GFM Requirements

Time domain testing… why and how?

ESIG Spring Technical Workshop

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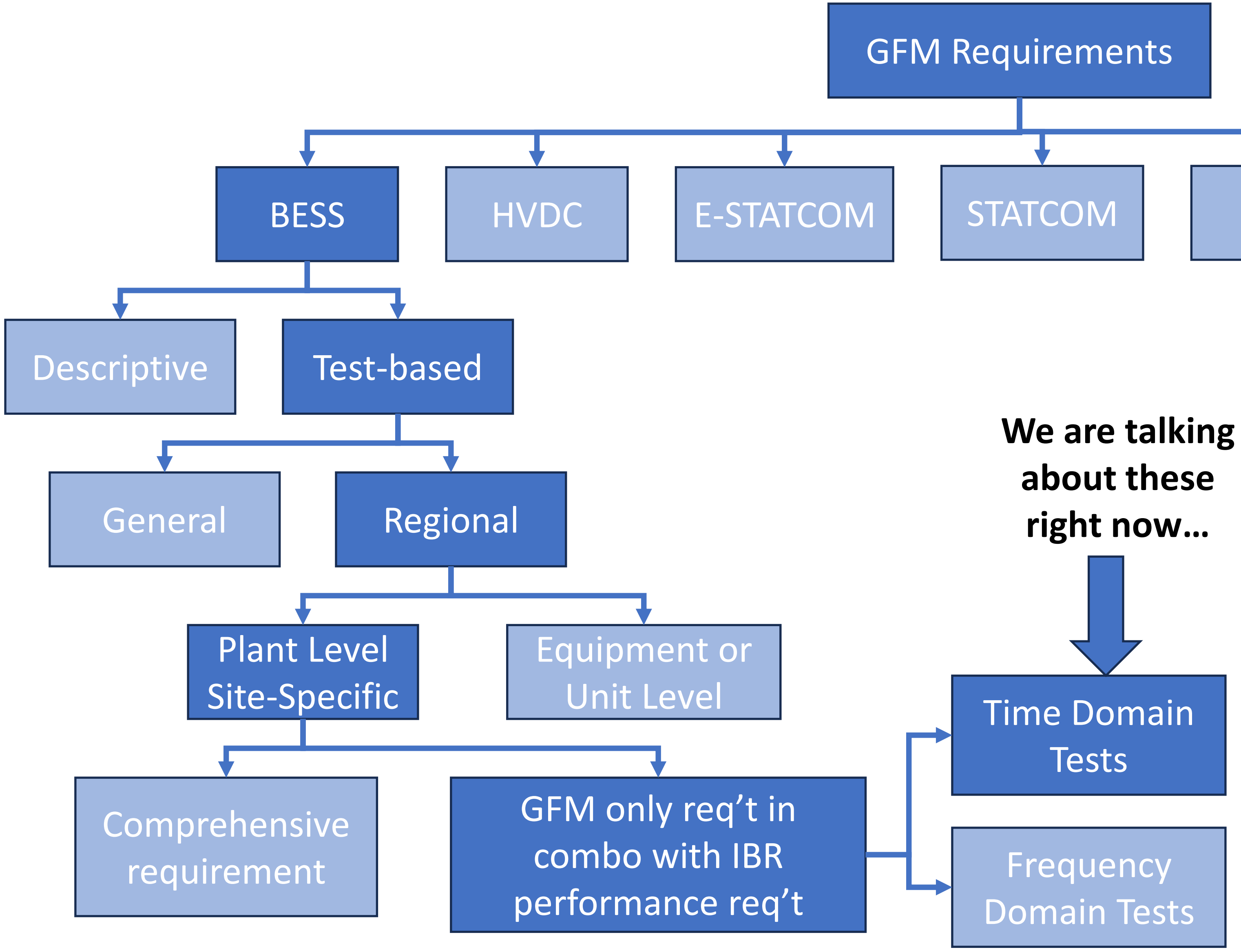
Andrew L. Isaacs



