SOO Green HVDC Link:
Securing Supply and Delivering Capacity

PJM HVDC Senior Taskforce Meeting #2
August 17, 2020

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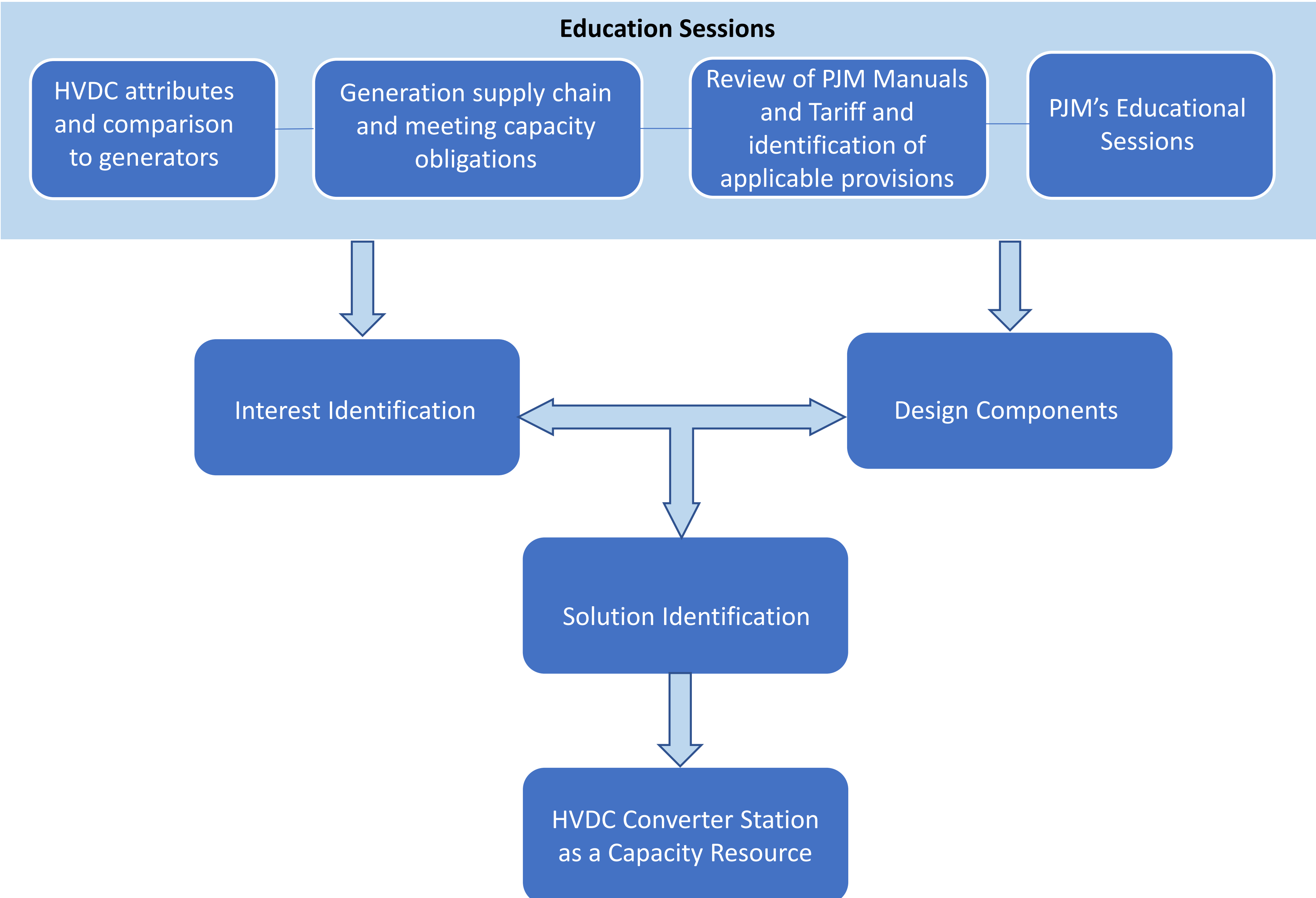
Introduction

- HVDCSTF Meeting #1 provided PJM and stakeholders an overview of HVDC Converter Station technology and a comparative discussion on operational attributes (from Manual 14D) of an HVDC Converter Station and various PJM capacity resource types
- This discussion brought-out a need for additional educational sessions on the following topics:
  - How do PJM Capacity Resources (such as CCGT generation resources) secure supply and deliver capacity?
  - Similarly, how do HVDC Converter Station resources secure supply and deliver capacity?
  - What are additional attributes critical for a PJM Capacity Resource based on review of PJM Manuals?
- Roadmap:
  - This discussion can inform future HVDCSTF discussions on Design Components, Options and Solution Packages by identifying relevant applicable manual and tariff provisions that may need to be addressed to enable HVDC converter stations as capacity resources

