VRT / PFR Controls Coordination

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Introduction

A practical look at frequency response issues

Why is this happening?

Understanding the root causes behind the frequency-related issues observed.

How can we avoid it?

Exploring practical measures and control strategies to prevent similar events in the future.

Background

- ERCOT continues to see IBR units reduce output during ride-through events due to high frequency calculations or PPC interactions during fault conditions
- These high frequency spikes are very short duration (a few msecs or often single sample) and often seen in PMU/DFR data from facilities close to the fault, and are not indicative of system frequency
- Inverters/turbines "ride-through" initial voltage disturbance but PPC reduces output during low system frequency
- First observed in Panhandle event in March 2022
  - NERC Panhandle Wind Disturbance report
  - Section *Wind Plant Controller Active Power-Frequency Response Interactions*
  - *"Plant controller active power-frequency response controls are incorrectly sending dispatch signal to individual turbines immediately following LVRT condition"*
  - **Appendix A** – Plant B, Plant C, Plant E are examples of PPC/PFR/VRT interactions
  - Lack of high-resolution frequency data likely impeded analysis
- Issue observed a few times in 2023 and 2024
- Multiple occurrences in 2025 – one of the most common root causes of potential Apparent Performance Failures

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Frequency Transients

Scenarios

1. **Faults and Short Circuits:**

Three-phase faults: An instantaneous short circuit across all three phases can create a sudden drop in voltage and induce high fault currents, leading to phase jumps.

Single-phase faults: They can cause an imbalance in the system by disrupting one of the phases, again potentially causing phase jumps.

2. Sudden Change in Load:

Connection/Disconnection of loads: Sudden connections of large electrical loads can cause a drop or increase in system voltage and frequency. The generators will adjust their power output, but during the adjustment, phase jumps can occur.

3. Switching Operations:

Switching on/off of capacitor banks: Switching of compensation devices, can cause transient voltage variations due to the abrupt change in reactive power in the system, potentially leading to phase jumps.

•**Switching on/off of large transformers or lines:** Engaging or disengaging large transmission elements, especially when the system is under heavy load, can cause voltage and power flow disturbances, which can disturb the phase angles across the system.

PPC and IBR Control Coordination

Considerations

Update Rate Differences

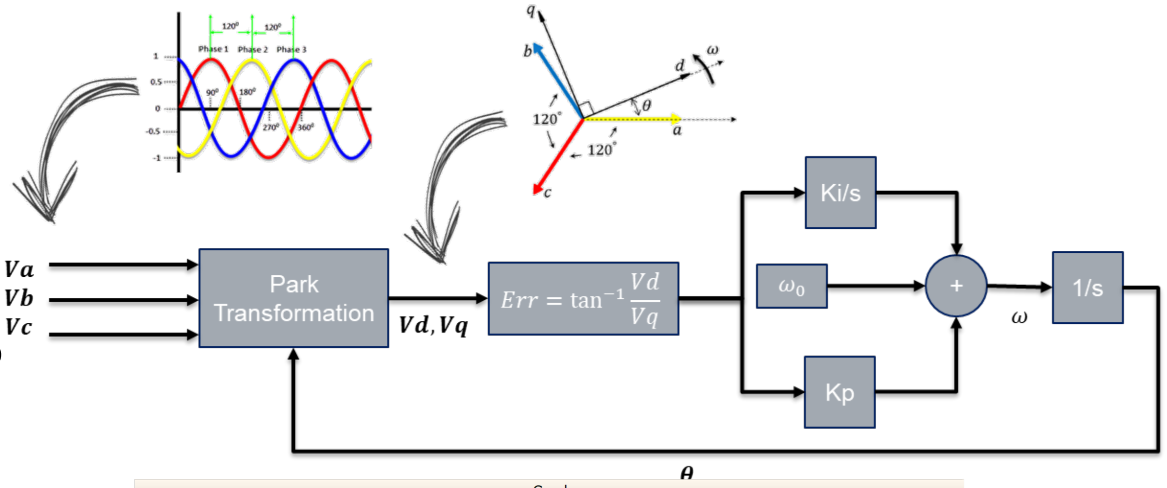
- IBR units: Very high refresh rates, often in the kHz range.
- PPC: Much slower refresh rates, typically in the mHz range.
- Result: IBRs react much faster to grid events than the PPC can update, so synchronization is essential.

