Generator Power Swing Out-of-Step Protection and Analysis of Misoperation Events

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Overview

- Generator Power Swing or Out-of-Step Protection Basics
- Planning Studies
- Setting and Calculation Verifications from Event Data
- Recent OOS Misoperation Event Analysis

Generator Power Swing or Out-of-Step (OOS) Protection Basics

Generator OOS Protection

- Detects loss of synchronism between a connected generator and power system
- Unstable power swings may cause a generator pole slip event
  - High currents
  - Winding stresses
  - Mechanical forces leads to transient high torque on the generator shaft
- OOS protection should detect an unstable power swing before damage occurs.

Generator OOS Protection

- Other generator protection elements will not detect OOS conditions
  - Typically is a reduced voltage and higher frequency event, so V/Hz will not operate
  - Frequency elements are not fast or sensitive enough to detect the condition
  - Does not plot in the same impedance location, so backup distance impedance elements are unlikely to operate before the elements time out
- Fast detection of the OOS condition is required to prevent system instability and damage to generator

Generator OOS Protection

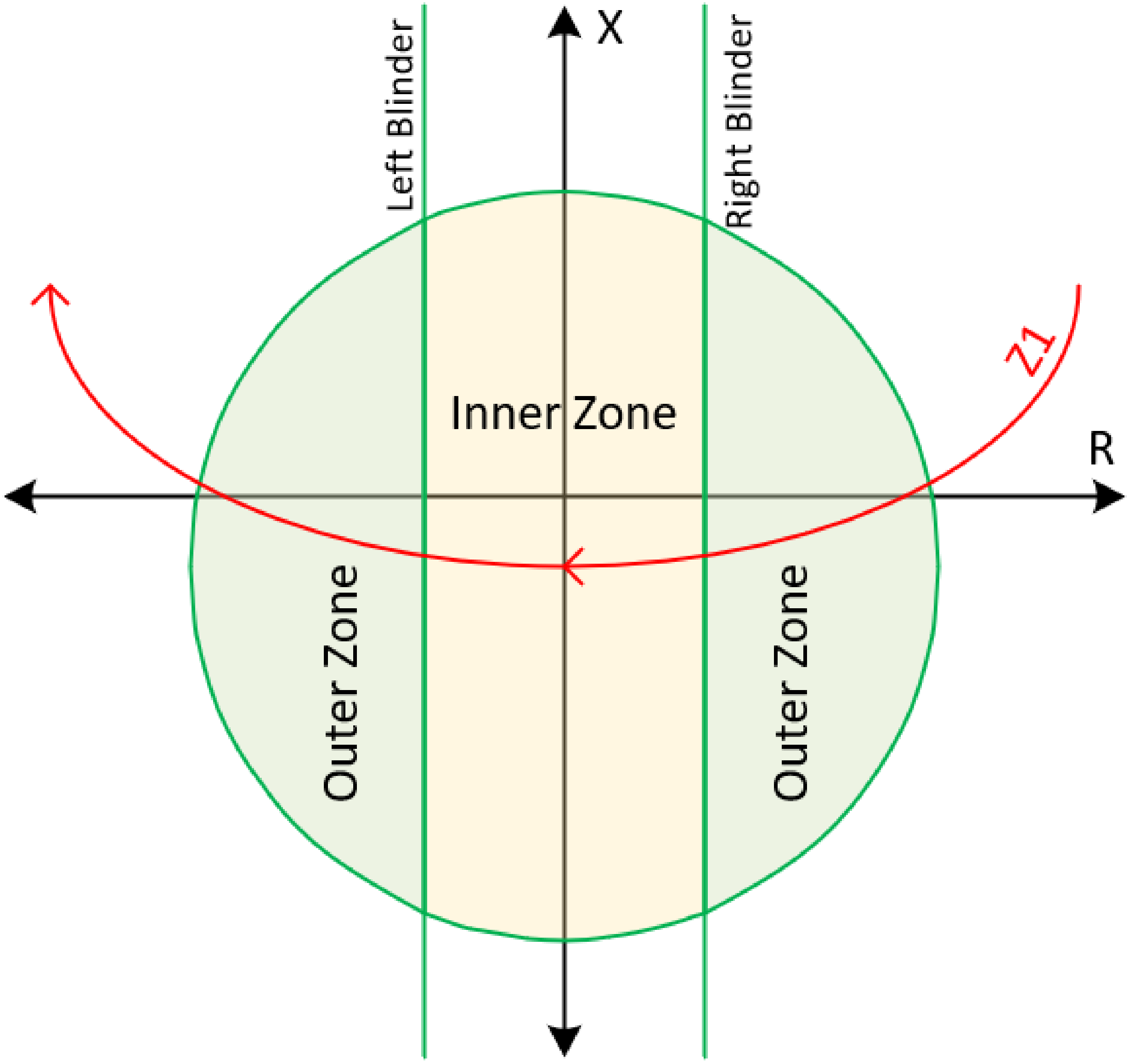
- OOS trip may be delayed to ensure separation between generator and system is reasonable
- At worst case 180° difference, the large voltage difference stresses the breaker tripped for the OOS condition
- Slow-clearing system faults and generator loss-of-excitation events can cause OOS conditions.

Generator OOS Protection

- Various OOS (ANSI 78) characteristics are employed
  - Mho circle impedance zones
  - Quad impedance zones
  - Multi-stage blinders
- System fault impedance moves inside the protection zone almost instantaneously
- Power swing impedance travels into the protection zone slower
- Transient stability study is required to determine timing

