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Potential of Solid-State Transformers to Improve Grid Resilience

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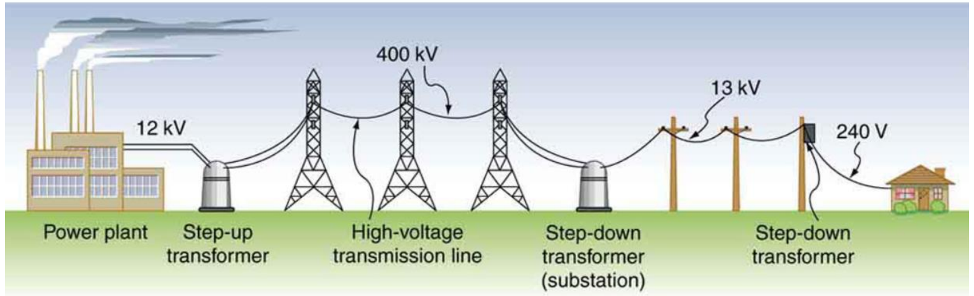
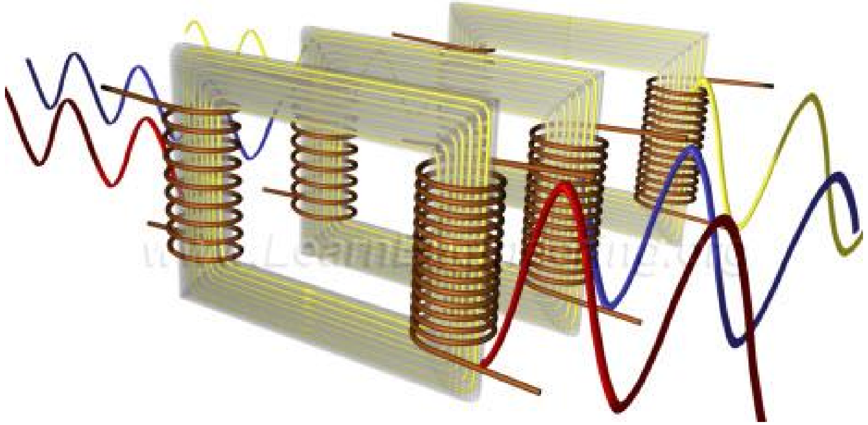
Background

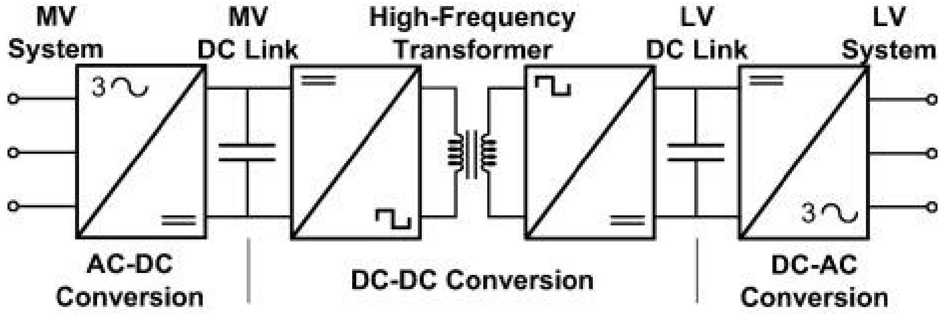
Conventional Transformers vs. Solid-State Transformers:

– Passive devices
– ~99% efficient
– Can introduce harmonics
– Pass disturbances along
– Very large footprint
– Require 1+ year for replacement

– Phase & frequency decoupling
– Reactive power control (e.g., VAR support)
– Power quality management
– Reduced footprint, deployment burden, and inventory overhead
– Potential to correct phase imbalance
– “DC in the middle” enables natural integration of DC-based IBRs (e.g., PV)
– Frequency insensitivity enables natural integration of variable frequency AC sources (e.g., wind)







Because of these advantages vs. conventional transformers, it is hypothesized that SSTs have potential to prevent/reduce cascading failures arising from severe events, thus improving grid resilience.

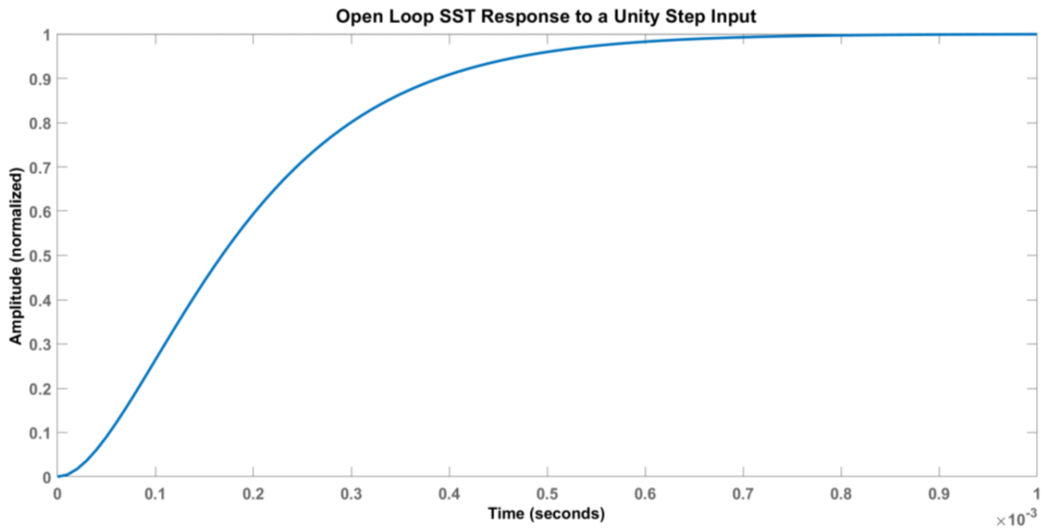
Methodology for SST Control Design

1. Develop High-level SST Model for Control Design

Grid-level transfer function of SST can be approximated as critically damped 2nd order lag system:

$$\frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

where K = DC gain, ζ = damping ratio, ω_n = natural frequency = $1/\tau$, τ = time constant; Example values for an SST: K = 1, ζ = 1 (critically damped), τ = 100 μs, ω_n = 10,000 rad/s

