GRID-FORMING PLANT CONTROL

Practical Considerations from the Perspective of an OEM

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WECC Modeling and Validation Subcommittee Meeting

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1. Introduction to grid-forming plant control
2. General considerations regarding plant control
3. Specific considerations relating to implementation of grid-forming plant control
4. Considerations relating to modeling of a GFM IBR plant

Introduction to grid-forming (GFM) plant control

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Common objectives of a grid-forming (GFM) Power Plant Controller (PPC):

- PPC manages overall IBR plant output—P, |V|, Q, etc.— at the plant's point of measurement (POM).
- PPC optimally coordinates individual assets in plant, balance of plant controls, etc.

Major objectives of GFM PPC can be similar in nature to that of conventional grid-following (GFL) PPC, but there are some new considerations.

Introduction to grid-forming (GFM) plant control

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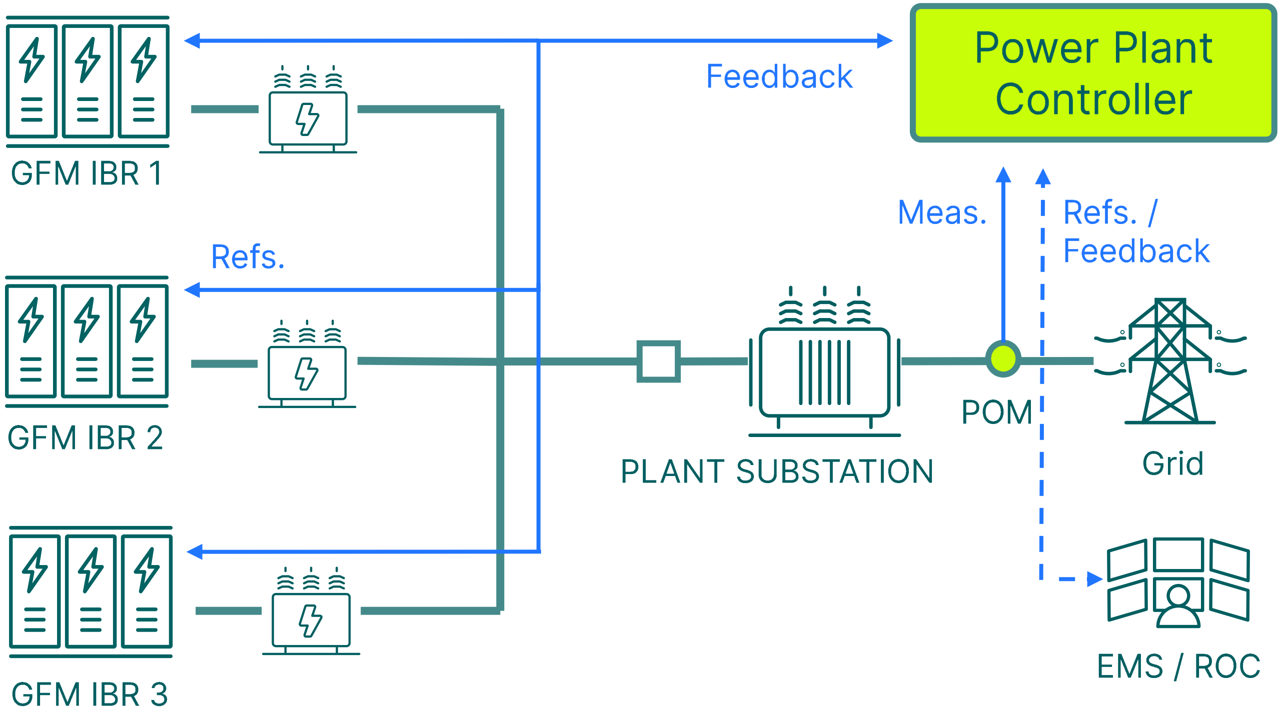


Basic functions of GFL and GFM PPCs:

- PPC will measure voltage and current at the point of interconnect (POM), compute quantities of interest (e.g. P, Q, f, |V|)
- The PPC uses these measurements to regulate key quantities at the POM (most frequently P, |V|, although it can also sometimes regulate Q or PF at POM).
- To actuate its control objective(s) the PPC issues control setpoints to downstream assets under its control authority, each of which employs its own local controller.
- Relative to a GFL PPC, a GFM PPC may alter the nature of the references sent to downstream assets.