Road Map



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Session 1 Recap:
Technology and Operational Capability

Technology and Operational Capabilities

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Fuel Source	Electric power from generating facility delivered by the power grid	Natural gas delivered using pipelines/ transportation	Uranium delivered using transportation	Electric power from generating facility delivered by the power grid
Categorization	Baseload, Intermediate load and Peaking scenarios	Baseload and Intermediate load scenarios	Baseload scenarios	Peaking load scenarios
Generator Real Power Control *				
Delivery of Energy at POI (for US grids)	Can deliver electric energy in the form of 3 phase, 60-Hertz alternating current at the nominal system voltage at the POI			
Governor/Speed Control	Can operate on electronic control to assist in maintaining interconnection frequency	Required to operate on unrestricted governor control to assist in maintaining interconnection frequency		Required to operate on electronic control to assist in maintaining interconnection frequency

* Attributes identified in PJM Manual 14D: Generator Operational Requirements

This table lays out technical and operational attributes of a typical PJM generator along with the functionality of an HVDC Converter Station

Technology and Operational Capabilities

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Voltage and Reactive Control *				
Voltage Regulation	Provide voltage regulation through automatic AC voltage control	Require available field-excitation regulators		Require voltage regulators
Reactive Power Variation (under absence of automatic voltage regulator)	Reactive output can be adjusted based on the grid system needs.			
	Reactive power can be adjusted independent of active power output			
Start-Up Voltage Control Requirements	Operation of AC voltage control instantaneous on startup	Operation of AVR in manual mode until full synchronism achieved		Operation of AVR in manual mode until full synchronism (through synchronous inverters) achieved

* Attributes identified in PJM Manual 14D: Generator Operational Requirements

This table lays out technical and operational attributes of a typical PJM generator along with the functionality of an HVDC Converter Station

Technology and Operational Capabilities

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Black Start Capability	Can be used as black start resources (VSC technology)	Open-cycle gas turbines can be used as black start resources	Not available	Can be used as black start resources
Typical Ramp-Up Time	Instantaneous	Typically between 10-30 minutes	Typically around 60 minutes	Instantaneous
Typical Ramp-Down Time	Instantaneous	Typically between 10-30 minutes	Typically around 60 minutes	Instantaneous

This table lays out technical and operational attributes of a typical PJM generator along with the functionality of an HVDC Converter Station

Session 1 Recap:

Interconnection and Reliability Application

Interconnection and Reliability Applications

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Interconnection	Transmission level	Primarily Transmission level	Transmission level	Transmission, Sub-transmission and/or distribution level
Typical Reliability Applications				
1. Capabilities	Provides baseload, intermediate load and peaking load capabilities	Provides baseload and intermediate load capabilities	Provides baseload capabilities	Provides peaking load capabilities
2. Provides reactive support to local system	✓	✓	✓	✓
3. Provides reserves to the RTO	✓	✓		✓
4. Provides frequency control	✓	✓	✓	✓

This table lays out the interconnection and reliability applications of a typical PJM generator along with the functionality of an HVDC Converter Station

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Interconnection and Reliability Applications

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Dispatchability	Fully dispatchable instantaneously with bi-directional continuous power transfer	Fully dispatchable with approx. 10-30 minutes of start-up time	Fully dispatchable with approx. 60 minutes of start-up time	Fully dispatchable instantaneously with bi-directional continuous power transfer (discharging vs charging)
Operational Availability	Operationally available based on contracted generation capacity	Operationally available based on contracted fuel supply		Operationally available for discharge based on existing charge and discharge efficiency
Congestion Management	Available for regional and local congestion management with potential reverse powerflow control	Available for local congestion management	Not widely used for congestion management	Available for local congestion management

This table lays out the interconnection and reliability applications of a typical PJM generator along with the functionality of an HVDC Converter Station

Generator Stations:

Capacity Resources Supply and Delivery Structure

Power Generation Supply Chain

Fuel Source

- Natural Gas
- Coal
- Uranium
- Water
- Solar/Wind
- Electricity from Power Grid

Fuel Delivery

- Pipeline
- Rail/Barge/Truck
- On-site Storage
- Reservoir
- Power Transmission

Energy Conversion

- Gas Turbine
- Steam Plant
- Hydro-Turbine
- Solar PV
- Wind Turbine
- Battery Storage
- **HVDC Converter**

