HIL TESTING OF AUTOMATIC VOLTAGE SETPOINT OPTIMIZER FOR A CLUSTER OF WIND FARMS

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Introduction - TGS

- We are a power systems consulting company based in Winnipeg, Canada.
- 20 years in the industry
- Experts in:
  - HVDC/FACTS
  - Power System Analysis
  - Renewable Energy integration studies
  - PSCAD/RSCAD – model development
  - RTDS HIL Testing

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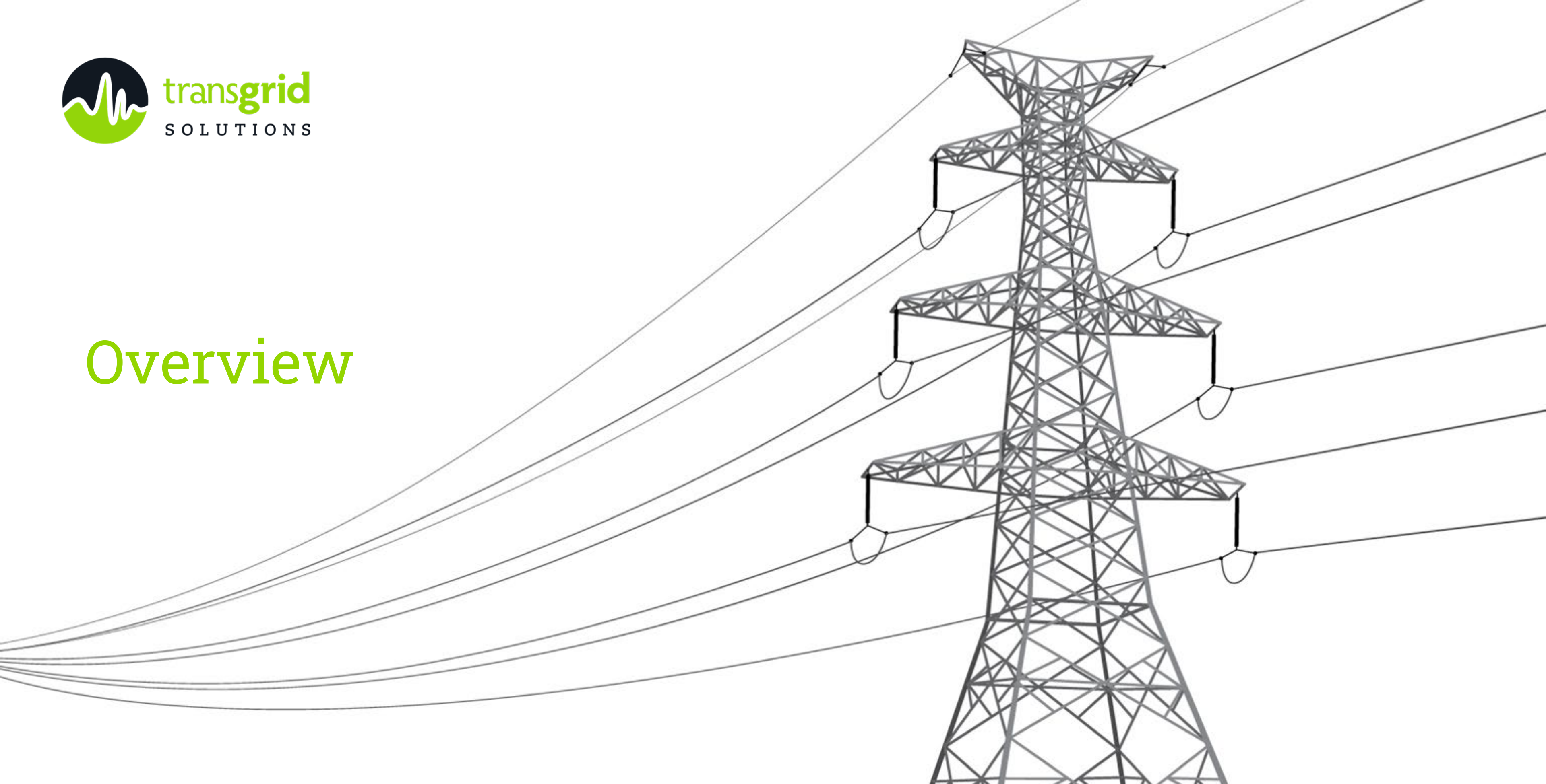
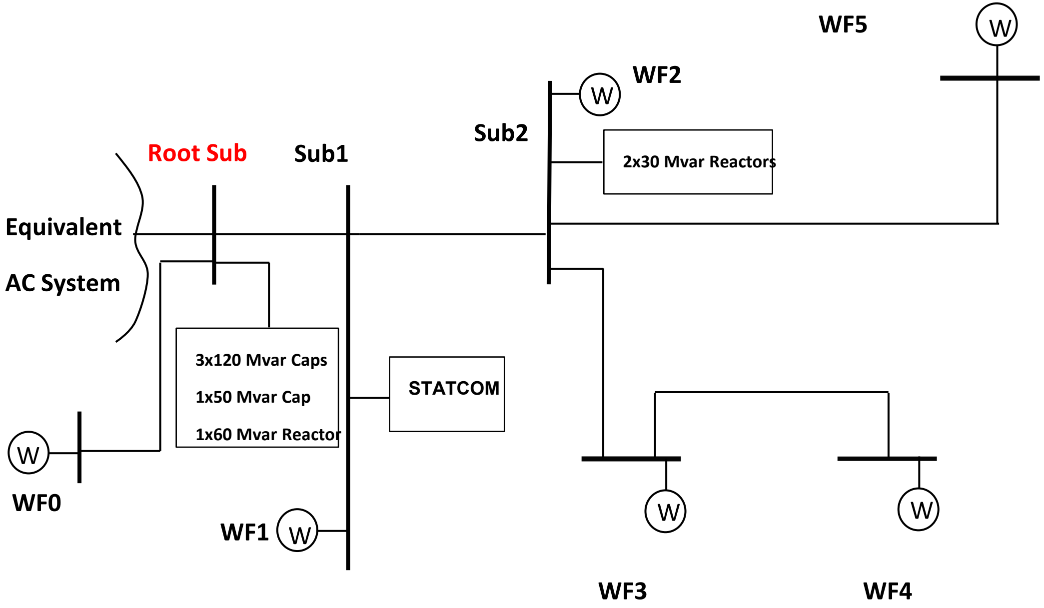
Overview



