2021 IEEE-NASPI Oscillation Source Location Contest

Team FIUBA

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Presentation Overview

- Methodology
- Example Cases
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  - Case 9
  - Case 10
  - Case 12
- Performance Summary
- Conclusion

Method Overview

1) Data pre-processing and network linear state estimator

2) Forced Oscillation (FO) frequency identification

3) Filtering of FO components

4) Dissipating Energy Flow (DEF) calculation to locate the source of FO in the network

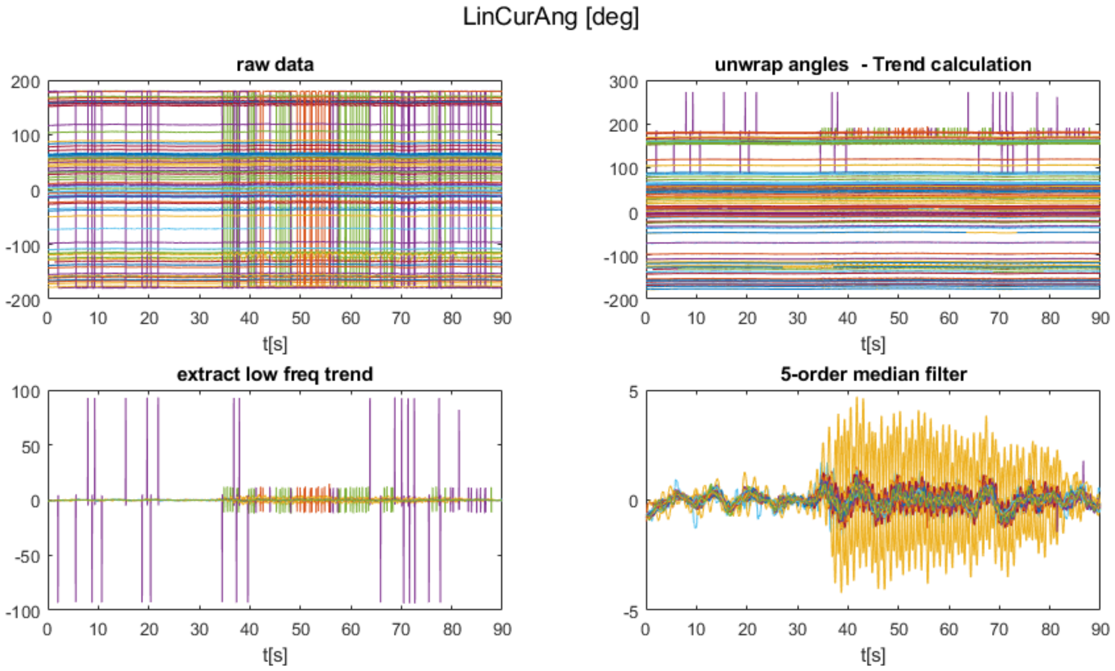
Time-frequency (TF) approach developed for the analysis of non-stationary FO with variable frequency over time

5) Controller identification based on Dynamic State Estimation (DSE) with unknown inputs and transient energy function

Extends the energy-based approach of the DEF method to locate FO in controllers

Methodology

1) Data pre-processing and network state estimator:
   a. Unwrap angles, using a jump threshold of 150º
   b. Application of a partial Linear State Estimation of network using transmission line parameters extracted from PSSE model. In this way, it is possible to expand the number of monitored branches, and have the measurements from both ends. Incomplete observability of the network.
   c. Extract Low frequency trend, calculated as 300 order median filter (10 second equivalent window).
   d. Outlier filtering applying 5-order median filter
   e. Replace `Nan` with zero on filtered data

