Phasor and EMT modelling and simulation of POSYTYF scenarios

Ongoing activities on WP1 Task 1.5

Vinícius A. Lacerda

Outline

- Introduction
- Phasor and EMT simulation
- The modelled systems in Phasor and EMT
- Examples and simulation guidelines
- Discussion

Introduction

- Prof. Oriol Gomis
- Eduardo Prieto
- Marc Chea
- Enric Sánchez
- Vinícius Lacerda
- Carlos Collados
- Jaume Girona
- Lluc Figueras

WP1 - Scenario definition, system modelling & specifications for RES-based DVPP

Task 1.1 Scenario definition Finished	Task 1.2 General system design Finished	Task 1.3 Specification definition for actual and future scenarios Active
Task 1.4 Role assignment Active	Task 1.5 Modelling guidelines EMT/Phasor Active	Task 1.6 Co-simulation

WP	Task Name	Duration	Year 1												Year 2												Year 3											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Scenario definition, system modelling and specifications for renewable-based Virtual Power Plants (VPP) for actual and futurepower systems	36 months																																				
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1.2	General system design																																					
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1.5	Power system model development and model guidelines																																					
1.6	Co-simulation																																					

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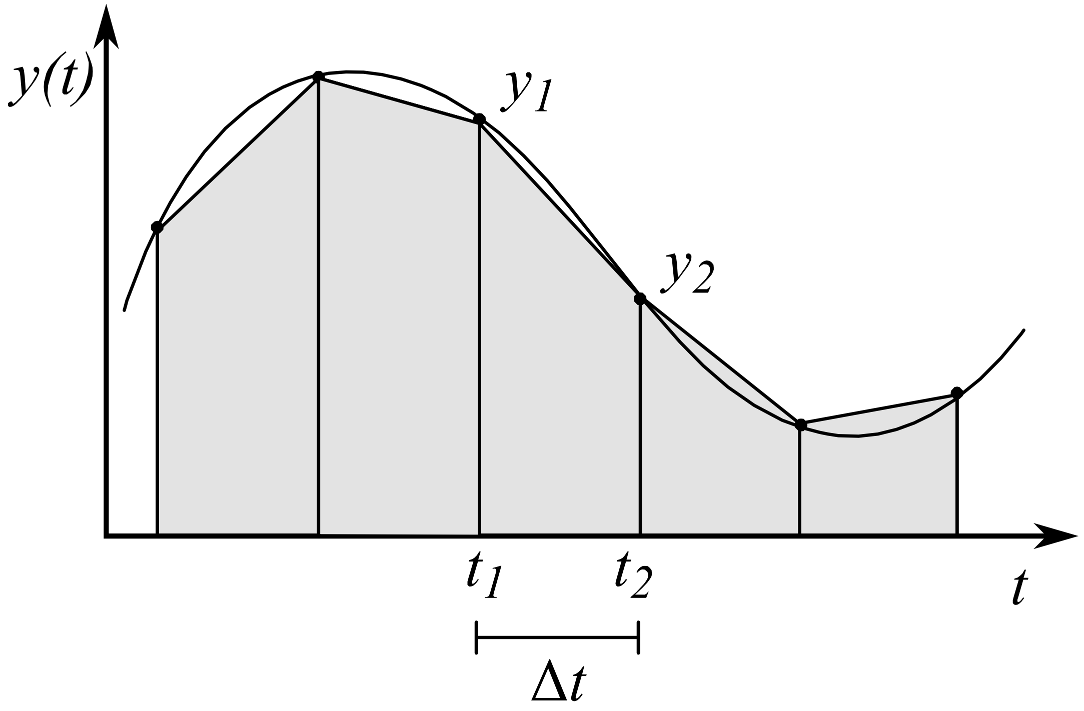
EMT and Phasor Simulation

EMT Simulation (Electromagnetic Transient)	Phasor simulation
• Full solution in the time domain	• Approximated solution neglecting grid electrical dynamics
• Use of real variables	• Use of complex variables
• Numerical solution of a system of ordinary differencial equations: $v(t) = Ri(t) + L\frac{di(t)}{dt}$	• Numerical solution of a system of ordinary algebraic equations: $\boldsymbol{V} = \boldsymbol{Z_{bus}I}$
• Used by: PSCAD, ATP, EMTP-RV, RTDS	• Used by: PSSe, Eurostag, PTI
• Well-known solver: EMTP = EMT program	• Phasor simulation works in 50 Hz or 60 Hz rotating reference: 50 Hz becomes 0 Hz, 51 becomes 1 Hz, etc.
• Trapezoidal rule approximates integral by an average between two time steps.	• Lower frequencies allow greater time steps to be used (PSSE uses 8.333 ms).
• Common studies: electromagnetic transients in general and control of power electronics	• Common studies: electromechanical transients in general and control of power systems

EMT and Phasor Simulation

- Trapezoidal rule

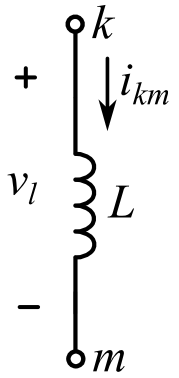
$$\underbrace{\int_{t-\Delta t}^{t} y dt}_{area} \approx \underbrace{\frac{\Delta t}{2}(y(t) + y(t - \Delta t))}_{Approximated\ area}$$



Source: https://www.bragitoff.com/2017/08/trapezoidal-rule-c-program/

EMT and Phasor Simulation

- EMT – example of an inductor



$$v_L = v_k - v_m = L\frac{di_{km}}{dt} \xrightarrow{\text{Integral format}} i_{km}(t) = i_{km}(t-\Delta t) + \int_{t-\Delta t}^{t} (v_k - v_m)dt$$

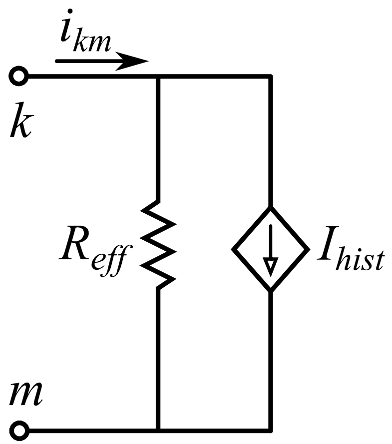
Applying the trapezoidal rule gives:

$$i_{km}(t) = i_{km}(t-\Delta t) + \frac{\Delta t}{2L}\Big(\big(v_k(t) - v_m(t)\big) + \big(v_k(t-\Delta t) - v_m(t-\Delta t)\big)\Big)$$

$$= i_{km}\,(t-\Delta t) + \frac{\Delta t}{2L}\big(v_k(t-\Delta t) - v_m(t-\Delta t)\big) + \frac{\Delta t}{2L}\big(v_k(t) - v_m(t)\big)$$

$$= I_{hist} + \frac{1}{R_{eff}}(v_k(t) - v_m(t))$$

Equivalent representation



Circuit theories and network reduction techniques can be use to reduce the computation time.

EMT and Phasor Simulation

Simulation time comparison

- EMT $\boldsymbol{Gv = i + I_{hist}}$
- Phasor $\boldsymbol{YV = I}$

Similar number of computations → Phasor is only faster when using a larger time step

Rule of thumb

Minimum simulation time step follows Nyquist sampling

$\Delta t < \tau_{min}/2$

→ Where τ_{min} is the smallest time constant simulated, or the fastest dynamics, either electrical or control

To be safe:

$\Delta t = \tau_{min}/5 \text{ or } \tau_{min}/10$

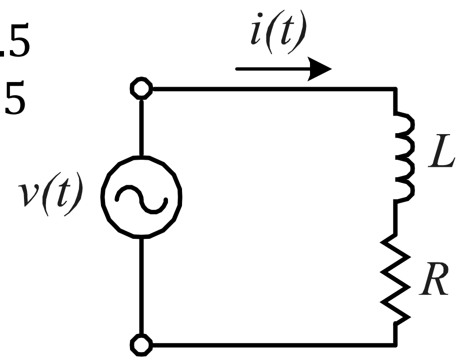
EMT and Phasor Simulation

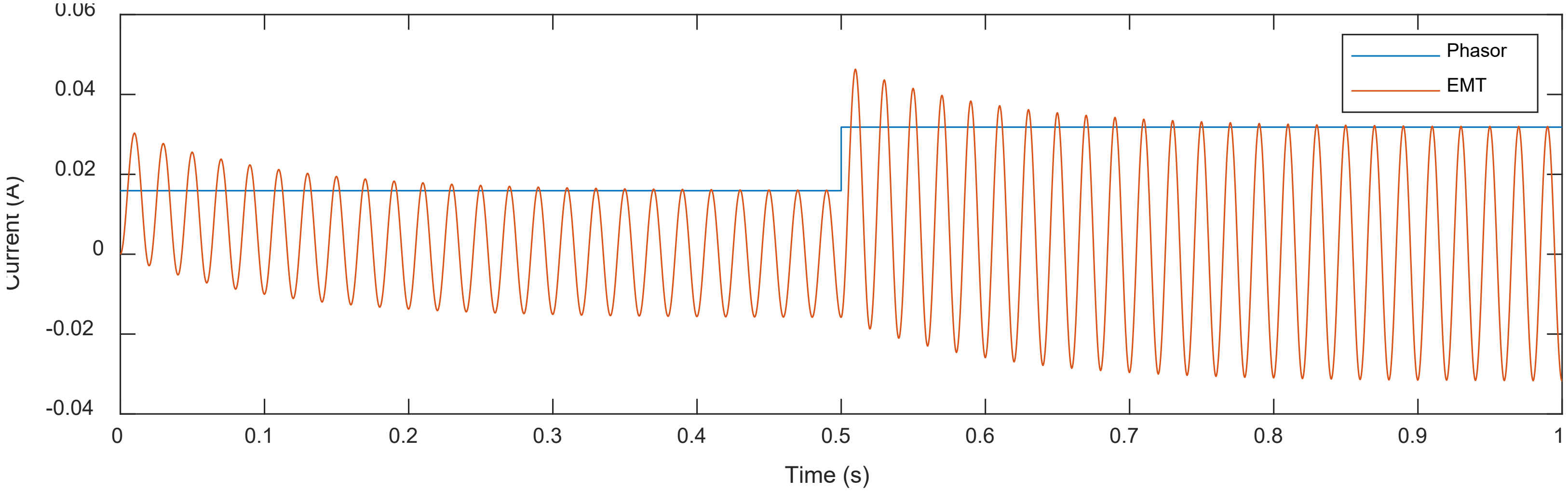
- RL circuit example

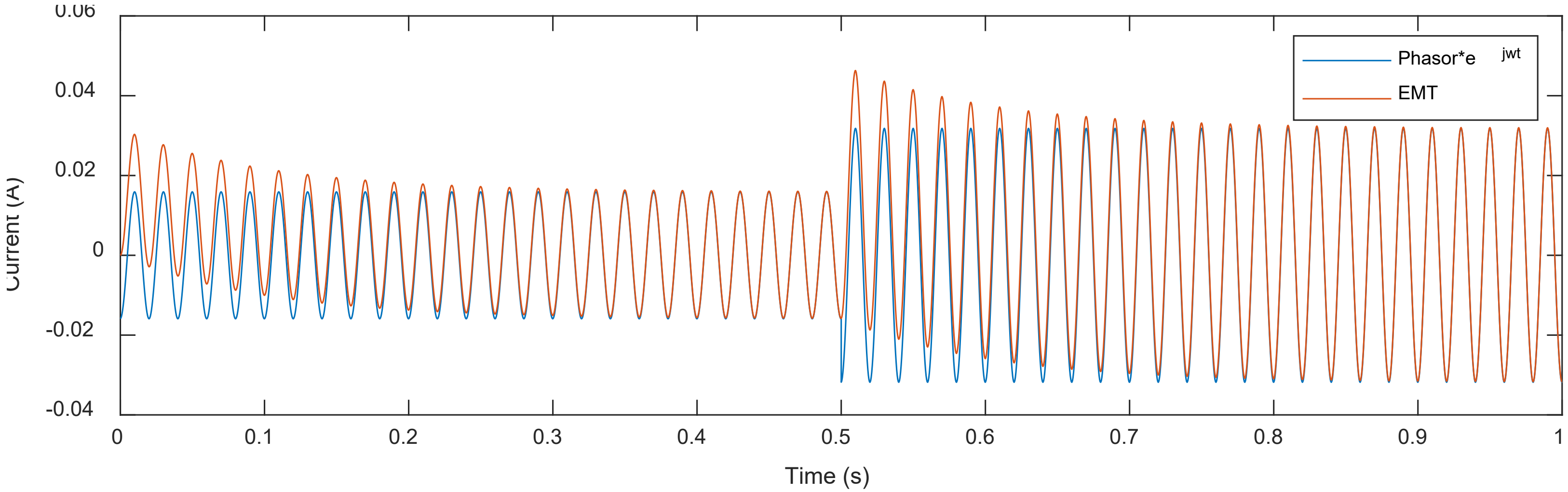
$R = 1\,\Omega \quad L = 100\text{ mH} \quad f = 50\,Hz$

