# A Practical Method to Monitor Generator Frequency Response and Screen Governor Models in Puerto Rico

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***Abstract*—This paper presents ongoing work to enhance primary frequency response on the Puerto Rico grid with a practical methodology and software toolkit to monitor generator frequency response performance and validate governor models using SCADA measurements. The automated pipeline includes event detection; data extraction and conditioning; frequency-response analysis with computation of the frequency response measure (FRM) to classify supportive versus adverse behavior; rapid droop estimation via a simplified characteristic; and in-depth, disturbance-based model validation using a PSS®E play-in. Benchmarking indicates that a simplified droop method agrees sufficiently with full-model simulations to enable rapid screening prior to detailed validation. Application across multiple units and events identifies disabled or mistuned governors, deadband effects, and needs for parameter calibration and model updates. Results show improvements in fleet frequency response relative to prior years, despite persistent variability in unit response and gaps in meeting performance requirements for some generators. The approach complements required staged testing and supports continuous fleet-performance monitoring.**

***Index Terms*—Model Validation, Frequency Response, Governor Response, Supervisory Control and Data Acquisition, Automatic Generation Control**

## I. Introduction

Reliable primary frequency control depends on well-performing turbines and other prime movers, and generators with properly tuned speed governors. In today's changing resource mix, where synchronous machines (and their inertia) are increasingly displaced by inverter-based resources (IBRs), continuous monitoring of speed-governor performance and rigorous model verification are essential to maintain system frequency response (FR) and satisfy reliability obligations [1], [2]. Maintaining stable frequency is a persistent challenge for island systems due to limited generation resources and lack of external support. There are multiple approaches to monitor FR and estimate governor parameters (e.g., droop and deadband) from measurements, ranging from practical methods that apply the algebraic droop relation [2] or turbine-specific empirical formulas [3] to more complex techniques such as Kalman-filter–based estimation [4]. Industry experience shows that high IBR penetrations may degrade traditional FR characteristics and tighten performance margins, underscoring the value of continuous, measurement-driven assessment [5]. A comprehensive review of online monitoring and data-driven analytics for frequency dynamics is provided in [6]. In practice, deployment can be hindered by mismatches between planning models and aging or evolving fleets, incomplete unit information (e.g., governor settings and operating mode during the event), and insufficient high-resolution measurements.

The Puerto Rico power system is undergoing significant transformation to improve reliability and resilience. As an islanded system without interconnections to neighboring grids, frequency control is inherently constrained by limited inertia and restricted frequency reserves. Persistent challenges, including historically weak primary frequency response, limited governor participation, aging conventional generation, and constrained operating reserves have been reported in prior studies [7]. Field observations further indicate that some generating units do not consistently meet expected frequency response performance, underscoring the need for systematic monitoring and model verification. Large-scale investments in generation, transmission, and distribution are underway as part of FEMA-supported recovery from Hurricanes Maria and Fiona. Although these efforts aim to strengthen system stability, the rapidly evolving resource mix and operating conditions necessitate systematic and practical approaches for continuous monitoring and validation of FR performance.

Within this context, this work introduces a practical framework for rapid monitoring of speed-governor performance and screening of dynamic model parameters requiring verification. This approach requires only readily available SCADA-grade measurements of any generation plants under analysis and utilizes: (i) qualifying event detection, frequency-response measure (FRM) calculation, and identification of frequency-responsive units; (ii) robust droop estimation from disturbance data using a simplified droop characteristic; and (iii) a disturbance "play-in" model-validation workflow implemented in PSS®E.

The framework is demonstrated using Puerto Rico's generation fleet. The results indicate practical improvements

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979-8-3315-8138-1

associated with the ongoing DOE–FEMA–national laboratories–PREPA–System Operator collaboration: fleet FR has improved relative to prior years, while persistent issues remain, including inconsistent unit response and the need for parameter calibration and planning model updates.

## II. Methodology

The proposed methodology for fleet-wide monitoring of generator FR performance and validation of speed-governor models integrates measurement-based event screening of responsive generators with droop-performance estimation and model validation, enabling generator owners and operators to understand fleet performance and ensuring modelers keep their generator models accurate and up to date.

