Heterogeneous Multi-agent Proximal Policy Optimisation based Control Technology for Fast Frequency Response

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Agenda

Modelling

- Ancillary Services
- SOEC and WT models

Intelligent Control

- Heterogeneous Multi-agent Proximal Policy Optimisation
- Fuzzy Control

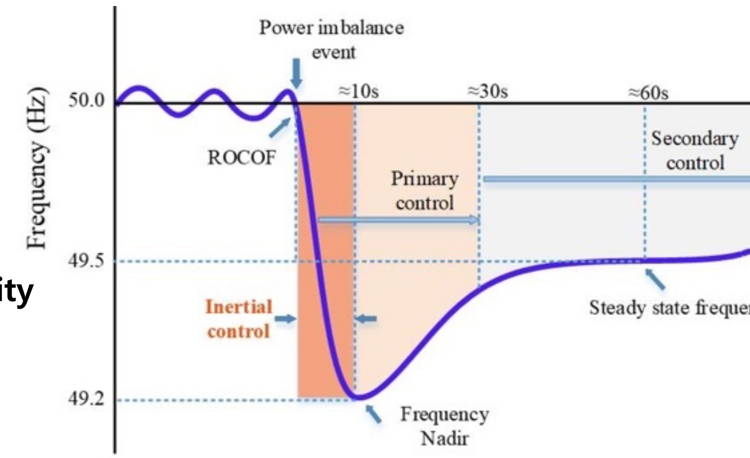
Real-time Validations

- Simulations case studies
- HIL testing

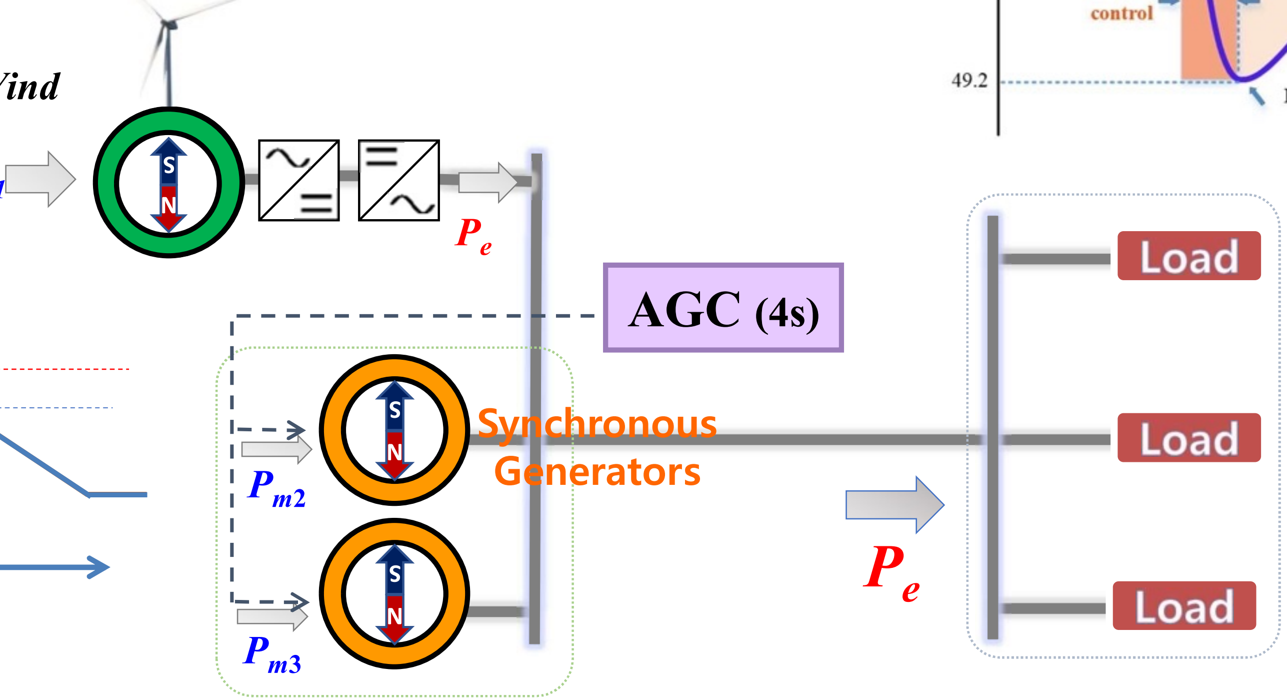
Ancillary Services

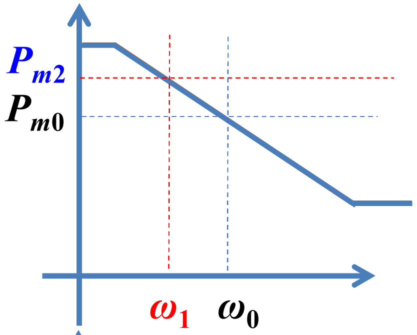
Large load change in multi-machine grid

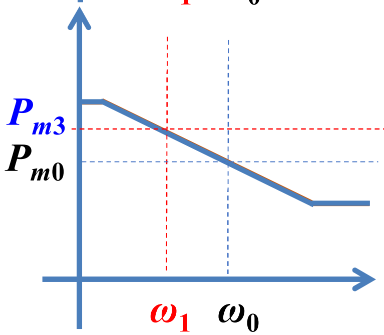
If we could control WT/rSOC P_e → improves frequency regulation → Security



$$J\omega \frac{d\omega}{dt} = P_m - P_e$$







- Win-Win-Win approach

ORE/rSOC developer-SO-Consumer

Inertia response: Large load increase → Frequency decline

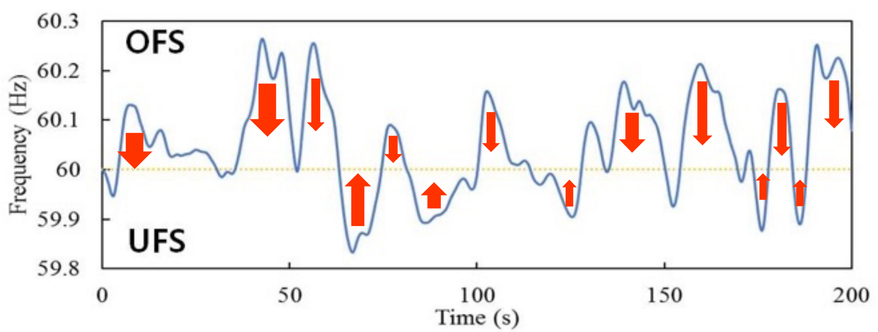
Primary control: Governor increase P_m, stabilizing f to ω_1

Secondary control: SO increases P_m, recovering f to ω_0

FS of a WTG: Same function of BESS but NO ADDITIONAL COST!!

Ancillary Services

Dynamic Regulation (DR) is a pre-fault service designed to slowly correct continuous but small deviations in frequency. The aim is to continually regulate frequency around the target of 50Hz.



Frequency regulation of an ORE-rSOC

Dynamic Regulation - Technical Requirements

Dynamic Regulation technical specifications:

Topic	Dynamic Regulation
Speed of response	10 seconds
Pre/post fault	Pre-fault
Delivery range	+/-0.015 -0.2 Hz
Deadband (delivery %)	+/-0.015 (0%)
Initial linear range (delivery %)	+/-0.015 -0.2 Hz (100% at +/-0.2Hz)
Knee point	No knee point
Second linear range (delivery %)	n/a
Full delivery point	+/-0.2Hz
Max ramp start	2 seconds

$\Delta f > 0$ (Over-frequency)

Reduces output power of a ORE-rSOC Decrease power of SOFC/ increase power of SOEC

Frequency decreases

KE is absorbed into the rotating masses, thereby increasing the rotor speed

$\Delta f < 0$ (Under-frequency)

Increases output power of a ORE-rSOC increase power of SOFC/ decrease power of SOEC