Overview

- Cluster of windfarms connected to a 345kV radial backbone
- Wind farms – multiple owners, multiple manufaturers, multiple PPCs and EMSs
- Reactive power management criterion is based on tight voltage regulation at the Root Substation at 1.02 pu
- Client – Developer of the firmware solution
- Client of the client – Transmission owner – a utility company in the USA.



Client-Proposed Solution

- Dynamically change the voltage setpoints of all windfarms and the STATCOM, based on their available reactive power capability to achieve 1.02pu at the Root Substation.

HIL Test Requirement

- Prove to the transmission system operator that the proposed solution work through a witnessed FAT

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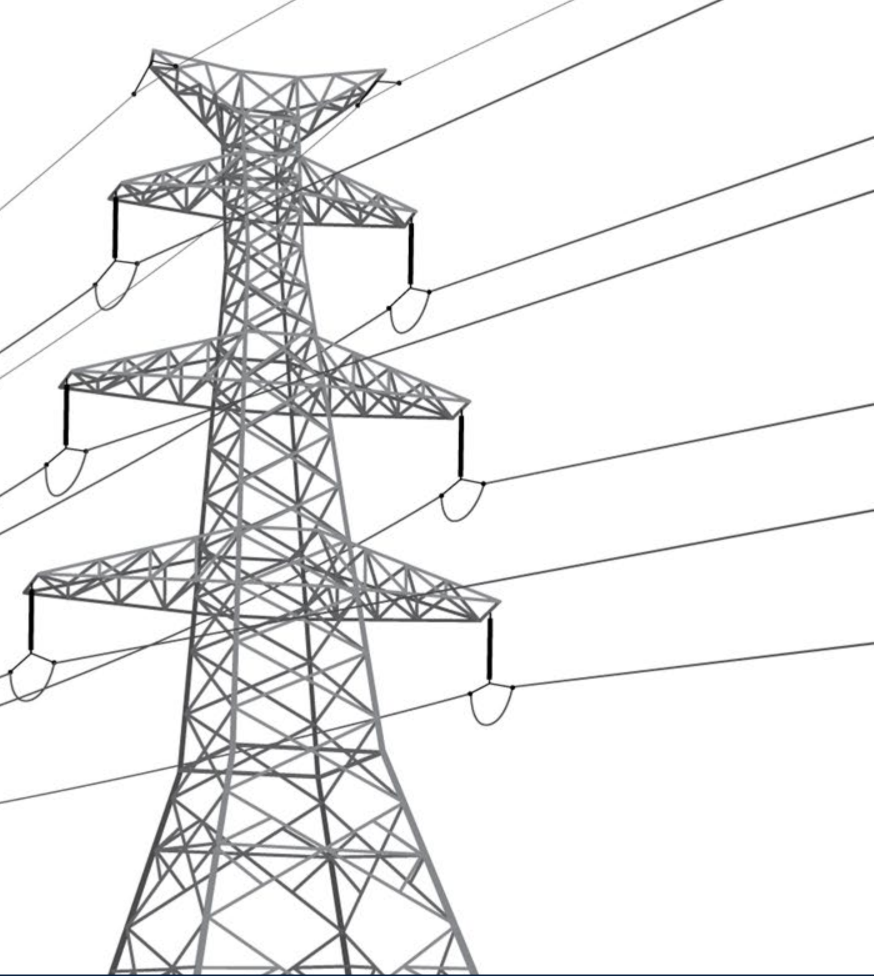
RTDS Test Setup



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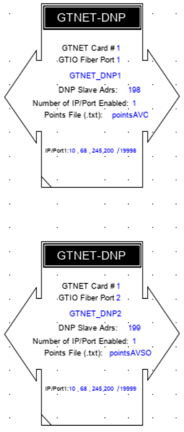
Hardware Used

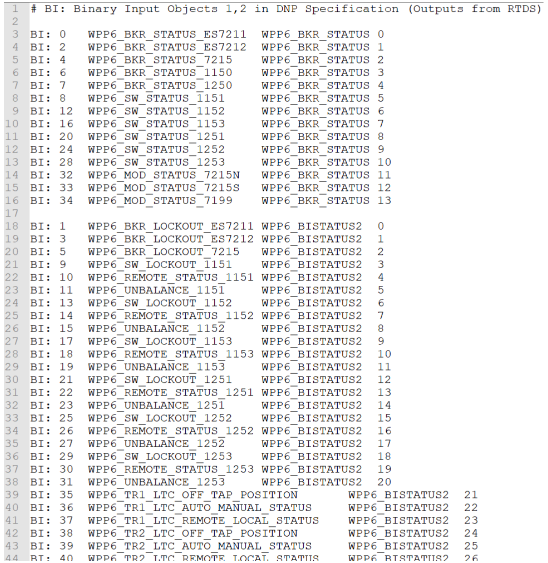
- 3 RTDS Racks (PB5) – AC system Model
- GTNETx2 Card – Communication Between RTDS and RTACS
- 2x SEL-3555 RTACs – AVSO primary and secondary controllers
- 2x SEL-3530 RTACs – Root substation AVC and Substation-2 AVC
- 1x SEL-3505 RTACs – EMS emulator
- HMI Interface

