Electric Grid Design, Take Two: Next Generation Grid Network Control Power Converters, and Renewable Energy Supply

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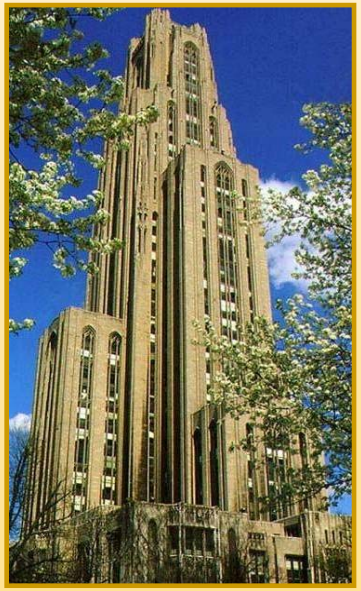
Hashim Al Hassan, Patrick Lewis, Alvaro Cardoza, & Benoit de Courreges

Electric **P**ower & **E**nergy **R**esearch for **G**rid **I**nfrastructure
University of Pittsburgh, Swanson School of Engineering
Pittsburgh, Pennsylvania; USA

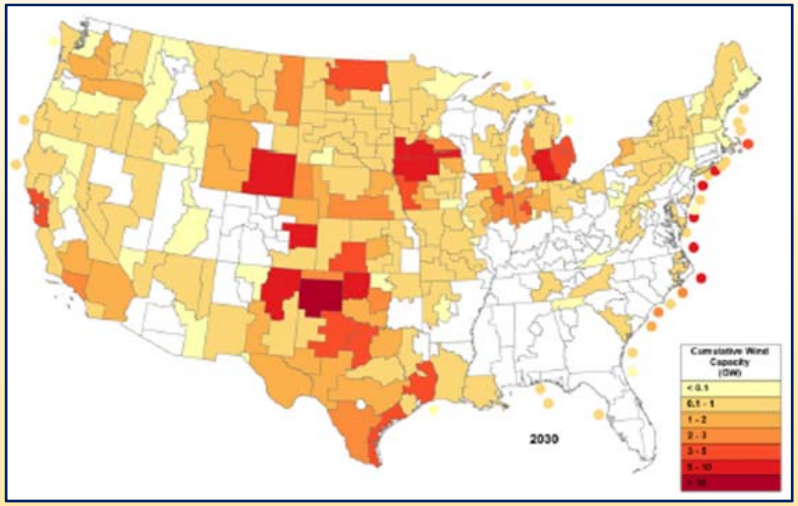


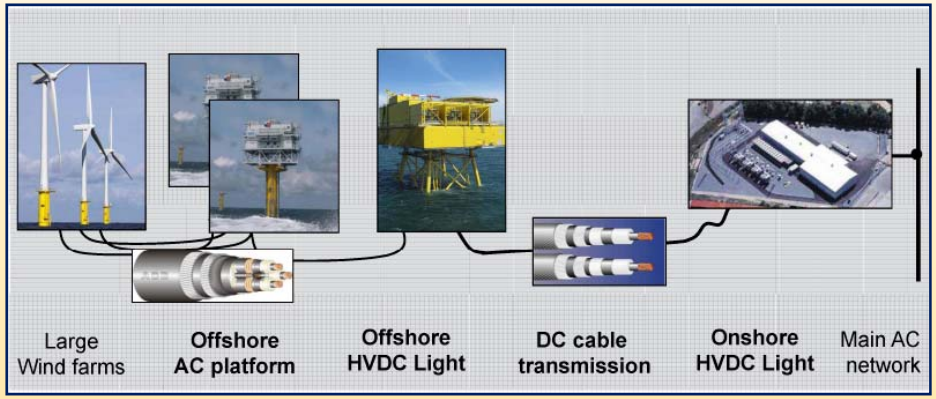
Hashim Al Hassan

National Offshore Wind Energy Grid Interconnection Study

General Background on the Project

- Funded through the Department of Energy, FOA-414: U.S. Offshore Wind, Removing Market Barriers.
- *National Offshore Wind Energy Grid Interconnection Study* contributes to achieving 20% Wind Energy by 2030.





- The scope of the work, as a general statement, is to evaluate the optimal location of setting up **offshore** wind turbines along the perimeter of the **United States** and evaluating ways of interconnecting to the grid.
- Pitt's responsibility is to determine and assess the equipment and vendors that would likely contribute to this cause.

