Lin paper

April 8, 2019

EE290

Outline

- Inverter Model
  - LCL Filter
  - Initial Conditions
- Machine Model
  - Changing from laplace to time domain
- Combining the Model
  - Time domain

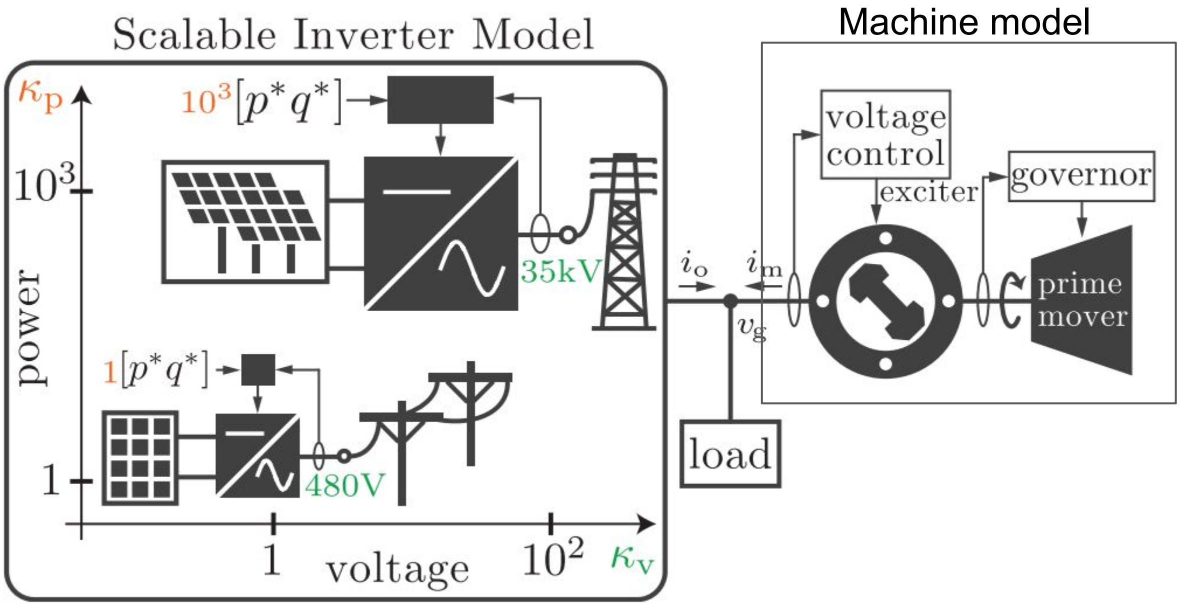


Fig. 1: Model of a single-machine single-inverter system,

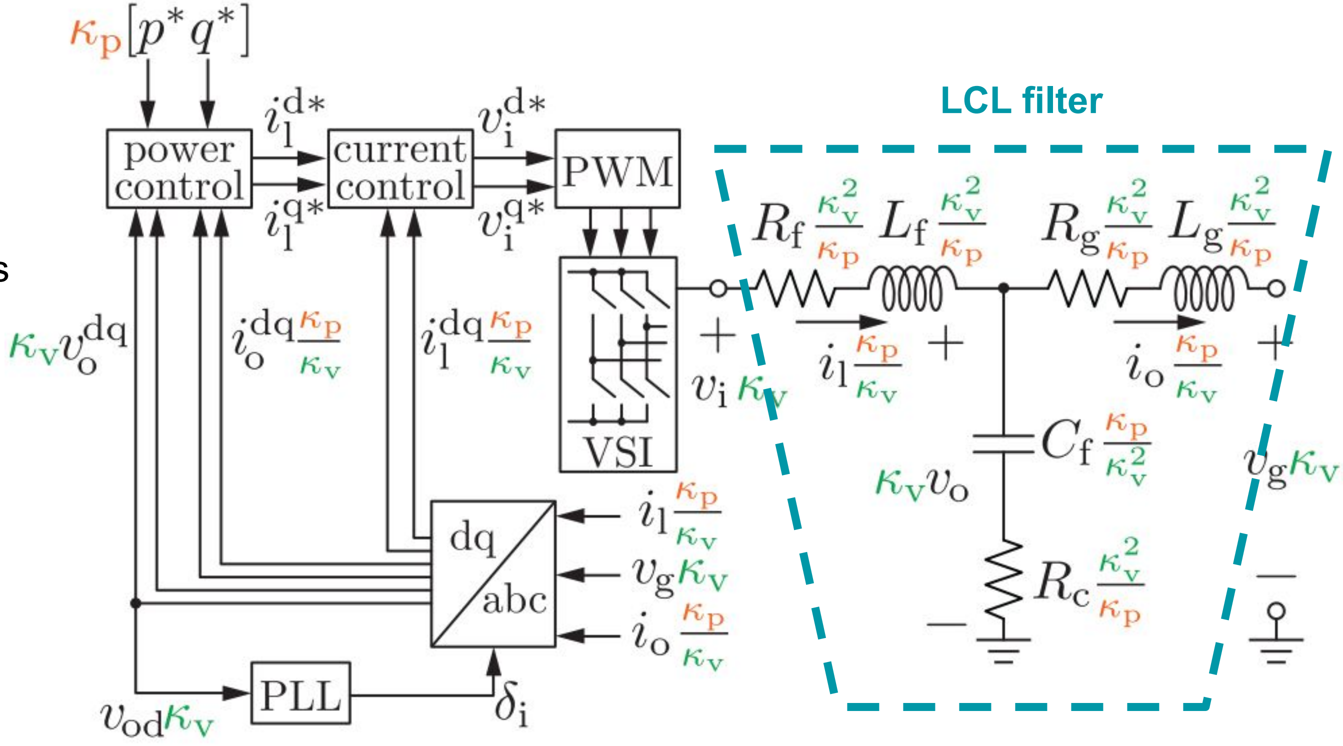
Inverter Model

Progress

- Implemented code in paper
- Model is running!
- Connected to an infinite bus
- Ignored series resistance of inductors
- No scaling factors yet

Challenges

- LCL filter: think we've solved it
- PLL: parameters not defined, assumptions made
- Initial conditions?



Inverter Model: states and parameters

where the dynamical states and inputs are given by

$$x_i = [i_{\mathrm{l}}^{\mathrm{dq}}, i_{\mathrm{o}}^{\mathrm{dq}}, v_{\mathrm{o}}^{\mathrm{dq}}, \gamma^{\mathrm{dq}}, p_{\mathrm{avg}}, q_{\mathrm{avg}}, \phi_{\mathrm{pq}}, v_{\mathrm{PLL}}, \phi_{\mathrm{PLL}}, \delta_{\mathrm{i}}]^{\top}, \quad (5)$$

$$u_i = [p^*, q^*, v_{\mathrm{g}}^{\mathrm{dq}}]^{\top}. \quad (6)$$

