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Worldwide Power System Oscillations Observed by Distribution Level Phasor Measurements

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SUMMARY

Oscillations in power systems could be a serious concern if not well damped. With the development of synchrophasor technology, oscillations can be easily detected at transmission level by Phasor Measurement Units (PMUs). The distribution level phasor monitoring system operated by University of Tennessee and Oak Ridge National Lab (FNET/GridEye) provides a low cost system to collect data from customer level voltages, usually an outlet at 220V or 115V. FNET/Grideye covers all of the major North American grids, and several other parts of the world. The system has provided continuous monitoring and event alerts for about 10 years. In 2009, an angle-based oscillation detection module was developed and implemented and has captured a large number of oscillations in North American and around the world. This information provides valuable insight into power system phenomenon that is used to help tune transmission level PMU systems. In this paper, sample oscillation cases in different grids are presented. With sufficient experience collecting these types of events we hope to identify trends and develop statistics related to this information.

KEYWORDS

Phasor measurement - Oscillations - Oscillation frequency - Distribution phasor unit.

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INTRODUCTION

In large interconnected power systems, changes in load, generation, topology, and control may initiate oscillations that could jeopardize reliability if not well damped [1]. This paper provides information on the oscillations detected in different grids based on distribution level measurements. The matrix pencil method is utilized for oscillation modal analysis because of its robustness in the presence of noise [2][3]. The information collected by this system can provide a benchmark for grid performance that will be useful as many interconnections are undergoing major changes with the introduction of renewable generation.

OVERVIEW OF FNET/GRIDEYE

FNET/Grideye is capable of monitoring grid dynamics at low cost and is quickly deployable with high dynamic accuracy and minimal installation expense. A single-phase Phasor Measurement Unit (PMU) known as a Frequency Disturbance Recorder (FDR) is used in FNET to collect synchronized voltage, angle, and frequency measurements at distribution level. These values are output at 100ms intervals, and transmitted via the Internet to a central location, where they are analyzed and archived [4]-[7]. A simplified outline of the system architecture is shown in Figure 1. Since 2004, the FDRs are deployed in North America, along with several units in China, Europe, Japan, South Korea, Grand Bahama, Hawaii, Egypt, Chile, Australia, Brazil, etc. Figure 2 shows the world wide deployment locations.

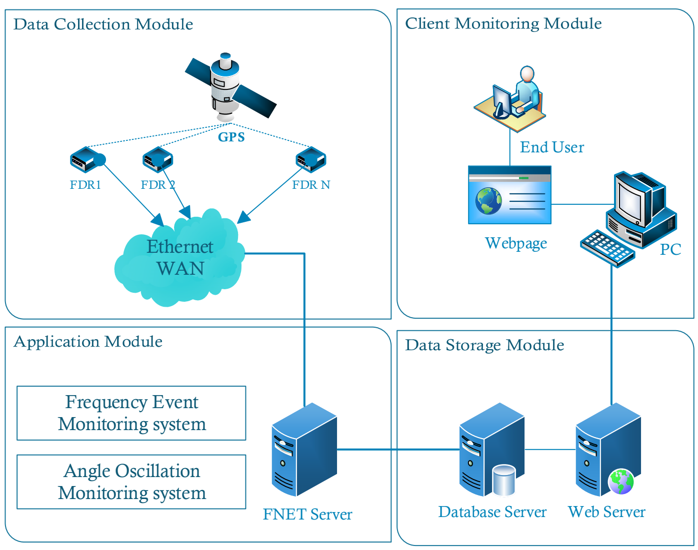

Figure 1. Frequency monitoring network system architecture.