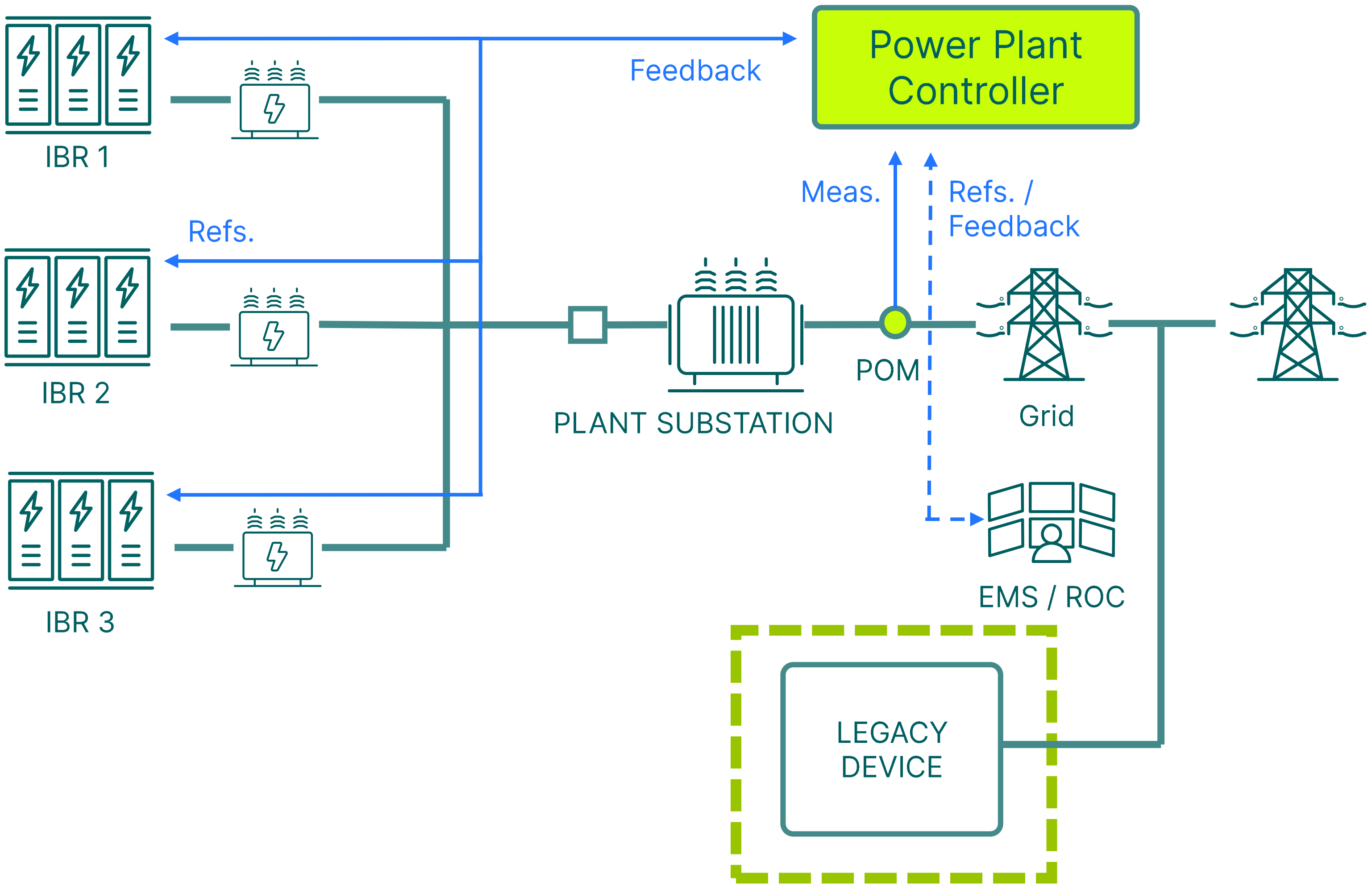
General plant control considerations

Applicable to plants containing either grid-following (GFL) or grid-forming (GFM) Inverter Based Resources

1. Site-specific plant performance requirements
2. Influence of resource type on PPC control strategy
3. Alternative control hardware configurations
4. Interoperability of power plant controllers