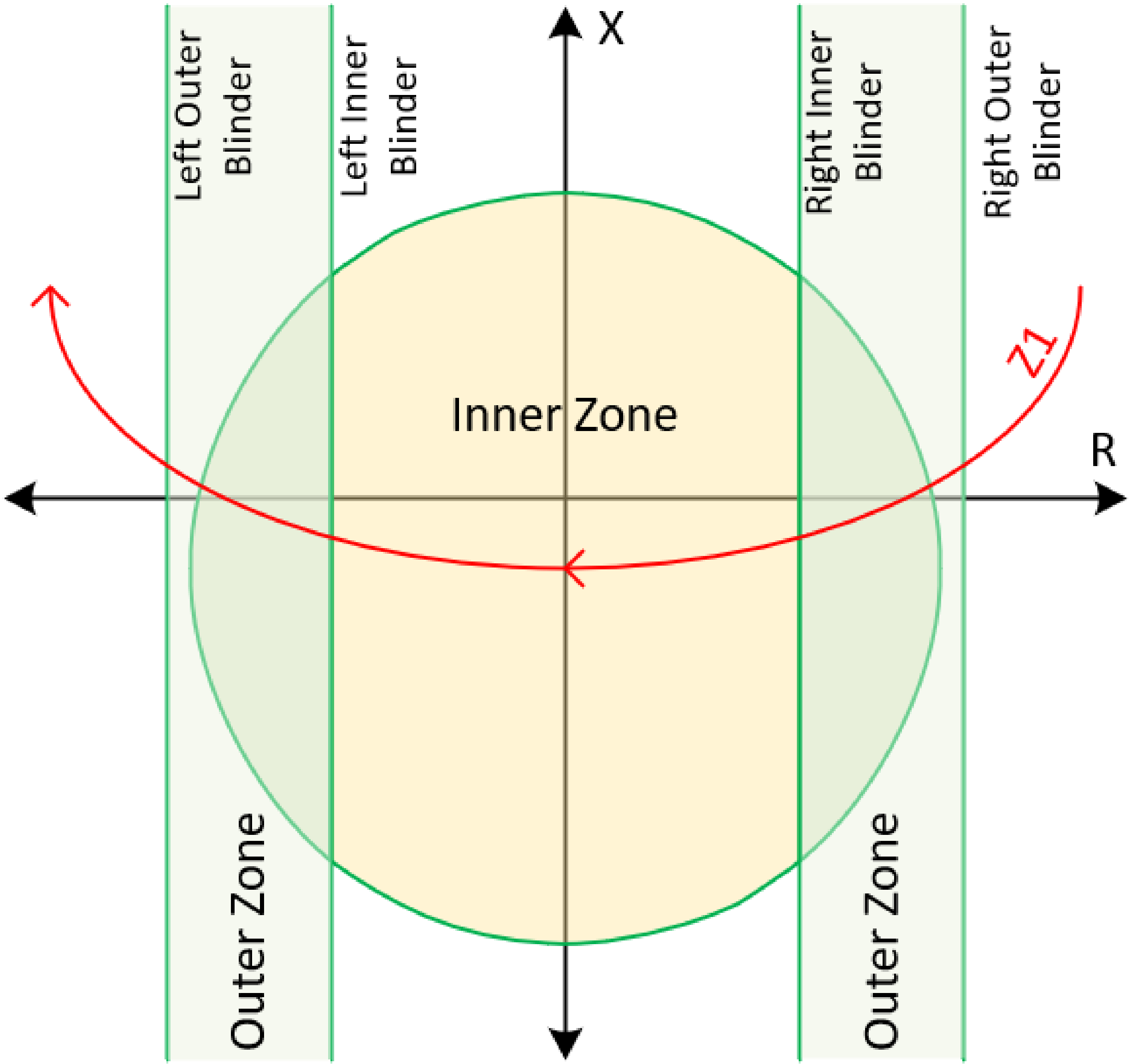
Single-Blinder Scheme

- Fault impedance must pass through outer zone and into the inner zone.
- Some characteristics have a small time for the impedance to plot in the outer zone while others just require it to pass through the zone.
- Fault impedance must persist in inner zone for short/settable time
- Trip on exit of mho circle on opposite side
- Limited system study is needed.



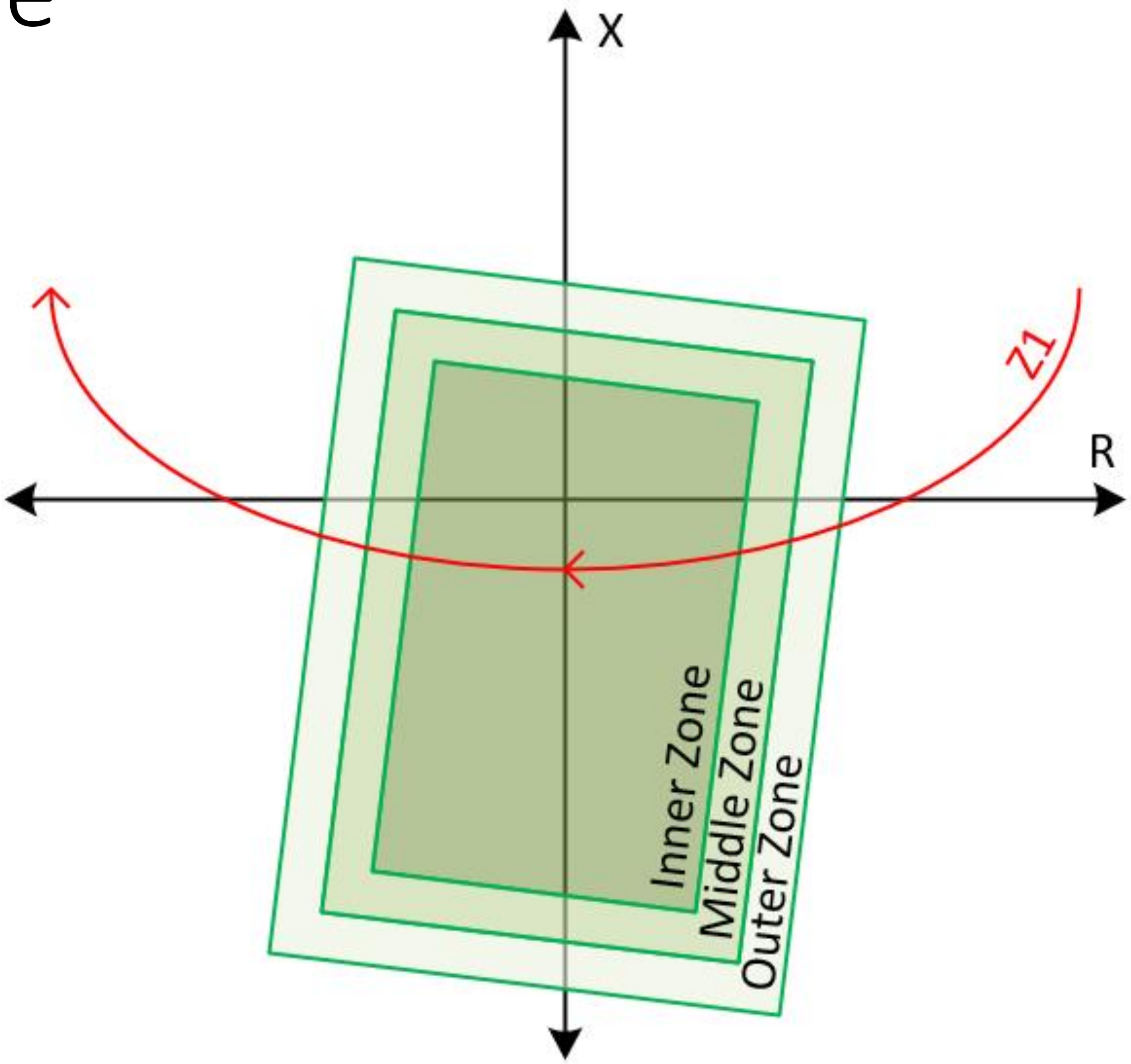
Double-Blinder Scheme

- Fault impedance must remain in outer zone for a settable time.
- Fault impedance must proceed into the inner zone for OOS Trip declaration
- Trip on exit of mho circle
- Detailed transient study required to determine time in outer zone



