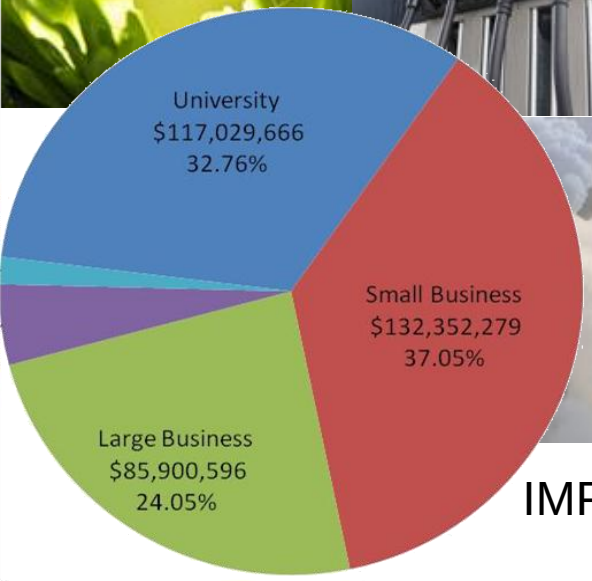
Stimulating Energy Innovation

Rajeev Ram
Program Director
ARPA-E
Pawel Gradzki
Booz Allen Hamilton

ARPA-E PORTFOLIO

Broad Solicitation Electrofuels



IMPACCT

PETRO

GRIDS

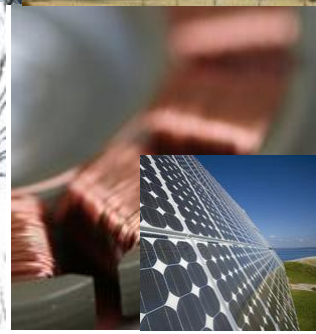
BEEST

HEATS

BEETIT

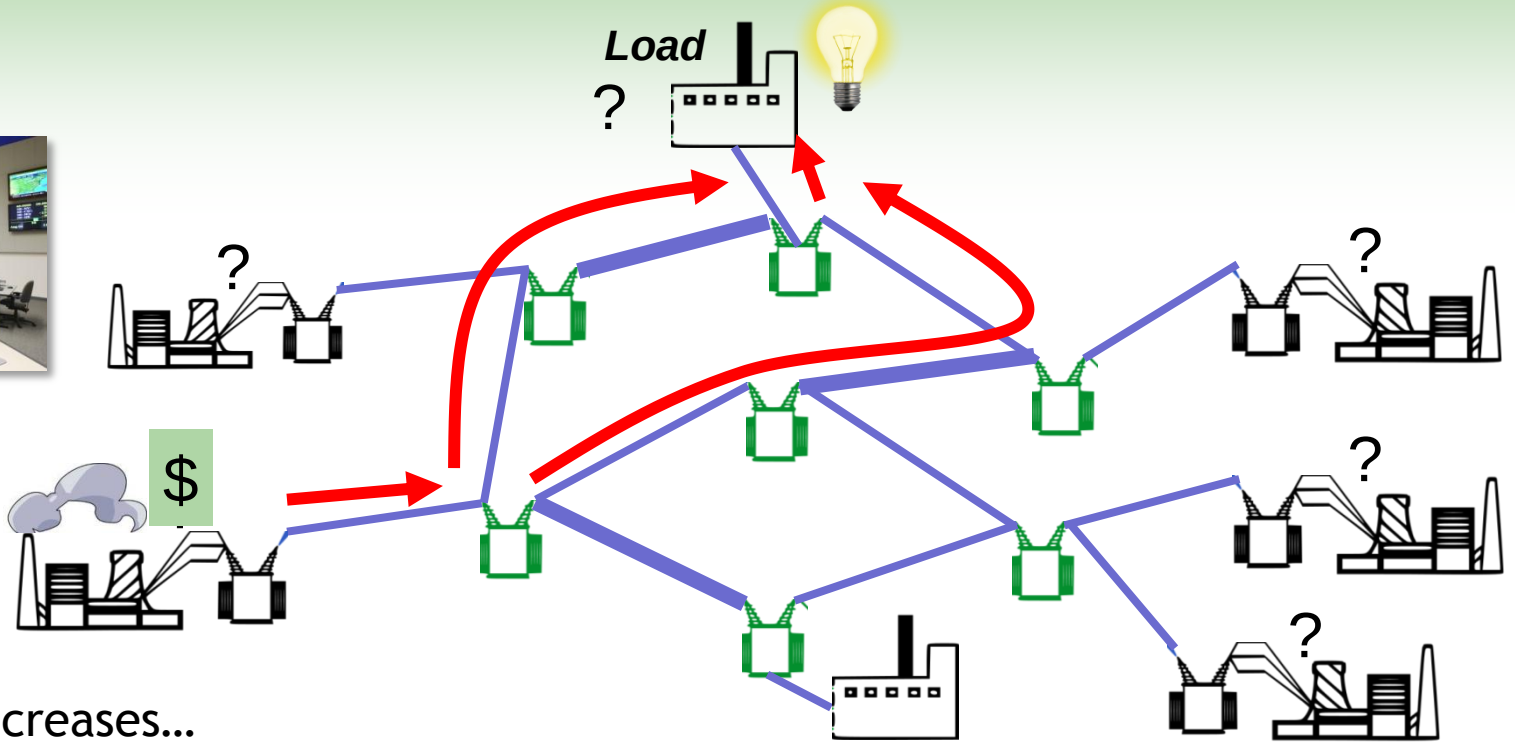
REACT

GENI



ADEPT

Delivering Electricity



As demand increases…

…day-ahead market & spot market coordinate additional generation

