A Comparison of Eigenvalues Obtained with Two Dynamic Simulation Software Packages

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Abstract—Eigenvalues of a power system give a good picture of the stability in the current operating point. In this paper the linear analysis capabilities of two software packages are evaluated and compared. It is shown in which way the linearization method influences the results, i.e., the location of the obtained eigenvalues in the complex plane.

Further, the paper illustrates the impact of the models of the power system components (such as generators) on the location of the eigenvalues. The conclusions drawn from eigenvalue analysis are thus not only dependent on the properties of the investigated system, but also on the software package which is used, as well as on how the components of the power system are modeled. Therefore, conclusions can differ when studying the same power system with different software packages.

Index Terms—Eigenvalue, Linear Analysis, Linearization Methods, Power System Dynamics, PSS/E, Sensitivity Analysis, Simpow, Simulation Software, Small-Signal Stability.

I. INTRODUCTION

LINEAR analysis is a useful tool to study whether a power system is stable or not as it enables the determination of the eigenvalues of the system. The locations of the eigenvalues in the complex plane give for instance information about the presence of weakly damped oscillations.

There are several software packages on the market that can extract eigenvalues [1]. However, the various programs are seldom evaluated and compared. In this paper two software packages are compared and differences between them are explained. Since the software packages use different linearization methods as well as different models of the power system components it is important to understand that there exist differences in the extraction of the eigenvalues. The analyzed software packages are PTI's PSS/E and ABB's Simpow.

Several synchronous machine models have been linearized using PSS/E and Simpow in [2]. This paper starts with linearization of the classical synchronous machine model to understand how linearization methods influence the results, later the synchronous machines in [2] are used but equipped with exciter and turbine models in order to study a more complete model.

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II. PAPER OUTLINE

The comparison of the two software packages focuses on the following topics:

- differences in linearization methods,
- differences in modeling of the power system components,
- sensitivity of the eigenvalues to variations of parameters in a power system, as in [3].

The sensitivity analysis is done to illustrate the fact that two engineers, using different software packages may obtain different results although they study the same power system.

The following synchronous machines are analyzed:

- a classical machine model connected to an infinite bus,
- a 6th-order machine model equipped with an exciter and turbine, connected to an infinite bus.

III. LINEARIZATION METHODS

In [2], the linearization methods used in PSS/E and Simpow were outlined. In this paper the methods are further analyzed and exemplified.

A. Linearization method in PSS/E

PSS/E uses a numerical linearization routine [4]. Starting from a valid equilibrium condition $\mathbf{x}_0$, a second state vector is created, $\mathbf{x}_i$, in which the i th component of the state vector $\mathbf{x}$ is perturbed from the equilibrium point $\mathbf{x}_0$.

$$\dot{\mathbf{x}}_i - \dot{\mathbf{x}}_0 = \dot{\mathbf{x}}_i - \mathbf{0} = \dot{\mathbf{x}}_i = \mathbf{A}_i \Delta \mathbf{x}_i \quad (1)$$

Equation (1) is used to calculate values of the i th column of the state matrix $\mathbf{A}$. In equation (1), $\mathbf{A}_i$ is a matrix of the same dimensions as $\mathbf{A}$, containing the i th column of matrix $\mathbf{A}$ and zeros for the rest. $\Delta \mathbf{x}_i$ is a vector containing the perturbation in element i and zeros for the rest. By sequentially perturbing all entries of vector $\mathbf{x}$ to get different $\dot{\mathbf{x}}_i$'s, all columns of the $\mathbf{A}$ -matrix are computed using equation (1). This method can be found in the literature named as *forward-difference approximation* [5].

The size of the perturbation h affects the obtained result, i.e. the $\mathbf{A}$ -matrix and its eigenvalues. This is shown below. Once the $\mathbf{A}$ -matrix has been derived, the eigenvalues of the matrix $\mathbf{A}$ are calculated using the Quick Response method (the QR-method) [6].

