Enhanced Controller Design and Development: Energy Storage System Testing and Model Validation

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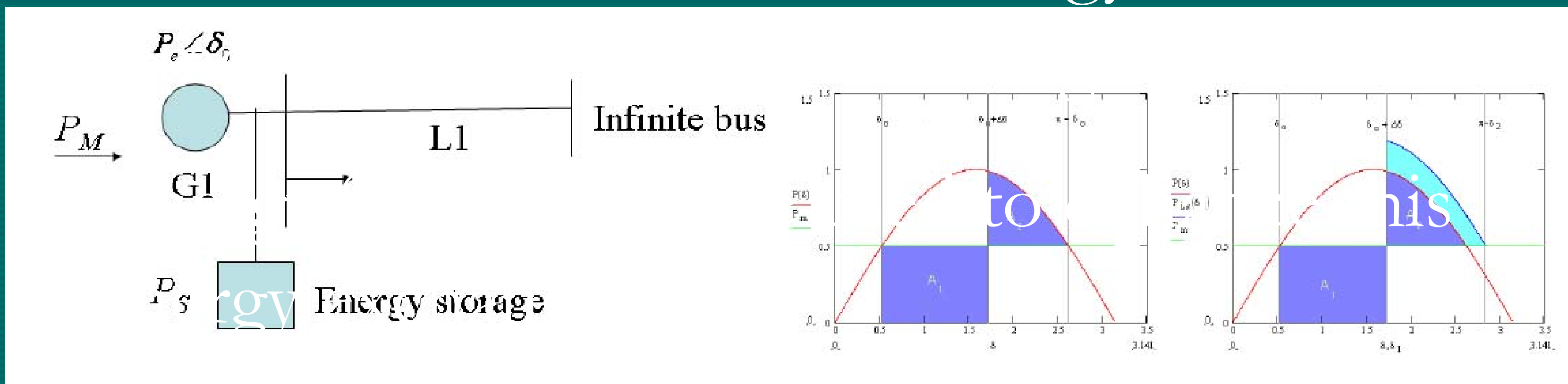
Project Background

- Investigating multiple applications of short term ESS in power systems
  - Increasing loadability of Inverter interfaced distributed energy resources (Patent received)
  - Sizing of ESS for transient (angle) stability √ and damping of oscillations
  - Improving Control Area Performance
  - Laboratory scale demonstration
  - Application of ESS in Distribution Microgrids
  - Use of the Laboratory in undergraduate √ education

Transient(angle) Stability

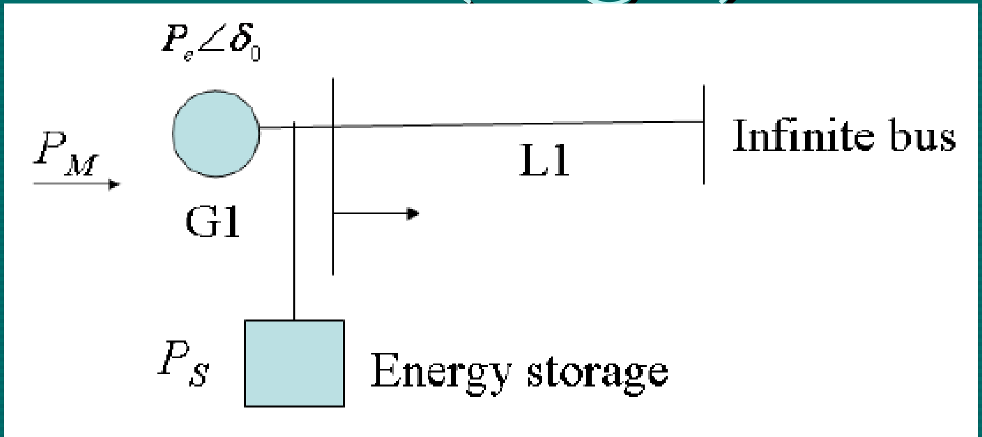
Fault close to the generator causes generator to accelerate and gain energy

After fault removal excess energy must be



- Estimate energy storage from equal area criterion.
- Most literature does not indicate size of energy storage