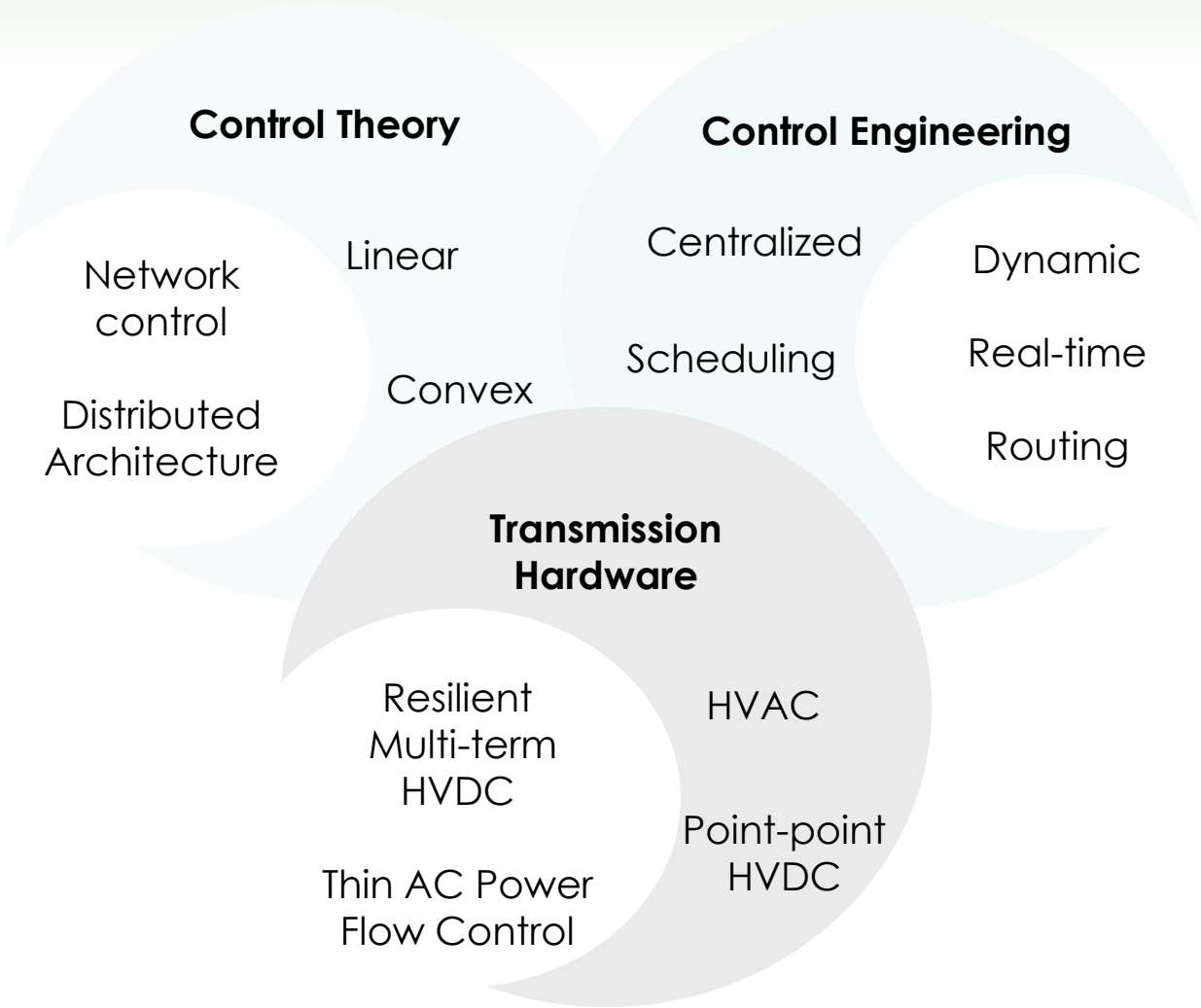
…generator spins up: coal/nuclear/gas (day-ahead), gas (spot market)

…power flows into the grid

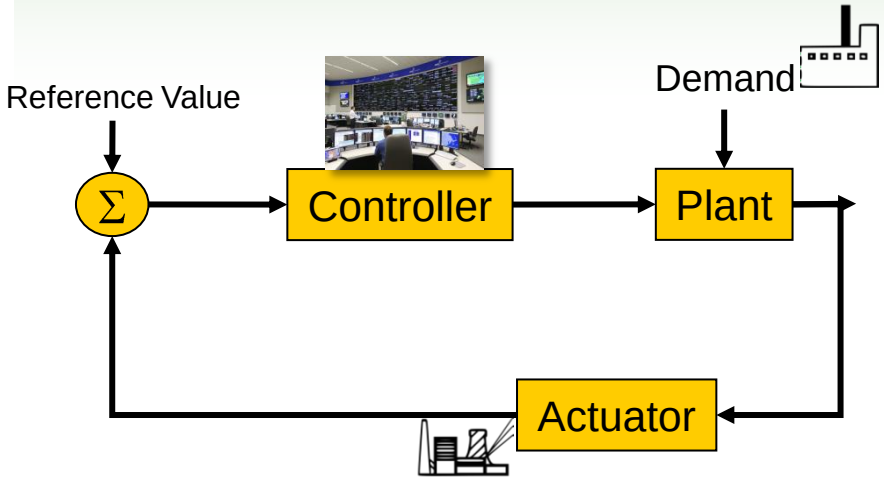
…electrons flow along path of least resistance

…the load draws power from the grid

Workshops find the white space

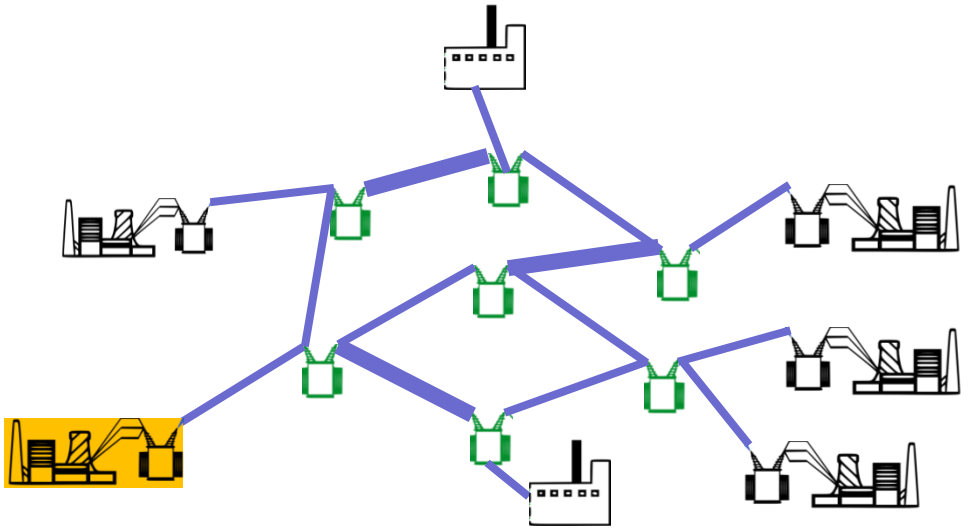


Actuators



Demand Response

Schedule demand
(eg. large industrial loads)