General plant control considerations I

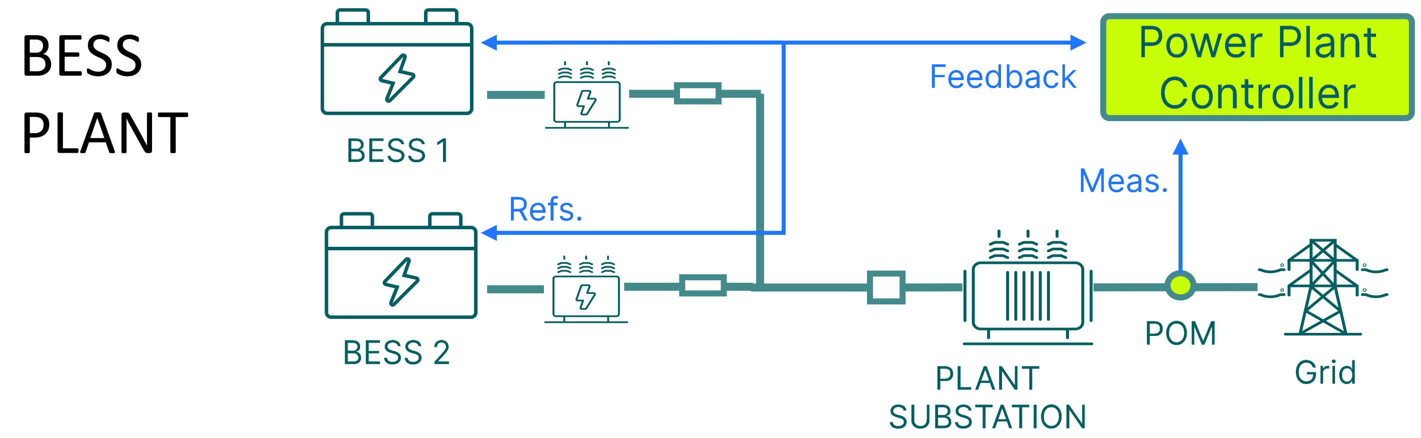
Applicable to plants containing either grid-following (GFL) or grid-forming (GFM) Inverter Based Resources

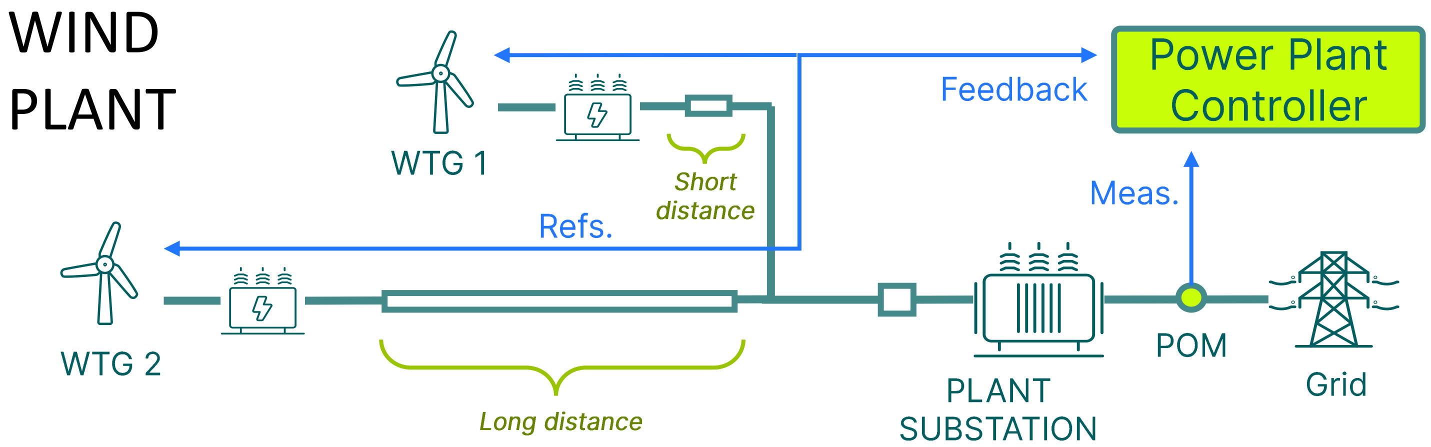


1. Site-specific performance requirements:
   - Standard design can cover most applications
   - However, there may be a particular resource or adjacent device that forces activation of specific features / tuning

General plant control considerations II

Applicable to plants containing either grid-following (GFL) or grid-forming (GFM) Inverter Based Resources





2. Influence of *resource type*:

   - BESS, wind and solar plants can have different requirements, requiring different plant control strategies.
   - Renewable plants may have heterogeneity in layout and feeder length, affecting how each downstream asset influences key quantities at the POM.