Study Collaborators and General Objective Per Organization

- ABB
  - Principal Investigators; Assess the current state-of-the-art collection and delivery technologies.
- AWS Truepower
  - Determine the wind generation production profile, enhance hypothetical offshore project selection process developed in EWITS, and asses the impact of aggregating onshore and offshore wind.
- NREL
  - Determine expected offshore wind development staging and conduct initial integration analysis.
- University of Pittsburgh
  - Make sure independent assessment of all leading manufacturers of the current state-of-the-art collection and delivery technologies is made and provide an assessment of regulatory issues.
- Duke Energy
  - Regulatory issues assessment.

Key Responsibilities of the Electric Power Program at the University of Pittsburgh

Assessment of Offshore Collection and Delivery Technologies

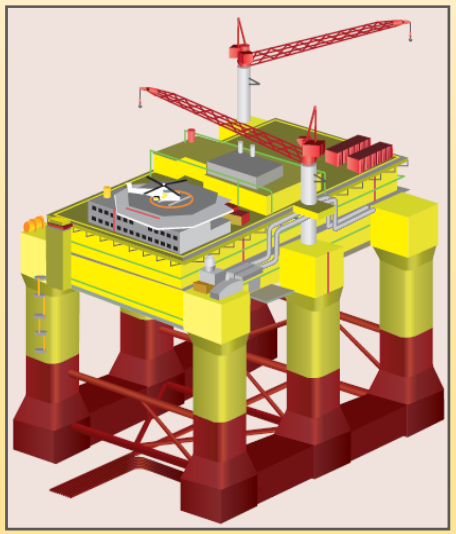
(1)Offshore Collection System Alternatives

(2)Sea-to-Shore Delivery System

(3)Marine Substation Design and Hardware

(4)Undersea Cabling and Installation

(5)Regulatory Issues



Siemens Offshore Design (Left) & ABB Offshore Design (Right)

7TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE
Presented by the Swanson School of Engineering & the Center for Energy

Patrick Lewis

NETL-RUA Grid Technologies Collaborative Next Generation Power Converter

NETL-RUA
Grid Technologies Collaborative

- The NETL-Regional University Alliance GTC
  - An integrated industry/university/government research and development group that advances the state of the art in transmission and distribution system power electronics technologies.
  - Vision: An advanced electricity T&D network

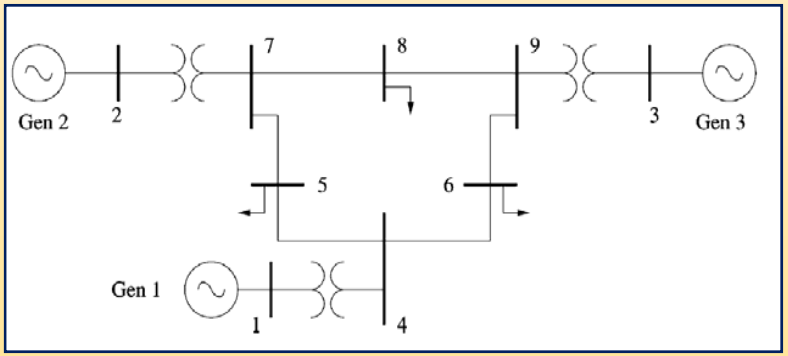
- R&D Project 2012-2013
  - The Next Generation Power Converter: key interface to power grid modernization and advancement, providing an efficient, bidirectional connection and control point.
  - Focus of modeling efforts:
    - Renewable energy integration
    - Energy storage integration
    - Various traditional and emerging AC and DC loads

