

Module 2 : Equipment and Stability Constraints in System Operation

Lecture 8 : Large disturbance Angle stability

Objectives

In this lecture you will learn the following

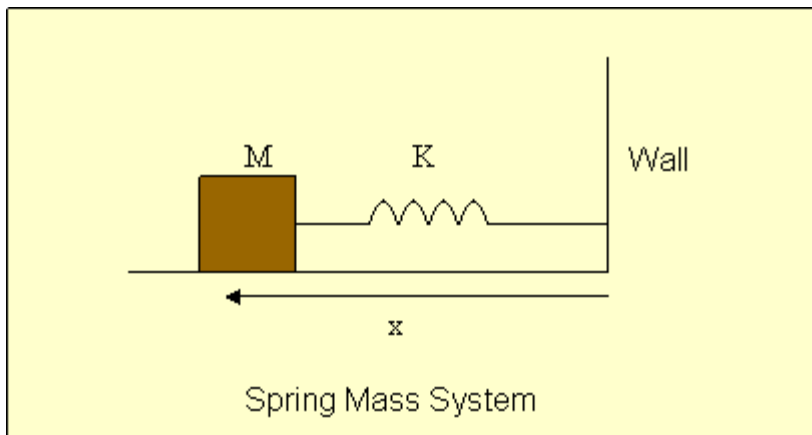
- Spring Mass analogy of a single machine infinite bus system.
- Large disturbance angular instability is demonstrated using an example.
- Angular stability in multimachine systems.
- Impact of angular stability problems on system operation.

A Simple Analogy of a single machine infinite bus system: A spring mass system

In this lecture we first understand the behaviour of the dynamical system qualitatively using a simple analogy and then use a numerical technique to simulate the behaviour of the system in an example.

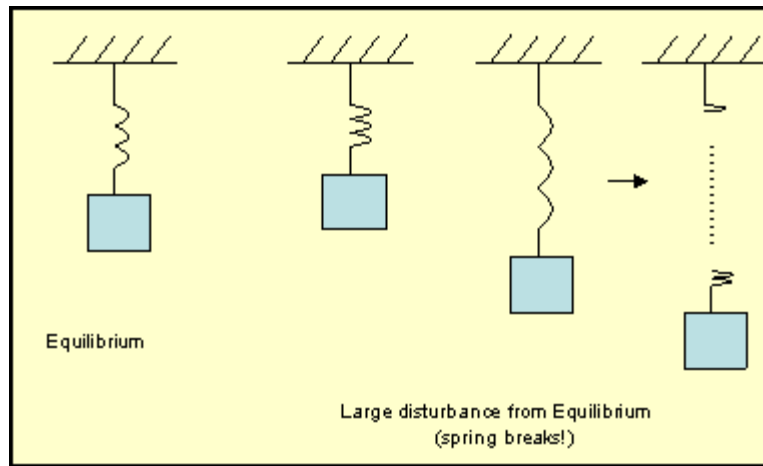
The differential equations of a single machine infinite bus (SMIB) system are similar to that of a "mass connected to a wall by a nonlinear spring" system.

For a *linear* spring, the restoring force is directly proportional to the stretch of the spring. If the mass is displaced from its equilibrium, then oscillatory motion results irrespective of the extent of the disturbance.



If the restoring force of the spring is a *nonlinear* function of the stretch, then the behavior may be different and depends on the extent of the disturbance.

For example, if the restoring force of the spring is almost a linear function upto a certain stretch but reduces to zero beyond that value, then for a large disturbance it is possible that the spring will break (as shown in the figure below).



To avoid instability (breaking of the spring), the following can be done:

- 1) Make the spring more stiff.
- 2) Reduce the disturbance.
- 3) Keep the equilibrium stretch of the spring small (so that it has more margin to stretch in case of disturbances).

The behavior of SMIB system is similar. Under normal operating conditions, there are restoring torques which tend to keep the synchronous machine in synchronism with the infinite bus. However when disturbances are large, the torque may not be able to "pull back" the machine to synchronism. We now illustrate this by an [example](#).