General plant control considerations III

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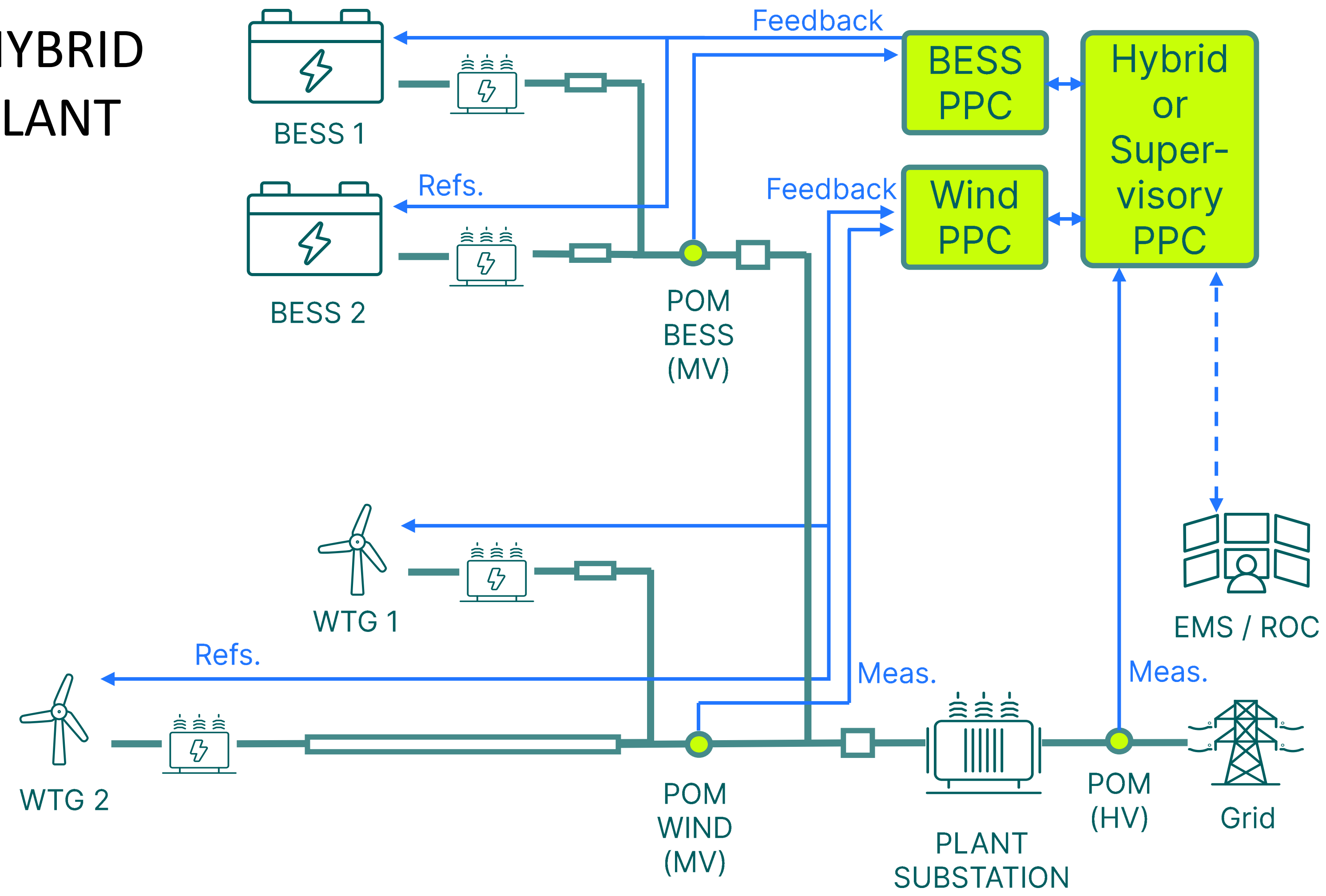
Applicable to plants containing either grid-following (GFL) or grid-forming (GFM) Inverter Based Resources

HYBRID PLANT



3. Control hardware configurations:

- Hybrid plants in particular may require a supervisory control layer.
- Larger sites with many hundreds of IBR may require multiple PPCs coordinated by a supervisory PPC.

