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Multi-Loop Transient Stability Control via Power Modulation From Energy Storage Devices

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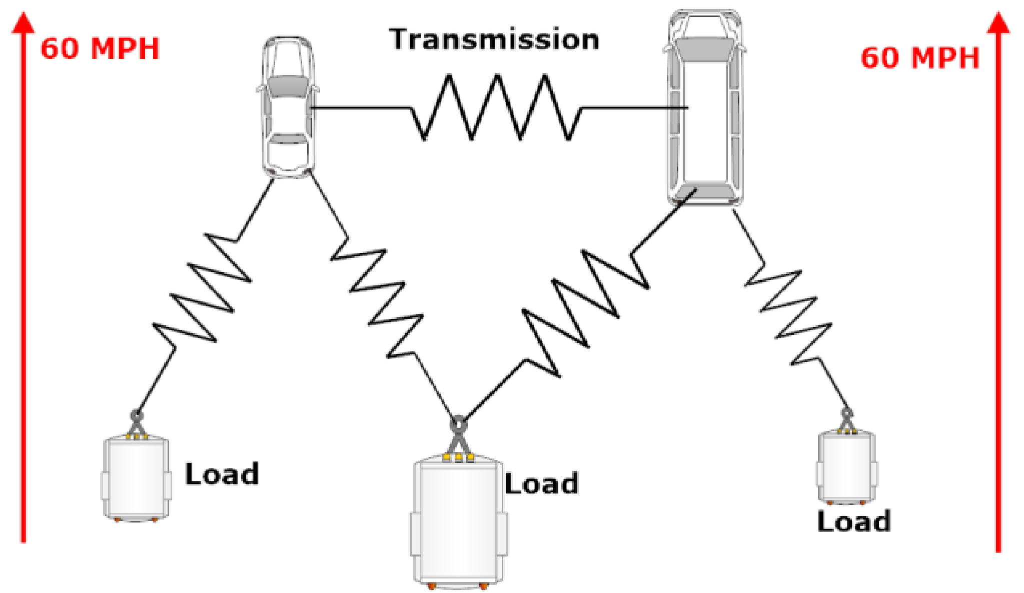
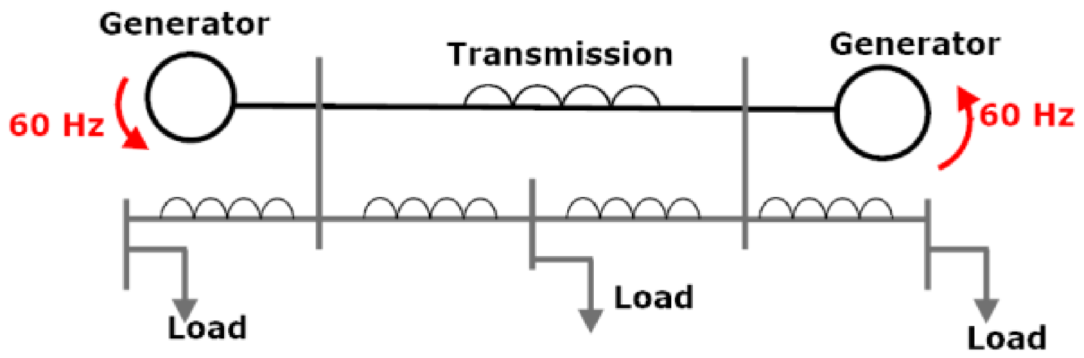
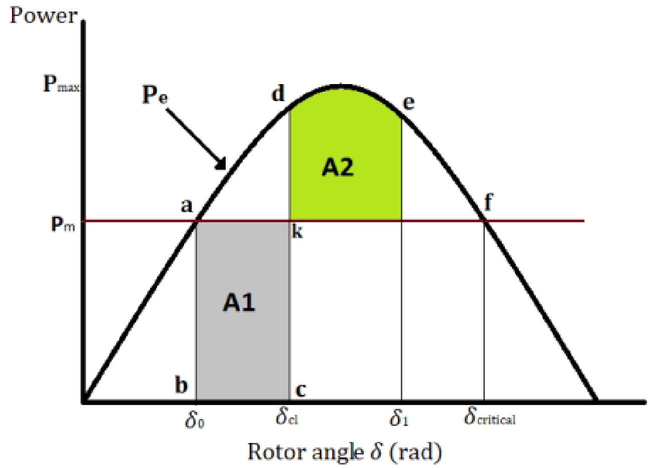
Transient Stability & Synchronism

