Power System Dynamics

Hamdi Abdi

Electrical Engineering Department, Razi University

A. Syllabus

1. General Background
2. Introduction to The Power System Stability Problem
3. Power System Loads
4. Excitation Systems
5. Prime Mover And Energy Supply Systems
6. Small-Signal Stability

B. Objectives

- Understand basic aspects of power-system stability with focus on:
  - Electromechanical dynamics.
  - Transient and long term stability.
  - Voltage stability issues.
- Obtain a feel for:
  - Stability analysis
  - Interpretation of results

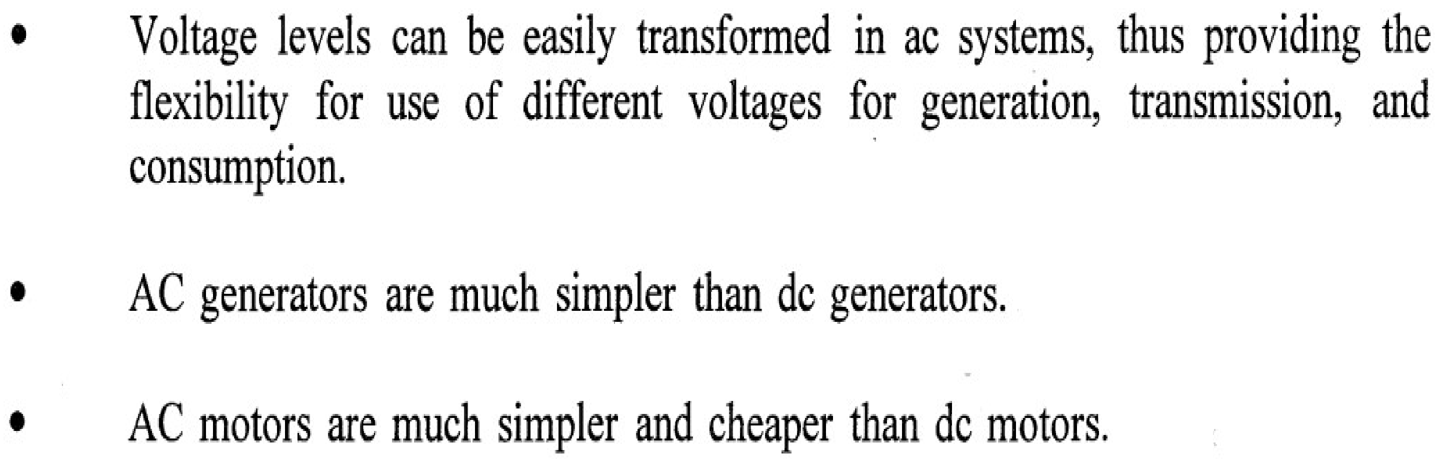
C. References

1. **Power System Stability and Control, P. Kundur, McGraw Hill, 1994.**
2. Operation and Control in power systems, P.S.R. Murty, BSP, 2004
3. Power System Dynamics, Stability and Control, K. R. Padiyar, BSP, 2008
4. Power System Dynamics and Stability, P. W. Sauer, M. A. Pai, Prentice Hall, 1998.
5. Power System Dynamics and Stability, Jan Machowski, Janusz W. Bialek, James R. Bumby, John Willey and sons, 1997.
6. POWER SYSTEM STABILITY and CONTROL, Leonard L. Grigsby, CRC Press, 2007.
7. Power System Control and Stability, P. M. Anderson, A. A. Fouad, IEEE, 2003.

1. General Background

1.1 History

- The commercial use of electricity began in the late 1870s (Arc Lamps).
- First complete electric power system (GTD), 1882, Thomas Edison. (Lighting System)
- Adding Motor Loads to system, 1884
- Adding Transformers to System, 1886, William Stanly.
- The First AC Transmission Line, 1889, North America,
- Dc or AC