GTNET DNP Configuration

- GTNET card can only act as a DNP slave
- AVSO/AVC RTACs act as:
  - Slave to measurement RTUs
  - Master to WPP PPCs
- The SEL-3505 acted as a master-master intermediary so that all for RTU measurement communication RTDS appear as master to AVSO/AVC and master to GTNET card as well



RSCAD DNP Component



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# BI: Binary Input Objects 1,2 in DNP Specification (Outputs from RTDS)

BI: 0   WPP6_BKR_STATUS_ES7211  WPP6_BKR_STATUS 0
BI: 2   WPP6_BKR_STATUS_ES7212  WPP6_BKR_STATUS 1
BI: 4   WPP6_BKR_STATUS_7215    WPP6_BKR_STATUS 2
BI: 6   WPP6_BKR_STATUS_1150    WPP6_BKR_STATUS 3
BI: 7   WPP6_BKR_STATUS_1250    WPP6_BKR_STATUS 4
BI: 8   WPP6_SW_STATUS_1151     WPP6_BKR_STATUS 5
BI: 12  WPP6_SW_STATUS_1152     WPP6_BKR_STATUS 6
BI: 16  WPP6_SW_STATUS_1153     WPP6_BKR_STATUS 7
BI: 20  WPP6_SW_STATUS_1251     WPP6_BKR_STATUS 8
BI: 24  WPP6_SW_STATUS_1252     WPP6_BKR_STATUS 9
BI: 28  WPP6_SW_STATUS_1253     WPP6_BKR_STATUS 10
BI: 32  WPP6_MOD_STATUS_7215N   WPP6_BKR_STATUS 11
BI: 33  WPP6_MOD_STATUS_7215S   WPP6_BKR_STATUS 12
BI: 34  WPP6_MOD_STATUS_7199    WPP6_BKR_STATUS 13

