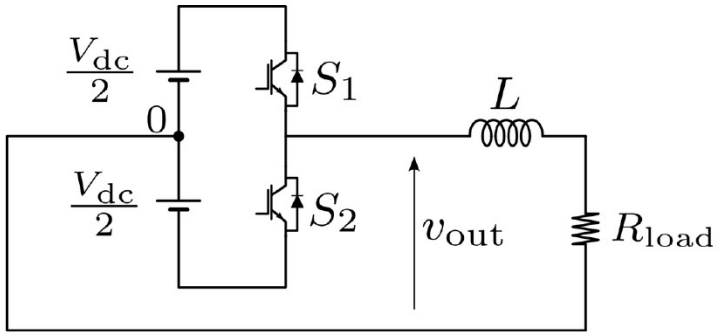
Sample

GMF 101: Fundamentals

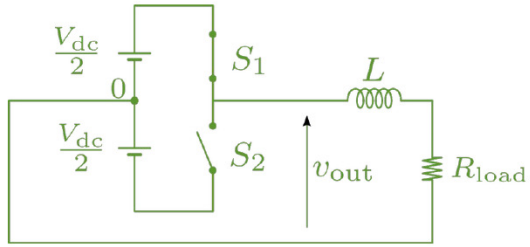
Short Course Sample Slides

Introduction to DC-AC conversion

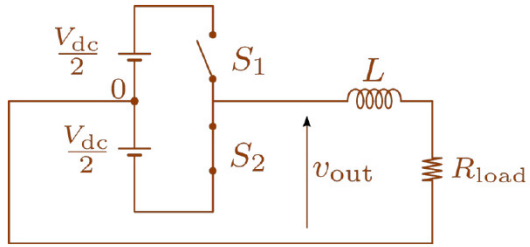
The half-bridge converter

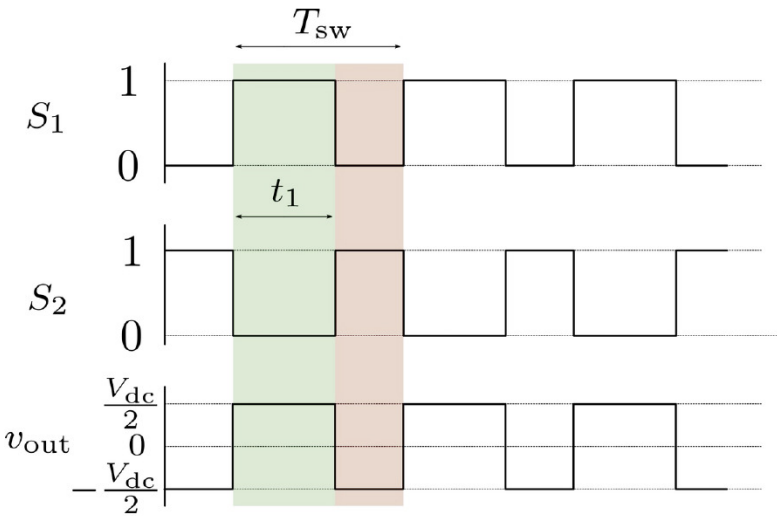


State 1 (S1 = 1, S2 = 0)



State 2 (S1 = 0, S2 = 1)