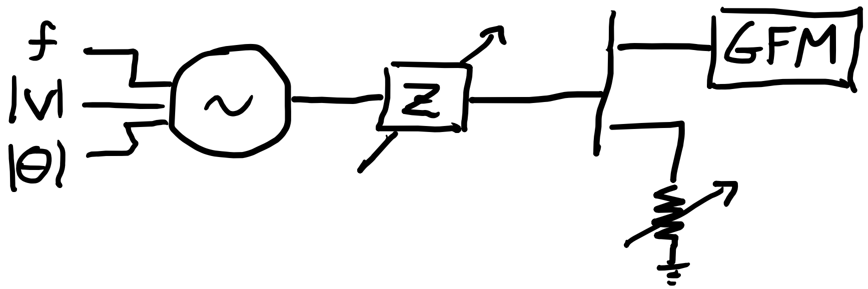
How you write a requirement depends on your end goal:

- Who is the requirement serving? OEM designers? TO/ISO?
- Many current requirements are written by and for TO/ISOs with specific performance needs

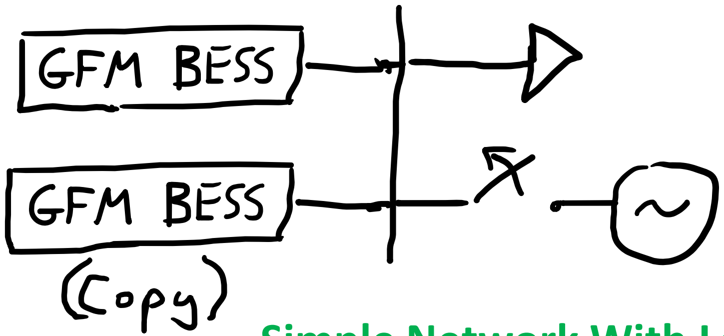
Why are we talking about time-domain, regional, plant level test requirements (for now)?

- These tests are popular because they may be directly written for an individual TO or ISO. They can be tailored for specific system performance needs.
- They can be quickly written and be explicitly clear on pass/fail criteria
- Non-regional types of requirements can valuable, but general standards tend to take longer to write, and may require softening to accommodate many types of regions, OEMs, or markets. They are often more vague in performance targets.
- Equipment level standards are directly actionable by OEMs, but the equipment must ultimately usually comply with plant level performance targets.

What are some common test elements?



Single Machine Variable Impedance (SMVI)



Simple Network With Load

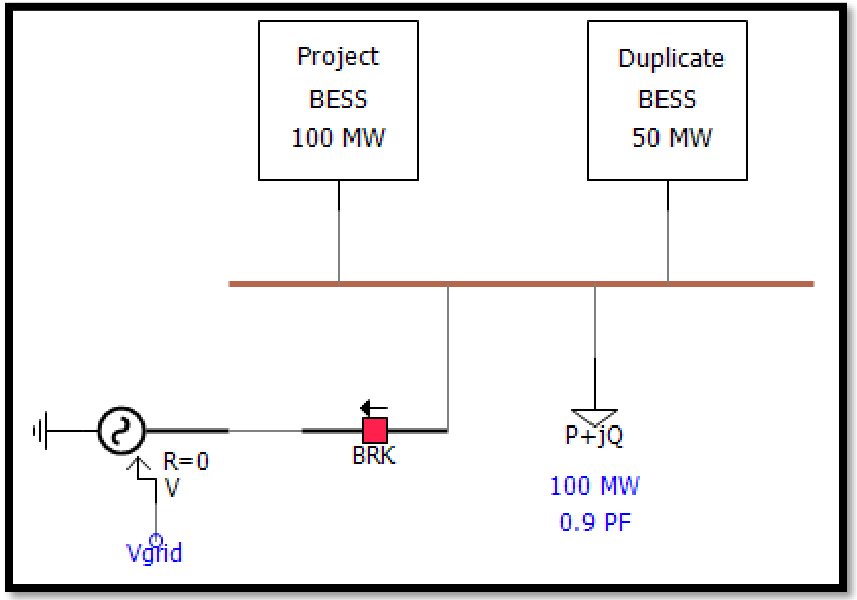
Test #	Test Name	Testing for:	Test Type	Testbench System	AEMO	ERCOT	Fingrid	HECO	MISO	NERC	UNIFI
1	Loss of synchronous machine - discharging	GFM core functions (BESS only)	Pass / Fail	2 - SNWL	■	■	■	■		■	■
2	Loss of synchronous machine - charging	GFM core functions (BESS only)	Pass / Fail	2 - SNWL	■	■		■	■	■	■
3	Loss of synchronous machine - limit test	GFM core functions, limits (BESS only)	Pass / Fail	2 - SNWL	■	■		■	■	■	■
4	Loss of synchronous machine - power balance	GFM core functions	Pass / Fail	2 - SNWL	■				■		
5	Large ROCOF up and down	Control stability	Pass / Fail	1 - SMVI	■	■	■	■	■		■
6	SCR step-down with fault	Control stability	Pass / Fail	1 - SMVI	■	■		■	■		■
7	Angle step change	GFM core functions	Pass / Fail	1 - SMVI	■	■	■	■	■		■
8	Special severe fault scenarios	Extreme disturbance stability	Pass / Fail	1 - SMVI				■			
9	Voltage step up and down	GFM core functions	Pass / Fail	1 - SMVI		■	■	■			■
10	Energy response test	Transient energy response	Informational	1 - SMVI		■					■
11	Frequency scan	Damping, impedance trend	Informational	4 - PVS	■		■				