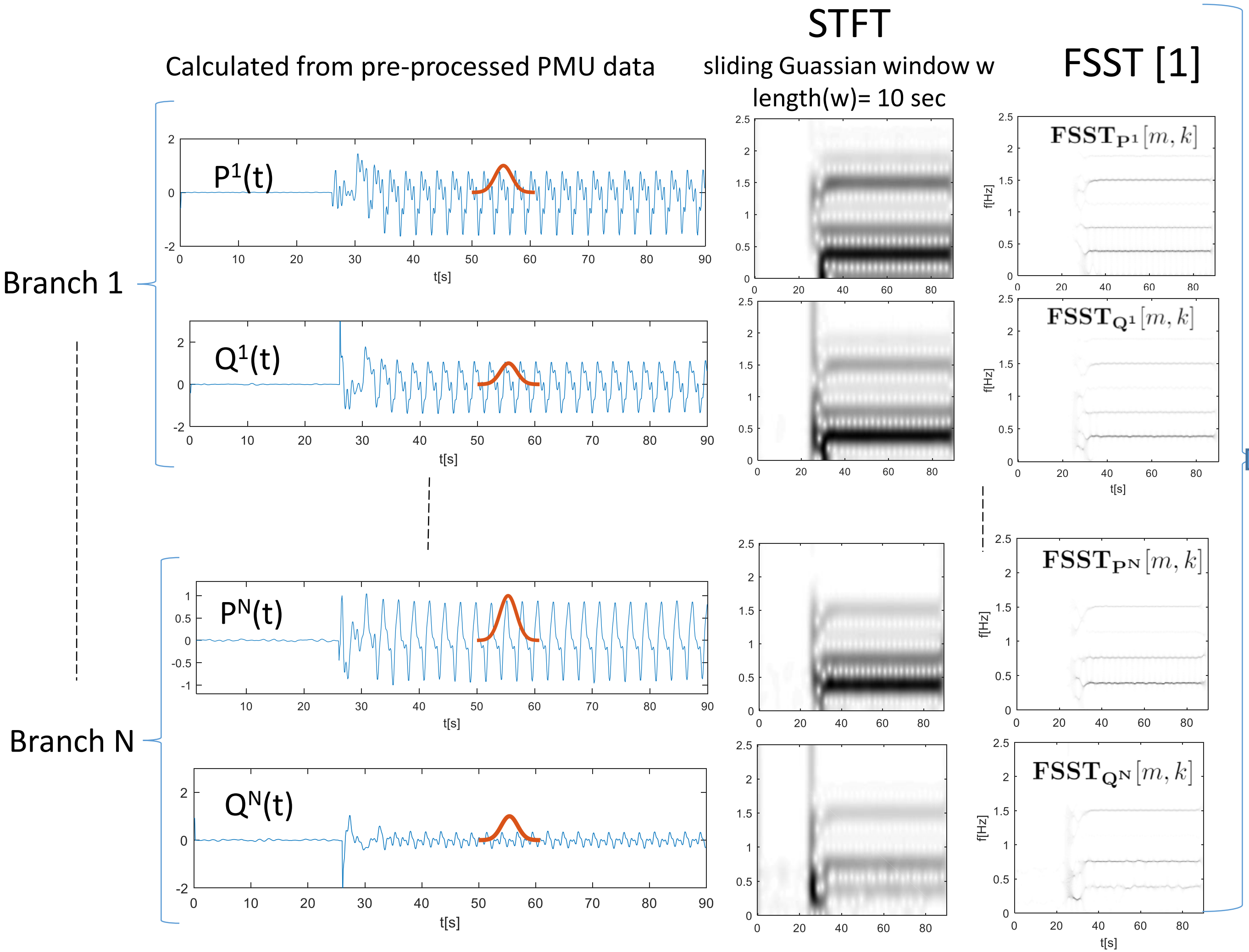


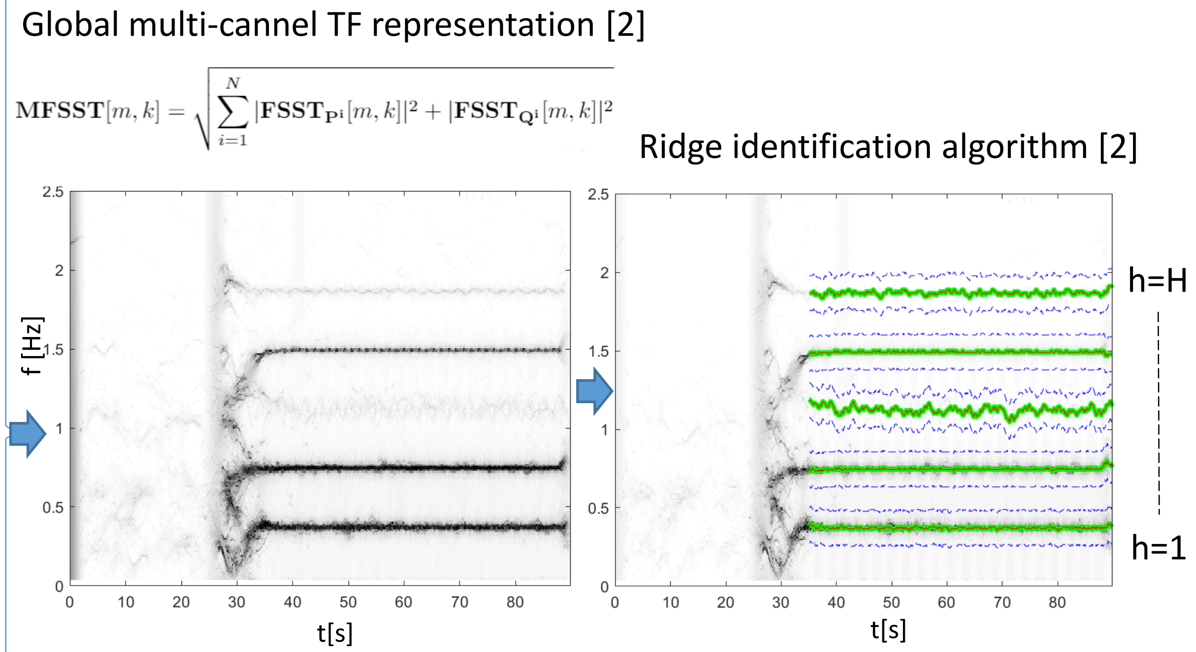
2) Forced Oscillation (FO) frequency identification

a. Calculation of short-time Fourier transform (STFT) based synchrosqueezing transform (FSST) of active power flow P and reactive power flow Q of each available branch [1]

b. Calculation of a unique time-frequency (TF) representation from individual FSST coefficients [2].

c. Application of algorithm on the resulting TF representation to identify the curves in TF plane (called “ridges”) corresponding to each signal oscillatory component [2].





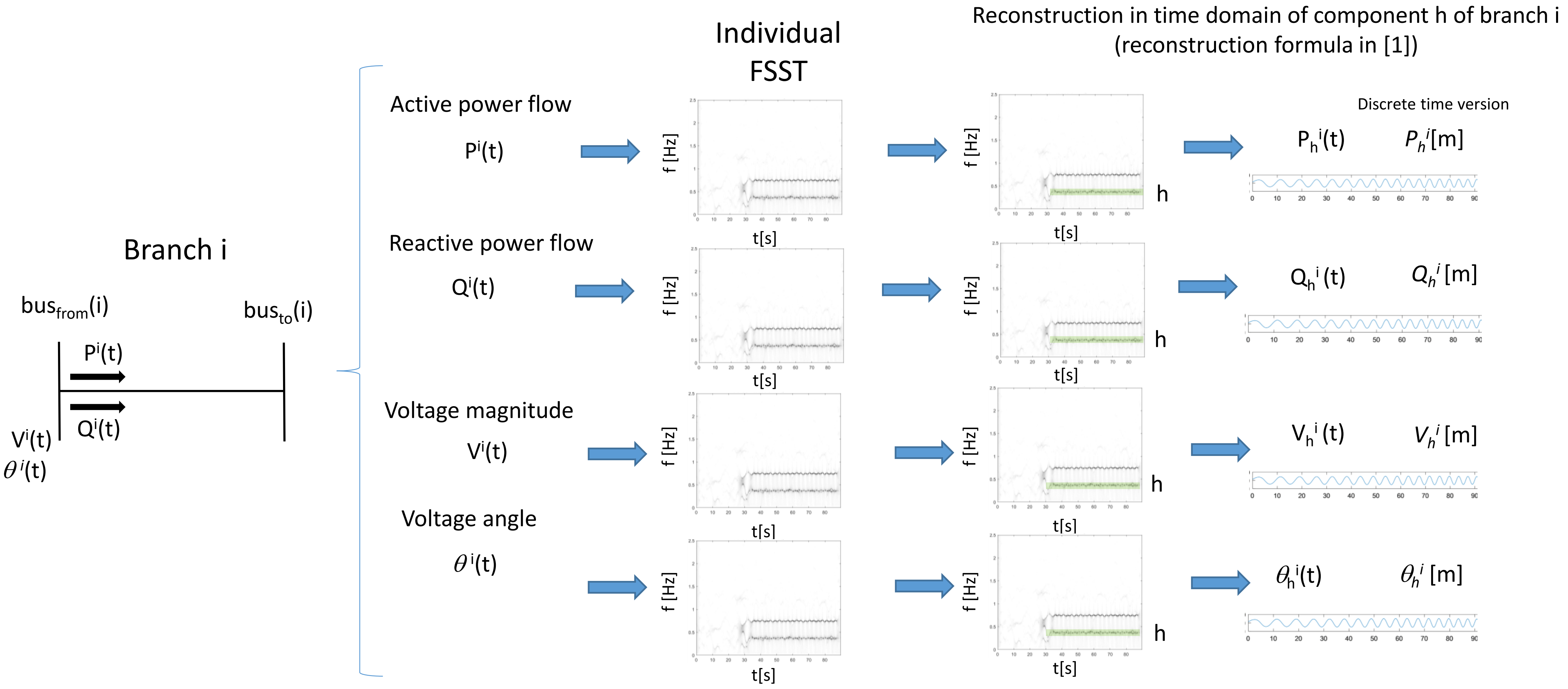
[1] P. Gill Estevez, P. Marchi, C. Galarza and M. Elizondo, "Non-Stationary Power System Forced Oscillation Analysis Using Synchrosqueezing Transform," in IEEE Transactions on Power Systems, vol. 36, no. 2, pp. 1583-1593, March 2021, doi: 10.1109/TPWRS.2020.3015145. https://ieeexplore.ieee.org/document/9162523

[2] P. Gill Estevez, P. Marchi, F. Messina, C. Galarza, “Forced Oscillation Identification and Filtering from Multi-Channel Time-Frequency Representation”, pre-print Aug 2021. https://arxiv.org/pdf/2108.08736.pdf

3) Filtering of FO components

Component decomposition in the time domain is made in each signal from individual FSST coefficients, using the identified TF ridges and integrating FSST around the corresponding ridge [1].

Performed for all identified components ($h=1,\dots,H$) and all monitored branches of the system ($i=1,\dots,N$).

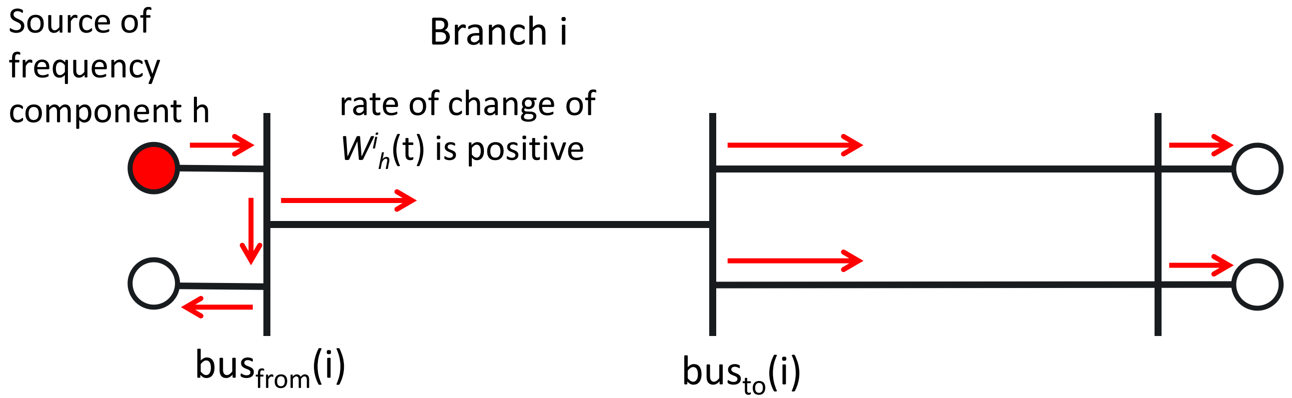


4) Dissipating Energy Flow (DEF) calculation to locate the source of FO in the network

DEF method calculates the flow of the transient dissipating energy in the network, which is equivalent to the energy dissipated by a damping torque. Finding the source of dissipating energy is equivalent to the finding of the source of negative damping [3].

