Synchronized Frequency Measurements & Applications

May, 2007

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Partial list of FDR locations

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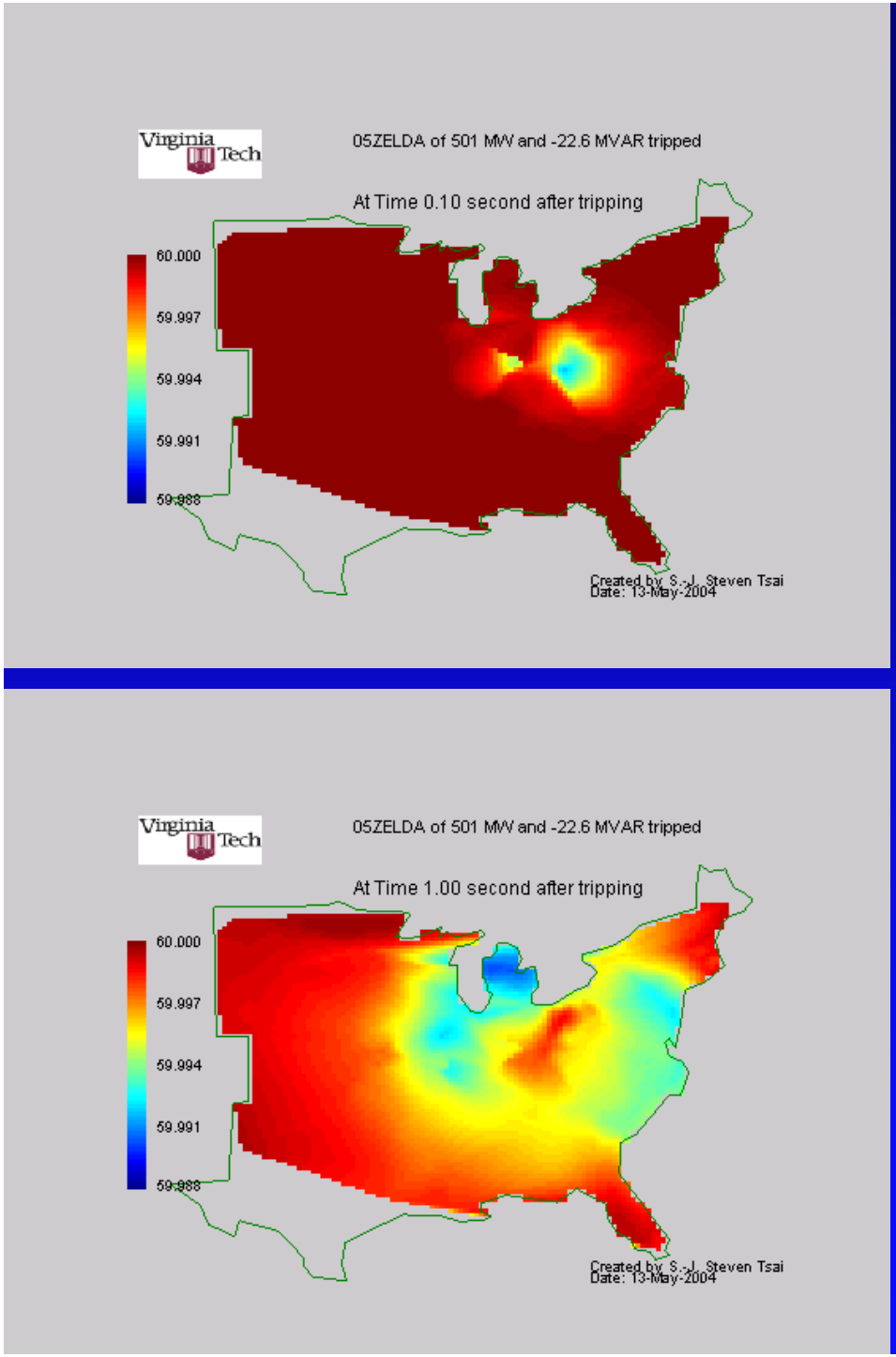
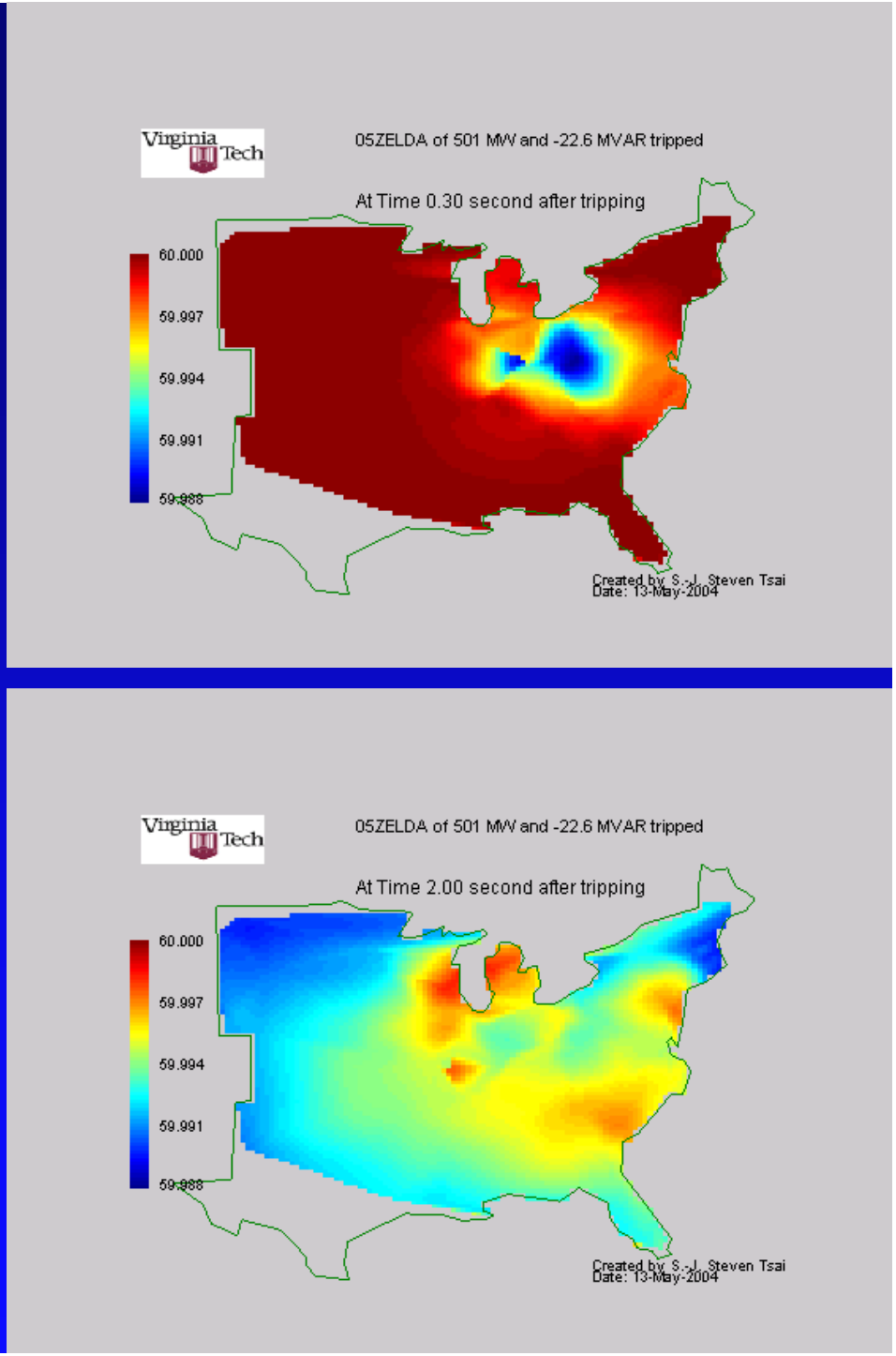
Application Example #1

