



Model Re-Validation/Invalidation and Calibration using PMU Disturbance Data

Bernie Lesieutre



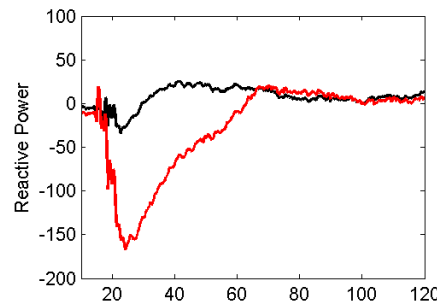
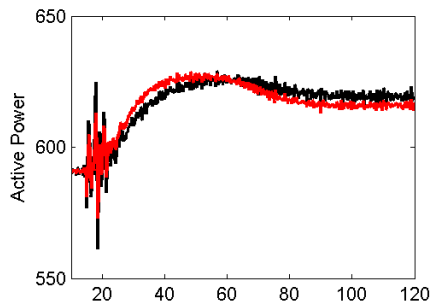
Use PMU Disturbance Data

1. Use disturbance data to evaluate modes:
 - Affirm models
 - Refute models
2. Recalibrate models
3. Identify structural changes

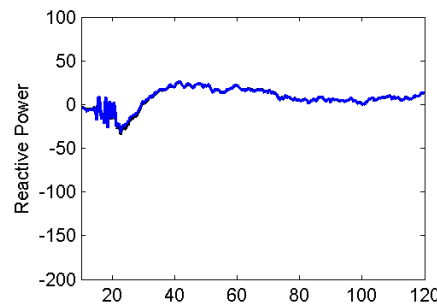
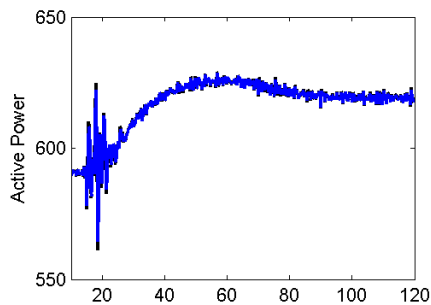


Affirm/Refute/Calibrate

Compare Data and Simulations



Refute Model



Recalibrate Model



Recalibration

We use a sensitivity model to represent changes in model parameters to outcomes of the simulations – trajectories and other features of interest.

We calculate the sensitivity model using perturbation analysis from repeated PSLF simulations.



Sensitivity Models

We rely on models to analyze the grid under various conditions - actual and anticipatory.

Sensitivity models relate features of model-based analyses, to model properties. This is useful for

- Understanding the model components
- **Tuning and improving models based on observations**
- Estimating the range of possible outcomes, i.e., map model uncertainties to responses.



Model Tuning

We've calculated sensitivity models to help

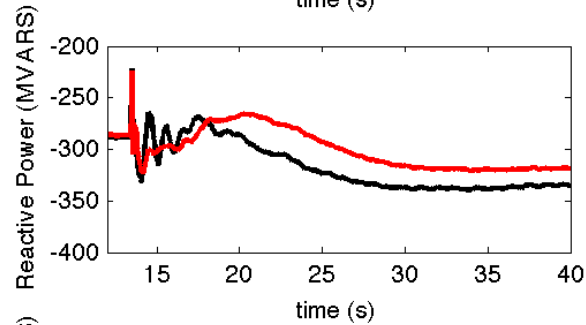
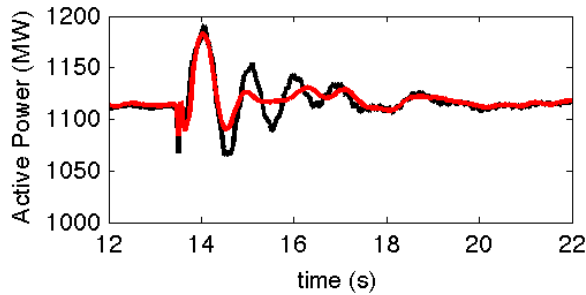
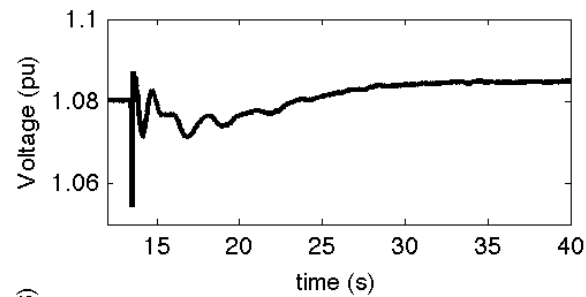
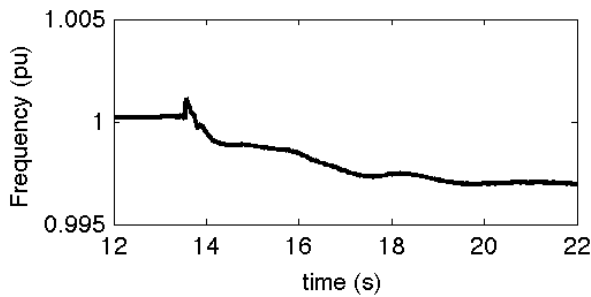
- Estimate load model parameters,
 - System wide simulations
 - Load models for FIDVR studies
- Estimate power plant parameters from PMU measurements



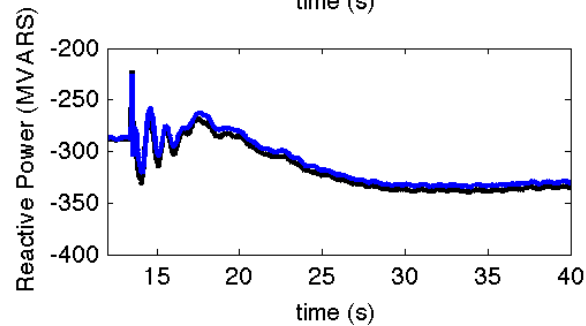
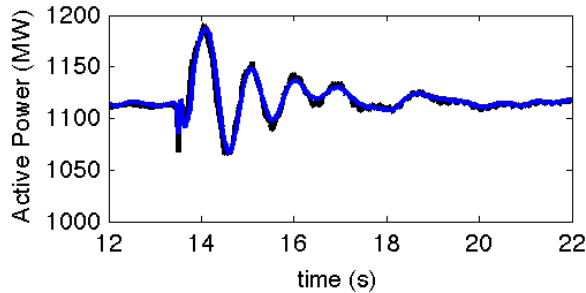
Sensitivities for Model Tuning

Example of using PMU data to fit observations

Before



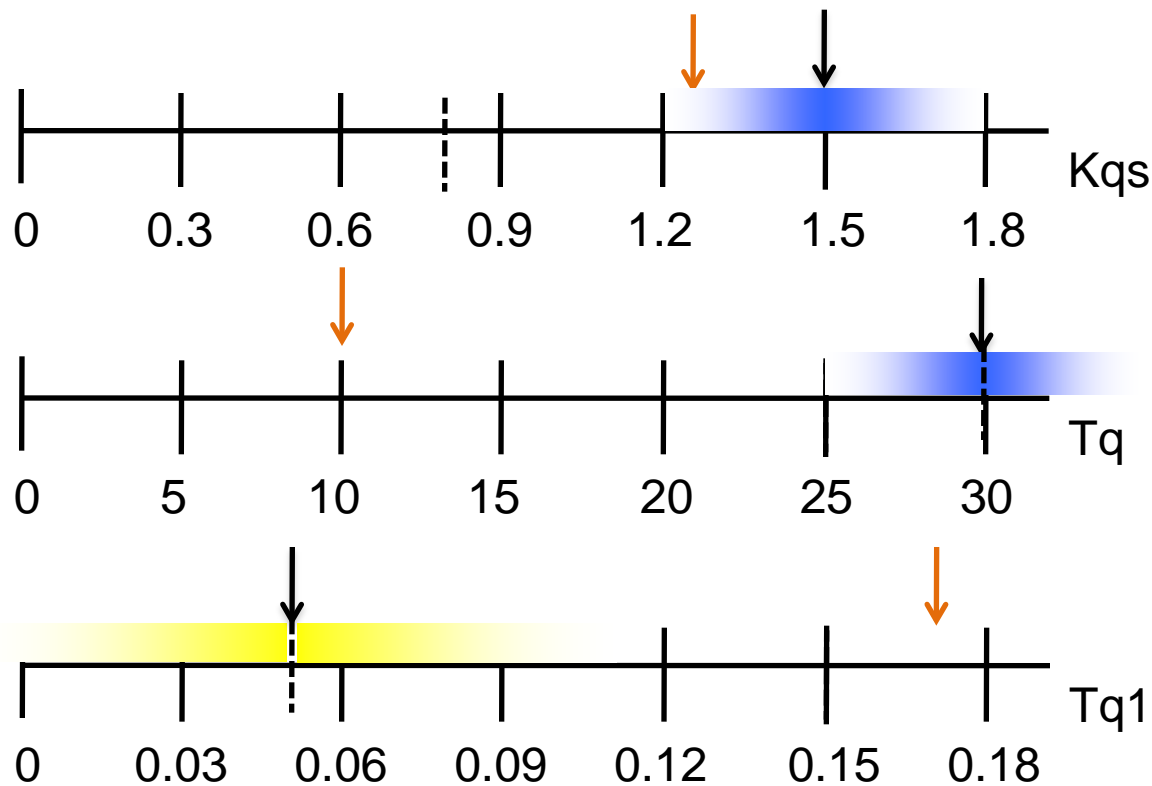
After





Sensitivities for Model Tuning

Example of some parameter adjustments



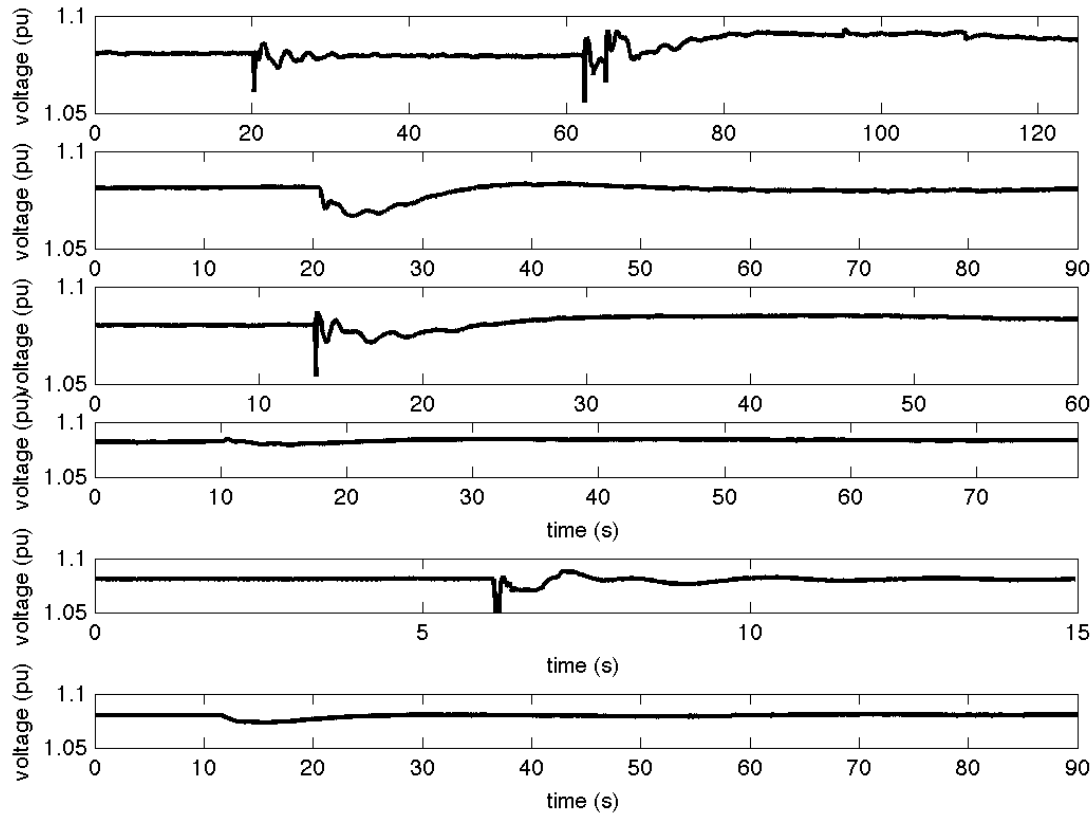
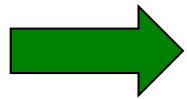
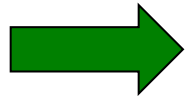
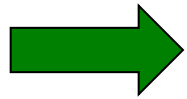
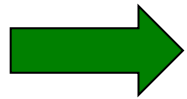


Three Test Cases

1. Recalibration: adjust parameter values
 - 4 study events, 2 verification events, + dozens of additional events studied by BPA.
2. Identify Structural Change: PSS Problem
 - Recalibrate parameters
 - Identify point at which PSS stops operating
3. Test Case – study process
 - Match disturbance data
 - Evaluate parameter values, and uncertainty.

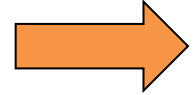
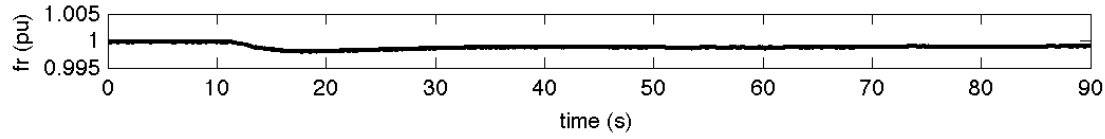
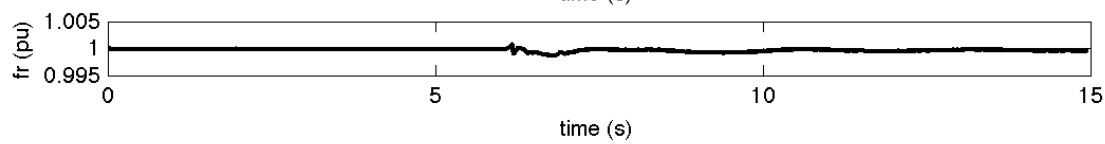
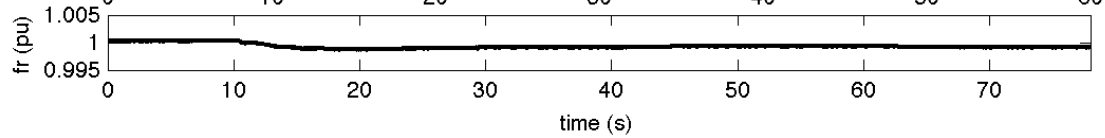
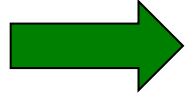
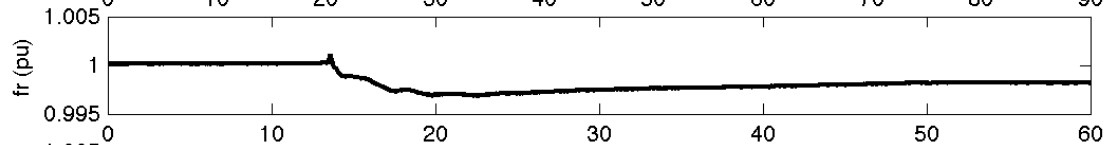
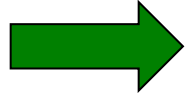
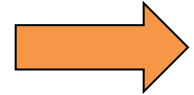
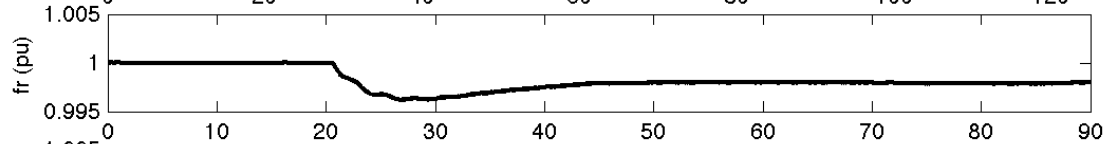
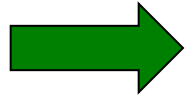
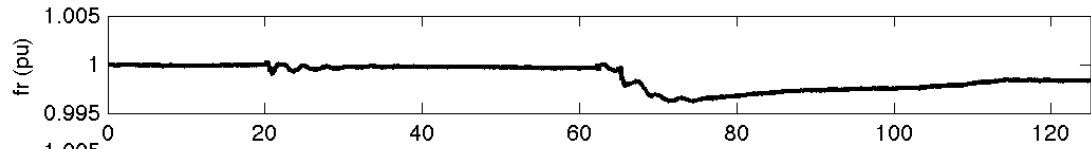
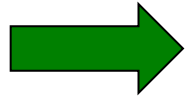