Above, $i_{\mathrm{l}}^{\mathrm{dq}} = [i_{\mathrm{l}}^{\mathrm{d}}, i_{\mathrm{l}}^{\mathrm{q}}]^{\top}$ is the filter current, $i_{\mathrm{o}}^{\mathrm{dq}} = [i_{\mathrm{o}}^{\mathrm{d}}, i_{\mathrm{o}}^{\mathrm{q}}]^{\top}$ is the terminal current, $v_{\mathrm{o}}^{\mathrm{dq}} = [v_{\mathrm{o}}^{\mathrm{d}}, v_{\mathrm{o}}^{\mathrm{q}}]^{\top}$ is the filter voltage, $\gamma^{\mathrm{dq}} = [\gamma^{\mathrm{d}}, \gamma^{\mathrm{q}}]^{\top}$ captures the states for the current PI controller, p_{avg} and q_{avg} are the low-pass-filtered measurements of the inverter real and reactive power, $\phi_{\mathrm{pq}} = [\phi_{\mathrm{p}}, \phi_{\mathrm{q}}]^{\top}$ captures the states for the real and reactive power PI controllers, v_{PLL} and ϕ_{PLL} are the filtered d-axis voltage measurement and the PI compensator state for the PLL, respectively, and δ_{i} is the angle for the dq transformation. The input signals p^* and q^* are the unscaled real and reactive power set points, and $v_{\mathrm{g}}^{\mathrm{dq}} = [v_{\mathrm{g}}^{\mathrm{d}}, v_{\mathrm{g}}^{\mathrm{q}}]^{\top}$ is the unscaled grid voltage at the point of interconnection.