Event Detection Based on Time of Arrival of Frequency Disturbance

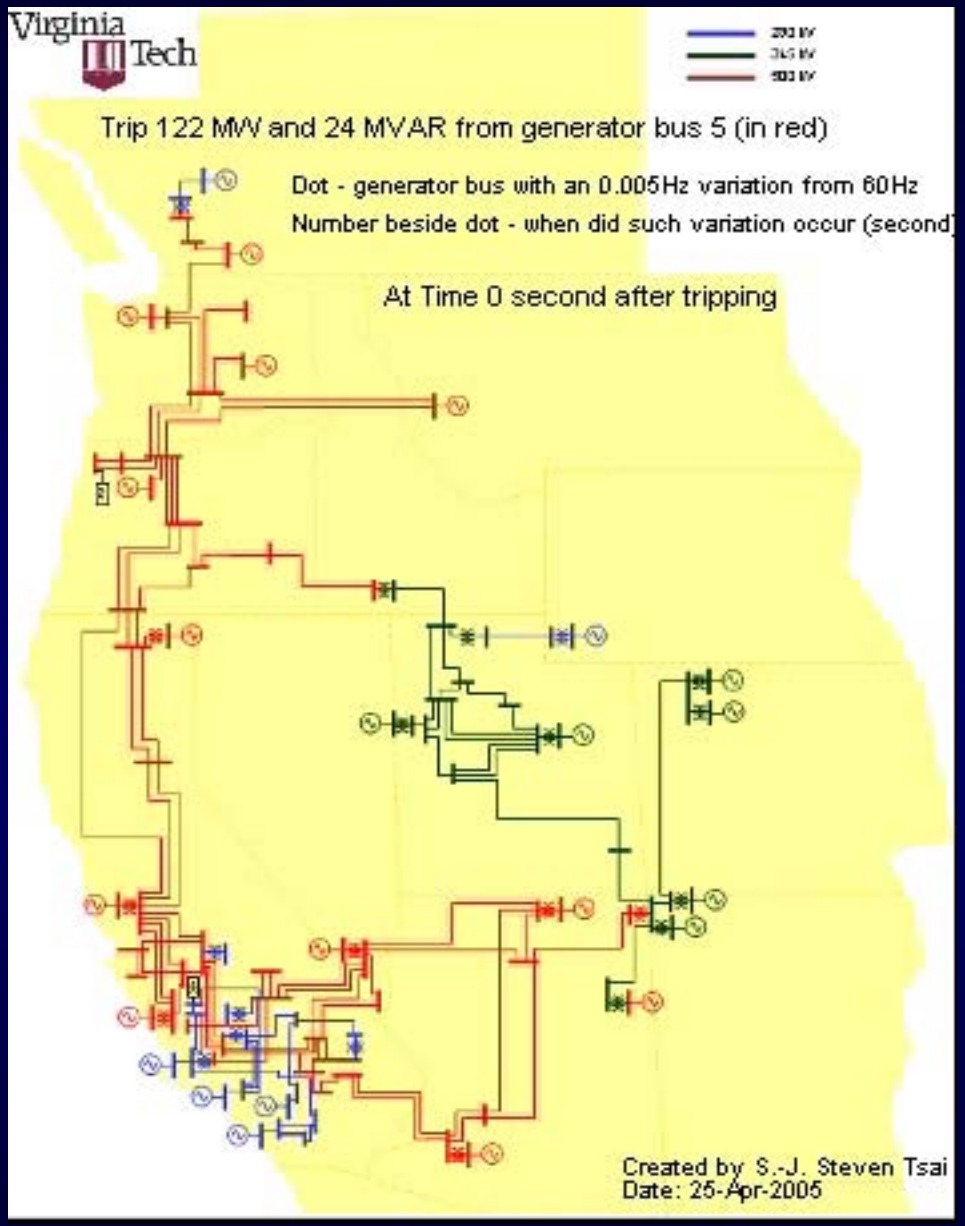

Virginia Tech
05ZELDA of 501 MW and -22.6 MVAR tripped
At Time 0.10 second after tripping
60.000
59.997
59.994
59.991
59.988
Created by S.-J. Steven Tsai
Date: 13-May-2004


Virginia Tech
05ZELDA of 501 MW and -22.6 MVAR tripped
At Time 0.30 second after tripping
60.000
59.997
59.994
59.991
59.988
Created by S.-J. Steven Tsai
Date: 13-May-2004

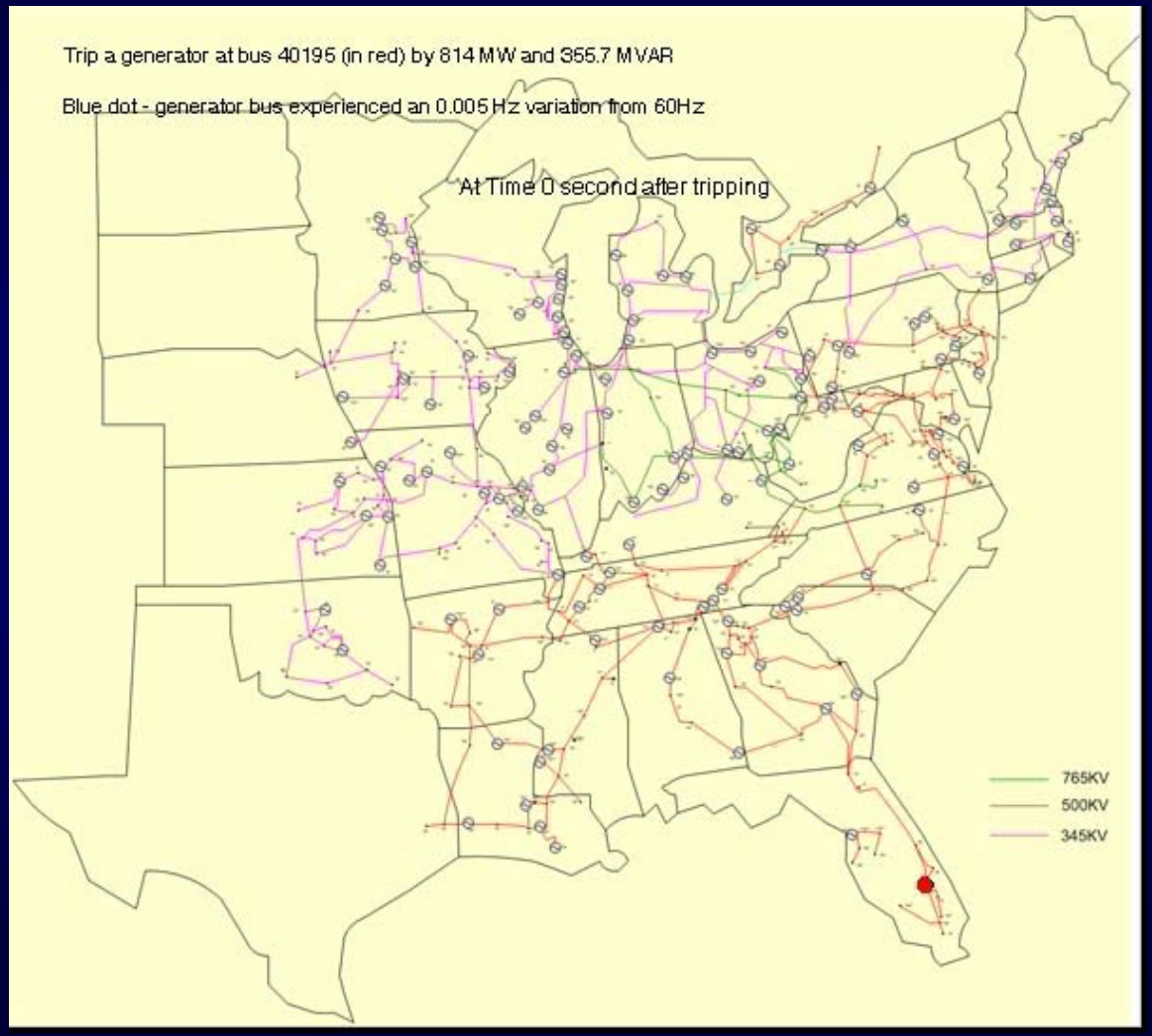
Virginia Tech
05ZELDA of 501 MW and -22.6 MVAR tripped
At Time 1.00 second after tripping
60.000
59.997
59.994
59.991
59.988
Created by S.-J. Steven Tsai
Date: 13-May-2004

Virginia Tech
05ZELDA of 501 MW and -22.6 MVAR tripped
At Time 2.00 second after tripping
60.000
59.997
59.994
59.991
59.988
Created by S.-J. Steven Tsai
Date: 13-May-2004