Event Voltages





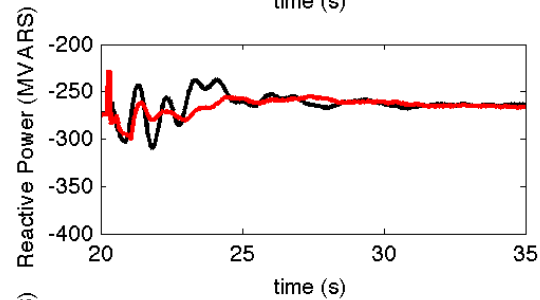
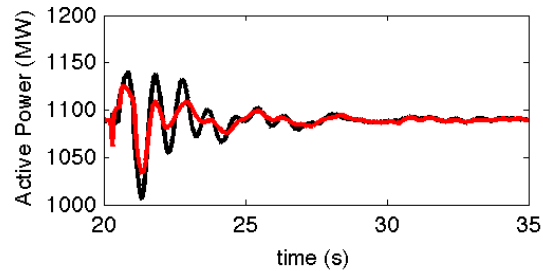
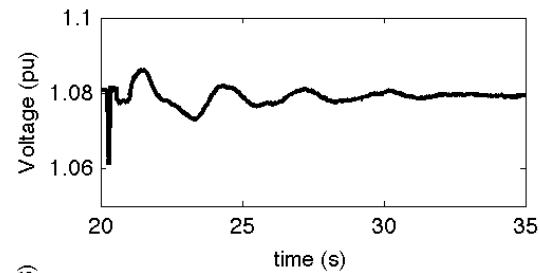
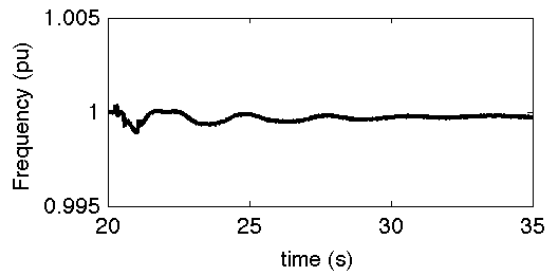
Event Frequencies



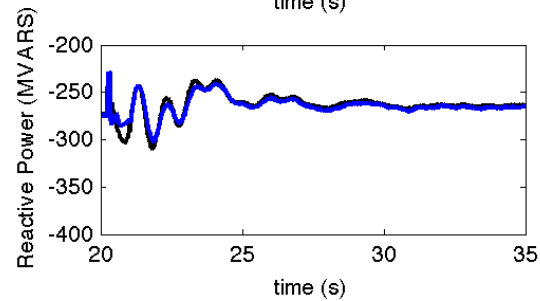
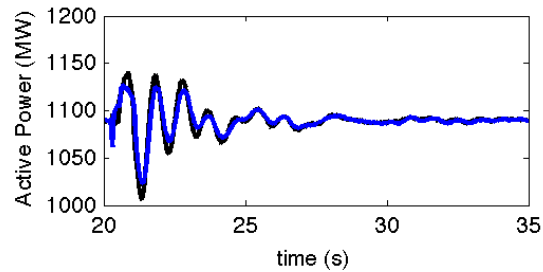


Event 1, part 1

Original
Parameters



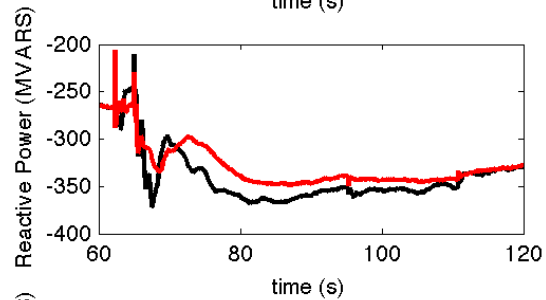
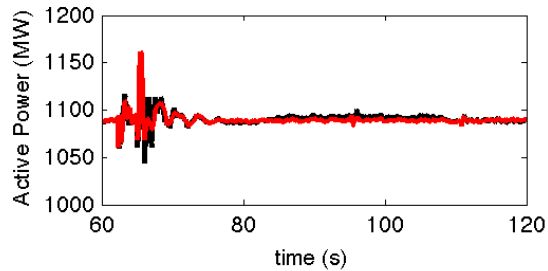
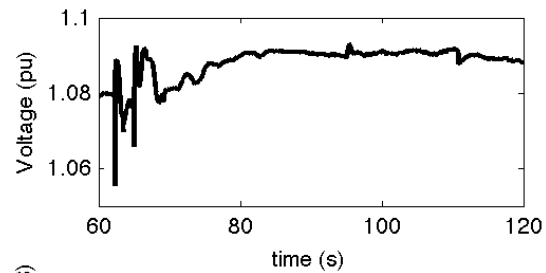
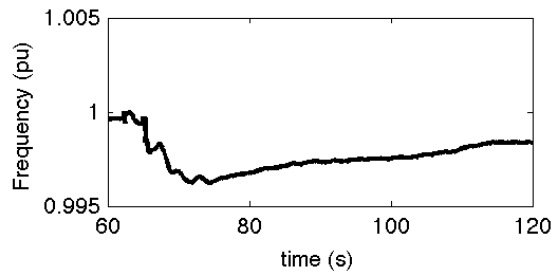
Modified
Parameters



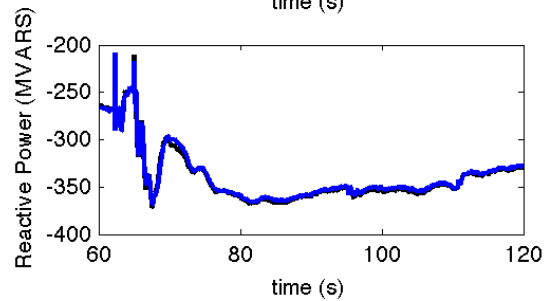
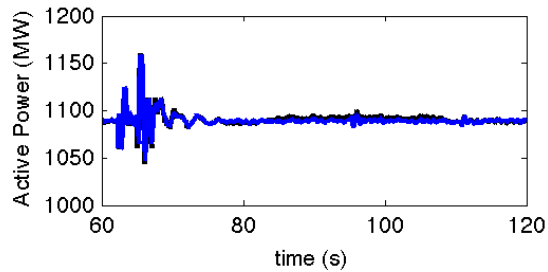


Event 1, part 2

Original Parameters

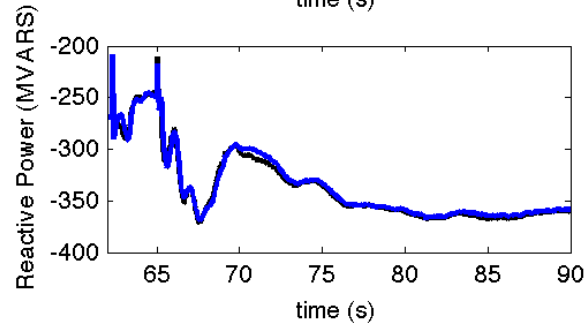
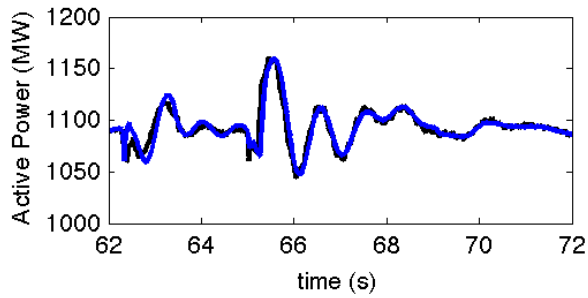
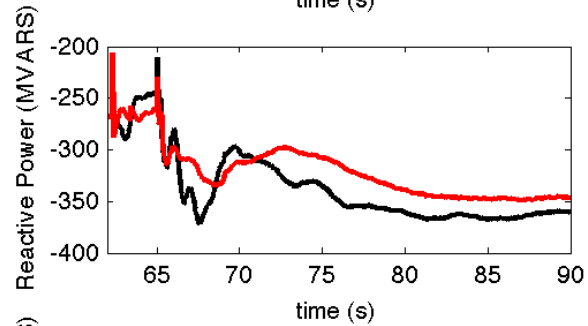
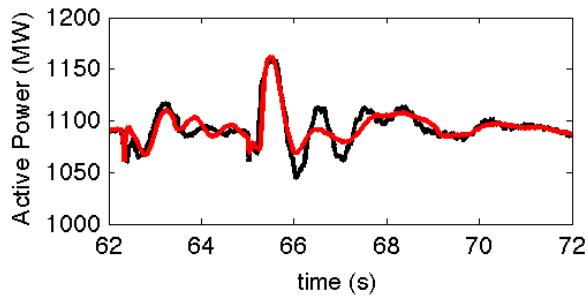
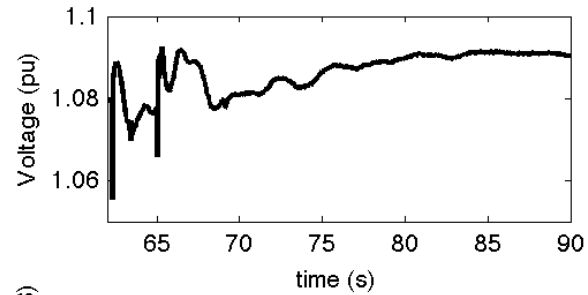
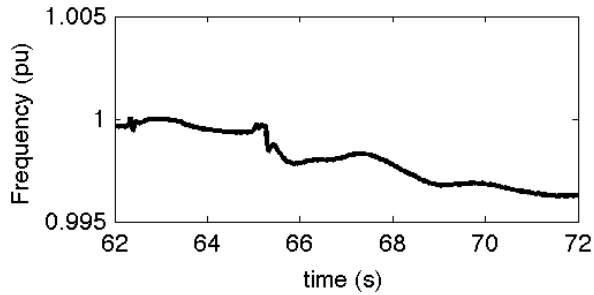


Modified Parameters



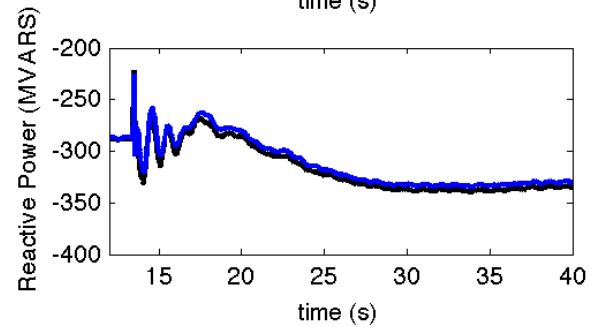
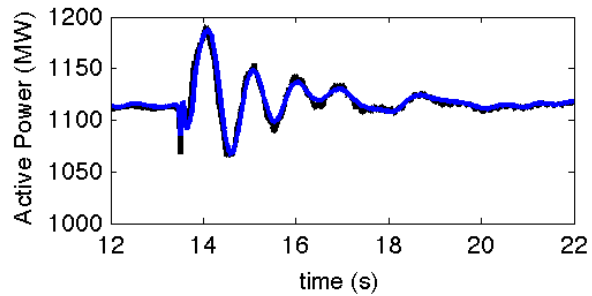
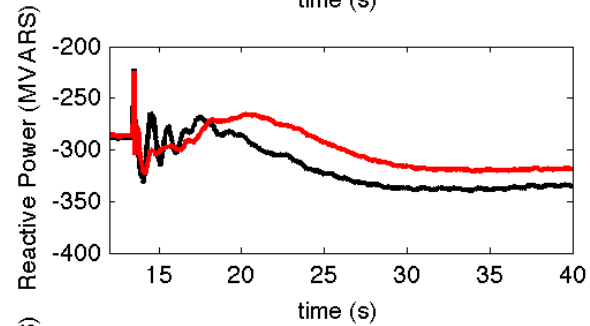
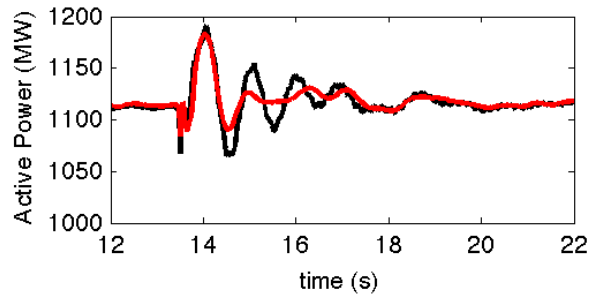
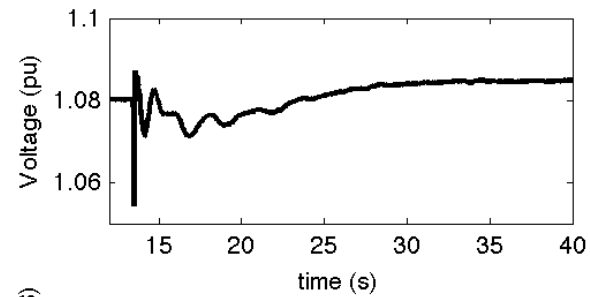
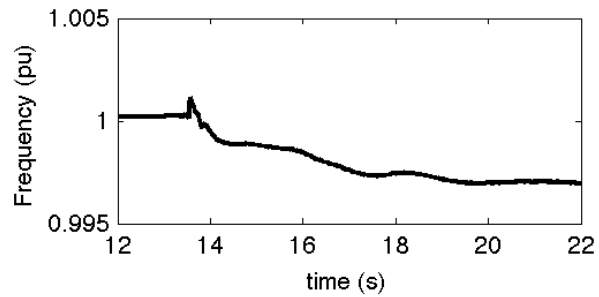


Event 1, part 2



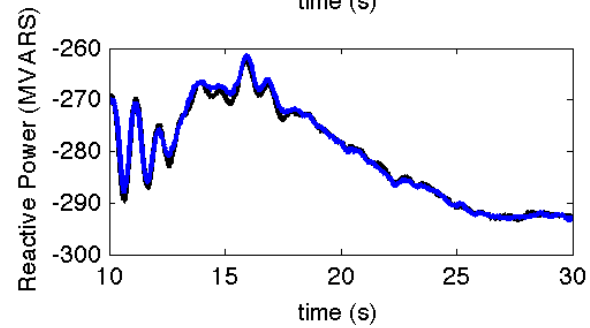
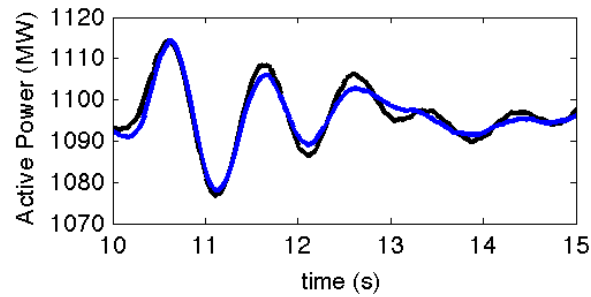
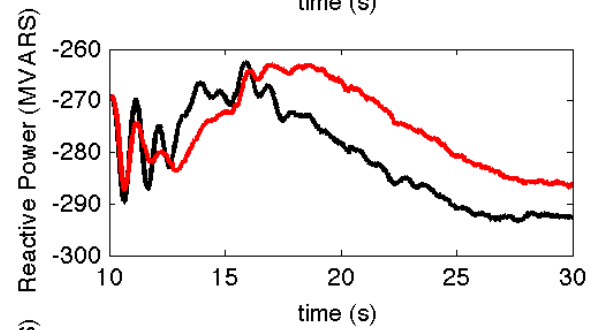
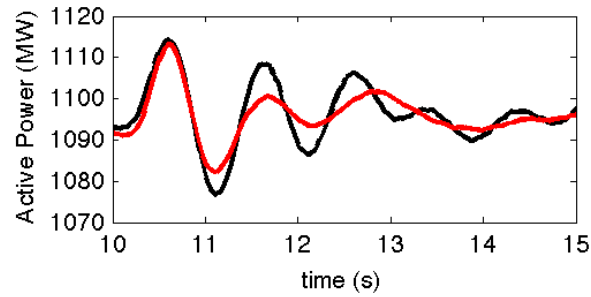
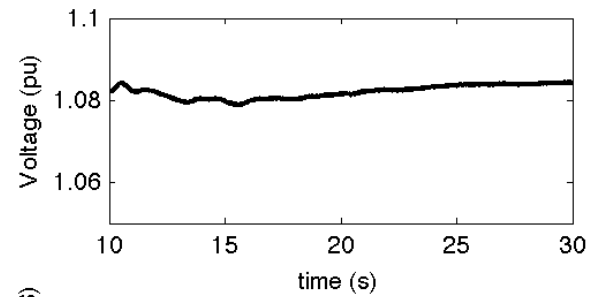
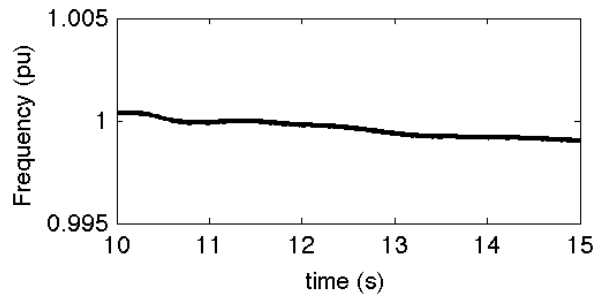


