Concepts of Synchronous Machine Stability as Affected by Excitation Control

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Abstract—**The phenomena of stability of synchronous machines under small perturbations is explored by examining the case of a single machine connected to an infinite bus through external reactance.**

The analysis develops insights into effects of thyristor-type excitation systems and establishes understanding of the stabilizing requirements for such systems. These stabilizing requirements include the voltage regulator gain parameters as well as the transfer function characteristics for a machine speed derived signal superposed on the voltage regulator reference for providing damping of machine oscillations.

Introduction

THE PHENOMENON of stability of synchronous machine operation has received a great deal of attention in the past and will receive increasing attention in the future. As economies in system design are achieved with larger unit sizes and higher per unit reactance generating and transmission equipment designs, more emphasis and reliance is being placed on controls to provide the required compensating effects with which to offset the reductions in stability margins inherent from these trends in equipment design [1].

Concurrent with these trends are improvements in calculating methods and computing capability which permit predicting complex dynamic effects [2]–[5], providing the means for designing control equipment with the proper characteristics.

Among several aspects of stability of synchronous machine operation, an important one is the mode of small perturbation stability referred to as steady-state, dynamic or conditional stability. Increasing attention has been focused recently on the effects of excitation control on the damping of oscillations which characterize the phenomena of stability. In particular, it has been found useful and practical to incorporate transient stabilizing signals derived from speed, terminal frequency, or power [6], [7] superposed on the normal voltage error signal of voltage regulators to provide for additional damping to these oscillations.

This paper deals with an analysis of the phenomena of stability of synchronous machines under small perturbations by examining the case of a single machine connected to a large system through external impedance. The object of this analysis is to develop insights into effects of excitation systems and to establish an understanding of the stabilizing requirements for such systems. By examining a wide range of system and machine parameters and probing into causes and effects, a logical set of guide rules and concepts is developed to explain the nature of the problem and to arrive at a set of recommendations for stabilizing through excitation control. In order to limit the scope of this paper, the excitation system investigated is one which could be characterized by a small time constant of between 0.03 and 0.05 second which is typical of thyristor-type systems.

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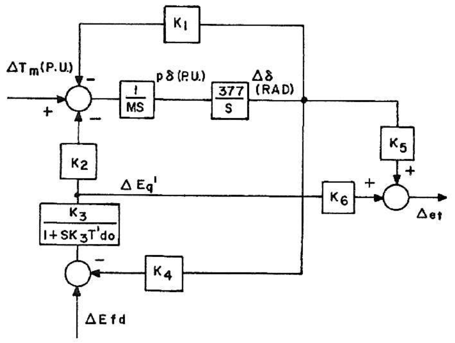

Fig. 1. Linearized small perturbation relations of a single generator supplying an infinite bus through external impedance.

The method of analysis of course can easily be extended to excitation systems with different dynamic characteristics. It is believed that from this analysis covering a wide range of conditions for the single machine case, one can project recommendations for stabilizing machines in multimachine systems.

Dynamics of a Single Machine Connected to a Large System—Fundamental Concepts

Block Diagram Relations

The phenomena of stability and damping of synchronous machines for the mode of small perturbations can be examined with the aid of block diagrams relating the pertinent variables of electrical torque, speed, angle, terminal voltage, field voltage, and flux linkages. The relations in the block diagrams discussed in this paper apply to a 2-axis machine representation with a field circuit in the direct axis but without amortisseur effects. Although a more rigorous representation should include amortisseur or solid iron eddy current effects in both axes, this simpler representation is sufficient to establish the basic effects and develop concepts.

The basic phenomenon in question is the stability of the torque-angle loop, i.e., the behavior of the rotor angle and speed following a small disturbance such as a mechanical torque disturbance. Although the whole subject can be and has been explored by various stability analysis techniques such as Routh's criterion [8], eigenvalue analyses [4], etc., considerable value is found in analyzing the phenomena in the light of elementary servomechanism and frequency response theory, thereby developing an insight into the basic elements that cause various effects.

We will attempt to relate the familiar concepts of small perturbation stability of a single machine supplying an infinite bus through external impedance to the elements and relations shown in Fig. 1. These relations and block diagram have been treated previously in [9]. The parameters in these relations are listed in the Appendix. They are derived by small perturbation