Gentpj/Genqec modeling and transistion

A Transmission Planner’s Perspective

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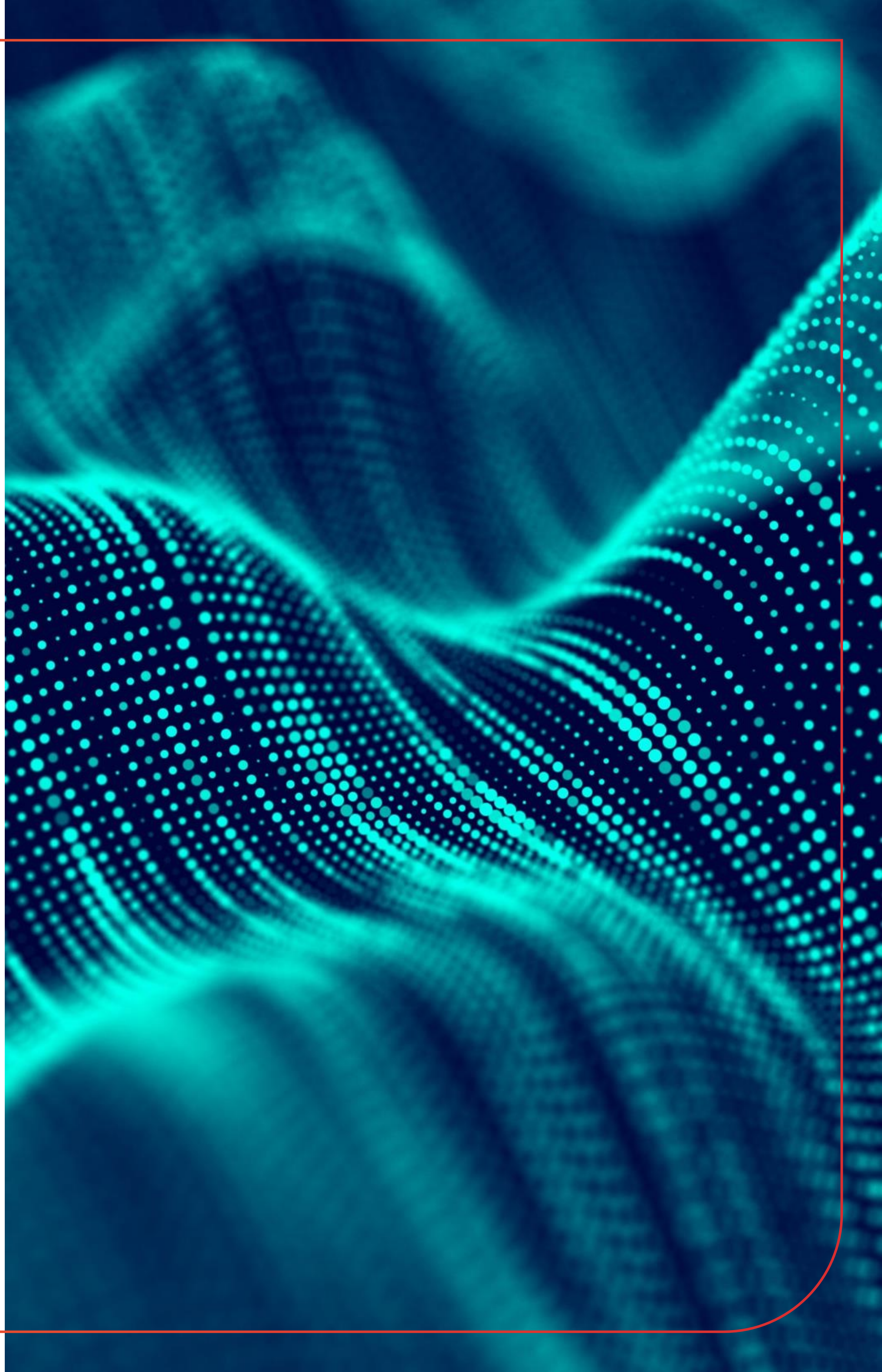
January 26, 2024



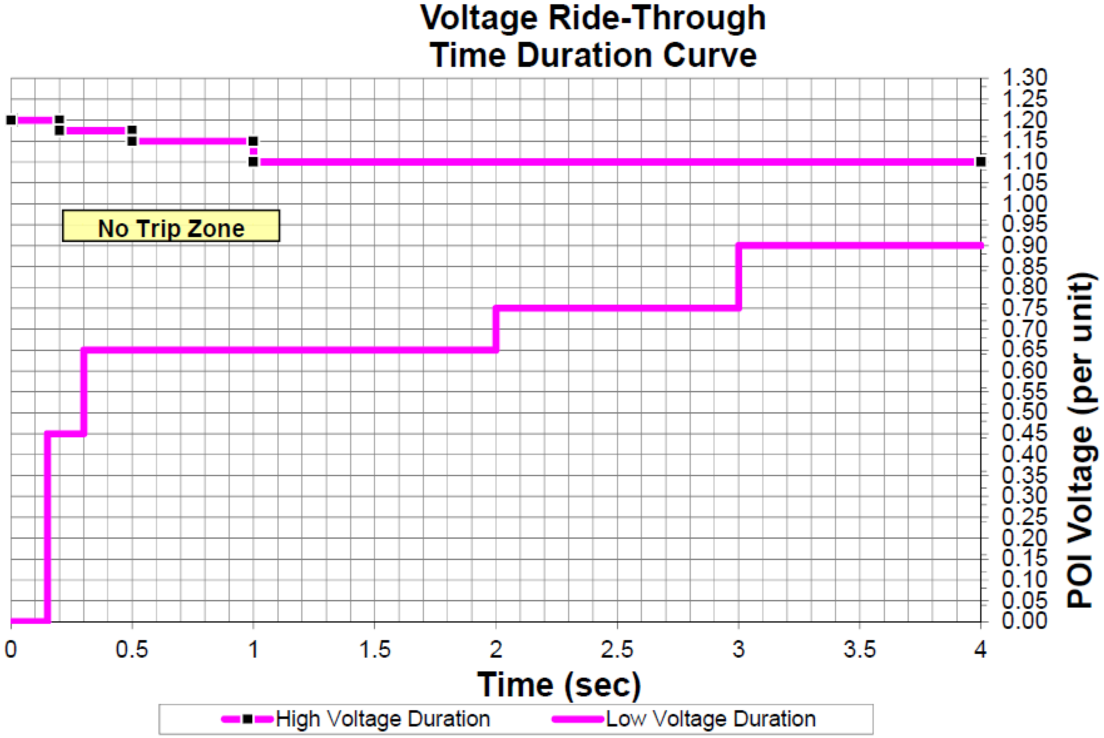
Transmission Planning perspective

- My perspective
- What I'm not
  - Not a machine expert
  - Not a mechanical engineer – as the models often deal with mechanical and/or thermal properties
  - Not a PhD
- I'm an Electrical Engineer
  - A Transmission Planner with decades of experience, using these models
    - Often before these models are fully vetted or we have data for them

Examples

NERC PRC-024 and the lhvrt and lhfrt models

- Generator Frequency and Voltage Protection Relay Settings (2015)
- We were required to submit these model for Gen Interconnection Request or in Trans Planning simulations before we had data
- Placed trip settings at the borders of the NERC "No-Trip" zones
  - A nice conservative assumption
  - But often proved to be way too sensitive, especially when connecting to weaker systems



FERC Order 842 and repc_a and repc_b

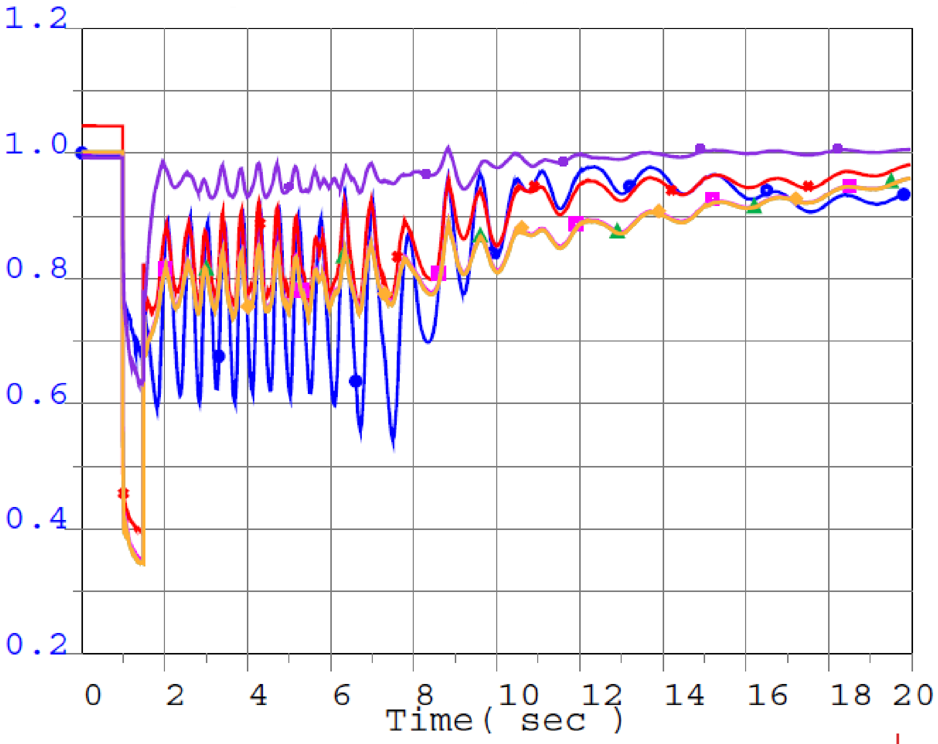
- Primary Frequency Response (2018)
- We were required to submit these model for Gen Interconnection Request or in Trans Planning simulations before many inverter manufacturers had these function and before we had data from them
- Set deadband and droop at maximums specified in FERC Order 842
- WECC had a 2015 PV Guideline that warned that the frequency response control loop was not fully vetted
- Many of us had no idea what a "pass" or "fail" look like.