$v = 0.5\,V\ t < 0.5$
$\quad\ 1.0\,V\ t > 0.5$

$\tau = \frac{L}{R} = 0.1\,s$



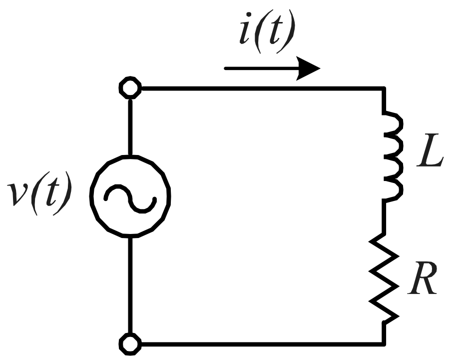




Phasor takes between 3τ and 5τ to match EMT

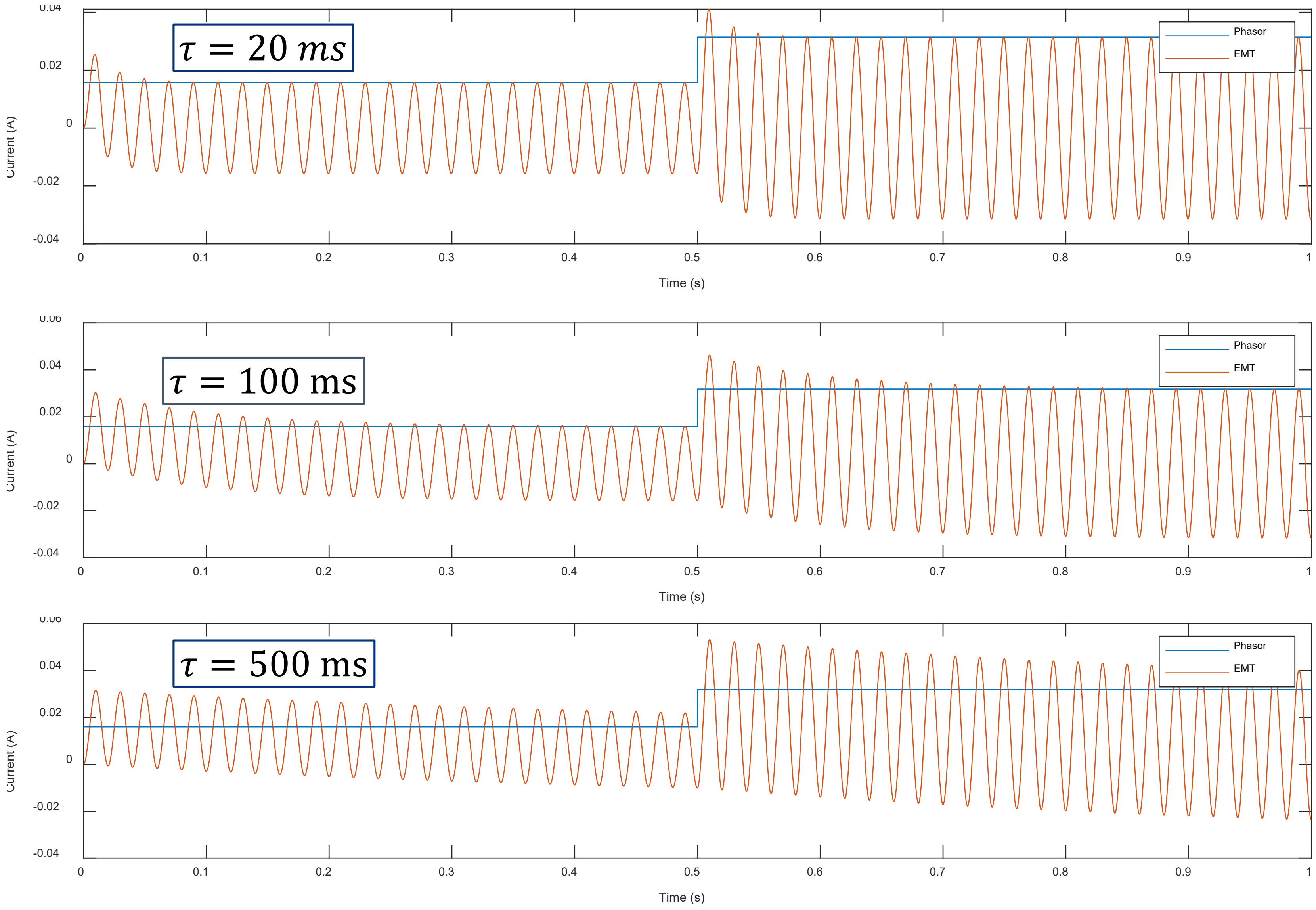
EMT and Phasor Simulation

- RL circuit example



X/R in transmission systems is normally between 5 and 15

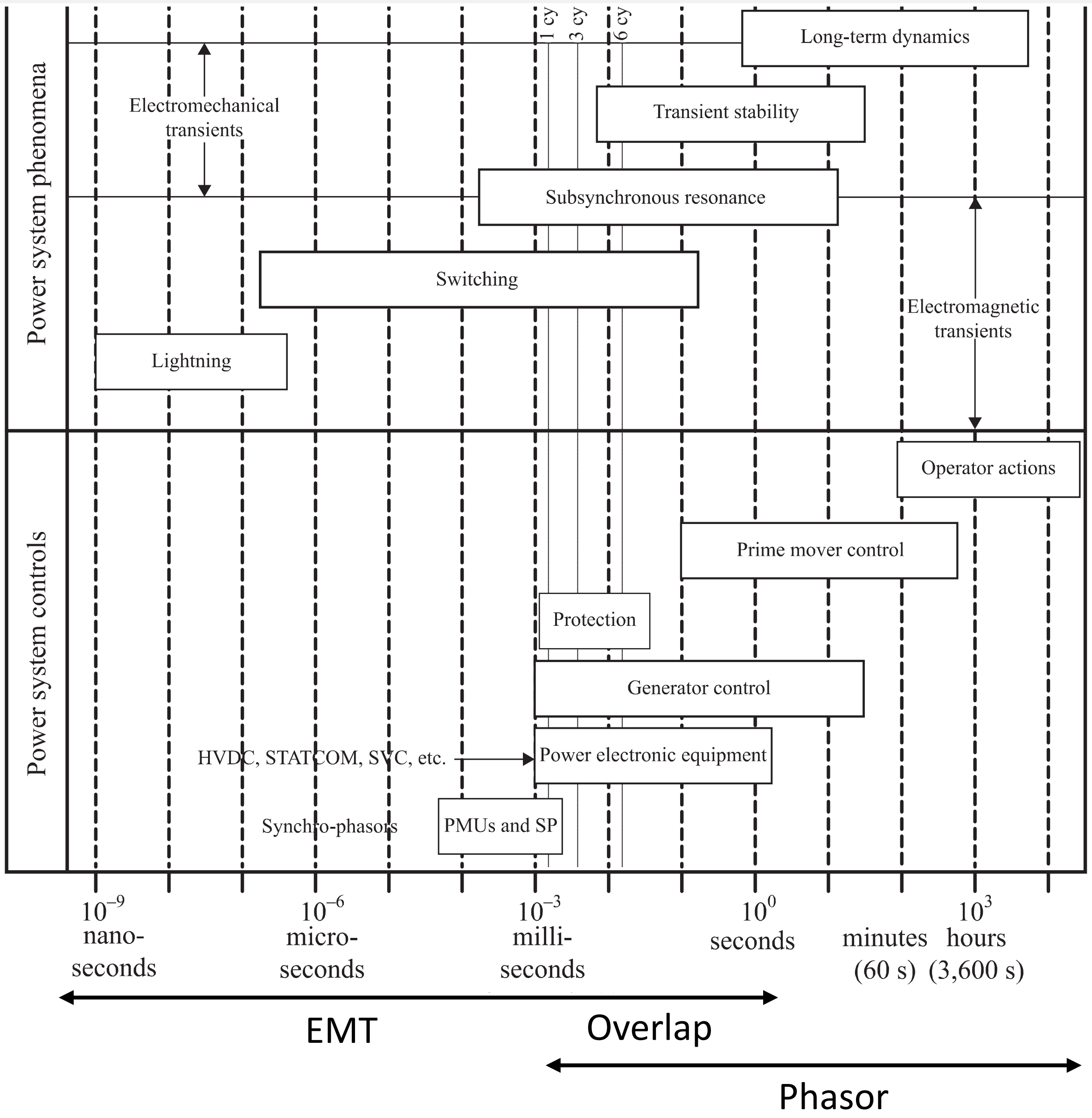
$$\frac{X}{R} = 10 \longrightarrow \tau = 32\text{ ms}$$



EMT and Phasor Simulation

Time scales of EMT and Phasor

- When PEs are used in transient stability studies, EMT and Phasor domains overlap.
- In this scenario, what would be the best choice? EMT, Phasor, cosimulation?



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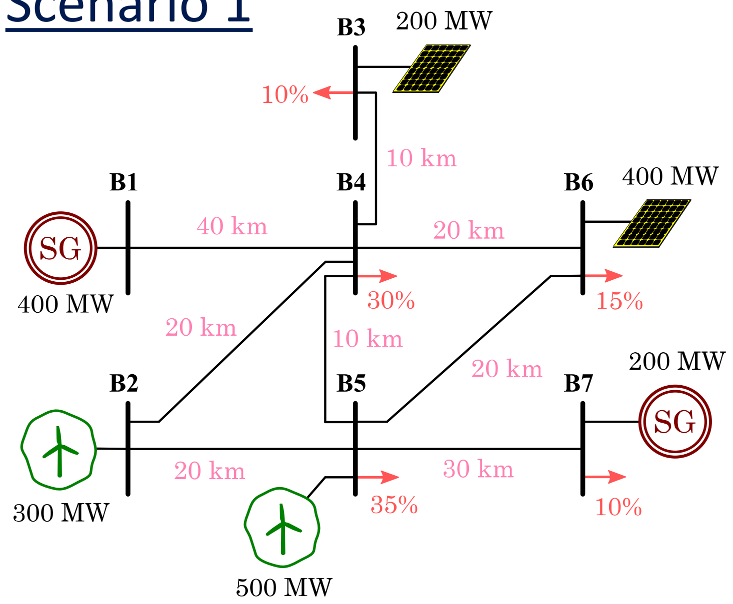
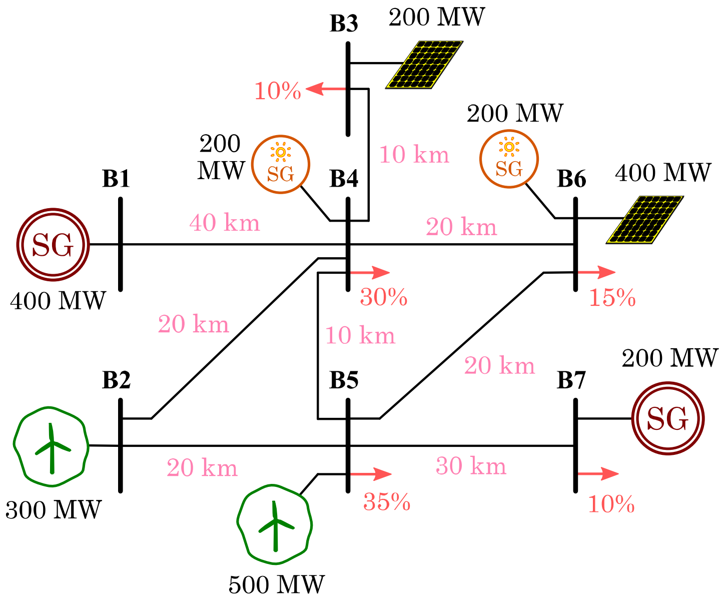
Modelled Scenarios

