Smart Wires

Distributed Series Reactance for Grid Power Flow Control

IEEE PES Chapter Meeting - Jackson, MS
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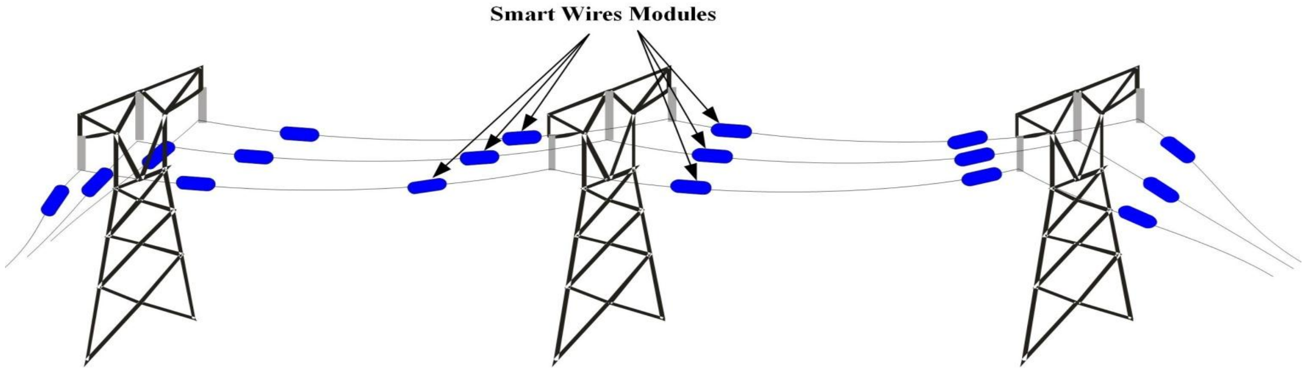
Agenda

- Technology History
- Smart Wires Overview
- Initial System Impact Simulations
- Smart Wires Design
- Commercialization Timeline
- Wrap-Up

INTRODUCTION

- **Solutions for Transmission Congestion/Reliability**
  - Traditional solutions, such as new lines, are expensive and subject to siting and ROW delays. New lines also deteriorate system utilization.
  - Shunt VAR compensation provides voltage support but has limited ability to control power flows in the system.
  - Technology solutions such as Flexible AC Transmission Systems (FACTS) are expensive and have been unable to meet utility expectations in terms of reliability and cost.
  - Distributed control of line impedances offers a new approach for controlling power flow in networked systems, allowing higher reliability & utilization

