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Small Signal Stability of a Power System

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Abstract ***: Power system (PS) stability is a major concern for an electrical power system (PS) in the past decades. Small signal stability (SSS) is a class of stability of the power system (PS) determined by eigenvalue analysis. The dynamic performance of the linearized power system (PS) model is determined by small signal stability (SSS) analysis by calculation of eigenvalues and eigenvectors of the state matrix. For satisfactory operation of a power system (PS), all modes, i.e. all eigenvalues, must be stable in a power system (PS). Small signal stability (SSS) is a key necessity for power system (PS) to operate successfully. The main objective of this study is to verify the sufficient damping of all modes associated with a system such that transfer of power takes place successfully. Small signal stability (SSS) analysis is performed on the power system (PS) models in MATLAB 7.8.0 with PSAT version 2.1.9 in this paper.***

Keywords: Eigenvalue, Inter-area, Power system (PS), Small-signal-stability (SSS).

I. INTRODUCTION

Stability of the power system (PS) is the power systems ability to stay in a state of operating equilibrium under the normal operating condition and recover an acceptable state of equilibrium subject to disturbance. The ability of the power system (PS) to maintain synchronism under small disturbance is small signal stability (SSS) a class of power system stability.

In general, such disturbances are due to small changes in load and generation within the system [1]. A disturbance in this regard is considered small if the equations describing the resulting system response for analysis can be linearised. The resulting instability can have two types:

(i) Steady increase in rotor angles of the generator due to insufficient synchronizing torque. (ii) Increased amplitude rotor oscillations due to insufficient damping torque. Small signal stability (SSS) is mainly an issue due to inadequate damping of the system in a modern practical power system (PS) [1, 2].

Small-signal stability (SSS)is obtained on the basis of a linearized system model around its equilibrium operating points, it is very important to formulate the problem. For small-signal stability (SSS) analysis, formulation of state equations means developing linearized equations at the point of operation and eliminating all the variables other than the state variables [2]. The model-based technique has been commonly used for the extraction of modal data and the identification of the transfer function [3].

Overall, this technique can be categorized into two types based on the model of the system or parameters of device: First is the linear technique such as an assessment of eigenvalue; second one is non-linear techniques, for instance

time-domain simulation and normal form analysis [3].

The benefits of this technique are that it is possible to examine the system's dynamic behaviour under different modes and to identify all the characteristics that lead to complex events. In addition, other controller's nonlinear behaviour is also taken into consideration simultaneously. However, the use of time-domain simulations has several constraints [3]:

(i) All oscillation modes cannot be triggered as the location of disturbance and style are to be selected specifically. (ii) Oscillation features are hard to determine solely on the basis of the response of time-domain analysis. (iii)The model of time-domain simulation depends upon element parameters and due to the benefits of manufacturers, it is impossible to accurately obtain those paramete (iv)Longer time for simulation and a heavy computation load is not compatible for online application requirements.

Both techniques should be used together and in a complementary way, according to the characteristics of time-domain simulation and eigenanalysis.

This paper is arranged as follows. Section II is about the basic preliminaries of small-signal stability (SSS) analysis. In Section III case studies for small signal stability (SSS) for different test system is carried out and Section IV describes conclusion and future scope.

II. SMALL SIGNAL STABILITY (SSS) ANALYSIS

Small signal (or small disturbance) stability represents the power system's (PS) ability to maintain synchronism with small disturbances like small load and generation variations [1]. Small-signal stability (SSS) analysis is about the stability of the power system (PS) when subjected to minor disturbances. If oscillations of the power system (PS) caused by small disturbances can be suppressed so that system state variable deviations remain small for a long time, the power system (PS) is stable. Instead, if the oscillation magnitude increases or persists indefinitely, the power system (PS) is unstable.

Small signal stability (SSS) in the power system (PS) will be governed by several factors, such as initial operating conditions, the strength of electrical connection between power system (PS) components, features of different control devices, etc [4].

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Because the operation of the power system (PS) is inevitable to be subject to minor perturbations, an unstable power system (PS) in terms of small-signal stability (SSS) can't operate in real-time means that a power system (PS) which can normally operate must be stable in terms of small-signal stability (SSS) first. Therefore, the main task in the analysis of power system (PS) is to perform small-signal stability (SSS) analysis to evaluate the power system (PS) under the specified operating conditions [4].

Oscillations in the power system (PS) have the following properties [2]:

(i) Oscillations are due to the system's natural modes and therefore cannot be totally eliminated.