The value and sign of the rate of change of DEF have a physical interpretation as the amount and direction of the dissipating energy flow. The sign, calculated in a branch, indicates the direction of the source location relative to the branch [4].

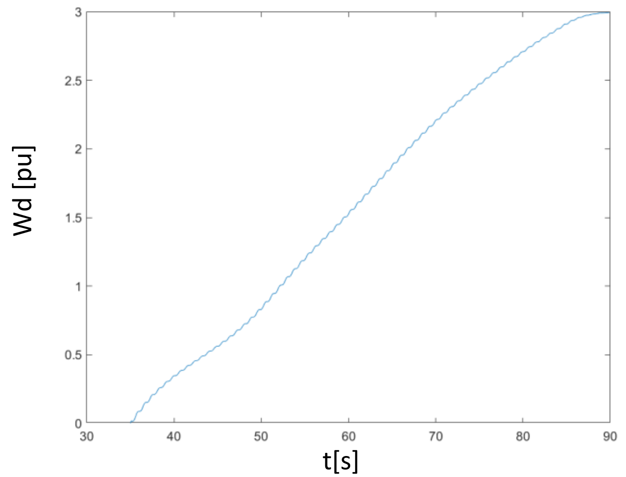
DEF is calculated in all the branches using the filtered components of active power flow, reactive power flow, voltage magnitude and angle for each identified oscillatory component ($P_h^i, Q_h^i, V_h^i, \theta_h^i$)[1].



DEF calculation Wd_h^i

discrete-time approximation [1]

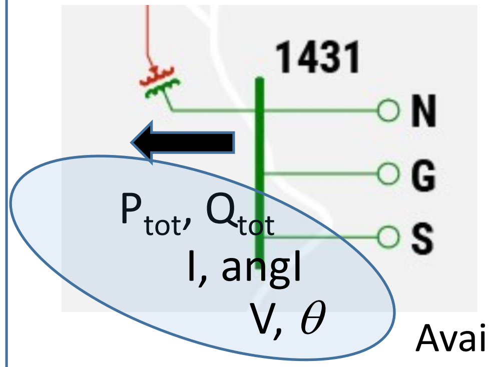
$$W_h^i[m] = W_h^i[m-1] + P_h^i[m-1]\,\left(\theta_h^i[m] - \theta_h^i[m-1]\right) + \frac{Q_h^i[m-1]}{V^i[m-1]}\left(V_h^i[m] - V_h^i[m-1]\right) \quad (1$$



[3] L. Chen, Y. Min and W. Hu, "An energy-based method for location of power system oscillation source," in IEEE Transactions on Power Systems, vol. 28, no. 2, pp. 828-836, May 2013. https://ieeexplore.ieee.org/document/6296740

[4] S. Maslennikov and E. Litvinov, "ISO New England Experience in Locating the Source of Oscillations Online," in IEEE Transactions on Power Systems, vol. 36, no. 1, pp. 495-503, Jan. 2021. https://ieeexplore.ieee.org/document/9132669

5) Dynamic State Estimation (DSE) for controller identification: Kalman filter with unknown inputs approach is used [5]. Terms of transient energy function associated to excitation system W_{field} and mechanical power W_{mech} are calculated to trace the source of FO in Exciter or Governor [6].



Dynamic models are known

FO are not in W or S

Available measurements

5.1) Estimated outputs from the different generator models without FO (woFO) are obtained using a playback simulation injecting measurements of V and frequency. The initial conditions are computed using the supplied load flow base case.

$P_{N\ woFO}(t)$ $Q_{N\ woFO}(t)$

$P_{G\ woFO}(t)$ $Q_{G\ woFO}(t)$

$P_{S\ woFO}(t)$ $Q_{S\ woFO}(t)$

Software: PSSEXplore. Model PLBVFU1 to Play-In voltage and frequency signal

5.2) Perform DSE on synchronous machines using GENROU model, considering Efd and Pmec as unknown inputs [5]. We assume that the source of the FO is only one generator:

Assuming FO is in N: $P_{N\ FO}(t) = P_{tot}(t) - P_{G\ woFO}(t) - P_{S\ woFO}(t)$
$Q_{N\ FO}(t) = Q_{tot}(t) - Q_{G\ woFO}(t) - Q_{S\ woFO}(t)$
→ $E_{fd}(t)$, $X_{ad}I_{fd}(t)$, $P_{mech}(t)$, $\delta(t)$ residuals

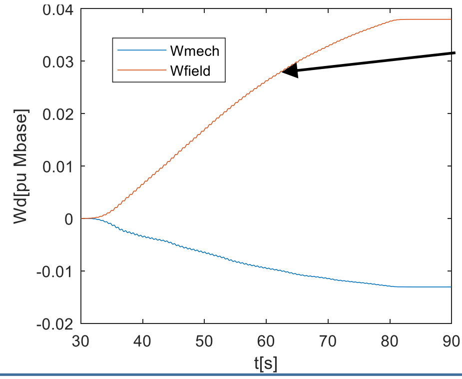
Assuming FO is in G: $P_{G\ FO}(t) = P_{tot}(t) - P_{N\ woFO}(t) - P_{S\ woFO}(t)$
$Q_{G\ FO}(t) = Q_{tot}(t) - Q_{N\ woFO}(t) - Q_{S\ woFO}(t)$
→ $E_{fd}(t)$, $X_{ad}I_{fd}(t)$, $P_{mech}(t)$, $\delta(t)$ residuals

A comparison between the residuals is made. The most likely source is considering as the generator with the smallest variance in their residuals.

5.3) Calculate W_{field} and W_{mech} to locate the controller with the FO, using filtered values of the variables [6]:

$$W^h_{field} = \int \frac{1}{(X_d - X'_d)T'_{d0}} X_{ad} I^h_{fd} (E^h_{fd} - X_{ad} I^h_{fd}) dt$$