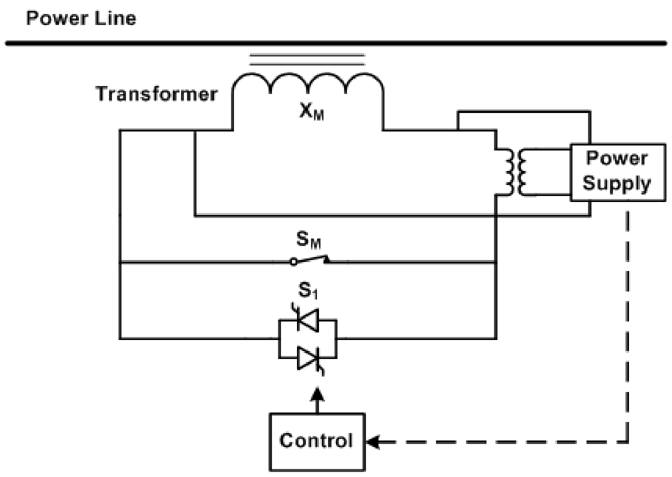


TECHNOLOGY

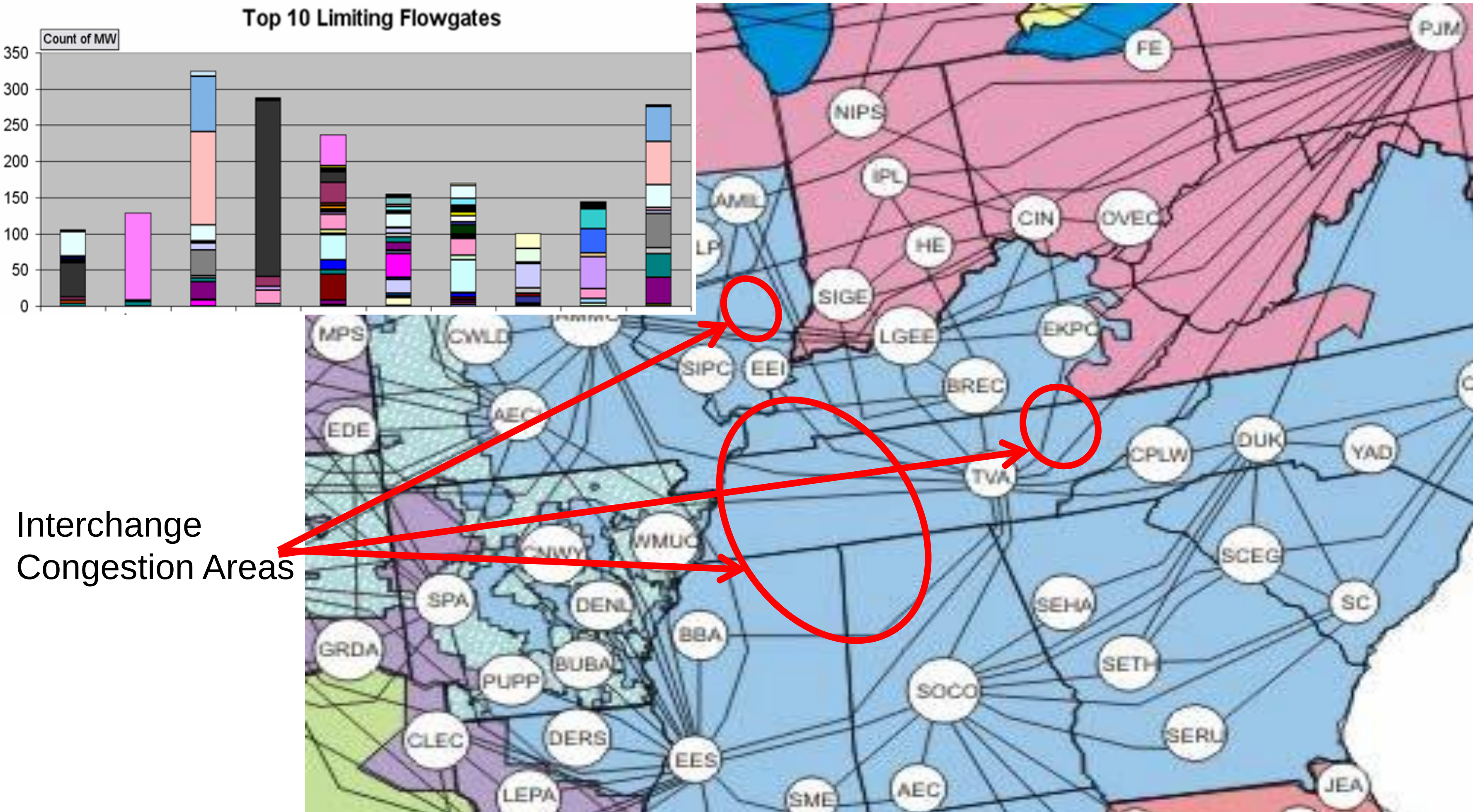
- **Technology History**
  - CEC sponsored the research program in 2006
  - TVA and DOE funded the development of a Smart Wires (DSR) prototype
  - Georgia Tech NEETRAC initiated the Smart Wires Focus Initiative (SWFI) to work with utilities and the commercialization partner
    - 5 members - Southern, TVA, BG&E, NRECA, Southwire
  - SWFI Goals
    - Re-designed for manufacture
    - Lab tested
    - Field testing in Q4 2012
  - Smart Wire Grid, has worldwide exclusive license for the technology from Georgia Institute of Technology

TECHNOLOGY - CONTINUED

- **Smart Wires Technology Overview**
  - Functions as a current limiter to divert current from the overloaded lines to underutilized ones
  - Increases line impedance by injecting a pre-tuned value of magnetizing inductance of the Single-Turn Transformer
  - Each module is triggered at a predefined set point to reflect a gradual increase in line impedance
  - No communication required and the devices operate autonomously