### *A. FRM-Based Units Prescreening*

Balancing Authorities must monitor and analyze the performance of the interconnection and individual generating units by quantifying FR performance. This is essential for reliable operation and is an established requirement with defined metrics and penalties for not meeting them [1]. NERC identifies the following reference points on the frequency-response curve in BAL-003-2 standard: t0, the event start time; Point A (starting frequency), the average system frequency over the 16 seconds immediately preceding t0; Point B (settling frequency), the average frequency over the 32-second window from t0+20 to t0+52; and Point C (initial nadir), the minimum frequency observed between t0 and t0+12s [1]. According to NERC BAL-003, the FRM of an interconnection is calculated as

$$FRM_{INT} = \frac{\Delta P}{10(f_B - f_A)}, \quad (1)$$

where $\Delta P$ is the size of generation and/or load loss, $f_A$ is the interconnection frequency at Point A and $f_B$ is the frequency at Point B. Although the FRM for individual generators or plants is not explicitly defined in the standard, a similar methodology can be applied to assess their individual performance. The frequency response of a plant or generator is computed as

$$FRM_{plant} = \frac{P_{plantB} - P_{plantA}}{10(f_B - f_A)}, \quad (2)$$

where $P_{plantA}$ and $P_{plantB}$ denote the generator's output at Points A and B, respectively.

### *B. Droop Estimation*

A generator performance tool was developed to compute the expected MW response from measured frequency using a droop-based characteristic with explicit modeling of deadband and available headroom/limits. The tool enables side-by-side visual comparison of measured and expected active-power responses. The expected response is computed from the well-known droop relation [2]

$$\Delta P = -\frac{P_{rated}}{f_0 \times R} \times \Delta f^*, \quad (3)$$

with the deadband-adjusted frequency deviation

$$\Delta f^* = \begin{cases} 0, & |\Delta f| \le db \\ \Delta f - sign(\Delta f) \times db, & |\Delta f| > db, \end{cases} \quad (4)$$

where $P_{rated}$ is the generator's rated capacity (MW), $f_0 =$ 60Hz is nominal frequency, $\Delta f = f - f_0$ is the frequency deviation from nominal (Hz), $R$ is droop, and $db$ is the deadband (Hz).

The tool estimates the effective machine governor droop using two complementary approaches. The first (primary) approach uses post-transient settling values of frequency and active power, moving from point A (pre-event baseline) to point B (post-transient), while the second uses a slope-based fit from A to point C (minimum frequency), which remains robust when output is constrained (e.g., IBR headroom or turbine/generator limits). Together, these approaches quantify governor behavior and provide quick estimates of generator response for compliance and performance monitoring.

The droop coefficient for primary approach is derived using the classical droop formula:

$$\text{Droop}_{\text{A}\to\text{B}}\,(\%) = \frac{|\Delta f_{\text{A}\to\text{B}}/f_0|}{|\Delta P_{\text{A}\to\text{B}}/P_{rated}|} \times 100\%, \quad (5)$$

where $\Delta f_{\text{A}\to\text{B}}$ represents the frequency deviation between windows (A→B), and $\Delta P_{\text{A}\to\text{B}}$ denotes the corresponding power change. This approach focuses on the sustained generator response rather than dynamic behavior during the initial frequency excursion and allows to minimize impact of oscillations and other noise. When the generator output is constrained, the second approach is used it is bases on the same equation (5), but window (A→C) is used instead.

To explicitly account for deadband in the droop estimate, the deadband-adjusted frequency deviation $\Delta f^*$ from (4) is used when computing either the A→B or A→C window pairs, consistent with the method described:

$$\text{Droop}_{\text{DB-adjusted}}(\%) = \left|\frac{\Delta f^*/f_0}{\Delta P/P_{\text{nom}}}\right| \times 100\% \quad (6)$$

### *C. Model Validation via Measurement Play-In*

Quick droop-based estimates provide an efficient first screening of primary frequency response because they rely on simple algebraic relations (5)-(6). However, actual plant equipment is often complex and turbine-governor and plant-level control interactions can render pure droop equations insufficient for accurate model verification, particularly for multi-loop or nonlinear governor structures (e.g., GGOV1), as also noted in NERC guidelines [2]. In such cases, a more detailed, full generator model-based approach is warranted, namely, the measurement play-in method [8], which enables time-domain validation using the complete dynamic model.

