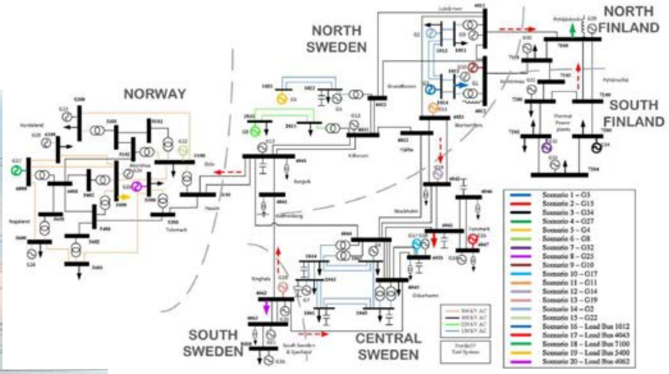
COSI: CO-simulation model for safety and reliability of electric systems in flexible environment of NPP

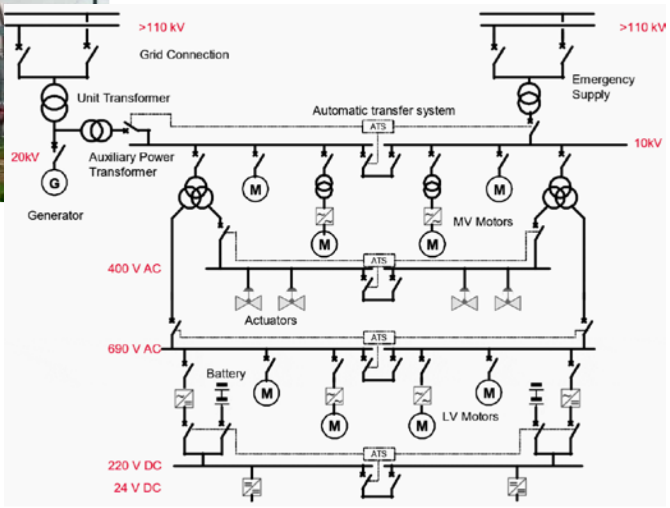
Poria Divshali, (VTT)
John Millar (Aalto)

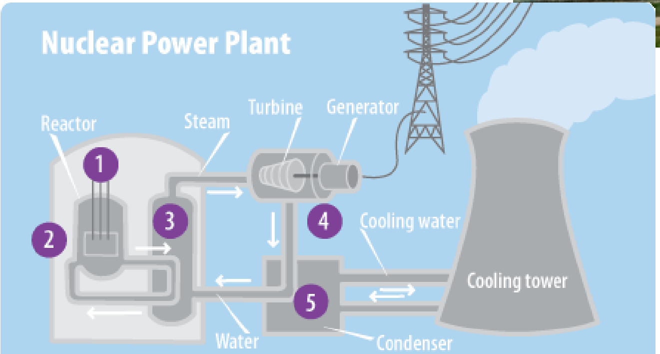
Nuclear Power Plant

Combination of several systems

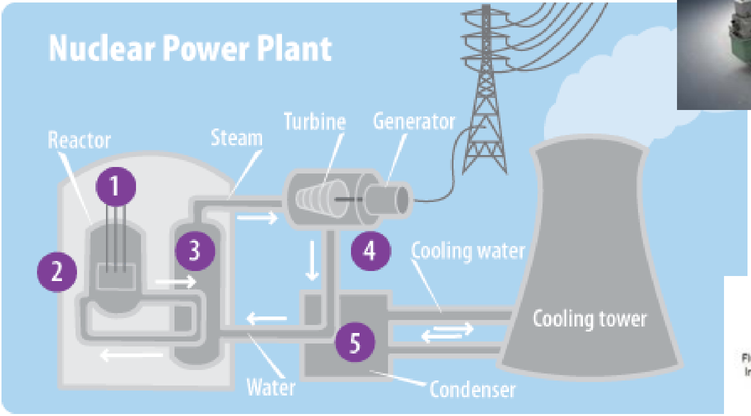
Nuclear Power Plant Model

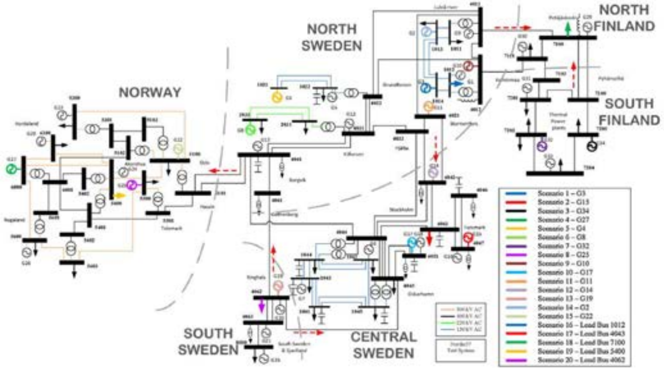


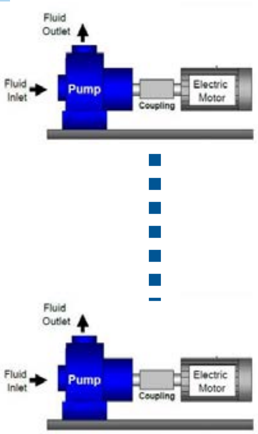


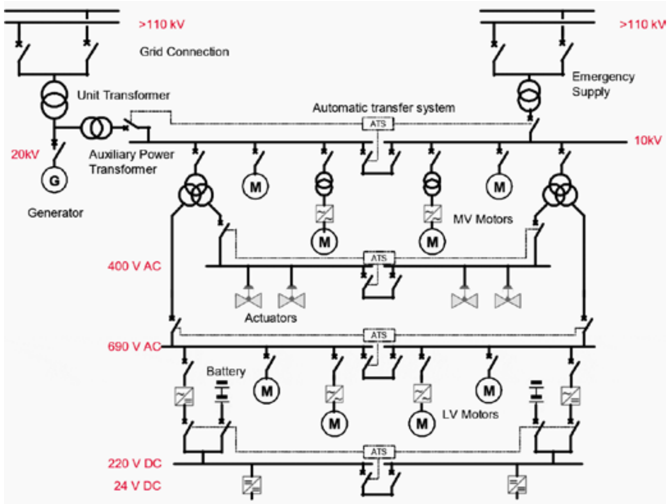


Nuclear Power Plant Model





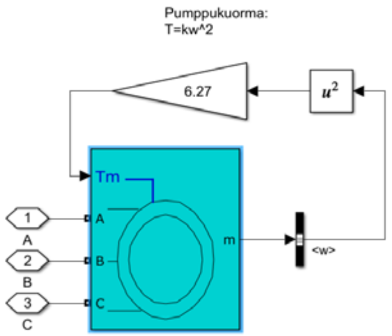




The existing power plant model

- Internal Electrical System Model
  - Each pump model by a Torque (T)

$$T = k \cdot w^2$$



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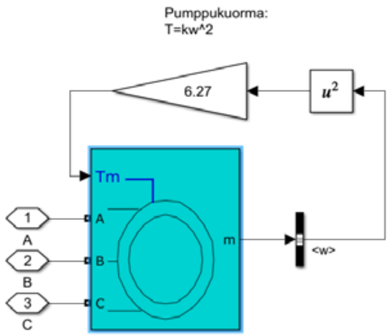

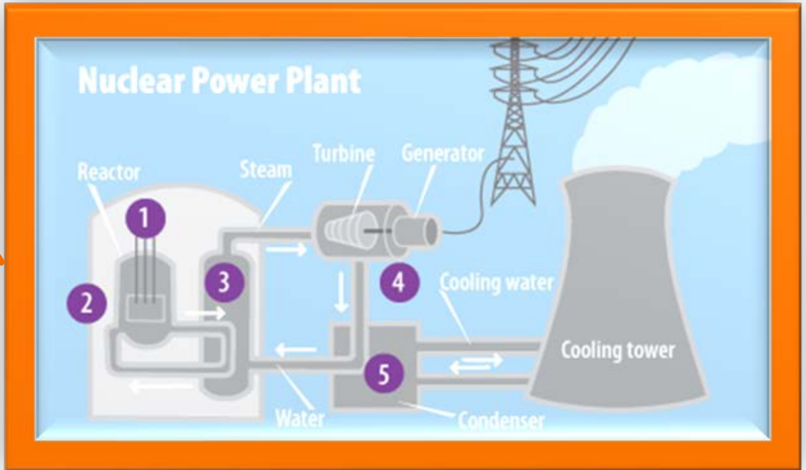

The existing power plant model

- Internal Electrical System Model
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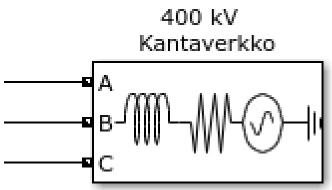
    T = k . w^2

  - Transmission grid model by Ideal or Thevenin equivalant



The existing power plant model

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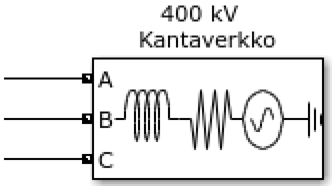
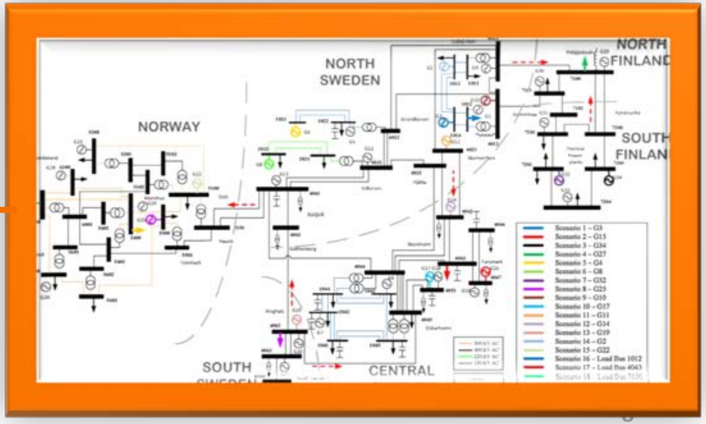




