



National Technical University of Athens
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Electric Energy Systems Lab

Contribution of doubly fed wind generators on power systems oscillation damping

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Contents



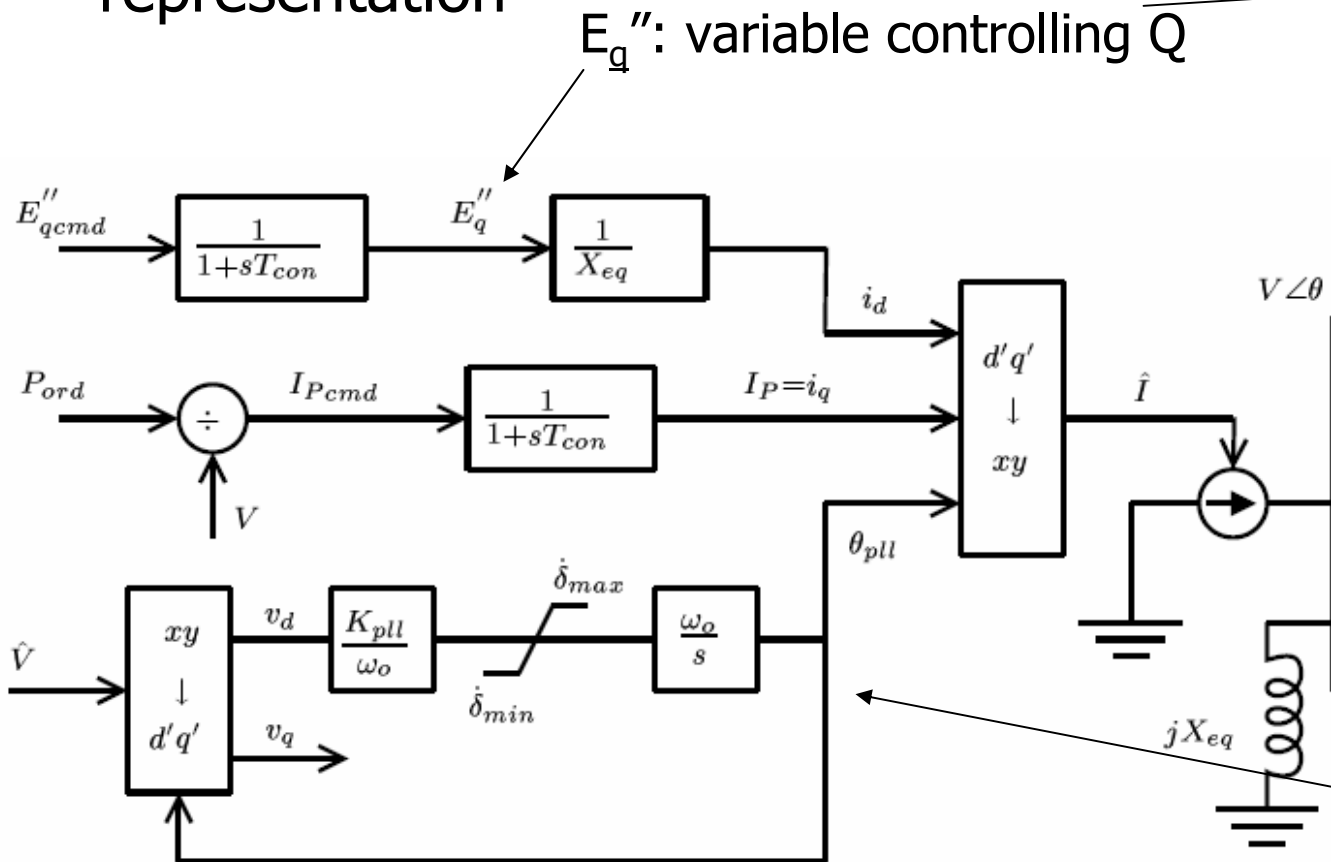
1. Model of wind farm with DFAGs (aka DFIG) for stability studies: WECC “generic DFAG model”, based on manufacturer data, implemented in PSS/E
2. Modes introduced by DFAGs (OMIB system)
3. Effect of DFAGs on small-signal stability of a small interconnected system
4. Wind PSS
5. Hellenic system case study