Each test must be intentional and have a defined purpose and criteria for success!

- All tests are vulnerable to “gaming”. It is important to balance individual tests against each other. Test sets should be internally coordinated.
- For example… a ROCOF stability test may offset an incentive to use very high inertia for an energy response test.
- Individual tests should each have a clear objective. For example:
  - “GFM yes/no”
  - Stability under varying conditions
  - Stability against limits
  - Specific desirable performance characteristics
- Each test must have a clear setup as well as a success or “pass” criteria.
- **Tests should always be extensively “tested” against multiple types and varieties of equipment. Bad tests result in high cost and unexpected consequences.**

Example Test Protocol: Loss of Last Synchronous Machine (pass/fail)

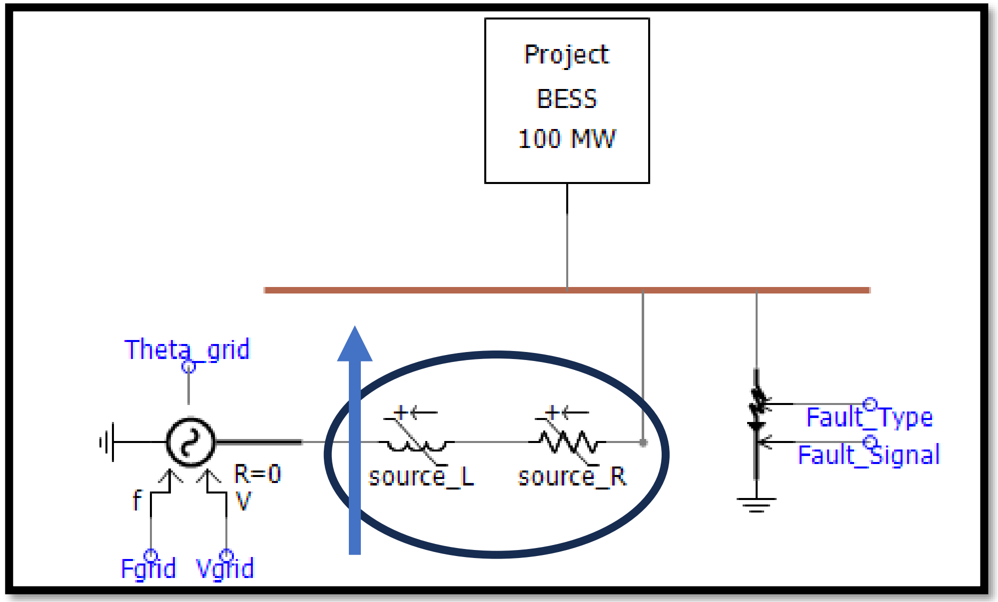
- Same tests proposed in NERC GFM specification white paper
- Tests for core GFM functions