(ii) As the power system (PS) is becoming more complex, oscillation frequency and damping can worsen and new ones can be added to it.

(iii)Automatic voltage regulator (AVR) control is the primary source of introducing negative damping torque in the power system (PS). With an increase in the number of controls, negative damping may further increase.

(iv)Inter-area oscillations are linked with weak transmission lines and larger line loadings.

(v)Damping of the system is to be enhanced to control these tie-line oscillations.

Modal analysis is usually used as a useful tool for the analysis of nonlinear dynamic systems to study small signals stability in the system. Nonlinear differential-algebraic equations (DAEs) can be linearized at a certain operating point using modal analysis. In order to estimate oscillation mode and its shape, the eigenvalues of the state matrix of the linearised model are then calculated [5]. The model-based method allows system operators to assess the dynamic features of the power system (PS) at certain operating points.

The stability (small-signal) of the power system (PS) is governed by the location of eigenvalues (poles of system). So if the eigenvalues are located on the left side of the imaginary axis in the complex plane the power system (PS) is stable whereas if the eigenvalues are on the right side of the imaginary axis or multiple eigenvalues are located on imaginary axis then the system is unstable [6].

The overall objective is to have all the eigenvalues to the left of the complex plane. The stability of the oscillatory modes corresponding to eigenvalue λ is confirmed by looking at the time-dependent characteristic given by $e^{\lambda t}$ [6].

III. EIGENVALUE ANALYSIS

A non-oscillatory mode is characterized by a real eigenvalue. A real negative eigenvalue implies that a mode declines with time (eigenvalue having larger magnitude will decay quickly). The mode corresponding to real positive eigenvalue will rise with time, and aperiodic instability in the system occurs [6].

Oscillatory modes of response occur due to conjugate pair complex eigenvalues given by $\lambda = \sigma \pm j\omega$.

The system is said to be globally stable if a conjugate pair of complex eigenvalues have negative real part σ and such oscillatory mode decays with time. If the real part of the complex eigenvalue is positive, then it grows exponentially with respect to time, and it corresponds to unstable oscillatory mode [6].

Dominant modes occur in a system due to the presence of unstable or poorly damped oscillatory modes and their contribution dominates system's time response. For an oscillatory mode, the oscillation frequency is determined by the imaginary part and the damping ratio is determined by the real part as given by following set of equations [6].

Oscillation frequency in Hz is given as:

$$f = \omega / 2\pi \quad \text{--------------------} \quad (1)$$

The damping ratio as:

$$\xi = -\frac{\sigma}{\sqrt{\sigma^2+\omega^2}} \quad \text{--------------------} \quad (2)$$

IV. CASE STUDY

In this section analysis of small-signal stability (SSS) is performed in MATLAB 7.8.0 with PSAT version 2.1.9[7] on the standard power system (PS) model.

For 9-bus, 3-generator WSCC test system [7,8] eigenvalues are obtained by small signal stability (SSS) analysis as shown below. Generators are equipped with automatic voltage regulator. The system parameter is reported in [7].

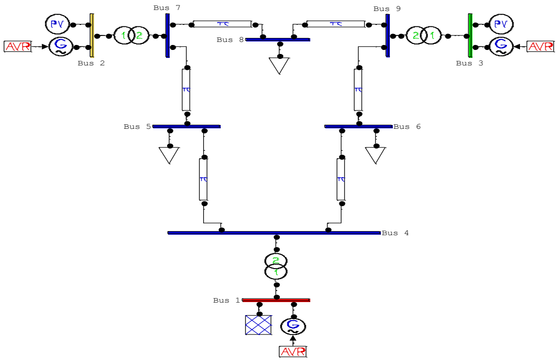

Fig.1 3-generator WSCC test system

For above given system the dynamic order of the system is twenty-four, in which there are six eigenvalues found to be negative and real, sixteen eigenvalues are complex-pairs with decaying in nature and two eigenvalues are located on the origin. The same is shown in the below figure with eigenvalues location in the complex plane. Eigenvalues having negative real part greater than six are not shown in the complex plane.

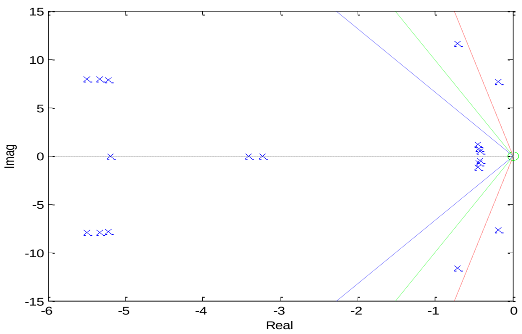

Fig.2 Plot of eigenvalues for 3-generator WSCC test system.

