How well does a model simulation match with system response?

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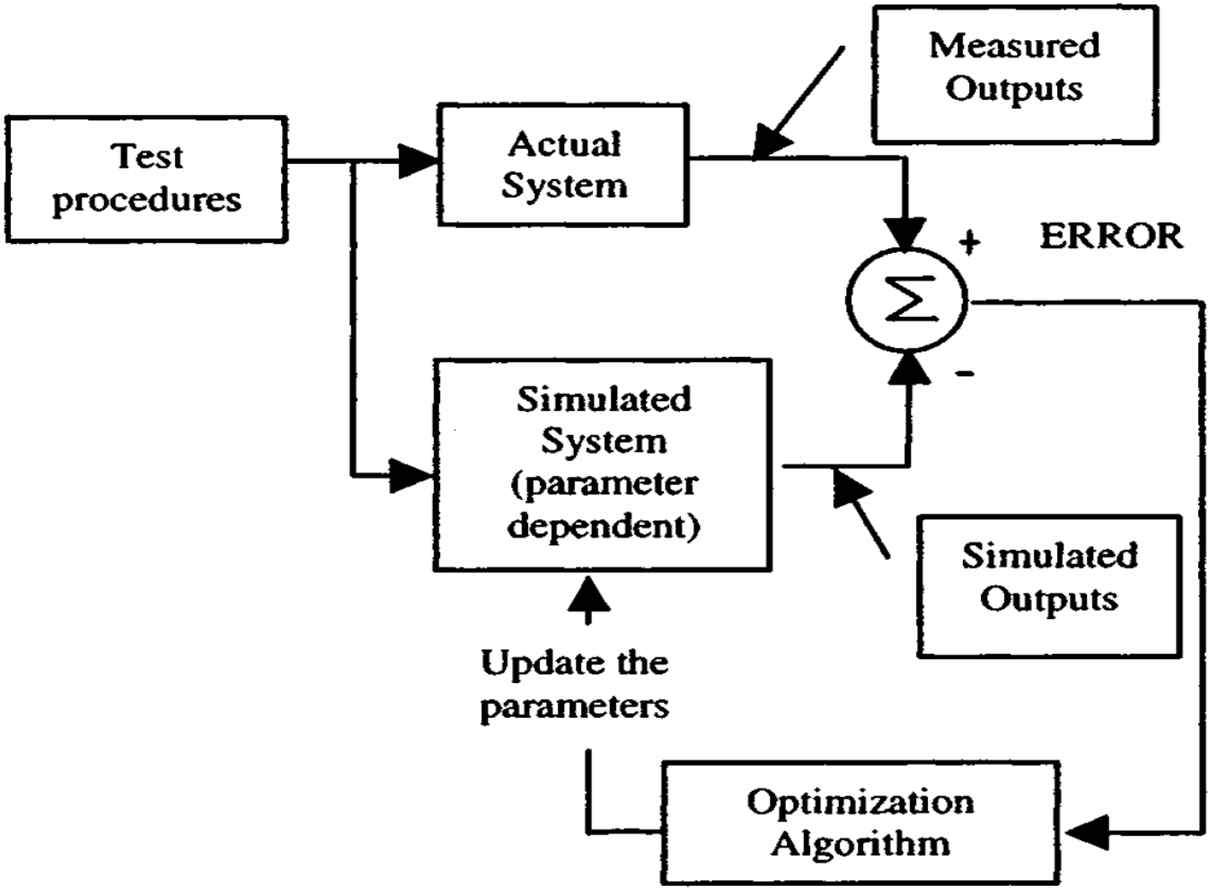
Power System Model Validation

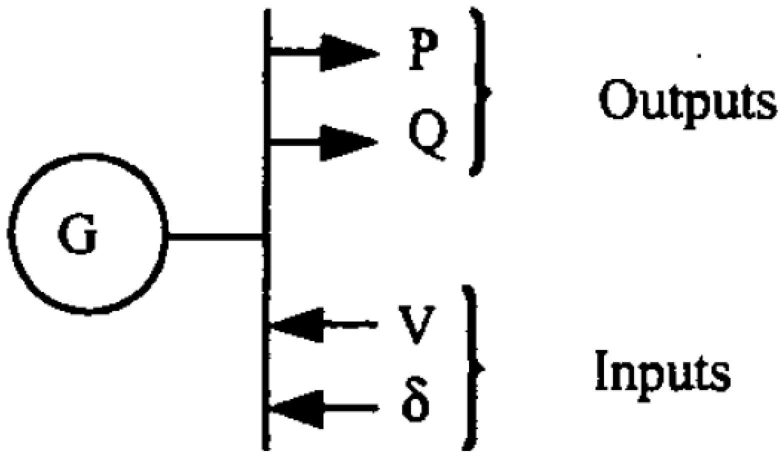
“A new framework for estimation of generator dynamic parameters”: IEEE Trans. Power Systems, 2000.



Meng Shen, PhD thesis, WSU, 2000

Power Plant Model Validation

"Decentralized estimation of power system dynamic models": IEEE CDC 2000 paper.



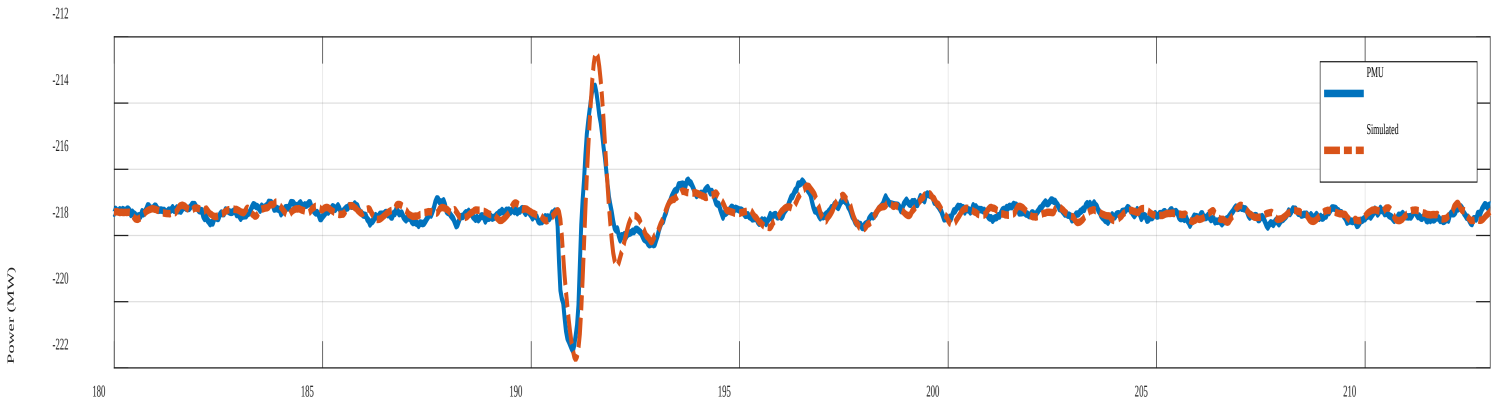
$$\min_{p \in P} E(p) \qquad (2)$$

where

$$E(p) = \sum_{k=1}^{n} (P_m(t_k) - P_c(t_k, p))^2 + (Q_m(t_k) - Q_c(t_k, p))^2$$