Inter-connecting Substation

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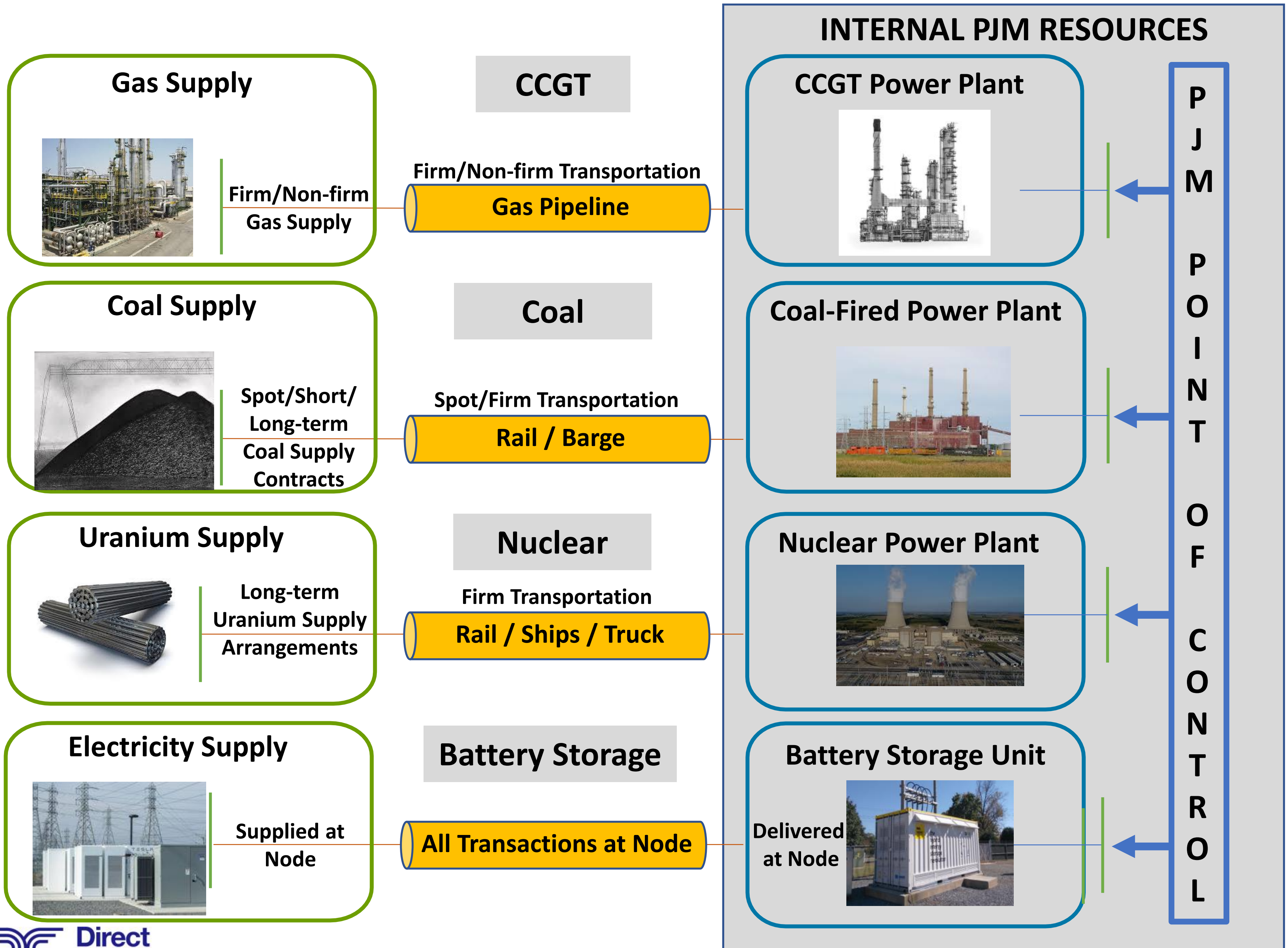
How Internal Capacity Resources Secure Supply and Deliver Capacity



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How Internal Capacity Resources Secure Supply and Deliver Capacity

Securing Supply: Generator operators manage fuel supplies with commercial arrangements that meet their capacity obligations. Different supply chain details and contractual arrangements result in similar commercial operations.