Generator/Converter 'algebraic' model

⌘ Active and reactive current source representation

$$P = VI_P$$

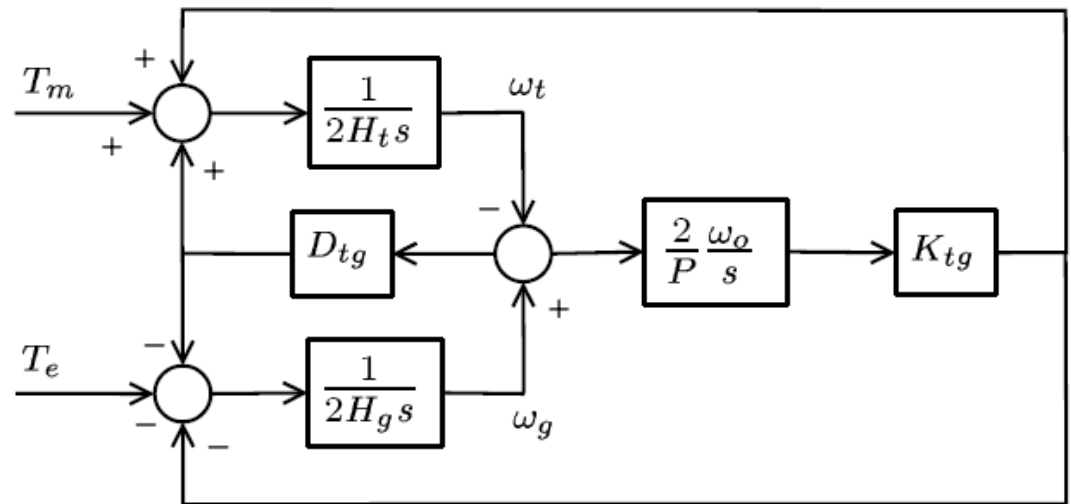
$$Q = V \frac{E_q'' - V}{X_{eq}}$$



Phase Locked Loop

Two-mass model

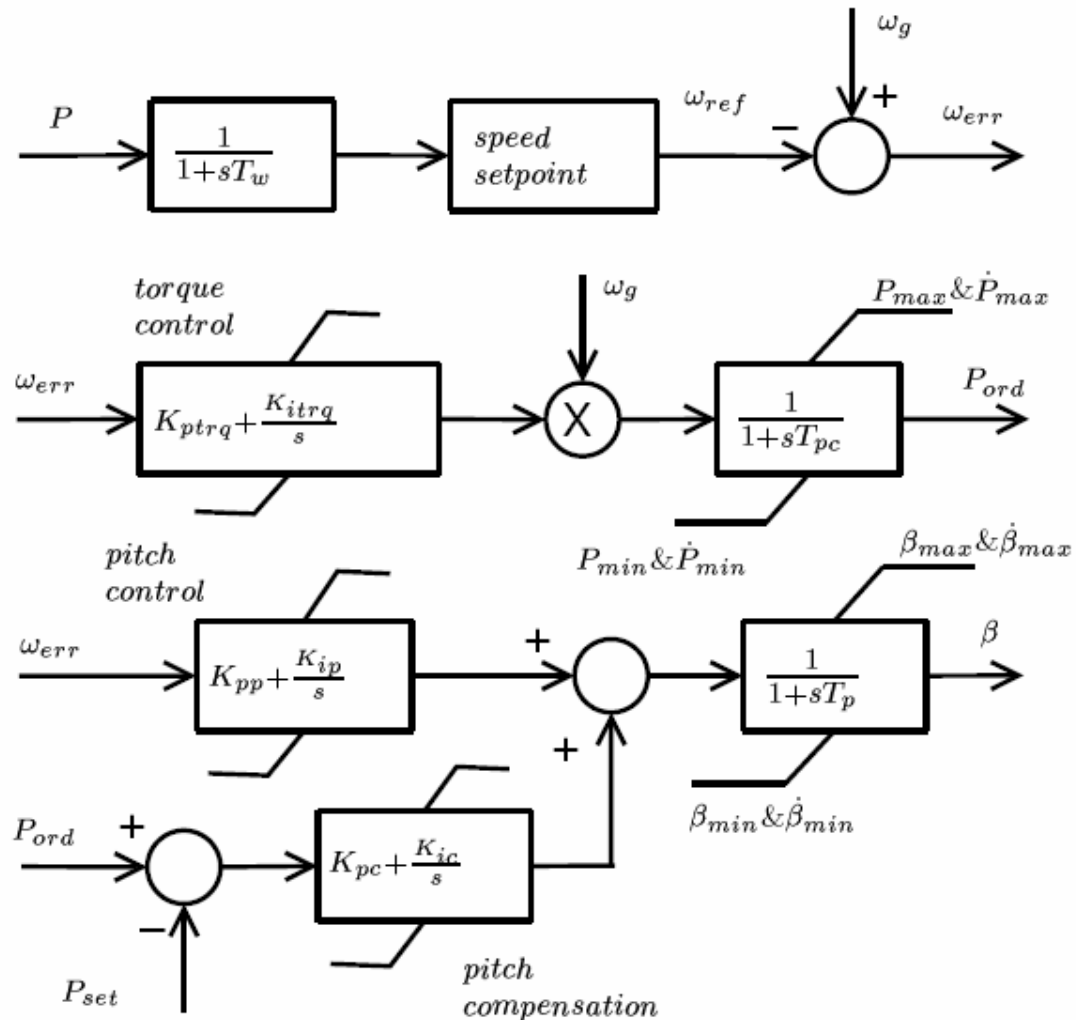
⌘ Shaft torsional mode of oscillation



Active power control

⌘ Speed control

⌘ Pitch control / pitch compensation



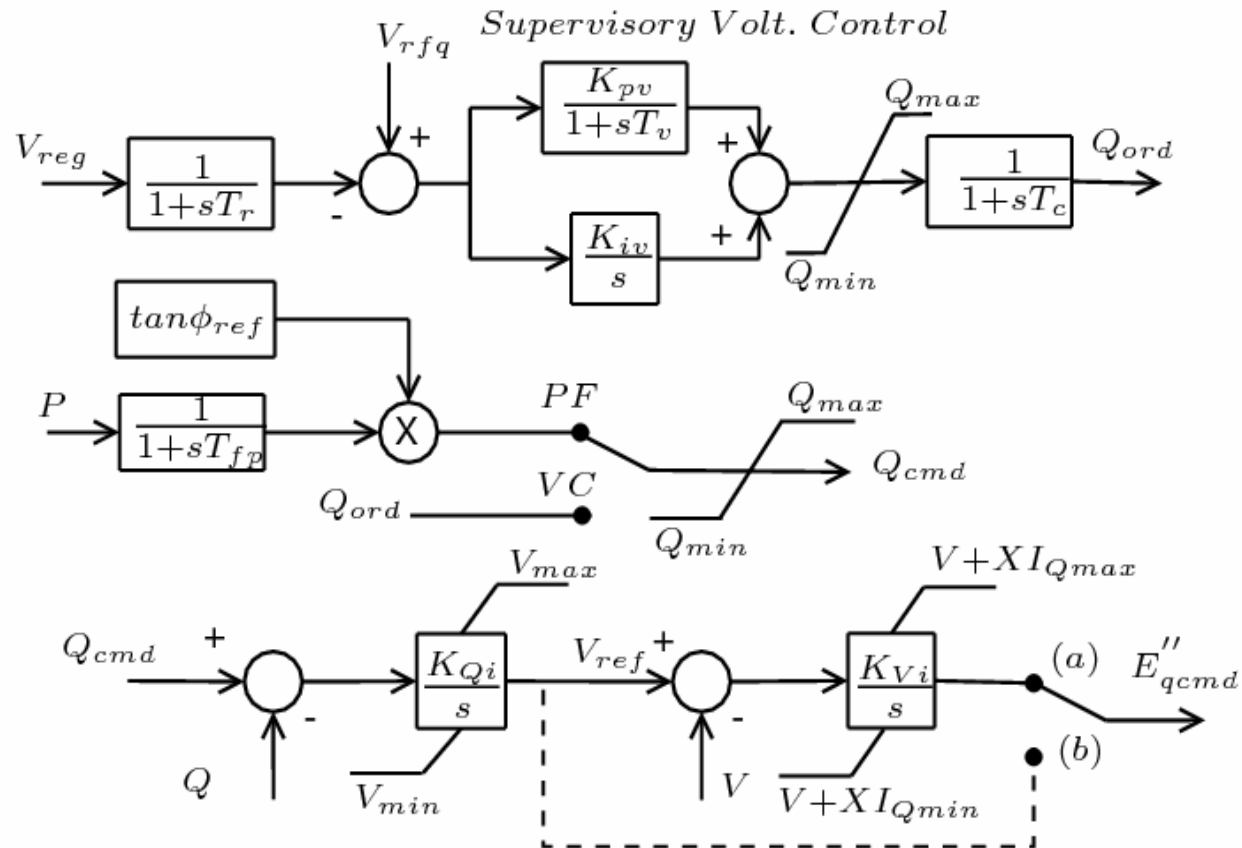
Reactive power control

Two control modes:

Power factor (PF) control

Voltage Control (VC)

Point of common coupling

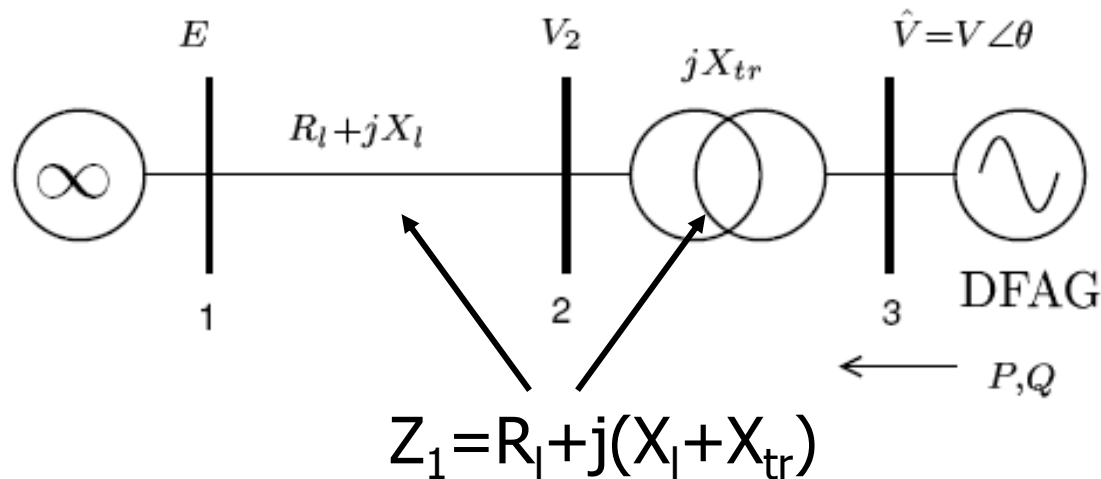


Terminal voltage control (TVC)

