© 2015 IJSRSET | Volume 1 | Issue 1 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology Article Type: Technical Note

Literature Review on Transient Stability

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ABSTRACT

Power system stability is defined as the ability of power system to recover its initial steady state after any deviation of the power system during its operation. Present time power systems are being operated nearer to their stability limits due to economic and environmental reasons. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. Transient stability has been given much attention by power system researchers and planners in recent years, and is being regarded as one of the major sources of power system insecurity. FACTS devices, transmission line design, AVR(automatic voltage regulators),load shedding, bundled conductors ,fast switching devices, high speed excitation system play an important role in improving the transient stability, increasing transmission capacity and damping low frequency oscillations. In this paper also factors affecting transient stability and how we can improve the transient stability are discussed.

Keywords: Angle Stability, Voltage Stability, Frequency Stability, Factors Affecting Transient Stability, Transient Stability Improvement Methods

I. INTRODUCTION

Power system stability has been recognized as an important problem for secure system operation since the 1920s.Many major blackouts caused by power system instability have illustrated the importance of this phenomenon. transient instability has been the dominant stability problem on most systems, and has been the focus of much of the industry's attention concerning system stability. As power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability, frequency stability and inter area oscillations have become greater concerns than in the past. This has created a need to review the definition and classification of power system stability. A clear understanding of different types of instability and how they are interrelated is essential for the satisfactory design and operation of power systems. As well, consistent use of terminology is required for developing system design and operating criteria, standard analytical tools, and study procedures.

II. DEFINITION OF POWER SYSTEM STABILITY

A. Proposed Definition

"Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact ".

III. CLASSIFICATION OF POWER SYSTEM STABILITY

A typical modern power system is a high-order multivariable process whose dynamic response is influenced by a wide array of devices with different characteristics and response rates. Stability is a condition of equilibrium between opposing forces. Depending on the network topology, system operating condition and the form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability. In this section, we provide a systematic basis for classification of power system stability.

B. Categories of Stability

The classification of power system stability proposed here is based on the following considerations:

- The physical nature of the resulting mode of instability as indicated by the main system variable in which instability can be observed.
- The size of the disturbance considered which influences the method of calculation and prediction of stability.
- The devices, processes, and the time span that must be taken into consideration in order to assess stability.

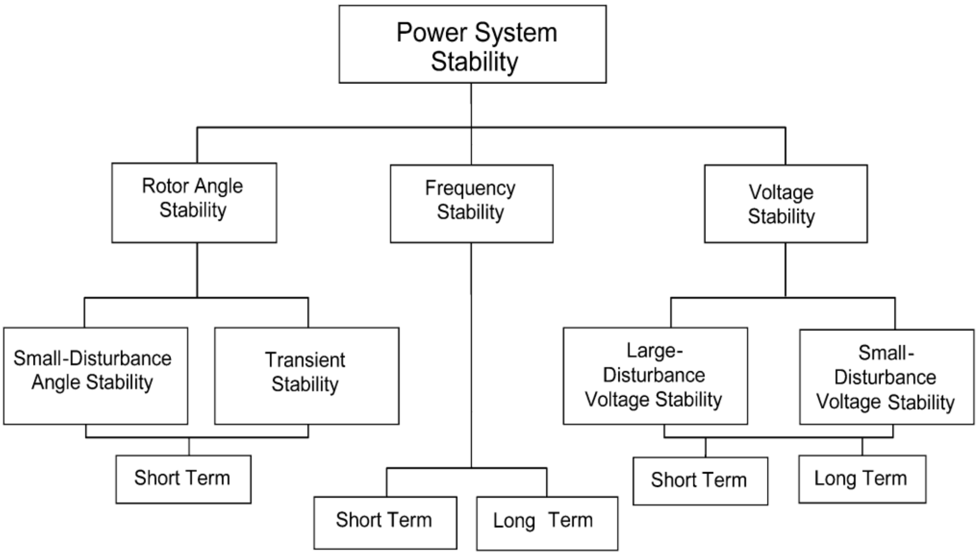

Figure 1. Classification of power system stability

C. Rotor Angle Stability

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. It depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system. Instability that may result occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators.