Caveat

- Some of what I present may be real-world solutions to problems with modeling and simulation

- But as a caveat:
- Some of what I present will not be valid, real-world solutions to problems or to modeling and running simulations
- They are me just playing with the model and trying to understand
  - The models
  - How they work, and
  - How they perform in simulations

Oscillations issues observed



Routine work in late 2022 and 2023

- Saw high frequency / small signal oscillations, which appeared to be on top of the voltage and frequency rms plots

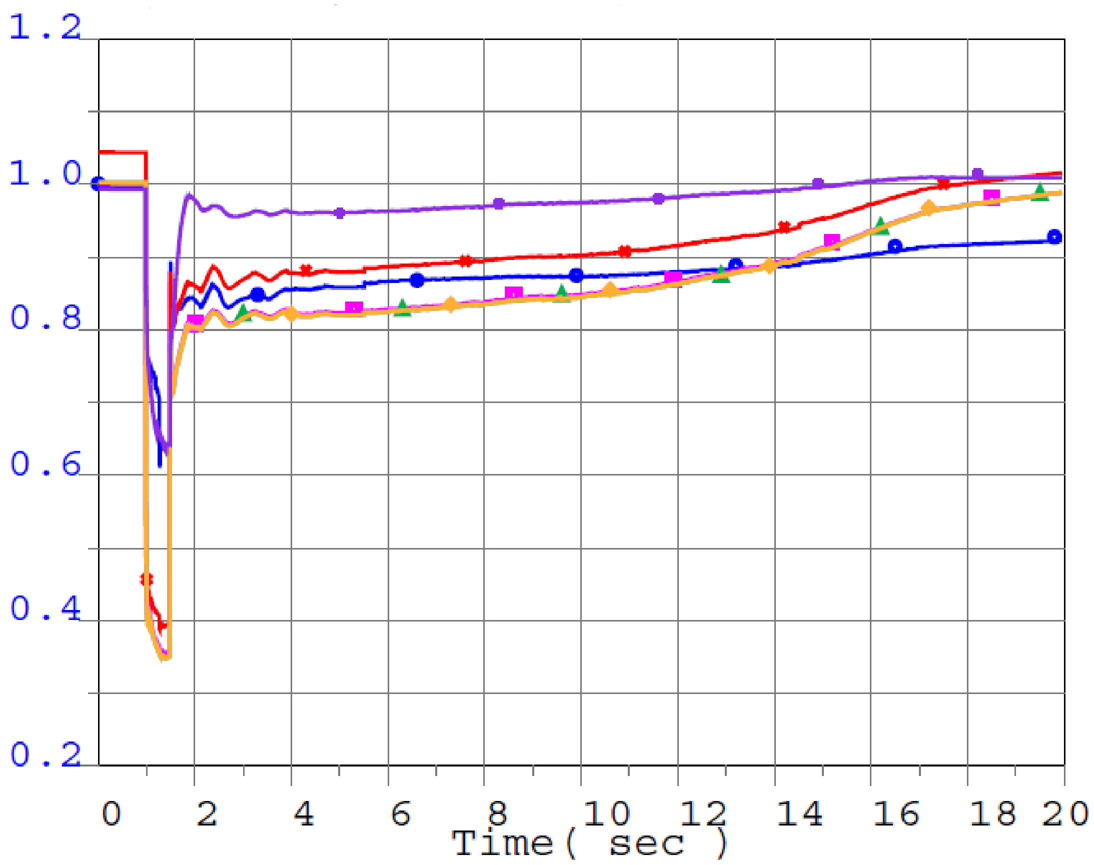
- In WECC
- Generation Interconnection Studies and NERC CIP-014 R1/R2 Studies
- A couple of clients, a couple of studies, a couple of base cases, a couple of severe / extreme contingencies
- These oscillations had not been seen in similar studies for the same client or the same or similar studies in previous years
- Newer, updated base cases and dynamic files
  - Fully vetted by us, our clients and regional planning groups

Oscillations

Fixes, improvements, or just seeking understanding

Modeling fixes (that may or may not necessarily be solutions)

- Reducing delayed clearing times
  - Minimum 1-2 cycles / Maximum 40%
- Removing OOS units as they go out of step
  - Either by adding them to the contingency description when they reach 180 degrees OOS
  - Outright Netting OOS units out



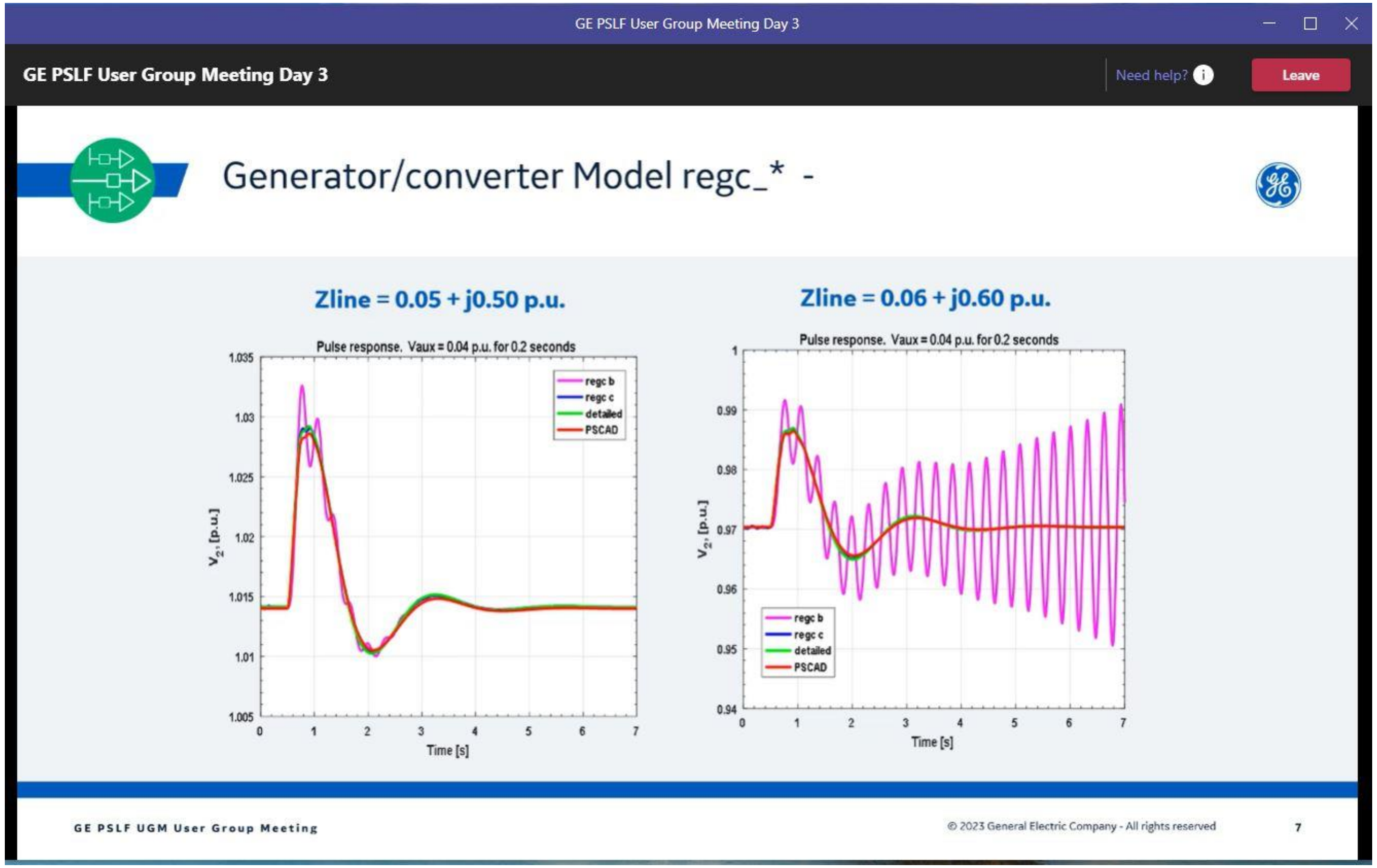
Oscillations
Fixes, improvements, or just seeking understanding

Improvements (but again, these may not necessarily be solutions)

- Changing the base load flag of Out-of-Step (OOS) units from 2 (pgen fixed) to either 1 (pgen can go down) or 0 (pgen can to up or down)
- Further improvement of the voltage profile
- Updating generator models for about a dozen units (genrou) in a near-by Area
- Changing the OOS units (most of which were gentpj, with a few genrou) to genqec

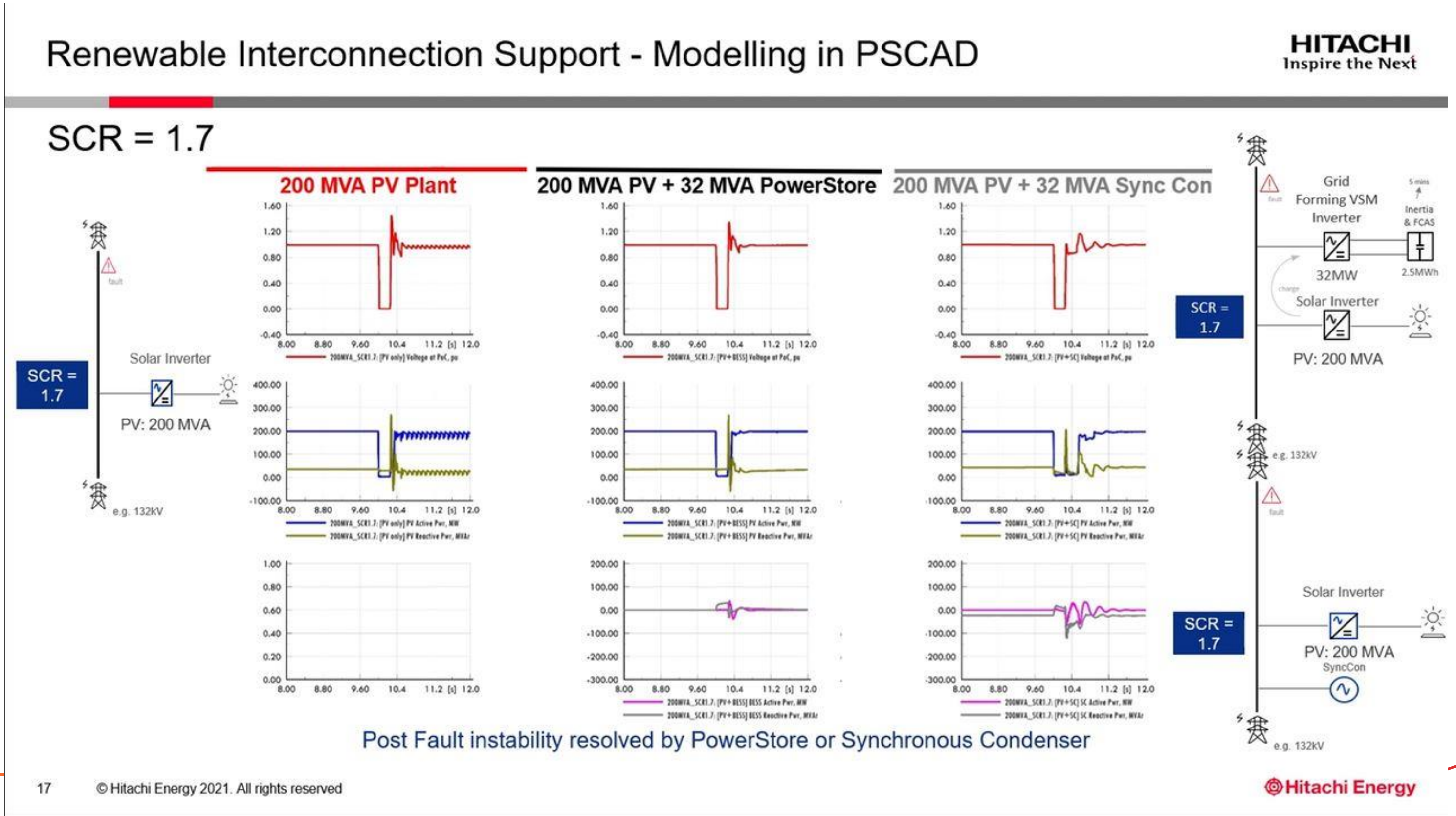
Oscillations, observation as to causes - IBR