Event 3





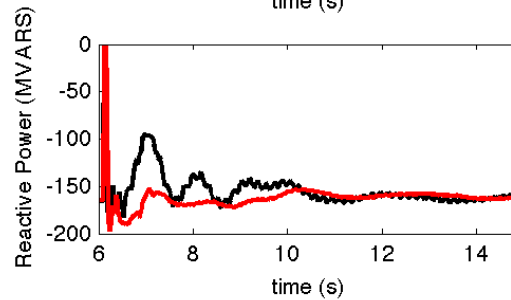
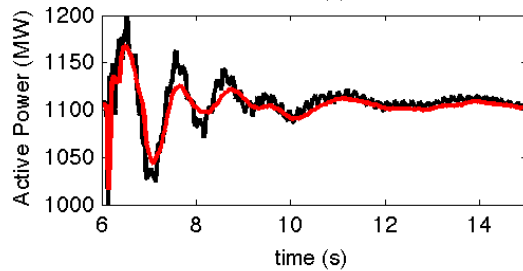
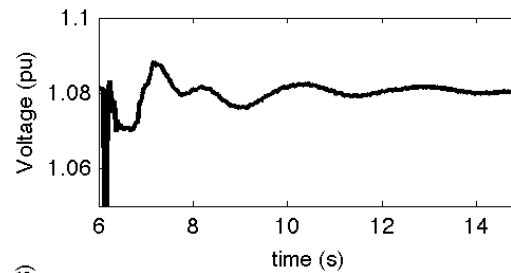
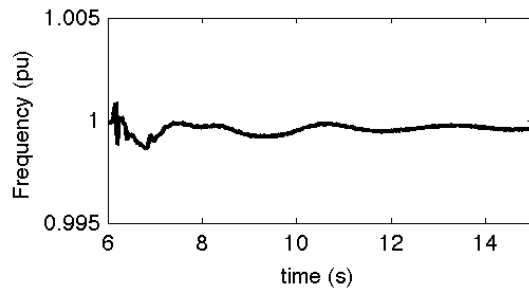
Event 4



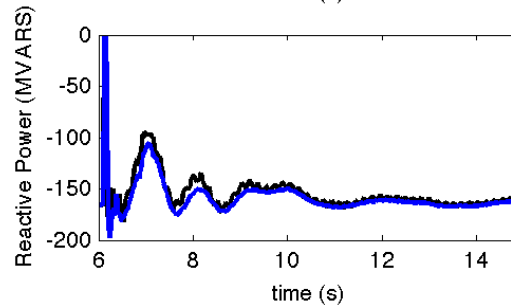
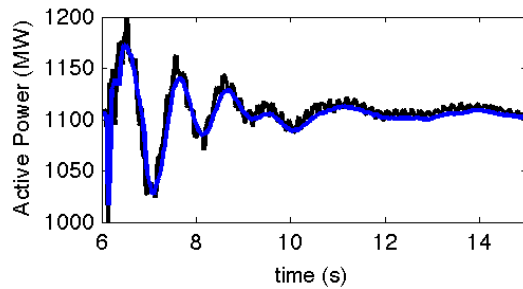


Event 5

Original Parameters

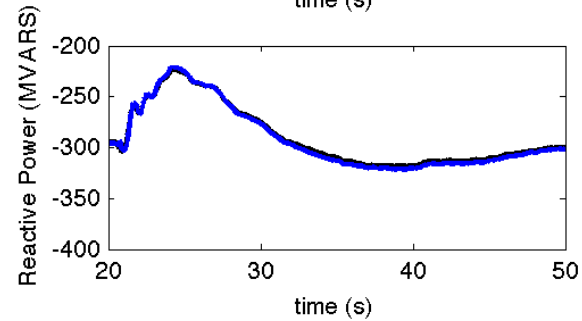
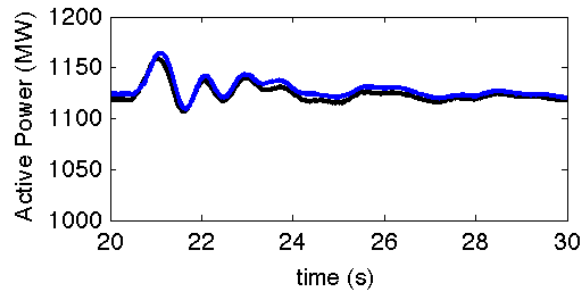
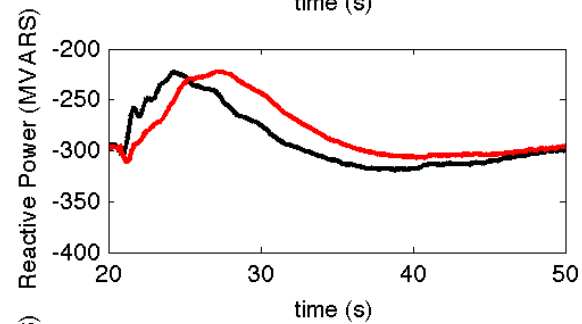
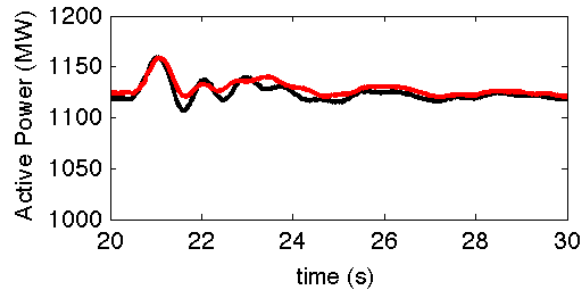
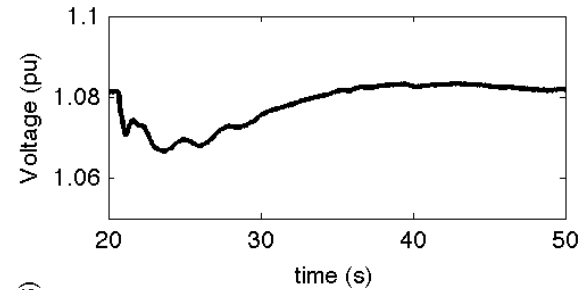
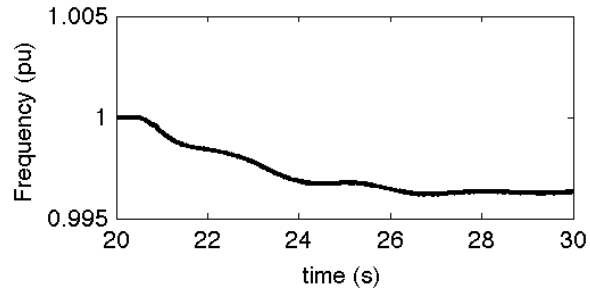


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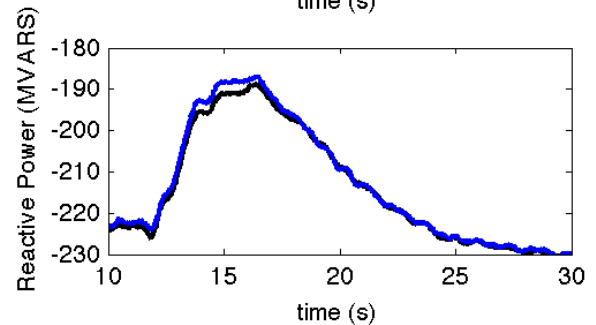
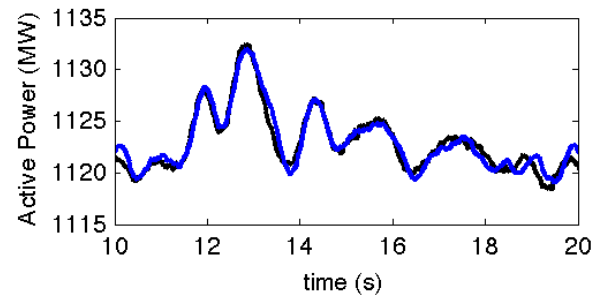
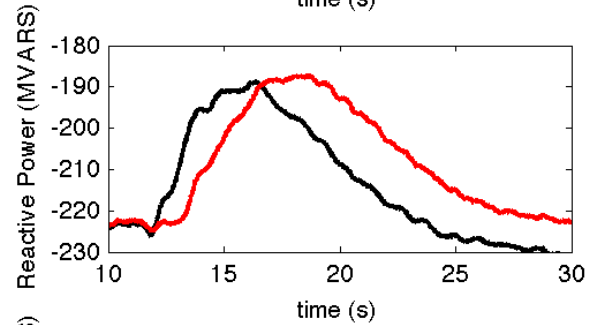
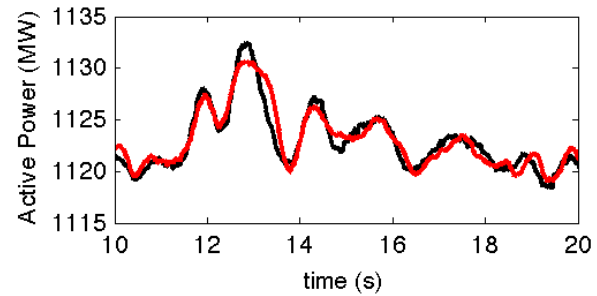
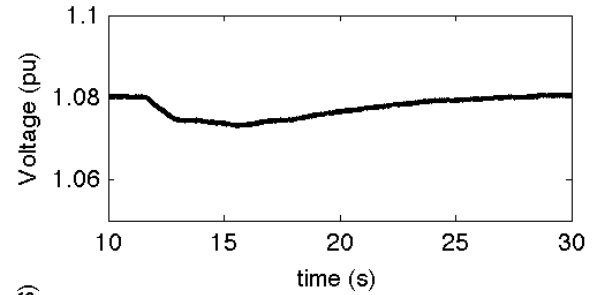
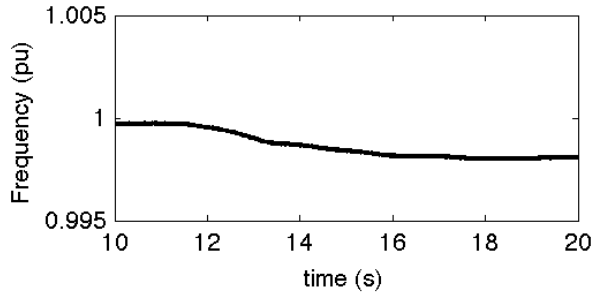


Validation: Event 2





Validation: Event 6



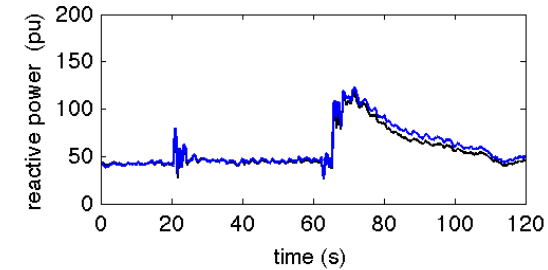
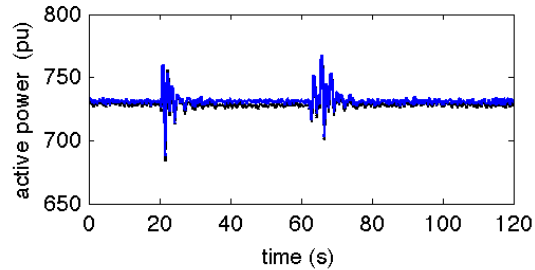
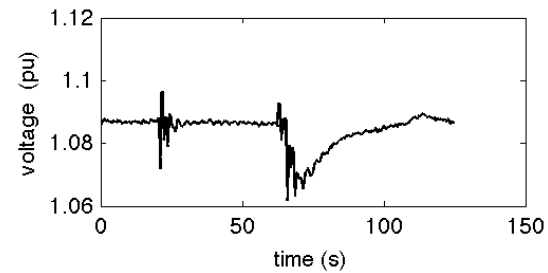
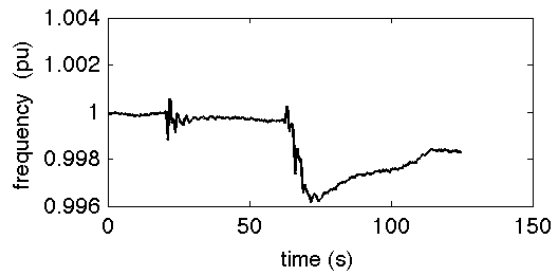


Second Plant

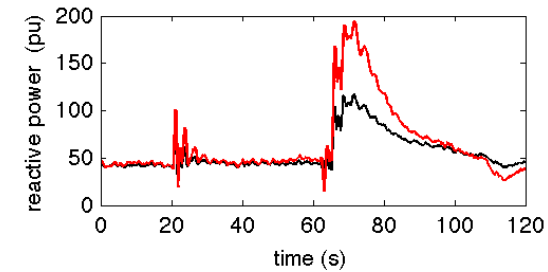
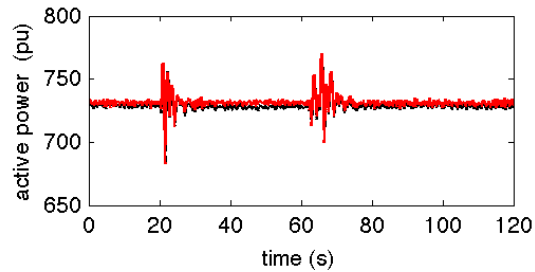
- Data from eight events over 14 months
- Parameters estimated using first two events
- Match is poor for events 4-8.
- Match is good when **PSS gain set to zero** for events 4-8.



