Modle 6 : Preventive, Emergency and Restorative Control

Lecture 29 : Emergency Control : An example

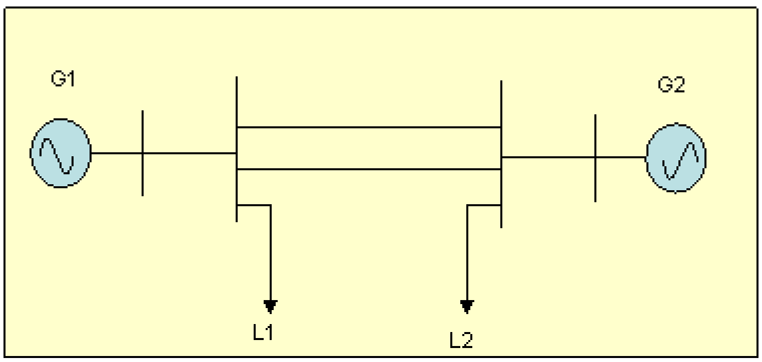
Objectives

In this lecture you will learn the following

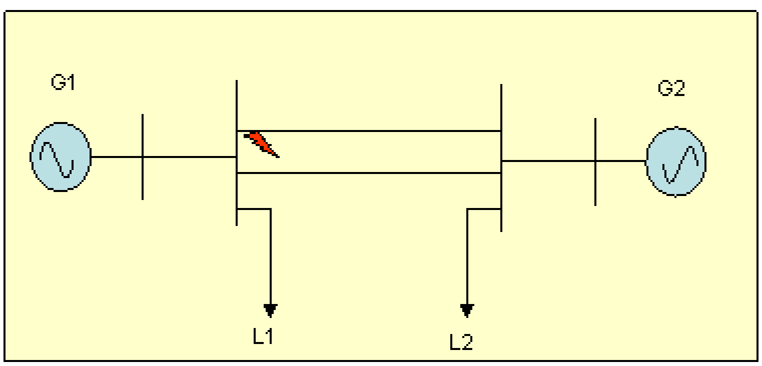
- An example to illustrate the system angular instability and islanding

A simple 2 machine example

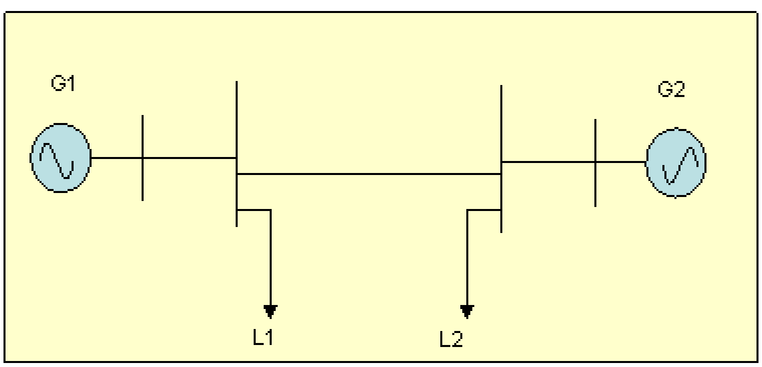
Consider the two machine system shown below:



Suppose it is subject to a fault on one of the interconnecting lines.



This fault is cleared by tripping the lines using Circuit Breakers which are triggered by protective relays



What are the possible consequences of such a disturbance ?

Possible Consequences

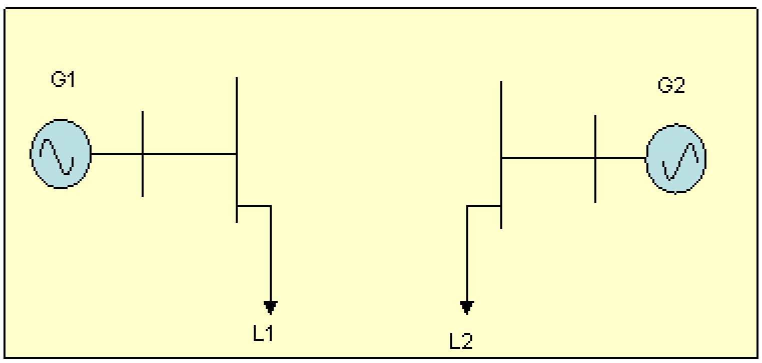
The possible consequences of a large disturbance like a fault (followed by line clearing) can be :

a) The system settles to a new acceptable equlibrium after some initial transients die down.

b) The system settles to a new equilibrium, but the equilibrium is violative of some steady state equipment limit (leading to tripping out of that equipment).

c) The system does not attain a new equilibrium due to angular or voltage instability.