BI: 1   WPP6_BKR_LOCKOUT_ES7211 WPP6_BISTATUS2  0
BI: 3   WPP6_BKR_LOCKOUT_ES7212 WPP6_BISTATUS2  1
BI: 5   WPP6_BKR_LOCKOUT_7215   WPP6_BISTATUS2  2
BI: 9   WPP6_SW_LOCKOUT_1151    WPP6_BISTATUS2  3
BI: 10  WPP6_REMOTE_STATUS_1151 WPP6_BISTATUS2  4
BI: 11  WPP6_UNBALANCE_1151     WPP6_BISTATUS2  5
BI: 13  WPP6_SW_LOCKOUT_1152    WPP6_BISTATUS2  6
BI: 14  WPP6_REMOTE_STATUS_1152 WPP6_BISTATUS2  7
BI: 15  WPP6_UNBALANCE_1152     WPP6_BISTATUS2  8
BI: 17  WPP6_SW_LOCKOUT_1153    WPP6_BISTATUS2  9
BI: 18  WPP6_REMOTE_STATUS_1153 WPP6_BISTATUS2  10
BI: 19  WPP6_UNBALANCE_1153     WPP6_BISTATUS2  11
BI: 21  WPP6_SW_LOCKOUT_1251    WPP6_BISTATUS2  12
BI: 22  WPP6_REMOTE_STATUS_1251 WPP6_BISTATUS2  13
BI: 23  WPP6_UNBALANCE_1251     WPP6_BISTATUS2  14
BI: 25  WPP6_SW_LOCKOUT_1252    WPP6_BISTATUS2  15
BI: 26  WPP6_REMOTE_STATUS_1252 WPP6_BISTATUS2  16
BI: 27  WPP6_UNBALANCE_1252     WPP6_BISTATUS2  17
BI: 29  WPP6_SW_LOCKOUT_1253    WPP6_BISTATUS2  18
BI: 30  WPP6_REMOTE_STATUS_1253 WPP6_BISTATUS2  19
BI: 31  WPP6_UNBALANCE_1253     WPP6_BISTATUS2  20
BI: 35  WPP6_TR1_LTC_OFF_TAP_POSITION           WPP6_BISTATUS2  21
BI: 36  WPP6_TR1_LTC_AUTO_MANUAL_STATUS         WPP6_BISTATUS2  22
BI: 37  WPP6_TR1_LTC_REMOTE_LOCAL_STATUS        WPP6_BISTATUS2  23
BI: 38  WPP6_TR2_LTC_OFF_TAP_POSITION           WPP6_BISTATUS2  24
BI: 39  WPP6_TR2_LTC_AUTO_MANUAL_STATUS         WPP6_BISTATUS2  25
BI: 40  WPP6_TR2_LTC_REMOTE_LOCAL_STATUS        WPP6_BISTATUS2  26
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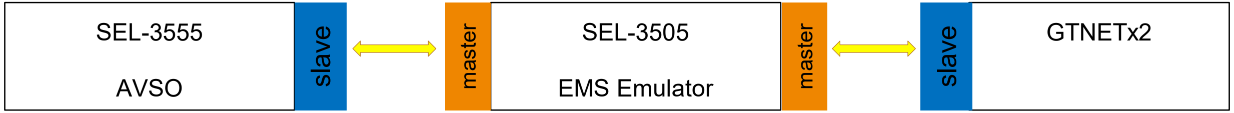
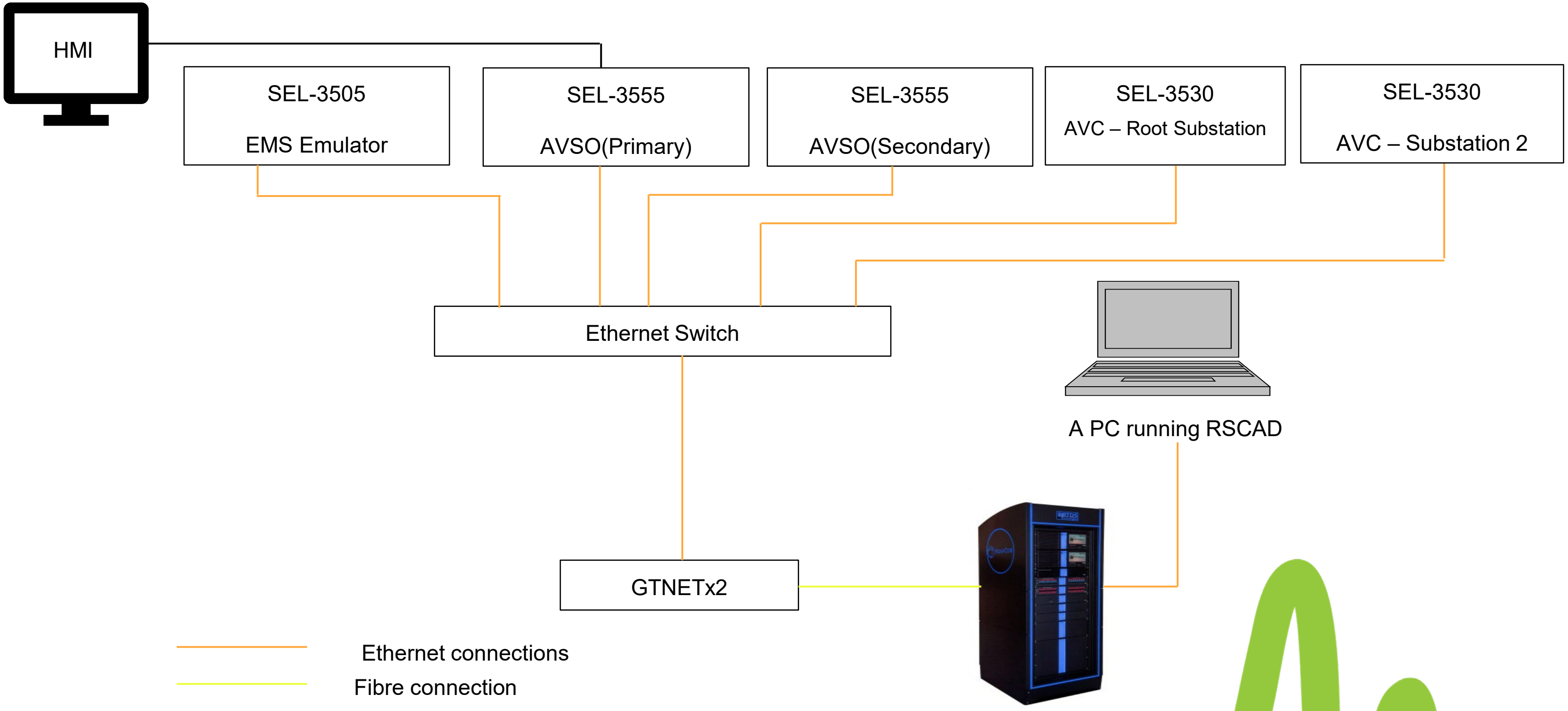
Points list for the AVSO RTAC



HIL Setup



HMI
SEL-3505
EMS Emulator
SEL-3555
AVSO(Primary)
SEL-3555
AVSO(Secondary)
SEL-3530
AVC – Root Substation
SEL-3530
AVC – Substation 2
Ethernet Switch
A PC running RSCAD
GTNETx2
Ethernet connections
Fibre connection

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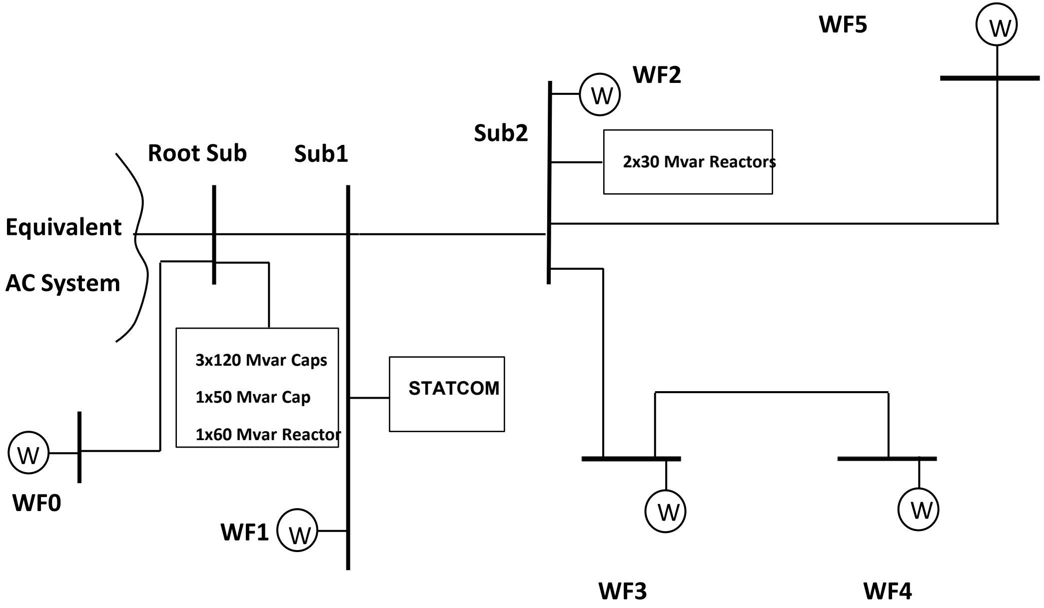
RSCAD Model