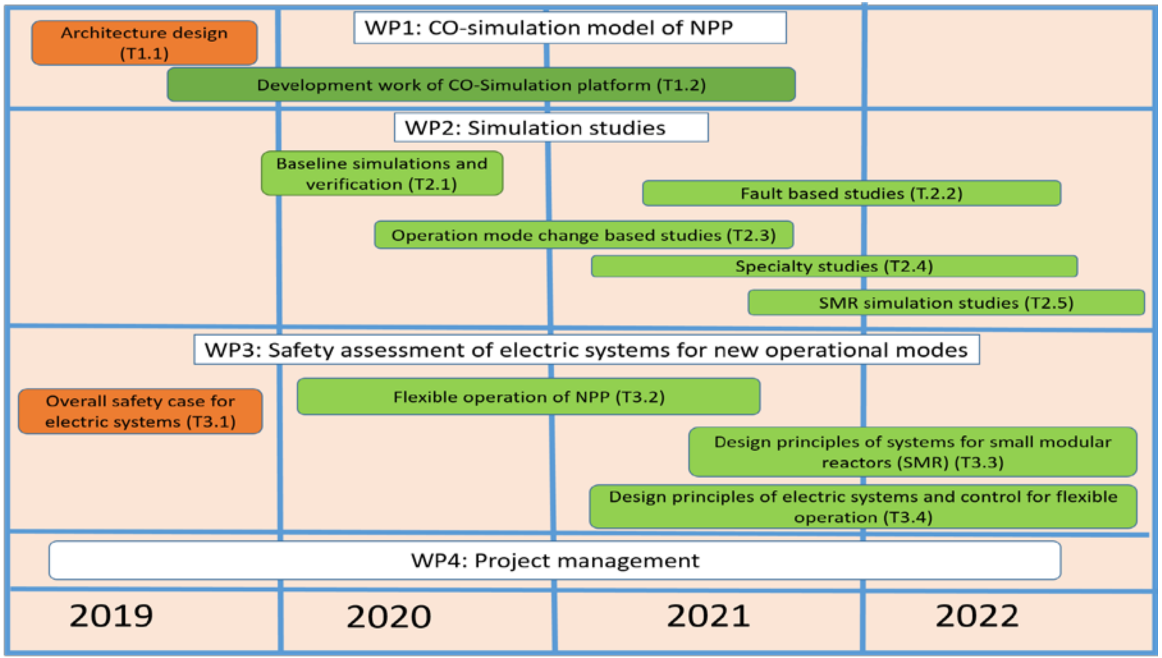
The existing power plant model

- Thermomechanical model
  - Apros has electrical system modeling, however limited to
    - Main component models
    - General studies, for example just symetrical studies
    - It is not popular/standard amoung power system experts

Objective

- Provide supporting analyses for safety case:
  - A detailed multi-physic simulation model for on-site electric power system of NPP interfaces to the off-site high voltage power system model and to thermal, reactor-physical and automation models.
  - COSI will develop plant specific co-simulation models starting with FORTUM's models and integrating later TVO's and possible Fennovoima models.
  - The simulation platform will be utilized for evaluation the adequacy and balance of safety requirements of the electrical systems in NPP in the cases of faults and disturbances

COSI Project Plan for 2020



WP1: COSI Simulation platform architecture

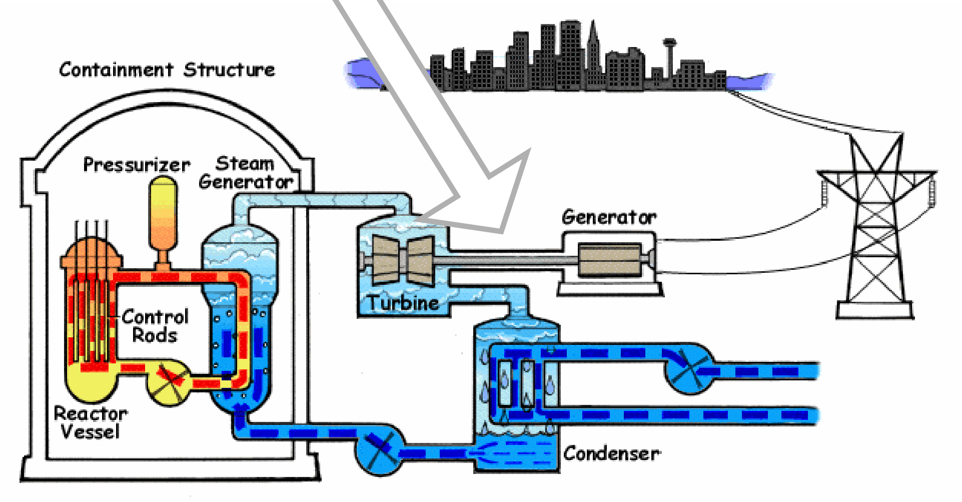
Poria Divshali, VTT

Exchange Layout (1)

- Turbine / Generator

Power System Simulator
e.g. Simulink

Coupling



Apros

Exchange Layout (2)

- Turbine / Generator

Coupling

$$\frac{d}{dt}\omega = \frac{1}{2H}(T_e - F\omega - T_m)$$

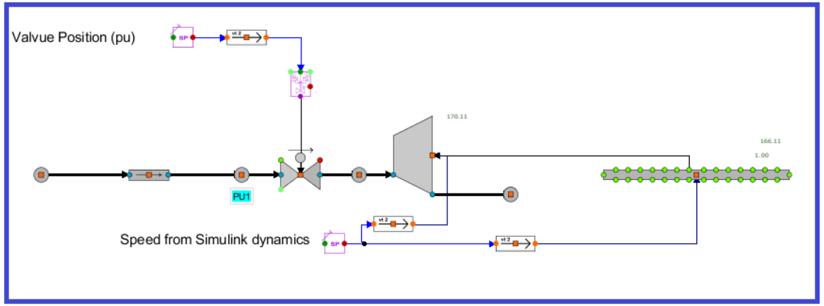
$$\frac{d}{dt}\theta = \omega$$

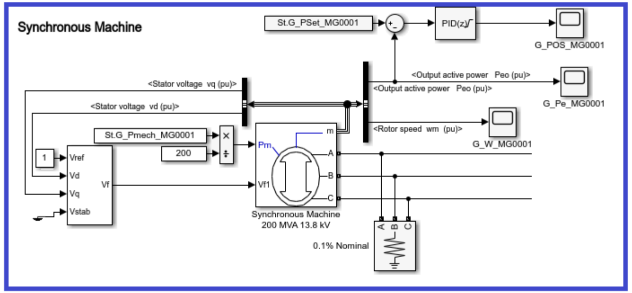
Power System Simulator e.g. Simulink

Rotational speed

Mechanical Power

Control Signals



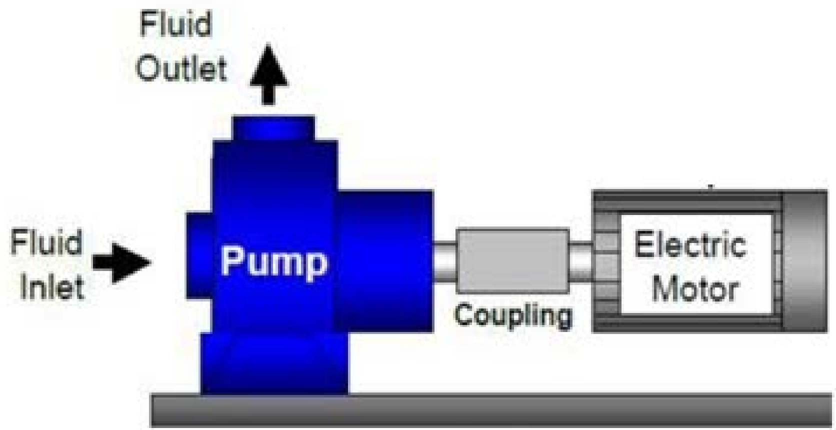


Apros

Exchange Layout (3)

- Pump / Turbine

Power System Simulator
e.g. Simulink



Apros

Exchange Layout (4)

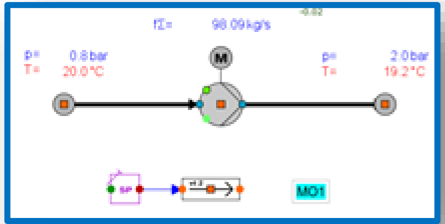
- Motor (common) Pump

Coupling

$$\frac{d}{dt}\omega = \frac{1}{2H}\left(T_e - F\omega - T_m\right)$$

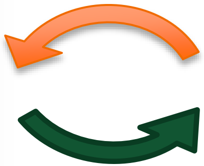
$$\frac{d}{dt}\theta = \omega$$

Power System Simulator e.g. Simulink

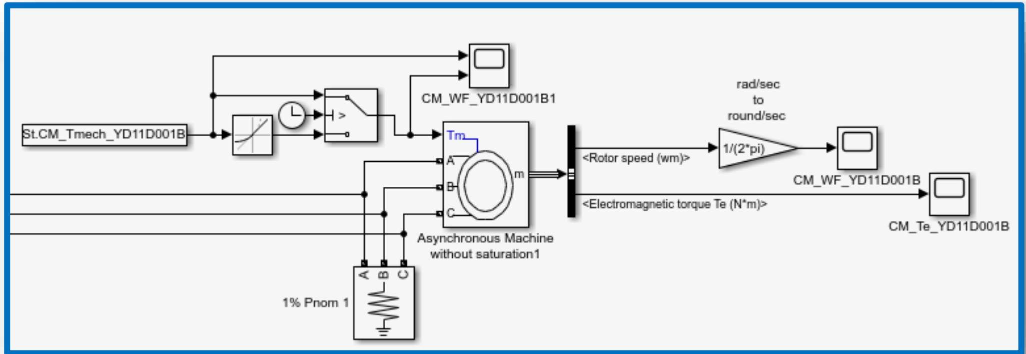


Apros

Rotational speed



Mechanical Power



New motor pump operation mode added to Apros

T1.1 Architecture design

- **Co-simulation challenges which should be answered in architecture**
  - Data Exchange layout among simulators
  - Time step handling between simulators

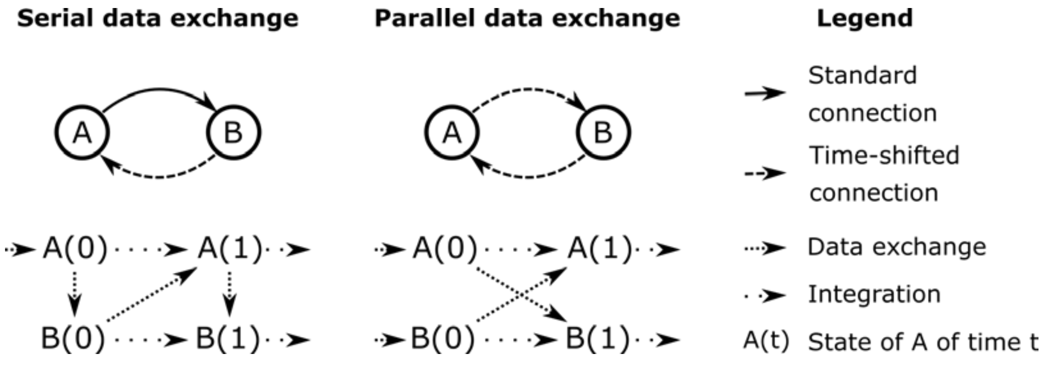
Each Simulator must follow its internal time step, which is totally different in these tools.

