2 POWER SYSTEM PROTECTION

Section 2.3a Out-Of-Step Protection

Section 2.3.1 Introduction - Theory

Power swings, particularly those caused by system faults, result in large currents in the lines and, therefore, they affect the operation of the system protective relaying. For the correct coordination of protection, it is necessary that relays distinguish between stable and unstable swings and block breaker tripping for the former case.

Impedance relays used for overcurrent or out-of-step protection are particularly sensitive to power swings, since these swings "produce" ohms that enter the region of the impedance relay. In this case, the response of the protection scheme is determined by the amplitude and duration of the swing as well as additional relay schemes such as blinders and time delays. The accurate time response of the system under various swing conditions and its effect on the protection characteristics must be known to properly apply and coordinate the protection scheme and to prevent breaker tripping for recoverable swings.

This section provides methods for simulating power swings and the corresponding impedance seen by the impedance relay. Graphic comparison between the relay characteristic and the transient response of the system can help in the application of blinders, the setting of time delays and other auxiliary logic for obtaining the proper coordination.

Section 2.3.2 Power Swings

The system of Figure 2.3.1 can be used to derive the system response during power swings. The two sources and their impedances represent system generators or equivalent generators and their transient impedances with angular momentums M1 and M2. The system dynamics are expressed by the following **equations in pu**.

$$\frac{d\omega}{dt} = \frac{1}{M} \cdot \left(P_m - P_e\right)$$

$$\frac{d\delta}{dt} = 2 \cdot \pi \cdot \omega$$

where

$$M = \frac{M_1 \cdot M_2}{M_1 + M_2}$$

The quantity, Pm, is the total pu mechanical input to the generators. Pm equals the line power at steady state. ω and δ are, respectively, the relative rotor speed and angle of the two generators.

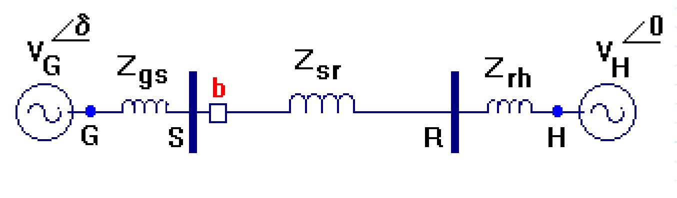

Fig. 2.3.1 Equivalent power system

The line power, Pe, is given as

$$P_e = \frac{V_G \cdot V_H}{Z_T} \cdot sin(\delta)$$

The impedance, ZT, represents the total impedance between the two sources (only reactive impedances are considered). System faults will cause ZT to vary and, as a result, will disturb the power balance between the two generators. Power unbalance will cause the generators to go out of step, and their rotors to swing with respect to each other. Depending on the magnitude and duration of the fault and the system prefault loading conditions, the swing may become unstable, requiring breaker operation and isolation of the two systems. In this case, the system load must be divided between the two generators according to their ratings to prevent further rotor acceleration. System swings tend to be unstable for disturbances occurring under heavy loading conditions.

Section 2.3.3 Impedance Relays Under System Swings

As the rotors swing against each other, the phase angle between the equivalent source voltages VG and VH will change. The system current produced by the swing is given as

$$I = \frac{V_G - V_H}{Z_T}$$

As δ increases from its prefault steady state, the current increases and approaches its maximum magnitude as δ approaches 180 degrees. This excessive current may trigger the overcurrent relays. In addition, an impedance relay at location b will see an equivalent impedance given by

$$Z_{eq} = \frac{V_S}{I}$$

On the R-X plane, Zeq appears as a circle defined as

$$center = Z_T + \frac{Z_T}{n^2 - 1} - z_{gs} \qquad\qquad radius = n \cdot \frac{|Z_T|}{|n^2 - 1|}$$

where

$$n = \frac{V_G}{V_H}$$

typically, n = 1.

The trajectory of Zeq will generally enter the protective region of the impedance relay. If the swing is stable, the swing ohms will eventually return and exit this region and stabilize at the postfault system equilibrium. An unstable swing, however, will produce ohms that traverse the relay characteristic. Therefore, proper protection coordination requires that

(a) sufficient time is provided before tripping is ensued to prevent system separation under stable swings, and

(b) fast swings are detected and tripping is ensued before the swing ohms traverse the relay protective region.

The steps to obtain correct system coordination include

(a) simulation of system swings under various operating conditions,

(b) determination, for each study, of the magnitude and duration of the system overcurrent, and

(c) determination of the swing ohms and the time these ohms remain within the protective region of the relay.

Information gathered from these studies is used to determine the settings of blinders, time delays or other additional relay logic.