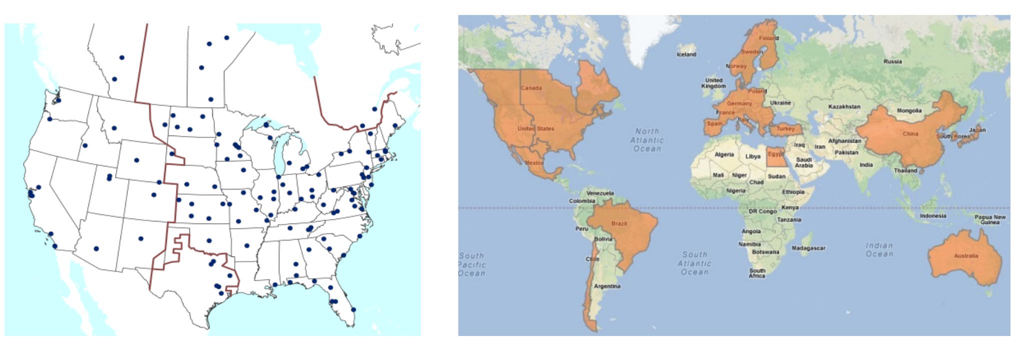

Figure 2. FDR Deployment map in North America and world wide

OSCILLATION CASES AROUND THE WORLD

Case 1: Oscillation caused by an incident in EI on the 500kV network (03/14/2013 11:15:33 UTC)

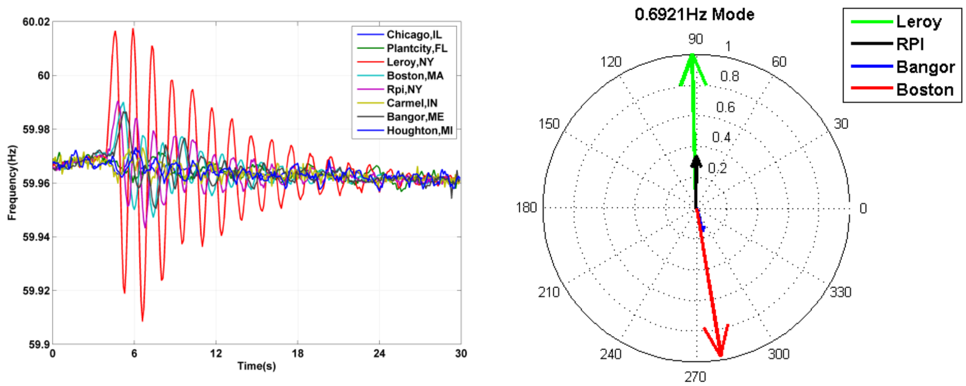

Figure 3. Frequency plots of oscillation and 0.69Hz mode shape in EI

Table 1. Modal analysis result of oscillation case in EI.

Modes(Hz)		Leroy	Boston	RPI	Bangor
Dominate	Frequency(Hz)	0.6880	0.6983	0.6910	0.6911
	Damping Ratio(%)	3.2711	6.2937	3.9281	3.5285

Case 2: Oscillation caused by Phase II HVDC trip in EI (06/05/2013 10:54:13 UTC)

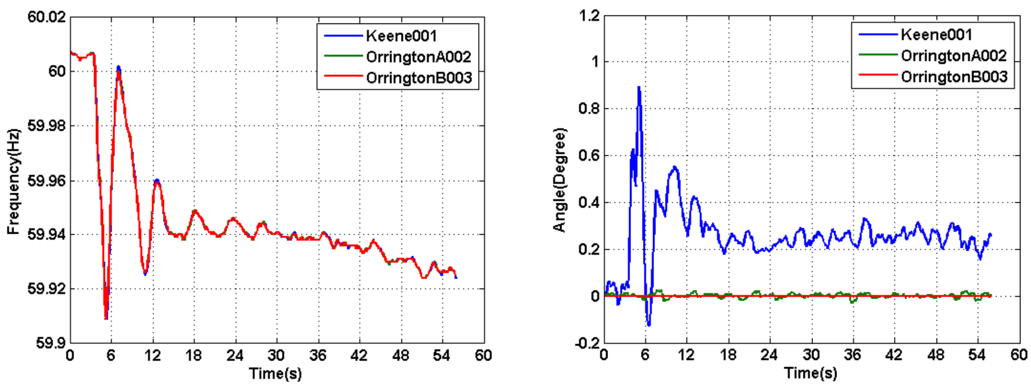

Figure 4. Frequency and angle plots of oscillation caused by Phase II HVDC trip in EI