$$W^h_{mech} = \int P^h_{mech} d\delta^h$$

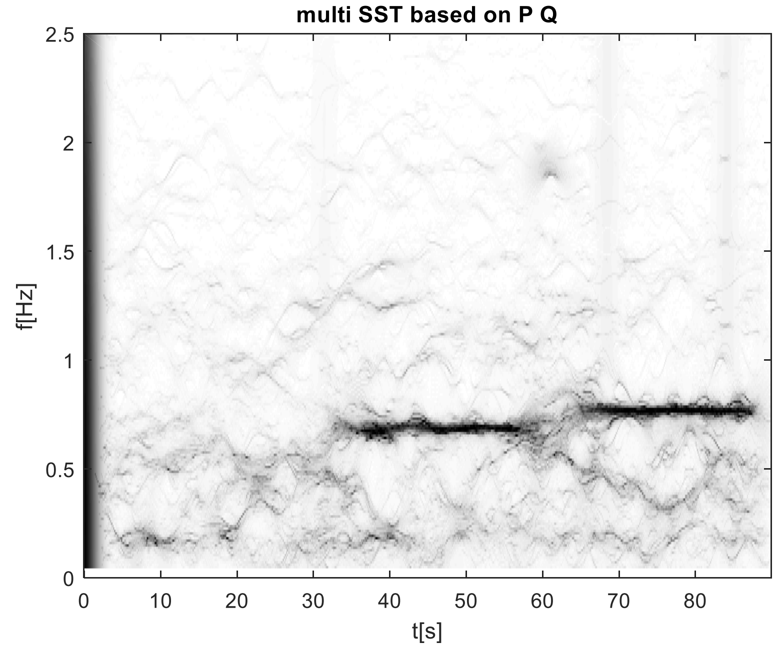


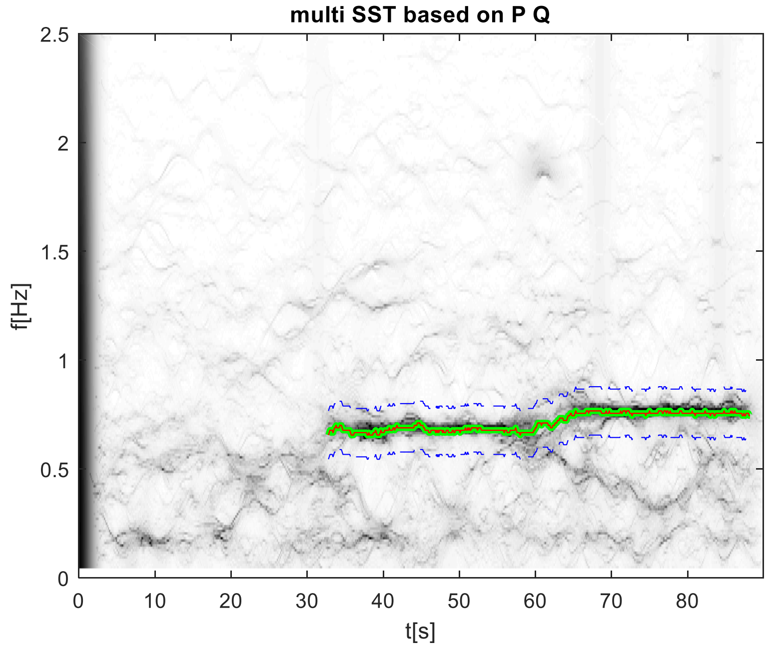
Example: Higher rate of change in W_{field}, then FO is in excitation

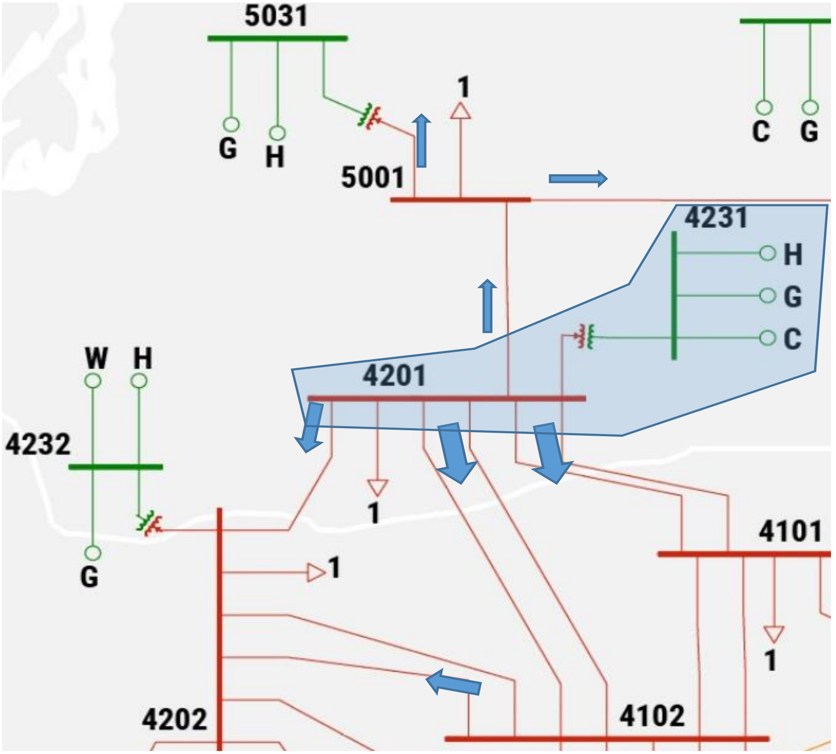
[5] G. Anagnostou and B. C. Pal, "Derivative-Free Kalman Filtering Based Approaches to Dynamic State Estimation for Power Systems With Unknown Inputs," in IEEE Transactions on Power Systems, vol. 33, no. 1, pp. 116-130, Jan. 2018, doi: 10.1109/TPWRS.2017.2663107. https://ieeexplore.ieee.org/document/7898823

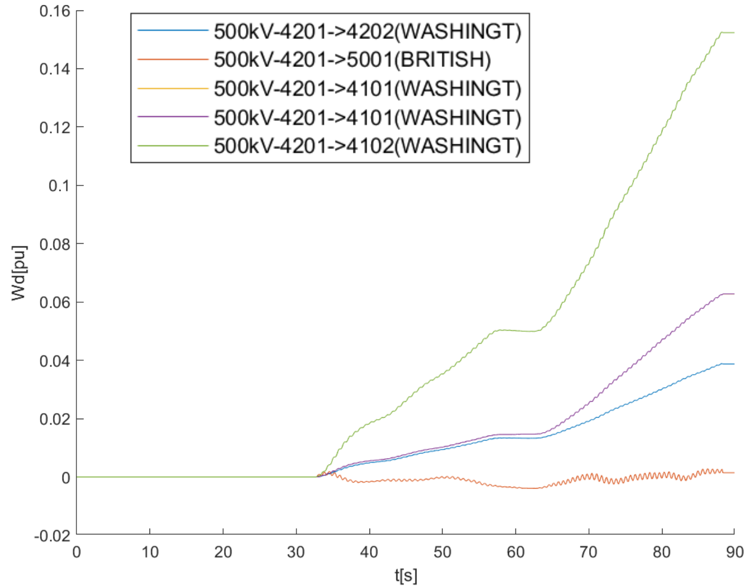
[6] L. Chen, Y. Min, Y. Chen and W. Hu, "Evaluation of Generator Damping Using Oscillation Energy Dissipation and the Connection With Modal Analysis," in IEEE Transactions on Power Systems, vol. 29, no. 3, pp. 1393-1402, May 2014, doi: 10.1109/TPWRS.2013.2291898. https://ieeexplore.ieee.org/document/6679304

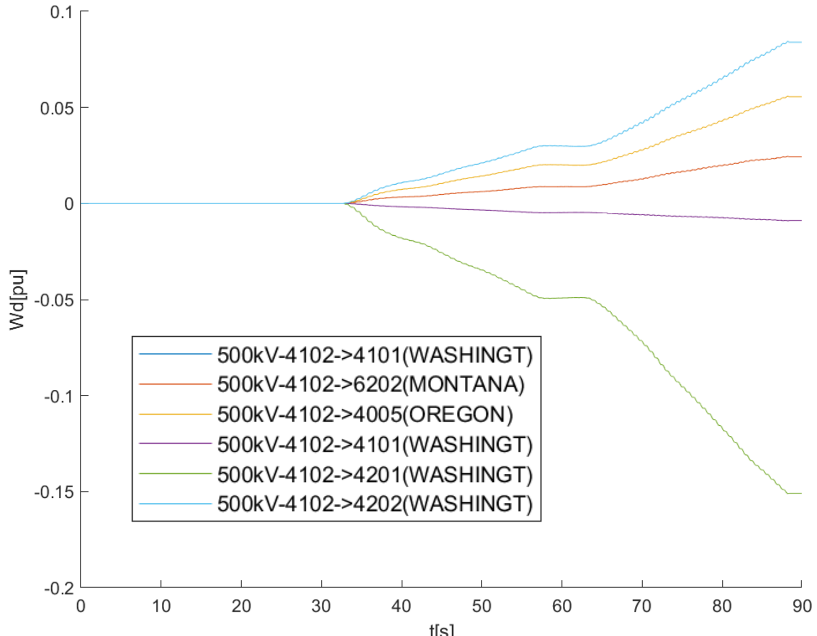
Case 5 FO frequency is 0.7 Hz in time interval from 30 s to 60 s, and then 0.75 Hz from 65 s to 88 s.