Frequency increases

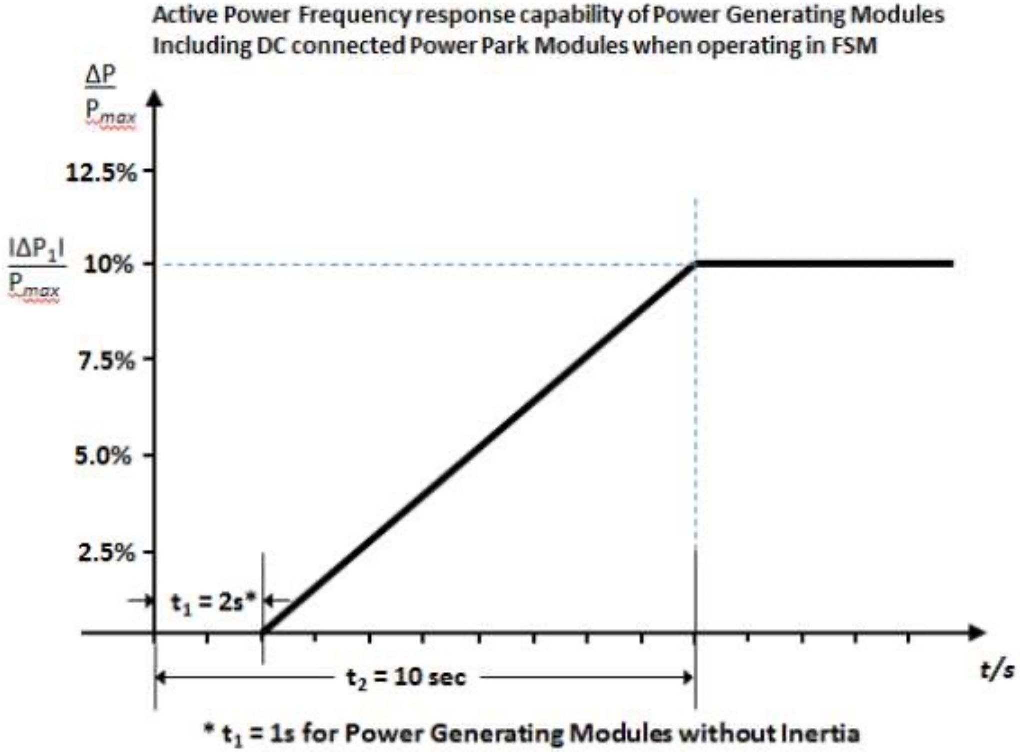
KE is released from the rotating masses, thereby decreasing the rotor speed

Overdeceleration of a WTG should be avoided for stable operation of a WTG

Ancillary Services

Parameter	Setting
Active Power as a percentage of **Maximum Capacity (frequency response range)** $(\frac{\lvert \Delta P_1 \rvert}{P_{max}})$	10%
Maximum admissible initial delay t_1 for **Power Generating Modules** (including **DC Connected Power Park Modules**) with inertia unless justified as specified in ECC.6.3.7.3.3 (iv)	2 seconds
Maximum admissible initial delay t_1 for **Power Generating Modules** (including **DC Connected Power Park Modules**) which do not contribute to **System** inertia unless justified as specified in ECC.6.3.7.3.3 (iv)	1 second
Activation time t_2	10 seconds

Table 6.3.7.3.3(b) – Parameters for full activation of **Active Power Frequency** response resulting from a **Frequency** step change. Table 6.3.7.3.3(b) also includes the mathematical expressions used in Figure 6.3.7.3.3(b).