- Dr. Sanchez-Gasca with GE in GE PLSF User's Group in May 2023
- Paraphrasing what I heard:
- *The weaker the system on the right shows greater oscillations*
- *Further, the earlier, simpler models (with fewer control parameters) show greater oscillations.*



Oscillations, observation as to causes - IBR

- Sasan Zabihi with Hitachi during a WECC MVS in 2023
- Paraphrasing what I heard:
- *Using Grid Forming (GFR) Inverters can augment system strength and reduced IBR oscillations*



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Oscillations, observation as to causes

- Weakened system
  - Reduced inertia in WECC
    - Calculated about a 10% WECC wide reduction in inertia every 2-2½ years for last 5 years
    - Based on a hand full of mostly Heavy Summer and Off-Peak base cases
  - Reduced available short circuit current
    - Reducing Short Circuit Ratio (SCR)
    - Calculated about a 1% reduction in available short circuit ratio every 2-2½ years for last 5 years at key selected buses
    - Based on a hand full of mostly Heavy Summer and Off-Peak base cases
- Delayed clearing times have increased over the years
  - Mostly because old assumptions were not found to match current protection settings

Oscillations, observation as to causes and another possible solution

- Despite evidence of similar oscillations in IBR, all these problems we observed appeared in synchronous generators with gentpj models
  - Or in two instances genrou models
- One of the reasons for removing gentpj model from the WECC Approved Dynamic Model List was
  - Dynamic response issue with less damping on electro-mechanical oscillations during simulation
  - As well as difficulty in field verifying the Kis, Saturation factor (current multiplier)
- Tried another solution - Converting the gentpj models to genqec
  - Converting single units improved but did not eliminate the oscillations
  - Caveat – No direct conversion between models, so it required some assumptions

Gentpj presences in WECC in one 2027 Heavy Summer base case

- Gentpj - 49%
- Gentpf - 10%
- Genrou - 20%
- Regc_a - 20%
- Other - < 1%
  - Gencc, Gewtg, Genwri, Gensal (not on WECC Approved List)

- Genqec - 0%

Gentpj / Gentpf characteristic in WECC

Gentpj

- Based on genrou – 31%
- Based on gensal – 68%
- Based on genal without amortisseur circuits (dampening windings) – ½%

- Kis > 0 – 52%
- Kis = 0 – 47%
- Kis < 0 - ½%

Gentpf

- Based on genrou – 81%
- Based on gensal – 19%
- Based on genal without amortisseur circuits (dampening windings) – 0%

- Kis – N/A

Gentpj Turbine Types in WECC - 1992 machines

- 0, unknown - 10.3%
- 1, steam turbine – 4.7%
- 2, combine cycle, steam – 2.9%
- 3, steam, cross-comp – 0.2%
- 4, combined cycle total – 2.4%
- 5, hydro – 52.5%
- 6, internal comb – 4.6%
- 7, diesel – 0.2%
- 11, gas turbine - 8.8%
- 12, aero deriv gas tur – 3.8%
- 13, single-shaft cc - 0.8%
- 14, synch con – 1.0%
- 19, turbine-binary cycle – 1.4%
- 29, combined cycle, comb – 2.5%
- 31, photovoltaic – 0.1% (1 gen)
- 41, motor/pump – 3.7%
- 47, energy storage, conc solar – 0.1%
- 54, energy storage, rev hydraulic – 0.1%
- 99, other - 0.2%

Gentpf Turbine Types in WECC - 384 machines

- 0, unknown – 23.4%
- 1, steam turbine – 5.5%
- 2, combine cycle, steam – 1.6%
- 4, combined cycle total – 0.8%
- 5, hydro – 19.8%
- 7, diesel – 2.6%
- 11, gas turbine – 6.0%
- 12, aero deriv gas tur – 0.3%
- 13, single-shaft cc – 0.3%
- 14, synch con – 1.6%
- 19, turbine-binary cycle – 3.6%
- 29, combined cycle, comb – 2.1%
- 31, photovoltaic – 0.3% (1 gen)
- 41, motor/pump – 32.3%

Gentpj conversion to Genqec

- No direct conversion between Gentpj to Genqec

- But a lot of parameter are the same
  - Inertia
  - Stator leakage reactance and resistance
  - Saturation factors
    - S1, S12
  - Reactances
    - D-axis and Q axis
    - synchronous, transient and sub-transient
  - Time Constants
    - D-axis and Q axis
    - Transient and sub-transient

Gentpj/Genqec
parameters map back to earlier models or generator type

- Genrou (round rotor machine)
  - T'_{d0}, T''_{d0}, T'_{q0}, $T''_{q0} > 0$; and
  - X_d, X'_d, X''_d, X_q, X'_q, X''_q, $X_l > 0$.
- Gensal (salient pole machine)
  - $T'_{q0} = 0$;
  - X_d, X'_d, X''_d, X_q, X''_q, $X_l > 0$; and
  - $X'_q = X_q$
- Genal without amortisseur circuits (w/o dampening windings)
  - $T''_{d0} = T''_{q0} = T'_{q0} = 0$;
  - $X''_d = X'_d$ and $X''_q = X'_q = X_q$; and
  - X_d, X'_d, X_q, X_l, $T'_{d0} > 0$;

Gentpj conversion to Genqec

No direct conversion between Gentpj to Genqec

Gentpj

- Accel – acceleration factor for network boundary iteration
- Kis – Current multiplier for saturation calculation
  - This is a function of **stator current** (important for salient pole hydro gens)
  - Range in WECC dynamic data: $-0.3 \leq Kis \leq 0.4$
  - Most values in WECC dynamic data (47%): $Kis = 0.00$
  - Most common range in WECC dynamic data (41%): $0.01 \leq Kis \leq 0.10$

Genqec

- Kw – Rotor field current compensation factor
  - Is related to additional rotor winding leakage flux when stator current is present
  - $0 \leq Kw < 1$
- Satflg – Saturation type selector
  - -1 – No saturation
  - 0 – Exponential saturation
  - 1 – Scaled Quadratic saturation
  - 2 – Quadratic saturation

Gentpj comparison to Genqec - Example 1

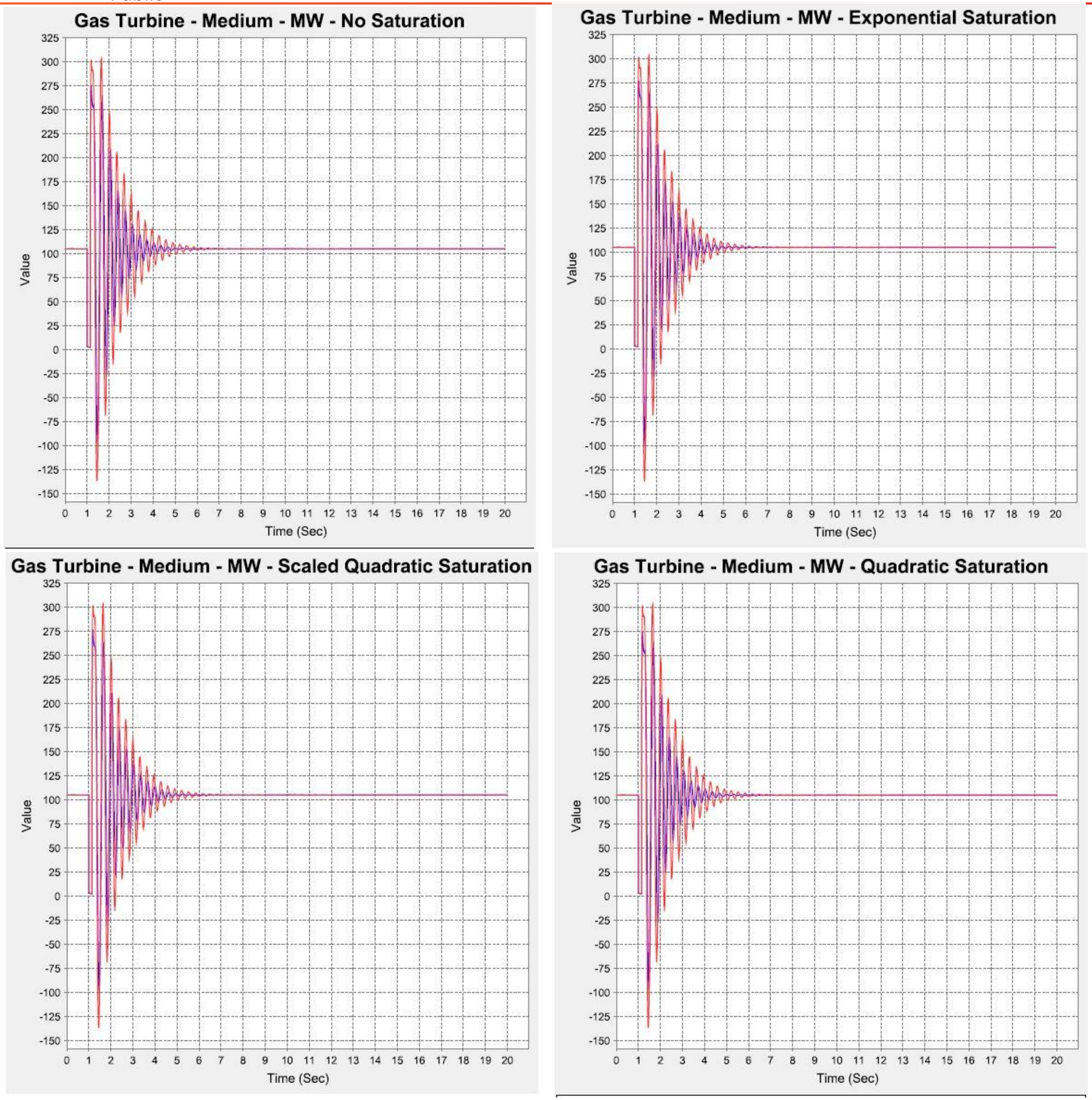
- Using a simple bump test
- gas turbine (single shaft, does not include turbine part)
  - Type 11
- Pmax = 105.0 MW
- Pmin = 24.0 MW
- Base = 155.07 MVA
- Kis = 0.120
- Based on a round rotor machine (genrou model)