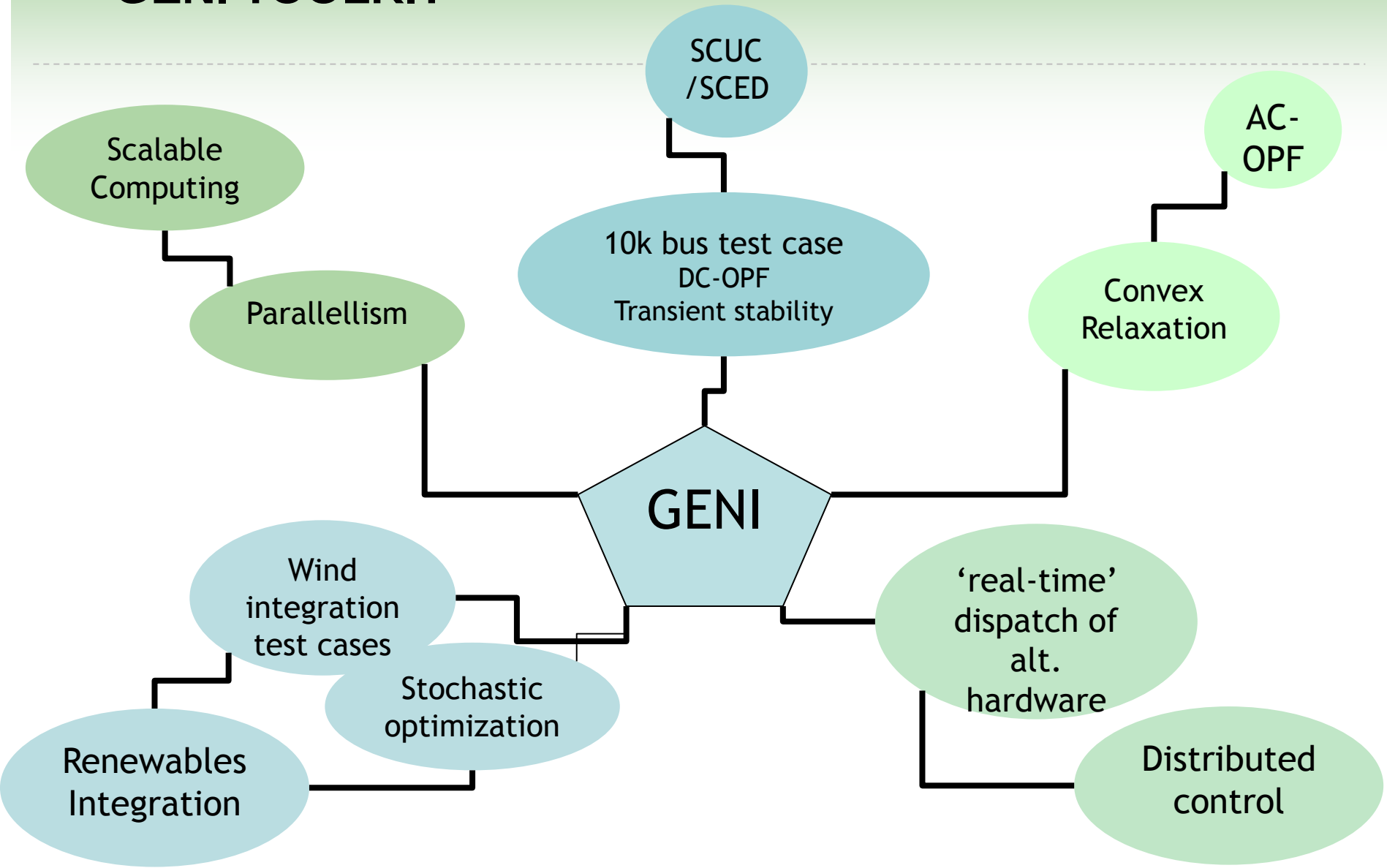
Control in the Grid

Flexible AC Transmission System

Storage

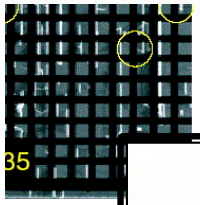
Make renewables dispatchable

GENI TOOLKIT

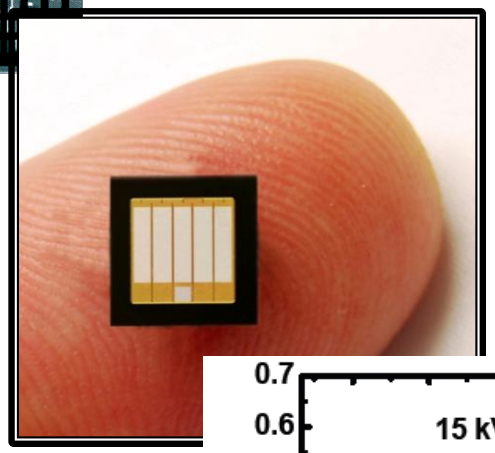


Vertically Integrated Teams

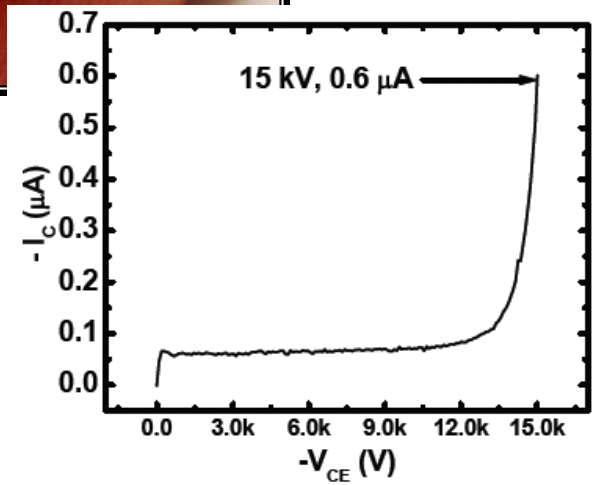
HV Grid-Scale Transistors and Solid-State Transformers



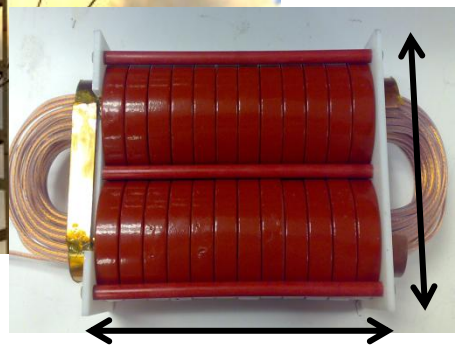
NRL



Cree



NCSU
ABB



30kVA, 50kHz link transformer

GENI ARCHITECTURES FOR THE GRID

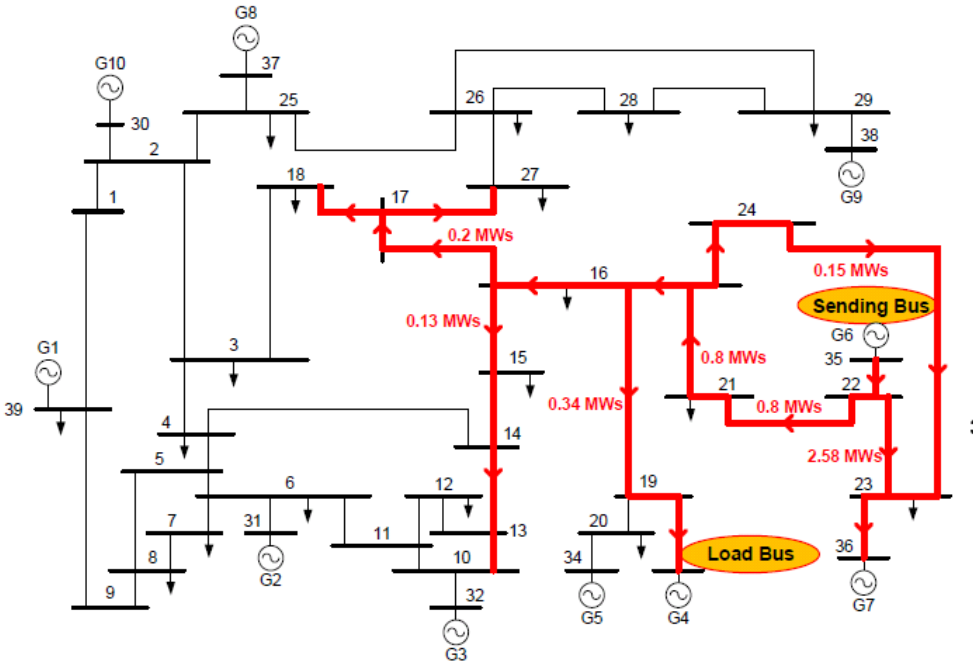
Routing electrical power

Mobilizing large numbers (100k) of small assets

Benefits of Routing Power

Today: Uncontrolled Flows

Power Routing



•Power flow control to route power along underutilized paths, 80% less transmission infrastructure required