Impedance-Zone Scheme

- These schemes use lenses, circles or quadrilateral shapes to define zones
- These schemes require transient studies to determine the time the impedance plots between the outer/middle/inner zones for an unstable swing
- Can be a 2-zone or 3-zone characteristic
- Trip on determination of swing in inner zone or exit of outer zone



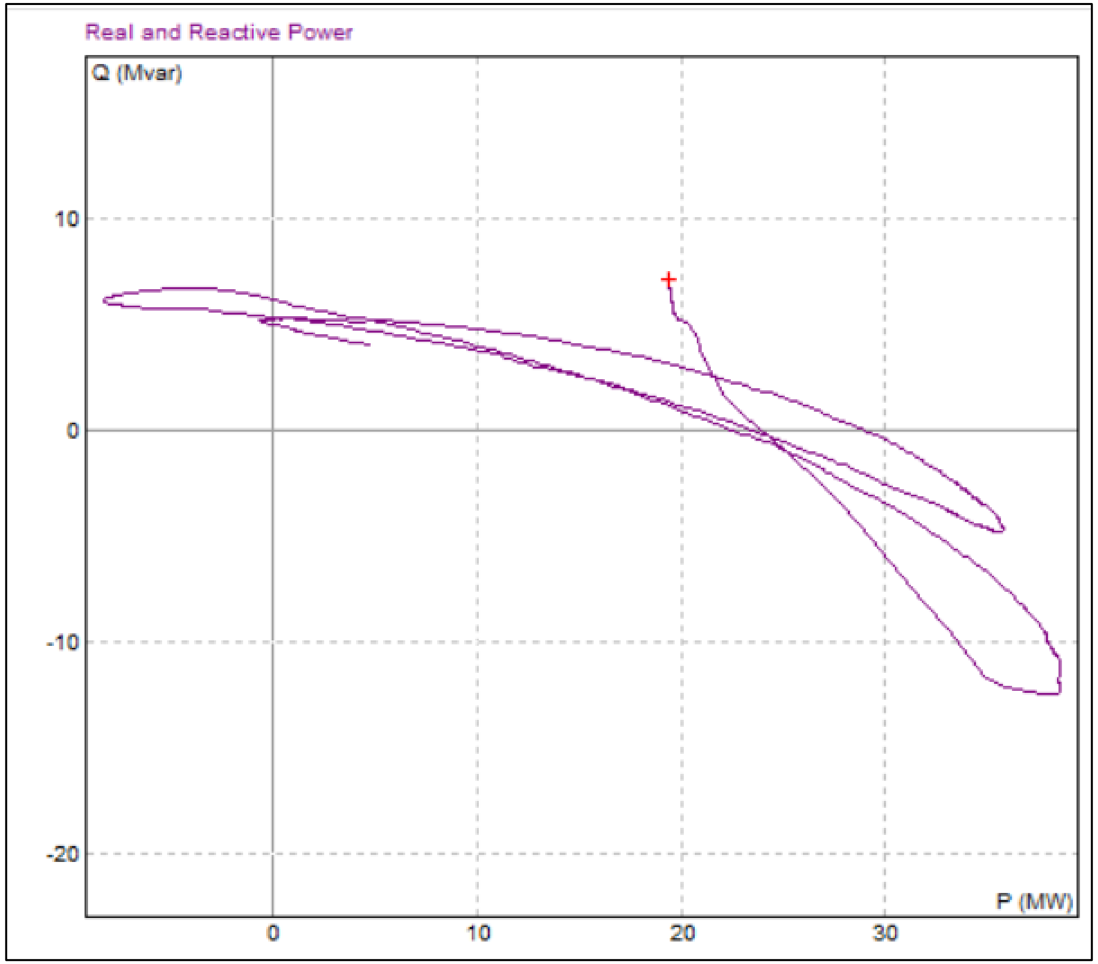
Planning Studies

Transient Stability Studies

- Stability studies determine how long a fault can persist and the system recover (stable) or require separation (unstable)
- An unstable system will result in generator and system angle increasing after the fault is cleared
- Three-phase faults lose connection with system; generators may speed up with loss of load
- If generator speeds up too much or system angle separation is too great, the generator may continue around to sync rather than slowing down – slipping a pole

