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Protection Modeling and Dynamic Model Validation – A Real-World Case Study for Puerto Rico

Nov 7-10, 2022

Introduction

- Dynamic model requirement for planning and event analysis
- Protective relay models in islanded systems (generation and load shedding)
- Governor models impact on frequency response in islanded systems
- Application of measurement data following an event in the system for model validation

Protection Scheme

- Generator Protection

Under/Over Frequency Generator Trip Relays (**FRQTPAT**) relay models are used in PSS/E **(standard library)** to demonstrate the generator under/over frequency protective relays.

- Load shedding scheme

LDSHBL relay model, which is an underfrequency load shedding protective relay in PSS/E has been utilized. This model has three frequency points, and there is a load shed percentage setting according to each frequency point that determines the amount of load that should be shed if the corresponding frequency point is violated.

When there is a rate of change of frequency (RoCoF) setting for the relays, the **DLSHBL** relay type is available in the **PSS/E standard model library**.

Protection Scheme – cont’d

- Under Frequency Line Tripping (UFLT) Relays

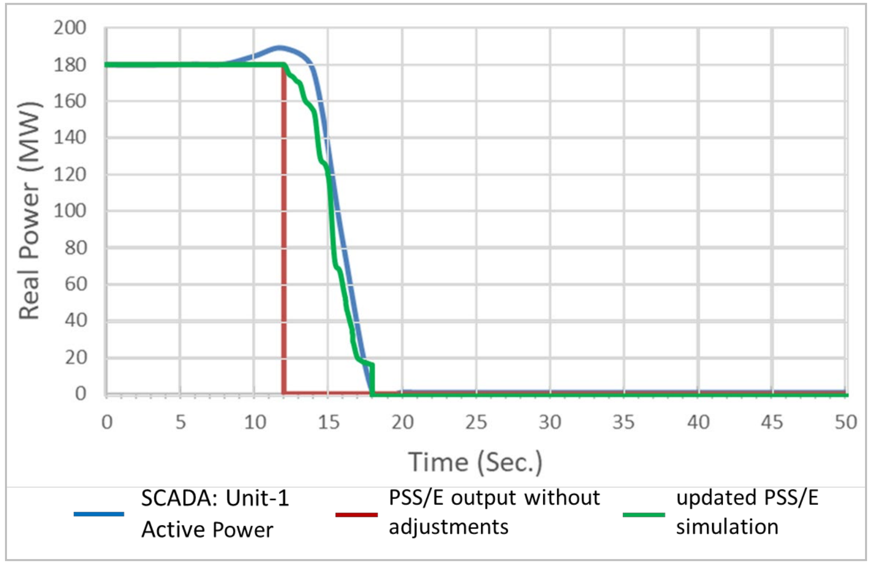
In some instances, entire taps and/or lines between the buses or substations are the targets of the load shedding. To this end, all the circuits and loads between the two ends of the desired section are disconnected after a specified time delay when the underfrequency threshold is met.

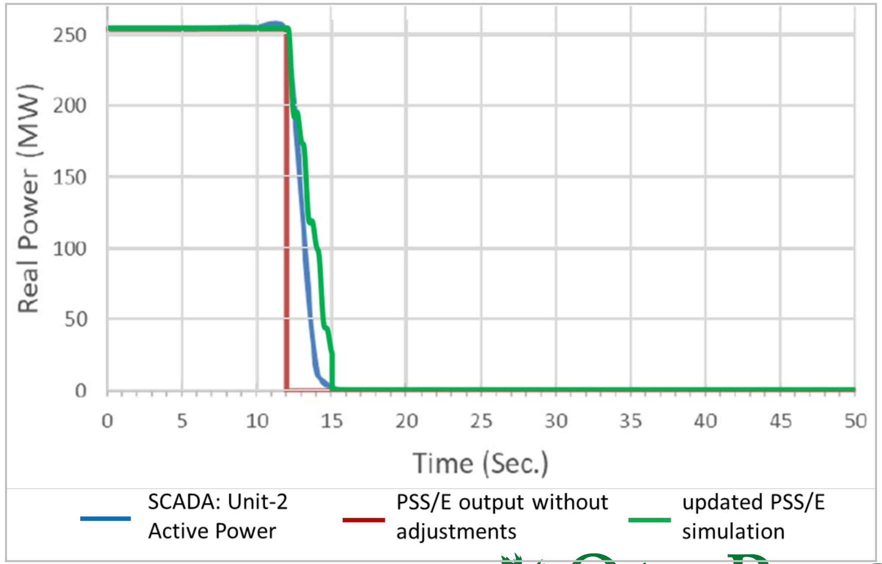
To model this type of relay, a **user-defined** relay model, namely, the **UFLT** relay, has been employed.

