Long-Term Dynamic Simulation of Power Systems using Python, Agent Based Modeling, and Time-Sequenced Power Flows

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Montana Technological University - Master Thesis Defense

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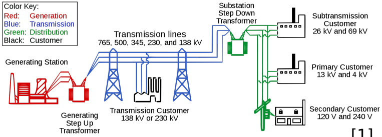
Power Systems

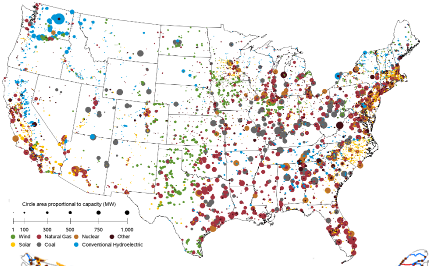
Physical Structure

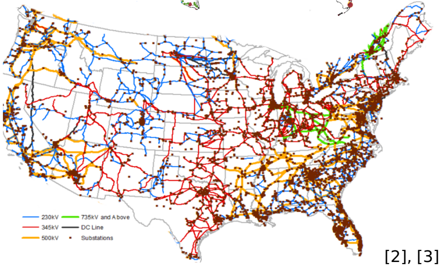
- Research focus on alternating current (AC) transmission level



[1]

- Generation,
  Step-up Transformers,
  High Voltage Transmission,
  Step-down Transformers,
  Customers



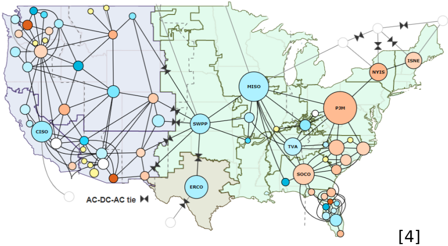


[2], [3]

Power Systems

Operational Structure

- Balancing Authorities (BAs)
  - Balance supply and demand
  - Forecasts (predictions)
  - Monitor system
  - Manage area control error (ACE)
  - Create dispatches
  - Buy and sell electricity
  - Follow mandatory reliability standards
- NERC
  North American Electric Reliability Corporation
- FERC
  Federal Energy Regulatory Commission



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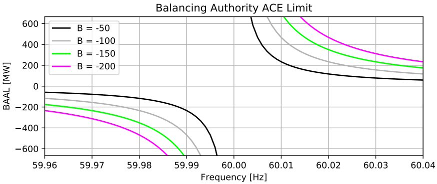
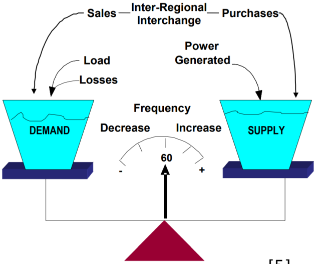


Automatic Frequency Controls

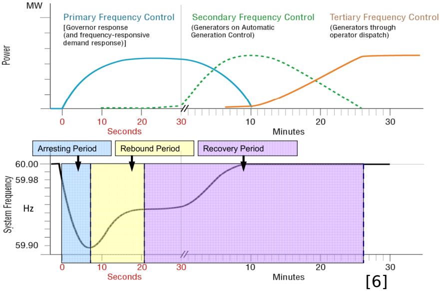
- Demand is always changing.



[5]

$$\dot{f}_{sys} \approx \frac{P_{supply} - P_{demand}}{2H_{sys} f_{sys}} \qquad (1)$$

- Primary Control
  ≈ Turbine Speed Governors
- Secondary Control
  ≈ Automatic Generation Control (AGC)



[6]

Dynamic Simulation

PowerWorld Corporation Simulator 21

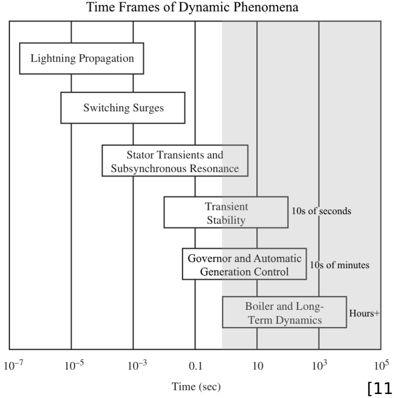
Energy Consulting GE PSLF 21

SIEMENS PSSE 34.7

RTDS Technologies RSCAD 4

[7]–[10]

- Power system simulation software exists.
- Dynamic focus often on transient events.