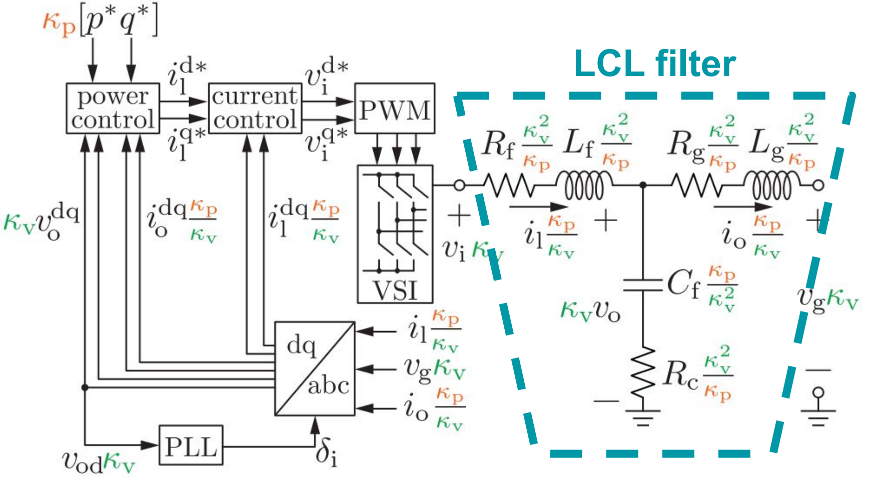


TABLE II: Parameters of the inverter model utilized in the case-study.

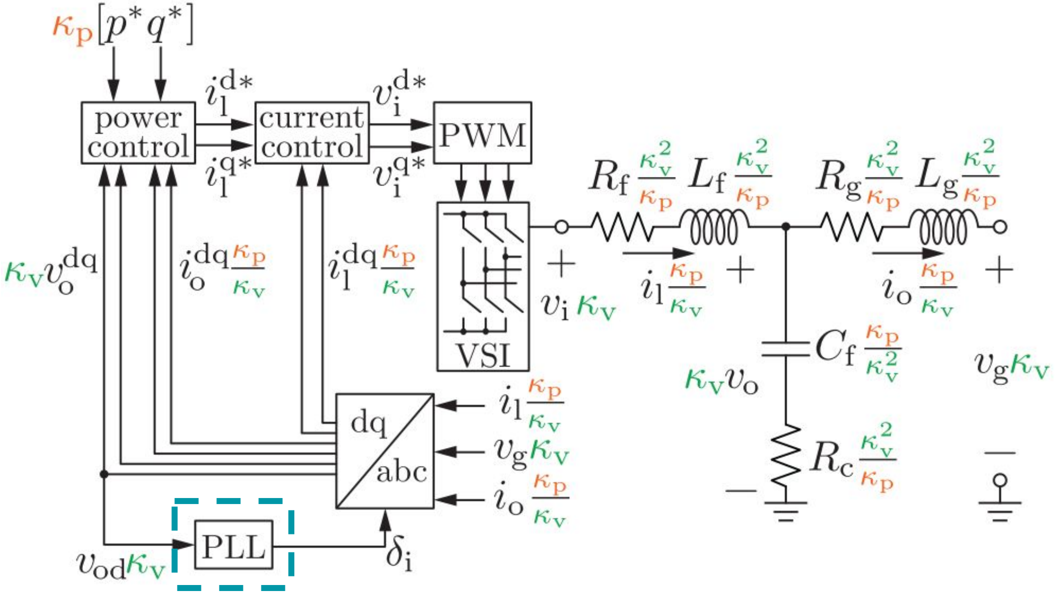
$L_{\mathrm{f}} = 1\,\mathrm{mH}$	$R_{\mathrm{f}} = 0.7\,\Omega$	$L_{\mathrm{o}} = 0.2\,\mathrm{mH}$ = Lg?
$R_{\mathrm{o}} = 0.12\,\Omega$	$C = 24\,\mu\mathrm{F}$	$R_{\mathrm{c}} = 0.02\,\Omega$
$k_{\mathrm{PQ}}^{p} = 0.01\,(\mathrm{V})^{-1}$	$k_{\mathrm{PQ}}^{i} = 0.1\,(\mathrm{V}\cdot\mathrm{s})^{-1}$	$k_{\mathrm{i}}^{p} = 16.4\,\mathrm{V/A}$
$k_{\mathrm{i}}^{i} = 30.4\,\mathrm{V/(A\cdot s)}$	$k_{\mathrm{PLL}}^{p} = 0.25\,\mathrm{rad/V}$	$k_{\mathrm{PLL}}^{i} = 2\,\mathrm{rad/(V\cdot s)}$