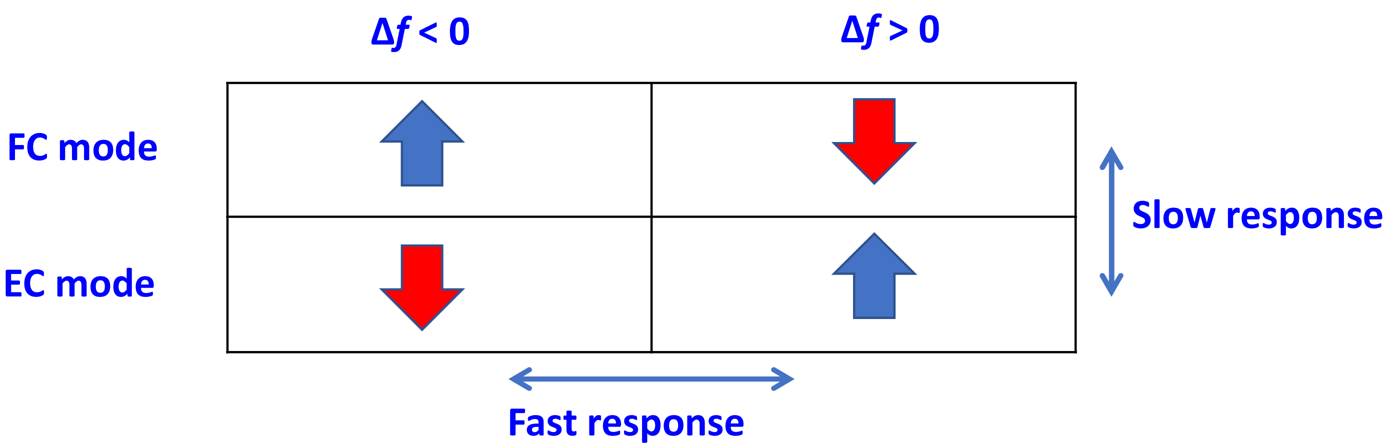


Type C Power Generating Module: with a Grid Entry Point or User System Entry Point below 110 kV and a Maximum Capacity of 10MW or greater but less than 50MW

Type D Power Generating Module: with a Grid Entry Point or User System Entry Point at, or greater than, 110 kV; or with a Grid Entry Point or User System Entry Point below 110 kV and with Maximum Capacity of 50MW or greater

Ancillary Services

Considerations for Frequency regulation using rSOC



Switching from EC mode to FC mode and vice versa, is a slow response. However, the change in output power magnitude within one mode of operation is a fast response. Therefore, we consider the following strategy for rSOC to participate in dynamic frequency regulation:

If the stack is in SOEC or SOFC mode, they operate within 10-100% of its capacity to ensure the device level stability and lifetime efficiency of the stack.

$\Delta f > 0$ (Over-frequency)

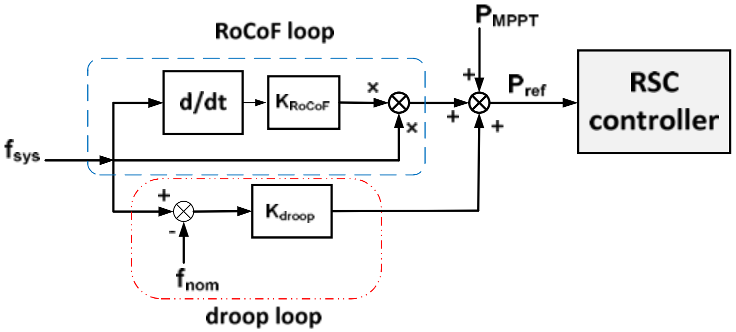
While the operation of the stack remain within 10-100% of its capacity: Decrease the power of SOFC, and increase the power output of SOEC in the grid.

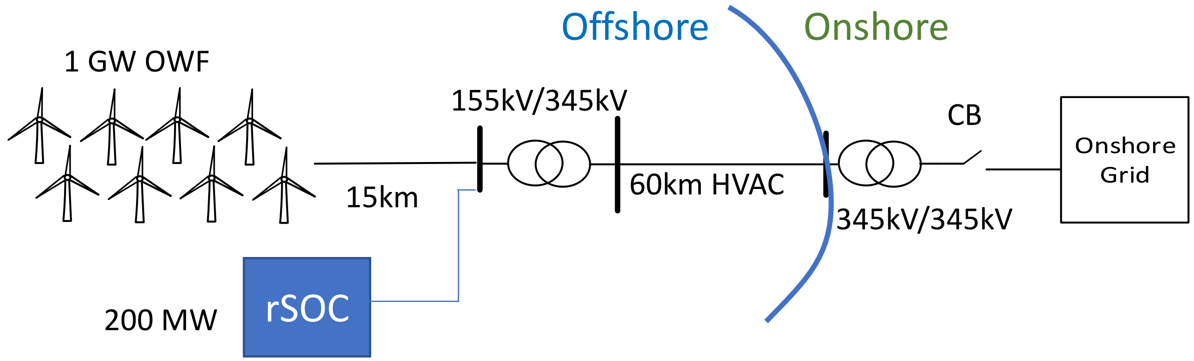
$\Delta f < 0$ (Under-frequency)

