Impact of Stability in Power System and Techniques for Improvement

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Abstract
Electrical power grid is most complex and densely interconnected, which increase instability when power is transferred through transmission lines for long distances. Historical data and blackouts analysis shows the importance of power system stability. This paper discusses power system stability such as rotor angle stability, transient stability, frequency stability and voltage stability. There are FACTs devices like TCSC & SVC, breaking resistor and fault current limiters may be used to enhance transient stability. Moreover, fast fault clearing and auto reclosing techniques can be designed to enhance power system stability. AVR & PSS with governor helps to damp out oscillation after fault clearance.

Keywords: *power system stability, rotor angle stability, transient stability, voltage stability, frequency stability*

INTRODUCTION

In power system has nonlinear load which is changing continuously and hence output of generator and other important parameters need to change accordingly. Acknowledgment of stability issues is recognized long back in 1920s [1] [2] [3] which were related with remotely operated power plants feeding load centers over long transmission lines [4]. Earlier power transfer capability was often limited by steady-state as well as transient rotor angle instability with slow exciters and noncontinuously acting voltage regulators, due to insufficient synchronizing torque [5].
With increase in population and awareness of ease of usage of electricity for daily life power demand is increases with reliability. From the economically optimum conditions Interconnections were found best option. But with this power system becomes complex and hence it increases stability issues.
Improvements in system stability came about by way of faster fault clearing and fast acting excitation systems. By the implementation of constantly acting voltage regulators Steady-state aperiodic instability was virtually eliminated. Synchronous Machines and excitation systems were needed to be illustrated with more details as stability problems dependency on control parameters increases as stability issues moved from transmission network problem to generator problems.
In the 1960s, most of the power systems in the U.S. and Canada were part of one of two large interconnected systems, one in the east and the other in the west. In 1967, between east and west systems of North America low capacity HVDC ties were developed. The power systems in North America form virtually one large system. There were similar trends in growth of interconnections in other countries.
Interconnections contributes to increased complexity of stability problems and increased occurrence of instability gives better operating economy and increased reliability through mutual assistance, they Public and regulatory agencies, as well as engineers noticed the problem of stability and importance of power system reliability that emphasized after the Northeast Blackout of November 9, 1965 [6].
Powerful transient stability simulation programs have been developed that are capable of modeling large complex systems using detailed device models. With the use of high-speed fault clearing, high-response exciters, series capacitors, and special stability controls and protection schemes significant improvements in transient stability performance of power systems is received.
The concentration on small signal (rotor angle) stability increase as use of high response exciters increases which coupled with lower strengths of transmission systems.
This type of angle instability is for single generator observed as local plant modes of oscillation and for weakly interconnected groups of machines as interarea modes of oscillation. Small signal stability problems have led to the development of special study techniques, such as modal analysis using eigenvalue techniques [7] [8]. Supplementary control of generator excitation systems, static Var compensators, and HVDC converters is being used additionally to solve system oscillation problems.
For damping of power system oscillations, there is use of application of power electronic based controllers referred to as FACTS (Flexible AC Transmission Systems) controllers (IEEE, 1996).
In the 1970s and 1980s, frequency stability problems experienced major system upsets which needed exploration of the causes of this problems and to the development of long term dynamic simulation programs to assist in their analysis [9] [10] [11]. During system upsets major investigations was on the performance of thermal power plants [12] [13] [14]. Guidelines were developed by an IEEE Working Group for enhancing power plant response during major frequency disturbances [15]. CIGRE Task Force report addressed major frequency disturbances analysis and modeling of power systems [16].
Since the late 1970s, several power systems collapses occur due to voltage instability worldwide [18] [19]. Due to large loadings and power transfer over long distances by weak radial distribution systems develops large voltage stability problems. As a result, voltage stability is addressed in system planning and operating studies.