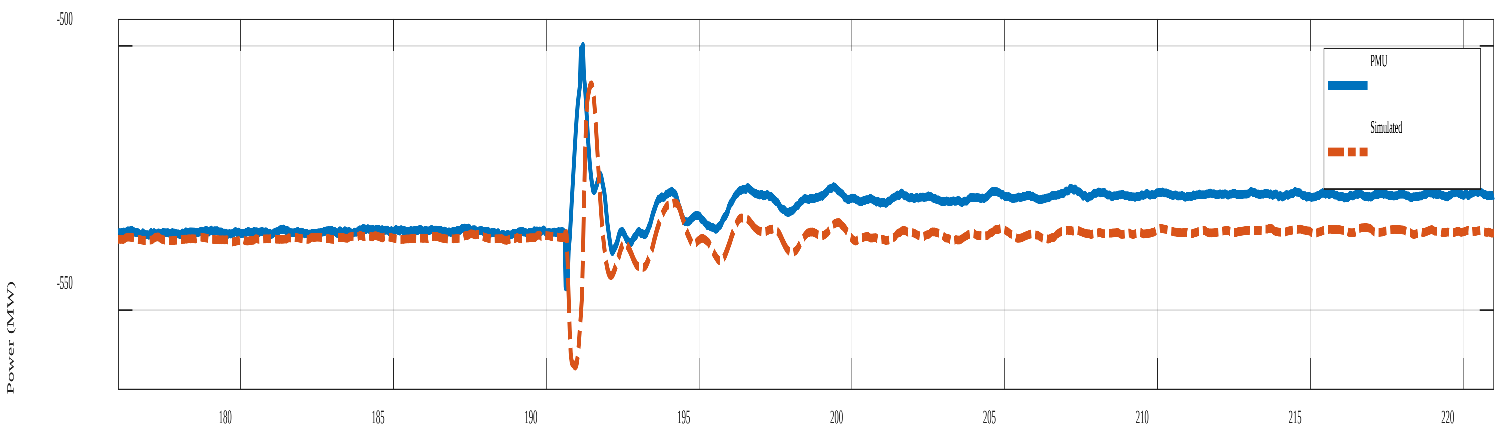
Meng Shen, PhD thesis, WSU, 2000

Power Plant Model Validation



1.5

Case 1: Reasonable match



10

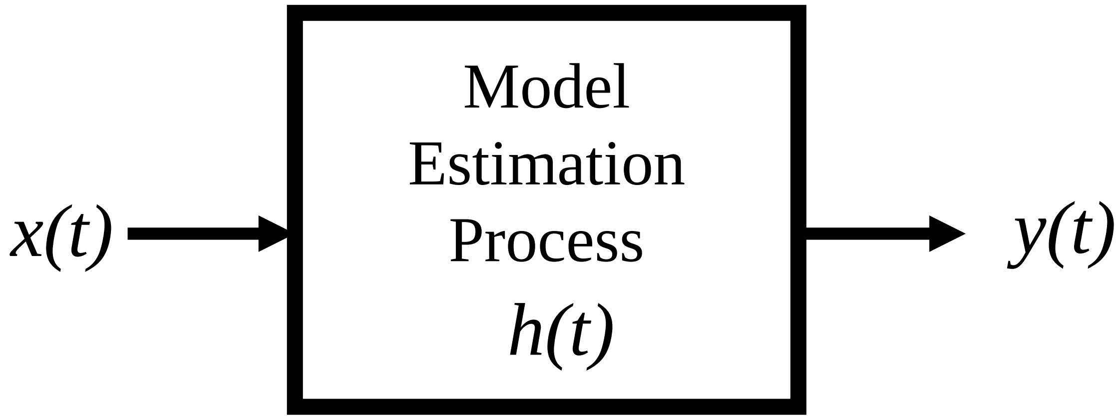
Case 3: Unacceptable match

Correlation Measure

$$Cor(x, y) = \frac{cov(x,y)}{\sigma_x \sigma_y}$$

- Simple
- Gives general information about similarity
- **Sources of model discrepancy cannot be identified**
- Not sufficient for model validation problem

Magnitude-Shape (M-S) Similarity Measure



$$H(f) = \frac{|Y(f)|}{|X(f)|} e^{j(\emptyset_y(f) - \emptyset_x(f))}$$

$x(t)$ and $y(t)$ similar

$$\left\{ \begin{array}{l} |H(f)| = 1 \\ \text{an} \\ \emptyset_h^{\mathrm{d}}(f) = 0 \end{array} \right.$$

K. Shin, “An alternative approach to measure similarity between two deterministic signals,” Journal of Sound and Vibration, Mar 2016.

Converting the Measures to Metrics

A semi-metric function must have three properties:

1. Non-negativity
2. Symmetry
3. Subadditivity
4. By having the property of identity of Indiscernible (*D(x, y)=0* if and only if *x=y*), a semi-metric will also be a metric

