UNIVERSITY OF PITTSBURGH
SWANSON school of engineering
Power & Energy Initiative

CONTROL AND COMMUNICATION CO-DESIGN OF MULTI-TERMINAL DC (MTDC) SYSTEMS

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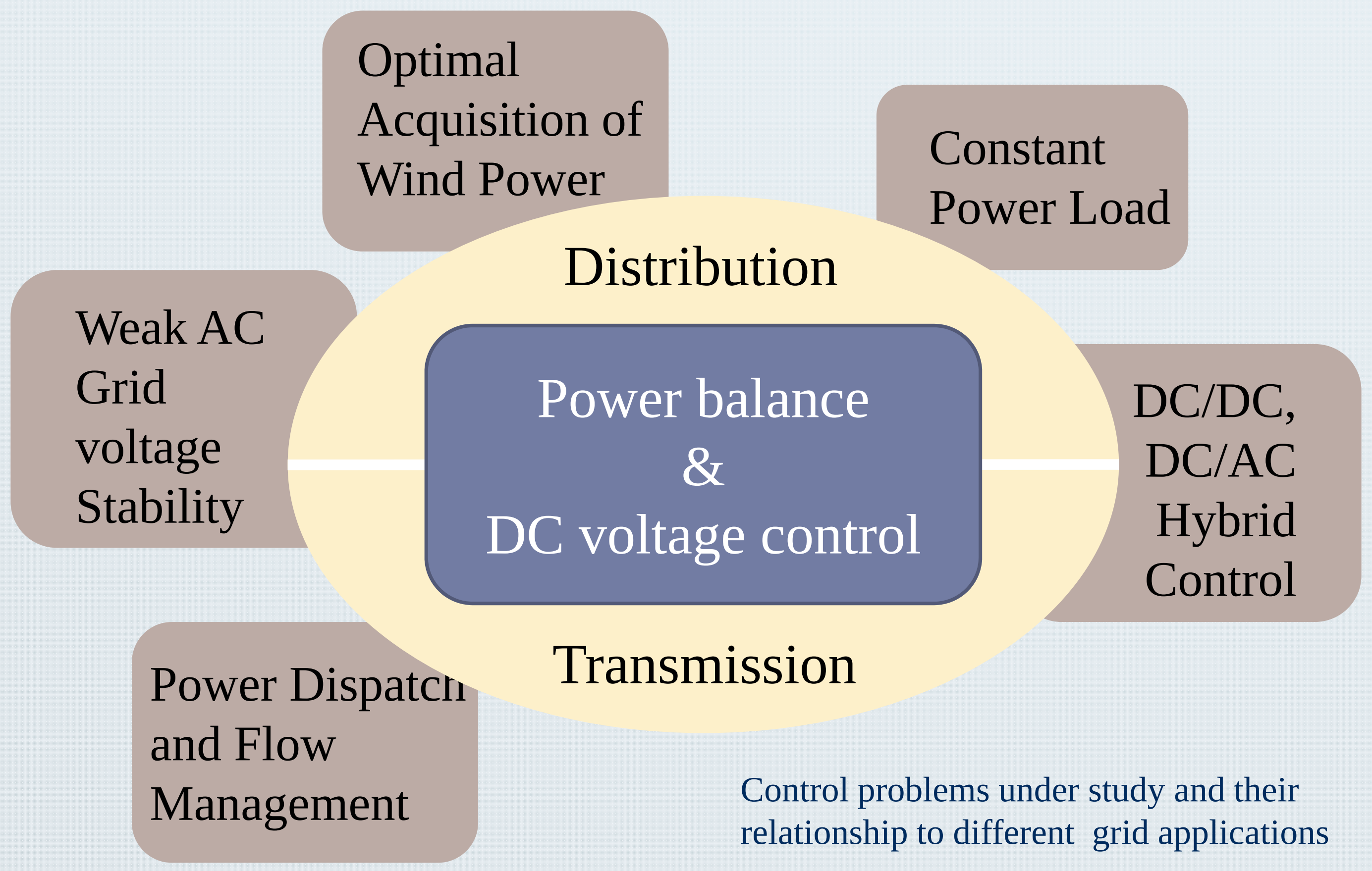
VSC-BASED MTDC SYSTEM