Machine Synchronisation

We have seen how the system behaves when subject to large disturbances in the previous [example](#). In the example, we had assumed that the machine was already connected and was initially in equilibrium (i.e., was in synchronism with the infinite bus).

It is natural of you to ask : How was the machine "synchronised" when it was first connected to the grid?

When a synchronous machine is connected to a grid, it is important to follow a particular procedure so that the transients which occur are minimised and the incoming generator is "pulled into synchronism".

This includes ensuring that the generator voltages and the system voltages are in the same phase sequence and the voltage magnitude of the generator and the grid at the point of interconnection are nearly equal.

Additionally:

- a) The electrical speed of the incoming generator should be almost equal to the grid frequency.
- b) The phase angular difference between the generator voltage and the grid voltage at the point of interconnection at the instant of interconnection should be small.

The situation is analogous to connecting two *moving* masses by a spring. To avoid excessive stretch in the spring when the masses are inter-connected (which may cause the spring to break), one would need to have the two masses to be close to each other and to be moving at nearly the same speed at the time of interconnection. If the interconnection is done smoothly, without breakage of the spring, then the masses move together at the same speed after transients die out. Thereafter, the masses are held together by the spring unless a large disturbance causes the spring to break.

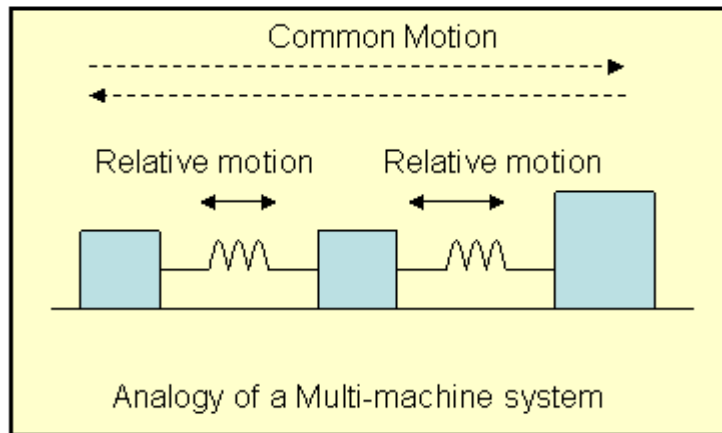
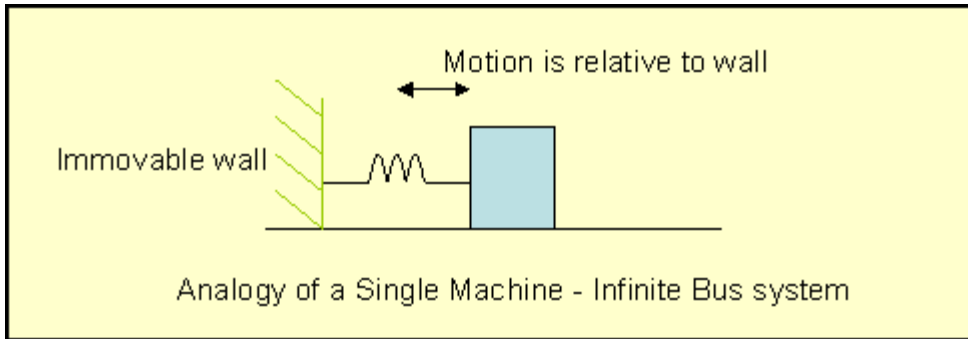
In practice, a plant operator starts rotating the generator by introducing a prime mover torque. He ramps up the speed to a value which is very close to the grid frequency by adjusting the prime mover torque. He then switches on the field excitation and brings voltage close to the grid voltage at the point of interconnection by adjusting the field voltage. Using an instrument called a **synchroscope**, he monitors the phase angular difference and switches on the interconnecting circuit breaker at the instant when the phase angular difference is very small.

You can simulate the process of synchronisation by downloading **all** of the following MATLAB/SIMULINK

simulation files: [1](#), [2](#), [3](#), [4](#), [5](#), [6](#). Run only the sync.mdl (1) file for simulation purpose.