Inverter model: PLL

Defines angle δ_i for inverter reference frame dq coordinates

PLL dynamics:

$$\dot{v}_{\mathrm{PLL}} = \omega_{\mathrm{c,PLL}}(v_{\mathrm{o}}^{\mathrm{d}} - v_{\mathrm{PLL}}),$$
$$\dot{\phi}_{\mathrm{PLL}} = -v_{\mathrm{PLL}},$$
$$\dot{\delta}_{\mathrm{i}} = \omega_{\mathrm{nom}} - k_{\mathrm{PLL}}^{p} v_{\mathrm{PLL}} + k_{\mathrm{PLL}}^{i} \phi_{\mathrm{PLL}} := \omega_{\mathrm{PLL}},$$



What are all the omegas?

ω = 2*pi*60 (Hz)
ω_{nom} = ω “nominal AC system frequency”
$\omega_{c,PLL}$ = 2*pi*250 “cutoff frequency of filter for v_od measurement”
ω_c = 2*pi*250 ?? used in power controller
ω_{PLL} = above used in current controller

Inverter model: power & current controllers

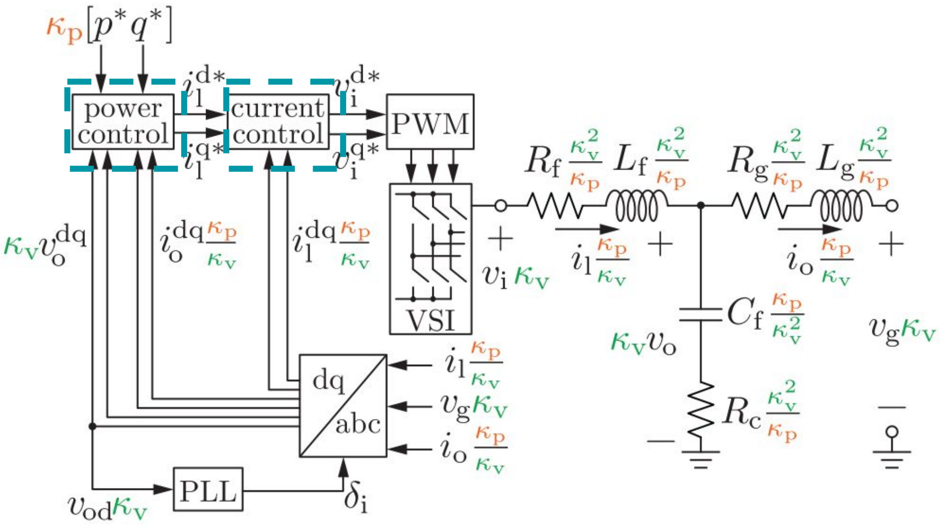
Power Controller

$$\dot{s}_{\mathrm{avg}} = \omega_{\mathrm{c}}\left([p,q]^\top - s_{\mathrm{avg}}\right),\ \dot{\phi}_{\mathrm{pq}} = [p^*,q^*]^\top - s_{\mathrm{avg}}, \tag{10}$$

$$i_{\mathrm{l}}^{\mathrm{dq}*} = k^{p}_{\mathrm{PQ}}\dot{\phi}_{\mathrm{pq}} + k^{i}_{\mathrm{PQ}}\phi_{\mathrm{pq}}, \tag{11}$$

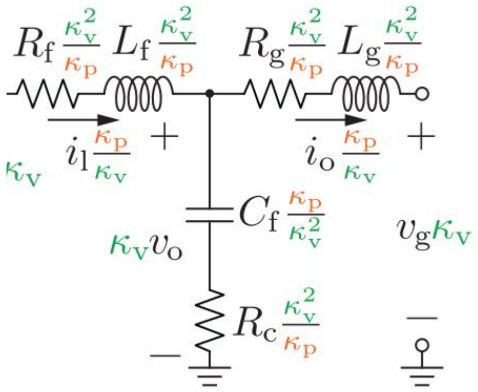
Current Controller

$$v_{\mathrm{i}}^{\mathrm{dq}*} = k^{p}_{\mathrm{i}}\dot{\gamma}^{\mathrm{dq}} + k^{i}_{\mathrm{i}}\gamma^{\mathrm{dq}} + \begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\omega_{\mathrm{PLL}}L_{\mathrm{f}}i_{\mathrm{l}}^{\mathrm{dq}}, \tag{13}$$

