Market mechanisms for frequency control

16th Wind integration workshop, Berlin

25-27 October 2017

Presented by: Tim George, DIgSILENT Pacific

Frequency control - fundamentals

- Frequency control ancillary services – FCAS – are required by system and market operators to control power system frequency

- Fundamentals are determined by the swing equation:

$$2H\frac{d^2\delta}{dt^2} = P_{mech} - P_{elec} \qquad (1)$$

  - Any disturbance in P_{mech} or P_{elec} causes acceleration (change in frequency)
  - The time constant (2H) is determined by the aggregated inertia
    - Synchronous machines have inertia – rotating components have kinetic energy
    - Kinetic energy is released (absorbed) in proportion to the rate of change of frequency
    - This inertia will consequently slow the rate of change of frequency
    - Inertial time constant is typically >3 seconds

Effects of variable renewable energy (VRE)

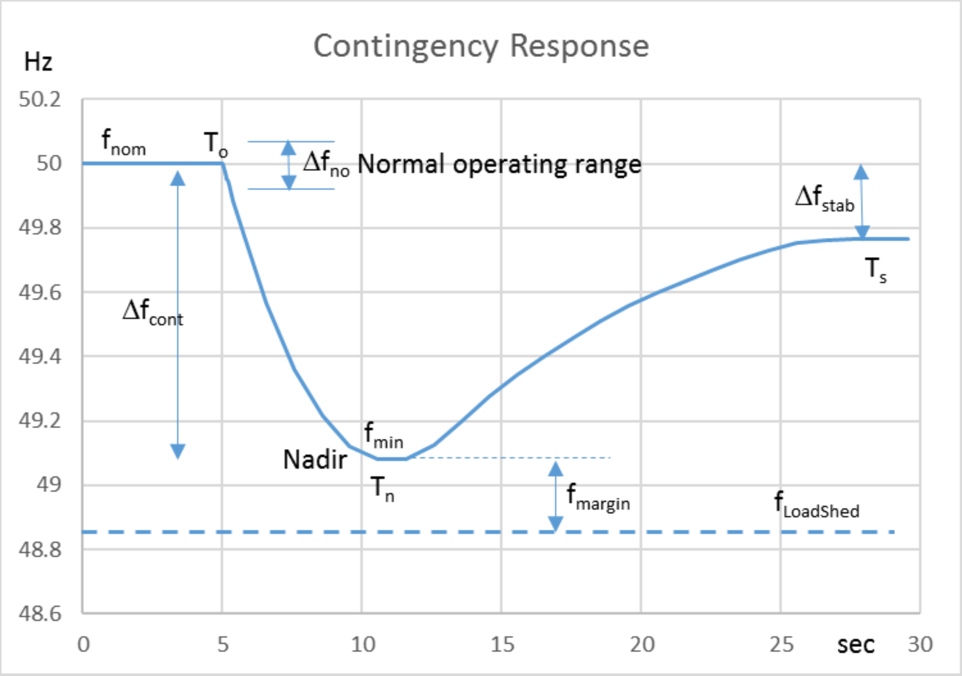
- VRE typically has no inertia (unless it is synthesised)
  - Inverters can be controlled to have no frequency sensitivity
  - Inertial effects can be synthesised if df/dt and f signals are incorporated in the control feedback

- As more inverters are added to a system:
  - Synchronous generators are displaced
  - Inertia reduces (and df/dt increases)
  - Fewer generators available to provide frequency control services

- Unless operated below optimum levels, VRE cannot provide ‘raise’ services to address low frequency conditions

Changing characteristics as VRE is added

Criterion	Low VRE	High VRE
H (inertia)	high	low
Tn (nadir)	5-8 s	1-3s
df/dt	<1Hz/s	4+ Hz/s
FCAS	fast	Very fast