Case 3: Oscillation case in EI (04/05/2013 23:31:01 UTC

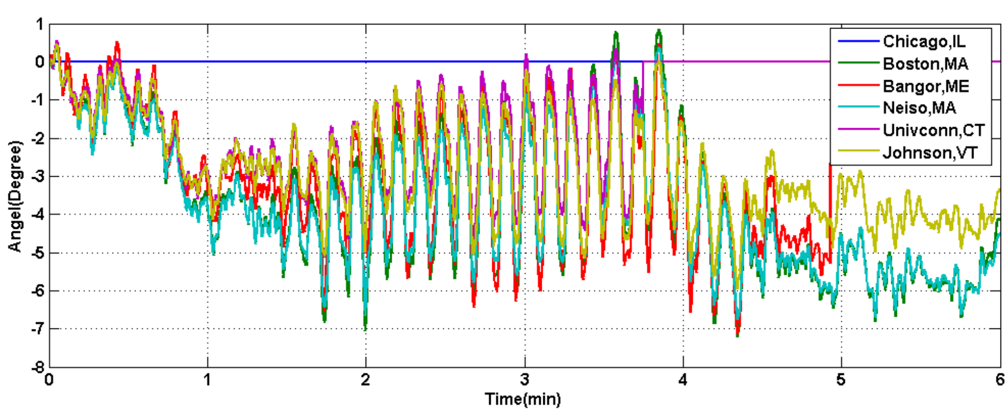

Figure 5. Angle plot of oscillation in EI

Case 4: Oscillation case in WECC (06/30/2013 07:35:47 UTC)

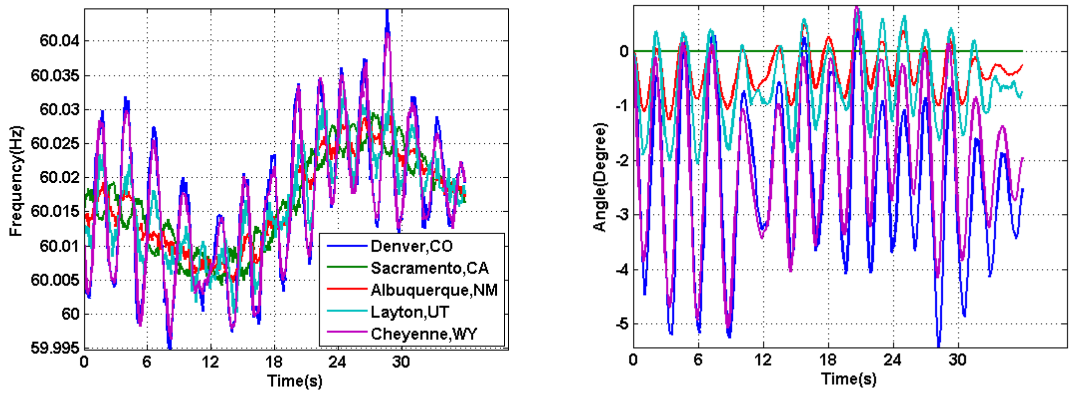

Figure 6. Frequency and angle plots of oscillation in WECC

Table 2. Modal analysis result of oscillation case in WECC.

Modes(Hz)		Denver	Layton	Cheyenne	Albuquerque
Dominate	Frequency(Hz)	0.3171	0.2965	0.3245	0.3571
	Damping Ratio(%)	12.0313	26.9299	14.1140	1.0915

Case 5: Oscillation case in WECC (06/29/2013 17:28:06 UTC)

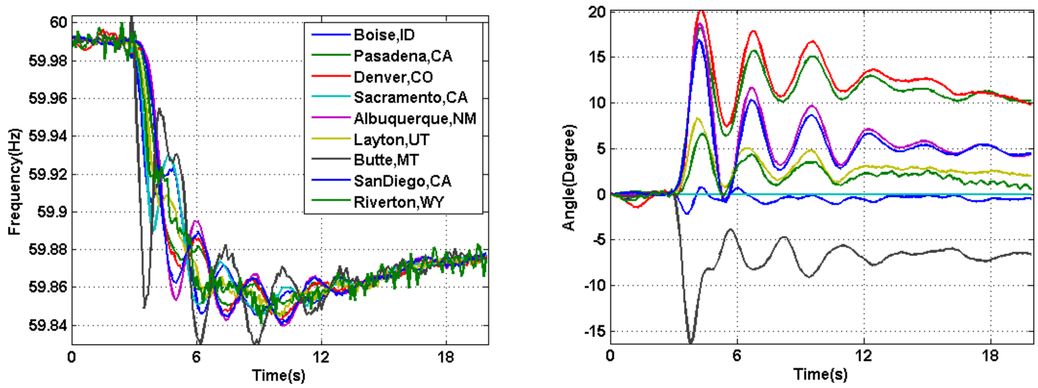

Figure 7. Frequency and angle plots of oscillation in WECC

Case 6: Oscillation in ambient situation in Continental European (03/14/2013 09:03:30 - 09:04:00)

Continental European power grid reached to Turkey in the east, Spain in the west, Italy in the south and Denmark in the north. Spain and Turkey oscillate against each other in the east-west direction due to weak connection.