T1.1 Architecture design

- **Co-simulation challenges which should be answered in architecture**
  - Data Exchange layout among simulators
  - Time step handling between simulators
  - Data exchange intervals between two simulators

A parallel Data Exchange is selected.

In each interval, the platform checks weather all Simulators finish their tasks?



T1.1 Architecture design

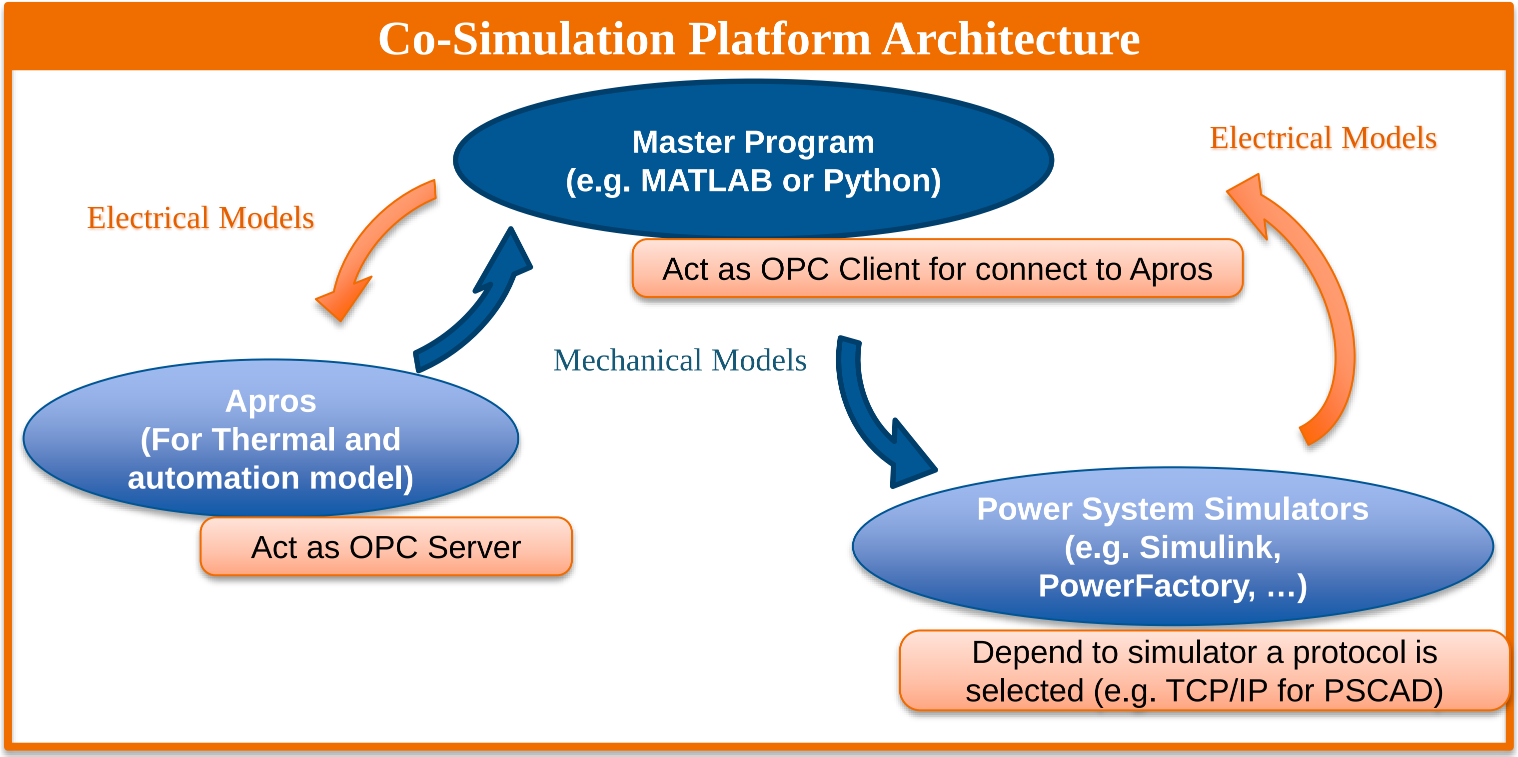
- **Co-simulation challenges which should be answered in architecture**
  - Data Exchange layout among simulators
  - Time step handling between simulators
  - Data exchange intervals between two simulators
  - Protocol of data exchange between simulators

Protocol of data exchange between simulators

- **Different simulators in electrical power system of NPP**
  - MATLAB/Simulink
  - PowerFactory DigSILENT
  - PSCAD
  - …
- **Different simulators in transmission power systems**
  - PowerFactory DigSILENT
  - PSS/E
  - PSCAD
  - …
- **Apros**

Open Platform Communications (OPC) standard

Architecture design



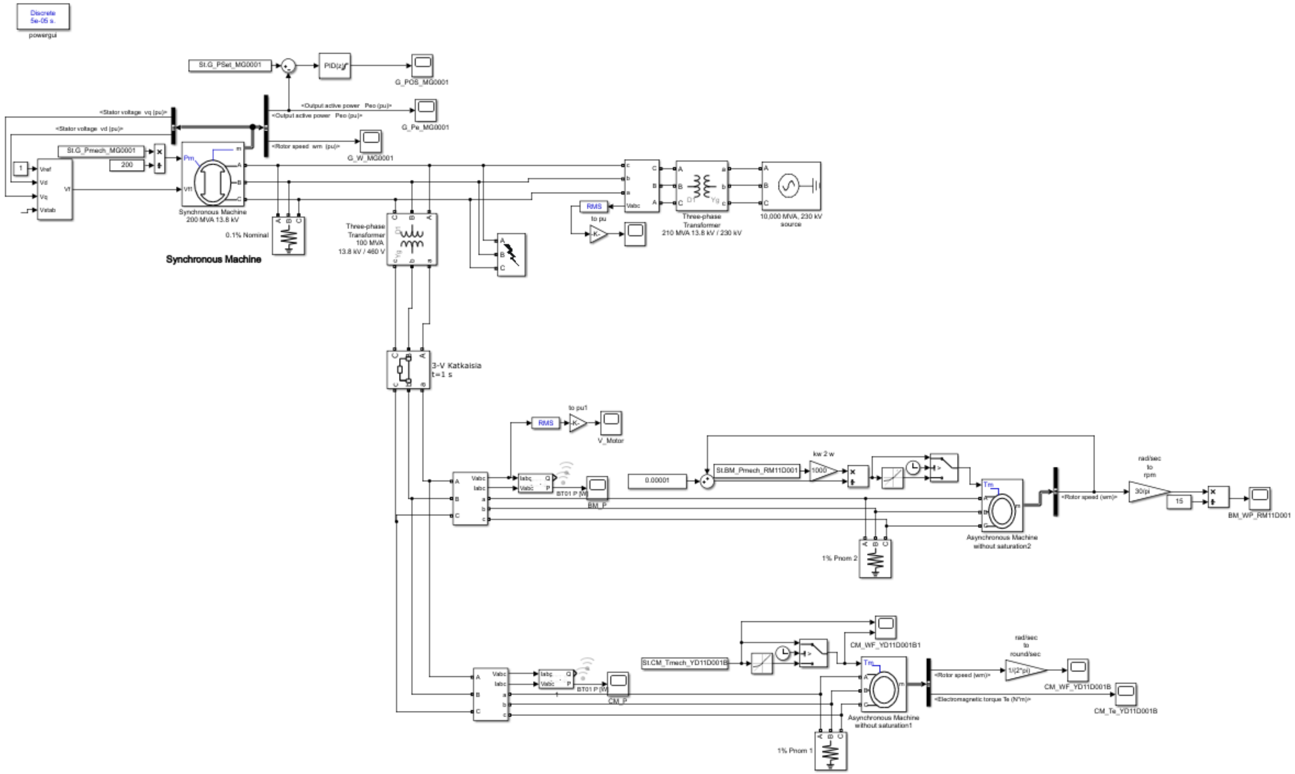
T1.1 Architecture design

- **Co-simulation challenges which should be answered in architecture**
  - Data Exchange layout among simulators
  - Time step handling between simulators
  - Data exchange intervals between two simulators
  - Protocol of data exchange between simulators
  - Initialising of all Simulators in steady-state
    - Load Apros IC
    - Load Simulink IC
    - Start master program from steady-state condition

Preliminary Co-Simulation (1)

