Grid Strengthening Solutions: Grid Forming Inverters vs SynCons

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Presentation Outline

- ☐ **Grid Strength Issues**
- ☐ **Synchronous Condensers**
- ☐ **Grid Forming Inverters**

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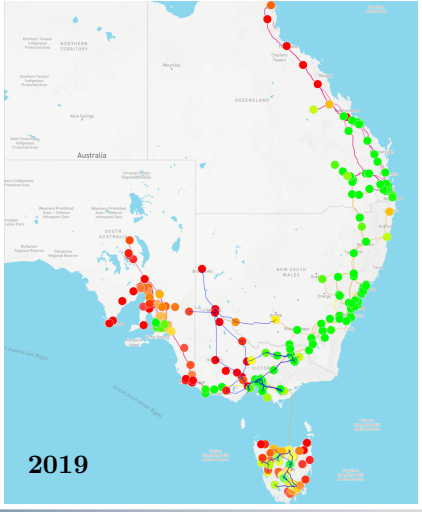
Projected System Strength in the NEM

System strength determines how a power system can **securely and reliably operate** upon various contingencies.



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MONASH University
Power Eng Advanced Research Lab [PEARL]

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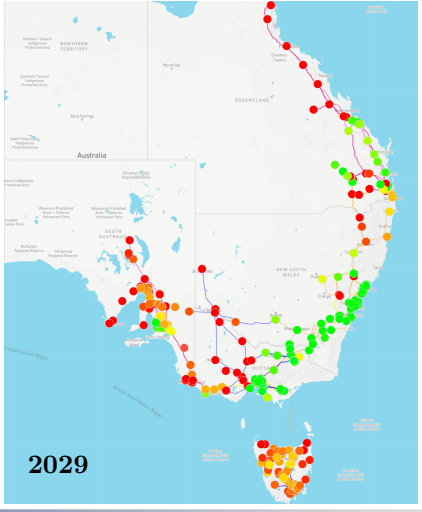

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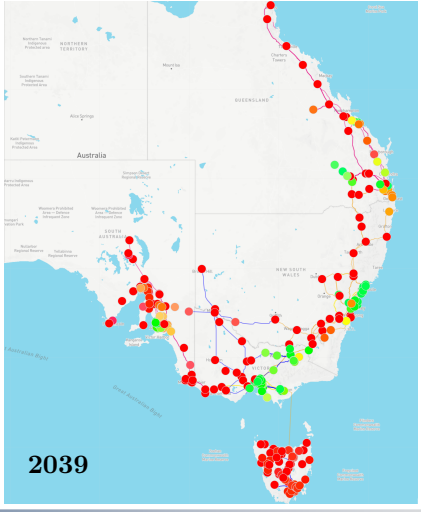

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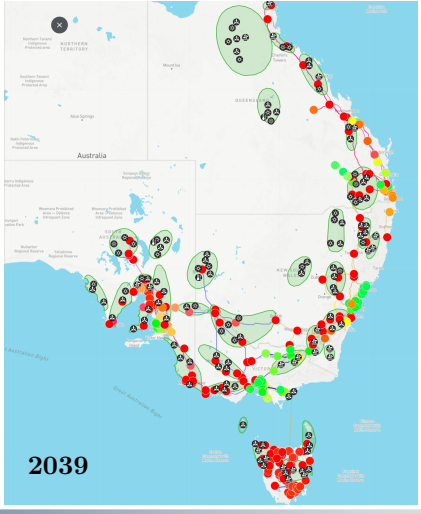
Most of these **low system strength areas overlap with REZs**, which means more farms will be integrated into these weak areas.



What services are required to operate a stable grid?

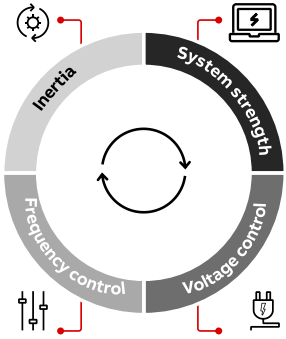
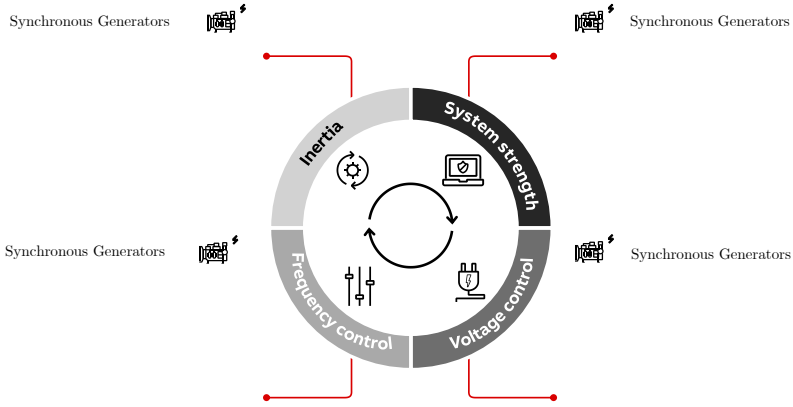


Image Source: Hitachi ABB

Who can provide these services to operate a stable grid?