Transient Stability Studies

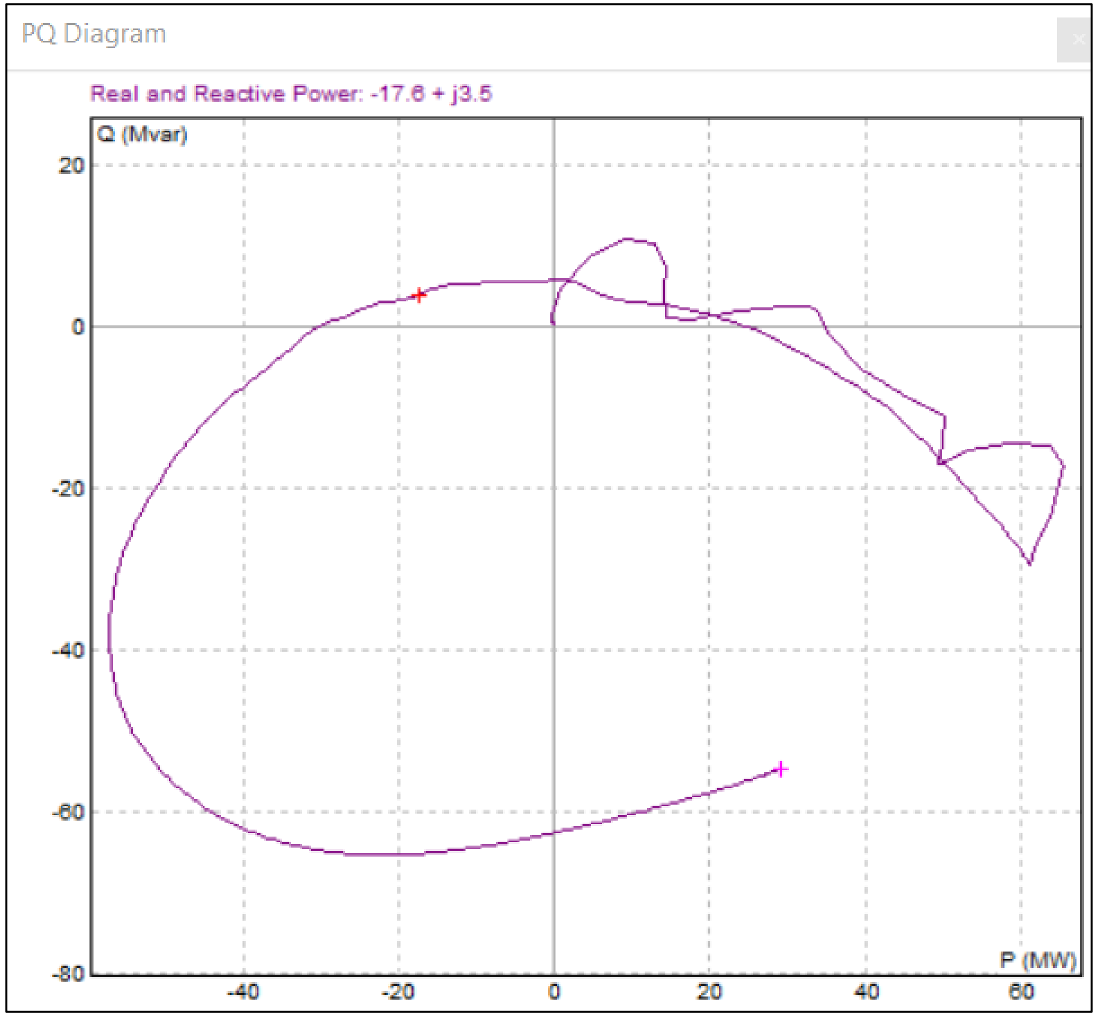
- Generator excitation and control system responses must be modelled accurately
- Example – studies showed this event should have caused an out-of-step condition and tripped
- Excitation system was tested to validate model, but did not match results
- Age of excitation system prevented valid model from test results



Real (MW) vs Reactive (MVAR) Power Diagram

Transient Stability Studies

- Exampe – Slow clearing fault on downstream utility 1mi away
- OOS condition on 3 units
- Two units has OOS protection and tripped while the 3rd did not have OOS protection
- Lack of information for downstream utility prevented model from providing accurate results