Powerful analytical tools are available for its analysis [20] [21], and well-established criteria and study procedures are evolving.
Power systems are operated under stressed conditions because there is usual trend to have the most of existing facilities. The operation of electric power system with increased competition, open transmission access, and construction and environmental constraints are presents greater challenges for secure system operation. Due to increasing number of major power-grid blackouts like Brazil blackout of March 11, 1999 [22]; Northeast USA-Canada blackout of August 14, 2003[23]; Southern Sweden and Italian blackout of September 28, 2003[24] need Planning and operation of today's power systems with careful consideration of all forms of system instability.
A novel technique for sizing and placement of DG in distribution systems with different loading conditions from minimization of real power loss of the system is proposed. The optimal DG planning gives advantages like reduce real and reactive power loss, reduces power system oscillations, enhance power system stability, such as voltage, frequency and rotor angle stability, enhance power system reliability and security, enhance power system load ability and enhance available power transfer capacity hence system is more flexible. The impact of distributed generation of small size on power system transient stability will be insignificant. Increased penetration level of distributed generation influences the dynamic behavior of the power system as a whole [25] [26].
A microgrid is represented as a combination of different distributed energy resources and various loads. Micro sources have a very little spinning reserve and reactive supports so it is important to perform a detailed transient stability analysis of a microgrid. The aspect of stability in a microgrid relied mostly on the system structure and control technique which varied according to application. The small signal, transient and the voltage stability aspects in each type of the microgrid are discussed along with scope of improvements. Various generalized stability improvement methods are demonstrated for different types of microgrids. The conventional stability study of microgrids facilitates an organized way to plan the micro source operation, microgrid controller design, islanding procedure, frequency control and the load shedding criteria. To prevent microgrid collapse due to a fault in utility grid it is necessary to isolate the microgrid, Islanding of micro generators and load shedding are two most efficient way to control transient instability [27].

POWER SYSTEM STABILITY

By 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.
Wide range of disturbances occurred in power system are like small and large. Small disturbances due to continuous changes in load; the system must be able to adjust to the changing conditions and operate satisfactorily. There are numerous disturbances of extreme type like a short circuit on a transmission line or loss of a large generator. A large disturbance may lead to structural changes due to the isolation of the faulted elements.
It is impossible and uneconomical for all kind of disturbances to design power systems to be stable at an equilibrium set; a power system may be stable for a given (large) physical disturbance, and unstable for another. There is need to select design parameters on the basis of reasonably high probability of occurrence.
Isolation of faulty equipment by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds. The changes in voltage variations will initiate the operation of voltage regulators of generator and transmission network. Prime mover governors actuated with changes in speed of generator; and the voltage and frequency variations will affect the depending on system loads characteristics. For this newly balance parameters protective relay of individual equipment may respond to variations in system variables and cause tripping of the equipment, thereby weakening the system and possibly leading to system instability.
The classification of power system stability proposed here is based on the following considerations [17]:

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

CLASSIFICATION OF POWER SYSTEM STABILITY

Fig. 1 gives complete information of the power system stability problem [28]. The following are descriptions of the corresponding forms of stability phenomena.

A. ROTOR ANGLE STABILITY

"It is the ability of the system to remain in synchronism when subjected to a disturbance".
The balance between the electromagnetic torque due to the generator electrical power output and mechanical torque due to the input mechanical power through a prime mover is key factor for the rotor angle of a generator. For Generators to remains in synchronism electromagnetic torque is exactly equal to the mechanical torque in the opposite direction. Due to disturbances in the system, the balance between electromagnetic and mechanical torque is upset in a generator, this will lead to oscillations in the rotor angle. Rotor angle stability is further classified into small disturbance angle stability and large disturbance angle stability or transient stability.

I. **Small-disturbance stability**: "It is the ability of the system to remain in synchronism when subjected to small disturbances". For small size disturbance nonlinear power system can be approximated by a linear system, then the study of rotor angle stability of that particular system is called as small-disturbance angle stability analysis. Small disturbances includes small variations in load like switching on or off of small loads, line tripping, small generators tripping etc. Small disturbances instability can be further categorized by non-oscillatory instability and oscillatory instability. In non-oscillatory instability the rotor angle of a generator keeps on increasing due to a small disturbance and in case of oscillatory instability the rotor angle oscillates with increasing magnitude.

II. **Large-disturbance or transient stability**: "It is the ability of the system to remain in synchronism when subjected to large disturbances". Large disturbances may include faults, switching on or off of large loads, large generators tripping etc. When large disturbance occurs in a power system, results in large changes rotor angles of generator and power system cannot be calculated by a linear representation like in the case of small-disturbance stability. Large-disturbance and small-disturbance angle stability is range between 0.1- 10s on time frame. In some literature "dynamic stability" is used in place of transient stability, according to IEEE task force committee report, only transient stability has to be used.

Fig. 2 shows the graphical representation of change in rotor angle with time.