$$D_{M,\alpha}(f) = tanh(\frac{|20log_{10}|H(f)||}{\alpha})$$

$$D_{A,\beta} = tanh(\frac{1}{2\pi}\frac{|\emptyset_h(f)|}{\beta})$$

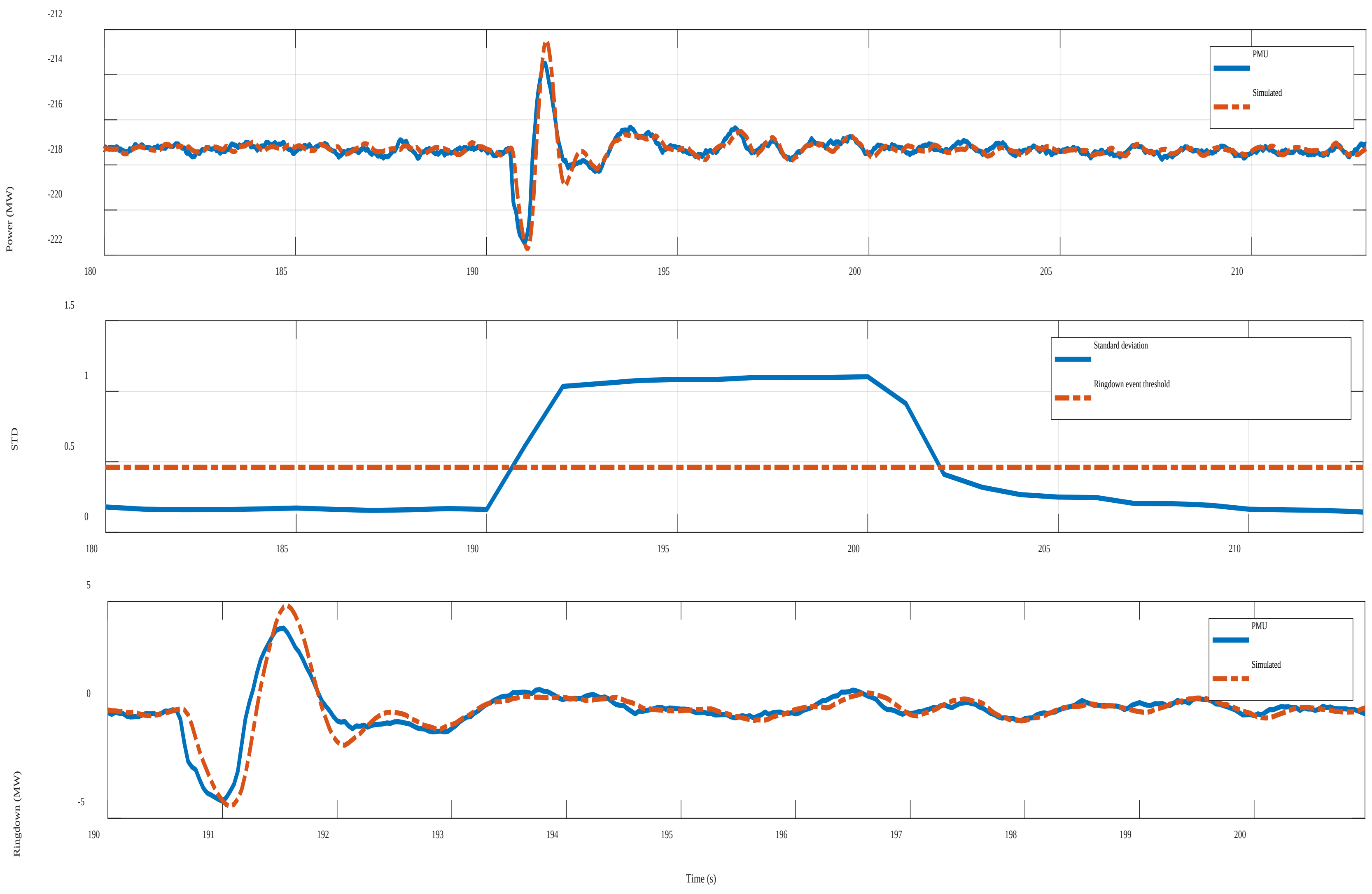
Distance measure for each frequency

$$M_\alpha(f) = 1 - D_{M,\alpha}(f)$$

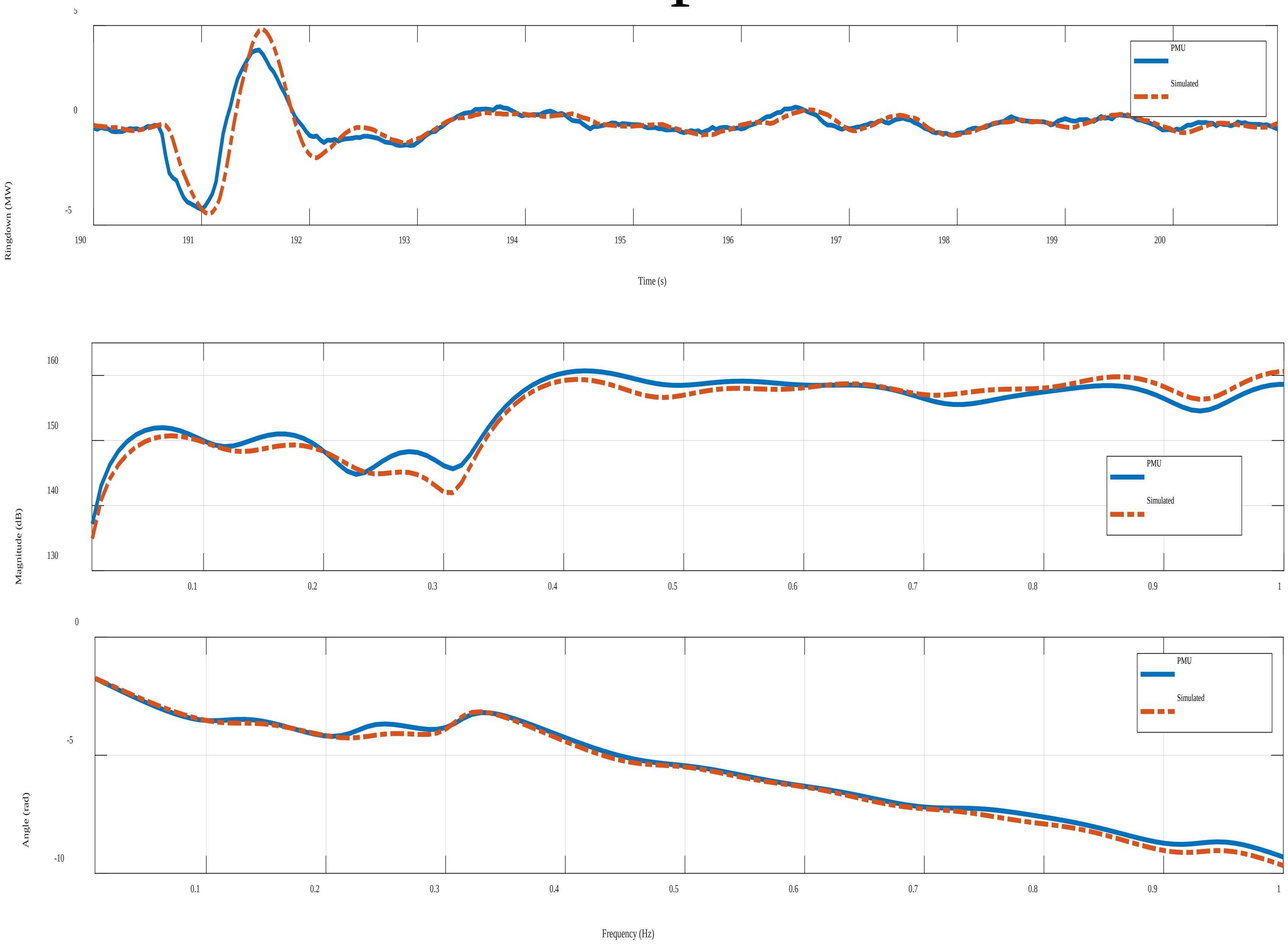
$$A_\beta(f) = 1 - D_{A,\beta}(f)$$

Similarity measure for each frequency

Example 1 – Power plant validation