From Bus, *To Bus*, frequency threshold, and time delay are the necessary inputs for this model.

Results: Case I - Two Generation Units Tripping

- Two critical generation units generating **254 MW and 180 MW tripped simultaneously, totalling 434 MW** of generation loss.
- In-service units began to adjust their generation considering their governor's dead band and droop settings. Based on the simulations, a large number of in-service units responded to the generation loss through their governor actions (**PSS/E output without adjustments**).
- Only three units had considerable governor contributions based on SCADA data. So, the governors of the rest of the units were disabled in PSS/E to mimic the reality of the event (**updated PSS/E simulation**).





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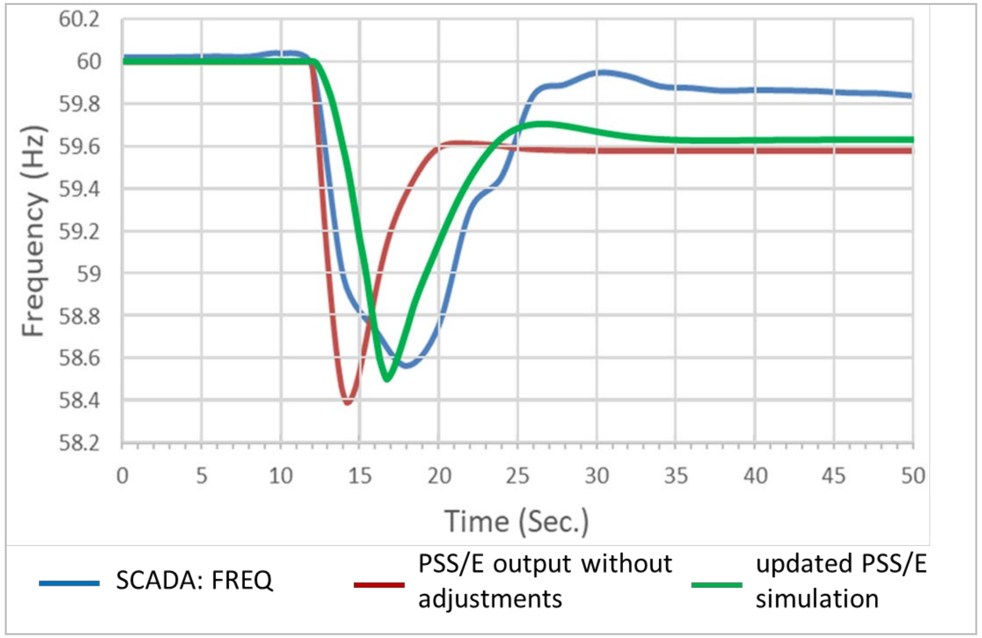
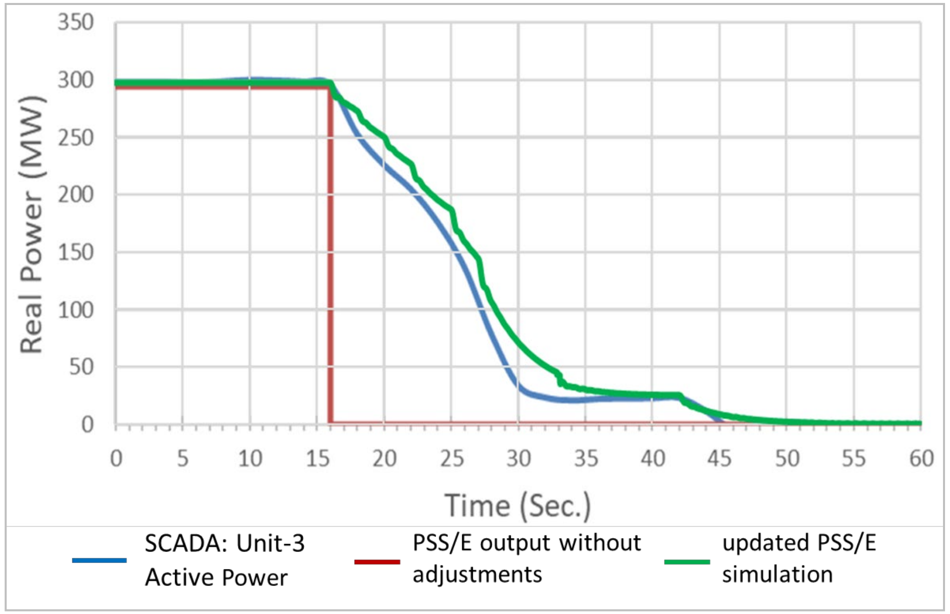
Results: Case I - Two Generation Units Tripping - cont'd