MW (pg)

- Exponential and Scaled Quadratic are a closer fit and appear identical to each other
- No-Saturation and Quadratic have reduced magnitude of oscillation and appear to mimic each other

Gentpj

Genqec



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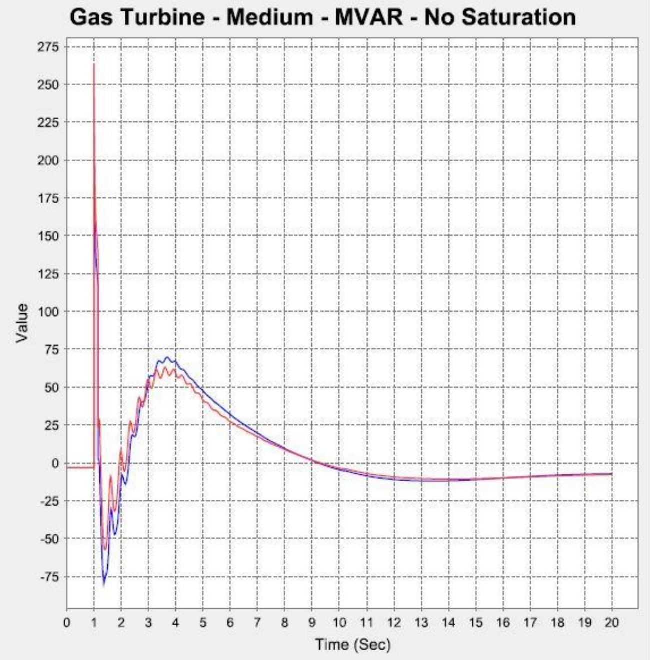
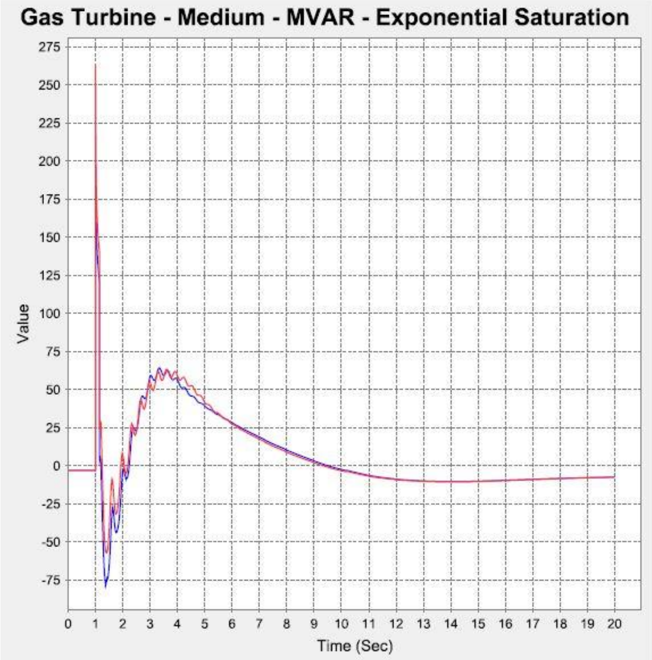
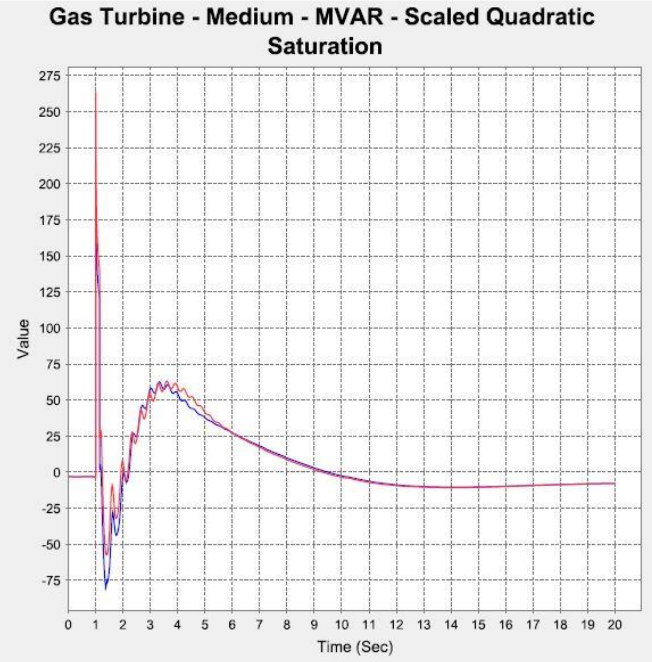
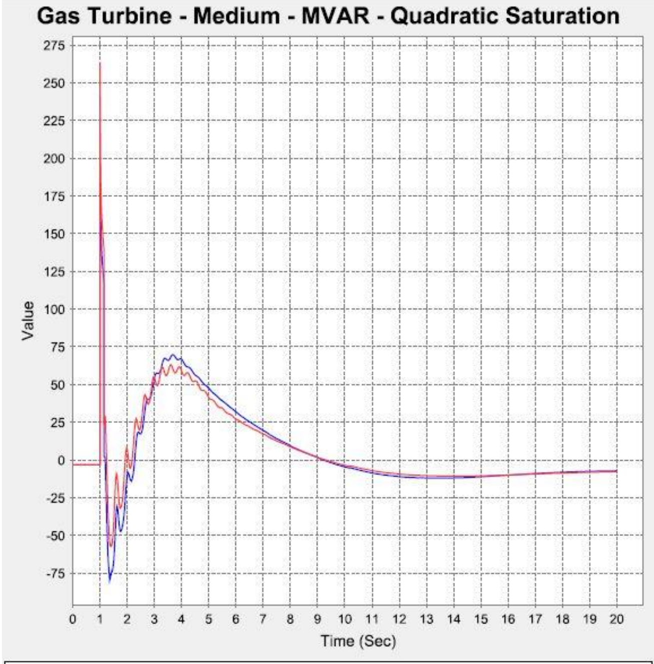
MVAR (qg)

- Exponential is a closer fit
- Scaled Quadratic is a close second
- No-Saturation and Quadratic both have slight overshoot









Gentpj
Genqec

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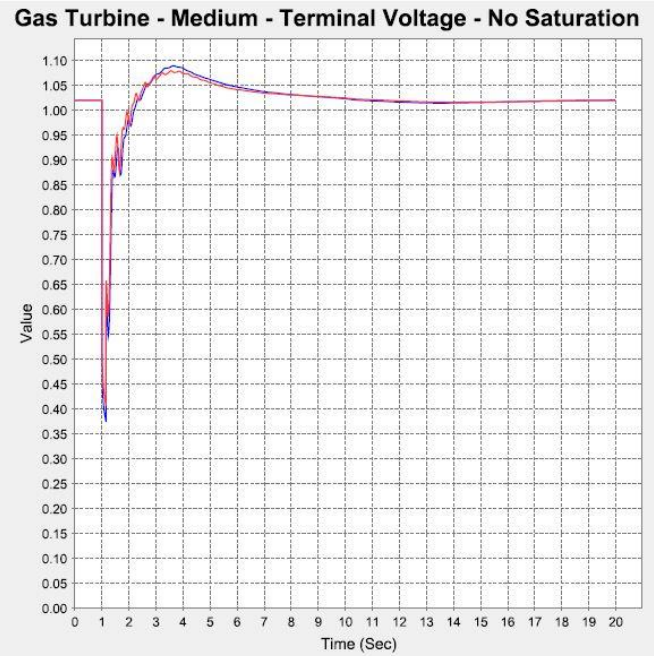
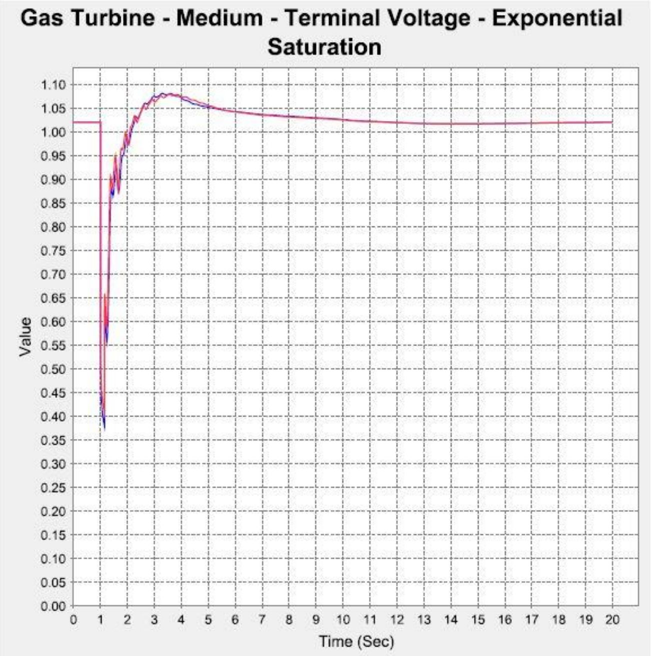
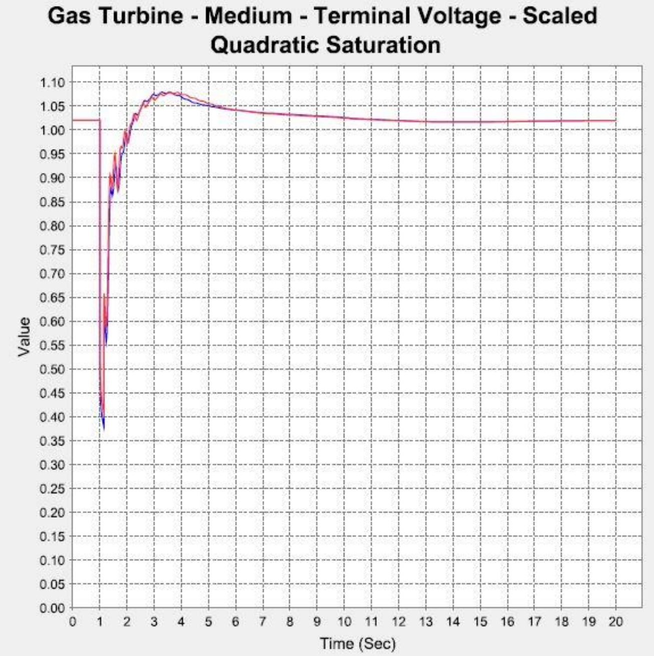
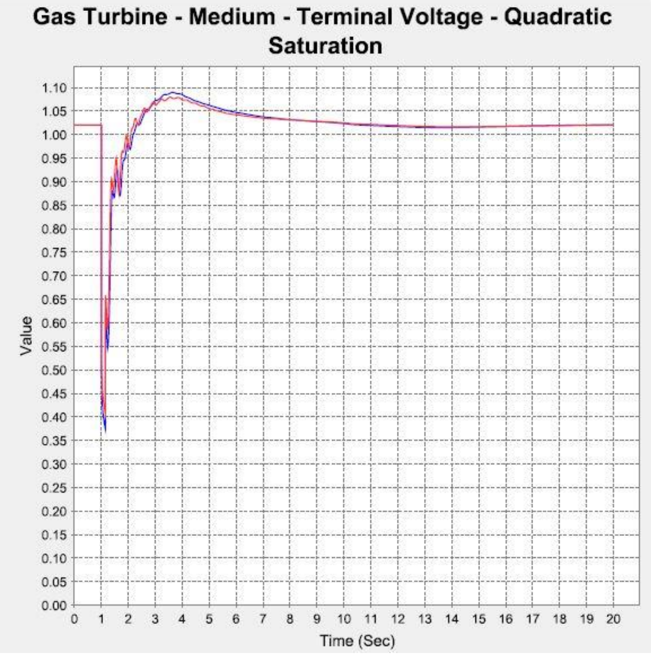
Terminal Voltage (vt)