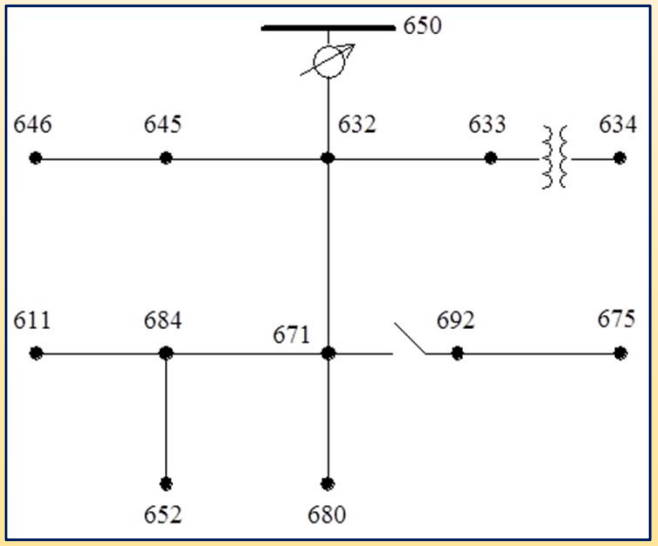
University Involvement

- Virginia Polytechnic Institute and State University
  - Explore functionality and performance of the scalable bidirectional three-phase ac-dc microgrid-interface converter for medium-voltage high-power applications.
- Carnegie Mellon University
  - Development of smart control methodology, focusing on system level aspects and the integration of storage devices via next generation power electronics converter.
- West Virginia University
  - Communication protocols and interface model development, for selected equipment and network facilities and the distribution and transmission/distribution interface.
- The Pennsylvania State University
  - Analyze Converter specifications with respect to microgrid test facilities at the Philadelphia Navy Yard (PNY) to determine device testing through various development stages.

University of Pittsburgh Involvement

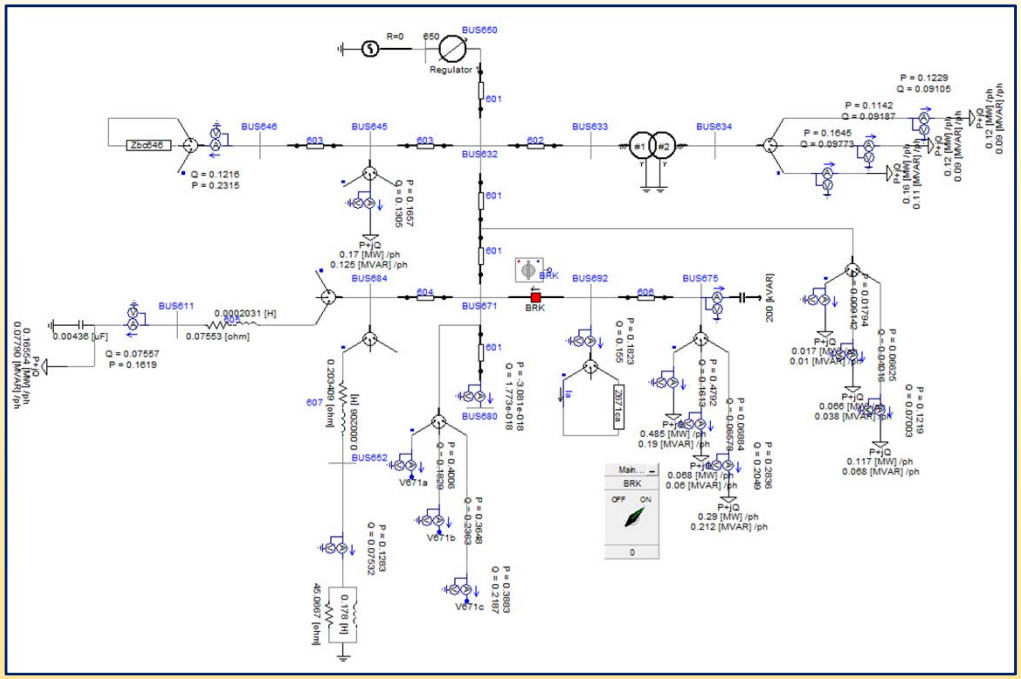
- Next Generation Power Converter
  - Base case model development of the T&D power system network topology in PSCAD/EMTDC program environment. Employment of standard PSCAD models for all selected equipment and network facilities, including generation sources, power electronics converters, feeders, and loads.
- Test Systems
  - WECC 9-Bus Test Case System
  - IEEE 13 Node Test Feeder System

