Evaluation of Two Validation Metrics Using New VV&UQ Framework Applicable to Power Electronics Systems

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Outline

• Motivations and Objectives

• Overview of Verification, Validation and Uncertainty Quantification Framework

• Validation Metric Definition

• System and The System Response Quantity Under Study

• Estimate Model form Uncertainty using:
  – Mean Comparison
  – Area Validation Metric
  – Modified Area Validation Metric (Voyles and Roy, 2014)

• Summary
Motivations and Objectives

There are large number of circuit simulators available in power electronics. Which one is the best for a specific intended use?

Circuit analysts propose different models for different systems. How much can these models be trusted?

Assume putting a model in a complex system. How accurate that whole system will be?
Overview of VV&UQ Process

Planning & prioritization

Conceptual Model

Verified Model

Validated and Verified Model for The Intended Use

Documentation of Modeling and Simulation Activities

Verification Process

Modeling Process

Validation Process

Ensemble Model (Study Subsystems)

Computerized model

Is the Model accurate enough for the intended use?

Yes

No

Are code and solution verified?

Yes

No

Is There enough information about the uncertainty of the model's contents?

Yes

No

Based on SRQ, System, Surrounding

Model Adaptation

Model Adaptation

Model Adaptation

Enhance Model

Is There enough information about the uncertainty of the model's contents?
Validation Metric Definition

- Validation: The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. [1]

- Validation Metric: Measure of agreement between simulation and experimental results.

  - Mean Comparison
  - Area Validation Metric
  - Modified Area Validation Metric

System of Study

Source

Load

LC Filter

V_{ab} \text{ bridge}(V)

V_{ab \text{ out}}(V)

V_{DC}(V)

V_{DC} \text{ (V)}

time (sec)

4.5 5 5.5 6 6.5 x 10^{-3}

0 20 40 60 80

0 20 40 60 80

V_{DC}(V)

V_{DC} \text{ (V)}

time (sec)

4.5 5 5.5 6 6.5 x 10^{-3}

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V_{DC}(V)

V_{DC} \text{ (V)}

time (sec)

4.5 5 5.5 6 6.5 x 10^{-3}

0 20 40 60 80
Single Phase Voltage Source Inverter

[Diagram of a single phase voltage source inverter]
Single Phase Voltage Source Inverter

\[ S_a = 1 \]

\[ S_a = 0 \]
Single Phase VSI output

\[ V_{dc}, s_a, L, C, R_{Load}, i_{dc}, i_{Ha}, v_a, v_{outa}, V_{out} \]
Three Phase Voltage Source Inverter

\[ i_{dc} \]

\[ s_a - \quad s_b - \quad s_c - \]

\[ v_a \quad v_b \quad v_c \]

\[ 1-s_a \quad 1-s_b \quad 1-s_c \]

\[ L_1 \quad i_{lla} \quad + \quad v_{outa} - R_{Load} \]

\[ L_1 \quad i_{llb} \quad + \quad v_{outb} - R_{Load} \]

\[ L_1 \quad i_{llc} \quad + \quad v_{outc} - R_{Load} \]

\[ V_{dc} \quad i_{dc} \quad V_{dc} \]

\[ + \quad v_{cc} \quad + \quad \]

\[ C \quad C \quad C \]

\[ - \quad - \quad - \]

\[ v_{outa} \quad v_{outb} \quad v_{outc} \]

\[ V_{outa} \quad V_{outb} \quad V_{outc} \]

\[ V_{outa} \quad V_{outb} \quad V_{outc} \]

\[ \text{time (sec)} \]

\[ \text{Voltage (V)} \]

\[ 0.02 \quad 0.021 \quad 0.022 \quad 0.023 \quad 0.024 \quad 0.025 \quad 0.026 \quad 0.027 \quad 0.028 \quad 0.029 \quad 0.03 \]

\[ -15 \quad -10 \quad -5 \quad 0 \quad 5 \quad 10 \quad 15 \]
What is THD?

the voltage-time relationship deviates from the pure sine function

All non-sinusoidal periodic functions can be represented as the sum of:

• A sinusoidal term at the fundamental frequency $nf$
• Sinusoidal terms (harmonics) with $nf$, $n = 2, 3, ...$
• A DC component (where applicable)

$$THD = \sqrt{\sum_{h=2}^{H} \left( \frac{Y_h}{Y_1} \right)^2} = \sqrt{Y_2^2 + Y_3^2 + \ldots + Y_H^2}$$
The Model implemented in Simulink and Simulation Results

With enough number of samples
Mean Value of THD = 3.822%
Hardware Set-up and Experimental Results
Hardware Set-up and Experimental Results
Hardware Set-up and Experimental Results

15 Replicated Measurements
Mean Value of THD = 4.36 %
Validation Metric: Mean Comparison

Experimental Results

15 Replicated Measurements
Mean Value of THD = 4.36%

Simulation Results

With enough number of samples
Mean Value of THD = 3.82%

Mean Comparison

\[
\left( \bar{u}_{\text{exp}} - \bar{u}_{\text{comp}} \right) \pm \left[ t_{n-1, \alpha/2} \right] \left[ \frac{s}{ \sqrt{n}} \right]
\]

With 95% Confidence Interval

THD Error : [0.45%, 0.64%]
Area Validation Metric

\[ F \rightarrow \text{Simulation distribution} \]
\[ S_n \rightarrow \text{Experimental distribution} \]

\[ d(F, S_n) = \int_{-\infty}^{\infty} |F(SRQ) - S_n(SRQ)| \]

\[ F \rightarrow \text{Simulation distribution} \]
\[ S_n \rightarrow \text{Experimental distribution} \]

\[ d(F, S_n) = \int_{-\infty}^{\infty} |F(SRQ) - S_n(SRQ)| \]
Area Validation Metric

- The model form uncertainty is shown by adding bounds to the SRQ from nondeterministic simulation with enough number of samples.

\[ d = 0.005 \]
Modified Area Validation Metric

Including measurement Errors:

\[ F_s \]

Model Form Uncertainty Interval:

\[
\left[ F(x) + \left( \frac{1 - F_s}{2} \right) d^+ - \left( \frac{1 + F_s}{2} \right) d^- \right],
\]

\[
F(x) + \left( \frac{1 + F_s}{2} \right) d^+ - \left( \frac{1 - F_s}{2} \right) d^- ]
\]

Model Error:

\[ E = d^- - d^+ \]

Modified Area Validation Metric $F_s=1$

Model Form Uncertainty Interval:

$[F(x) - d^-, F(x) + d^+]$

$d^+ = 0.005$
Modified Area Validation Metric $Fs=2.58$

$Fs(N_{\text{exp}}) = 1.25 + 1.2 \left( \frac{4 - 1.25}{N_{\text{exp}}^{1/3}} \right)$

Model Form Uncertainty Interval:

$$[F(x) + \left( \frac{1 - F_s}{2} \right) d^+ - \left( \frac{1 + F_s}{2} \right) d^-],$$

$$F(x) + \left( \frac{1 + F_s}{2} \right) d^+ - \left( \frac{1 - F_s}{2} \right) d^-]$$

THD of $V_{ab}$ cumulative probability

$F(x)$  $n=25$  $ne=5$

$F(x)-$negative

$F(x)$

$F(x)+$positive

$Sn(x)$
Mean Comparison, AVM, MAVM

![Graph showing Mean Comparison, AVM, MAVM](image)

- Sim Mean
- True Mean
- Mean comp.
- AVM
- MAVM Fs=2.58
- MAVM Fs=1
Summary

• Mean Comparison:
  - Minimum number of replicated measurement is required.
  - It is just based on mean value without considering standard deviation.

• Area validation metric
  - Could be used with any number of experimental data available.
  - Model error cannot be calculated.
  - Does not include measurement uncertainties.

Modified Area Validation Metric:
  - Could be used with any number of experimental data available.
  - Model error could be calculated.
  - Factor of safety could be used to include the measurement errors.
Thank you!
References