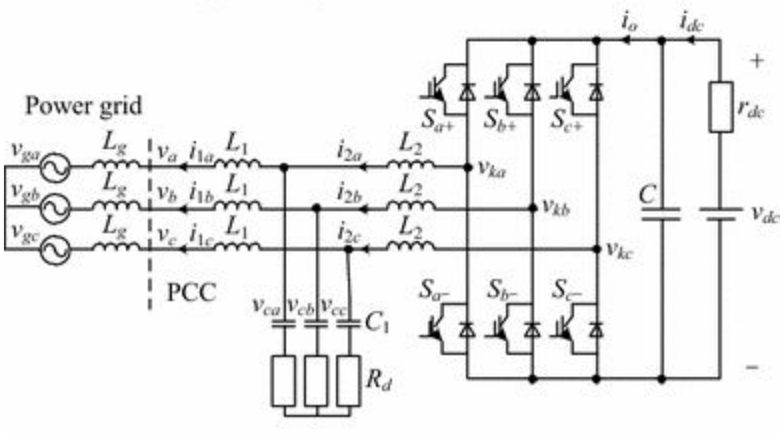


Inverter Model: LCL Filter

- Used [1] as reference for creating DQ transformed LCL filter.
- Currently neglecting series resistance for inductors.

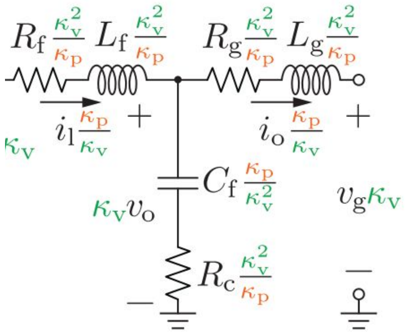


[1] Huang, Meng and Sun, Jianjun and Peng, Yu and Zha, Xiaoming,"Optimized damping for LCL filters in three-phase voltage source inverters coupled by power grid", Journal of Modern Power Systems and Clean Energy, 2017.

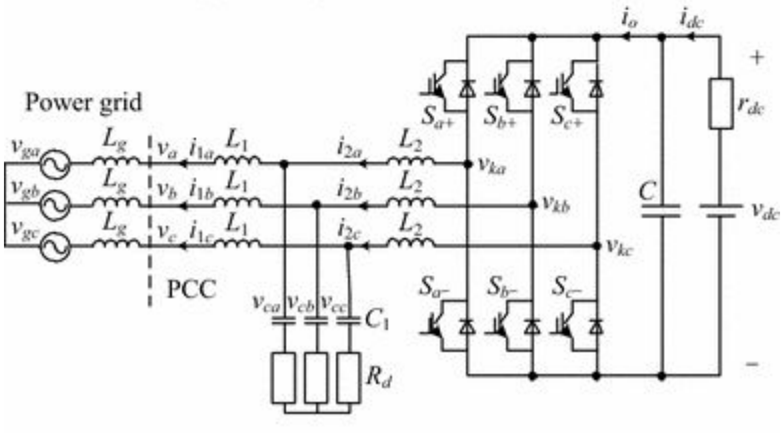


(b) Three-phase VSI with LCL filter [1]