Measurements of real grid disturbances (PMU/DFR preferred; SCADA acceptable) enable dynamic model validation using the measurement play-in method (Fig. 1). In this workflow, recorded terminal-bus frequency and voltage are injected into the simulation, and the unit's modeled active- and reactive-power responses are compared against the measured traces. This approach provides an industry-accepted path for continuous monitoring and verification of generator models (including turbine-governor) and is recommended by NERC as a complement to staged testing (the primary method for generation unit performance testing for compliance and model verification). Developed and refined in BPA/WECC

979-8-3315-8138-1

practice, with early implementations in GE PSLF, and later adopted across the industry, disturbance play-in capabilities are now available in major tools, including PSS®E [9], [10].

The model-validation tool was developed using a Python-based automation toolkit to orchestrate PSS®E play-in studies. The pipeline performs data preprocessing and prepares play-in channels in PSS®E PLB format, then builds a validation case from the planning model for the selected generator under study with all required dynamic models. Measured signals are played into PSS®E via the PLBVF1 model (Fig. 1) and the simulation is executed [11]. The tool then extracts results from channel/output files, visualizes and compares measured and simulated responses, and auto-generates an HTML report with interactive figures and tables.

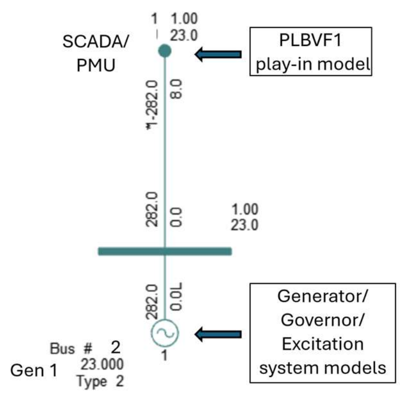

Figure 1. PSS®E play-in setup.

## III. Analysis Results

Results presented in this section are based on one month of SCADA data sampled at two-second resolution, including system frequency and active power output for all generation units on the Puerto Rico grid. The dataset was analyzed, and eight frequency events were detected and used to assess generator FR performance. To ensure data privacy, the actual unit names were anonymized and replaced with generic identifiers ranging from Gen 1 to Gen 113.

### *A. The Puerto Rico Generation Fleet Description*

Puerto Rico's electric power system is currently operated as follows. The current T&D Operator began operation of the transmission and distribution system in 2021, and the Generation Operator began operation of the conventional generation fleet in 2022. The total installed generation nameplate capacity is in the order of 6–7 GW, currently dominated by fossil fuels. Oil-fired power plants (burning diesel or bunker oil) account for roughly 60–62% of capacity, with natural gas about 24%, coal 8%, and 7% from renewables (e.g., solar, wind, hydro) [12]. However, the dependable capacity as of June 2025 is only about 3GW, as many units cannot produce near their nameplate, and there are many scheduled forced outages [13]. Conversely, peak electricity demand of the system is also in the order of 3 GW. As a result, there have been hundreds of recent occurrences where load consumption exceeds generation, forcing the T&D Operator to manually shed load through rotating brownouts to maintain frequency near nominal. These manual load sheds are triggered when spinning reserve becomes negative [12]. The generation fleet includes numerous oil-fired steam units and gas turbines (at sites like San Juan, Palo Seco, Aguirre), as well as two large gas-fired power plants – the 766 MW Costa Sur and the 580 MW EcoEléctrica LNG facility and a single 454 MW coal-fired plant (AES Puerto Rico). In 2025, the T&D Operator reported over 1.14 GW of grid-connected distributed solar capacity and 2.34 GWh of distributed batteries connected to the grid. For further context, Puerto Rico contains an extensive transmission network of about 2,478 miles of lines at high voltages (230 kV and 115 kV) forming an island-wide loop, plus an extensive sub-transmission network operated at 38 kV.