CONGESTION EXAMPLE FROM TVA SERVICE AREA



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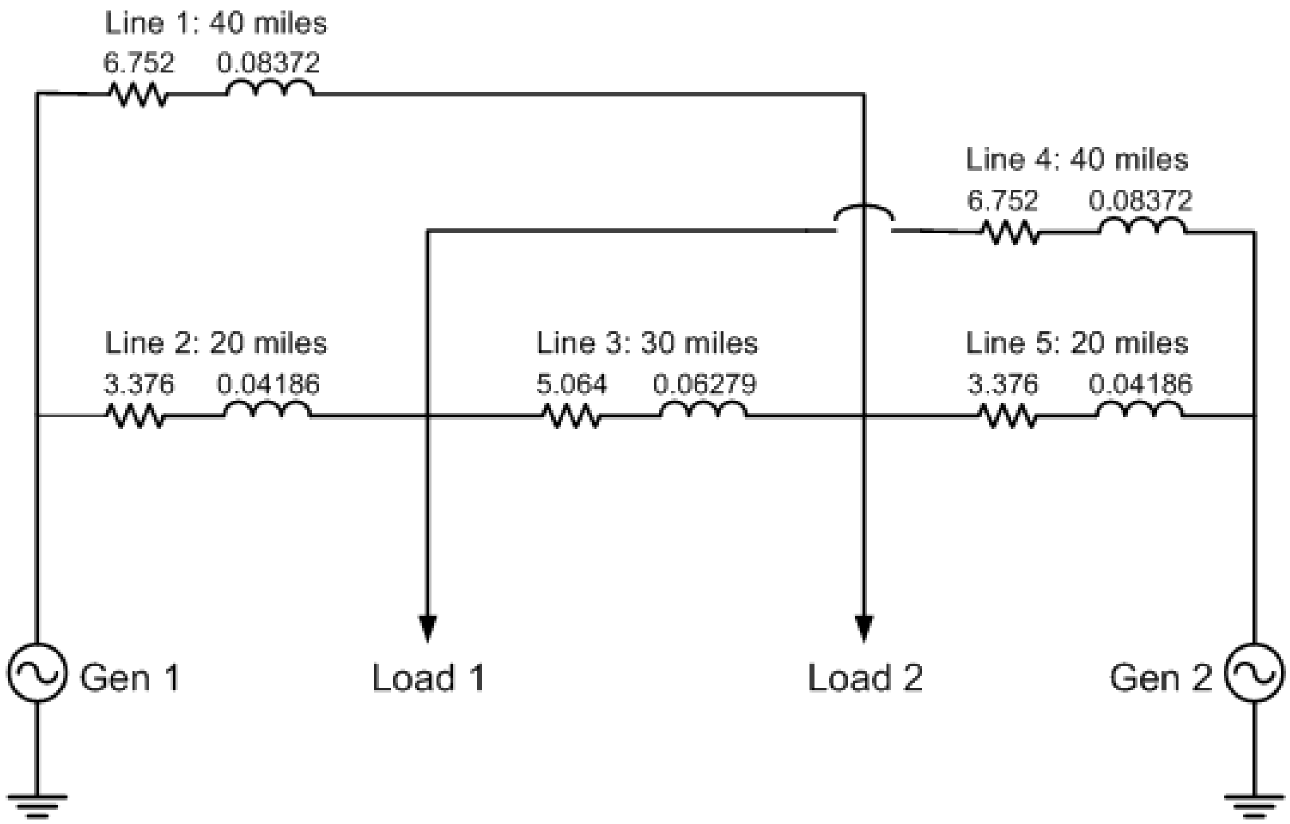
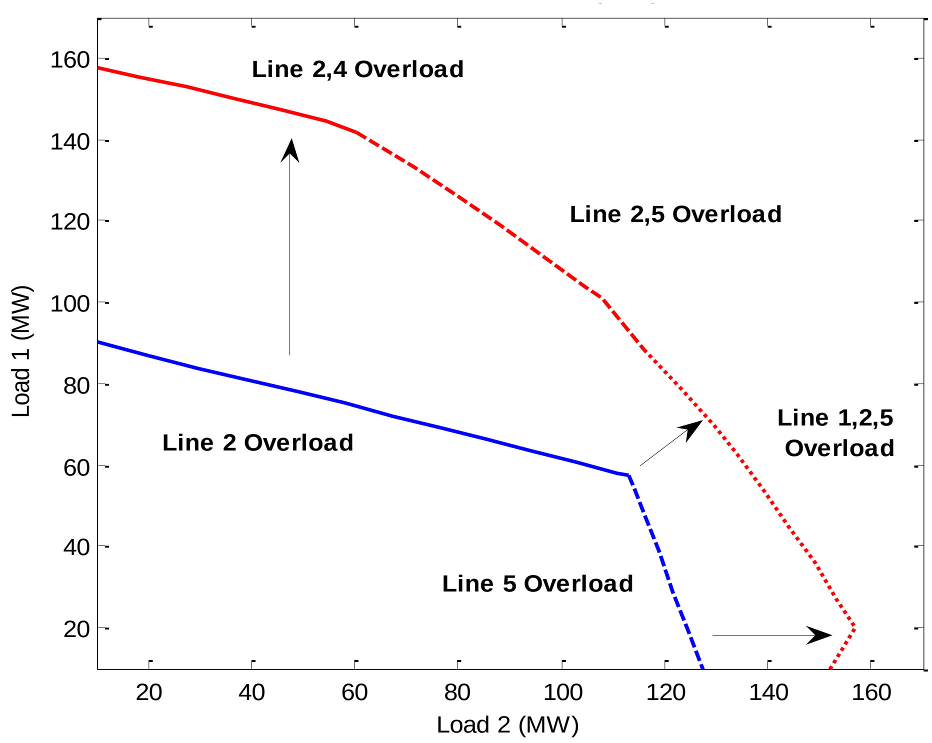
SIMULATION EXAMPLE -1

