A New Method to Prevent Distance Protection from Operating Due to Power Swing

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Abstract: A power swing may cause unwanted tripping of the distance protection. The power swing blocking is a function commonly used to prevent the distance protection from operating during power swing. When a distance relay is blocked, it cannot react to faults anymore. This paper proposes a new method to prevent this protection from operating during power swing condition when no fault occurs. In this method, swings are removed from the voltage and current signals, using (d-q) frame, and then these signals are used in the impedance calculation of the distance relay. So, the distance protection is not blocked and can trip when a fault occurs. Simulation results are presented for a typical system using PSCAD software.

Keywords: Blocking prevention, Distance relay, Power swing blocking, Symmetrical fault.

1 Introduction

Certain power system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between neighboring interconnected utility power systems [1]. Such conditions create power fluctuations between two areas of a power system. At a certain point of power system, power swing causes Current and Voltage, swing in amplitude and phase. An impedance calculation based on these voltages and currents demonstrates swing with the power swing frequency in impedance [2]. This frequency that depends on the rate of change of the power angle between two areas is characterized by "slip" frequency. The impedance can become so small that it will cause the distance protection to trip.

In order to prevent digital distance relay from mal-operation during power swing, Power Swing Blocking (PSB) device is used. Tracing the rate of changes of measured apparent impedance is a fundamental method to distinguish between faults and power swings. The difference in the rate of change of the impedance has been traditionally used to detect an out of step condition [1]. The PSB function has the role of detecting the power swing cycle and blocks the distance relay [2]. One of the most important issues for distance protection is that once the distance relay is blocked, it will not be able to react to faults anymore. The other difficulty of using power swing blocking is the determination of a fixed time to provide a continuous blocking signal for the distance relay until stability improvement. This blocking time delay is usually considered 2 seconds. In some cases, the distance relay may encounter more severe disturbances after the blocking time expired.

Up to now, some methods are proposed to detect faults during a power swing and clear the distance relay blocking. Mechraoui and Thomas [3], for the first time, utilized time invariant (d-q) frame to differentiate between a swing and a fault. They tracked the load angle between the relay and the end of the protected zone to identify a fault condition and unblock the relay. Mechraoui and Thomas [4] continued with detecting a high resistance earth fault during a power swing. References [3] and [4] do not report the performance for symmetrical faults. Jiao et al. [5] proposed waveform of swing center voltage (SCV) and the synthetic negative sequence vector (SNSV) to detect all earth and non-earth faults. Su et al. [6] reported a new fast detector of symmetrical faults during power swing based on the SCV. Brahma [7] introduced wavelet transform to detect any fault during a power swing.

In this paper, a new method is proposed that prevents the distance relay from tripping under a power swing condition and permits it to trip if a fault occurs. In this method, the distance relay is not blocked during power swing but transfers the voltage and the current to the d-q frame. Therefore, once the power swing is detected, the voltage and the current are transferred to the time invariant d-q frame with the rotating frequency as the swing frequency and then are utilized in the impedance calculation of the distance relay. A typical system is simulated with PSCAD software to test the proposed method. Fault detection during power swing in the distance relay operation is considered in the test.

2 Basic principle

In transient and dynamic stability studies of a large scale power systems, the variables of all power system compo-

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nents, except for the synchronous machines, are represented in a reference frame rotating at synchronous speed. Fortunately, all known real transformations for these components are also contained in the transformation to the arbitrary reference frame. We could formulate one transformation to the arbitrary reference frame which could be applied to all variables [8]. A change of variables which formulates a transformation of a 3-phase variables of stationary circuit elements to the arbitrary reference frame may be expressed as:

$$\mathbf{f}_{dqo} = \mathbf{K}_s \mathbf{f}_{abc} \tag{1}$$

Where

$$\boldsymbol{K_s} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2}$$

$$\theta = \int_0^t \omega(\xi)d\xi + \theta(0) \tag{3}$$

Where ξ is a dummy variable of integration and ω is the angular speed of arbitrary frame. Certain major system disturbances cause severe oscillations in machine rotor angles and severe swings in power flows. The oscillation of rotor could be separated from nominal speed as arbitrary frame and the stationary variables such as voltage and current could be transformed to this (d-q) frame. In this frame the frequency of rotating frame is the same as slip frequency. If voltage and current are transformed to (d-q) frame with slip frequency, swings are completely removed from their waveforms.

