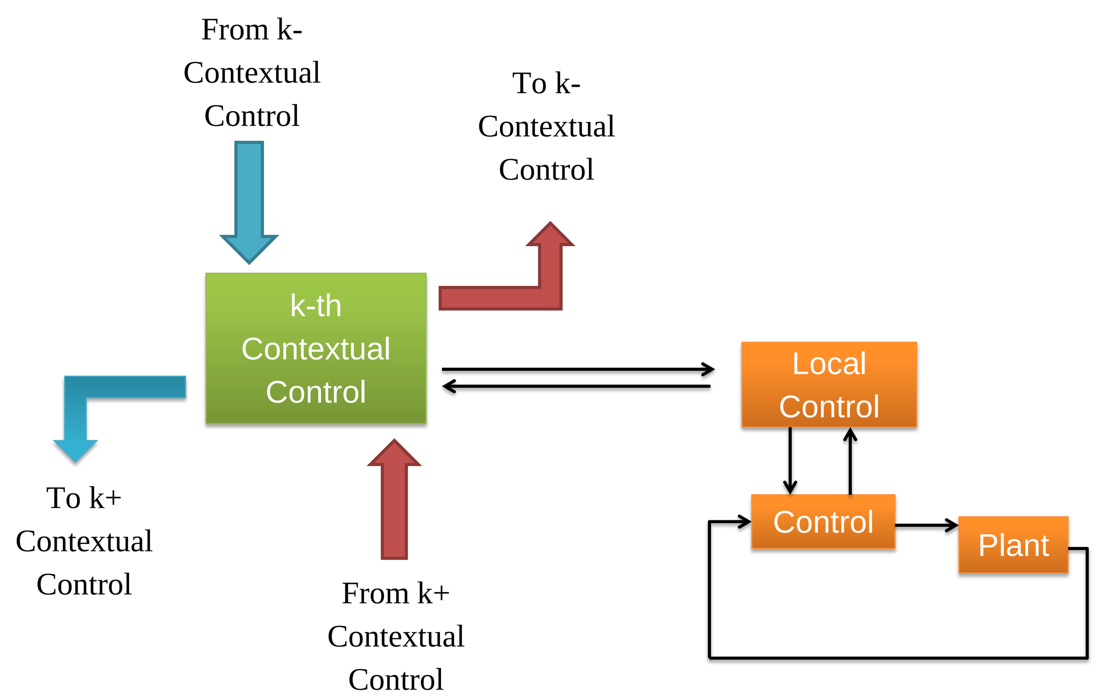
Flatness-Based Automatic Generation Control with High Penetration of Wind Energy

Maryam H Variani, Kevin Tomsovic
University of Tennessee, Knoxville

1. Introduction

- Existing energy systems are characterized by multiple, largely hierarchical systems for transient stability control, load frequency control,…
- To allow for distributed generation and alternative energy units, these controls need to be replaced by a simpler structure with a local control operating within a global context of situational awareness
- Two-tier structure of local and contextual control is proposed:
  - Local control: individual components and individual loads operate in a manner to follow some desired trajectory based on local observations
  - Contextual control: selects one of a finite number of system-level control goals that best reflects needs based on overall system status at a given moment



- Flatness as an extension of controllability is a key to enabling planning and optimization at various levels of the grid in this structure
- Frequency and inter area power control is one of the large number of engineering issues that are affected by the introduction of wind units
- In this study:
  - Flatness-based approach is applied to automatic generation control(AGC) of multi-area systems with wind generation units

2. Flat Systems

- When a system is flat it is an indication that the nonlinear structure of the system is well characterized
- The nonlinear system

$$\dot{x} = f(x,u)$$

is said (differentially) flat if and only if there exists $y = (y_1, \dots, y_n)$ such that:

  - y and successive derivatives $\dot{y}, \ddot{y}, \dots$,are independent
  - $y = h(x, u, \dot{u}, \dots, u^{(\gamma)})$
  - Conversely, x and u are given by:

$$x = \varphi(y, \dot{y}, \dots, y^{(\alpha-1)})$$
$$u = \psi(y, \dot{y}, \dots, y^{(\alpha)})$$

- Flat systems structure can be exploited in designing control algorithms for trajectory generation and tracking
  - Trajectory generation: Build a smooth curve $t \rightarrow y(t)$ for $t \in [t_i, t_f]$ by interpolation, possibly satisfying further constraints
  - Trajectory Tracking: Find a feedback law such that the system tracks the reference trajectory following a perturbation

3. Flatness-Based AGC

- Flatness-based AGC: deriving equation in flat space
  - AGC equations in original space