Transient(angle) Stability



•Fault close to the generator causes generator to accelerate and gain energy

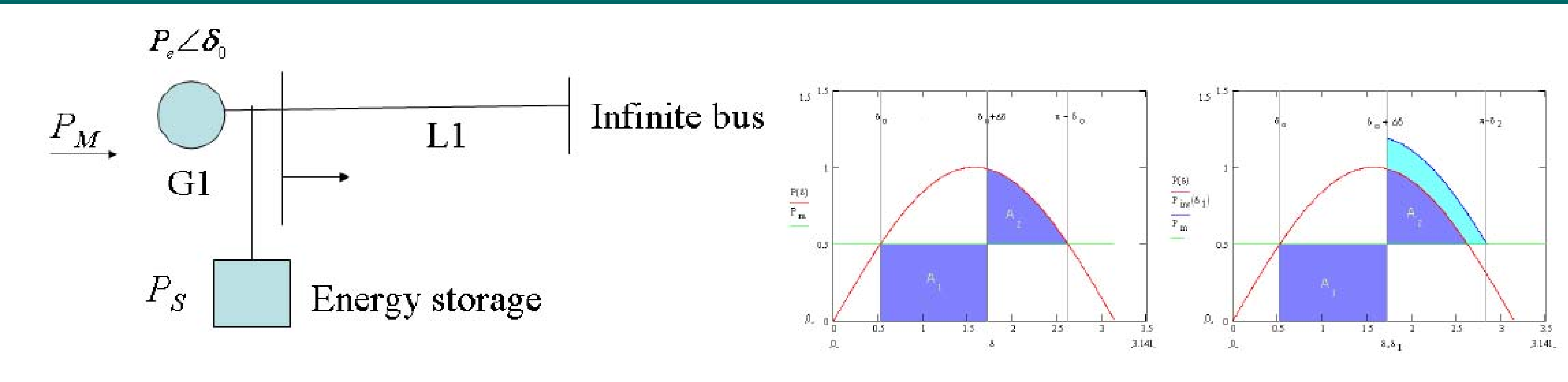
•After fault removal excess energy must be removed usually by transmitting to infinite bus

•Energy Storage can be used to enhance this energy exchange

•Most literature does not indicate size of energy storage

- Estimate energy storage from equal area criterion.

Transient(angle) Stability



- Result shows needed energy storage to maintain stability is almost as large as the rating of generator.
- More realistic sizes when fault is further away from generator
- Role of energy storage is most effective if can support multiple generators for faults somewhat removed from the generator

Damping of rotor angle oscillations

- Subsequent to first swing system may oscillate
- PSS widely used to damp oscillations.

