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BRADLEY DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

WAMs Based Control ?

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The issue: Slow Development of WAMS based control

- In every survey paper or encyclopedia chapter we have to observe that there has been less progress in WAMS based control than we expected. The expectation was that some control would be possible with a modest number of PMUs and that by now there would be a number of successes. There are >200 papers in IEEE Xplore under Control and WAMs but

  A 2005 survey paper concluded that “WAMS based control was not fully developed”[1]

  A 2008 survey paper concluded that “although great progress has been made … there is still plenty to do”[2]

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Findings from “The Future of the Electrical Grid” MIT 2011 Study [3]

- “The control systems of the future are less understood than many individual technologies” (in power systems ?)

- “PMUs could improve the performance of energy management systems by providing real-time data to determine system state faster and more accurately than current estimation tools. A more extensive deployment of PMUs is required to make this possible”.

- “Automatic control action based on real-time data from a wide-area network of PMUs represents a major change in system operations. Today such system are limited in number and capability. Significant research in control algorithms and improved confidence in the reliability and accuracy of PMU data is needed to make such control more prevalent.”

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Issues

- Natural conservatism – responsible for keeping the lights on
  – Reluctance to close the loop or use feedback. A history of discrete controls, Dynamic brake, Line Switching, specific changes in DC line flow. Mistrust of communications

- Too few PMUs. “Transmission 101” [4] estimates there are 15,700 transmission substations in the US. A PNNL study [5] has 48,000 nodes. That’s Transmission not EHV but even 1,000 is probably below the threshold

- Lack of confidence in the reliability and accuracy of PMU by some (reason for standards)

- Persistent concerns about PMU locations and latency.

PROs and Cons

- 1) The control has to work

  Aerospace applications use triple redundant signal paths and controllers. They also must deal with different operating conditions
- 2) Model: The challenge of structures in zero gravity. Identonauts ~ John Hauer in orbit
- 3) A wide variety of robust control techniques applied in other areas. Sophisticated equivalents

- Airplanes are smaller and cheaper than power systems
- Still lack appropriate system models for many important control problems
- The number of states that can be measured will be a **very** small fraction of total states for a long time.

Progress on MIT Finding 2

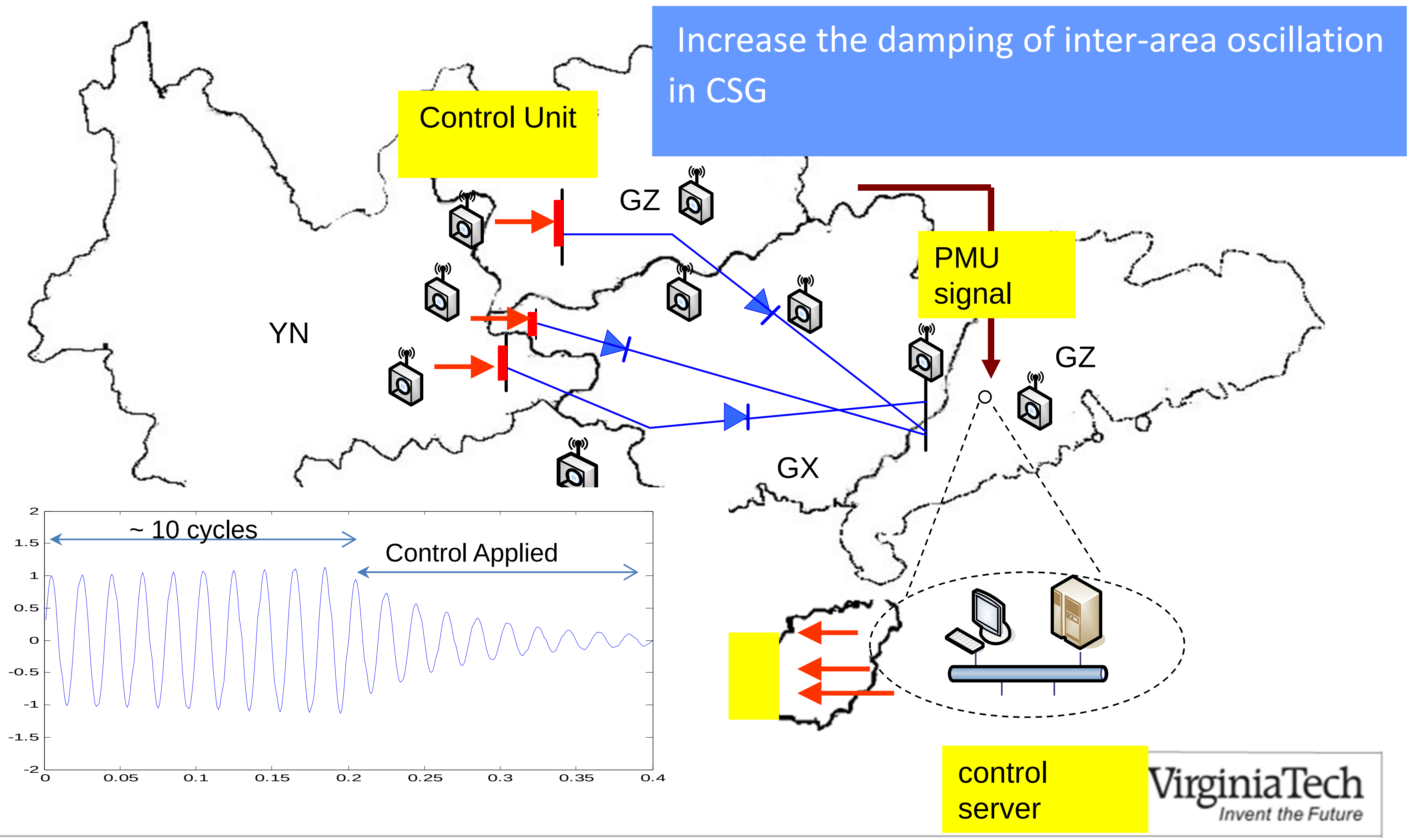
- DOE Demonstration Project:
  - Dynamic State estimation of Dominion Virginia Power 500 kV network at 1/30 sec interval
  - Provide measurements for control applications with latency of < 40ms, i.e. appropriate for bandwidths of 5 or 6 Hz. (40ms from Ken Martin –some papers now using larger numbers)