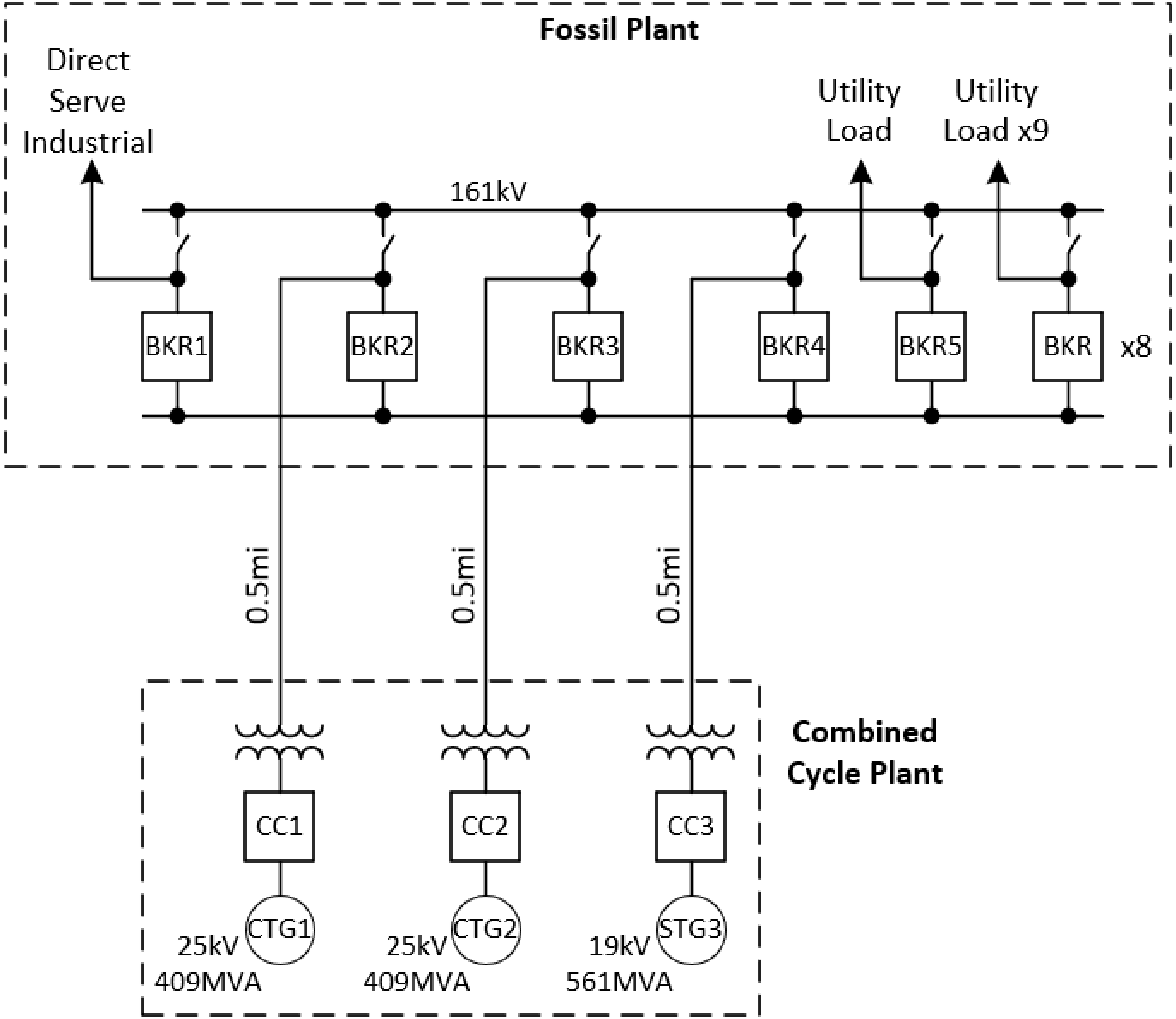


Real (MW) vs Reactive (MVAR) Power Diagram

Misoperation Event

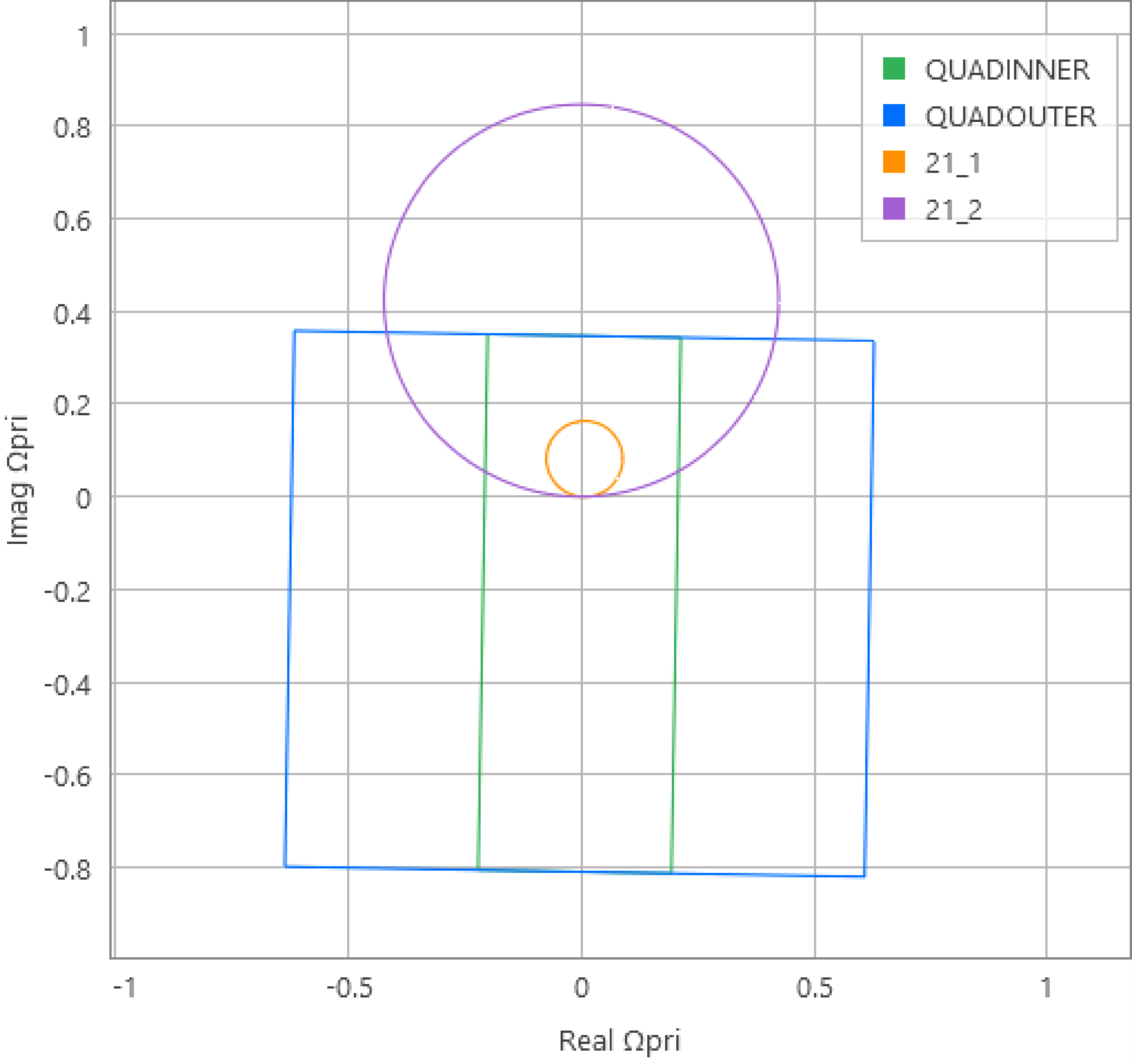
Single Line Overview

- CTG2 was offline
- CTG1 configured for a dual quadrilateral zone power swing element
- Utility experienced a slow-clearing evolving fault on a transformer