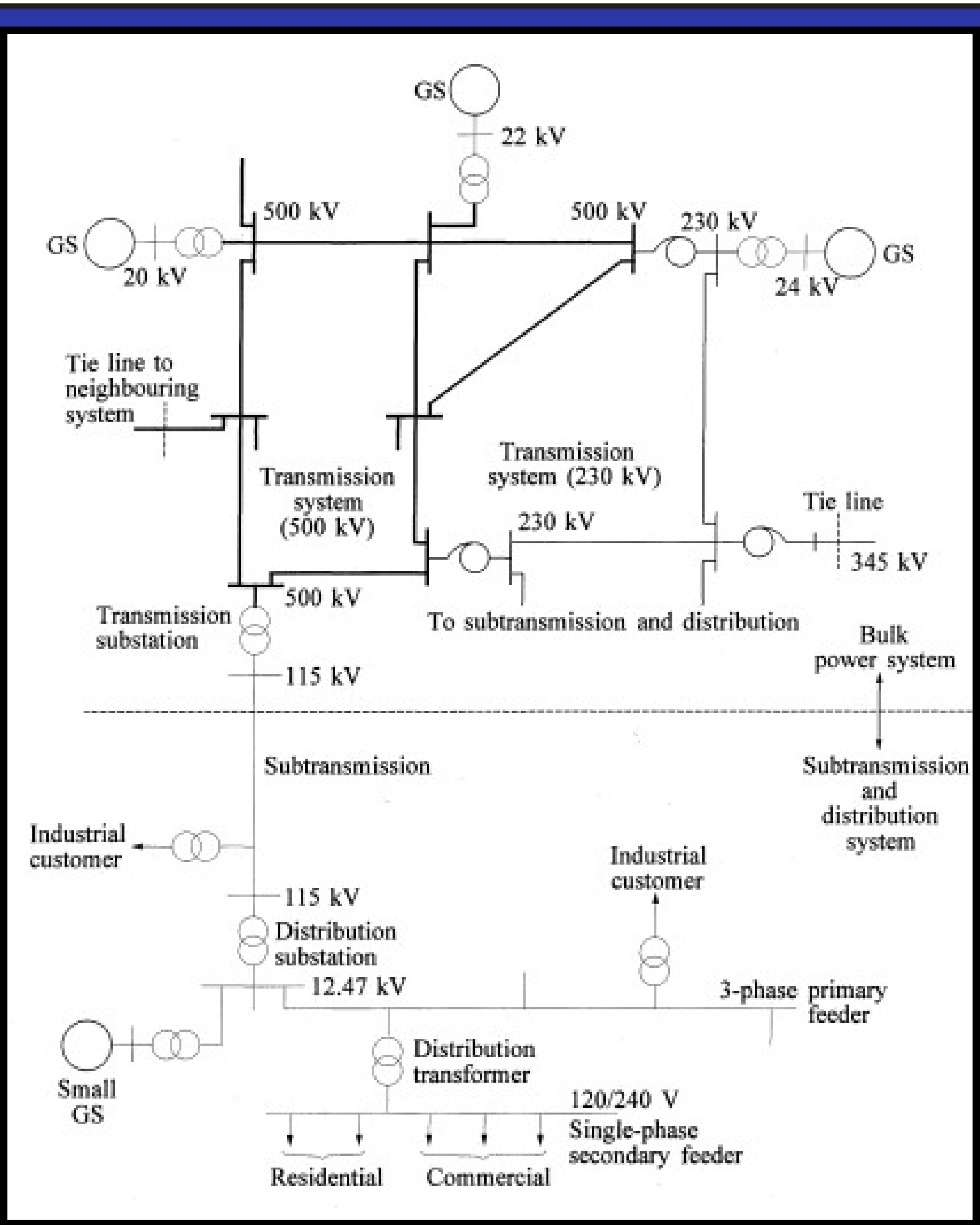


  - Voltage levels can be easily transformed in ac systems, thus providing the flexibility for use of different voltages for generation, transmission, and consumption.
  - AC generators are much simpler than dc generators.
  - AC motors are much simpler and cheaper than dc motors.

- First Three Phase system, 1893, North America
- Various Frequencies, 25, 50, 60, 125, 133 Hz, 50, 60 HZ.
- AC Voltage Levels, LV, MV, HV(115-230 kV) , EHV (345-765 kV)
- HVDC, 1972, Canada.

1.2 Structure

- Are comprised of three-phase ac systems operating essentially at constant voltage. Generation and transmission facilities use three-phase equipment. Industrial loads are invariably three-phase; single-phase residential and commercial loads are distributed equally among the phases so as to effectively form a balanced three-phase system.
- Use synchronous machines for generation of electricity. Prime movers convert the primary sources of energy (fossil, nuclear, and hydraulic) to mechanical energy that is, in turn, converted to electrical energy by synchronous generators.
- Transmit power over significant distances to consumers spread over a wide area. This requires a transmission system comprising subsystems operating at different voltage levels.


GS
22 kV
500 kV
500 kV
230 kV
GS
20 kV
GS
24 kV
Tie line to neighbouring system
Transmission system (500 kV)
Transmission system (230 kV)
230 kV
Tie line
345 kV
500 kV
Transmission substation
To subtransmission and distribution
Bulk power system
115 kV
Subtransmission
Subtransmission and distribution system
Industrial customer
Industrial customer
115 kV
Distribution substation
12.47 kV
3-phase primary feeder
Small GS
Distribution transformer
120/240 V
Single-phase secondary feeder
Residential
Commercial

1.3 Power System Control

1. The system must be able to meet the continually changing load demand for active and reactive power. Unlike other types of energy, electricity cannot be conveniently stored in sufficient quantities. Therefore, adequate "spinning" reserve of active and reactive power should be maintained and appropriately controlled at all times.