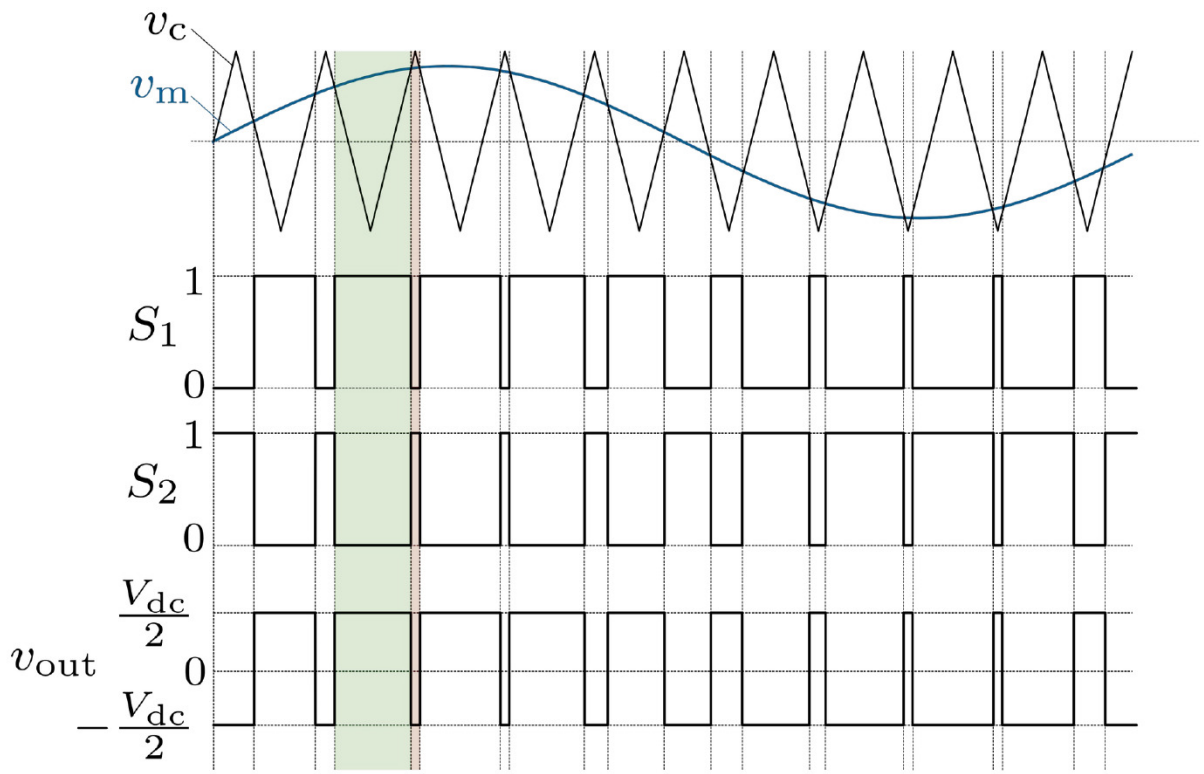




We can switch the voltage between +Vdc/2 and –Vdc/2. We can create AC but not quite sinusoidal (yet).

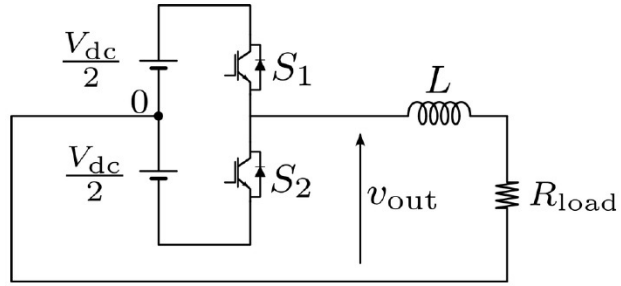
Introduction to Pulse Width Modulation (PWM)

To create a nice sinusoidal AC signal, we need to introduce PWM.



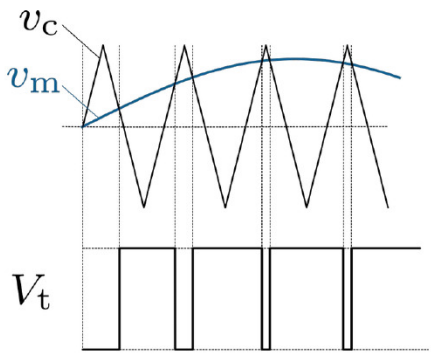
v_c = Carrier signal

v_m = modulation signal



- The modulation signal is the sinusoidal waveform we 'want' to see at the AC side of the bridge
- The carrier frequency is typically a saw-tooth-like signal to generate a dynamically changing duty cycle
- The output AC voltage is still choppy, but filter on the AC side will average that out.
- We created an AC sinusoidal waveform from DC.

Introduction to averaged-value models



Square wave

Fourier series of the square wave

Slow moving dynamics.

