Generator Model Verification Result Analysis System

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Background

In collaboration with ISO New England and the Computer Science and Engineering group, we are working towards improving the Power Plant Model Verification Tool (PPMV) which the company uses to plan for certain changes within their Bulk Power Systems (BPS) and to keep track of disturbances and outliers within these systems. The issue is the models within the tool appear to not match the actual system results at times. A scoring engine is therefore needed to measure the accuracy of the models against the actual Bulk Power Systems. This scoring engine is used by both the planning teams and the day-to-day operations teams at ISO New England in order to make decisions for upgrades. The engine must be as accurate as possible to ensure correct decisions are made.

Current Implementation

The current system in place at the company that is being used is called the Automatic Power Plant Model Verification tool, APPMV. This tool runs 24/7 and is activated by certain events within the system (i.e. a power surge). The tool verifies the event, runs the PPMV, and sends out the results in an email to the engineers. These results are purely qualitative. An example can be seen below.

Requirements

Determine readable metrics that allow engineers to take a quick look and understand the current state of the system. Additionally, we needed to develop a way to score and rank the different models of an event: highlight bad models and provide a way to automatically rank the models of an event.

Approach

We reviewed literature to determine the best method to score and rank the different models. Eventually we decided to use the normalized root mean square error (NRMSE) and a signal similarity metric (defined in a paper from Washington State University: Quantitative Indicators for Quality of Fit Assessment in Power System Model Validation Problems by Dr. Rezai and Dr. Venkatasubramanian). We determined the normalized root mean square error would be used as a pre-score and focused on making sure that models had a good fit before being run through the signal similarity metric. The signal similarity metric would be used as the overall scoring metric.

Initial Issues

The current system issue is that results the engineers at ISO New England receive from the APPMV are purely qualitative. These results are basically graphs from the two models at the time of the event. There is no way to quantitatively rank the models and make decisions about potential improvements.

Distance and Angle Semimetrics

In order to obtain the distance and angle semimetrics, an estimate of the transfer function is taken by using the simulated data as input and the measured data as output.

\[ H(f) = \frac{Y(f)}{X(f)} \]

The distance semimetric measures the distance of the gain from 0 dB. Alpha acts as a sensitivity parameter to tighten or loosen restrictions on magnitude distance.

\[ D_{M\alpha}(f) = \tanh \left( \frac{20\log|H(f)|}{\alpha} \right) \]

Similarly, the angle semimetric measures the distance of the phase angle from 0 radians. Beta acts as a sensitivity parameter to tighten or loosen restrictions on angular distance.

\[ D_{A\beta}(f) = \tanh \left( \frac{\phi(f)}{2\pi\beta} \right) \]

These semimetrics are finally averaged over a range of frequencies to produce the final magnitude and angle scores. This is done by performing a fast Fourier transform (FFT) of the PMU data and locating the first peak to determine the lowest fundamental frequency of the signal. The semimetrics are then averaged over this range.

Signal Similarity Metric

The signal similarity metric is used to score the component parts of simulated signals in comparison to phasor measurement unit (PMU) data. It is calculated by first breaking the model into three components: the correlation, the magnitude, and the phase. Each of these components will factor into the overall score.

To calculate the overall score, the three metrics are combined: we add the absolute value of the correlation to the sum of the magnitude semimetric and the phase semimetric. This is then divided by 3. This ensures that each component has an equal impact on the overall score. This final calculation can be seen below.

\[ S = \frac{|\rho| + M_\alpha + A_\beta}{3} \]

Example Signal

Below is an example signal comparison, with measured data in blue and model data in orange.

Function

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<th>Normalized Root Mean Square Error</th>
<th>Calculating Fit Percentage, Filtering</th>
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Normalized Root Mean Square Error

To calculate the normalized root mean square error, we must first calculate the root mean square error (RMSE). This is done by taking each value of the model and subtracting the actual from the predicted. This value is then squared and added to the sum of the other values. This is then divided by the total number of values and then raised to the ½ power. The formula is shown here.

\[ RMSE = \sqrt{\frac{1}{N} \sum (\text{Predicted}_i - \text{Actual}_i)^2} \]

To calculate the normalized root mean square error, we divided the root mean square error (RMSE) by the range of the actual (the highest value of the actual - the lowest value of the actual). The formula is shown below.

\[ \text{NRMSE} = \frac{\text{RMSE}}{\text{MAX}_{\text{actual}} - \text{MIN}_{\text{actual}}} \]

To determine the fit percentage of the models, we take 1 - the NRMSE. This gives us an approximate idea of how well the two models match. This is necessary to maximize the accuracy of the estimated transfer function used in the signal similarity algorithm.

Lessons Learned

The team learned how to interact with working professionals at a power company. We learned the importance of time management and flexibility. Additionally, we collaborated with students from different majors and were able to observe their interaction with ISO New England. Finally we learned how to work purely from home as a result of COVID-19. This taught us the valuable lesson of flexibility in the workplace.