

# Power Swing Phenomena and its Detection and Prevention

Umar Naseem Khan and Lu Yan

**Abstract**—Power Swing which is basically caused by the large disturbances in the power system which if not blocked could cause wrong operation of the distance relay and can generate wrong or undesired tripping of the transmission line circuit breaker. And if not prevented from the generator could cause severe damage to the machine. To prevent unwanted distance or other relay operation during a Power Swing, we did fundamental studies of traditional and advanced detection and prevention methods. Further, we did research on setting of Power Swing Blocking (PSB) scheme to realize real applications.

**Index Terms**—power system, power swing, detection, prevention, protective relay.

## I. INTRODUCTION

IN the past few years we have experienced big disturbances in the power system which caused complete blackout and million of users including industry have suffered big economical losses. These disturbances cause big oscillations in active and reactive power, low voltage, voltage instability and phase or angular instability between the generated and consumed power which results in loss of generation and load which effected both the power generation and the end customers.

During the steady state condition, power systems operate on the nominal frequency (50Hz or 60Hz). The complete synchronism of nominal frequency and voltage at the sending and receiving ends cause complete balance of active and reactive power between generated and consumed active and reactive powers. In steady state operating condition Frequency=Nominal frequency (50 or 60 Hz) +/- 0.02 Hz and Voltage=Nominal voltage +/- 5% [1].

Power system faults, line switching, generator disconnection, and the loss or application of large blocks of load result in sudden changes to electrical power, which is due to the causes shown in Fig. 1.

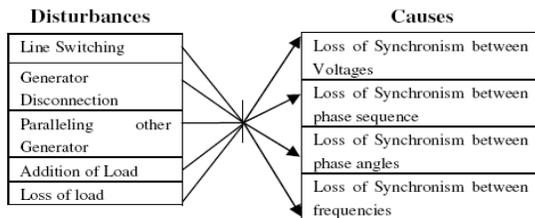


Figure 1. Causes due to different disturbances

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Whereas the mechanical power input to generators remains relatively constant.

The electrical power,  $P_g$  transferred from the generator, an electric machine, to the load is given by the equation:

$$P_g = \frac{E_g E_l}{X} \sin \delta \quad (1)$$

where:

$E_g$  = Internal voltage and is proportional to the excitation current

$E_l$  = Load Voltage

$X$  = Reactance between the generator and the load

$\delta$  = Angle that the internal voltage leads the load voltage

$$P_a = P_m - P_g \quad (2)$$

$P_m$  = Mechanical Turbine Power of the generating unit

$P_g$  = Electromagnetic Power output of the generating unit

$P_a$  = Accelerating Power

The mechanical power,  $P_m$ , is provided by the turbine and the average mechanical power must be equal to the average electrical power. When a system disturbance occurs there is a change in one of the parameters of the electrical power equation. For faults, typically the reactance between the generator and the load ( $X$ ), the load voltage ( $E_l$ ), or some combination of these two parameters causes the electrical power to change. For example, for a short circuit the load voltage is reduced, for a breaker opening the reactance increases. When a generation unit trips, the required electrical power from the remaining generators increases. In this case, the instantaneous mechanical power provided by the turbine is no longer equal to the instantaneous electrical power delivered or required by the load. When the load on a unit is suddenly increased, the energy furnished by the rotor results in a decrease in the rotor angular velocity [2]. And this decrease in rotor velocity will cause oscillations in rotor angle and can result in severe power flow swings.

### A. Example: Generator disconnection due to fault

Suppose we have two generators G1 & G2 in parallel, and both the generators are sharing load. On the sudden disconnection of G2, there will be an increase in load on G1 and due to this there will be the oscillations in the rotor angle of G1, which is represented in Fig. 2.

In Fig. 2,  $\delta$  is the steady state rotor angle and  $\delta'$  is the change in rotor angle due to oscillations which will result in

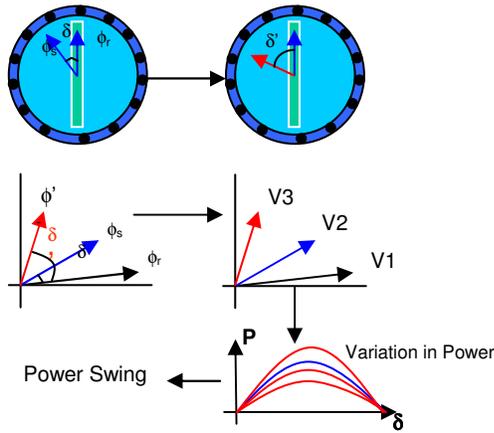


Figure 2. Representation of the power swing due to change in rotor.

the oscillation of nominal voltage, and this oscillation in the nominal voltage causes loss of synchronism between the generators in parallel or between the generation and load.