Test 1 (Loss of synchronous machine - discharging) – Setup and Success Criteria (Testbench 2)	
Testbench setup	
The project plant is dispatched at 20% of its maximum discharge power limit.	
The duplicate plant is dispatched at 20% of its maximum discharge power limit	
The load (constant impedance) is set to 100% of the project 1 active power limit, with a power factor of 0.95	
The voltage source is supplying 100% of the reactive power to the load	
Voltage and frequency of the voltage source are fixed at 1 pu	
Test Sequence	
1. Run until the system is stable at the given power flow conditions, without oscillations.	
2. Trip the voltage source (no fault).	
Success Criteria	
Post-Trip	**Pass/Fail**
a. Immediately following the trip, plant output should be well controlled. System frequency and voltage should not oscillate excessively or deviate from steady state levels. For example, oscillations should be damped within 10 seconds, and quantities not exceed nominal ranges for more than a few cycles, and should reach settled values within 5 seconds.	
b. Voltage settles to a stable operating point.	
c. The final voltage is as expected based on the droop and deadband settings.	
d. Frequency settles to a stable operating point.	
e. The final frequency is as expected based on the droop and deadband settings.	
f. Any oscillation shall be settled.	
g. Any distortion observed in phase quantities should dissipate over time.	
h. Active power from each plant should move immediately to meet the load requirement and settle according to its frequency droop setting. Note that response time to 90% of initial change in instantaneous active power[1] should occur within 15ms	
i. Reactive power from each plant should move immediately and settle according to its voltage droop setting.	
j. RMS voltage does not deviate beyond [0.8, 1.1] pu for longer than 0.1s throughout the test . These voltage bounds and the time threshold are based on preliminary testing, may be adjusted as more experience with this requirement is gained.	

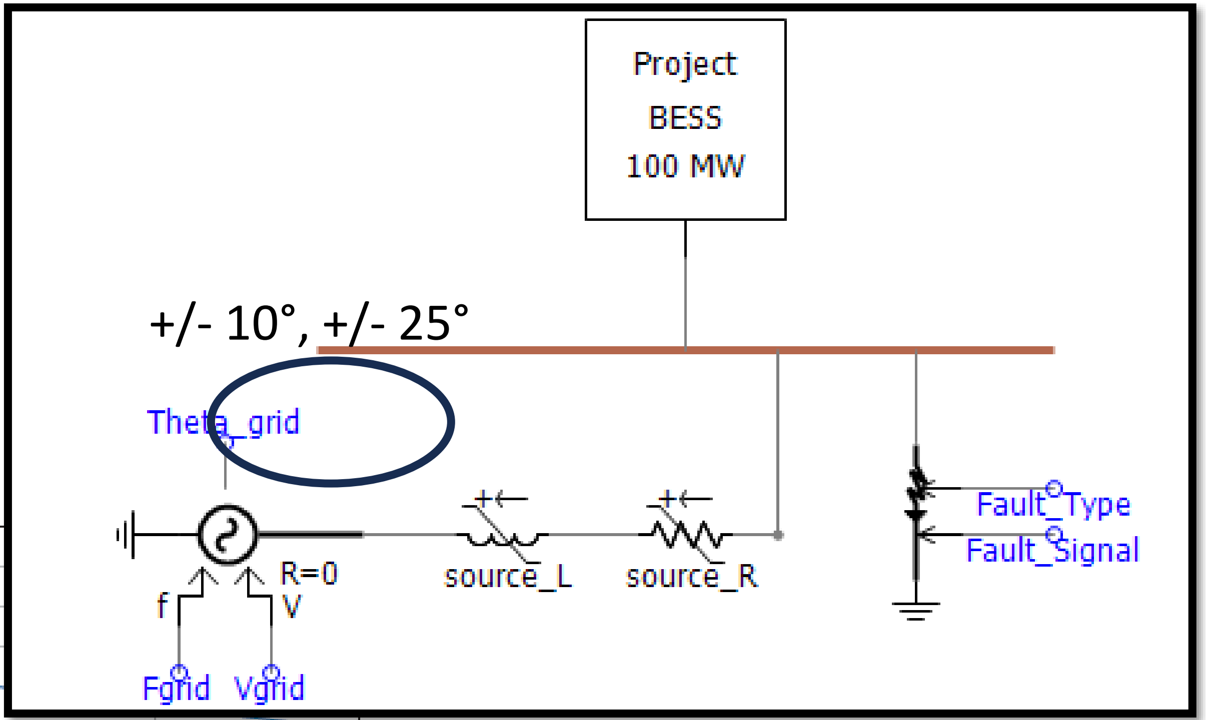
SCR Step Down with Fault (pass/fail)