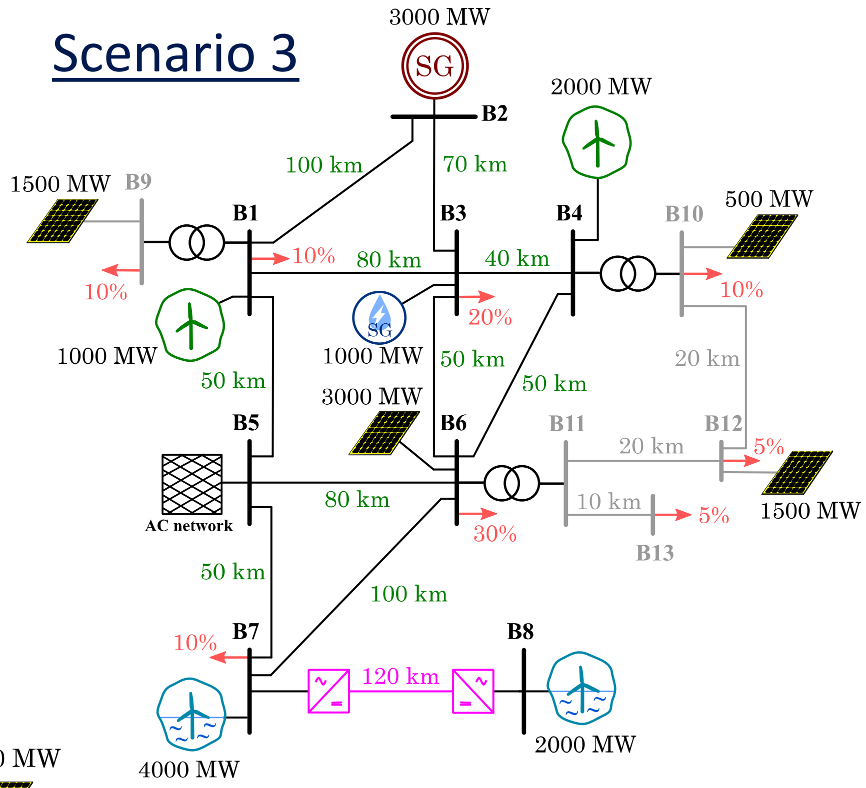
Scenario 1



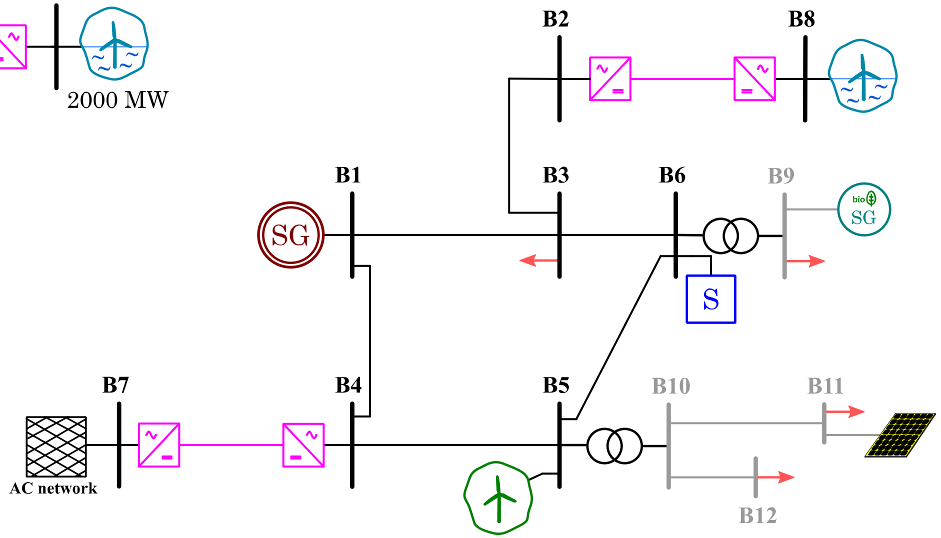
Scenario 2



Scenario 3



Scenario 17

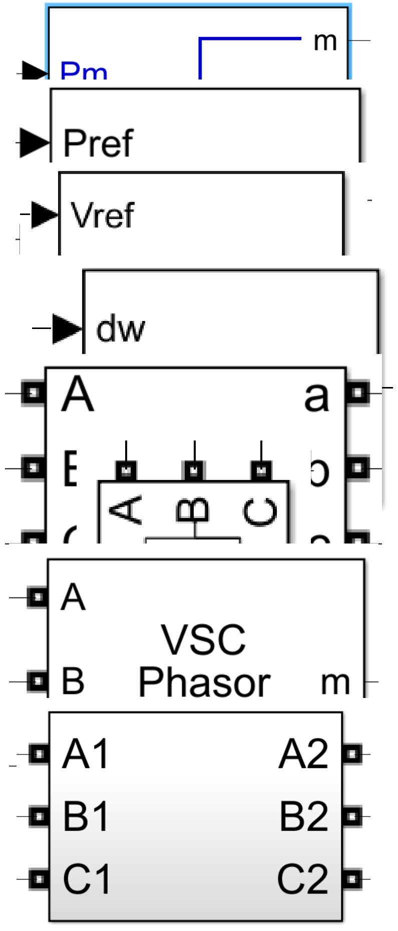


Models

Basic building blocks

Element	Model	Comment/Ref
Generator	IEEE Model 2.2	IEEE Std 1110-2019
Governor	TGOV1	Used in ENTSO-E 131127 Report [1]
Exciter	AC4A	IEEE Std 421.5-2016
PSS	PSS2A	IEEE Std 421.5-2016 (previous version of PSS2C)
Lines	PI lines	
Loads	Constant Z	defined in terms of PQ
VSC grid-following	2 EMTs and 4 Phasors	detailed next
HVDC	Back-to-back	DC dynamics considered

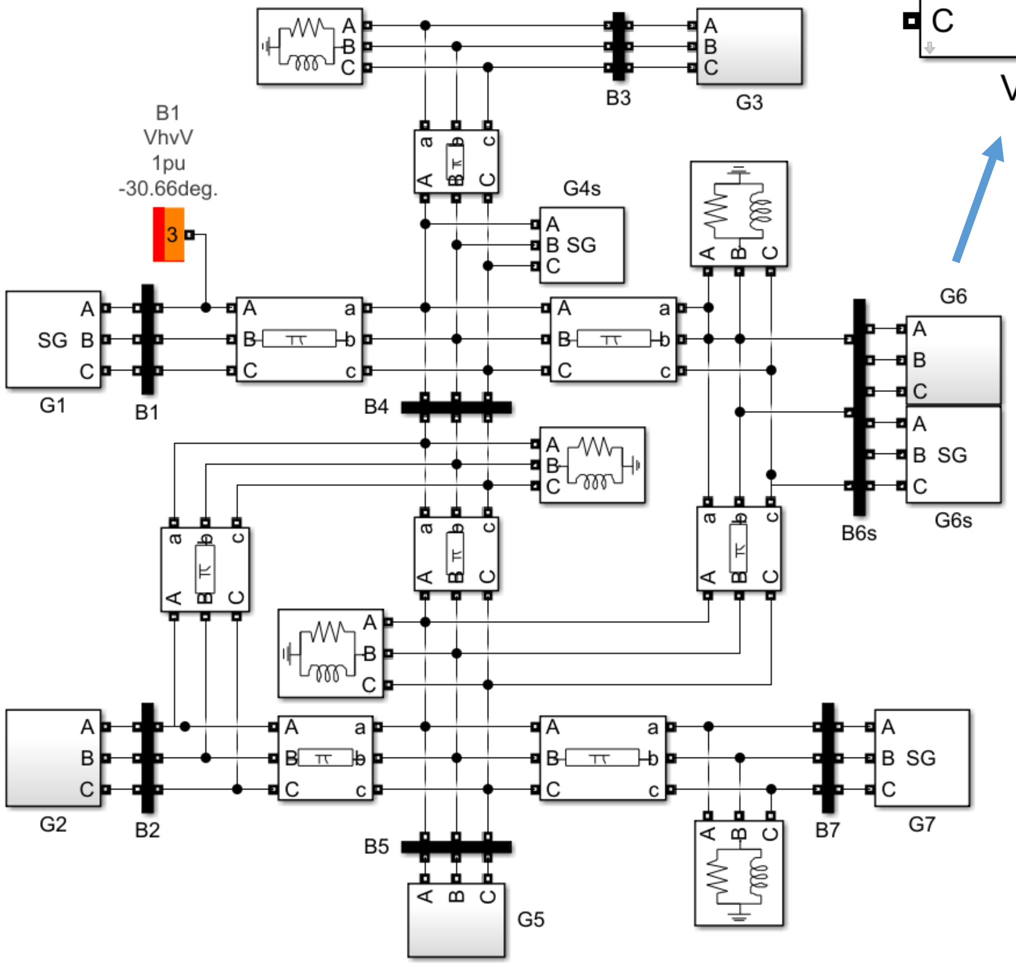
In Simulink

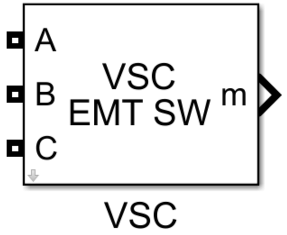


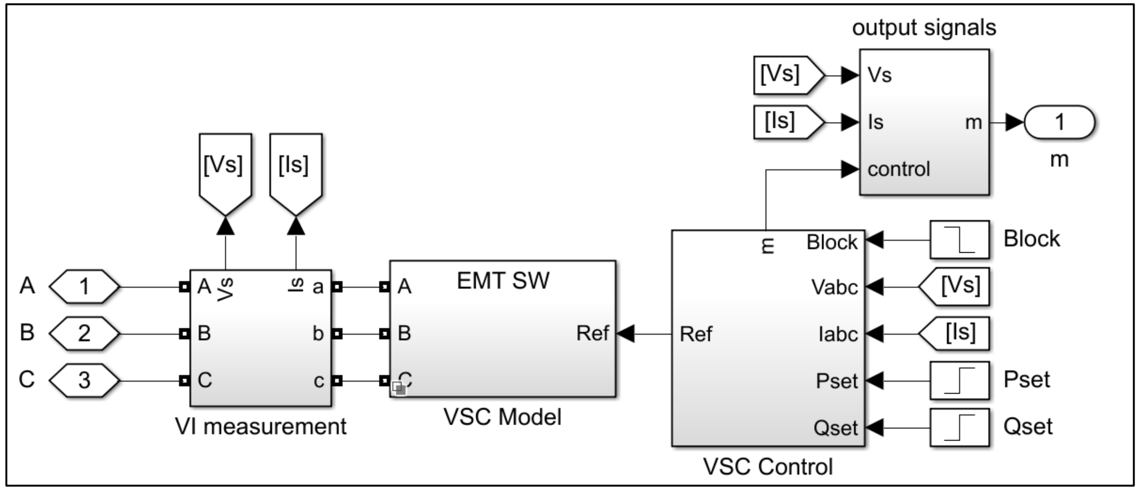
[1] https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/entsoe/RG_SOC_CE/131127_Controller_Test_Report.pdf

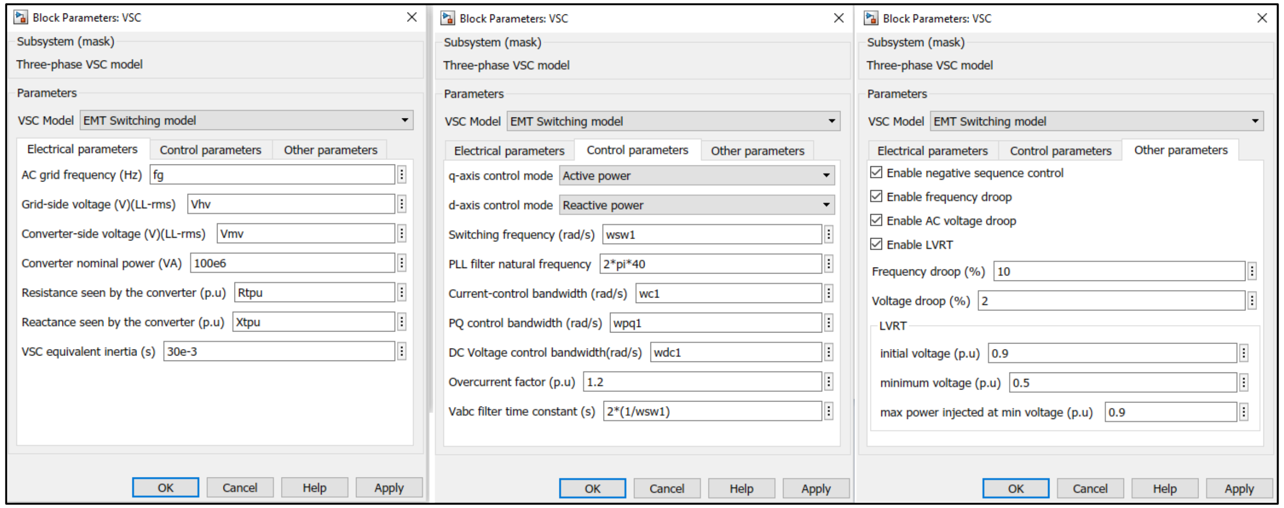
Modelled Scenarios

Scenario 2 in Simulink








Block Parameters: VSC
Subsystem (mask)
Three-phase VSC model
Parameters
VSC Model: EMT Switching model
Electrical parameters | Control parameters | Other parameters