- **Simplified Four Bus System**



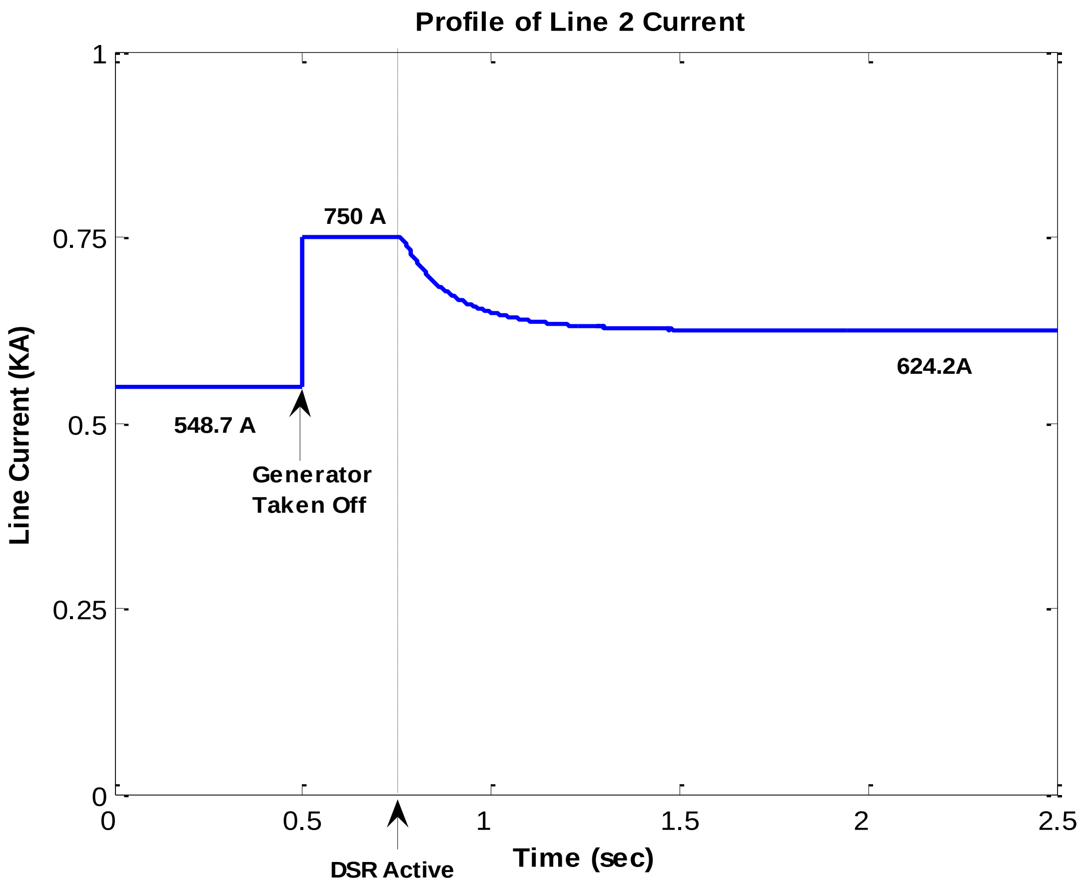
RESULTS

- **Initial Results - 1**
  - Max System Load with and without Smart Wires



RESULTS - CONTINUED

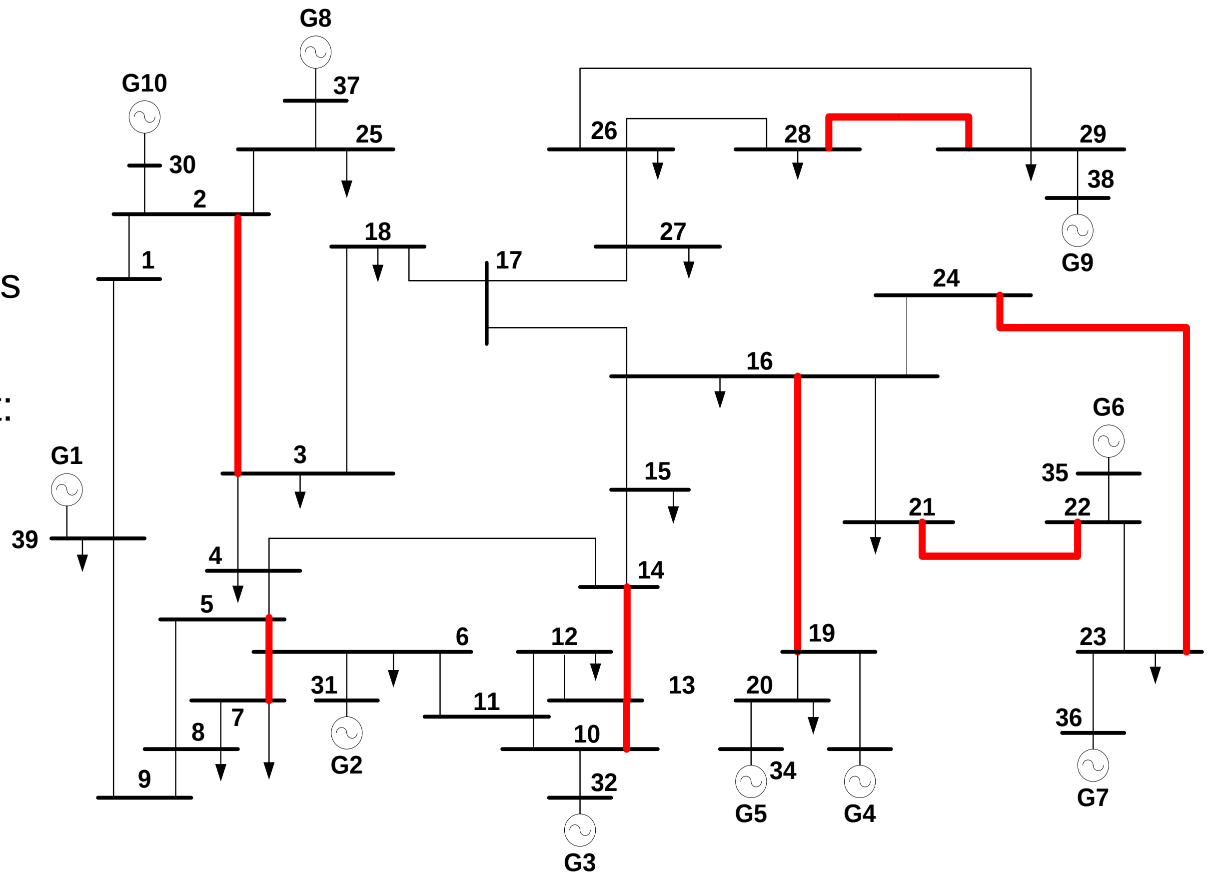
- **Contingency Condition: Generator Outage**