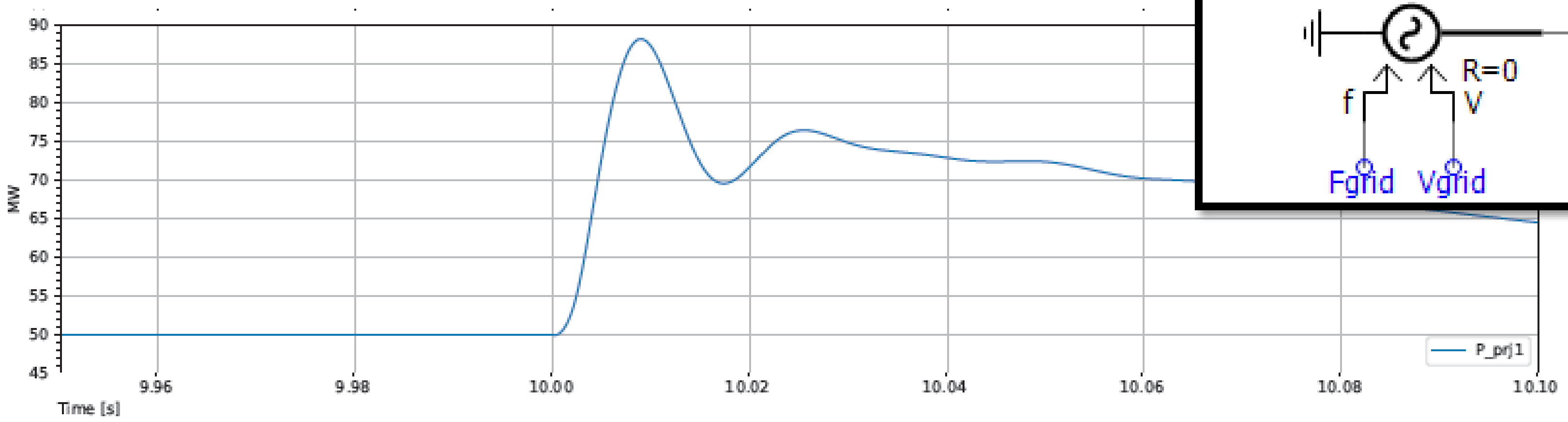
- Testing GFM core functions
- Incrementally increase grid impedance, applying brief faults at each step
- Plant required to perform well down to an SCR of 1.25



Angle Step Change (pass/fail)

- Testing GFM core functions
- Step changes in system angle
- GFM power expected to respond within 15 mS and be sustained for at least 50 mS for 10 degree step





Angle Step Change setup and criteria define:

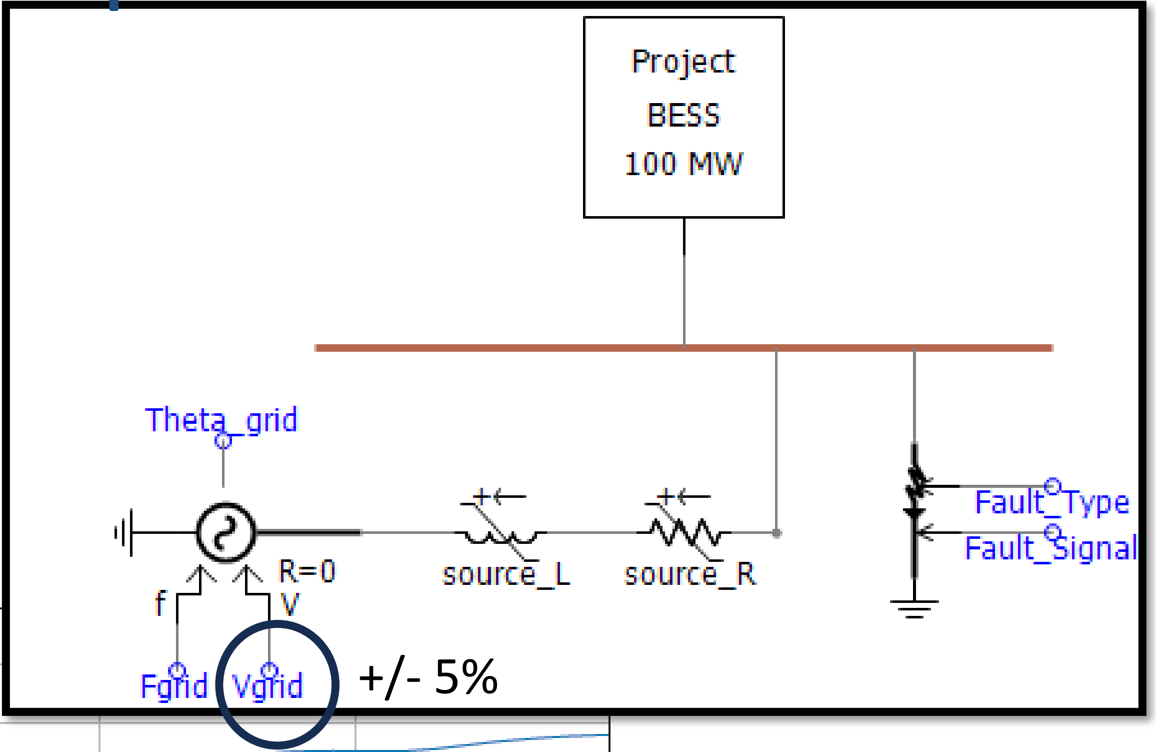
- SCR, X/R
- Dispatch
- Angle change
- Degree and shape of response