Inverter Model: LCL Filter



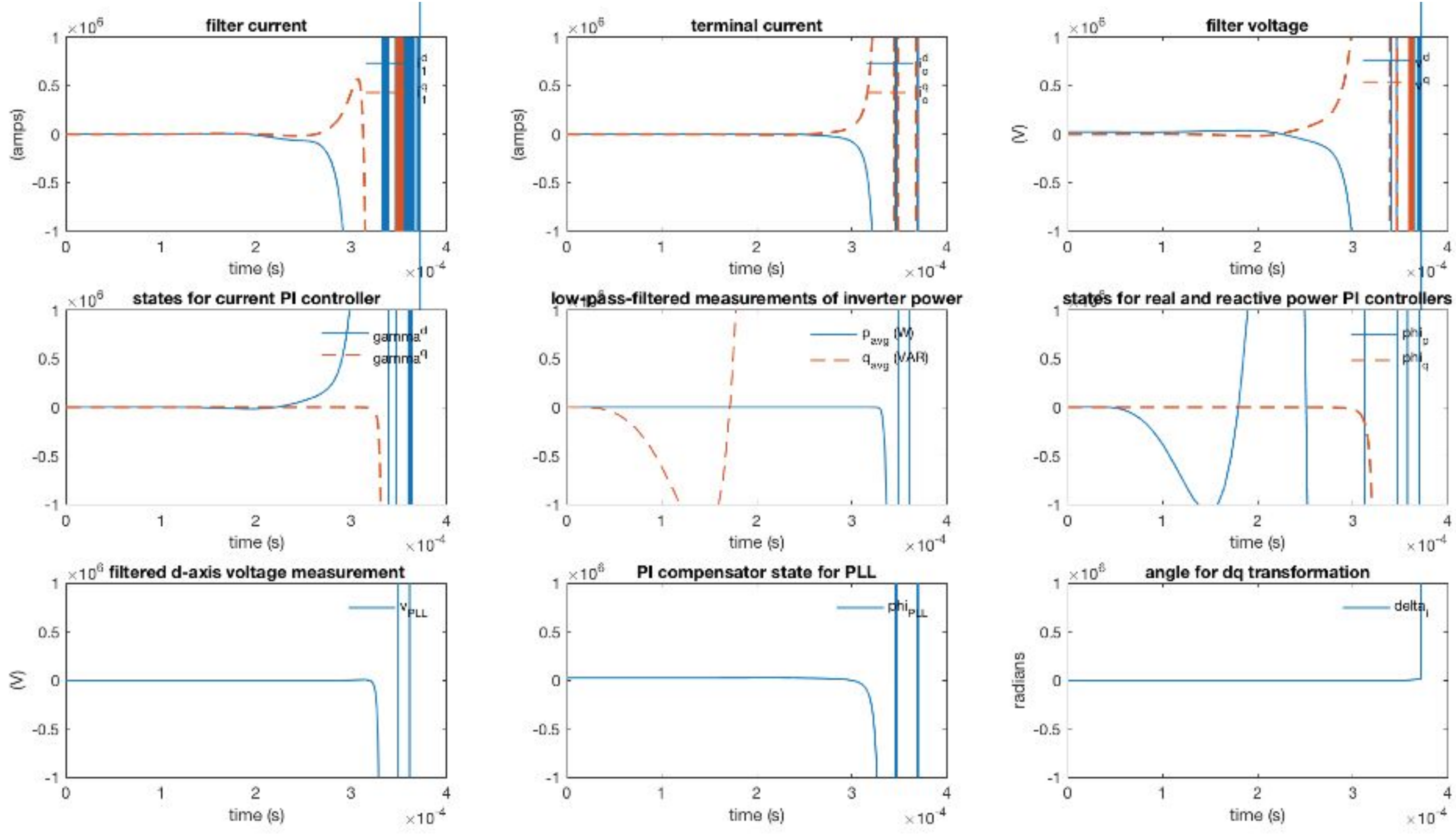

```
di_od = 1/L_g * (L_g*omega*i_oq + v_od - (i_1d - i_od)*R_c - v_gd - R_c*i_od + R_c*i_1d);
di_oq = 1/L_g * (-L_g*omega*i_od + v_oq - (i_1q - i_oq)*R_c - v_gq - R_c*i_oq + R_c*i_1q);
di_odq = [di_od, di_oq];

di_1d = 1/L_f * (L_f*omega*i_1q - (v_od - (i_1d - i_od)*R_c) + v_id + R_c*i_od - R_c*i_1d);
di_1q = 1/L_f * (-L_f*omega*i_1d - (v_oq - (i_1q - i_oq)*R_c) + v_iq + R_c*i_oq - R_c*i_1q);
di_1dq = [di_1d, di_1q];

dv_od = 1/c * (c * R_c * (di_1d - di_od) + c * omega * (v_oq - (i_1q-i_oq) * R_c) - i_od + i_1d);
dv_oq = 1/c * (c * R_c * (di_1q - di_oq) - c * omega * (v_od - (i_1d-i_od) * R_c) - i_od - i_1d);
dv_odq = [dv_od, dv_oq];
```



(b) Three-phase VSI with LCL filter [1]

[1] Huang, Meng and Sun, Jianjun and Peng, Yu and Zha, Xiaoming,"Optimized damping for LCL filters in three-phase voltage source inverters coupled by power grid", Journal of Modern Power Systems and Clean Energy, 2017.