Event 1

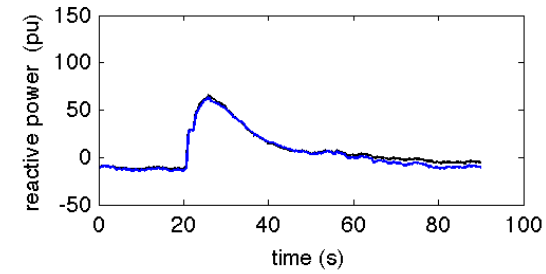
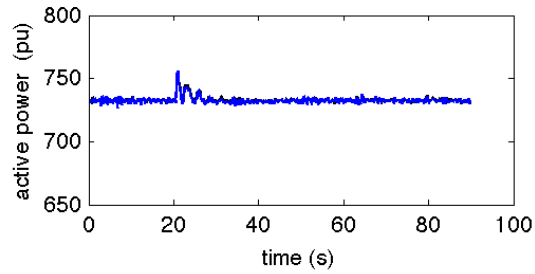
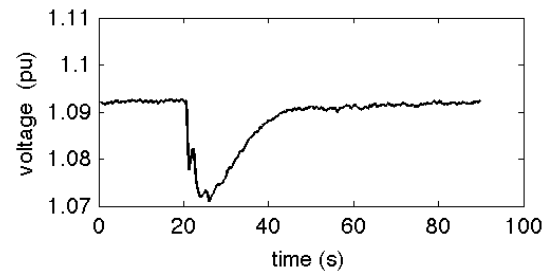
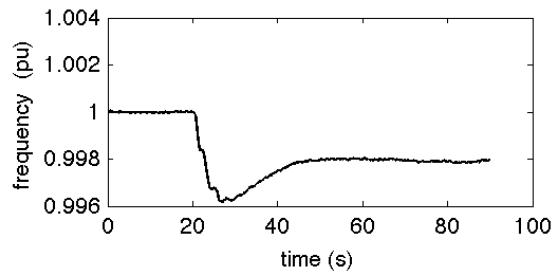


No PSS

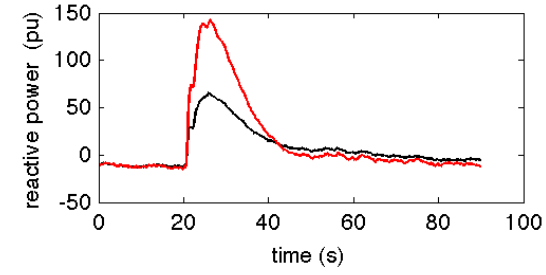
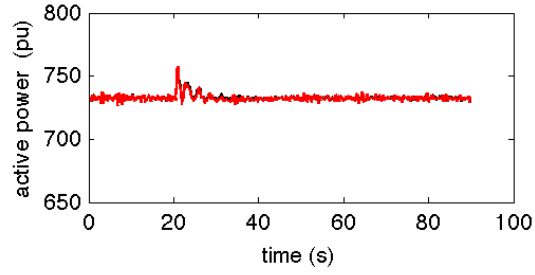




Event 2

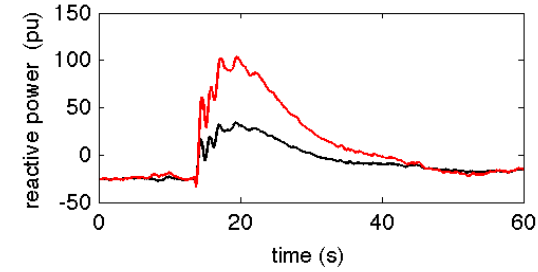
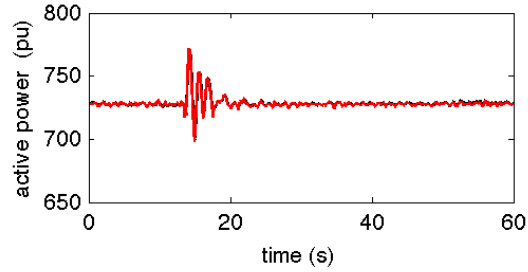
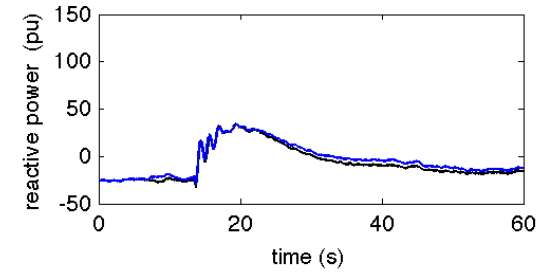
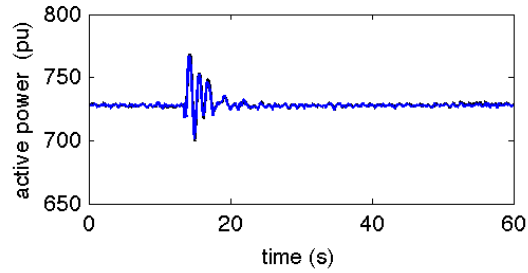
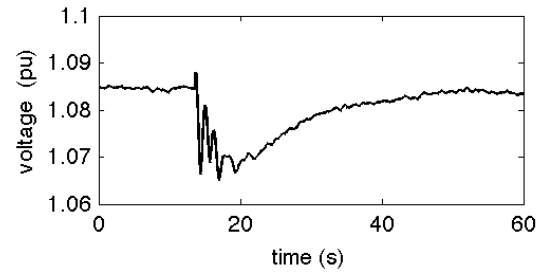
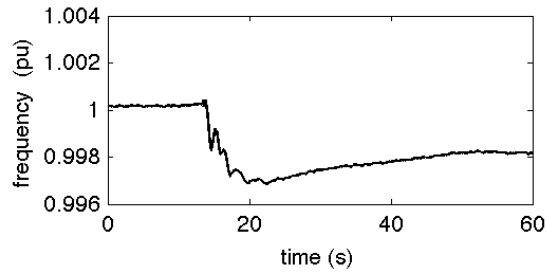


No PSS



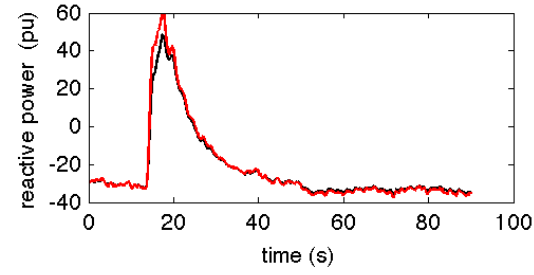
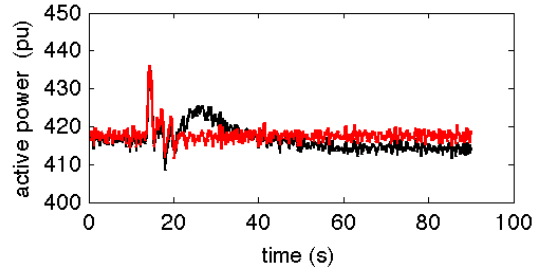
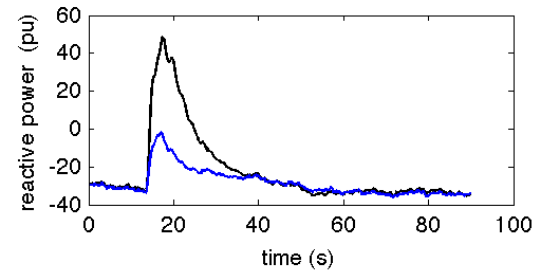
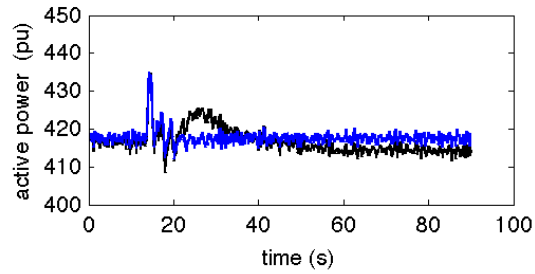
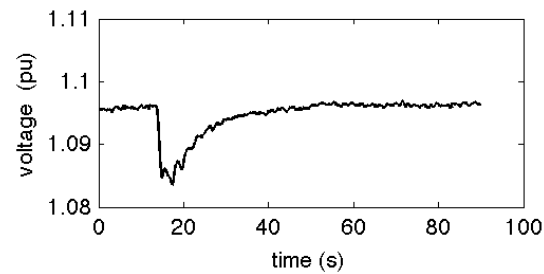
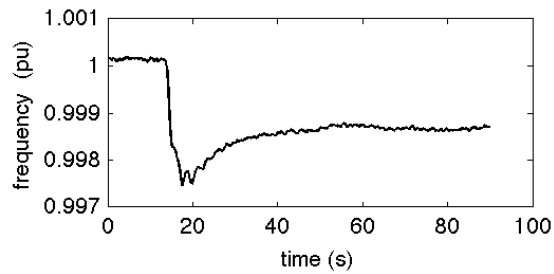


Event 3



No PSS

Event 4

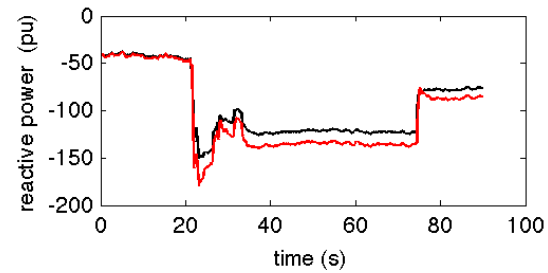
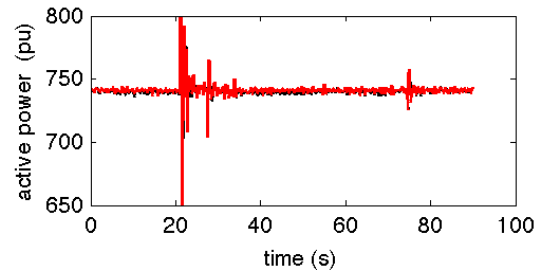
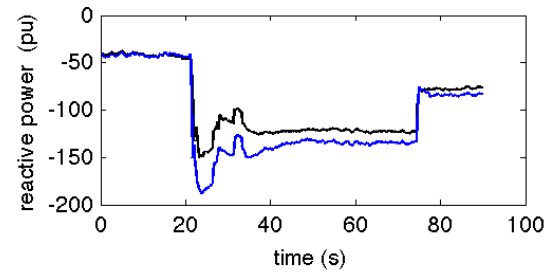
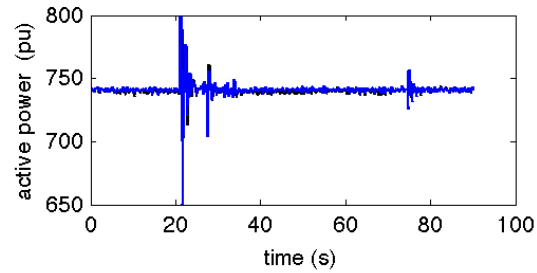
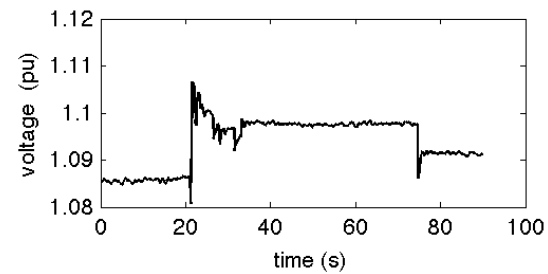
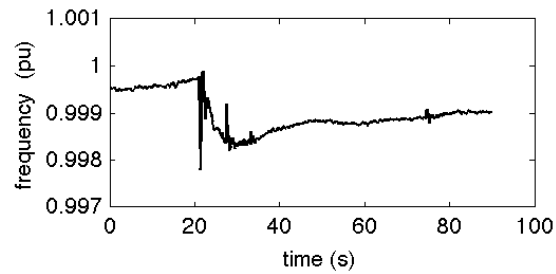


No PSS





Event 5

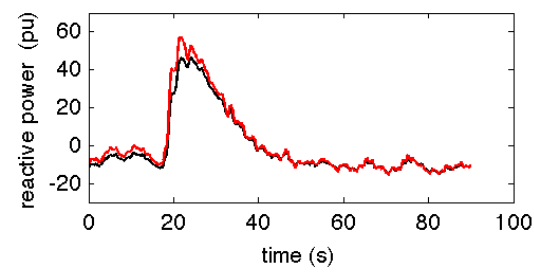
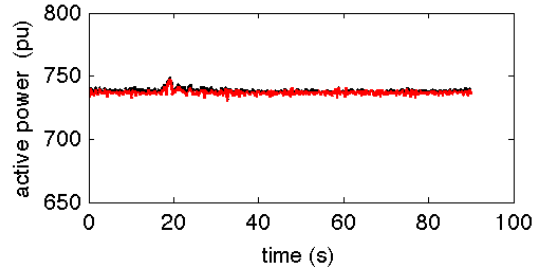
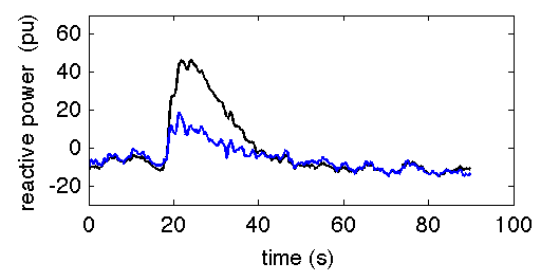
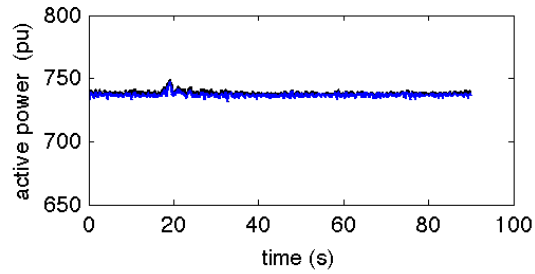
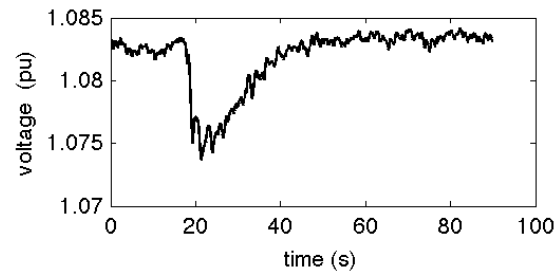
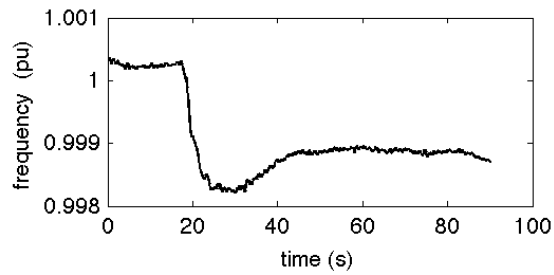


No PSS





Event 6

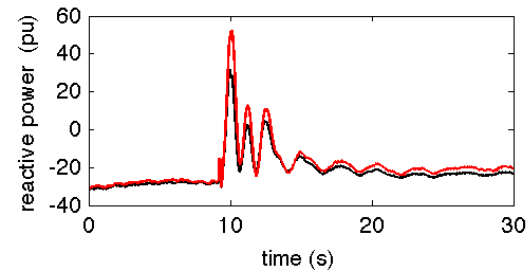
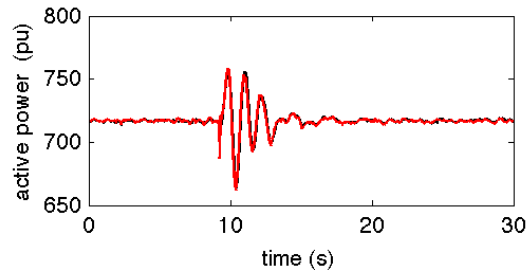
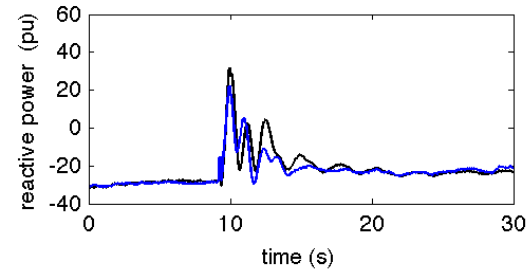
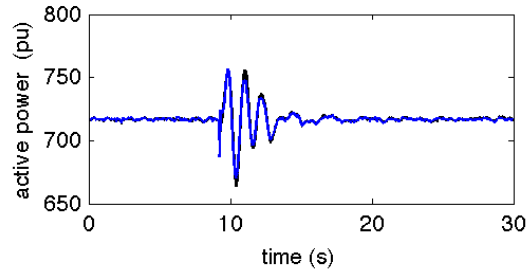
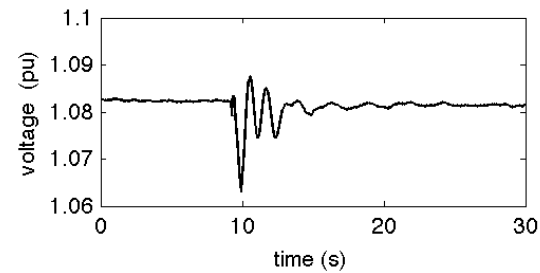
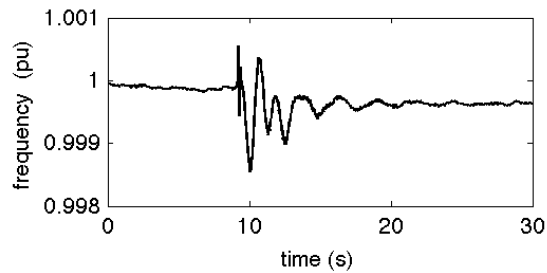


