Magnetic Amplifier-based Power Flow Control Technology

A Hybrid Approach to Power Flow Control

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Why Power Flow Control?

• In 2008, transmission congestion costs the EI grid around $8 billion, about $40 per person.
• Only 50% of the over 300,000 miles transmission lines in U.S. have been utilized at any given time.
• The median cost for adding new transmission capacity to accommodate the new wind generation is about $300/kW, exceeding the cost of the most expensive FACTS devices.
• Better power flow control can boost the transfer capacity of transmission line up to 2-3 times of the uncontrolled case.
# Generations of FACTS

<table>
<thead>
<tr>
<th></th>
<th>1st Generation</th>
<th>2nd Generation</th>
<th>3rd Generation</th>
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</thead>
<tbody>
<tr>
<td>Typical Devices</td>
<td>SVC, TSC, TSR</td>
<td>TCSC, STATCOM, SSSC</td>
<td>UPFC, IPFC</td>
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<tr>
<td>Functionality</td>
<td>Reactive power compensation, voltage regulation, little dynamic &amp; transient capability</td>
<td>Real &amp; Reactive power compensation, voltage/current regulation, oscillation damping, limited dynamic &amp; transient capability</td>
<td>Full power control, voltage/current control, oscillation damping, fault current limiting, full dynamic &amp; transient capability</td>
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<tr>
<td>Control Type</td>
<td>On/Off or Discrete</td>
<td>Continuous</td>
<td>Continuous</td>
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<tr>
<td>Current Cost ($/kVA)</td>
<td>15-25</td>
<td>50-100</td>
<td>100-300</td>
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SVC - Static VAR compensator, TSC - Thyristor switched capacitor, TSR - Thyristor switched reactor, TCSC - Thyristor controlled series capacitor, STATCOM - Static synchronous compensator, SSSC - Static synchronous series compensator, UPFC - Unified power flow controller, IPFC - Interline power flow controller.
Project Objectives

• Simple, reliable, and efficient power flow control device that is cost-effective for system-wide deployment and full control of the power grid

• Based on a special magnetic amplifier design with:
  – power electronics isolated from the high voltage current and power flow
  – low power dc source without need for superconductive windings and cryogenic equipment
  – smooth reactance regulation
  – minimized harmonics
Series Reactor Controlled Flow

263.5 MW

24.9 Ω (66 mH)

98% Amps

250.0 MW
Variable Reactor Provides Flexibility

260.8 MW

14.8 Ω (39 mH)

220.0 MW

A 95% Amps

A 95% Amps

A 71% Amps

30.0 MW
Maximum Reactance
Minimum Reactance
MAPFC in Service at ORNL’s μGrid

480 V, 200 Aac, 150 Adc

H-bridge inverter and DSP-based control system
Device Performance

Reactance

- 120 A (green)
- 24 A (red)
- 60 A (orange)

Transient response

bias current (A)
Use in Transient Conditions

Inter-area oscillation simulation of Kundur’s two-area system:

A single MAPFC performs better than two PSSs
Field Demonstration

115 kV, 1500 A unit under construction
Conclusions

• Magnetic amplifier concept for continuous power flow control
• Combination of familiar and proven with modern technologies
• Cost-effective for system-wide deployment and comprehensive grid control
• Potentially a versatile control tool for other applications
• Straightforward path to commercialization