SIMULATION EXAMPLE - 2

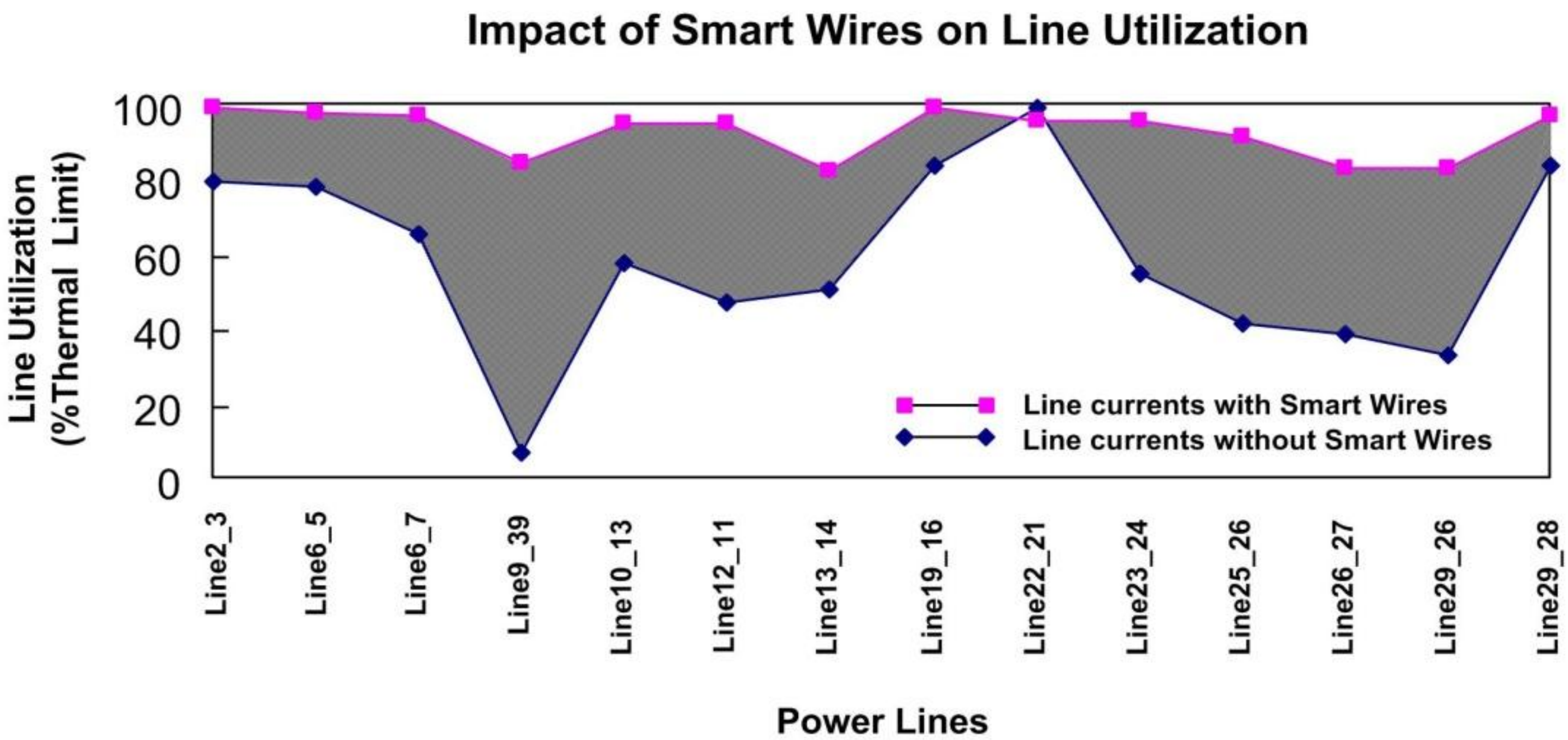
39 BUS SYSTEM

- Baseline MW: 1904 MW
- Increase in ATC possible: 638 MW
- Number of modules required: 45,000
- Total Control effort: 378 MVARs (8.4kVAR/module)