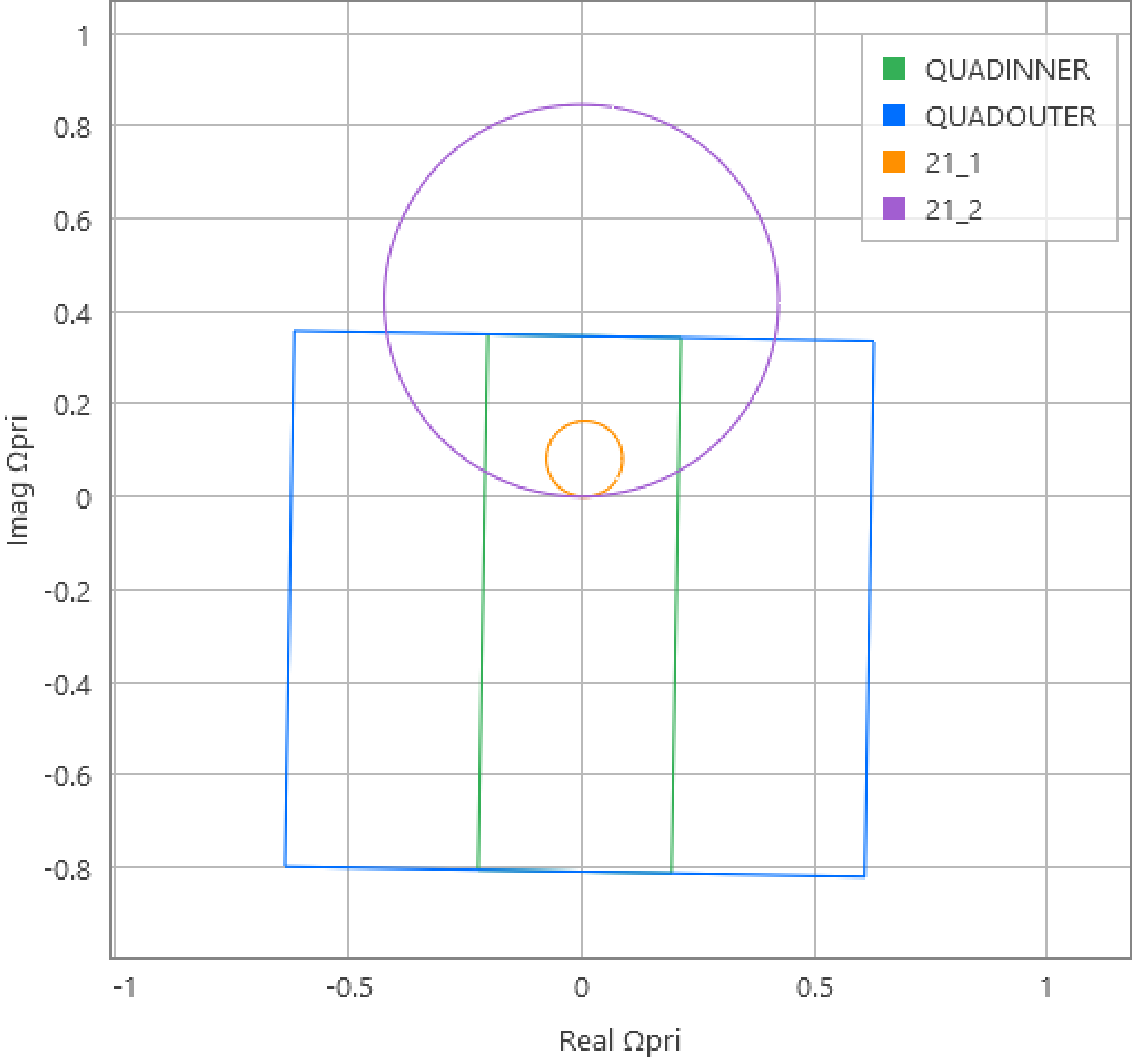
CTG1 OOS Element

- Dual zone quad power swing element
- Backup distance element shown as well
- Inner zone determines when generator and system are 120/240° apart
- Outer zone detects stable swings and assures angle is <60° for trip



CTG1 OOS Element

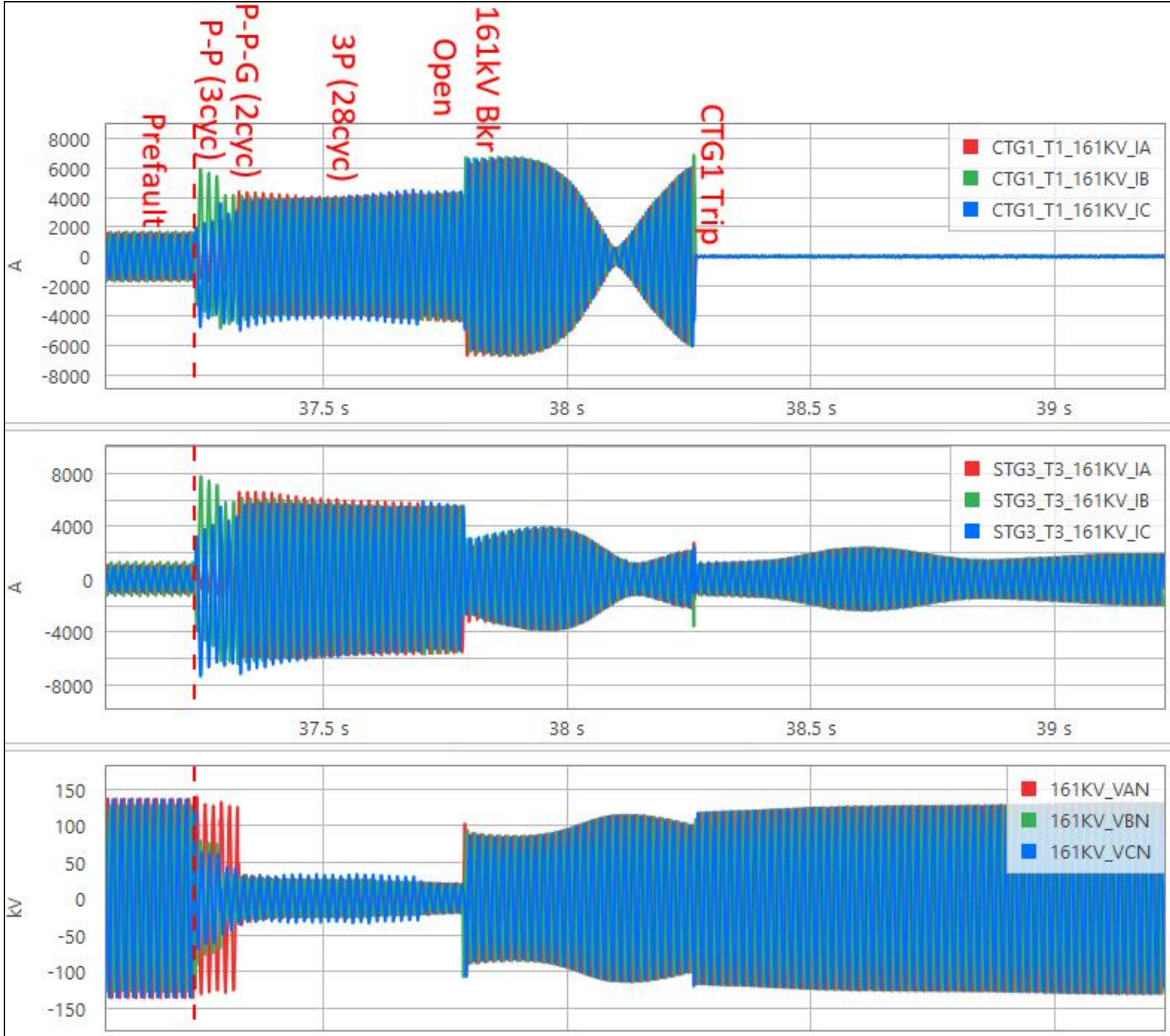
- Transient stability study determined critical clearing time is 16 cycles for GSU high-side fault
- At 17 cycles, 0.132s to shift 60°, 0.288s to shift 120°
- 100ms time threshold for power swing between outer and inner zones