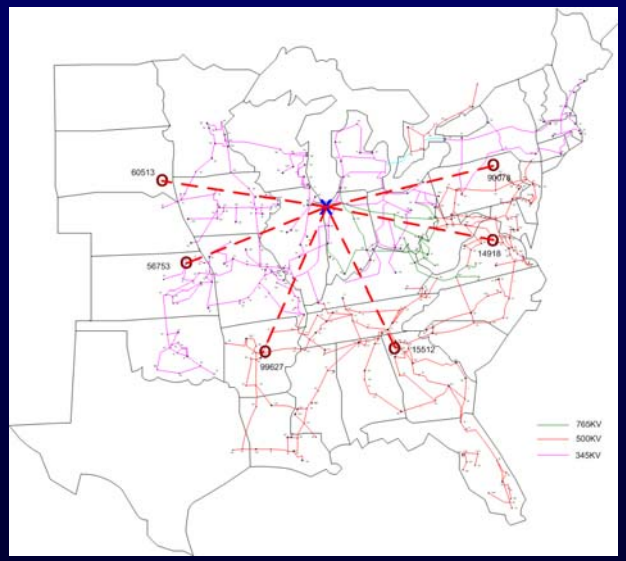
A gen. trip in British Columbia



Eastern US Frequency Disturbance -Movie

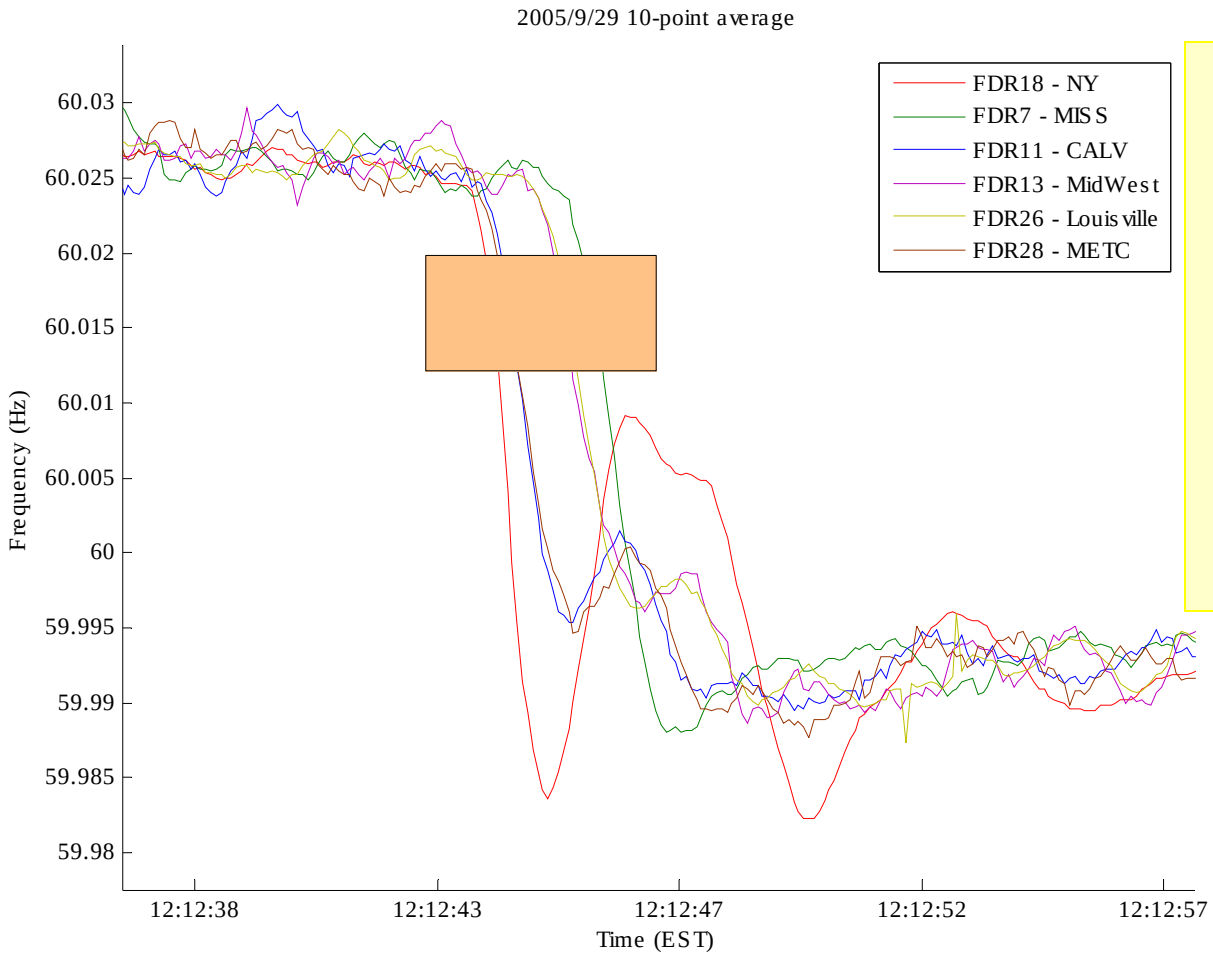


“Speed” of Frequency Waves



- Frequency wave travel faster in WECC then in EI
- Frequency wave travels faster from South to North in EI
- Frequency wave propagates faster to the western part of the system than to the eastern part of the system.
- Frequency wave propagates slightly faster from the central part of the EI system than from the rim of the system
- Eastern US --- about 350 miles/s
- WECC --- about 1100 miles/s

On-line Event Location



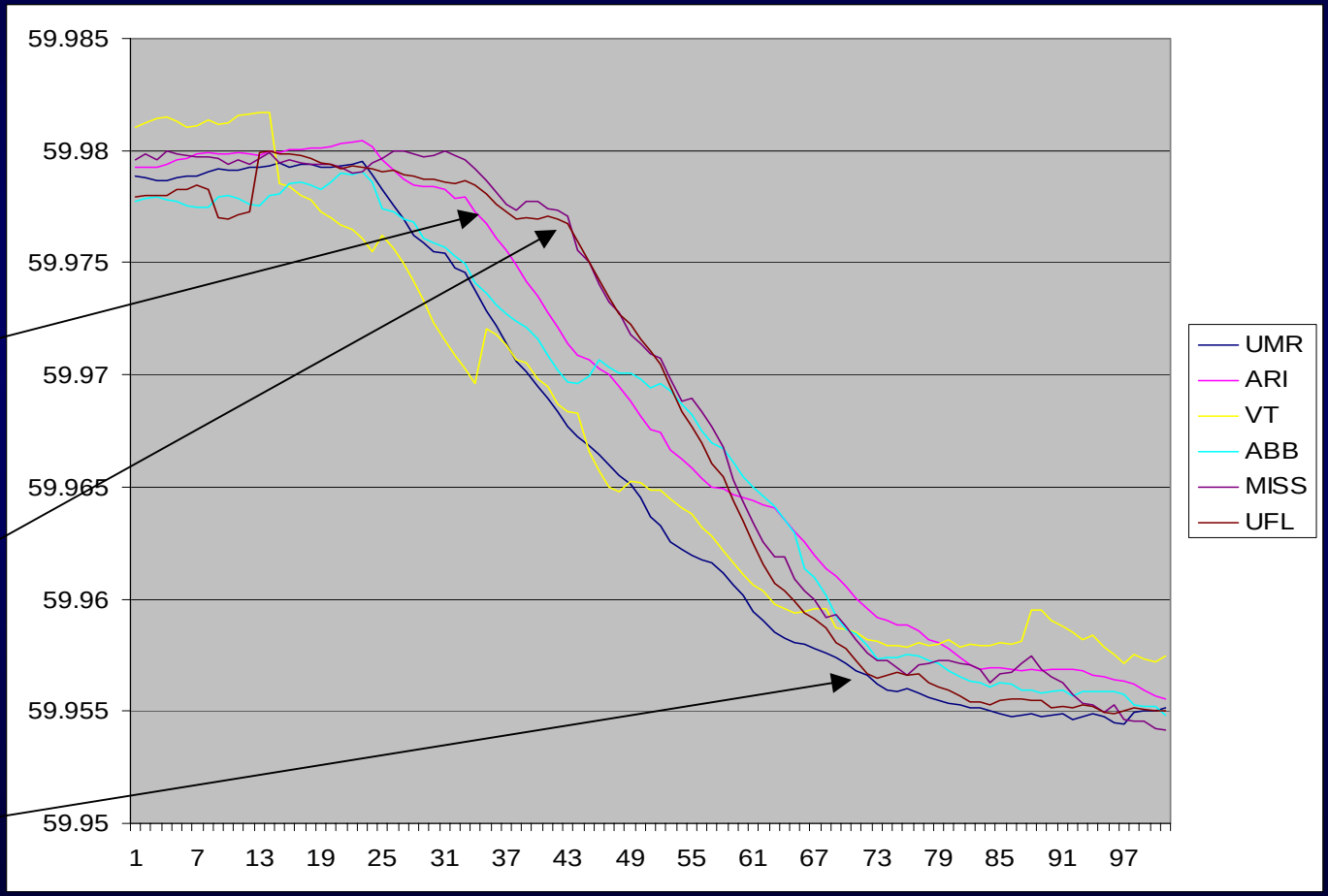
Virginia Tech has a Patent pending on the concept of using frequency time delay of arrival in determining the location of the source of power system disturbances

8/04/2004 Eastern System Event Analysis (EDT Time)

10:23:8.8

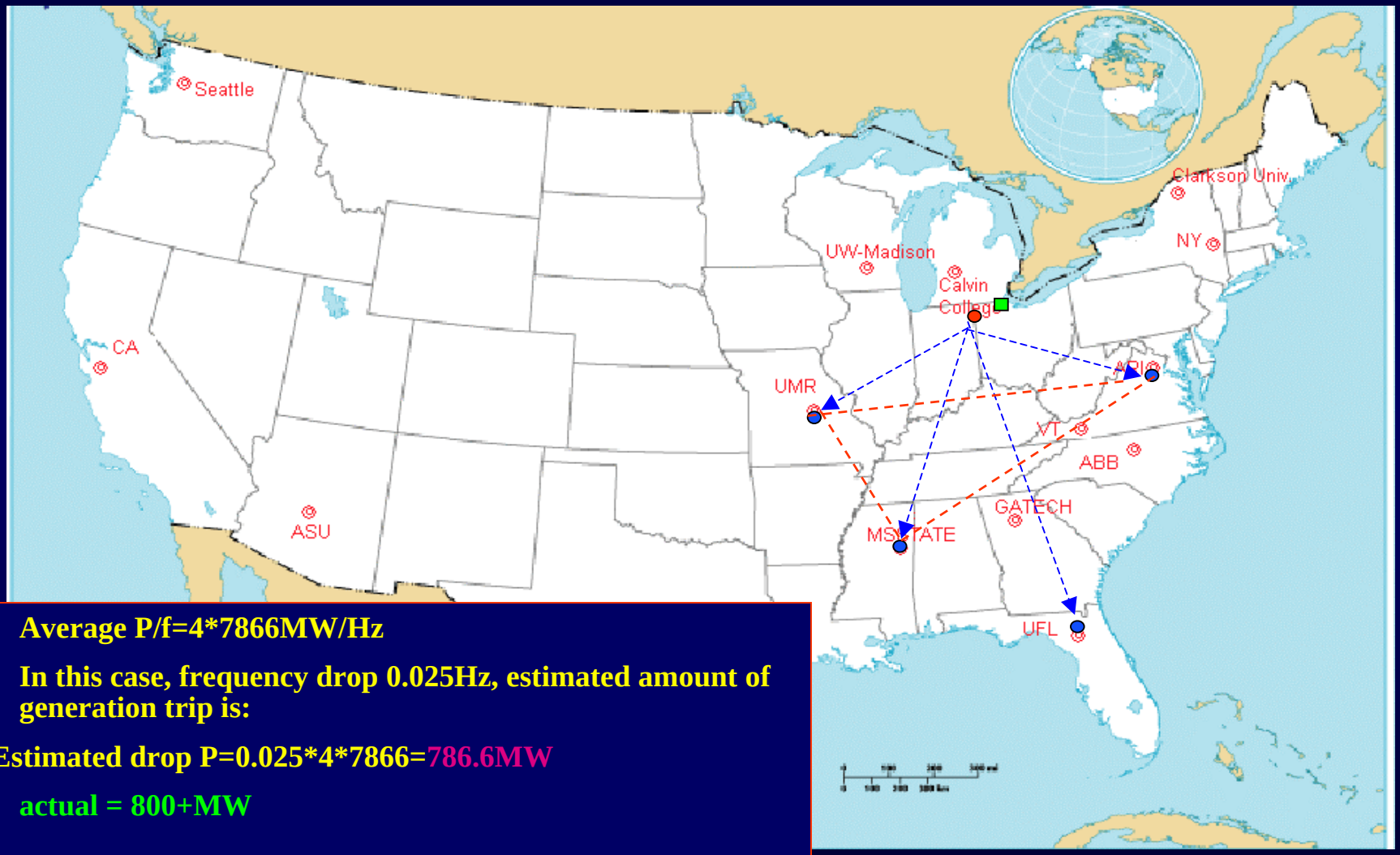
10:23:9.8

10:23:12.8



Triangulation of event location based on data from 4 of the FNET units

Red dot estimated location, Green square is actual location



- **Average P/f=4*7866MW/Hz**
- **In this case, frequency drop 0.025Hz, estimated amount of generation trip is:**