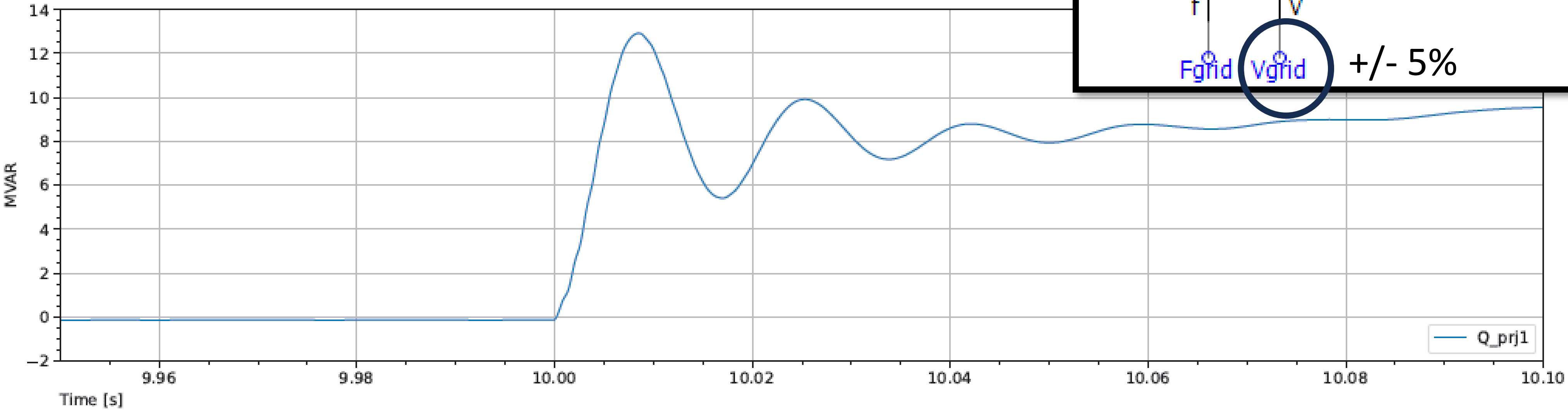
Quantitative…

Test 7 (Angle step change) – Setup and Success Criteria (Testbench 1)	
Testbench setup	
SCR at connection point is set to 3, system equivalent X/R ratio is set to 6	
Only the project BESS, no duplicate.	
The following initial active and reactive power scenarios will be considered for the GFM plant: 1. P=50%, Q=approximately zero 2. P=max, Q=approximately zero	
Test Sequence:	
1. Angle of the voltage source behind the equivalent grid impedance is decreased instantaneously by 10 degrees	
2. A few seconds later, angle of voltage source is increased by 10 degrees	
3. A few seconds later, repeat steps 1 & 2 with a +/- 25 degree phase angle change	
Success Criteria	**Pass/Fail**
a. Instantaneous active power output of the plant should quickly respond to oppose the angle change for each of the 10 degree voltage phase angle jumps , with a peak active power change of at least 0.2 pu on the rated active power base (e.g. a 100 MW rated plant should temporarily increase active power output from 50 MW to at least 70 MW when source voltage angle is decreased by 10 degrees, and should temporarily decrease active power from 50 to 30 MW or below when voltage source angle is increased by 10 degrees) **Note:** If the plant is on a limit and the phase jump is larger than 10 deg and in the direction towards exceeding its limit, above initial power jump criteria may not apply.	
b. For each of the 10 degree voltage phase angle jumps, response time to 90% of initial change in instantaneous active power should occur within 15 ms	
c. Active power does not return to the pre disturbance level within 50 ms	
d. if active power / current reaches limits for the 25 degree phase change, the plant should return to pre-event power levels in a stable manner.	
e. Any oscillation shall be settled.	
f. Any distortion observed in phase quantities should dissipate over time.	