High-frequency harmonics caused by the PWM

$$V_t(t) = \underbrace{\frac{1}{T_s}\int_0^{T_s} V_t(\tau)d\tau}_{\overline{V}_t(t)} + \underbrace{\sum_{h=1}^{h=+\infty} [a_h \cos(h\omega_s t) + b_h \sin(h\omega_s t)]}_{\widetilde{V}_t(t)}$$

$$V_t(t) = \overline{V}_t(t) + \widetilde{V}_t(t)$$

With a reasonable filter at the inverter terminal, the high-frequency harmonics will mostly be filtered out. As such, we can approximate:

$$V_{out}(t) = \overline{V}_{out}(t) + \widetilde{V}_{out}(t) \approx \overline{V}_{out}(t)$$
$$i_{out}(t) = \bar{i}_{out}(t) + \widetilde{i}_{out}(t) \approx \bar{i}_{out}(t)$$

This means: We can approximate the switching bridge's behavior in simulation by setting the terminal voltage equal to the modulation signal:

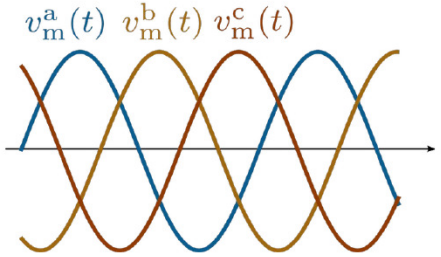
$$V_t(t) \approx v_m(t)$$

Introduction to averaged-value models

$$V_{\mathrm{t}}(t) \approx v_{\mathrm{m}}(t)$$

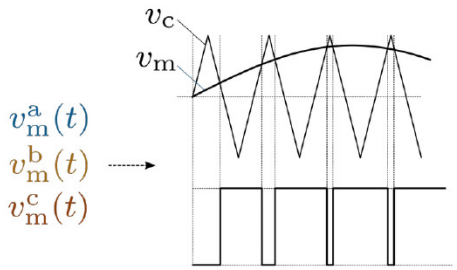
What does that mean?