AC grid frequency (Hz)	fg
Grid-side voltage (V)(LL-rms)	Vhv
Converter-side voltage (V)(LL-rms)	Vmv
Converter nominal power (VA)	100e6
Resistance seen by the converter (p.u)	Rtpu
Reactance seen by the converter (p.u)	Xtpu
VSC equivalent inertia (s)	30e-3

OK Cancel Help Apply

Block Parameters: VSC
Subsystem (mask)
Three-phase VSC model
Parameters
VSC Model: EMT Switching model
Electrical parameters | Control parameters | Other parameters

q-axis control mode	Active power
d-axis control mode	Reactive power
Switching frequency (rad/s)	wsw1
PLL filter natural frequency	2*pi*40
Current-control bandwidth (rad/s)	wc1
PQ control bandwidth (rad/s)	wpq1
DC Voltage control bandwidth(rad/s)	wdc1
Overcurrent factor (p.u)	1.2
Vabc filter time constant (s)	2*(1/wsw1)

OK Cancel Help Apply

Block Parameters: VSC
Subsystem (mask)
Three-phase VSC model
Parameters
VSC Model: EMT Switching model
Electrical parameters | Control parameters | Other parameters

- ☑ Enable negative sequence control
- ☑ Enable frequency droop
- ☑ Enable AC voltage droop
- ☑ Enable LVRT

Frequency droop (%)	10
Voltage droop (%)	2

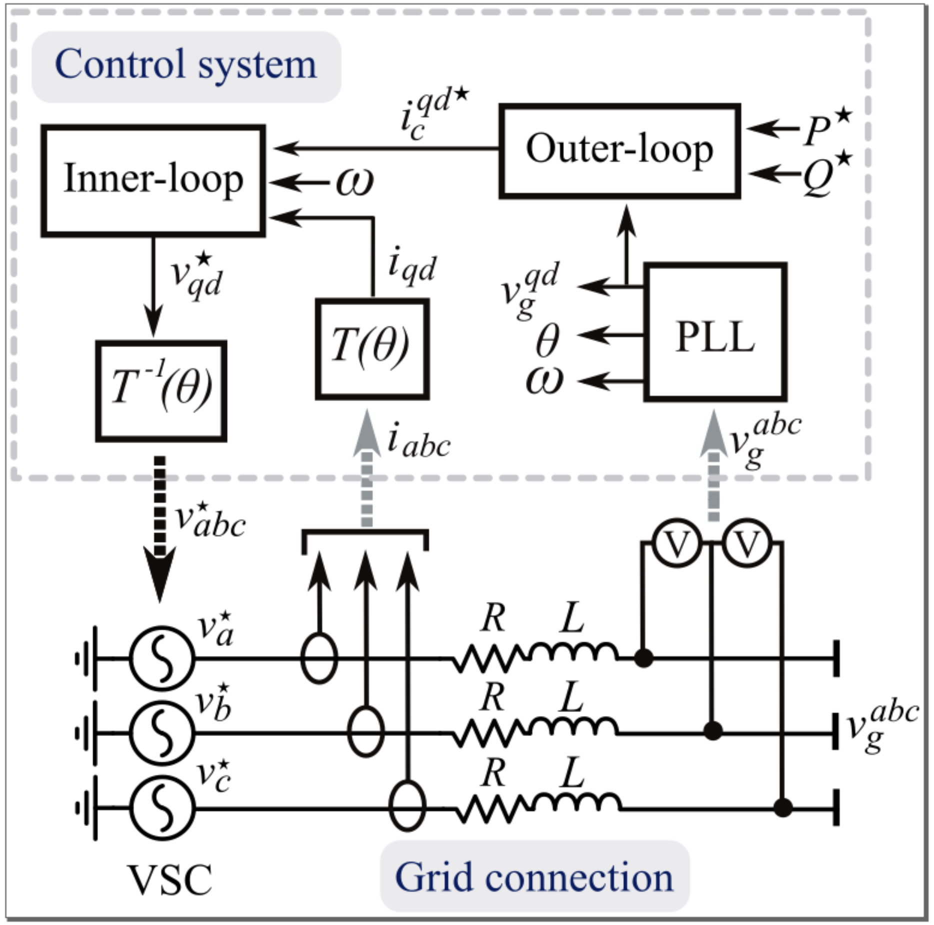
LVRT

initial voltage (p.u)	0.9
minimum voltage (p.u)	0.5
max power injected at min voltage (p.u)	0.9

OK Cancel Help Apply

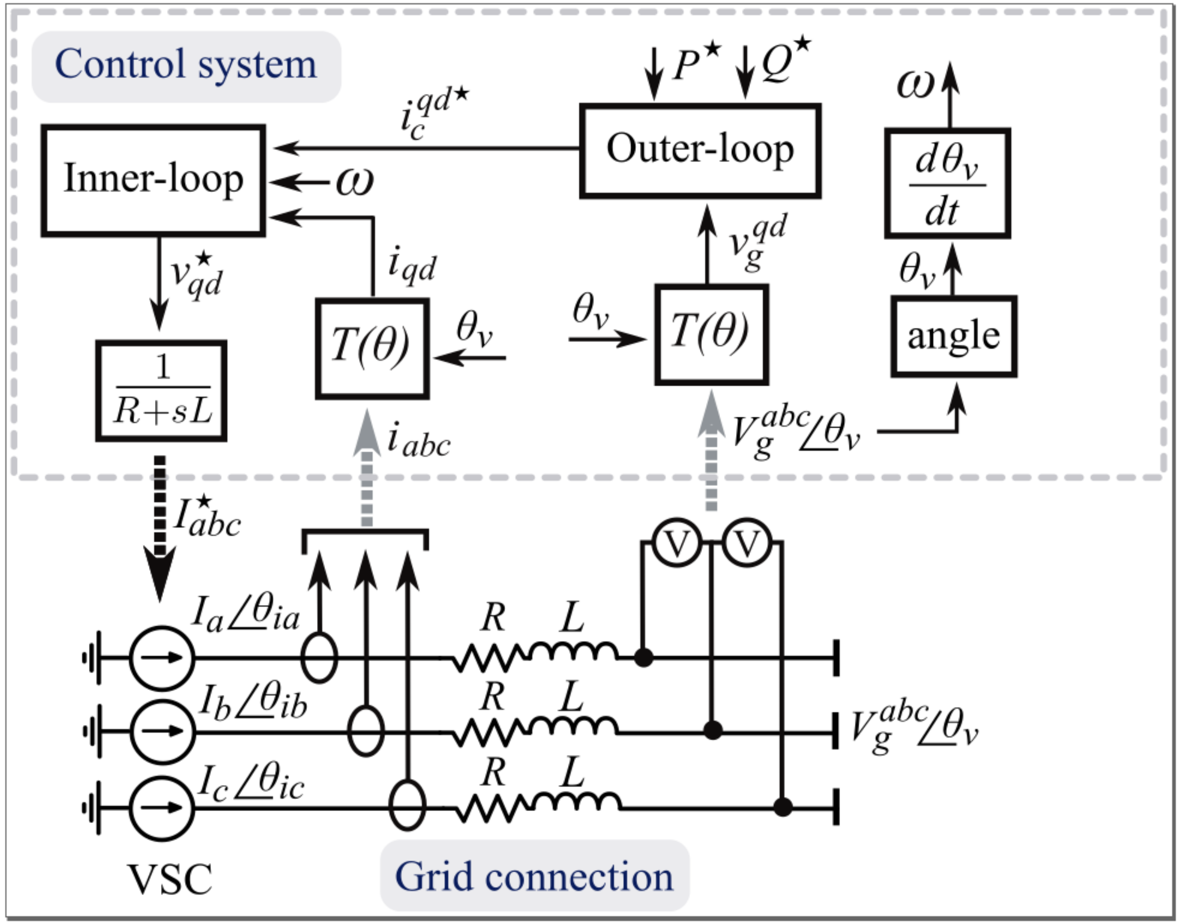
Grid-following VSC in EMT and Phasor

- Average-value model in EMT

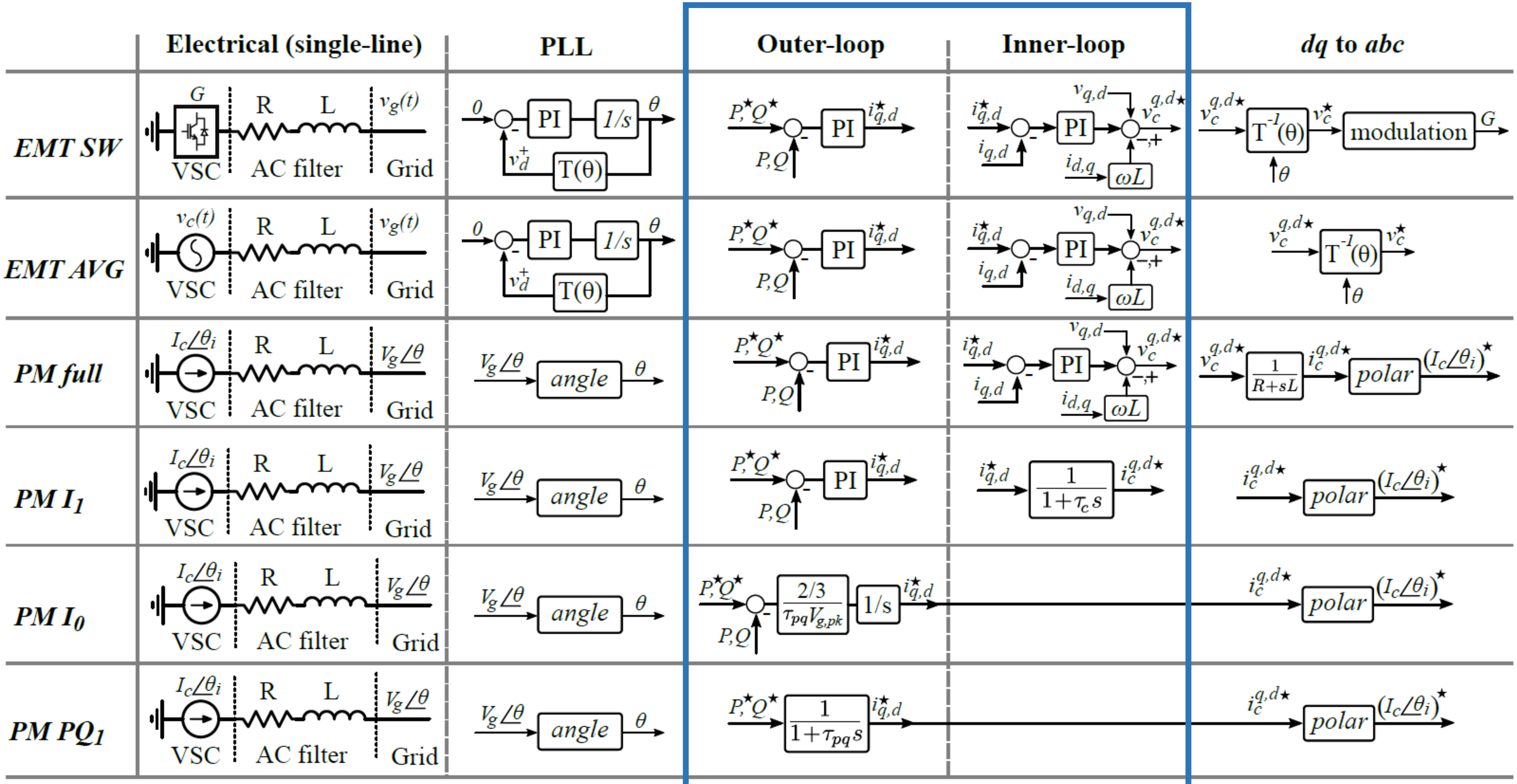


Same
control structure

- Phasor (one possibility)