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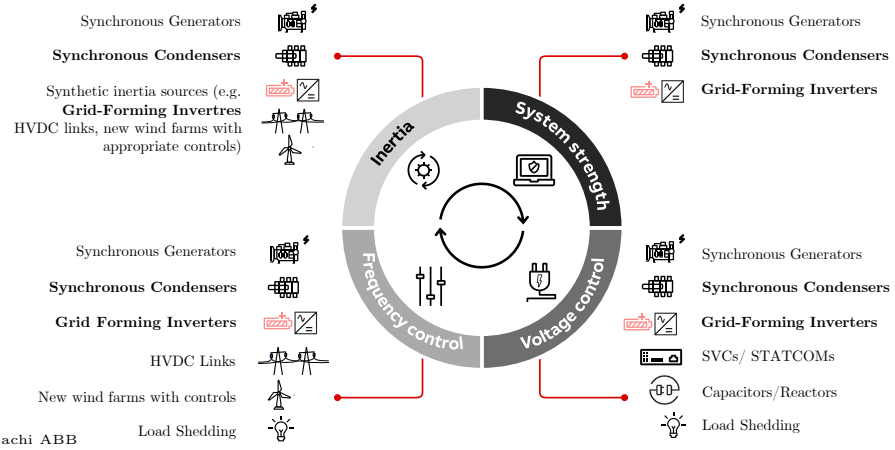

Image Source: Hitachi ABB

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Synchronous Condenser (SynCon) is a synchronous machine without a prime mover.

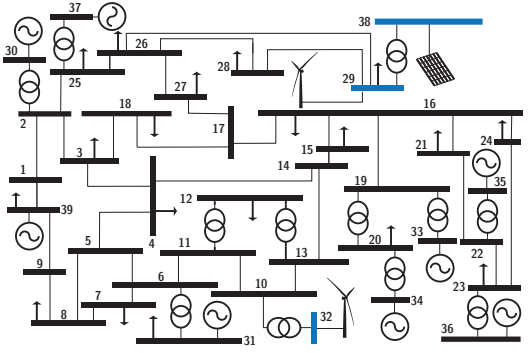
Source:https://siemens.com/

Advantages

- Contribution of short-circuit power
- Voltage support (exciter)
- Providing inertia

Drawbacks

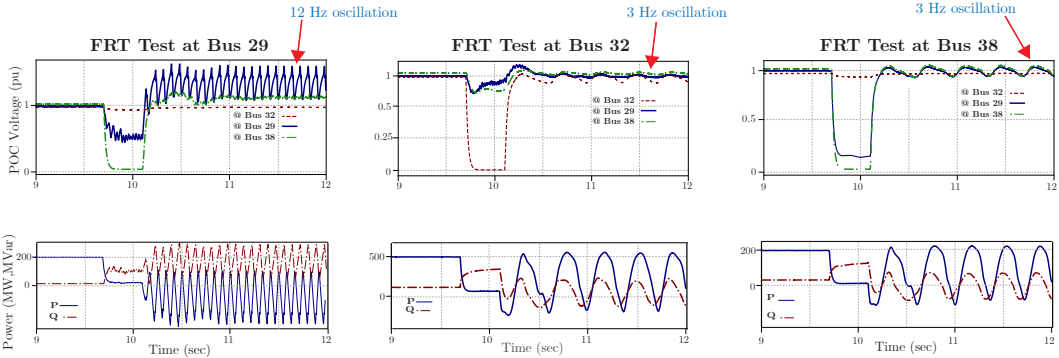
- Installation/operation costs
- Lead-time



