Solid State Power Substation Roadmap and Request for Information

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Purpose: To provide an overview of the draft Solid State Power Substation (SSPS) Roadmap, the context for DOE’s Request for Information (RFI), and an opportunity to answer clarifying questions.

• Overview of Roadmap and RFI Questions
  - Roadmap objective
  - Substations, power system trends, and challenges
  - SSPS Converters and their benefits
  - SSPS technology development pathway
  - SSPS technology challenges, gaps, and goals

• Q&A
Roadmap Objective

Solid state power substation (SSPS): the strategic integration of high voltage power electronic converters in substations to provide enhanced capabilities and support the evolution of the grid.

- Provide context, rationale, and potential benefits of utilizing SSPS technology
- Articulate a research and development pathway to accelerate maturation of SSPS
- Capture the state-of-the-art in critical enabling technologies
- Highlight research gaps and opportunities
- Align disparate activities across stakeholder communities
Electric Power System with Substation Types

- Generation Substation
- Transmission Substation
- Distribution Substation
- Customer Substation

Transmission System:
- 500 kV Transmission
- 230 kV Transmission
- 69 kV Sub-Transmission

Distribution System (12 kV):
- Urban Customer
- Residential Customer
- Commercial/Industrial Customer

Generation:
- Power Plant
## Trends and Challenges in a Modernizing Grid

<table>
<thead>
<tr>
<th>Trends:</th>
<th>Challenges:</th>
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<tbody>
<tr>
<td>• Greater deployment of variable and distributed energy resources</td>
<td>• Accommodating distributed generation</td>
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<tr>
<td>• Potential mass-market adoption of electric vehicles</td>
<td>• Enhancing security and resilience</td>
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<td>• Broader customer engagement</td>
<td>• Ensuring reliable operations</td>
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<td>• Increasing use of information and communication technology</td>
<td>• Making prudent investments</td>
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<td>• Aging infrastructure</td>
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<td>• Growing risks</td>
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**RFI Questions:** What issues and concerns not captured in the roadmap most deeply impact the ability of substations to meet the demands of an evolving grid? What are additional challenges faced by utilities that would necessitate power electronic converters in substations?
Solid State Power Substations

- **Grid-scale power electronic systems:**
  - Flexible AC Transmission System
  - High Voltage Direct Current
  - Grid-tied inverters
  - Solid state transformers

- **SSPS converters:**
  Ultimately envisioned as a modular, scalable, flexible, and adaptable power block that can be used within all substations, SSPS converters will serve as power routers or hubs that have the capability to electrically isolate system components and provide bidirectional AC or DC power flow control from one or more sources to one or more loads - indifferent to magnitude and frequency

**RFI Questions:** Is there evidence of a growing need for power electronic converters in substations? If so, in what capacity? What specific challenges would the use of power electronic converters address?
### SSPS Classification and Defining Functions and Features

<table>
<thead>
<tr>
<th>SSPS</th>
<th>Defining Functions and Features</th>
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<tbody>
<tr>
<td><strong>SSPS 1.0</strong></td>
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<tr>
<td>25 kVA – 1 MVA</td>
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</tbody>
</table>
| Up to 34.5 kV | • Provides reactive power compensation  
• Provides voltage and frequency control  
• Capable of bi-directional power flow  
• Allows for multi-frequency systems (i.e., AC and DC)  
• Capable of riding through faults and disruptions (e.g., HVRT, LVRT) |
| **SSPS 2.0** |  |
| 25 kVA – 100 MVA |  |
| Up to 230 kV | + Capable of serving as a communications hub  
+ Enables system coordination of fault current and protection  
+ Provides bidirectional power flow control between transmission and distribution  
+ Enables distribution feeder islanding and resynchronization |
| **SSPS 3.0** |  |
| All Power Levels |  |
| All Voltage Levels | + Distributed control of multiple SSPS for global optimization  
+ Autonomous control for plug-and-play features  
+ Provides black start support and recovery coordination  
+ Enables fully decoupled, asynchronous systems |

**RFI Question:** Comments are requested on the SSPS vision and the three classification of SSPS converters articulated in the roadmap, as well as on the defining feature and functions and the voltage and power ratings.
SSPS Benefits

- Increase energy efficiency
- Improve power quality and system operations
- Increase asset utilization and system optimization
- Enhance protection and system reliability
- Simplify and reduce the costs of capacity expansion and upgrades
- Increase security and resilience
- Enable new grid paradigms and novel business models