VSC models created in EMT and Phasor

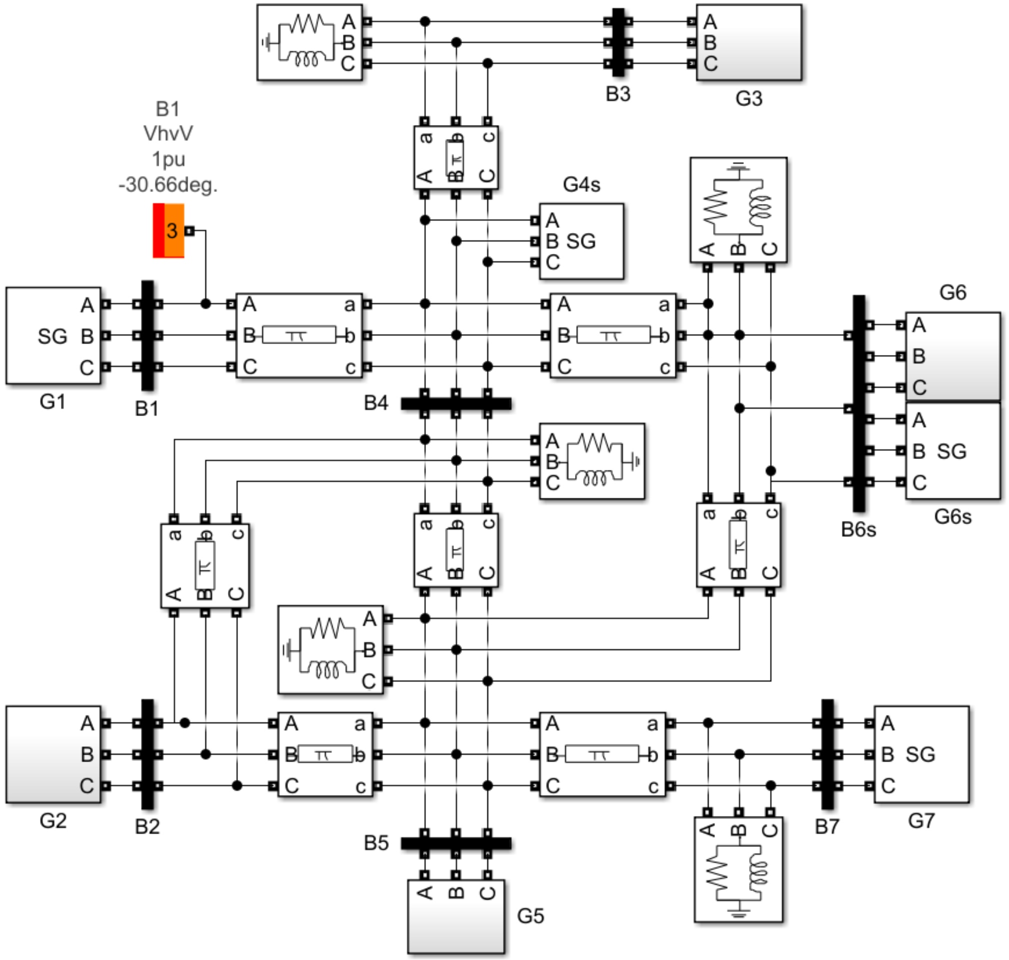


Same closed-loop time constant

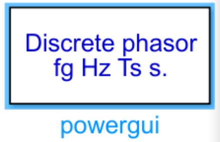
Lower Time step

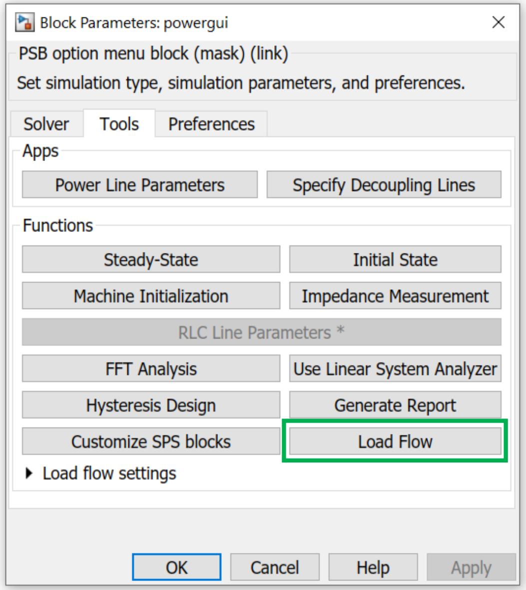
Higher Approximation

Initialization

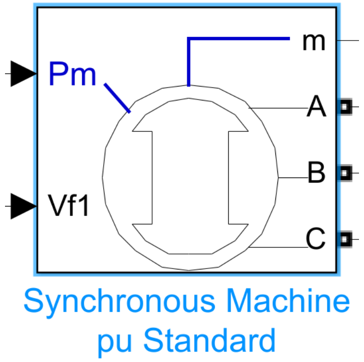


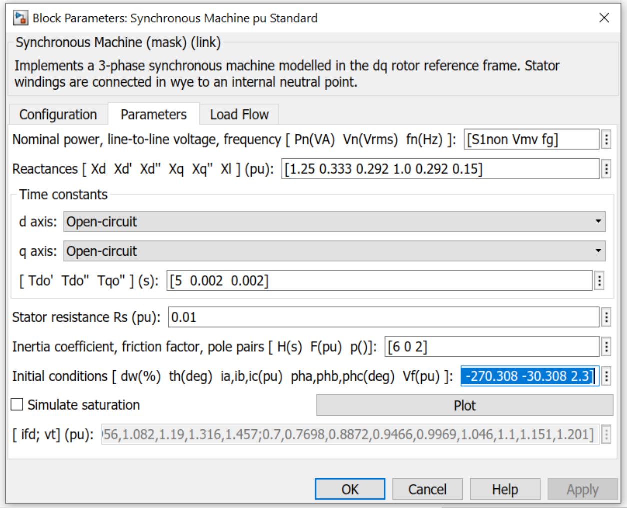
Run load flow and apply result



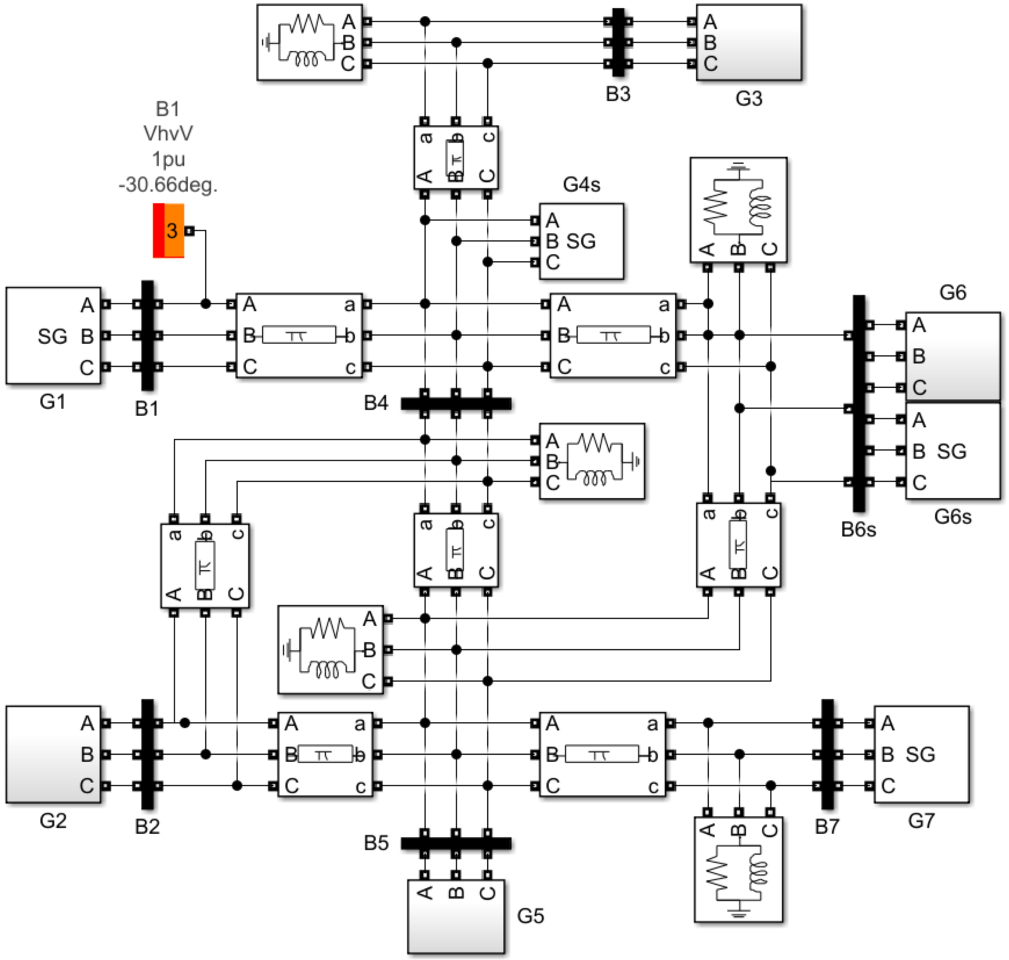


Initial currents, fluxes and field voltage are applied to generators

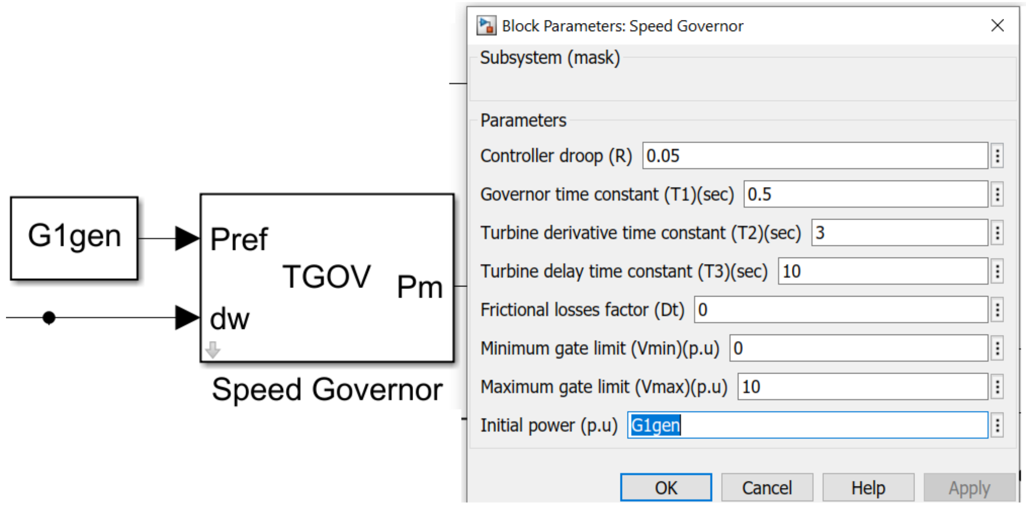




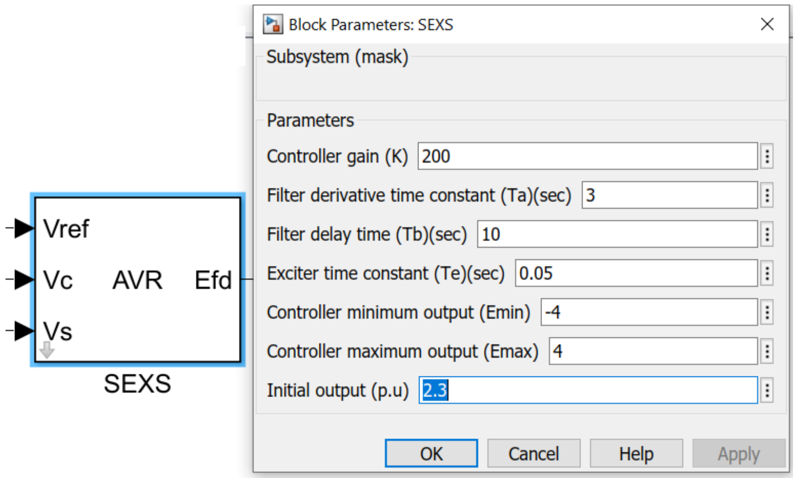
Initialization



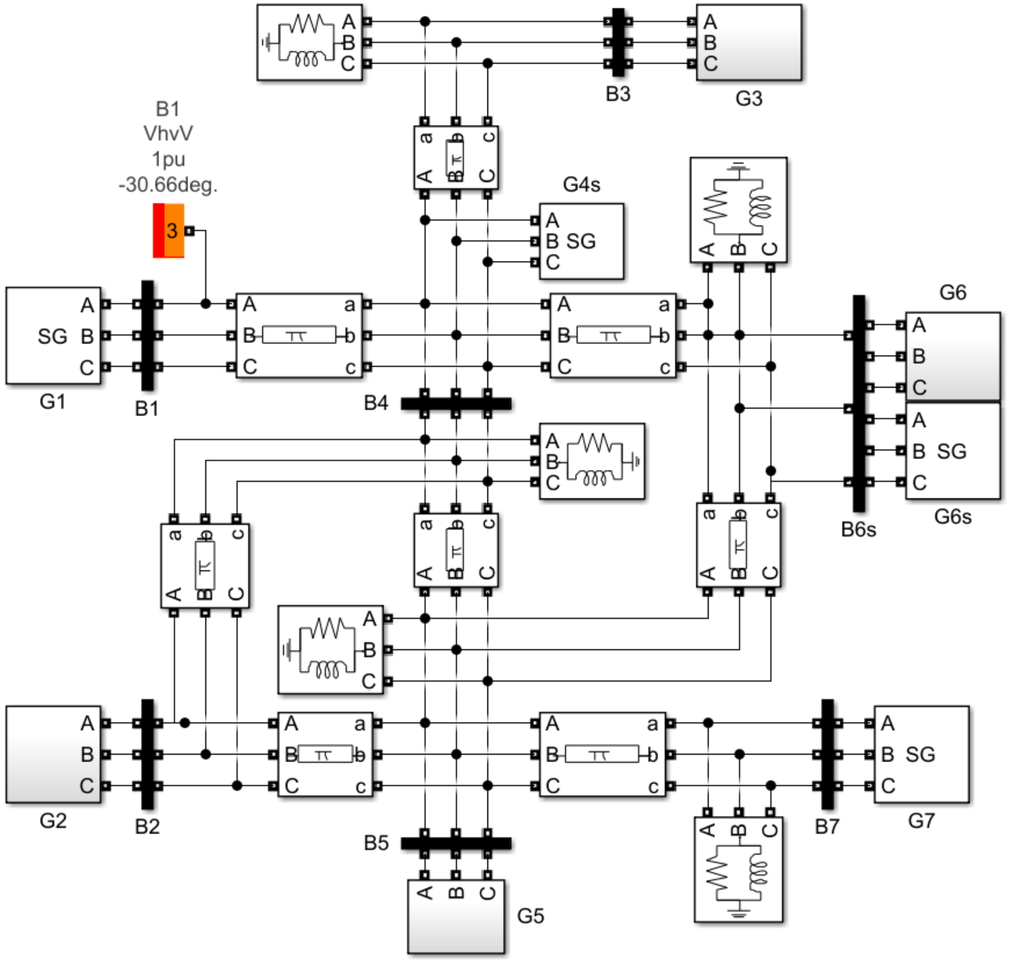
Governor



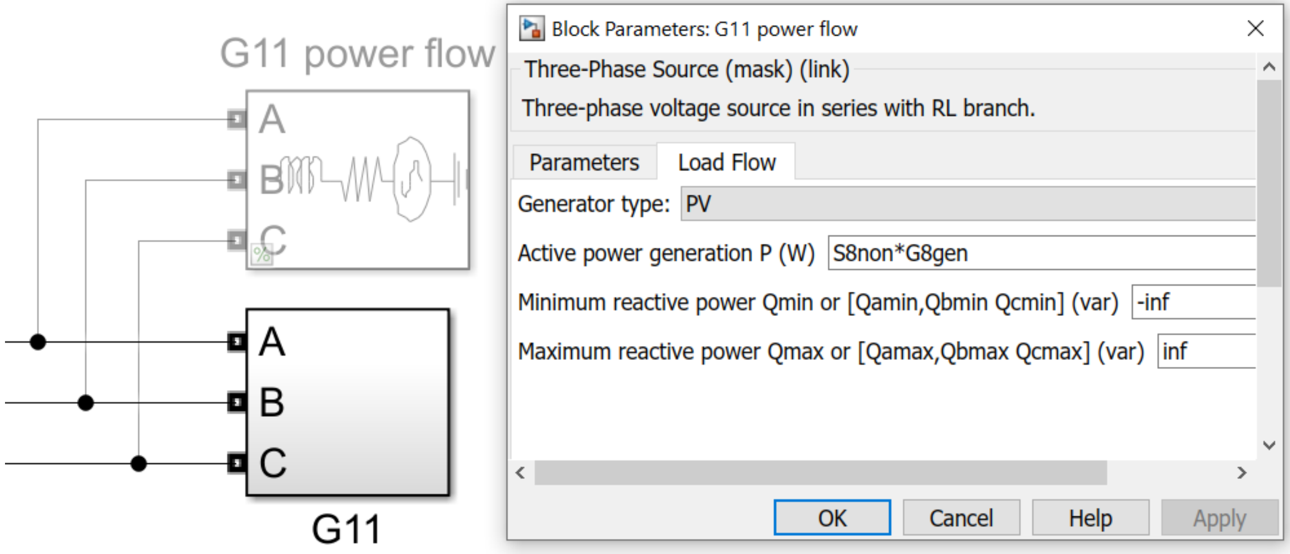
Exciter



