Lin paper

May 6, 2019
EE290

Outline

Inverter model

- PLL and LCL work independently
- Remaining issue: controllers

Machine model

- Works!

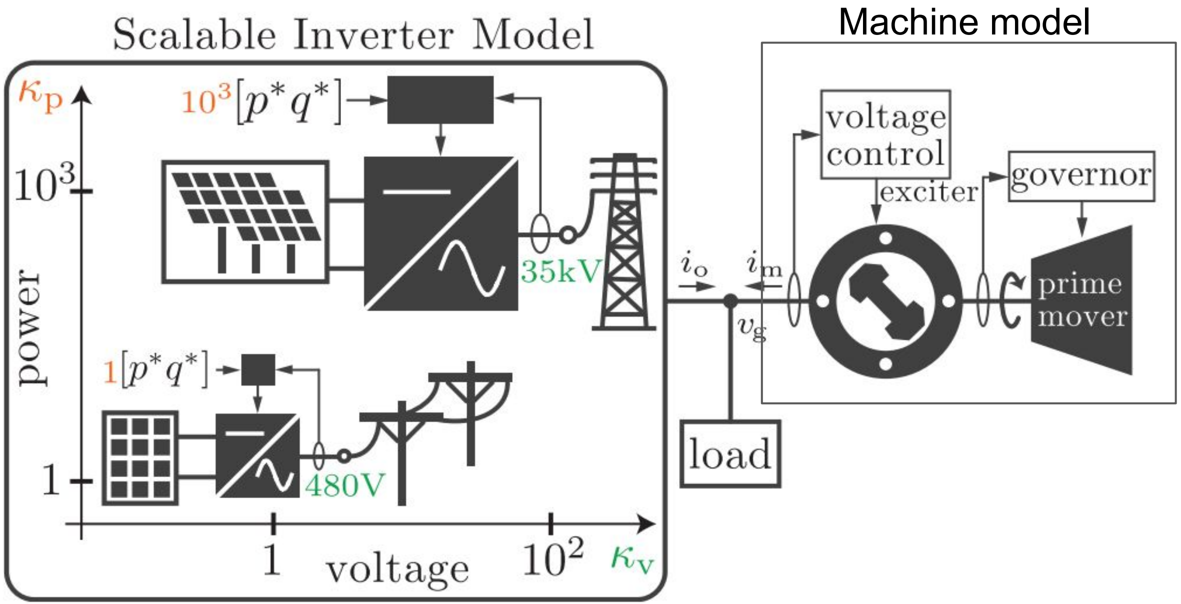


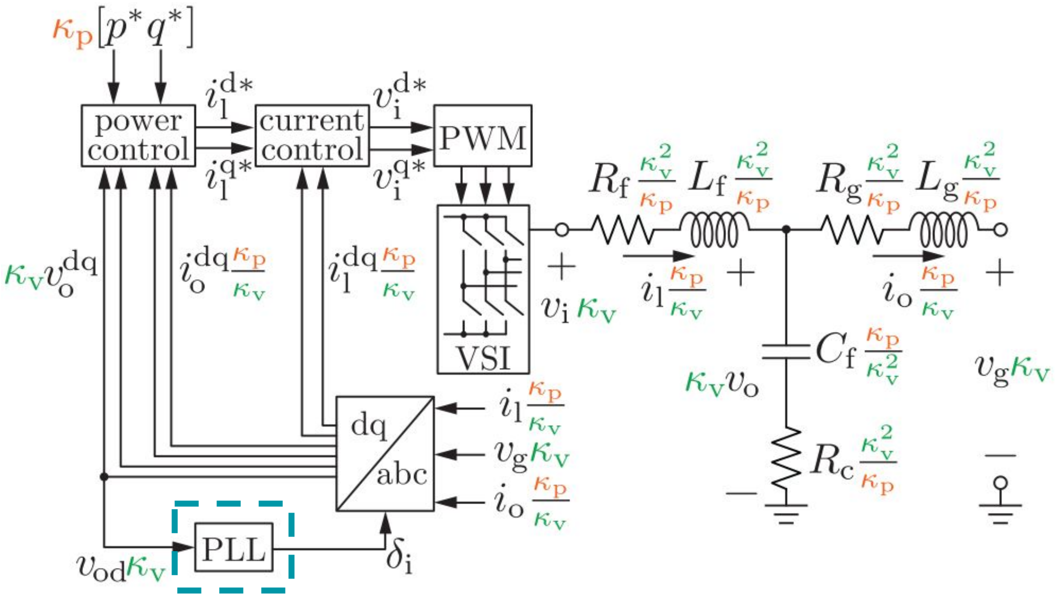
Fig. 1: Model of a single-machine single-inverter system,