**RFI Question:** What are additional benefits of using SSPS converters that should be captured?
RFI Questions: Comments are requested on the SSPS technology development pathway presented in the roadmap. For each classification of SSPS converters, are there other potential applications that have not been captured?
## SSPS Technology Challenges, Gaps, and Goals

<table>
<thead>
<tr>
<th>Category</th>
<th>R&amp;D Challenges</th>
<th>Goals</th>
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</thead>
<tbody>
<tr>
<td>Substation Application</td>
<td></td>
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<tr>
<td>Power Converter Architecture</td>
<td>Modular, flexible, and scalable for various applications with high reliability</td>
<td></td>
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<tr>
<td>Converter Controller and Communications</td>
<td>Local Controls; Basic Plug-and-Play</td>
<td>Grid Forming &amp; Synchronization; Wide Area Connectivity</td>
</tr>
<tr>
<td>Converter Protection and Reliability</td>
<td>Fault and Over-Voltage Tolerant; Withstand EMI and meets BIL; Manages Inrush/Fault Currents</td>
<td>Adaptive/Dynamic; Self-Healing</td>
</tr>
<tr>
<td>System Costs and Performance</td>
<td>$ &lt; 150/kVA &gt; 96% 5 MW/m³ 10 Year MTTF</td>
<td>$ &lt; 125/kVA &gt; 96.5% 10 MW/m³ 20 Year MTTF</td>
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<tr>
<td>Converter Building Block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Module Costs and Performance</td>
<td>$ &lt; 20/kVA &gt; 97% 2.5 W/cm³ 2 Year MTTF</td>
<td>$ &lt; 15/kVA &gt; 98% 5 W/cm³ 4 Year MTTF</td>
</tr>
<tr>
<td>Drivers and Power Semiconductors</td>
<td>1.7 kV $0.1/kW</td>
<td>3.3 kV $0.1/kW</td>
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<tr>
<td>Dielectric, Magnetic, and Passive Components</td>
<td>160 kV/mm 0.1 H/m 6.0x10⁷ S/m</td>
<td>600 kV/mm 1.0 H/m 1x10⁸ S/m</td>
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<tr>
<td>Packaging and Thermal Management</td>
<td>$ &gt; 500 W/(m²°C)</td>
<td>$ &gt; 1000 W/(m²°C)</td>
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<td>Grid Integration</td>
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<tr>
<td>Grid Architecture</td>
<td>Distribution Platform Paradigm</td>
<td>Asynchronous, Fractal, and Multi-frequency Paradigm</td>
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<tr>
<td>Grid Control and Protection Systems</td>
<td>Coordinates with Existing Protection</td>
<td>Dynamic Fault Detection and Adaptive Protection</td>
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<tr>
<td>System Modeling and Simulation</td>
<td>Tools and models capable of analyzing advanced controls, power flows, short circuit, faults, power quality, dynamics, and transient stability</td>
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</tbody>
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SSPS Technology Challenges, Gaps, and Goals

RFI Questions:

• Comments are requested on the R&D challenges identified in the roadmap and their associated goals.

• What R&D challenges not yet identified would prevent SSPS technologies from being realized, as envisioned?

• Comments are requested on the state-of-the-art and the research gaps identified in the roadmap for each of the R&D challenges.

• What additional gaps needs to be highlighted to address the R&D challenges identified?

• What specific actions will need to be taken in the near-, mid-, and long-term to sufficiently address the gaps identified?
Industry Acceptance

- Cost benefit analysis
- Industry standards
- Markets and regulations
- Testing, education, and workforce

RFI Questions: What additional non-technical challenges are there that would prevent SSPS converters from being accepted by industry? What additional standards would be relevant to SSPS technology, as envisioned? What are potential market or regulatory barriers that will need to be addressed?
General RFI Questions:

- Comments are requested on the technology topic described in the roadmap,
- What is the appropriate Federal role in advancing this technology area?
- What are some organizational roles in helping to advance this technology concept?
- What amount of resources would be required to fully implement the roadmap?
Questions?

Request for Information:

- Submit comments using Excel spreadsheet by May 7, 2018
- Submit comments to: DOE.SSPS.Roadmap@hq.doe.gov
- Submit any questions to: kerry.cheung@hq.doe.gov