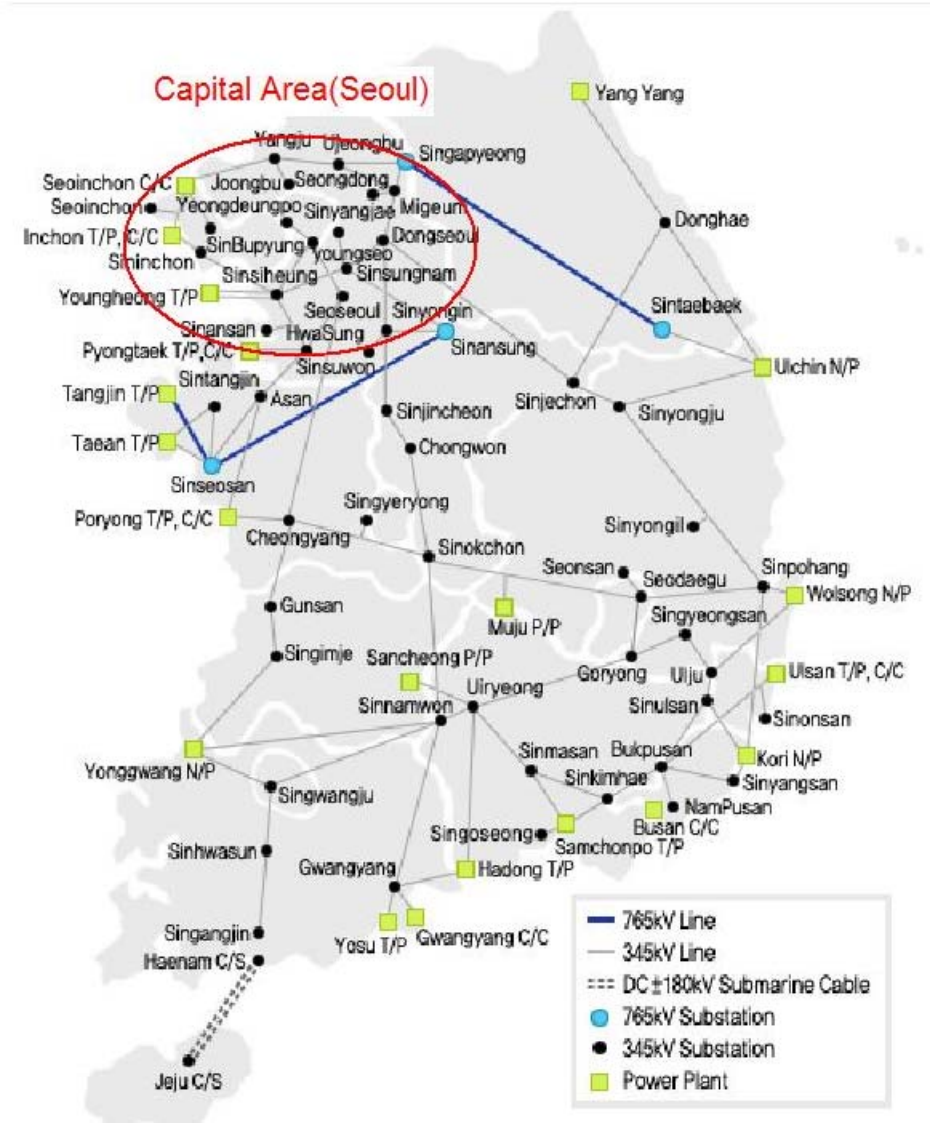
Estimated drop P=0.025*4*7866=786.6MW

- **actual = 800+MW**

Will it work for Smaller Grid?

Korean Example

Characteristics of Korean power systems



- ✓ Peak load: 57,420MW (Generation Capacity: 63,720MW) as of 2006

  ※TVA peak load : 32,000MW

- ✓ Concentrated Electric demand in capital area (42%[24,000MW]] of the national demand)
- ✓ High generating cost of generators within capital area
- ✓ Large amount of power flow transmitted to capital area through 6 main interface lines (over 100km)
- ✓ Voltage stability limits of interface lines below the thermal limits

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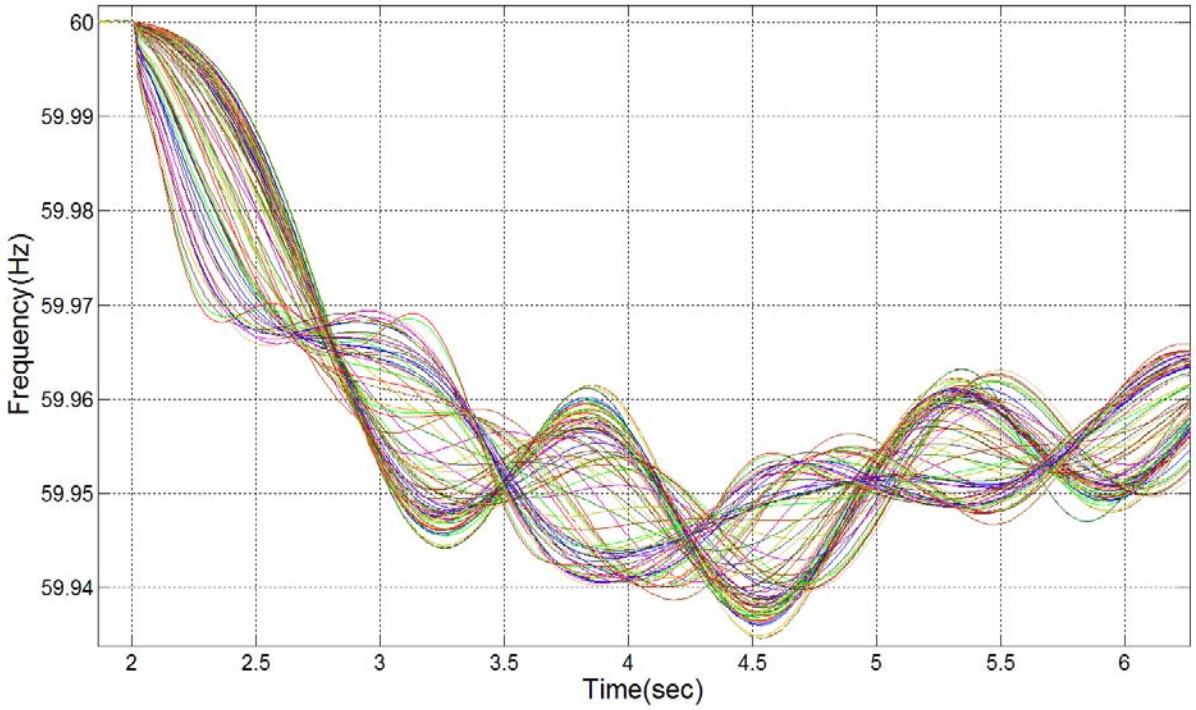
Propagation Speed of Frequency Wave

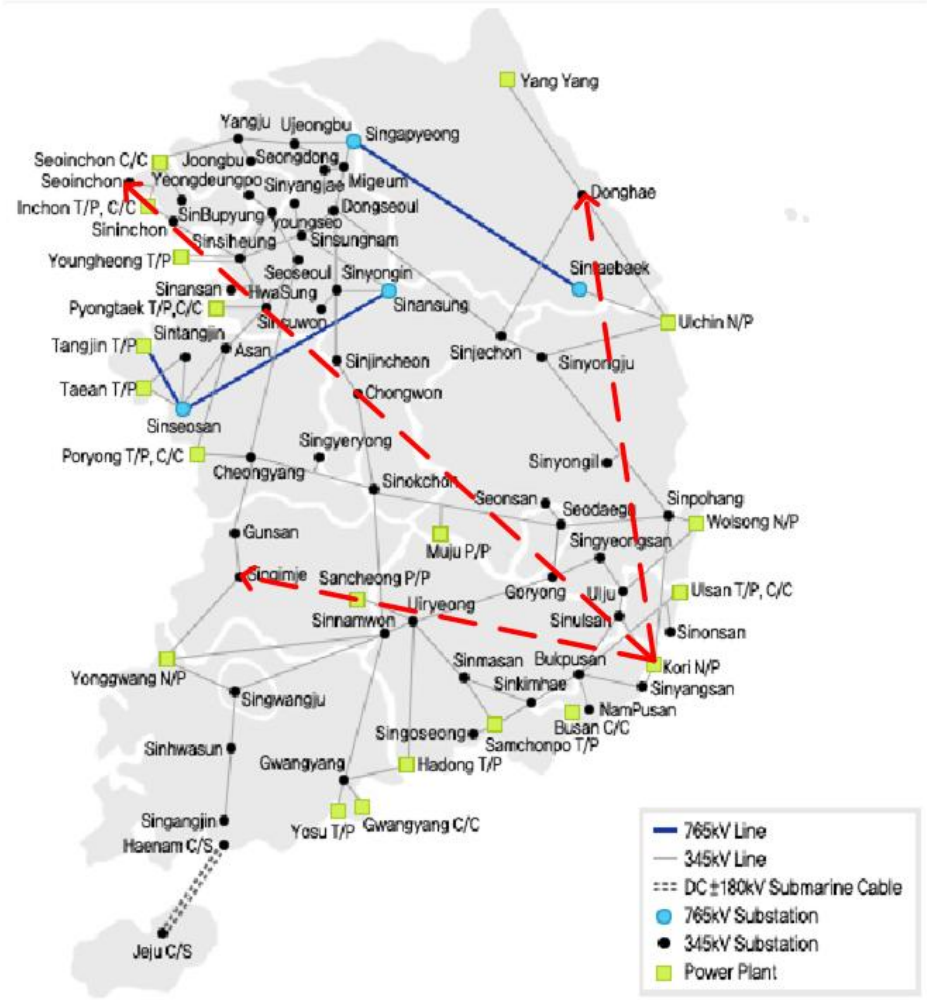
- Frequencies on all substations above 345kV