[11], [12]

- Long-term dynamics exists outside of transient stability.

Research Goal 1

- Create software that performs long-term dynamic (LTD) simulations of AC power systems.

LTD software is required to simulate long-term events of engineering interest.

- AGC action and tuning
- Long-term event recreation and study

Research Goal 2

- Software must be expandable and accommodate systems of various size and composition.

Realistic power system topographies vary in size and composition.
Software should be reusable for future research.

Research Goal 3

- Simulation results must be validated and engineering applications demonstrated.

Show the viability and usefulness of the created software as an engineering tool.

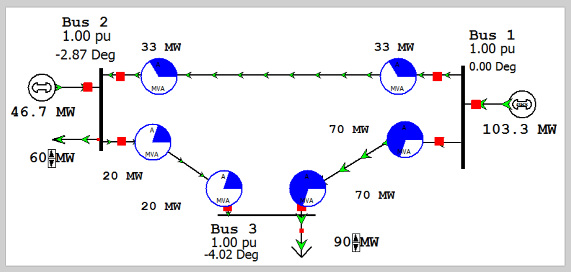
Research Approaches

- Incorporate PSLF power-flow solver, system models, and dynamic model information into software.
  - Avoid starting from scratch.
- Validate using PSLF dynamic simulation (PSDS).

Research Approaches

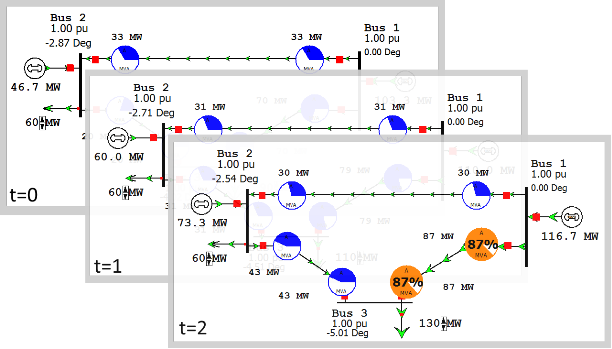
- Write software in Python
- Apply agent based modeling (ABM)
  - Any situation can be described by agents in an environment, and a definition of agent-to-agent and agent-to-environment interactions [13].
  - In this case:
    Environment $\longrightarrow$ power system
    Agents $\longrightarrow$ areas, BAs, generators, loads, etc.
  - Naturally modular and scalable
- Use time-sequenced power flow (TSPF) technique

Power-Flow Solution



- A steady state power system solution (power injections and voltage phasors of every bus)
- Power flows are not dynamic.

Time-Sequenced Power Flows



- Sequence of power-flow solutions.
- Dynamic modeling calculations performed between each power-flow solution.

TSPF Simplifications

- Single system frequency based on system intertia.

$$\dot{\omega}_{sys} = \frac{1}{2H_{sys}} \left(\frac{P_{acc,sys}}{\omega_{sys}} - D_{sys} \Delta\omega_{sys} \right) \tag{2}$$

$$P_{acc,sys} = \sum_{i=1}^{N} P_{m,i} - \sum_{i=1}^{N} P_{e,i} - \sum \Delta P_{pert} \tag{3}$$

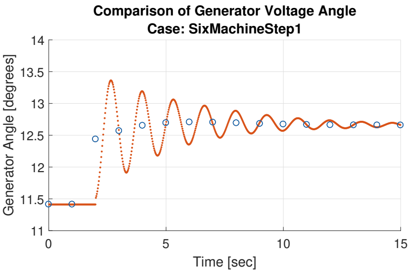
$$H_{sys} = \sum_{i=1}^{N} H_{PU,i} M_{base,i} \tag{4}$$

- Generator power estimates based on ratio of inertia.

$$P_{e,EST,i} = P_{e,i} - P_{acc,sys} \left(\frac{H_i}{H_{sys}} \right) \tag{5}$$

