Quadrennial Technology Review: Infrastructure and Power Electronics

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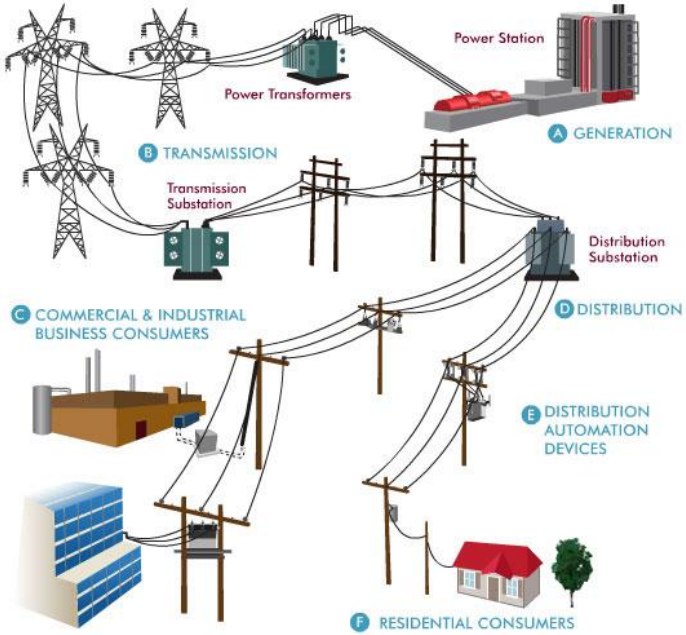
An Evolving System

- Changing generation mix
  - Intermittent renewable resources
  - Distributed generation
- Changing load
  - Vehicle electrification
  - Demand response
  - Energy management systems
- Changing operational paradigms
  - Active consumer participation
  - More spatial and temporal variability

- ***To enable and adapt to these changes, the infrastructure must evolve to meet the new and growing challenges facing the transmission and distribution systems***

Bulk Congestion and Reliability Issues

- Solutions can come from lines and substations ("nodes")
  - 180,000 miles HV lines
  - 15,000 transmission substations
  - 11 million miles of LV lines
  - 60,000 distribution substations
- Advanced substations can enable routable power as well as other new functions and capabilities



<u>Substation Components</u>

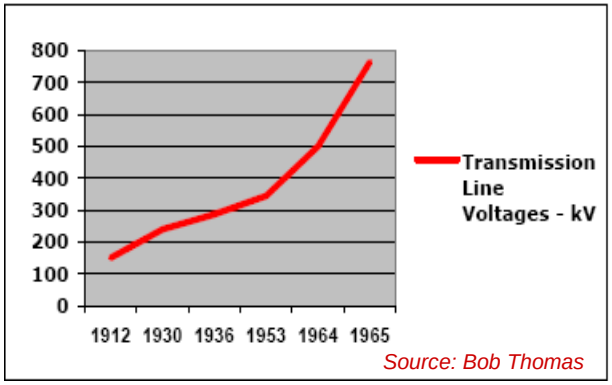
- Transformers
- Power Converters
- FACTS & Controllers
- Breakers & Switches
- Arresters & Limiters

Opportunities for Technologies and Crosscuts

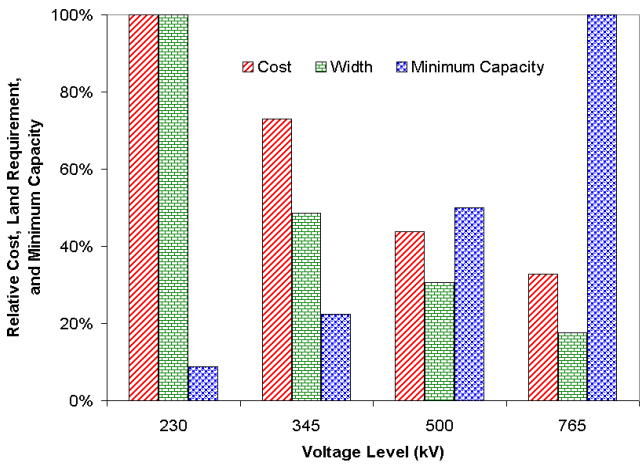
	Conductors & Cables	Transformers	Power Converters	FACTS & Controllers	Switches & Breakers	Limiters & Arresters
Wires	x	x	-	-	-	x
Dielectrics & Insulators	x	x	x	x	x	x
Magnetics	-	x	x	x	-	-
Power Electronics	-	x	x	x	x	x
Thermal Management	x	x	x	x	-	x