Augmented IEEE 39-bus

- Type IV wind farm at **bus 29,32**
- Solar farm at **bus 38**

FRT test results without optimized SynCons



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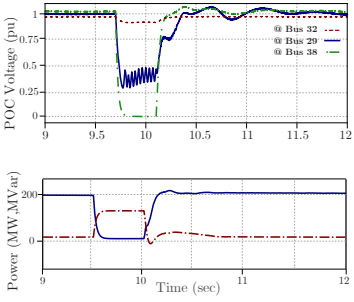
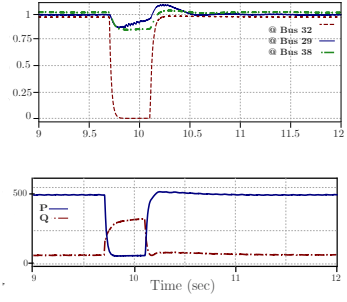
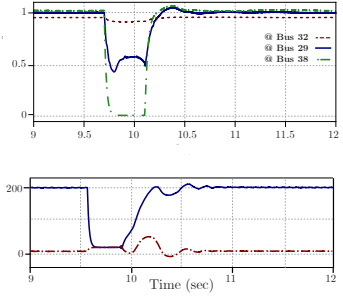
FRT Test at Bus 29



FRT Test at Bus 32



FRT Test at Bus 38



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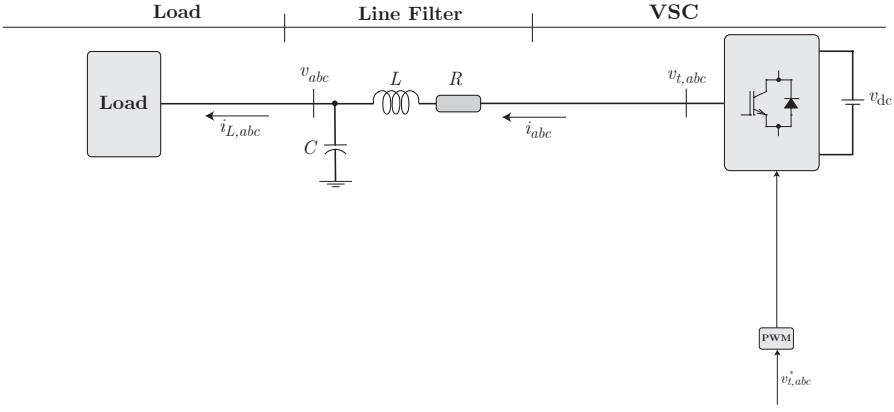
Grid Forming Inverter Internal Controller



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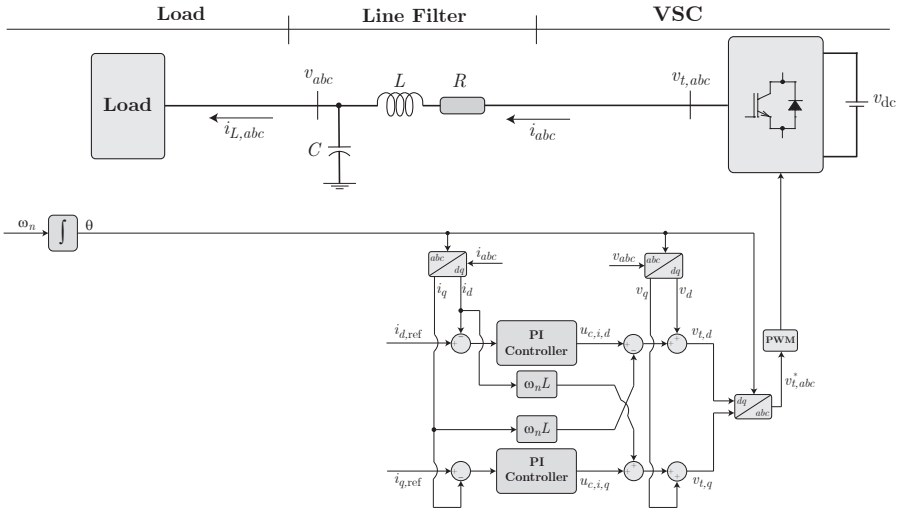

