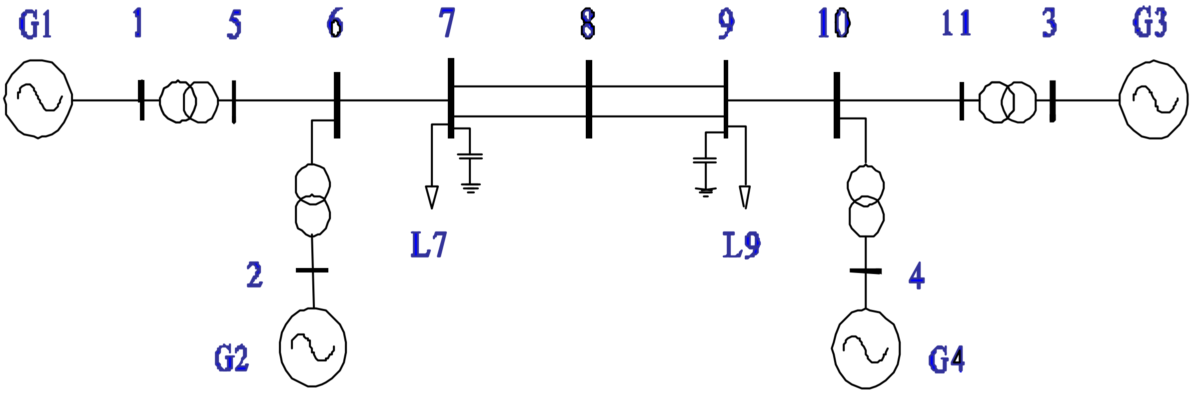
Kundur's Two-Area System



Two-area system used to demonstrate the
power system simulation software Simpow

- *Adapted to Simpow, release 10.1 (revision 105 or later)* -

Written by Jonas Persson, STRI AB, July, 1996 and revised September, 2004.

STRI

STRI AB
Technology & Consulting Services
Box 707
SE-771 80 Ludvika, Sweden
Phone +46 240 795 62
Fax +46 21 32 89 95
simpow-support@stri.se
www.stri.se/simpow

TABLE OF CONTENTS

1. Introduction to Kundur's Two-Area System

The following pages contain an example of power-flow calculation, time-domain simulation, and linear analysis in the power system simulation software Simpow.

The two-area system used is example 12.6 at page 813 in the textbook "Power System Stability and Control", written by Prabha Kundur [1]. The basic topology is depicted in Figure 1.

The system contains eleven buses and two areas, connected by a weak tie between bus 7 and 9. Totally two loads are applied to the system at bus 7 and 9. Two shunt capacitors are also connected to bus 7 and 9 as shown in the figure below. The system has the fundamental frequency 60 Hz.

It is recommended to run the training cases and read the textbook in parallel since the training follows pages 813 -816.

The system comprises two similar areas connected by a weak tie. Each area consists of two generators, each having a rating of 900 MVA and 20 kV. We will perform:

- Power-flow calculation
- Linear Analysis and Modal Analysis
- Time-domain simulation

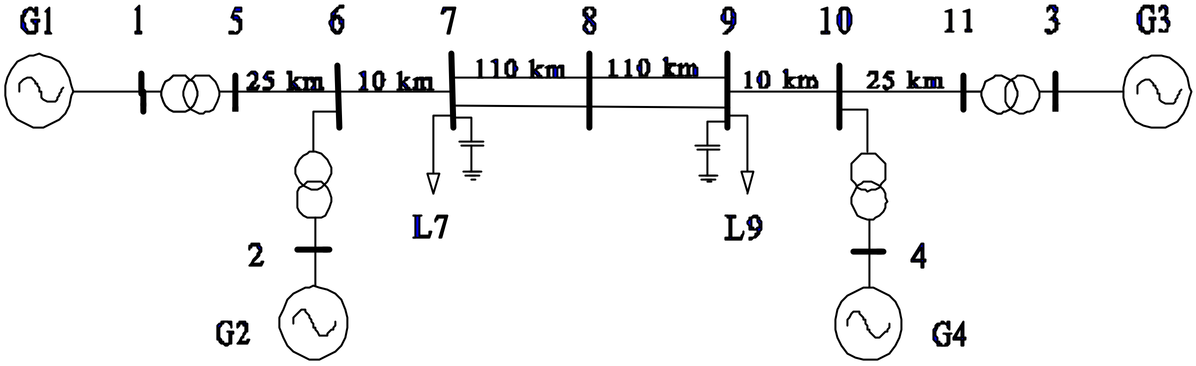


Figure 1. Single line diagram of Kundur's Two-Area System

The left half of the system is identified as area 1 and the right half is identified as area 2.

The saturation of the synchronous machines are not identical with the ones described in the textbook, see a comment in section **3.1.2** below. That may influence the dynamic simulations in section **3**.

Simpow always starts with a power-flow calculation. That session is called Optpow. To do an Optpow-execution a file with the extension name ".optpow" must be prepared. In this case study we will select the prepared file "kundur.optpow". The power-flow file contains static network data for the network depicted in the figure above.

In dynamic simulations, faults and other events in the network can be simulated. In Simpow that session is called Dynpow. To perform a Dynpow execution a file with the extension name ".dynpow" must be prepared. Furthermore, a dynamic simulation must be associated to a power-flow calculation. In the training we will combine six dynamic simulations with one power-flow calculation.

The system can also be found in [1]. In that paper, slight modifications have been done from the system used in the current training cases.

In [2,3] comparisons between two power system simulation software are done. Simpow and PSS/E are evaluated with [4]. Slight modifications have been done in [2] from the system used in the training cases in this report.

For further details in how to run Simpow and what is viewed in each program window, see documentation "Getting Started with SIMPOW®" that can be ordered from STRI AB [5]. The ordering address can be found at page 2 in this document.