Challenges for System and Market Operator

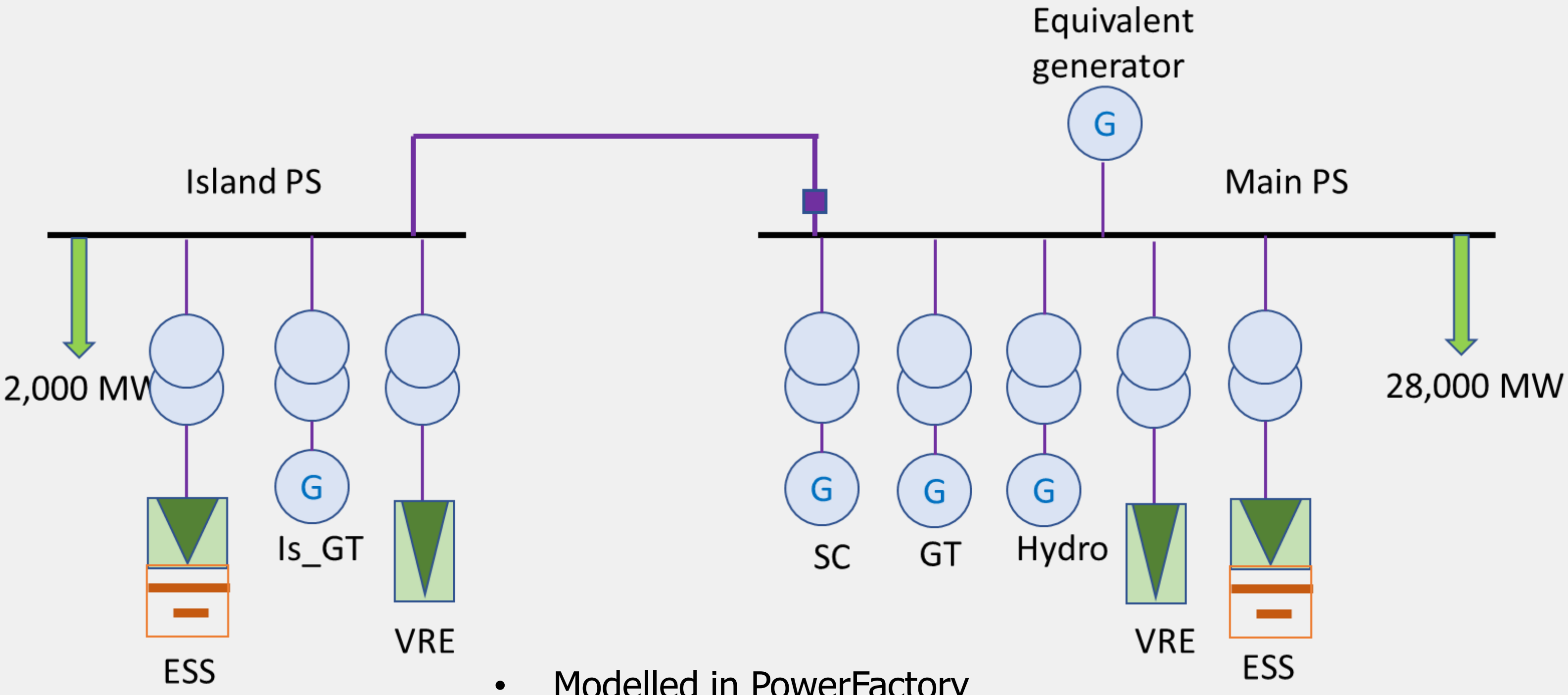
- Frequency must be controlled to the **standard**
- As inertia reduces, need faster FCAS
  - Pre-determined FCAS time bands may not be appropriate
- Parts of the power system may be subject to islanding
  - May have very high concentrations of VRE
  - May require very fast FCAS to meet standard
- How can investment signals be provided to encourage fast FCAS?

Options for FCAS in low inertia systems

1. Grid Code
   - Easiest option – mandate response from someone
     - Generators, including VRE, have to [be capable of] supplying FCAS
     - Load serving entities must fund or provide FCAS (batteries, contracts)

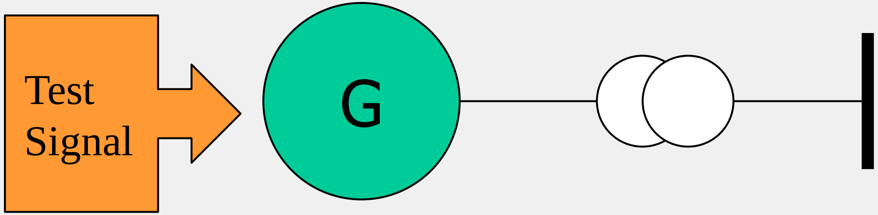
2. Market approach
   - Define the standard – this is the required output
   - System and Market Operator dispatches FCAS providers based on:
     - Capability [response time vs MW]
     - Inertia