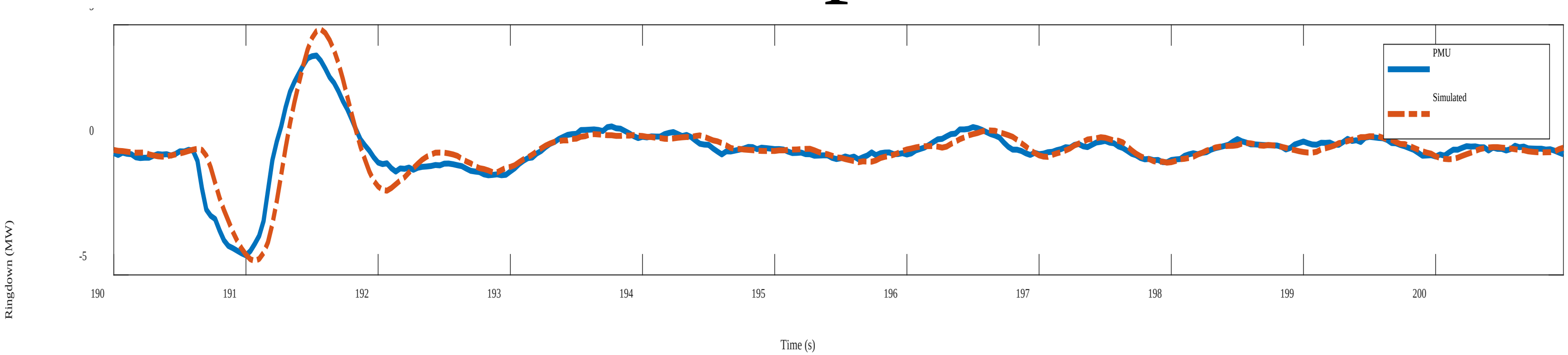


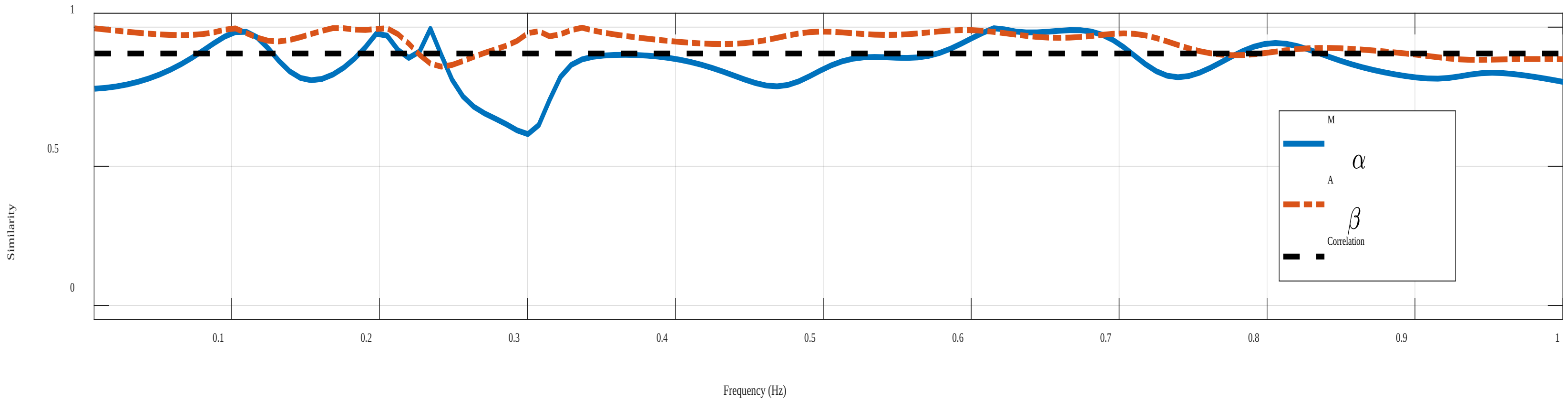
Example 1



5
0
-5
Ringdown (MW)
190
191
192
193
194
195
196
197
198
199
200
Time (s)
PMU
Simulated
160
150
140
130
Magnitude (dB)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PMU
Simulated
0
-5
-10
Angle (rad)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PMU
Simulated
Frequency (Hz)