General plant control considerations IV

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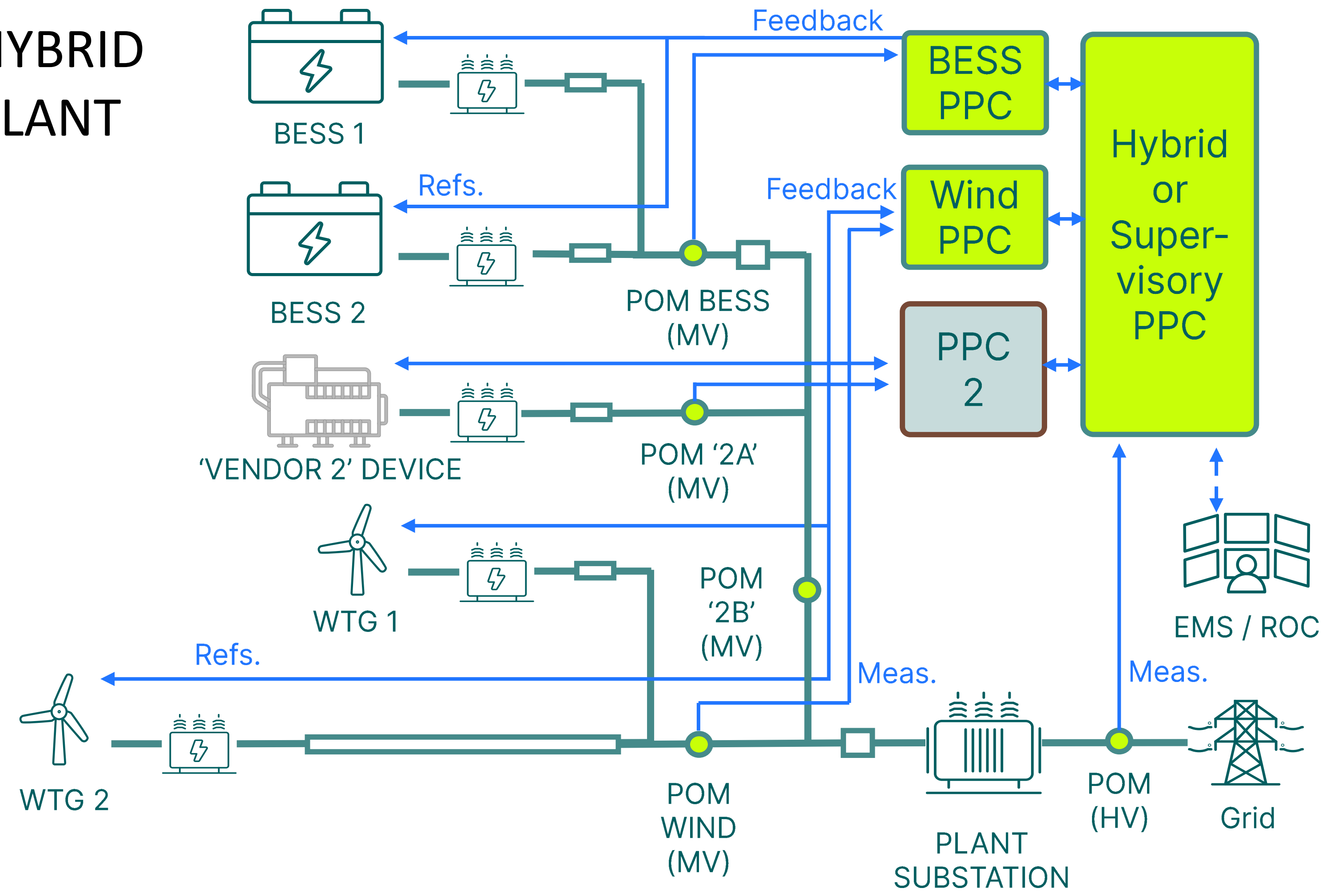
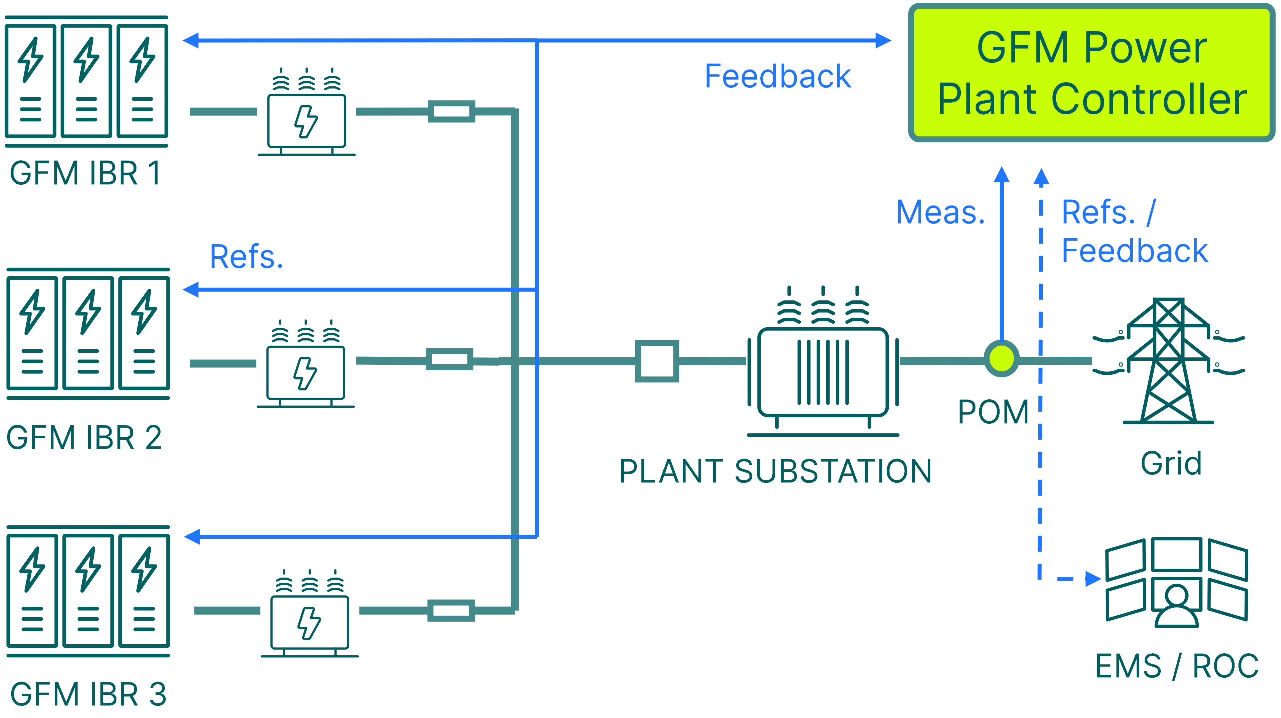
Applicable to plants containing either grid-following (GFL) or grid-forming (GFM) Inverter Based Resources