Inverter model: PLL

Defines angle δ_i for inverter reference frame dq coordinates

PLL dynamics:

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



Initial conditions:

```
v_PLL0 = 0;             % filtered d-axis voltage measurement, 24 kV
phi_PLL0 = 0;           % PI compensator state for PLL
delta_i0 = 0;           % angle for dq transformation
delta_g0 = 2*pi/3;         % grid angle
```

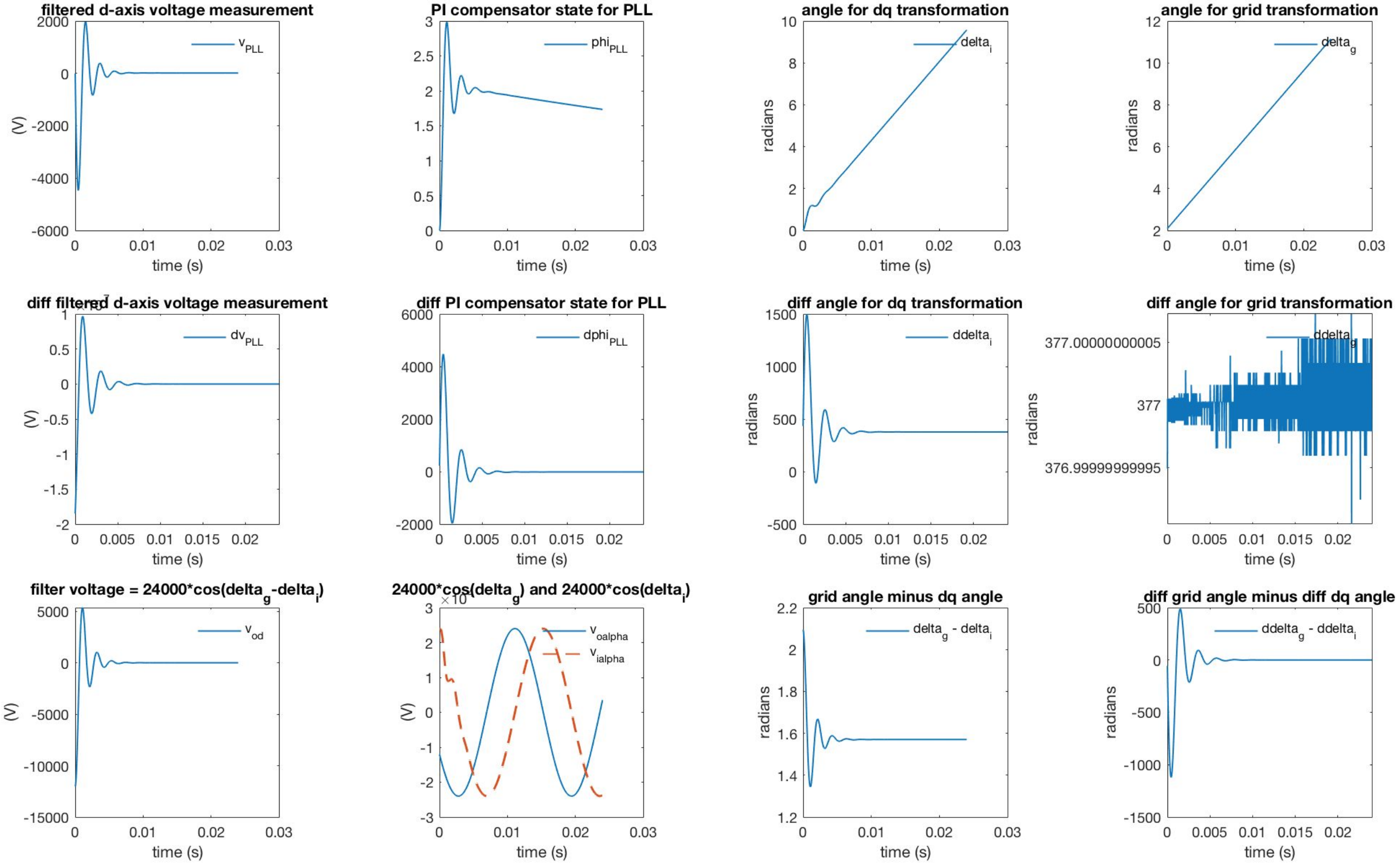
Inverter model: PLL

What we're looking for:

ddelta_i = ddelta_g = omega_nom = 377 rad

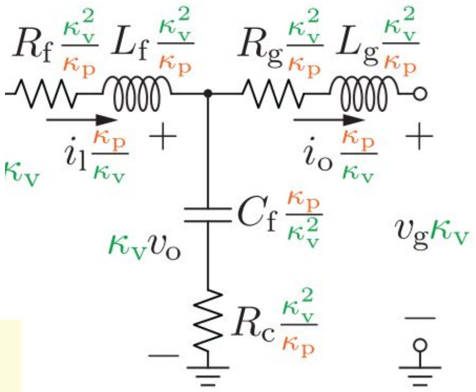
