Effect of Governor Deadbands on Valve Travel using Long-Term Dynamic Simulation

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Abstract—**This paper investigates the impact of governor deadbands on valve travel using a novel long term dynamic (LTD) simulation software environment. The LTD software wraps a commercial power flow solver within a Python ODE solver to execute a sequence of power flows capturing long term power system dynamics. The software enables simulations of much longer duraion than classical transient stability simulation – from tens of minutes to hours on full system base cases. While classic transient stability simulation is sufficient for investigating the imact of governor deadbands on system frequency response, the LTD software is needed for analyzing the impact of governor deadbands on overall steam/water valve travel over longer periods of time. Cumulative gate valve travel is proposed as a metric for evaluating the impact of various deadband settings and AGC algorithms. It is shown that widespread use of governor deadbands can actually increase cumulative valve travel over what would be expected without deadbands, or with so-called nonlinear deadband settings.**

Index Terms—**Governor deadband, long-term dynamic simulation, time-sequenced power flow, valve travel, automatic generation control (AGC)**

I. Introduction

Deadbands are commonly implemented in turbine speed governors to prevent a machine from responding to small frequency deviations that are ever present in electrical systems. Recently, the North American Electric Reliability Corporation (NERC) undertook an initiative to study the degradation of primary frequency response in the eastern interconnection. The initiative culminated in NERC Industry Advisory A-2015-02-05-01**NERCxxxx** recommending a maximum deadband setting of $\pm 0.036 Hz$ for generators intended to supply primary frequency response. The recommendation was later adopted by the Federal Energy Regulatory Commission (FERC) in FERC Order 842, which mandates that utility pro forma Interconnection Agreements include the deadband limitation**FERCxxxx**.

The NERC advisory, and the body of work leading to the advisory, also document a lack of accurate modeling related to governor deadbands, and commensurate accuracy issues when using classical transient stability models for studying primary frequency response issues. Industry usage of deadbands is widely known, however, it is often overlooked in power system simulation. **kou2016** details how incorporating governor deadbands into transient simulation models can lead to results that better match measured power system events. [TODO: clean this up... **nercFRI2012** reports frequency profile improvement caused by no step deadband. Also uses MW-min calculation to state smaller no step deadbands reduce movement, calls for immediate dev of gov guidelines - led to standard TRE BAL-001 for ERCOT - in full effect april 2015. Most Recent Report **nercFRAA2018** has odd ERCOT frequency probability - more U shaped, less normal.]

Transient stability simulation is useful for the study of primary frequency response, however there is little understanding of the impact of governor deadbands on valve travel of individual generating units. Do deadbands really reduce overall valve travel? By how much? Does a deadband on one unit increase overall valve travel of other units within the Balancing Authority (BA)? Outside of the BA? It is difficult to answer these questions within the framework of a classical transient stability simulation due to the relatively small integration timestep. These questions require the development of a simulation environment capable of simulating tens of minutes to hours.

Cresap and others proposed solving the equations of motion for a single swing equation incorporating the entire aggregated system inertia in **AGCCresap** and **CarsonTaylor**. Using this concept, the aggregate system frequency response can be reasonably captured. In this work, the authors take the concept further to enable the study of governor deadbands over a much simulation duration than can be reasonably accomplished with a classical transient stability simulation. The paper explores the impact of governor deadbands using a novel long term simulation environment based on GE Energy's Positive Sequence Load Flow (PSLF)**PSLFUserManual**. The paper proposes a cumulative valve travel metric for comparing the impact of various deadband scenarios. Section II describes the long term simulation environment used to perform the studies. Section III discusses governor and deadband modeling within the simulation environment. In Section IV, the long term simulation is validated against mature transient stability simulations. Finally, Section V presents some initial results demonstrating the viability of the proposed valve travel metric and Section VI offers conclusions.

II. Long-Term Dynamic Simulation Technique

Time-sequenced power flow (TSPF) is a method for long-term dynamic (LTD) simulation proven to generate useful results **DonnellyVoltageControl**. The basic idea behind TSPF is to solve a power flow, represent system dynamics of interest independent of the power flow solver, 're-seed' the power flow with new values, and repeat. A python based simulation software, Power System Long-Term Dynamic Simulator (PSLTDSim), has been developed to perform LTD simulations using TSPF. PSLTDSim has the ability to calculate system frequency, perform governor dynamics, model automatic generation control (AGC), and insert step, ramp, and noise type perturbances into a power system.