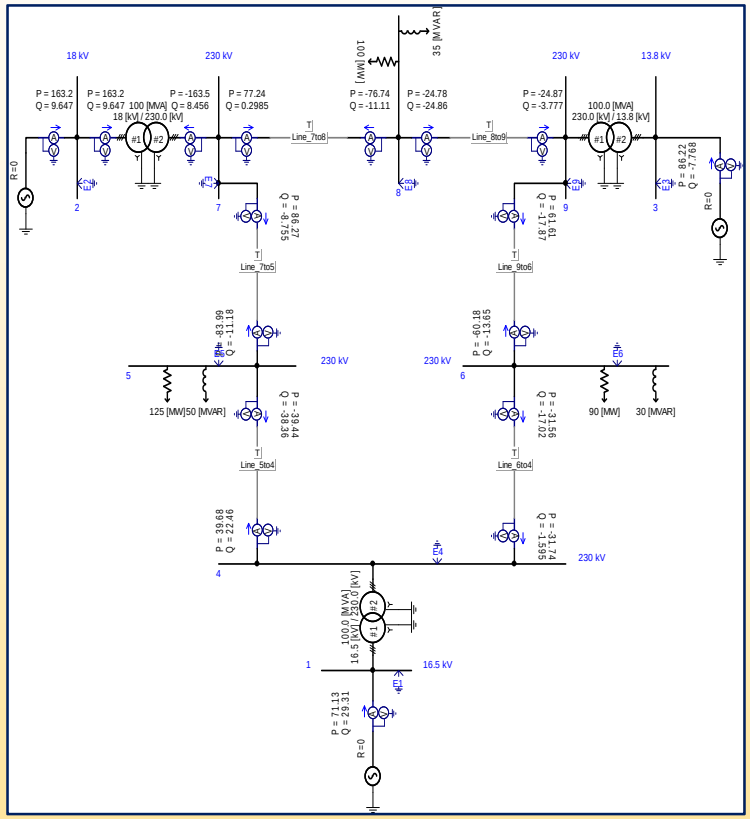




University of Pittsburgh Involvement

- Test Systems Modeled in PSCAD
  - WECC 9-Bus Test Case System
  - IEEE 13 Node Test Feeder System



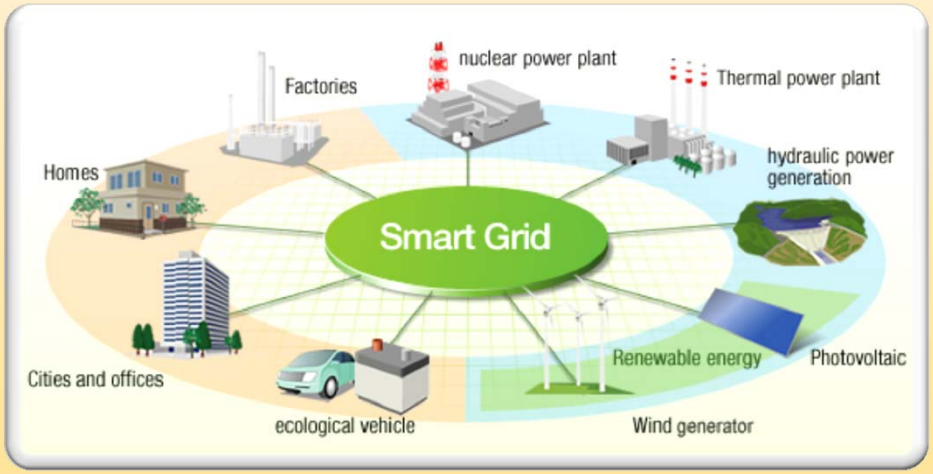


Alvaro Cardoza

Intermeshed MVAC / MVDC Distribution Architecture

Medium Voltage DC Potential

- DC system research is drawing the attention of the smart grid community, including many power equipment vendors, utilities, end-users, universities and other market participants.
- Power electronics technologies continue to advance, and an emerging portfolio of generation resources and DC-based loads either utilize a DC link or produce/consume DC power, such as battery energy storage systems.
- However, the legacy of a reliable and robust AC system will remain as the base supply for many loads.
- For this reason, methods will need to be established for intermeshing and integrating AC systems with future DC systems.