1.1 Files used in the training cases

To run the training cases the following files and library must be available:

File name	Explanation
kundur.optpow	A power-flow file, Optpow
casea.dynpow	A dynamic file, Dynpow
casebi.dynpow	A dynamic file, Dynpow
casebii.dynpow	A dynamic file, Dynpow
casebiii.dynpow	A dynamic file, Dynpow
casebiv.dynpow	A dynamic file, Dynpow
casefault.dynpow	A dynamic file, Dynpow
casefault.dynpost	A diagram file
exc_htg.dsl	A DSL process used in cases (b) (ii) and (b) (iv)
exc_tgr.dsl	A DSL process used in case (b) (iii)
stabiliser.dsl	A DSL process used in case (b) (iv)

Table 1. Necessary files for running the training cases

2. Power-flow calculation - Optpow

A power-flow calculation is the initial analysis done for a power system simulation. This activity is called Optpow in Simpow. Use the power-flow file "kundur.optpow" in the following.

Execute the power-flow calculation according to "Getting Started with SIMPOW" [5].

2.1 Power-flow data

Here follows a copy of the power-flow file "kundur.optpow".

```
Prabha Kundur "Power System Stability and Control", Example 12.6 on page 813.
**  kundur.optpow  **
GENERAL
 SN=900
 LBASE=100
END
NODES
 BUS1   UB=20   AREA=1
 BUS2   UB=20   AREA=1
 BUS3   UB=20   AREA=2
 BUS4   UB=20   AREA=2
 BUS5   UB=230  AREA=1
 BUS6   UB=230  AREA=1
 BUS7   UB=230  AREA=1
 BUS8   UB=230  AREA=3
 BUS9   UB=230  AREA=2
 BUS10  UB=230  AREA=2
 BUS11  UB=230  AREA=2
END
TRANSFORMERS
 BUS1  BUS5  SN=900  UN1=20  UN2=230  ER12=0  EX12=0.15
 BUS2  BUS6  SN=900  UN1=20  UN2=230  ER12=0  EX12=0.15
 BUS3  BUS11 SN=900  UN1=20  UN2=230  ER12=0  EX12=0.15
 BUS4  BUS10 SN=900  UN1=20  UN2=230  ER12=0  EX12=0.15
END
LINES
 BUS5  BUS6   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=25
 BUS10 BUS11  TYPE=12  R=0.0001    X=0.001   B=0.00175  L=25
 BUS6  BUS7   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=10
 BUS9  BUS10  TYPE=12  R=0.0001    X=0.001   B=0.00175  L=10
 BUS7  BUS8   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=110  NO=1
 BUS7  BUS8   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=110  NO=2
 BUS8  BUS9   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=110  NO=1
 BUS8  BUS9   TYPE=12  R=0.0001    X=0.001   B=0.00175  L=110  NO=2
END
SHUNT IMPEDANCES
 BUS7  Q=-200
 BUS9  Q=-350
END
LOADS
 BUS7  P=967   Q=100  MP=0  MQ=0
 BUS9  P=1767  Q=100  MP=0  MQ=0
END
POWER CONTROL
 BUS1   TYPE=NODE  RTYP=UP  U=20.6  P=700    NAME=G1
 BUS2   TYPE=NODE  RTYP=UP  U=20.2  P=700    NAME=G2
 BUS3   TYPE=NODE  RTYP=SW  U=20.6  FI=-6.8  NAME=G3
 BUS4   TYPE=NODE  RTYP=UP  U=20.2  P=700    NAME=G4
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

2.1.1 Comments to power-flow data

Both the active and reactive parts of the loads are modeled with constant power character, i.e., MP = MQ = 0 in the data group "LOADS" in section **2.1**. If the user wants to get constant current character, select MP = MQ = 1. To get constant impedance character, select MP = MQ = 2.

BUS3 is the slack bus and its voltage angle is fixed to -6.8 degrees, according to the textbook, see data group "POWER CONTROL" in section **2.1** above.

2.2 Power-flow results

The four generating units have the following results in the textbook, see page 813.

Synchronous machine	P [MW]	Q [Mvar]	E_t [p.u.]
G1	700	185	$1.03 \angle 20.2°$
G2	700	235	$1.01 \angle 10.5°$
G3	719	176	$1.03 \angle -6.8°$
G4	700	202	$1.01 \angle -17.0°$

Table 2. Power-flow results within the textbook

The four generating units have the following results in Simpow.

Synchronous machine	P [MW]	Q [Mvar]	E_t [p.u.]
G1	700.0	184.8	$1.03 \angle 20.17°$
G2	700.0	234.2	$1.01 \angle 10.41°$
G3	718.9	175.7	$1.03 \angle -6.80°$
G4	700.0	201.4	$1.01 \angle -16.99°$

Table 3. Power-flow results from Simpow

As the reader can see, there are slightly differences in the reactive power production for two of the machines, G2 and G4, and for the voltage angle for machine G2. The differences are not necessary to analyze further since they are small.

3. Dynamic simulations and Linear Analysis - Dynpow

Dynpow is Simpow's tool for among other activities, run dynamic simulations and make linear analysis of the power system. Faults, disconnection of lines, and connection of shunt capacitors are example of events that can be applied to a dynamic simulation. Linear Analysis is included in Dynpow.

In the Kundur textbook, no time-domain simulations are included. However, a time-domain simulation is included in section **3.3** below.

All cases below use the power-flow solution computed in section **2** above.

From the Kundur textbook, case

- (a)
- (b) (i)
- (b) (ii)
- (b) (iii)
- (b) (iv)

are simulated in sections **3.1** and **3.2**, see page 814 in the textbook. An additional time-domain simulation can be found in section **3.3**.

3.1 Case (a)

In case (a) it is assumed that:

- manual excitation control for the synchronous machines, i.e., no exciters are used
- active components of loads have constant current characteristics, i.e., MP = 1
- reactive components of loads have constant impedance characteristics, i.e., MQ = 2

The points in the list are formulated in the dynamic file "casea.dynpow" in section **3.1.1** below.

3.1.1 Dynamic data in case (a)

Here follows a copy of the dynamic file "casea.dynpow".