A. Simulation Assumptions and Simplifications

Due to the relatively large time steps of 1 second involved with TSPF, numerous assumptions were made. Ideal exciters are assumed as modern exicters are typically fast enough to maintain reference voltage under stable conditions. Intermachine oscillations are ignored since the time resolution used is not fine enough to capture these phenomena.

Simplifications of transient stability models are used in PSLTDSim. The only parameters required to model a generator are MW cap, MVA base, and machine inertia. Additionally, a deadband modified tgov1 governor model, Fig. 1, was created to model system governors.

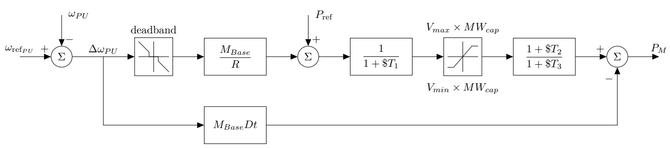

Fig. 1. Block diagram of modified tgov1 model.

B. Modeling the System-Wide Frequency Response

Instead of frequency being calculated for every bus, a combined swing equation is used to model only one system frequency. As shown in (1), accelerating power from the entire system, as well as total system inertia $H_{PU,sys}$, is used to calculate $\dot{\omega}_{sys}$.

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

C. Distribution of Accelerating Power

In a system with N generators, total system accelerating power is calculated by

$$P_{acc,sys} = \sum_{i=1}^{N} P_{m,i} - \sum_{i=1}^{N} P_{e,i} \tag{2}$$

where $P_{m,i}$ is mechanical power and $P_{e,i}$ is electrical power of generator i.

System accelerating power is distributed to all generators in the system according to machine inertia as

$$P_{e,i} = P_{e,i} - P_{acc,sys} \left(\frac{H_i}{H_{sys}} \right) \tag{3}$$

where H has units of $MW \cdot s$.

The new value for $P_{e,i}$ is used in the next power flow solution for each generator. If the difference between expected and resulting power supplied by the slack generator is larger than a set slack tolerance, the difference is redistributed according to (3) until the resulting difference is below the slack tolerance, or a maximum number of iterations take place **Stajcar**.

III. Implementation of Deadbands

FERC minimum requirements for droop and deadband are 5% and 36 mHz respectively**ferc2018**. However, practical implementation is left to generator operators.

A. Types of Deadbands

Fig. 2 presents implementations of deadbands that follow FERC requirements. If a governor has no deadband, a change in output power is requested for any frequency deviation. A step deadband ignores any frequency smaller than the setpoint $\pm db1$ and then steps to meet the set droop curve. A no step deadband pushes the original droop curve away from the nominal frequency allowing for the droop curve to cross zero at $\pm db1$. A non-linear deadband linearly increases from $\pm\alpha$ to $\pm\beta$, after which it follows the original droop curve.

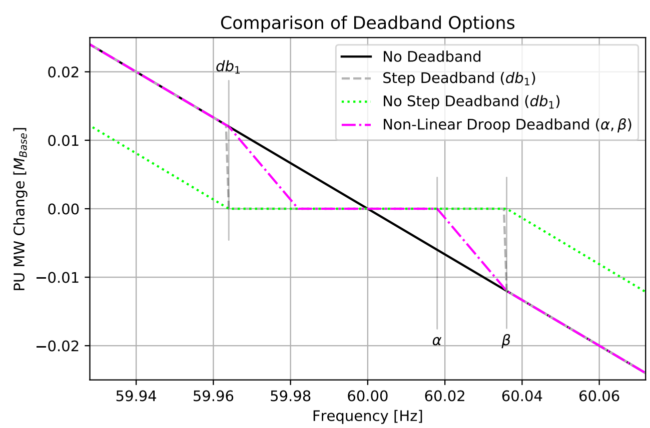

Fig. 2. Different types of deadbands.