- Speed calculation : v=d/t, where
  - ✓ d : the direct geographical distance between the dropped generator and the measuring location
  - ✓ t : the time when a frequency drops more than the threshold at each monitoring location after the generation trip is occurred

Propagation Speed Calculation 1

- The generation trip at Kori power plant (South)



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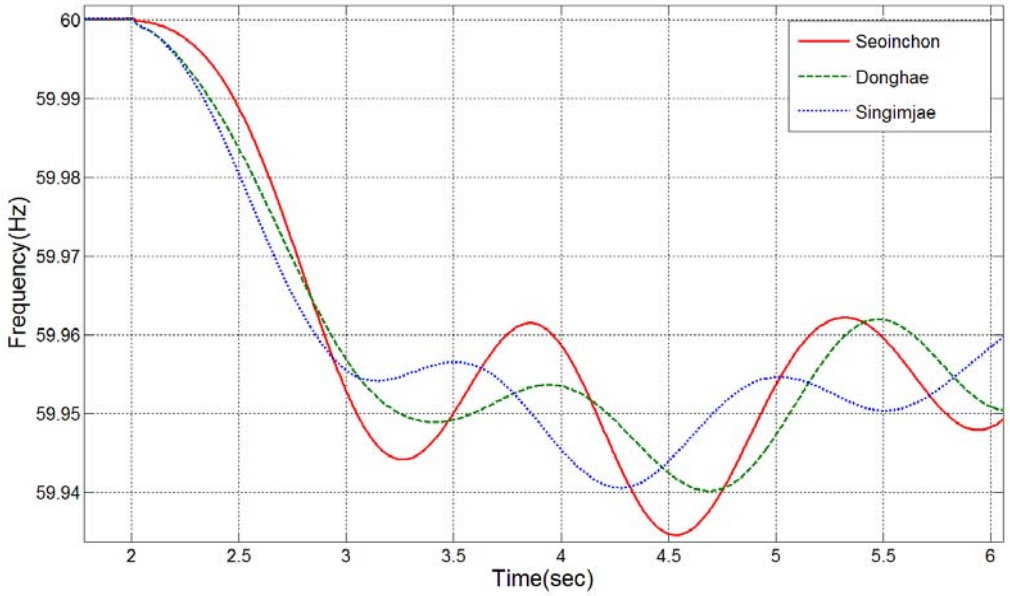
Propagation Speed Calculation 1

- Frequencies at monitored 345kV substations



- Calculated Speed

Tripped Gen.	345kV Substation	Arrival time [sec]	Speed [mile/sec]
Kori N/P (587MW)	Seoinchon	0.358	595
	Donghae	0.233	649
	Singimje	0.225	611

Average Propagation Speed, Korean vs. US system

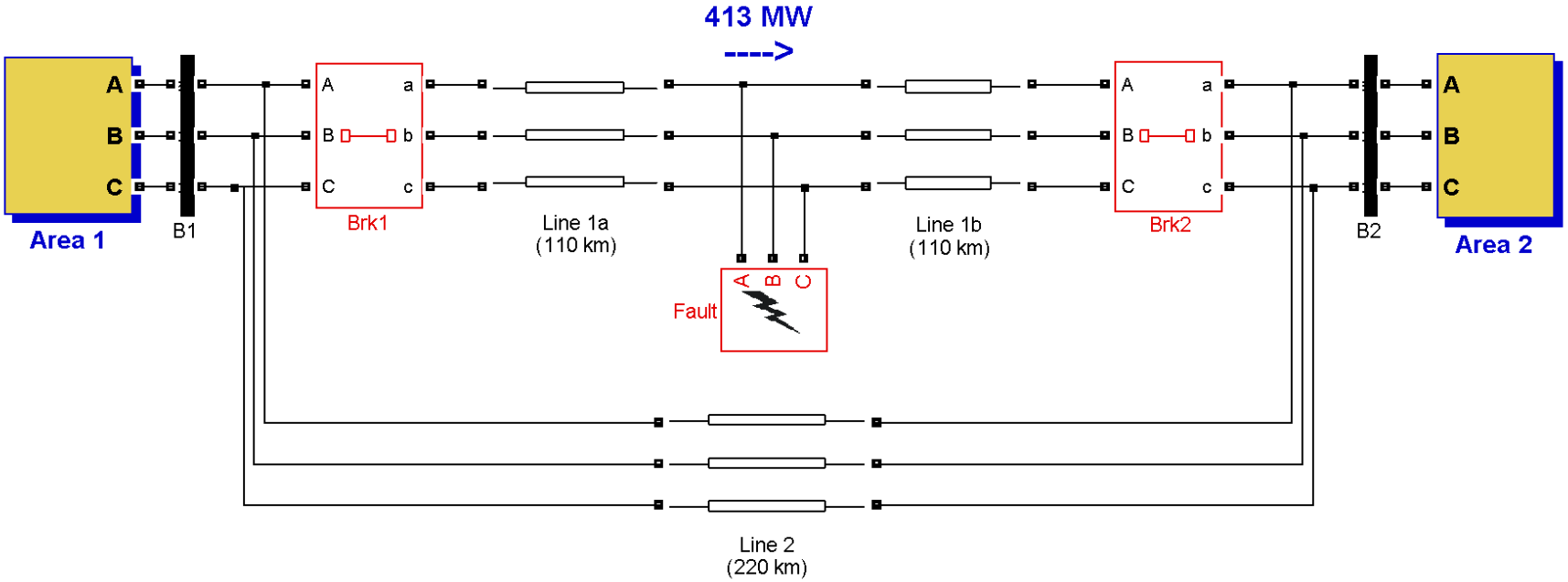
	Detailed	Speed [mile/sec]
Korean system	In the same direction as the main power flow (From South to North)	600
	In the reverse direction to the main power flow (From North to South)	400
US System	Eastern Interconnection	350~500
	WECC system	1100~1300

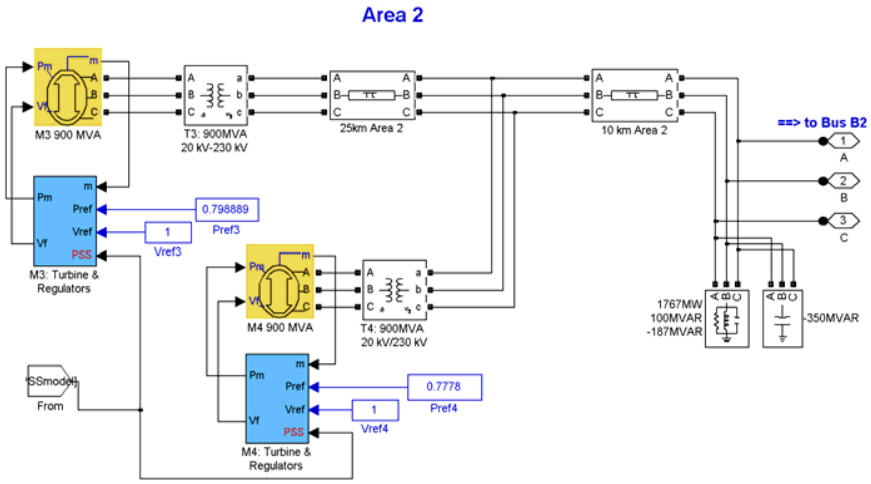
Application Example #3

Wide Area Frequency and HVDC in Controlling

Inter-area Oscillations

(Josh Wang, Jim Thorp)