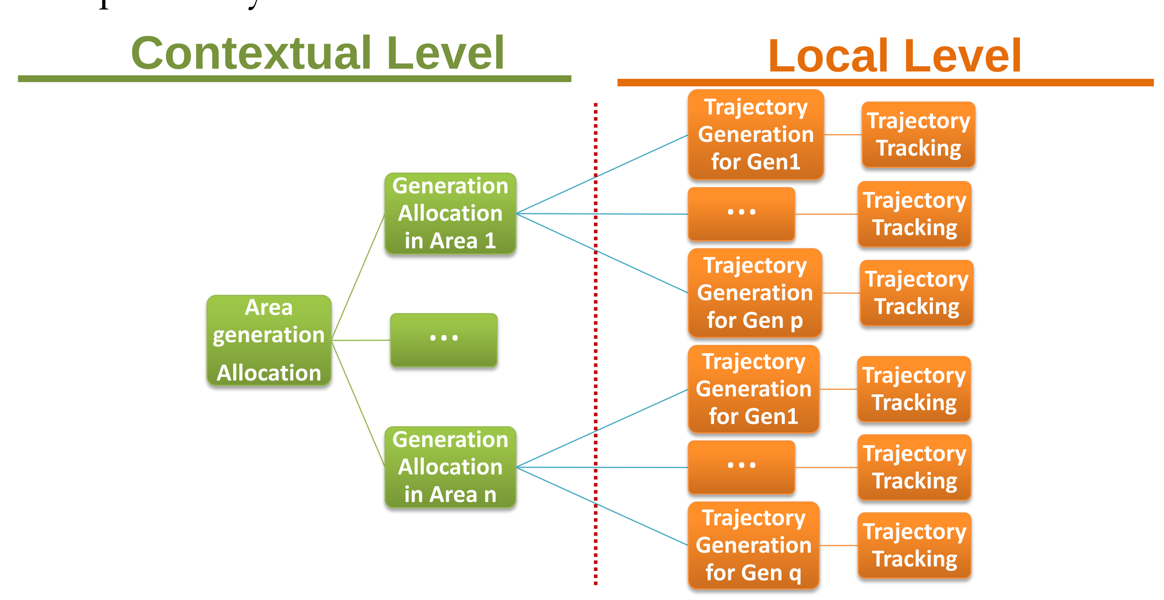
$$\dot{\delta}_i = \omega_i - \omega_s$$
$$\dot{\omega}_i = \frac{1}{2H}\left[P_{mi} - D(\omega_i - \omega_s) - \frac{E_i V_i}{x'_{di}} sin(\delta_i - \theta_i)\right]$$
$$\dot{P}_{gvi} = \frac{1}{\tau_{gi}}\left(P_i^{ref} - \frac{\omega_i - \omega_s}{R\omega_s} - P_{gvi}\right)$$
$$\dot{P}_{mi} = \frac{1}{\tau_{Ti}}(P_{gvi} - P_{mi})$$
$$\dot{P}_{wi} = \beta_1 P_{wi} + \beta_2 v_{wind} + \beta_3 \qquad \text{for } i=1, \dots, n$$

  - AGC equation in flat space

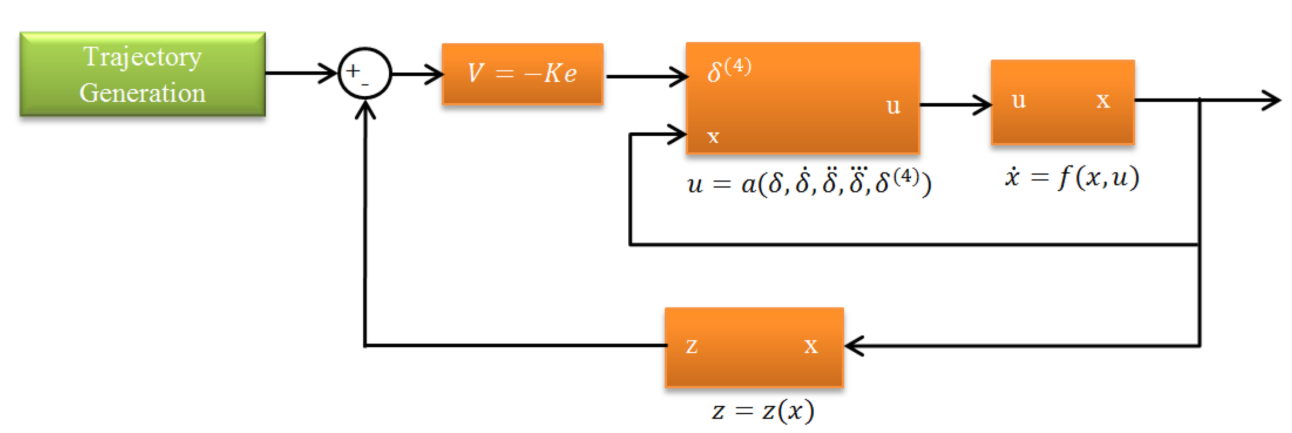
$$\delta_i^{(4)} = v_i \qquad \text{for } i=1, \dots, n$$