GA Tech study of simplified IEEE 39 Bus system with 4 control areas, operation simulated for 20 years, 20% RPS phased in over 20 years, sufficient transmission capacity added each year to eliminate curtailment of renewable generation

TOPOLOGY CONTROL ALGORITHM

- Large size of most real-world power system models (~10k) in the US
- Large number of additional integer variables representing on/off line states
- Not separable
  power flow equations embedded in the optimization formulation

Example

ISO-NE: 689 generators, 2209 loads, 4500 bus, 6600 binary variables

Topology control (DC-OPF approx):

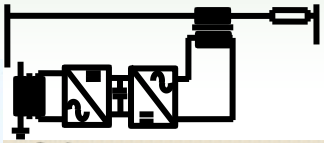
82 hrs [CPLEX on dual-core. 3.4GHz, 1GB RAM]
to optimize state **only 4** transmission lines

savings +5% for summer peak conditions / + 7% for a medium load summer condition

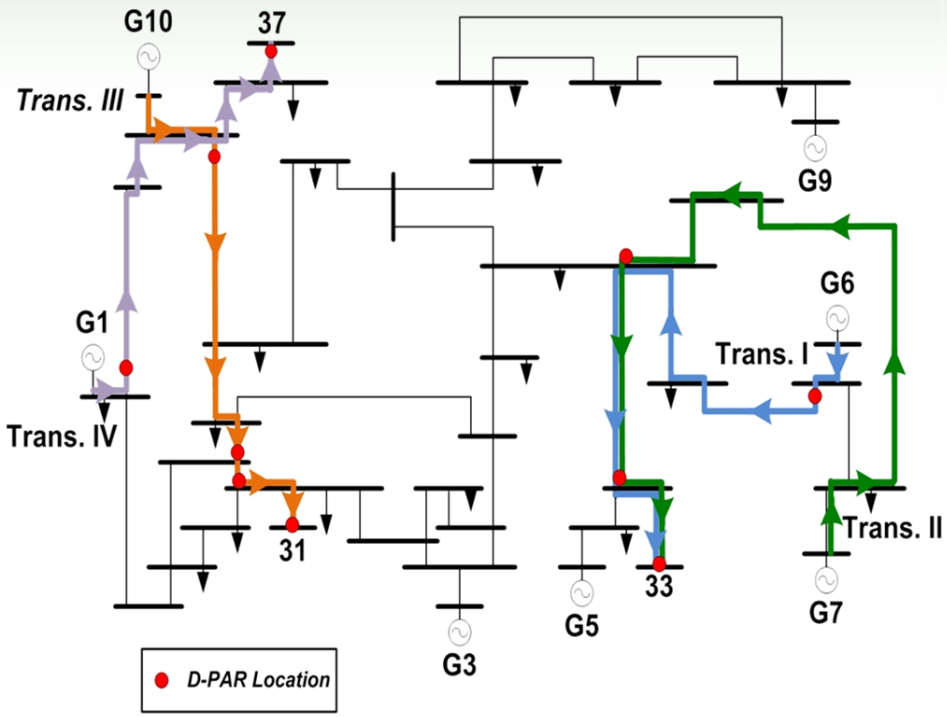
Hedman, K. W., O'Neill, R. P., Fisher, E. B., and Oren, S. S. (2011), "Smart flexible just-in-time transmission and flowgate bidding," IEEE Transactions on Power Systems,Feb 2011.

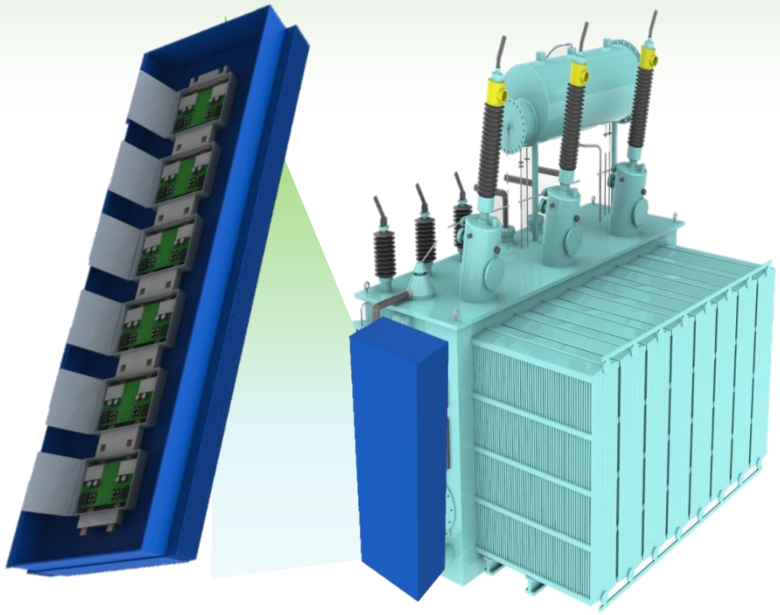
ROUTING POWER TODAY

Utility: AC Univesal Power Flow Controller



Vertically Integrated Teams
Power Routers





augment existing transformers

Varentec EPRI

Georgia Tech

AUKESHA TRANSFORMERS · SERVICE TRAINING · COMPONENTS

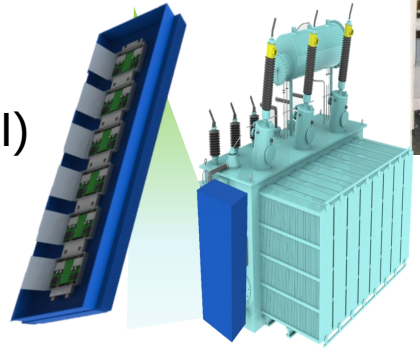
- 10X lower than BAU ($30/kW)
- 13 kV/1MW units in tie-line field demo
- 13 kV 5 bus test bed to show routing