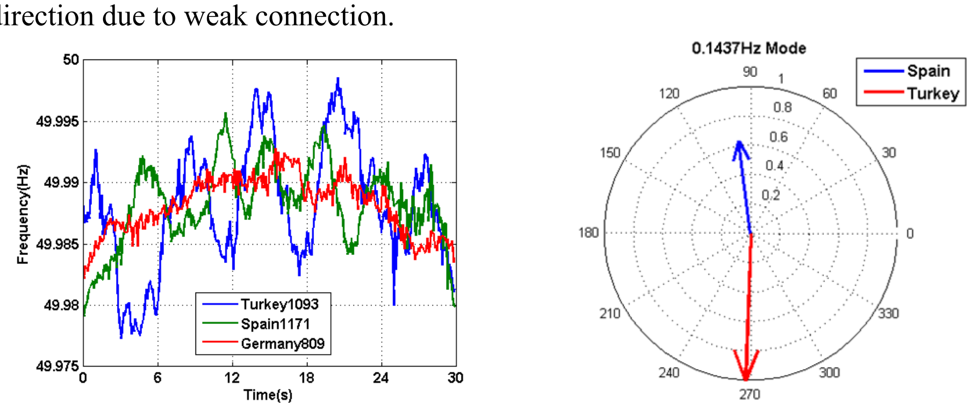

Figure 8. Frequency plot (left) and 0.14Hz mode shape (right) of oscillation in Continental European

Case 7: Oscillation caused by earthquake in Sichuan, China (Central China Grid) (05/12/2008 06:28:01UTC)

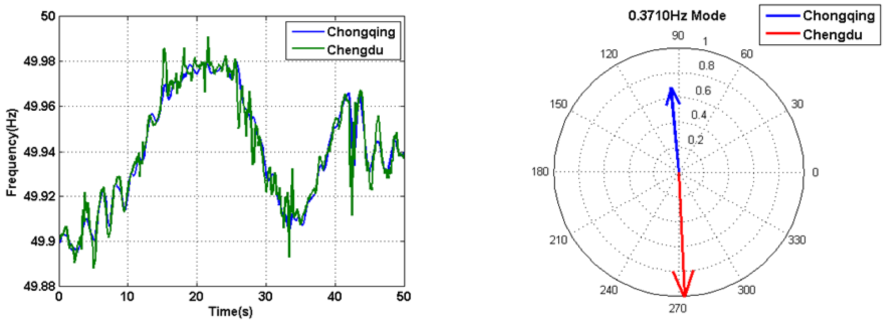

Figure 9. Frequency plot (left) and 0.37Hz mode shape (right) of oscillation in Sichuan, China

Case 8: Oscillation in ambient situation in Hawaii.

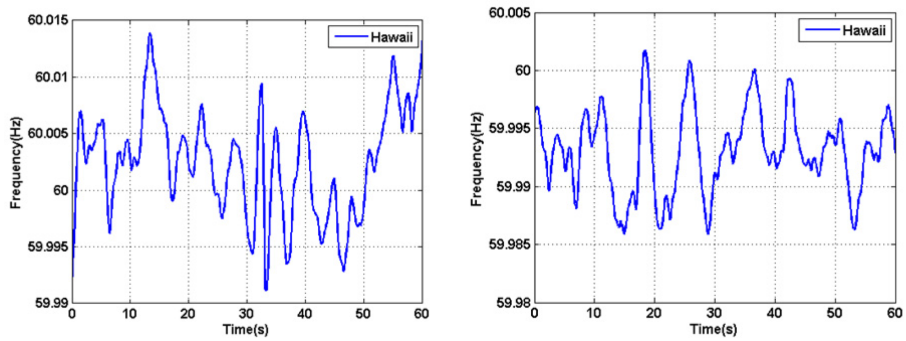

Figure 10. Frequency plots of oscillation in Hawaii

Case 9: Oscillation in ambient situation in Quebec.