- Emphasis on renewable energy implies more energy storage.
  - Energy storage is a new potential control means added to the power electronic arsenal

A positive example: Control of Inter-area Oscillations in China

- China's growth rate is such that fixed frequency PSSs are unworkable
- The demand has a doubling time of ~ 7.5 years, they are commissioning a 1000MW plant a week.
- Frequency of modes change rapidly.
- They designed a WAMS Based Wide-area Coordinated Modulation Control of Multi-infeed HVDC assuming they knew the system. When a mode is observed the operator inserts the system which does a real-time Prony to determine the frequency of the wave. Then the system adjusts parameters in the controller to match the frequency and the loop is closed. The operator removes the controller after the mode is successfully damped

WAMS Based Wide-area Coordinated Modulation Control of Multi-infeed HVDC



Generalizations of the previous

- Not continuously adaptive control but a control that is engaged by an operator like a SIPs system and observes and adjusts before acting. SIPs as we know them do not change parameters before engaging. Adaptive SIPs? (SIPS system integrity protection system)
- From observations of the actual event the system selects parameters of the control or even the controller structure from a large predetermined list and then engages. At least one author has labeled things like this as "enumeration based robust control"
- Perhaps "Synchrophasor Aided Gain Scheduling"?

  900 papers in gain scheduling in power systems [6] but many are for a power plant and none mentions WAMs

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Gain Scheduling (from Wikipedia)

- "In control theory, **gain scheduling** is an approach to control of non-linear systems that uses a family of linear controllers, each of which provides satisfactory control for a different operating point of the system.