❖Voltage Source Converter (VSC)
- Independent control of real and reactive power exchange with AC systems
- Appropriate technology for multi-terminal DC system
- Higher converter loss due to switching

❖Technical Limitations
- DC breaker
- Communication
- Standards for operation and interface

❖Possible Future Applications
- Power distribution on vehicles
- Backbone of microgrid
- Offshore wind integration
- SuperGrid: massive integration and transmission of renewable energy
- AC islanding: splitting AC system into smaller segments

DC NETWORK CONTROL PROBLEMS UNDER INVESTIGATION


Optimal Acquisition of Wind Power

Constant Power Load

Weak AC Grid voltage Stability

Distribution

Power balance & DC voltage control

Transmission

DC/DC, DC/AC Hybrid Control

Power Dispatch and Flow Management

Control problems under study and their relationship to different grid applications

❖Power balance is the core of stable DC grid operation

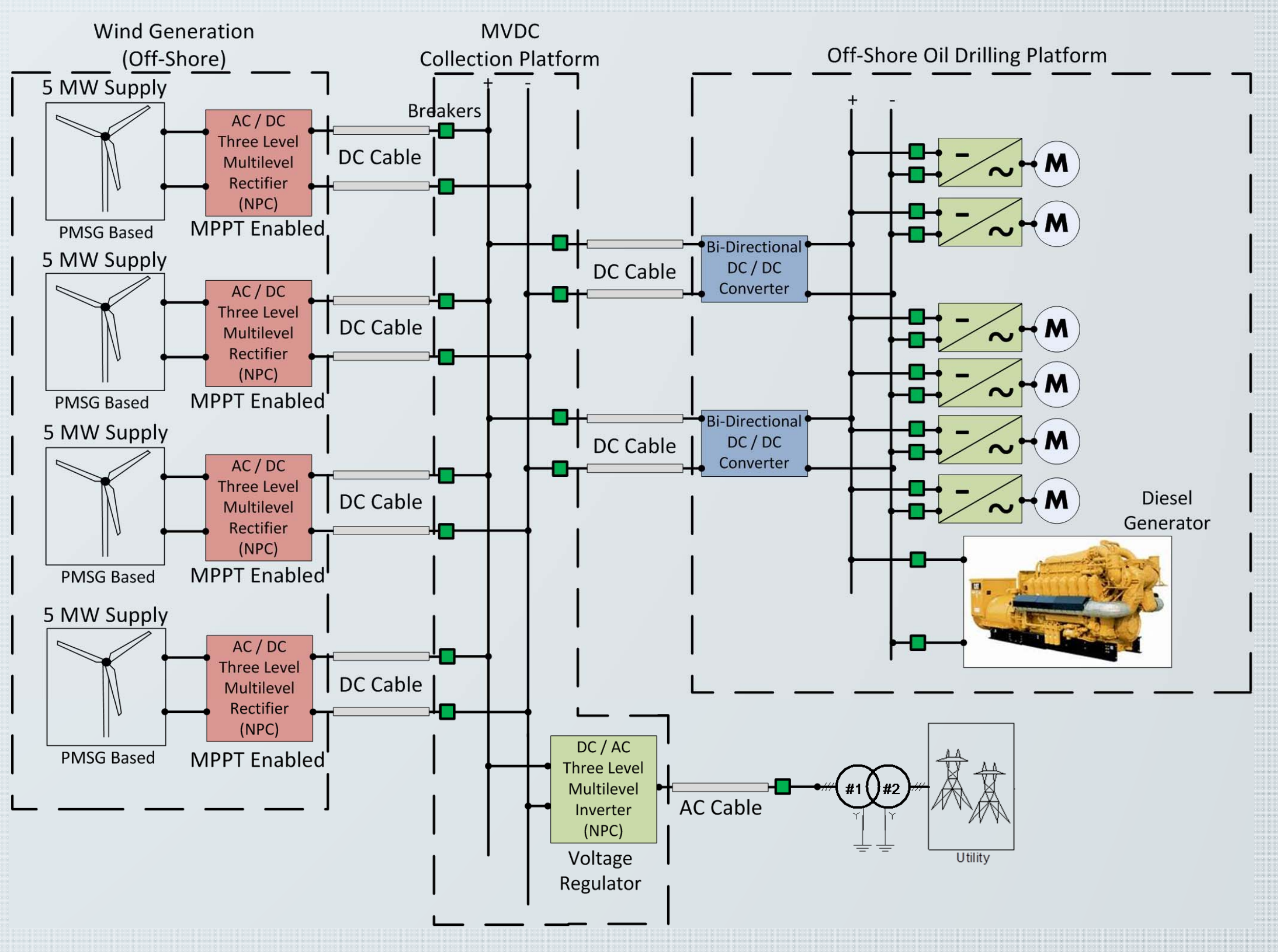
❖Control Goals
- DC voltage
- AC stability or efficiency
- Power dispatch
- Converter’s hard limit