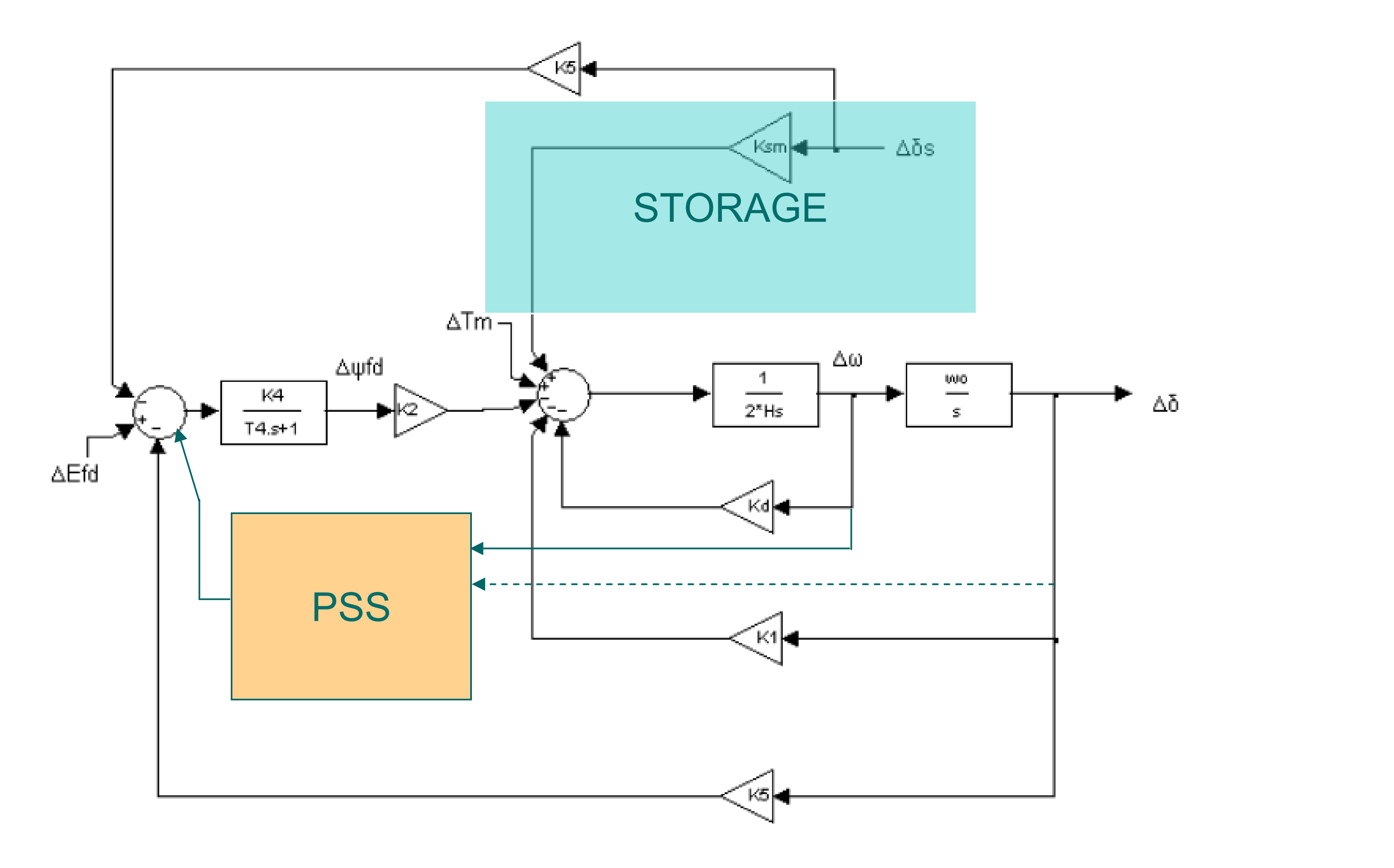
- Energy storage devices make sense only if a comparatively small amount of energy is necessary to damp oscillations.
- Relation between damping and energy storage required.
- Does storage rating depend on control algorithm?

Damping of rotor angle oscillations

Approach

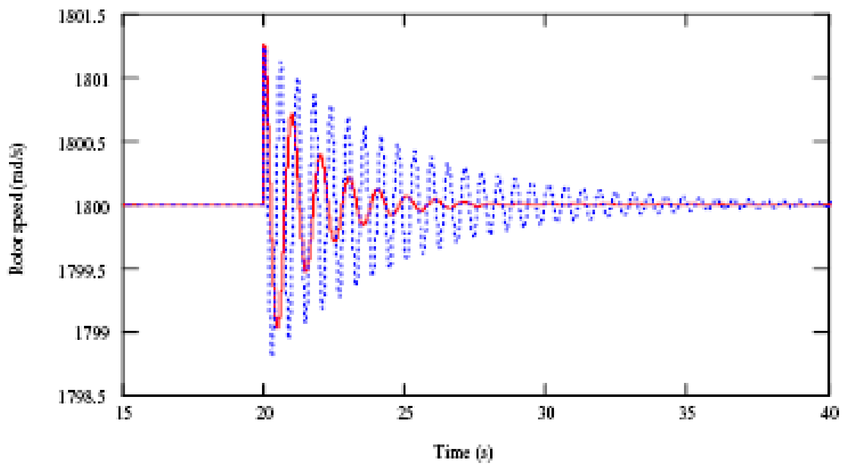
- Derive small signal model of synchronous machine to infinite bus (SMIB) with an energy storage unit tied to generator bus.
- State model block diagram.
- Choose the control methods for damping.
- Compare linear model with simulations in PSCAD/EMTDC and Laboratory Experiments