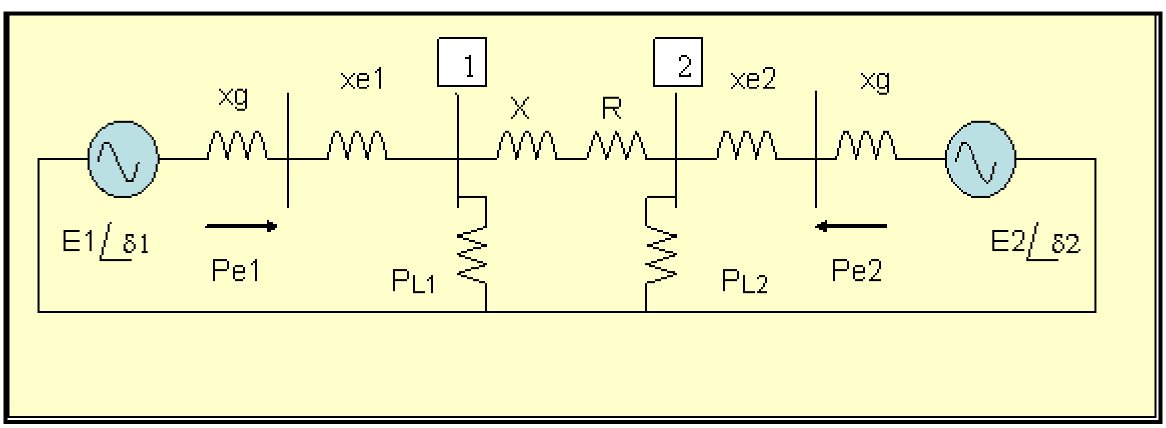
Voltage instability leads to unacceptably low voltages (which can be corrected by under-voltage load shedding), while angular instability (loss of synchronism) leads to violent excursions in current, voltage and power leading to equipment damage. Therefore, the generators which have lost synchronism have to be disconnected from each other. This may occur "naturally" due to distance relays (which mistake the large variations in voltage and current for a fault and trip the interconnecting lines), or intentionally -- controlled system separation --- by action of specially designed out of step relaying schemes. This situation is shown below.



The resulting two islands may have substantial real and reactive power deficit or surplus. This may result in decline or rise of frequency and//or voltage. Therefore excitation control, governors, generator overspeed control, and under-frequency/under-voltage load shedding are essential to make the islands stable.

We now anaylse this disturbance ...

In order to understand the various possibilities, we consider the system shown below which is modelled as follows:



A **generator** in this example is modelled as a voltage source (constant magnitude) behind a reactance. The angle dynamics is described by the swing equation:

$$\frac{d(\omega_i - \omega_o)}{dt} = \frac{d\omega_i}{dt} = \frac{\omega_B}{2H_i}(P_{mi} - P_{ei})$$

$$\frac{d\delta_i}{dt} = (\omega_i - \omega_o)$$

where, i = 1 and 2 for generator 1 and 2 respectively. $\omega_i - \omega_o$ is the speed deviation from nominal, $(P_{mi} - P_{ei})$ is the difference in mechanical input and electrical output power. The electrical power is obtained from the circuit solution for the figure shown above. ω_B is the base (nominal frequency) and H_i is the inertia constant.

The value of the rotor angle and speed is obtained by **numerical integration** (e.g. Runge Kutta Method) of the equations.

Caution: In actual practice, a generator model is much more complicated due to the dynamics of stator and field fluxes and the excitation system.

The **loads** are assumed to be resistance type (no frequency dependence and unity power factor).