❖DC/DC converter node in a DC network

❖Correlation and tradeoff between multiple control goals is a controllability problem

❖Power Flow Management in Complex DC Network Topology
- Converter can individually control power injection but not DC power flow
- Distributed DC voltage control and reference setting
- Cooperation between controllers is required

MTDC SYSTEMS UNDER STUDY

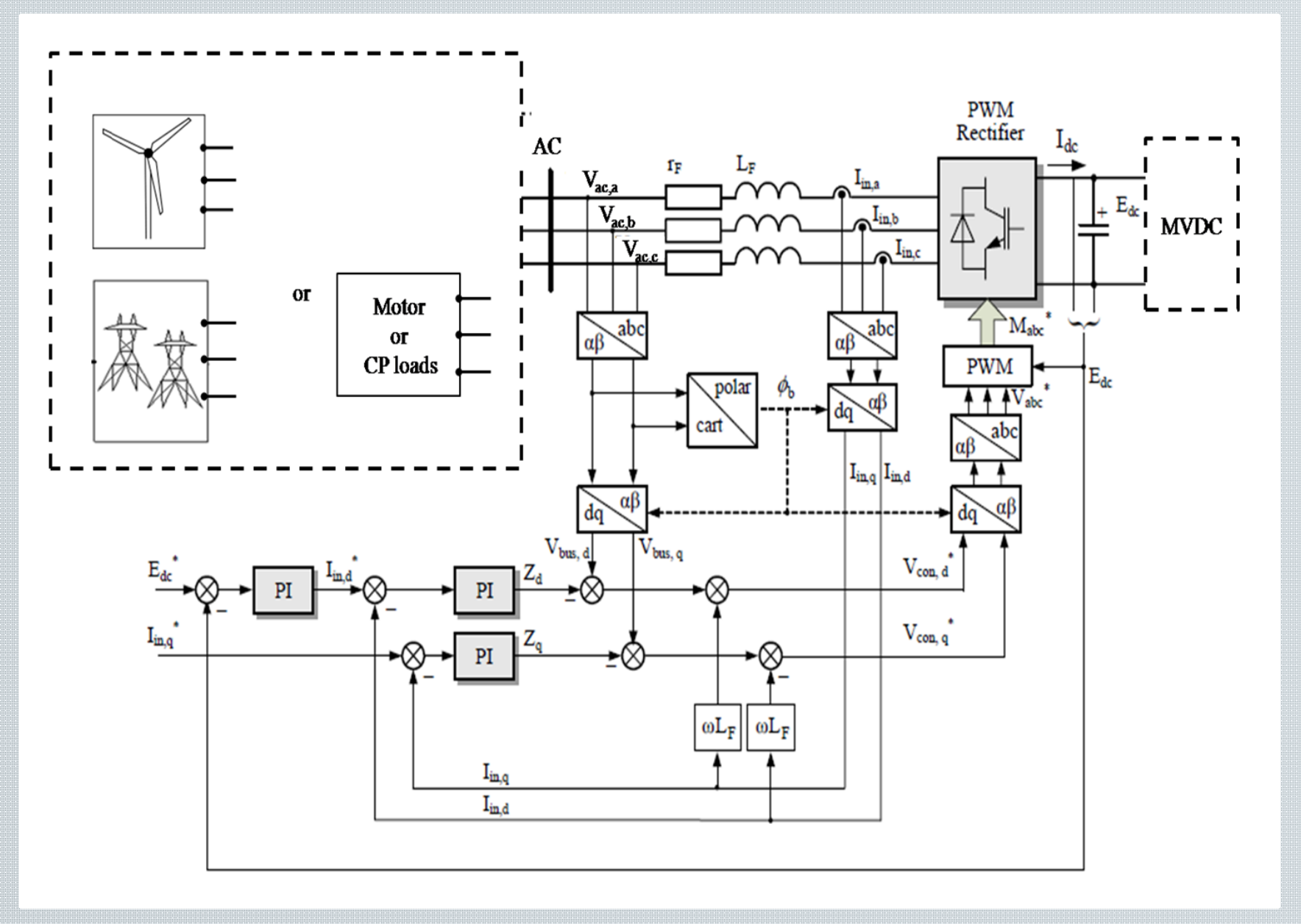


MVDC Microgrid for Offshore Wind Power and Oil Drilling Platform Integration