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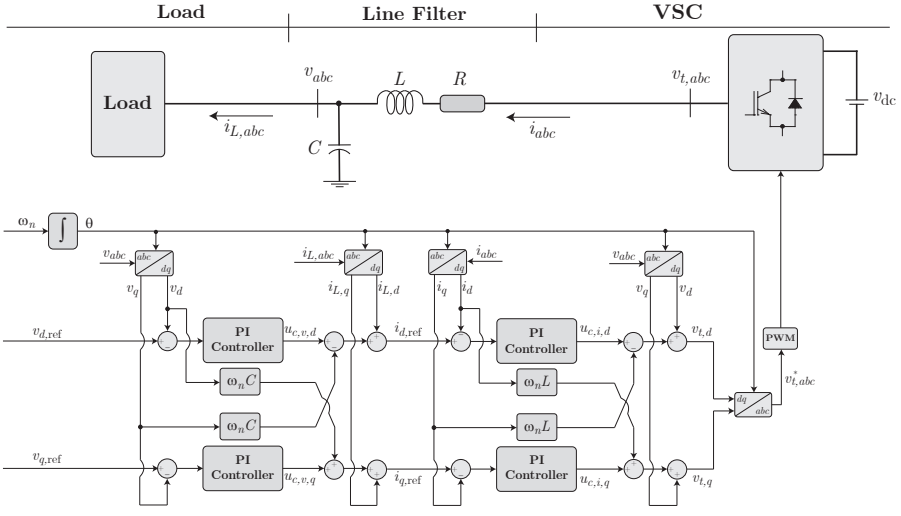
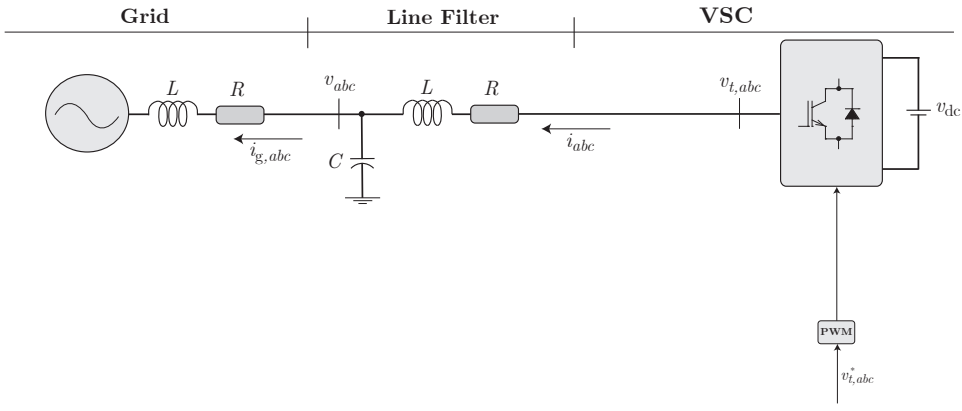
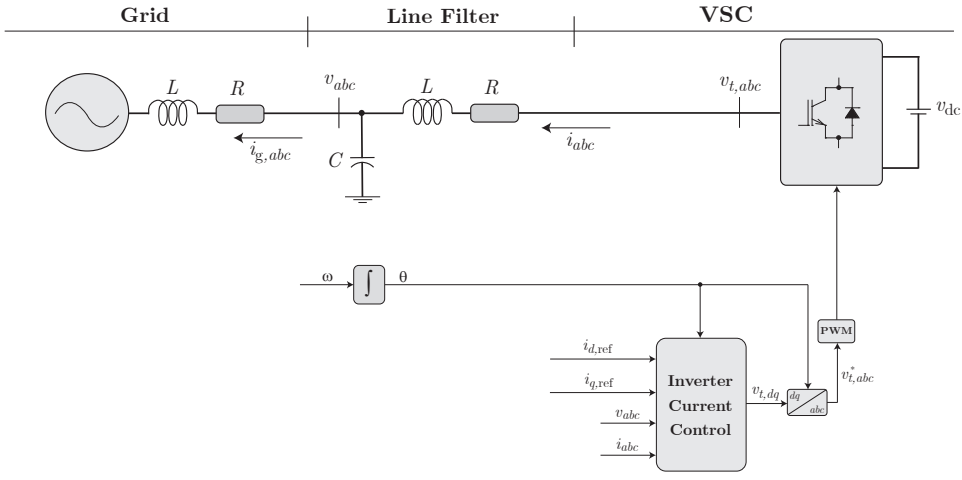


Grid Forming Inverter Primary Control




Grid
Line Filter
VSC
L
R
v_{abc}
L
R
$v_{t,abc}$
v_{dc}
$i_{\mathrm{g},abc}$
C
i_{abc}
ω
∫
θ
PWM
$i_{d,\mathrm{ref}}$
$i_{q,\mathrm{ref}}$
v_{abc}
i_{abc}
Inverter Current Control
$v_{t,dq}$
dq
abc
$v^*_{t,abc}$