```
case a - "Power System Stability and Control", P. Kundur, page 814.
**
CONTROL DATA
 TEND=0.0
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
```

```
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Below follows saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in the document below.
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.1.2 Comment about the synchronous machines' saturation characteristic

In section **3.8.2** in the textbook, the used saturation characteristic is described wherein the saturation parameters A_{sat}, B_{sat}, and y_{T1} are given. With this, two segments of the saturation curve are defined. Since y_{T2} is omitted at page 813 in the textbook, it can be assumed that the third segment mentioned at page 114 can be excluded since we will perform linear analysis in the initial operating point wherein a third segment will not come in question.

The *d*- and *q*-axis saturation are assumed to be identical.

For the unsaturated part, segment I, when the flux linkage $y_{at} \le y_{T1}$, we will use

$$y_I = 0 \tag{1}$$

and for segment II, when $y_{at} > y_{T1}$ we will use an exponential function,

$$y_I = A_{sat} e^{B_{sat}(y_{at} - y_{T1})} \tag{2}$$

When $y_{at} = y_{T1}$, equation (2) will be equal to $y_I = A_{sat}$. Hence, this representation results in a small discontinuity at the junction of segments I and II. This discontinuity causes problem in Simpow.

Saturation in Simpow is formulated by using the standard parameters V1D, V2D, SE1D, SE2D, V1Q, V2Q, SE1Q, and SE2Q. In the Kundur textbook it is said that the saturation function should be designed as in equation (1) and (2), hence it must be formulated as an $U(I_f)$-table in Simpow where U is the open-circuit characteristic of the stator voltage in p.u. and I_f is the field current in p.u..

I_f has the following relation to i_{fd};

$$I_f = L_{adu} i_{fd} \tag{3}$$

where

$$L_{adu} = X_d - X_a = 1.8 - 0.2 = 1.6 \tag{4}$$

see generator data[1].

To get the saturation on the $U(I_f)$-form, we have to reformulate the saturation as follows.

---

[1] X_a is equal to X_l in generator data.

Expression (3.186) in the textbook is reformulated to,

$$y_{at0} = y_{at} + y_{I} \tag{5}$$

In (5) should either (1) or (2) replace y_I, depending on the value of y_{at}.

y_{at0} in (5) is identified with $y_{at0} = I_f$. Hence equation (5) is rewritten as

$$I_f = y_{at} + y_{I} \tag{6}$$

For the unsaturated part, segment I, equation (6) is

$$I_f = y_{at} \tag{7}$$

and for segment II, equation (6) is

$$I_f = y_{at} + A_{sat} e^{B_{sat}\left(y_{at} - y_{T1}\right)} \tag{8}$$

In the textbook $A_{sat} = 0.015$, $B_{sat} = 9.6$, and $y_{T1} = 0.9$. With these values and by identifying $U = y_{at}$ in equation (8), we get the following saturation curve, $U(I_f)$.

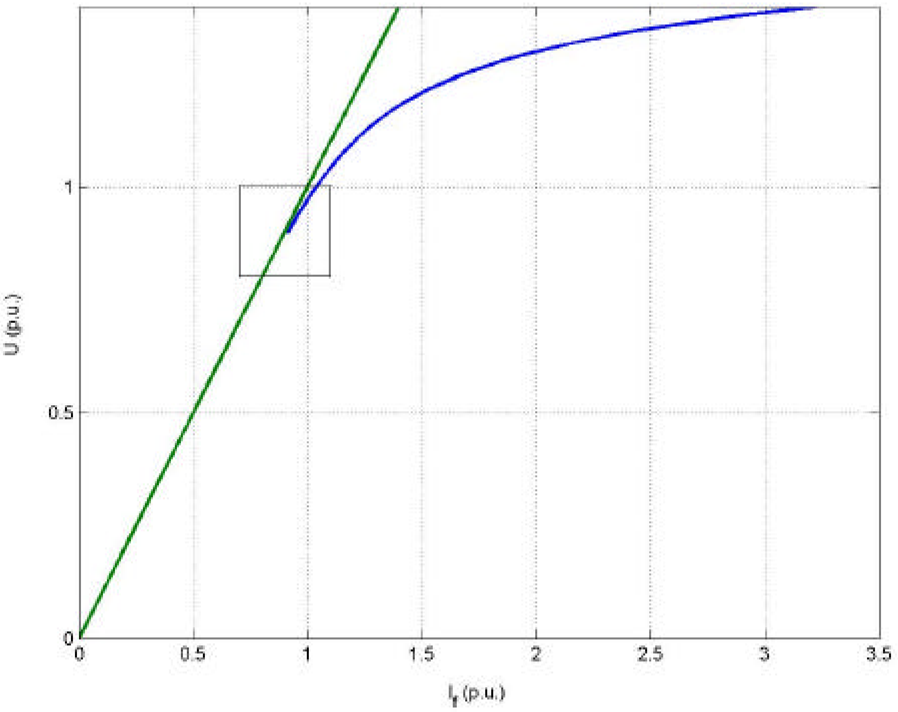


Figure 2. U as a function of I_f in the textbook. The straight line is describing the air-gap line. The marked area is up-scaled in the following figure