(by Brandon M. Grainger)

GRID LEVEL SYSTEM MODELING

❖Coupling between subsystems will:
- Cause instability in a stable subsystem
- Help stabilize an unstable subsystem
- Introduce conflicting control goals

❖Grid Level Modeling
- Study interaction among converters
- Check stability in grid level
- Coordinate local controllers



Model of Individual Converter as Basic Block

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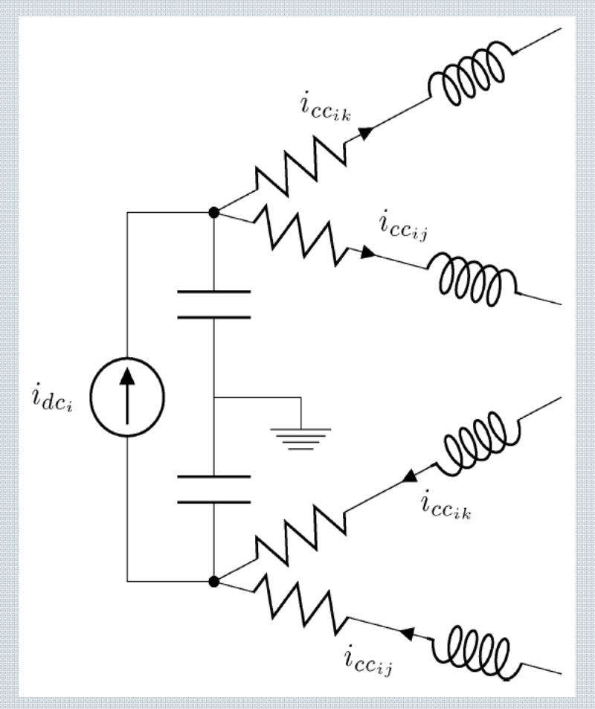