TSPF Assumptions

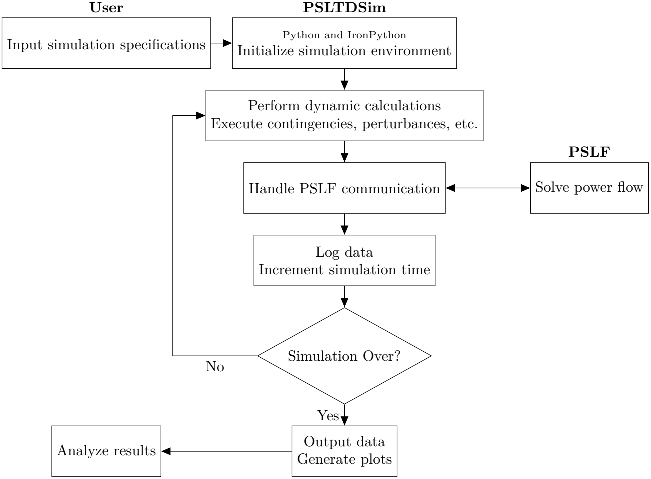
- System transient stable
  (i.e. remains synchronized)
- Ideal exciters
- Long-term behavior more important than transient behavior
- 1 second time steps are adequate to capture dynamics of interest



PSLTDSim

- Uses a time-sequence of power flows and select dynamic calculations to simulate LTD power system behavior.
- Python based
- Relies on GE PSLF

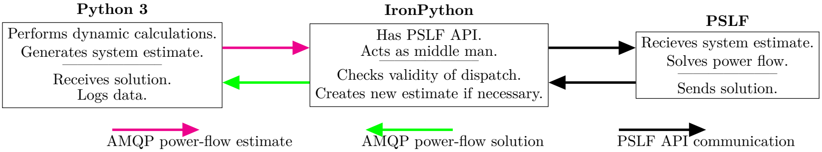
High Level Software Overview



PSLTDSim AMQP Overview

Advanced Message Queuing Protocol

- Uses a ‘virtual broker’ for handling messages.
- Allows for inter-process communication.



Current Software Capabilities

Perturbance Agents

- Steps
- Ramps
- Load Noise
- Forecast / Demand

Governor Modeling

- Simplified model
- Generic casting process
- Optional deadband
- Input filtering and delays

BA Modeling

- ACE calculation
- Verify adherence to federal mandates
- Customizable AGC model

Definite Time Controller

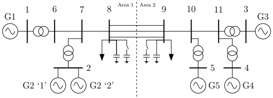
- ≈Programmable logic control
- Act as relays, shunt controllers, etc.

Modifiable System Parameters

- System damping
- Variable system inertia

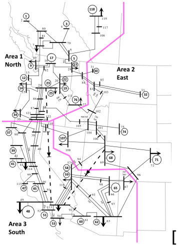
Validation Systems

Six machine



- 2 Areas
- 11 Buses
- 6 Generators
- 2 Loads

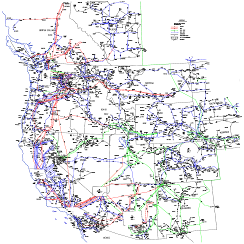
Mini WECC



[14]

- 3 Areas
- 120 Buses
- 34 Generators
- 23 Loads

Full WECC

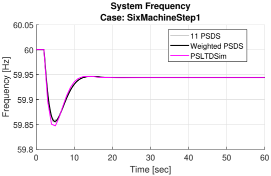


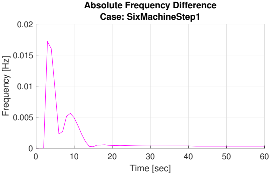
[15]

- 22 Areas
- 21,879 Buses
- 4,231 Generators
- 11,048 Loads

Step Event - Frequency results

Six machine





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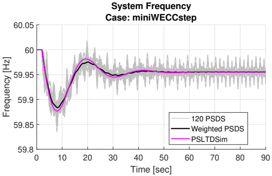
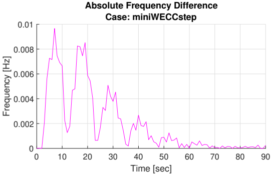
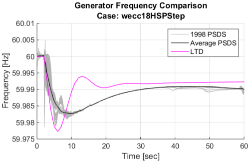
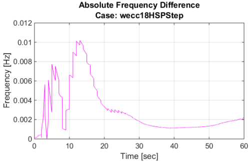