3 Proposed anti-blocking algorithm during power Swing

The fundamental method for preventing the distance relay from operating during power swing is blocking. Power swing blocking is a device that sends a continuous blocking signal to the distance relay after power swing is identified and prevents it from any operation until a fixed blocking time is expired.

In this paper, a new method is proposed which does not fully block the distance relay when a power swing occurs, but uses a function to remove swings of variables utilized in the distance relay.

The basic difference between the conventional and the proposed method is shown in Figure 1. In this condition the distance relay cannot see the power swing. It also operates correctly whenever a fault occurs.

In this technique, after power swing detection, knowing slip frequency, the voltage and current signals are transferred to the (d-q) frame with this slip frequency before using them in the distance relay. In many systems the slip frequency increases and so it is time variant variable. A relay cannot determine that because of the complexity of the power system; however, the average of slip frequency can be estimated.

In many systems the amplitude of signals which oscillate during the power swing, is the same as their amplitude in the steady state condition or with a little change. In such condition, the signal obtained from the (d-q) transformation is equal to the amplitude before transformation. Nevertheless, if the amplitude increases more, it has not any effect on the distance relay operation because the change in amplitude due to (d-q) transform occurs approximately in the same ratio for the voltage and current signals.

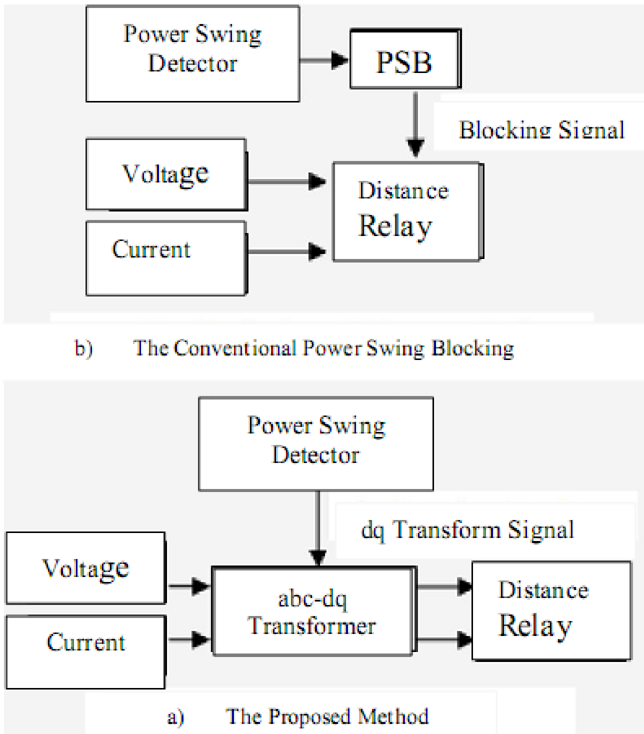


Figure 1 The conventional and the proposed methods structures.

Suppose the slip frequency is constant as the signal shown in Figure 2. Moreover the main signal measured, two

Other signals as other phases of slip frequency is created in order to use in the (d-q) frame. These signals should have 120 degrees phase difference of slip frequency e.g. as shown in Figure 2. The transformed signal is shown in Figure 3.

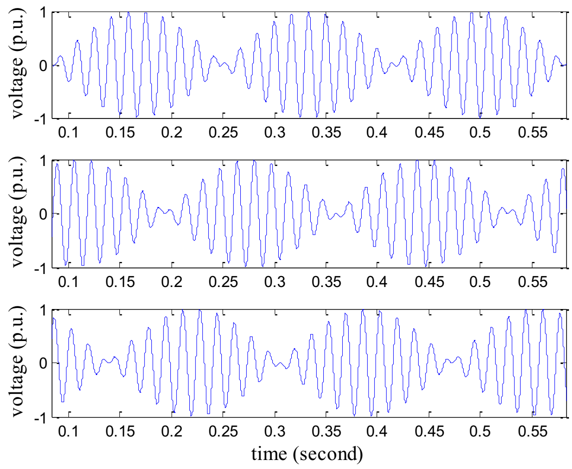


Figure 2 The voltage in any phase of slip frequency using in the (d-q) frame

Although the slip frequency is time variant, we are able to estimate its average to use in the transformation. Therefore, after transforming a signal to this new (d-q) frame according to the approximate slip frequency, swing is not completely removed, but it dampens well enough so that it does not affect the distance relay. Thus the distance relay does not need blocking although the slip frequency is approximate.