- Exponential is a closer fit
- Scaled Quadratic is a close second
- No-Saturation and Quadratic both have slight overshoot







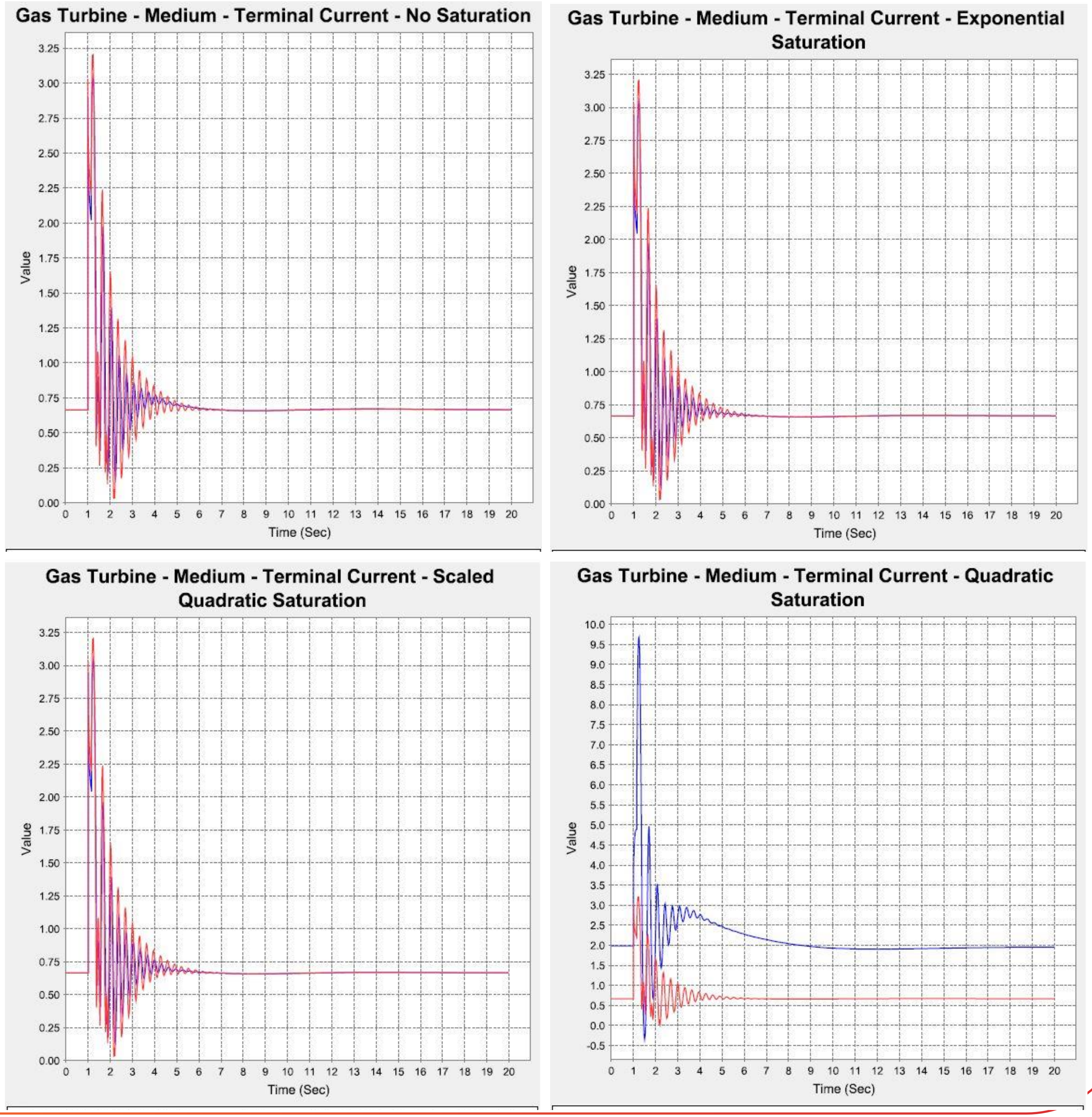


Gentpj

Genqec

Terminal Current (it)

- Exponential is a closer fit
- Scaled Quadratic is very similar and a close second
- No-Saturation has slight offset (rise) as it dampens
- Quadratic is very different and has an offset



Gentpj

Genqec

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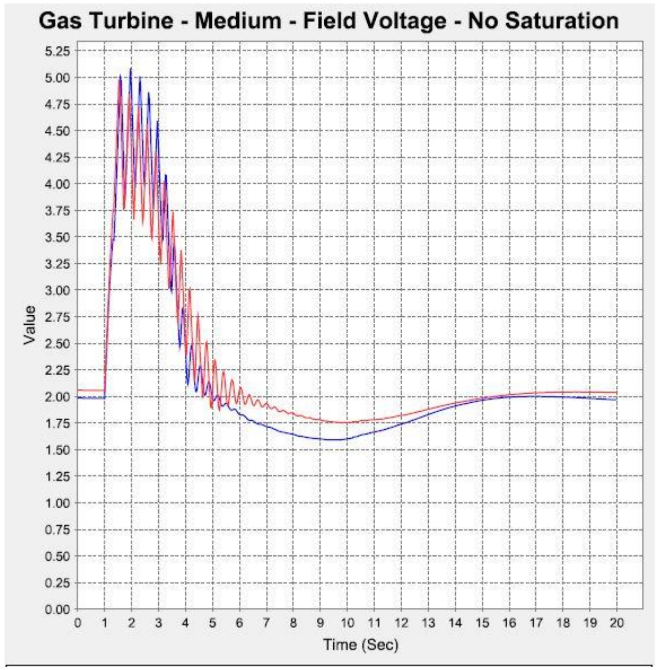
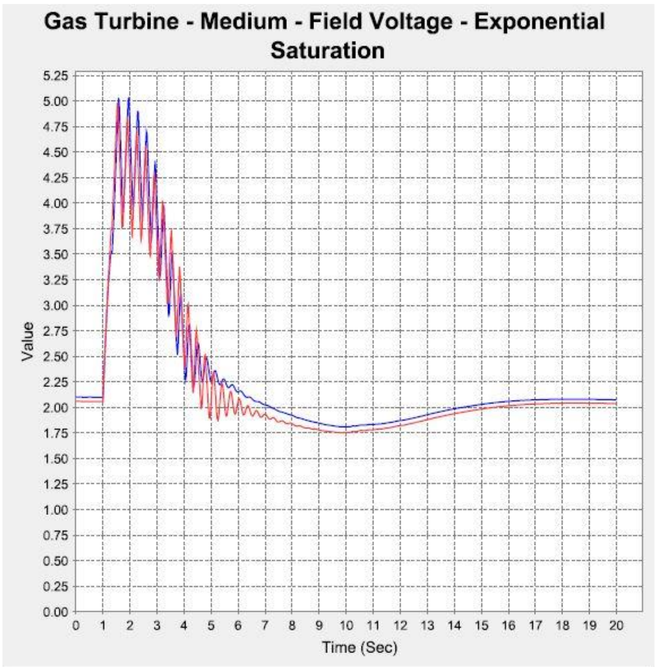
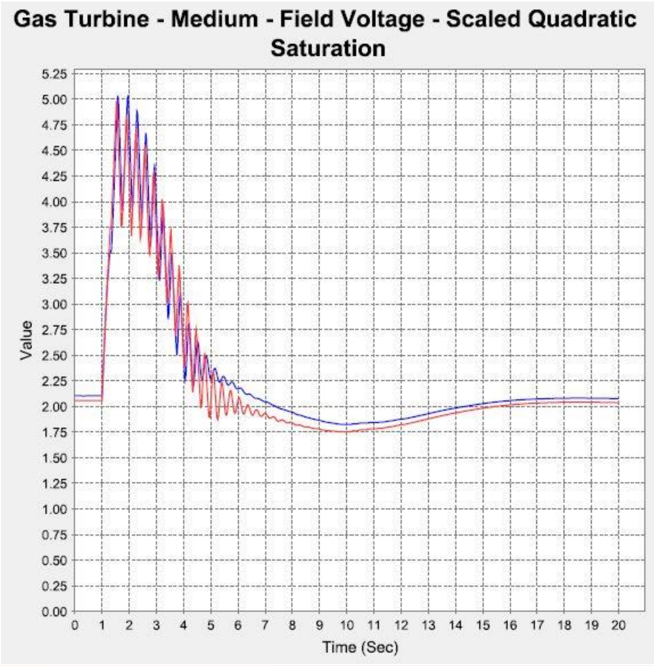
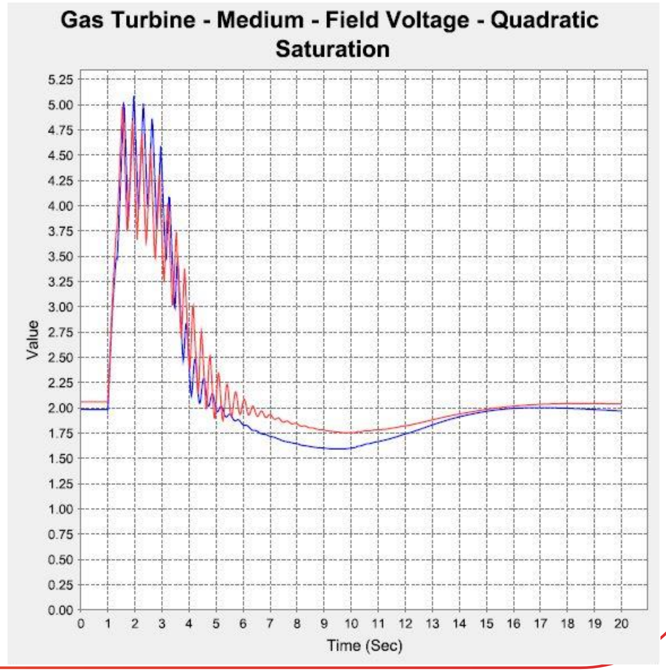
Field Voltage (edf)