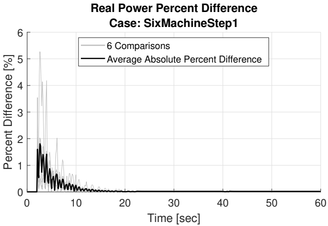


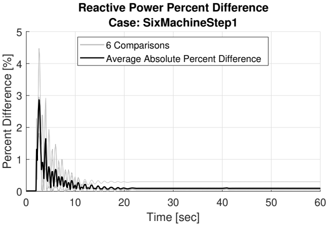
Full WECC

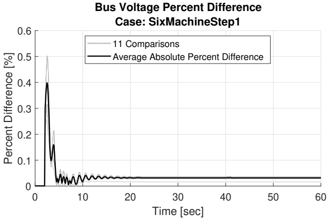


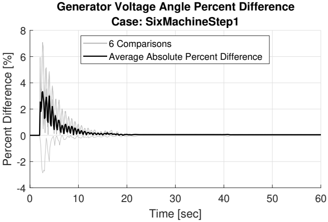


Six Machine PQVδ Comparisons

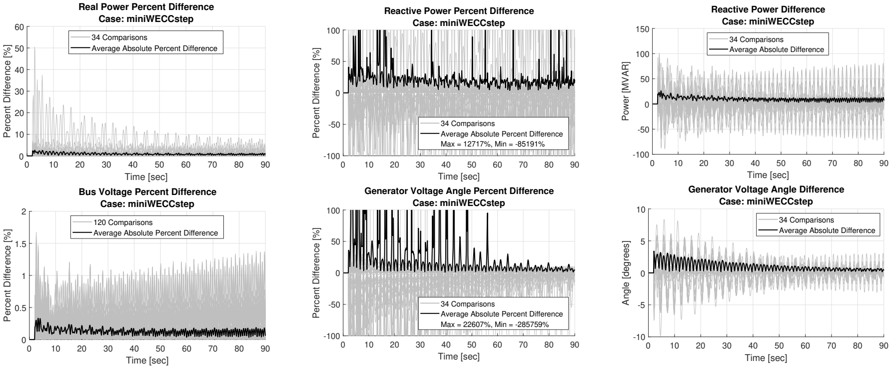




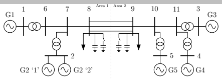




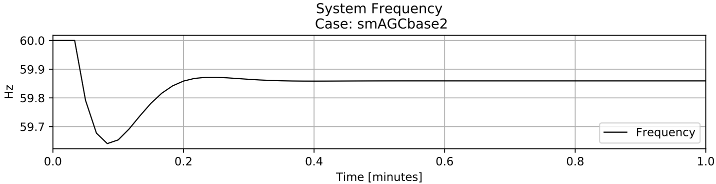
Mini WECC PQVδ Comparisons

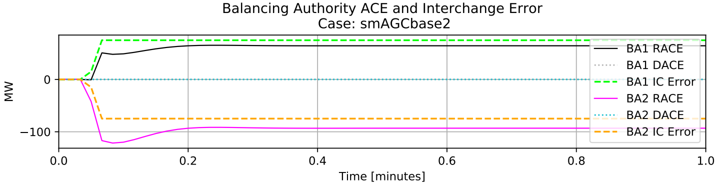


AGC Tuning

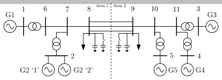


Two Area Six Machine - Loss of Generation - No AGC Response

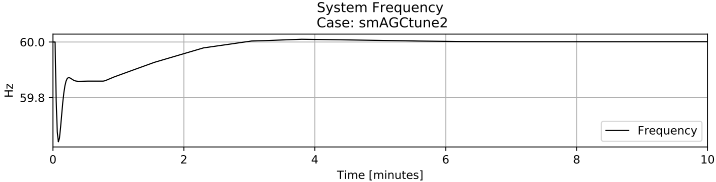