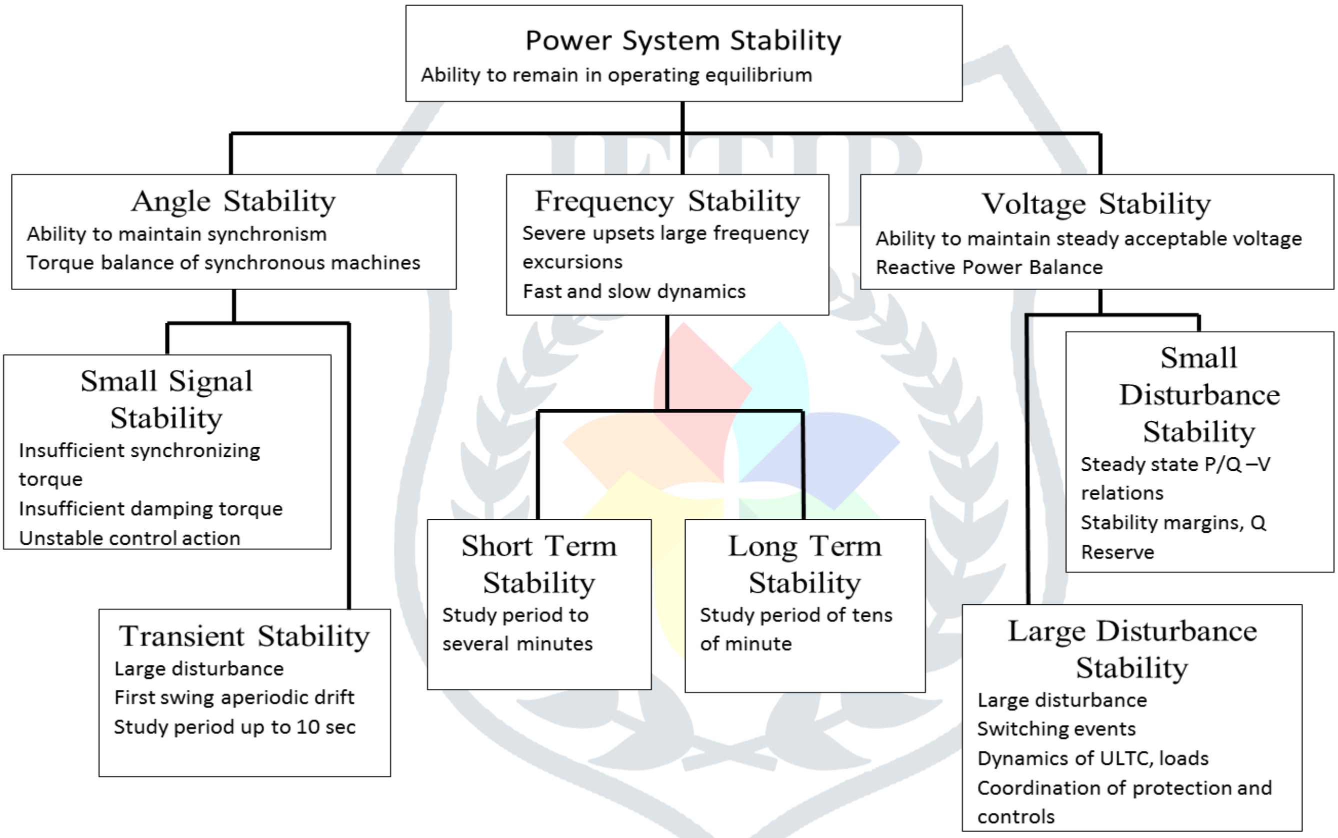

Fig. 1: Classification of Power System Stability

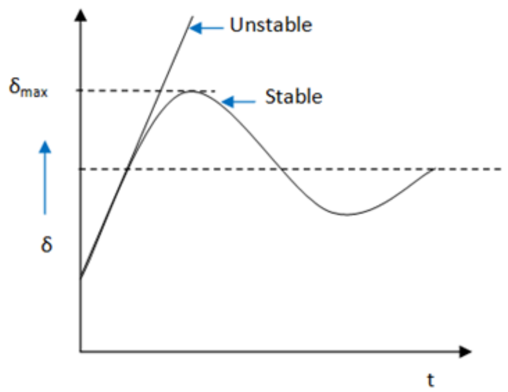

Fig. 2: Relationship between Rotor Angle Verses Time

If $\frac{d\delta}{dt} = 0$, after some time system remains stable, $\frac{d\delta}{dt} > 0$, for longer time system becomes unstable.

