ELEC0047 - Power system dynamics, control and stability

Dynamic simulation of a five-bus system

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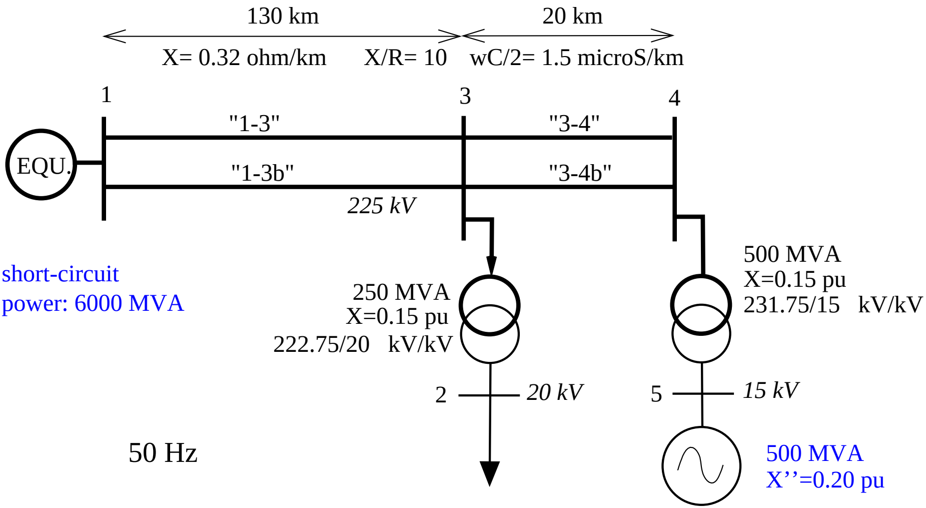
System modelling and operating points



Load tap changer controlling voltage at bus 2

transformer ratio : minimum : 0.88 maximum : 1.20
number of tap positions : 33
voltage dead-band : $[V^o - 0.01 \;\; V^o + 0.01]$ *pu*
delay before first tap change : 25 s between subsequent tap changes : 10 s

Generator G5: synchronous machine data

$$R_a = 0. \quad X_\ell = 0.15 \; pu \quad m = 0.10 \quad n = 6.0257$$

$$X_d = 2.20 \quad X'_d = 0.30 \quad X''_d = 0.20 \; pu$$

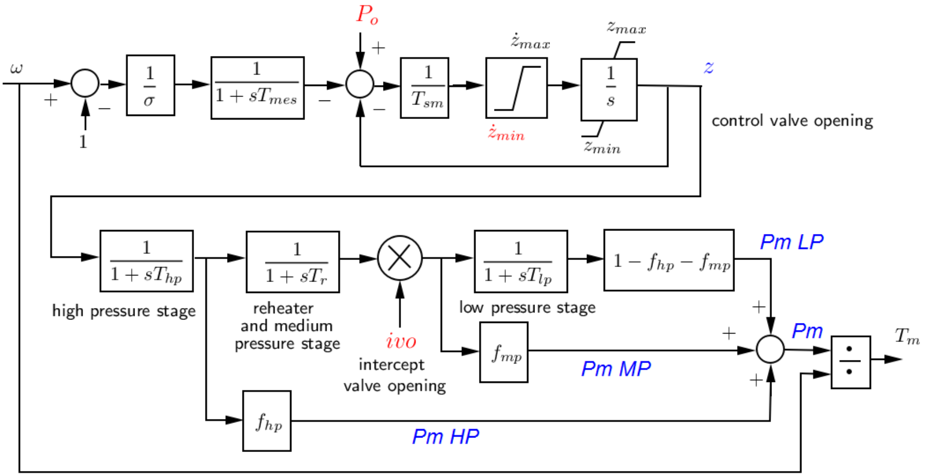
$$X_q = 2.00 \quad X'_q = 0.40 \quad X''_q = 0.20 \; pu$$

$$T'_{do} = 7.00 \quad T''_{do} = 0.05 \quad T'_{qo} = 1.50 \quad T''_{qo} = 0.05 \; s$$

$$H = 4 \; s$$

(values in pu on the generator 500 MVA base)

