Definition and Classification of Power System Stability

IEEE/CIGRE Joint Task Force on Stability Terms and Definitions

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***Abstract*—The problem of defining and classifying power system stability has been addressed by several previous CIGRE and IEEE Task Force reports. These earlier efforts, however, do not completely reflect current industry needs, experiences and understanding. In particular, the definitions are not precise and the classifications do not encompass all practical instability scenarios.**

This report developed by a Task Force, set up jointly by the CIGRE Study Committee 38 and the IEEE Power System Dynamic Performance Committee, addresses the issue of stability definition and classification in power systems from a fundamental viewpoint and closely examines the practical ramifications. The report aims to define power system stability more precisely, provide a systematic basis for its classification, and discuss linkages to related issues such as power system reliability and security.

***Index Terms*—Frequency stability, Lyapunov stability, oscillatory stability, power system stability, small-signal stability, terms and definitions, transient stability, voltage stability.**

I. Introduction

POWER system stability has been recognized as an important problem for secure system operation since the 1920s [1], [2]. Many major blackouts caused by power system instability have illustrated the importance of this phenomenon [3]. Historically, 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 interarea 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.

The problem of defining and classifying power system stability is an old one, and there have been several previous reports on the subject by CIGRE and IEEE Task Forces [4]–[7]. These, however, do not completely reflect current industry needs, experiences, and understanding. In particular, definitions are not precise and the classifications do not encompass all practical instability scenarios.

This report is the result of long deliberations of the Task Force set up jointly by the CIGRE Study Committee 38 and the IEEE Power System Dynamic Performance Committee. Our objectives are to:

- Define power system stability more precisely, inclusive of all forms.
- Provide a systematic basis for classifying power system stability, identifying and defining different categories, and providing a broad picture of the phenomena.
- Discuss linkages to related issues such as power system reliability and security.

Power system stability is similar to the stability of any dynamic system, and has fundamental mathematical underpinnings. Precise definitions of stability can be found in the literature dealing with the rigorous mathematical theory of stability of dynamic systems. Our intent here is to provide a physically motivated definition of power system stability which in broad terms conforms to precise mathematical definitions.

The report is organized as follows. In Section II the definition of Power System Stability is provided. A detailed discussion and elaboration of the definition are presented. The conformance of this definition with the system theoretic definitions is established. Section III provides a detailed classification of power system stability. In Section IV of the report the relationship between the concepts of power system reliability, security, and stability is discussed. A description of how these terms have been defined and used in practice is also provided. Finally, in Section V definitions and concepts of stability from mathematics and control theory are reviewed to provide background information concerning stability of dynamic systems in general and to establish theoretical connections.

The analytical definitions presented in Section V constitute a key aspect of the report. They provide the mathematical underpinnings and bases for the definitions provided in the earlier sections. These details are provided at the end of the report so that interested readers can examine the finer points and assimilate the mathematical rigor.

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II. Definition of Power System Stability

In this section, we provide a formal definition of power system stability. The intent is to provide a physically based definition which, while conforming to definitions from system theory, is easily understood and readily applied by power system engineering practitioners.

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.*

B. Discussion and Elaboration

The definition applies to an interconnected power system as a whole. Often, however, the stability of a particular generator or group of generators is also of interest. A remote generator may lose *stability* (synchronism) without cascading instability of the main system. Similarly, stability of particular loads or load areas may be of interest; motors may lose *stability* (run down and stall) without cascading instability of the main system.

The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs and key operating parameters change continually. When subjected to a disturbance, the stability of the system depends on the initial operating condition as well as the nature of the disturbance.

Stability of an electric power system is thus a property of the system motion around an equilibrium set, i.e., the initial operating condition. In an equilibrium set, the various opposing forces that exist in the system are equal instantaneously (as in the case of equilibrium points) or over a cycle (as in the case of slow cyclical variations due to continuous small fluctuations in loads or aperiodic attractors).

Power systems are subjected to a wide range of disturbances, small and large. Small disturbances in the form of load changes occur continually; the system must be able to adjust to the changing conditions and operate satisfactorily. It must also be able to survive numerous disturbances of a severe nature, such as 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.

At an equilibrium set, a power system may be stable for a given (large) physical disturbance, and unstable for another. It is impractical and uneconomical to design power systems to be stable for every possible disturbance. The design contingencies are selected on the basis they have a reasonably high probability of occurrence. Hence, large-disturbance stability always refers to a specified disturbance scenario. A stable equilibrium set thus has a finite region of attraction; the larger the region, the more robust the system with respect to large disturbances. The region of attraction changes with the operating condition of the power system.

The response of the power system to a disturbance may involve much of the equipment. For instance, a fault on a critical element followed by its isolation by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds; the voltage variations will actuate both generator and transmission network voltage regulators; the generator speed variations will actuate prime mover governors; and the voltage and frequency variations will affect the system loads to varying degrees depending on their individual characteristics. Further, devices used to protect 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.

If following a disturbance the power system is stable, it will reach a new equilibrium state with the system integrity preserved i.e., with practically all generators and loads connected through a single contiguous transmission system. Some generators and loads may be disconnected by the isolation of faulted elements or intentional tripping to preserve the continuity of operation of bulk of the system. Interconnected systems, for certain severe disturbances, may also be intentionally split into two or more "islands" to preserve as much of the generation and load as possible. The actions of automatic controls and possibly human operators will eventually restore the system to normal state. On the other hand, if the system is unstable, it will result in a run-away or run-down situation; for example, a progressive increase in angular separation of generator rotors, or a progressive decrease in bus voltages. An unstable system condition could lead to cascading outages and a shutdown of a major portion of the power system.

Power systems are continually experiencing fluctuations of small magnitudes. However, for assessing stability when subjected to a specified disturbance, it is usually valid to assume that the system is initially in a true steady-state operating condition.

C. Conformance With System—Theoretic Definitions

In Section II-A, we have formulated the definition by considering a given operating condition and the system being subjected to a physical disturbance. Under these conditions we require the system to either regain a new state of operating equilibrium or return to the original operating condition (if no topological changes occurred in the system). These requirements are directly correlated to the system-theoretic definition of asymptotic stability given in Section V-C-I. It should be recognized here that this definition requires the equilibrium to be (a) stable in the sense of Lyapunov, i.e., all initial conditions starting in a small spherical neighborhood of radius δ result in the system trajectory remaining in a cylinder of radius ε for all time $t \geq t_0$, the initial time which corresponds to all of the system state variables being bounded, and (b) at time $t \rightarrow \infty$ the system trajectory approaches the equilibrium point which corresponds to the equilibrium point being attractive. As a result, one observes that the analytical definition directly correlates to the expected behavior in a physical system.

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. Sta-