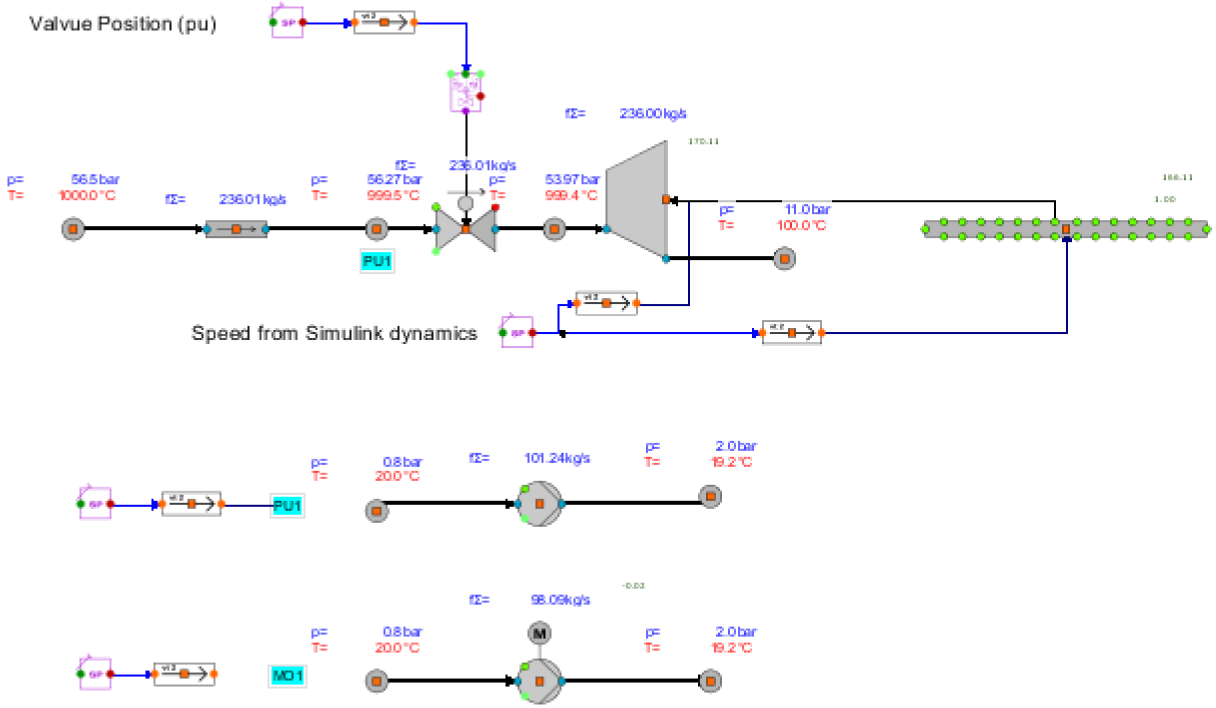
- **Power System in Simulink (Generator and Motors)**

3 Phase Fault at t=3 s



Preliminary Co-Simulation (2)

- **Turbine and Pumps Models in Apros**



Preliminary Co-Simulation (3)

- Improve the master code to a more user friendly version
  - For changing the model need to update just the lay-out file

```
%% Generators Model
% Layout.GenSet = { 1)Name , 2) Parameters , 3) Inputs, 4)Output;
%            ....
%                  };
% 1)Name : Exact Name in Appros and Simulink
% 2) Parameters:[ 2-1)G_PSet_ ]
    % 2-1)G_PSet_:  Initialize seting for Pelectrical (PeoSet)(pu)
% 3) Inputs: [ 3-1)G_Pmech_ ]
    % 3-1)G_Pmech_ : Initialize  Mechanical power of Turbine (MW)
% 4) Output: [ 4-1)G_POS_, 4-2)G_W_ ]
    % 4-1)G_POS_: Initialize valve position
    % 4-2)G_W_: Initialize rotation speed (RPM)

Layout.GenSet = {'MG0001' 0.9 166.5 [0.51 3000]};

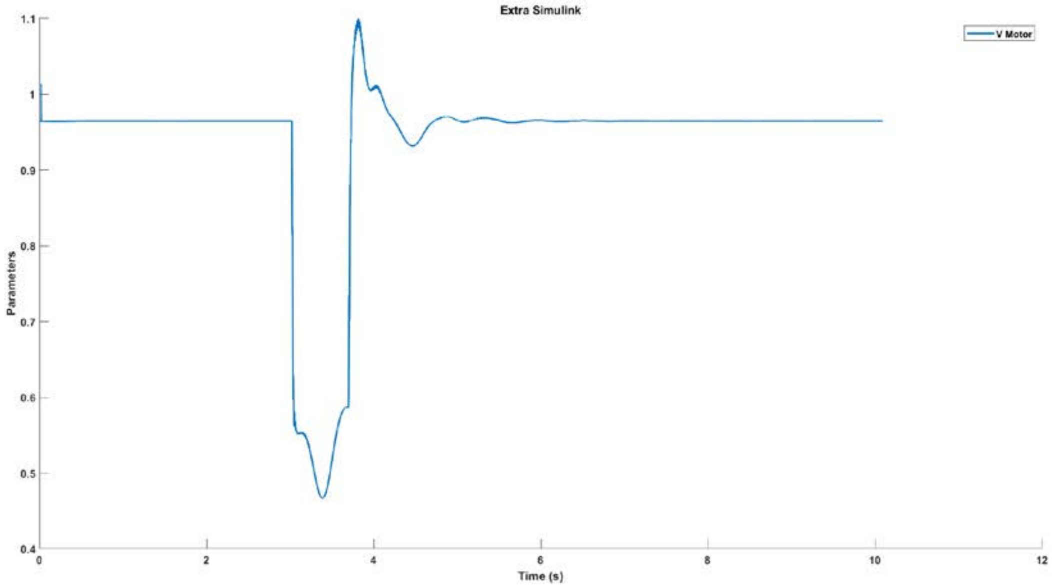
%% BasicPump Model
% Layout.BasicMotor = { 1) Name , 2) Inputs, 3)Output;
%            ....
%                  };
% 1) Name : Exact Name in Appros and Simulink
% 2) Inputs: St.BM_Pmech_...: Initialize Mechanical Power (kW) of Motor
% 3) Output: BM_WP_...: Initialize Speed of Motor (%)

Layout.BasicMotor = {'RM11D001' , 15.72, 98.03};

%% CommonPump Model
% Layout.ComMotor = { 1) Name , 2) Inputs, 3)Output;
%            ....
%                  };
```

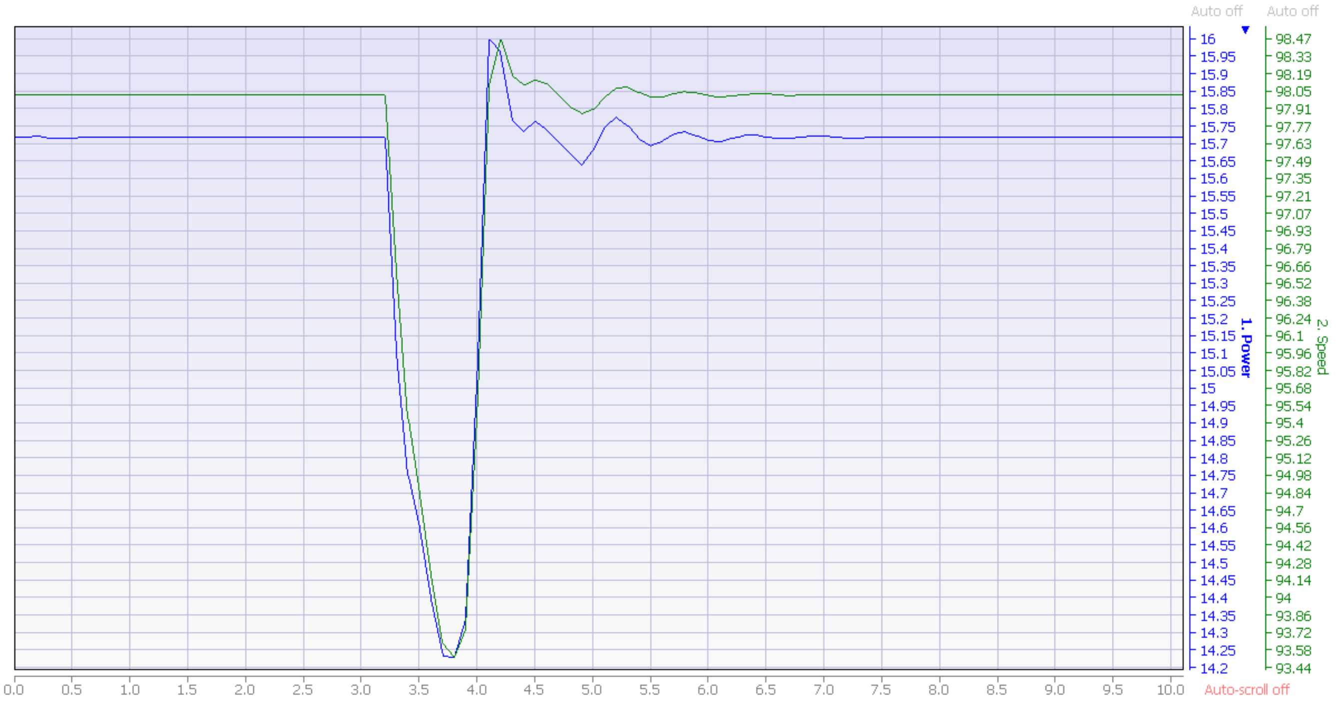
Preliminary Co-Simulation Results (1)