### *B. Units Prescreening*

Following event detection and disturbance size estimation, the interconnection FRM is computed using (1) and results are shown in Fig. 2. Generator-level FRM values were computed for each detected event according to (2). Figure 3 presents a heatmap of unit-level FRM across all events; generators with negligible response are omitted for clarity. In the heatmap, shades of red indicate positive FR, darker red denotes stronger, more effective response consistent with expected governor behavior, whereas blue cells indicate a negative FR (the unit moved in the opposite direction during the event). Units that tripped during an event are marked with red crosses, and events deemed unsuitable for frequency-response analysis (i.e., NERC "unqualified events") are flagged accordingly. This visualization enables quick identification of consistently well-performing units, underperformers, and non-participatory resources.

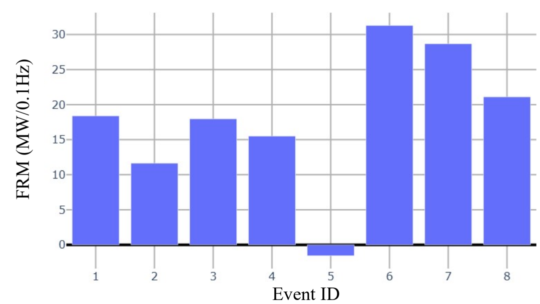

Figure 2. Interconnection FRM for detected events.

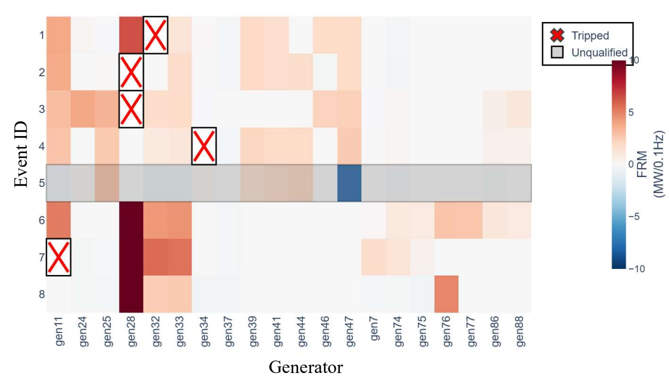

Figure 3. Individual unit FRM values heatmap.

### *C. Droop Estimation*

Individual unit droop estimates calculated from settled values using (5) are shown in Fig. 4. The expected droop for

979-8-3315-8138-1

properly tuned governors is about 5% (shown in shades of green on the heatmap). It should be noted that actual values depend on unit-specific characteristics, operating conditions, and constraints. Significantly underperforming units with droop greater than 15% are shown in yellow and orange in Fig. 4. An example for Gen 25 (a major generator) using the estimated droop (~20%) is presented in Fig. 5. The figure shows agreement between the measured and estimated responses, calculated using (3), over the settling interval.

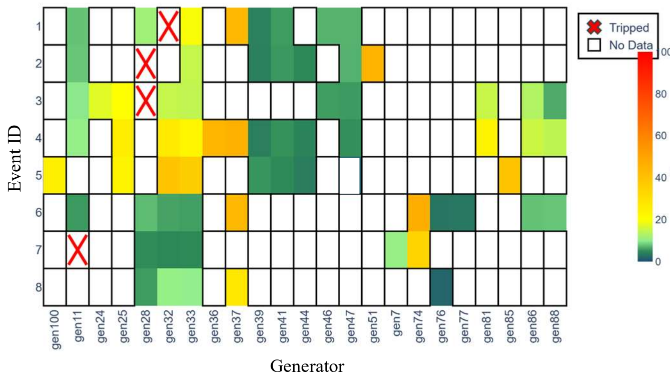

Figure 4. Individual unit droop estimates heatmap.