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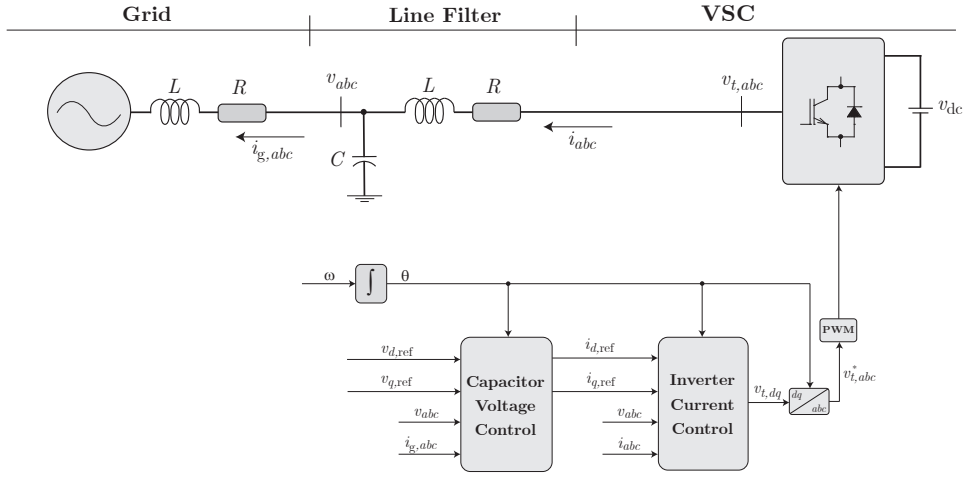

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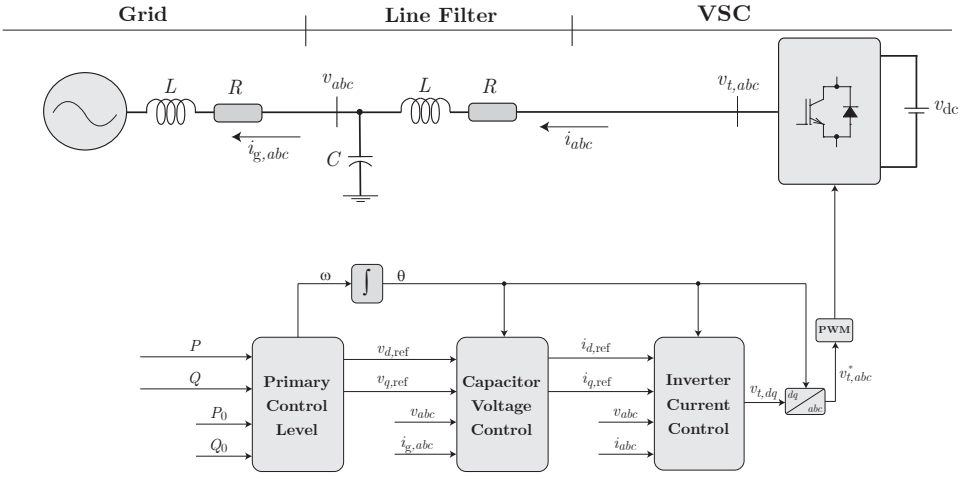

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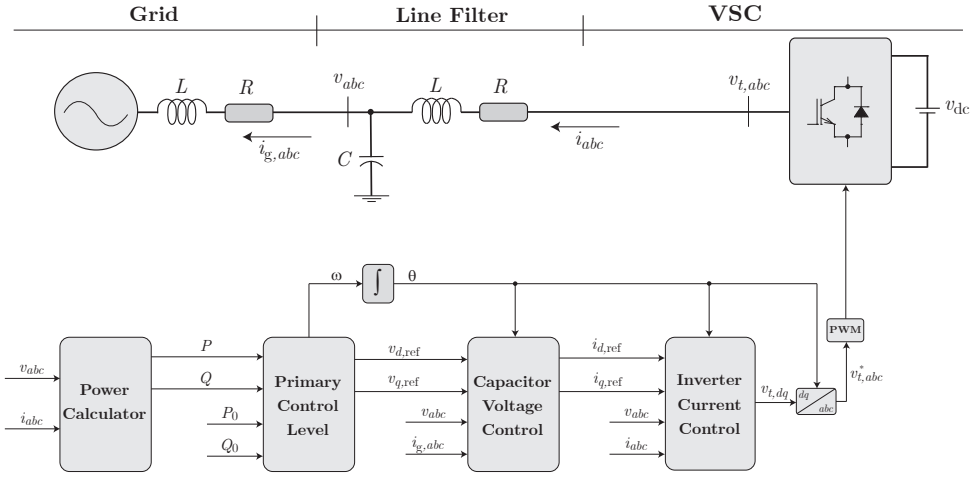
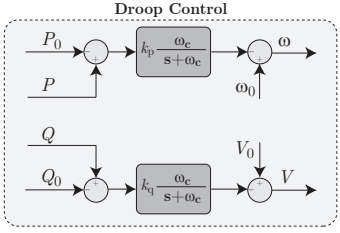


Primary Control Methods

There two main control methods for the primary level that provide the inverter angular frequency, ω, and the reference for the direct component of the voltage $v_{d,\text{ref}} = V$ (note that $v_{q,\text{ref}}$=0):