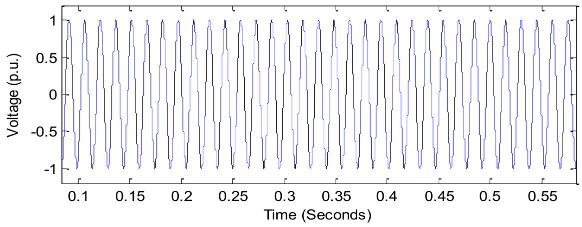


Figure 3 The voltage with constant slip frequency as 3Hz after (d-q) transformation.

Besides the fault detection during power swing, another advantage of the new method is the monitoring of the voltage and current after transformation to (d-q) frame that makes it possible to observe changes in slip frequency and to apply a new slip frequency that optimizes removing the swings. On the other hand, the PSB blocks the relay for a fixed blocking time and it may encounter more severe instability after the blocking time expired, but the monitoring of the signals obtained from (d-q) frame let us decide for either continuing the transformation or stopping it.

4 Simulation results

In this section, performance of the proposed method is evaluated in a typical power system. Figure 4 shows the system selected for simulation as in reference [7].

The system is simulated using PSCAD software. The sending end (SE) is modeled as an equivalent machine and the receiving end (RE) is modeled as an infinite bus. In normal conditions, power is transferred from SE to RE through two parallel lines. Line-1 has two sections, each of 140 km length, and Line-2 is 280 km long. Lines are modeled with distributed parameters in the simulation. Power angle δ is the difference between the voltage angles at SE and RE [7].

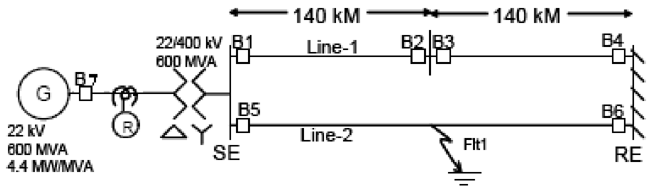


Figure 4 The simulated system

The offset mho distance relay for the loss of excitation protection of synchronous generators at breaker B7 in generator terminals is considered in this study. Zone-1 of this relay covers 2.4 Ohm of impedance as the same as 1 p.u. according to Δ connection with offset.

Two pre-fault conditions are simulated corresponding to $\delta = 45^o$ and $\delta = 60^o$. A fault occurring at 0.6 seconds in the simulation on Line-2 is cleared after 0.1 seconds by opening of breakers B5 and B6. This sends the system into a power swing. The slip frequency of the swing for different values of the pre-fault power angle is different. The current and voltage waveforms at generator terminals for $\delta = 45^o$ are shown in Figure 5(a) and 5(b) respectively. Figure 5(c) shows the positive sequence apparent impedance Z1 seen by the relay at B7. Figure 6 shows the similar waveforms for $\delta = 60^o$.

The R-X diagram shown in Figure 7, clearly indicates that the system is going through a power swing and impedance travels into Zone-1 from time to time in both case of $\delta = 45^o$ and $\delta = 60^o$. According to Figure 7, the times of the impedance entrance to the relay characteristic in the case of $\delta = 45^o$ is more. However, the slip frequencies are different in both cases and impedance approaches Zone-1 at different times. The relay characteristic is also shown in R-X diagrams to distinguish tripping of the relay. R1 and X1 are calculated using Fourier Transform using one-cycle data window with a lower sampling rate (10.16 kHz considered in this study).