For previous test system i.e. WSCC test system, an SVC is added to the system at bus 8, and new eigenvalues are obtained. The system parameter is reported in [7].

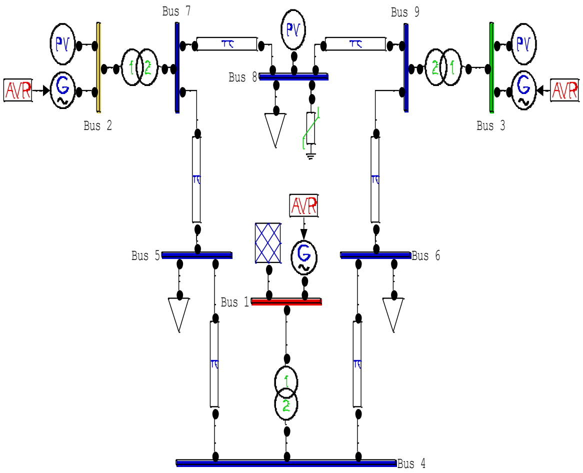

Fig.3 3-generator WSCC test system with SVC

For above given the system the dynamic order of the system is twenty-five, in which there are five eigenvalues found to be negative and real, eighteen eigenvalues are complex-pairs with decaying in nature and two eigenvalues are located on the origin. The same is shown in the below figure with eigenvalues location in the complex plane. Using additional control, by means of static var compensator (SVC) system's dynamic stability can be improved.SVC is used for damping oscillations of the power system (PS). With the addition of SVC stability of system increases which can be visualized by the plot of eigenvalues. Eigenvalues having negative real part greater than six are not shown in the complex plane.

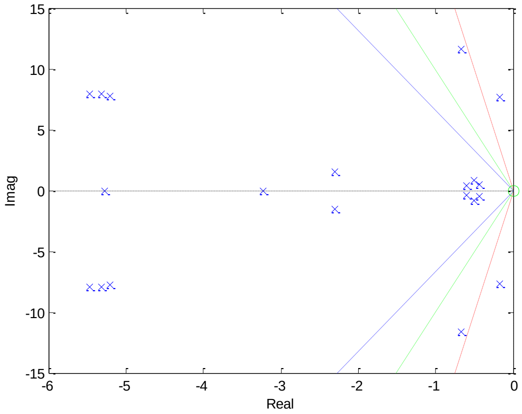

Fig.4 Plot of eigenvalues for 3-generator WSCC test system with SVC.

V. CONCLUSION AND FUTURE SCOPE

From the above test cases, as shown, the small-signal stability (SSS) analysis can be performed which provides complete information of modes (eigenvalues) of the system. Depending upon the location of eigenvalues suitable control action can be performed to maintain the system in a stable state of operation. Effect of addition of SVC on eigenvalue and stability is visualized in this paper. The future scope also includes the effect of penetration of renewable energy sources on modes (eigenvalues) of the system.

REFERENCES

1. Kundur P, Balu NJ, Lauby MG. Power system (PS) stability and control, vol. 7. NewYork: McGraw-Hill; 1994.
2. Mondal D, Chakrabarti A, Sengupta A. Power system (PS) Small signal stability(SSS)Analysis and Control, 1st edition. Academic Press;2014.
3. Li Y, Yang D, Liu F, Cao Y, RehtanzC, Interconnected Power system (PS)s, 1st edition, Springer-Verlag Berlin Heidelberg;2016.
4. Wang XF, Song Y, Irving M.Modern Power system (PS)s Analysis, Springer; 2008.
5. Jiang T,Bai L, Li G, Jia H,Hu Q, Yuan H : 'Estimating inter-area dominant oscillation mode in bulk power grid using multi-channel continuous wavelet transform', Journal of Mod. Power Syst. Clean Energy,2016,4,(3),pp (394–405).
6. Chennakesavan C,Nalandha P: ' Multi-Machine Small Signal Stability Analysis For Large Scale Power system (PS)', Indian Journal of Science and Technology 2014, 7,(S6), pp(40–47).
7. PSAT http://faraday1.ucd.ie/psat.html
8. https://icseg.iti.illinois.edu/power-cases/

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