Depending on the severity of the disturbance and the actions of power system controls, the system may remain stable and return to a new equilibrium state experiencing what is referred to as a stable power swing. Severe system disturbances, on the other hand, could cause large separation of generator rotor angles, large swings of power flows, large fluctuations of voltages and currents, and eventual loss of synchronism between groups of generators or between neighboring utility systems [1]. **Stable Power Swing:** Small disturbances which can be control by the action of Power System and the system remain in its steady state condition. **Unstable Power Swing:** Severe disturbances can produce a large separation of System Generator Rotor angles, large swings of power flow, large fluctuations of voltages and currents, and eventually lead to lose synchronism.

### B. Power Swing Effect on the Distance Relay

Power swings can cause the load impedance, which under steady state conditions is not within the relay's operating characteristic, to enter into the relay's operating characteristic, Fig 3. Operation of these relays during a power swing may cause undesired tripping of transmission lines or other power system elements, thereby weakening the system and possibly leading to cascading outages and the shutdown of major portions of the power system.

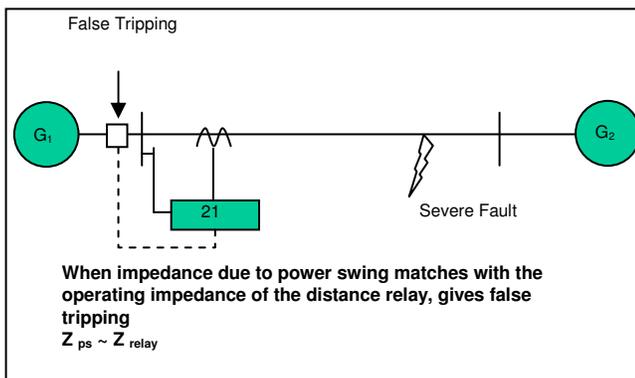


Figure 3. Wrong operation of distance relay due to Power Swing

Distance or other relays should not trip during such as stable or unstable power swings, and allow the power system to return to a stable operating condition. Distance relay elements prone to operate during stable or transient power swings should be temporarily inhibited from operating to prevent system separation from occurring at random or in other than pre-selected locations. A Power Swing Block (PSB) function is available in modern relays to prevent unwanted distance relay element operation during power swings. The main purpose of the PSB function is to differentiate between faults and power swings and block distance or other relay elements from operating during a power swing. However, faults that occur during a power swing must be detected and cleared with a high degree of selectivity and dependability. Severe system disturbances could cause large separation of the rotor angles between groups of generators and eventual loss of synchronism between groups of generators or between neighboring utility systems. When two areas of a power system, or two interconnected systems, lose synchronism, the areas must be separated from each other quickly and automatically to avoid equipment damage and power blackouts. Ideally, the systems should be separated in predetermined locations to maintain a load-generation balance in each of the separated areas. System separation may not always achieve the desired load-generation balance. In cases where the separated area load is in excess of local generation, some form of load shedding is necessary to avoid a complete blackout of the area. Uncontrolled tripping of circuit breakers during an Out-of- Step (OOS) condition could cause equipment damage, pose a safety concern for utility personnel, and further contribute to cascading outages and the shutdown of larger areas of the power system.

Therefore, controlled tripping of certain power system elements is necessary to prevent equipment damage and widespread power outages and to minimize the effects of the disturbance. The Out-of-Step Trip (OST) function accomplishes this separation. The main purpose of the OST function is to differentiate stable from unstable power swings and initiate system area separation at the predetermined network locations and at the appropriate source-voltage phase-angle difference between systems, in order to maintain power system stability and service continuity.

## II. FUNDAMENTAL POWER-SWING DETECTION PROBLEM

Power swings can cause the load impedance which under steady state conditions, whereas within the relay's operating characteristic, to induce unwanted relay operations at different network locations. These undesirable measurements may aggravate the power-system disturbance and cause major power outages, or even power blackout. Particularly, distance relays should not trip unexpectedly during dynamic system conditions such as stable or unstable power swings, and allow the power system to return to a stable operating condition.