IV. Simulation Validation

To validate the chosen simulation approach, identical system perturbances were performed in the GE Energy Positive Sequence Load Flow (PSLF) Dynamic Subsystem (PSDS) and PSLTDSim. Frequency is compared to validate the single system frequency assumption calculated by PSLTDSim, and governed generator mechanical power is compared to validate governor action.

To simplify the comparison of frequency data from PSDS to LTD, a single weighted frequency based on generator inertia was calcualted using (4) and (5).

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

$$\text{where } H_{sys} = \sum_{i=1}^{N} H_{PU,i} M_{base,i} \tag{5}$$

Due to the different time steps, when calculating the difference between PSDS and LTD, multiple PSDS values have the same held LTD value subtracted from them. For instance, any PSDS($t = 3.x$) would have the LTD($t = 3$) value subtracted from it for comparison.

A. The MiniWECC System

The power system used for validation and valve travel experiments, the miniWECC shown in Fig. 3, is a 120 bus 34 generator system created in PSLF. All governors in the miniWECC are modeled with the tgov1 which enabled easier validation. Further details about the creation and use of the miniWECC may be found in **trudnowski2012**, **sandia2015**, **RJminiWECC**.

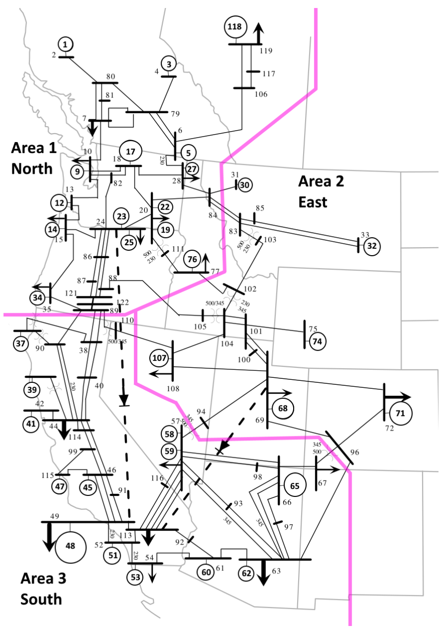

Fig. 3. MiniWECC System adapted from **RJminiWECC**.

1) Load Step Results: A 400 MW load step was simulated to occur at 2 seconds. As shown in Fig. 4, all individual PSDS frequencies begin to oscillate after the perturbance while the weighted PSDS frequency appears to follow the general center of oscillation. The LTD system frequency is less oscillatory than the weighted frequency with only minor differences between the two. Fig. 9 quantifies these differences.

When comparing mechanical power output in Fig. 6, large MW differences can be seen, however, the percent difference data in Fig. 7 shows results less than 5% max difference, and an average percent difference of less than ≈0.5%.

2) Load Ramp Results: Simulation results from a 40 second 400 MW load ramp, in Fig. 8-10 show frequency of LTD being within 1.2 mHz of PSDS and mechanical power differences of less than ±10 MW or 1% difference max (0.2% average).

B. Validation Summary

The step tests show the software is not meant to simulate large transient events with great accuracy. However, small

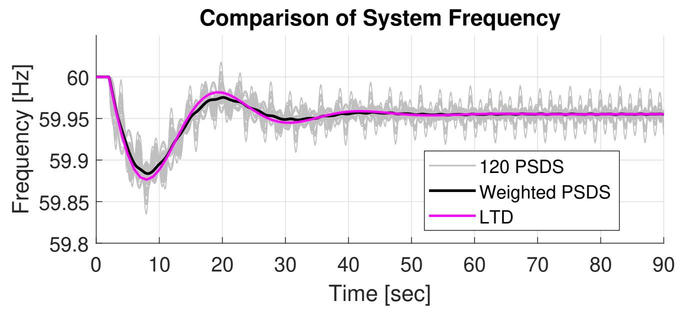

Fig. 4. Comparison of frequency during load step.