VAR control oscillation mode

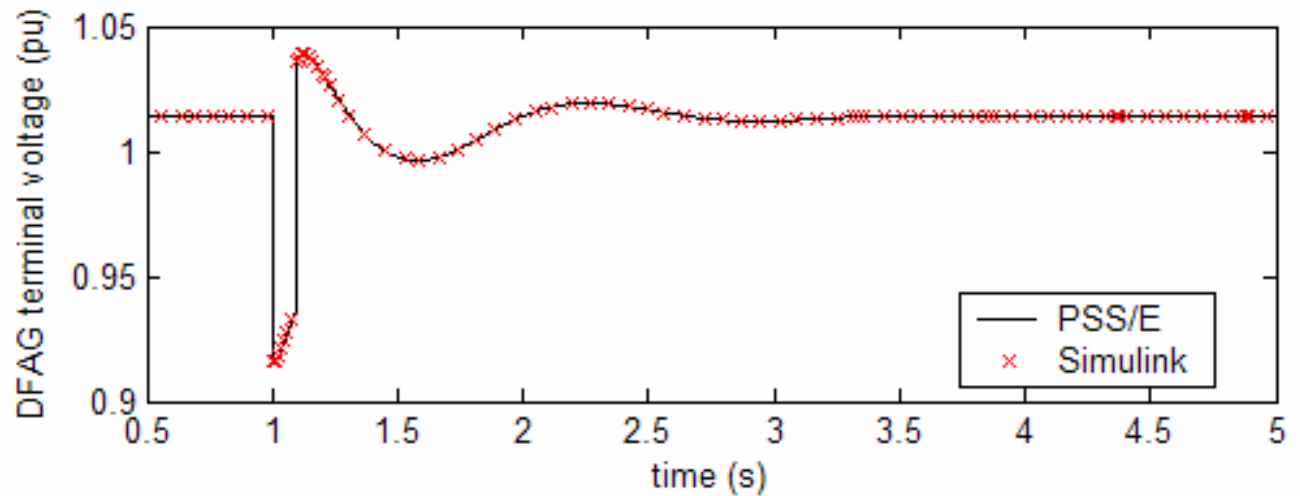
Modes introduced by DFAG

- ⌘ Model implemented in Matlab/Simulink
- ⌘ Fault response and eigenvalues (3-bus system)
- ⌘ Model validation by comparing with PSS/E program
- ⌘ Examined case: PF control with TVC