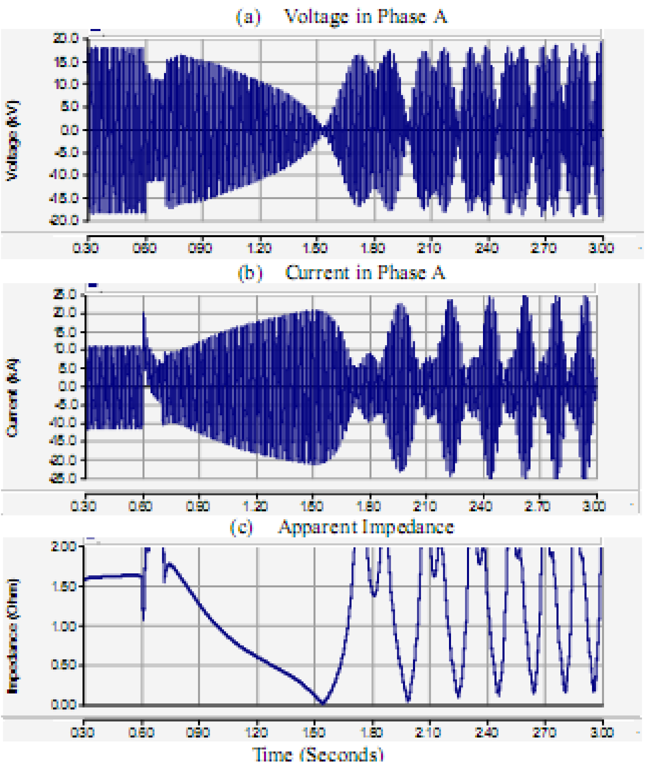


Figure 5 Voltage, current and apparent impedance for a power swing with pre-fault power angle δ = 45º.

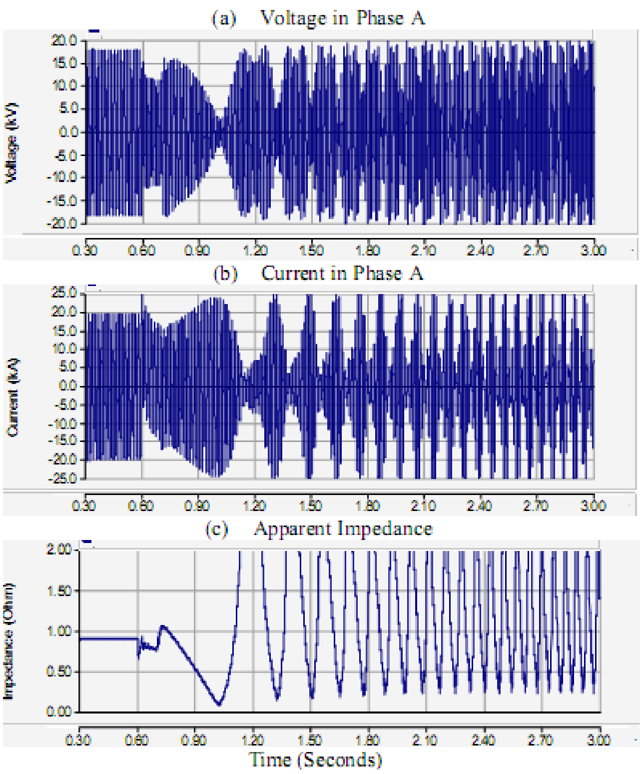


Figure 6 Voltage, current and apparent impedance for a power swing with pre-fault power angle δ = 60º.