- Firm or non-firm (interruptible) fuel supply contracts
- Firm or non-firm (interruptible) fuel transportation/delivery contracts
- Additional onsite fuel storage may be available

Delivering Energy and Capacity:

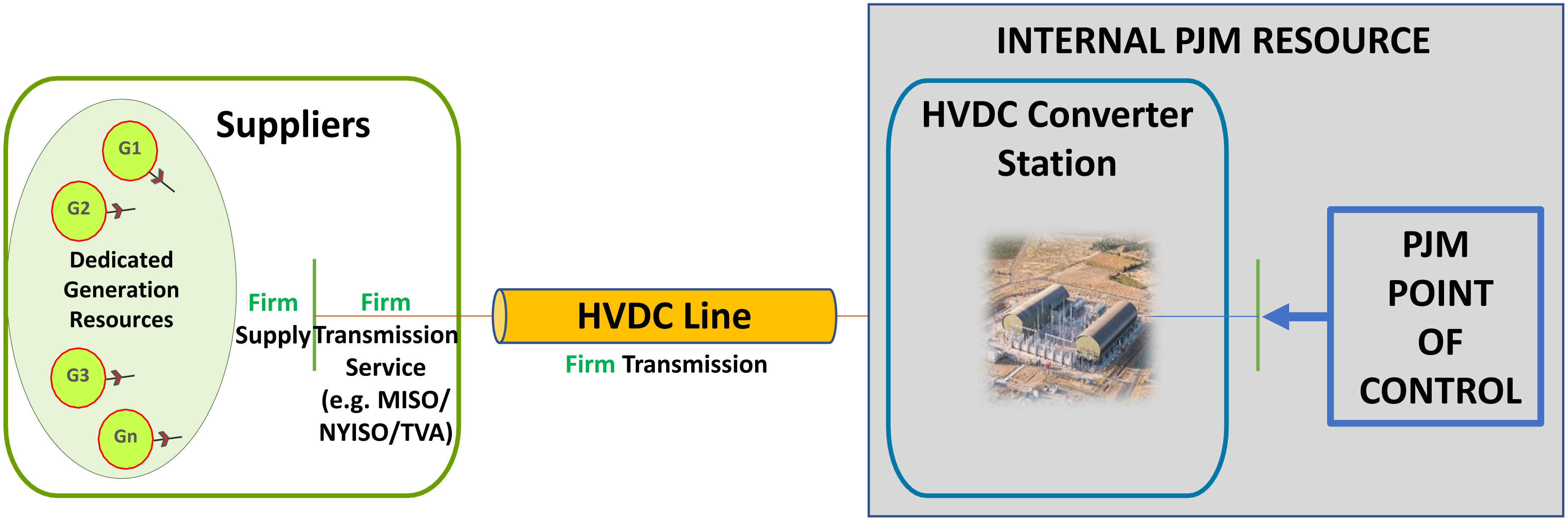
- Generators as capacity resources are subject to Capacity Performance standards and non-performance penalties
- Firm fuel supplies can ensure greater operational availability (energy delivery) and reduction in Capacity Performance penalties

HVDC Converter Station:

Capacity Resources Supply and Delivery Structure

How HVDC Converter Stations Secure Supply and Deliver Capacity

Illustrated here is a generalized HVDC Converter Station supply-delivery structure between an adjacent market area and PJM.



How HVDC Converter Stations Secure Supply and Deliver Capacity

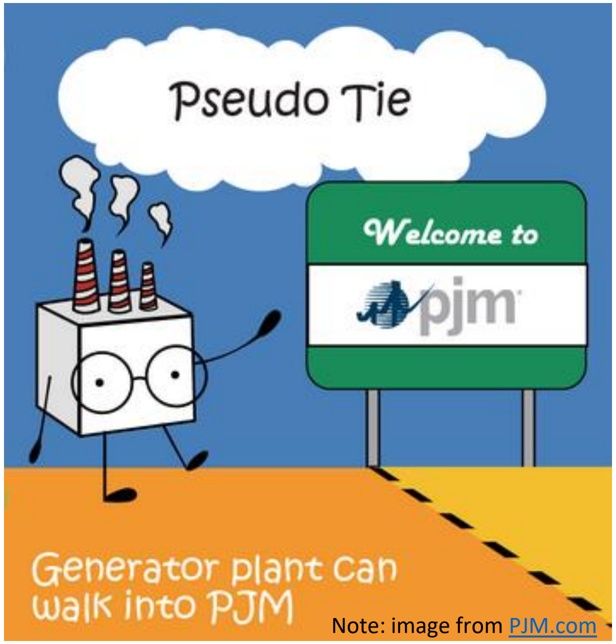
Securing Supply:

- Dedicated (firm) capacity contracts with specific generating resources (steel-in-the-ground) with the ability to over-subscribe supply (i.e. subscribe more generation than the HVDC line capability) to ensure capacity delivery
- Firm drive-out transmission service from adjacent market area along with firm capacity subscription arrangements between Shippers and the HVDC line