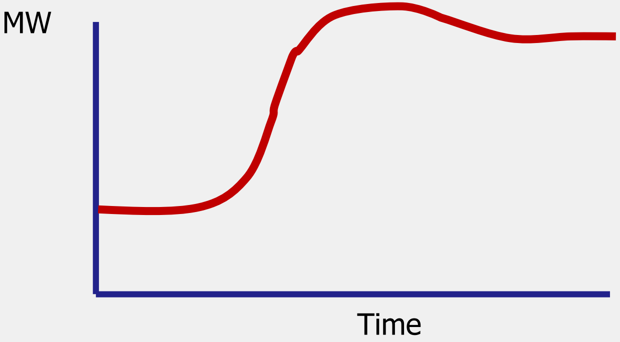
Test system: 30 GW with a potential 2 GW island



- Modelled in PowerFactory
- Standard models used
- Load frequency dependency modelled
- Equivalent Gen has inertia to match scenario

FCAS response

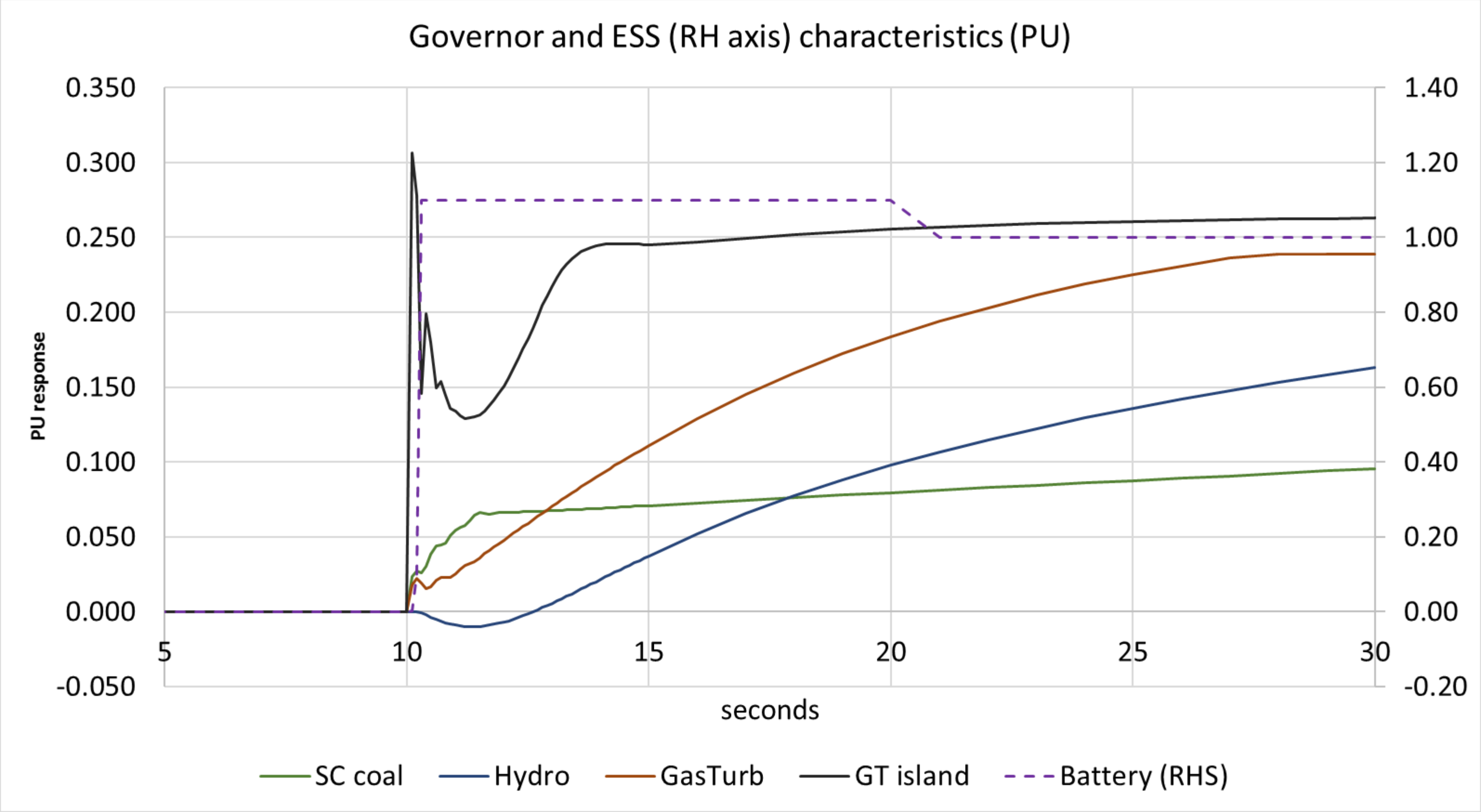




Time	MW
3.1	75.5
3.2	79.3
…	
600.0	124.2

Tabulate performance
In 0.1 s steps from 0 to 600 s

Test system: FCAS responses



Normal Approach to FCAS co-optimization

- Our approach to co-optimizing energy and contingency FCAS is slightly different to the usual approaches to co-optimization.
- The normal approach is to categorize the contingency FCAS into categories of fast, slow and delayed contingency services.
- For each category, the dispatch process determines the requirements directly as an input or indirectly via the co-optimization of requirements.