Voltage Magnitude Step Response (informational)

- Informational test, assists in confirming GFM core functions
- +/- 5% step changes in system voltage
- GFM power expected to respond within 15 mS and be sustained for at least 100 mS





Energy Response Test (informational)

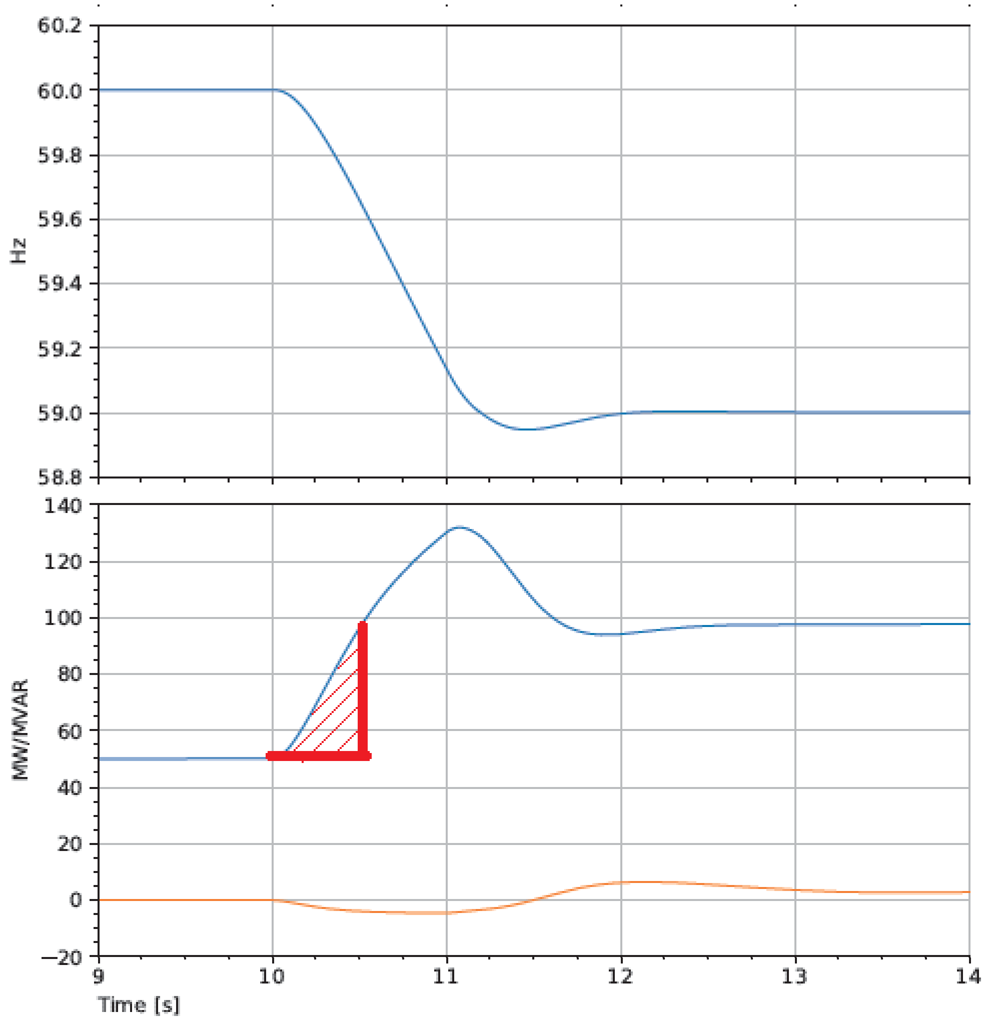
- Quantifies short-term (first 0.5s) energy provided by GFM for frequency events
- System frequency ramps +/- 1 Hz at 1 Hz/s
- Test setup so that there is 50% power headroom
- Energy constant calculated as:

$$\textit{Energy Constant} = \frac{\Delta E}{RoCoF}$$

Where;

$\Delta E = $ *Area under the* ΔP *(pu) curve (i.e.* $P - P_{Pre-Disturbance}$*) for a period of 0.5s from RoCoF application (pu.s)*

$RoCoF = 1/60\ (pu/s)$



Questions?

Andrew L. Isaacs
Power Systems Engineer, Vice-President
Electranix Corporation
ai@electranix.com
1-204-953-1833
Winnipeg, MB, Canada