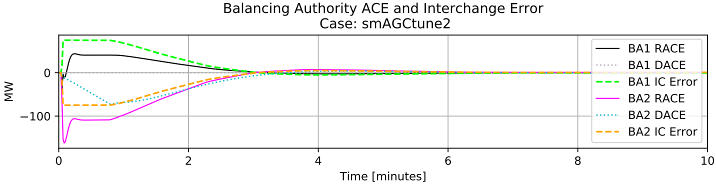


AGC Tuning

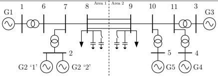


Ideal Control Response

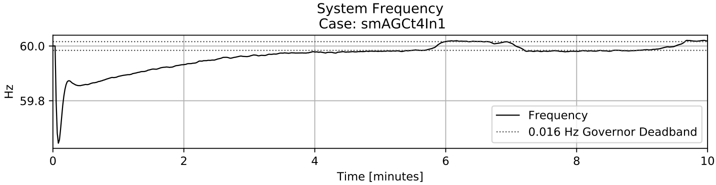


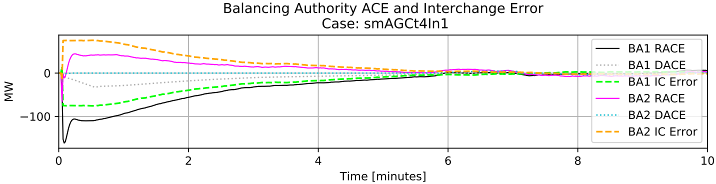


AGC Tuning

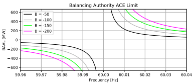


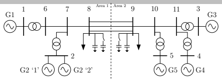
Added load noise and governor deadbands



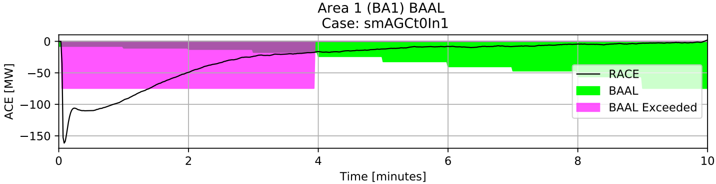


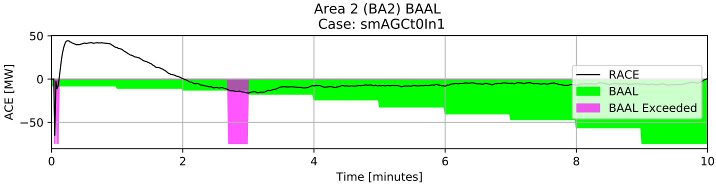
AGC Tuning



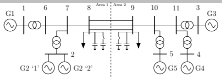


Adherence to federally mandated BA ACE limit (BAAL)