- The co-optimization of requirements and the co-optimization of energy and the provision of the services (enabling of the services – reserving the capability) are normally done as a single optimization.

New Approach to FCAS co-optimization

- The problem with the usual approach to co-optimizing energy and FCAS is that with greater penetration of VRE technologies and a corresponding drop in system inertia, the simple categories of contingency FCAS and the assumption that all service providers within a category are providing an equivalent service are no longer fit for purpose.

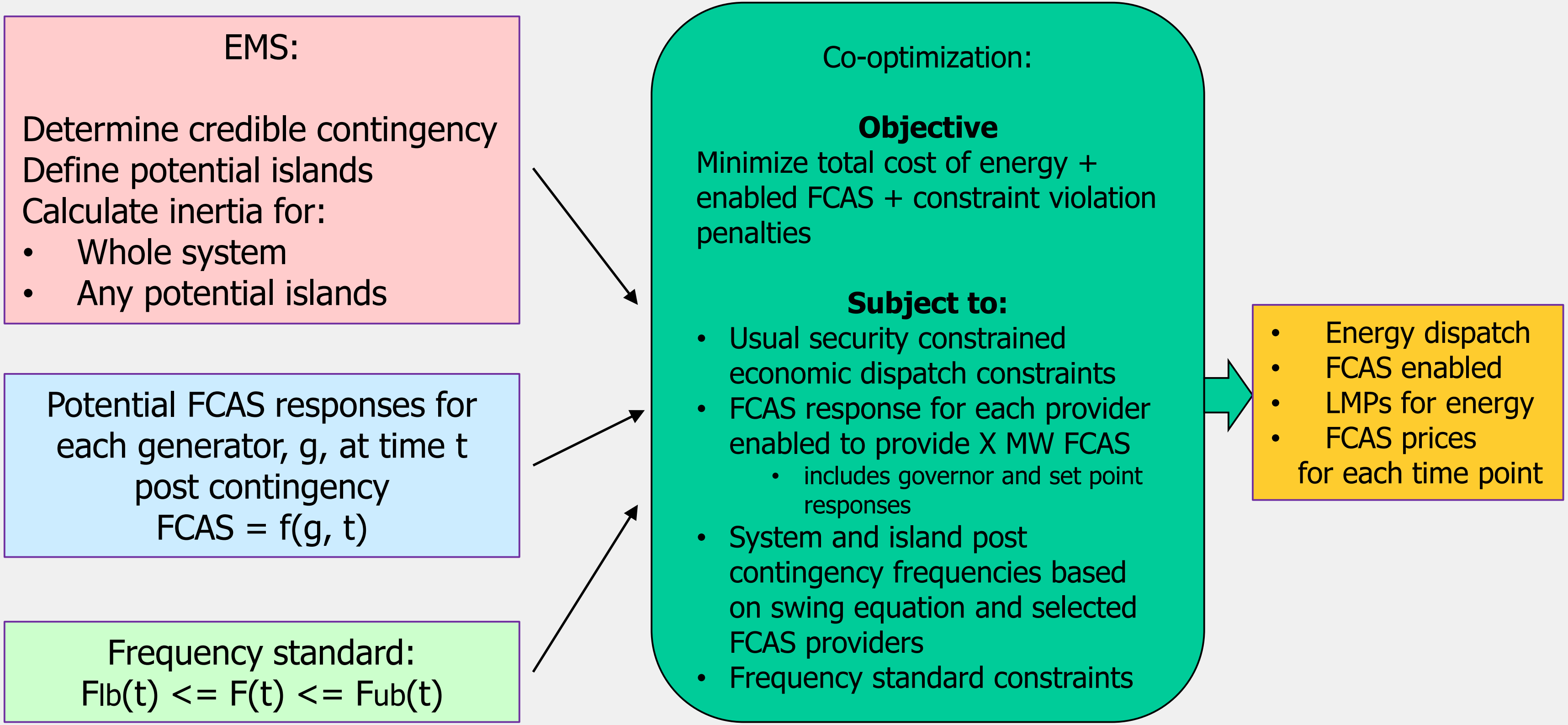
- Our proposed approach to co-optimizing energy and FCAS is to directly model system and island frequency following the most severe credible contingencies in the co-optimization using a discrete version of the swing equation.