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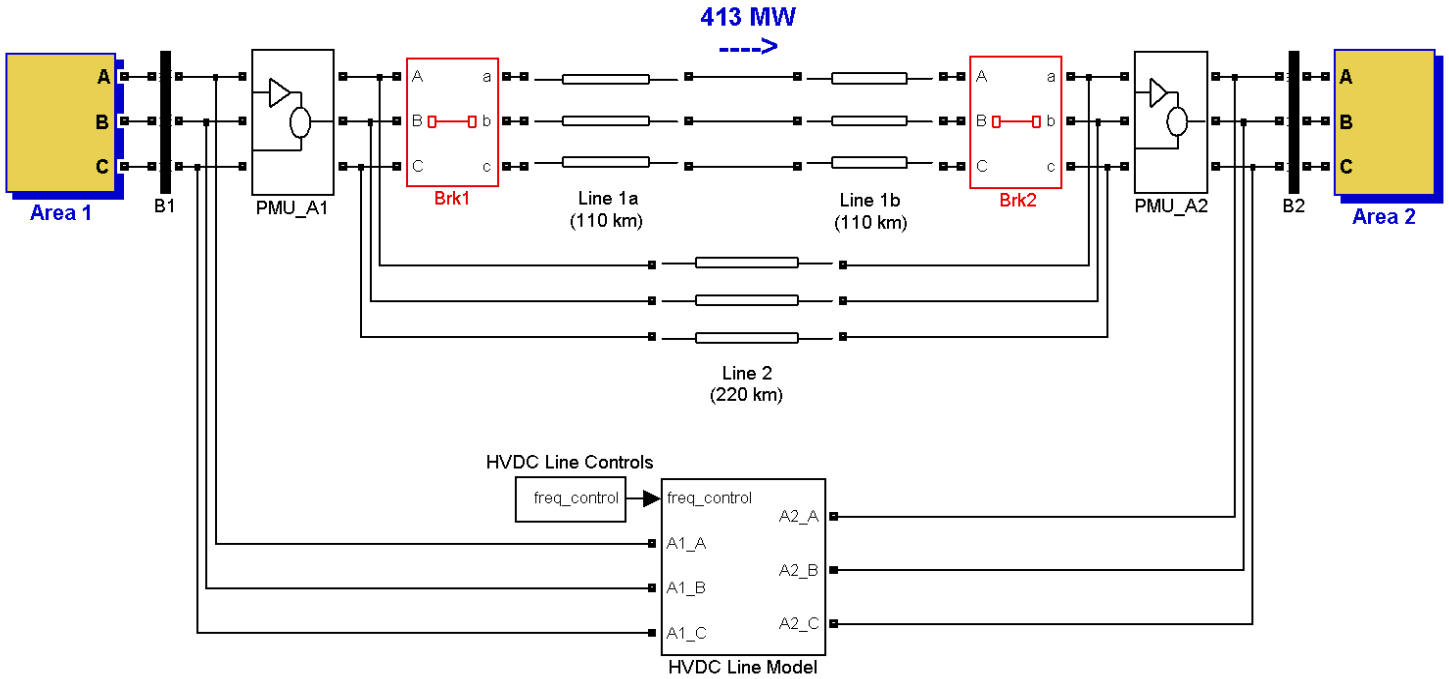

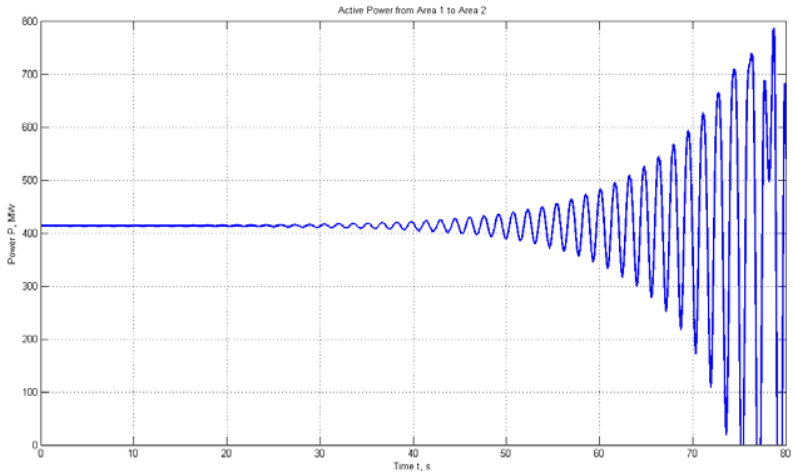

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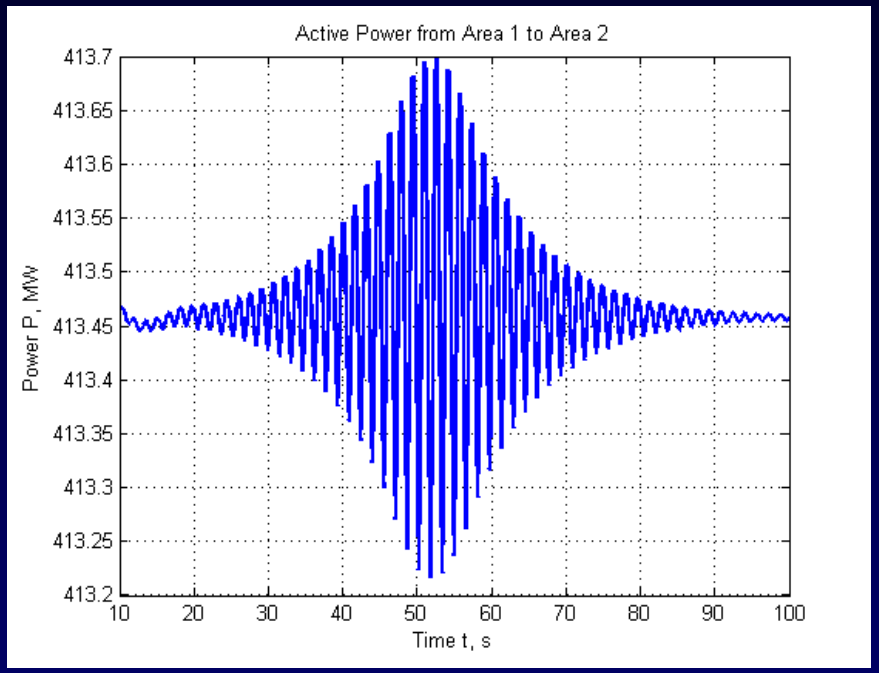
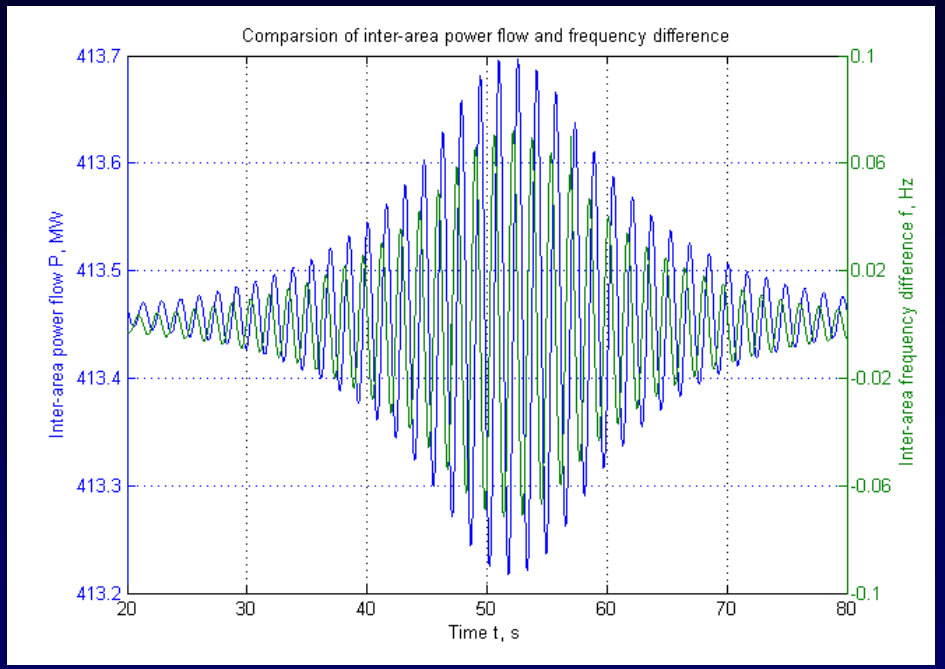
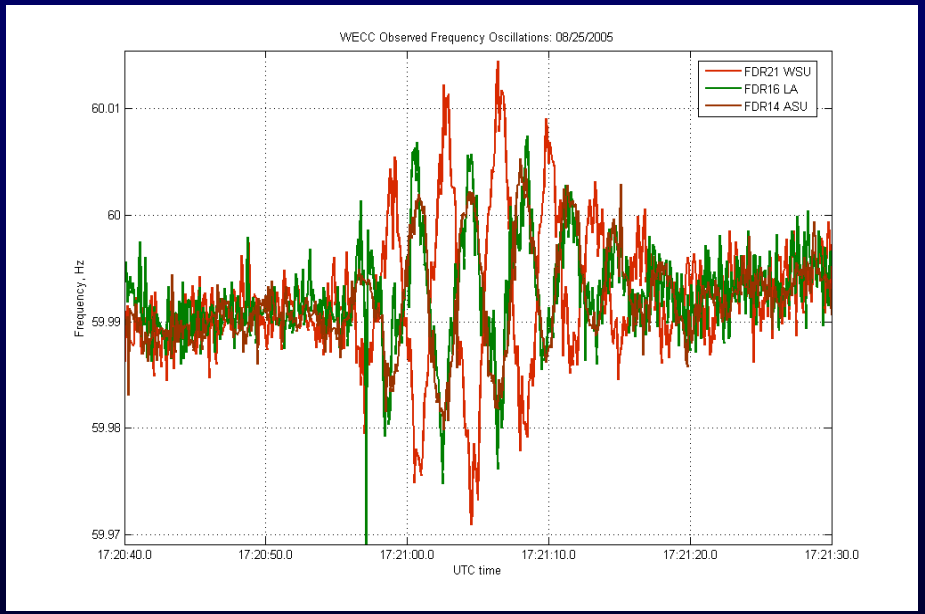
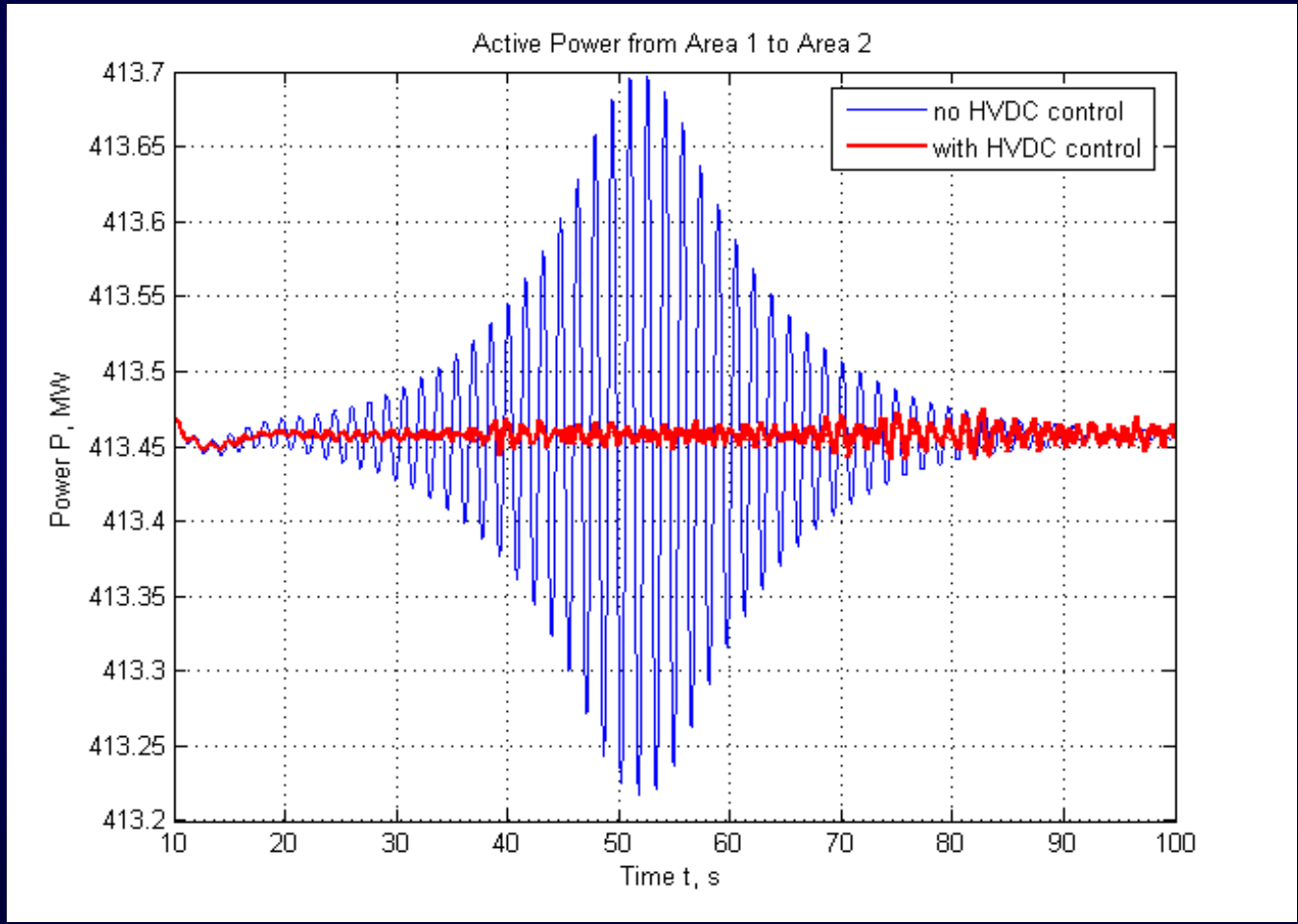