SOUTHERN COMPANY

ARPAE PROGRAMS DEFINE PROBLEMS…
…NOT SOLUTIONS

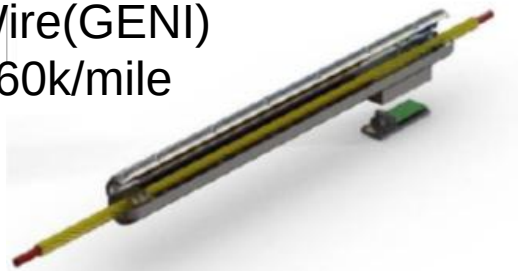
NYPA UPFC

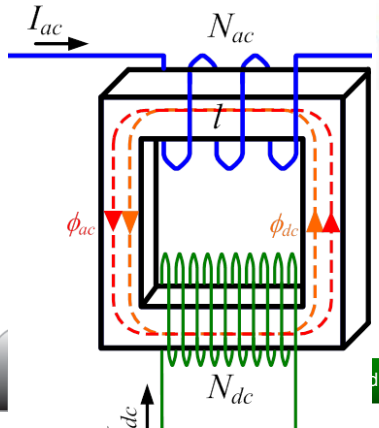
$140-300/kVA



Varentec (GENI)
$20-30/kVA

SmartWire(GENI)
$36k-60k/mile



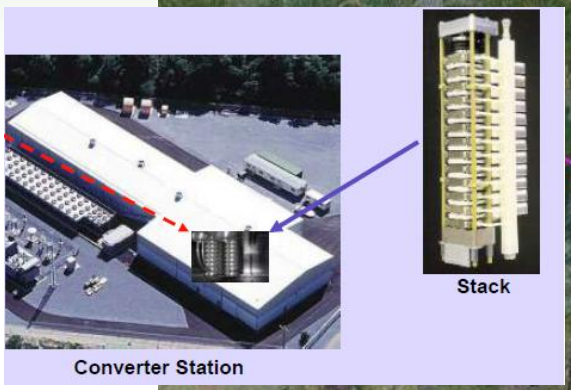


ORNL (GENI)
$4/kVA

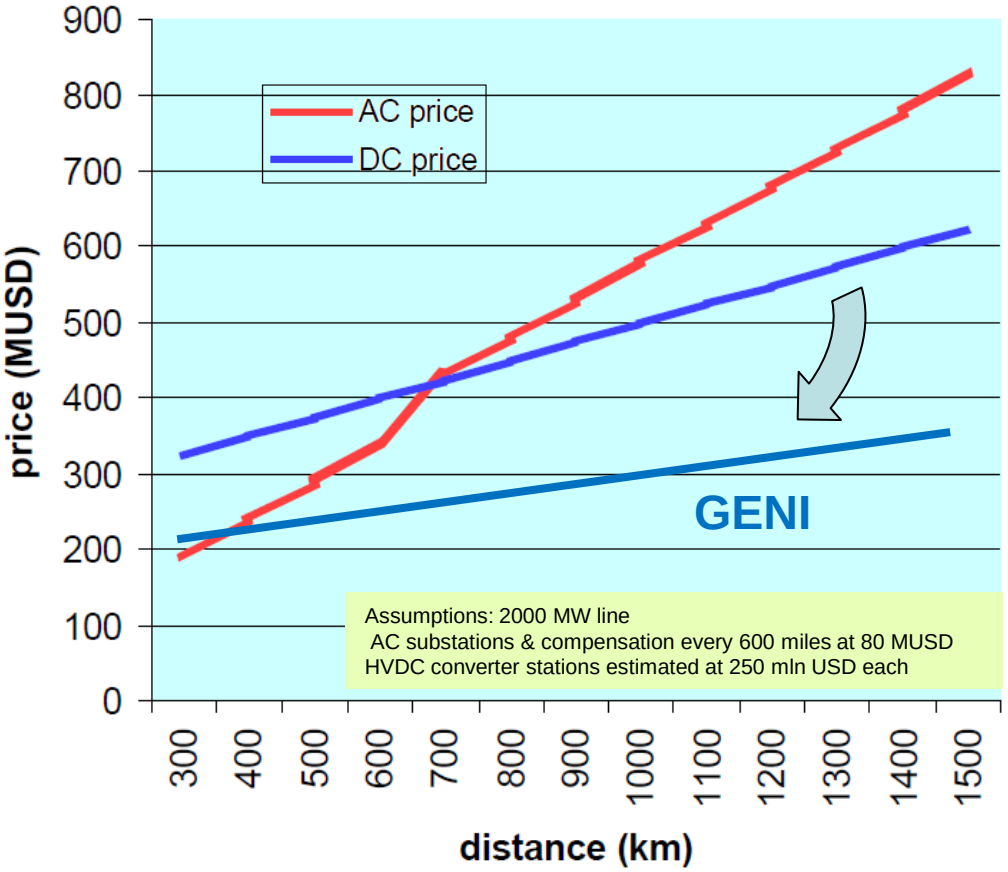
A PORTFOLIO OF APPROACHES

ROUTING POWER TODAY

Multiterminal HVDC



Source: Rudervall (2000)

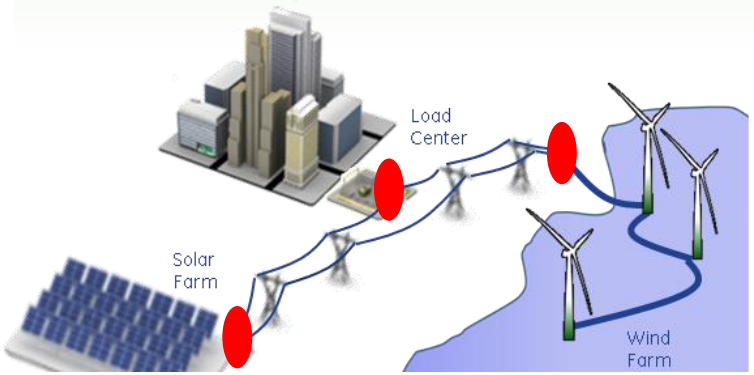


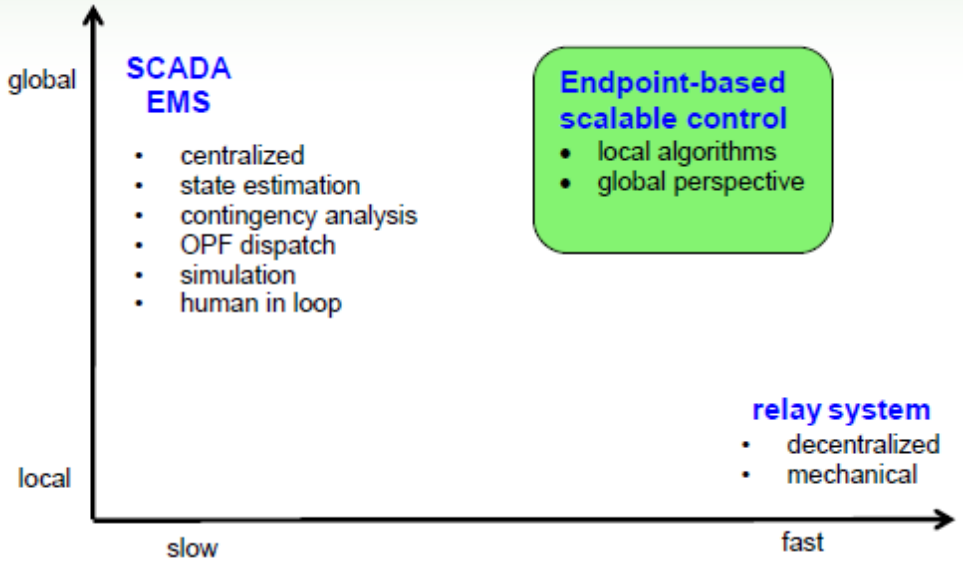
GENI ARCHITECTURES FOR THE GRID

Routing electrical power

Mobilizing large numbers (100k) of small assets

Scalable real-time decentralized Volt/VAR control





Key Innovations

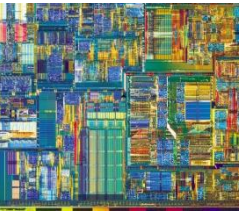
- Distributed control through local sensing, computation, and communication, yet jointly optimize certain global objectives
- ***Characterize AC-OPF subproblems that are polynomial-time solvable***
- Propose a new approach to solve OPF
- 100k inverters for Volt/VAR control