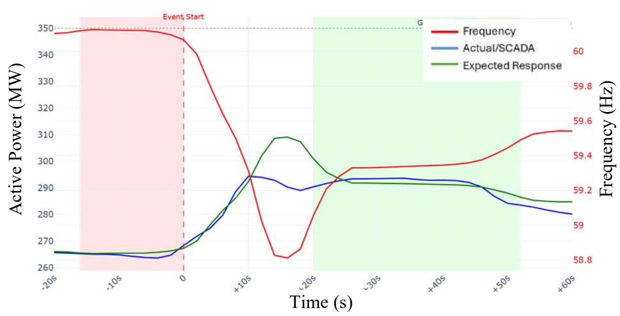

Figure 5. Generator 25 (Event 3) actual vs droop-based response.

## D. Model Validation

An in-depth analysis using full generator/governor models was subsequently performed to investigate inconsistencies and underperformance in selected units. Results and key findings for these generators are presented below.

### 1) Generator 25

Model validation results for Gen 25 for Events 2 and 3 are shown in Figs. 6 and 7. The red trace shows the measured SCADA response; the blue trace shows the simulated response with the speed governor enabled (IEESGO model, droop set to ~33%); and the orange trace shows the simulated response with the governor disabled. For Event 2 (Fig. 6), the FRM aligns closely with the no-governor simulation, indicating the governor was likely disabled. For Event 3 (Fig. 7), the measured response matches the governor-enabled simulation using the planning-case droop setting, indicating proper governor action.

Play-in simulations for Gen 25 align with the droop heatmap in Fig. 4: the speed governor was in operation during Events 3–5 and not in operation during Events 1–2 and 6–8. Another important finding concerns the difference between the estimated droop (~20%) and the model setting (33%). As noted in [2], droop can be implemented in different ways (model-, vendor-, and tool-specific), and different bases may be used (e.g., machine MVA base, turbine base, generator nominal/max capacity). The IEESGO model uses the machine MVA base, and in the planning case for Gen 25 the MVA base exceeds the maximum capacity used for droop estimation via (5). Using the Gen 25 MVA base in (5) yields a droop estimate close to 33%, reconciling much of the discrepancy.

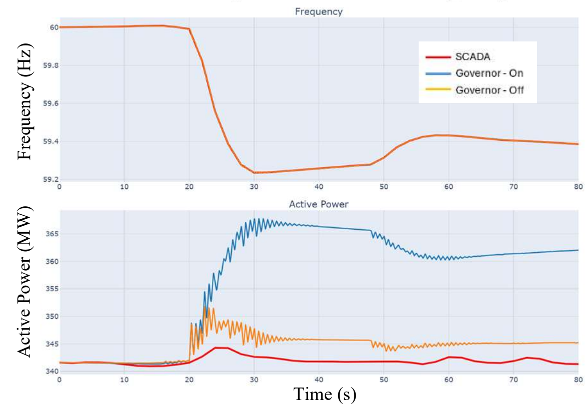

Figure 6. Generator 25 (Event 2) actual vs model-based response.

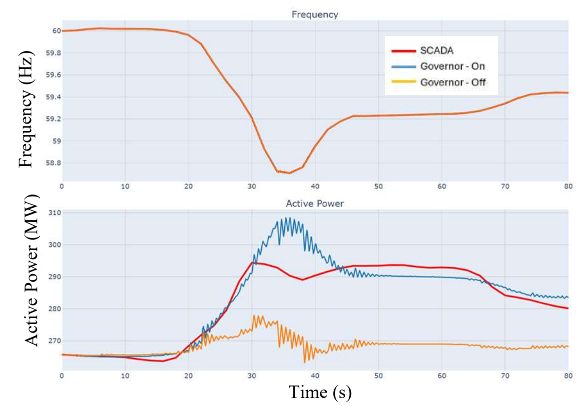

Figure 7. Generator 25 (Event 3) actual vs model-based response.

### 2) Generators 46 & 47

Gen 46 and Gen 47 are similar units and, based on Fig. 4, exhibit an average droop of about 10%. However, in the planning case the governor droop is set to 5%, and the GAST model is used. Fig. 8 compares the measured response with model simulations using droop settings of 5% (current planning case) and 10% (proposed update). The 10% droop produces a substantially better match, confirming the droop estimate; the play-in validation thus supports updating the model to better reflect observed behavior.