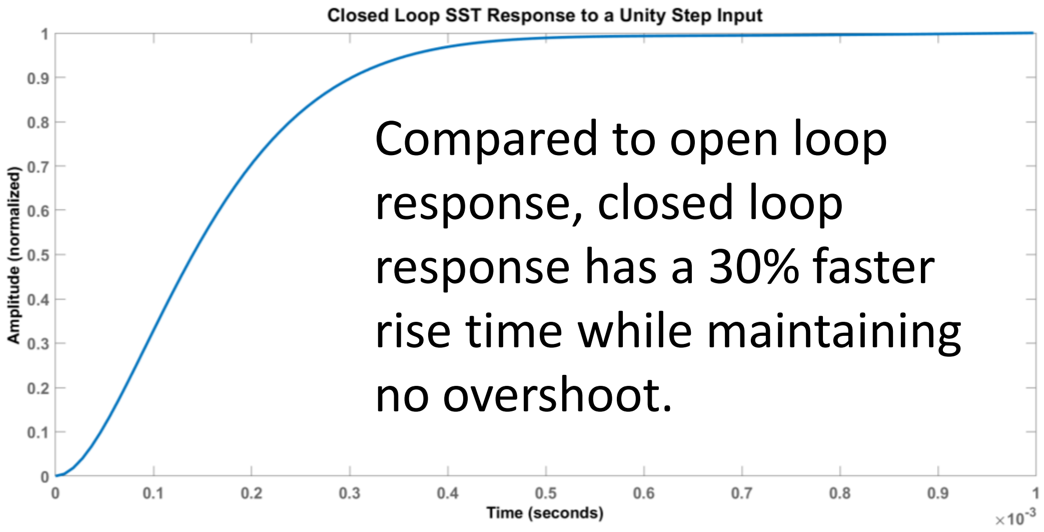


2. Design compensator for SST

Example: PI compensator transfer function

$$K_p + \frac{K_I}{s}$$

where K_p is the proportional gain and K_I is the integral gain
Example control parameters for an SST: K_p = 0.3 and K_I= 10

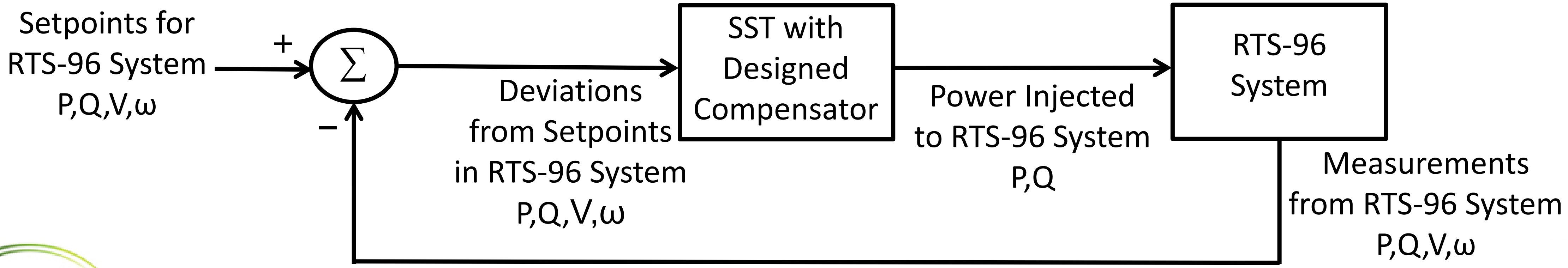


Compared to open loop response, closed loop response has a 30% faster rise time while maintaining no overshoot.

Implementation and evaluation of SST vs. conventional transformer under severe grid events

3. Implement compensator design for SST to evaluate in grid simulations
4. Example simulation study:
   a. Base case – RTS-96 3-area system with conventional transformer in Area 3
   b. Test case – Same as above except SST with designed compensator replaces conventional transformer in Area 3
   c. Events – (i) Severe generation trip in Areas 1 and 2; (ii) Severe load trip in Areas 1 and 2

Grid-level block diagram for closed-loop SST control testing



Conclusions

- The SST is an important step to creating a more resilient power grid to disturbances caused by multiple threat vectors, e.g., cyber-attacks and natural disasters
- An SST modeling and control design methodology was presented
- A simulation example based on the IEEE RTS-96 3-area system compared a base case with no SST to the same base case except with an SST using the control design methodology
- The base case illustrated a weak connection between Area 3 and Areas 1 and 2 due to the severe disturbances leading to significant load shedding
- The base case with an SST showed significant improvements in reducing load shedding and improving frequency nadir vs. conventional transformer for the same events
- Future work will focus on:
  - Optimization strategies using SSTs to maximize grid resilience
  - Robust control designs given parameter uncertainties and measurement noise