No PSS





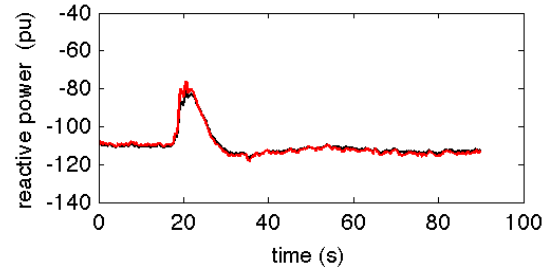
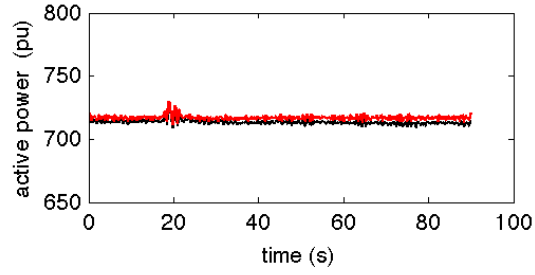
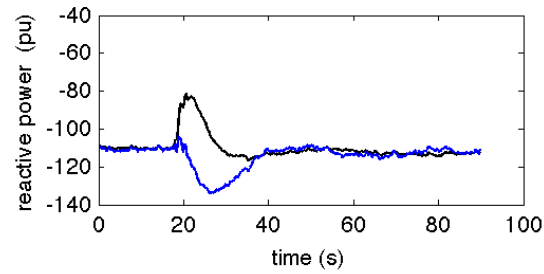
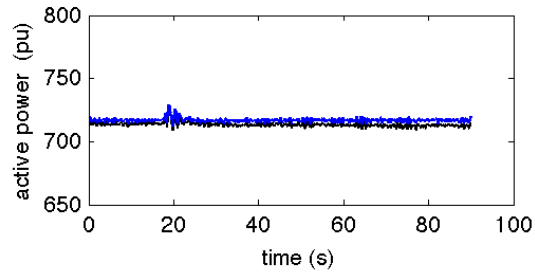
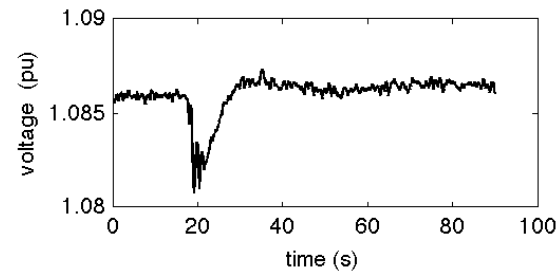
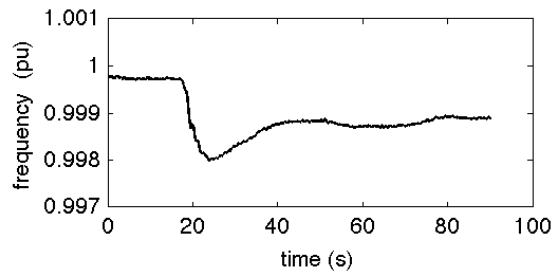
Event 7



No PSS



Event 8



No PSS





Example 2 Conclusion

For this plant, the simulations are consistent with the hypothesis that the PSS is operating differently for the latter events than for the earlier events.

The process also involved recalibration of parameter values.



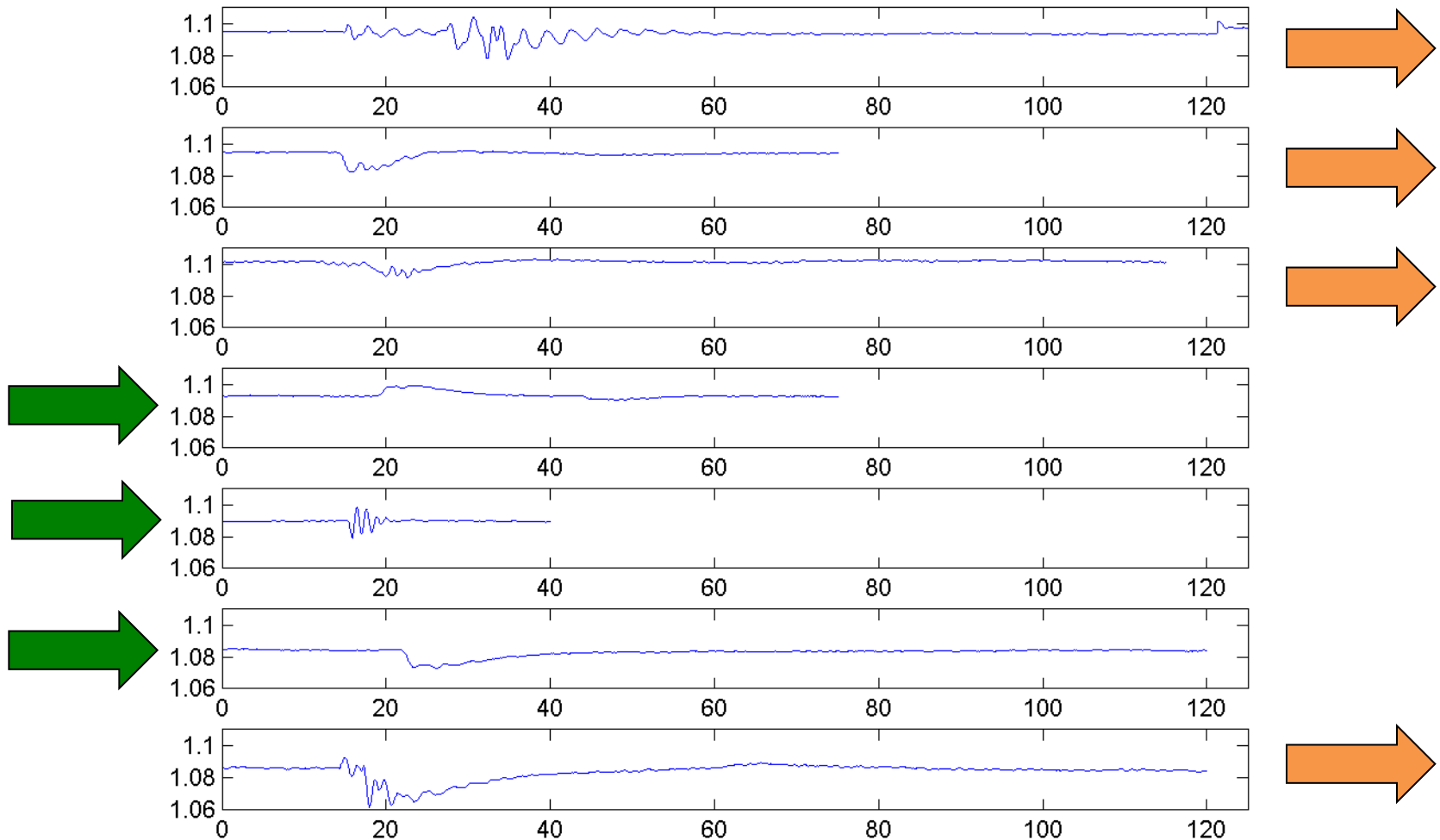
Example 3: Model Calibration Test

- Data from 7 simulated events
 - 3 sets used for model calibration
 - 4 sets used for model consistency check
 - + model independently checked by others using data from other events

Discuss need for engineers - best parameter sets

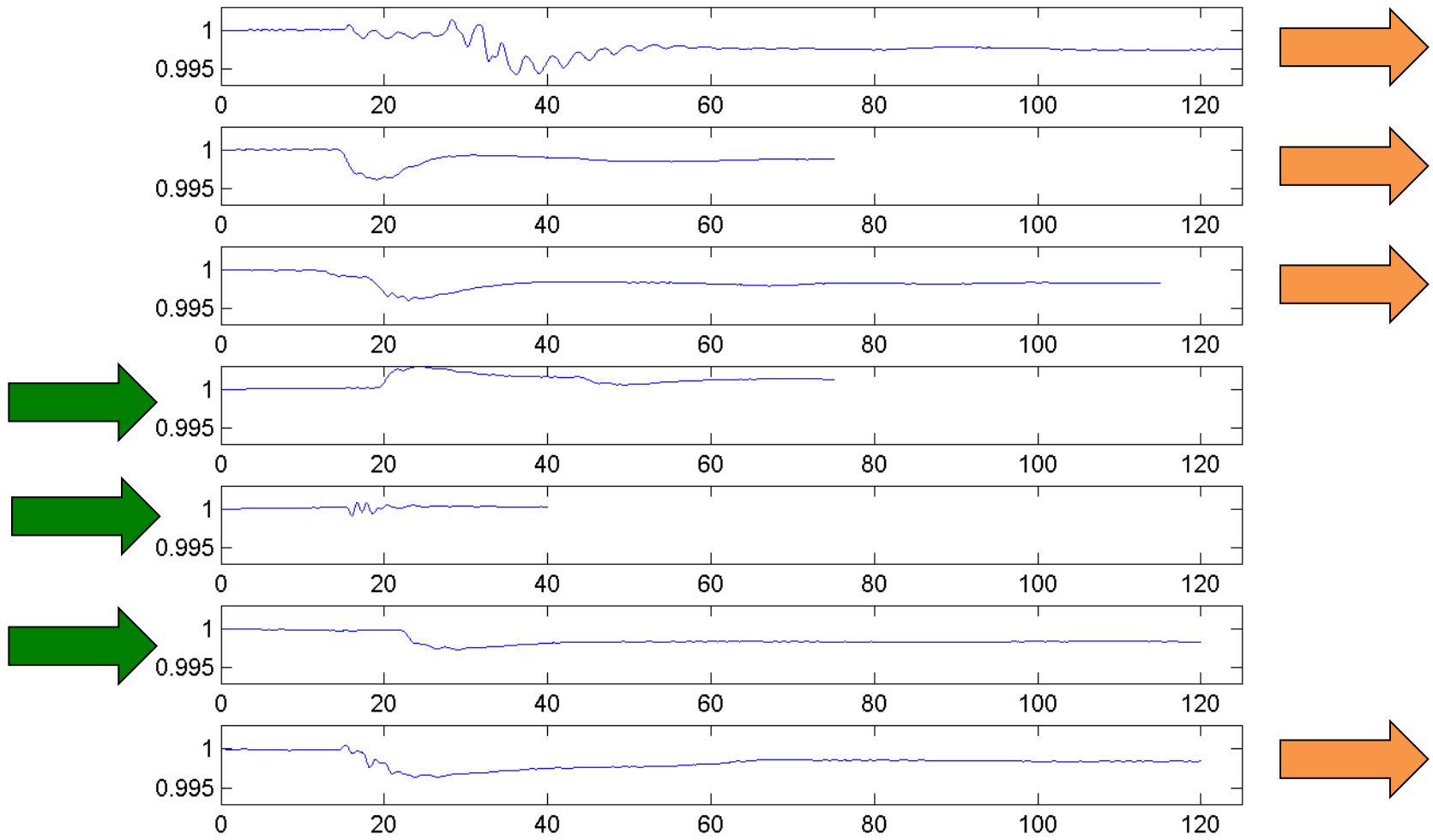


Test Case Voltages





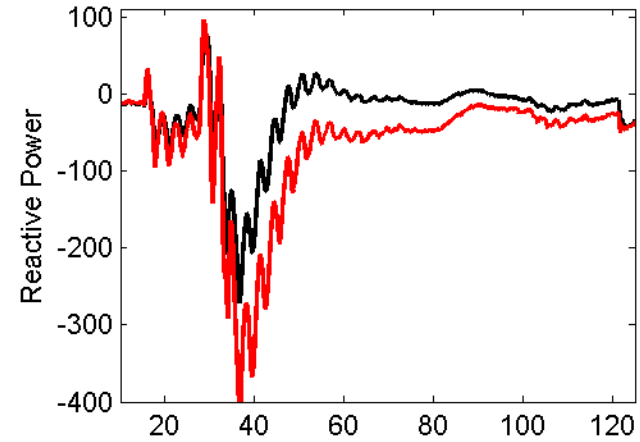
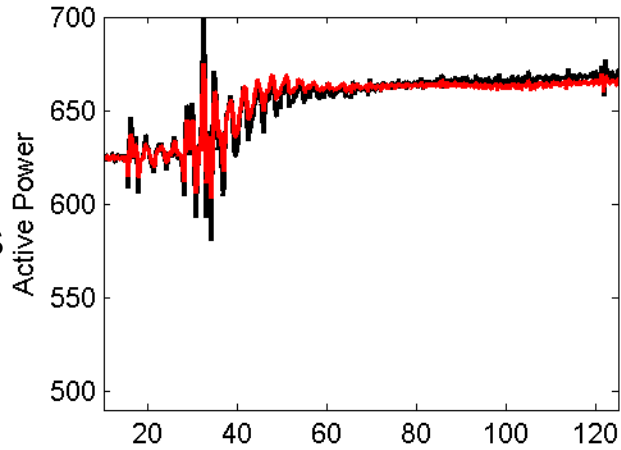
Test Case Frequencies



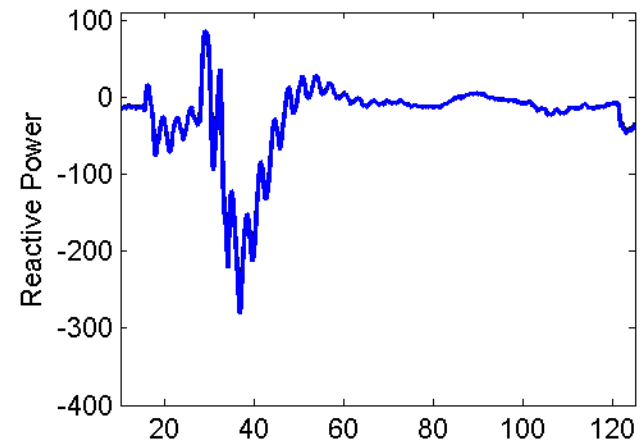
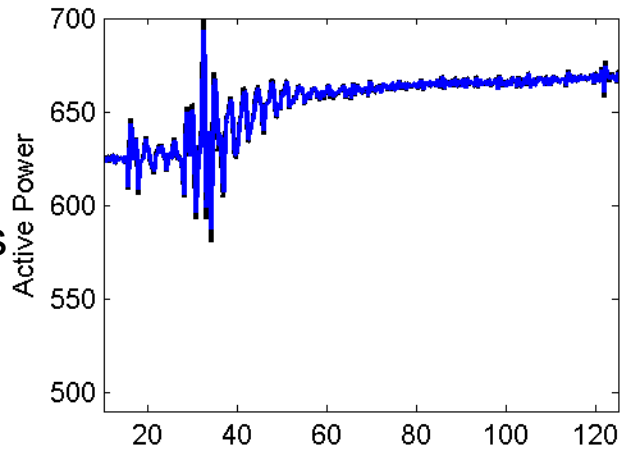


Event 1

Original Parameters



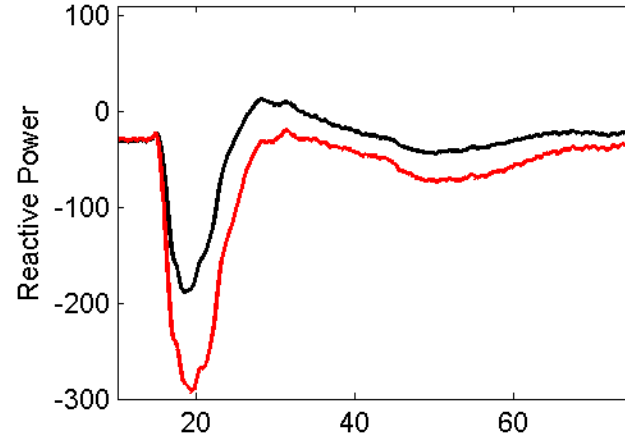
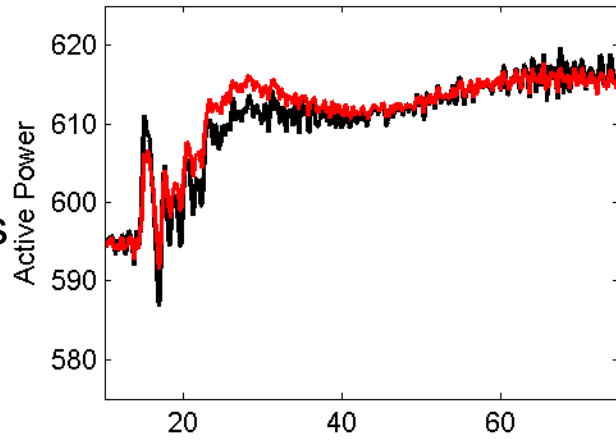
Modified Parameters