The values of various parameters shown in the figure and the swing equations are:

PL1 = 0.63 pu, PL2 = 1.27 pu, xe1=xe2=0, xg = 0.25 pu, H1=H2=6 MJ/MVA, wo=wB=2*p*50 rad/s

Initial operating conditions: V1 = V2 = 1.0, and Pm1 = Pm2 = 0.95 pu

Note that initially power flows from bus 2 to bus 1 via **two parallel lines** (shown in the figure above as one *equivalent* line with impedance R+jX)

Prefault : Two identical lines in parallel : R = 0, X = 0.5,

Three Phase Fault : On one of the parallel lines at bus 1, and lasts for Tclear seconds

Post Fault : The faulted line is tripped. Therefore after the fault, R = 0 and X = 1.0

Results

We perform numerical integration using the MATLAB/SIMULINK files init.m and emergency.mdl, which can be downloaded from here. The various possibilities are shown below:

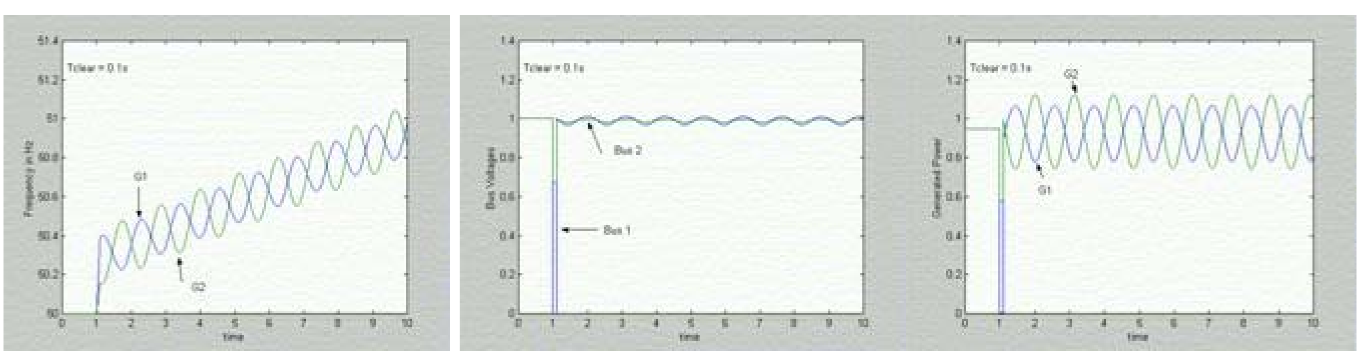
Case 1: Tclear = 0.1 s

In this case, the disturbance does not lead to a loss of synchronism. However power, frequency and voltage undergo "swings" which are caused by relative motions of the generator rotors. These swings are acceptable and will usually die down due to effect of damper and field windings in a generator (not modelled here).*

*Sometimes (not in the example shown here), these swings do not die down but grow with time. This is due to the effect of large gain feedback controllers - like voltage regulators in a generator excitation system.

Note: Due to slightly lower voltages at the buses 1 and 2 after tripping of the line, the total power drawn by the resistive loads decreases. Since the mechanical power is not changed, the frequency of both generators keeps increasing.

The frequencies will settle down -- to a value greater than 50 Hz -- if the loads are frequency dependent or if governors adjust the mechanical input to the generators (not considered here).



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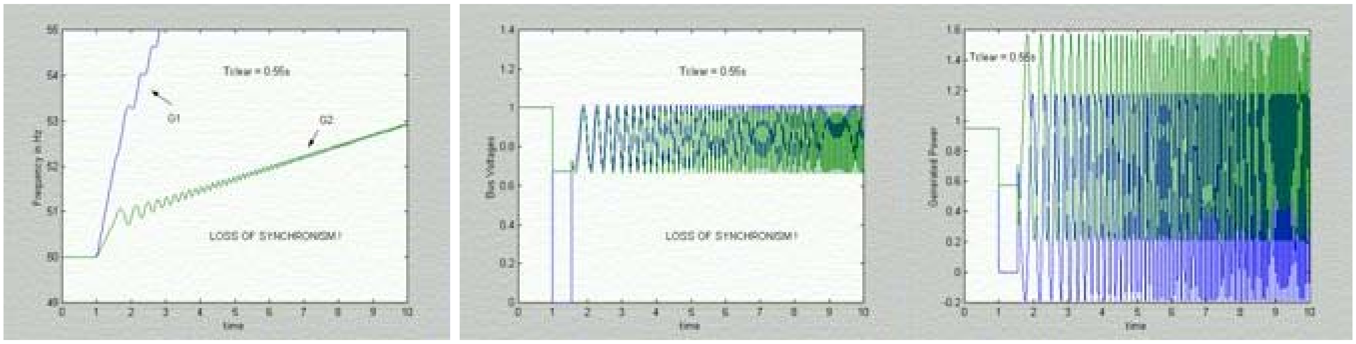
Case 2 : Tclear = 0.55 s