Generator G5: speed governor and steam turbine $P_{nom} = 460\ MW$

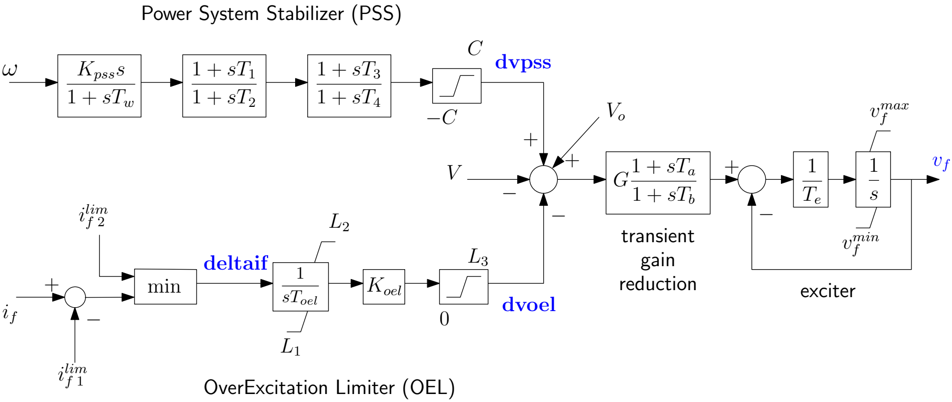


$\sigma = 0.04 \quad T_{mes} = 0.1\ s \quad T_{sm} = 0.4\ s$

$\dot{z}_{min} = -0.05\ pu/s \quad \dot{z}_{max} = 0.05\ pu/s \quad z_{min} = 0. \quad z_{max} = 1.\ pu$

$T_{hp} = 0.3\ s \quad f_{hp} = 0.4 \quad T_r = 5.0\ s \quad f_{mp} = 0.3 \quad T_{lp} = 0.3\ s \quad ivo = 1$

Generator G5: automatic voltage regulator, excitation system, overexcitation limiter



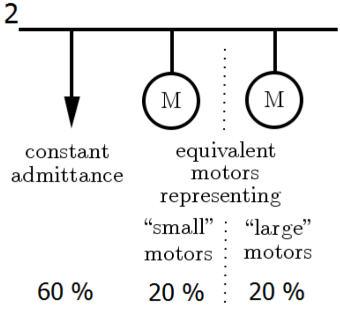
$$G = 70. \quad T_a = T_b = 1\ s \quad T_e = 0.4\ s \quad v_f^{min} = 0. \quad v_f^{max} = 5\ pu$$

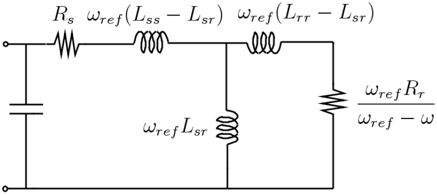
$$K_{pss} = 50 \quad T_w = 5\ s \quad T_1 = T_3 = 0.323\ s \quad T_2 = T_4 = 0.0138\ s \quad C = 0.06\ pu$$

$$i_{f\,1}^{lim} = 2.90\ pu \quad i_{f\,2}^{lim} = 1.00\ pu \quad T_{oel} = 8\ s \quad K_{oel} = 2.0$$

$$L_1 = -1.1 \quad L_2 = 0.1 \quad L_3 = 0.2\ pu$$

Modelling of load at bus 2





Mechanical torque: $T_m = T_{mo}(A\omega^2 + B)$

"small motors":