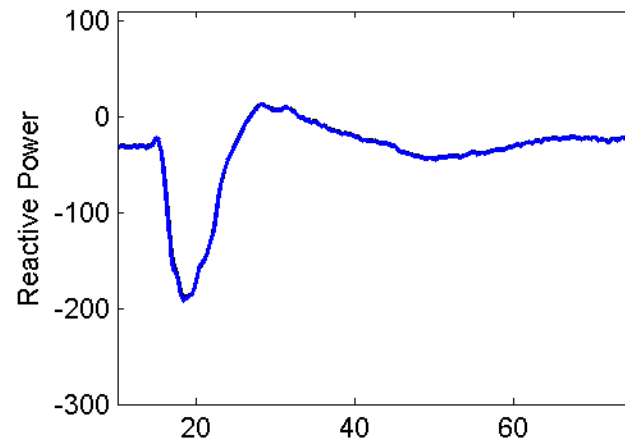
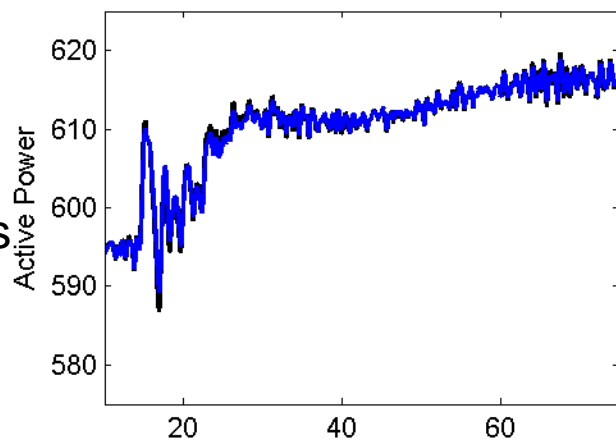


Event 2

Original Parameters



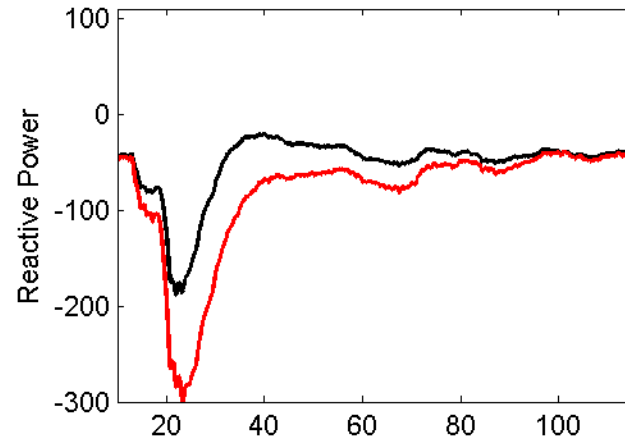
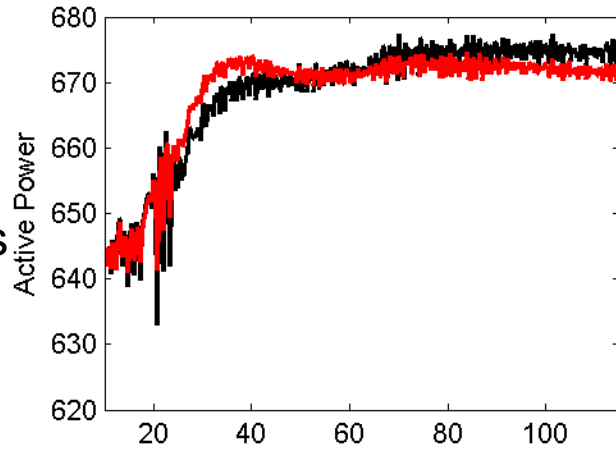
Modified Parameters



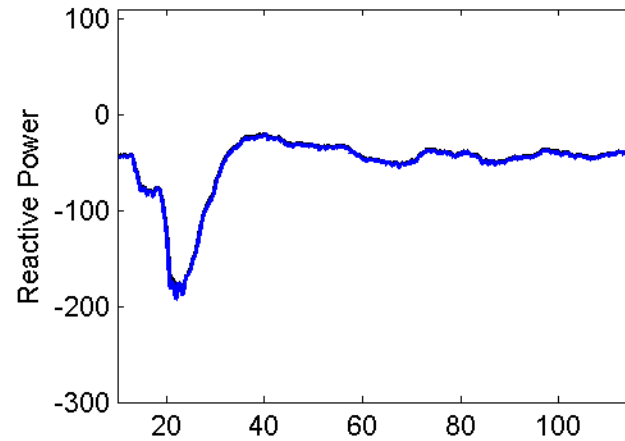
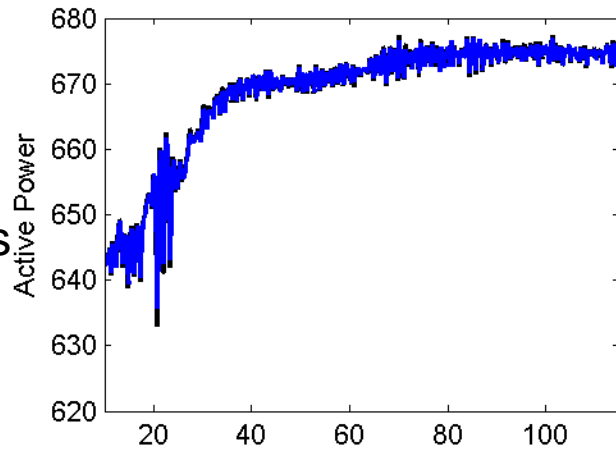


Event 3

Original Parameters



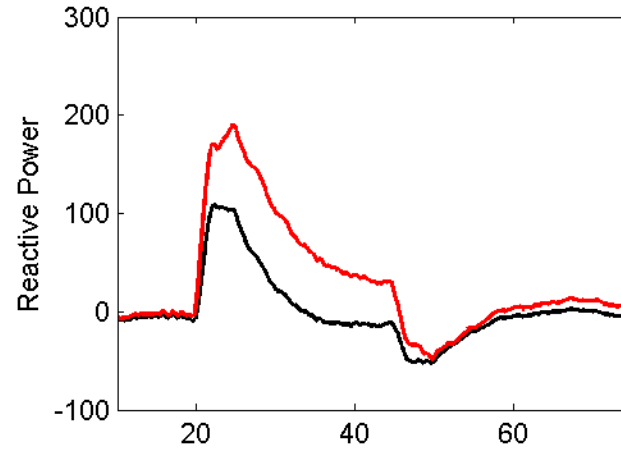
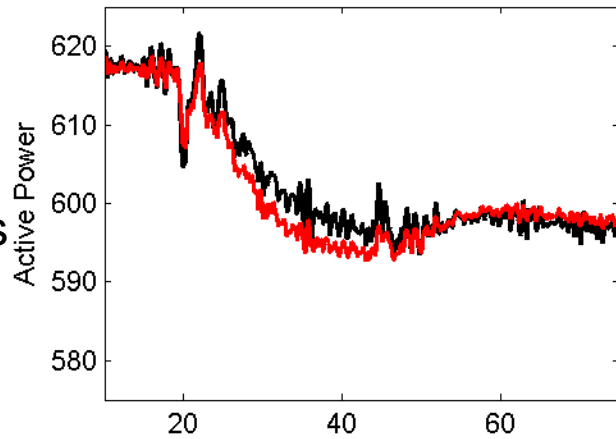
Modified Parameters



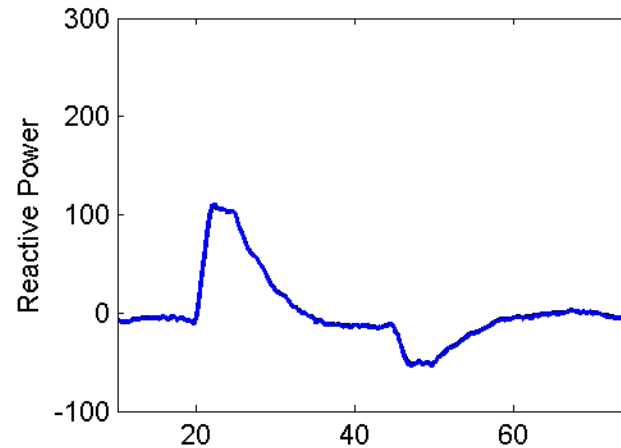
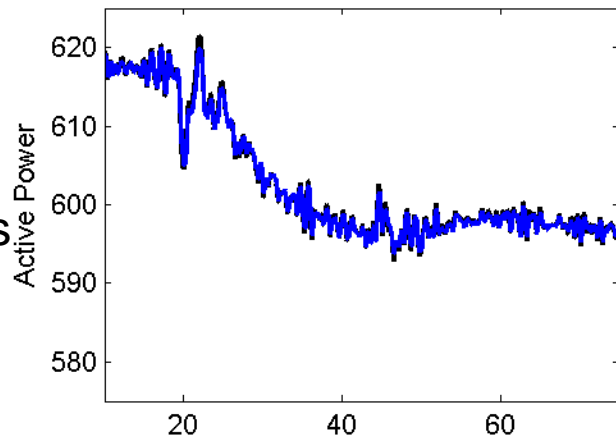


Event 4

Original Parameters



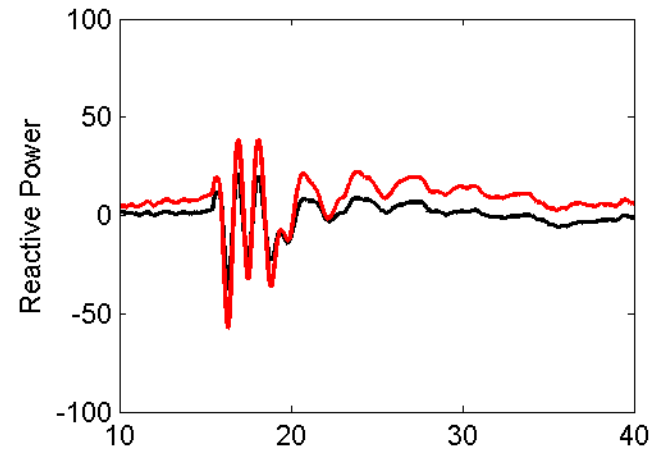
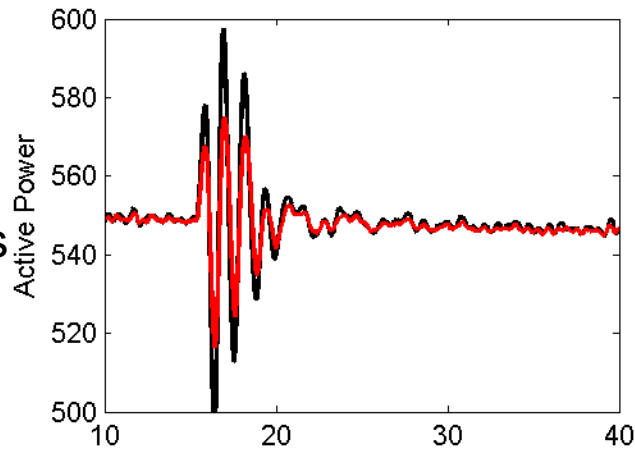
Modified Parameters



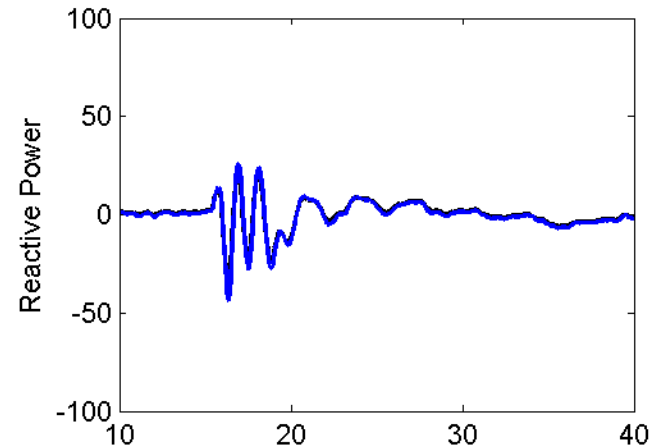
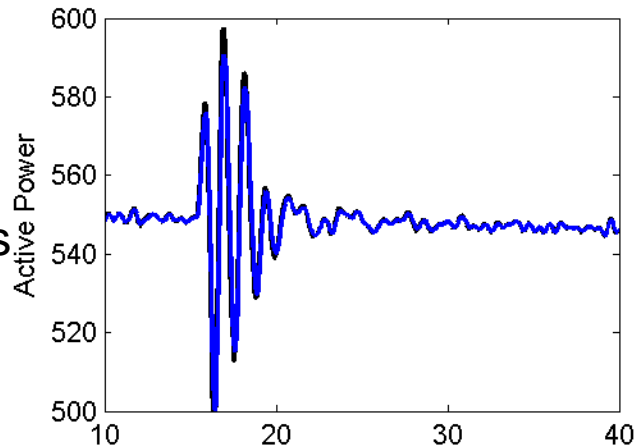


Event 5

Original
Parameters



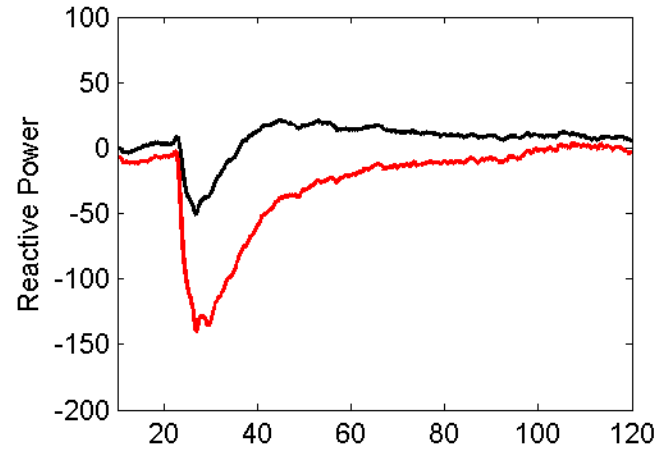
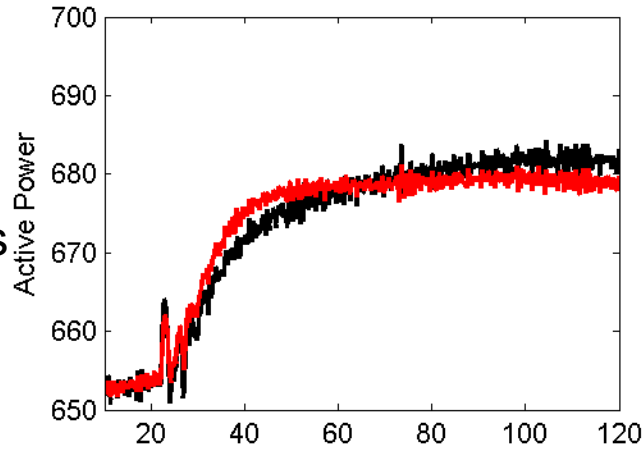
Modified
Parameters



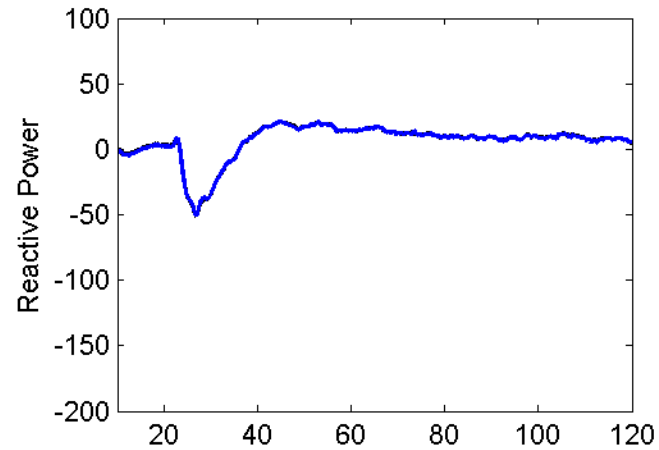
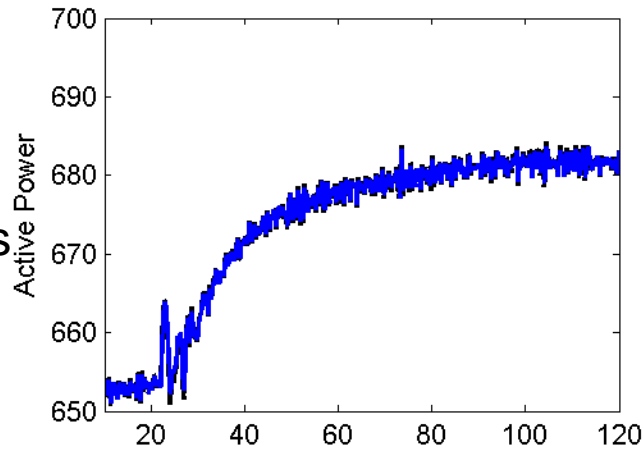