The rotor angle stability problem involves the study of the electromechanical oscillations inherent in power systems. A fundamental factor in this problem is the manner in which the power outputs of synchronous machines vary as their rotor angles change. Under steady-state conditions, there is equilibrium between the input mechanical torque and the output electromagnetic torque of each generator, and the speed remains constant. If the system is perturbed, this equilibrium is upset, resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of a rotating body. If one generator temporarily runs faster than another, the angular position of its rotor relative to that of the slower machine will advance. The resulting angular difference transfers part of the load from the stomaching to the fast machine, depending on the power-angle relationship. This tends to reduce the speed difference and hence the angular separation. The power-angle relationship is highly nonlinear. Beyond a certain limit, an increase in angular separation is accompanied by a decrease in power transfer such that the angular separation is increased further. Instability results if the system cannot absorb the kinetic energy corresponding to these rotor speed differences. For any given situation, the stability of the system depends on whether or not the deviations in angular positions of the rotors result in sufficient restoring torques . Loss of synchronism can occur between one machine and the rest of the system, or between groups of machines, with synchronism maintained within each group after separating from each other.

Small-disturbance (or small-signal) rotor angle stability is concerned with the ability of the power system to maintain synchronism under small disturbances. The disturbances are considered to be sufficiently small that linearization of system equations is permissible for purposes of analysis.

Small-disturbance stability depends on the initial operating state of the system.
Instability that may result can be of two forms:
i) increase in rotor angle through a non-oscillatory or aperiodic mode due to lack of synchronizing torque
ii) Rotor oscillations of increasing amplitude due to lack of sufficient damping torque.

Small-disturbance rotor angle stability problems may be either local or global in nature. Local problems involve a small part of the power system, and are usually associated with rotor angle oscillations of a single power plant against the rest of the power system. Such oscillations are called local plant mode oscillations.

Large-disturbance rotor angle stability or transient stability as it is commonly referred to, is concerned with the ability of the power system to maintain synchronism when subjected to a severe disturbance, such as a short circuit on a transmission line. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship.

Transient stability depends on both the initial operating state of the system and the severity of the disturbance. Instability is usually in the form of aperiodic angular separation due to insufficient synchronizing torque, manifesting as first swing instability. However, in large power systems, transient instability may not always occur as first swing instability associated with a single mode; it could be a result of superposition of a slow inters area swing mode and a local-plant swing mode causing a large excursion of rotor angle beyond the first swing. It could also be a result of nonlinear effects affecting a single mode causing instability beyond the first swing.

The time frame of interest in transient stability studies is usually 3 to 5 seconds following the disturbance. It may extend to 10–20 seconds for very large systems with dominant inter-area swings.

D. Voltage Stability Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition.

It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result occurs in the form of a progressive fall or rise of voltages of some buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protective systems leading to cascading outages. Loss of synchronism of some generators may result from these outages or from operating conditions that violate field current limit . Voltage stability problems may also be experienced at the terminals of HVDC links used for either long distance or back-to-back applications. They are usually associated with HVDC links connected to weak ac systems and may occur at rectifier or inverter stations, and are associated with the unfavourable reactive power “load” characteristics of the converters. The HVDC link control strategies have a very significant influence on such problems, since the active and reactive power at the ac/dc junction are determined by the controls. If the resulting loading on the ac transmission stresses it beyond its capability, voltage instability occurs.

Such a phenomenon is relatively fast with the time frame of interest being in the order of one second or less. Voltage instability may also be associated with converter transformer tap-changer controls, which is a considerably slower phenomenon.

Recent developments in HVDC technology (voltage source converters and capacitor commutated converters) have significantly increased the limits for stable operation of HVDC links in weak systems as compared with the limits for line commutated converters.

Large-disturbance voltage stability refers to the system’s ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. This ability is determined by the system and load characteristics, and the interactions of both continuous and discrete controls and protections. Determination of large-disturbance voltage stability requires the examination of the nonlinear response of the power system over a period of time sufficient to capture the performance and interactions of such devices as motors, under load transformer tap changers, and generator field-current limiters. The study period of interest may extend from a few seconds to tens of minutes.

Small-disturbance voltage stability refers to the system’s ability to maintain steady voltages when subjected to small perturbations such as incremental changes in system load. This form of stability is influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. This concept is useful in determining, at any instant, how the system voltages will respond to small system changes. With appropriate assumptions, system equations can be linearized for analysis thereby allowing computation of valuable sensitivity information useful in identifying factors influencing stability. This linearization, however, cannot account for nonlinear effects such as tap changer controls (dead bands, discrete tap steps, and time delays). Therefore, a combination of linear and nonlinear analyses is used in a complementary manner.