- **Voltage @ Motor Terminal**



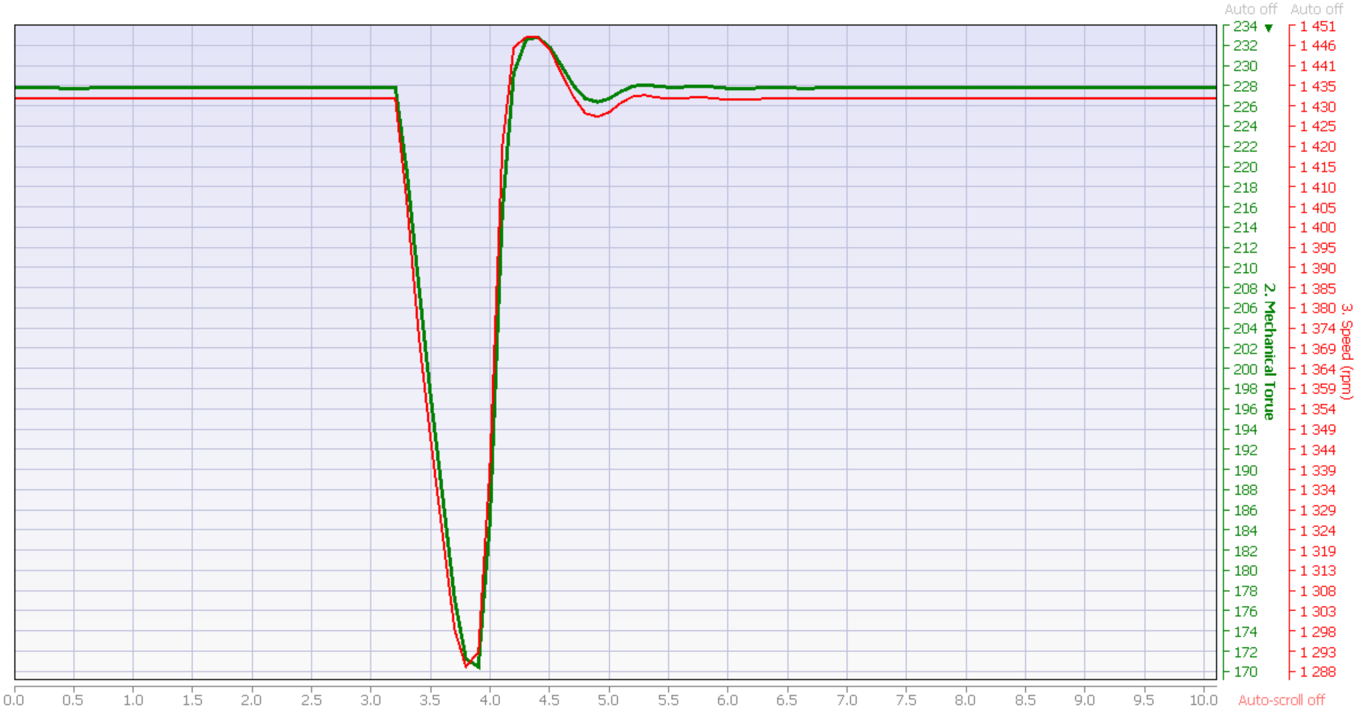
Preliminary Co-Simulation Results (2)

- **Motor 1**



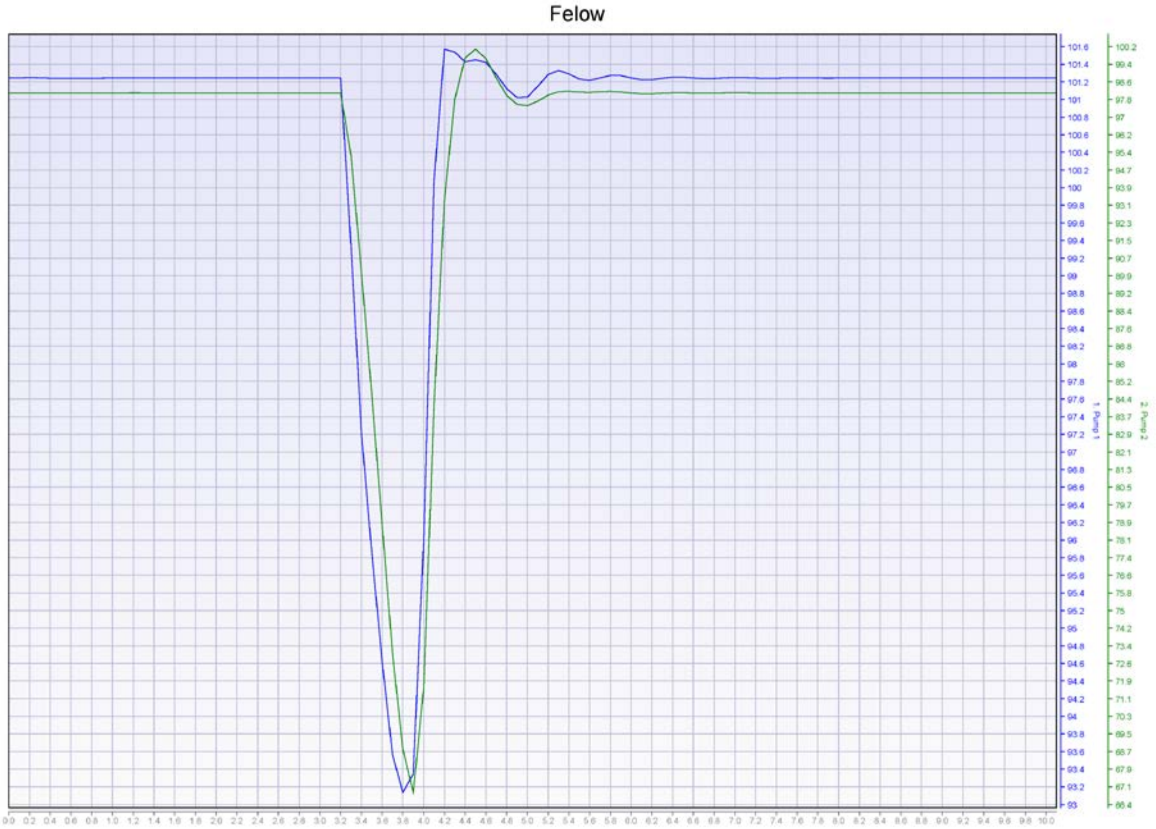
Preliminary Co-Simulation Results (3)

- Motor 2



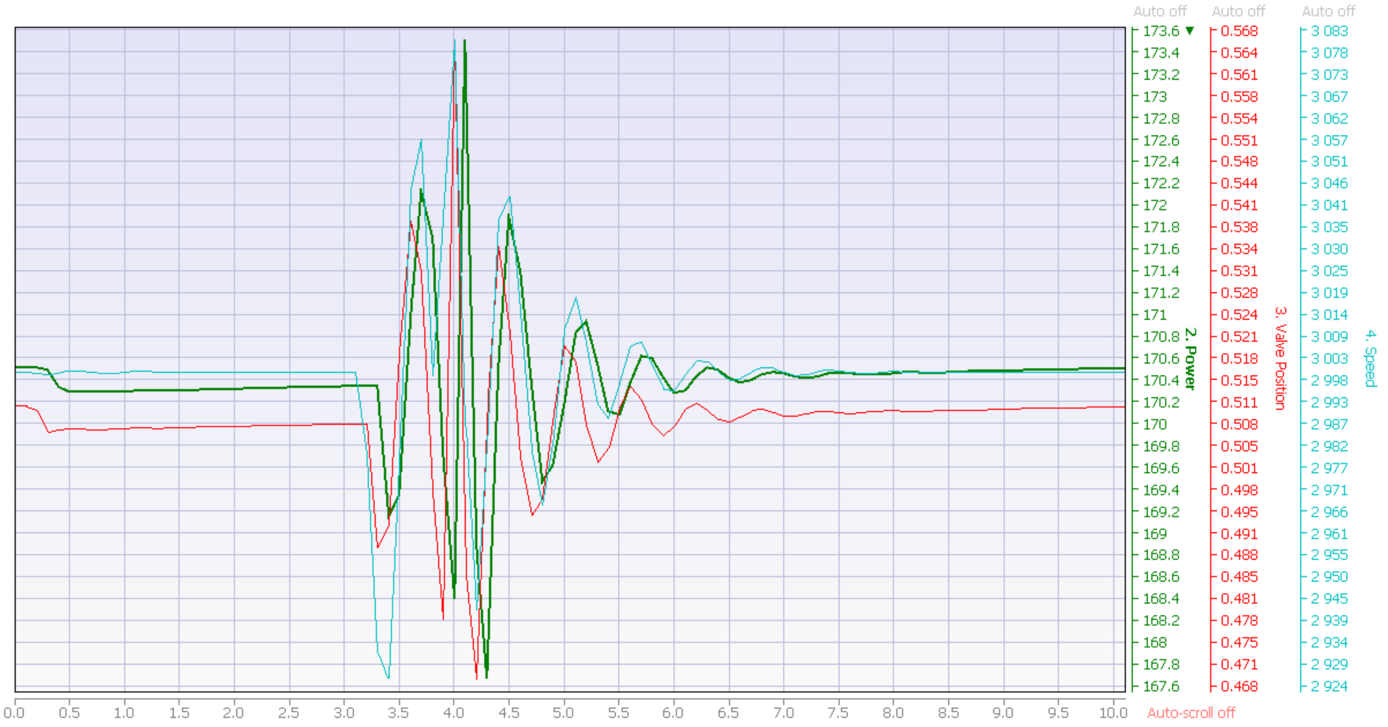
Preliminary Co-Simulation Results (4)

- **Mass Flow**



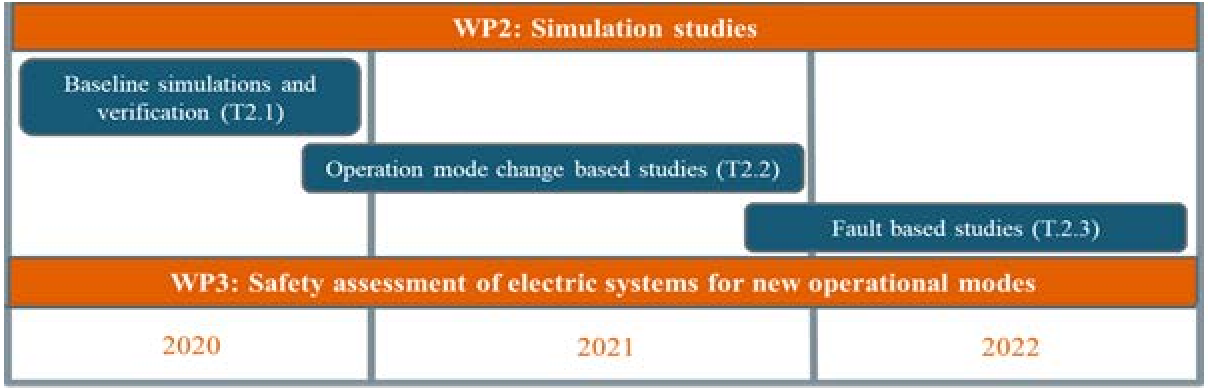
Preliminary Co-Simulation Results (5)