*Model of DC network as interconnection

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$$\begin{bmatrix}\dot{\mathbf{x}}_1\\ \dot{\mathbf{x}}_2\\ \vdots\\ \dot{\mathbf{x}}_{N-1}\\ \dot{\mathbf{x}}_N\end{bmatrix}=\begin{bmatrix}\mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1,N-1} & \mathbf{A}_{1N}\\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2,N-1} & \mathbf{A}_{2N}\\ \vdots & \vdots & \ddots & \vdots & \vdots\\ \mathbf{A}_{N-1,1} & \mathbf{A}_{N-1,2} & \cdots & \mathbf{A}_{N-1,N-1} & \mathbf{A}_{N-1,N}\\ \mathbf{A}_{N1} & \mathbf{A}_{N2} & \cdots & \mathbf{A}_{N,N-1} & \mathbf{A}_{NN}\end{bmatrix}\begin{bmatrix}\mathbf{x}_1\\ \mathbf{x}_2\\ \vdots\\ \mathbf{x}_{N-1}\\ \mathbf{x}_N\end{bmatrix}+\begin{bmatrix}\mathbf{B}_1 & 0 & \cdots & 0 & 0\\ 0 & \mathbf{B}_2 & \cdots & 0 & 0\\ \vdots & \vdots & \ddots & \vdots & \vdots\\ 0 & 0 & \cdots & \mathbf{B}_{N-1} & 0\\ 0 & 0 & \cdots & 0 & \mathbf{B}_N\end{bmatrix}\begin{bmatrix}\mathbf{u}_1\\ \mathbf{u}_2\\ \vdots\\ \mathbf{u}_{N-1}\\ \mathbf{u}_N\end{bmatrix}$$

Grid Level Dynamic Model

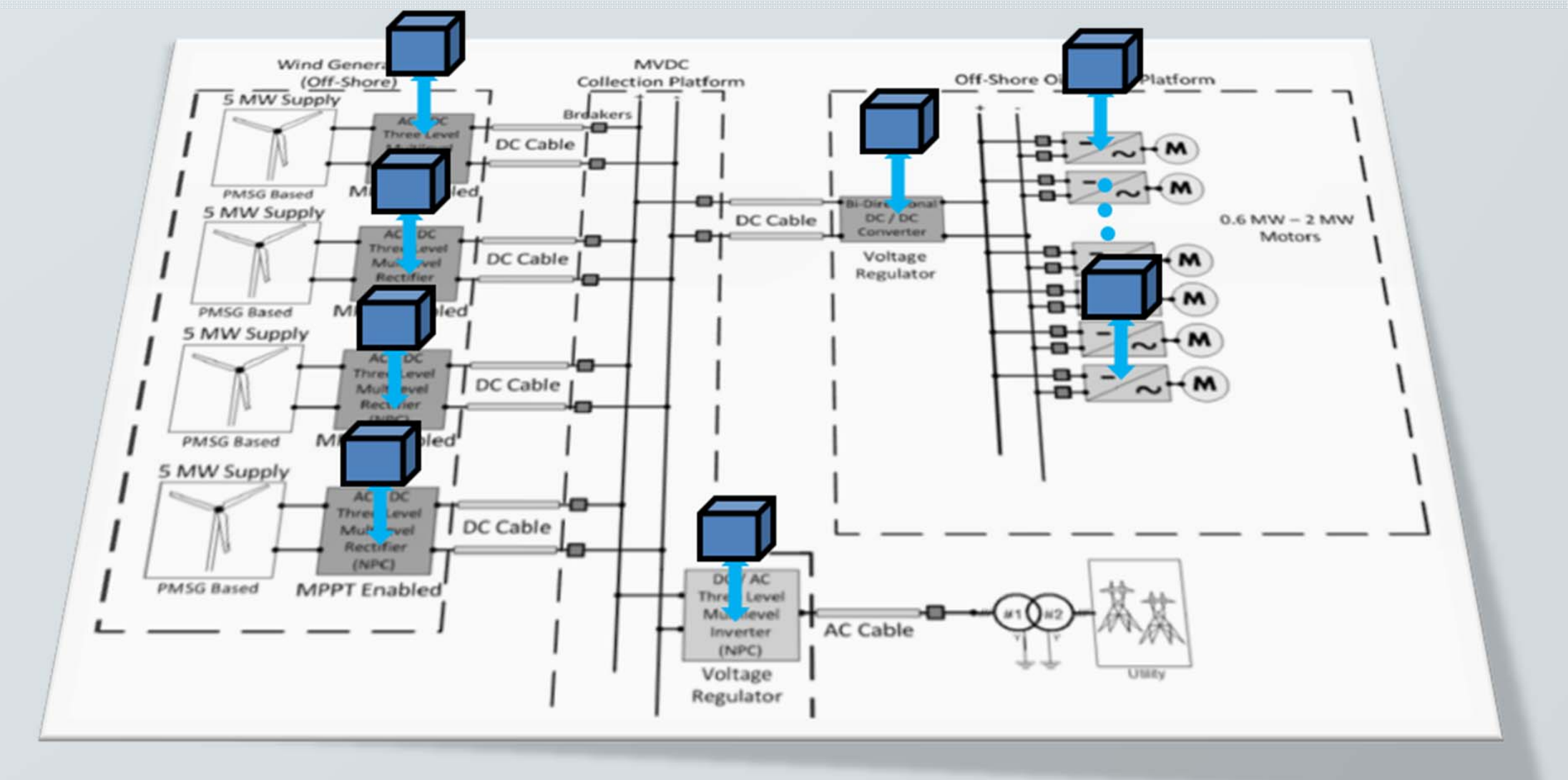
*S. Cole, J. Beerten, R. Belmans, “Generalized Dynamic VSC MTDC Model for Power System Stability Studies”, IEEE Transactions on Power Systems,Vol 25, No. 3, August 2010