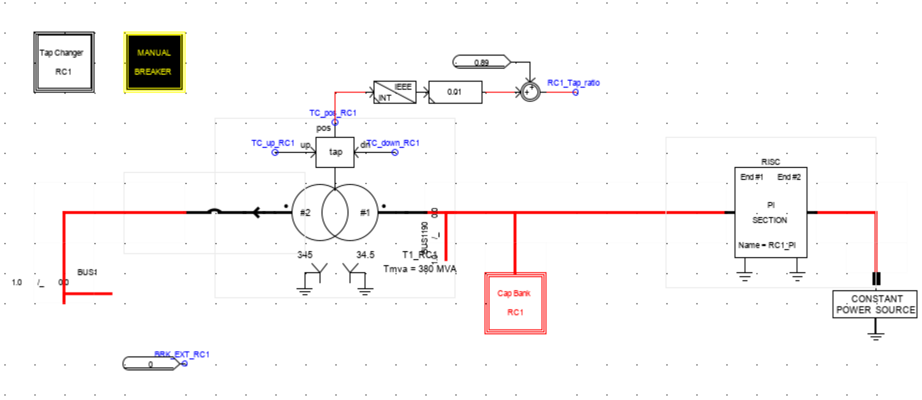
AC Network Model

- Only PCC voltage regulation is modelled
- Aggregated model of WF0 is also included
  - Controls Root Substation voltage with line droop compensation
  - Voltage regulator response time = 40 s



Wind Farm Models

- Each wind farm in the Gen-tie has been modeled as a lumped controlled PQ source (Benchmarked with PSCAD response)
- PQ capability modelled as per Vestas 2.2MW and 2.0MW turbine specification
- For WF5: Assumed capable to maintain +/-0.95 pf.
- Collector system and pad mount transformer impedances are represented by a PI section model.
- MV Capacitor and Reactor banks and their switching logic has been modeled.
- Grid interface transformers have been modeled with the tap changer logic.



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MV Shunts

- MV shunt switching of the Gen-tie facilities are modelled

WF1

- Switch in capacitors at 60% of Q at PCC
- Switch off capacitors at 20% of Q at PCC
- Switch 2 reactors if P less than 60 MW for 3 minutes
- Switch remaining reactors if P less than 60 MW for an additional 3 minutes
- When P is above 60 MW for 3 minutes switch off one reactor every 3 minutes

WF2

- Switch in capacitors at 60% of Q at PCC
- Switch off capacitors at 20% of Q at PCC
- Switch 1 reactor if P less than 60 MW for 3 minutes
- Switch remaining reactors if P less than 60 MW for an additional 3 minutes
- When P is above 60 MW for 3 minutes switch off one reactor every 3 minutes

WF3 and WF4

- Switch 2 reactors if P less than 10% for 3 minutes
- Switch remaining reactors if P less than 10% for an additional 3 minutes
- When P is above 10% for 3 minutes switch off one reactor every 3 minutes

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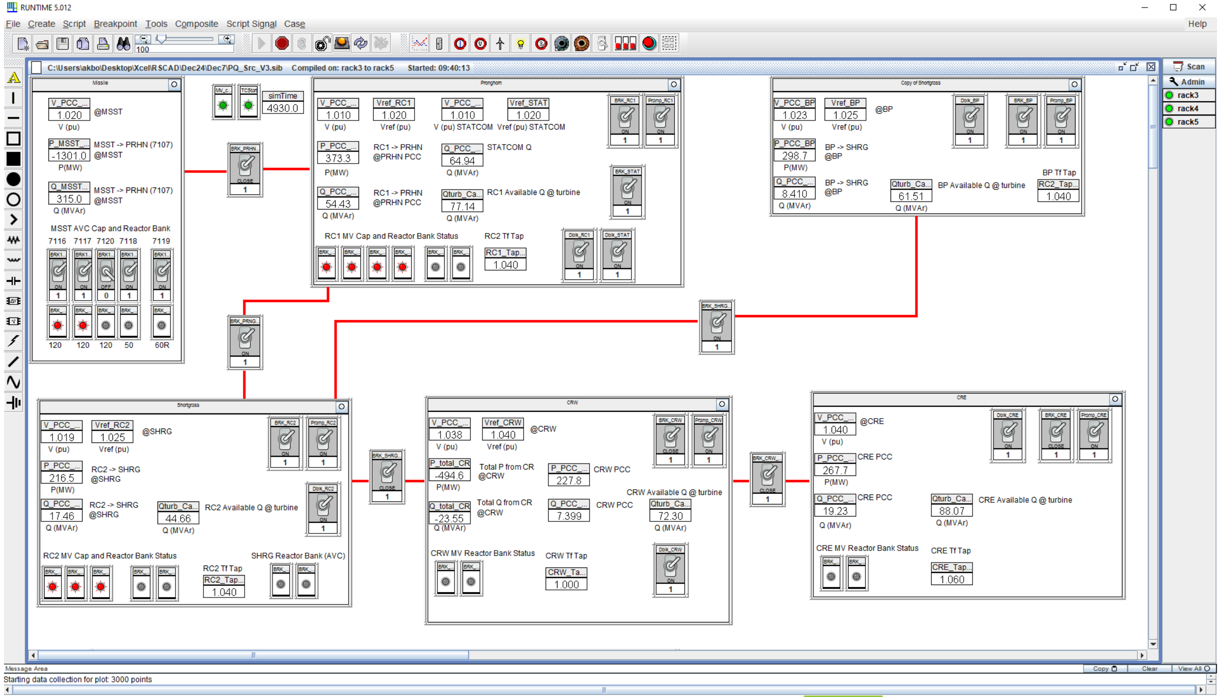
RSCAD Runtime

- RSCAD Runtime captures the plots required for offline analysis.
- The runtime has been setup to view voltages, power readings and capacitor/reactor statuses in real time.
- Necessary interventions can be done using the switches, in real time.