While the operation of the stack remain within 10-100% of its capacity : Increase the power of SOFC, and decrease the power output of SOEC in the grid.

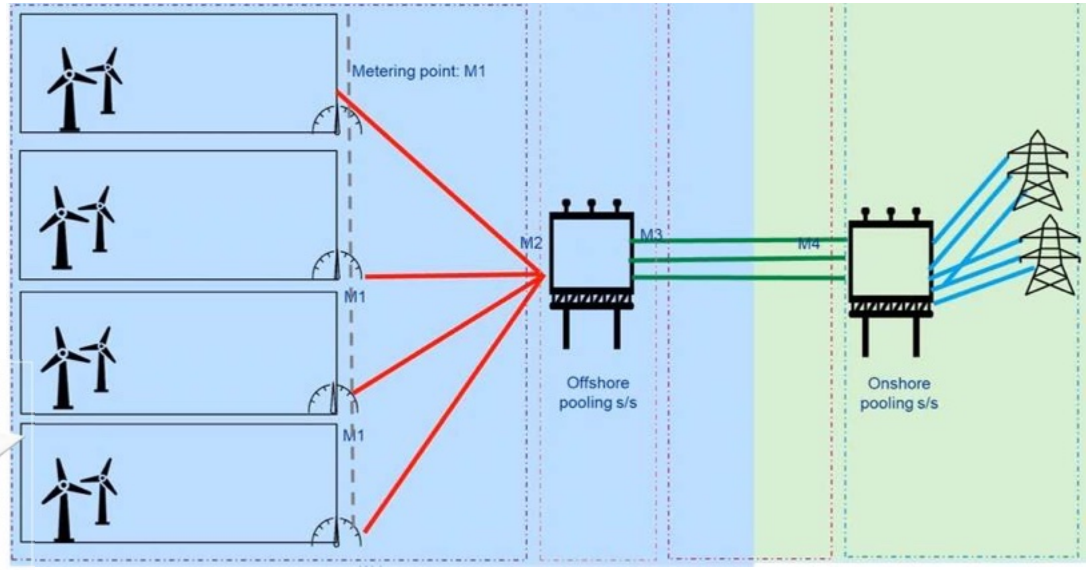
Ancillary Services

OWF:
Frequency-dependent Inertial Control (FDIC)

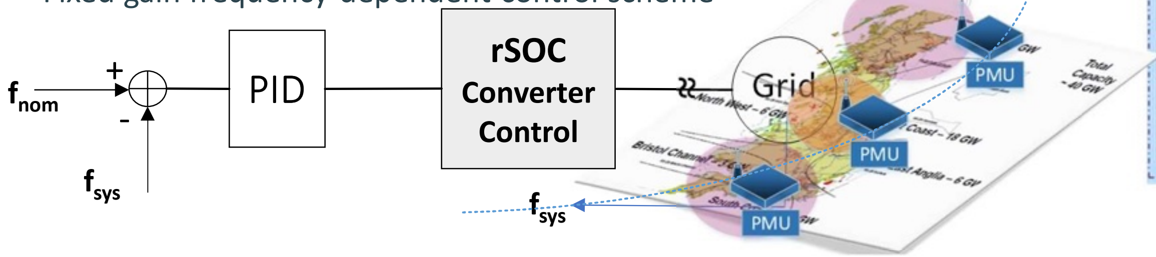




- Emulate inertial and governor response of SGs
- Inject active power corresponds to frequency deviations



rSOC:
Fixed gain frequency-dependent control scheme



- SOFC mode to generate power
- SOEC mode to absorb the surplus power