System Event

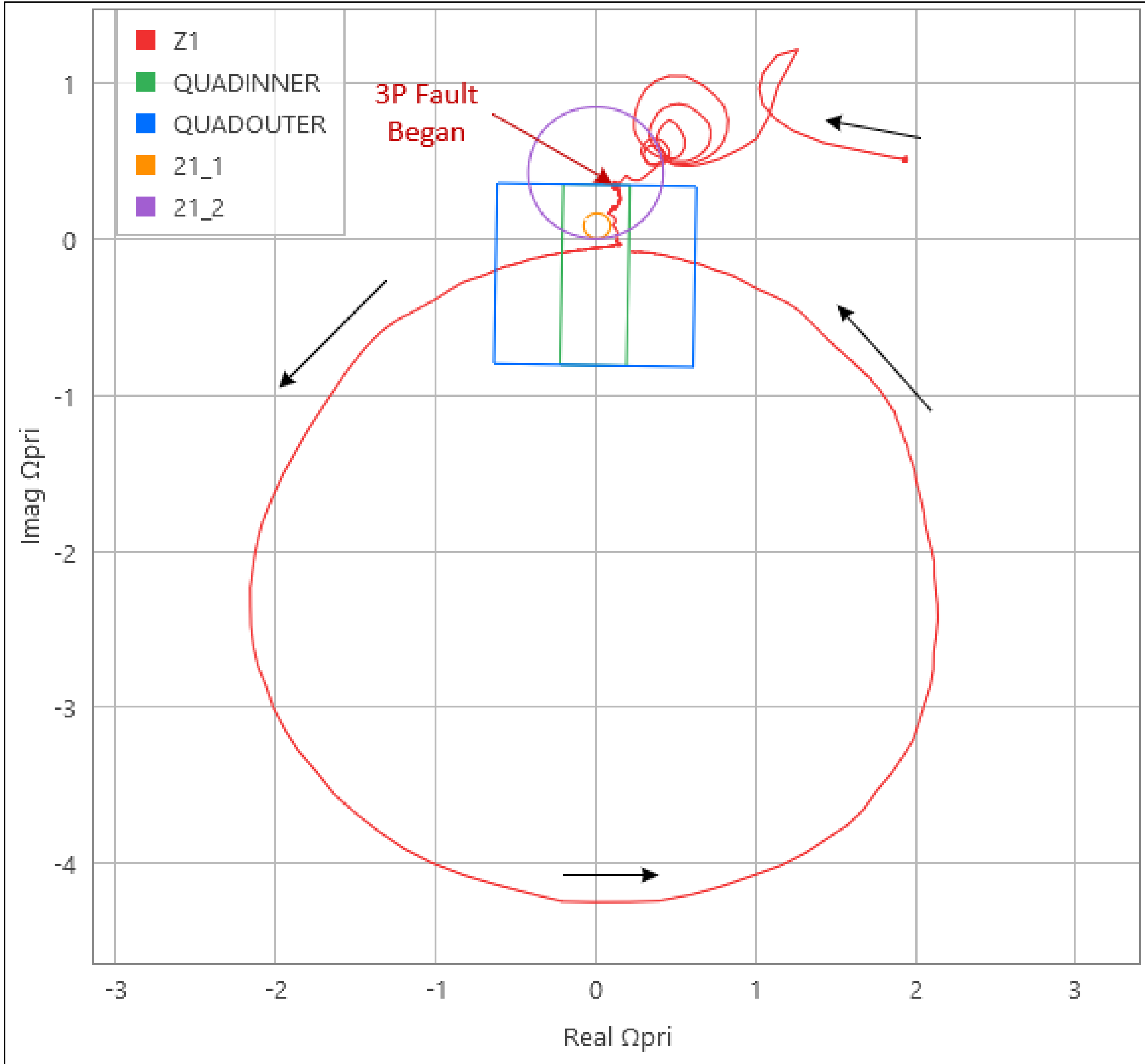
- CTG1 current
- STG3 current
- 161kV bus voltage