HYBRID PLANT



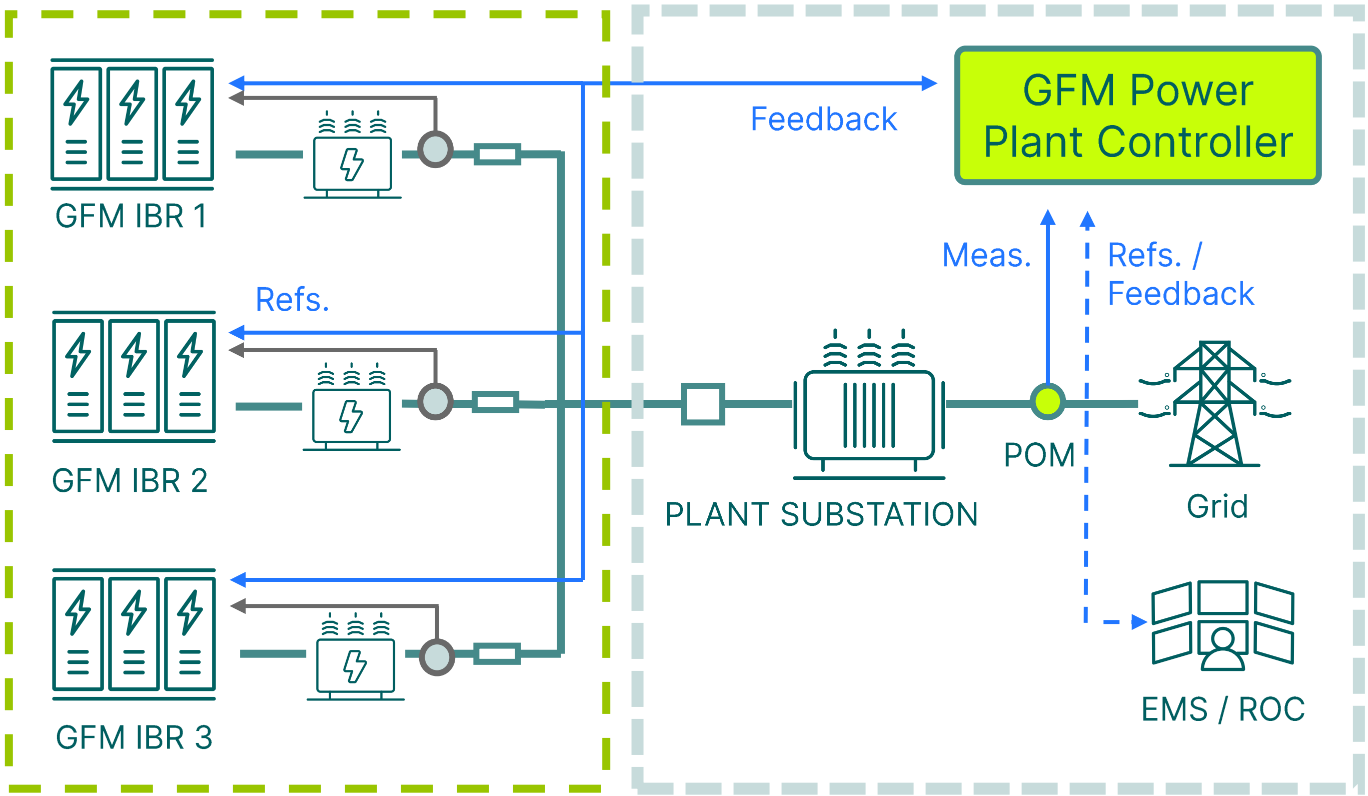
4. Interoperability and need for signal exchange:
    - This is particularly relevant in the case of multi-vendor sites, or new additions to existing site.
    - If there are limitations associated measurement location (e.g. PPC 2 must use POM 2B instead of 2A), communication may be required between PPCs to accommodate.