v_PLL = dv_PLL = 0

cos(delta_g) and cos(delta_i) phase shifted by 90 deg.



Inverter Model: LCL Filter

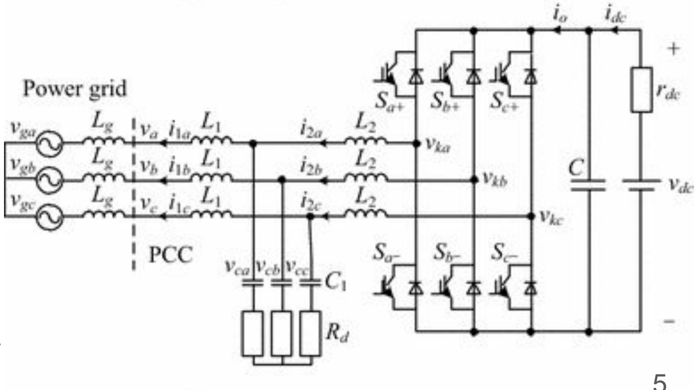
- Tried to use [1] as reference for creating DQ transformed LCL filter.
- Decided to include series resistance for inductors.



Initial conditions:

```
i_1dq0 = [0,0];      % filter current, amps
i_odq0 = [0,0];         % terminal current
v_cdq0 = [0,24e3];          % filter voltage, 24 kV
```

```
% unscaled grid voltage at point of interconnection
v_gd = 0;           % kV
v_gq = 24e3;        % 24kV
v_gdq = [v_gd, v_gq]';
```