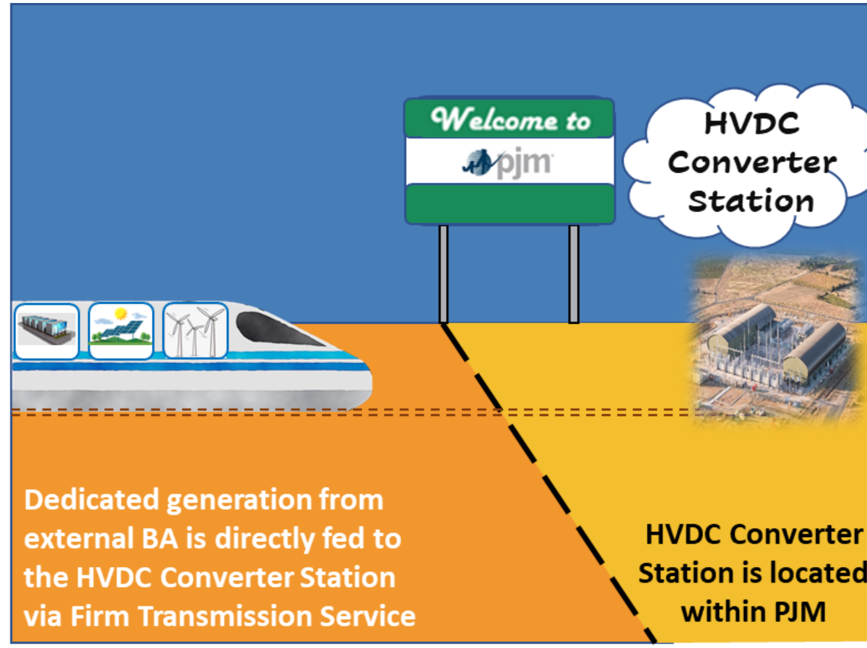
Delivering Energy and Capacity:

- HVDC Converter Station is fully dispatchable by PJM
- PJM issues dispatch instructions to the converter station and energy is scheduled in real-time to effect deliveries into PJM
- Converter Station holds capacity rights and Capacity Performance obligations
- HVDC Converter Station as an internal capacity resource would be subject to Capacity Performance standards and non-performance penalties

Pseudo-Tie Structure Does Not Apply to Internal Resources



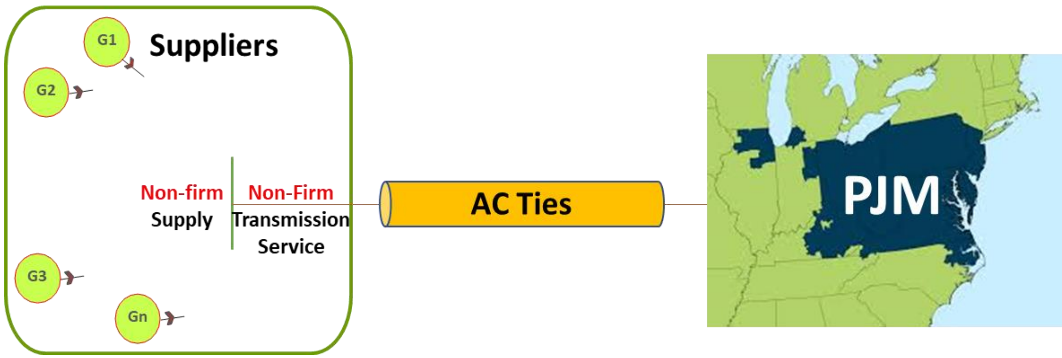
- A Pseudo-tie generating resource electrically transfers its output from an external BA to PJM, enabling functionality similar to an internal resource
- Market-to-Market coordination needed for congestion management
- Seams coordination performed across AC ties



- An HVDC Converter Station is **physically located within PJM, so is an internal PJM resource**
- **PJM can directly control this resource**
- HVDC Converter Station capacity resource is **fully dispatchable** by PJM
- No Market-to-Market coordination (improves market efficiency)
- No seams coordination needed (increases operational flexibility)