Example 1

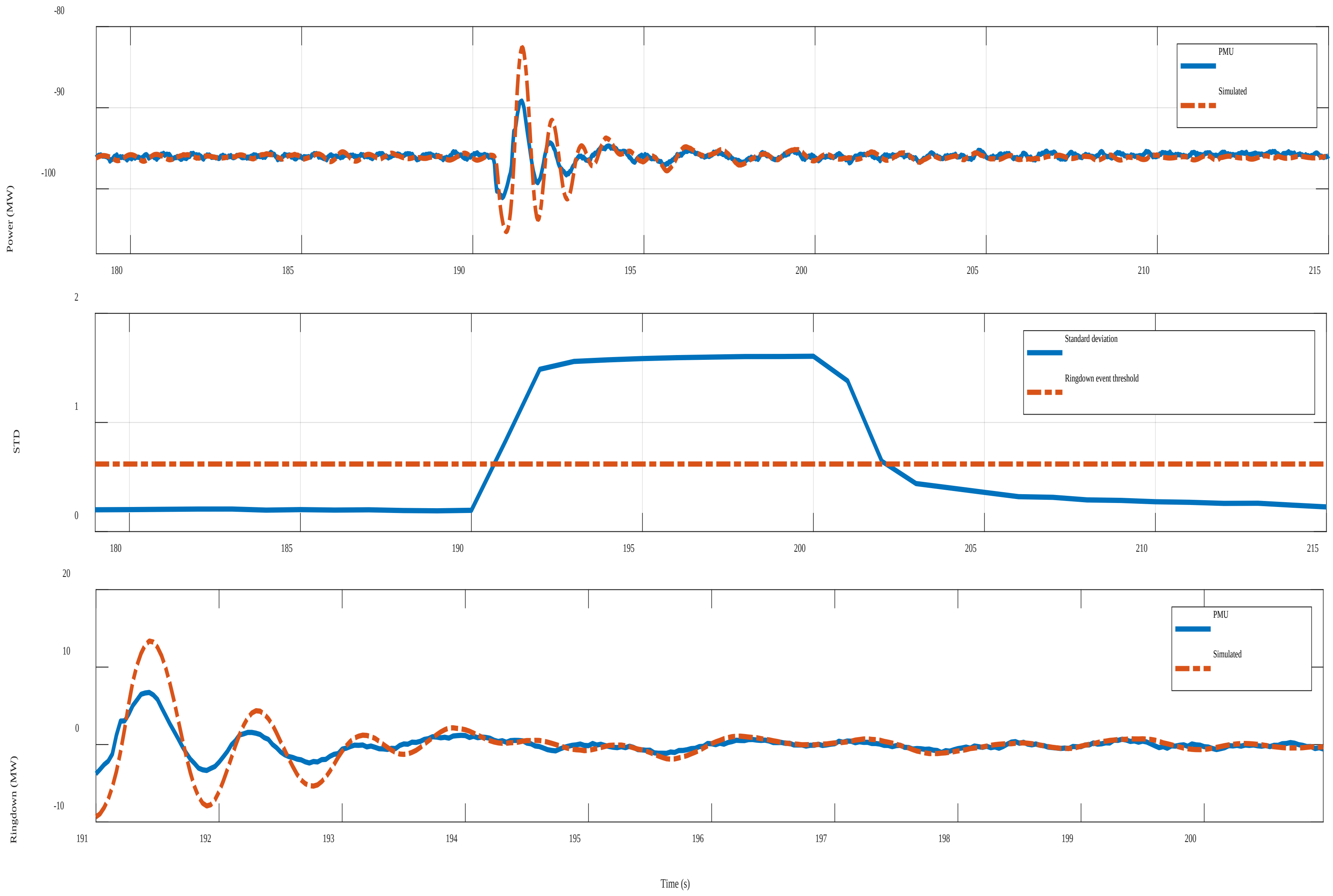




Index	Correlation	M_α	A_β	Average	Worst
Value	0.91	0.87	0.95	**0.91**	**0.87**

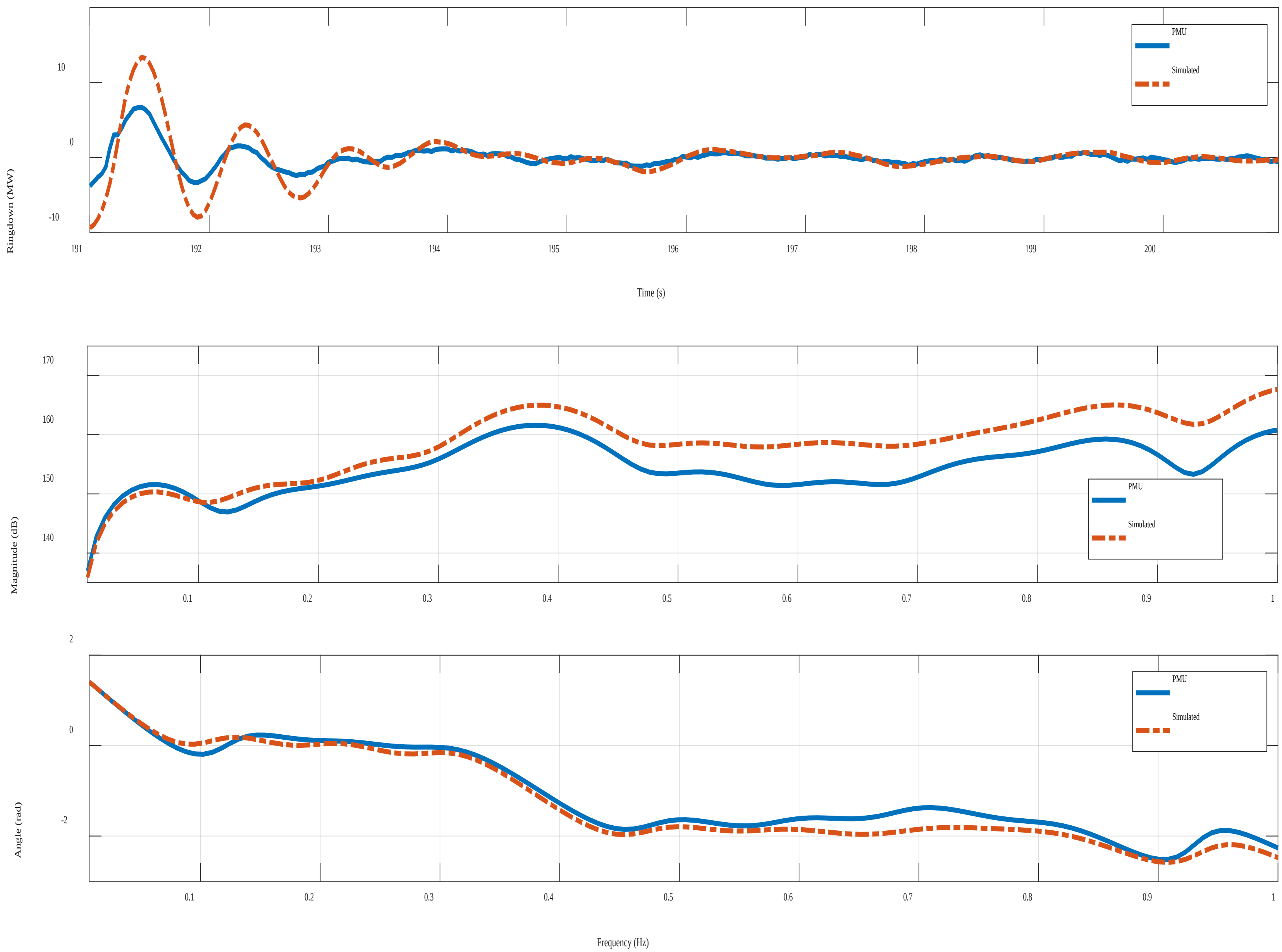
All three measures show strong resemblance

Example 2



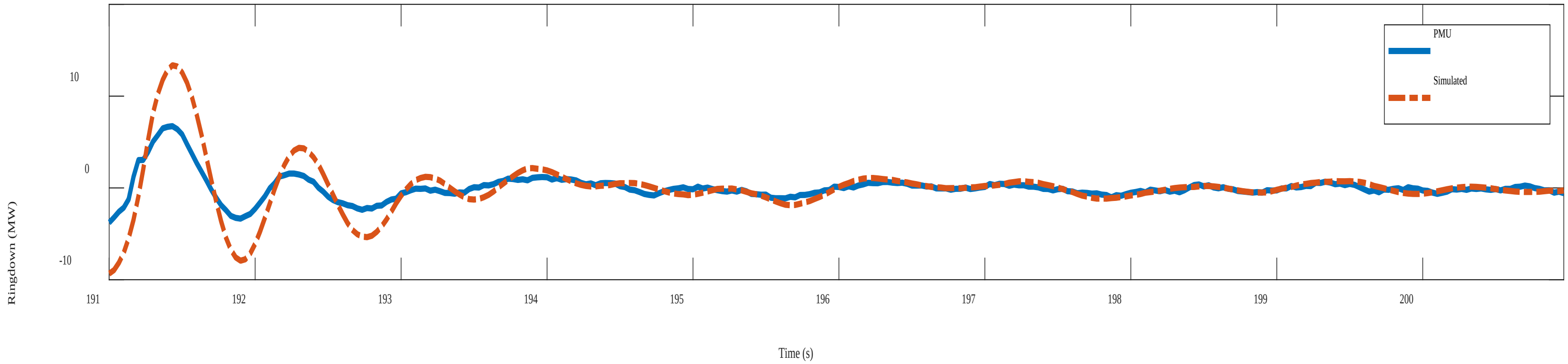
-80
-90
-100
Power (MW)
PMU
Simulated
180
185
190
195
200
205
210
215
2
1
0
STD
Standard deviation
Ringdown event threshold
180
185
190
195
200
205
210
215
20
10
0
-10
Ringdown (MW)
PMU
Simulated
191
192
193
194
195
196
197
198
199
200
Time (s)

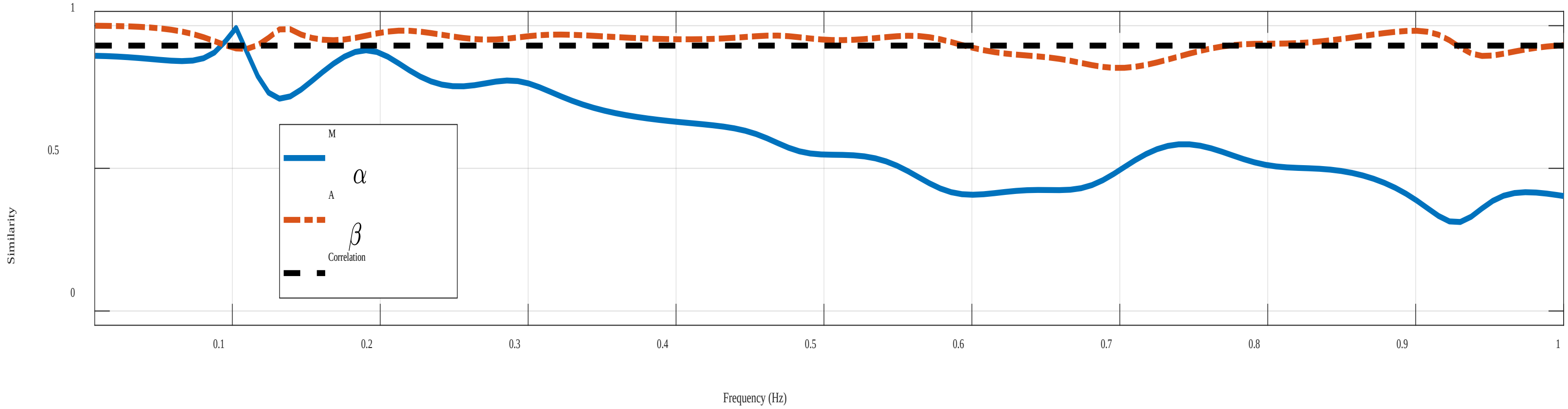
Example 2



PMU
Simulated
10
0
-10
Ringdown (MW)
191
192
193
194
195
196
197
198
199
200
Time (s)
170
160
150
140
Magnitude (dB)
2
0
-2
Angle (rad)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Frequency (Hz)