### 3) Generator 32 & 33

Generators 32 and 33 exhibit inconsistent droop estimates in Fig. 4. Both units use the GGOV1 model – a generic thermal governor/turbine model (developed by GE) that incorporates base loading and load-controller effects. The effective droop in GGOV1 depends on operating mode (base-loaded vs. load-control) and controller settings (fast/slow/no load controller) [14]. For Generators 32 and 33, the load controller is configured as very slow, with droop parameter r = 5%. Play-in simulations with this configuration show very good agreement with the SCADA responses across all events (Fig. 9), despite simplified droop estimates averaging approximately 20% in

979-8-3315-8138-1

Fig. 4. This discrepancy arises because the GGOV1 controls and plant equipment are sufficiently complex that the simple algebraic droop equation (5) is not suitable for droop estimation in such cases, as noted in [2].

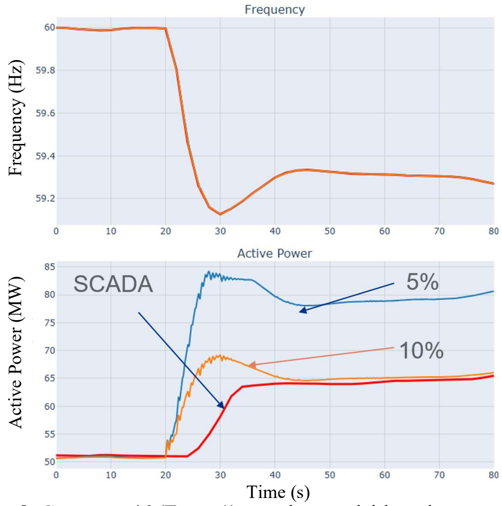

Figure 8. Generator 46 (Event 1) actual vs model-based response.

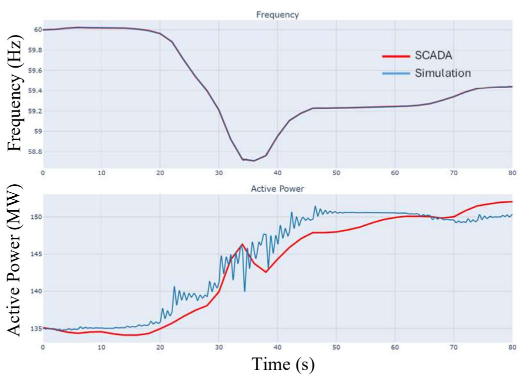

Figure 9. Generator 32 (Event 3) actual vs model-based response.

## IV. CONCLUTIONS

This paper presents practical results and experience with fleetwide FR performance monitoring and compliance assessment on Puerto Rico's islanded grid, where maintaining stable frequency is a principal challenge. An automated pipeline was developed and applied to one month of operational SCADA data, enabling end-to-end screening, analysis, and reporting of generator FR performance and model validation. The FRM-based workflow efficiently prescreens events to identify those suitable for evaluating unit response. A simplified droop-characteristic method then provides rapid assessment; however, its accuracy depends on correct selection of the unit's nominal (rated) capacity and the configured droop and deadband, and care is required to ensure the unit's MVA base matches the power-flow planning case. The simplified method also may not yield reliable estimates for generators represented by more complex models (e.g., GGOV1).

For model-based verification, the PSS®E play-in approach supports detailed validation of planning-model dynamic parameters. This method complements, rather than replaces, generator staged testing, which remains the primary means for parameter verification and should be performed periodically per regulatory requirements. Good agreement between measured and simulated responses across events indicates appropriate models and parameters in the planning case; persistent mismatches can signal the need for parameter calibration, a more suitable model structure (e.g., replacing a generic IEEE model with a vendor-specific model), or potential equipment issues.

The tool has been adopted for operational use to support assessment of fleet FR. Despite inconsistencies in unit behavior for some generators identified in this paper, ongoing tool testing has provided actionable insights and suggests potential performance improvements. Continuous fleetwide monitoring and periodic model validation can support compliance and enhance the accuracy of planning models. Future work will also obtain higher-resolution data and implement governor parameter calibration where warranted.

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