Medium Voltage DC Integration

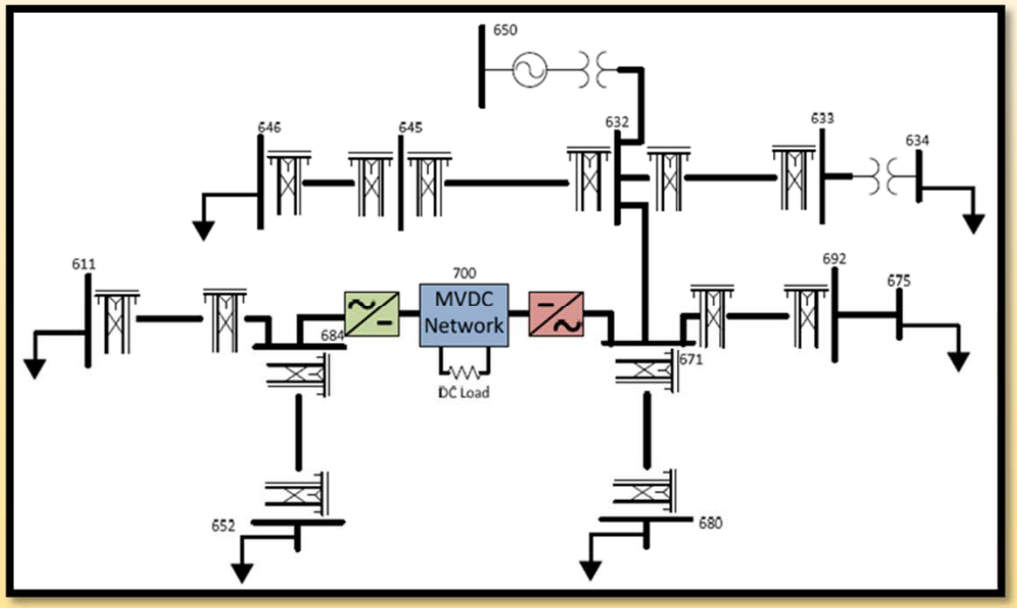
- Traditionally, DC systems have not been intermeshed into AC systems, instead serving as stand-alone or singly-supplied networks such as in microgrids.

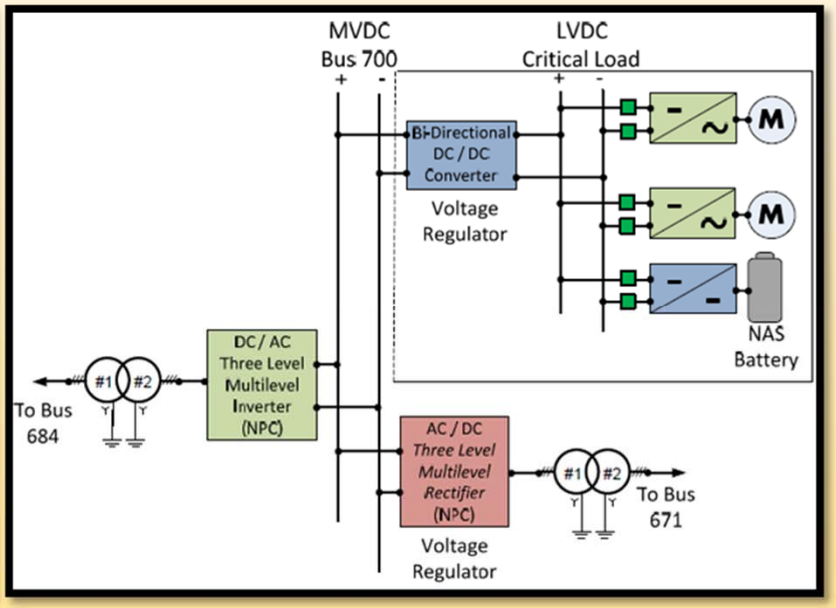
- Our research intends to investigate the potential benefits of integrating an MVDC framework within a larger AC distribution network.

- By placing an MVDC bus between two AC buses, all power flowing between the two AC buses must pass through the DC bus, intermeshing the DC bus into the AC system, and making it vital to the system's operation.

Intermeshed MVAC/MVDC Concept

- A custom distribution model will be created using MATLAB® Simulink loosely based off the IEEE 13-Bus network shown below
- The model will contain two tied substations with two feeders per substation
- One of the substation's feeders will integrate MVDC architecture





Left: IEEE 13-Bus Network with Integrated MVDC Architecture

Right: Subsystem Architecture of MVDC Network with Battery Storage

Benefits of an Intermeshed MVAC/MVDC Network

- The MVDC network can be used to interconnect and supply various DC loads:
  - Adjustable/variable speed drives, batteries, data centers, and LED lighting
  - Renewable energy resources
- A LVDC bus will be connected to the MVDC bus via a bidirectional DC-DC converter allowing for the LVDC bus to act as a load or as a source of generation.
  - Important for battery energy storage systems (BESS) in the form of distributed energy storage systems (DESS)
    - ➢ Systems become self-sustaining and help support grid health by sending power out to the MVDC bus and the larger AC grid when needed

Conceptual Energy Storage Model

  - Converter provides LVDC bus with regulated current and voltage
    - ➢ Important for handling critical/sensitive loads such as hospitals, data centers, and semiconductor manufacturers