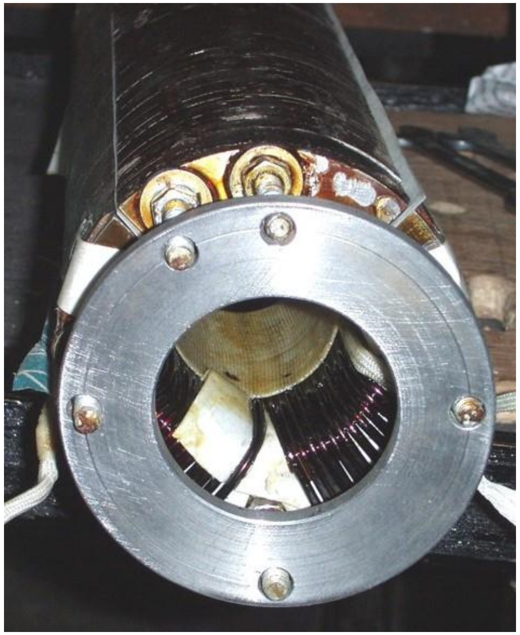


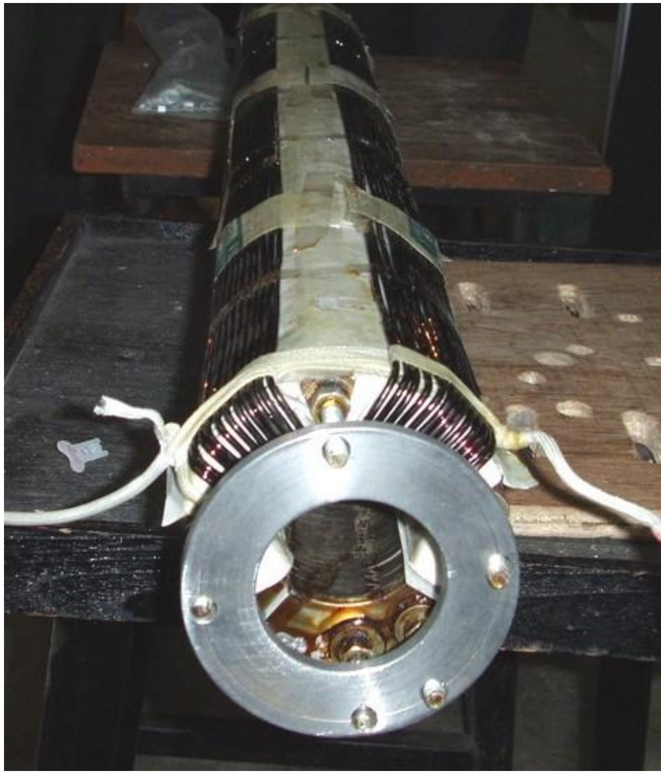
RESULTS

- **Initial Results**
  – Increase in line utilization from 59% to 93.3%



DSR Prototype – GA Tech





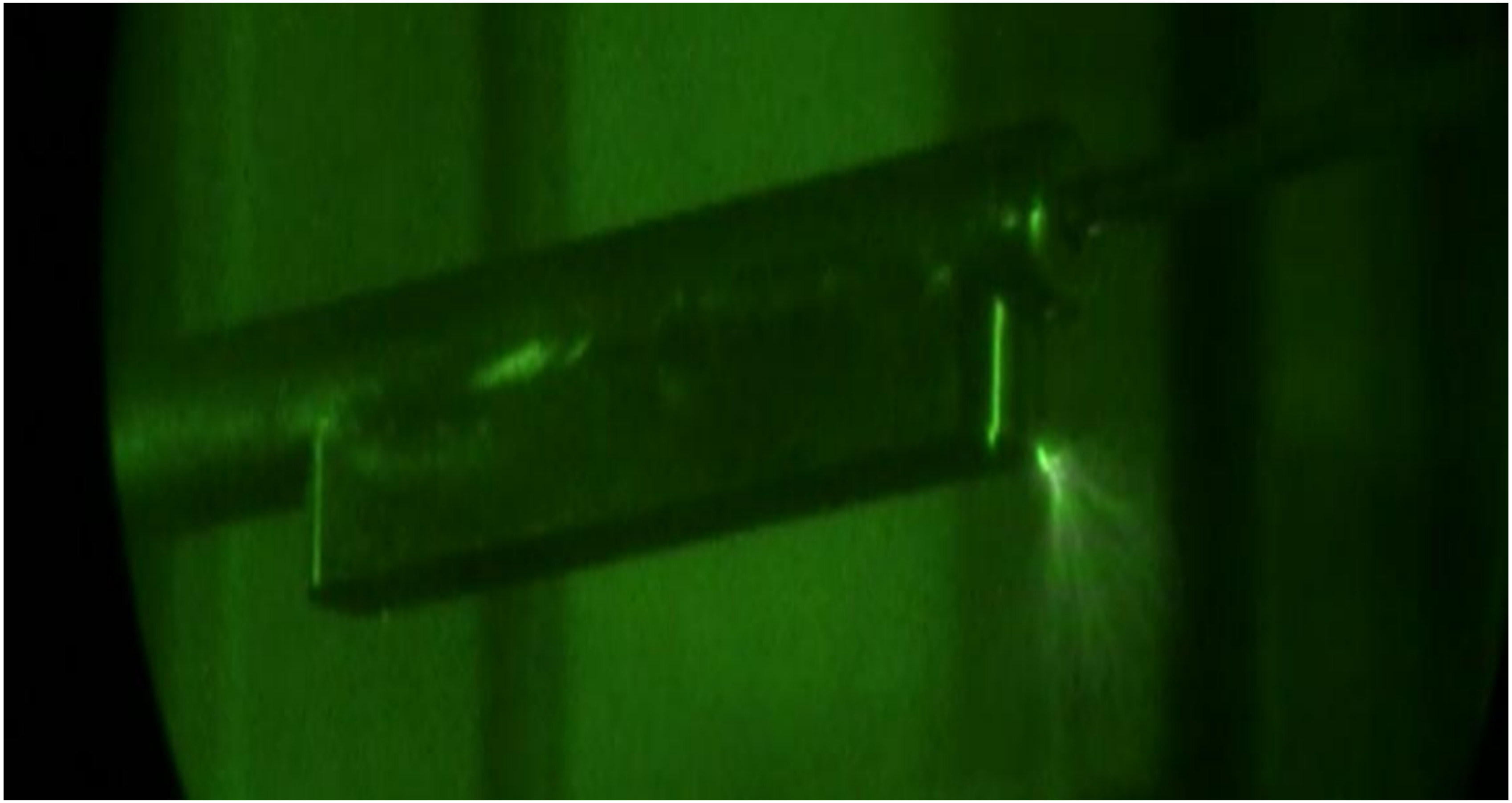
DESIGN SPECIFICATIONS

- **Initial and Current Design Specifications, Ratings**
  - Preliminary Alpha Prototype Spec
    - Max weight : 150 lb.
    - Conductor size: 336 to 1590 kcmil,
    - Operating voltage level: 115-230 kV
    - Fault current: 63kA
    - Life: 20+ year life w/o maintenance
    - Install: Live line or outaged
    - No corona at operating voltage
    - Environmental: Resistant to salt fog, Aeolian vibration, ice buildup, thermal cycling
    - Conductor impact: No mechanical or thermal conductor degradation
    - Lightning Strike: tested to line BIL
    - Wind loading: up to 150 mph, Communications: Module to ground or SCADA link
  - Module rating
    - 10 kVA, 1000 A (50 µH per module)