- Droop Control
- Virtual Synchronous Generator (VSG) Control



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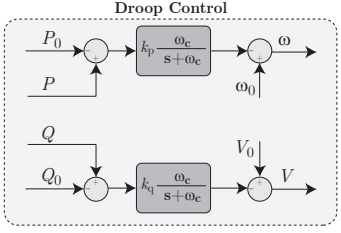

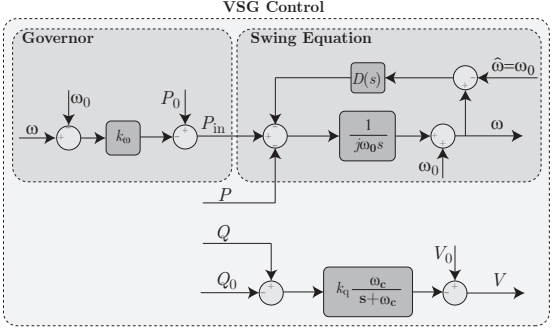

Grid-forming inverter model

$$G_{para}^{f\to P}(s) = \frac{\partial P}{\partial f} = 6\pi \frac{\omega \mathrm{L_g} V_g V_c}{(\mathrm{L_g} s + \mathrm{R_g})^2 + (\omega \mathrm{L_g})^2} \frac{1}{s}$$

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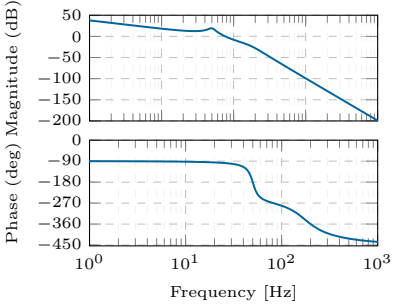

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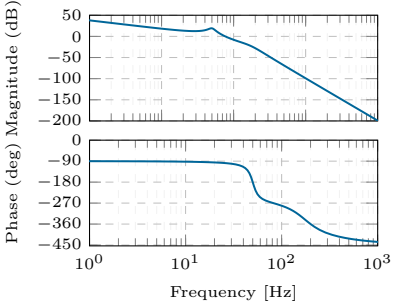

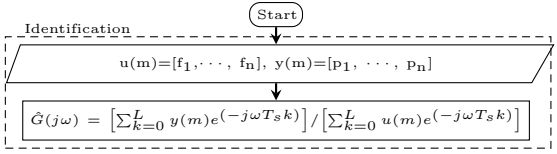

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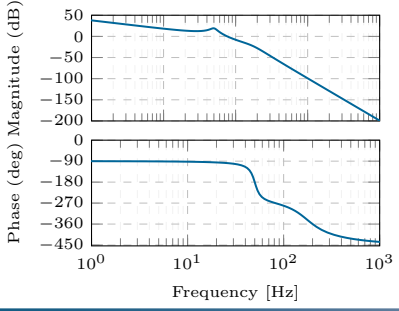
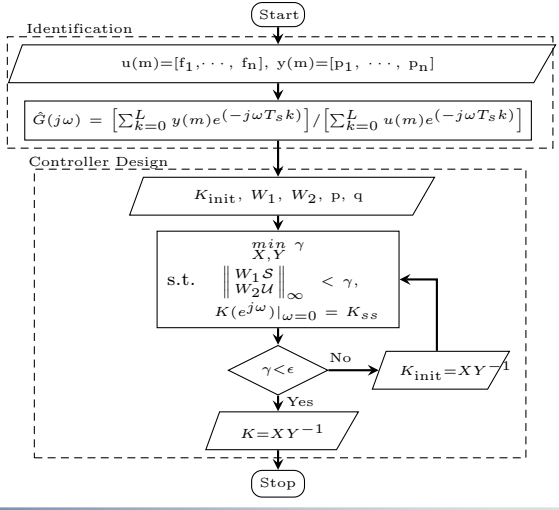
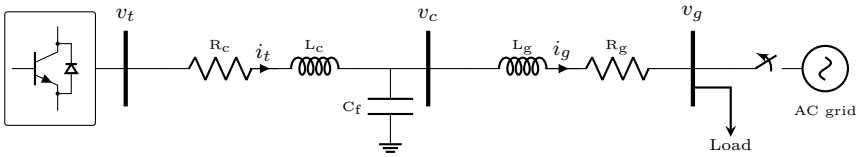




Simulation Results



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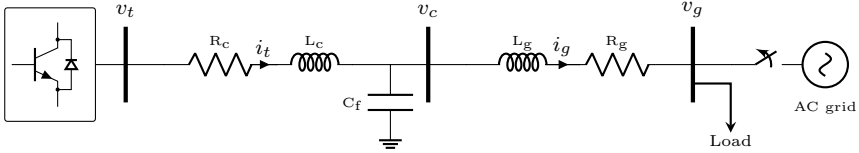