- Grid modernization provides many opportunities for replacement of aging infrastructure with advanced components
- DOE strength lies in leveraging crosscutting materials research and concepts to partner with industry for applied research on grid components
- Technology areas funded (past and present) are denoted by circles

Reconductoring



- Historically, transmission lines have trended towards higher voltages for efficiency
- Reconductoring with advanced conductors and cables permit higher power densities, with more power at lower voltages, and is the current trend

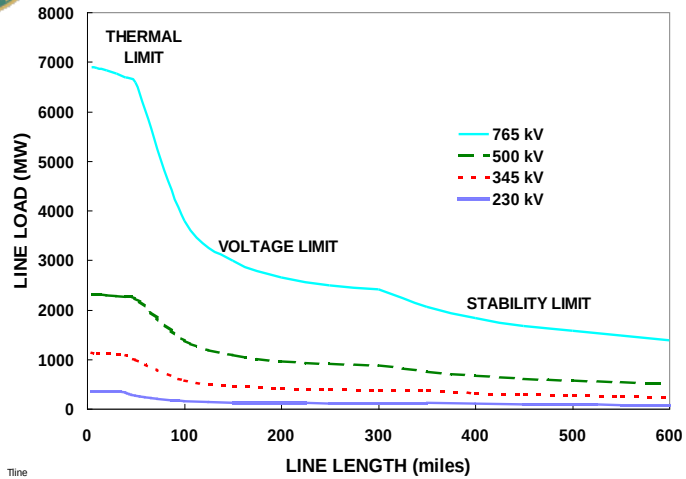


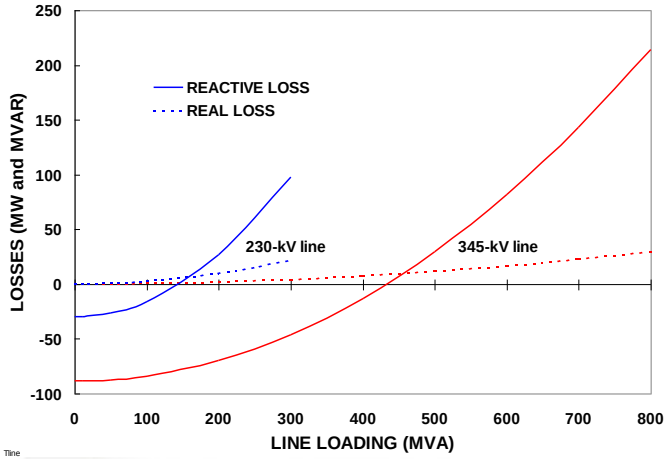
Potential for High Impact:

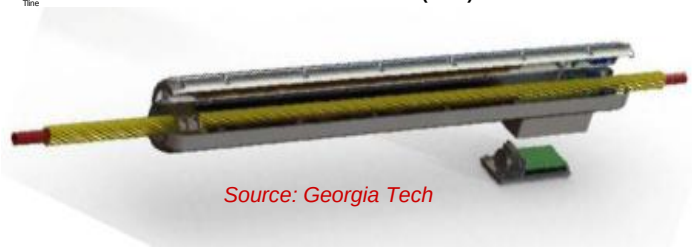
Can address capacity issues, access large amounts of clean energy resources from far off locations, reduce losses, improve reliability (less sag), be resilient to weather (coatings), boost capacity of existing corridors, and minimize siting impacts (underground)

	Product			
Criteria	ACSR	Aluminum Conductor Steel Supported	Aluminum Conductor Composite Core	Polymer Carlene Fiber Composite
Rated Ampacity	905 Amps	2 x ACSR	2.2 x ACSR	2.1 x ACSR
Max. Operating Temperature	75°C	250°C	240°C	200°C
Sag	0.125 ft/°C	0.125 ft/°C	0.04 ft/°C	<0.04 ft/°C
Cost (Est).	1 x ACSR	1.2 x ACSR	10-25 x ACSR	5 x ACSR