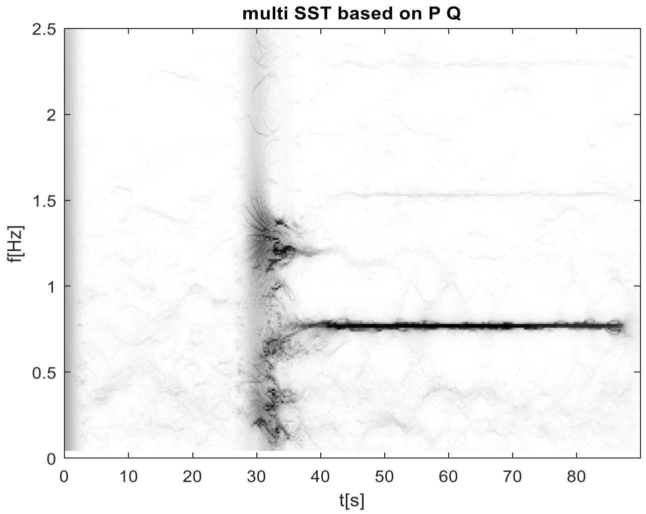


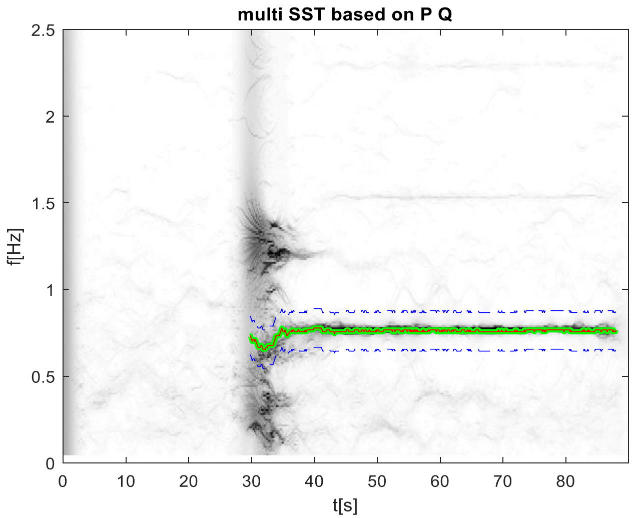
4231 is identified as the source of oscillation

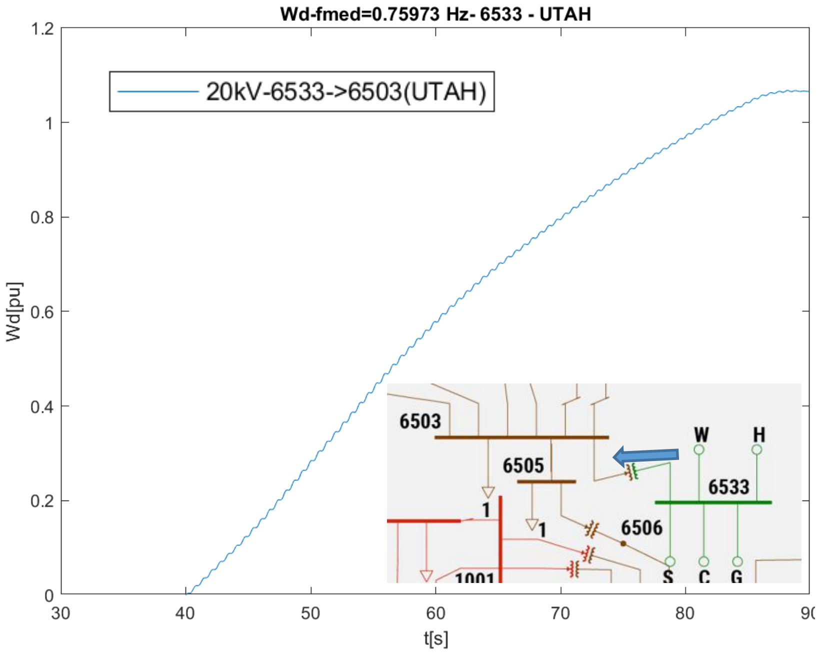
The methodology based on time-frequency analysis allows to identify frequency variations of the source

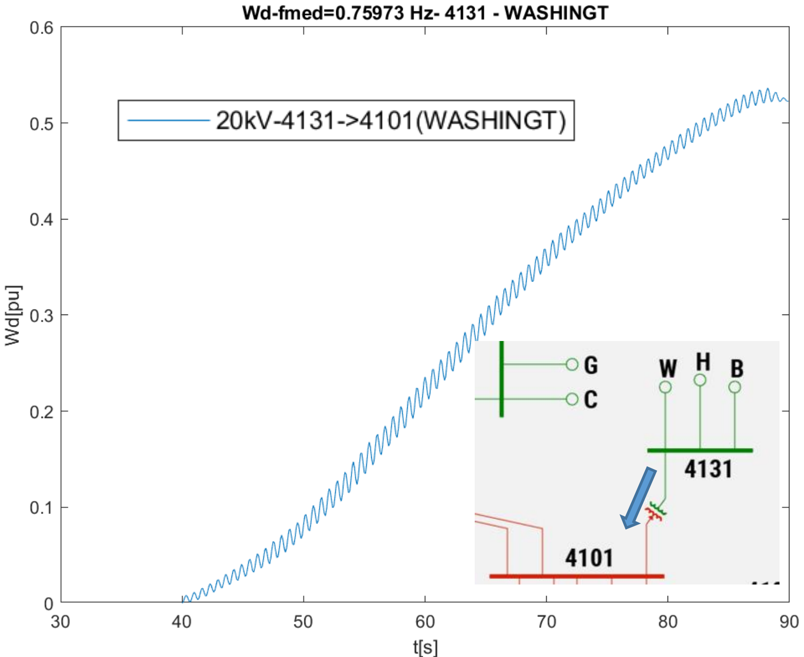
Case 9. FO localization in the Network with DEF

Two simultaneous sources with the same fundamental frequency of 0.76 Hz (6533 and 4131). Harmonics 1.52 Hz and 2.28 Hz can also be identified with much lower intensity.



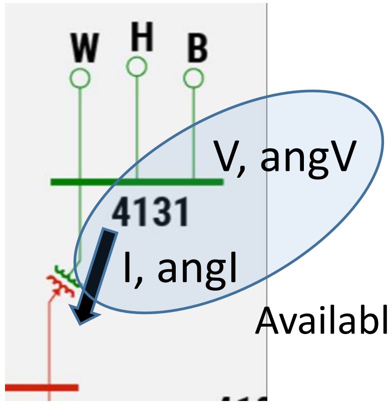






Buses 4131 and 6533 identified as sources

Case 9. Controller identification of 4131

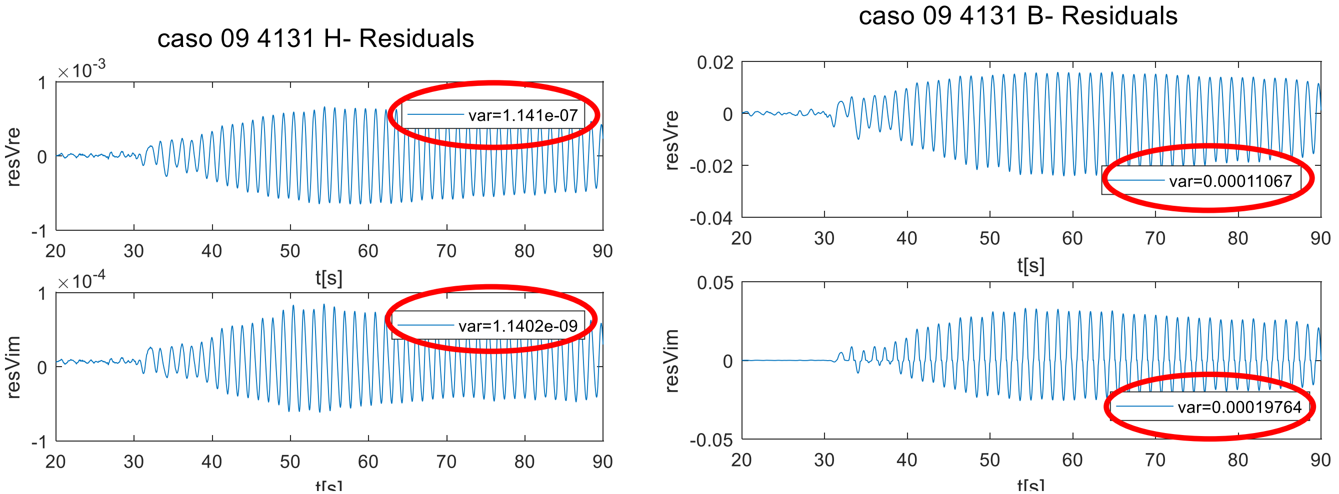


Available PMU measurements

Bus Number	Bus Name	Id	Mbase (MVA)	Generator	Exciter	Turbine Gov	Stabilizer
4131	COULEE 20.000	B	711	GENROU	SEXS	TGOV1	None
4131	COULEE 20.000	H	12613	GENROU	SEXS	HYGOV	IEEEST