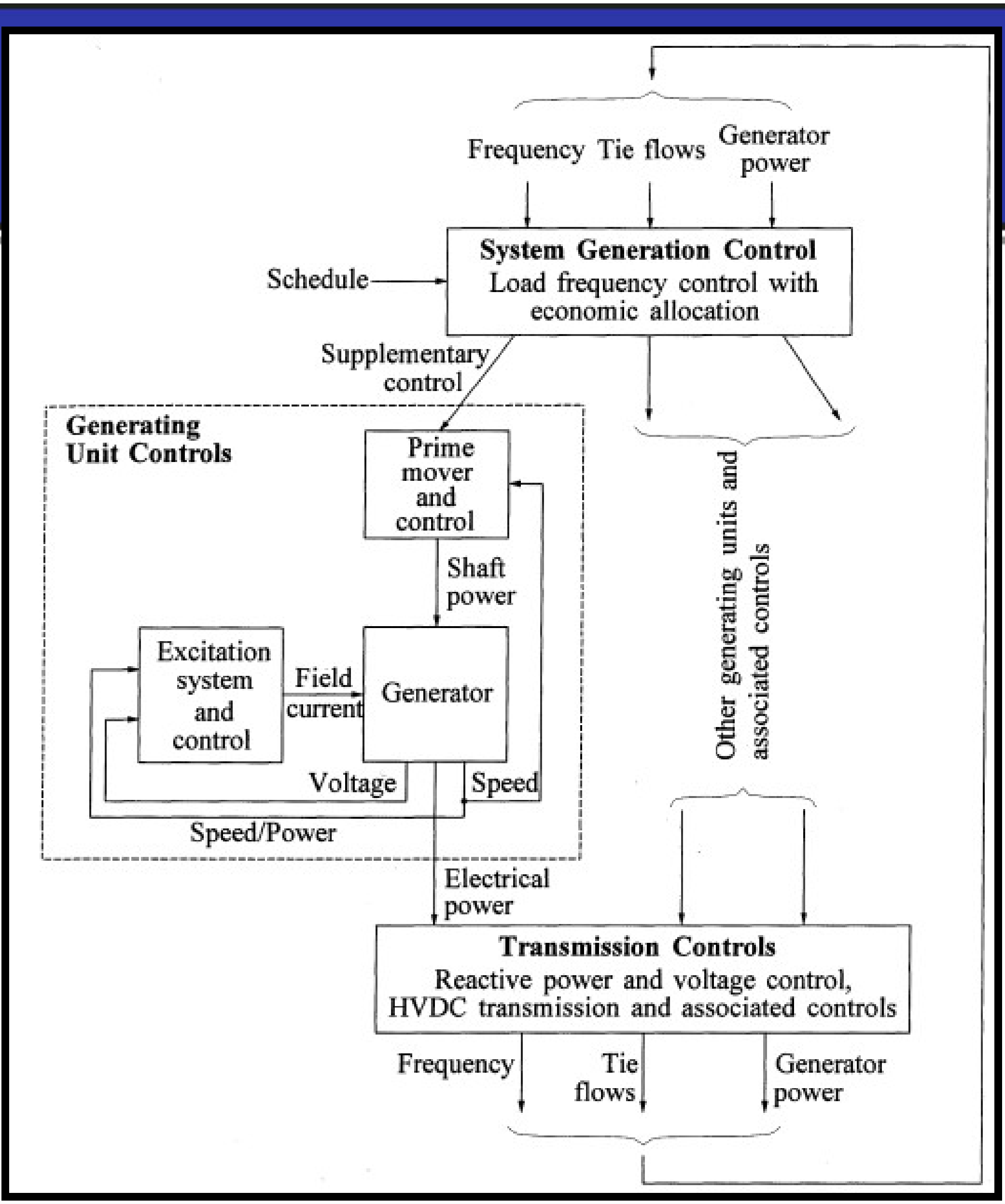
2. The system should supply energy at minimum cost and with minimum ecological impact.

3. The "quality" of power supply must meet certain minimum standards with regard to the following factors:

   (a) constancy of frequency;