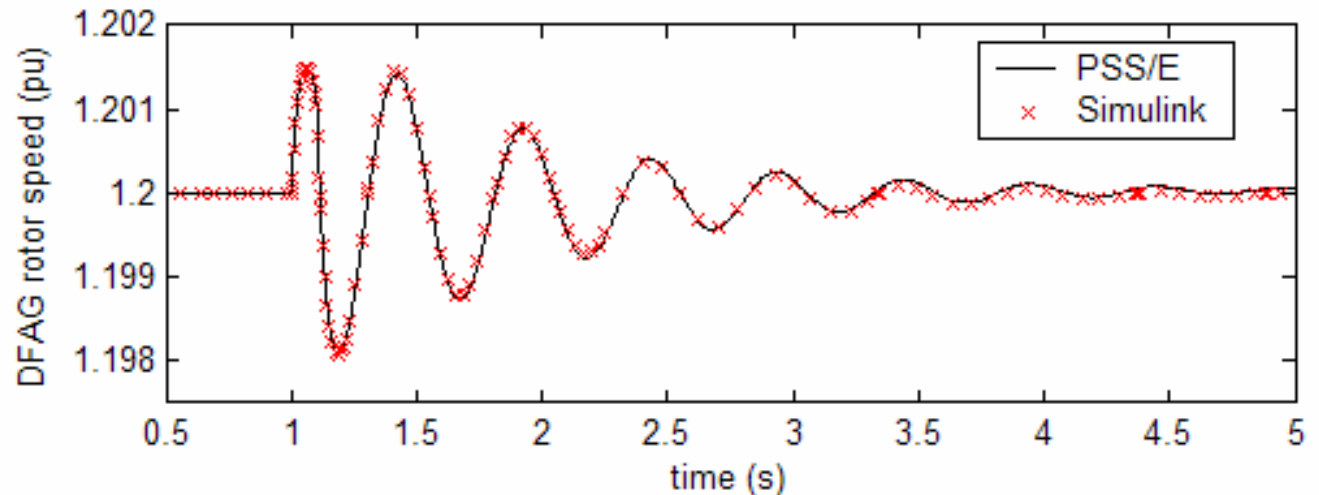


OMIB system: fault response

⌘ DFAG terminal voltage



⌘ DFAG rotor speed

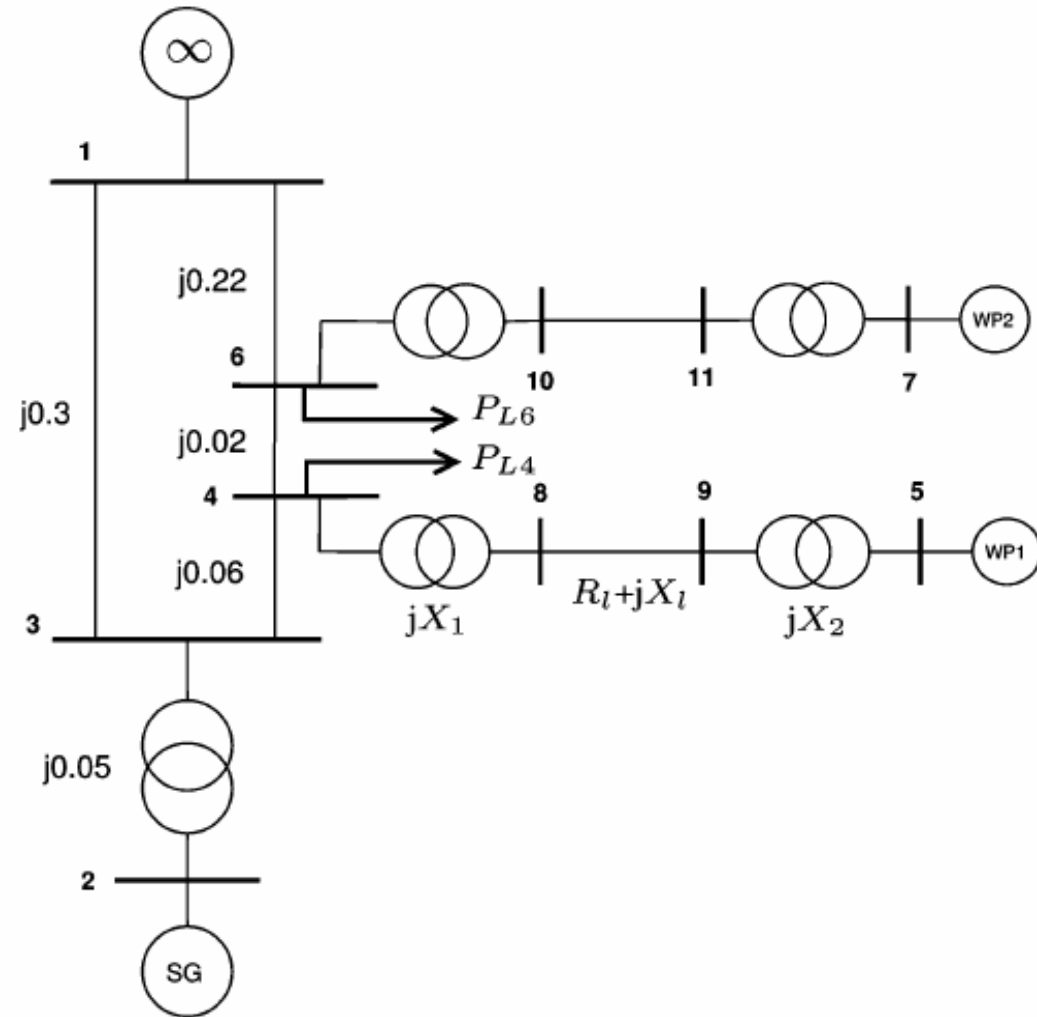


OMIB system: eigenvalues

PSS/E		Simulink		Response mode
Real	Imag.	Real	Imag.	
-1.124	12.50	-1.127	12.50	Shaft
-1.696	4.64	-1.690	4.64	VAR controller
-0.165	0.23	-0.189	0.19	Speed control
-51.084		-51.084		I_p time constant
-47.348		-47.356		E'_q time constant
-27.966		-27.976		PLL
-17.219		-17.224		P_{ord} actuator
-0.200		-0.200		T_w filter
-3.322	0.01	-3.324		Pitch delay & P filter, T_p
-0.035				Pitch compensation
0.000				Pitch control

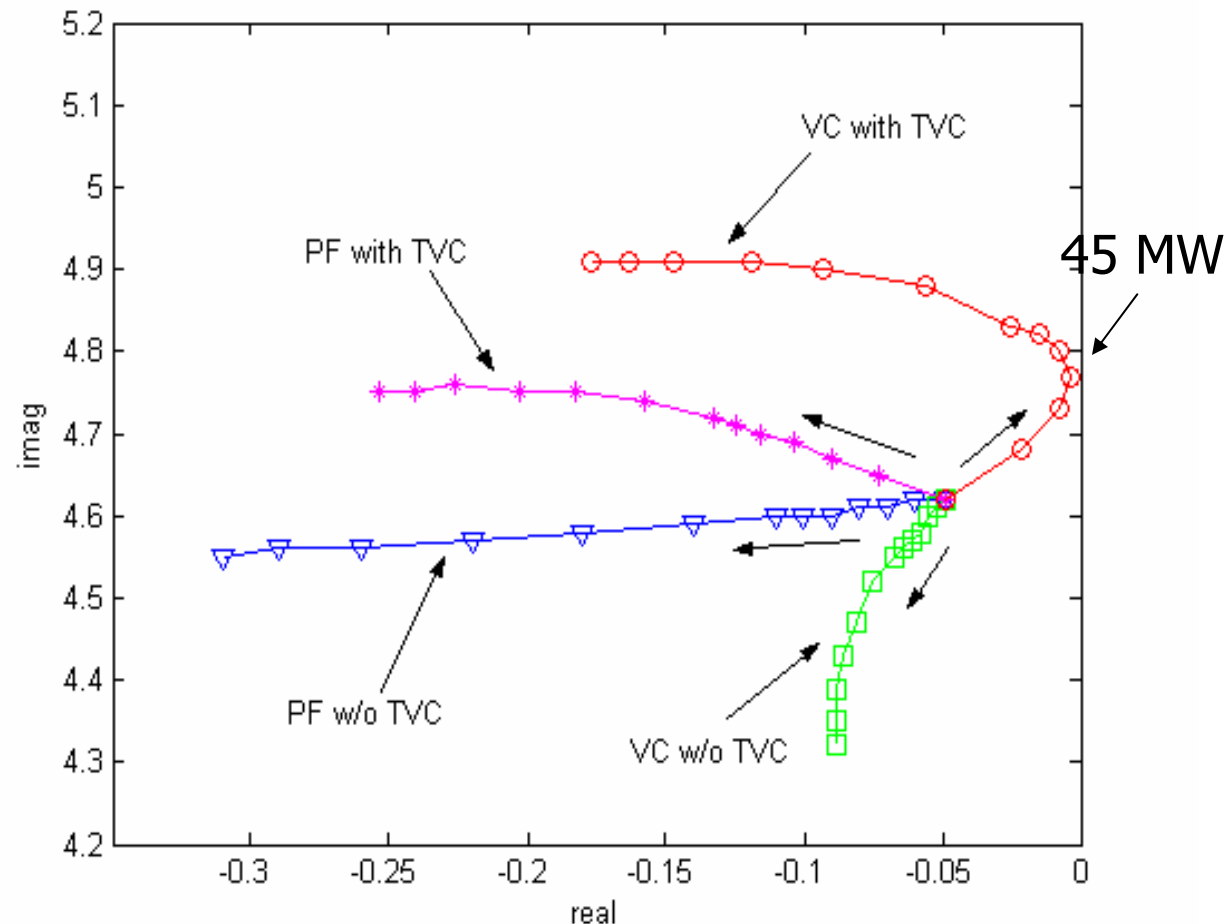
Small-signal stability of interconnected power system with high DFAG-based wind power production

- ⌘ System with one (equivalent) local synchronous generator in Simulink ($P_{gen} = 378$ MW)
- ⌘ Gradual increase of wind power together with equal increase of system load \rightarrow SG operating point remains constant