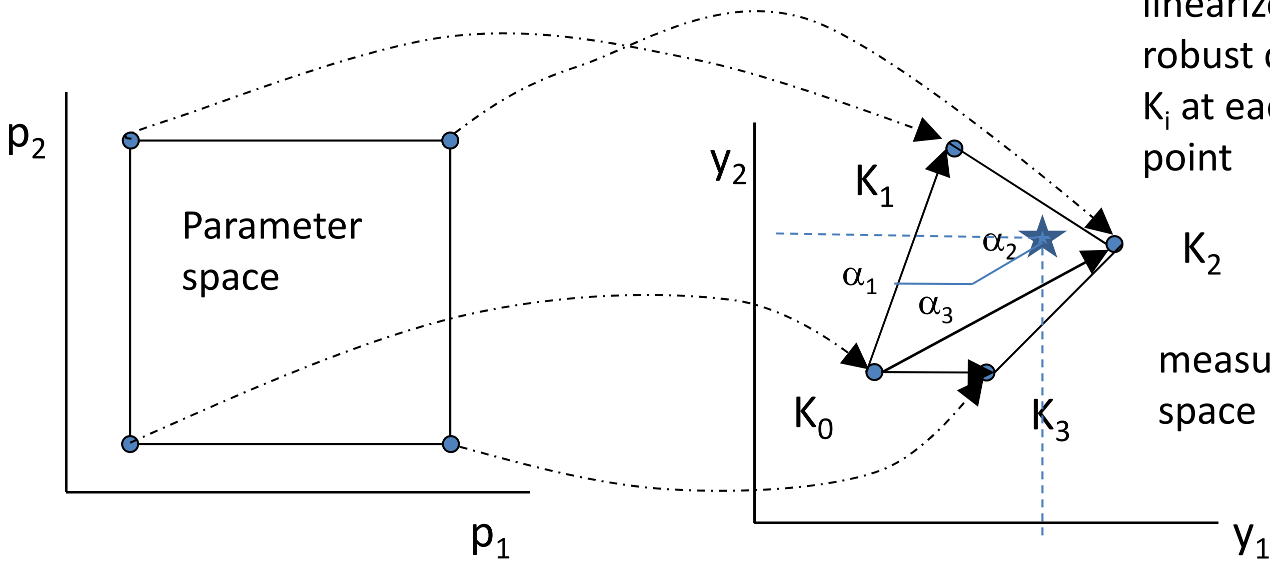
- One or more observable variables, called the *scheduling variables*, are used to determine what operating region the system is currently in and to enable the appropriate linear controller. For example in an aircraft flight control system, the altitude and Mach number might be the scheduling variables, with different linear controller parameters available (and automatically plugged into the controller) for various combinations of these two variables"

Gain scheduling applied to Power System Control.

- Will have to estimate the *scheduling* variables from PMU measurements. We don't have an equivalent of altitude and Mach number.
- There is a way to not only estimate the *scheduling* variables but to establish the quality of the estimate [7]. Based on :
  - a parameterization of all feedback controls that stabilize a given system,
  - a parameterization of all systems stabilized by a given feedback gain using
  - Use of Linear Fractional Transformation (LFT) which has also been proposed as a method to model delay uncertainty in WAMS [8]
- Observer variables (PMU measurements) determine the operating region of the system and hence the *scheduling* variables.
- There do not seem to be applications of this to systems as large as the power system, MIT finding 3. But there are flight controllers with several thousand design points.

Gain Scheduling

Operating points: linearized system and robust control with gain K_i at each operating point

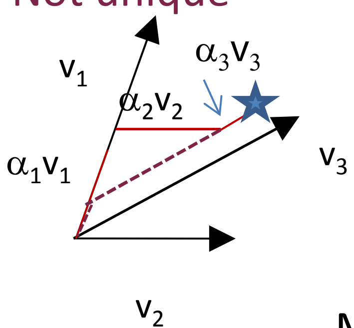


measurement space

★ measurement

$K(\alpha_1,\alpha_2,\alpha_3)$

Not unique



$$y = \alpha_1 v_1 + \alpha_2 v_2 + \alpha_3 v_3 = [v_1 v_2]\begin{bmatrix}\alpha_1\\ \alpha_2\end{bmatrix} + v_3\alpha_3 = \Lambda a + Vb$$

$$a = \Lambda^{-1}(y - Vb)$$

Minimize the distance $\sum_{i=1}^{i=n+k} \alpha_i^2 \|y - v_i\|^2$ such that $a = \Lambda^{-1}(y - Vb)$

Get a*, b*, α* K(α*)

Favors v's close to y

Have 3 vectors in 2 dimensions in the example. In general k+n vectors in n dimensions

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To create such a control system

- Create a large data base of situations (~contingencies).
- (It’s also time to consider data mining actual PMU archives – different topic)
- Bank on Moore’s law- this is not in real time- many load flows on large systems are imaginable.
- Use Data Mining with lots of options to find out what works, Again done off-line (cancer researchers are succeeding in finding DNA markers for various cancers with data bases of millions of cases)
- We have used simulation to create a data base with more than 10,000 cases for a 4000+bus model.[9]
- Use data mining to select the *scheduling* variables. Give CART*the option of using many possible *scheduling* variables. CART will select the best. There are solvable technical issues with complex measurements in CART [10]

*CART Classification And Regression Trees

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Thank You