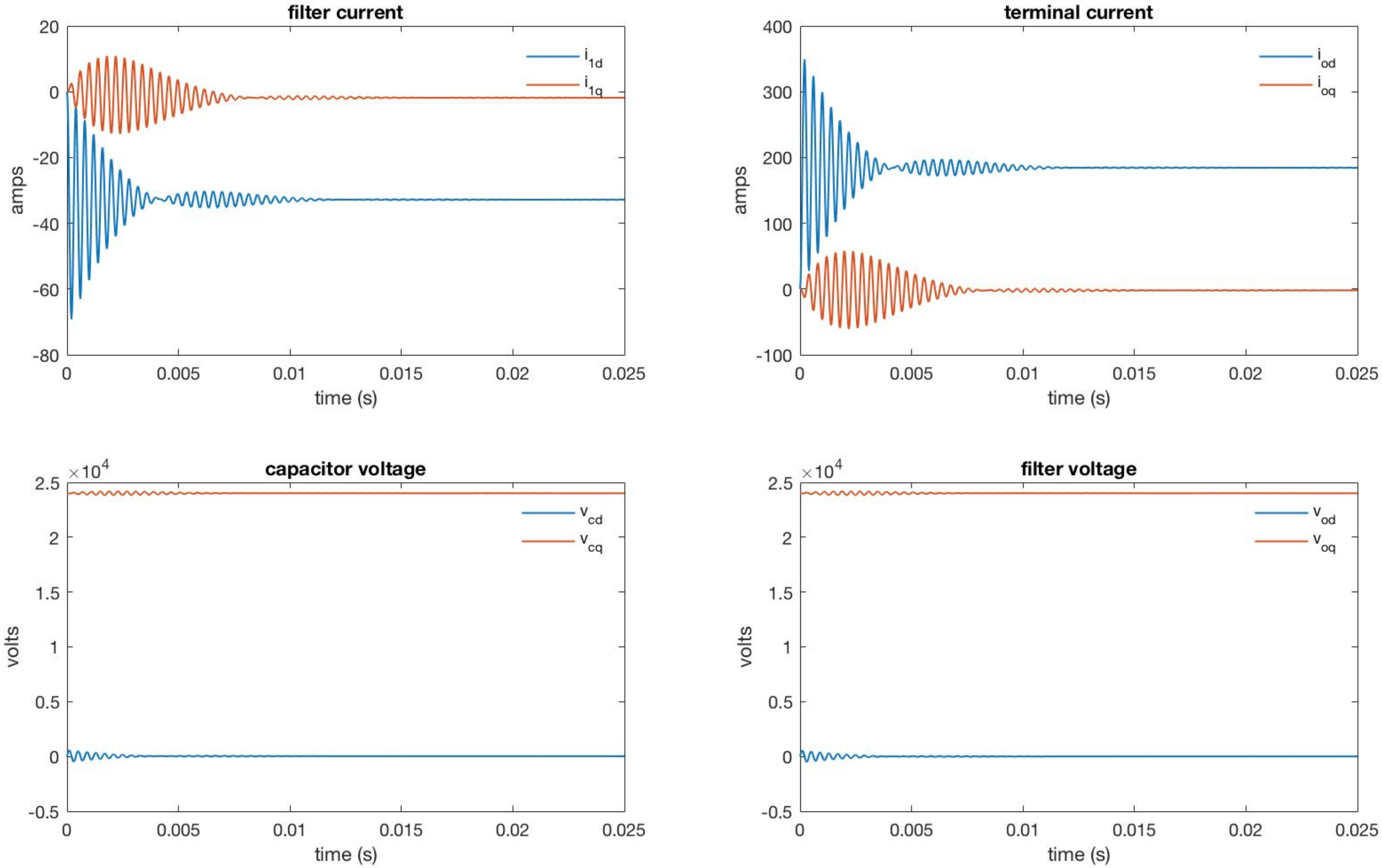
(b) Three-phase VSI with LCL filter

[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: LCL

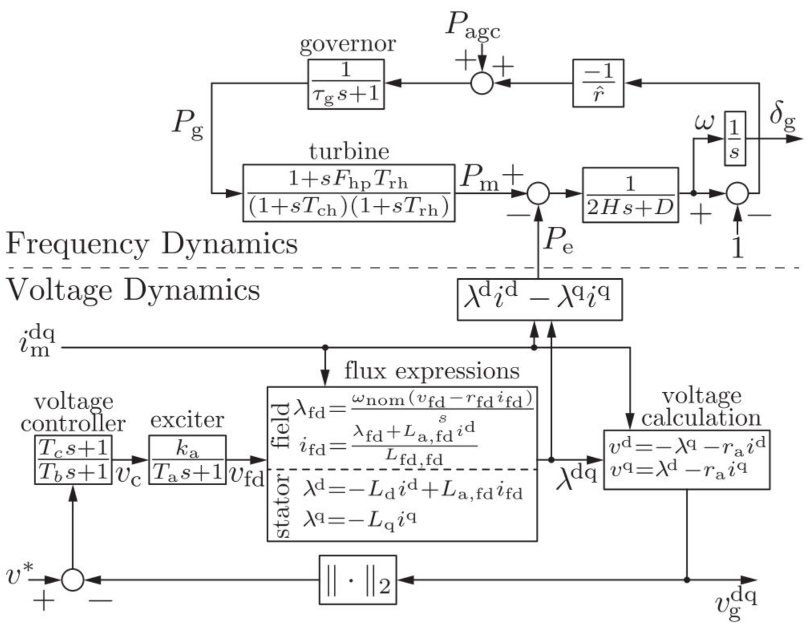
What we're looking for:

Currents and voltages stabilize at desired levels



Machine Model

- Decided against implementing in Laplace domain
- Instead: we are now using 2-state model with algebraic constraint (credit to Ramasubramanian group for help)




```
% parameters
omega = 2*pi*60; % Hz, frequency
omega_g = 1;      % p.u. reference grid frequency

H = 2.9;          % s, machine starting time
D = 10;            % p.u., damping coefficient of oscillations
X = 0.5;          % impedance of the machine
v_g = 1;          % p.u., grid voltage
theta_g = 0;      % voltage angle of the system (infinite bus,
p_m = 1;          % 555e6; % MVA
v_m = 1;          % 24e3; % kV, voltage of the machine
```

```
% dynamical states and inputs
delta_m = x(1); % machine rotor angle
omega_m = x(2); % want this to be equal to 1
p_e = x(3);      % power transfer
%u_m = [P_agc, v_star, i_mdq]';

ddelta_m = omega*(omega_m - omega_g);
domega_m = 1/(2*H) * (p_m - p_e - D*(omega_m - omega_g));
% p_e = (v_m*v_g)/X * sin(delta_m - theta_g);

dxdt = [ddelta_m, domega_m, (3*(v_m*v_g)/X * sin(delta_m - theta_g) - p_e)]';
```

States, inputs, and parameters:

$$x_m = [\delta_g, \omega, P_g, P_{gt}, P_m, v_c, v_{fd}, \lambda_{fd}]^\top,$$

$$u_m = [P_{agc}, v^*, i_m^{dq}]^\top.$$

$H = 2.9\,\mathrm{s}$	$D = 1$	$\hat{r} = 0.05$
$\tau_g = 0.2\,\mathrm{s}$	$F_{hp} = 0.3$	$T_{rh} = 7\,\mathrm{s}$
$T_{ch} = 0.3\,\mathrm{s}$	$k_a = 0.0745$	$T_a = 0.04\,\mathrm{s}$
$T_b = 12\,\mathrm{s}$	$T_c = 1\,\mathrm{s}$	$R_{fd} = 0.0006$
$R_a = 0.003$	$L_{a,fd} = 1.66$	$L_{fd,fd} = 1.825$
$L_d = 1.81$	$L_q = 1.76$	$P_{agc} = 0.9\,\mathrm{pu}$