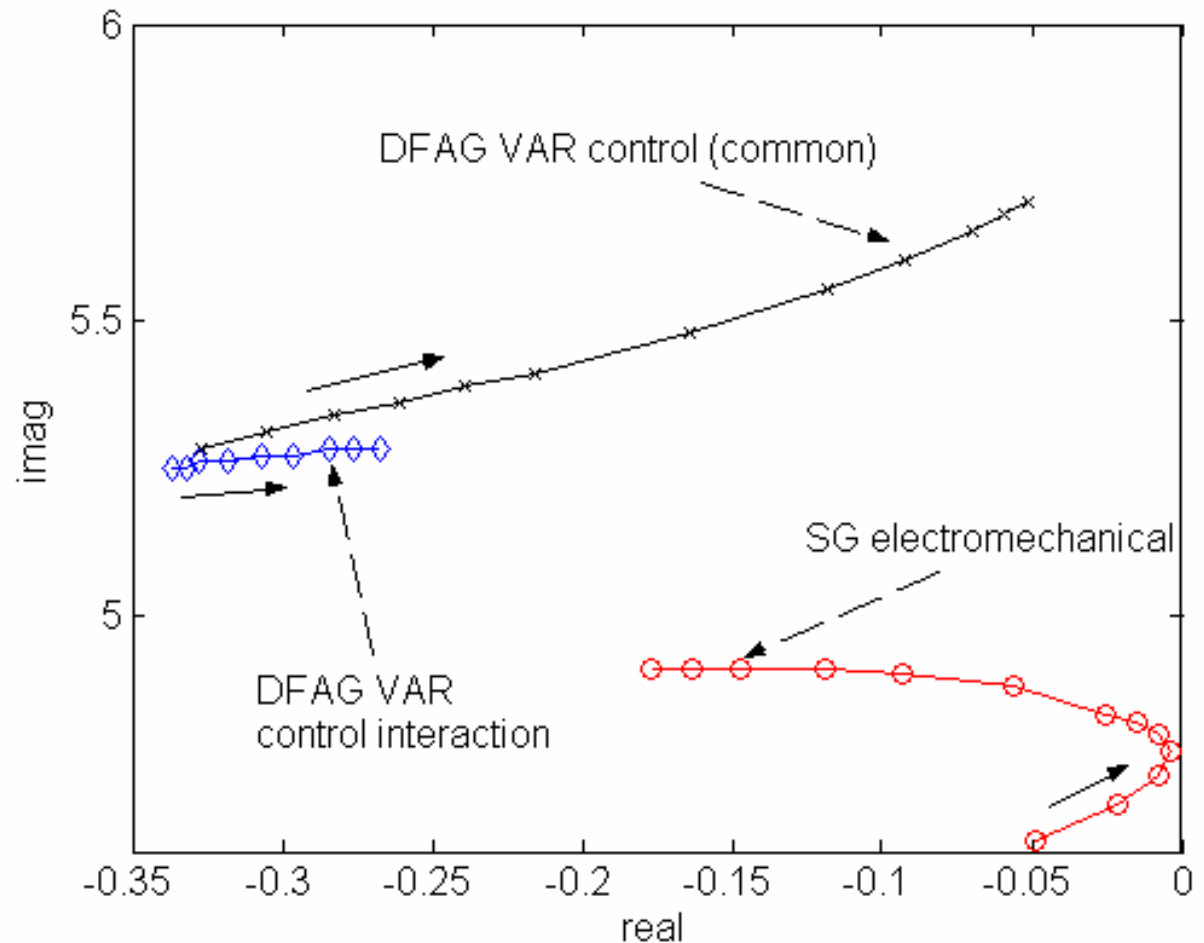
Locus of electromechanical eigenvalues with wind power production increase

- ⌘ 0 – 380 MW of wind power
- ⌘ 4 DFAG model configurations:
 - ⊞ With or without terminal voltage control (TVC)
 - ⊞ Power factor (PF) control or voltage control (VC)
- ⌘ Base case: lightly damped ($\zeta=1\%$)



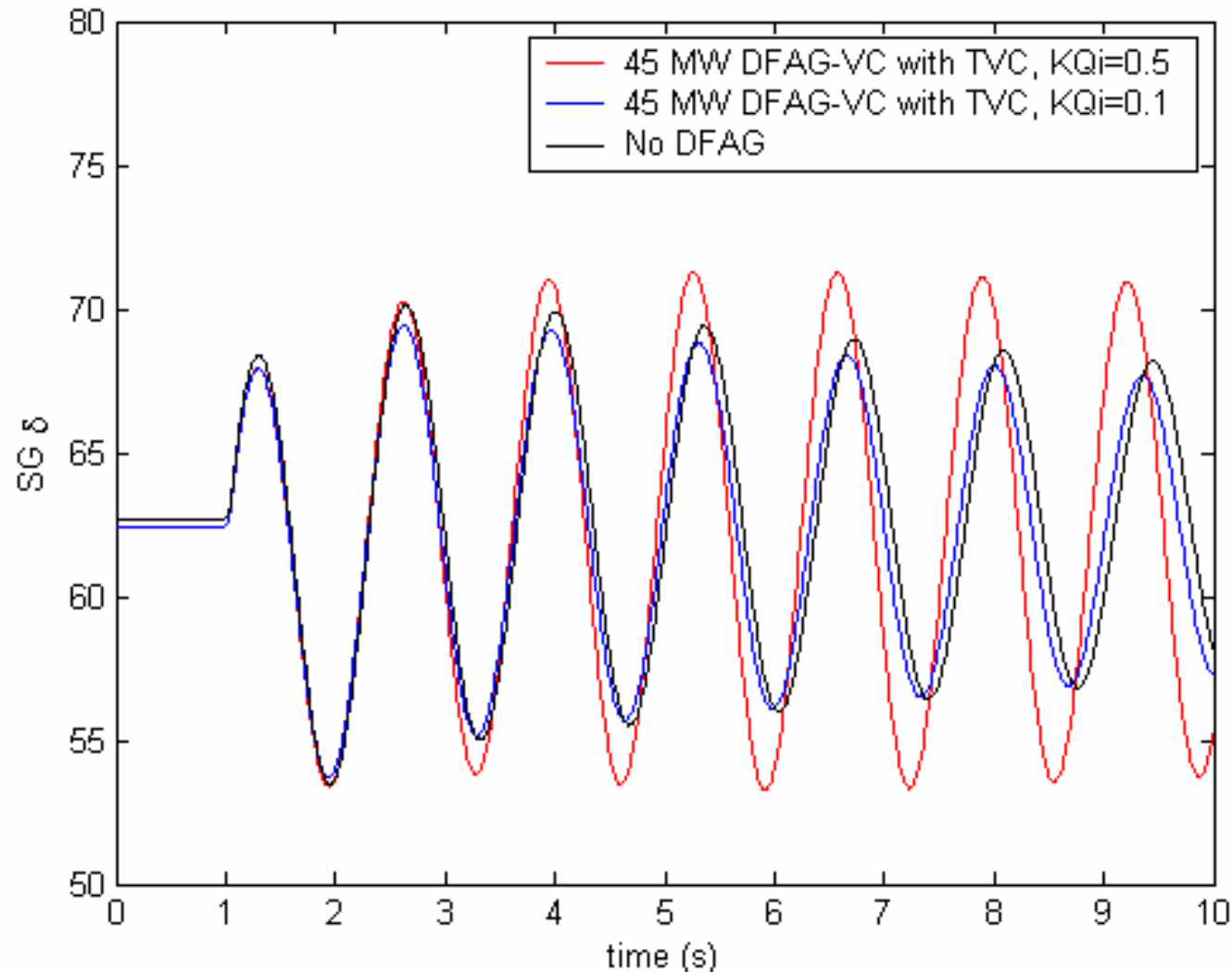
Dominant eigenvalues locus as wind power increases. DFAG in voltage control mode with TVC

⌘ VAR control
oscillation mode
frequency close to
electromechanical
one → adverse
interaction is
possible



Tuning of VAR control mode

- ⌘ Decrease K_{Qi} → Avoid interaction
- ⌘ Damping almost unchanged for 45 MW of wind
- ⌘ VAR control mode:
 - $-0.283 + j*5.34$,
 $\zeta = 0.053$
($K_{Qi} = 0.5$)
 - $-1.796 + j*2.09$,
 $\zeta = 0.653$
($K_{Qi} = 0.1$)