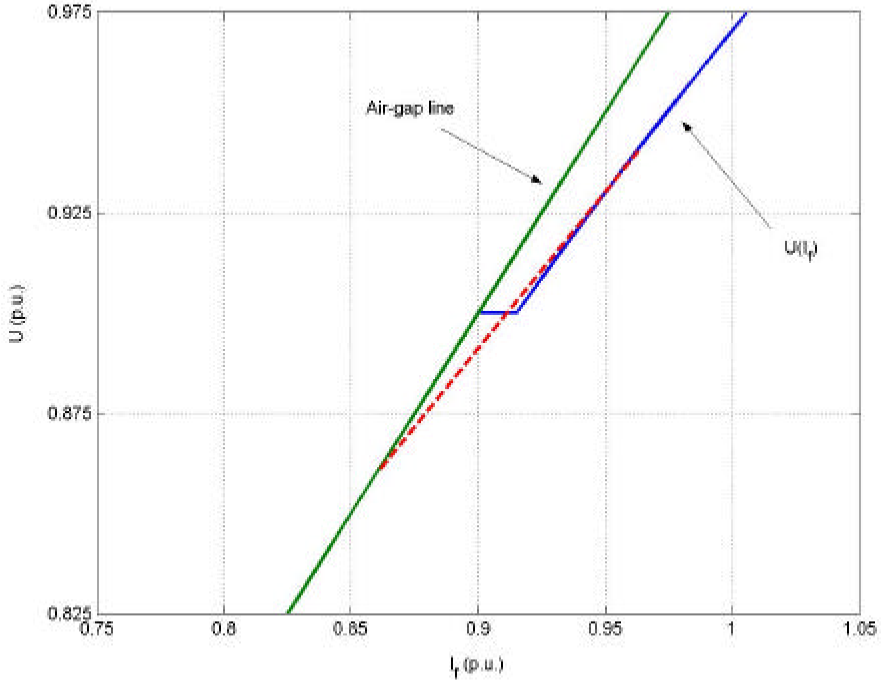


Figure 3. U as a function of I_f in the textbook. The discontinuity at y_{T1} = 0.9 is focused

When formulating the curve as a table, the discontinuity in y_{T1} = 0.9 will cause problem. In Simpow, a saturation table should contain increasing values, both in I_f -axis and U-axis. To solve this problem, the table has been "softly" formulated around the discontinuous point y_{T1} = 0.9, see data group "tables" in the Dynpow file in section **3.1.1**.

No table-values have been given between U = 0.86 and U = 0.94. In the figure above it is shown how the discontinuity is then ignored and how the saturation is formulated as a dashed line around the discontinuity to get a smooth and continuous junction between segment I and II. Therefore:

The formulation of the saturation characteristic have influence on the system's dynamic behaviour and the location of the system's eigenvalues in the following sections.

In addition to the saturation characteristic, also the used synchronous machine models in Simpow are different from the ones used in [4]. This affects the location of the eigenvalues in the following sections. Simpow's synchronous machine models can be found in [6].

3.1.3 Running case (a)

In this section we will perform Linear Analysis for the initial operating point, as described in the textbook. Use the power-flow solution "kundur" that was computed in section **2** and "casea.dynpow" in the following.

Use phasor models (Transta) and calculate the eigenvalues of the system. Phasor representation is valid for oscillation of approximately up to 20% of the fundamental frequency.

In case (a) we will focus on the eigenvalues that can be found in the linearized initial operating point. We will also perform Modal Analysis. The power system will be linearized for t = 0 sec.

First, all eigenvalues are computed with the quick response method (QR-method). Then, select all eigenvalues with real part greater than –1 and improve each of them (using the inverse iteration method).

After all eigenvalues have been recomputed, the list of eigenvalues with real part greater than –1 is reduced with one eigenvalue, see table 4 and 5 in the next section.

3.1.3.1 Linear Analysis of case (a)

In the textbook the following eigenvalues with real part greater than –1 are presented, see corresponding table **E12.3**, at page 815. Column 1, 2, and 4 in table **E12.3** are printed below.

Eigenvalues	Real part, [1/s]	Imaginary part , [Hz]
1, 2	-0.00076	± 0.0003
3	-0.096	-
4, 5	-0.111	± 0.545
6	-0.117	-
7	-0.265	-
8	-0.276	-
9, 10	-0.492	± 1.087
11, 12	-0.506	± 1.117

Table 4. Eigenvalues in case (a), as calculated in the textbook, page 815.
Eigenvalues with real part less than –1 are omitted in the table.

In Simpow, the following eigenvalues in the table below with real part greater than –1 exists. The enumeration of the eigenvalues in Simpow are not the same as in the table below.

Eigenvalues	Real part, [1/s]	Imaginary part , [Hz]
-, -	Not viewed in Simpow*.	Not viewed in Simpow*.
-	-	-
4, 5	-0.115	± 0.546
3, 6	-0.099	± 0.005
7	-0.204	-
8	-0.218	-
9, 10	-0.637	± 1.053
11, 12	-0.651	± 1.084

* Zero eigenvalues (eigenvalues close to the origin) are not presented in Simpow.

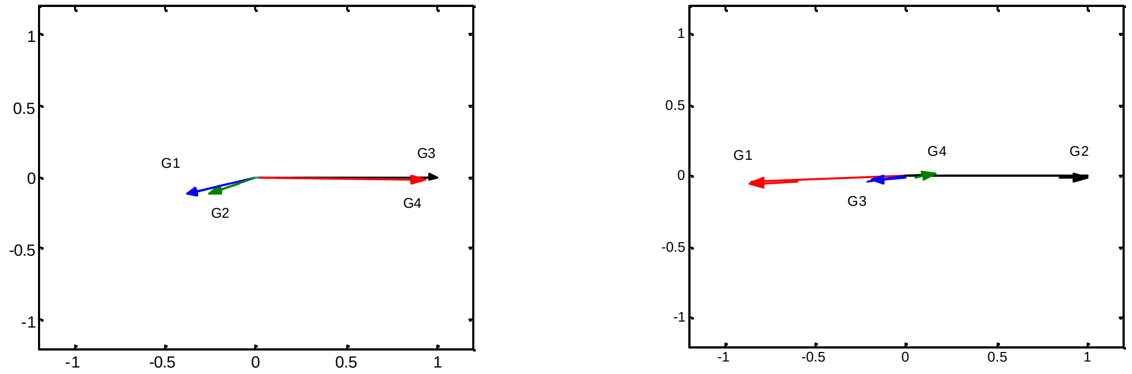
Table 5. Eigenvalues in case (a), as calculated in Simpow

In Simpow the imaginary part of an eigenvalue is measured in Hz.