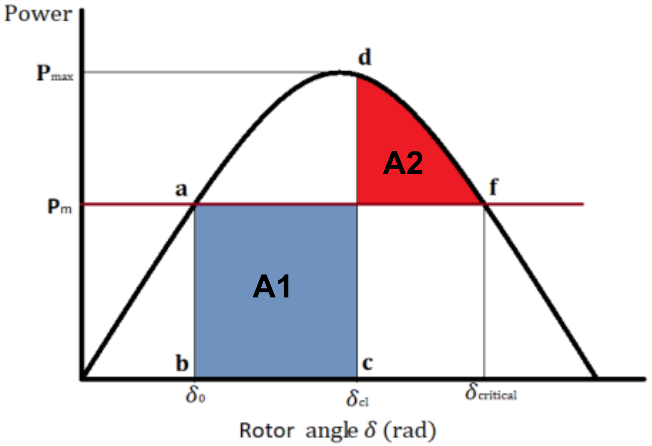




Transient stability is NOT frequency regulation

Energy Function and the Equal Area Criterion





- There is a general agreement that the first integral of the equation of motion a one-machine infinite-bus system constitute a proper energy function.
- Since the system is conservative, the energy function remains a constant after fault is cleared.

$$U = \frac{1}{2}M\omega_{cl}^2 - P_m(\delta_{cl} - \delta_0) - P_{max}(cos\delta_{cl} - cos\delta_0)$$

$$U = U_{KE} + U_{PE}$$

ω_{cl}, δ_{cl} is the relative speed and angle of the generator after fault is cleared.

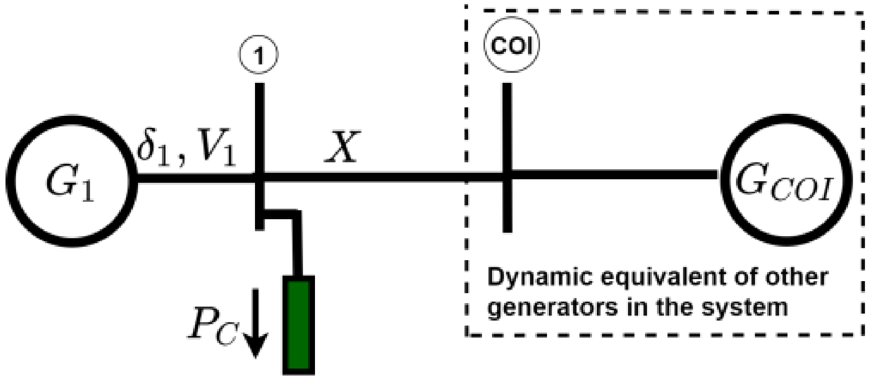
δ_0 is the angle's stable equilibrium point.

$$A1 = \int_{\delta_0}^{\delta_{cl}} (P_m - P_e) d\delta = \int_{\delta_0}^{\delta_{cl}} M\dot{\omega} d\delta = \int_{\delta_0}^{\delta_{cl}} M\dot{\omega}\omega dt$$

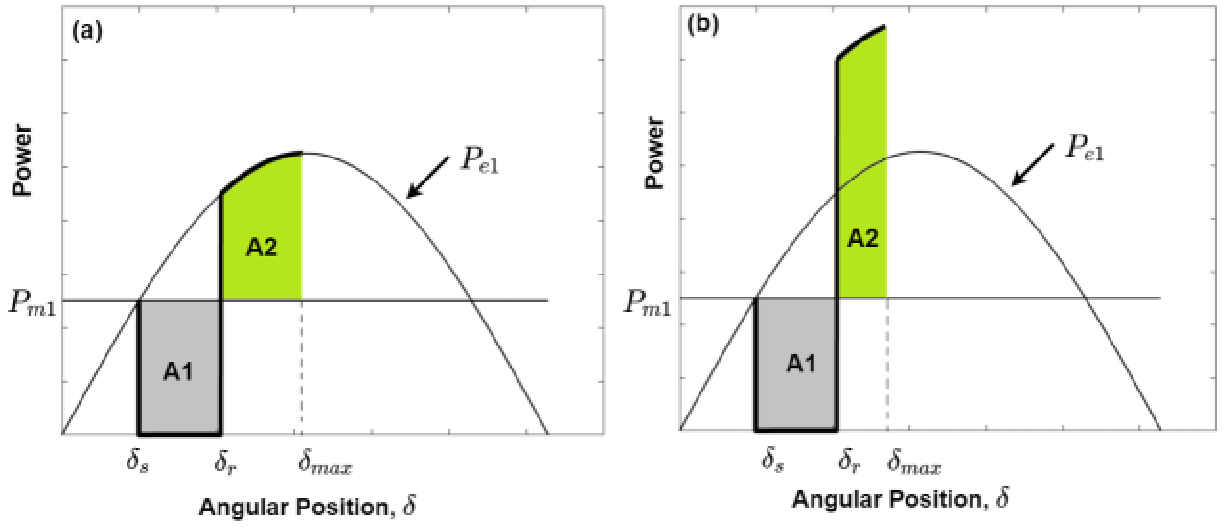
$$A1 = \frac{1}{2}M\omega_{cl}^2 = U_{KE}$$