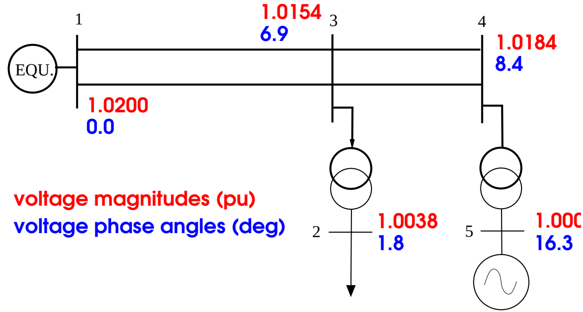
$$R_s = 0.031 \quad L_{ss} = 3.30 \quad L_{sr} = 3.20 \quad L_{rr} = 3.38 \quad R_r = 0.018\ pu$$
$$H = 0.7\ s \quad A = 0.5 \quad B = 0.5$$

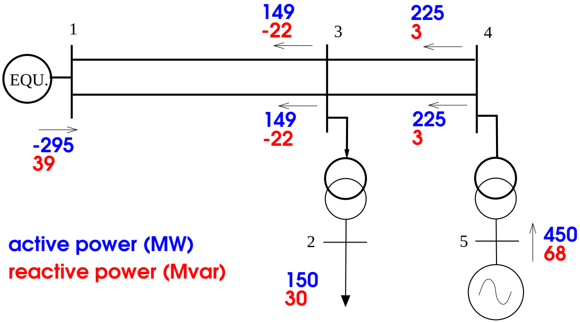
"large motors":

$$R_s = 0.013 \quad L_{ss} = 3.867 \quad L_{sr} = 3.80 \quad L_{rr} = 3.97 \quad R_r = 0.009\ pu$$
$$H = 1.5\ s \quad A = 0.5 \quad B = 0.5$$

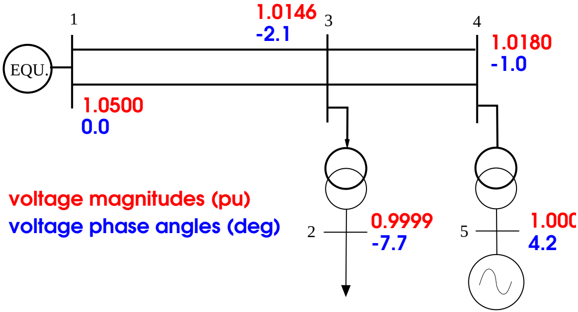
(values in pu on the motor MVA base)

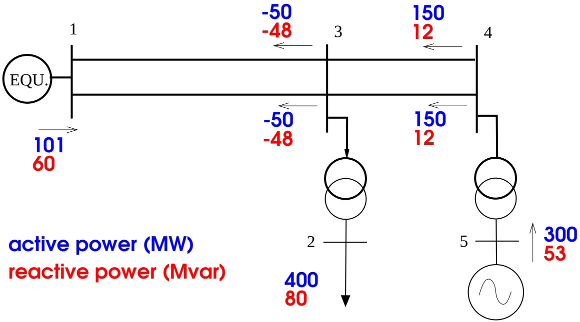
Operating point # 1





Operating point # 2





Syntax of disturbance file

```
  0.000 CONTINUE SOLVER BD 0.010 0.001 0.0 ALL
! add your events here, by increasing order of times.
 20.000 STOP
```

To increase the power setpoint of generator G by D pu in T seconds :

```
<time>  CHGPRM  TOR  G  Po  value_of_D  value_of_T
```

To increase the voltage setpoint of generator G by D pu in T seconds :

```
<time>  CHGPRM  EXC  G  Vo  value_of_D  value_of_T
```

To increase the value of the Thévenin voltage by D pu in T seconds :

```
<time>  CHGPRM  INJ  EQUIV1  ETH  value_of_D  value_of_T
```

To apply a fault at bus B with resistance R and reactance X (in Ω, can be zero) :

```
<time>  FAULT  BUS  B  value_of_R  value_of_X
```

To clear a fault at bus B :

```
<time>  CLEAR BUS B
```

To trip line XYZ:

```
<time>  BREAKER  BRANCH  XYZ  0  0
```

Case 1

- Operating point : # 2
- disturbance : at $t = 1$ s, increase of power set-point P_o by 115 MW in 10 s [1]
- simulated time : 60 s.