- Total generation drop: 434 MW.
- The SCADA measurements show that only 59 MW of this loss is compensated by generation increase, implying that almost 375 MW of the generation loss is compensated by load shedding actions.
- The updated underfrequency relay models in PSS/E with the existing UFLT models resulted in a load shed of 248.5 MW, which is less than the MW load shed obtained from SCADA.



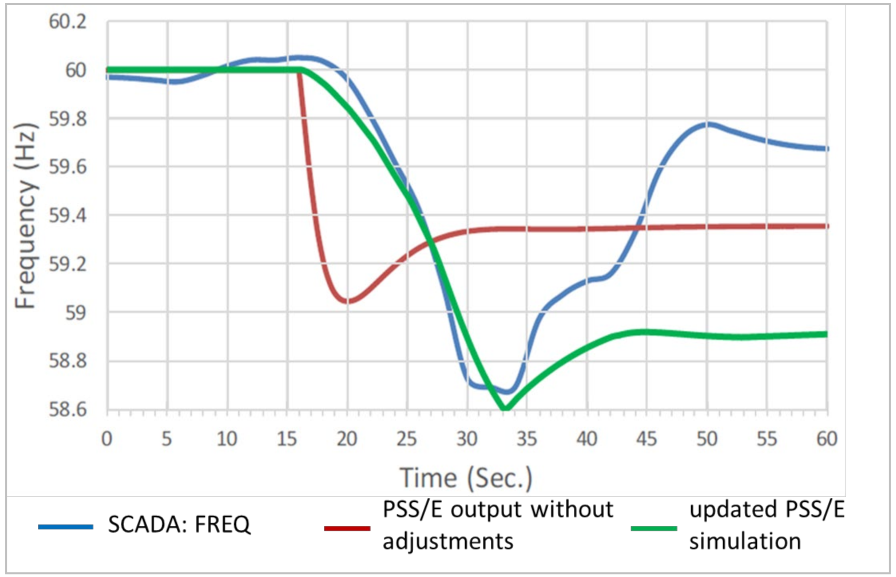
Results: Case II - A Large Generation Unit Tripping

- One of the critical units which was generating 300 MW, tripped.



Results: Case II - A Large Generation Unit Tripping - cont'd

- Total generation drop: 279.9 MW.
- The SCADA measurements show that only **49.6 MW** of this loss is compensated by a generation increase, implying that almost **248.3 MW** of the generation loss was compensated by load shedding actions.
- The updated underfrequency relay models in PSS/E resulted in 100 MW of load shed, which is less than the amount reported by SCADA records.
- matching the frequency recovery requires tuning the parameters of the active governors obtained from machine datasheets or field tests.



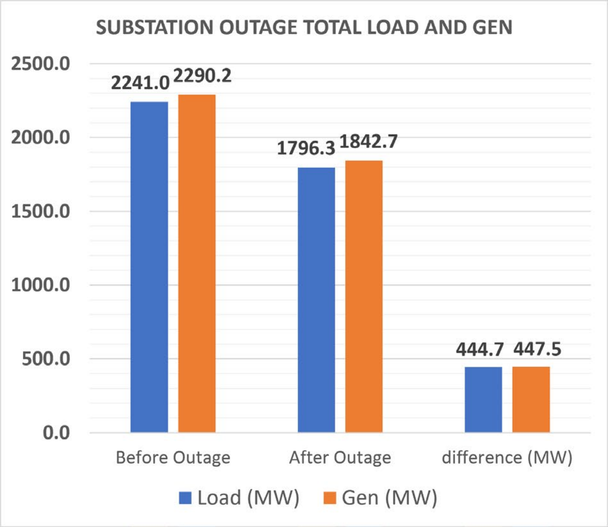
Results: Case III – Generation Mix Impact Analysis