Event 6

Original Parameters



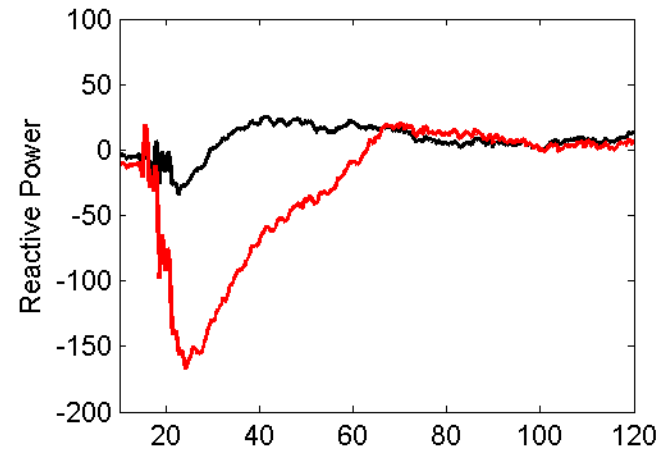
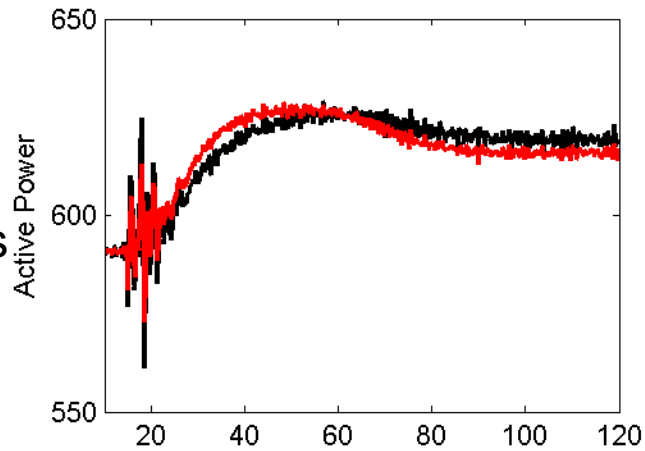
Modified Parameters



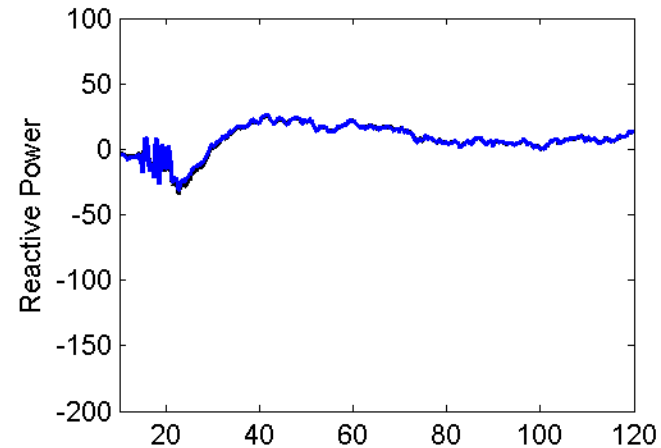
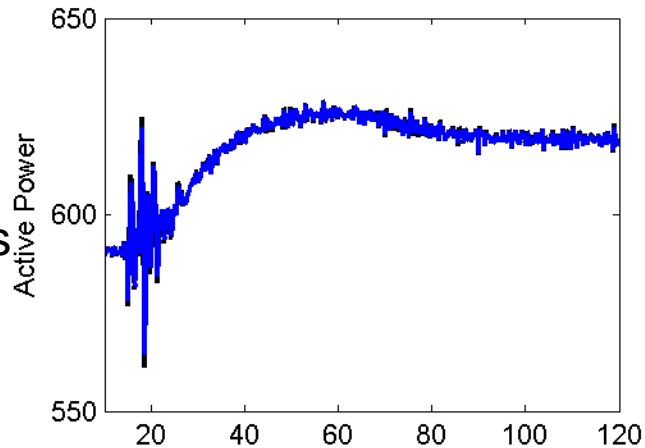


Event 7

Original
Parameters



Modified
Parameters



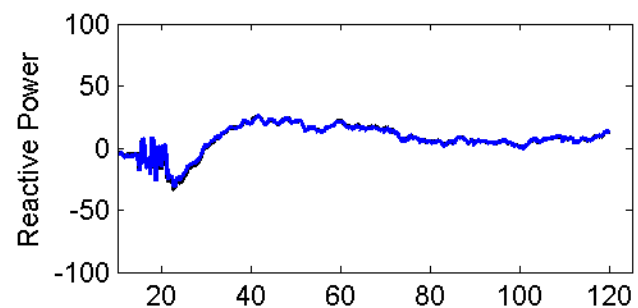
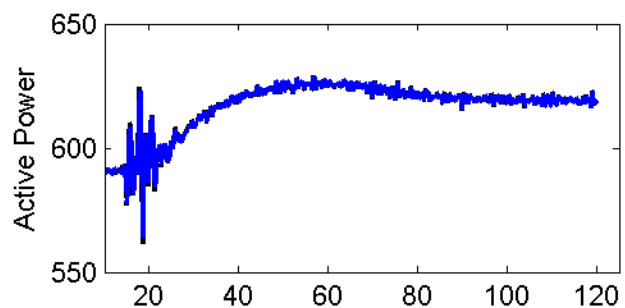
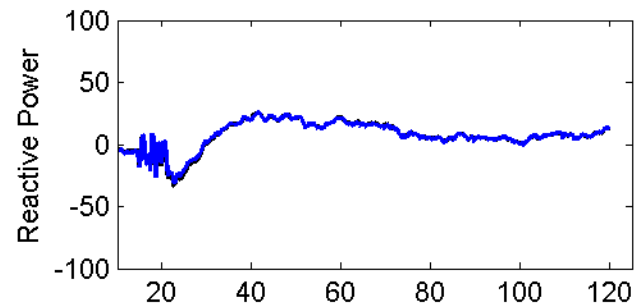
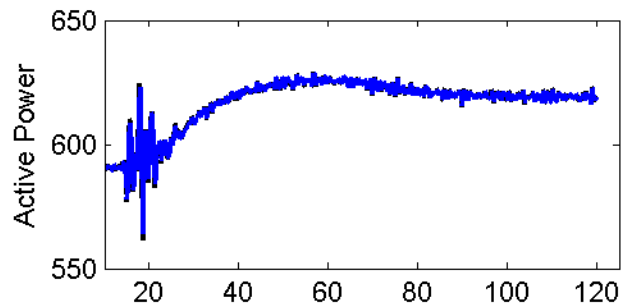
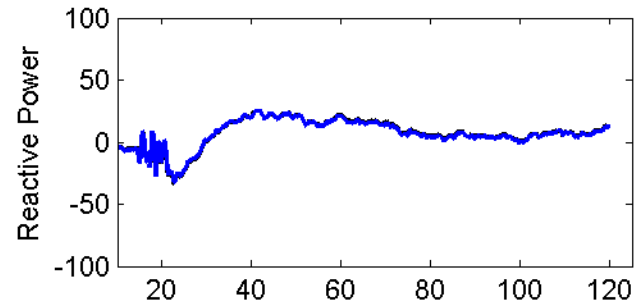
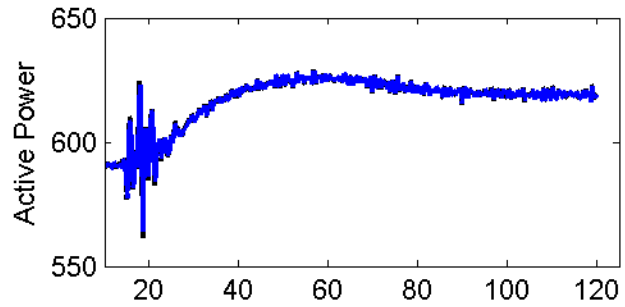


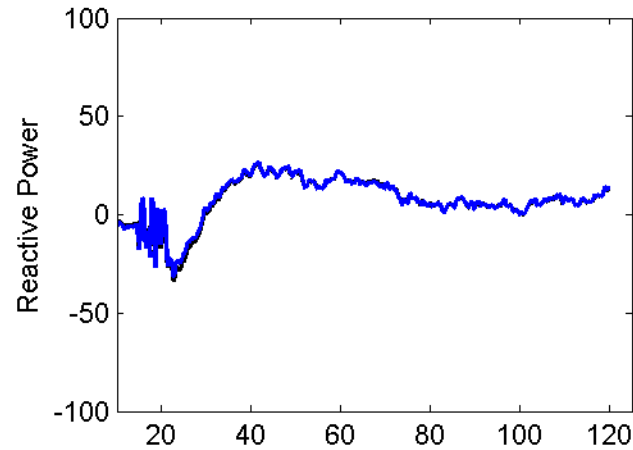
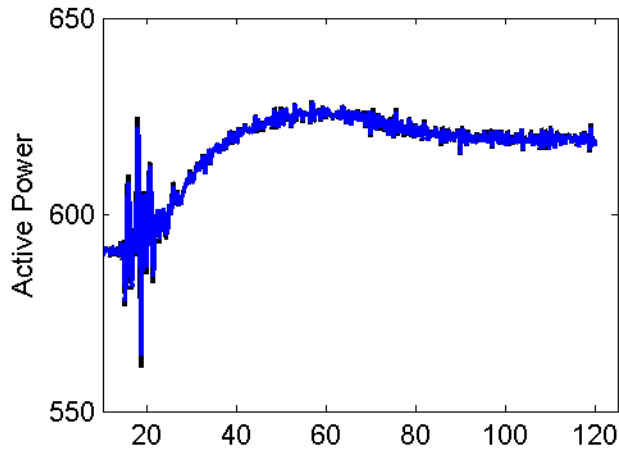
Too Many Knobs to Turn

Analyses of the sensitivity model and of the parameter covariance matrix suggests that certain parameter adjustments will have negligible affect on the simulations.



Fit for values of $Ka=443$, 400, and 250.





H 4.42 4.42

Xc 0.052 0.052

Ka 443 **400**

Kf 0.021 0.021

Tf 0.79 0.78

T5 12.6 12.6

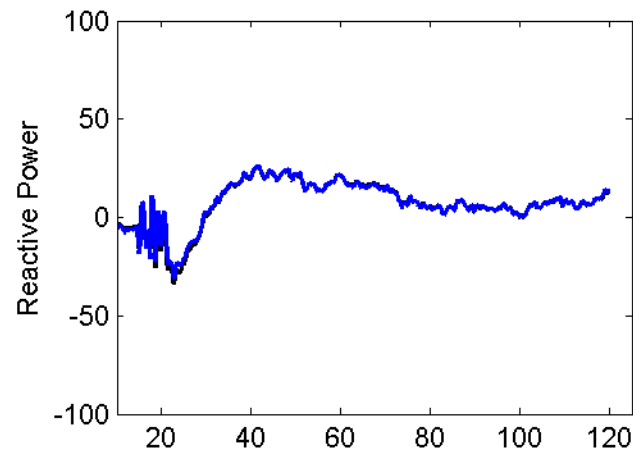
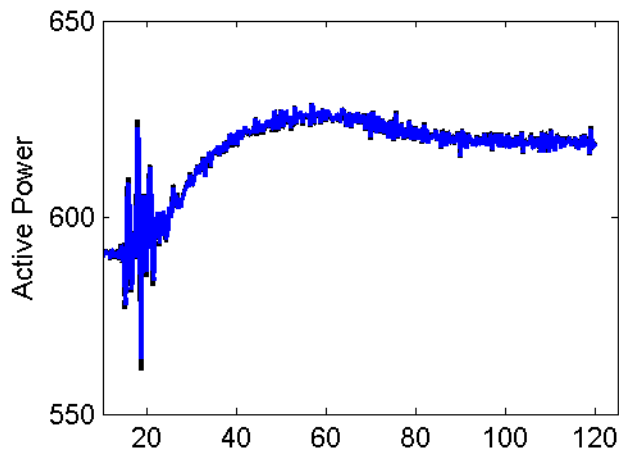
Ks 8.23 8.23

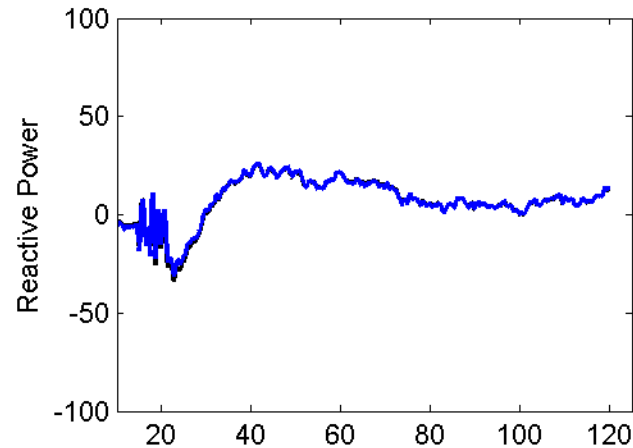
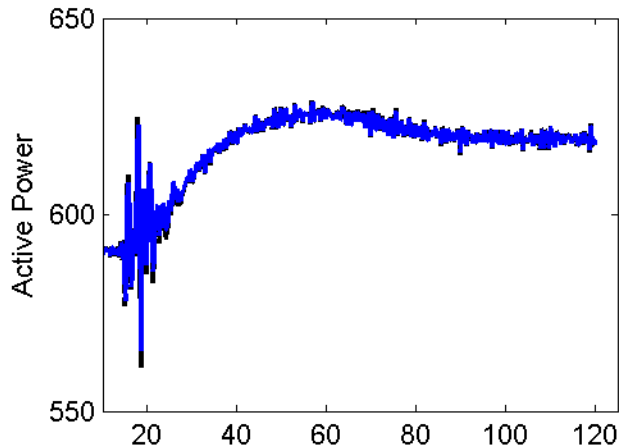
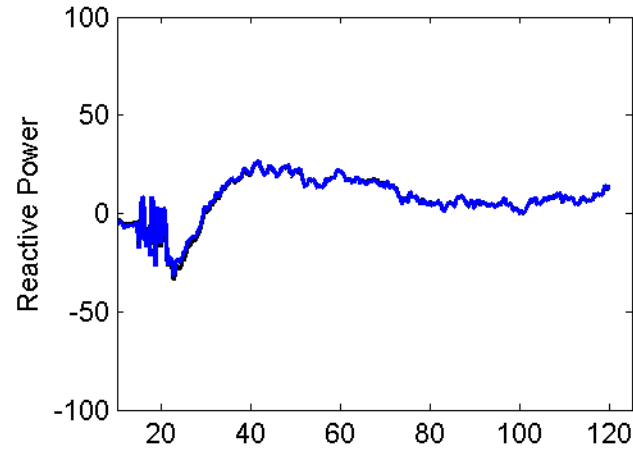
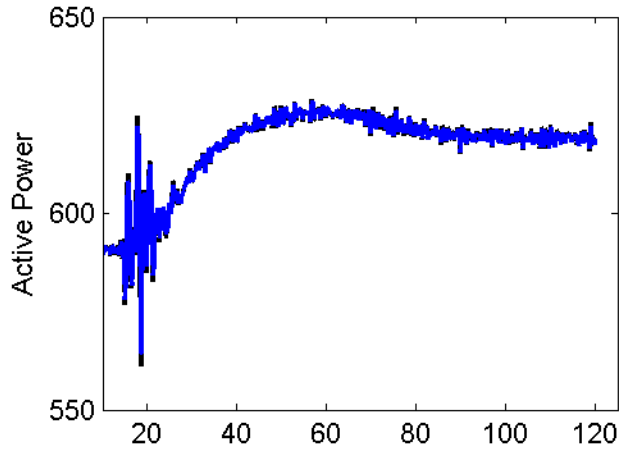
Rp 0.045 0.045