Benoit de Courreges

Next Generation Optimal Control Design for Multi-terminal HVDC system

HVDC Installation

- **The number of HVDC installations world wide has significantly increased**
  - Integration of renewable energy resource
  - The increase in energy needs in the world has necessitated the transport of electrical energy over long distance from the generation to the load
  - The expansion of the electrical market within the continents has revealed the lack of robustness of the grid
- **Existing control strategies are based in PI controller**
- **These control strategies consider each terminal independent from the frequency point of view**
  - It allows connection between nonsynchronous sub-system
  - It helps to prevent the possible cascade of outages
  - However, it prevents each sub-system from sharing their primary reserves within the DC grid

Optimal State Feedback Regulator

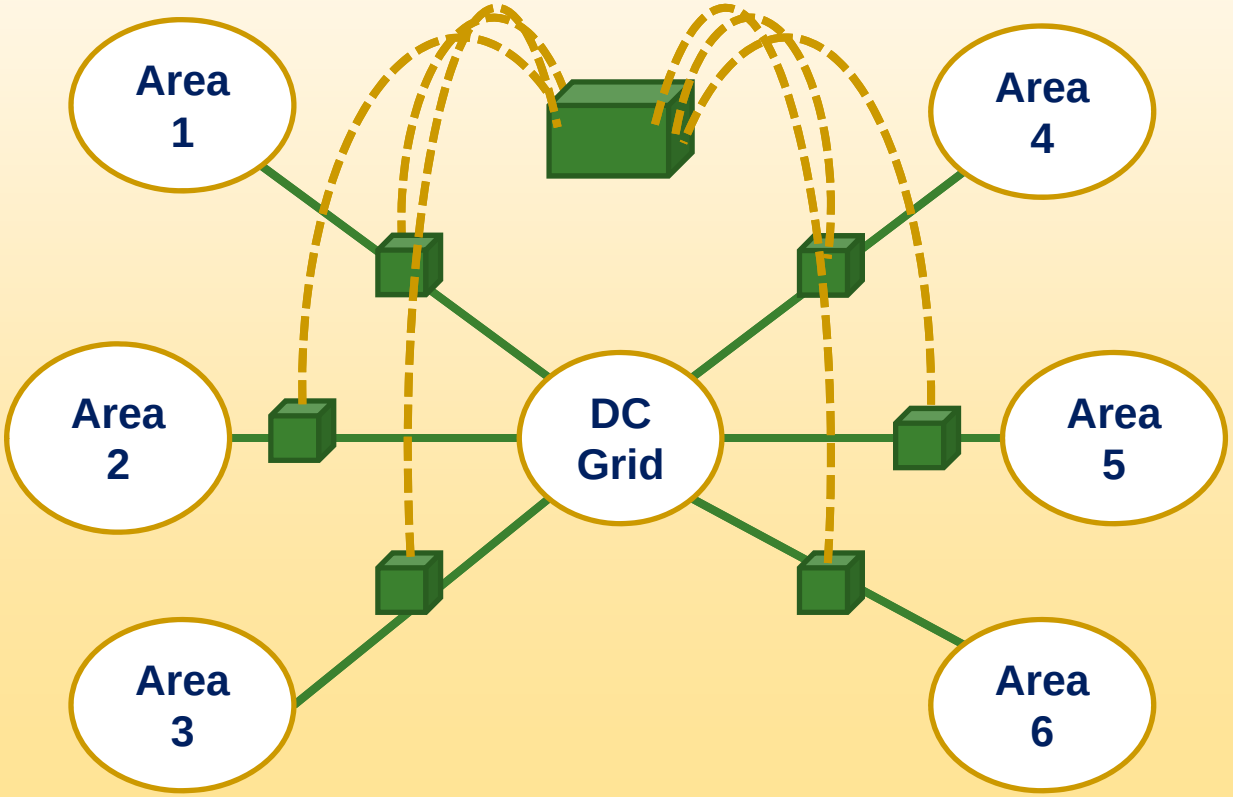
- **A distributive configuration using state feedback regulator:**
  - It allows the stabilization of the system by controlling the states of the system
  - It can be applied to various advance control method
  - It matches the multi-terminal configuration

- **Optimal control method:**
  - It is based on state feedback regulator
  - It gives the optimal controller parameters
  - The coordination of the primary reserve can be controlled through the cost function of the optimal problem

Control Model & Procedure

State space equation of the system → Optimal full state feedback → Regulates the states of the system under perturbation

Minimizes the transient response and ensures the primary reserves to be shared



Thank You