CONTROL AND COMMUNICATION CO-DESIGN FOR DC POWER SYSTEMS

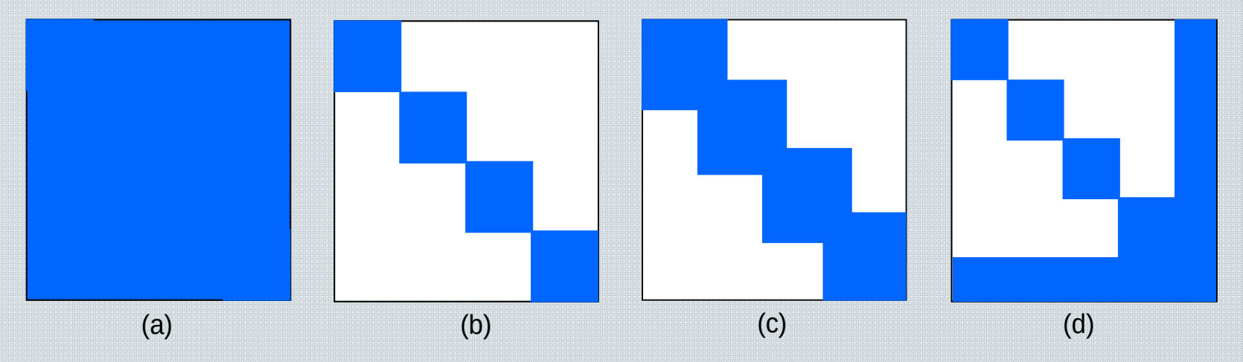
❖Enable coordinated control between controllers to improve grid stability and efficiency

❖Proposed Two Layer Hierarchical Controller
- Lower layer: local controllers with possible communication with one another
- Upper layer: single central controller adaptively optimizes topology of lower layer in real time