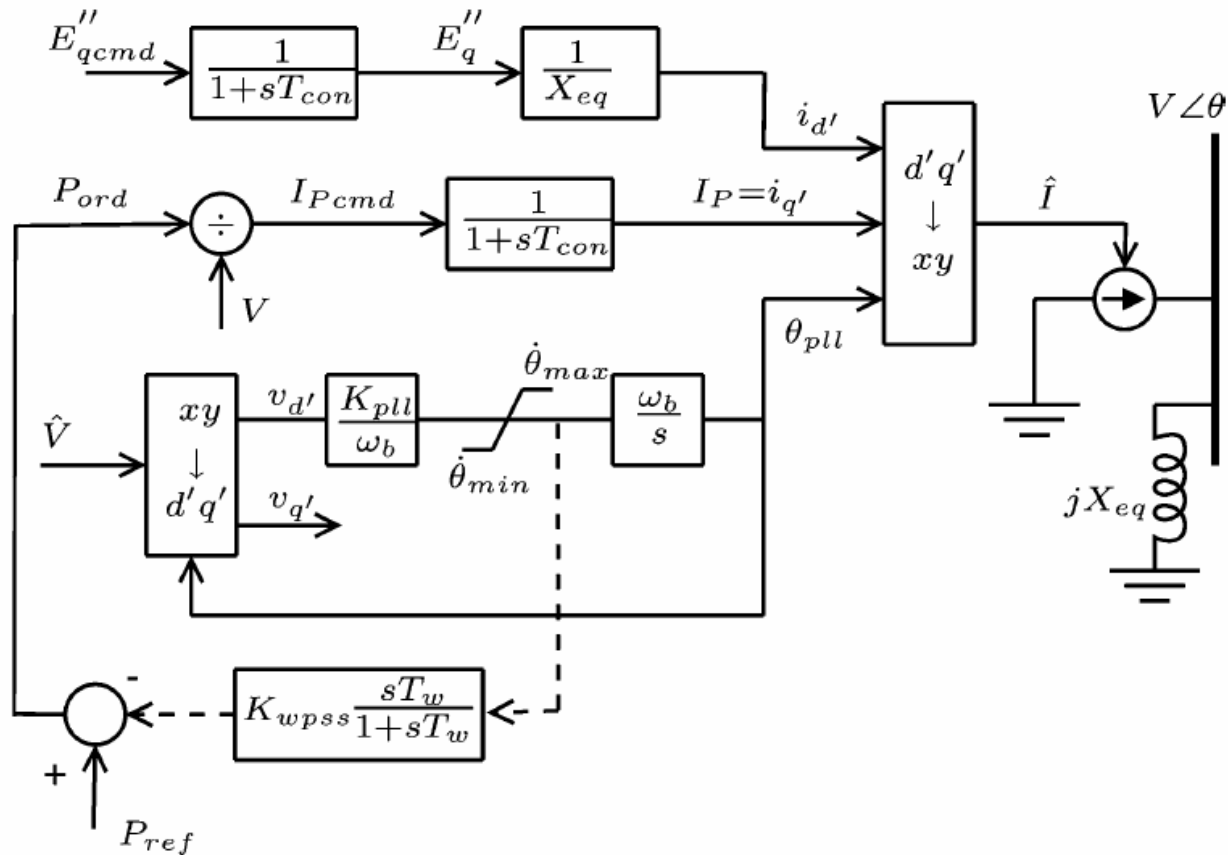
Wind PSS (1)

⌘ Auxiliary signal proportional to frequency deviation, subtracted from Pref

⌘ $\Delta f > 0 \rightarrow$
 P_{DFAG} decrease \rightarrow
 P_{SG} increase \rightarrow
 SG rotor decelerates

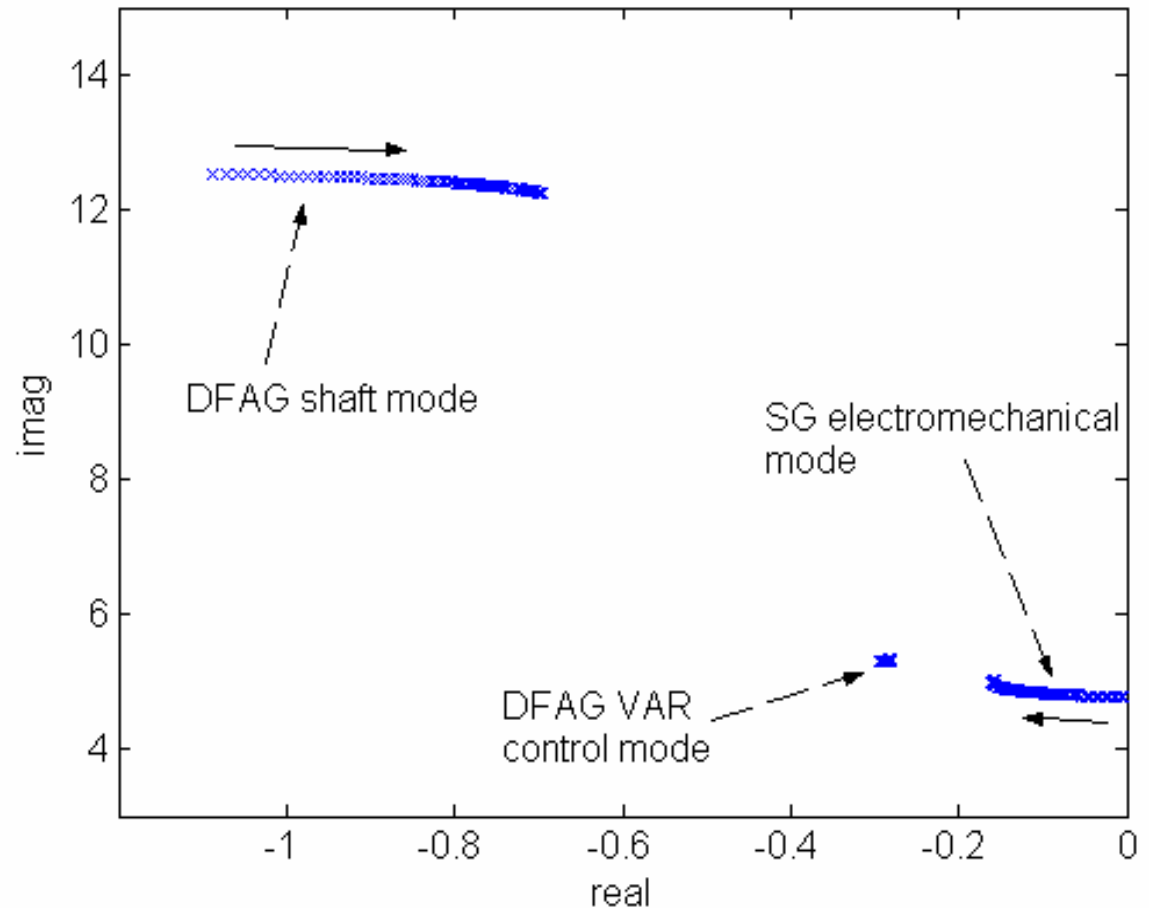
⌘ Wash-out filter

⌘ Also adds inertia



Wind PSS (2)