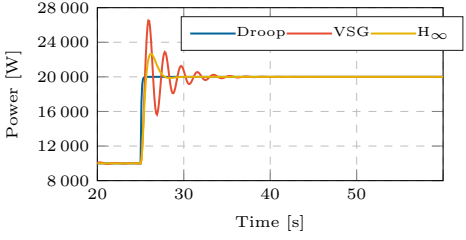

Grid-connected Case - 10 kW Setpoint Change

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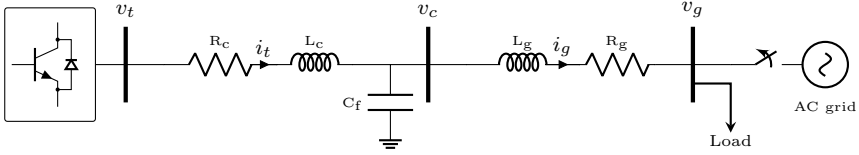

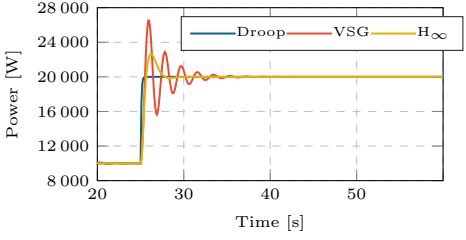

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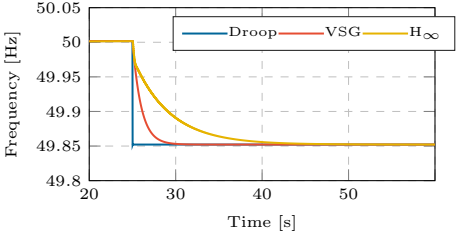
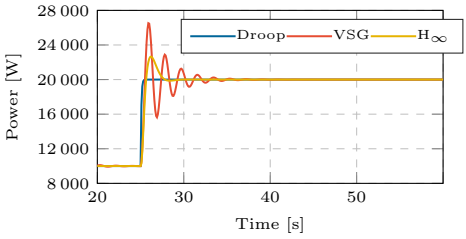
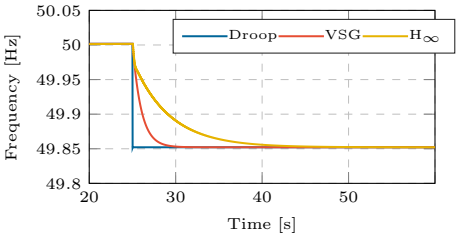


Islanded Case - 10 kW Load Change

Results Comparison





	Grid-connected mode		Islanded mode
	Overshoot	Settling time	Initial RoCoF
Droop	No overshoot	0.18 s	200 rad/s^2
VSG	65%	6 s	1 rad/s^2
H$_{n\infty}$	26.6%	3.2 s	1 rad/s^2

- Grid-connected mode - Follow the power reference commands accurately.
- Islanded mode - Comply with the RoCoF requirement (1 rad/s^2 in this case).

SynCon vs Grid Forming Inverter for Solar Farms

In collaboration with Fimer, we have conducted some studies to evaluate the performance of Grid Forming Inverters and SynCons when installed in parallel to a solar farm.

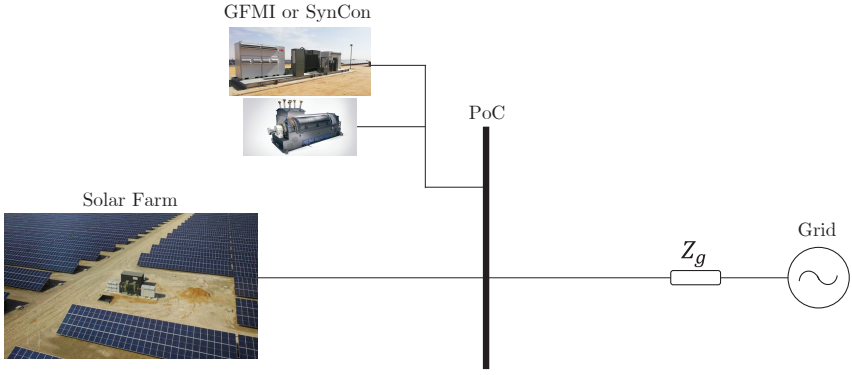
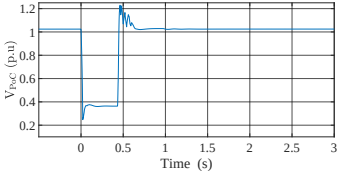
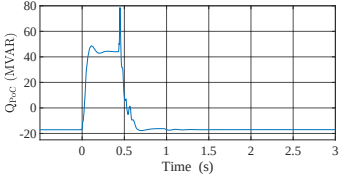