- Exponential is a closer fit
- Scaled Quadratic is a close second
- No-Saturation and Quadratic don't follow final damping swing









Gentpj
Genqec

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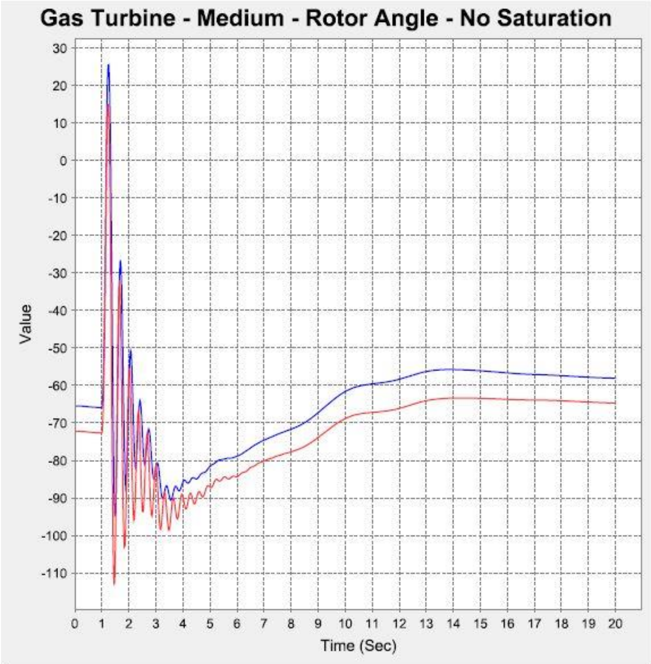
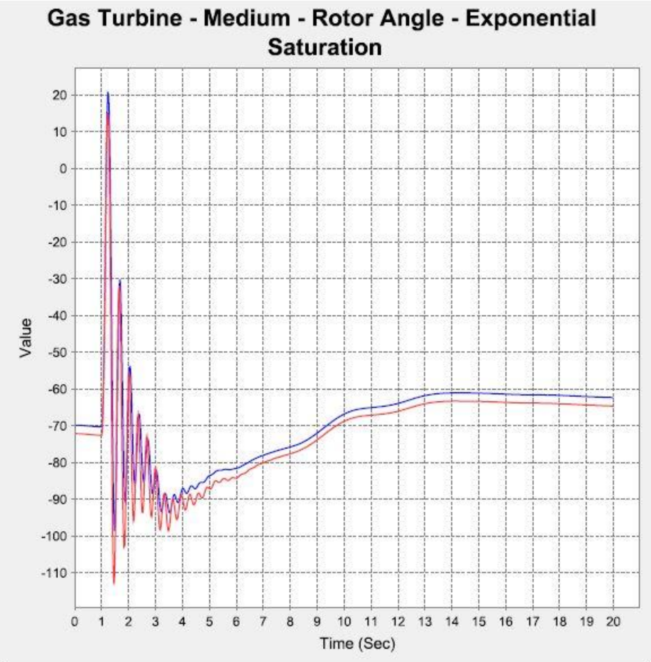
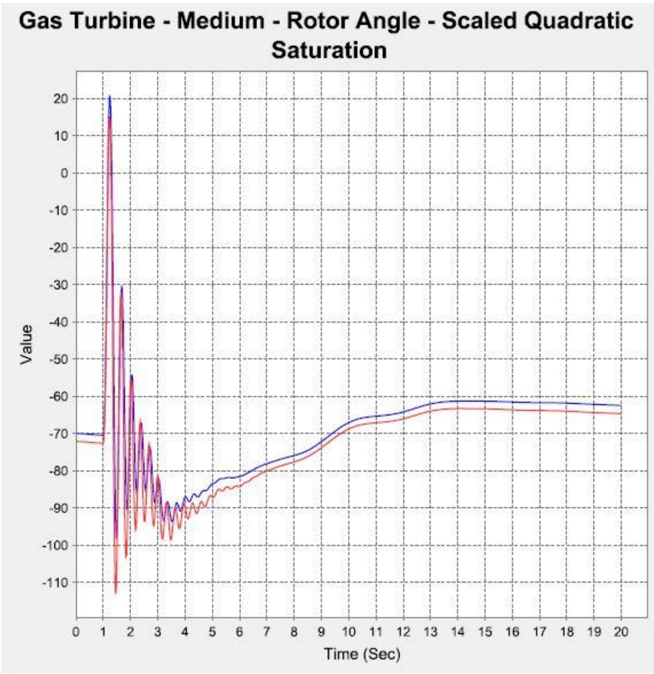
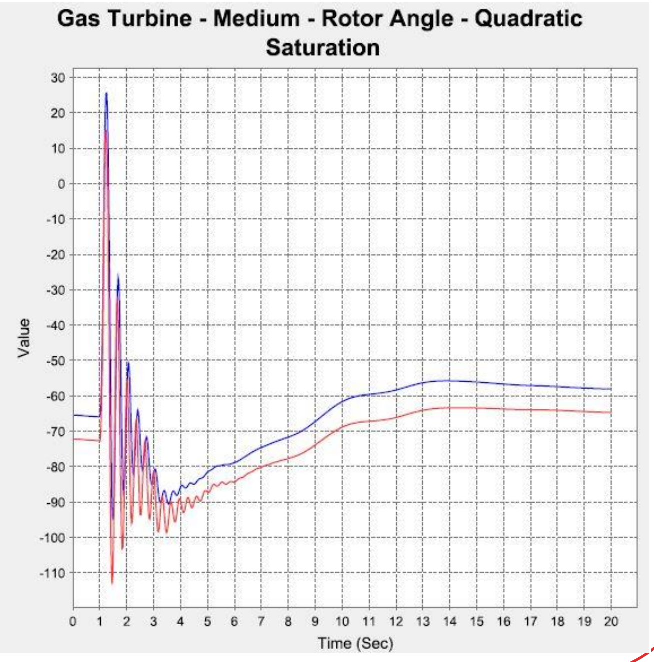
Rotor Angle (ang)

- Scaled Quadratic is a closer fit
- Exponential is a close second
- No-Saturation and Quadratic have a bigger off-set, dampen quicker, and the frequency of rotor angle oscillation deviates slightly









Gentpj

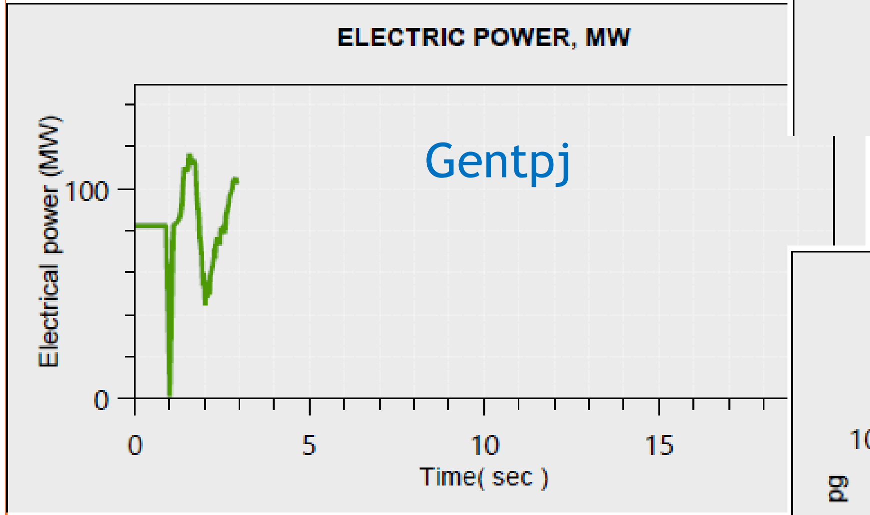
Genqec

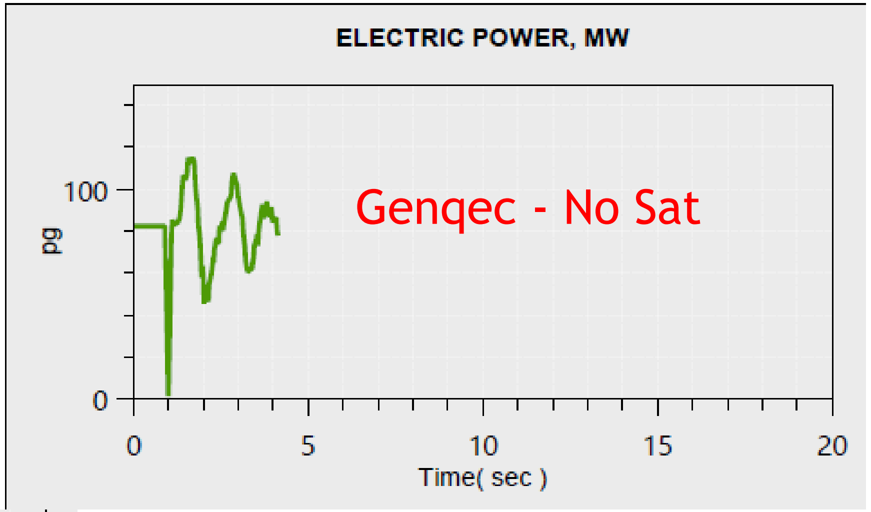
Gentpj comparison to Genqec - Example 1

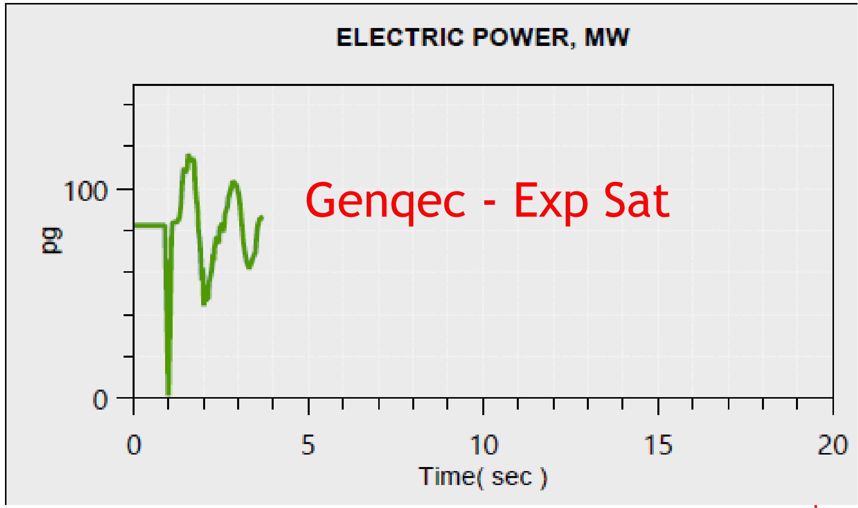
- gas turbine (single shaft, does not include turbine part)
  - Type 11
- Pmax = 105.0 MW
- Pmin = 24.0 MW
- Base = 155.07 MVA
- Kis = 0.12