Eigenvalues 9 – 12 are better damped in Simpow compared to the textbook. This is a consequence of that Simpow uses other synchronous machine models than the textbook. This can also be seen in section 3.2.2 below.

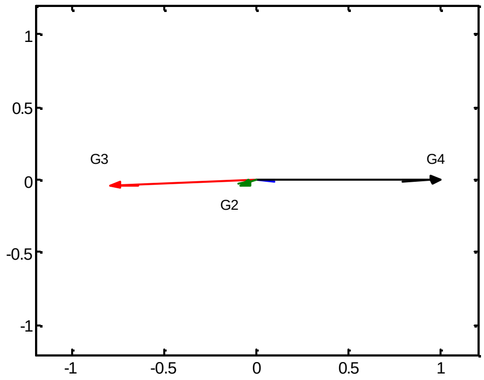
3.1.3.2 Modal Analysis of case (a)

By performing Modal Analysis of the three rotor angle modes, we can plot the three figures seen in figure **E12.10** at page 816 in the Kundur textbook. The three rotor angle modes are the eigenvalue pairs; 4/5, 9/10, and 11/12, see table 4 and 5 above.



(**a**) Interarea mode f = +0.546 Hz.

(**b**) Area 1 local mode f = +1.053 Hz.



(**c**) Area 2 local mode f = +1.084 Hz.

Figure 4. Mode shapes of rotor angle modes with manual excitation control, case (a)

In figure 4 (a), synchronous machines 3 and 4 are oscillating against 1 and 2. The machines in the right half of the system (area 2) are oscillating against the machines in the left half of the system (area 1). This is called an interarea mode, one area oscillating with another.

In figure 4 (b) synchronous machine 2 are oscillating against 1. The machines in the left half of the system (area 1) are oscillating locally. This is called a local mode.

In figure 4 (c) synchronous machine 4 are oscillating against 3. The machines in the right half of the system (area 2) are oscillating locally, a local mode.

3.1.3.3 Sensitivity of case (a)

The Simpow tool Sensitivity could also be used to provide the information above. With Sensitivity it is possible to see how much each power system component interacts with an oscillation from an eigenvalue.

3.2 Case (b) (i), (ii), (iii), and (iv)

Case (b) is split in four subcases named (i) – (iv). In all subcases all generators are equipped with different excitation controls.

In subcases (ii), (iii), and (iv) the inbuilt tool, DSL Code Generator in Simpow have been used to create the needed regulators. To run these three subcases, the DSL files "exc_htg.dsl", "exc_tgr.dsl", and "stabiliser.dsl" has to be compiled into a DSL Library. The necessary steps for doing this is described in [5]. The created DSL Library must be associated to the dynamic simulation.

The corresponding Dynpow files for the four cases are shown in section **3.2.3** below. The Dynpow files are named "casebi.dynpow", "casebii.dynpow", "casebiii.dynpow", and "casebiv.dynpow".

3.2.1.1 Case (b) (i)

In case (b) (i) it is assumed that the synchronous machines are equipped with:

- self-excited dc exciter.

3.2.1.2 Case (b) (ii)

In case (b) (ii) it is assumed that the synchronous machines are equipped with:

- thyristor exciter with a high transient gain, see figure 4.

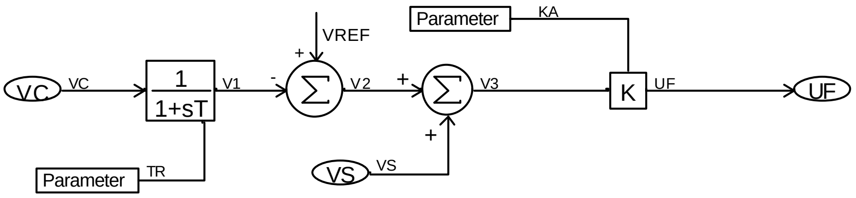


Figure 5. Thyristor exciter with a high transient gain, named EXC_HTG

3.2.1.3 Case (b) (iii)

In case (b) (iii) it is assumed that the synchronous machines are equipped with:

- thyristor exciter with a transient gain reduction (TGR), see figure 5.

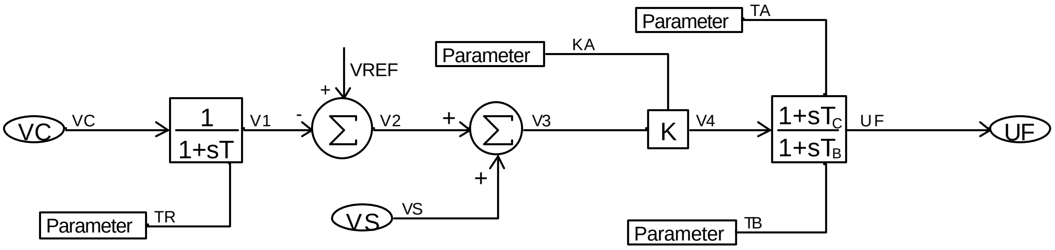


Figure 6. Thyristor exciter with a transient gain reduction (TGR), named EXC_TGR

Observe that the signs of the reference block diagram in figure 4 and 5 above are the opposite from figure **E12.9** in the textbook. This is caused by a small misprint in the textbook.