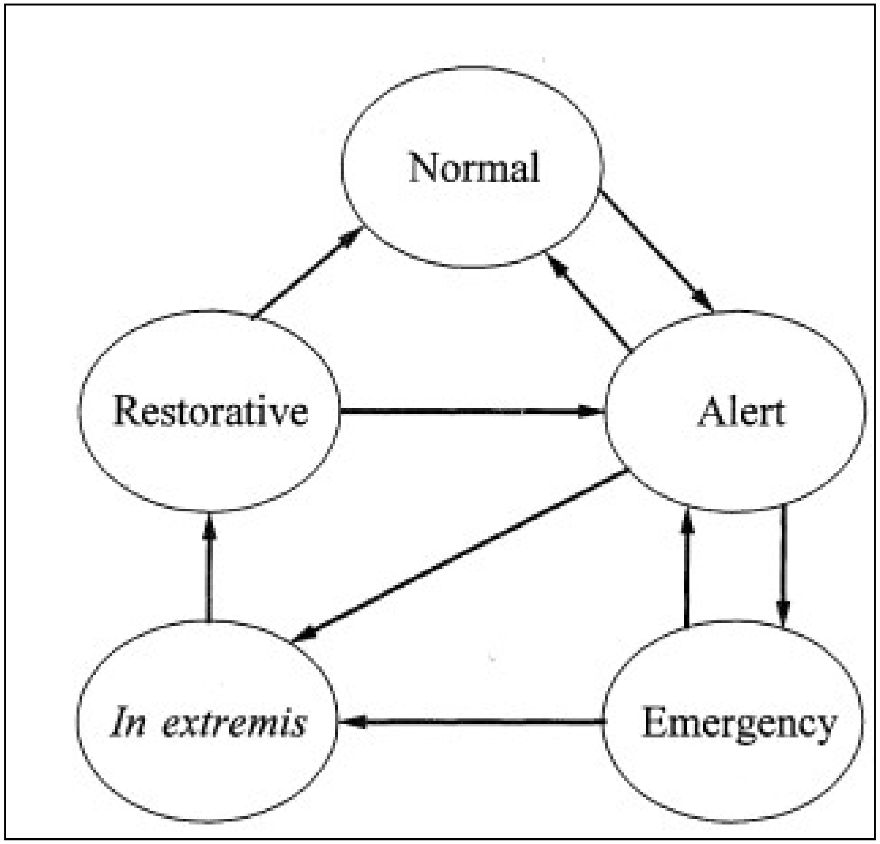
   (b) constancy of voltage; and

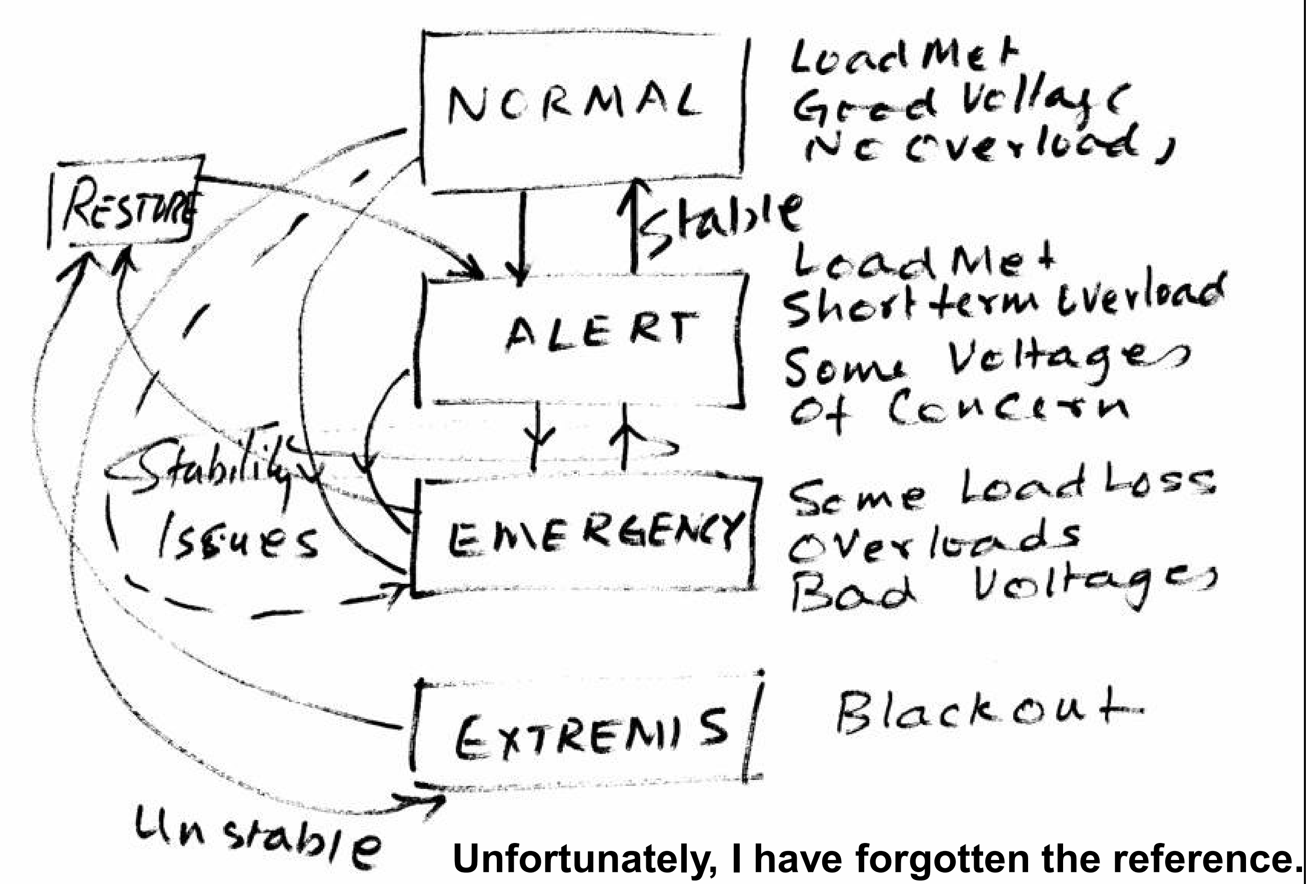
   (c) level of reliability.