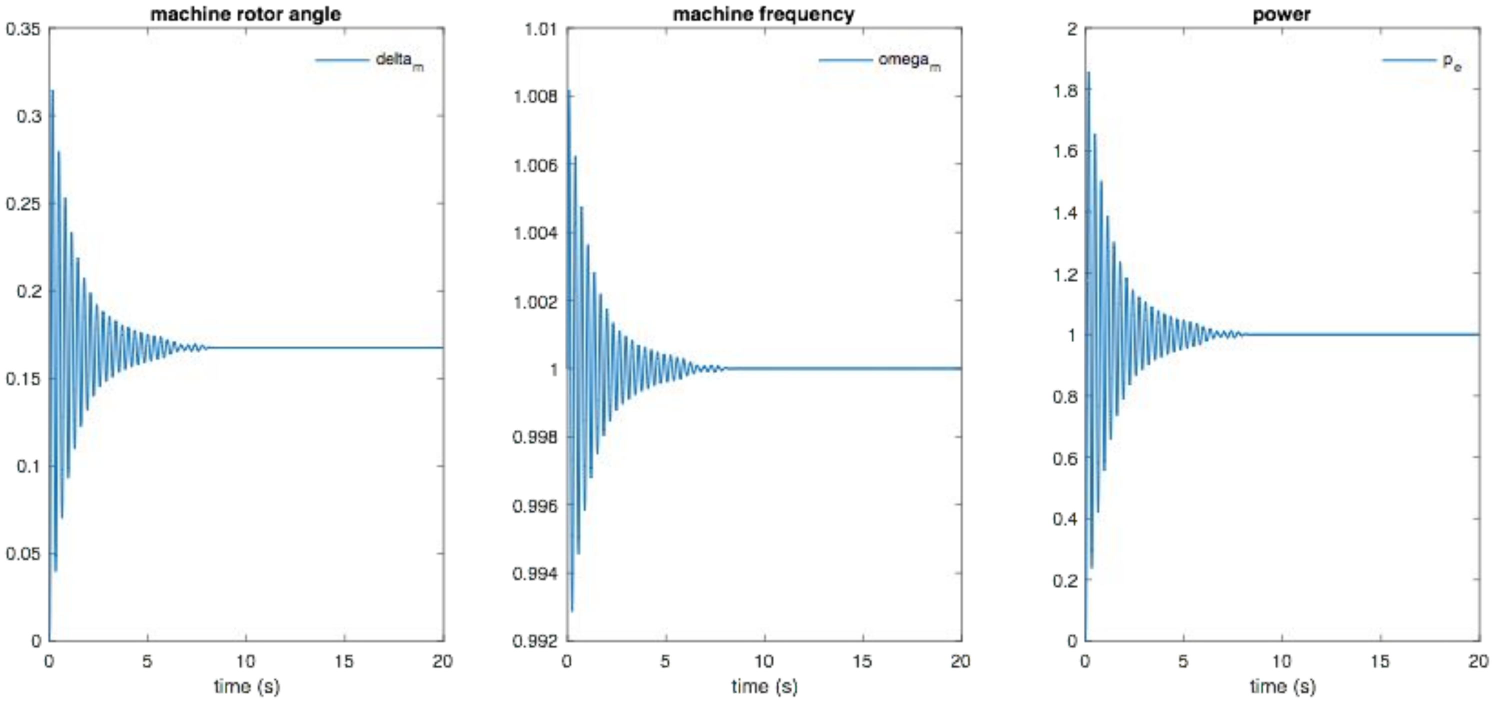
Machine model

```
% initial conditions for dynamical states:
delta_m0 = 0;
omega_m0 = 1;
p_e0 = 0.5;
```

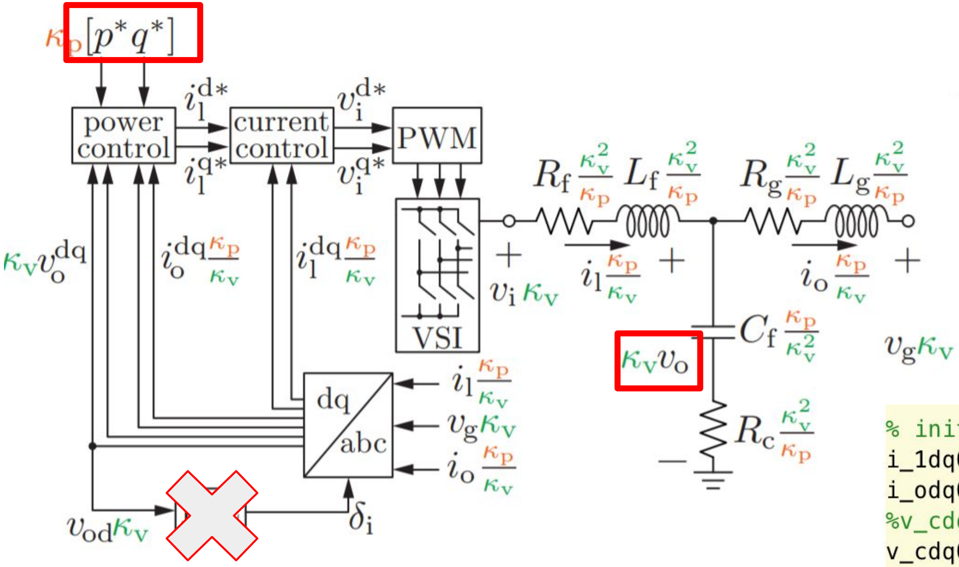
What we're looking for:

Stability!

omega_m = 1
p_e = 1



Inverter model: controllers



Power Controller

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

$$i_l^{\mathrm{dq}*} = k^p_{\mathrm{PQ}} \dot{\phi}_{\mathrm{pq}} + k^i_{\mathrm{PQ}} \phi_{\mathrm{pq}}, \qquad (11)$$

Current Controller

$$v_i^{\mathrm{dq}*} = k_i^p \dot{\gamma}^{\mathrm{dq}} + k_i^i \gamma^{\mathrm{dq}} + \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \omega_{\mathrm{PLL}} L_f i_l^{\mathrm{dq}}, \qquad (13)$$

```
% initial conditions for dynamical states
i_1dq0 = [0,0];      % filter current, amps
i_odq0 = [0,0];        % terminal current
%v_cdq0 = -(0.2e-3)*[0, 20e3]*[0, 2*pi*60; -2*pi*60, 0] + [0, 24e3];
v_cdq0 = [0,24e3];          % filter voltage, 24 kV
gamma_dq0 = [0,0];  % states for current PI controller
p_avg0 = 500e6; %500e6;            % low-pass-filtered measurements of rea
q_avg0 = 50e6; %50e6;            % low-pass-filtered measurements of react
phi_pq0 = [0,0];     % states for real and reactive power PI controllers
```

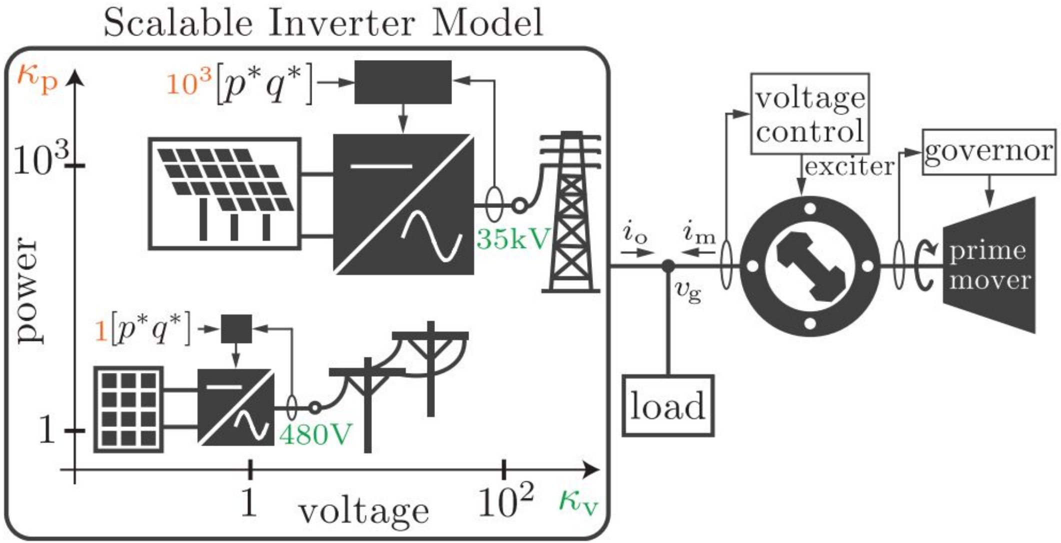
```
Warning: Failure at t=1.805350e-04.  Unable to meet integration tolerances
without reducing the step size below the smallest value allowed (4.336809e-19)
at time t.

ans =

    'finish'
```

Combining the models

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



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