Metrics for Storage, an Application Model

Sandia National Laboratories

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Background

In today's electrical power grid, energy storage devices can be utilized in 17 different applications. Some of these applications have control signals that are stochastic in nature and hence can be quantified by their statistical properties. An Auto-Regression (AR) model has been developed to extract these properties such that they can be analyzed, compared, and reproduced in laboratory testing signals.

Model Parameters

Model Equation

$$z(kT) = a_1 z((k-1)T) + a_2 z((k-2)T) + a_3 z((k-3)T) + a_4 k((k-4)T + v(kT)$$

Prediction Based on Model

$$\check{z}(kT) = a_1 z((k-1)T) + a_2 z((k-2)T) + a_3 z((k-3)T) + a_4 k((k-4)T + v(kT)$$

Prediction Error

$$e(kT) = z(kT) - \check{z}(kT)$$

Performance Metric

$$J = ||e||^2 / ||z||^2$$

v(kT) is noise input taken as zero mean Gaussian white noise with variance given by the AR modeling calculations

Model Validation

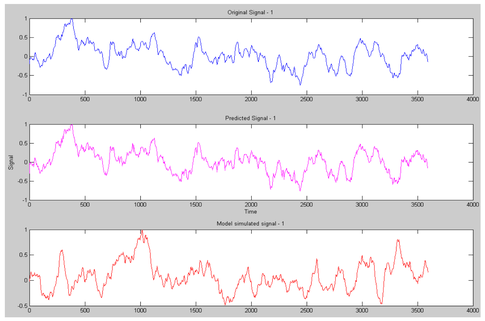


Figure 4 - Graph 1: Recorded Utility Signal, Graph 2: Auto Regression Model Signal, Graph 3: Random Signal w/ utility signal characteristics

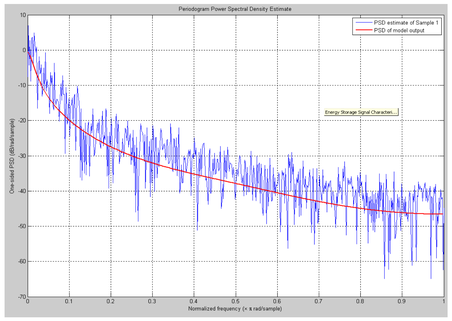
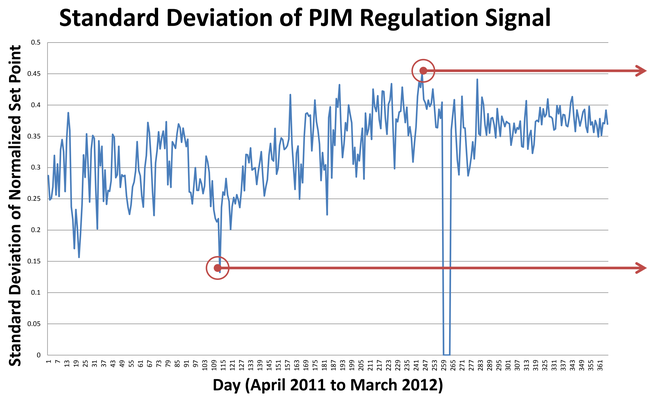
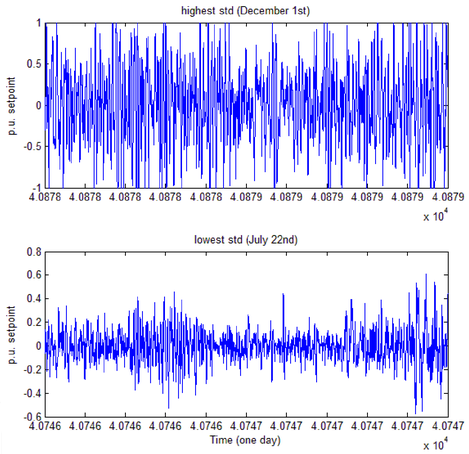


Figure 6 - Power Spectral Density estimate of the original signal versus the random signal created from the auto regression model

Statistics of PJM Frequency Regulation

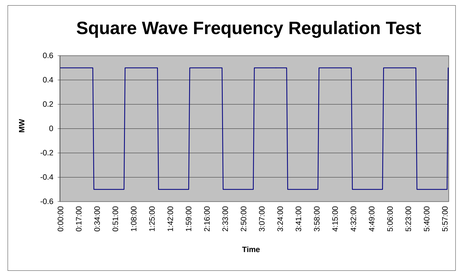




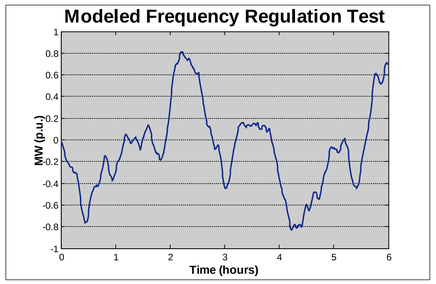
	Min	Mean	Max	Std	Min Delta	Mean Delta	Max Delta	Std Delta
Min	-1.000	-0.015	0.607	0.132	-0.800	0.000	0.056	0.012
Mean	-0.994	0.000	0.993	0.333	-0.166	0.000	0.175	0.023
Max	-0.578	0.007	1.000	0.451	-0.055	0.000	0.800	0.030
Std	0.034	0.002	0.038	0.057	0.081	0.000	0.094	0.003

[Source] http://www.pjm.com/markets-and-operations/ancillary-services/mkt-based-regualtion.aspx

Effect on Testing and Standards



We are progressing the state of the art in energy storage testing by determining the benefits (if any) of using more realistic duty cycles



Project and Results

Work is underway to further validate the model using real data. Several statistical comparison techniques are being analyzed to determine if the signals being generated by the model accurately represent the regulation signal. In addition to validation, preliminary analysis of the regulation data shows that the signal in non-stationary and so model validation should account for variations from winter to summer as well as night to day.

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OFFICE OF ELECTRICITY DELIVERY & ENERGY RELIABILITY

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