Frequency
Tie flows
Generator power
Schedule
System Generation Control
Load frequency control with economic allocation
Supplementary control
Generating Unit Controls
Prime mover and control
Shaft power
Excitation system and control
Field current
Generator
Voltage
Speed
Speed/Power
Electrical power
Other generating units and associated controls
Transmission Controls
Reactive power and voltage control, HVDC transmission and associated controls
Frequency
Tie flows
Generator power

1.4 Operating States of a Power System and Control Strategies

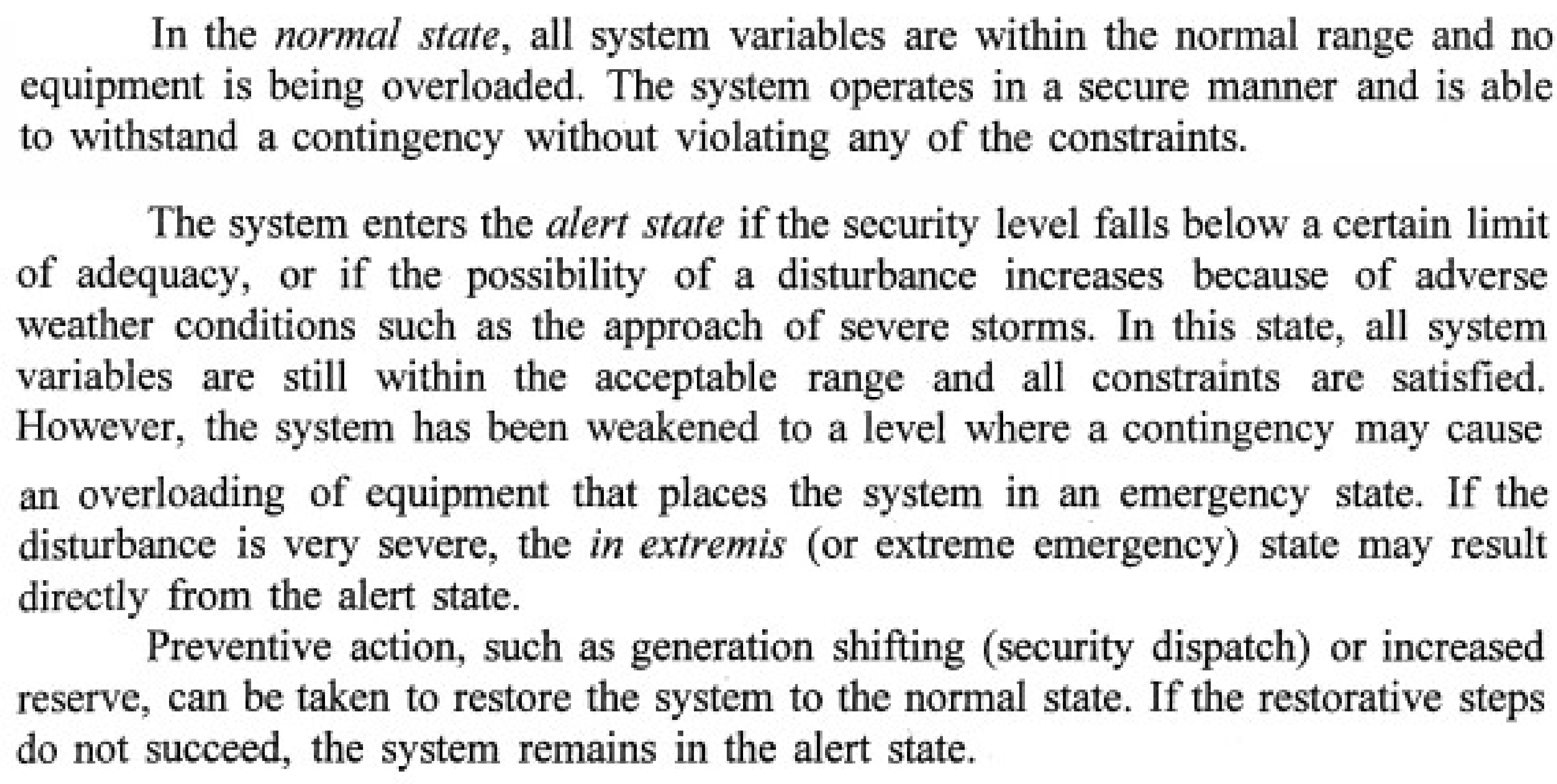
1. Normal
2. Alert
3. Emergency
4. In-Extremis
5. Restorative





Unfortunately, I have forgotten the reference. Thanks the author.

