Regulating Transformers and FACTS Devices

Lab 3

EEEN40550 - Power System Dynamics & Control

Learning and Program Outcomes

The purpose of this lab activity is to get familiar with the dynamic behaviour of regulating transformers and FACTS devices. The learning outcomes of this lab activity are twofold:

- To understand the effect on steady-state and transient operation of power systems of the voltage regulation of ULTCs and shunt FACTS devices.
- To understand the effect on steady-state and transient operation of power systems of active power regulation of phase-shifting transformers and series FACTS devices.

The program outcome of the lab is to familiarize with a software tool for time domain simulation of electric power systems.

Exercises

Consider the dynamic model of the IEEE 14-bus system with AVRs. Consider the outage of line connecting buses 2 and 4, occurring at $t = 1$ s. Determine the effect on bus voltages and machine rotor speeds in the following scenarios:

Steady-state analysis (power flow) :

1. Determine whether varying the tap ratio and/or the phase-shift of transformers allows reducing system losses.
2. Include an SVC at bus 14 and determine whether varying the reference voltage allows to reducing system losses.
3. Substitute line 5-4 for a TCSC device controlling the active power flow and determine whether varying the reference power allows to reducing system losses.

Dynamic analysis (time domain simulation) :

1. Simulate the outage of the line connecting buses 2 and 4 and discuss the dynamic response of the system with inclusion of the following devices and controllers:

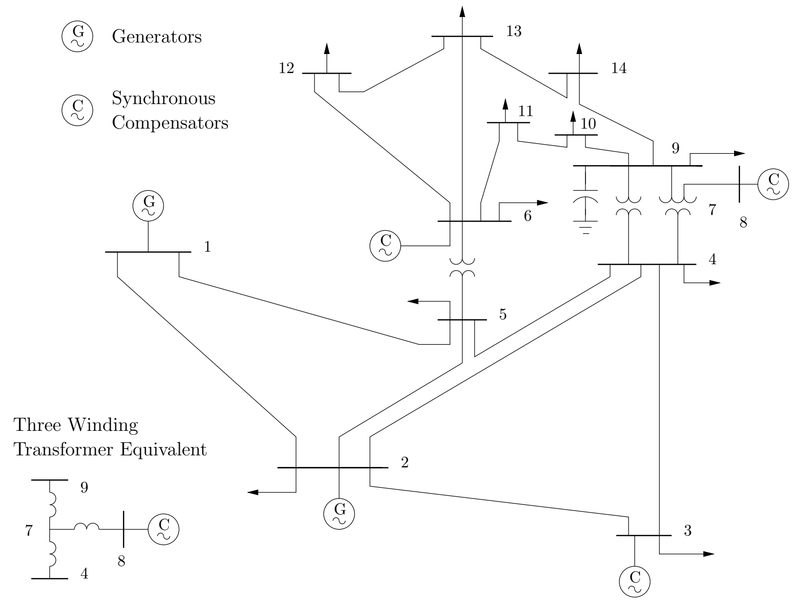


Figure 1 IEEE 14-bus test system.

- a ULTC controlling the secondary voltage on the transformer connecting buses 4 and 9.
- a Phase shifter on the transformer connecting buses 5 and 6.
- an SVC at bus 14.
- a TCSC connecting buses 5 and 4.

For both static and dynamic analyses, indicate which devices are most effective to improve the overall system performance.

Data File

Use the file `ieee14_dynamic.dm` that can be found in the collection of data files on the module website. Note the `ALTER` commands at the end of the data that impose a load increase of 20% with respect to the base case. The one-line diagram of the network is shown in Fig. 1.

Hints

- For static analysis with ULTCs and Phase Shifters, simply use the `Line` model. Use `Ultc1` and `Phs` for dynamic analyses.
- For the SVC use the device `Svc1`. This is a dynamic device and can be used for both static and dynamic analyses.

- For the TCSC use the device `TcscLine` for static anlaysis and `Tcsc1` for dynamic analysis. To properly set up the regulated power flow of the TCSC, follow the following procedure.

  1. First set the power regulated by the TCSC equal to the power that flows in the line for the base case condition.
  2. Then increase and decrease the power regulated by the TCSC and discuss the results.

- The time domain integration can be solved using the command:

  ```
  >> dome -r TDS ieee14_dynamic.dm
  ```

  Help on available options can be obtained using the command:

  ```
  >> dome -A TDS
  ```

- Time domain simulation results can be plotted using the `domeplot` command.
- It may be necessary to modify default control parameters (e.g., regulator gains and time constants) of regulating transformers and FACTS devices. Run some simulation to determine whether varying such parameters improves the transient response of the system.
- 20 to 30 s of simulated time should be sufficient to fully define the behaviour of the system.
- It can be useful to run an eigenvalue analysis of pre- and/or post-disturbance conditions to determine whether the inclusion fo regulating transformers and FACTS devices in the system leads to an acceptable (e.g., stable) operating point.
- Set `Settings.coi = True` for all simulations.
- For all exercises, set `TDS.pq2z = False` and `SSSA.pq2z = False`.
- It can be convenient to set a fixed time step for the time domain integration: `TDS.fixt = True` and a reasonably small time step, e.g., `TDS.tstep = 0.1`.
- The IEEE 14-bus system models a US network. The system frequency should be set to 60 Hz, e.g., `Settings.freq = 60`.