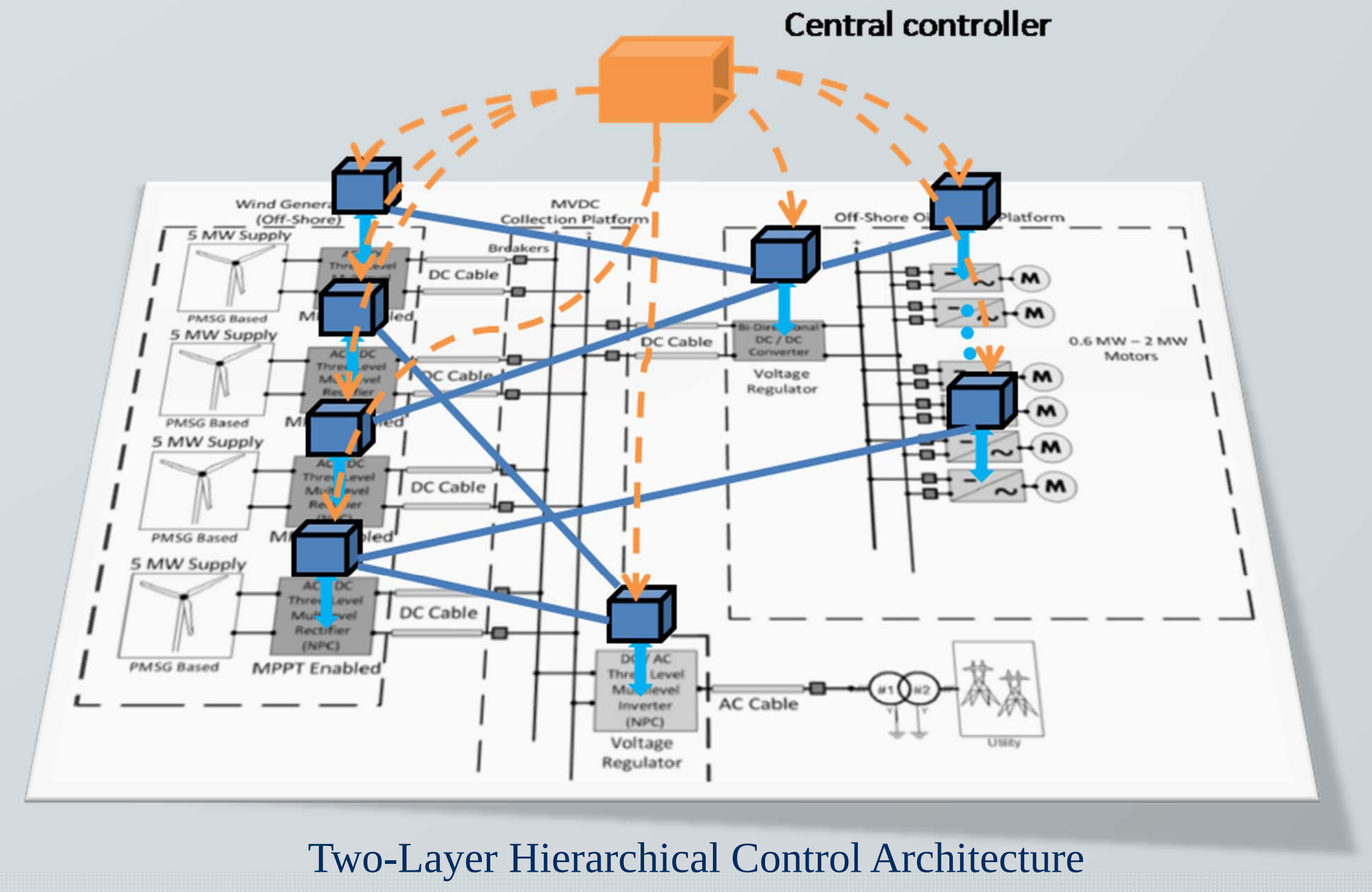
❖Derived Innovative Control Algorithm to:
- Solve the stabilization problem with arbitrary controller structure, with/without communication
- Minimize the connection topology among distributed controllers, given the model of communication limits and complexity



Decentralized , Non-Cooperative Control Architecture



Different controller structures can be indicated by different nonzero patterns of the control gain matrices



Two-Layer Hierarchical Control Architecture