Initialization



Substitute the VSCs by voltage sources



The same can be done using a Matlab script

```
set_param([prjname blockname2],'vscmod','EMT Average')
set_param([prjname '/powergui'],'SimulationMode','Discrete')
```

```
set_param('VSC_model_other_Phasors/HLoadEMT','commented','off')
set_param('VSC_model_other_Phasors/HLoadPhasor','commented','on')
```

```
LF = power_loadflow('-v2',modelname,'solve','report','PF_result1');
```

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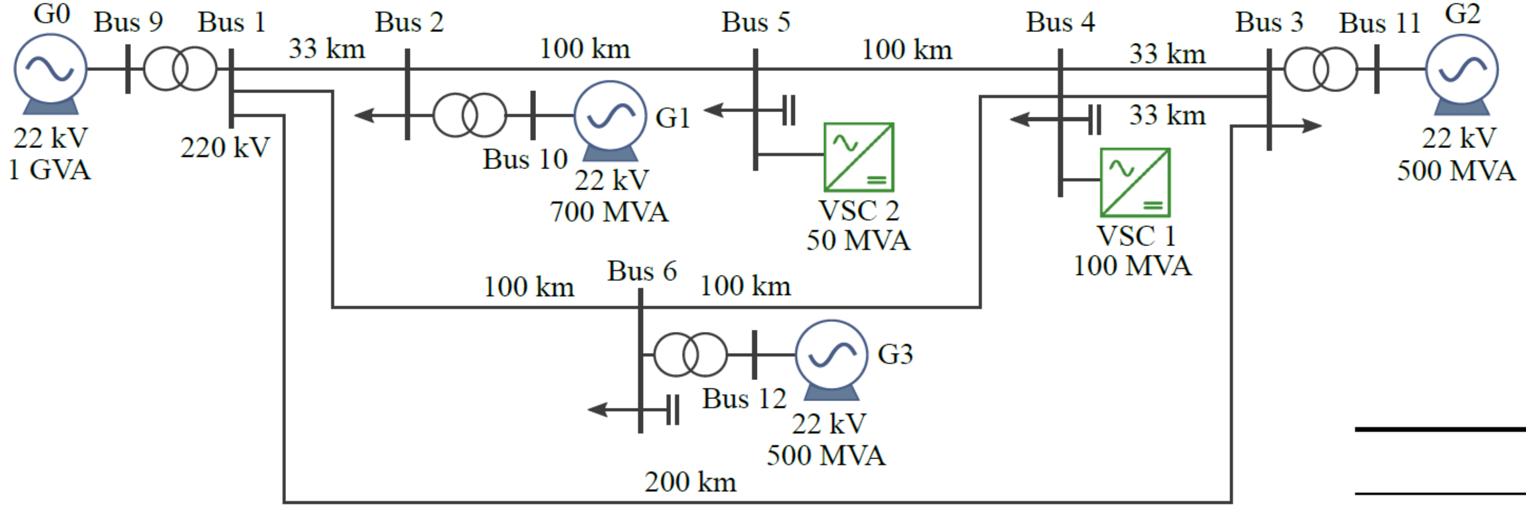
Suitability of each VSC model



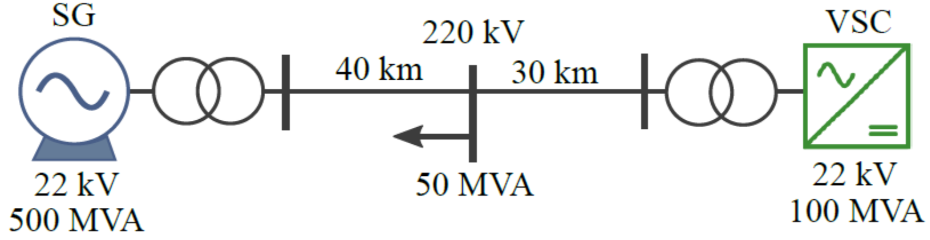
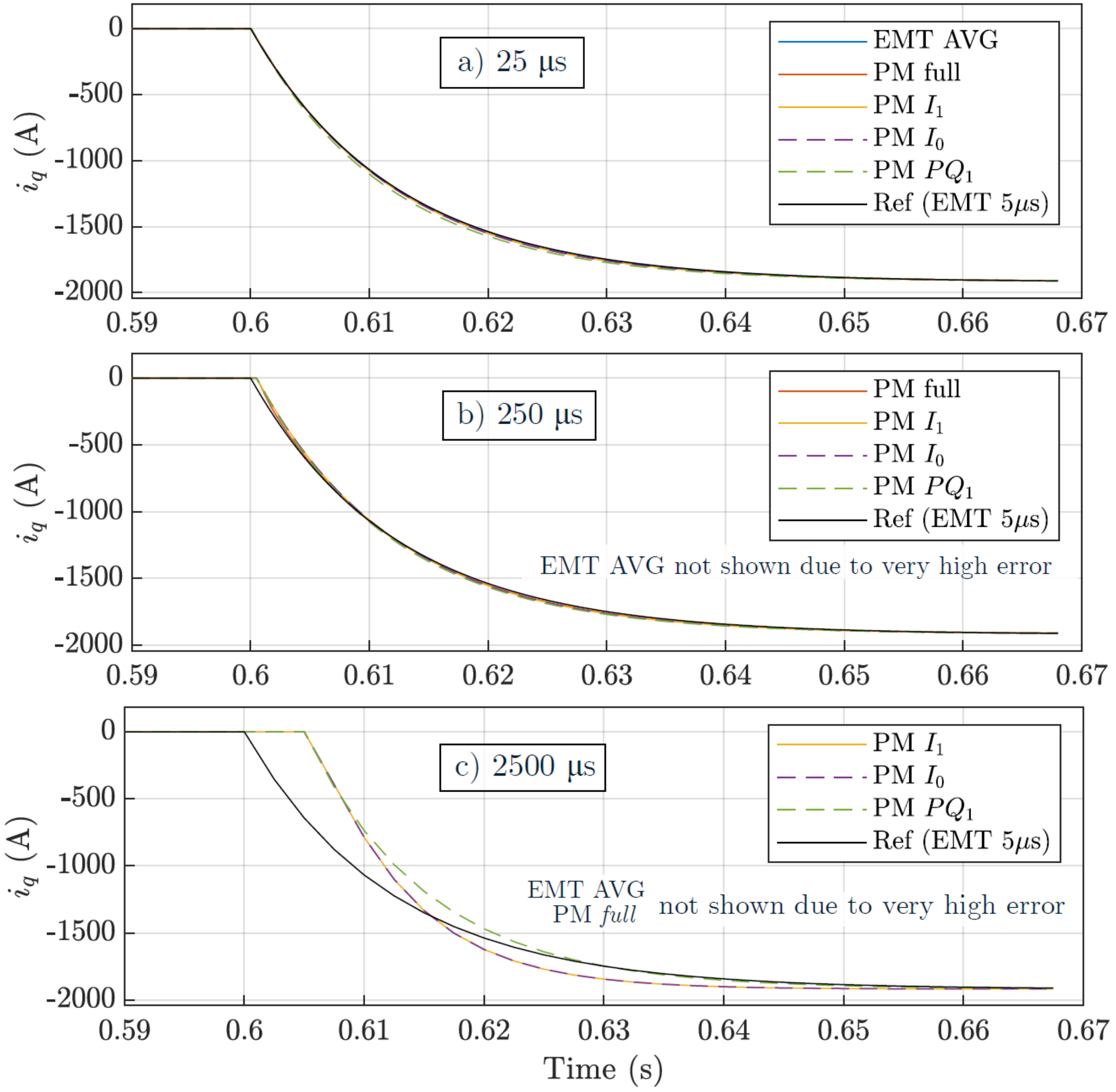
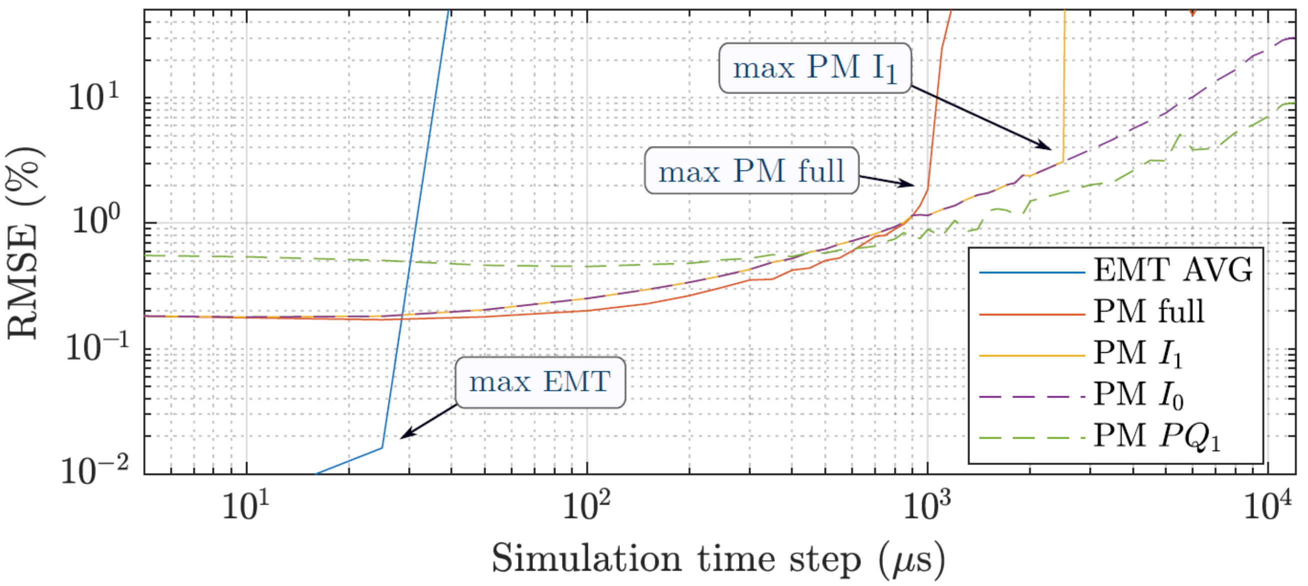