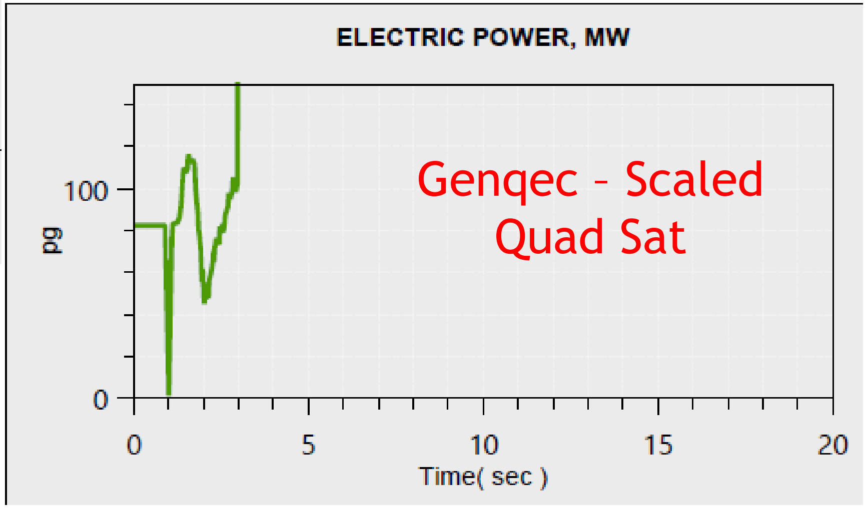
- Exponential is a closer fit
- Scaled Quadratic is a close 2nd
- No-Saturation and Quadratic are often similar to each other and are ranked 3rd

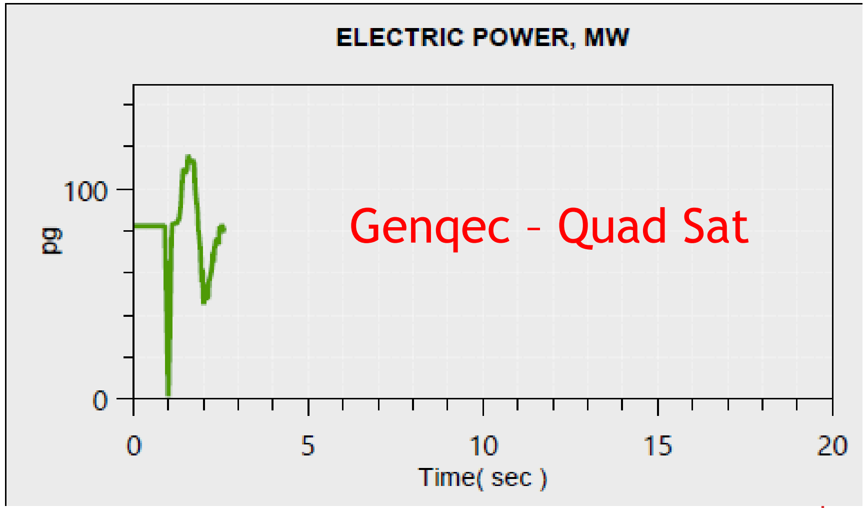
Example 2


ELECTRIC POWER, MW
Gentpj
Electrical power (MW)
100
0
0
5
10
15
Time(sec)


ELECTRIC POWER, MW
Genqec - No Sat
pg
100
0
0
5
10
15
20
Time(sec)


ELECTRIC POWER, MW
Genqec - Exp Sat
pg
100
0
0
5
10
15
20
Time(sec)


ELECTRIC POWER, MW
Genqec – Scaled Quad Sat
pg
100
0
0
5
10
15
20
Time(sec)

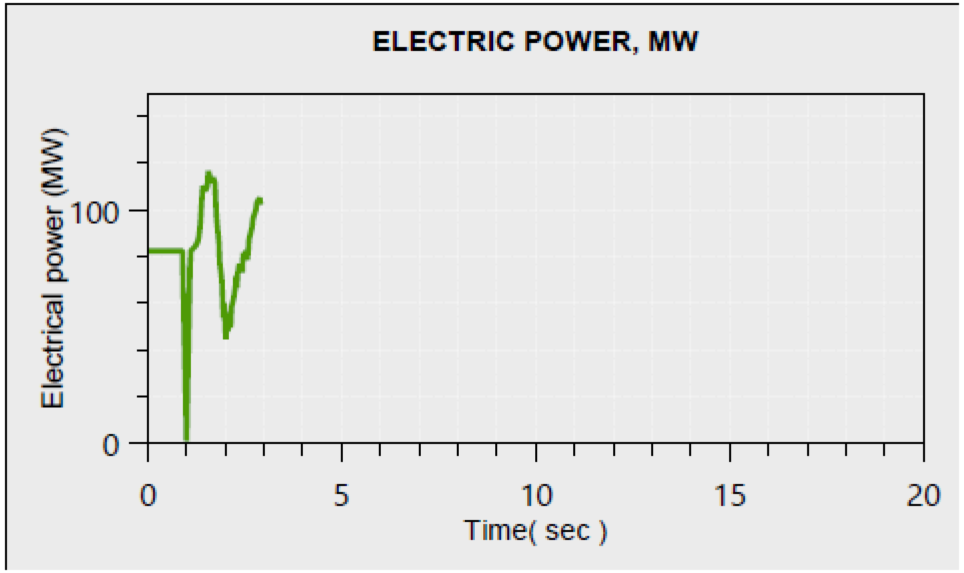

ELECTRIC POWER, MW
Genqec – Quad Sat
pg
100
0
0
5
10
15
20
Time(sec)

Gentpj comparison to Genqec - Example 2

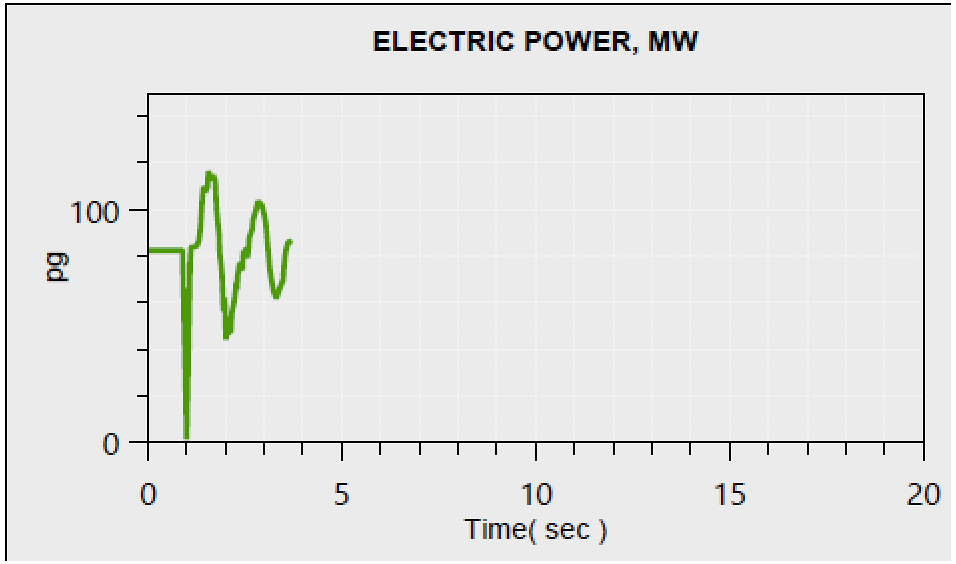
- Using a simple bump test
- Unknown turbine type
  - Type 0
- Pmax = 82.5 MW / Pmin = 0.0 MW
- Base = 97.0 MVA
- Kis = 0.03
- Based on a round Rotor Machine (genrou model)