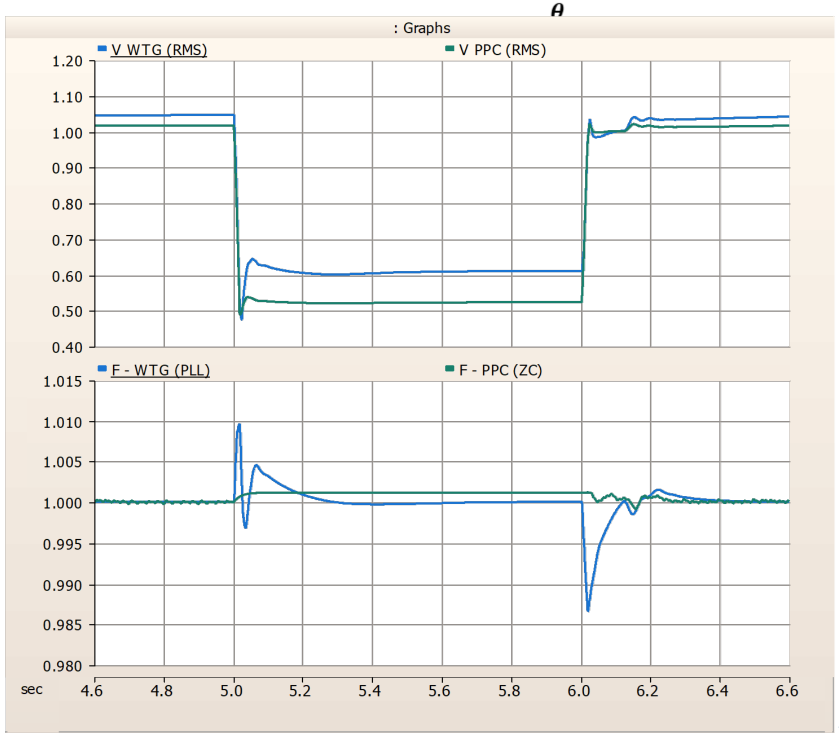
Frequency Calculation

- Due to slow refresh rates, some OEMs rely on third-party high-speed meters for frequency calculation instead of the PPC itself.
- This ensures PPC commands are based on accurate, real-time frequency data.

IBR Advanced Capabilities

- Accurately calculate frequency in real time.
- Apply advanced filtering techniques to avoid false triggers or malfunctions.
- Provide fast corrective action to complement slower PPC updates.





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PPC and IBR Control Coordination