- Impact of a three-phase fault at a critical substation followed by the whole substation outage on the grid stability.
- The system is in a steady state until t = 2 sec. at which time a three-phase fault occurs at the substation. The fault remains on the bus for seven cycles until the entire substation (all voltage levels) is disconnected.
- This event is simulated on the **Case III generation mix** <u>and</u> the generation mix of **Case I**.

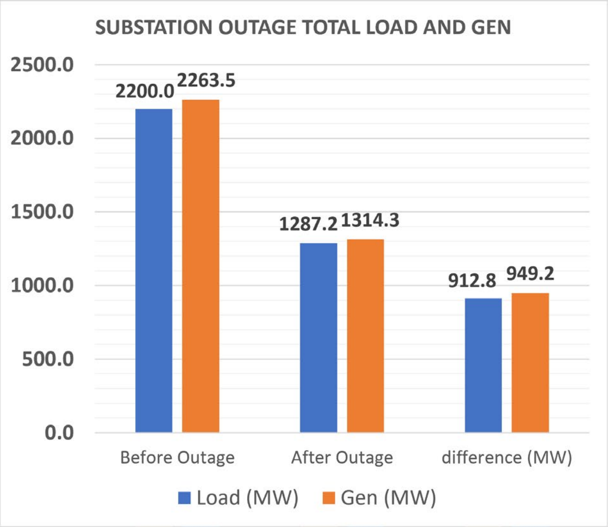
Results: Case III – Generation Mix Impact Analysis on the Frequency Stability

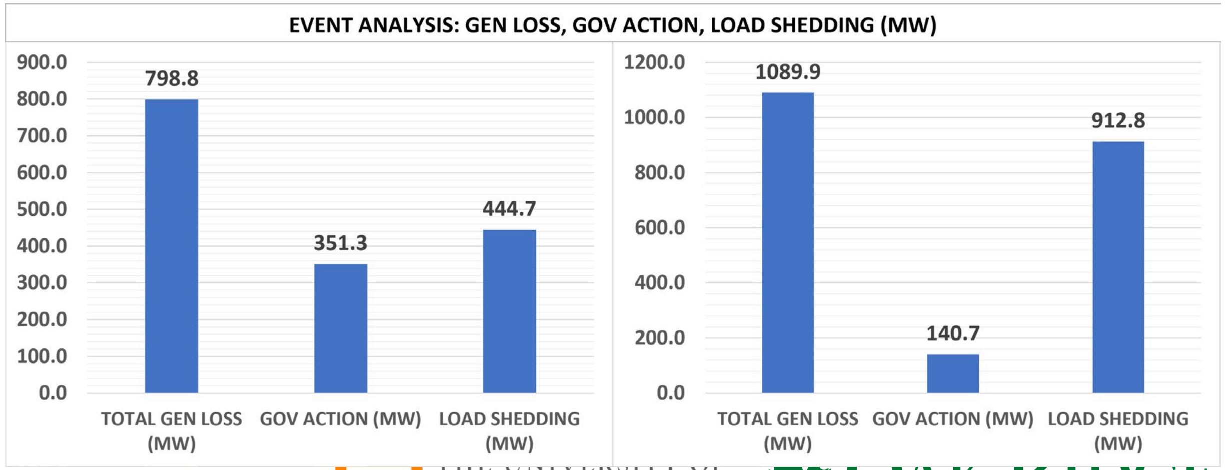
- ✓ maintaining the frequency in the Case I dispatch relies more on the load shedding scheme.