Description



In the *normal state*, all system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any of the constraints.

The system enters the *alert state* if the security level falls below a certain limit of adequacy, or if the possibility of a disturbance increases because of adverse weather conditions such as the approach of severe storms. In this state, all system variables are still within the acceptable range and all constraints are satisfied. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that places the system in an emergency state. If the disturbance is very severe, the *in extremis* (or extreme emergency) state may result directly from the alert state.

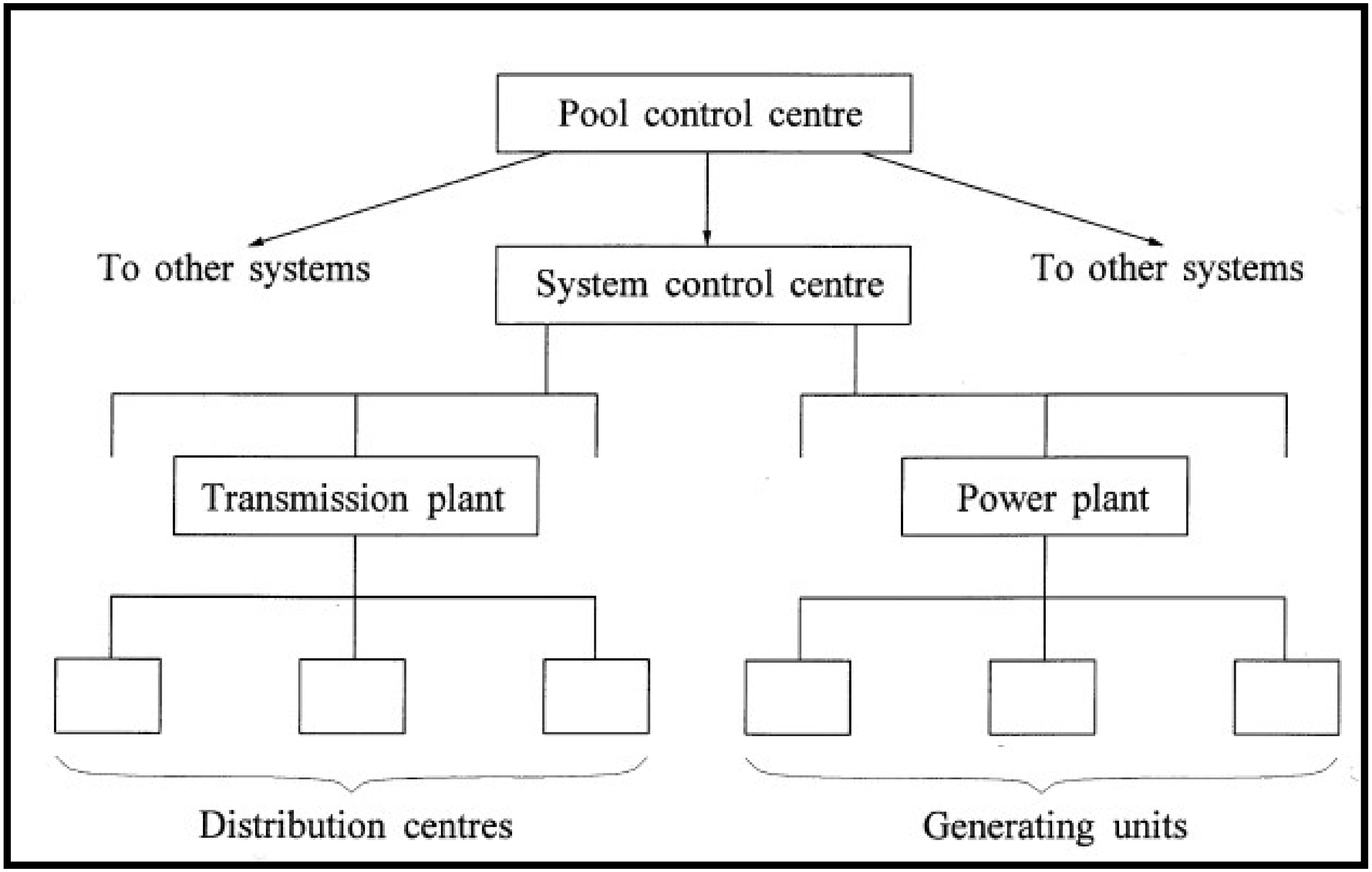
Preventive action, such as generation shifting (security dispatch) or increased reserve, can be taken to restore the system to the normal state. If the restorative steps do not succeed, the system remains in the alert state.