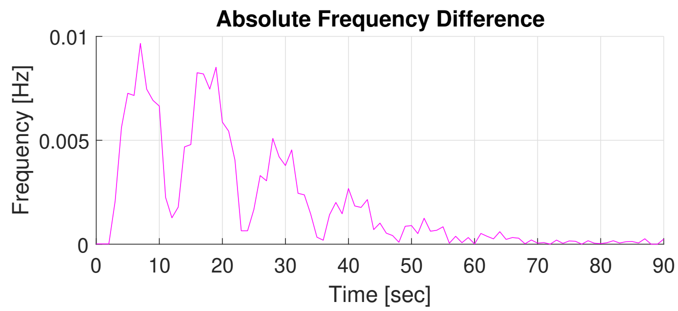

Fig. 5. Absolute difference of weighted frequency during load step.

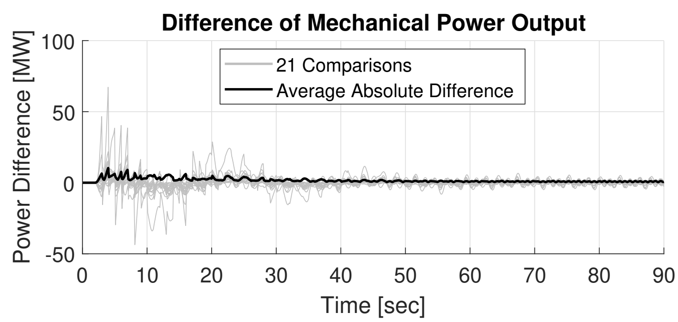

Fig. 6. Difference of mechanical power output during load step.

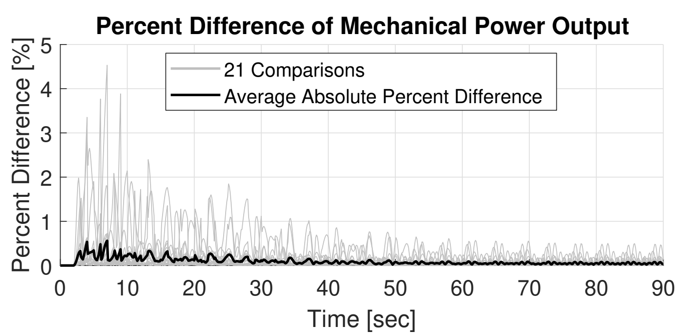

Fig. 7. Percent difference of mechanical power output during load step.

perturbances are modeled with less deviation from transient simulation methods.

V. Initial Results

Explanation of simulations to do...

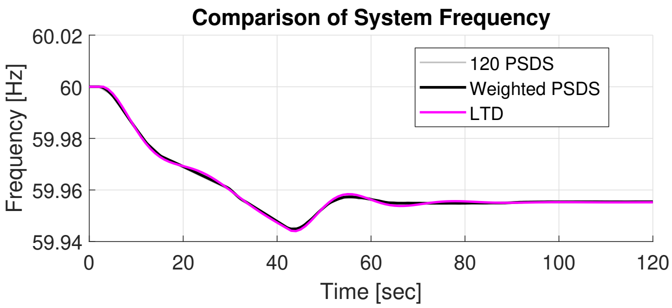

Fig. 8. Comparison of frequency during load ramp.

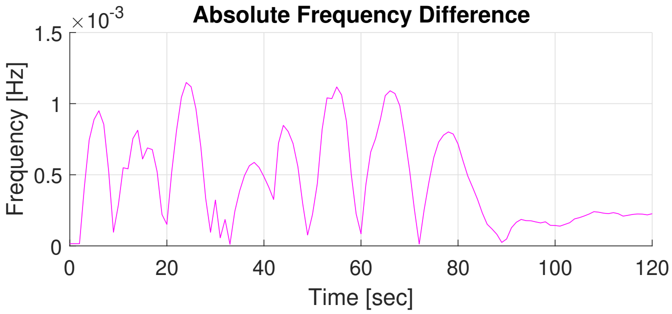

Fig. 9. Absolute difference of weighted frequency during load ramp.

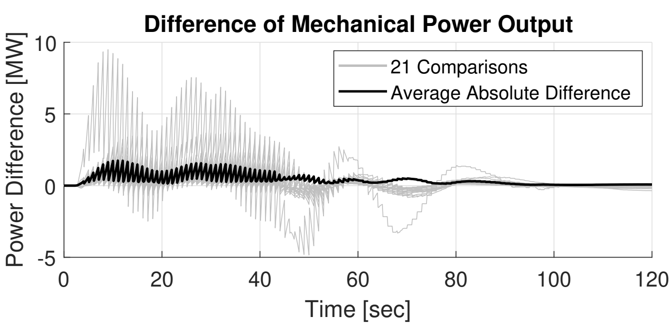

Fig. 10. Difference of mechanical power output during load ramp.