B. Linearization method in Simpow

Simpow uses an analytical linearization routine wherein all differential equations and algebraic equations are linearized by their analytical expressions [7]. The differential equation describing the time-derivative of the speed deviation, $\Delta \dot{\omega}$, for a synchronous machine,

$$\Delta\dot{\omega} = \frac{1}{2H}(T_m - T_e - D\Delta\omega) \quad (2)$$

is in Simpow linearized as:

$$\Delta(\Delta\dot{\omega}) = \frac{1}{2H}\Delta T_m - \frac{1}{2H}\Delta T_e - \frac{D}{2H}\Delta(\Delta\omega) \quad (3)$$

The linearization procedure as described with equations (2) and (3) is possible because mathematical rules prescribing the differentiation of the various operators are implemented in the program, i.e., enabling symbolic differentiation.

Equation (3) contains two algebraic variables, ΔT_m and ΔT_e , and one state variable $\Delta(\Delta\omega)$. Algebraic variables are variables that are not time-derivated in the system of equations. The state and the algebraic variables are put in the state vector $\mathbf{x}$ and the algebraic variable vector $\mathbf{v}$ respectively as:

$$\mathbf{x} = \begin{bmatrix} \vdots \\ \Delta(\Delta\omega) \\ \vdots \end{bmatrix} \quad \mathbf{v} = \begin{bmatrix} \vdots \\ \Delta T_m \\ \Delta T_e \\ \vdots \end{bmatrix} \quad (4)$$

The linearized system is described with a Jacobian-matrix $\mathbf{J}$, consisting of four sub-matrices $\mathbf{J}_{aa}$, $\mathbf{J}_{as}$, $\mathbf{J}_{sa}$, and $\mathbf{J}_{ss}$ as in equation (5), see [2]:

$$\begin{bmatrix} \mathbf{0} \\ \dot{\mathbf{x}} \end{bmatrix} = \begin{bmatrix} \mathbf{J}_{aa} & \mathbf{J}_{as} \\ \mathbf{J}_{sa} & \mathbf{J}_{ss} \end{bmatrix} \begin{bmatrix} \mathbf{v} \\ \mathbf{x} \end{bmatrix} \quad (5)$$

The sub-matrix $\mathbf{J}_{aa}$ contains partial derivatives of algebraic variables in algebraic equations and $\mathbf{J}_{as}$ contains partial derivatives of state variables in algebraic equations. Since there are no time-derivatives of algebraic variables, the upper part of the left-hand side of equation (5) equals the zero-vector. Examples of algebraic equations are the expressions giving the node voltages, which are thus algebraic variables.

$\mathbf{J}_{sa}$ contains partial derivatives of algebraic variables in differential equations, among other elements; $1/2H$ and $-1/2H$ from equation (3) above. $\mathbf{J}_{ss}$ contains partial derivatives of state variables in differential equations, among other elements; $-D/2H$ from equation (3).

The $\mathbf{A}$ -matrix is defined with the expression

$$\mathbf{A} = -\mathbf{J}_{sa}\mathbf{J}_{aa}^{-1}\mathbf{J}_{as} + \mathbf{J}_{ss} \quad (6)$$

which is derived in [2]. The eigenvalues of matrix $\mathbf{A}$ are in Simpow solved using the QR-method [6] and the inverse iteration method [8] is used to calculate the eigenvectors.

IV. CASE 1: COMPARISON OF LINEARIZATION METHODS IN PSS/E AND SIMPOW WITH A CLASSICAL MACHINE MODEL

With both packages, a small test system containing an infinite bus, a transmission impedance x_{line} , and a synchronous machine represented by the classical machine model are modeled, see figure 1 and [9], p. 732 where all data can be found.

Fig. 1. A small test system.

The models of the power system components are in this case identical in both software packages and therefore it is possible to observe what impact the different linearization methods have on the obtained eigenvalues.

In figure 2 the classical machine model and its connection to the rest of the power system is shown.

Fig. 2. The classical machine model in a small test system.