The controls generate the appropriate **modulation signals**

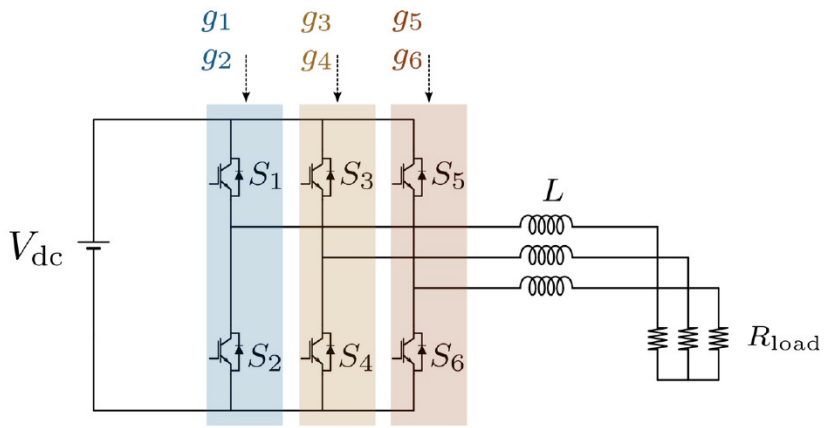


Switch model

Create **gate signals** through PWM

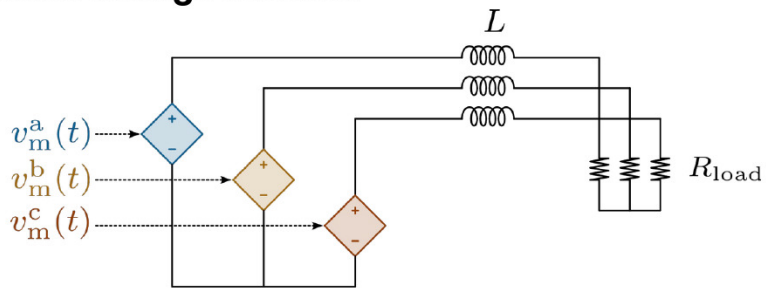


Gate signals switch the **semiconductor switches**



AVM

Modulation signals plugged into **controllable voltage sources***

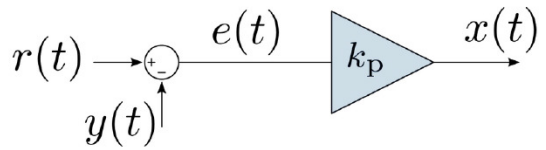


***Evidently, this is only possible in a simulation environment**

Introduction to PI control

Proportional + Integral control is extensively used in inverter controllers.

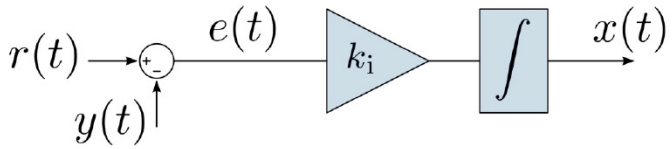
Proportional control



$$x(t) = k_\mathrm{p} e(t)$$

- Output is proportional to error
- Fast response (instantaneous)
- Cannot eliminate steady-state error

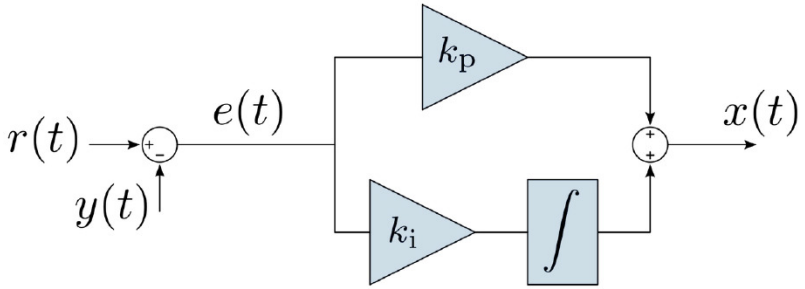
Integral control



$$x(t) = k_\mathrm{i} \int_t e(t)\mathrm{d}t$$

- Error integrated over time
- Eliminates steady-state error
- Slower response

PI control

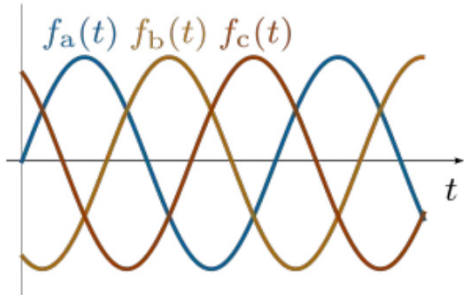


$$x(t) = k_\mathrm{p} e(t) + k_\mathrm{i} \int_t e(t)\mathrm{d}t$$

- Combination of both

Introduction to reference frames

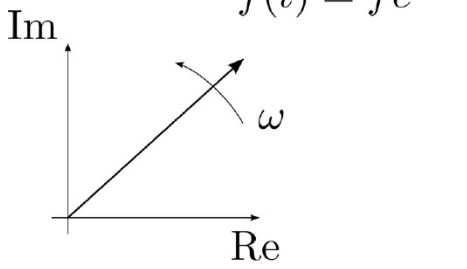
Balanced set of three-phase signals



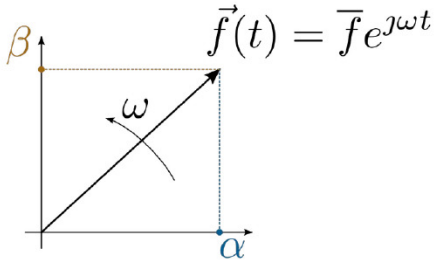
Natural reference frame (abc-frame)