- Fault evolved from PP to PPG to 3P
- 3P fault persisted 28 cycles



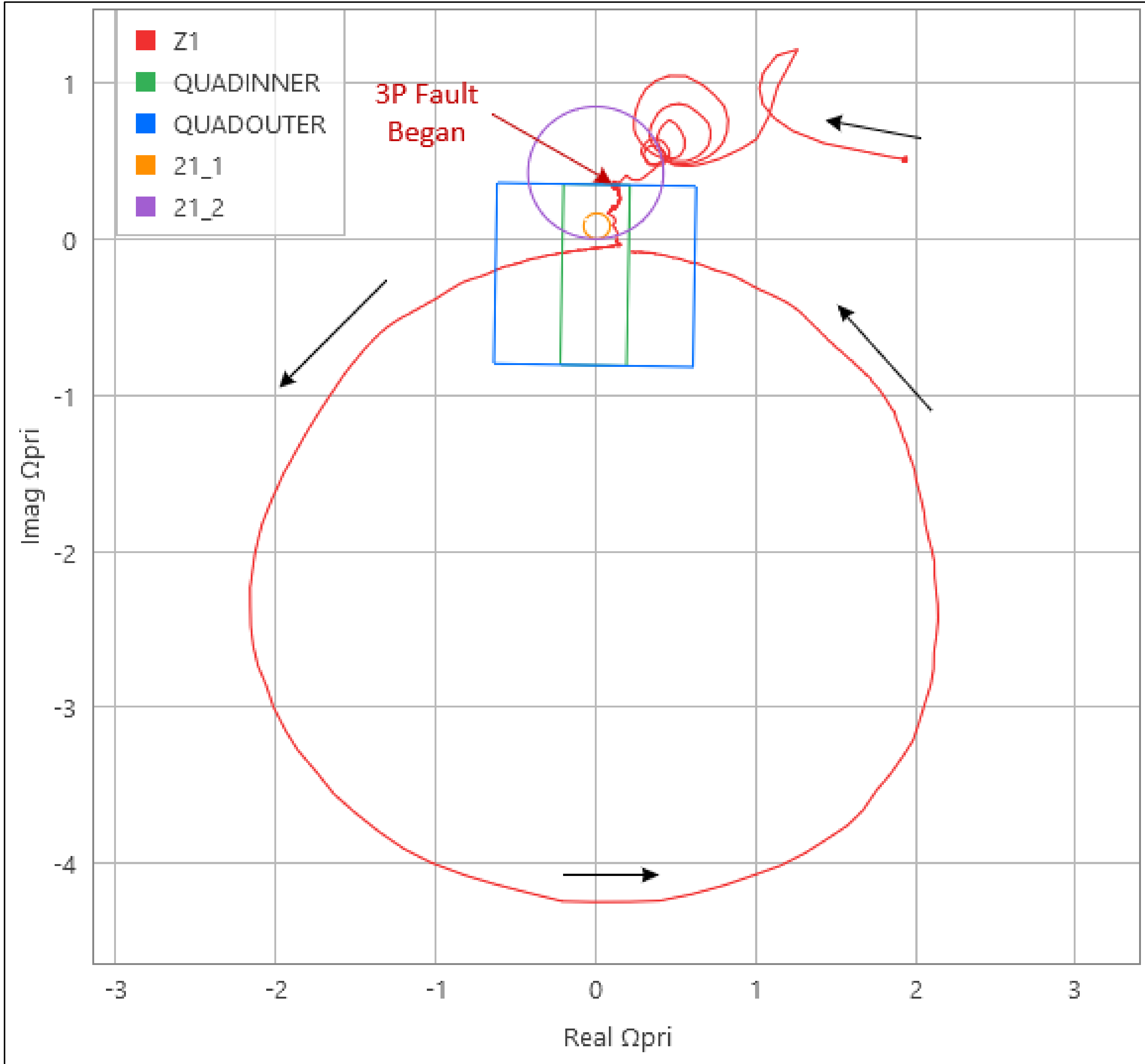
System Event

- Upper quad reach set to 1.5x GSU Impedance
- Backup 21-2 Time delay is 75 cycles
- CTG1 shifted 95° between initial 3P fault and start of pole-slip
- No differentiation between inner/outer OOS zones at top, so not considered a swing



System Event

- Fault impedance between right outer/inner blinders for 80ms (less than 100ms) after pole slip
- OOS element would not have caught this on further pole slips
- CTG1 tripped on rate-based acceleration overspeed from turbine control system

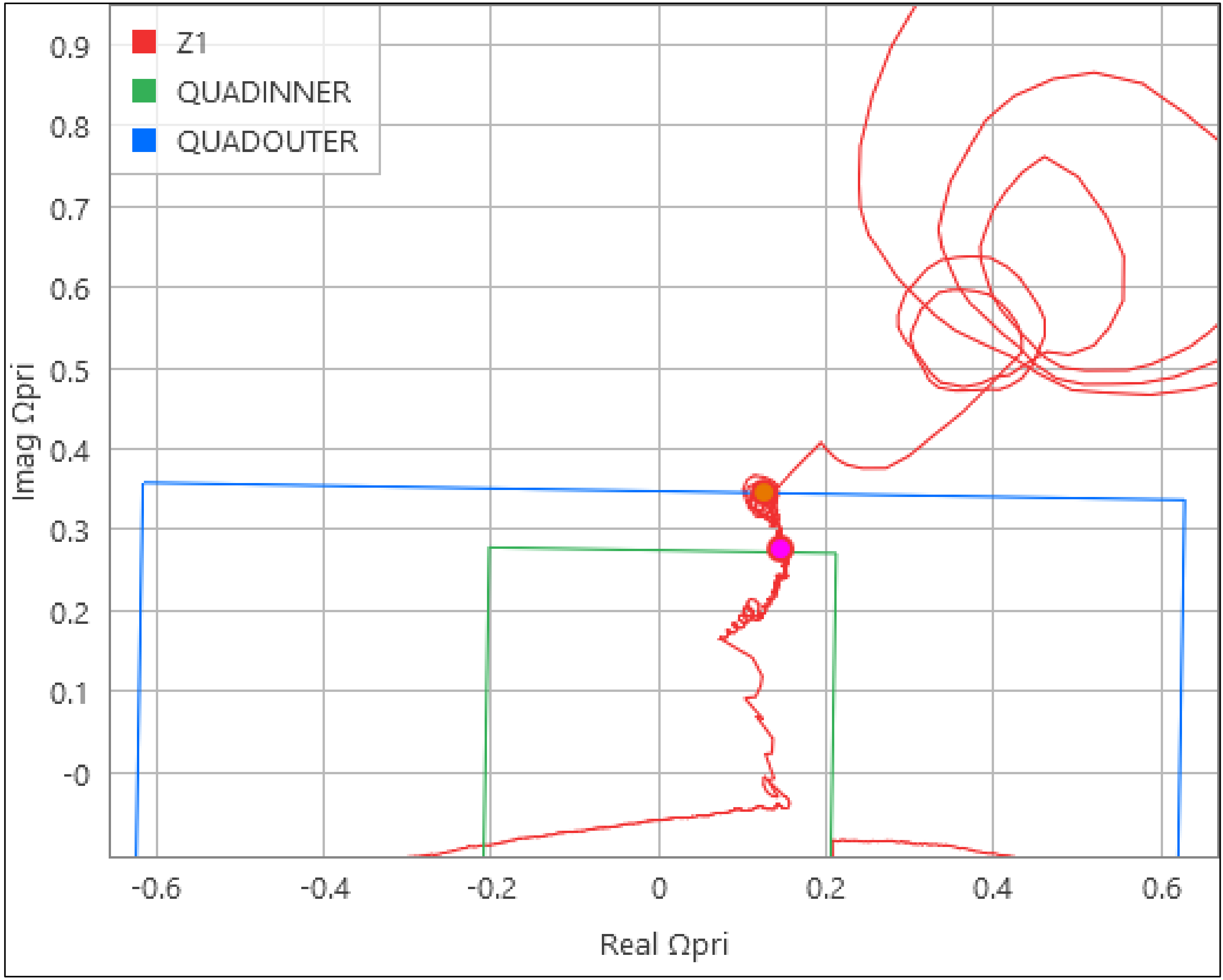


System Event

- Turbine control system also had a communications system failure and could not directly trip the unit. This signal was sent to the generator protective relays as a Breaker Failure Initiate (BFI)
- Gen relays issued a re-trip, which opened the gen breaker
- The comm system failure prevented the excitation system from tripping and remained energized for 4 minutes after the fault.
- After CTG1 tripped, STG3 remained online for 2 seconds, tripping on reverse power from low current/motoring condition

System Event

- Reducing inner zone upper reach from 0.35 to 0.27Ω would allow Z1 to plot between the zones for 0.16s and arm the OOS element
- 100ms power swing threshold will also be re-examined



Summary

- Fault occurred on downstream utility equipment, which may not be modelled in system accurately
- Single-blinder and two-zone OOS power swing elements can be easier to set, but should still consider worst case conditions and perform some transient study verifications
- Double-blinder and three-zone OOS elements require more effort to set correctly, but provide a secure element
- Verification of OOS element for any longer fault is recommended during analysis

Questions