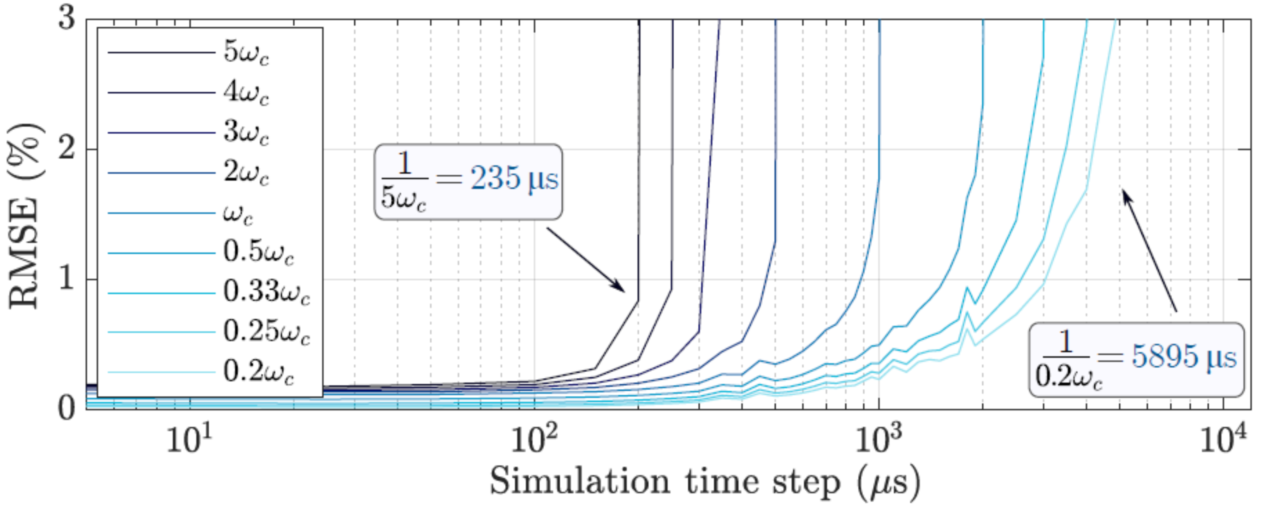
TABLE I
TESTS PERFORMED

	Small system	Large system	Variables
Setpoint tracking	•		P_{ac}, i_{dq}
Harmonics	•		i_{dq}, v_{dq}
Frequency/Voltage deviation	•		f,V_{abc}
Symmetrical faults	•		i_{dq}, v_{dq}, T_e, ω_m
Asymmetrical faults	•	•	i_{dq}, v_{dq}, T_e, ω_m
Loss of generation		•	i_{dq}, v_{dq}, T_e, ω_m
Line outage		•	i_{dq}, v_{dq}, T_e, ω_m
Simulation time steps	from 5 μs to 12000 μs		

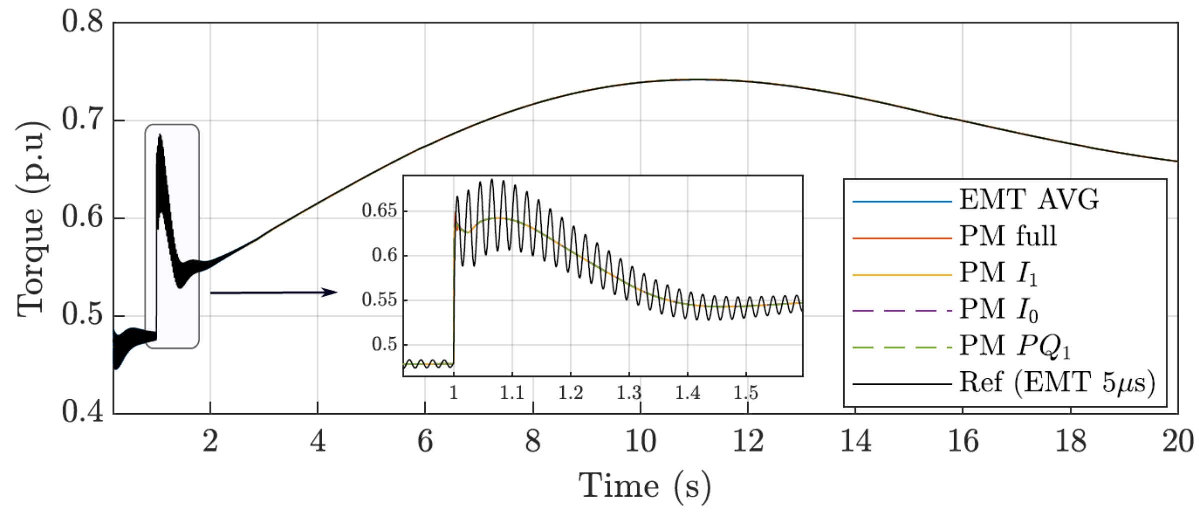
Suitability of each VSC model



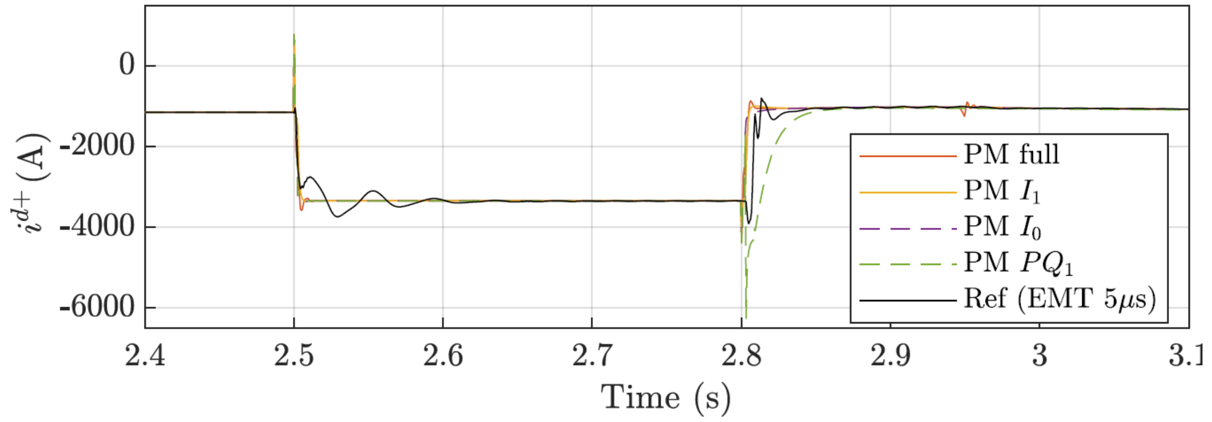




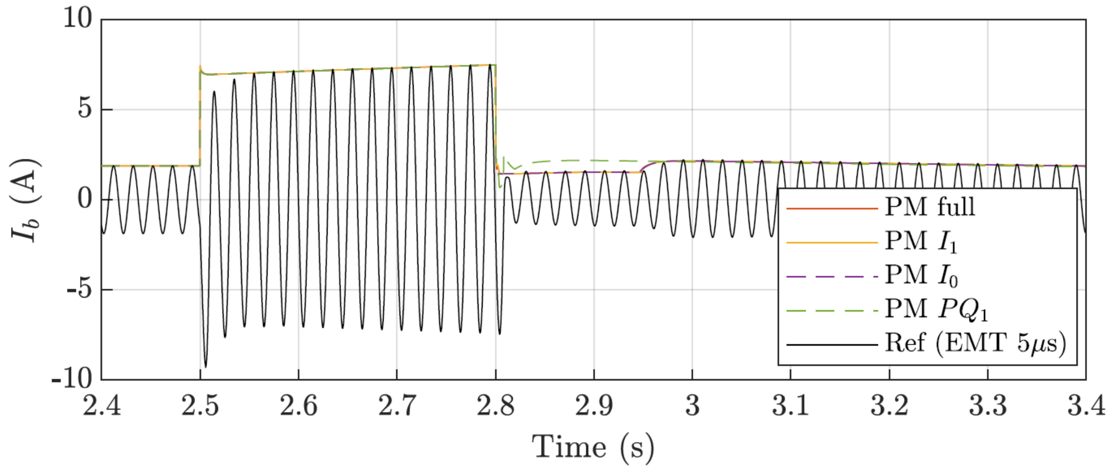
Suitability of each VSC model



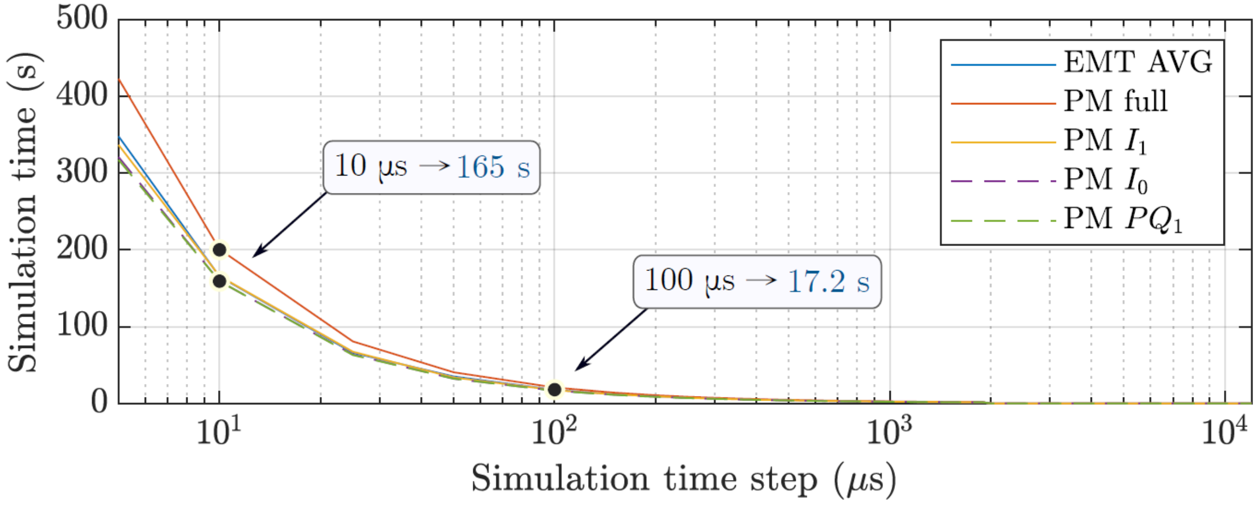
Test 2 – Te simulated by each model at 25 μs.



Test 3 – i^{d+} simulated by each model at 600 μs.