Thereby, a Power Swing Block (PSB) function is adopted in modern relays to prevent unwanted distance relay element operation during power swing [1]. The main purpose of the PSB

function is to differentiate between power faults and power swings, and block distance or other relay elements from operations during a power swing.

It should be prudent to master the impacts to power system brought by power swing, especially for Out-of-Step (OOS) phenomena, which is same as an unstable power swing [4]. Uncontrolled tripping of circuit breakers during an OOS condition could cause equipment damage, pose a safety concern for operating personnel, and further contribute to cascading outage and shutdown of larger areas of the power system. So, the main purpose of the Out-of-Step Trip (OST) function should be taken into account to accomplish differentiation stable from unstable power swings, and separation to system areas at the predetermined network locations and at the appropriate source-voltage phase-angle difference between systems, in order to maintain power system stability and service continuity.

### III. POWER SWING DETECTION METHODS

For power swing detection methods, this section covers traditional methods for PSB and OST based on the rate of change of impedance and advanced methods used in microprocessor-based relays.

#### A. Traditional

Traditionally, according to detecting the difference in the rate of change of the positive-sequence impedance vector, we can distinguish a power swing or an OOS condition. This detection method is based on the fact that it takes a certain time for the rotor angle to advance because of system inertias. Namely, the rate of change of the impedance phasor is slow during power swings, while situation is exactly converse during a system fault with very fast changing of the impedance rate [1].

Practical implementation of measuring the rate of change of the impedance is normally performed through the use of two impedance measurement elements together with a timing device. If the measured impedance stays between the settings of the two impedance measurement elements for a predetermined time, the relay declares a power swing condition and issues a blocking signal to block the distance relay element operation. After a predetermined time the relay will trip if the power swing element is not reset. A timer is started when the apparent impedance enters the outer characteristic, see Fig. 3.

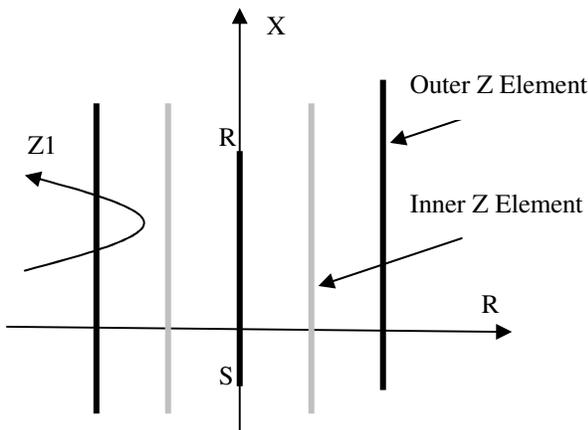


Figure 3. Double-blinder impedance-based Power Swing detection characteristic

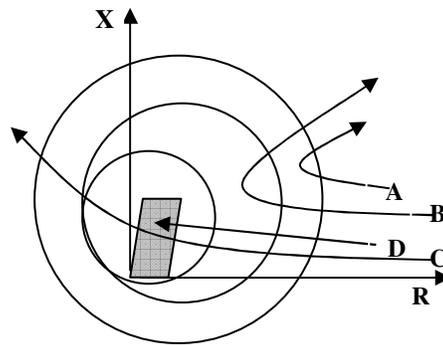


Figure 4. "Mho" type Out-of-Step detector

If the apparent impedance remains between the inner and outer characteristics for the setting time delay, the PSB element operates and selected distance element zones are blocked from operation for a period of time.

An out-of-step tripping scheme may use the same measuring element or a different set of measuring elements. The general operation is similar to PSB except the expected behavior is that the apparent impedance passes through both the inner and outer characteristic (see Fig. 4).

Where:

Shadow area: Fault zone

A: Z moves into OOS zone and leaves slowly

B: Z moves into OOS & Trip zones and leaves slowly

C: Z moves slowly across = network becomes asynchronous

D: Fault = Z moves rapidly into Trip zone

When the criteria for power swing detection are not met and when out-of-step tripping is selected, all zones of the relay are blocked temporarily, in order to prevent premature tripping [4]. When impedance vector "Z" leaves the power swing area, the vector is checked by its "R" component. If the component still has the same sign as at the point of entry, the power swing is in the process of stabilizing. Otherwise, the vector has passed through the Mho characteristic (trace "C" in Fig. 4) indicating loss of synchronism.