Vertically Integrated Teams
Algorithms for Topology Control

Charles River Associates	Project management, algorithms, impact assessments, integration, commercialization
Boston University	Optimization algorithms, market design issues
Tufts University/ Northeastern University	Express algorithms for voltage and transient stability analysis
Polaris Systems Opt./ Paragon Decision Technology	Software implementation
PJM Interconnection	Operation and implementation consulting and review

Estimates indicate that implementation of TC in the entire US electrical grid would save of $1-2 billion in generation costs and would reduce the needs for transmission investments

STIMULATING INNOVATION FROM ADJACENT FIELDS



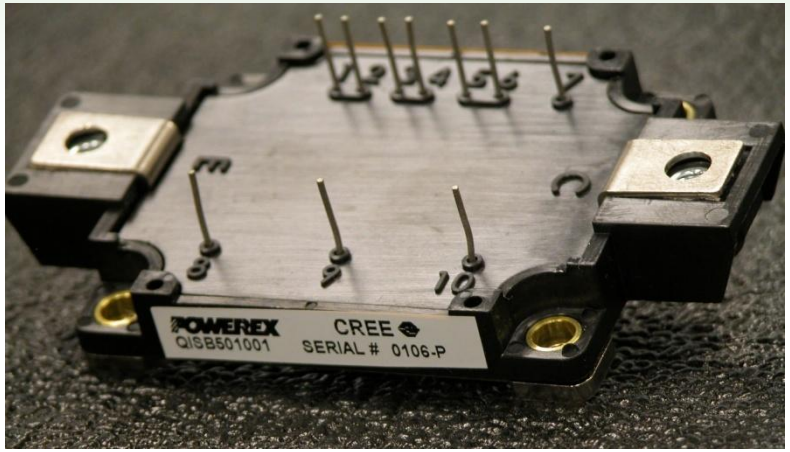
COLUMBIA UNIVERSITY
DIGITAL KNOWLEDGE VENTURES

BERKELEY LAB

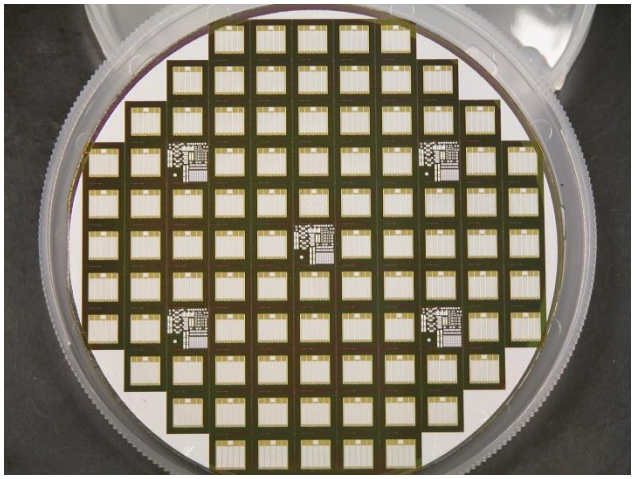
OpenADR, low-cost, internet-protocol based telemetry solutions, and intelligent forecasting and optimization techniques to provide "personalized" dynamic price signals to *millions* of customers in timeframes suitable for providing ancillary services to the grid

Grid Scale Electronics

Cree, NRL, NCSU, ABB



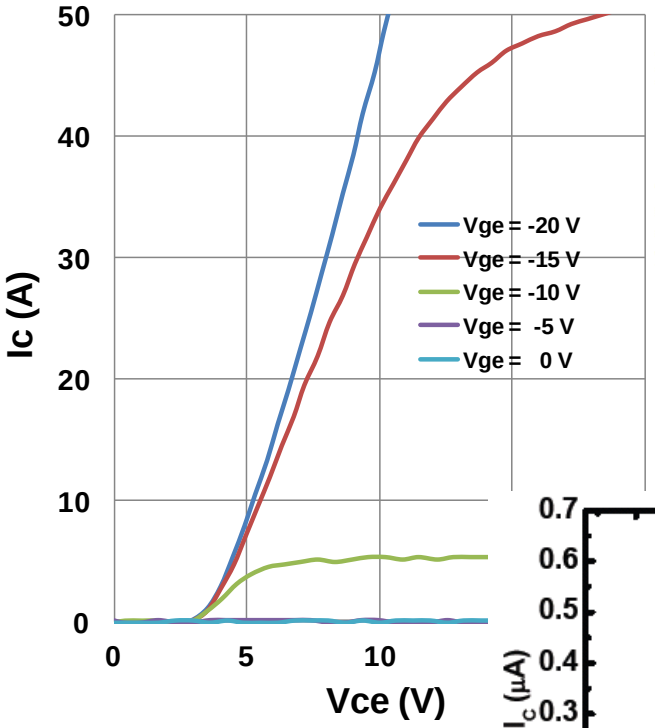
- 15 kV SiC IGBT Switch Module – World's Highest Voltage Semiconductor Switch

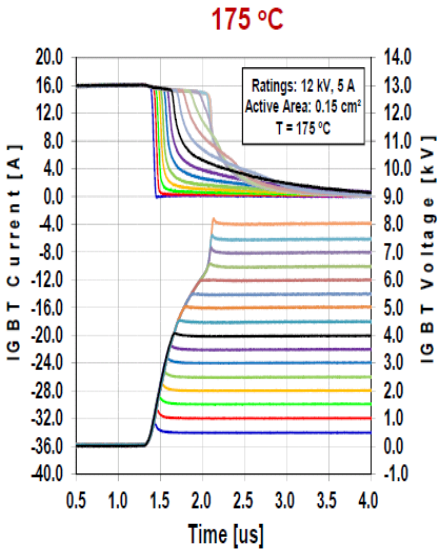


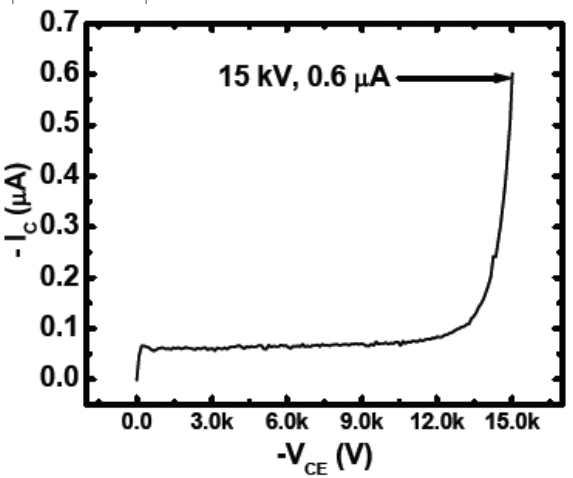
- 15 kV/10 A SiC p-IGBTs Fabricated On 100 mm 4HN-SiC Wafer

Copyright © 2012, Cree, Inc.