The system enters the *emergency state* if a sufficiently severe disturbance occurs when the system is in the alert state. In this state, voltages at many buses are low and/or equipment loadings exceed short-term emergency ratings. The system is still intact and may be restored to the alert state by the initiating of emergency control actions: fault clearing, excitation control, fast-valving, generation tripping, generation run-back, HVDC modulation, and load curtailment.

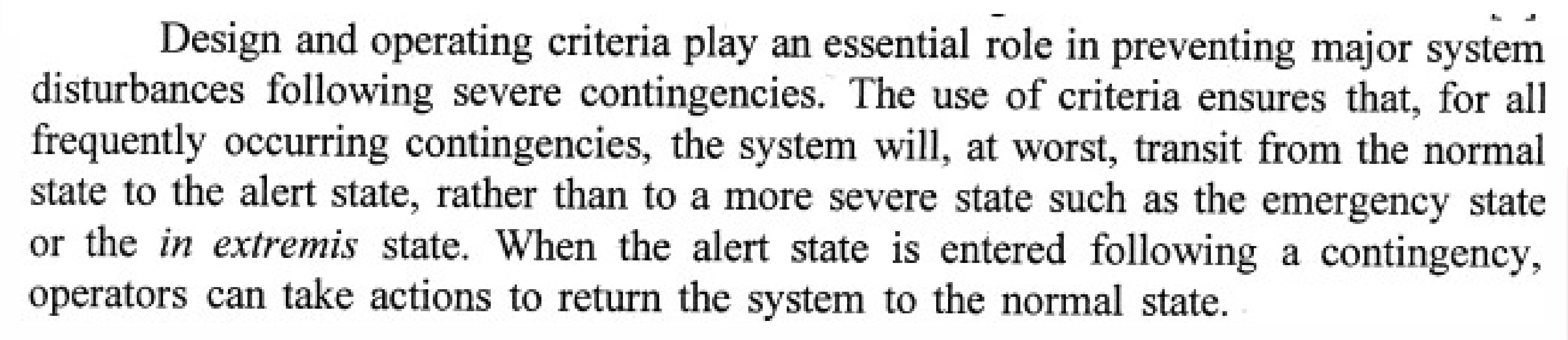
If the above measures are not applied or are ineffective, the system is *in extremis*; the result is cascading outages and possibly a shut-down of a major portion of the system. Control actions, such as load shedding and controlled system separation, are aimed at saving as much of the system as possible from a widespread blackout.

The *restorative state* represents a condition in which control action is being taken to reconnect all the facilities and to restore system load. The system transits from this state to either the alert state or the normal state, depending on the system conditions.

1.5 Power System Control Hierarchy



1.6 Design and Operating Criteria for stability



Design and operating criteria play an essential role in preventing major system disturbances following severe contingencies. The use of criteria ensures that, for all frequently occurring contingencies, the system will, at worst, transit from the normal state to the alert state, rather than to a more severe state such as the emergency state or the *in extremis* state. When the alert state is entered following a contingency, operators can take actions to return the system to the normal state.

A. Normal Design Contingencies

(a) A permanent three-phase fault on any generator, transmission circuit, transformer or bus section, with normal fault clearing and with due regard to reclosing facilities.

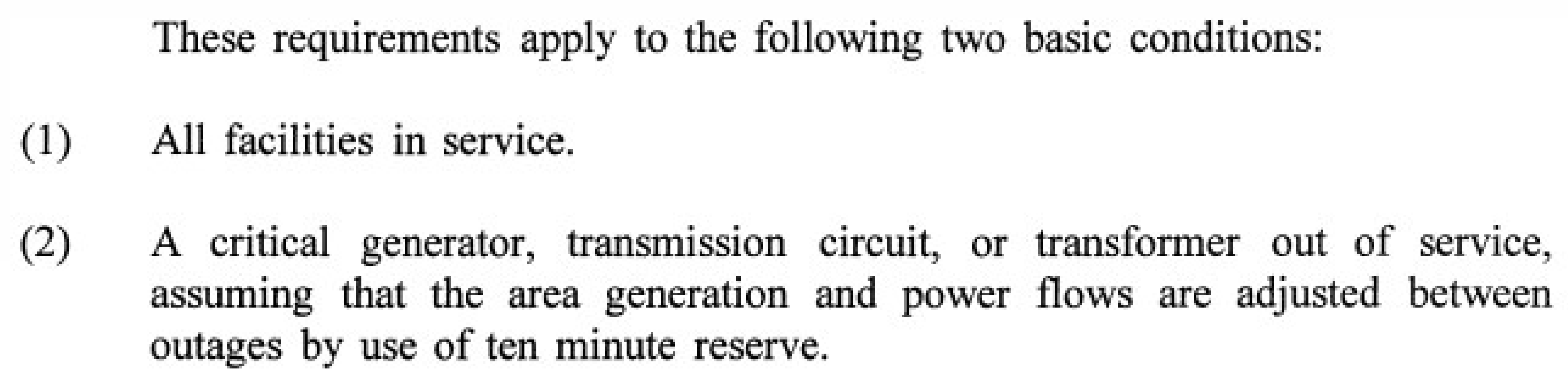
(b) Simultaneous permanent phase-to-ground faults on different phases of each of two adjacent transmission circuits on a multiple-circuit tower, cleared in normal time.