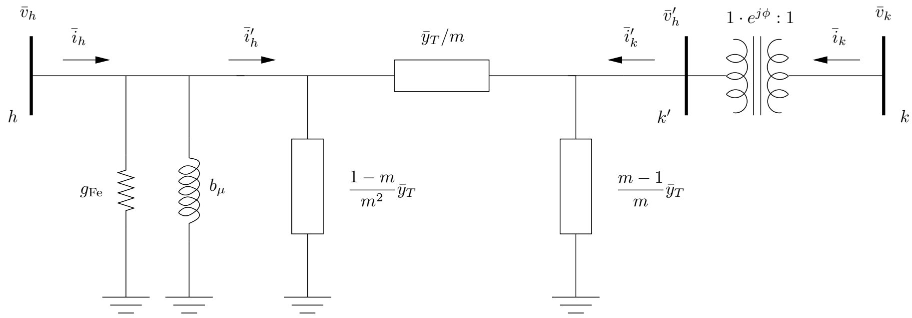
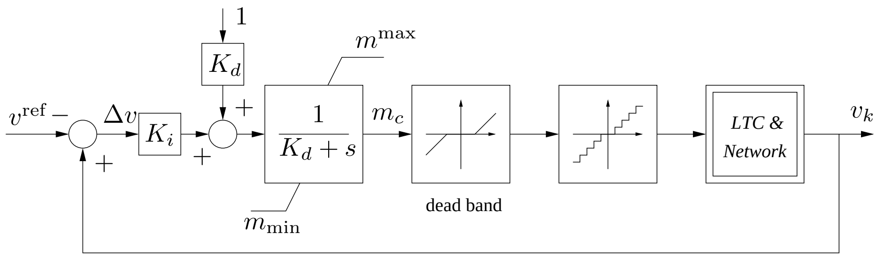


Figure 2 Transformer equivalent circuit.



Models and Controller Schemes

The dynamic synchornous machine models used in this laboratory activity are 5^{th} and 6^{th} order models. The Dome devices that implement these models are `Syn5d` and `Syn6a`, respectively. No saturations are considered.

Figures 2, 3, 4, and 5 show the control schemes of the transmission line that can be used to define static regulating transofrmers as well as control scheme diagrams of dynamic regulating transformers and FACTS devices. Note that the data of dynamic regulating transformers and FACTS devices are **not** included in the data file `ieee14_dynamic.dm`.

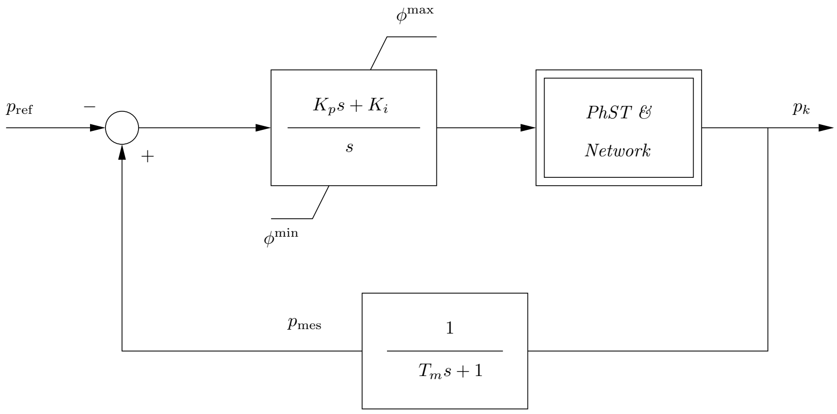


Figure 3 Phase shifting transformer control diagram.

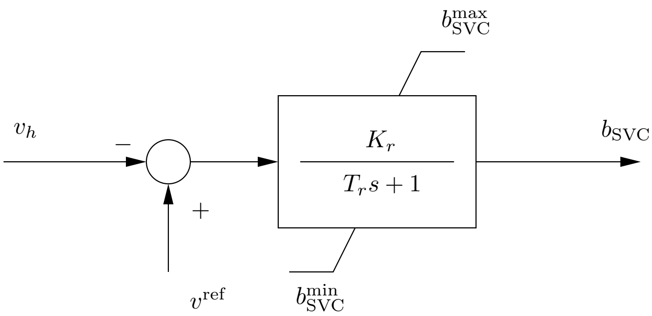


Figure 4 SVC control diagram.

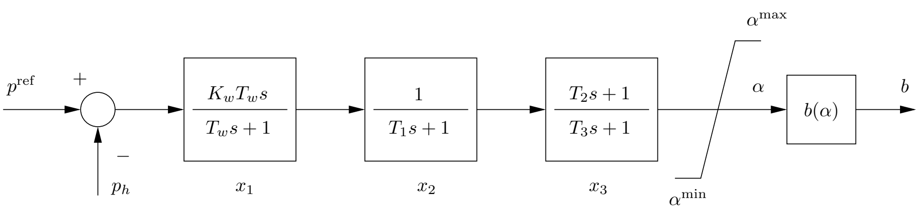


Figure 5 TCSC control diagram.