- Similarly $A2 = U_{PE}$
- The synchronous machine must be able to convert all the total kinetic energy gained during the fault to potential energy.

Improving Transient Stability



If the post fault system is controlled, such that the kinetic energy gained during the fault is quickly absorbed before it is converted to potential energy, the transient stability of the system is improved.



Install an energy storage device at the terminal of the generator.

After fault is cleared, the electrical power of the generator, P_e is increased such that the generator transfers some of the kinetic energy gained to the storage device.

$$U_{KE} = \frac{1}{2} M (\omega_1 - \omega_{COI})^2$$

Make this equal to Zero as quick as possible

Connection to an Optimal Control

- The energy storage device is modeled as a real power absorption, $P_c(t)$ at the generator bus,

$$\ddot{\delta} = \frac{1}{M}(P_{m1} - P_{e1}) - \frac{1}{M_1}P_c(t)$$

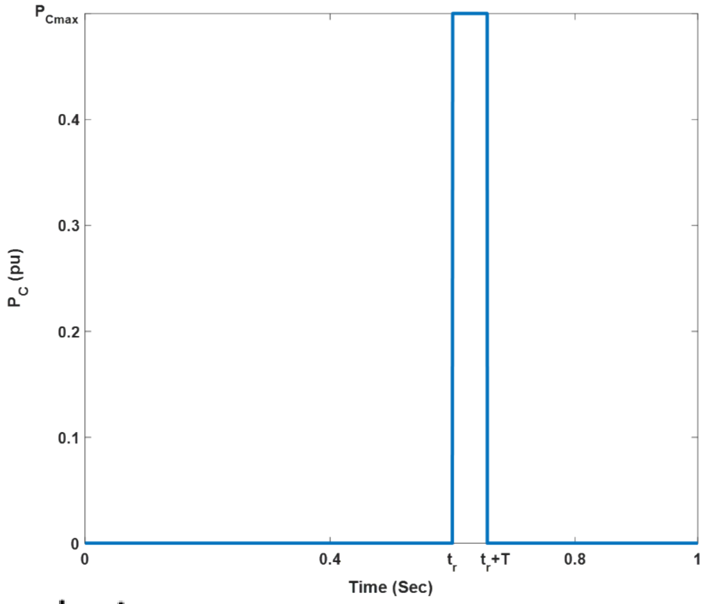
- An Optimal control problem is formulated to determine the best trajectory for $P_C(t)$.
- Find $P_c(t)$ that minimizes the performance index,