    - One DSR module per phase per mile changes line impedance (138 kV) by roughly 2%

ALPHA SMART WIRE DEVICE UNDER TEST
CORONA TEST WITH 10' GROUND PLANE

Corona inception at 265kV, Extinction 263kV

SWG DEVICE TESTING – CORONA TEST



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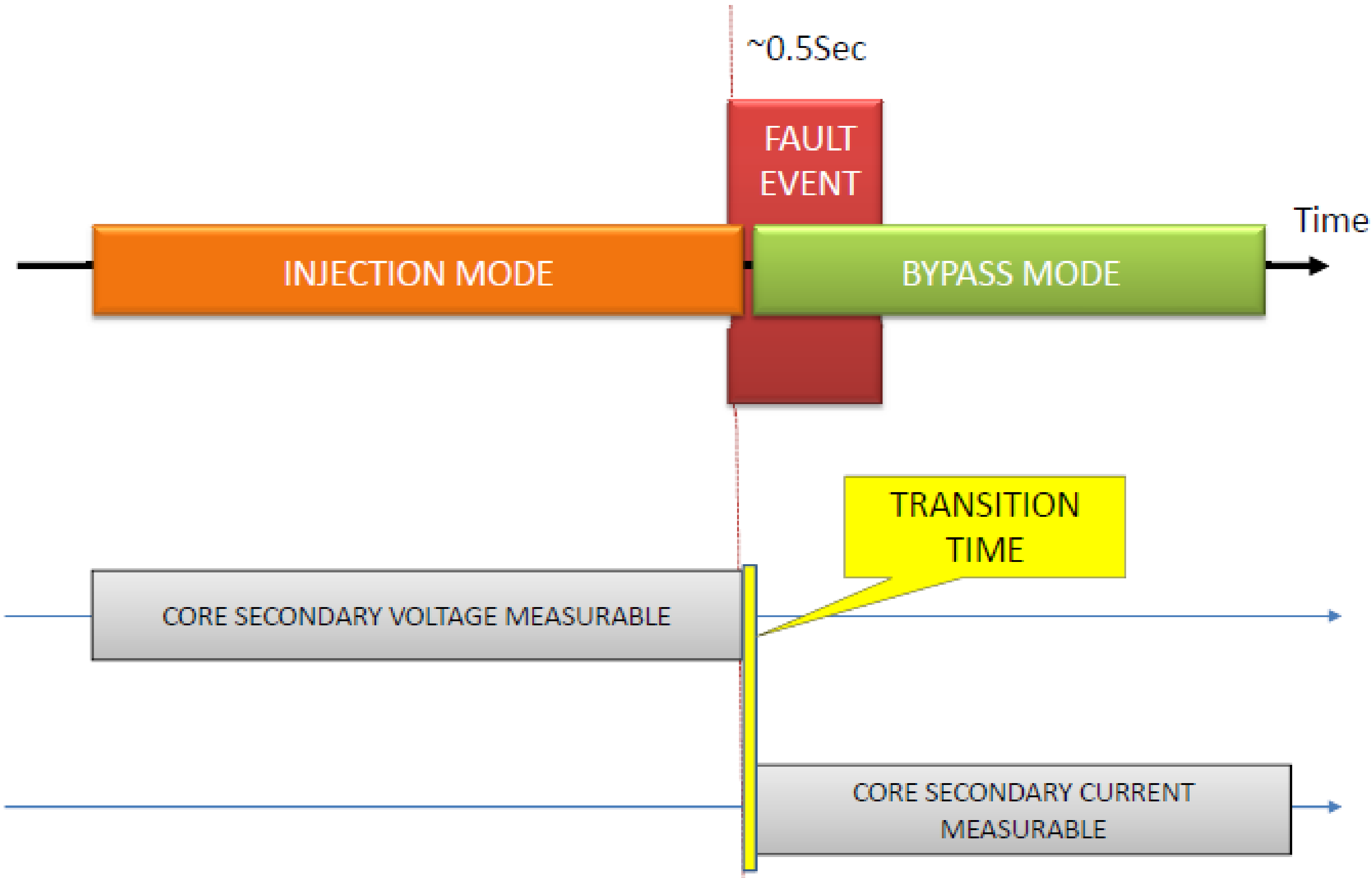
Smart Wires Prototype Testing – 17 kA Fault



PROTECTION

- **Impact on Power System Protection**
  - Changing the impedance of the line can result in under reach of the distance relay
  - By-pass of Smart Wires modules must be faster than the operating time of the protection algorithm
  - Distance relays operate by decomposing voltage and current into fundamental components. Operating time can be around 1 cycle (16666 µs).
  - Smart Wires modules are by-passed in about 40µs. An example is shown below where by-pass has been considered up to about 600 µs based on early DSR designs.

