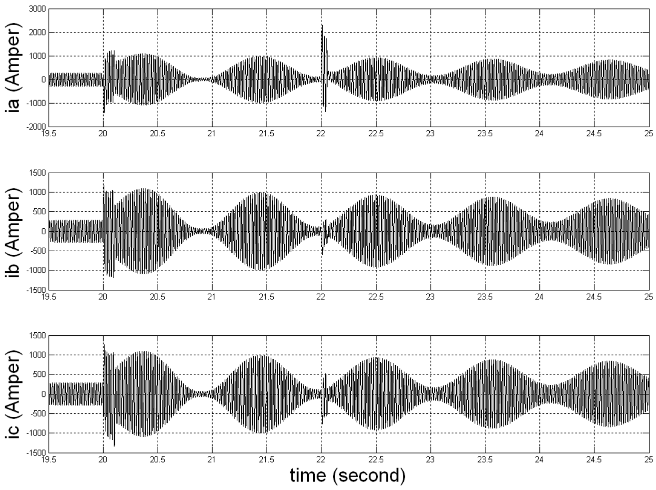

Figure 6. Current waveforms for phase A, B and C

TABLE II
DC COMPONENT PERCENTAGE FOR A THREE-PHASE FAULT LOCATED AT 5KM

CASE	$\frac{\text{DC componenet}}{\text{fundamental}}\%$					
	t=21.9			t=22		
	i_a	i_b	i_c	i_a	i_b	i_c
1	4.51	2.86	1.68	87.28	40.50	48.59
2	3.10	0.63	2.51	86.96	37.86	49.43
3	3.11	0.62	2.53	54.17	16.67	43.26
4	3.33	1.08	2.30	9.20	2.69	13.41

TABLE III
DC COMPONENT PERCENTAGE FOR A THREE-PHASE FAULT LOCATED AT 50KM

CASE	$\frac{\text{DC componenet}}{\text{fundamental}}\%$					
	t=21.9			t=22		
	i_a	i_b	i_c	i_a	i_b	i_c
1	4.44	3.41	1.00	80.27	34.94	48.06
2	4.39	3.3	1.07	76.33	31.81	47.62
3	3.07	0.66	2.44	51.01	13.56	43.57
4	3.11	0.76	2.38	9.22	3.68	14.85

TABLE IV
DC COMPONENT PERCENTAGE FOR A THREE-PHASE FAULT LOCATED AT 95KM

CASE	$\frac{\text{DC componenet}}{\text{fundamental}}\%$					
	t=21.9			t=22		
	i_a	i_b	i_c	i_a	i_b	i_c
1	3.20	1.19	2.05	79.08	32.78	48.77
2	3.06	0.86	2.23	72.24	27.54	47.79
3	3.37	1.40	2.00	30.86	4.05	33.84
4	3.42	1.58	1.87	5.66	2.08	8.32

TABLE IV
DC COMPONENT PERCENTAGE FOR A SINGLE-PHASE FAULT LOCATED AT 50KM

case	$\frac{\text{DC componenet}}{\text{fundamental}}\%$					
	t=21.9			t=22		
	i_a	i_b	i_c	i_a	i_b	i_c
1	4.60	3.08	1.53	74.97	110.53	75.60
2	2.82	0.40	2.46	68.62	105.88	72.31
3	3.09	0.69	2.43	48.36	87.92	55.41
4	3.18	0.89	2.32	6.86	20.83	9.61

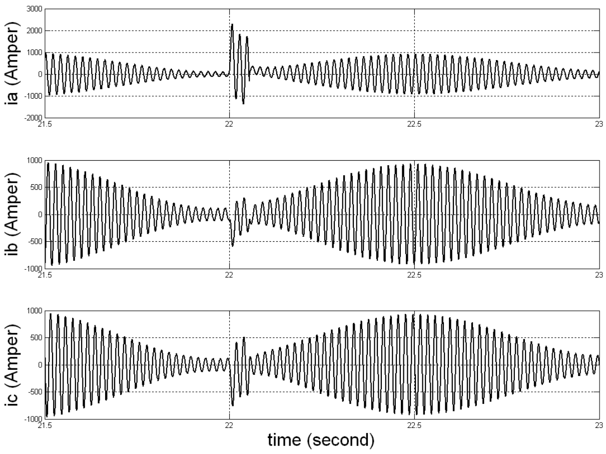

Figure 7. Current waveform for phase A, B, C during single phase fault

V. CONCLUSIONS

In this paper a new method to detect a fault during a power swing is proposed. Using DC component of phase currents is the main feature of this research. In this method, SFT analysis should be carried out every cycle for DC component detection. The threshold value of DC component to unblock the distance relay could be obtained by comprehensive simulations of fault during power swing. According to simulation results it was shown that the proposed method works under asymmetrical and symmetrical fault conditions.

APPENDIX

Generator Data

Rated Power:	600 MVA
Voltage:	13.8 kV
Frequency:	50 Hz
Inertia constant:	4.4 MW/MVA.

Transformer Data

Rate Power:	600 MVA
Voltage Ratio:	13.8/400 kV
Frequency:	50 Hz
Impedance:	12.5 %

Transmission lines: $Z=0.12+j0.88 \frac{\Omega}{km}$

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