$$J = \int_{t\_r}^{t_r+T} 1dt = T$$

- Subject to the constraints

$$P_{C\,min} \leq P_c(t) \leq P_{C\,max}$$

$$\omega(tr + T) = 0$$

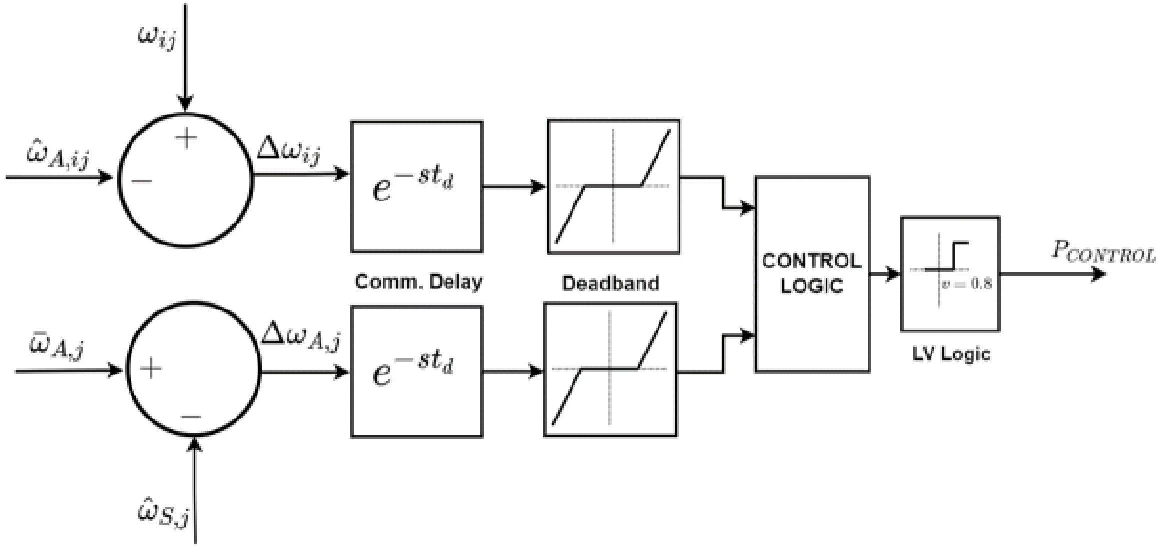


This is a classical constrained-input, minimum-time optimal control problem.

- The application of Pontryagin's principle yields a well-known "bang-bang" solution.

Control Strategy

- The control strategy consists of 2 parallel feedback loops.
- The first focuses on preserving the synchronism of a given generator with its area.
- The second loop focuses on preserving the synchronism of a given area with other areas.
- Each control loop's strategy is based on local frequency and center-of-inertia frequency measurements.



ω_{ij} = Speed of gen. i

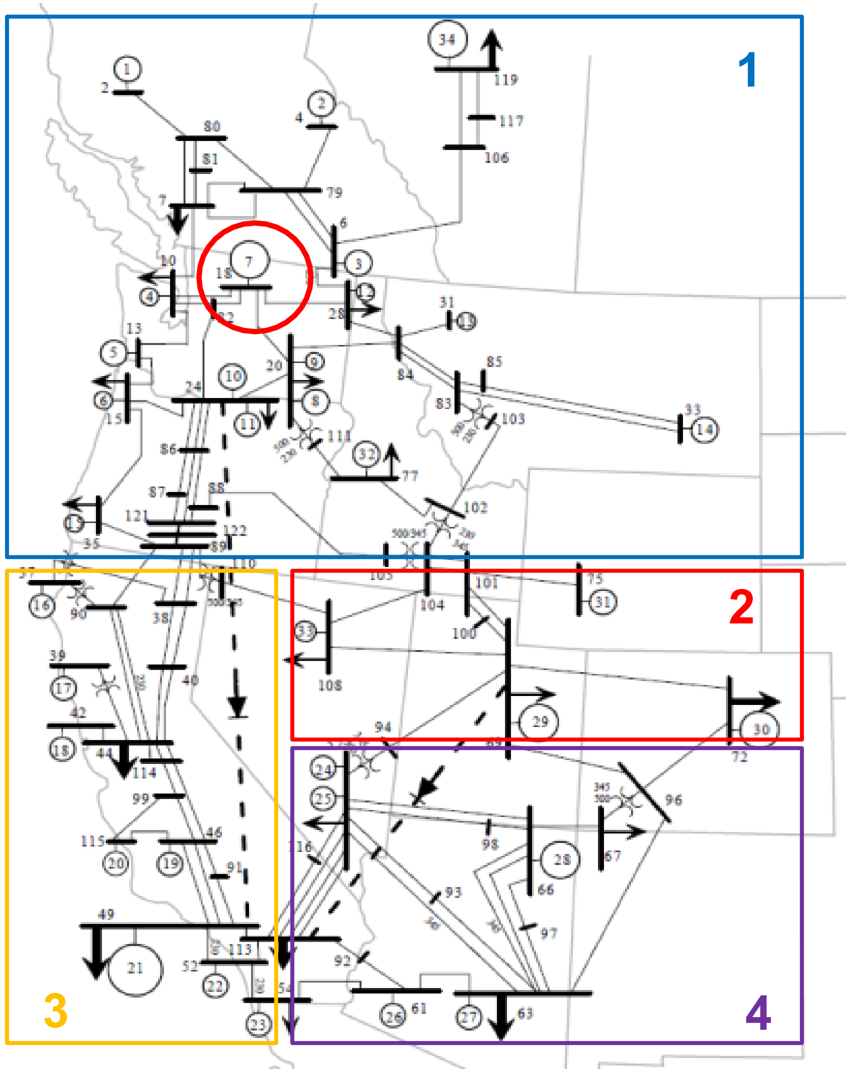
$\bar{\omega}_{A,j}$ = COI speed of area j