Outline of New Approach to FCAS co-optimization

Our proposed approach:

- Determines inertia for the whole system and any potential islands in near real time by using the EMS system
- Uses measured (or simulated) response profiles for FCAS providers
- Directly models post contingency frequencies for the main system and any potential islands in the optimization for a number of points in time, say, 0.1s, 0.2s …1s, 2s … 100s, 110s …600s
- Directly uses the ***frequency standards*** as constraints in the optimization
- Selects the energy and FCAS providers based on minimizing the total energy and FCAS costs and ensuring that the all the frequency standards are satisfied.

FCAS co-optimization



EMS:

Determine credible contingency
Define potential islands
Calculate inertia for:

- Whole system
- Any potential islands

Potential FCAS responses for each generator, g, at time t post contingency
FCAS = f(g, t)

Frequency standard:
Flb(t) <= F(t) <= Fub(t)

Co-optimization:

Objective
Minimize total cost of energy + enabled FCAS + constraint violation penalties

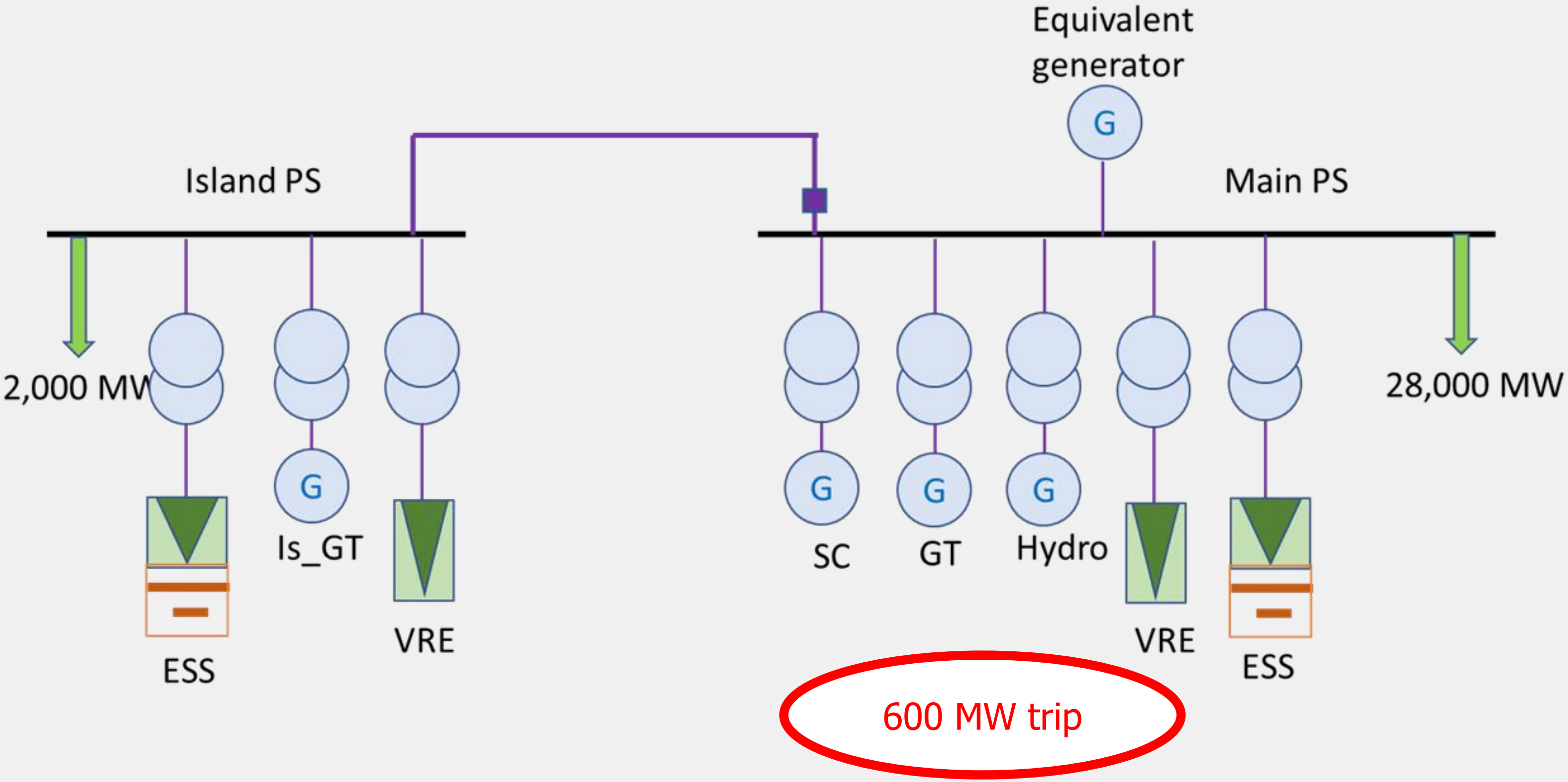
Subject to:

- Usual security constrained economic dispatch constraints
- FCAS response for each provider enabled to provide X MW FCAS
  - includes governor and set point responses
- System and island post contingency frequencies based on swing equation and selected FCAS providers
- Frequency standard constraints

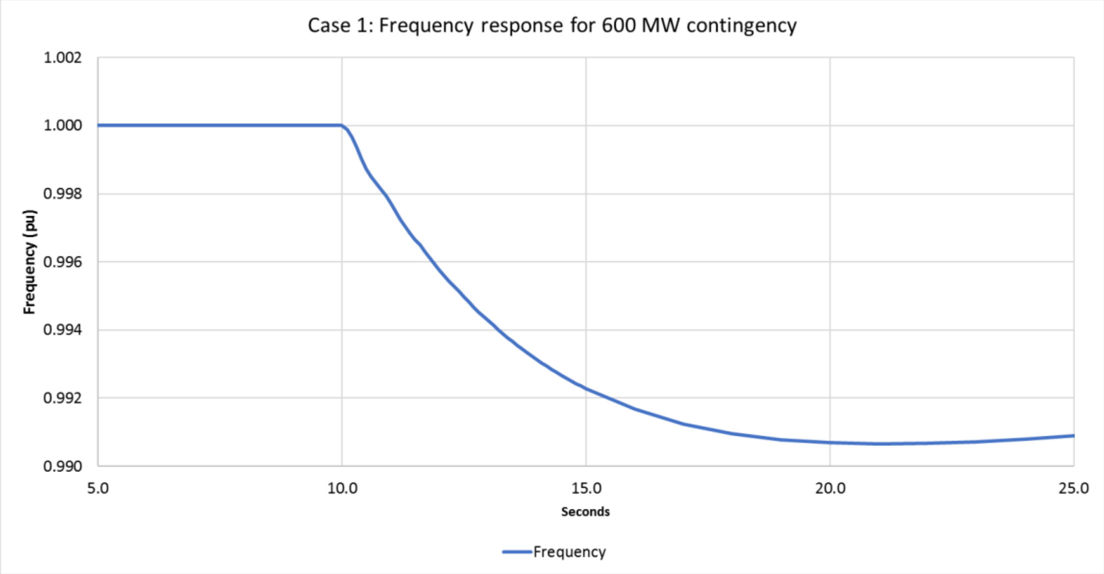
- Energy dispatch
- FCAS enabled
- LMPs for energy
- FCAS prices