Multi-generator systems

In a realistic system, there are many interconnected generators. Moreover, in practice there is no "infinite bus". The rotor angles swing relative to one another during transients although they settle to the same electrical speed if stable. Aggregate motion of the entire system (all masses move together) is also possible in addition to the relative motion. This is illustrated below by the spring mass analogy.

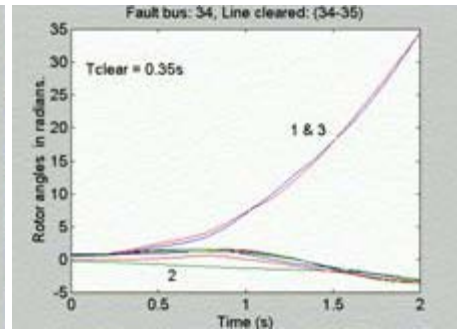
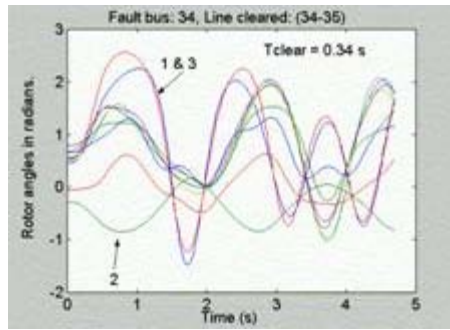
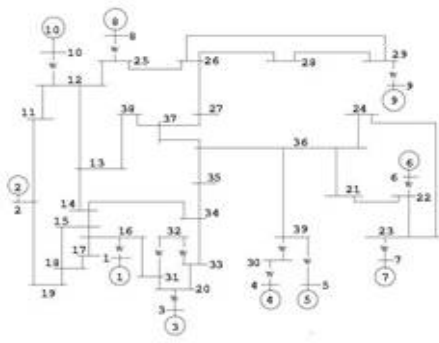


When a practical multimachine system is subjected to a large disturbance, loss of synchronism may take place if one or more groups of machines "separate out" from each other. It is not meaningful to see rotor angles relative to an infinite bus, since there isn't one! Instead they are plotted relative to the rotor angle of one machine, or to the *center of inertia* of the system which is defined as follows:

$$\delta_{COI} = \frac{H_1\delta_1 + H_2\delta_2 + \dots}{H_1 + H_2 + \dots}$$

Note: Movement of all generator rotors together (or equivalently, movement of the center of inertia) *does not* indicate loss of synchronism. Instead it tells us that overall load and generation in the system are not balanced. This issue is discussed in the next module. Loss of synchronism means that the *relative motion* between generator rotors is unstable.

This is illustrated by the plot of rotor angles for a 10 machine system for a large disturbance (detailed machine model and constant impedance loads are considered). Machines 1 and 3 separate out from the other machines if the clearing time is greater than 0.34 s.



(click on figures to enlarge)

Angular Stability and System Operation

Operation under loss of synchronism conditions is not feasible as voltage, torques etc. undergo large fluctuations and may damage equipment.

How does one prevent loss of synchronism due to disturbances?

Some of the methods used to reduce the possibility of loss of synchronism are:

- Reducing the magnitude of disturbance:** Large disturbances are typically due to faults which are cleared by line tripping. Reducing the duration of fault is one method of preventing loss of synchronism. These days, it is possible to clear faults within 3-5 cycles (taking into account relay and circuit breaker opening times).
- Planning:** (for a "stronger" transmission network). This would mean augmenting the transmission network with new transmission lines. Increasing the power transfer capability of transmission lines by compensating transmission reactance with series capacitors and shunt capacitors.
- Control:** The short term or excess capacity of many equipment can be used to enhance stability by appropriate controls. For example, excitation systems can allow for short term boosting of field voltage. Also, capacitors can be switched into the network in series and shunt. The switching may be done by means of circuit breakers or power electronic controls (power electronic controllers also allow for continuous control; this will be discussed in later modules).
- Operation:** During operation, it is ensured that the system is operated such that there exists sufficient "margin" for the system to withstand a credible disturbance (like a fault). This imposes a constraint on the level of power transfers which are permissible -- for larger levels of power flow, the synchronous generators are more likely to lose synchronism after a large disturbance. A system operator continuously monitors a power system and ensures that this is unlikely to happen. If the system is unlikely to withstand a credible disturbance, then *preventive control actions* like reducing the power transfer levels are taken. This may be achieved by *re-scheduling* power generated at various generators.