In this case, the disturbance causes the two generators to lose synchronism. The frequencies of the two generators "separate out" and electrical power and voltage undergo violent pulsations. (Normally this will not be allowed to continue).



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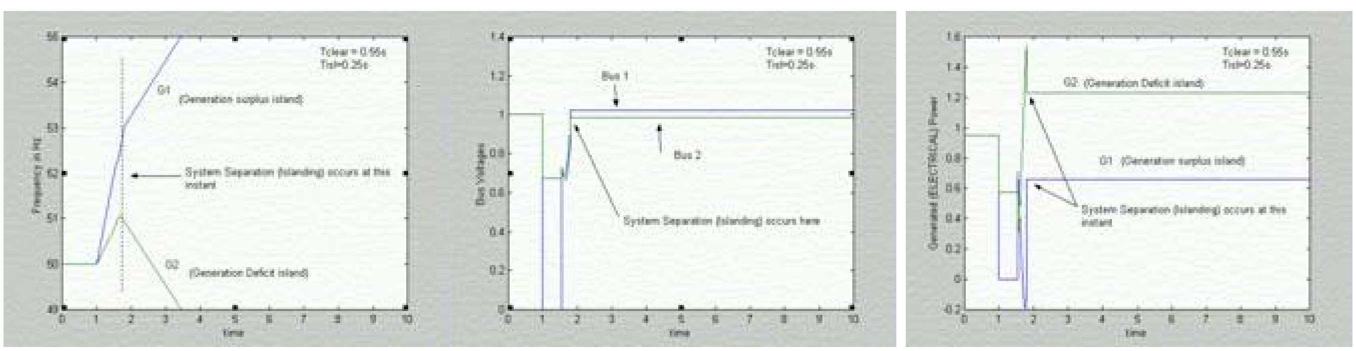
Results (contd.)

Case3 : Tclear = 0.55s, Tisl=0.25s

In this case, the disturbance leads to a loss of synchronism, but the two generators are separated by disconnecting the remaining line connecting them 0.25s after the faulted line is cleared.

Frequency in the "islands", one of which has excess load and the other which has surplus generation, changes very rapidly due to the large imbalance, calling for quick measures.



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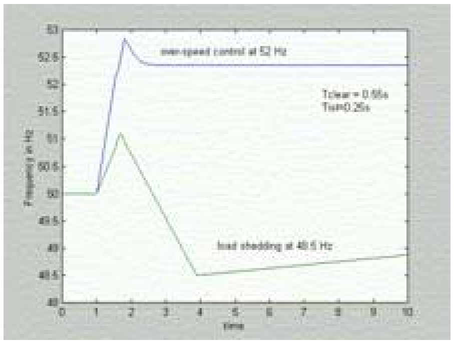
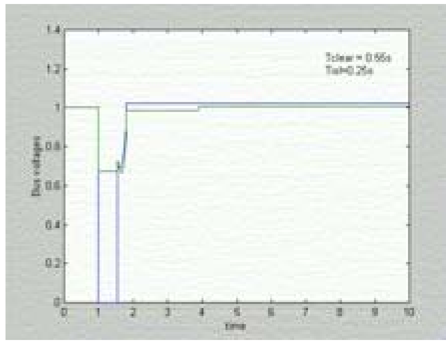
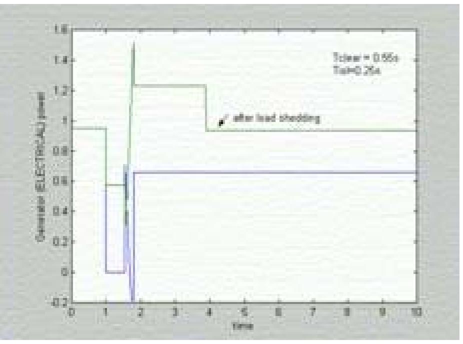
Case 4 : Tclear = 0.55s, Tisl=0.25s, Frequency Controls enabled

The effect of two **(idealized)** emergency frequency control schemes (see SIMULINK block diagram emergency.mdl for details) is shown here: Shedding of some load when frequency < 48.5 Hz, in the under-generated island, and *fast acting* overspeeding control to reduce mechanical power at frequency > 52 Hz in the over-generated island, prevents large frequency deviations.