The machine contains two state variables, the speed deviation $\Delta\omega$ and the machine angle δ (indicated as DELTA in figure 2). There are no other state variables in the power system. The initial values of all variables are calculated from the steady-state solution. In the following subsection, linear analysis is carried out with both PSS/E and Simpow. The machine parameters are given in table I.

TABLE I
SETTINGS OF THE CLASSICAL MACHINE MODEL IN SECTION IV

x_d'	0.30 (p.u.)	D	0.00 (1/sec)	H	3.50 (sec)
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A. Linear analysis of the classical machine model in PSS/E

The $\mathbf{A}$ -matrix is column by column identified in PSS/E by applying a perturbation in each state variable $\Delta\omega$ and δ . In this section the size of the applied perturbation h is 0.01 p.u. which is the default perturbation size in PSS/E. By adding it to each state variable in an equilibrium point, it is calculated how the left-hand sides of differential equations (7) and (8) change.

$$\Delta\dot{\omega} = \frac{1}{2H}(T_m - T_e - D\Delta\omega) \quad (7)$$

$$\dot{\delta} = \omega_0\Delta\omega \quad (8)$$

Equations (7) and (8) and the algebraic equations in figure 2 are used to derive a state matrix describing linear relations of the left-hand side's $\Delta(\Delta\dot{\omega})$ and $\Delta\dot{\delta}$ and the right-hand side's $\Delta(\Delta\omega)$ and $\Delta\delta$ in equation (9) below. In the following this is done for each state variable.

$$\begin{bmatrix} \Delta(\Delta\dot{\omega}) \\ \Delta\dot{\delta} \end{bmatrix} = \underbrace{\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}}_{=\mathbf{A}} \begin{bmatrix} \Delta(\Delta\omega) \\ \Delta\delta \end{bmatrix} \quad (9)$$

1. Perturbing the speed deviation, $\Delta\omega$

The left-hand sides of equations (7) and (8) when perturbing $\Delta\omega$, noted as $\Delta(\Delta\omega)$, are used to identify the matrix-elements A_{11} and A_{21} . When perturbing $\Delta\omega$, all other state variables are

assumed to be unperturbed, see section III-A. The feedback of δ to the variable T_e in equation (7) is therefore neglected. Since the damping constant D is zero, the left-hand side of equation (7) is equal to zero when perturbing $\Delta\omega$. Therefore the matrix-element A_{11} is:

$$A_{11} = \frac{\Delta(\Delta\dot{\omega})}{\Delta(\Delta\omega)} = \frac{0}{0.01} = 0 \quad (10)$$

When perturbing $\Delta\omega$ the left-hand side of equation (8) changes proportional to the perturbation multiplied with ω_0 , see figure 2. Therefore the matrix-element A_{21} is:

$$A_{21} = \frac{\Delta\dot{\delta}}{\Delta(\Delta\omega)} = \frac{0.01 * \omega_0}{0.01} = \omega_0 \quad (11)$$

2. Perturbing the machine angle, δ

The left-hand sides of equations (7) and (8) when perturbing δ , noted as $\Delta\delta$, are used to identify the matrix-elements A_{12} and A_{22} in equation (9). δ is not direct included in the differential equation (7) and therefore δ 's feedback to the variable T_e is calculated using the algebraic equations of figure 2. The matrix-element A_{12} is:

$$A_{12} = \frac{\Delta(\Delta\dot{\omega})}{\Delta\delta} = \frac{-1.07486 * 10^{-3}}{0.01} = -0.107486 \quad (12)$$

The feedback of the state variable $\Delta\omega$ in equation (8) is neglected when perturbing the state variable δ , see section III-A, and therefore the matrix-element A_{22} is:

$$A_{22} = \frac{\Delta\dot{\delta}}{\Delta\delta} = \frac{0}{0.01} = 0 \quad (13)$$

The **A**-matrix is composed of the four matrix-elements A_{11} , A_{12} , A_{21} , and A_{22} as in equation (14) and its eigenvalues is given in equation (15).

$$\mathbf{A} = \begin{bmatrix} 0 & -0.107486 \\ \omega_0 & 0 \end{bmatrix} \quad (14)$$

$$\lambda_{1,2} = 0 \pm j6.3655 \quad [1/s, \text{rad/s}] \quad (15)$$

The eigenvalues in equation (15) were calculated when the state matrix **A** in equation (14) was identified with a perturbation size of 0.01 p.u. In section IV-C below, eigenvalues are shown derived from state matrices constructed with different perturbation sizes, both "by hand" as in this section and also direct by PSS/E.

