



Power Systems Engineering Research Center

PSERC Background Paper

Transient Stability and Control of Large Scale Power Systems

Vijay Vittal

Harpole Professor, Department of Electrical and Computer Engineering
Iowa State University

September 4, 2003

I. Transient Stability

The Eastern Interconnected power system in North America (depicted in Fig. 1), which stretches from the Rockies to the Atlantic Ocean including the eastern provinces of Canada to the North and Florida to the South but excluding the State of Texas, is the largest “machine” engineered by humankind. Every generator or synchronous machine connected to the system operates in synchronism with every other generator in the interconnection. The electrical speed or frequency chosen for this operation is sixty cycles per second, commonly referred to as sixty Hertz. Generators are devices that convert mechanical energy to electrical energy.

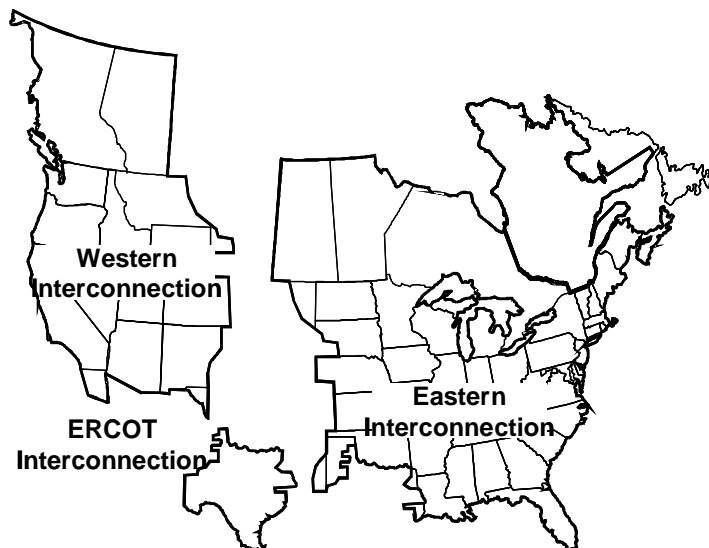


Figure 1. North American Interconnections

The mechanical energy is provided to each generator by a turbine, which in turn is powered by either steam generated by burning fossil fuels, by heat derived from nuclear fission, or by the kinetic energy of water. Each generator operates at the same synchronous speed and frequency of sixty Hertz while a delicate balance between the input mechanical power and output electric power is maintained. Whenever generation is less than actual customer load, the system frequency falls. On the other hand, when generation exceeds load, the system frequency rises. The generators are also interconnected with each other and with the loads they supply via high voltage transmission lines.

An important feature of the electric power system is that electricity has to be generated when it is needed because it cannot be efficiently stored. Hence, using a sophisticated load forecasting procedure, generators are scheduled for every hour in the day to match the load. In addition, generators are also placed on active standby to provide electricity in times of emergency. This is referred to as spinning reserve.

The power system is routinely subjected to a variety of disturbances. Even the act of switching on an appliance in the house can be regarded as a disturbance. However, given the size of the system and the scale of the perturbation caused by the switching of an appliance in comparison to the size and capability of the interconnected system, the effects are not measurable. Large disturbances do occur on the system. These include severe lightning strikes, loss of transmission lines carrying bulk power due to overloading or weather conditions like a tornado or ice storm, loss of a generating station, or the loss of major load. The ability of a power system to survive the transition following a large disturbance and reach an acceptable operating condition is called *transient stability*.

The physical phenomenon following a large disturbance can be described as follows. Any disturbance in the system will cause the balance between the mechanical power input to the generator and the electrical power output of the generator to be affected. As a result, some of the generators will tend to speed up and some will tend to slow down. If, for a particular generator, this tendency is too great, it will no longer remain in synchronism with the rest of the system and will be automatically disconnected from the system. This phenomenon is referred to as a generator going out of step.

Acceleration or deceleration of these large generators causes severe mechanical stresses. Generators are also expensive. Damage to generators results in costly overhaul and long downtimes for repair. As a result, they are protected with equipment safety in mind. As soon as a generator begins to go out-of-step, sensors in the system sense the out-of-step condition and trip the generators. In addition, since the system is interconnected through transmission lines, the imbalance in the generator electrical output power and mechanical input power is reflected in a change in the flows of power on transmission lines. As a result, there could be large oscillations in the flows on the transmission lines as generators try to overcome the imbalance and their outputs swing with respect to each other.

A mechanical analogy to this phenomenon can be visualized in Fig. 2. Suppose that there is a set of balls of different sizes connected to each other by a set of strings. The

balls represent generators having a specific mechanical characteristic (that is, inertia). The strings represent the transmission lines interconnecting the generators.