Short-term voltage stability involves dynamics of fast acting load components such as induction motors, electronically controlled loads, and HVDC converters. The study period of interest is in the order of several seconds, and analysis requires solution of appropriate system differential equations; this is similar to analysis of rotor angle stability. Dynamic modelling of loads is often essential. In contrast to angle stability, short circuits near loads are important. It is recommended that the term transient voltage stability not be used.

Long-term voltage stability involves slower acting equipment such as tap-changing transformers, thermostatically controlled loads, and generator current limiters. The study period of interest may extend to several or many minutes, and long-term simulations are required for analysis of system dynamic performance. Stability is usually determined by the resulting outage of equipment, rather than the severity of the initial disturbance. Instability is due to the loss of long-term equilibrium (e.g., when loads try to restore their power beyond the capability of the transmission network and connected generation), post-disturbance steady-state operating point being small-disturbance unstable, or a lack of attraction toward the stable post-disturbance equilibrium (e.g., when a remedial action is applied too late). The disturbance could also be a sustained load build up (e.g., morning load increase). In many cases, static analyses are can be used to estimate stability margins, identify factors influencing stability, and screen a wide range of system conditions and a large number of scenarios. Where timing of control actions is important, this should be complemented by quasi-steady-state time-domain simulations.

E. Frequency Stability

Frequency stability refers to the ability of maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load.

It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads. Severe system upsets generally result in large excursions of frequency, power flows, voltage, and other system variables, thereby invoking the actions of processes, controls, and protections that are not modelled in conventional transient stability or voltage stability studies. These processes may be very slow, such as boiler dynamics, or only triggered for extreme system conditions, such as volts/Hertz protection tripping generators. In large interconnected power systems, this type of situation is most commonly associated with conditions following splitting of systems into islands. Stability in this case is a question of whether or not each island will reach a state of operating equilibrium with minimal unintentional loss of load. It is determined by the overall response of the island as evidenced by its mean frequency, rather than relative motion of machines. Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment, or insufficient generation reserve.

In isolated island systems, frequency stability could be of concern for any disturbance causing a relatively significant loss of load or generation. During frequency excursions, the characteristic times of the processes and devices that are activated will range from fraction of seconds, corresponding to the response of devices such as under frequency load shedding and generator controls and protections, to several minutes, corresponding to the response of devices such as prime mover energy supply systems and load voltage regulators.

An example of short-term frequency instability is the formation of an under generated island with insufficient under frequency load shedding such that frequency decays rapidly causing blackout of the island within a few seconds. On the other hand, more complex situations in which frequency instability is caused by steam turbine over speed controls or boiler/reactor protection and controls are longer-term phenomena with the time frame of interest ranging from tens of seconds to several minutes. During frequency excursions, voltage magnitudes may change significantly, especially for islanding conditions with under frequency load shedding that unloads the system. Voltage magnitude changes, which may be higher in percentage than frequency changes, affect the load-generation imbalance. High voltage may cause undesirable generator tripping by poorly designed or coordinated loss of excitation relays or volts/Hertz relays. In an overloaded system, low voltage may cause undesirable operation of impedance relays.

Factors Affecting Transient Stability

From the swing equation, the acceleration of the rotor is inversely proportional to the inertia constant M of the machine when accelerating power is constant. This means higher the inertia constant, the slower will be the change in the rotor angle of the machine and thus large the critical clearing time. However, it is uneconomical to improve the transient stability by increasing the inertia constant and is normally not used.

The methods normally used for improving the transient stability are:

1. Higher system voltage – an increase in system voltage results in higher value of the steady-state stability limit (Pmax).

2. The higher the Pmax value, the smaller will be the transmission angle required to transfer a given amount of power. This means the greater is the margin between the steady-state transmission angle and the critical clearing angle.

TRANSIEANT STABILITY IMPROVMENT METHODS

1. Breaking Resistor

For improving stability, when large load is suddenly lost a resistive load called a breaking resistor is connected at or near the generator bus. This load compensates for at least some of the reduction of load on the generators and so reduces the acceleration. During fault ,resistor are applied to the terminals of the generators through circuit breaker. The control scheme determines the amount of resistance to be connected and its duration.