B. Linear analysis of the classical machine model in Simpow

In Simpow the two state variables and the algebraic variables are put in the state vector **x** and the vector **v** respectively.

$$\mathbf{x} = \begin{bmatrix} \Delta(\Delta\omega) \\ \Delta\delta \end{bmatrix} \quad \mathbf{v}^T = [\Delta i_d \quad \Delta i_q \quad \Delta u_{re} \quad \Delta u_{im} \quad \Delta i_{re} \quad \Delta i_{im}]$$

The mechanical torque T_m is constant for the classical machine model and is therefore not included in vector **v**. The electrical torque T_e is expressed by using the variables in vectors **v** and **x** and is therefore also not included in vector **v**.

From the block diagram in figure 2 the differential and algebraic equations are formulated. The following two differential equations exist:

$$\Delta\dot{\omega} = (T_m - (u_{re}i_d + u_{im}i_q)\sin\delta + (u_{im}i_d - u_{re}i_q)\cos\delta - D\Delta\omega)/2H \quad (16)$$

$$\dot{\delta} = \omega_0\Delta\omega \quad (17)$$

The rest of the equations are the algebraic equations:

$$i_d = -(u_{re}\cos\delta + u_{im}\sin\delta - E_{fd0})/x'_d \quad (18)$$

$$i_q = (u_{re}\sin\delta - u_{im}\cos\delta)/x'_d \quad (19)$$

$$u_{re} = u_{rebusinf} - x_{line}i_{im} \quad (20)$$

$$u_{im} = u_{imbusinf} + x_{line}i_{re} \quad (21)$$

$$i_{re} = i_d\sin\delta + i_q\cos\delta \quad (22)$$

$$i_{im} = i_q\sin\delta - i_d\cos\delta \quad (23)$$

By deriving equations (16) – (23) with all algebraic variables and state variables, the four sub-matrices described in section III-B, **J_{aa}**, **J_{as}**, **J_{sa}** and **J_{ss}** are constructed as:

$$\mathbf{J}_{aa} = \begin{bmatrix} -1 & 0 & -\cos\delta/x'_d & -\sin\delta/x'_d & 0 & 0 \\ 0 & -1 & \sin\delta/x'_d & -\cos\delta/x'_d & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & -x_{line} \\ 0 & 0 & 0 & -1 & x_{line} & 0 \\ \sin\delta & \cos\delta & 0 & 0 & -1 & 0 \\ -\cos\delta & \sin\delta & 0 & 0 & 0 & -1 \end{bmatrix}$$

$$\mathbf{J}_{as} = \begin{bmatrix} 0 & (u_{re}\sin\delta - u_{im}\cos\delta)/x'_d \\ 0 & (u_{re}\cos\delta + u_{im}\sin\delta)/x'_d \\ 0 & 0 \\ 0 & 0 \\ 0 & i_d\cos\delta - i_q\sin\delta \\ 0 & i_q\cos\delta + i_d\sin\delta \end{bmatrix} \quad \mathbf{J}_{sa}^T = \frac{1}{2H} \begin{bmatrix} u_{im}\cos\delta - u_{re}\sin\delta & 0 \\ -u_{re}\cos\delta - u_{im}\sin\delta & 0 \\ -i_q\cos\delta - i_d\sin\delta & 0 \\ i_d\cos\delta - i_q\sin\delta & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\mathbf{J}_{ss} = \frac{1}{2H} \begin{bmatrix} -D & \sin\delta(u_{re}i_q - u_{im}i_d) - \cos\delta(u_{re}i_d + u_{im}i_q) \\ 0 & 0 \end{bmatrix} \quad (24)$$