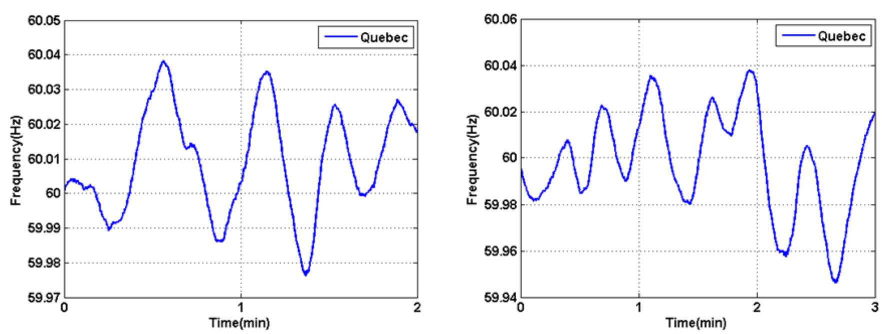

Figure 11. Frequency plots of oscillation in Quebec

Case 10: Oscillation in ambient situation in ERCOT.

Case 11: Oscillation in ambient situation in Brazil.

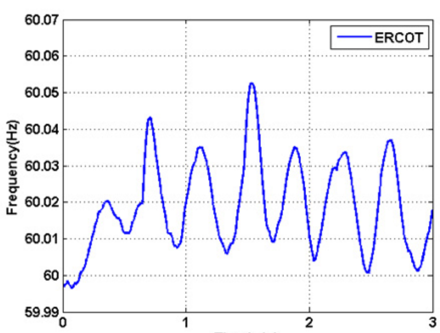

Figure 12. Frequency plot of oscillation in ERCOT

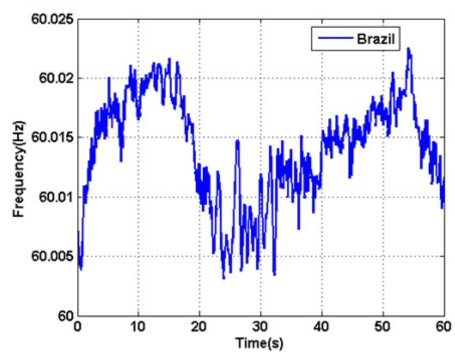

Figure 13. Frequency plot of oscillation in Brazil

Case 12: Oscillation in ambient situation in Grand Bahama.

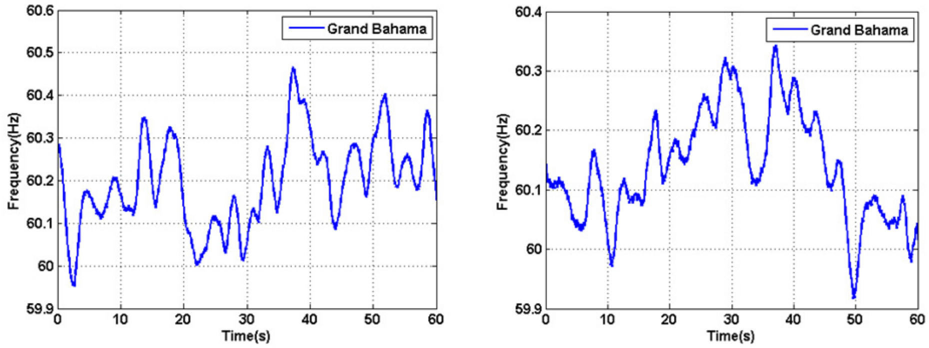

Figure 14. Frequency plots of oscillation in Grand Bahama

CONCLUSION

With FNET/GridEye, dynamic behavior of the system can be easily observed at the distribution level. Figure 15 illustrates that the oscillation frequency decreases as the size of grid increases. With more FDRs deployed, it will be possible to identify the source of an oscillation in real time and devise damping control strategies.

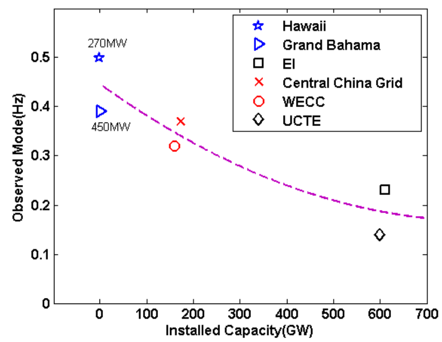

Figure 15. Observed mode vs installed grid capacity

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