Case III Mix



Case I Mix





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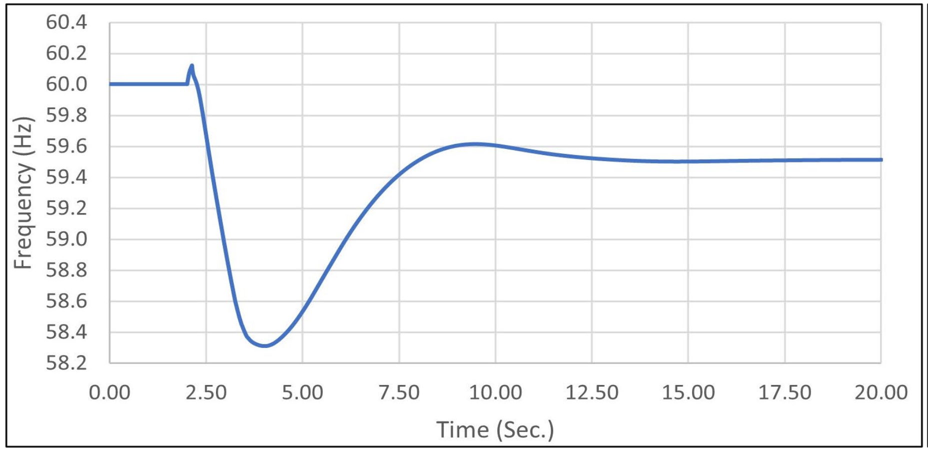
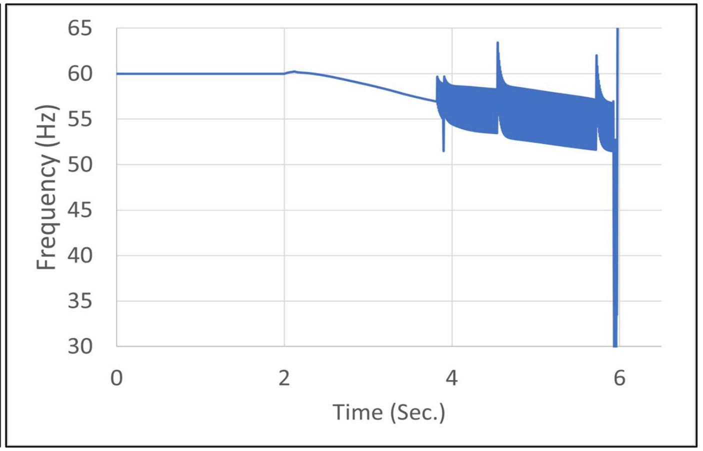
Results: Case III – Generation Mix Impact Analysis on the Frequency Stability





- ✓ The left figure shows the frequency trace of Case I mix with the updated relay time delays and the right-hand side figure shows the frequency of the system when larger time delays are selected.
- ✓ In the latter case, frequency destabilized a few cycles after the event due to the sensitivity of the case to the load shedding scheme.

Frequency Response Validation due to Machine Governor

- Primary focus is to validate governor droop and deadband settings
- Case IV validation event is a loss of 175 MW
- Minimum event frequency measured is 59.02 Hz
- No load shedding is suspected during the event
- Validated powerflow case differed by 3 MW from measurements
- Bus voltage and reactive power is not validated in the powerflow

Results: Case IV - Summary of Governor Validation

- Several machine's governors are disabled since measurement indicates no response during the event
- The recommended settings of deadband (36 mHz) and droop (5%) are based on FERC order 842

Responding Unit	Governor Model	Droop setting	Deadband setting
Swing Bus	IEEESGO	5%	n/a
Unit 1	GGOV1	5%	0.0083 → 0.0006 (36 mHz)
Unit 2	GGOV1	5%	0.0083 → 0.0006 (36 mHz)
Unit 3	GGOV1	20%	0.000 → 0.0006 (36 mHz)
Unit 4	GGOV1	20%	0.000 → 0.0006 (36 mHz)
Unit 5	IEESGO	5% → 20%	n/a
Unit 6	IEESGO	5% → 20%	n/a