By applying expression (6) and entering values in the current operating point for the elements of the four sub-matrices, the **A**-matrix and its eigenvalues are calculated:

$$\mathbf{A} = -\mathbf{J}_{sa}\mathbf{J}_{aa}^{-1}\mathbf{J}_{as} + \mathbf{J}_{ss} = \begin{bmatrix} 0 & -0.108131 \\ \omega_0 & 0 \end{bmatrix} \quad (25)$$

$$\lambda_{1,2} = 0 \pm j6.3847 \quad [1/s, \text{rad/s}] \quad (26)$$

The result in Simpow is analytically derived and the eigenvalues in equation (26) can also be found in [9], p. 735.

C. Conclusions of linear analysis of the classical machine model in PSS/E and Simpow

Table II summarizes sections IV-A and IV-B. The table contains the obtained eigenvalues also for the perturbation size 0.0001 in PSS/E. When comparing the columns, differences are seen in the imaginary parts of the eigenvalues and therefore we proceed in this subsection with varying the perturbation size h in PSS/E.

TABLE II
EIGENVALUES OF THE CLASSICAL MACHINE MODEL IN SECTION IV

Eigenvalues	PSS/E* $h = 0.0100$	PSS/E* $h = 0.0001$	Simpow
$\lambda_{1,2}$	$0 \pm j6.3655$	$0 \pm j6.3843$	$0 \pm j6.3847$

The eigenvalue's real and imaginary parts are shown in [1/sec] and [rad/sec].

* The perturbation size h is 0.0100 and 0.0001 respectively.

The curve indicated as 1) in figure 3 shows the result from the linearization method described in section IV-A for perturbation sizes h in the range between 0.0001 and 0.1000 in 1000

steps. The curve indicated as 2) shows result obtained direct from PSS/E where h has been varied from 0.0001 to 0.1000 in 32 steps. Since curves 1) and 2) are very close it shows that PSS/E's linearization method is as shown in section IV-A.

The curve indicated as 3) in figure 3 shows the result from the linearization made in Simpow. Since analytical linearization is carried out, no perturbation is used and the result is therefore independent of the perturbation size h .

Figure 3 shows that the smaller h , the closer the result from PSS/E (curves 1) and 2)) is to the analytical calculation obtained from Simpow (curve 3)). If all equations of the system had been linear, curves 1) and 2) had perfectly followed curve 3) also for large values of h , but since non-linear block diagrams are included when the four matrix-elements are identified, the result is depending on h . As can be seen by comparing the A-matrices in equation (14) and (25) it is only element A_{12} that is dependent on h .

Figure 4 shows how matrix-element A_{12} , see equation (12), is varying with h in PSS/E. If the system had been linear, the value of A_{12} had been independent of h , i.e., an horizontal line had been obtained. A_{12} 's variation with h is also a consequence of the used *forward-difference approximation* in PSS/E: The numerical expression (12) includes a truncation error since higher orders of the Taylor expansion is neglected [5].

It can be shown that the truncation error ΔA_{12} in figure 4 has the following relation to h if we skip higher orders of h :

$$\Delta A_{12} = \sin \delta \frac{u_{rebus} E_{fd0}}{4H(x'_d + x_{line})} h \quad (27)$$

In general when using *forward-difference approximation*, truncation errors Δ are of first order for small values of h as:

$$\Delta = O(h) \quad (28)$$

In [10] it has been shown that the perturbation size h has to be set according to whether the variables are defined with single or double precision. As a rule of thumb h should not be smaller than $h \approx \sqrt{\text{tol}}$ where tol is the used precision by which the variables are calculated. The other matrix-elements of equation (9) are independent of h .