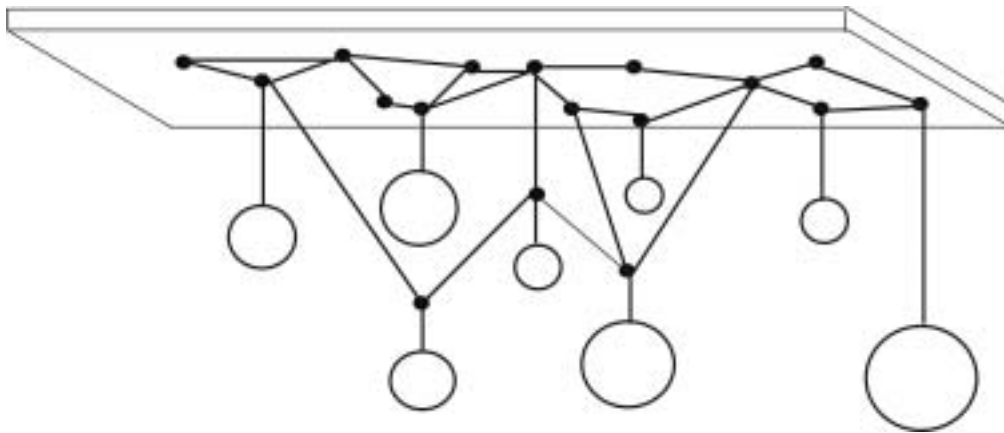


Figure 2. Mechanical Analogy for Transient Stability

Now suppose that there is a disturbance in which one of the balls is struck with a cue. The ball now begins to swing, and as a result, the string connected to the ball also oscillates. In addition, the other strings to which this string is connected are also affected, and this in turn affects the other balls connected to these strings. As a result, the entire interconnected system of balls is affected, and the system experiences oscillations in the strings and motion of the balls. If these oscillations in the strings become large, one of the strings may break away from the rest, resulting in instability. On the other hand if the oscillations die down and the entire system comes back to rest as in the situation prior to the ball being struck. This condition is analogous to a power system being “transiently stable.”

In a power system, an additional important characteristic is the operating condition. As the loading on the system increases, the system becomes more stressed and operates closer to its limits. During these stressed conditions, a small disturbance can make the system unstable. Dropping a marble into a pitcher of water provides a suitable analogy to understand why the operating condition makes a difference in maintaining transient stability.

1. Take a pitcher and fill it with water to quarter its capacity. Now drop a marble in the pitcher. The dropping of the marble is akin to a disturbance in the power system. In this situation no water from the pitcher will splash out, indicating the system is stable.
2. Now fill the pitcher with water close to its brim and drop the same marble into the pitcher. In this case, water will splash out, indicating the system is unstable.

In these two situations, the same disturbance was created. However, the system was operating at different conditions, and in the latter situation, the system was more stressed. Again, this analogy illustrates that the degree of stability is dependent on the initial operating condition.

II. Protection

The large oscillations in the connecting strings correspond to the large power swings on transmission lines. If these swings persist, or if the flows exceed the transmission line capabilities, the transmission lines are protected by using large mechanical switches called circuit breakers that isolate the transmission lines. This also happens to be the principal philosophy in protecting the electric grid and all major power system components. In the event of a disturbance, the faulted portion of the network or the component is isolated from the rest of the system to prevent additional damage to equipment. Isolation also arrests the progress of the initial disturbance from cascading into other parts of the system. System protection is mainly achieved using a host of sensors to measure critical parameters, intelligent logic devices called relays that compare these parameters with limiting thresholds, and mechanical switches called circuit breakers that are operated by the relays when the thresholds are exceeded. The protection system constitutes an important safeguard against transient instability because it prevents the effect of the large disturbance from affecting a larger portion of the system.

III. Control

Another important tool in the prevention of transient instability is control. Large power systems have a number of controllers that are continuously acting to keep the system operating within limits in a stable manner. These controllers largely work on the principle of feedback. This is the same principle that guides several mechanisms that we encounter in every day life, such as the cruise control in the automobile. When the cruise control is set for a particular speed, and the automobile goes up a hill, sensors in the car measure the speed and compare it with the set speed. As the speed drops when the hill is approached, the error between the measured speed and the set speed increases. This error is used as a signal to actuate control that will force more fuel through the fuel injector (and the driver notices the gas pedal being automatically depressed). This extra fuel is combusted in the engine, and the speed of the car increases. This process continues until the measured speed is equal to the set speed.

Similar controllers also exist in power systems. They maintain the generator output voltage and speed at a constant level. These controllers are critical for maintaining the stability of the system. These controllers also respond to large disturbances. However, certain large disturbances may tax these controllers beyond their capability. As a result, special stability controls are used to stabilize the system. These controls primarily act to reduce the tendency of generators to speed up or decelerate (described in Section I) following a large disturbance. When generators tend to speed up, these controls reduce the generator output power and bring parity between the generator mechanical input and

electric power output. In the decelerating case, these controls measure frequency and appropriately drop specific customer loads to reduce generation requirements and the electric output of the generators. Newer controls involving power electronic components can also change the flow on transmission lines at a very fast rate and are effective in damping oscillations.

Proper coordination and tuning of these controls is essential in operating the system with a high degree of reliability and efficiency.

Contact Information

Vijay Vittal
PSERC Site Director
Harpole Professor, Department of Electrical and Computer Engineering
Iowa State University
1126 Coover Hall
Ames, Iowa 50011
Phone: 515-294-8963
Fax: 515-294-4263
e-mail: vvital@iastate.edu

[Power Systems Engineering Research Center](#)
428 Phillips Hall
Cornell University
Ithaca, NY 14853-5401
Phone: 607-255-5601

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