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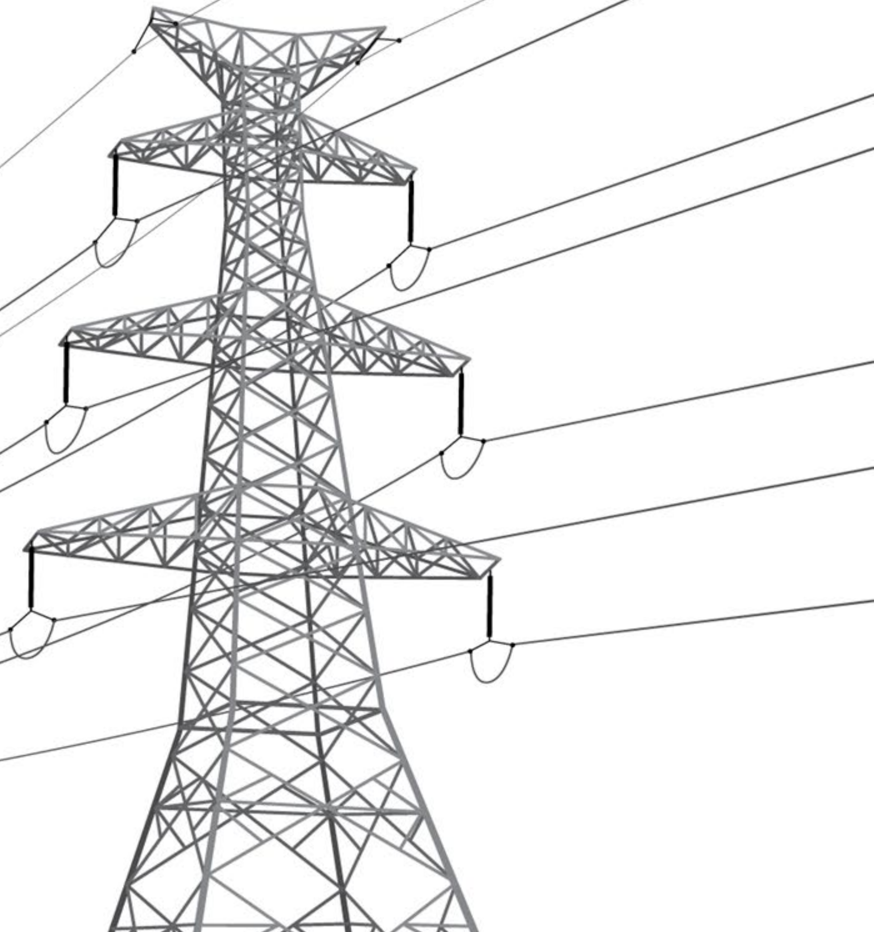
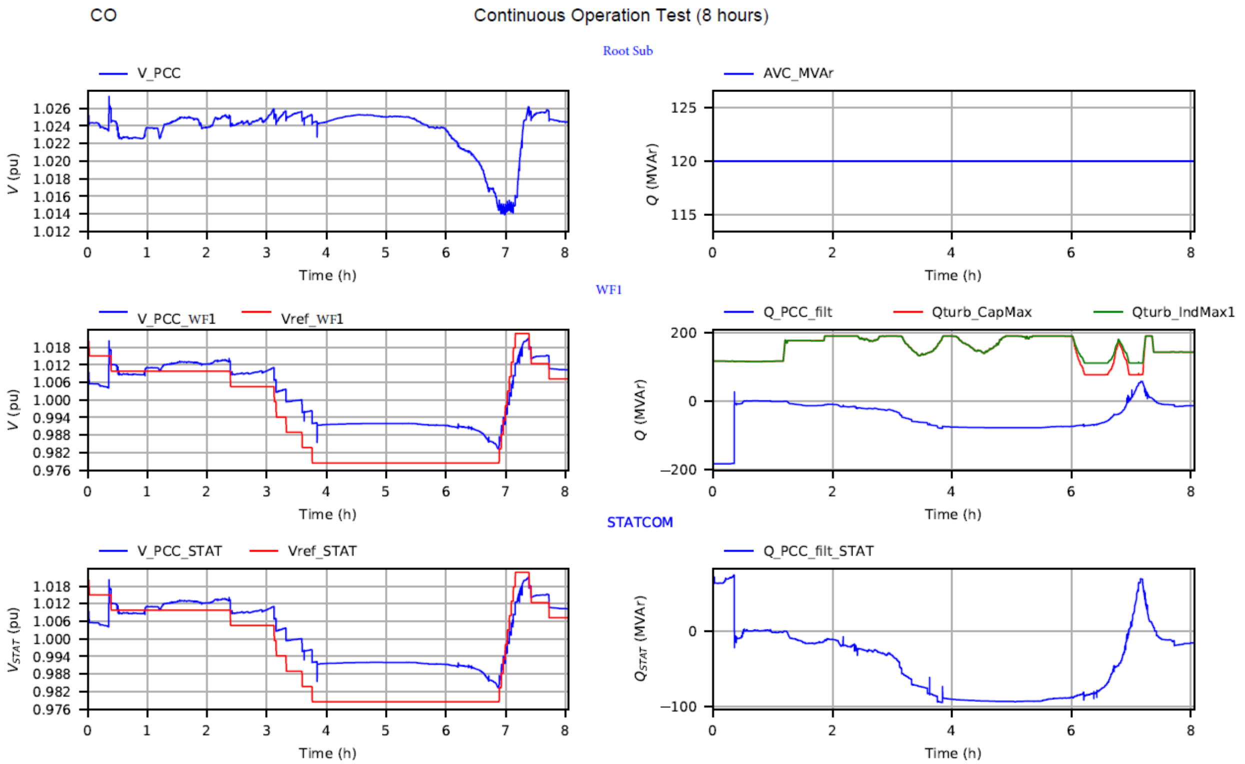
Tests