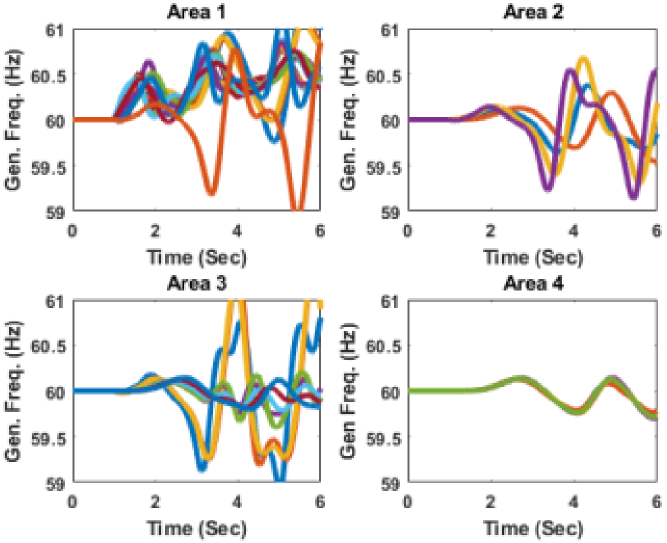
$\hat{\omega}_{A,ij}$ = COI speed of area j calculated **excluding** gen. i

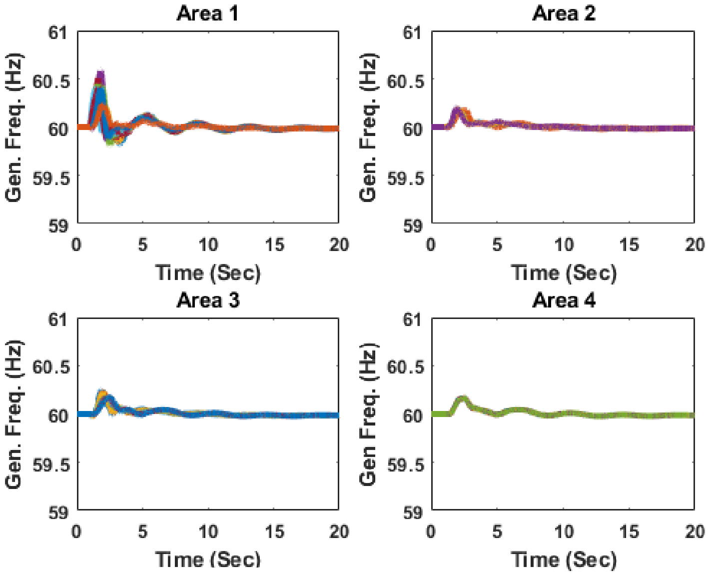
$\bar{\omega}_{S}$ = COI speed of full system

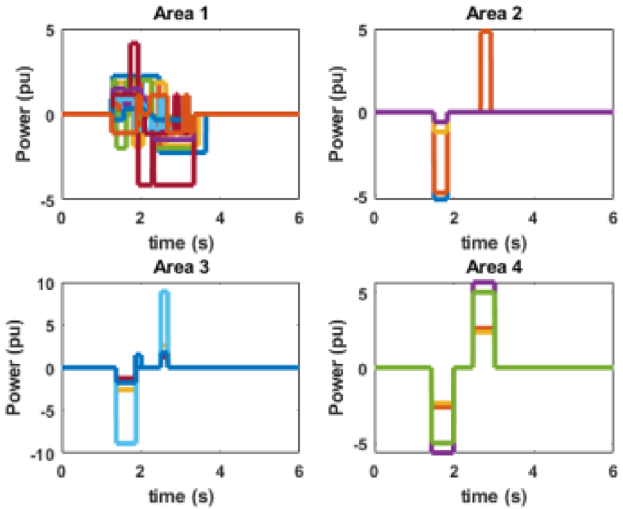
$\hat{\omega}_{S,j}$ = COI speed of the system calculated **excluding** area j

miniWECC


1
2
3
4


Area 1
Area 2
Area 3
Area 4
Gen. Freq. (Hz)
Time (Sec)


Area 1
Area 2
Area 3
Area 4
Gen. Freq. (Hz)
Time (Sec)


Area 1
Area 2
Area 3
Area 4
Power (pu)
time (s)

In Conclusion

More in the Paper

- Single loop control vs Two loop control.
- Latched Control vs Unlatch Control.

Future Work

- The optimal location for the distributed energy storage devices in a multimachine power system.
- Sizing the energy storage device.
- Explore minimizing a different optimal control cost function subject to various constraints

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