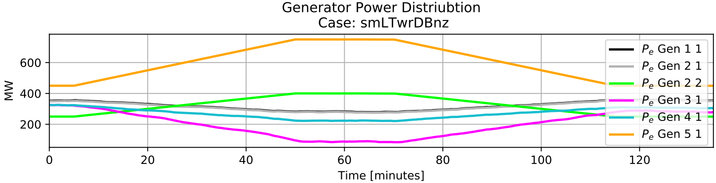


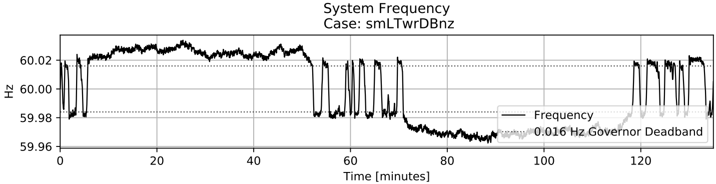


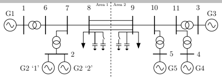
Virtual Wind Ramp



Effect of noise and deadbands on frequency

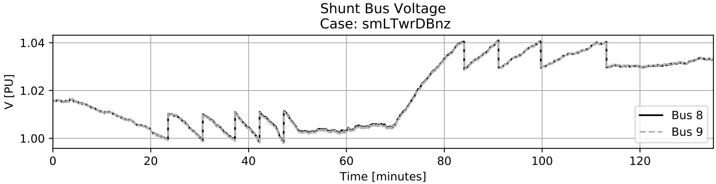


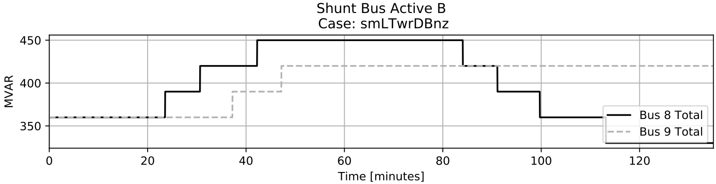




Virtual Wind Ramp

Definite time controller voltage control

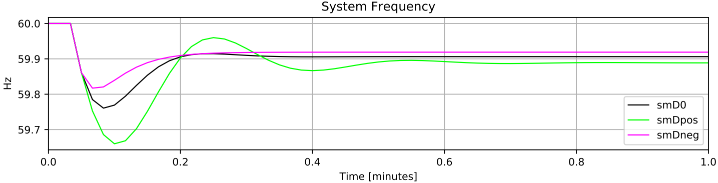


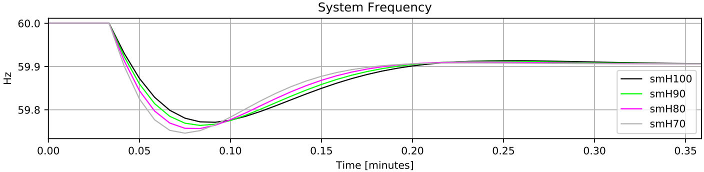


Simulation Modifications

Variable system damping and inertia

$$\dot{\omega}_{sys} = \frac{1}{2H_{sys}} \left(\frac{P_{acc,sys}}{\omega_{sys}} - D_{sys} \Delta\omega_{sys} \right), \; \Delta\omega_{sys} = \omega_{rated} - \omega_{sys}$$





Conclusions

- All research goals met.
- PSLTDSim:
  - Successfully simulates LTD events.
  - Handles various system topographies.
  - Was validated against an industry standard transient software.
- Engineering applications exist.
- Future research work is possible.

Possible Future Work

- Move away from reliance on PSLF
- Incorporate variable time step / transient dynamic capabilities
- Improve code efficiency
- Addition of:
  - Governor models
  - Exponential load characteristics
  - Under-load tap changers
  - Power plant controllers
  - ...

Questions?

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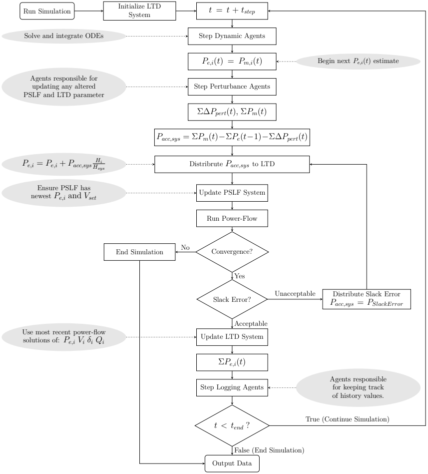
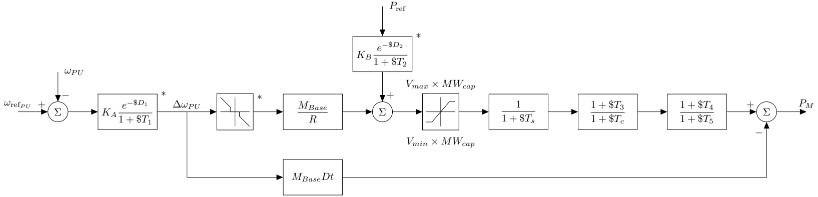
Time Step overview