3.2.1.4 Case (b) (iv)

In case (b) (iv) it is assumed that the synchronous machines are equipped with:

- thyristor exciter with high transient gain in combination with a PSS, see figure 4 and 6.

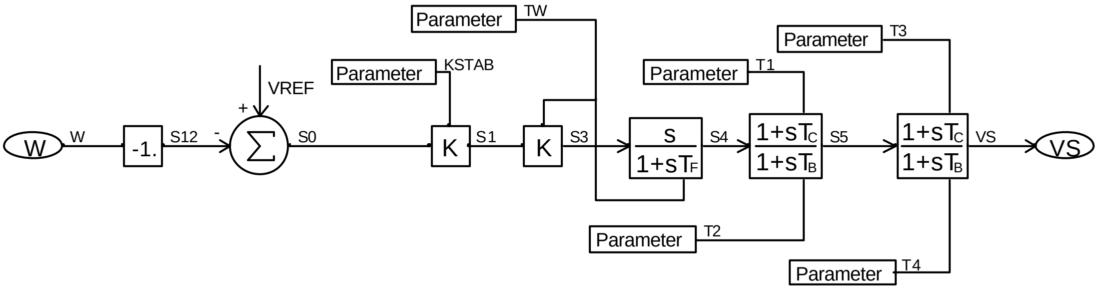


Figure 7. Power System Stabilizer (PSS), named STABILISER

A difference from figure **E12.9** in the textbook and the stabiliser above is the reference block diagram applied to the input signal. In Simpow, a stabiliser must be equipped with a reference block diagram as above. That expansion of the stabiliser should not generate any differences from the stabilizer depicted in the book.

3.2.2 Linear Analysis of case (b) (i), (ii), (iii), and (iv)

Below, table **E12.4** at page 816 in the Kundur textbook is shown. Damping ratio and imaginary part in [rad/s] are omitted but can be found in the textbook.

Type of Excitation Control	Eigenvalue (Real part [1/s] and imaginary part [Hz])		
	Interarea Mode	Local Mode in area 1	Local Mode in area 2
(i) DC Exciter	-0.018 ± j0.52	-0.485 ± j1.08	-0.500 ± j1.11
(ii) Thyristor with high gain	+0.031 ± j0.61	-0.490 ± j1.14	-0.496 ± j1.17
(iii) Thyristor with TGR	+0.123 ± j0.55	-0.450 ± j1.09	-0.462 ± j1.12
(iv) Thyristor with PSS	-0.501 ± j0.60	-1.826 ± j1.28	-1.895± j1.33

Table 6. Eigenvalues for case (b) (i), (ii), (iii), and (iv) in the textbook

Below, the results from the four cases simulated in Simpow are shown. Some differences can be seen among the eigenvalues in comparison with the textbook.

Type of Excitation Control	Eigenvalue (Real part [1/s] and imaginary part [Hz])		
	Interarea Mode	Local Mode in area 1	Local Mode in area 2
(i) DC Exciter	-0.038 ± j0.52	-0.622 ± j1.05	-0.637 ± j1.08
(ii) Thyristor with high gain	+0.052 ± j0.61	-0.804 ± j1.10	-0.808 ± j1.13
(iii) Thyristor with TGR	+0.108 ± j0.55	-0.615 ± j1.06	-0.626 ± j1.09
(iv) Thyristor with PSS	-0.512 ± j0.61	-2.354 ± j1.29	-2.413 ± j1.35

Table 7. Eigenvalues for case (b) (i), (ii), (iii), and (iv) as calculated in Simpow

The Local Modes in area 1 and 2 are better damped in Simpow compared to the textbook. This is a consequence of that Simpow uses other synchronous machine models than the textbook. This can also be seen in section 3.1.3.1 above.

3.2.3 Dynamic data in case (b)

3.2.3.1 Dynamic data in case (b) (i)

Here follows a copy of the dynamic file "casebi.dynpow".

```
case (b) (i) - "Power System Stability and Control", P. Kundur, page 814.
**
CONTROL DATA
 TEND=0.0
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=1
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=1
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=1
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=1
END
REGULATORS
1    TYPE=1    KA=20        TA=0.055  TE=0.36   KF=0.125   VR=0
     TF=1.8    SATTAB=2     TR=0.05   VRMAX=4.0 VRMIN=-4.0
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Table 1 below is the saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in document "Kundur's Two-Area System".
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
 2 TYPE=1 F 0.207 0.20  0.409 0.40  0.611 0.60
            0.813 0.80  1.000 1.00  1.528 1.50
            2.048 2.00  2.582 2.50  3.141 3.00
            3.741 3.50  4.413 4.00  5.206 4.50
            6.209 5.00  7.570 5.50  9.543 6.00
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.2.3.2 Dynamic data in case (b) (ii)

Here follows a copy of the dynamic file "casebii.dynpow".

```
case (b) (ii) - "Power System Stability and Control", P. Kundur, page 814.
```

```
**
CONTROL DATA
 TEND=0.0
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
END
REGULATORS
!!!! Regulator constructed within the DSL Code Generator:
 2    TYPE=DSL/EXC_HTG/     KA=200    TR=0.01
END
DSL-TYPE
 EXC_HTG(VC,TR,KA,VS/0/,UF,UF0)
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Below follows saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in the document "Kundur's Two-Area System".
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.2.3.3 Dynamic data in case (b) (iii)

Here follows a copy of the dynamic file "casebiii.dynpow".

```
case (b) (iii) - "Power System Stability and Control", P. Kundur, page 814.
**
CONTROL DATA
 TEND=0.0
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=3
```

```
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=3
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=3
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=3
END
REGULATORS
!!!! Regulator constructed within the DSL Code Generator:
 3    TYPE=DSL/EXC_TGR/     KA=200    TR=0.01  TA=1.0      TB=10.0
END
DSL-TYPE
 EXC_TGR(VC,TR,KA,TB,TA,VS/0/,UF,UF0)
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Below follows saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in the document "Kundur's Two-Area System".
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.2.3.4 Dynamic data in case (b) (iv)

Here follows a copy of the dynamic file "casebiv.dynpow".