Grid-forming plant control considerations I



1. All ‘general’ plant control considerations discussed previously may still be relevant.
2. Introduction of GFL vs. GFM control mode adds another dimension to consider, with respect to the possible control configurations.
3. References to downstream assets may also contain new variables: e.g., voltage & frequency commands.

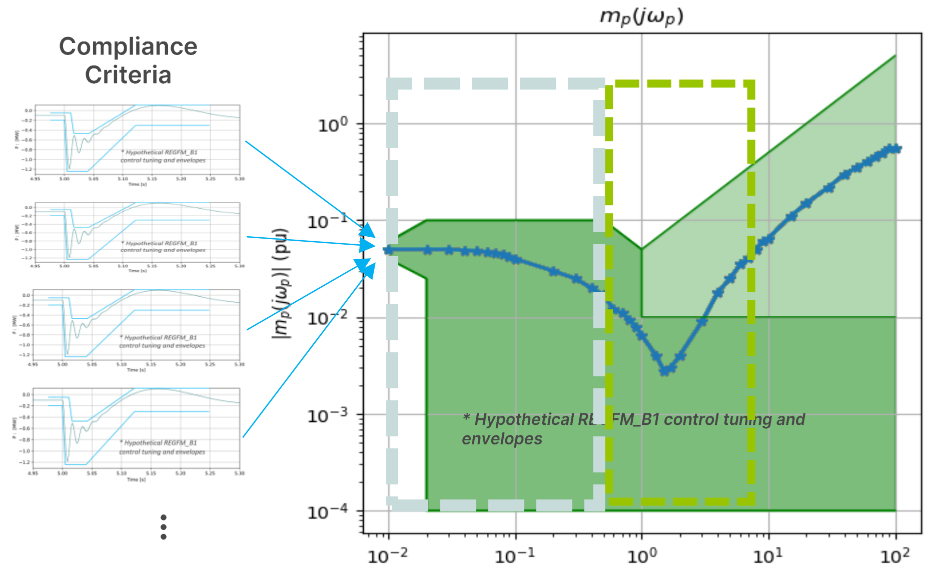
Grid-forming plant control considerations II



4. Grid services offered by plant now includes voltage and frequency strengthening. But since grid-forming is a fast-timescale control behavior, the main plant POM may not be the location in which we are assessing compliance of the grid-forming grid service.

5. This raises questions: for GFM, where is RPA? Also, what should be max. electrical distance between IBR and POM?

UNIFI freq. specification applied to REGFM_B1: *



Reduced-order modeling of GFM plants

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- When modeling a GFL IBR plant, the IBR are often aggregated together and lumped into a single 'scaled' unit.
- Fortunately, in the case of GFM plants, there is justification to this practice: the phenomenon of coherency.
- For virtual synchronous machine-based GFM IBR, we can employ slow coherency or generalized eigenvalue perturbation techniques.
- What about other families of GFM IBR control structure, besides the virtual synch. machine? Can coherency techniques also be applied, e.g., to justify aggregation of GFM *droop-controlled* IBR?