- **Generator**



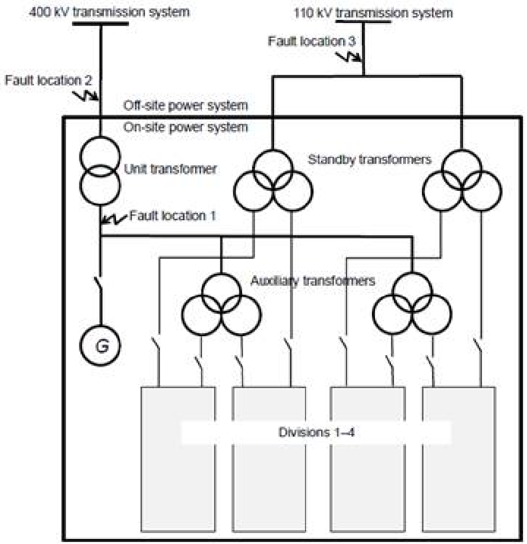
WP2: Simulation Study
Matti Lehtonen, Aalto

WP 2 Simulation studies



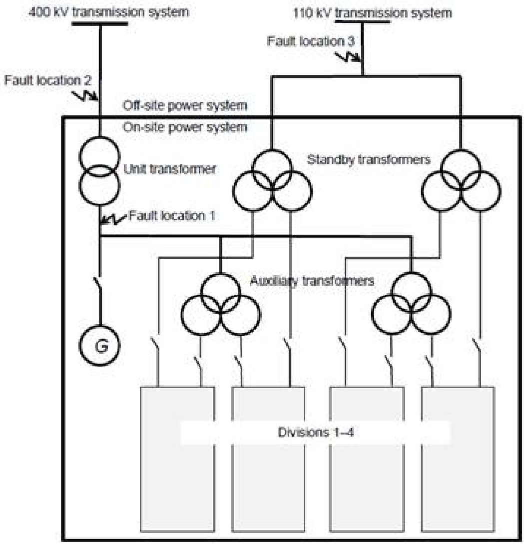
Internal grids

- Loviisa 1



Internal grids

- Loviisa 1
  - Find the steady state condition using separate models

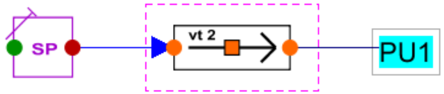


Internal grids

- Loviisa 1
  - Find the steady state condition using separate models

  - Update Apros model by adding required transmitter
    - For all motors and Generators

Selecting output component
XXXX_PU1 P_SPEED_OLD

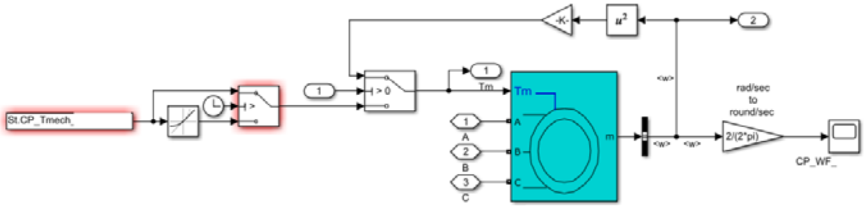


Name based on instruction
e.g. for basic pump: (speed as in put)
BM_WP_XXX

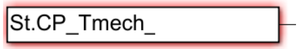
Internal grids

- Loviisa 1
  - Find the steady state condition using separate models
  - Update Apros model

  - Update Simulink model
    - For all motors and Generators

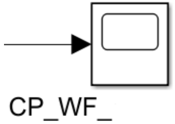


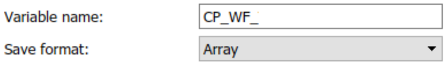
  - Input



Name based on instruction
e.g. for comon pump: St.CP_Tmech_XXX

Output





Internal grids

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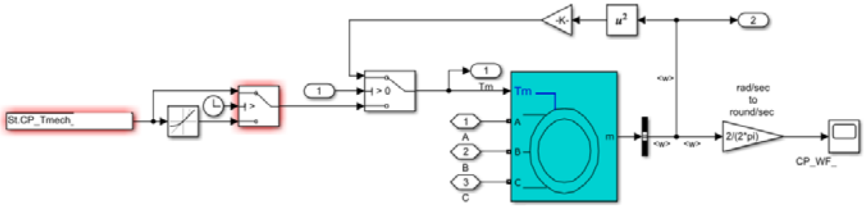
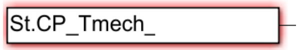
  - Update Simulink model
    - For all motors and Generators



- Input



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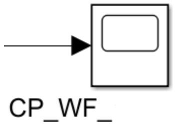
Output



Variable name: CP_WF_
Save format: Array

Internal grids

- Loviisa 1
  - Find the steady state condition using separate models
  - Update Apros model
  - Update Simulink model
  - Update the layour file in master program

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```

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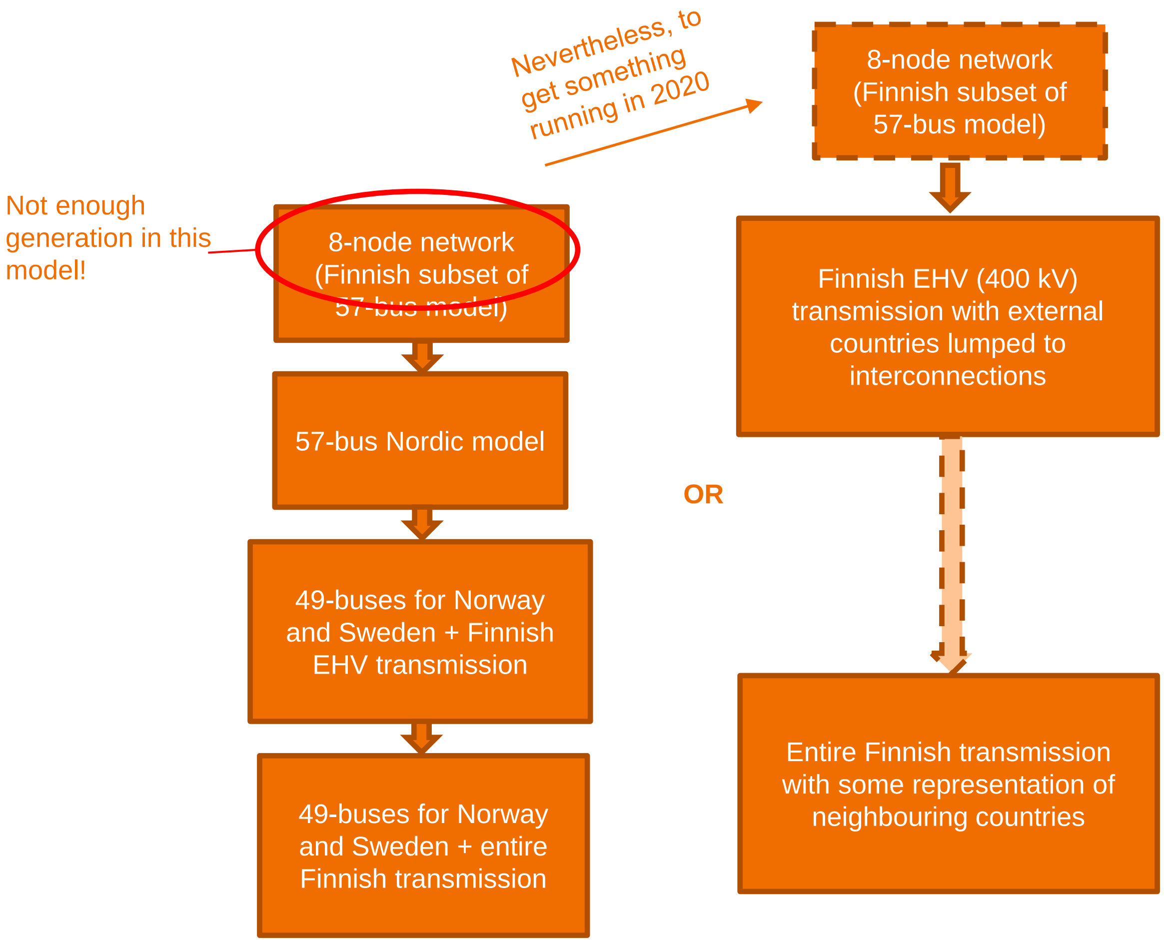
School of Electrical
Engineering

COSI – recent Aalto activities

So far

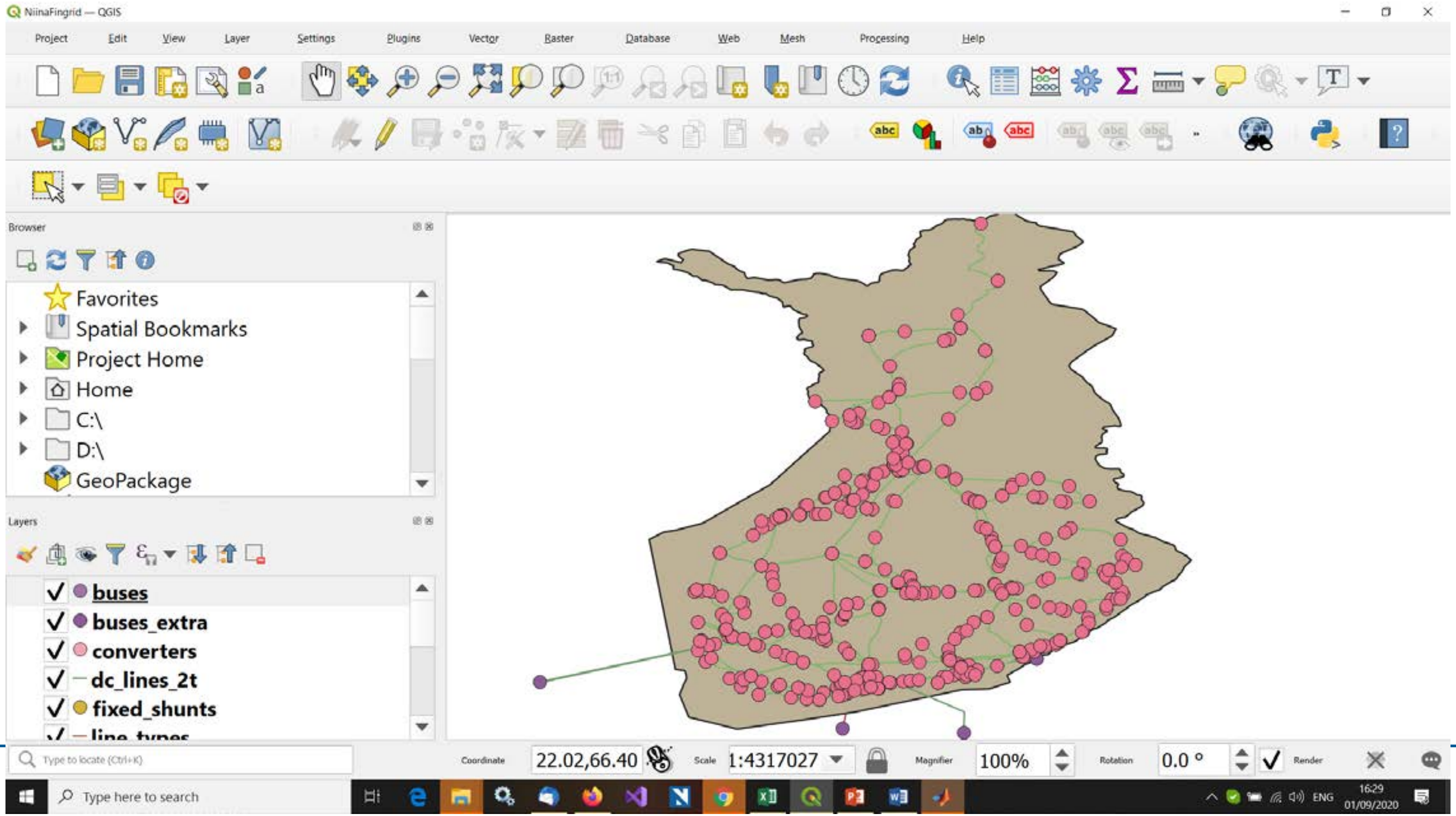
- **Brushing up on transmission system basics**
  - Modelling nodes
  - Modelling lines
  - 3-phase power flow basics, noting that we will be dealing with asymmetric scenarios
- **Gleaning Fingrid data from QGIS-related files (→Excel (done) →some other database format?)**
- **Learning and slowly building up a simple network in Simulink (some 'steady-state' success)**