Line Loadability and Stability Constraints:

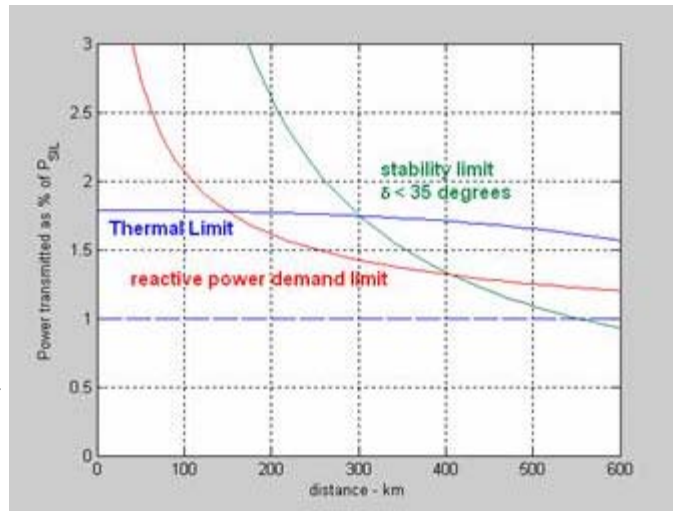
We mentioned in the previous slide that during operation, it is ensured that the system is operated such that there exists sufficient margin for the system to withstand a disturbance. It is ensured that phase angular difference across transmission paths is not too large. Thus angular stability puts a limit on the levels of power which can be transferred *securely*. One of the constraints for long distance AC transmission (other than thermal / voltage constraints) is the large phase angular difference which is required to transmit a given amount of power.

The modified loadability of a line (see a previous [example](#) on line loadability) by taking into account stability limits is shown in the figure on the right.

It is not easy to specify stability limits as they depend on the parameters of power system components and the operating conditions. However, for convenience it is specified by the maximum

phase angular difference which is allowed across the line.

It is clear that stability is *the* major constraint for lines more than 300 km long.



(click on figure to enlarge)

A thought which may come to your mind at this point is: if ac interconnections have these constraints (voltage/ angular stability), why not go in for DC transmission especially when transmitting power over long distances? This is an important planning option.

To answer this question dispassionately, let us consider the following points:

1. Long distance transmission requires us to use high voltages and lower currents (otherwise resistive losses will be too large). So step-up will still be required (it is not feasible (as yet) to generate power by ac or dc machines at high voltage). So transformers will be used to step-up generated ac voltage to higher ac voltage, and then rectify it to DC using power electronic converters. DC is again inverted to ac at the receiving end of the line. Thus a [dc interconnection](#) will require 2 large ac to dc converters at either end.
2. Voltage profile along a line is not an issue since series inductive and shunt capacitive effects are not manifested in steady state for DC transmission. Resistive drop is usually small.
3. Power Flow **can be controlled** using firing angle of thyristors used in the rectifier and inverter. Power flow is *independent* of the phase angular difference between sending(rectifier) and receiving(inverter) ends! So angular stability constraint is not there. In fact if two areas are connected by only dc inter-connections, then even frequency of the two areas need not be the same.

Thermal limit is the only limit for DC transmission lines and loadability is practically independent of distance.

The main disadvantage of dc links is the *high cost* of the power electronic converters. However, in many cases DC may be most suitable option inspite of the cost. Therefore, you do see several applications of dc links in our country (as an exercise, can you do a survey of this ?).

Recap

In this lecture you have learnt the following

- AC systems face an inherent angular stability problem: Synchronous machines lose synchronism with each other when subjected to large disturbances
- System operators avoid the angular stability problem by operating the system conservatively
- Operating conservatively implies that power flow in long ac transmission is severely curtailed due to angular stability constraints. HVDC transmission is an option for transmitting bulk power over large distances
- Congratulations, you have finished Lecture 8. To view the next lecture select it from the left hand side menu of the page.