Inverter Model: Results?



Initial Conditions

- How do we determine realistic initial conditions?
  - Currently we are connecting the inverter model to an infinite bus.
- Per unitize parameters?
  - Model is “scaled” (not implemented) but not per unitized.

Initial Conditions

Parameter	Initial Condition	Unit
Filter Current	[0,217]	A
Terminal Current	[0,0]	A
Filter Voltage	[24E3,0]	V
PI States	[0,0]	-
Real Power (LPF)	0	W
Reactive Power (LPF)	5.2E6	VAR
Real and Reactive (PI Cont)	[0,0]	W, VAR
PLL Voltage	24E3	V
DQ Transform Angle	0	Radians

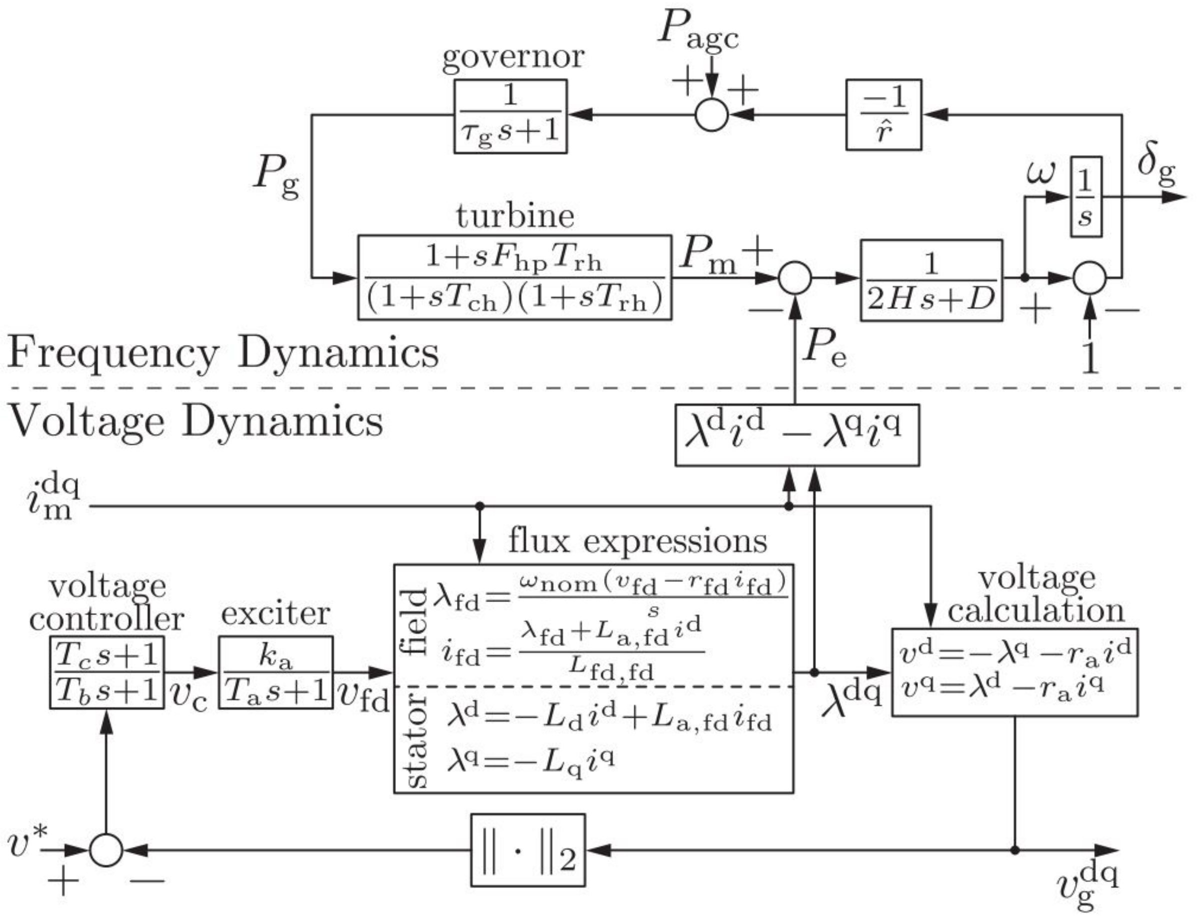
Machine Model

- We attempted to implement in Laplace domain. (Not possible with solver)
- Either use new model or go one by one and convert to time by hand.

States, inputs, and parameters:

$$x_{\mathrm{m}} = [\delta_{\mathrm{g}}, \omega, P_{\mathrm{g}}, P_{\mathrm{gt}}, P_{\mathrm{m}}, v_{\mathrm{c}}, v_{\mathrm{fd}}, \lambda_{\mathrm{fd}}]^\top,$$