Rt 0.46 **0.50**

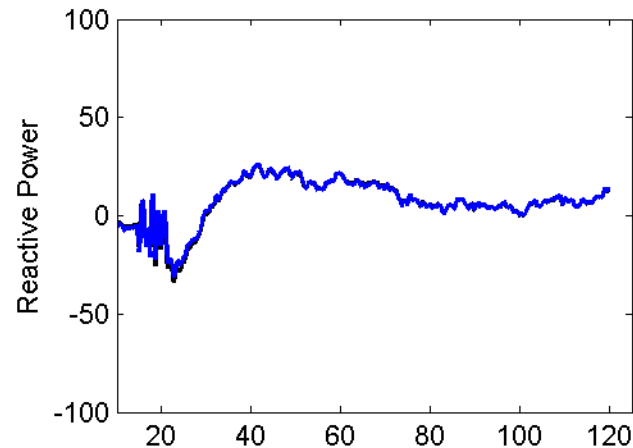
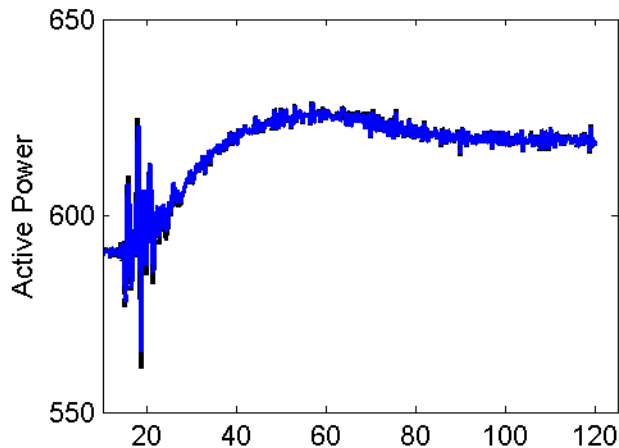
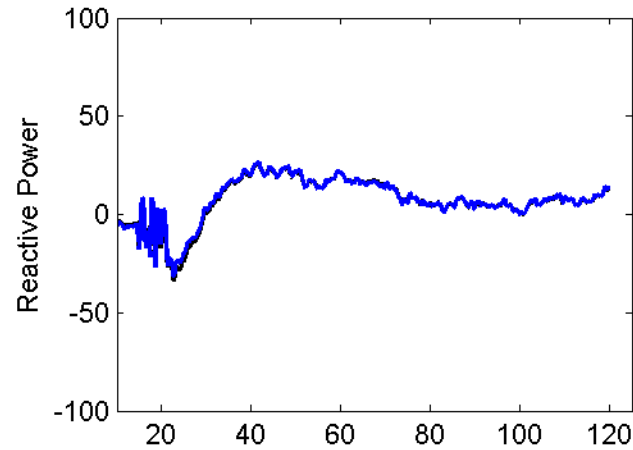
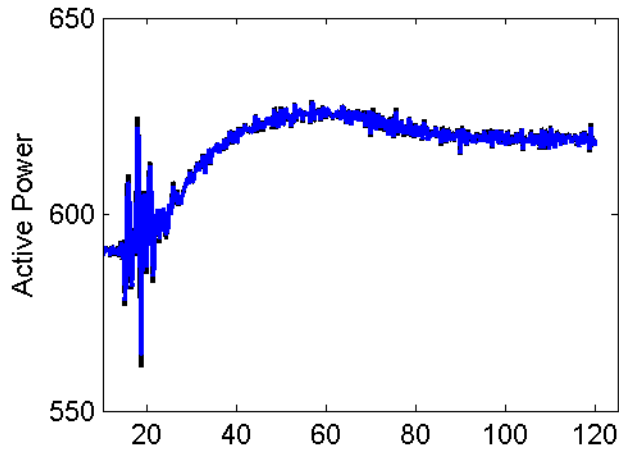
Tr 1.82 1.65

Tw 1.76 1.76

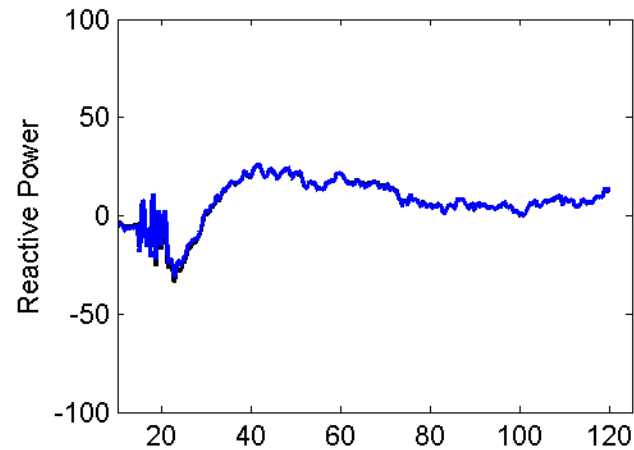
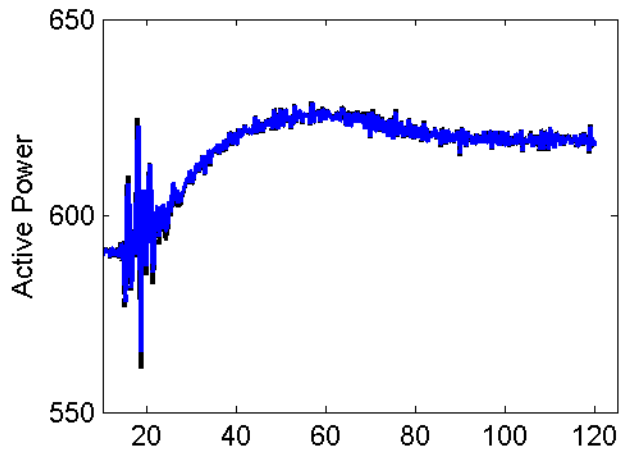
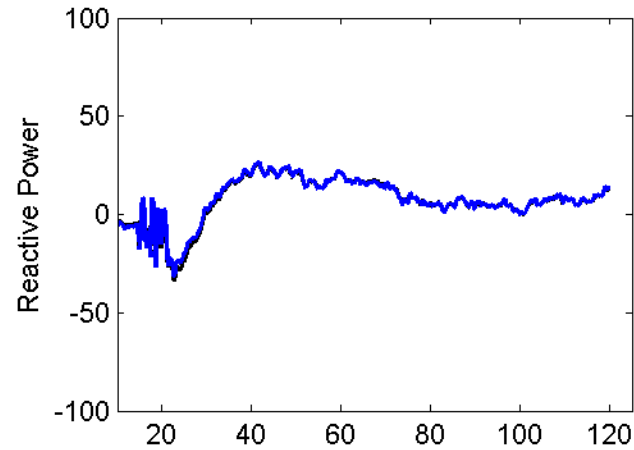
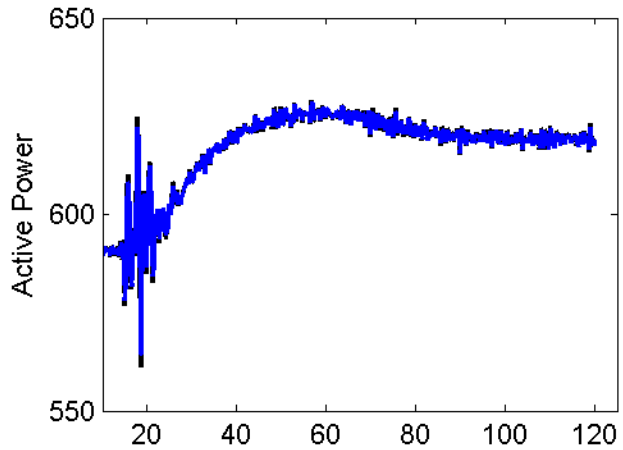




H	4.42	4.38
Xc	0.052	0.052
Ka	443	400
Kf	0.021	0.021
Tf	0.79	0.77
T5	12.6	12.6
Ks	8.23	8.25
Rp	0.045	0.045
Rt	0.46	0.52
Tr	1.82	1.67
Tw	1.76	1.27



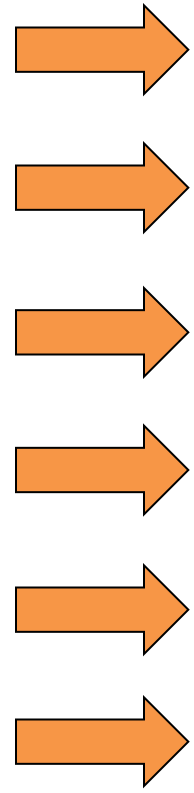
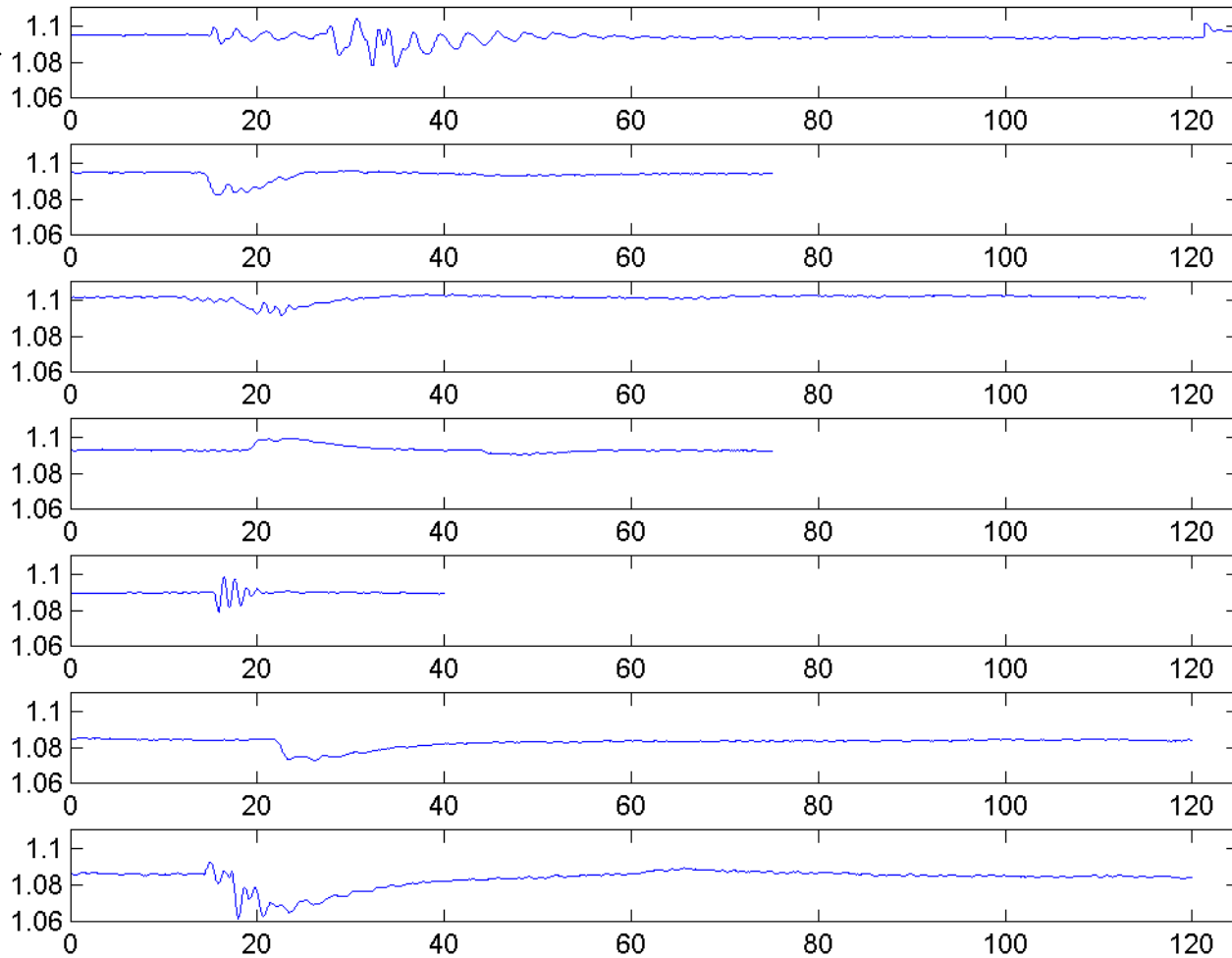
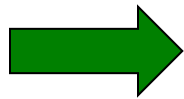
H	4.42	3.62
Xc	0.052	0.052
Ka	443	400
Kf	0.021	0.020
Tf	0.79	0.71
T5	12.6	12.6
Ks	8.23	8.27
Rp	0.045	0.045
Rt	0.46	0.50
Tr	1.82	1.74
Tw	1.76	1.27



H	4.42	4.47
Xc	0.052	0.052
Ka	443	400
Kf	0.021	0.021
Tf	0.79	0.72
T5	12.6	12.6
Ks	8.23	8.26
Rp	0.045	0.045
Rt	0.46	0.40
Tr	1.82	2.02
Tw	1.76	2.00

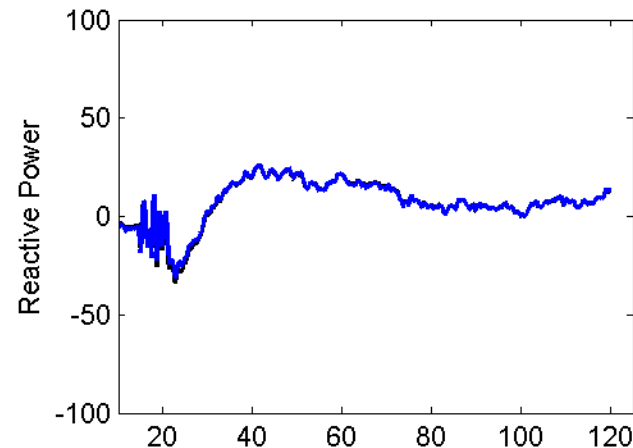
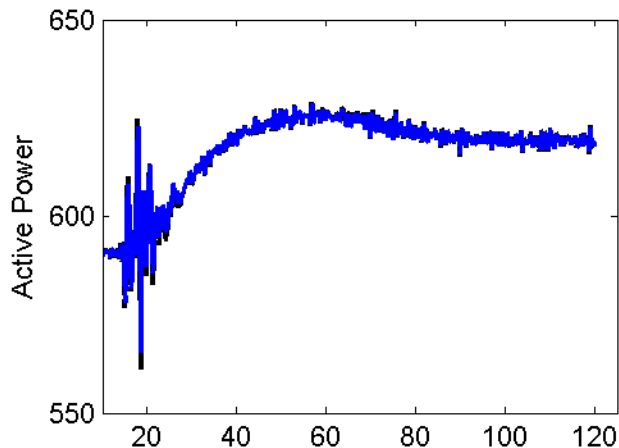
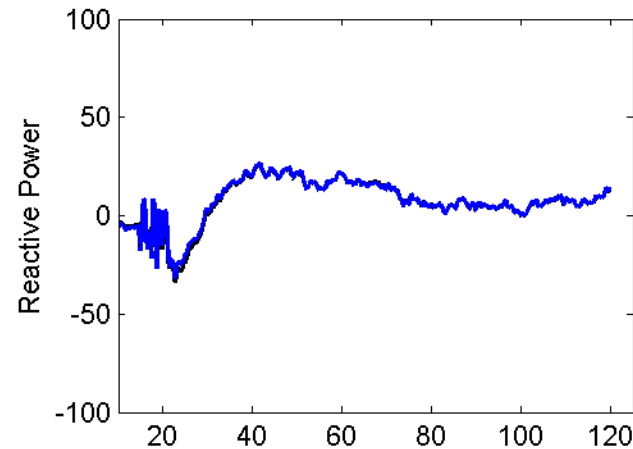
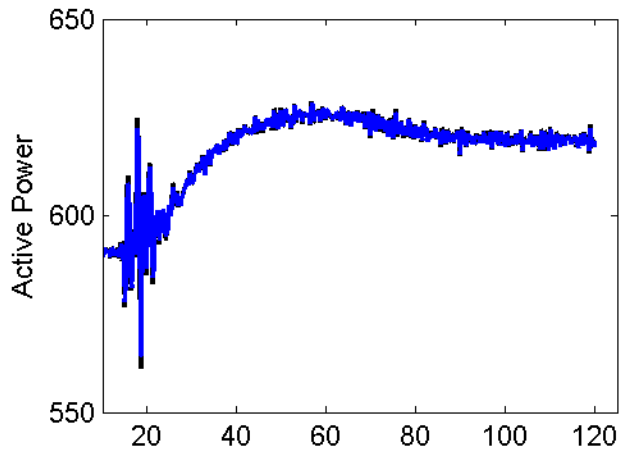


Test Case Voltages





Training Signal 1



H	4.42	4.47
Xc	0.052	0.046
Ka	443	500
Kf	0.021	0.027
Tf	0.79	0.89
T5	12.6	12.2
Ks	8.23	8.58
Rp	0.045	0.045
Rt	0.46	0.32
Tr	1.82	2.61
Tw	1.76	2.04



Conclusions

- PMU data is absolutely valuable for affirming, refuting and recalibrating models.
- Engineering judgment is (still) required to understand models, to
 - know which knobs to turn in calibration, and how far,
 - Identify structural changes in the data.