Reduced-order modeling of GFM plants

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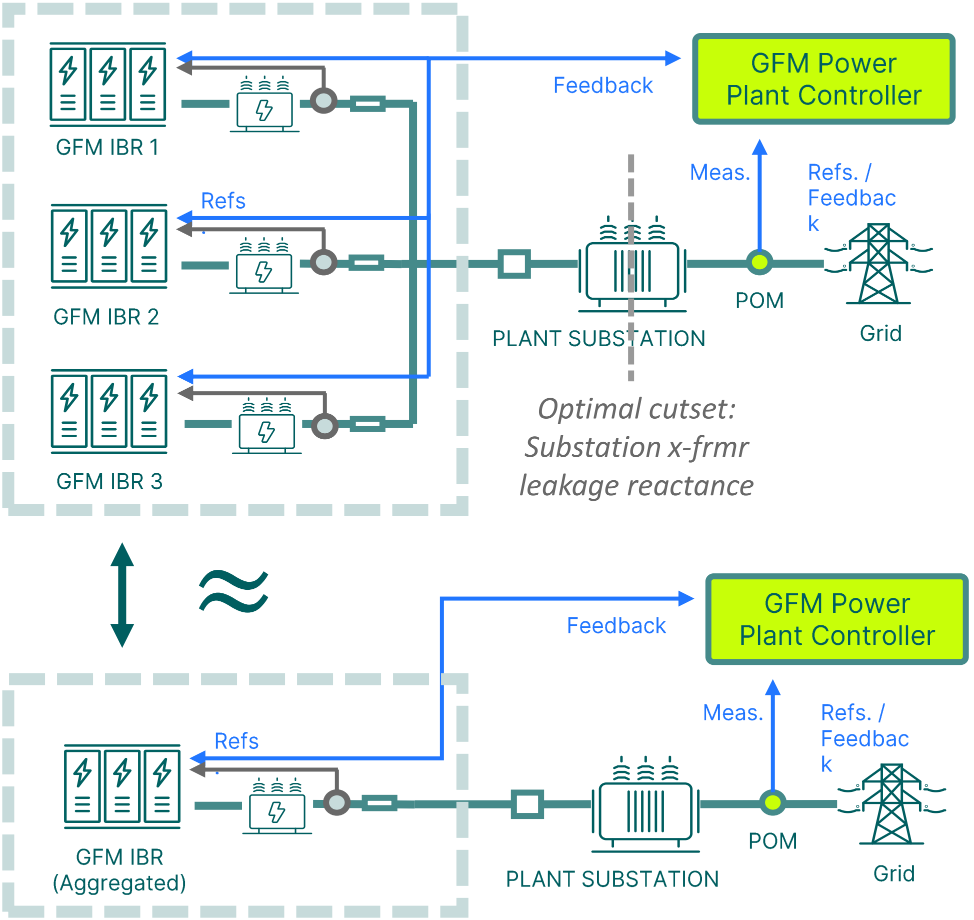
- Generalized Eigenvalue Perturbation technique (DeMarco & Wassner) finds the optimal cutsets in the network, dividing it into coherent clusters.
- This approach relies on a known relationship between eigenvalues of the full asymmetric DAE and an associated symmetric DAE.
- Fortunately, under assumptions of constant bandwidth of software power measurement filter, droop-controlled GFM IBR can, like VSM, be shown to possess the required eigenvalue relationship[1]:

$$\tau_{P,1} = \tau_{P,2} = \ldots \tau_{P,m} = \tau$$

Full, asym. DAE: $\gamma \tilde{\mathbf{E}}\mathrm{w} = \tilde{\mathbf{R}}\mathrm{w}$

$$\gamma = j\sqrt{\lambda} \quad \text{(✗)} \qquad \gamma = -\frac{1}{2\tau} + j\sqrt{\lambda - \left(\frac{1}{2\tau}\right)^2} \quad \text{(✓)}$$

Sym. DAE: $\lambda \mathbf{E}\mathrm{v} = \mathbf{R}\mathrm{v}$



Coherency identification techniques can help rigorously justify the aggregation for multiple families of GFM IBR.

[1] *P. J. Hart, R. H. Lasseter and T. M. Jahns, "Coherency Identification and Aggregation in Grid-Forming Droop-Controlled Inverter Networks," in IEEE Transactions on Industry Applications, vol. 55, no. 3, pp. 2219-2231, May-June 2019. (Extends GEP method from DeMarco & Wassner's 1995 paper.)*

Conclusions

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- Plant control is a rich topic, with many considerations at play:
    - Site-specific requirements; resource types; control and measurement configurations; multi-vendor plants
- Grid-forming control adds yet another dimension, and additional considerations:
    - Reference point of applicability for various grid services
    - What kinds of control references should be sent to downstream assets
- Coherency techniques can be extended to accommodate various types of grid-forming control structures in order to help rigorously justify the common practice of IBR aggregation.

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