#### B. Advanced

The advent of digital technology has given relay design engineers the ability to develop and realize new methods for detecting power swings. Reference [1] [3] outline numerous new techniques, which do not require user-entered settings and greatly simplify the application of power swing detection and protection.

Some of these new methods determine a power swing condition based on a continuous impedance calculation. For example, an impedance calculation is performed for each 5ms step, and compared with the previous 5ms' result. Thus two continuous deviations can be predicted as traveling impedance because of power swing.

Others estimate the Electrical System Center, i.e. Voltage Zero, which is the point or points in the system where the voltage becomes zero during an unstable power swing, and determine if there is a power swing with detecting Voltage Zero's rate of change.

In addition, Synchrophasor-based Out-of-Step Relaying measurement has also been proposed as a way to detect and take action for power swings. Many utilities are currently evaluating the use and application of synchronized phasor measurement systems. As this technology develops, new and innovative methods of power swing detection are sure to be developed.

#### IV. SETTING THE POWER SWING BLOCKING SCHEME

Setting a power swing element is typically accomplished by extensive and time-consuming stability studies. Although using the stability study to set the power swing element is the best method, power swing elements can also be set by using known system conditions and making certain assumptions about the performance of the power system. However, these methods work well for PSB schemes but do not work well for Out-of-Step tripping.

Comparatively, using an impedance-based setting method performs well for most applications [1], particularly those where there are not significant changes in the source and transfer impedance.

Once the equivalent impedances are calculated, another piece of information is required, the power swing slip rate, which is equivalent to the rate at which the system is oscillating or the rate of change of impedance as viewed from the relay location.

Reference [1] [3] outline a few steps for setting the PSB blinder schemes shown in Fig. 3.

1. Set the outer characteristic impedance blinders inside the maximum possible load with some safety margin.
2. Set the inner impedance blinders outside the most over-reaching protection zone that is to be blocked when a swing condition occurs.
3. Based on the outer and inner blinders set previously, the predetermined PSB timer value, T1, can be calculated from the equation (3), while the maximum slip frequency, Fslip, is also assumed between 4 to 7 Hz.

$$T1 = \frac{(Ang1R - Ang2R) * Fnom(Hz)}{360 * Fslip(Hz)} \text{ (cycle)} \quad (3)$$

From Fig. 5, we know it is difficult to obtain the proper source impedances in a complex power system, which are necessary to establish the blinder and PSB timer settings.

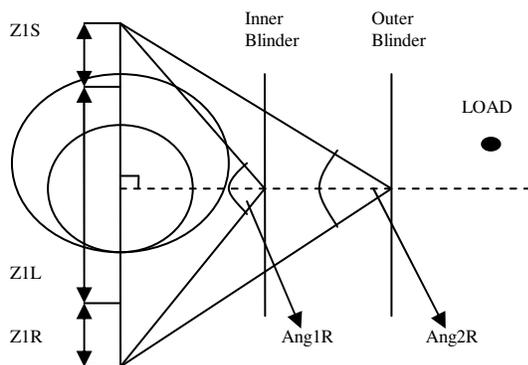


Figure 5. Equivalent two-source machine angles during OOS

where:

Z1S: the local source impedance

Z1L: the line impedance

Z1R: the remote source impedance

Ang2R and Ang1R: machine angles at the outer and inner blinder reaches, respectively

Normally, very detailed system stability studies are necessary to consider all contingency conditions to construct equivalent source impedance for conventional PSB function.

Besides, a modern relaying system with “load encroachment” capabilities should be required, because the load region will be close to the distance element that needs to be blocked when suffering a long line with heavy loads [1].

#### V. CONCLUSIONS

Power swing is a variation in three-phase power flow which occurs when the generator angles are advancing or retarding relative to each other in response to changes in load magnitudes and direction, line switching, loss of generation, faults, and other system disturbance.

In real applications, PSB elements may be set using an impedance-based method requiring development of system equivalents. Power swing tripping must be set using data obtained from extensive stability studies. It is difficult to calculate all of the varying system conditions, create boundary equivalents, and then determine the best place to apply the scheme and separate the system.

Besides, it is not recommended to apply PSB for unstable power swings without some form of OST being applied at some scheduled location.

#### VI. REFERENCES

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#### VII. BIOGRAPHIES

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