B. VOLTAGE STABILITY

"It is the ability of the system to maintain steady state voltages at all the system buses when subjected to a disturbance. If the disturbance is large then it is called as large-disturbance voltage stability and if the disturbance is small it is called as small-disturbance voltage stability".

Due to fast acting devices like induction motors, power electronic drive, HVDC etc voltage fluctuations may occur then the time frame is in the range of 10-20 s and hence can be treated as short term phenomenon. Due to slow change in load, over loading of lines, generators hitting reactive power limits, tap changing transformers etc may possible that voltage varies for time frame from 1 minute to several minutes for voltage stability. Voltage stability and angle stability differs mainly that the unbalance of reactive power demand and generation in the system cause voltage stability whereas unbalance between real power generation and demand cause angle stability.

C. FREQUENCY STABILITY

"It refers to the ability of a power system to maintain steady frequency following a severe disturbance between generation and load".

It depends on the ability to restore equilibrium between system generation and load, with minimum loss of load. Due to frequency instability the sustained frequency swings leads to tripping of connected generators or loads. During frequency excursions, the characteristic times of the processes and devices that are activated will range from fraction of seconds like under frequency control to several minutes, like the response prime mover. Frequency stability may be a short-term phenomenon or a long-term phenomenon.

In spite of classification of stability into rotor angle, voltage and frequency stability it may not be occur individually or isolated events. Large excursions in rotor angle and frequency may occur due to a voltage collapse. Similarly, large changes in frequency may lead to large variation in magnitude of voltage. Each component of the power system i.e. prime mover, generator rotor, generator stator, transformers, transmission lines, load, controlling devices and protection systems should be mathematically modeled to calculate the rotor angle, voltage and frequency stability through appropriate analysis tools. To analyse system stability whole power system described with set of Differential Algebraic Equations (DAE).

METHODS TO ENHANCE POWER SYSTEM STABILITY

Power system stability can be categorized broadly by transient stability and small signal stability. Following are the list of possible methods used to improve transient stability and small signal stability [29].

1. After clearing the fault, there is need have to increase post fault synchronizing power transfers. To increase post fault synchronizing power, there is a need to reduce transfer reactance of transmission line [30]. To Reduce Transfer reactance of transmission line by using FACTS device like Thyristor Controlled Series Capacitor [31] [32].
2. After removing the faulty line, would cause additional loading on the remaining adjacent lines. There is considerable reduction in terminal voltage at load centers due to extra reactive power demand. By providing reactive power compensation in the line able to maintain terminal voltage and to supply reactive power demand. [33] To enhance power transfer and rapid bus voltage control during low voltage condition like during faults by using SVCs. Provide Shunt compensation to inject reactive power and control the terminal voltage. SVC can be used as shunt compensating device which also helps to the damping the system oscillation.
3. During large disturbance, the load on the line is removed. Hence there is large amount of accelerating power available which increases the rotor speed and rotor angle. There is need to reduce this large accelerating power available due to removal of loaded line by providing some artificial load for the few seconds [34]. To use shunt resistors to providing dynamic braking by switching in for few seconds such as fault clearing time (approx. 0.5 sec) with first power swing. Shunt resistors or braking resistors reduces the accelerating power of nearby generators and remove the kinetic energy gained during the fault [35].
4. There is need to remove faulty line from the power system as fast as possible. So that there is less accelerating power gained by the rotor. The total fault clearing time is summation of time required for relay time and breaker interrupting time. Careful study needed to design protective scheme. With autoreclosure facility as most of fault occurred in transmission line are of transient nature. Need to design fast fault clearing & Auto Reclosing methods for power system with added TCSC to enhance the transient stability [36].
5. There is required to develop fast restoring of synchronization forces after removal of faulty line so that healthy grid receives power and fault will not be developing contingency in other healthy line. By rapid increase in field excitation it is possible to increase internal voltage of generator and synchronising power also increases. Automatic Voltage Regulator used to increase the field excitation voltage and in turn increase the terminal voltage. Fast excitation often leads to reduce damping power of the generator. Supplementary excitation controller Power System Stabilizer (PSS) is provides easy way of damping system oscillation [37].

CONCLUSIONS

This paper gives historical progress on concepts of power system stability. Three main types of stability like rotor angle stability, Voltage stability and Frequency stability definition and characteristics are discussed. Newly developed techniques FACTs devices like TCSC and SVC are discussed for enhancement to power system stability.

In conjunction with FACTs devices, other techniques like breaker resistor with fault current limiter can be used. Automatic voltage regulator with power system stabilizer is help to improve transient stability.

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