Advanced Conductors and Cables







Source: Georgia Tech

- Improvements in efficiencies and other wire properties (mechanical, thermal, electrical)
- Self-healing and diagnostics capabilities
- New technologies can reduce reactive power losses and provide control

Overhead Conductors Targets

Conductors that are 10x ACSR
Low sag, operating temp > 200 °C
Operating voltages > 765 kV
Improve loss by 10%
Lower costs, longer life

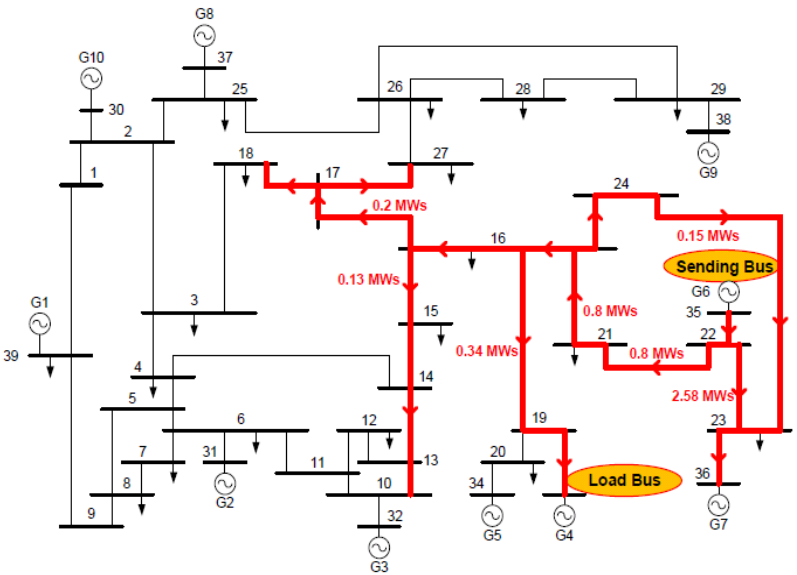
Needs: improved wire materials, dielectrics, heat dissipation

Underground Cables Targets

Cables that are 5x ACSR
High operating temperatures
Improved loss by 10%
Lower costs, longer life

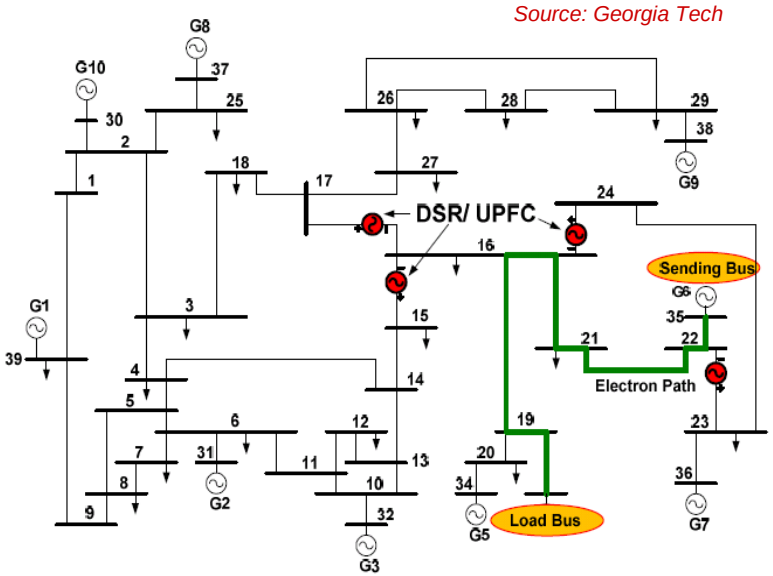
Needs: advanced wire materials (HTS), dielectrics, cryogenic coolers

Routable Power



Base Case: 3.4 MW sent; 0.34 MW recd

Source: Georgia Tech



PCAT Case: 3.4 MW sent; 3.4 MW recd

Simulation Results

- BAU case requires upgrade of 3 inter-regional paths for a total of 186,000 MW-miles
- Power flow control to route power along underutilized paths needs 36,000 MW-miles of new lines (20% of BAU)