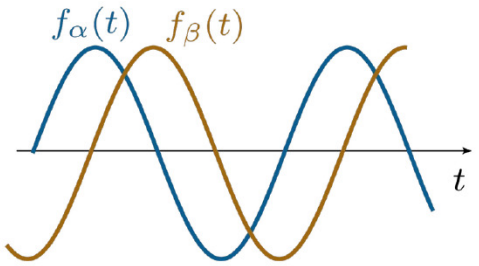
Space phasor

$\vec{f}(t) = \overline{f}e^{j\omega t}$

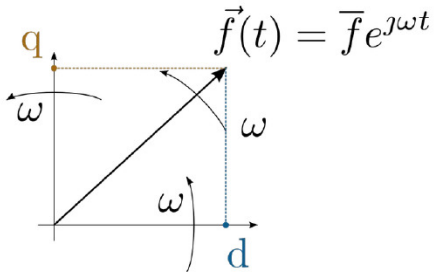


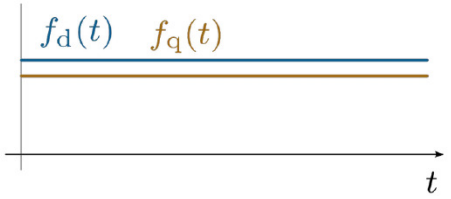
Stationary reference frame ($\alpha\beta$-frame)





Synchronous reference frame (dq-frame)



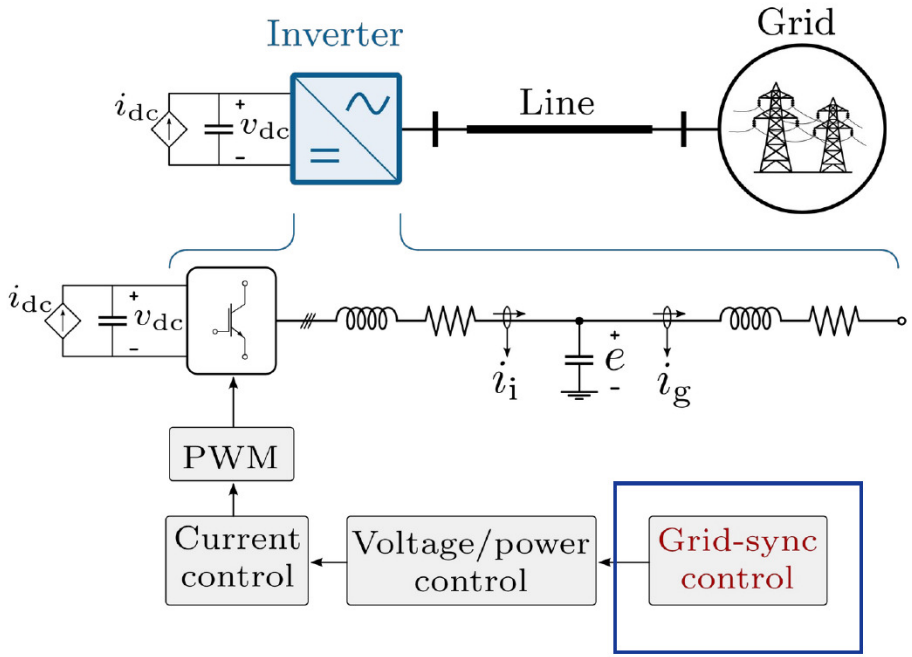


In a balanced* system, going from one reference frame to another has no loss of information.

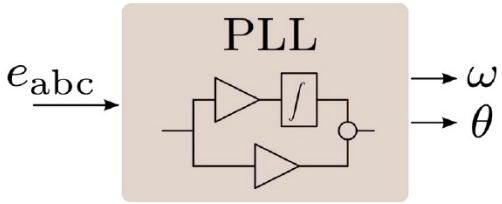
*During unbalanced conditions, going from one frame to another can compromise zero sequence information

Introduction to grid-connected inverters

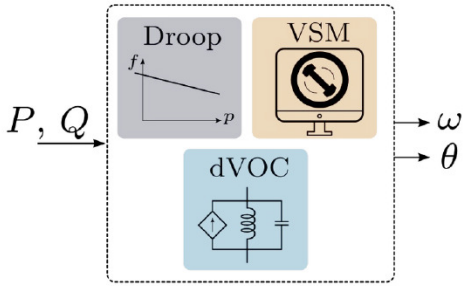
Let's have a closer look at grid-connected inverters.