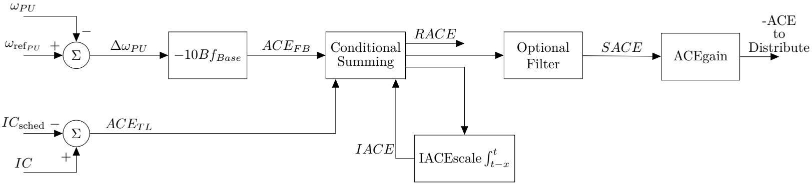
Governor Model Casting

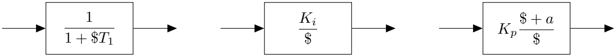


genericGov	Steam	Hydro	Gas
PSDS	ccbt1	g2wscc	ggov1
	gast	hyg3	ggov3
	w2301	hygov4	gpwscc
	ieeeg3	hygov	
	ieeeg1	hygovr	
		pidgov	

Parameter	Steam	Hydro	Gas
Ts	0.04	0.40	0.50
Tc	0.20	45.00	10.00
T3	0.00	5.00	4.00
T4	1.50	−1.00	0.00
T5	5.00	0.50	1.00

BA AGC Model





$$RACE = (NI_A - NI_S) - 10B(F_A - F_S) - I_{ME} + I_{ATEC} \qquad (6)$$

WECC Governor Details

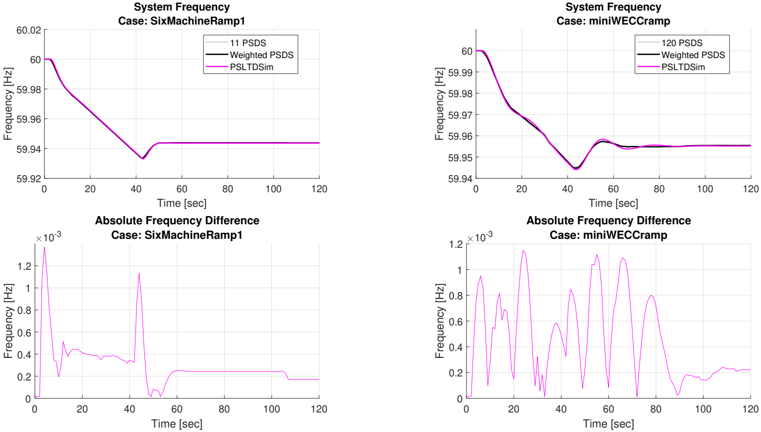
Model	Count	Capacity [MW]
ggov1	1,006	74,804.11
hyg3	315	28,755.47
hygov	196	8,883.36
ieeeg1	191	49,022.45
hygov4	167	8,044.68
ieeeg3	133	9,174.48
gpwscc	56	3,028.33
pidgov	56	8,034.54
gast	29	1,162.56
ggov3	28	5,010.32
hygovr	25	6,249.37
tgov1	20	1,140.45
g2wscc	18	818.95
ccbt1	3	32.53
Total	2,243	204,161.59

Model	Count	Capacity [MW]
gas	1,090	82,842.76
hydro	777	60,786.37
steam	356	59,392.02
tgov1	20	1,140.45
Total	2,243	204,161.59

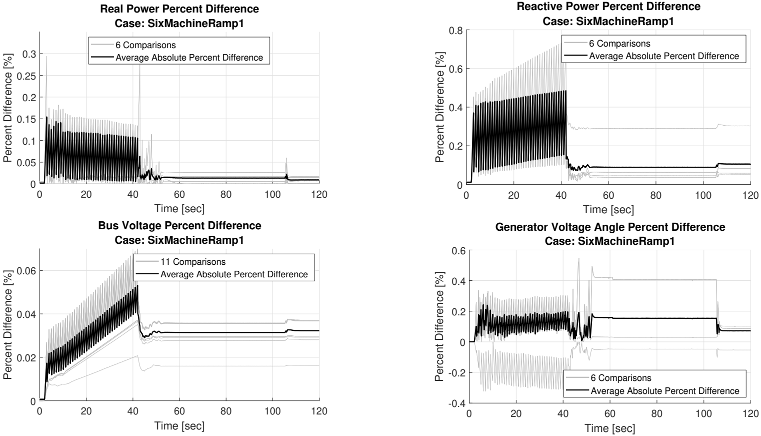
Ramp Event - Frequency results

Six machine

Mini WECC



Six Machine PQVδ Comparisons



Mini WECC PQVδ Comparisons