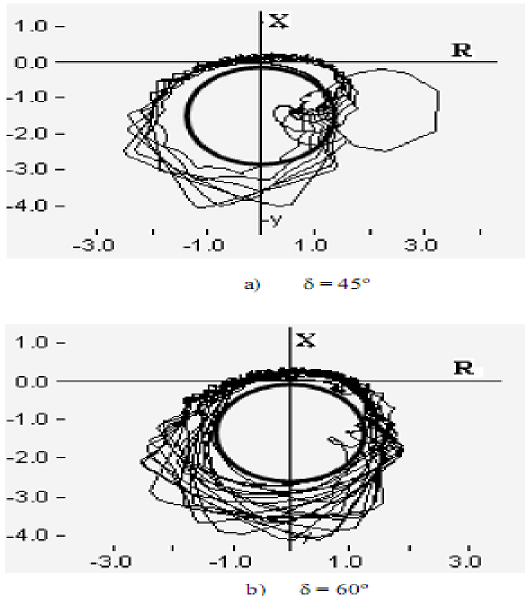


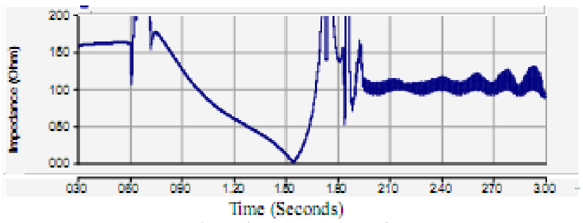
Figure 7 The impedance during power swing in R-X Diagram for two different conditions.

After power swing detection in the first cycle, the (d-q) frame is utilized. The frequency of the frame is equal the slip frequency estimated about 1.7 Hz for preventing the relay from operating during swings in the case of δ = 45º. The Fourier Transform is used to determine the slip frequency. The apparent impedance and the impedance in R-X diagram after using (d-q) transform at 1.6 seconds for δ = 45º is shown in Figure 8.

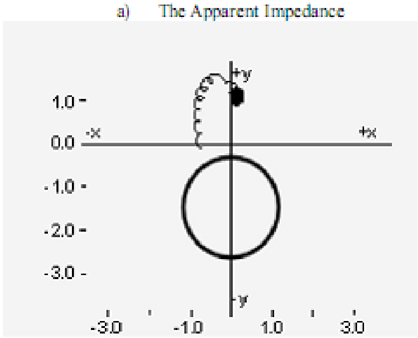
Figure 9 shows the apparent impedance and the impedance in R-X diagram for the case of δ = 60º with (d-q) transform used after the power swing detection at about 1.2 seconds. The average of slip frequency is determined as 5Hz.

Two amount of frequency can be used for the average of slip frequency in the (d-q) frame if the rate of change in the slip frequency is more. In such conditions, if the frequency of power swings changes more it should be used another proper amount of slip frequency. Monitoring of the voltage and current after the first (d-q) transform offers the ability of decision for the next operation; Because if the slip frequency is not proper after a period, the swings become obvious and observable again.

Two different kind of fault is tested in two cases at 2.7 seconds to show the ability of fault detection during power swing in this method. The first one is a loss of excitation fault created by separating the excitation. It is cleared after 0.3 seconds. This fault is used in both cases of δ = 45º and δ = 60º. The R-X Diagram for δ = 45º is shown in Figure 10. The result of this condition for the case of δ = 60º is shown in Figure 11. It can be observed that this fault is correctly detected during power swing after using the (d-q) frame.

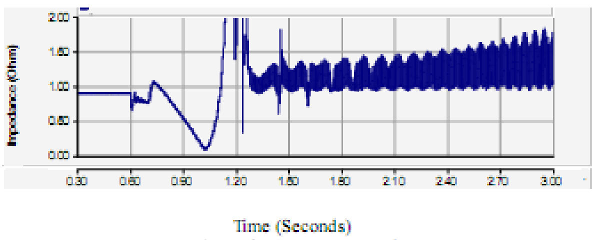


a) The Apparent Impedance

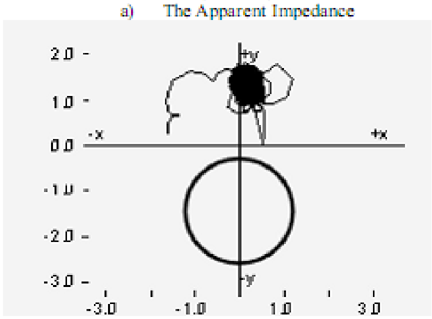


b) The Impedance in R-X Diagram

Figure 8 The impedance during power swing after using (d-q) frame in the case of δ = 45º .



a) The Apparent Impedance



b) The Impedance in R-X Diagram

Figure 9 The impedance during power swing after using (d-q) frame in the case of δ = 60º