```
case (b) (iv) - "Power System Stability and Control", P. Kundur, page 814.
**
CONTROL DATA
 TEND=0.0
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
```

```
END
REGULATORS
!!!! Regulators constructed within the DSL Code Generator:
 2    TYPE=DSL/EXC_HTG/     KA=200    TR=0.01  SWS=4
 4    TYPE=DSL/STABILISER/  KSTAB=20  TW=10    T1=0.05 T2=0.02 T3=3 T4=5.4
END
DSL-TYPE
 STABILISER(W,T4,T3,T2,T1,TW,KSTAB,VS,VS0)
 EXC_HTG(VC,TR,KA,VS/0/,UF,UF0)
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Below follows saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in the document "Kundur's Two-Area System".
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.3 Case fault connection

In this section a time-domain simulation is done.

In one of the lines between BUS8 and BUS9 a solid three-phase fault occur close to BUS8 in three periods with a following disconnection of the faulted line. The prepared dynamic file that should be used is "casefault.dynpow" and the power-flow file is "kundur.optpow".

Steam turbine models have been associated to the four synchronous machines, see dynamic data in section **3.3.1** below. This case is an extension of case (b) (iv).

Add the diagram information that can be found in the file "casefault.dynpost" to the simulation.

Diagram 1 shows the produced power in the four synchronous machines, diagram 2 shows the speed of the four machines, and diagram 3 shows the bus voltage in the faulted bus, BUS8. See figure 7, 8, and 9 below.

3.3.1 Dynamic data in case ‘fault’

Here follows a copy of the dynamic file "casefault.dynpow".

```
case fault - A three-phase fault close to BUS8 with disconnection of the line BUS8 - BUS9.
**
CONTROL DATA
 TEND=20
END
GENERAL
 FN=60
END
SYNCHRONOUS MACHINE
G1  BUS1  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1     TURB=1
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G2  BUS2  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1     TURB=1
```

```
                  H=6.5     SN=900    UN=20     D=0        VREG=2
G3  BUS3  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1     TURB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
G4  BUS4  TYPE=1  XD=1.8    XQ=1.7    XA=0.2    XDP=0.3    XQP=0.55
                  XDB=0.25  XQB=0.25  RA=0.0025 TD0P=8.0   TQ0P=0.4
                  TD0B=0.03 TQ0B=0.05 TAB=1     TURB=1
                  H=6.175   SN=900    UN=20     D=0        VREG=2
END
REGULATORS
!!!! Regulators constructed within the DSL Code Generator:
 2    TYPE=DSL/EXC_HTG/     KA=200    TR=0.01   SWS=4
 4    TYPE=DSL/STABILISER/  KSTAB=20  TW=10     T1=0.05 T2=0.02 T3=3 T4=5.4
END
DSL-TYPE
 STABILISER(W,T4,T3,T2,T1,TW,KSTAB,VS,VS0)
 EXC_HTG(VC,TR,KA,VS/0/,UF,UF0)
END
TURBINES
 1  TYPE = ST1 GOV=10 TC = 0.3 KH = 0.6 TR    7
 10 TYPE = SGC YMAX=1 YMIN = -1 K = 20 T1 = 0.1
END
LOADS
 BUS7 MP=1 MQ=2
 BUS9 MP=1 MQ=2
END
!!!! Below follows saturation characteristic for the synchronous machines.
!!!! See section 3.1.2 in the document below.
TABLES
 1 TYPE=1 F 0.000 0.00 0.700 0.70
            0.800 0.80 0.830 0.83
            0.860 0.86 0.962 0.94
            0.974 0.95 1.039 1.00
            1.113 1.05 1.202 1.10
            1.315 1.15 1.467 1.20
            1.682 1.25 1.998 1.30
            2.478 1.35
END
FAULTS
 F1 TYPE=3PSG NODE BUS8
END
RUN INSTRUCTION
 AT 1.000 INST    CONNECT FAULT F1
 AT 1.050 INST DISCONNECT FAULT F1
 AT 1.050 INST DISCONNECT LINE BUS8 BUS9 NO=1
END
END
!!!! The document "Kundur's Two-Area System",
!!!! revised August, 2001 refers to this file.
```

3.3.2 Time-domain simulation results from case 'fault'

Here are the three prepared diagrams viewed.