for each time point

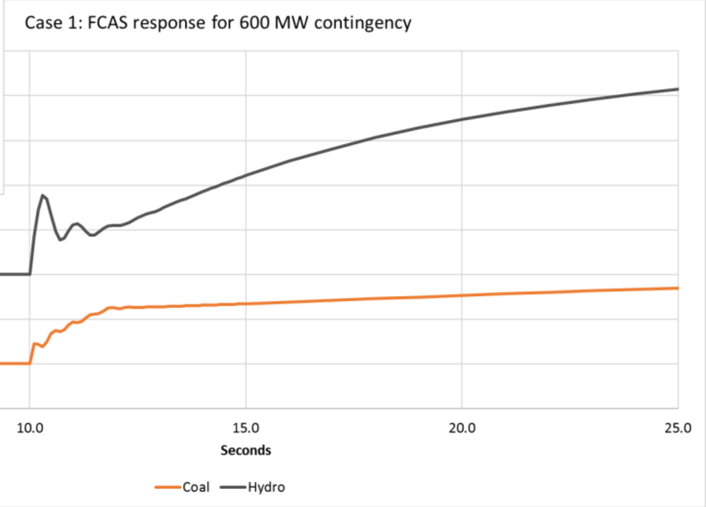
Results – Case 1: 600 MW trip on main system



Results – Case 1: 600 MW trip on main system

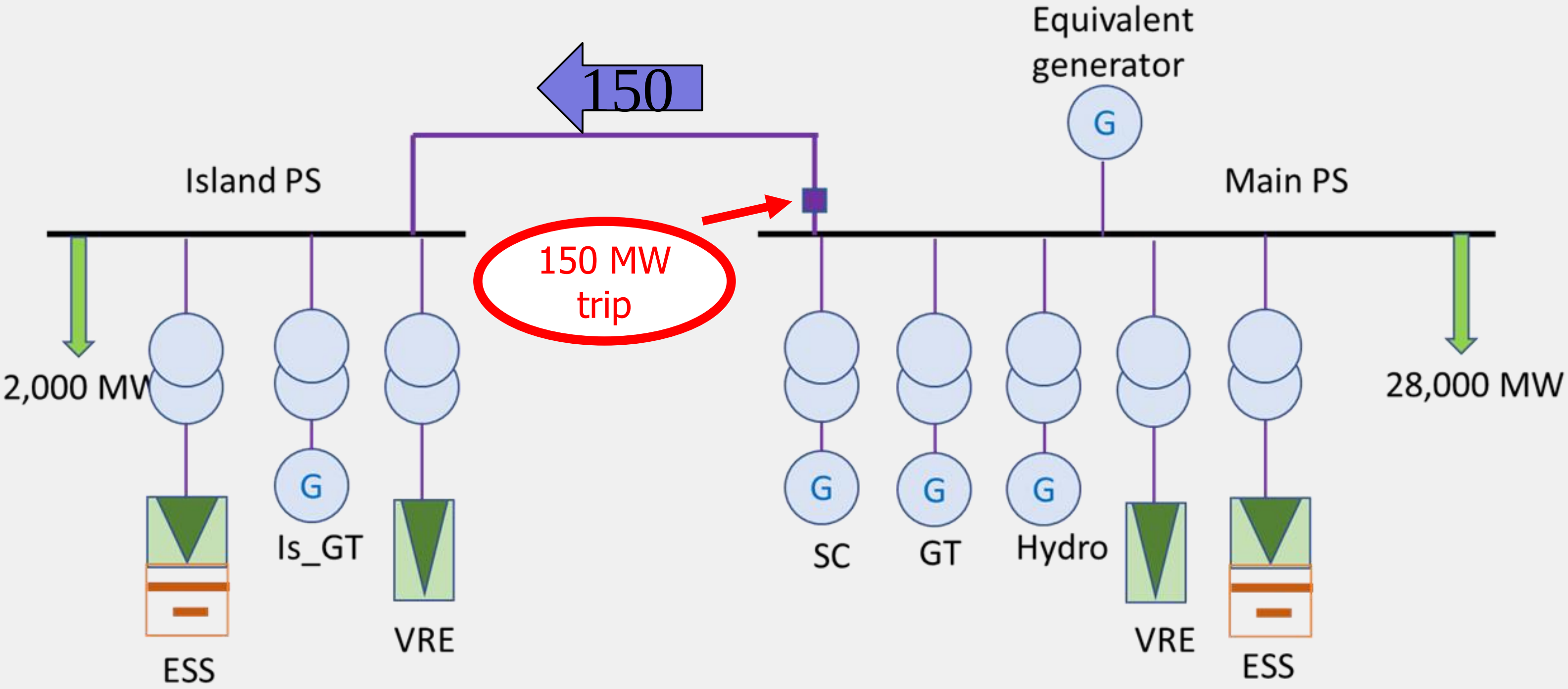


- Island not considered
- Slow responding Hydro is OK
- Medium cost gas not required
- High cost ESS not required