AGC in a n-machine power system is decoupled into n subsystems in canonical form

- Two level control structure
  - Contextual control
    - Economic dispatch is performed to find the desired operating points
    - To follow load changes and wind variations the operating point is updated every 5 minutes
  - Local Control
    - Trajectory generation: The trajectory is calculated for each generator independently through solving equations. The operating points are received from contextual level
    - Trajectory tracking: Appropriate input $v(t)$ is found using linear or any desired control method such that tracking the generated trajectory is guarantied. The controller design is also operated at each generator independently

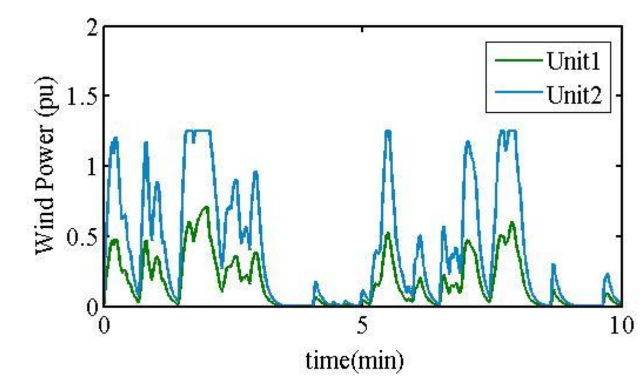


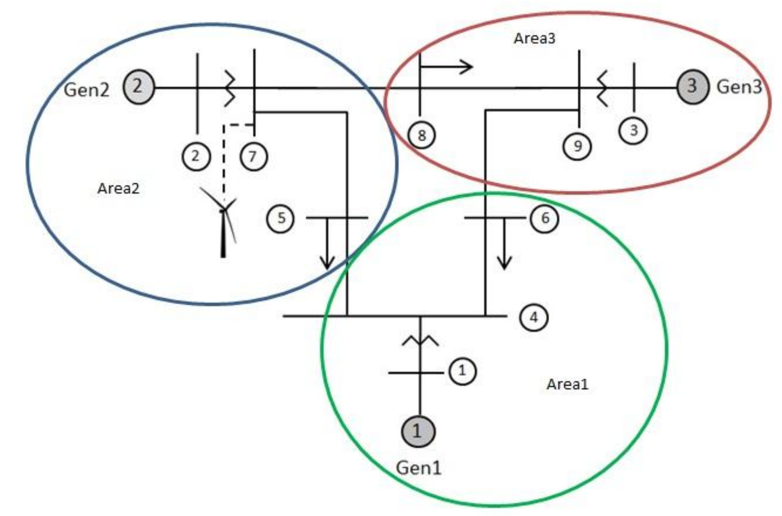
- Flatness-based AGC block diagram for each generator