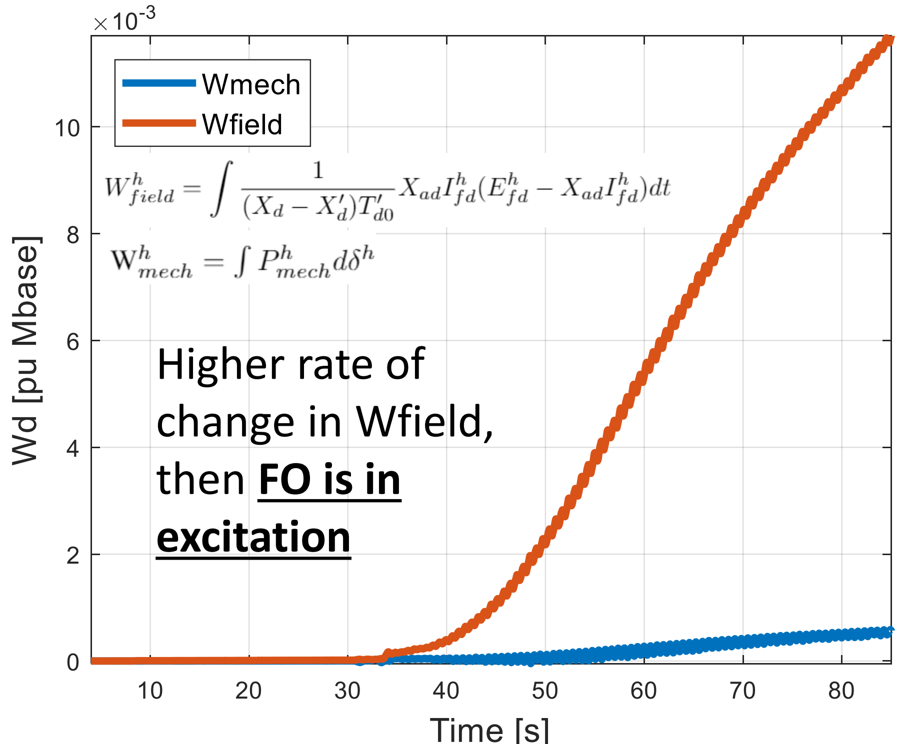
Bus Number	Bus Name	Id	Mbase (MVA)	Generator	Electrical	Auxiliary control
4131	COULEE 20.000	W	790	REGCA1	REECB1	REPCA1

Combining playback simulation and Kalman filter with unknown inputs:

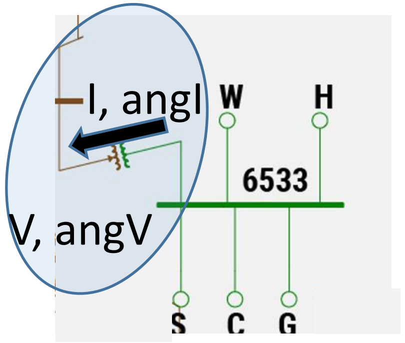


Assuming that the **FO is located in H** provides residuals with a variance of two orders of magnitude smaller than if it were in B.

Energy terms in excitation and mechanical power of generator H using filtered values of estimated state variables and inputs:



Case 9. Controller identification of 6533

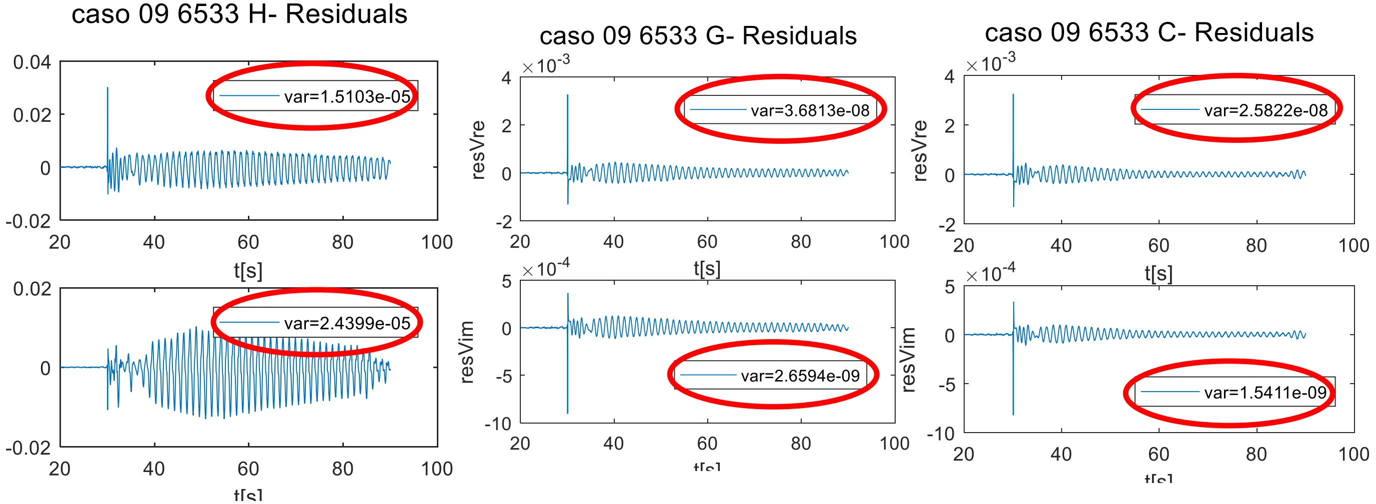


Bus Number	Bus Name	Id	Mbase (MVA)	Generator	Exciter	Turbine Gov	Stabilizer
6533	EMERY 20.000	C	3276	GENROU	SEXS	TGOV1	IEEEST
6533	EMERY 20.000	G	3239	GENROU	SEXS	GAST	None
6533	EMERY 20.000	H	275	GENROU	SEXS	HYGOV	None

Bus Number	Bus Name	Id	Mbase (MVA)	Generator	Electrical	Auxiliary control
6533	EMERY 20.000	S	1407	REGCA1	REECB1	REPCA1
6533	EMERY 20.000	W	391	REGCA1	REECB1	REPCA1

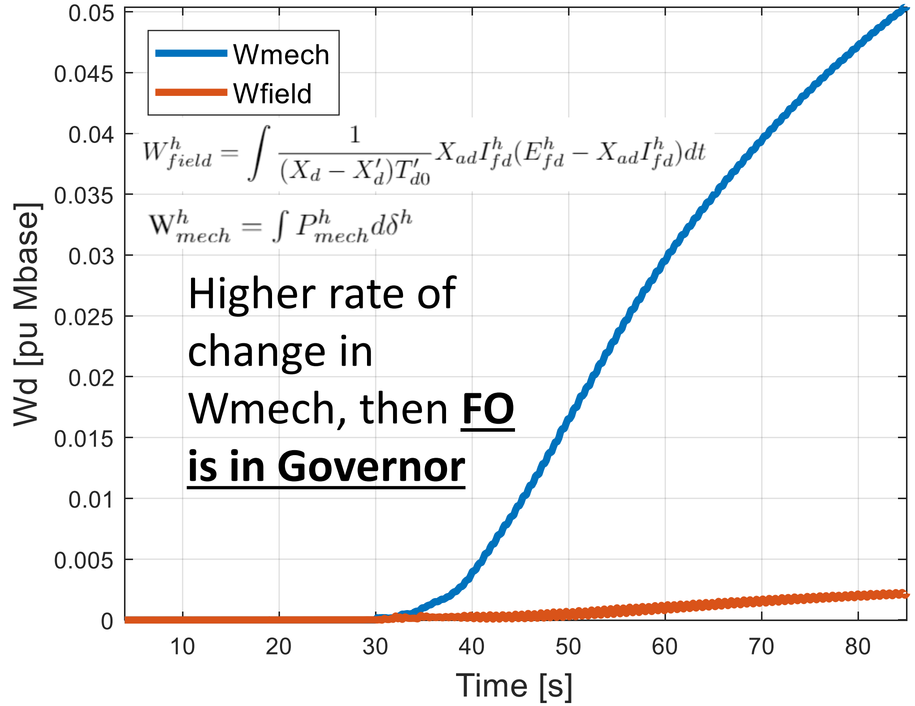
Available PMU measurements

Combining playback simulation and Kalman filter with unknown inputs:

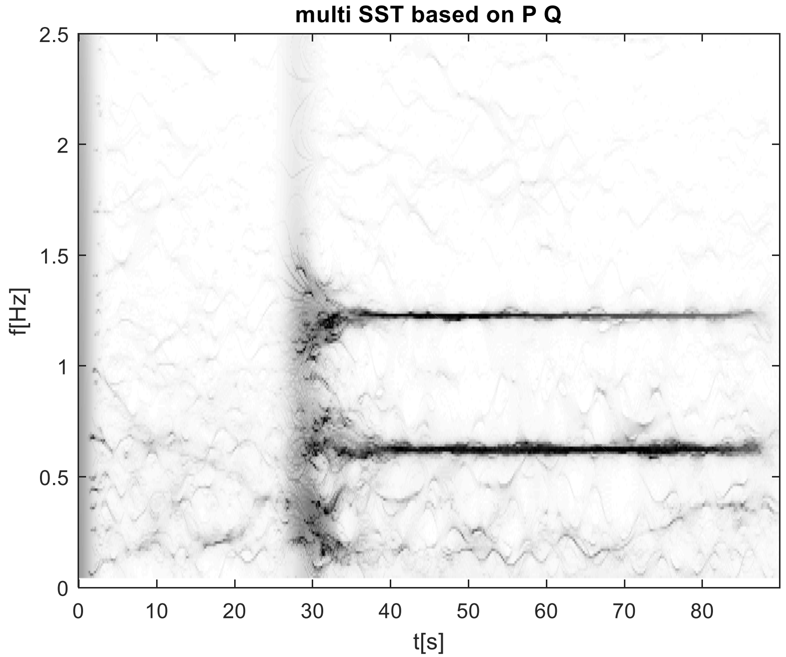


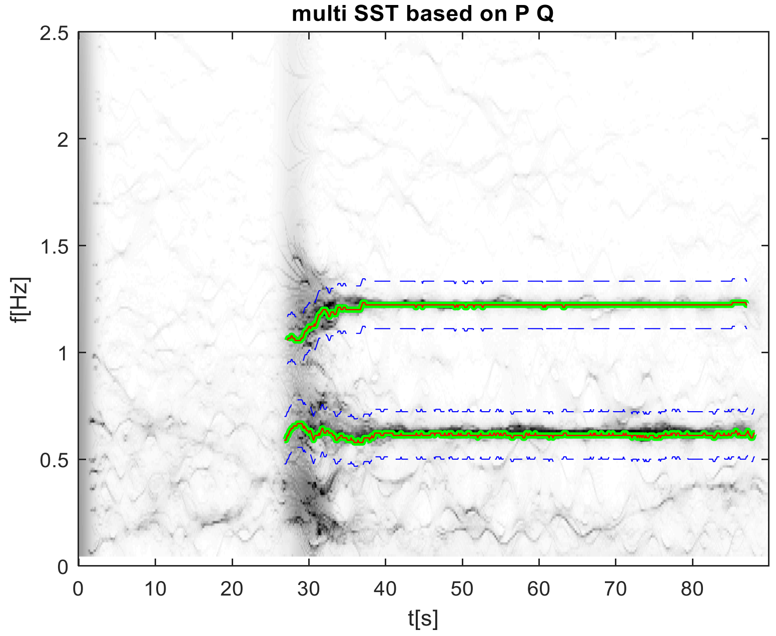
Assuming that the **FO is located in C** provides the smallest values of residuals.

Energy terms in excitation and mechanical power of generator C using filtered values of estimated state variables and inputs:



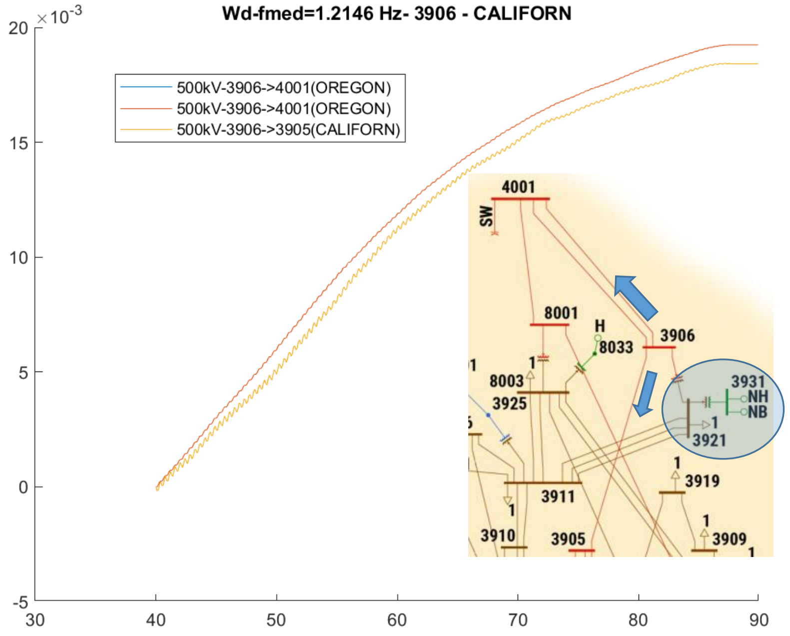
Case 10 There are two forced oscillations, each resonates with a natural mode.



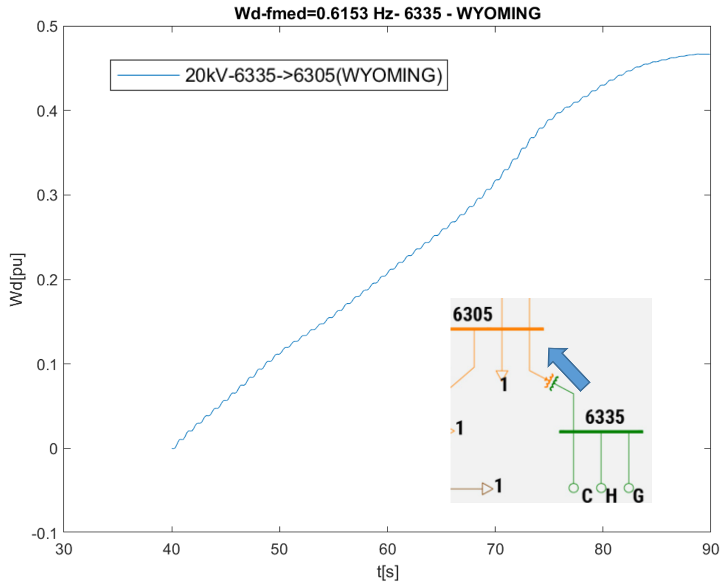


Calculation of the DEF in each oscillatory component makes it possible to identify different sources associated with different frequencies.

3906 is classified as source for 1.215 Hz. Closest generator is 3931, which is considered the source

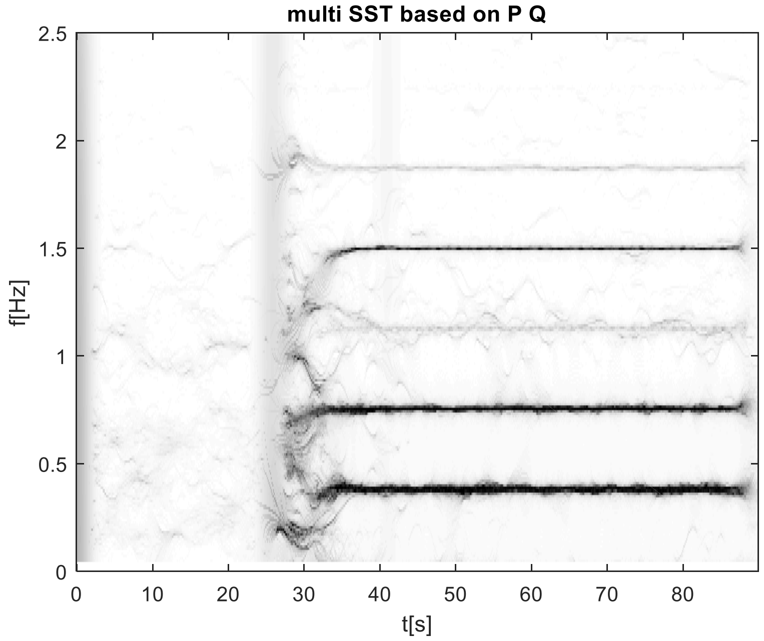


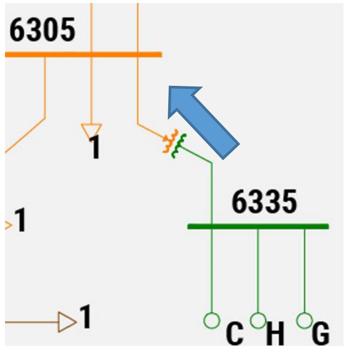
6335 is the source for 0.615 Hz FO:

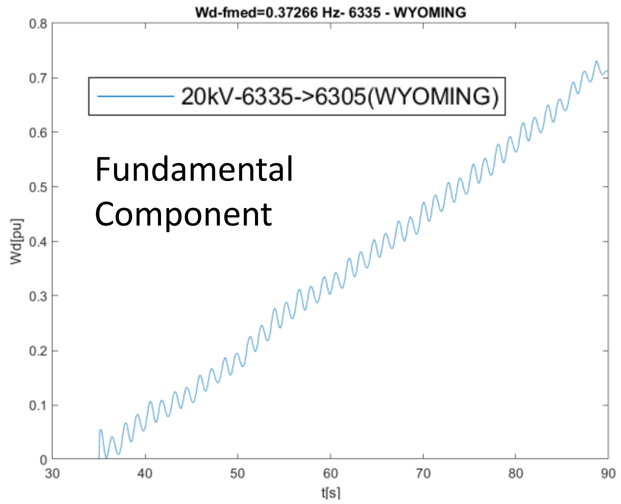


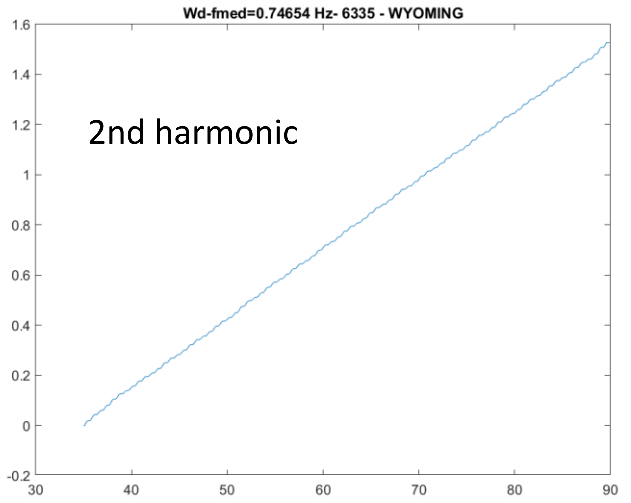
Case 12

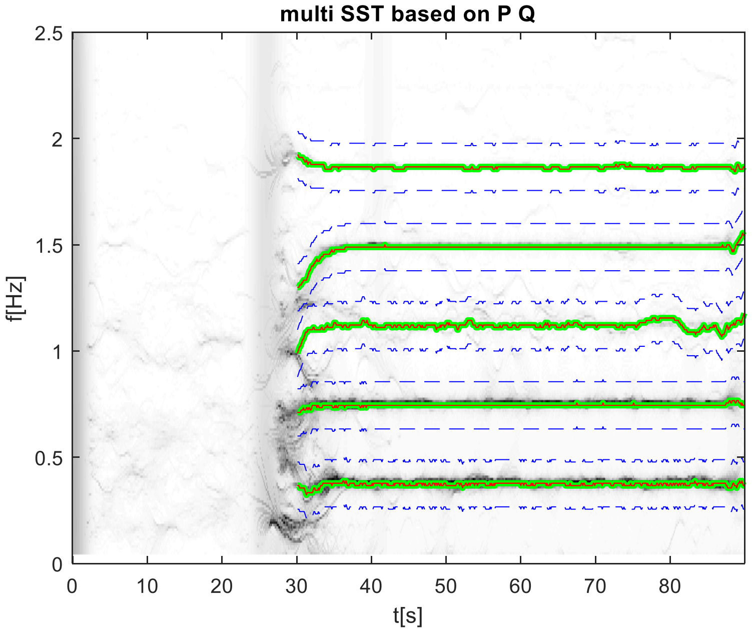
Non-sinusoidal source. Multiple components correspond to the harmonics of fundamental frequency 0.37 Hz.

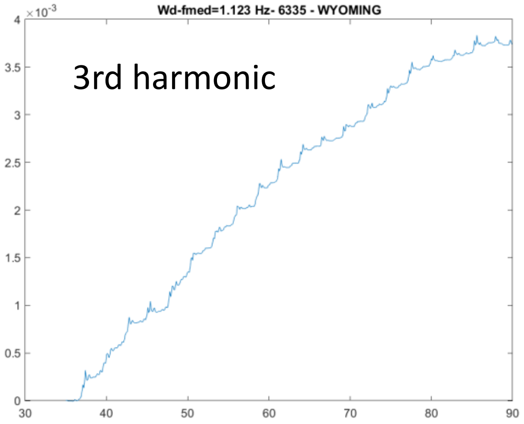


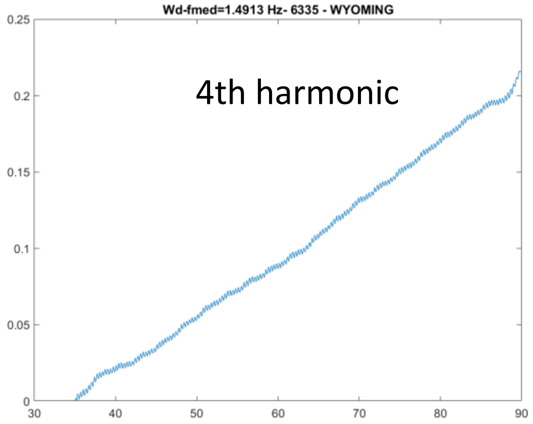


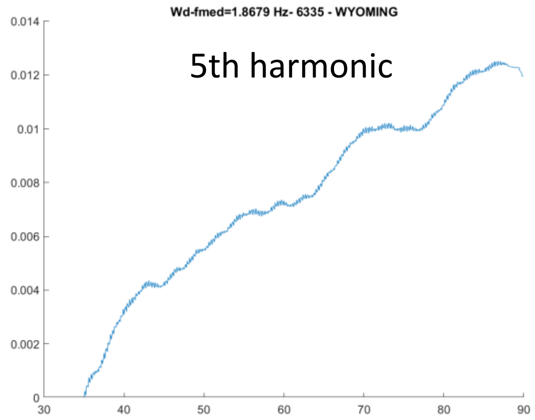












The same source (bus 6335) is identified for all the oscillatory components

Team FIUBA. Performance Summary (3rd place)

fiuba CONICET CSC

Case	Frequency	Area	Bus	Asset Type	Controller
1	✓	✓	✓	✓	✗
2	✓	✓	✓	✓	✗
3	✓	✓	✓ Within 1 bus	N/A	N/A
4	✓	✓	✓ Within 1 bus	N/A	N/A
5	✓	✓	✓	✓	N/A
6	✓	✓	✓	✓	N/A
7	✓	✓	✗	✗	✗
8	✓	✓	✓	✓	N/A
9	✓	✓	✓	✓	N/A
	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	N/A
	✓	✓	✓	✓	N/A
11	✓	✓	✓	✓	✓
12	✓	✓	✓	✓	N/A
13	✓	✓	✓	✓	✓
	✓	✓	✓	✓	✓

The methodology was in a maturing stage during the contest and we had some errors in the code of DSE. With the corrected code, we would have correctly identified the controller.

Case 7 presented very strong interaction between a generator (FO source) and controls of HVDC link, located very close in the network. Our calculation of DEF wrongly identified HVDC station as source.

N/A were because lack of measurements in generator bus.

Conclusion

- What did we learn from the contest?
  - The contest helped us to improve the methodology that we had been developing for detection of FO
  - We were able to combine different research topics that we were studying in our laboratory, which were previously being developed separately (analysis of non-stationary signals and DSE)
- Next steps?
  - Extend DSE to a larger region (no only monitored buses).

Thank you

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