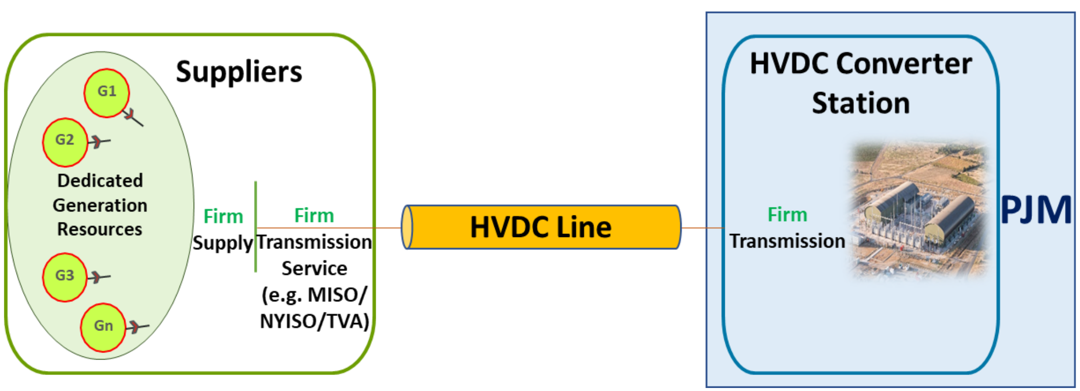
How an HVDC Converter Station Structure Differs from a 'Slice of System' Arrangement

Slice-of-System Arrangement



- X Dedicated supplier generating resources
- X Suppliers with long-term capacity contracts
- X Steel-in-the-ground generating resources
- X Firm transmission service
- X Allows for PJM Control and Dispatch
- X Accountability of each supplier generating resource under CP Penalties/Payments
- ! Use of AC Ties between external BA and PJM, requiring congestion management

HVDC Converter Station Arrangement



- ✓ Dedicated supplier generating resources
- ✓ Suppliers with long-term capacity contracts
- ✓ Steel-in-the-ground generating resources
- ✓ Firm transmission service
- ✓ Allows for PJM Control and Dispatch
- ✓ Accountability of each supplier generating resource under CP Penalties/Payments
- ✓ Use of HVDC Line between external BA and PJM, removing need for congestion management

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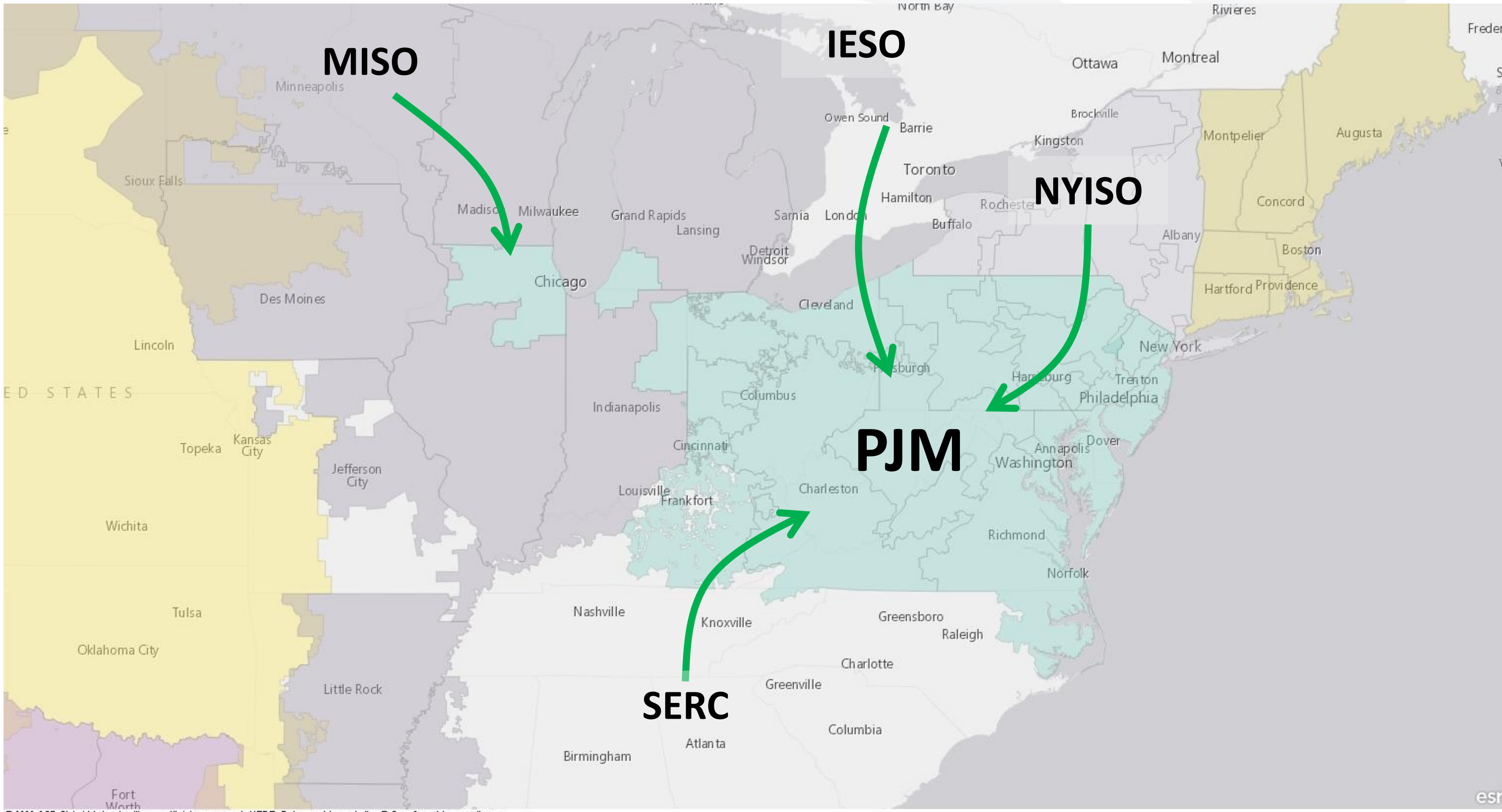
Adjacent Markets with Available Resources for Potential Delivery to PJM