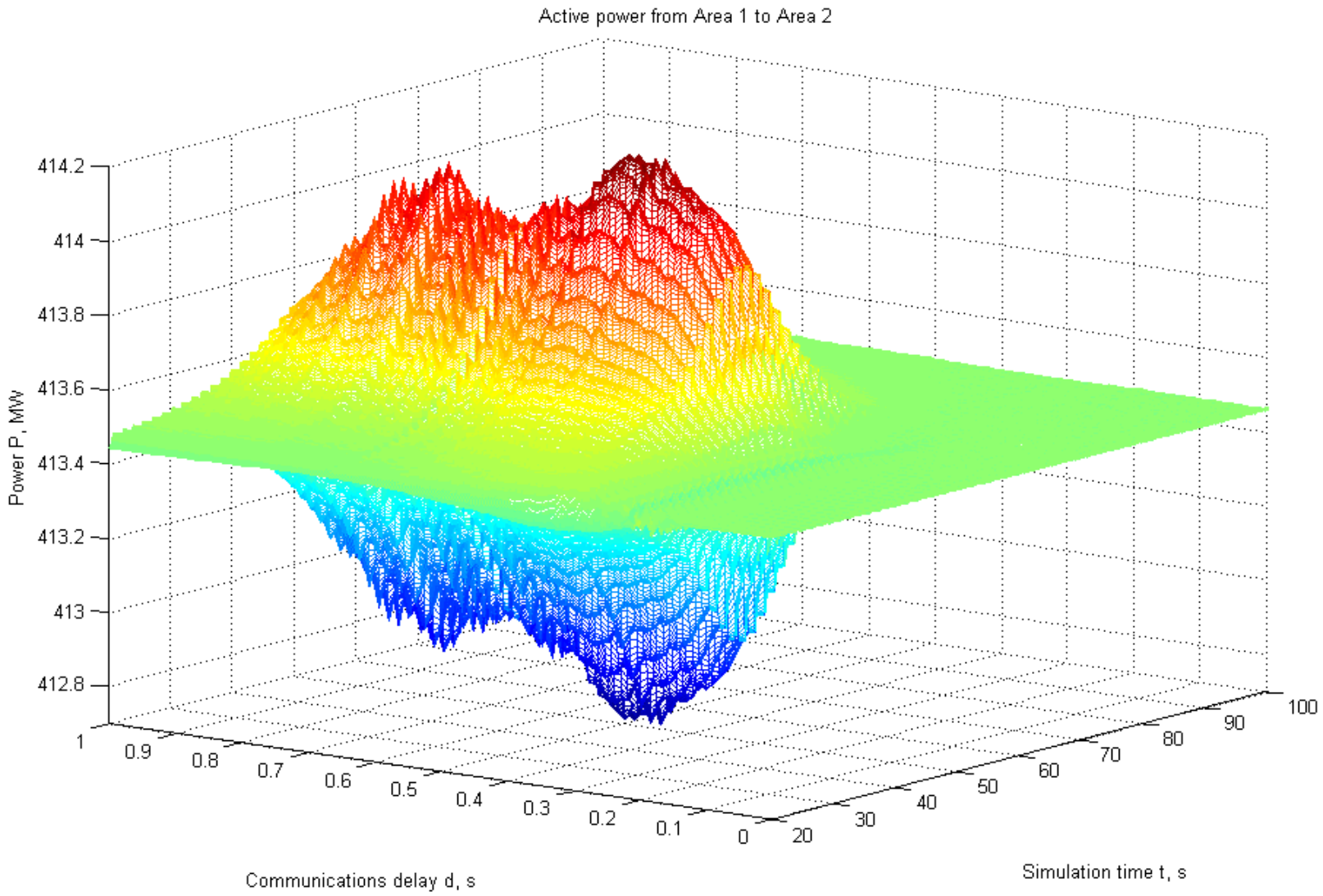


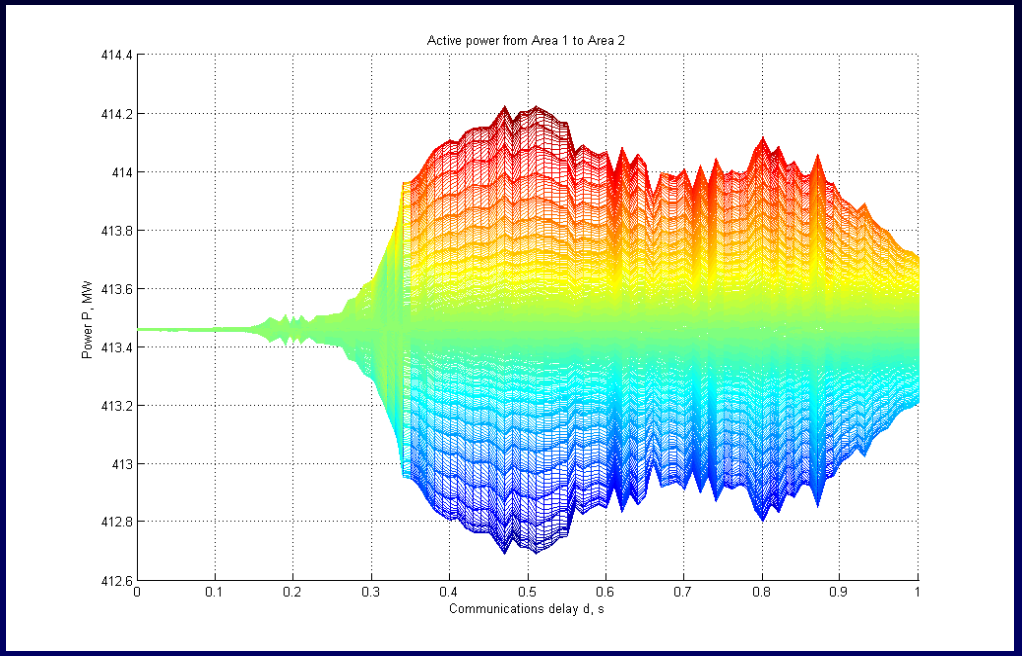
HVDC control to damp oscillations

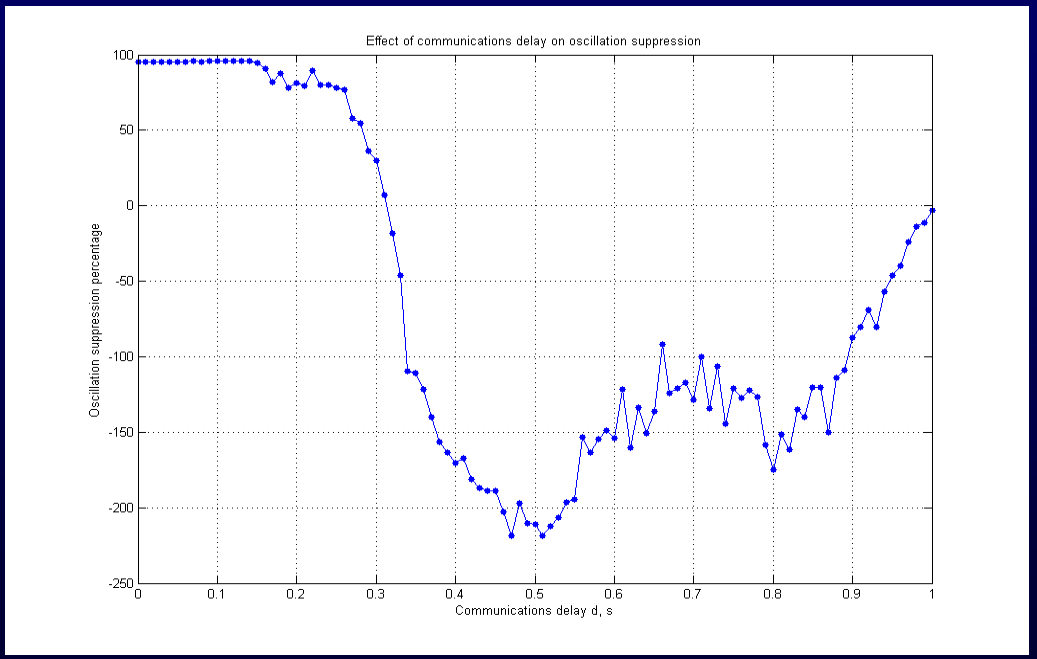
(Zero time delay in remote frequency signal)

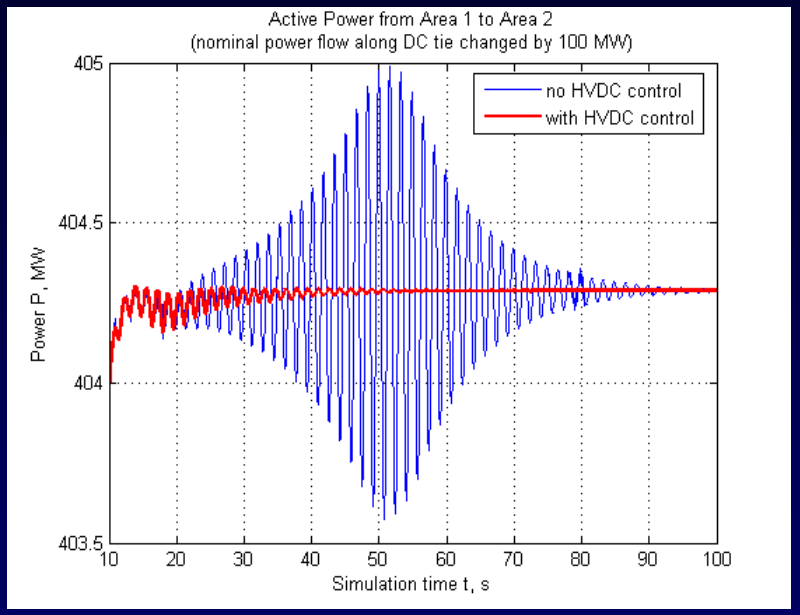


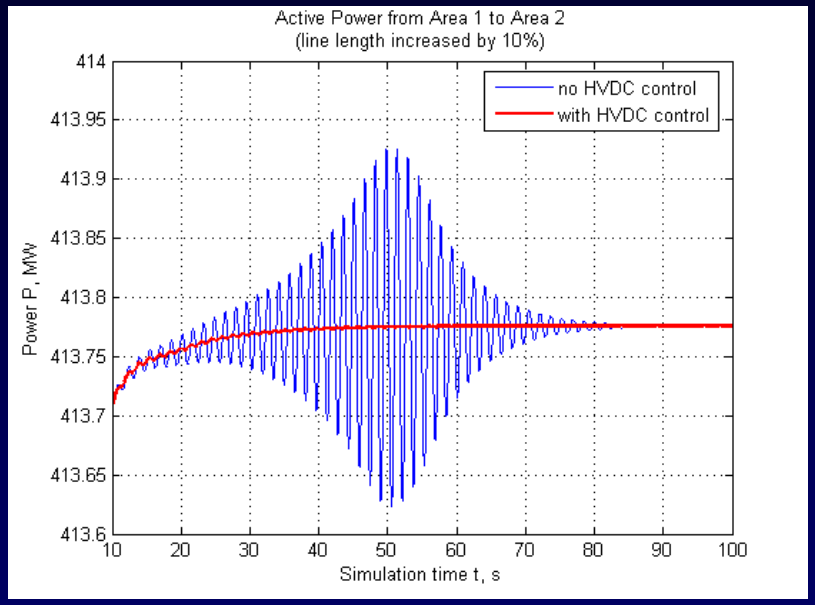
Effect of time delay in remote signal

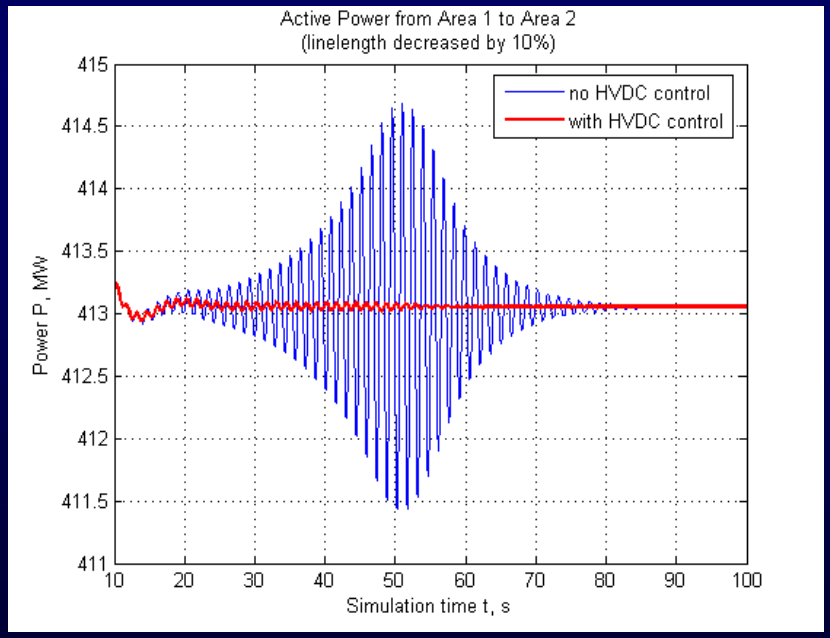


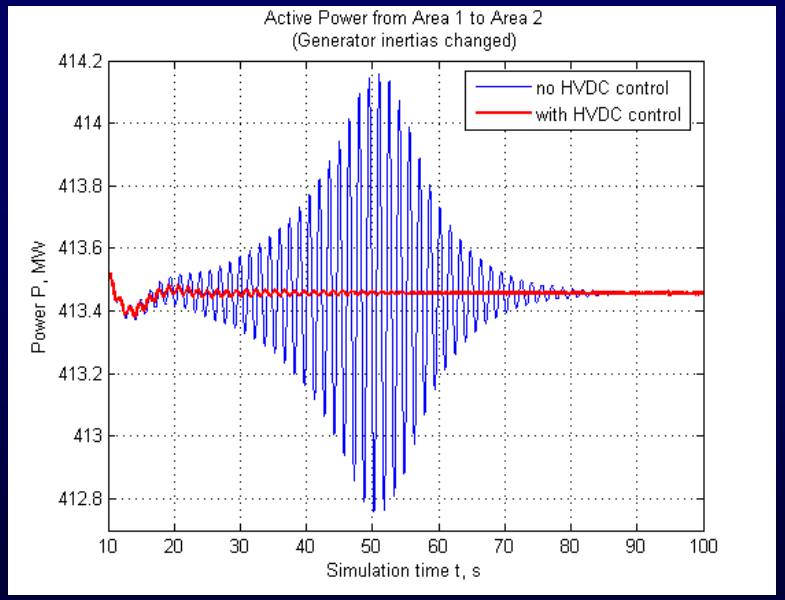












Application research at VT

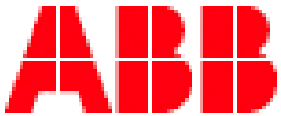
- Wide area frequency data visualization and graphic display
- Develop algorithms to triangulate generator tripping location and predict trip size.
- Study frequency disturbances travel pattern (propagate) as electromechanical waves in power systems. Analyze speed of travel from FNET data and PSS/E simulations.
- Dynamic clustering from FNET data (frequency and angle). Inter-area oscillation modes identification based FNET data.
- Post-disturbance scenario reconstruction and tracking sequence of events leading to an emergency.

Application Research at VT

- Use FNET data to verify system models used in simulations.
- Adaptive under-frequency load shedding algorithm development using wide-area frequency information as inputs.
- Wide area FACTS, PSS/HVDC control and coordination using FNET as inputs for damping inter-area oscillations.
- Monitoring DG impact on system operations, DG control
- Trending and system response speed analysis of static frequency for all interconnections. Monitoring tool for compliance of NERC frequency response requirements
- ACE accuracy improvement with FNET data (Our preliminary results show that ACE can be calculated with better precision from FNET data).

Acknowledgement

sponsors



The FNET
Team Students
Summer of 2006

FDR Host universities and companies

UMR, ASU, **Calvin College, ARI, EPRI, Seattle U, WSU, TVA, EPG, Miss State, Tulane, UFL, FSU, Huston, NCSU, RPI, EnerNex, UK, MW-ISO, NYC, RCM, Ameritech, ISU, Metatech, Wayne State,**

Ohio-Tiffin, WVU, Tulane, *Midwest-ISO, ISO-NE, Manitoba,* *MDU_Bismarck*

Future sites: *Pan State, NERC, OSU, UIUC, GATech,*