- No Saturation Performs better, followed by Exponential Sat

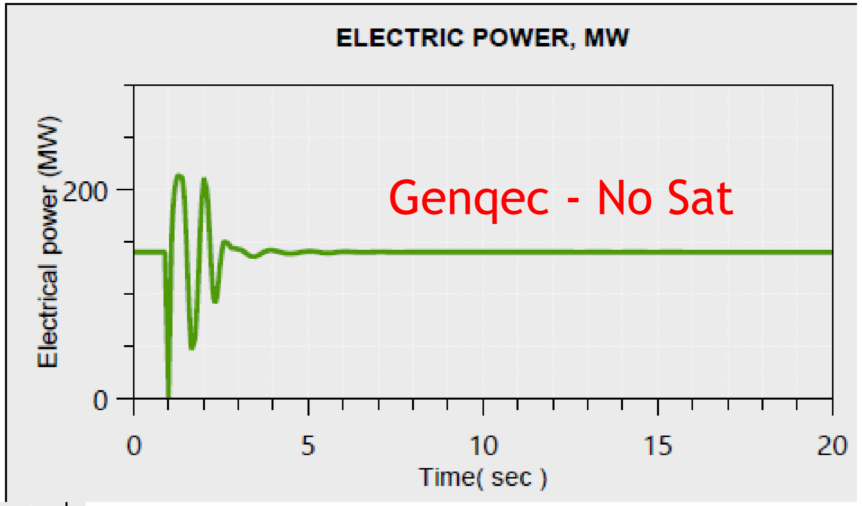
Gentpj

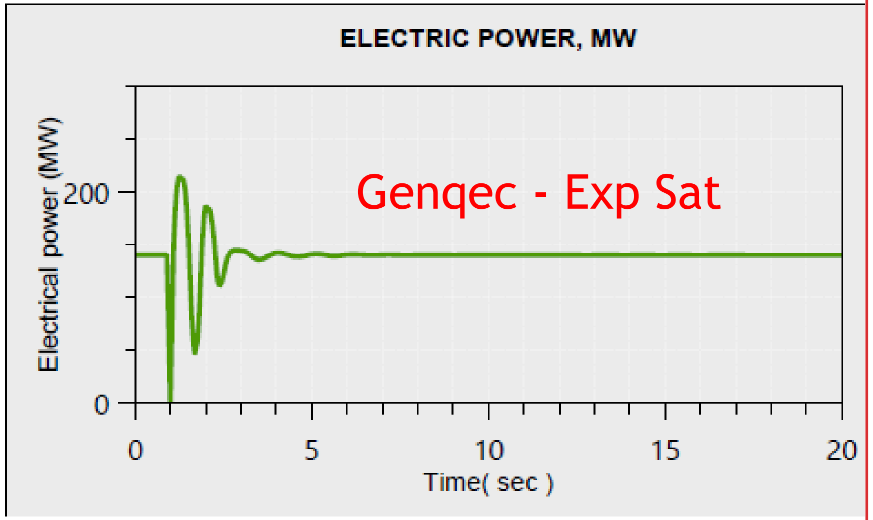


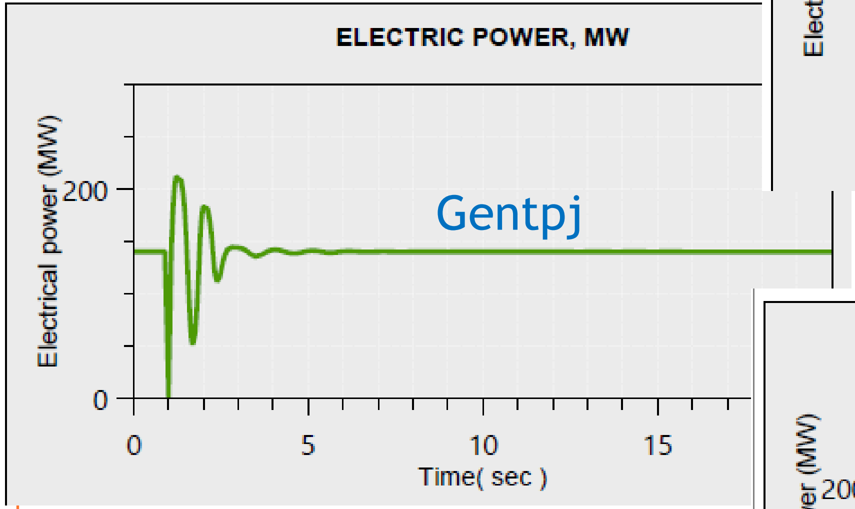
Genqec
Exp Sat

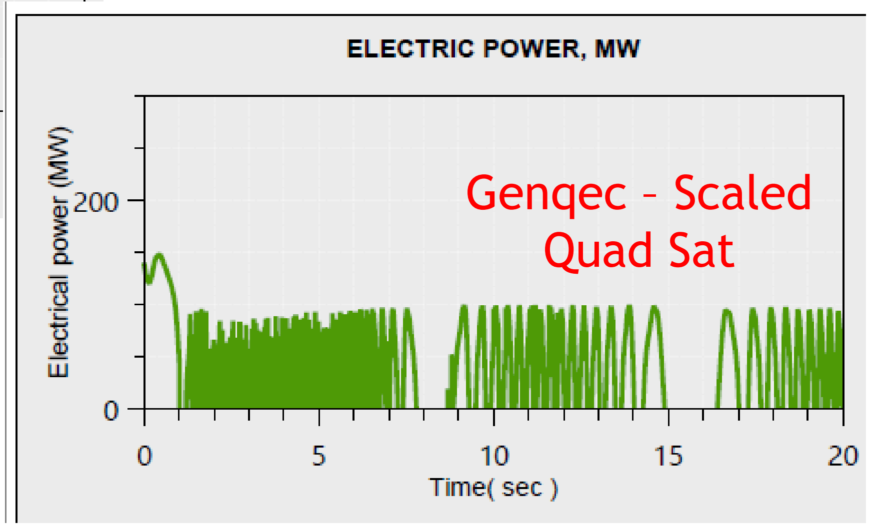


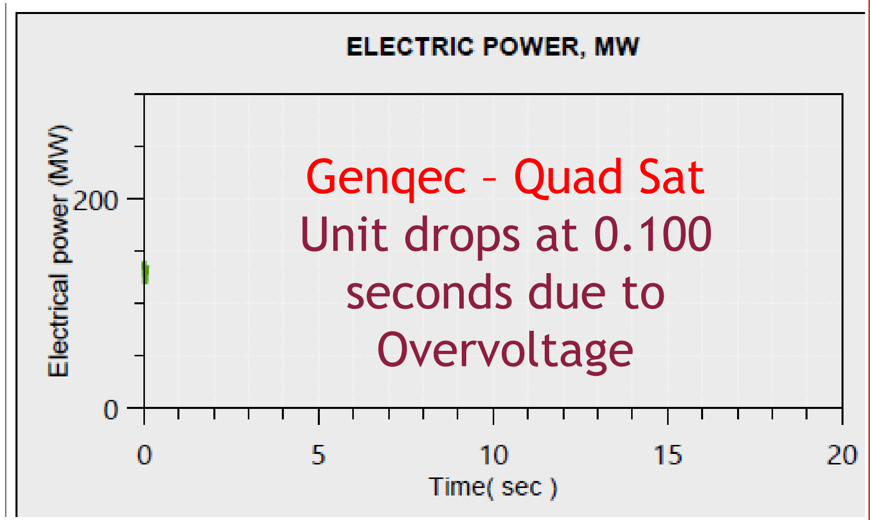
Example 3


ELECTRIC POWER, MW
Genqec - No Sat
Electrical power (MW)
200
0
0 5 10 15 20
Time(sec)


ELECTRIC POWER, MW
Genqec - Exp Sat
Electrical power (MW)
200
0
0 5 10 15 20
Time(sec)


ELECTRIC POWER, MW
Gentpj
Electrical power (MW)
200
0
0 5 10 15
Time(sec)

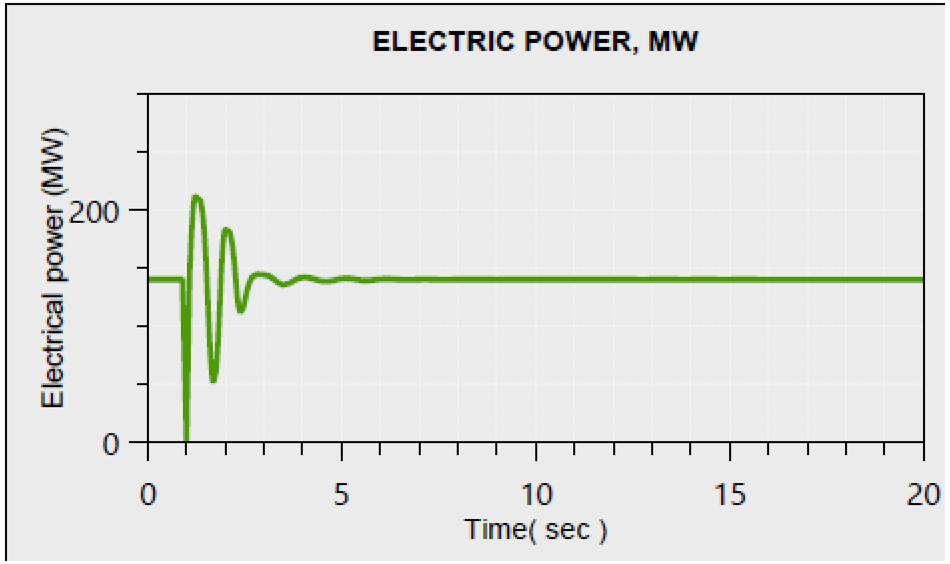

ELECTRIC POWER, MW
Genqec - Scaled
Quad Sat
Electrical power (MW)
200
0
0 5 10 15 20
Time(sec)


ELECTRIC POWER, MW
Genqec - Quad Sat
Unit drops at 0.100
seconds due to
Overvoltage
Electrical power (MW)
200
0
0 5 10 15 20
Time(sec)

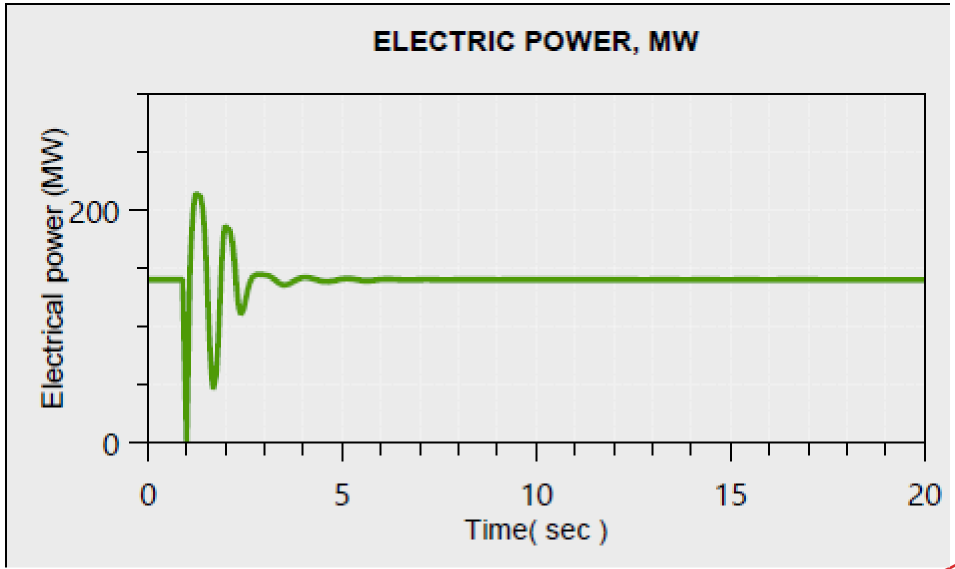
Gentpj comparison to Genqec - Example 3

- Using a simple bump test
- Unknown turbine type
  - Type 0
- Pmax = 142.0 MW / Pmin = 0.0 MW
- Base = 142.0 MVA
- Kis = 0.040
- Based on a Salient Pole Machine (gensal model)
- Exponential Saturation Performs better, followed by No Saturation
- Scaled Quad and Quad have troubles
- To be fair, this unit was dispatched above its Pmax and Base

Gentpj



Genqec
Exp Sat



Gentpj update to Genqec General Early Observations

- Look forward to field validating Genqec models
- The new Genqec Kis parameter should be field verified using
  - WECC White Paper on Genqec Model in Power System Studies, Aug 12, 2021

- In general
  - In most instances Genqec models performed better than Gentpj
    - Although in a very few instances Gentpj model performed better
      - May be dependent on what Saturation Type (Satflg) is selected
  - Curve matching to the existing Gentpj models
    - Not recommending this or advocating this, but
    - Better and closest match comes with Satflg = 0 – Exponential saturation
      - Could serve as starting point to curve match field data

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