- Developed **15 kV SiC IGBT – World's Highest Voltage Semiconductor Switch**



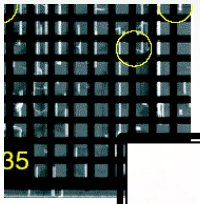


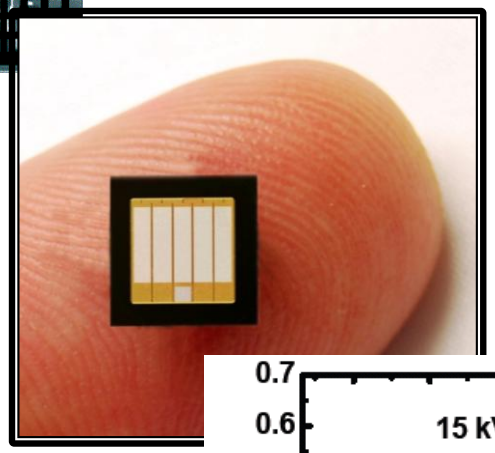


- **15 kV/20 A SiC p-IGBT**
- V_F = 6.5 V @ 20 A, V_{GE} = 20V
- State-of-the-Art SiC p-IGBT Developed Under ARPA-E ADEPT Program

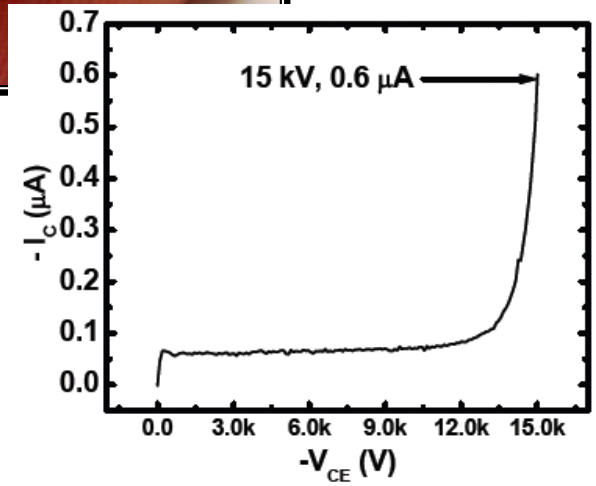
HV Grid-Scale Transistors and Solid-State Transformers

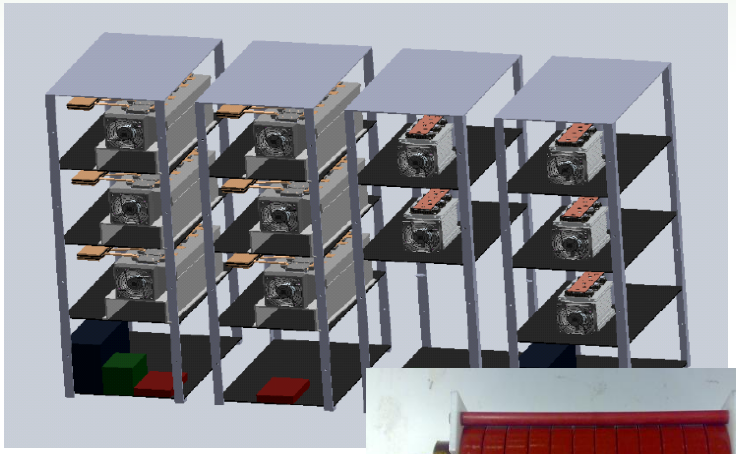
NRL



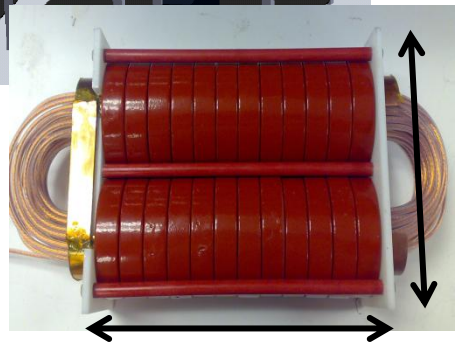


Cree





NCSU



30kVA, 50kHz link transformer

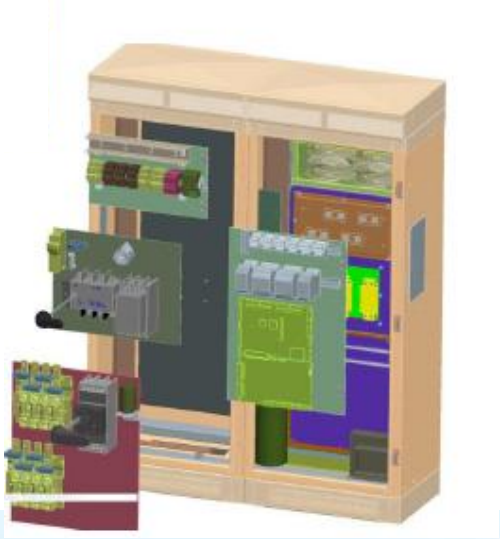
CREE POWEREX
NC STATE UNIVERSITY ABB

SOLAR ADEPT TARGETS

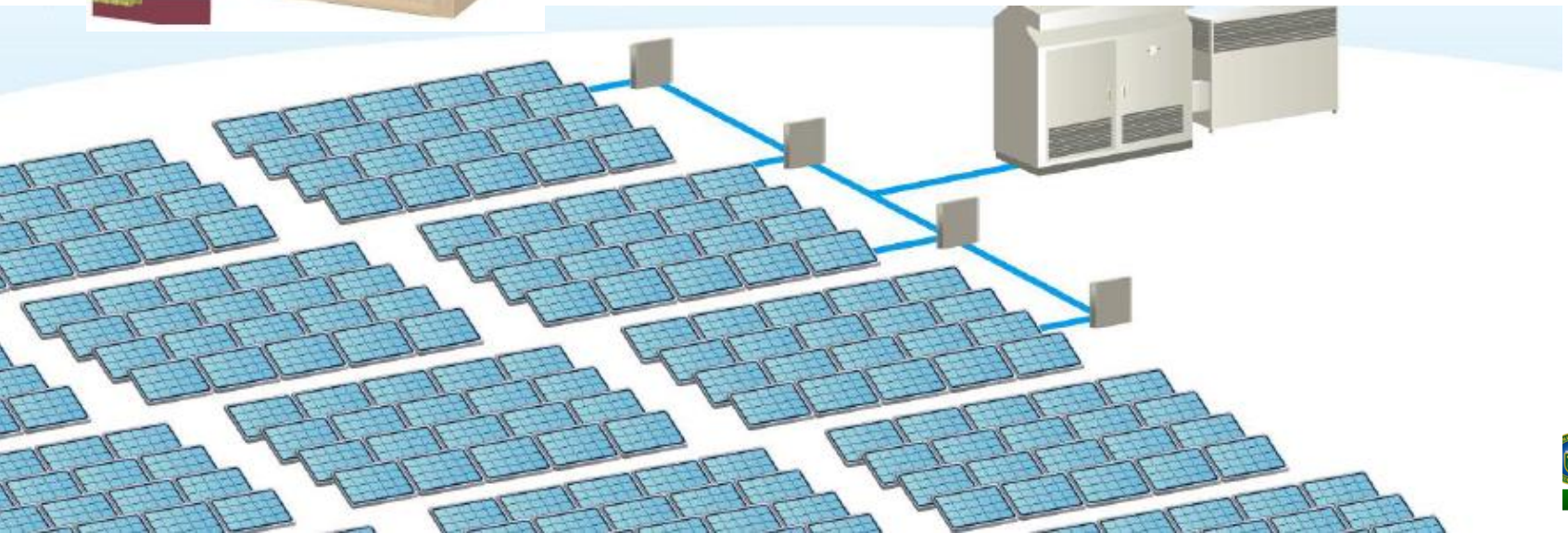
System Categories	Cost	Voltage & Power	CEC Efficiency	Size
Category 1 **Sub-module converter (Smart bypass)**	$0.05/W	>3 converters /module	>98% cell-to-AC MPPT	Single-chip DC/DC Inside Module Frame
Category 2 **Microinverter (Residential)**	$0.20/W	>600 V >250 W	>98% cell-to-AC	< 2 lbs Integrated: < 10 parts
Category 3 **Lightweight (Commercial)**	<$0.10/W	100kW	>98% cell-to-AC MPPT	< 50 lbs
Category 4 **Utility-scale Converters**	$0.10/W	> 2 MW scalable	>98% module-to-grid	< 1000 lbs