2. Single Pole Switching

Most of the transmission line faults are single phase to ground faults. Single pole switching means independent pole operation. If the protection scheme and breaker are properly arranged, in the event of line to ground fault, the circuit breaker opens the faulty line(1 phase) and the remaining two healthy phases continue to supply power. Since a large percentage of these faults are transitory, this phase can also be returned to service after it has been de-energized for sufficient time. The system should not operated for long period with one phase opened. Therefore , some means is to be employed for tripping the entire line of one phase remaining open for a predetermined time.

3. Fast Acting AVR

The satisfactory operation of synchronous generators of an interconnected power system at high load angles and during transient condition is very much dependent on the source of field excitation and on the automatic voltage regulators. A voltage regulator is the heart of the excitation system. The output voltage of the generator changes only when the voltage regulator instructs the excitation system to do so irrespective of the speed of response of the exciter. A regulator senses changes in the output voltage and/or current and causes corrective action to take place. If the regulator is slow, the system will be a poor one. The settings and physical limits on the AVR will have a direct impact on the system performance. With a good setting, both the steady-state and transient stability limits can be improved with the use of AVR

4. Use Of Double Circuit Line

The impedance of a double-circuit line is less than that of single –circuit line. A double-circuit line makes twice the transmission capability. The continuity of supply is maintained over one line with reduced capacity when the other line is out of service for maintenance or repair.

5. Series Compensation of Lines

When the STATCOM is connected to the midpoint terminals, reactive power controller adapts the value of the inverter firing angle according to system requirements. As STATCOM firing angle, the firing angle should remain zero at normal operating conditions and there is no reactive power exchange between the system and the STATCOM. When the fault occurs, the firing angle is changed instantly and the reactive power is supplied by the STATCOM to the system. When the fault is cleared, the firing angle is reduced to zero again and the STATCOM back to the idle condition . The impact of reactive power modulation using STATCOM on system performance can be seen in Fig. Connecting the STATCOM to the midpoint terminals will maintain the rotor speed and the power angle at their nominal values even during the fault. The voltage sag at the generator terminals will be reduced substantially. The shaft oscillations and torsion forces will be reduced to almost the normal steady state condition.

6. Use of Bounded Conductors

Bounded conductors reduce the line reactance to a considerable extent so increases the power limit of line. the power transfer P from the generator to the infinite bus is given by

$$P_{max}=EV/X$$

7. High Speed Excitation System

High-speed excitation system is very helpful to maintain synchronism during a fault by quickly increasing the excitation. High-speed governors help by quickly adjusting the governor inputs though speed governing control has little effects in terms of steady-steady stability, fast acting governor can certainly improve multi-swing transient stability. In the short period (1s) after the disturbance, the governor and turbine will be too slow to have any significant effect on the generator rotor response. However, the governing effects will kick in and improve the system response as excess mechanical power coming the steam turbine has been reduced by the closing the main steam controlling and interceptor valves.

8. Fast Switching

It is necessary that the fault should be cleared as fast as possible. It should be noted that the time required for fault removal is the sum of relay response time plus the circuit breaker operating time. Therefore high speed relaying and circuit breaking are commonly used to improve stability during fault condition.

9. HVDC Links

HVDC links are helpful in maintaining stability due to the following advantages

A D.C line provides a loose coupling between two A.C system to be interconnected. A D.C line may connected two A.C system at different frequencies. There is no transfer of fault energy from one A.C system to another if they are interconnected by a D.C tie line.

10. Load shedding

If there is insufficient generation to maintain system frequency, some of the generators are disconnected during or immediately after a fault. Thus, the stability of the remaining generators is improved. Load shedding (removal of load) is also helpful in improving transient stability.

IV. CONCLUSION

This review report has addressed the issue of stability definition and classification in power systems from a fundamental viewpoint and has examined the practical ramifications of stability phenomena in significant detail. A precise definition of power system stability that is inclusive of all forms is provided.

A salient feature of the report is a systematic classification of power system stability, and the identification of different categories of stability behaviours. The report also includes a factors affecting transient stability and transient stability improvement methods. by using this methods we can improve the transient stability.

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