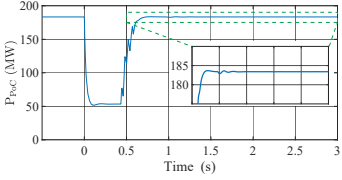
Image Source: Fimer

3-Φ-to-Ground Fault

A 3-Φ-to-ground fault with 0.35 pu voltage remaining is applied at the PoC at 0 s and cleared at 0.43 s.







Results without SynCon and GFMI

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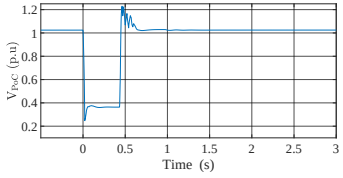

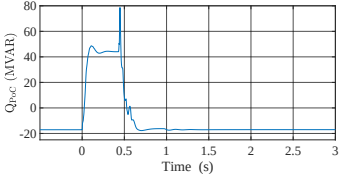

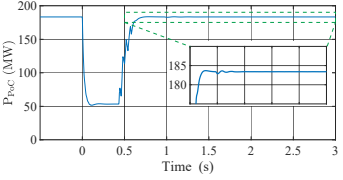

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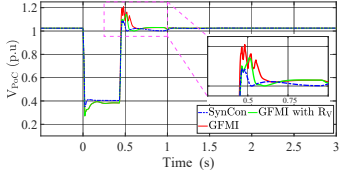
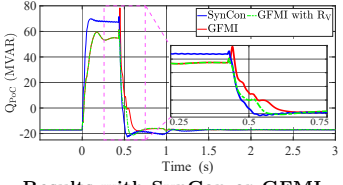
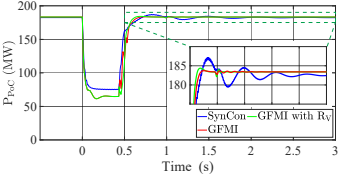


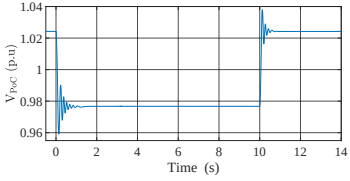


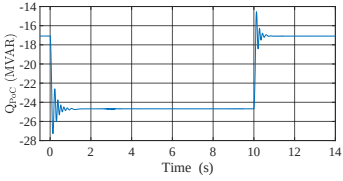


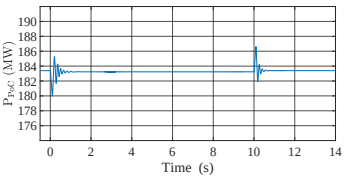
Results with SynCon or GFMI

Voltage Reference Tracking

A step change from 1.02 pu to 0.97 pu at t=0 s and then to 1.02 pu at t=10 s.







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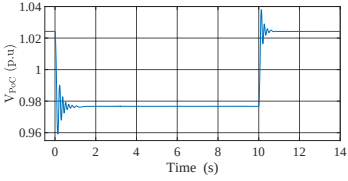
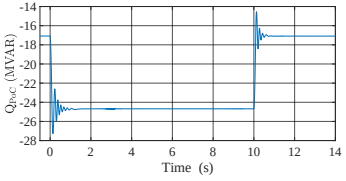
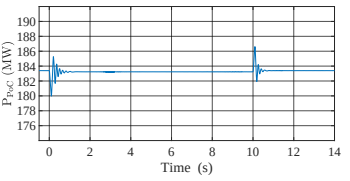
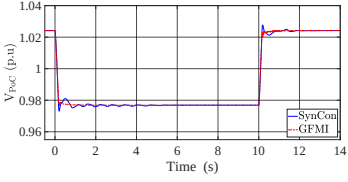
A step change from 1.02 pu to 0.97 pu at t=0 s and then to 1.02 pu at t=10 s.

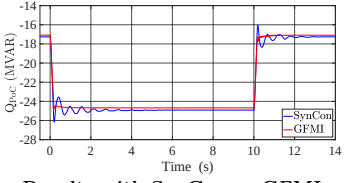


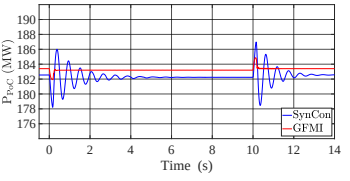




Results without SynCon and GFMI







Results with SynCon or GFMI

Questions