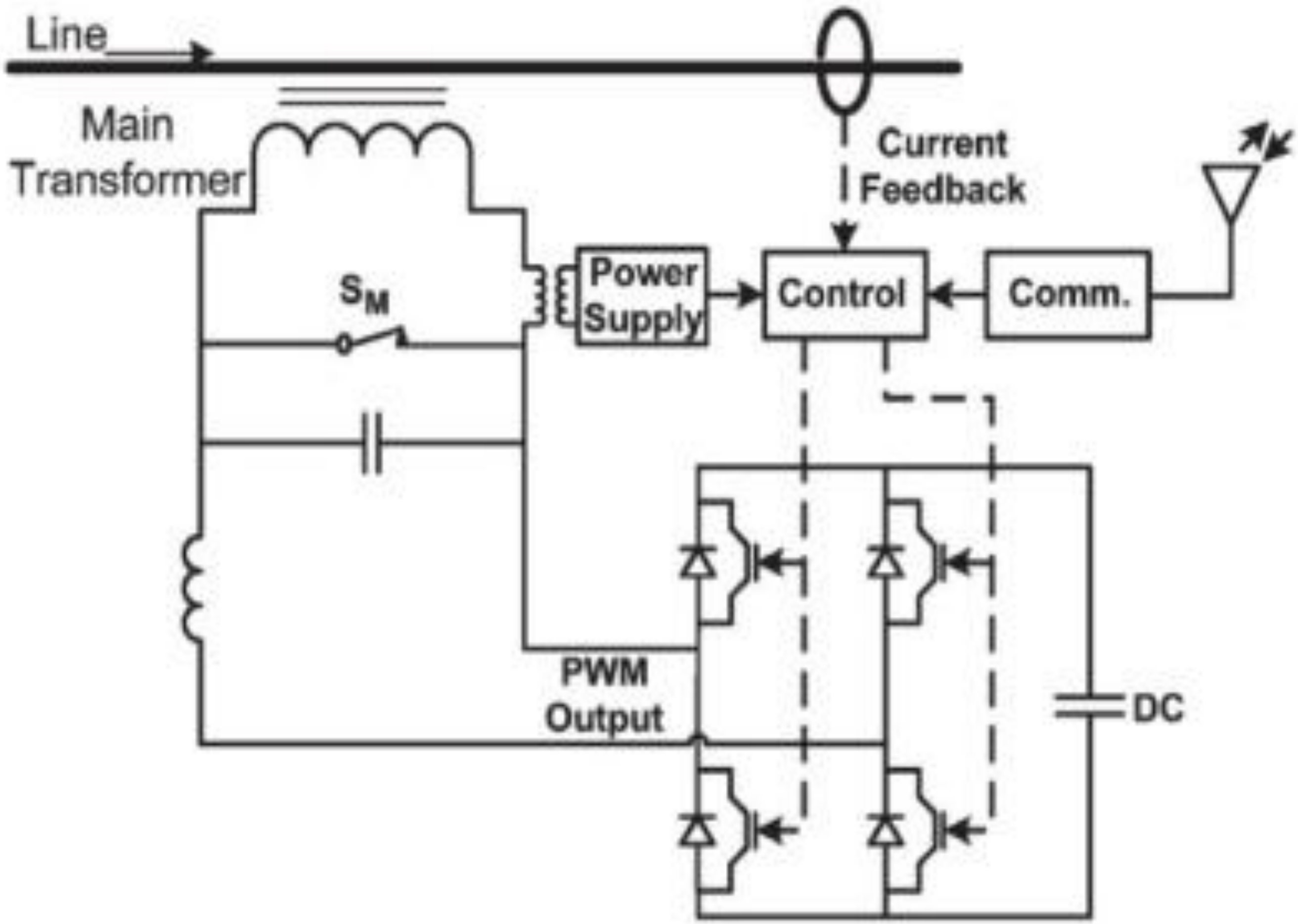
3φ fault Location	Fault Level	Fault Clearing Time - Nominal Conditions	Fault Clearing Time - With DSR Modules Injecting
25% of line length	31,640 A	15.8 ms	16.2 ms
50% of line length	39.500 A	10.3 ms	10.6 ms
75% of line length	50, 000 A	8.3 ms	8.9 ms

Market Study and Investments

Evaluating available solutions for power flow control

Solution	Cost	Limitation
Transmission Lines	$500,000/mile, Substation estimate $80M	• Mitigates congestion at one point • Lumpy investment • ROW and siting issues
HVDC Transmission	$500,000/mile, Converter Stations $250M	• Point to point solution (merchant lines) • ROW and siting issues
Sen Transformers	$100/KVA*	• Low reliability due to fault modes • Bulky solution
Shunt FACTS	$60-$120/KVAR	• Weak influence on active power flow control • Lower reliability than grid
Series FACTS	$60-$160/KVAR+	• Very high installation and operating costs • Bulky solution
Distributed Series Reactance	$100/KVAR*	• Cannot reduce line impedance without communications

Smart Wires Topology - II



Summary

- DOE ARPA-E Awardee, contract Apr 2012
- Pilot DSR manufacturing Jun 2012
- Test bed installation planned at TVA - Q4 2012
- Others early 2013

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