GFL **measures** the existing grid voltage and latches onto it --- it **follows** the existing grid. For that, it uses a phase-locked loop (PLL).

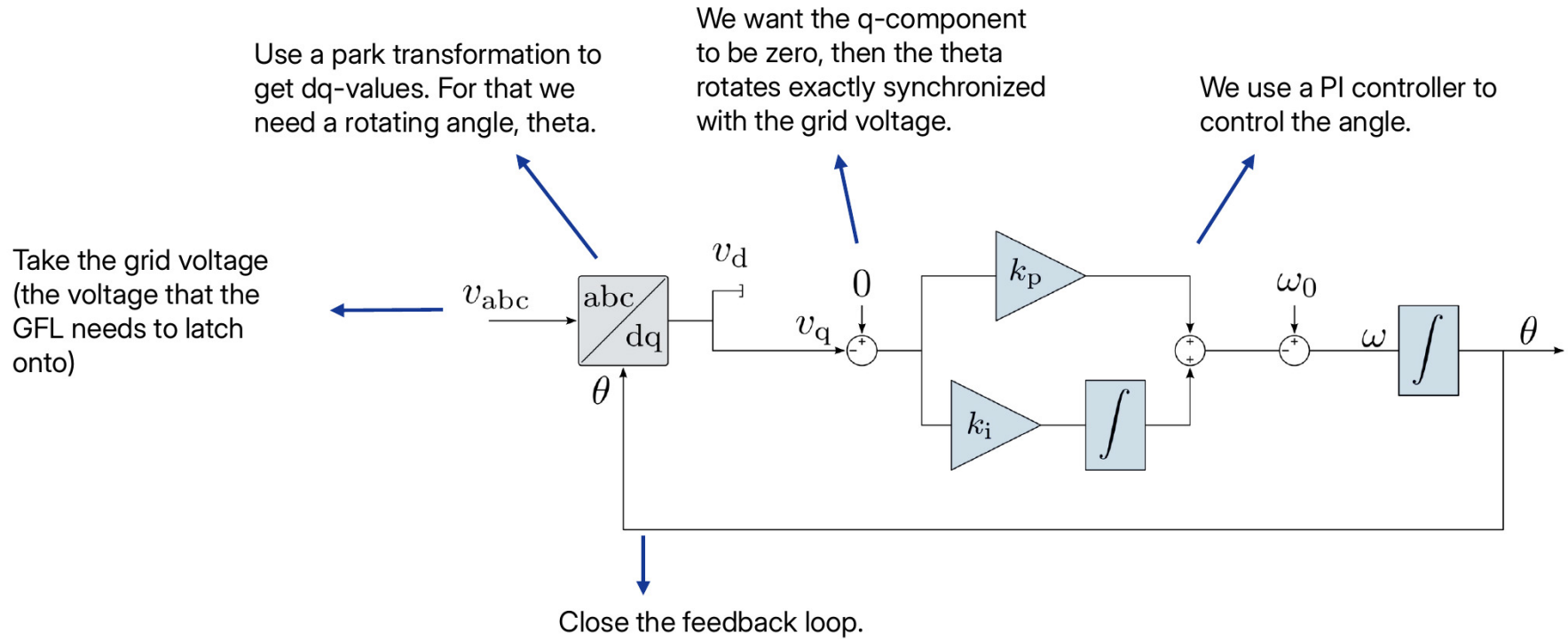


GFM creates or **forms** its own frequency and angle reference based on the output power. For that, it uses a primary controller (e.g., droop, VSM, dVOC).



GFL inverters: Introduction to the PLL

The **phase-locked loop** (PLL) is a critical part of the GFL inverter. It facilitates the **synchronization** with the power grid.