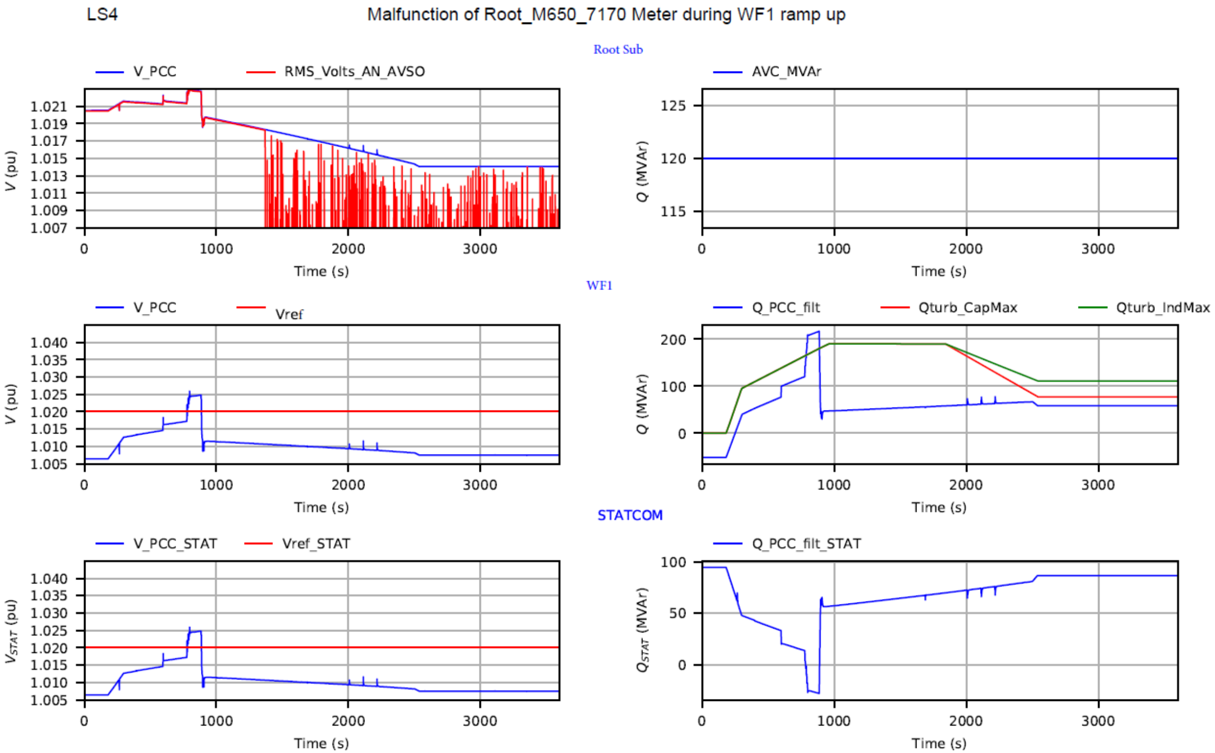
Type of Tests

- Power ramp tests
- Root substation voltage step changes
- Facility trip tests
- Line trip tests
- Loss of signal tests
- Continuous operation
- Gen-tie energization
- AVSO primary-secondary change over

Sample Results



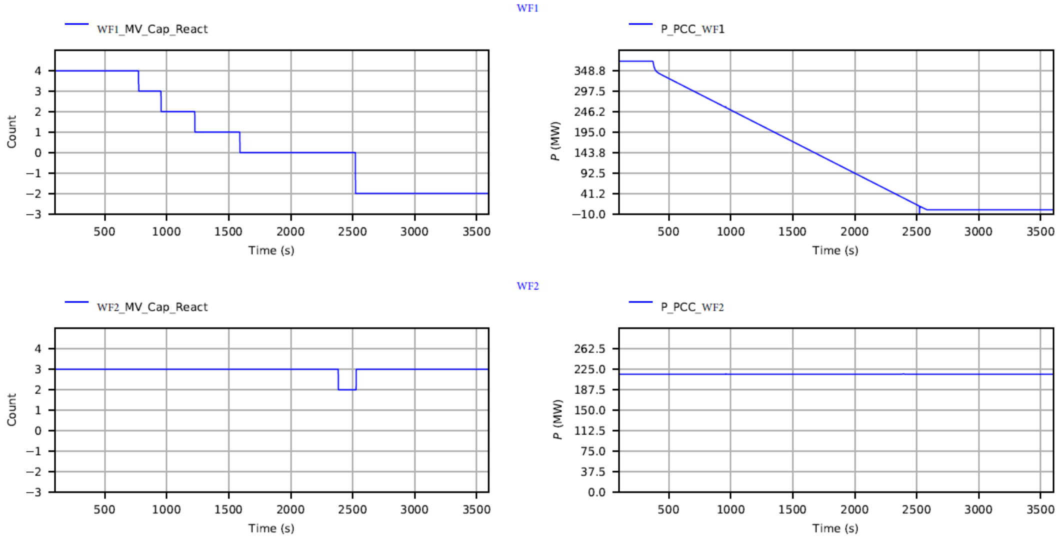
Sample Results



Sample Results

Power ramp down test (1/2)