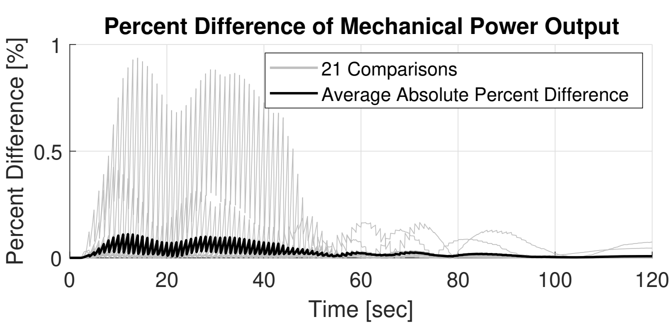

Fig. 11. Percent difference of mechanical power output during load ramp.

30 minutes of noise with various deadbands and resulting valve travel. Cases of interest: No deadband, step deadband, no-step deadband, nl-droop deadband.

Universal acceptance sim: At least 1 area with a step deadband, others with linear or no deadband. Should show unequal distribution of valve travel.

A. System Modifications

The miniWECC system was modified to include three areas for AGC simulation. PSLTDSim was used to set all area governor deadbands to 5%. Governors were removed from some units so that only ≈20% of generation capacity in each area has governor control. A generic AGC routine that filters area control error (ACE) through a proportional-intergal (PI) controller was added to each area. AGC messages are sent select generation units with governors representing ≈9% of total generation capacity every 15 seconds.

B. Simulation Results

To verify desirable AGC control operation, a simple 1500 MW generation loss event was simulated...

... Noise test frequency plots and valve travel movement, table of results

VI. Conclusion

Basic theme: Maybe having deadbands is a bad move - an extra work caused by procrastination type of situation. But everyone probably needs to be on board, otherwise some may ride free while others unfairly pick up the slack.

Acknowledgment

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VII. Non-Text Format Templates

This section meant to provide template figures, tables, equations, and references that can be copied and pasted to other parts of the document in a simple manner.

Figures will behave as Fig. 12. Note that the placement may seem random, but is chosen by LaTeX automatically.

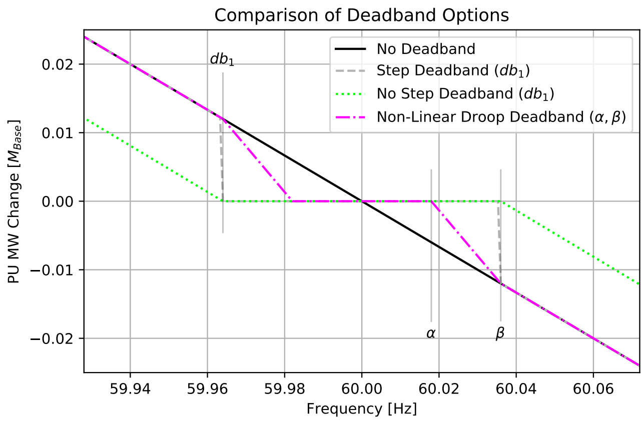

Fig. 12. Testing of figure format.

The default IEEE table example leaves something to be desired that is fulfilled by using the `booktabs` package. This is shown in Table I.

TABLE I
GENERIC GOVERNOR MODEL PARAMETERS.

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

Equations are entered as one may normally do in a LaTeX situation and referenced as (6) and (7).

$$f_{ss} = f_{ref} + \Delta f = f_{ref} + \frac{\Delta P}{S_{Base}\beta} \tag{6}$$

$$\beta = \sum_{i=1}^{N} \frac{1}{R_i \frac{S_{Base}}{M_{Base,i}}} \tag{7}$$

References are only included if cited. For instance **Kundur** or **DonnellyVoltageControl** are randomly cited. Note that the sorting order is set to `none`, which lists references in order cited.