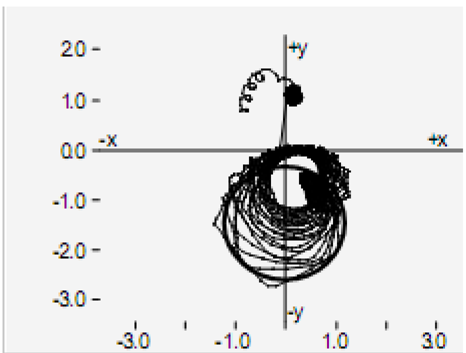


Figure 10 The R-X Diagram when loss of excitation fault occurs during power swing after using (d-q) frame in the case of δ = 45º.

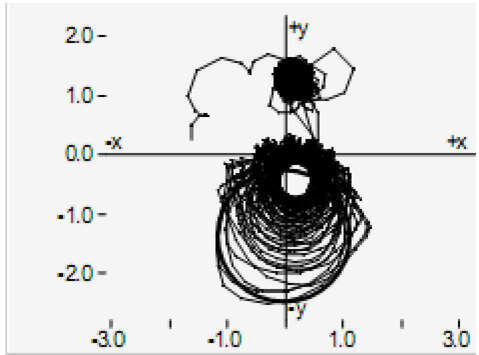


Figure 11 The R-X Diagram when loss of excitation fault occurs during power swing after using (d-q) frame in the case of δ = 60º.

The second fault is a three-phase fault created at generator terminals. It is cleared after 0.3 seconds. This fault is also used in both cases of δ = 45º and δ = 60º. The R-X Diagram for δ = 45º is shown in Figure 12. The result of this condition for the case of δ = 60º is shown in Figure 13. It can be observed that this fault is not detected during power swing after using the (d-q) frame as we expect

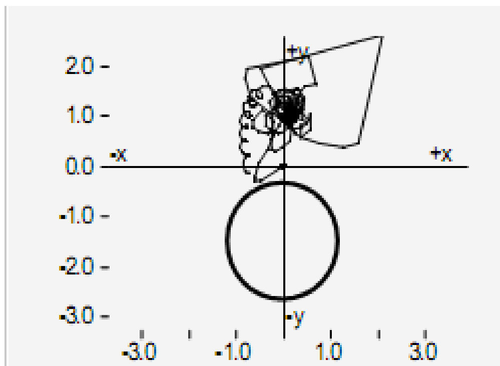


Figure 12 The R-X Diagram when three phase fault occurs during power swing after using (d-q) frame in the case of δ = 45º.

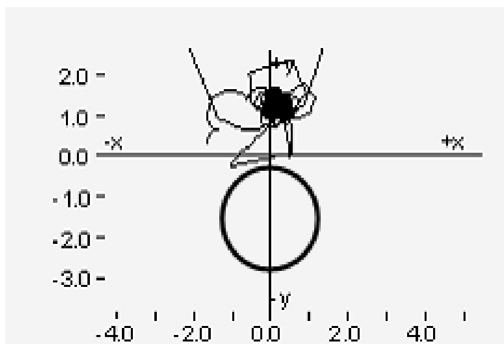


Figure 13 The R-X Diagram when three phase fault occurs during power swing after using (d-q) frame in the case of δ = 60º.

5 Conclusion

This paper introduces clearing of power swing from the voltage and current waveforms instead of blocking the distance relay during power swing. The (d-q) frame is used for removing the swings from the signals used by the distance relay. The (d-q) transform with the frequency as the same as the slip frequency dampens swings of the voltage and current signals and prevents the distance relay from operating during power swing. This transformation does not affect fault detection of the relay during power swing. The other advantage of this method is the ability of monitoring the signals obtained from the (d-q) frame in order to decide for the next operation. Therefore determination of a fixed time as in the PSB is not necessary, the frequency of the (d-q) frame can either be changed according to the change of slip frequency or the frame stops the operation if the swings are dampen in the system. The proposed method is tested for two different power angles that the average of slip frequency is utilized for the (d-q) frame in these cases. Detection of fault during power swing is also considered in this test.

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