Example 2

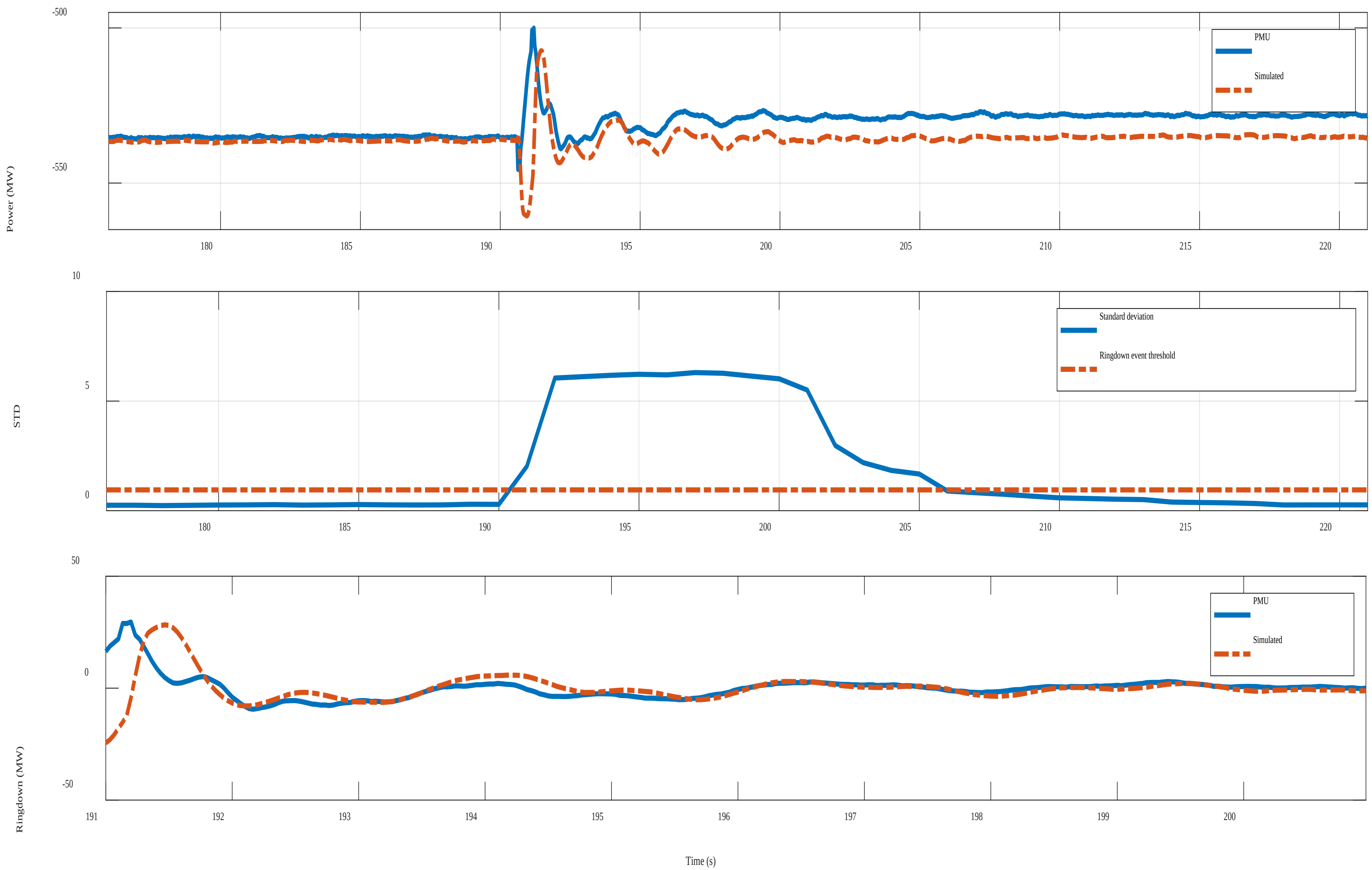




Index	Correlation	M_α	A_β	Average	Worst
Value	0.93	0.62	0.95	**0.83**	**0.62**

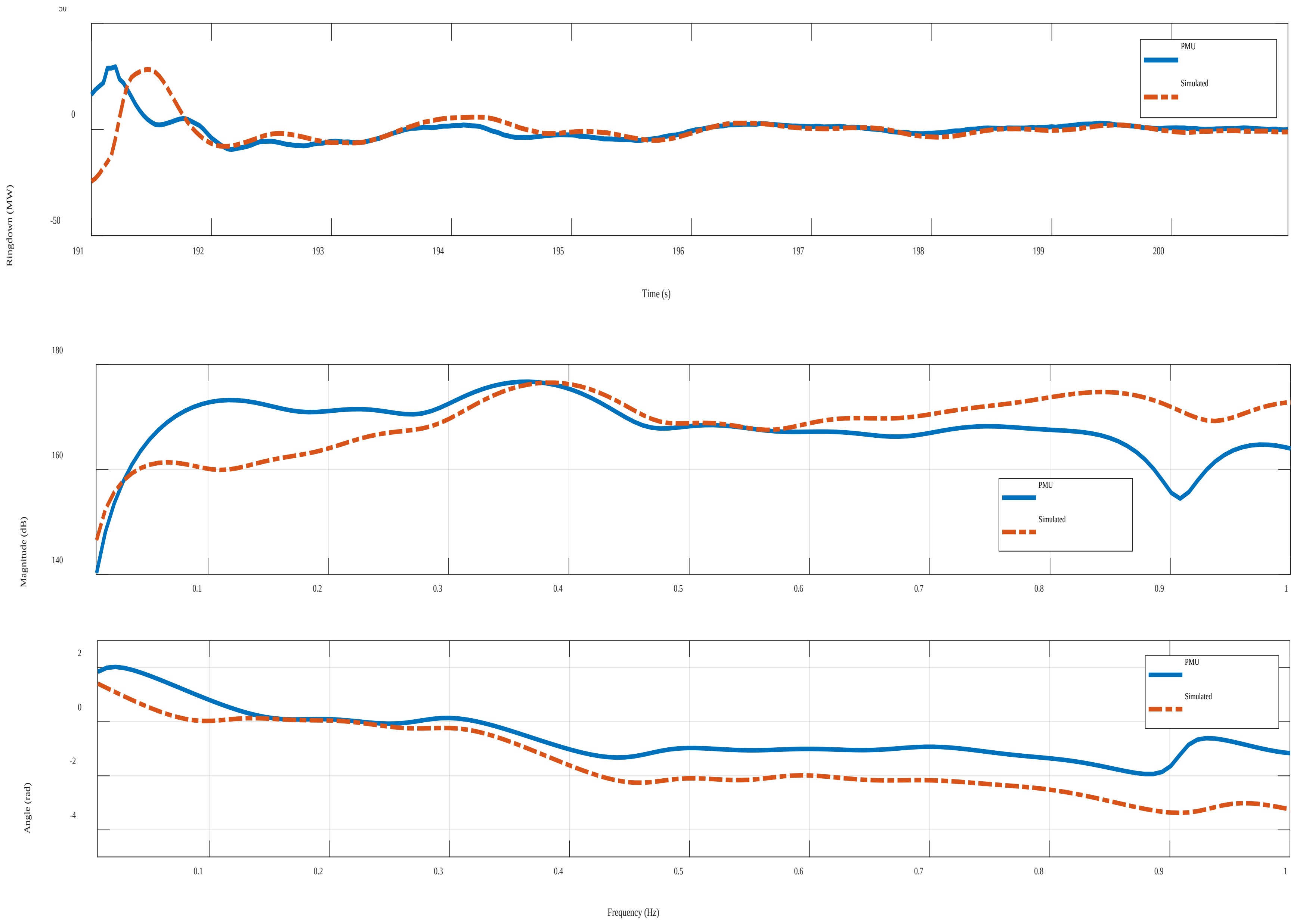
Poor Magnitude similarity

Example 3

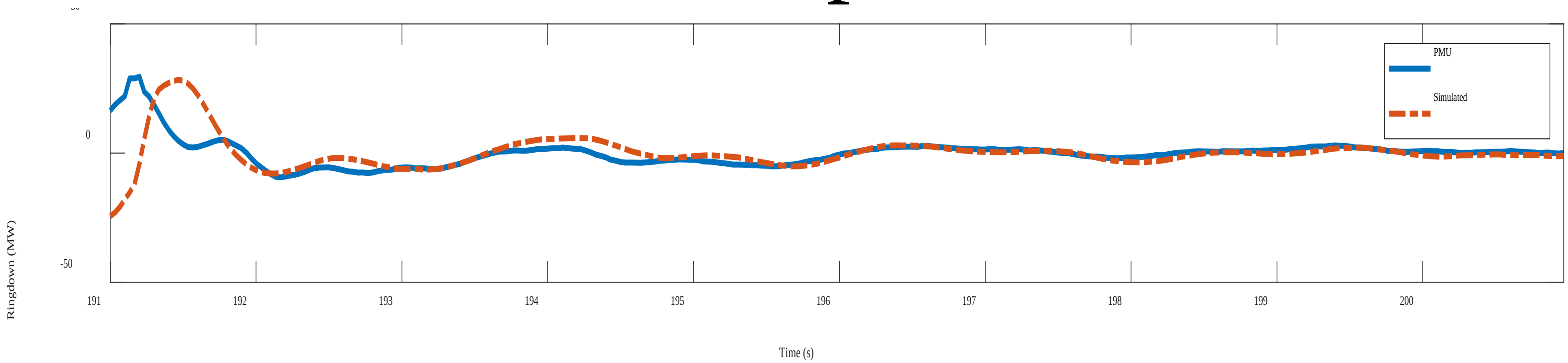


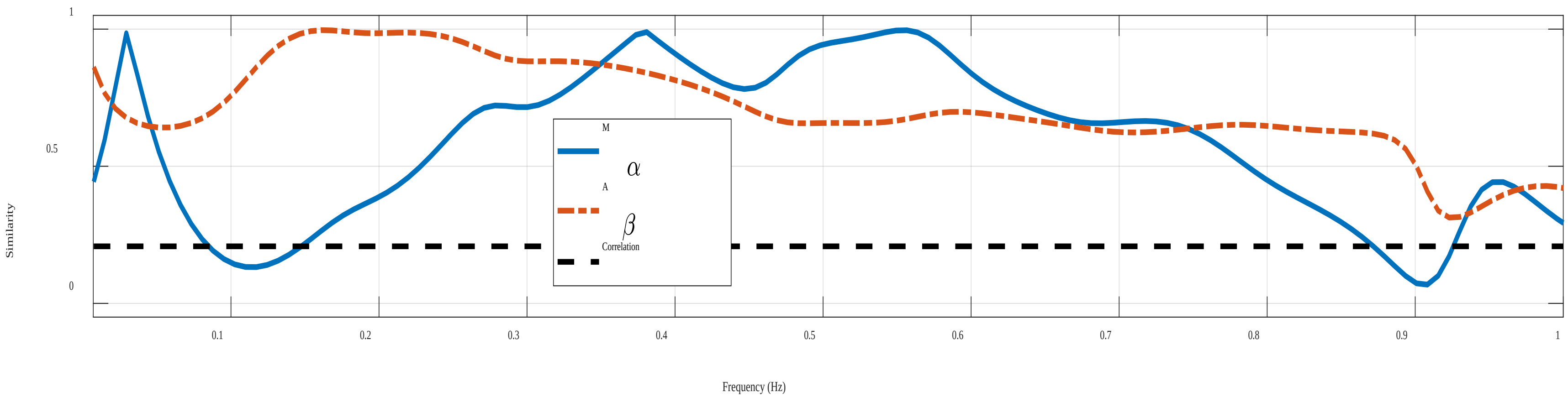
-500
-550
Power (MW)
PMU
Simulated
180
185
190
195
200
205
210
215
220
10
5
0
STD
Standard deviation
Ringdown event threshold
180
185
190
195
200
205
210
215
220
50
0
-50
Ringdown (MW)
PMU
Simulated
191
192
193
194
195
196
197
198
199
200
Time (s)

Example 3


50
0
-50
Ringdown (MW)
191
192
193
194
195
196
197
198
199
200
Time (s)
PMU
Simulated
180
160
140
Magnitude (dB)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PMU
Simulated
2
0
-2
-4
Angle (rad)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Frequency (Hz)
PMU
Simulated