Possible directions for transmission model development



How far we get in this roadmap will depend on time and benefit - noting that we are aiming for minimum sufficient transmission models that are relevant to the nuclear power station of interest.

Visualising data in QGIS



Data has been extracted from QGIS (&/or .dbf files and Energiavirasto)

Line data

1											
2		1:load, 2:generator, 3: Swing, 4: disconnected bus						WGS84			
3	bus_id	type	station_id	voltage	name	Station name	comments	x	y	pl	ql
4	20101	2	234	110	KS1	KRISTIINA		21.33021	62.255	50.2176	8.03482
5	20016	4	279	110		FLYB–CKIN HAARA	Not connected	21.37614	62.292	97.829	15.6526
6	20352	2	356	110	KD	KRISTINESTAD		21.37629	62.292	17.0222	2.72355
7	30074	1	356	21	KD_TER1	KRISTINESTAD	Needed if there will be a 3-winding transformer in Kristinestad.	21.37629	62.292	84.4881	13.5181
8	5018	1	356	400	KD4	KRISTINESTAD		21.37629	62.292	#N/A	#N/A
9	4163	2	145	400	MP4	TAHKOLUOTO	Added this bus to TAHKOLUOTO station, Erkka	21.40762	61.633	#N/A	#N/A
10	20355	2	145	110		TAHKOLUOTO	Added this bus for Tahkoluoto KT-laitos (Niina Helistö).	21.40762	61.633	151.368	24.2189
11	20278	4	62	110		TORNA	Not connected	21.40798	61.042	15.0296	2.40474
12	20349	2	240	110	OLT1	OLKILUODON KT-LAITOS	Slack bus for COSI purposes?	21.44494	61.24	8.5063	1.36101
13	4160	2	27	400	OL4	OLKILUOTO		21.4712	61.245	#N/A	#N/A
14	4168	2	27	400	OL42	OLKILUOTO		21.4712	61.245	#N/A	#N/A

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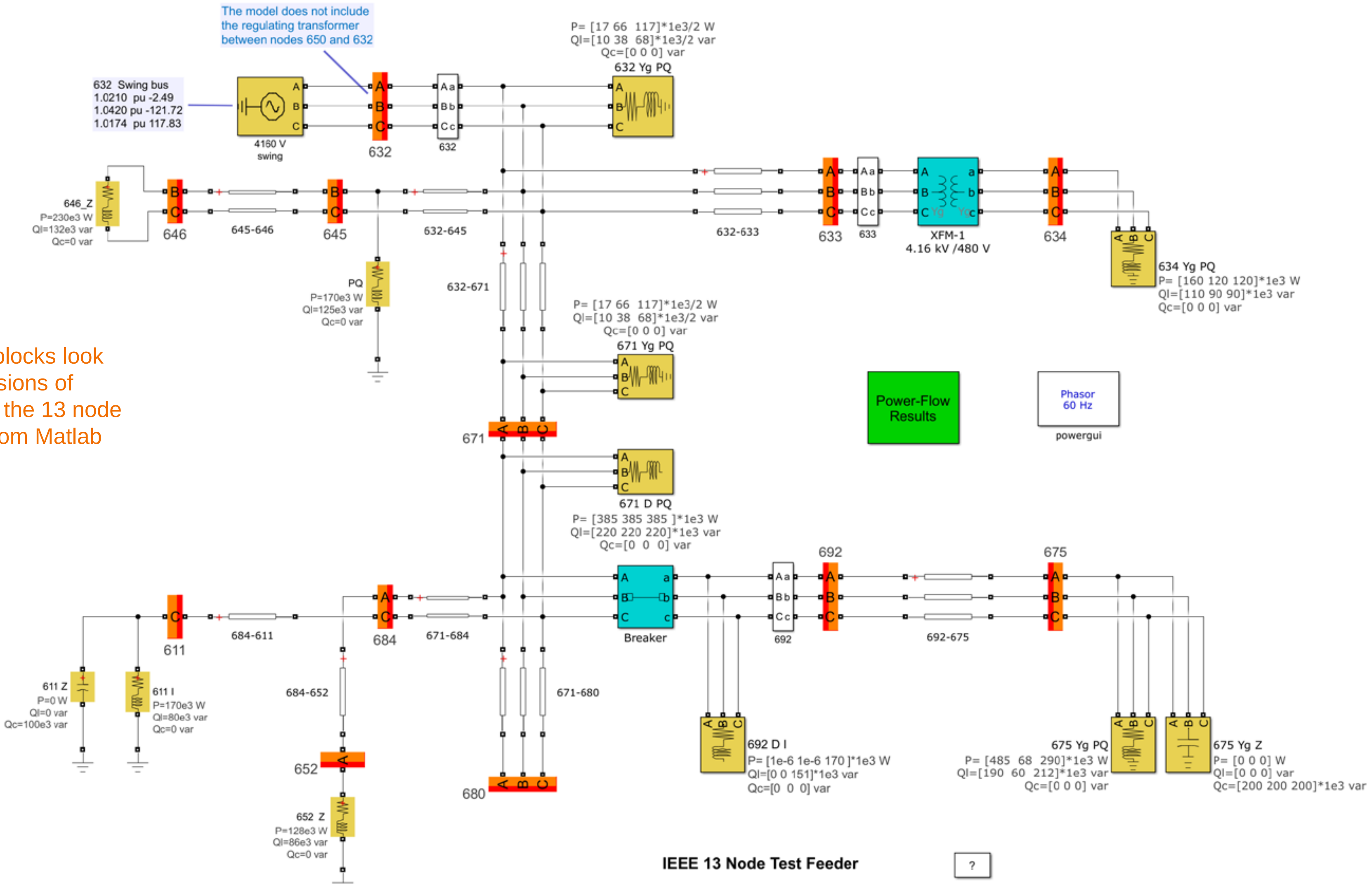
This is how the blocks look in the newer versions of Matlab… This is the 13 node demo network from Matlab



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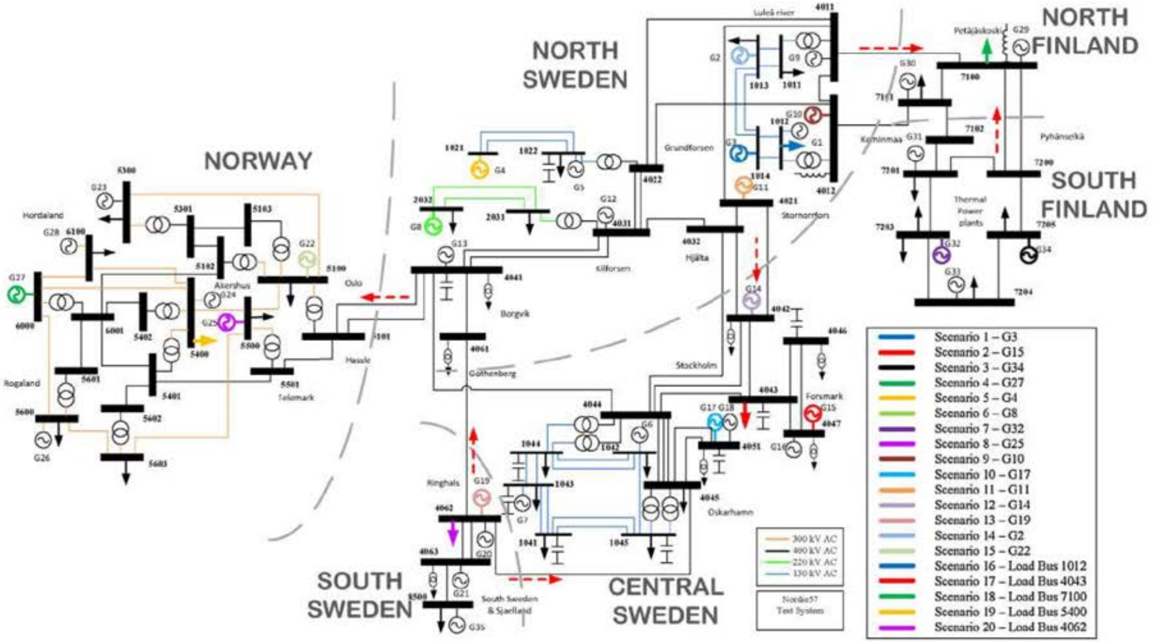
Possible roadmap for grid model development