Curves 1) and 2) in figure 3 indicate the situation when perturbations are large. This has been verified with time-domain simulations and for large perturbations h in the system the oscillation frequency is indeed decreasing as in figure 3 and is as low as 5 [rad/s] for very large perturbations. However, when small-signal behaviors of systems are studied, the perturbation is assumed to be so small so that the system can be linearized in the current working point. Figure 3 shows that the linearization method in PSS/E is sensitive to the degree of linearity of the equations of the studied system as well as to the size of the perturbation.

In section 4.1 of [2] it is concluded that the linearization routines bring different results in PSS/E and Simpow and it is not further studied if PSS/E's result is dependent on the perturbation size. During further studies it was observed that the input data for the two programs of [2] is not fully identical making the quantitative comparison in section 4.1 of [2] invalid. However, in figure 3 it is clearly shown that there exist differences in the results obtained with the two programs and that the perturbation size in PSS/E influences the calculated eigenvalues, thus confirming the earlier conclusion of [2].

Fig. 3. The imaginary part of the eigenvalue-pair for the classical machine model when linearized in PSS/E and Simpow.

Fig. 4. Matrix-element A_{12} and the truncation error ΔA_{12} in PSS/E as a function of the perturbation size h .

Fig. 5. Exciter model IEEE T2.

V. CASE 2: COMPARISON OF A 6TH-ORDER MACHINE MODEL

In this section a standard model of a 6th-order synchronous machine in the two software packages is used to show how analysis of an identical power system by two engineers working in parallel but using different software packages may yield different results. The synchronous machine is equipped with an exciter and a turbine model. The block diagram of the exciter is shown in figure 5 and the turbine GAST can be found in [4]. The machine, exciter, and turbine parameters are given in table III.

In PSS/E the synchronous machine model GENROE is used and in Simpow the machine model 1A is used. Magnetic

saturation is neglected. Differences between the two machine models are for instance how the stator fluxes are calculated. However, both are used frequently for studying transient stability. With the same settings it is below documented differences when linearizing them in the two software packages.

TABLE III
SETTINGS OF THE 6th-ORDER MACHINE, EXCITER IEEE2 AND TURBINE GAST

6 th -order machine*		Exciter IEEE2*		Turbine GAST	
H	3.5 (s)	T_R	0.05 (s)	D_{TURB}	0.01
D	0	K_A	60.0	T_1	0.4 (s)
x_d	1.81 (p.u.)	T_A	0.1 (s)	T_2	0.1 (s)
x_q	1.76 (p.u.)	VR_{MAX}	32.8	T_3	3.0 (s)
x_d'	0.30 (p.u.)	VR_{MIN}	0.0	R	0.05
x_q'	0.65 (p.u.)	K_E	1.0	K_T	2.0
x_d''	0.25 (p.u.)	T_E	0.4	A_T	1.0
x_l	0.16 (p.u.)	K_F	0.02	V_{MAX}	1.0
T_{d0}'	8.0 (s)	T_{F1}	0.6 (s)	V_{MIN}	-0.1
T_{d0}''	0.03 (s)	T_{F2}	1.2 (s)		
T_{q0}'	1.0 (s)				
T_{q0}''	0.07 (s)				

* Synchronous machine and exciter are modeled unsaturated.

+ x_d'' equals to x_q'' and R_d equals to 0 due to the generator model in PSS/E.

The machine parameters can be found in [9], pp. 752 and 789, the exciter and turbine parameters are selected to typical values. GAST represents both the turbine and the governor model.

TABLE IV
EIGENVALUES IN THE 14th-ORDER SYSTEM IN SECTION V

Eigenvalues	PSS/E $h = 0.0100$	PSS/E $h = 0.0001$	Simpow
$\lambda_{1,2}$	-0.3023 +/- j6.5415	-0.2971 +/- j6.5647	-0.3011 +/- j6.5803
$\lambda_{3,4}$	-1.0903 +/- j0.3084	-1.0870 +/- j0.3130	-1.1063 +/- j0.3026
$\lambda_{5,6}$	-1.2098 +/- j3.4668	-1.2246 +/- j3.4497	-1.1883 +/- j3.4858
λ_7	-0.3333	-0.3333	-0.3333
λ_8	-1.7175	-1.7219	-1.9708
λ_9	-2.2194	-2.2211	-2.3107
λ_{10}	-10.280	-10.279	-10.285
λ_{11}	-11.112	-11.100	-11.173
λ_{12}	-19.240	-19.252	-19.222
λ_{13}	-21.730	-21.756	-22.043
λ_{14}	-35.521	-35.510	-35.536

An eigenvalue's real and imaginary parts are shown in [1/sec] and [rad/sec].