Results: Case IV - Governor Validation Results

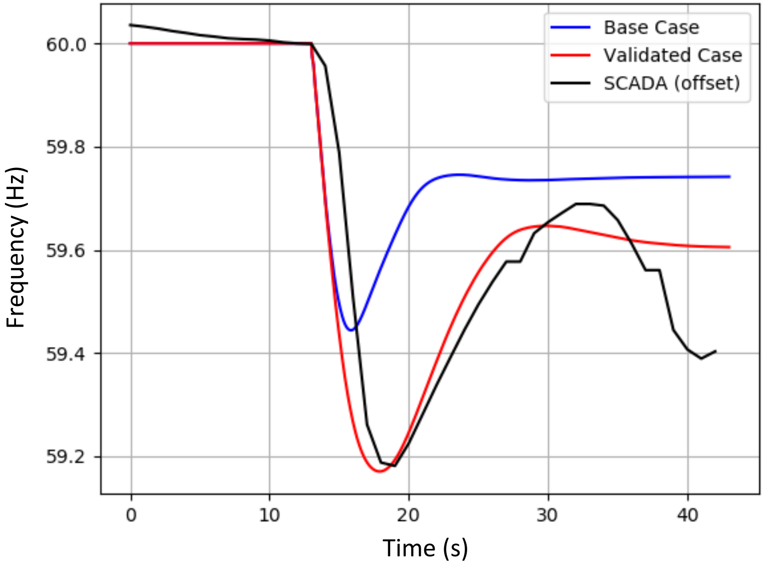
Base Case Model:

- Frequency response recovers much faster than measurements indicate
- Generator governors in the model provide too much support during the disturbance

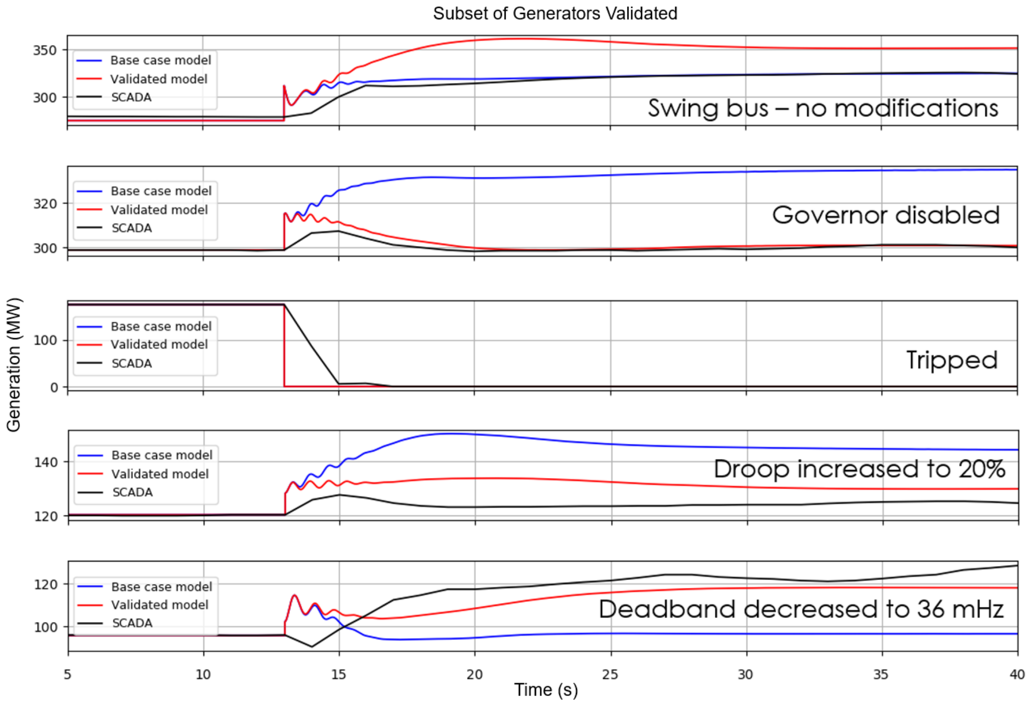
Validated Model:

- Removing the participation of several generator governors shows a more realistic response
- Modifying governor settings of actively participating generators better captures frequency

Frequency Response



Select Generator Response



Time (s)

Conclusion & Future Work

- Frequency relay models have been added for conventional units with available data.
- PRC-024 minimum requirement has been used for frequency and voltage relay of the other units.
- Load shedding relay models (LDSHBL and DLSHBL) are selected based on the PSS/E manual for SUBST data due to the radial structure.
- User-defined underfrequency line tripping models are used for BKR models.
- Pre-existing machine governors may yield an overly optimistic frequency response.
- Disabling some governors and adjusting droop and deadband yields more realistic frequency response.
- Future work: Studying the interaction between updated dynamic models of governors and relay models is a necessary and interesting follow-up study.

Thank You