Metrics for Storage, an Application Model

**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**
  
  \[ z(kT) = a_1z((k-1)T)+a_2z((k-2)T)+a_3z((k-3)T)+a_4k((k-4)T)+v(kT) \]

- **Prediction Based on Model**
  
  \[ \hat{z}(kT) = a_1z((k-1)T)+a_2z((k-2)T)+a_3z((k-3)T)+a_4k((k-4)T) \]

- **Prediction Error**
  
  \[ e(kT) = z(kT) - \hat{z}(kT) \]

- **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.

**Statistics of PJM Frequency Regulation**

- **Standard Deviation of PJM Regulation Signal**
  
  ![Graph showing standard deviation of PJM regulation signal](source)

- **Statistics of PJM Frequency Regulation**
  
<table>
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<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>Std</th>
<th>Delta Min</th>
<th>Delta Mean</th>
<th>Delta Max</th>
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**Effect on Testing and Standards**

- **Square Wave Frequency Regulation Test**
  
  ![Graph showing square wave frequency regulation test](source)

- **Modeled Frequency Regulation Test**
  
  ![Graph showing modeled frequency regulation test](source)

- 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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