FREEDM System: Changing The Paradigm for Innovation

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Innovation: What can it do in one hundred years!

Evolution of Computer Power/Cost

MIPS per $1000 (1998 $)

- 1 Billion
- 1 Million
- 1 Million

1000

1

Universal Robots

G4 eta 2050 (reasoning)

G3 eta 2040 (imagination)

G2 eta 2030 (adaptation)

G1 eta 2020 (skills)

Utility Robot

e 2010-2015

3D perception
2000 in use

2D mapping robots

SRI Shakey

Stanford Cart

1970-1980

Hopkins Beast

Grey Walter

Tortoise

1960

after Moravec
Innovation in Electric Distribution
1930s to 2009

We need a major paradigm shift in the industry
A Paradigm Shift like the Internet

Pre-1980s

Centralized Mainframes

Paradigm Shift

Internet

Distributed Computing
- Shipping 250M pcs/yr.
- Ubiquitous ownership
- Ubiquitous use
- Ubiquitous sharing

Innovation & Industry Transformation

FREEDM Systems Center
Paradigm Shift for the Power Industry

Today
Centralized Generation

Paradigm Shift
FREEDM System

Innovation & Industry Transformation

Distributed Renewable Energy Resources (DRER)
- Ubiquitous sales
- Ubiquitous ownership
- Ubiquitous use
- Ubiquitous sharing

New technologies for distributed renewable energy
New energy companies based on IT and power electronics technologies

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A Comparison

**Internet/Computer**
1) Plug-and-Play Interface (RJ45, USB)

2) Router

3) Open Standard Protocol and Operation System (TCP/IP, HTML)

**Power Grid**
1) ?

2) ?

3) ?

A New Grid
Like an Energy Internet
FREEDM System Vision

Legacy grid

User Interface

Market & Economics

69kV

FREEDM Substation

IFM: Intelligent Fault Management

IEM: Intelligent Energy Management

DRER: Distributed Renewable Energy Resource

DESD: Distributed Energy Storage Device
Plug-and-Play Energy Home

SST: Solid State Transformer
DGI: Distributed Grid Intelligence
Solid State Transformer
Based on 15 kV, 10 kHz IGBT

Distribution Transformer

Solid State Transformer (SST)

Size reduction
Weight reduction

7.2 kV
AC

120V / 240V
AC

10 kHz IGBT

High Voltage H-Bridge

Low Voltage H-Bridge

DC/DC Converter

DC/AC Inverter

AC/DC Rectifier

High Frequency Transformer

12 kV DC

7.2 kV AC

120V / 240V AC

Ls Cs

Port 1

Port 2
Simulated SST Capabilities

Project Y1.E.C5
Prof. Raja Ayyanar (ASU)

- A SST model is developed and used by center teams
- Unity power factor or arbitrary VAR support
- Voltage regulation (120V and 400VDC)
- Voltage Sag Rid Through
- Short circuit current limiting
## Comparison With Existing Systems

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<td>High DER/DESD penetration</td>
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<td>Enabling energy market</td>
<td>No energy market</td>
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Research Plan

Toward Green Energy Society

Today's non-green legacy grid

12 kV 1 MW FREEDM Green Energy Hub Testbed

System Demonstration

Integration

Current system lacks:
- Distributed control
- Communication
- Controllable transformer
- Storage
- Fast fault protection

Requires:
- New power devices
- Better storage
- New systems theory

Four Generation Development

Enabling Technology

Fundamental Science

Intelligent Fault Management (IFM)
Intelligent Energy Management (IEM)
Plug-In Hybrid Electric Vehicle (PHEV)
Plug-In Electric Vehicle (PEV)

Basic Deliverables

Theory & Models
Devices
Storage Cell

- Reliable & Secured Communication
- Distributed Grid Intelligence
- Solid-State Transformer
- Distributed Energy Storage Device
- Fault Isolation Device

Theory & Models

System Theory Modeling & Control

Post-silicon Devices

Advanced Storage

Four Generation Development

FREEDM Systems Center
Control Roadmap

Multiple FREEDM Systems

Level 3 FREEDM System Level

Level 2 SST Level

Level 1 User Level

Sub-Transmission Line

1MVA IEM

Functions:
- IEM functions
- PHEV control
- Islanding from main grid
- IFM functions

IFM

12 kV AC Bus

DGI

IEM

20 kVA SST

IFM

120V AC

400V DC Bus

LOAD

DESD

DRER

DRER

20kVA IEM

Functions:
- Unit Power Factor
- Regulation of AC and DC output voltage
- Voltage sag ride through
- Limit Fault Currents
- IFM functions

120V AC

DC Bus

Functions:
- Plug-and-play
- Communication with IEM
- Bi-direction Charging
- MPPT (for PV)
- Rectification (variable AC)
- IFM functions
The control must be implemented in a flat-architecture, or distributed environment, self-configured and self-governing.
A generation-III Engineering Research Center (ERC) established in 2008

- **US Partner Universities**
  - NC State University
  - Missouri University of Science & Technology
  - Florida State University
  - Arizona State University
  - Florida A & M University

- **International Universities**
  - Aachen University (Germany)
  - Swiss Federal Institute of Technology (Switzerland)

- **Industry Partners** (35)

- **Innovation Partners** (18)
  - 10 Venture Capital Firms
  - 2 Incubators
  - 4 Economic Development
  - 2 Innovation Education

- **Pre-College Partners**
  - 9 middle schools
  - 5 high schools