Calculations of electromechanical eigenvalues based on instantaneous power waveforms at a step disturbance

Piotr Pruski, Stefan Paszek

Faculty of Electrical Engineering, Silesian University of Technology, Akademicka 10, Gliwice, Poland,
e-mail: Piotr.Pruski@polsl.pl, Stefan.Paszek@polsl.pl

Abstract **The paper presents the calculation results of state matrix eigenvalues (associated with electromechanical phenomena) of the power system model based on the analysis of simulated instantaneous power disturbance waveforms of power system generating units at a step disturbance introduced in a voltage regulation system of one of the units. The method for calculations of electromechanical eigenvalues used in investigations consists in the approximation of instantaneous power disturbance waveforms in particular generating units with the waveforms being a superposition of the modal components associated with the searched eigenvalues and their participation factors.**

Keywords **power system, electromechanical eigenvalues, transient states, angular stability.**

I. Introduction

Keeping the angular stability of a power system (PS) is one of the most important conditions of the system proper operation. The PS angular stability can be assessed with use of stability factors calculated on the basis of PS state matrix eigenvalues [1], [2]. The eigenvalues can be calculated with a good accuracy from the analysis of the disturbance waveforms occurring in the PS after various disturbances [1]. The aim of this paper is to calculate the eigenvalues (associated with electromechanical phenomena) of the PS model state matrix on the basis of instantaneous power waveforms of PS generating units.

The power system model linearized around the working point is described by the state and output equations [1]. For a disturbance being a step change in the j-th input quantity $\Delta \boldsymbol{U}_j(t) = \Delta U \mathbf{1}(t)$, the waveform of the i-th output quantity (for $\boldsymbol{D} = \mathbf{0}$ [1]) is given by:

$$\Delta Y_i(t) = \sum_{h=1}^{n} F_{ih} \lambda_h^{-1} \left(e^{\lambda_h t} - 1 \right) \Delta U, \tag{1}$$

where: λ_h – h-th eigenvalue of the state matrix, F_{ih} – participation factor of the h-th eigenvalue in the i-th output quantity waveform [1]. The eigenvalues associated with motion of generating unit rotors (electromechanical eigenvalues) [1] are of high significance.

II. Exemplary calculations

The method for calculating electromechanical eigenvalues used in investigations consists in approximation of instantaneous power waveforms of particular PS generating units by means of expression (1). The eigenvalues and their participation factors are selected iteratively so as to minimise the objective function value:

$$\varepsilon_{\mathrm{w}}(\boldsymbol{\lambda}, \boldsymbol{F}) = \sum_{i=1}^{N} \left(\Delta P_{i(\mathrm{m})} - \Delta P_{i(\mathrm{a})}(\boldsymbol{\lambda}, \boldsymbol{F}) \right)^2, \tag{2}$$

where: $\boldsymbol{\lambda}$ – vector of the eigenvalues, $\boldsymbol{F}$ – vector of the participation factors, N – number of the waveform samples, index m denotes the approximated waveform and index a – the approximating waveform. A hybrid optimisation algorithm [1] consisting of genetic and gradient algorithms was used for minimisation of the objective function (2).

The calculations were performed for a 7-machine test PS CIGRE model [1] including a central frequency regulator. The assumed disturbance was a step change of the voltage regulator reference voltage in unit G4 of the height equal to -5% of the steady value. The eigenvalues can be calculated directly on the basis of the PS model (*original eigenvalues*) [1]. Table 1 presents the original eigenvalues λ and the absolute errors $\Delta\lambda$ of calculations of these eigenvalues based on the instantaneous power waveforms. For instance, Fig. 1 shows the instantaneous power waveforms of unit G3.

TABLE I
ORIGINAL EIGENVALUES AND THEIR CALCULATION ERRORS

λ_1	-0.8763±j10.4448	λ_2	-0.8324±j10.6182	λ_3	-0.7627±j9.6686
$\Delta\lambda_1$	0.0729±j0.0201	$\Delta\lambda_2$	-0.0471∓j0.1066	$\Delta\lambda_3$	0.0492∓j0.1426
λ_4	-0.5274±j8.7481	λ_5	-0.4165±j7.8724	λ_6	-0.1888±j6.5421
$\Delta\lambda_4$	-0.0341∓j0.0969	$\Delta\lambda_5$	0.0305±j0.0180	$\Delta\lambda_6$	0.0071∓j0.0103

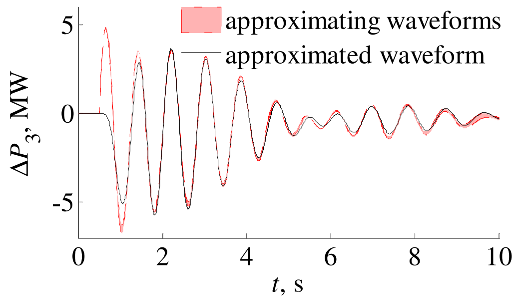

Fig. 1. Exemplary waveform of the instantaneous power deviation

III. Conclusion

It is possible to calculate with a good accuracy the electromechanical eigenvalues based on the analysis of the instantaneous power waveforms occurring after a step disturbance in the voltage regulator system of a generating unit. The good accuracy was achieved for the calculations on the basis of the analysis of most waveforms, in which the eigenvalues had sufficiently large absolute values of participation factors.

IV. References

[1] Pruski P., Paszek S.: "Determination of electromechanical eigenvalues based on analysis of different disturbance waveforms of a power system", Computer Applications in Electrical Engineering, Vol. 12, Poznań 2014, pp. 130-143.

[2] Cetinkaya, H.B., Ozturk, S., Alboyaci, B.: "Eigenvalues Obtained with Two Simulation Packages (SIMPOW and PSAT) and Effects of Machine Parameters on Eigenvalues", Electrotechnical Conference, 2004. MELECON 2004. Proceedings of the 12th IEEE Mediterranean, Vol. 3, pp. 943-946.