Comment as far as possible the evolution of :

- the generator active power
- the generator reactive power
- the generator rotor angle
- the generator field current
- the control valve z of the turbine
- the voltage magnitude at bus 3.

[1] power ramping are much slower in real life !

Case 2

- Operating point : # 1
- disturbance : at $t = 1$ s, increase of voltage set-point V_o by 0.05 pu in 2 s
- simulated time : 60 s.

Comment as far as possible the evolution of :

- the voltage magnitude at bus 3. In particular, explain the three "spikes" with the help of the proper curves
- the generator active power
- the generator reactive power
- the generator field current.

Case 3

- Operating point : # 1
- disturbance : at $t = 1$ s, “voltage dip” in the external system simulated by a decrease of the Thévenin voltage by 0.20 pu during 0.04 s
  (can be seen considered as an impulse response)
- simulated time : 20 s.

- Observe the evolution of the rotor speed of the generator
- Observe the evolution of the PSS output
  (select: generator G5 - observable of excitation control - dvpss)
- take the Power System Stabilizer (PSS) out of service, simulate the same disturbance and compare the evolution of the rotor speed with the previous one
- observe the evolution of the voltage magnitude at bus 3 and comment on the similarity
- what is the period of the dominant oscillation ?

Put the PSS back in service !

Case 4

- Operating point : # 1
- disturbance : at $t = 1$ s, a solid fault on line 1-3, cleared after 4 cycles (0.08 s) by opening the faulted circuit. The fault takes place very near bus 3, so that it can be applied at bus 3
- simulated time : 20 s.

Comment as far as possible the evolution of :

- the terminal voltage of the generator
- the active and reactive powers of the generator
- the rotor speed of the generator
- the field voltage of the generator
  (select: generator G5 - observable of excitation control - vf)
- the active power consumed by the impedance load at bus 2
- the active power consumed by one of the motors at bus 2
- the speed of one the motors at bus 2.

From RAMSES outputs, determine the current in line 3-4 during the short-circuit. Consider the value just after fault occurrence, for security. Check this value with a simple circuit calculation involving the generator equivalent circuit.

Case 5

- Operating point : # 2
- disturbance : at $t = 1$ s, tripping of **both** circuits of line 1-3 (without fault)
- simulated time : 25 s.

Comment as far as possible the evolution of :

- rotor speed of G5
- active power produced by G5
- control valve opening
  (select: generator G5 - observable of torque controller - z)
- turbine mechanical power
  (select: generator G5 - observable of torque controller - Pm ; in pu on the turbine nominal power).

Compute the final rotor speed using a formula from primary frequency control. Comment on the accuracy and try improving it.

Case 6

- Operating point : # 2
- disturbance : at $t = 1$ s, a solid fault on line 1-3, cleared after 10 cycles (0.20 s) by opening the faulted circuit. The fault takes place very near bus 3, so that it can be applied at bus 3
- simulated time : 20 s.

- Observe that the voltage at bus 3 does not recover near 1 pu, but stays "locked" near 0.84 pu[2]. Find which system component is responsible for this, with the help of the proper curves
- show that for some shorter fault duration (i.e. smaller than 0.20 s), the voltage does not stay "locked" at such a small value. Explain the underlying instability mechanism.

[2] this is a totally unacceptable value ! The system is considered unstable

Case 7

- Operating point : # 1
- disturbance : at $t = 1$ s, severe disturbance in the external system simulated by a decrease of the Thévenin voltage by 0.2 pu in 1 s
  (the voltage remains at its low value)
- simulated time : 120 s.

- Explain why the voltage at bus 3 drops so much after some time.