(c) A permanent phase-to-ground fault on any transmission circuit, transformer, or bus section with delayed clearing because of malfunction of circuit breakers, relay, or signal channel.

(d) Loss of any element without a fault.

(e) A permanent phase-to-ground fault on a circuit breaker, cleared in normal time.

(f) Simultaneous permanent loss of both poles of a dc bipolar facility.



These requirements apply to the following two basic conditions:

(1) All facilities in service.

(2) A critical generator, transmission circuit, or transformer out of service, assuming that the area generation and power flows are adjusted between outages by use of ten minute reserve.

B. Extreme Contingency Assessment

(a) Loss of the entire capability of a generating station.

(b) Loss of all lines emanating from a generating station, switching station or substation.

(c) Loss of all transmission circuits on a common right-of-way.

(d) A permanent three-phase fault on any generator, transmission circuit, transformer, or bus section, with delayed fault clearing and with due regard to reclosing facilities.

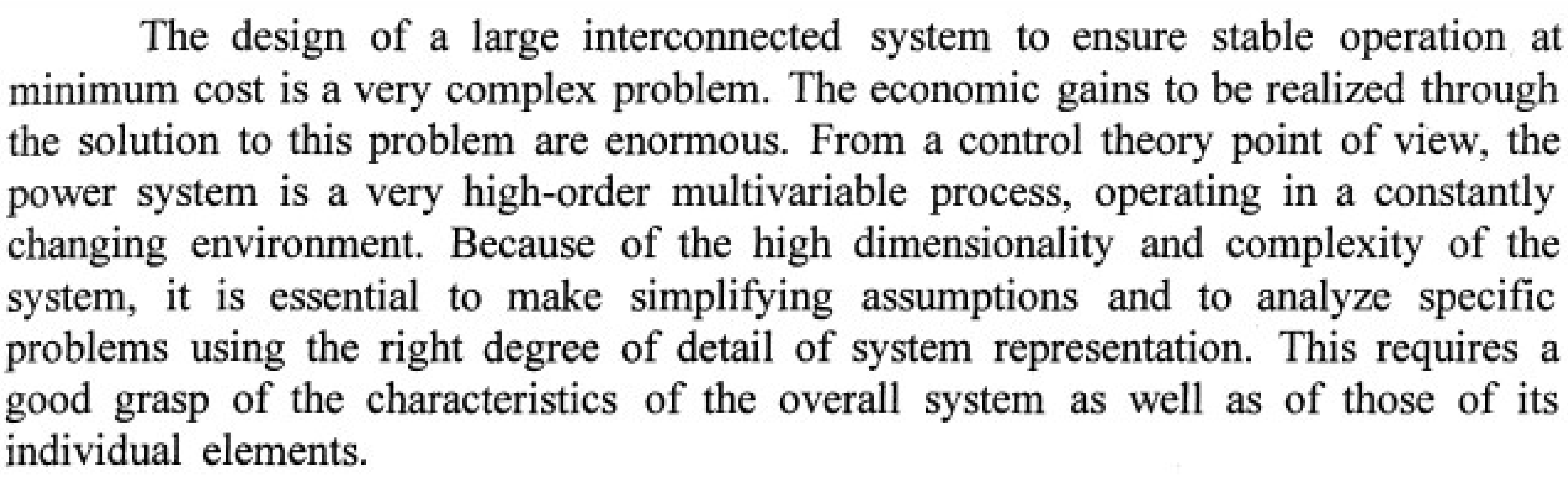
(e) The sudden dropping of a large-load or major-load centre.

(f) The effect of severe power swings arising from disturbances outside the NPCC interconnected systems.

Northeast Power Coordinating Council

(g) Failure or misoperation of a special protection system, such as a generation rejection, load rejection, or transmission cross-tripping scheme.

1.7 System Design for Stability



The design of a large interconnected system to ensure stable operation at minimum cost is a very complex problem. The economic gains to be realized through the solution to this problem are enormous. From a control theory point of view, the power system is a very high-order multivariable process, operating in a constantly changing environment. Because of the high dimensionality and complexity of the system, it is essential to make simplifying assumptions and to analyze specific problems using the right degree of detail of system representation. This requires a good grasp of the characteristics of the overall system as well as of those of its individual elements.