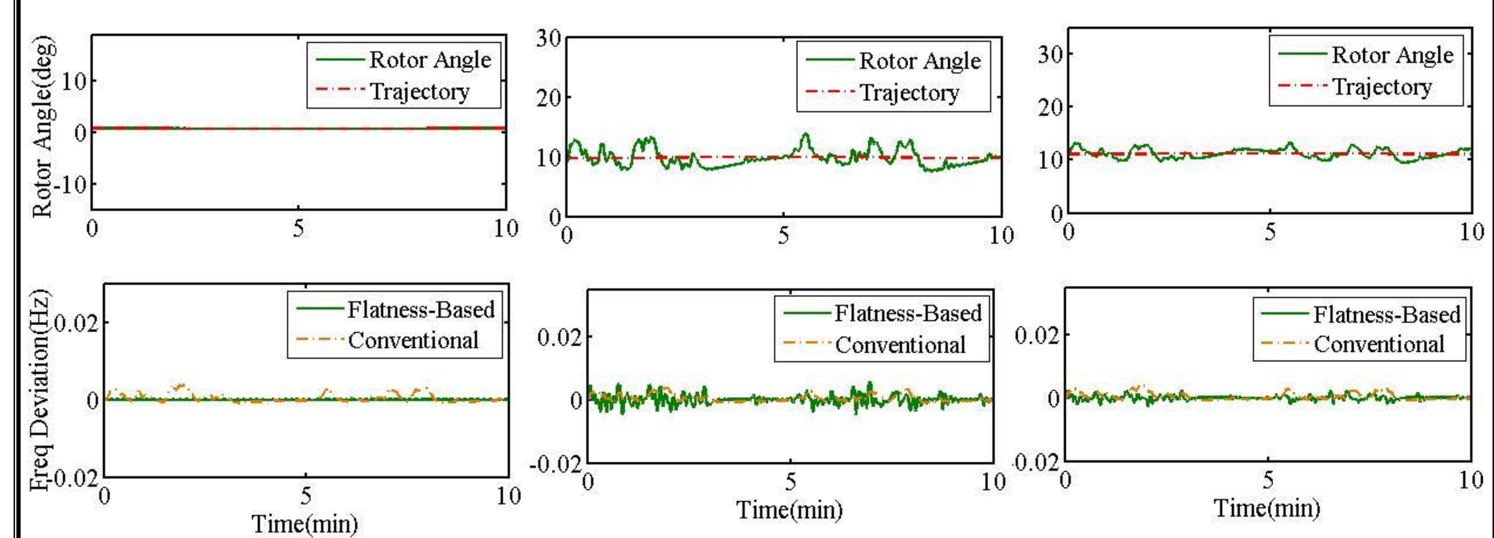
4. Simulation & Results

- The approach is implemented on WSCC 3-machine, 9-bus system (Ref: P. Sauer and A. Pai, Power System Dynamics and Stability)
- The system is split into 3 areas and wind units are applied to areas 2
- Two wind power profiles applied to system :

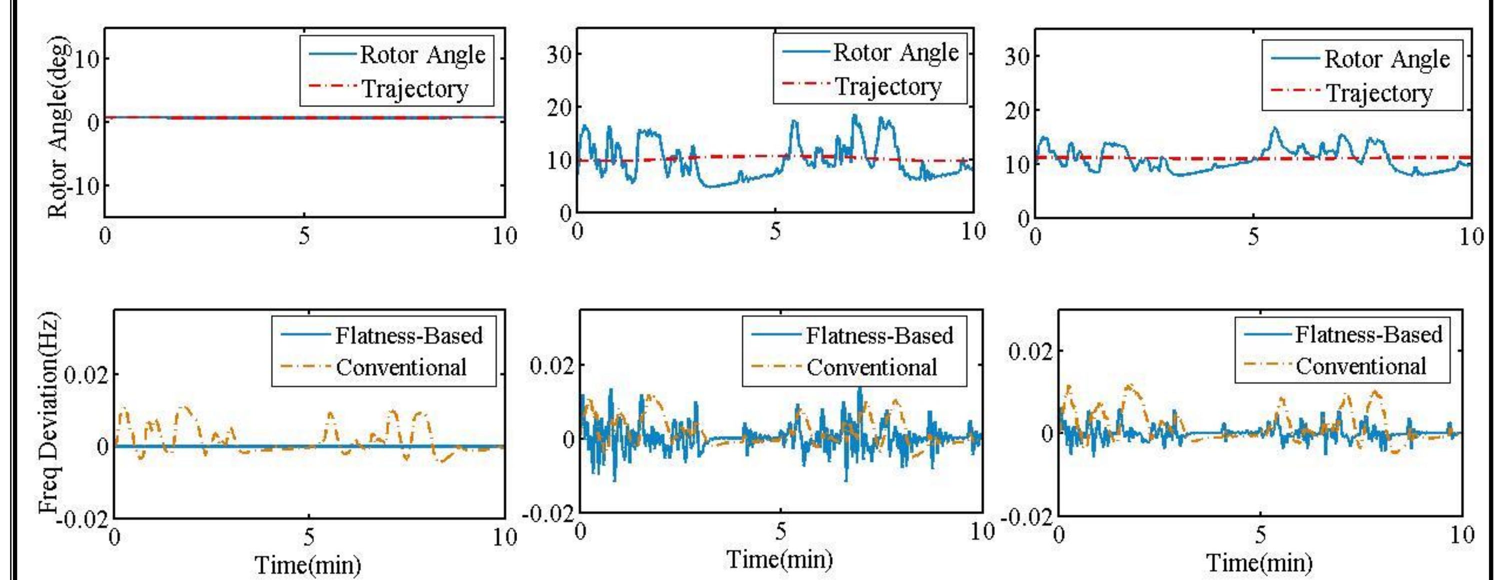




- Scenario1: wind power generation unit 1 is connected to bus 7
  (The wind generation in peak period is about 20% of the total load)



- Scenario2: wind power generation unit 2 is connected to bus 7
- (The wind generation in peak period is about 40% of the total load)



5. CONCLUSIONS

- The two level control consisting of trajectory generation and trajectory tracking replaces the conventional AGC
- The set of nonlinear equations corresponding to an n-area system is decoupled into n linear controllable sub-systems in canonical form and local linear controllers are designed for each subsystem
- The flatness-based control method demonstrates promising performance in mitigating frequency and tie-line flow deviation
- This approach could also replace the conventional area based frequency control and can be applied to other control systems in power system