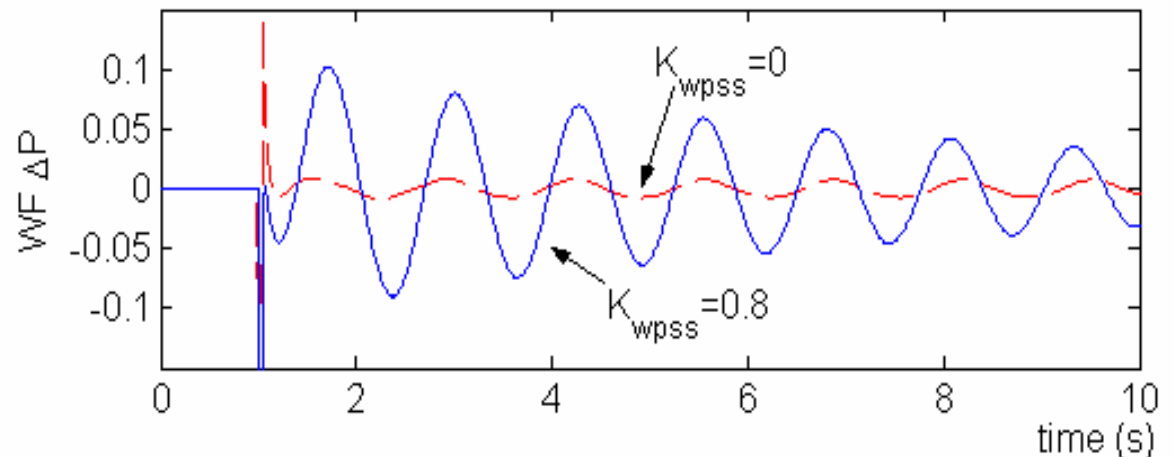
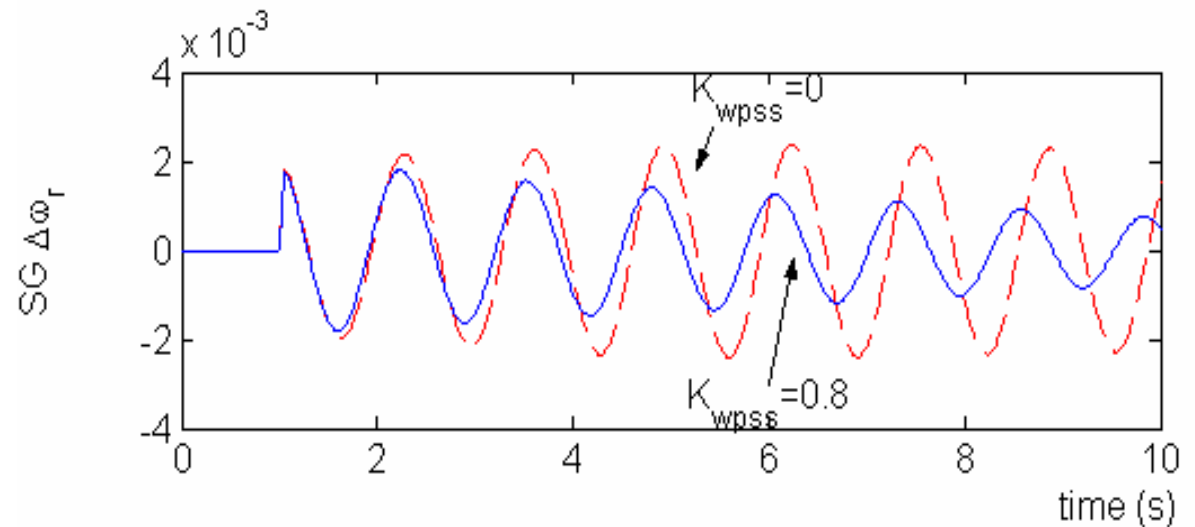
- ⌘ Case of 45 MW, DFAG in voltage control mode with TVC
- ⌘ Root locus for WPSS gain values 0-1
- ⌘ Interarea oscillation damping increase
- ⌘ Shaft mode damping decrease



Wind PSS (3)

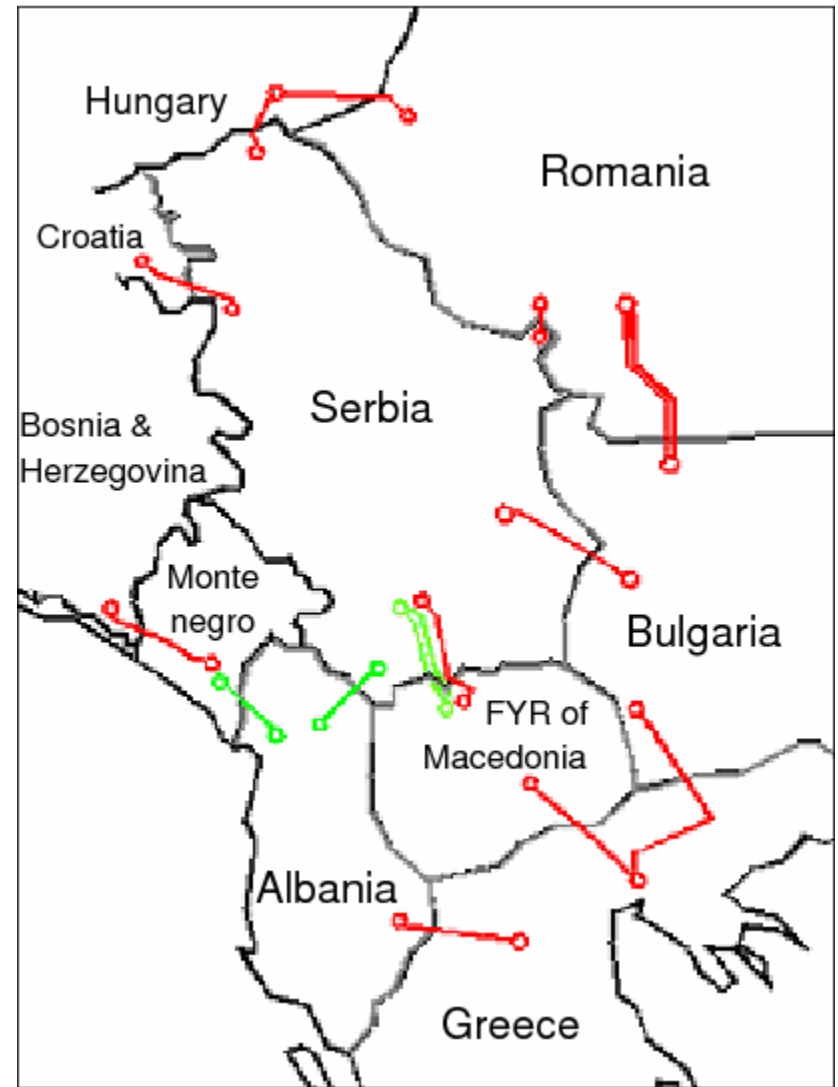
⌘ Fault simulation with and without Wind PSS (45 MW of wind)

⌘ $\zeta > 3\%$



Hellenic system case study (1): system model

- ⌘ Model of HV and EHV system of Greece & EHV system of rest of South-Eastern part of UCTE interconnection (Balkan peninsula) in PSS/E (research project with HTSO)
- ⌘ Total load of Hellenic (Greek) system: 12 GW (2012 peak estimation)
- ⌘ 2500 MW from wind power, 1890 MW of DFAGs (GR)