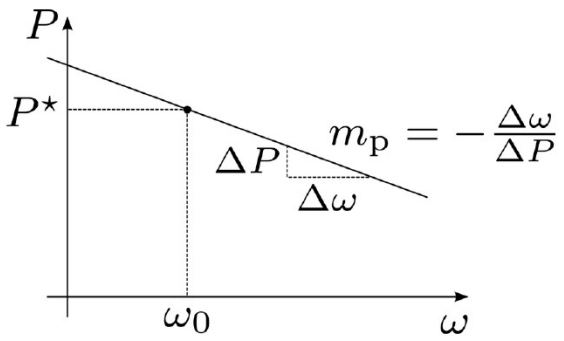


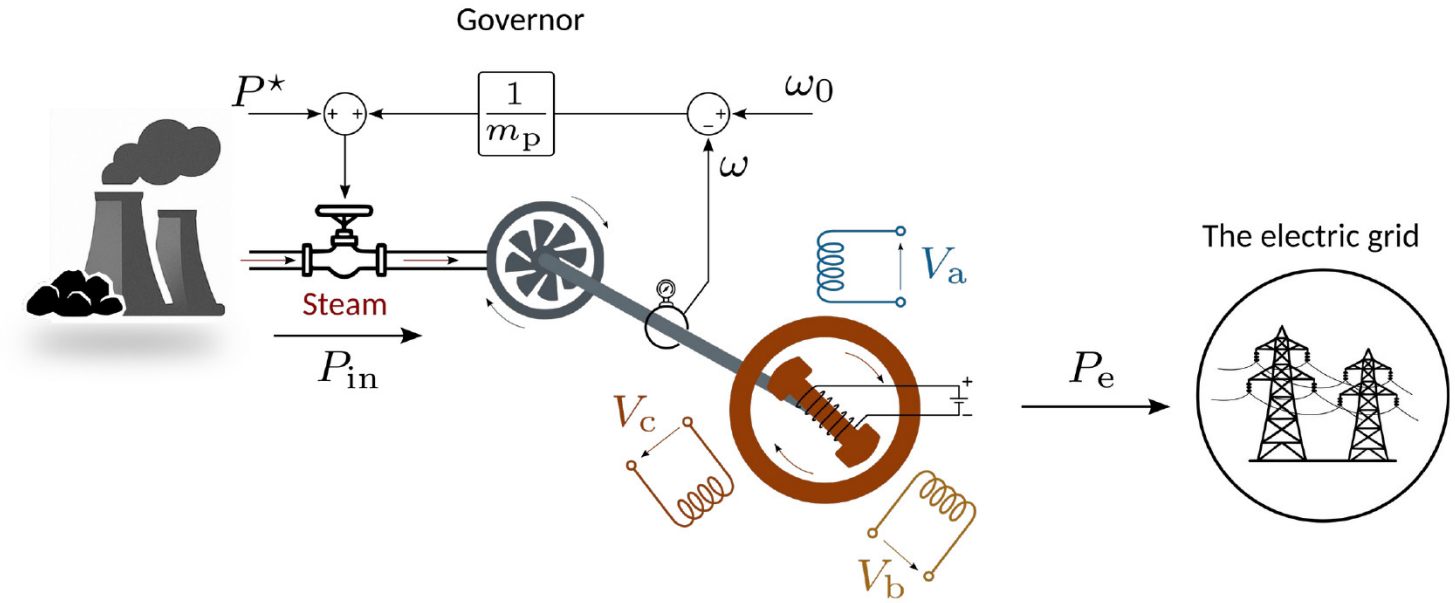
A PLL in the control system is usually an easy way to determine if a control system is GFL or not.

Introduction to primary control

Droop control is simply a linear function between the output power of the generator and its rotor frequency.

$$P_{\text{in}} = P^{\star} + \frac{1}{m_{\text{p}}}(\omega_0 - \omega)$$





$P^{\star}$ = dispatched active power
ω_0 = the desired nominal frequency of the grid

Where m_p denotes the power-frequency droop gain: it determines the slope of the power-frequency characteristic.

In words: the governor (i.e., droop control) will linearly increase the power output as a function of the rotor-frequency drop and visa versa.

GFM: putting the pieces together

How can we define what a GFM inverter is? According to NERC, GFM means:

“GFM IBR controls maintain an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame.”