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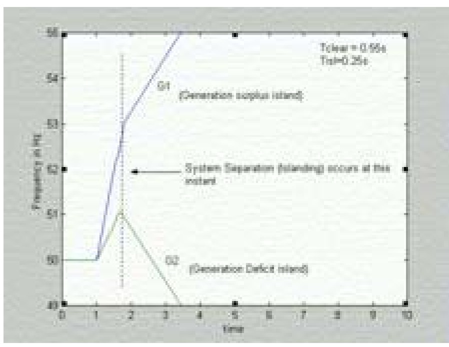

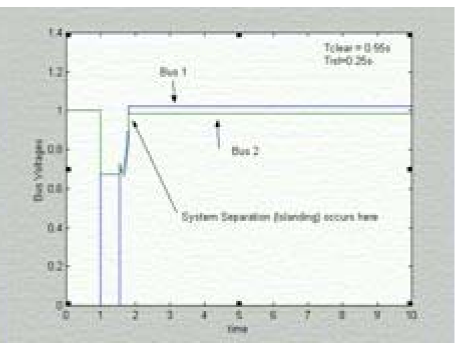

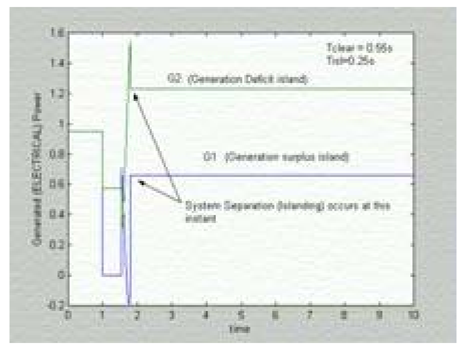

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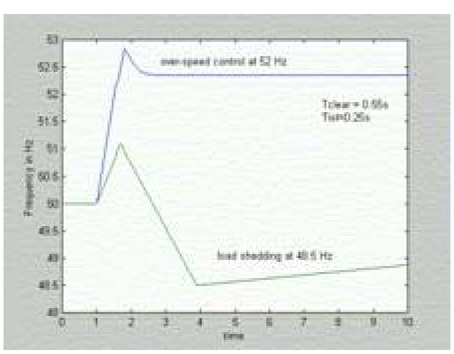

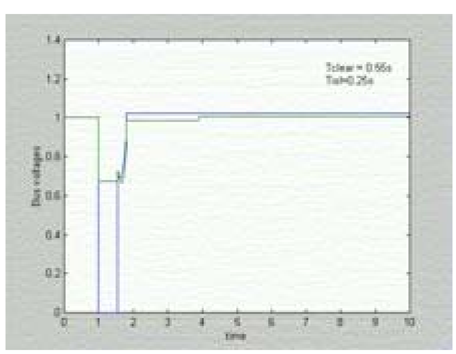

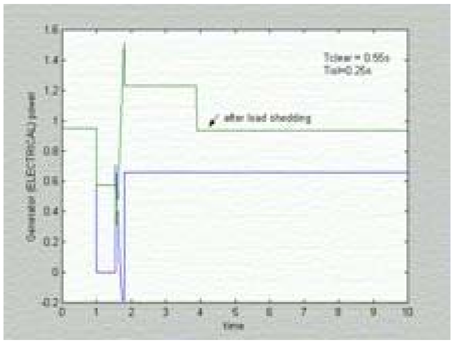

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Recap

In this lecture you have learnt the following

- An example to illustrate the system angular instability and islanding.
- If generators within a grid lose synchronism, then they have to be disconnected from each other.
- The separate subsystems (islands) may not survive if adequate frequency control measures are not in place.

Congratulations, you have finished Lecture 29. To view the next lecture select it from the left hand side menu of the page.