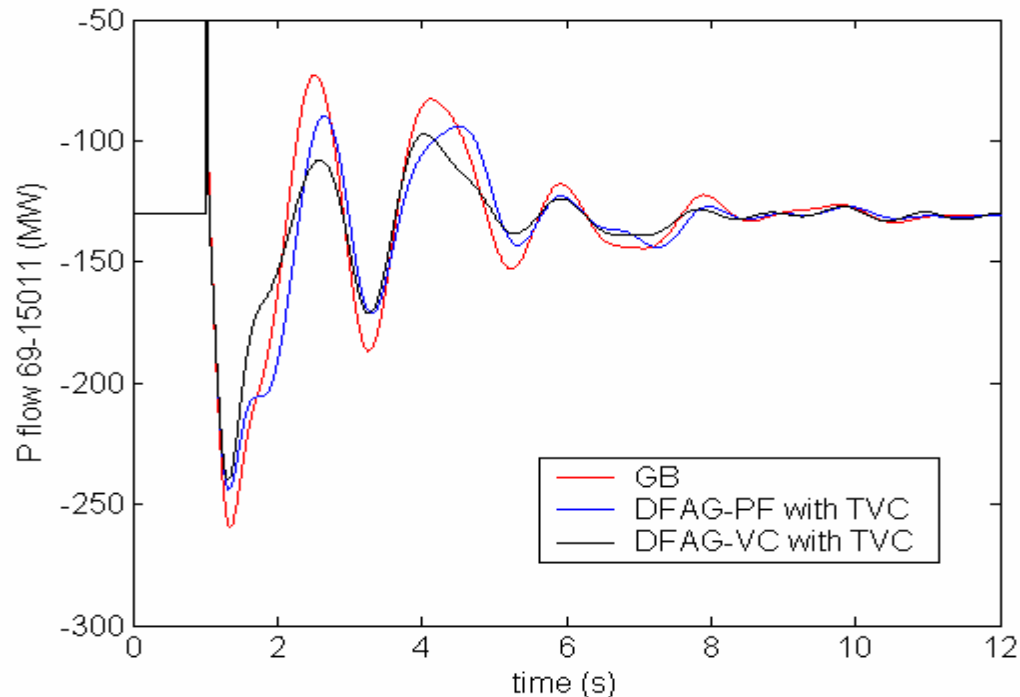
Hellenic system case study (2): base case

- ⌘ Base case: DFAGs modeled as constant admittances (approx. cancels out with part of the load)
- ⌘ Base case oscillation modes with light damping:

No.	eigenvalues	ζ	Hz	Mode
1	$-0.391 \pm j9.53$	0.041	1.52	Local VHSES1K
2	$-0.415 \pm j7.86$	0.053	1.25	Local JHBBAS G1-G2
	$-0.415 \pm j7.86$	0.053	1.25	Local JHBBAS G3-G4
3	$-0.397 \pm j7.78$	0.051	1.24	Local JHBBAS G12-G34
4	$-0.408 \pm j7.69$	0.053	1.22	Intra-GR POLUF-ALOUM
5	$-0.359 \pm j6.18$	0.058	0.98	Intra-GR KOM-MEG
6	$-0.403 \pm j5.38$	0.075	0.86	Intra-area AL-GR
7	$-0.423 \pm j3.45$	0.122	0.55	Interarea GR
8	$-0.329 \pm j1.29$	0.248	0.20	Interarea UCTE

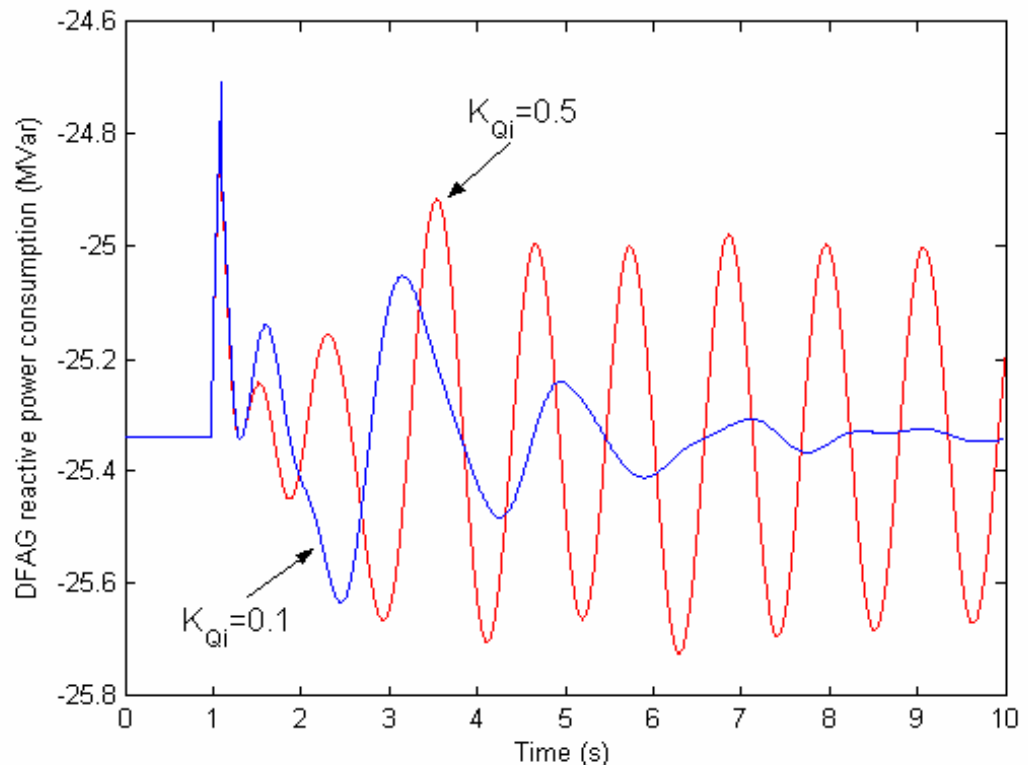
Hellenic system case study (3): effect of DFAG modeling on GR interarea mode

DFAG Modeling	Linearization		Prony	
	f (Hz)	ζ	f (Hz)	ζ
GB	0.55	0.122	0.55	0.133
DFAG-PF with TVC	0.54	0.134	0.55	0.145
DFAG-PF w/o TVC	0.55	0.146	0.55	0.156
DFAG-VC with TVC	0.55	0.140	0.55	0.150
DFAG-VC with TVC, $K_{Qi} = 0.1$	0.54	0.141	0.54	0.155
DFAG-VC w/o TVC	0.55	0.151	0.55	0.165



Hellenic system case study (4): tuning of DFAG reactive power control

- ⌘ Case of DFAG in voltage control mode with TVC
- ⌘ Some of the VAR control oscillation modes appear with low damping
- ⌘ Tuning by reduction of gain K_{Qi}



Conclusions



1. Wind power generally improves oscillation damping
2. Care should be taken for appropriate tuning of control loops
3. Wind PSS:
 1. Simple (no special design of lead/lag compensators),
 2. Also adds inertia,
 3. Needs to be implemented in every machine