The total power system, see figure 1, is of 14th order and therefore 14 eigenvalues are derived as shown in table IV. In PSS/E, linearizations have been made for two perturbation sizes. In columns 2 and 3 it is possible to see the influence of the perturbation size h as was shown earlier in section IV-C. However, the main difference between the eigenvalues obtained by the two software packages are caused by the differences in the machine models as can be seen by comparing columns 2 and 3 with 4. Eigenvalue λ_8 is the eigenvalue that differs most between the two software packages. Since the rest of the power system components are identical in the two programs, columns 3 and 4 in table IV show how the difference in the machine models influence the result.

Eigenvalue analysis is often used to study the possibility to improve the damping of oscillations. For this system it will be investigated how the electromechanical mode $\lambda_{1,2}$ in table IV moves in the complex plane when exciter parameters are changed. This is often a real task when improving the stability of a power system. To this end, the exciter gains K_A and K_F are varied. The perturbation size in PSS/E is set to 0.01 and 0.0001.

Fig. 6. The path of the electromechanical mode when K_A is varied from 5 to 90 in steps of 5.

Fig. 7. The path of the electromechanical mode when K_F is varied from 0 to 0.5.

In figure 6 we can see how the oscillation frequency and the damping of the electromechanical mode $\lambda_{1,2}$ changes when K_A is varied from 5 to 90 in steps of 5. The paths are not identical in the two software packages and for every value of K_A , the oscillation frequency is lower in PSS/E than in Simpov. However, when increasing K_A the path of the mode has the same direction in the complex plane and therefore the analysis is in both software packages that K_A should be increased to damp the mode. The other parameters are unchanged, see table III.

In figure 7 we can see how the oscillation frequency and the damping of the electromechanical mode $\lambda_{1,2}$ change when K_F is varied from 0 to 0.2 in steps of 0.01 and from 0.2 to 0.5 in steps of 0.05. Again, the paths are not identical in the two

programs. However, the mode is in both software packages less damped for $K_F = 0.16$. The values of the other parameters are left unchanged, see table III.

In this section we have shown that the location of the electromechanical mode differs between PSS/E and Simpow when varying exciter parameters. The analysis of how to damp the electromechanical mode in each of the two software packages are, however, very similar and largely independent on the differences of the machine models and the linearization routines. One difference is that the value of the real part (Sigma in figure 7) differs for $K_F = 0.16$ in the software packages.

VI. CONCLUSIONS

The linear analysis capabilities of the two software packages PSS/E and Simpow have been evaluated in this paper. PSS/E uses numerical linearization while Simpow uses analytical linearization. The analytical linearization is achieved by writing the models in terms of the most elementary components for which a linearization formula is known.

It has been shown that the perturbation size in PSS/E influences the calculated eigenvalues. However, for small values of the perturbation h , results from PSS/E are very similar to those obtained from Simpow. It is not shown in the paper and has to be further studied if a small perturbation size can be used when studying large power systems.

The impact of the differences between the 6th-order synchronous machine models in the two software packages has also been evaluated. The result was that the eigenvalues are slightly different.

When analyzing the electromechanical mode of a small power system, the impact of the difference in machine models and linearization routines were investigated. It was concluded that the analysis of how to improve the damping of the electromechanical mode—by changing regulator parameters—is the same in the two software packages, except for small quantitative differences.

We are working on analyzing the effect of the linearization method on the eigenvalues of large power systems since small perturbations might be impossible to apply in that case according to numerical accuracy.

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