$$u_{\mathrm{m}} = [P_{\mathrm{agc}}, v^*, i_{\mathrm{m}}^{\mathrm{dq}}]^\top.$$

$H = 2.9\,\mathrm{s}$	$D = 1$	$\hat{r} = 0.05$
$\tau_{\mathrm{g}} = 0.2\,\mathrm{s}$	$F_{\mathrm{hp}} = 0.3$	$T_{\mathrm{rh}} = 7\,\mathrm{s}$
$T_{\mathrm{ch}} = 0.3\,\mathrm{s}$	$k_{\mathrm{a}} = 0.0745$	$T_{\mathrm{a}} = 0.04\,\mathrm{s}$
$T_{\mathrm{b}} = 12\,\mathrm{s}$	$T_{\mathrm{c}} = 1\,\mathrm{s}$	$R_{\mathrm{fd}} = 0.0006$
$R_{\mathrm{a}} = 0.003$	$L_{\mathrm{a,fd}} = 1.66$	$L_{\mathrm{fd,fd}} = 1.825$
$L_{\mathrm{d}} = 1.81$	$L_{\mathrm{q}} = 1.76$	$P_{\mathrm{agc}} = 0.9\,\mathrm{pu}$



Combining the models

- Then the combined model needs to be linearized.
- Add series impedance?

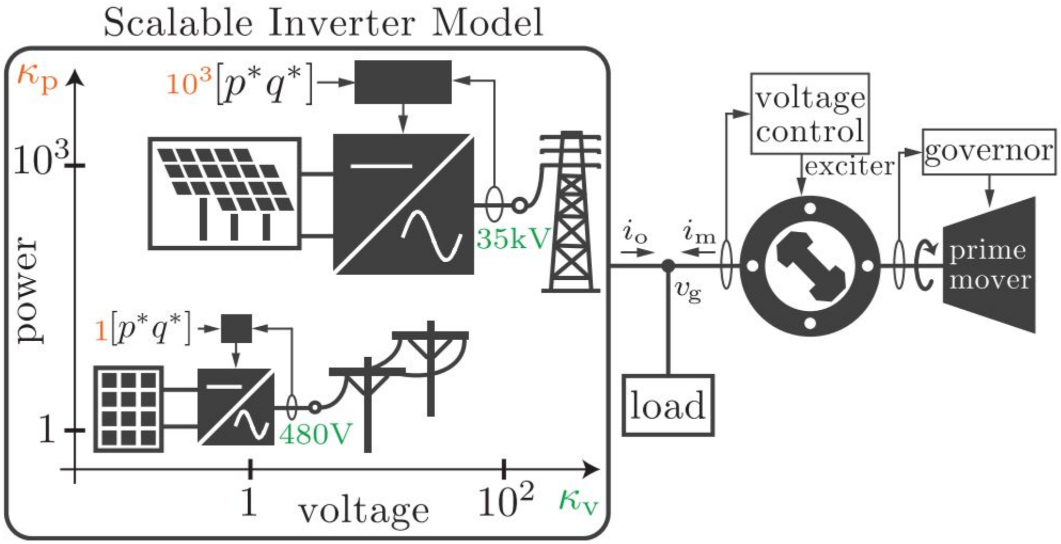


Fig. 1: Model of a single-machine single-inverter system,