Example 3

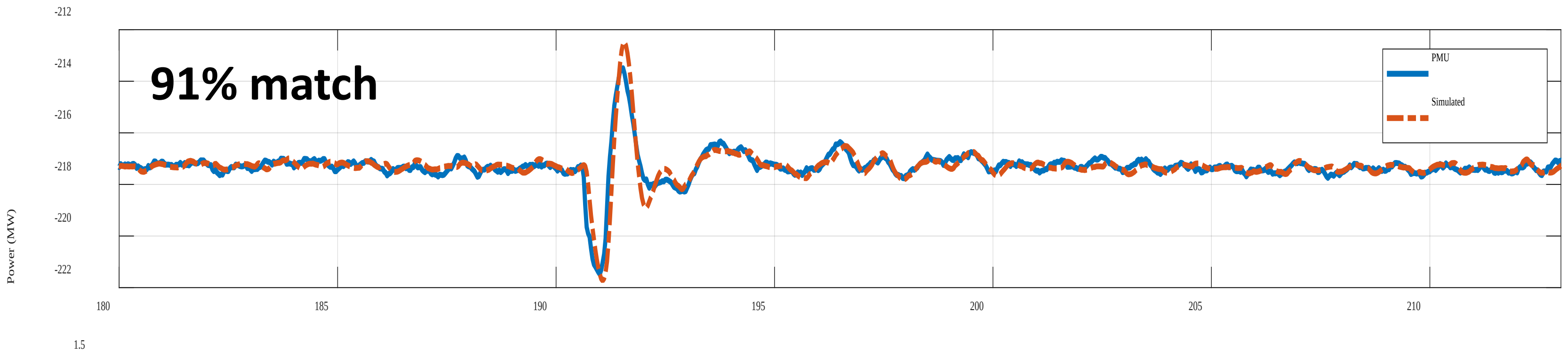


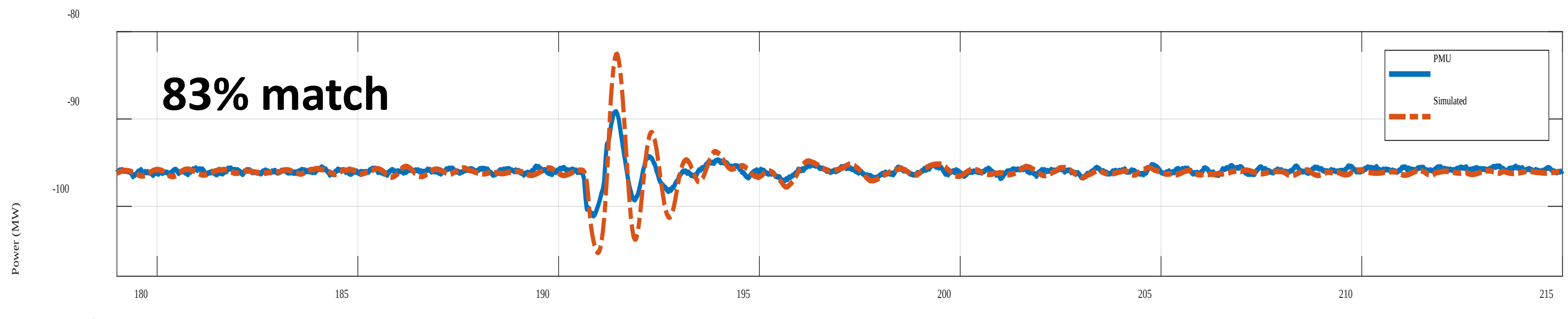


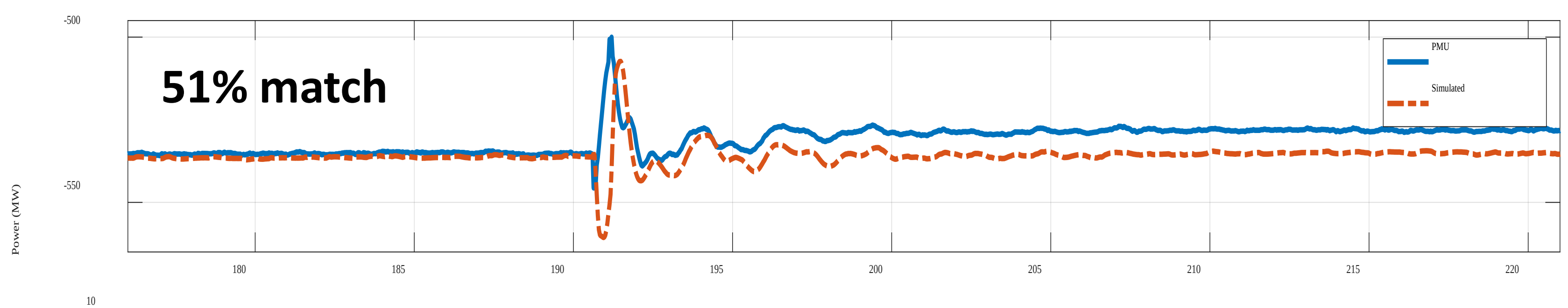
Index	Correlation	M_α	A_β	Average	Worst
Value	0.21	0.59	0.72	**0.51**	**0.21**

Poor similarity measures in all indices

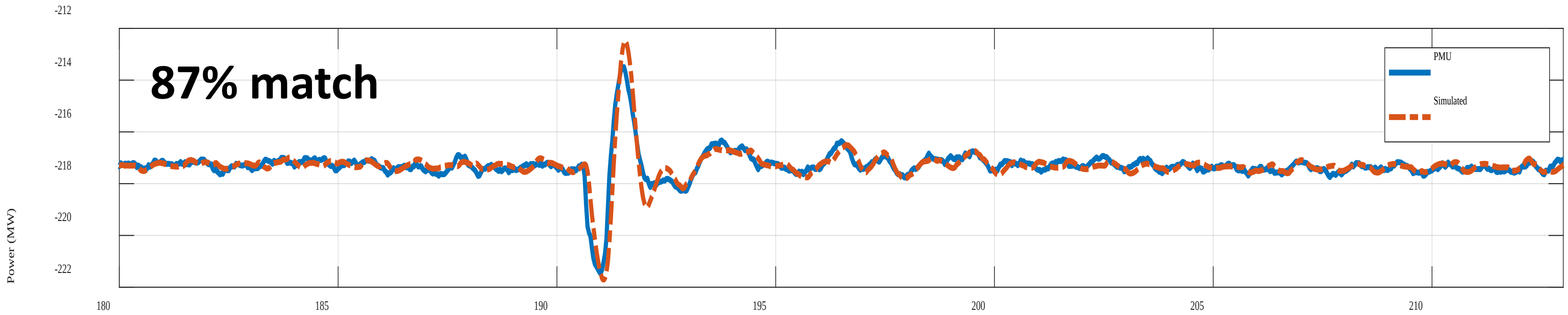
Summary with Average Scores

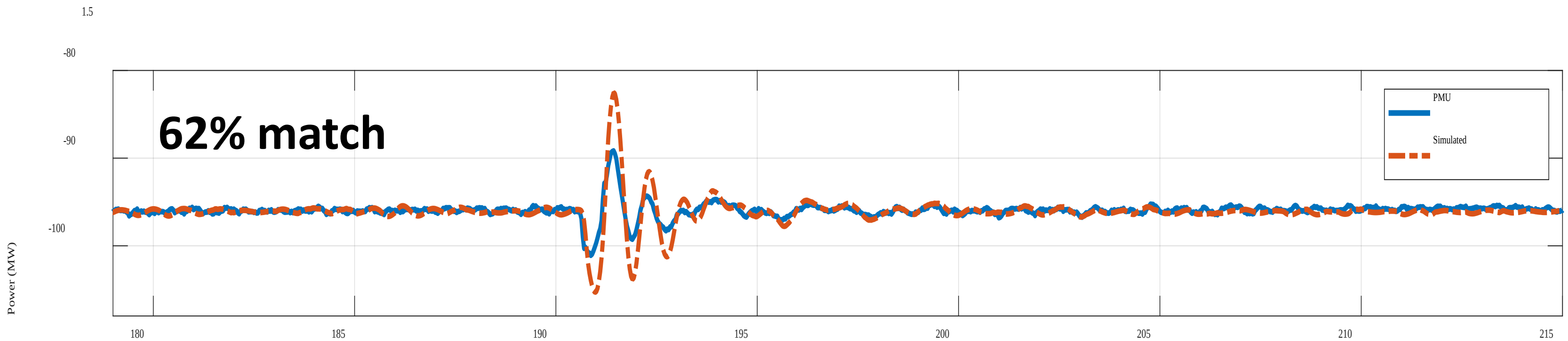


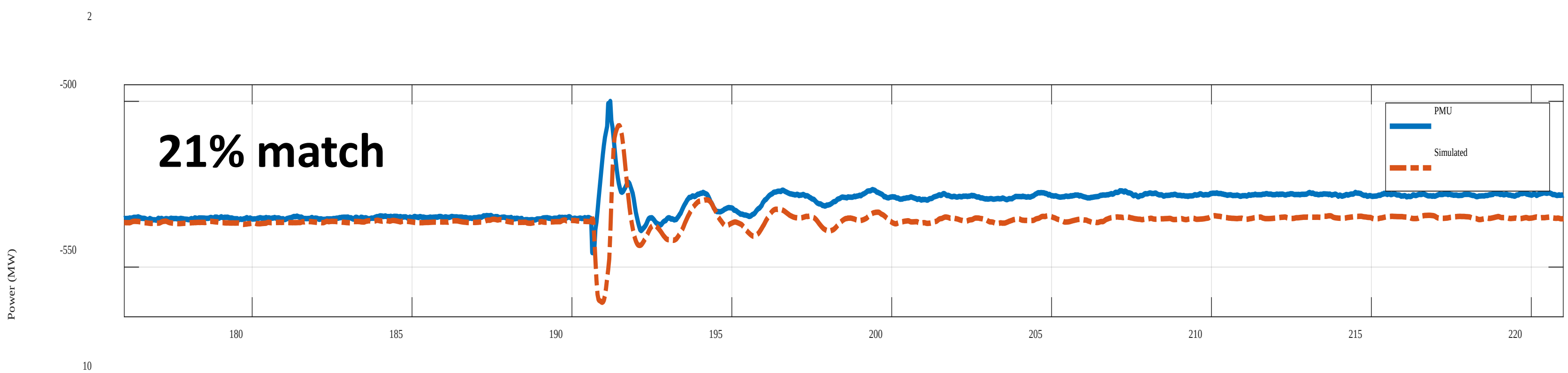




Summary using Worst Scores







Conclusions

- **A procedure for judging how well a model simulation matches with the system response.**
- **Average score or worst score?**
- **Sensitivities of the metrics can be tuned so that a baseline for a good model can be defined.**
- **The procedure is useful for ringdown modal analysis.**