Potential for High Impact:

Can address capacity issues, improve asset utilization, reduce need for new transmission build out, enhance reliability and resiliency, facilitate automation and restoration, improve power quality, and enable new markets and services

Power Electronic Systems

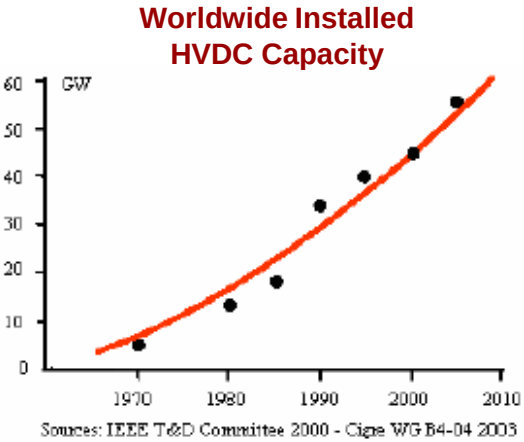
FACTS and Controllers

- Increased power control and VAR support needed as loads become more reactive
- Currently are expensive and utilized in limited applications
- Not used in the distribution level
- Key components to enable the routing of power

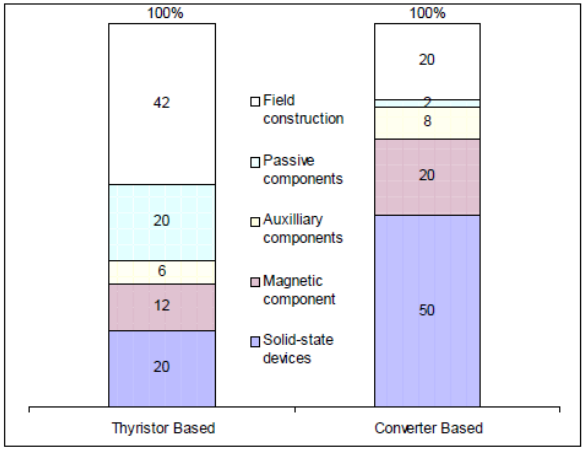
Power Converters

- Constitute a large portion of cost associated with HVDC use
- Efficiency is important as installed HVDC capacity continues to grow
- Needed for the integration of intermittent renewables, electric vehicles, and storage
- Multi-terminal HVDC possible

Source: Siemens



Power Electronic Devices

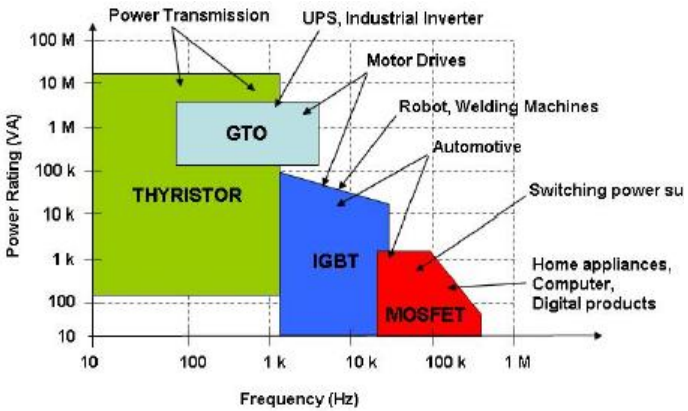


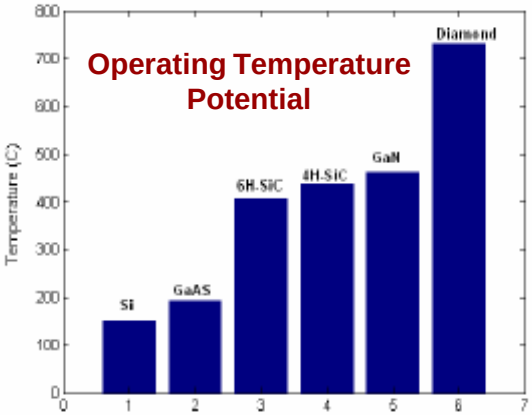
- Cost and performance of devices limit the application of power electronic systems
- Advances in semiconductor materials (SiC, GaN, diamond) and new architectures will help improve this technology