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Attributes of PJM Capacity Resources:

Review of PJM Manuals 14, 18 & 21

Review of PJM Manual 14A – New Services Request Process

Process for interconnecting planned PJM generation capacity resources:

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
New Service Request Type: New resources seeking interconnection in PJM are classified in Manual 14A				
	To be categorized as 'Generation'	Categorized under 'Generation' new service customer request type		
Interconnection Queue Entry: According to the Tariff, there are different agreements required to request service depending on the type of planned generation capacity resource				
	To be subjected to Manual 14G and OATT Att. N, Y, BB	Manual 14G and OATT Attachment N, Y, BB		
New Service Request Studies: Phases of study for a New Service Request are identified in Manual 14A				
	To be subjected to all studies associated with 'Generation' service type	Feasibility Study, System Impact Study, Facilities or Combined Feasibility/System Impact Study		

Review of PJM Manual 14A – New Services Request Process

Process for interconnecting planned PJM generation capacity resources:

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
New Service Request Agreements: Manual 14A Section 5 summarizes the types of agreements that PJM tenders to a New Services Customers.				
	To be tendered ISA, IISA, ICSA	Interconnection Service Agreement (ISA), Interim Interconnection Service Agreement (IISA), Interconnection Construction Service Agreement (ICSA) and WMPA (Wholesale Market Participation Agreement)		

Review of PJM Manual 18 – Capacity Market Participation

Capacity market participation requirements for existing and planned PJM generators:

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Participation of Resource Providers: Participation in PJM's Capacity Market is mandatory or voluntary based on classification of resource				
Existing and Planned Capacity Resources	To be included	✓		
Resource Performance Assessment: For a Capacity Resource to qualify as a Capacity Performance Resource product type, the resource must be capable of sustained, predictable operation that allows the resource to be available throughout the entire Delivery Year to provide energy and reserves whenever PJM determines an emergency condition exists.				
RPM Commitment Compliance, Generating Unit Peak-Hour Period Availability (PHPA), Non-Performance Assessment, Summer/Winter Capability Testing	To be subjected to all Resource Performance Assessments	✓		

Review of PJM Manual 18 – Capacity Market Participation

Capacity market participation requirements for existing and planned PJM generators:

<table>
<tr><th>Attributes</th><th>HVDC Converter Station</th><th>CCGT Generator</th><th>Nuclear Generator</th><th>Energy Storage Resource</th></tr>
<tr><td colspan="5">Credit Requirements: The purpose of the RPM credit requirement is to encourage future physical performance, but not necessarily fully guarantee financial obligations related to Capacity</td></tr>
<tr><td>RPM Credit Limit, RPM Credit Requirement, Credit Milestones</td><td>To be required</td><td colspan="3">✓</td></tr>
<tr><td colspan="5">Energy Market Offer Requirements: All generation resources with RPM Resource Commitments are required to offer into PJM’s Day Ahead Energy Market under PJM Manual 11 requirements.</td></tr>
<tr><td></td><td>To be required</td><td colspan="3">✓</td></tr>
<tr><td colspan="5">Base Residual Auction Participation and Incremental Auction Participation: Existing Generation Capacity Resources and Planned Generation Capacity Resources are both eligible to participate in a BRA, with specific requirements. Existing Generation Capacity Resources that were offered and not cleared in a prior auction for the same Delivery Year and Planned Generation Capacity Resources are both eligible to participate in an IA, with specific requirements</td></tr>
<tr><td></td><td>To be required</td><td colspan="3">✓</td></tr>
</table>