PR1 WF1 ramp down 100%-0% @2.5%/min



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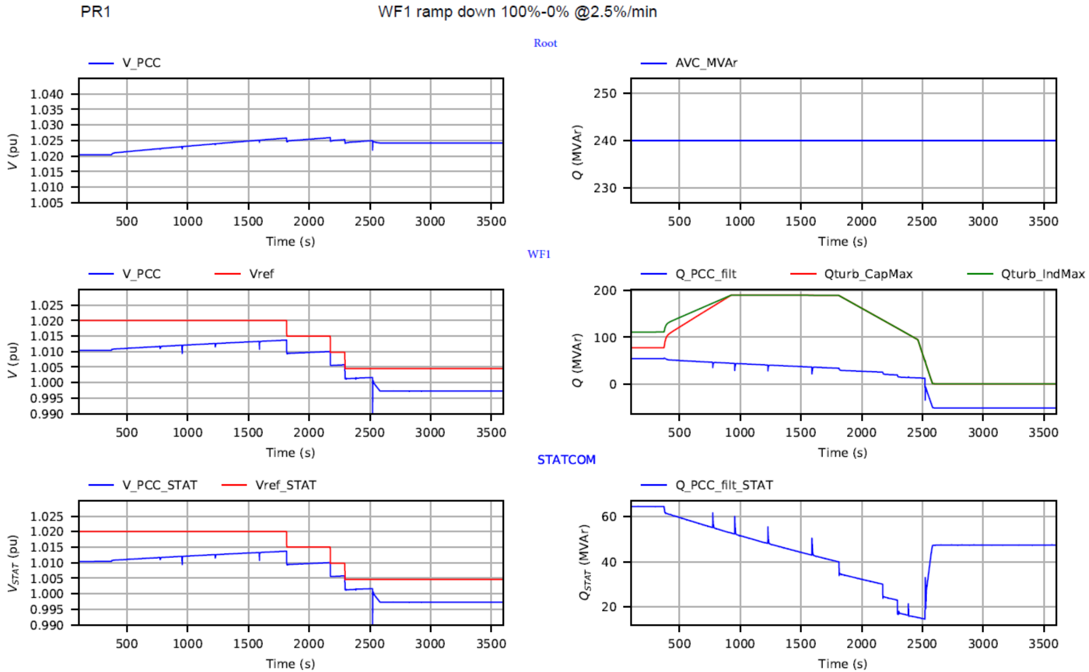
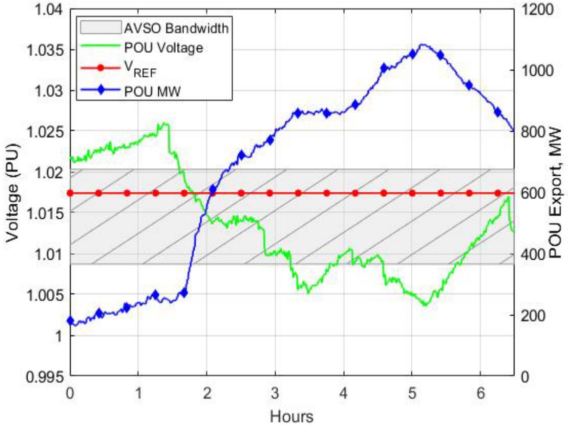
Sample Results

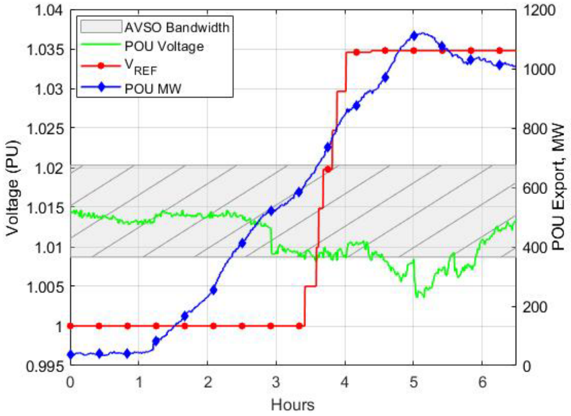
Power ramp down test (2/2)



Field Measurements



System response to wind-ramp event
pre-AVSO implementation



System response to wind-ramp event
post-AVSO implementation

Challenges

- Pandemic! – Entire project, including FAT, was carried out remotely
- Remote debugging
- Time constraints – Wind Farms were already in operation. The studies portion of the AVSO development was embedded with HIL testing, saving precious time

Conclusions

- Inverter-based resource integration demands for high-level automatic system control to assist with operator task offload and voltage coordination.
- RTDS and field testing provided operators and engineers the confidence that the AVSO would handle unique operating scenarios
- FATs and HIL testing used to require travel, but this FAT was done entirely remotely, with a timely delivery
- RTDS is not only for studying fast transients. It was very useful in this slower voltage control testing
- RTDS studies for slower dynamics can be done without the full manufacturer models. Simple RSCAD models benchmarked with PSCAD models served the purpose.

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Thank You