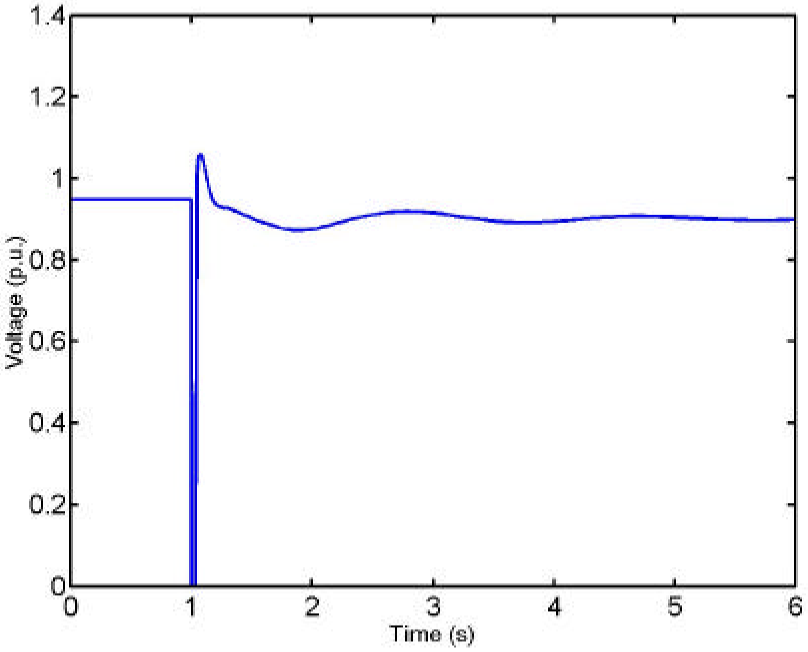


Figure 8. Bus voltage in the faulted bus, BUS8

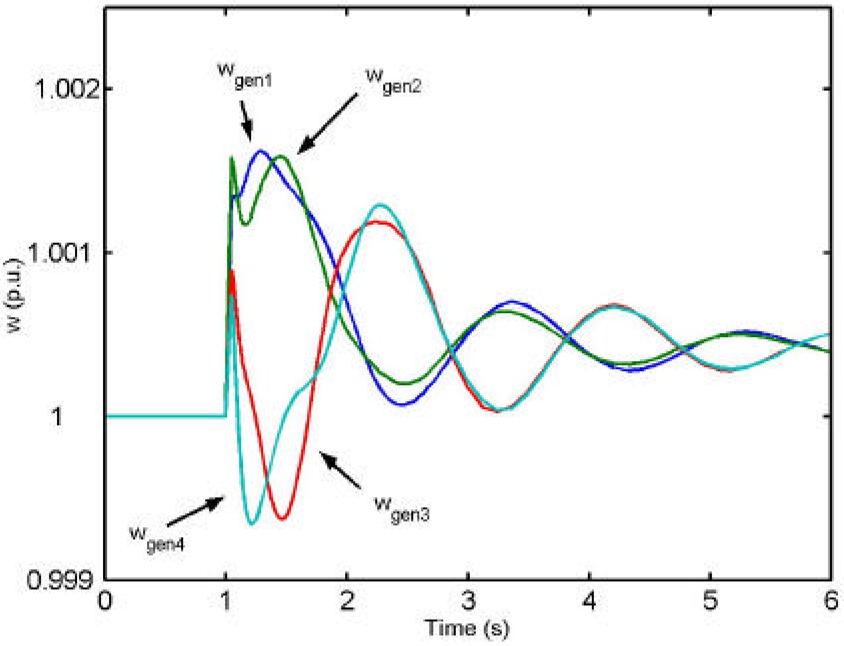


Figure 9. Speed of the four synchronous machines

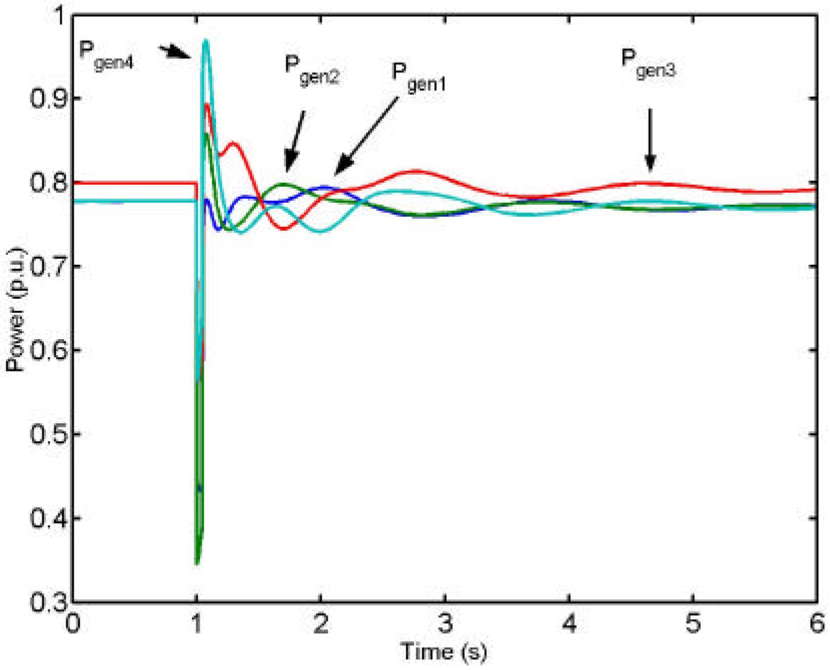


Figure 10. Produced power in the four synchronous machines

4. References

[1] M. Klein, G.J. Rogers, and P. Kundur: "A Fundamental Study of Inter-Area Oscillations", *IEEE Trans.*, Vol. PWRS-6, No. 3, pp. 914-921, August, 1991.

[2] J.G. Slootweg, J. Persson, A.M. van Voorden, G.C. Paap, W.L. Kling: "A Study of the Eigenvalue Analysis Capabilities of Power System Dynamics Simulation Software", presented at the Fourteenth Power Systems Computation Conference 2002, PSCC'02, Sevilla, Spain, June 24th – 28th, 2002.

[3] J. Persson, J.G. Slootweg, L. Rouco, L. Söder, W.L. Kling: "A Comparison of Eigenvalues Obtained with Two Dynamic Simulation Software Packages", presented at the IEEE Bologna Power Tech Conference 2003, BPT'03, Bologna, Italy, June 23rd – 26th, 2003.

[4] Prabha Kundur: "Power System Stability and Control", *The EPRI Power System Engineering Series*, 1994, McGraw-Hill, ISBN 0-07-035958-X.

[5] "Getting Started with SIMPOW®", STRI AB, Ludvika, Sweden.

[6] Emil Johansson: "Detailed description of Synchronous Machine Models used in Simpow", Technical Report TR H 01-160, ABB Utilities, Västerås, Sweden, December, 2001.

Good luck with your simulations!