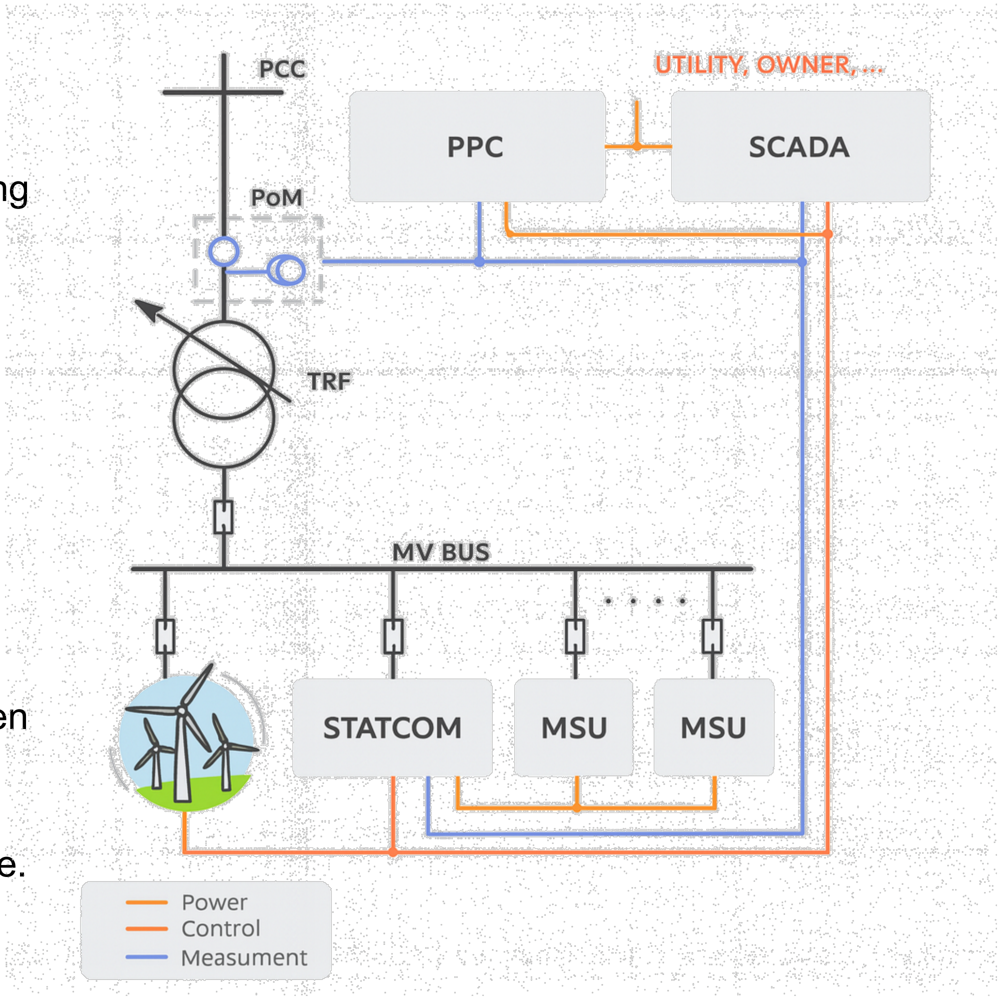
Considerations

PPC Role

- The Power Plant Controller (PPC) operates under both **normal** and **abnormal** grid **voltage** and **frequency** conditions.
- Wind Turbine Generators (WTGs) follow PPC commands in all conditions, but during abnormal events, the PPC issues additional corrective commands to stabilize the system.

Localized vs. Centralized Control

- Inverter-Based Resources (IBRs) may or may not include localized voltage and frequency control, depending on OEM design.
- If both local (IBR-level) and central (PPC-level) control are active, proper coordination is critical to avoid conflicts or instability.
- Important note:
- Voltage at the Point of Interconnection (PoI) can differ significantly from voltage seen at individual WTGs, depending on grid strength and Balance of Plant (BoP) design.
- This means PPC LVRT (Low Voltage Ride-Through) mode and WTG LVRT mode may not activate at the same time, potentially creating mismatches in fault response.



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PPC Support

Voltage Disturbances

Normal:

Standard operation of control loops. No faults detected.

Freeze:

Both Q (reactive) and P (active) loops are held constant while timers run. Timers allow WTGs to stabilize and complete LVRT sequence.

Qref options: 0 / UVRT feedforward Qref / Pre-fault Qref

Active Power: Maintains pre-fault setpoint. Option to apply curtailment → PPC setpoint = min(pre-fault P, curtailment level).