Review of PJM Manual 21 – Rules and Procedures for Determination of Generating Capacity

Rules for determining generating capacity for existing and planned PJM generators:

Attributes	HVDC Converter Station	CCGT Generator	Nuclear Generator	Energy Storage Resource
Attaining CIRs (Capacity Interconnection Rights): Based on Net Capability of a unit at the expected summer peak				
	To be assigned CIRs	✓ (are assigned CIRs)		
Installed Capacity (ICAP): Summer Net Capability within the CIR limits				
	To be calculated	✓		
Net Capability: The gross electric power output that can be delivered without restriction after serving ancillary and station load requirements during summer conditions				
	To be calculated	✓		
Summer Capability Verification Testing Requirement: Each resource type is subjected to specific testing requirements				
	To be determined	✓		

New FERC Report to Congress on High Voltage Transmission

On August 7th FERC submitted a report on the *Barriers and Opportunities for High Voltage Transmission* to the House and Senate Appropriations Committees

The report found that High Voltage Transmission can…

- Benefit consumers, the grid and the environment
- Integrate renewable resources onto the grid and connect them to high-demand regions
- Improve access to location-constrained resources in support of renewable resource goals
- Improve grid reliability and resilience by allowing utilities to share generating resources
- Improve frequency response and ancillary services throughout the existing system
- Use existing transmission corridors, such as railroad rights-of-way, to reduce project costs and negative effects on "private landowners and environmental, cultural and visual resources."

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Integration of HVDC Converter as a New Type of Capacity Resource

Problem / Opportunity Statement

PJM's existing Tariff (Reliability Assurance Agreement/RAA and OATT) and manuals allow dispatchable generation resources, intermittent resources and energy storage resources to participate in PJM's Reliability Pricing Model (RPM) capacity market. High Voltage Direct Current (HVDC) transmission lines that have a converter station directly connected to the PJM system, that can follow PJM dispatch instructions and that are backed by a portfolio of firm generation supply are similarly situated to these other capacity resources and can provide reliability benefits to PJM. However, current PJM Tariffs do not allow such HVDC converters to participate in the RPM market—presenting a market barrier to merchant resources seeking to sell bundled energy and capacity in the PJM market.

An HVDC converter station connected to PJM would be capable of performing like any other generating resource on the PJM system. It could contract for firm "fuel" (generation) supply, enabling it to be fully dispatchable with high availability. In fact, HVDC converter stations utilizing modern Voltage Source Conversion (VSC) technology have a demonstrated ability to respond to dispatch instructions quickly. Such stations can provide substantial amounts of reactive power at the point of interconnection, independent of the amount of real power requested. If connected to the PJM grid, such a station could enhance PJM grid stability by mimicking rotating inertia and could provide voltage and frequency support. An HVDC converter could undergo the interconnection process in accordance with PJM Manual 14 like any other generator. Furthermore, the ability to respond to dispatch signals from the PJM system operator would allow an HVDC converter to operate with the same or better responsiveness as other PJM dispatchable generating resources. Finally, in the same way that generating resources can contract for firm fuel supply, shippers on an HVDC facility could secure firm generation supply.

Any other similarly interconnected resource in PJM with the technical capabilities and firm fuel contracts analogous to the technical capabilities and firm supply described above would be eligible to participate in the RPM. However, PJM's existing Tariff (Reliability Assurance Agreement/RAA and OATT) and manuals preclude RPM participation to existing or new generating resources, intermittent resources, and energy storage resources. Given the essential similarities described above, an HVDC converter station located in PJM, delivering generation from another RTO, with the necessary interconnection and shipper arrangements, should be eligible to provide capacity through the RPM.

We would like to work with PJM and its stakeholders to develop a mechanism that would allow HVDC converter stations configured as described above to participate directly in the PJM capacity market. By providing for the integration of merchant inter-RTO HVDC connections into the capacity market, PJM and its customers would benefit from increased competition, greater geographic and technological generation diversity, and the additional instantaneous control offered by dispatchable HVDC facilities.

Direct Connect Development Company

Contacts

Trey Ward, CEO
Direct Connect Development Company
(404) 783-7757
tward@directconnect-dc.com

Joseph DeVito, President
Direct Connect Development Company
(512) 608-8448
jdevito@directconnect-dc.com

Steve Frenkel, Vice President
Direct Connect Development Company
(312) 590-8888
sfrenkel@directconnect-dc.com

Ruta Skucas, Partner
PierceAtwood
(202) 530-6428
rskucas@pierceatwood.com