UTILITY SCALE INVERTER

1MW Photovoltaic Inverter

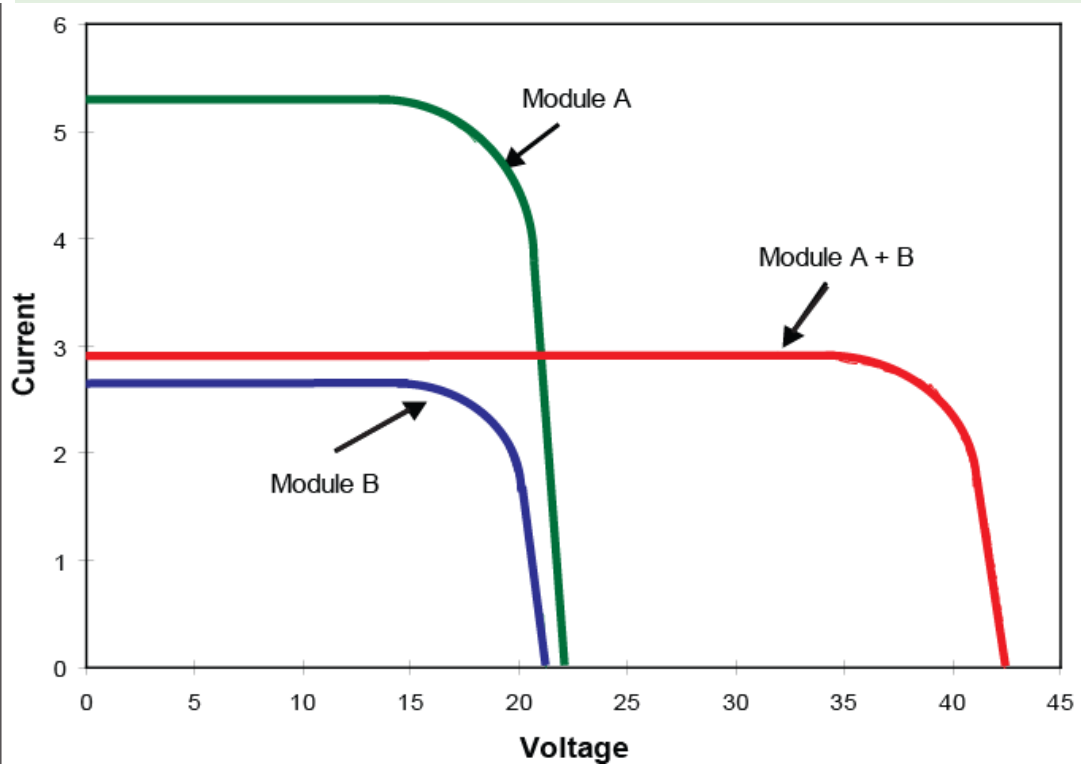


- Weight 10,000 lbs
- Modular from 50 kW – 1 MW
- Si IGBT (motor parts)
- 30% cost magnetics (steel & copper)
- $0.2/W (in China $0.17/W)
- 10 yr life (20 yr extended warranty)
- >500kW (approx annual sales 1k units)



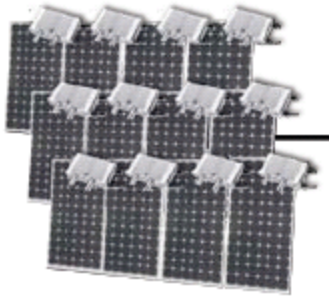
U.S. DEPARTMENT OF ENERGY

DISSIMILAR MODULES IN SERIES



Shade	Power Loss Series Connection
0.15%	3.7%
2.6%	16.7%

MICROINVERTERS



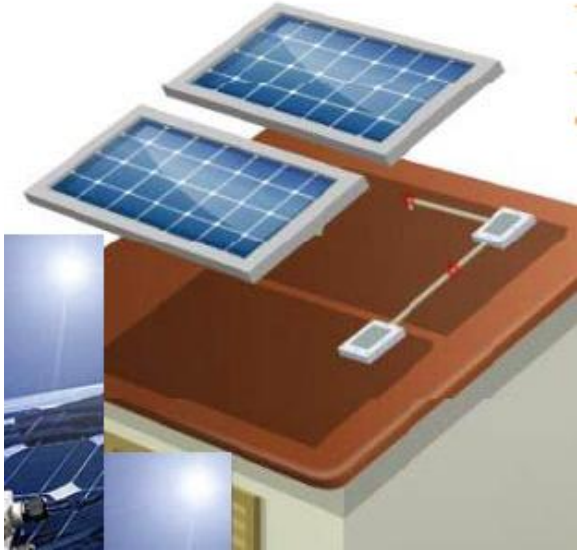
PV Modules
with Microinverters

Barriers to adoption:

- Cost to Install
- Risk Averse Customers
- Cost to Maintain/Repair
  (multiple point of failure)

Transformer

Utility Grid



MULTISTAGE INVERTER

BASE CASE

1/10 the weight , 1/3 lower losses, ½ the manufacturing cost

	Power (Watt)	Weight (lbs)	Lbs/kW	CEC Efficiency	Est. Mfg Cost
PVPowered	35K	1200	34	95.5%	$10K
SatCon Power Systems	30K	1204	40	95.0%	$10K
Ideal Power Converters	30K	80	2.7	97.0%	<$5K

Hi-voltage switches and hi-frequency transformer

Advanced Research Projects Agency • ENERGY

SEARCH

U.S. DEPARTMENT OF ENERGY

Investing in High Risk/High Reward Energy Research

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- Programs
- ADEPT
- BEEST
- BEETIT
- Electrofuels
- GENI
- GRIDS
- HEATS
- IMPACCT
- Other Projects
- PETRO

PROGRAMS MAIN OVERVIEW

ARPA-E programs explore creative "outside-the-box" technologies that promise genuine transformation in the ways we generate, store and utilize energy. Unlike conventional DOE research, ARPA-E funds concepts that industry alone cannot support, but whose success would dramatically benefit the nation. Its high risk, high reward programs aim to substantially reduce foreign energy imports; cut energy-related greenhouse gas emissions; and improve efficiency across the energy spectrum.

arpa·e INTERACTIVE PROJECT MAP

Search and view information on projects funded by ARPA-E using our **interactive map**.

PETRO

REACT

HEATS