Post Fault:

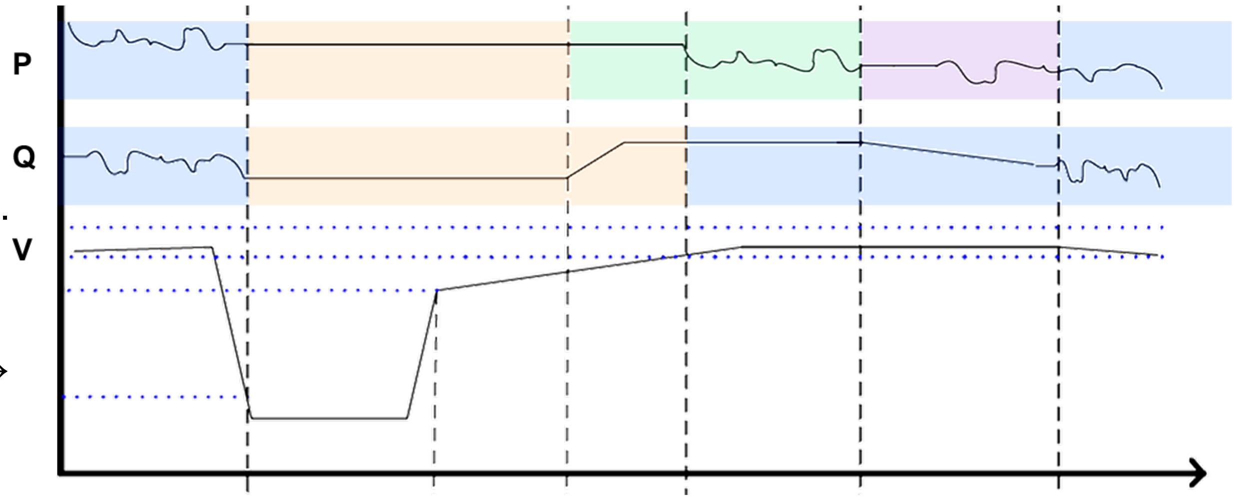
Activated when: Voltage > Max, or Timer expires and Voltage > Min.

Qref options: Feedforward Qref (same as Freeze) / Vslope control (uses FRT Voltage Slope + VRPM if enabled).

Active Power: Same behavior as in Freeze.

Regain:

Enters if UVRT state exits before TimePWTG completes loop: Returns to normal control. P loop: Same as in Freeze until timer ends.



Normal Operation

Post Fault

Freeze

Regain

Reminder:
LVRT: Current Control
Normal: Power Control

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Advance PPC Features

Frequency Control

Delays: Introduces a configurable delay before applying a new power reference once frequency crosses the deadband. A zero setting means immediate response, while a delay helps filter out short disturbances and reduces unnecessary oscillations.

Freeze: defines whether the active power ramp rate limiter continues or is held when frequency leaves the normal operating band. This determines if output should keep adjusting or remain fixed during frequency excursions.

Hysteresis: sets the upper and lower hysteresis band for frequency response. Once frequency exceeds the deadband plus this band, the controller recalculates the power adjustment. This prevents constant switching near the boundary and results in a smoother control action.

Latch: enables a latch feature. When active, the power reference is held at the value just before an over-frequency event, preventing additional increases in power until the system stabilizes.

Hold: allows the power reference to be frozen for a specified time during an over-frequency event. This avoids rapid rebounds when frequency begins to fall again, supporting a more stable recovery.

Counter: filters out noisy signals near the deadband by requiring frequency to remain outside the band for a defined period before the controller reacts. This minimizes oscillations while still ensuring a timely response to larger deviations.

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Conclusions

- RMS and frequency are post-processed estimates derived from sampled waveforms. They are not truly accurate when computed over very short windows (e.g., less one cycle).
- Control actions based on RMS or frequency must account for estimation delay, filtering, and numerical stability.
- Real frequency events in large interconnected grids do not usually produce extreme ROCOF values. When extreme ROCOF is observed, it often indicates artificial artifacts, measurement noise, or unrealistic simulations. However, in small or weak systems, large ROCOF values can occur physically, especially after severe contingencies.
- Primary Frequency Response (PFR) or Fast Frequency Response (FFR) should not trigger on raw transients or noise — they must be validated and filtered to avoid counterproductive reactions.
- Advanced coordination between PPC and IBR controls is required to ensure responses reflect real system phenomena rather than spurious signals.