This thesis used a 57 node model for the Nordics

http://kth.diva-portal.org/smash/get/diva2:1369967/FULLTEXT01.pdf



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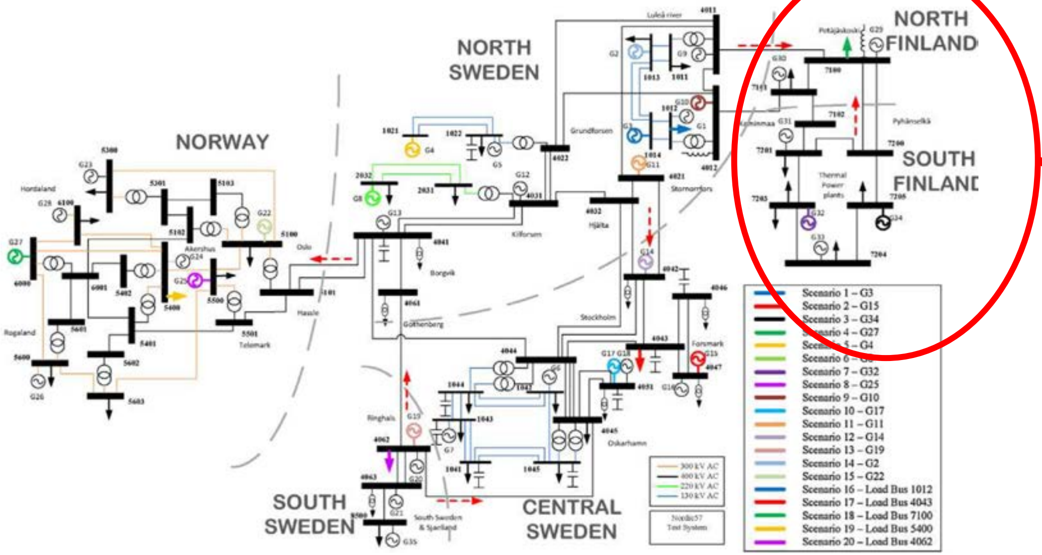
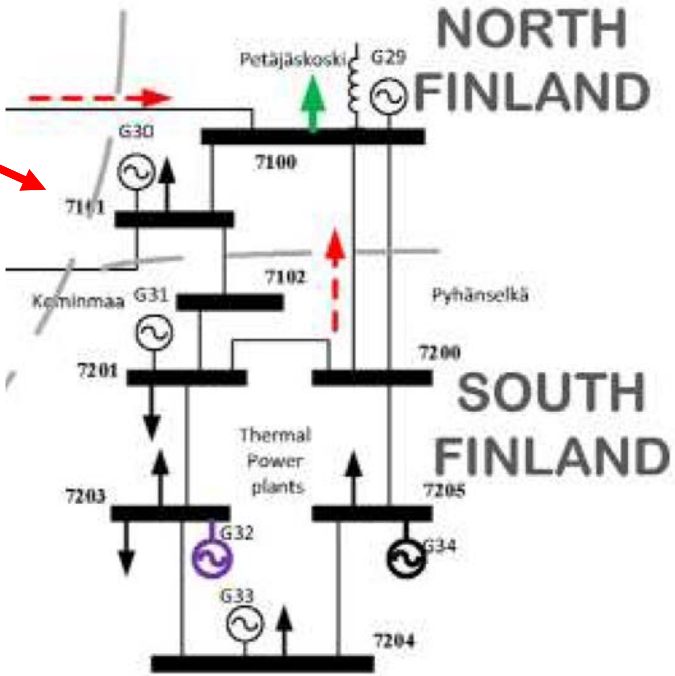
It would be nice to start simple!

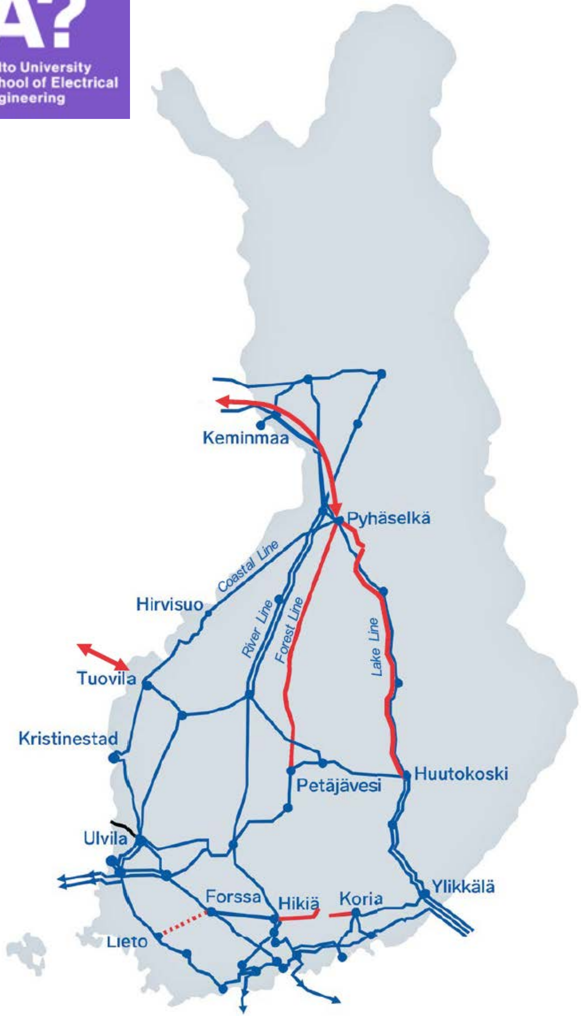




But, the generation in the (8-bus) Finnish part of the 57-bus network is perhaps too scenario-specific, but a good first approximation?

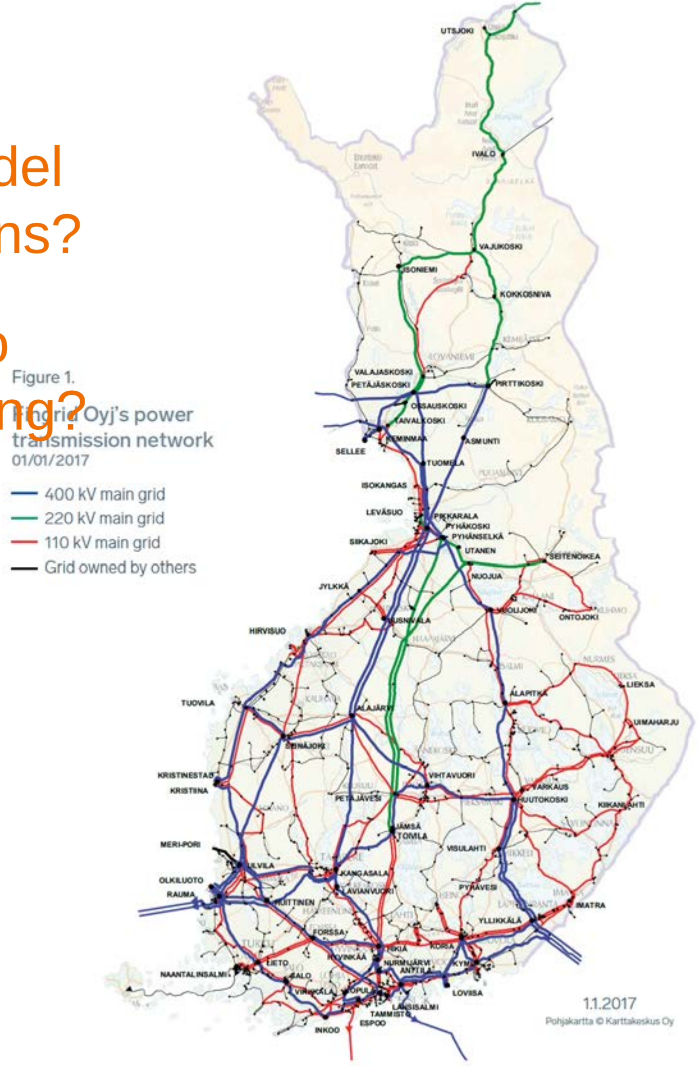
Should we model new connections?

Will we need to model everything?



- 400 kV main grid
- 400 kV under construction
- Basic main grid solutions

Figure 20. Flexible and long-term investment strategy.



Conclusion, for WP2

- Model the 400 kV grid of Finland and any necessary sections of lower voltage transmission
- We have the data for that
- But it will be quite tedious modelling it all in Simulink – but great once we've done it!
- Check modelling with another platform
- Simulations and case studies!

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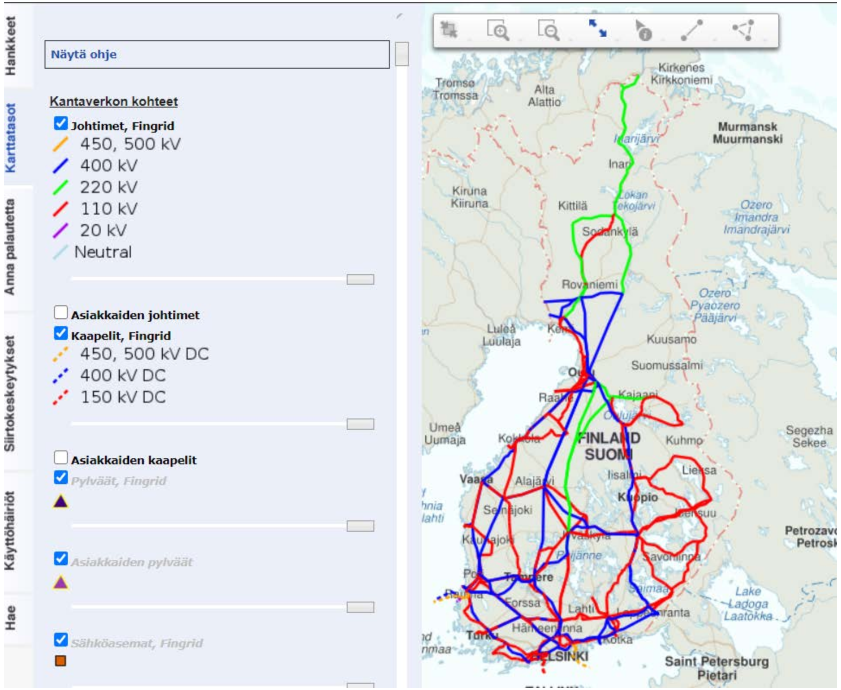

VTT

beyond
the obvious

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