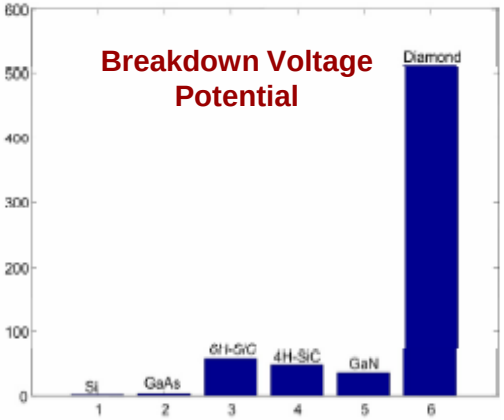
Semiconductor Switch Targets

20 kV, 100 A, 20 kHz
Operating temperatures > 200 °C

Needs: Improved materials processing, thermal management





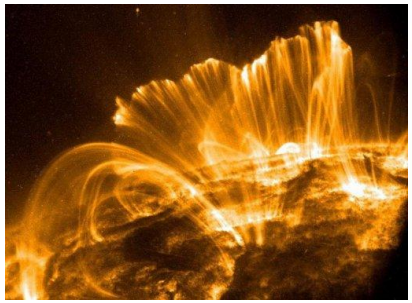


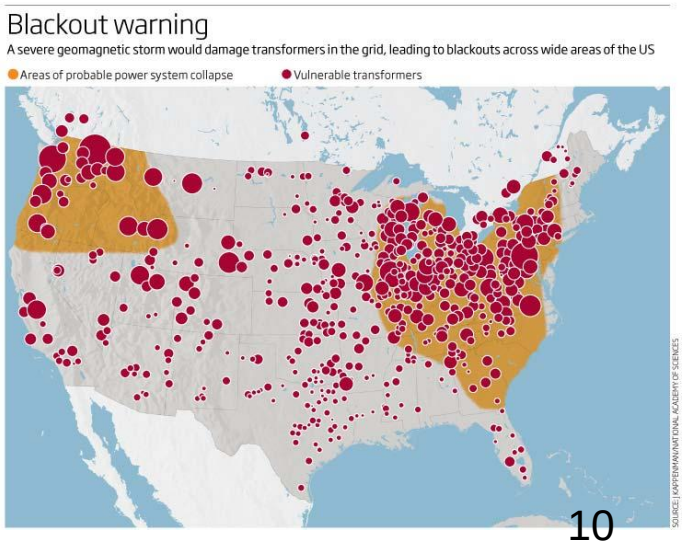
Advanced Transformers

- Ubiquitous and critical component in the grid infrastructure
- Potential for size/weight reduction and multi-functional capabilities (fault current limiting, etc.)
- Can leverage power electronic devices for solid-state transformers
- Improved resiliency to geomagnetic storm events (main point of failure that can lead to blackouts)

Source: OSHA

Source: NASA





Advanced Protection Devices

- Two-way power flows (increased distributed generation, use of electric vehicles, community storage, etc.) can lead to fault currents that are much larger than previously experienced or anticipated
- Advanced protection devices can leverage power electronic advances

Switches & Breakers

- There are no HVDC breakers currently available
- Switches facilitate automation, self-healing, and restoration

Arresters & Limiters

- Protects equipment from surges due to lightning strikes, faults, and interruptions
- HVDC limiters also possible

Summary

- Grid modernization provides many opportunities for replacement of aging infrastructure with advanced components
- Reconductoring is a readily accessible solution that is used
- Routable power will provide significant benefits to the system but will require advanced power electronics that are affordable
- Changing grid will require increase use of new protective functions, protection devices, and approaches

- **Smart Grid Technology and Systems Hub (FY2012 request)** – will focus around the substation to rethink functional characteristics of components and associated material needs for a modernized grid. It will also explore redesigns and retrofits of components for the seamlessly integration with increased data flows, and to enable new markets and services.