Damping of rotor angle oscillations



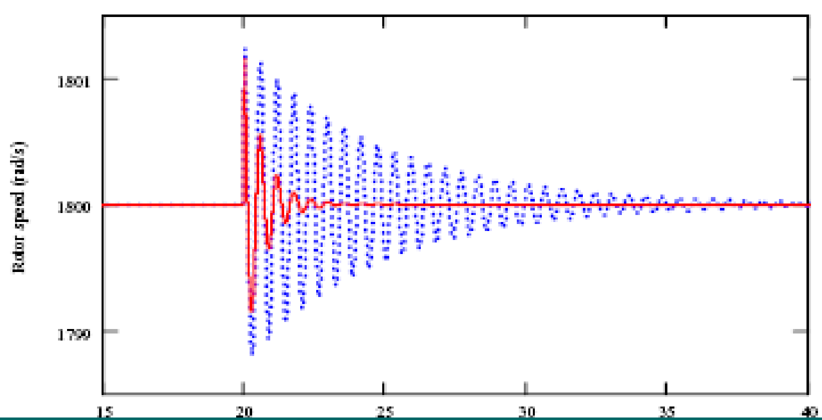
Block diagram shows classical PSS feedback path through field and more direct ESS feedback path

Damping of rotor angle oscillations



Lag compensator control of energy storage device

$$\Delta\delta_s = \frac{K}{1+sT}\Delta\delta$$



Optimal feedback gains control (from LQR program) of energy storage device

$$\Delta\delta_s = K_{t1}\Delta\omega + K_{t2}\Delta\delta + K_{t3}\Delta\psi_{fd}$$

Damping of rotor angle oscillations

TABLE I

COMPARISON OF ENERGY ESTIMATES FOR DIFFERENT CONTROL SCHEMES

Uncontrolled	Lag	LQR-based
0.006131 p.u.	0.005569 p.u.	0.002634 p.u.

TABLE II

COMPARISON OF PEAK POWER ENERGY STORAGE OUTPUT FOR DIFFERENT CONTROL SCHEMES

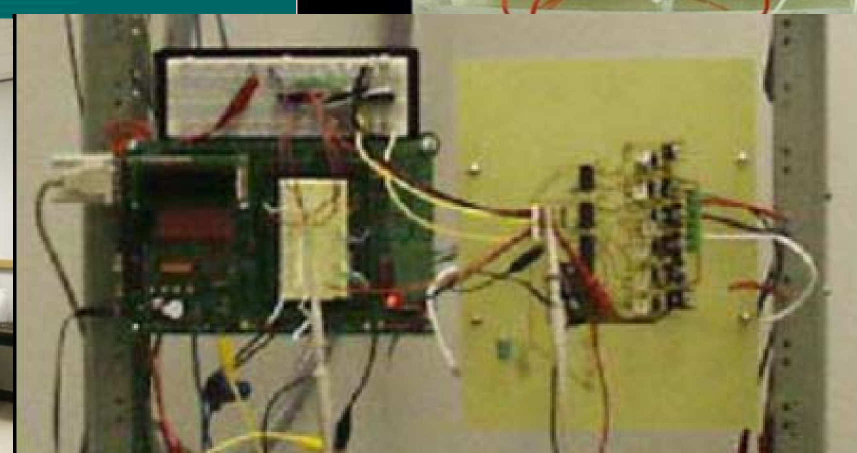
Uncontrolled	Lag	LQR-based
0.032507 p.u.	0.015434 p.u.	0.015724 p.u.

For 0.1 p.u. torque disturbance on a 1.0 p.u. SMIB

Education

Supports Senior Design Projects

Scale Model Power System
Renewables and Energy Storage
Microgrids



Conclusion

- Analytical and Laboratory Based Study of Sizing
- Control of Transient Stability Requires High Power Converters of the order of System Rating
- Damping can be achieved with relatively small amounts of storage
- Advanced controllers and Laboratory Demonstration continuing
- Use of scale model laboratory to demonstrate microgrid operation in progress