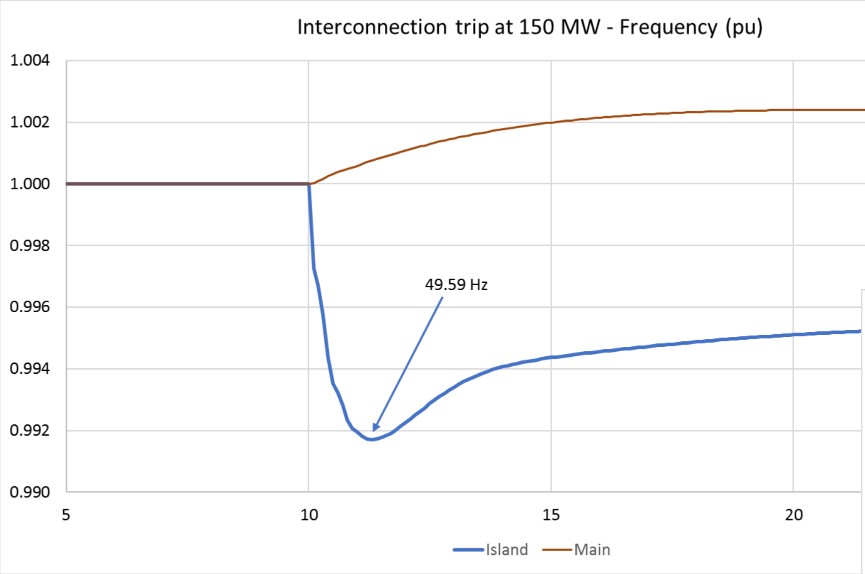


- System meets frequency standard
- Tn is 10s – high inertia
- Rapid response not required
- Inertial response is apparent

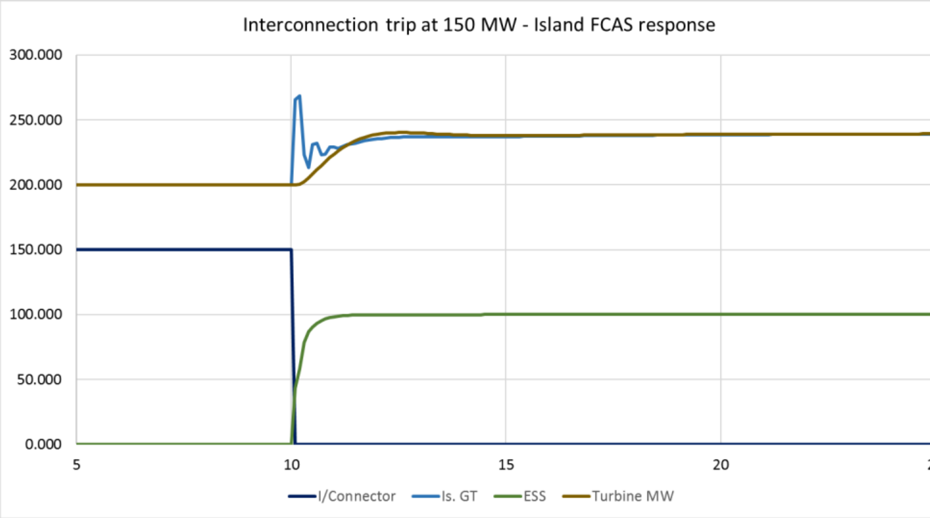
Results – Case 2: 150 MW trip on islanded system



Case 2: 150 MW interconnector trip



- Interconnector flow was co-optimized
- Reduces size of contingency
  - IC flow is 150 MW
- Lowers overall cost:
  - Energy+FCAS



- Island meets frequency standard
- Tn is only 1.4s – very low inertia
- Rapid response of ESS required
- Rapid inertial response of GT is significant

Conclusions

SUMMARY

Findings

- The co-optimization is technology neutral
  - If VRE concentration is high, faster FCAS will be required
  - Prices will signal the need for all classes of FCAS

- Inertia is considered but not explicitly priced
  - Could be added to the method
  - Provide pricing and investment signalling for syncons

- Simultaneous optimization across an island is demonstrated
  - Optimization of traded energy (interconnector flow) for FCAS
  - Would constrain flow if insufficient FCAS available