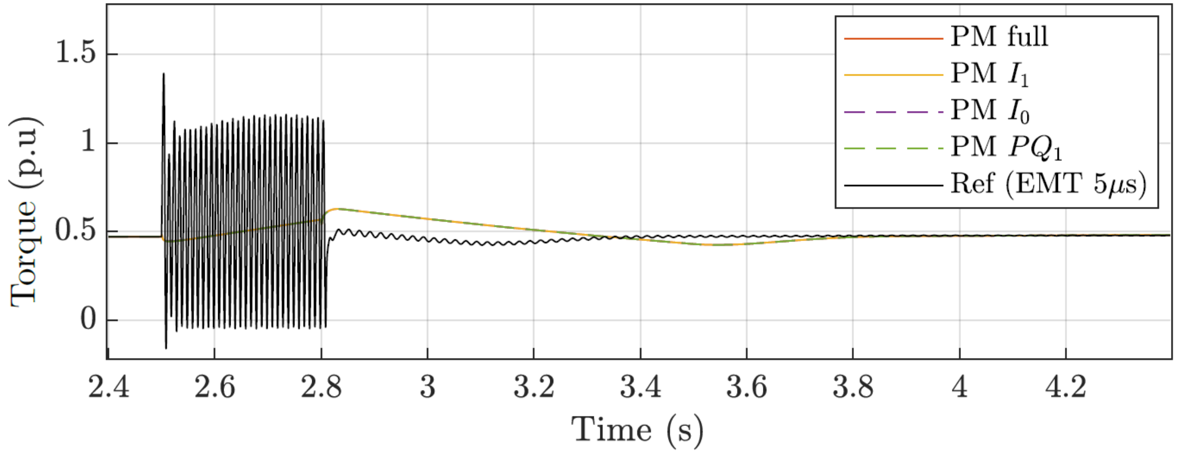


Test 3 – I_b simulated by each model at 350 μs.

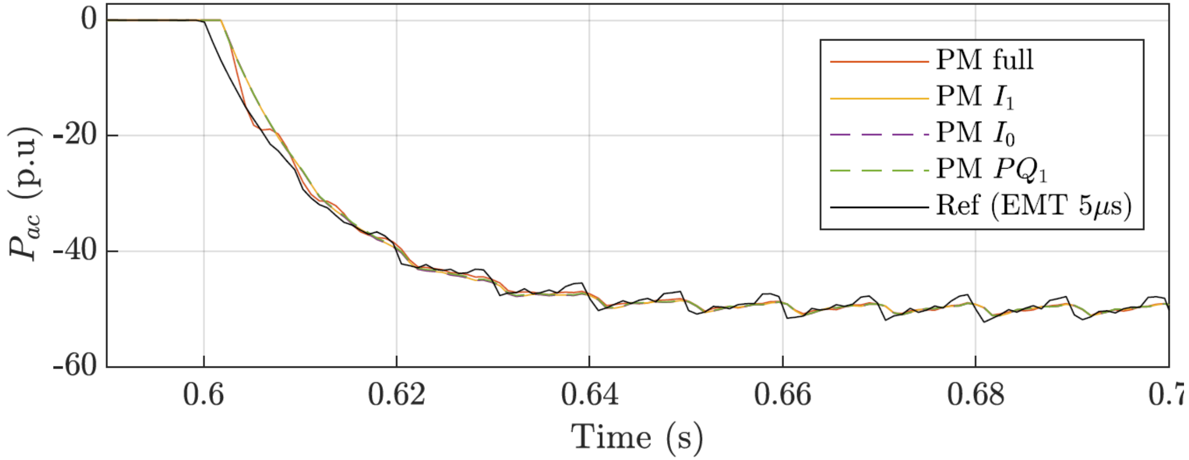


EMT and PM models simulation times for several time steps.

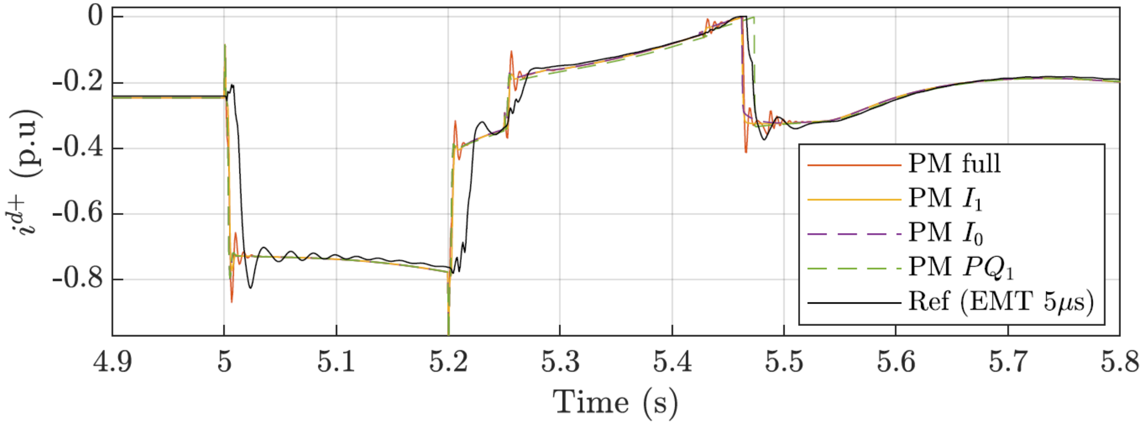
Suitability of each VSC model



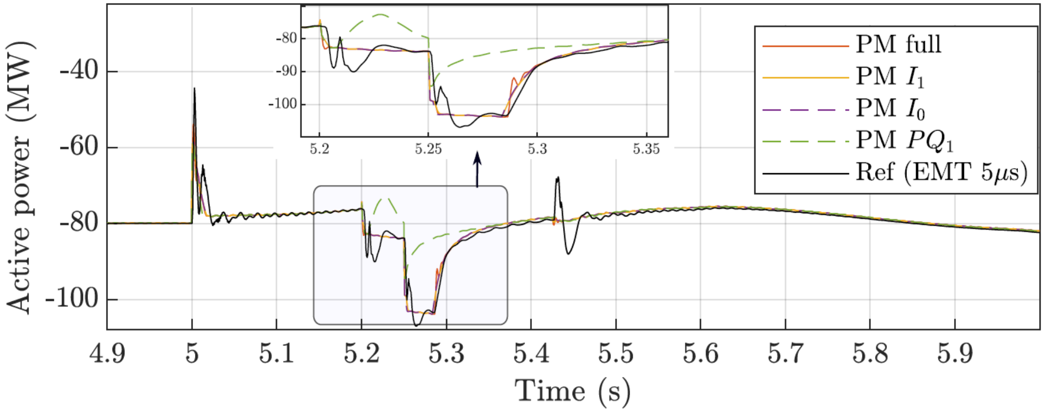
Test 4 – T_e simulated by each model at 350 μs.



Test 5 – P_{ac} simulated by each model at 850 μs.

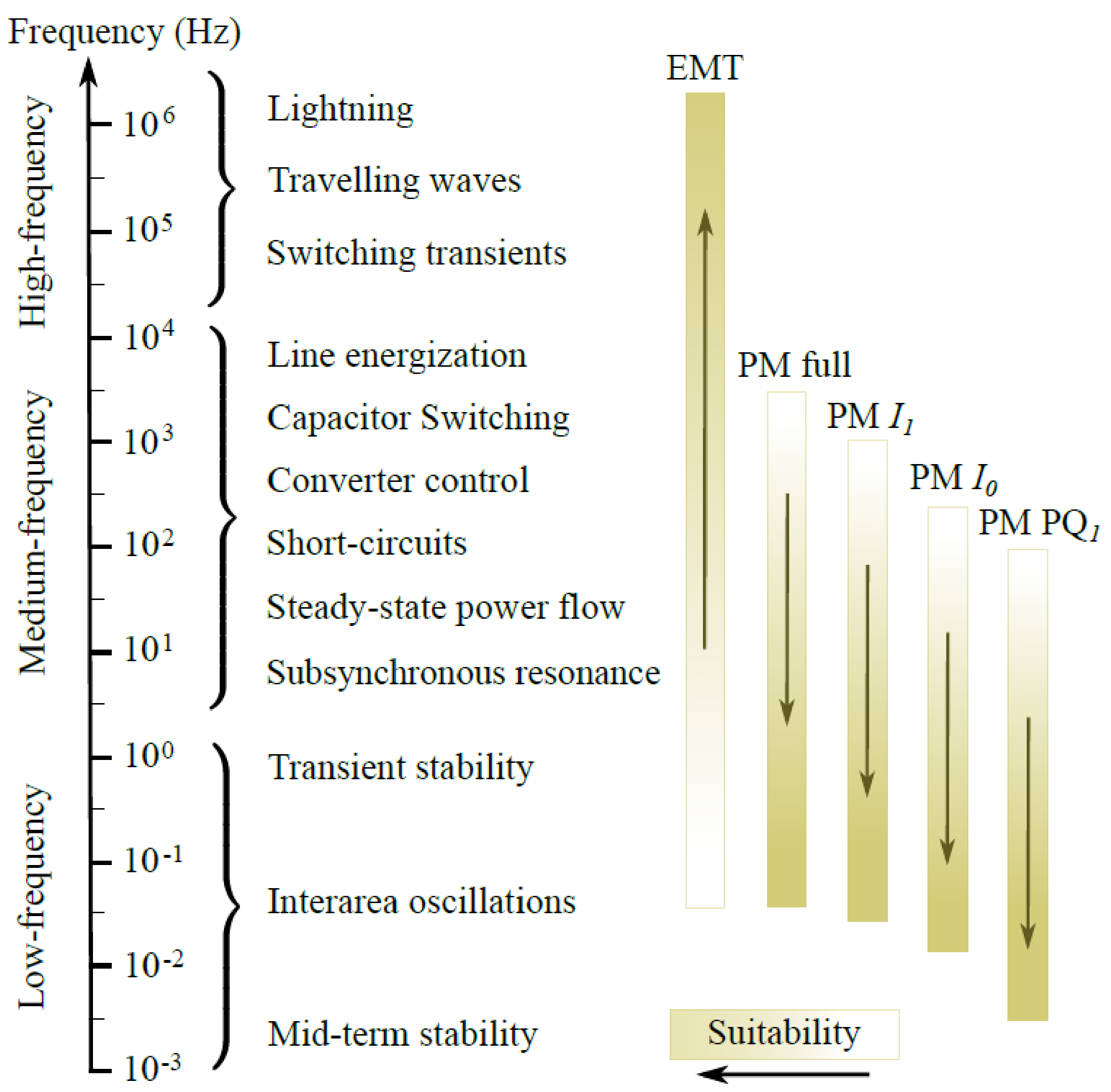


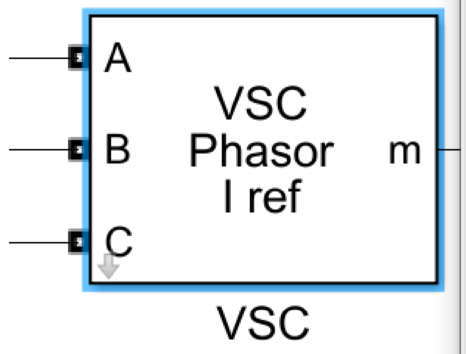
Test 3 large system – VSC 1 i^{d+} simulated by each model at 850 μs.

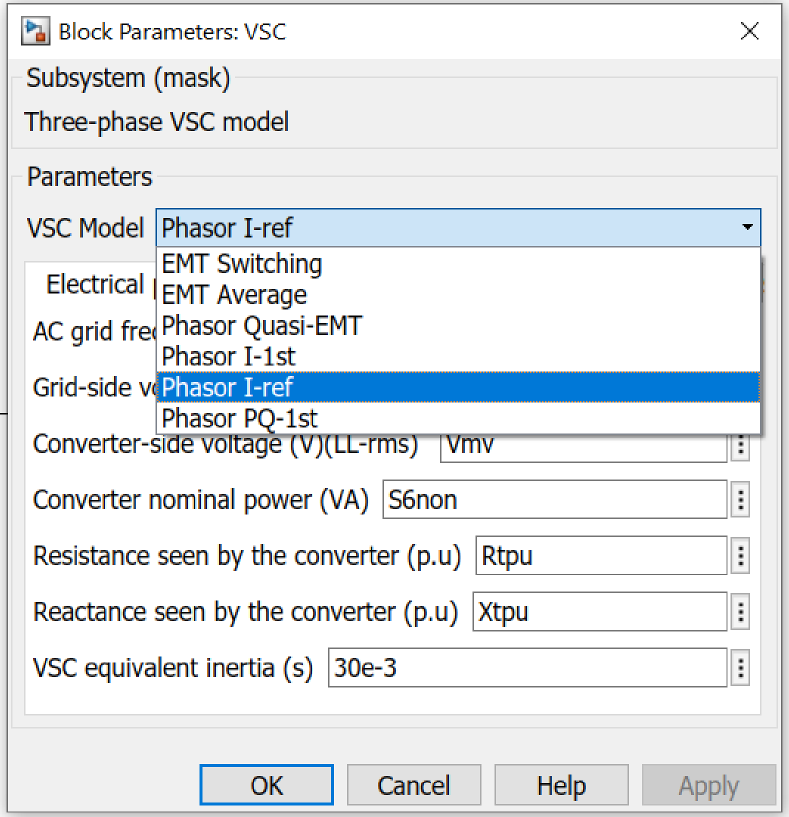


Test 3 large system – VSC 1 P_{ac} simulated by each model at 700 μs.

Suitability of each VSC model







Questions?

Phasor and EMT modelling and simulation of POSYTYF scenarios

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