



中国科学院
Chinese Academy of Sciences

直流微电网研究与示范 DC Microgrid R&D&D

唐西胜

tang@mail.iee.ac.cn

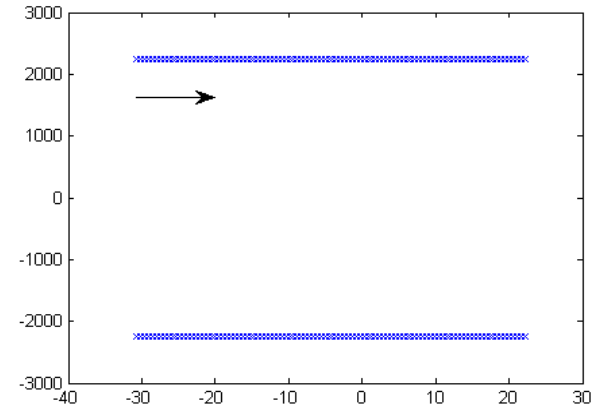
Introduction

- DC grid or hybrid AC/DC grid is considered as an effective solution for the integration of intermittent sources and pulsed loads with high efficiency, high power reliability and quality.
- Some works developed in IEE, CAS including DC grid stability analysis and simulation, Planning, flexible DC converters, energy management and DC breaker.
- A DC microgrid research and demonstration platform in Yanqing County, Beijing is established recently years.

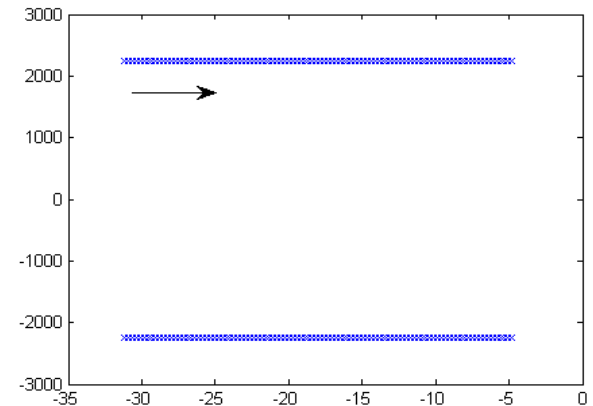
DC MG Modelling & Stability Analysis

- Small-signal model of DC MG.
- The influence of load type, overhead wire/cable, micro-source and its control method, AC/DC interface converter and its control method.

$$\left\{ \begin{array}{l} \frac{d\Delta I_{pv}}{dt} = -\frac{1}{L_{dd}} [(2\beta_{pv0} U_{dc0} K_{pvP} + R_{pv} - K_{pvP} E_{pv}) \Delta I_{pv} \\ \quad + (2\beta_{pv0} U_{dc0} - E_{pv}) \Delta \beta_{pvl} + \beta_{pv0}^2 \Delta U_{dc}] \\ \frac{d\Delta \beta_{pvl}}{dt} = K_{pvl} \Delta I_{pv} \\ \frac{d\Delta I_{ess}}{dt} = -\frac{1}{L_{dd}} [(2\beta_{ess0} U_{dc0} K_{essP} + R_{ess0} - K_{pvP} U_{b0}) \Delta I_{ess} \\ \quad + (2\beta_{ess0} U_{dc0} - U_{b0}) \Delta \beta_{essl} + \beta_{ess0}^2 \Delta U_{dc} + I_{ess0} \Delta R_{ess} \\ \quad - \beta_{ess0} \Delta U_b] \\ \frac{d\Delta \beta_{essl}}{dt} = K_{essl} \Delta U_{dc} \\ \frac{d\Delta U_b}{dt} = -\frac{1}{C_b} \frac{1}{\beta_{ess0}} \Delta I_{ess} + \frac{1}{C_b} \frac{I_{ess0}}{\beta_{ess0}^2} \Delta \beta_{essl} \\ \quad + \frac{1}{C_b} \frac{I_{ess0}}{\beta_{ess0}^2} K_{essP} \Delta U_{dc} \\ \frac{d\Delta U_{dc}}{dt} = \frac{1}{C} \left(\Delta I_{pv} + \Delta I_{ess} - \left(\frac{P_{CRL}}{U_{dc}^2} - \frac{P_{CPL}}{U_{dc}^2} \right) \Delta U_{dc} \right) \end{array} \right.$$



恒功率负荷比例增大时系统的稳定性能下降至不稳定区域

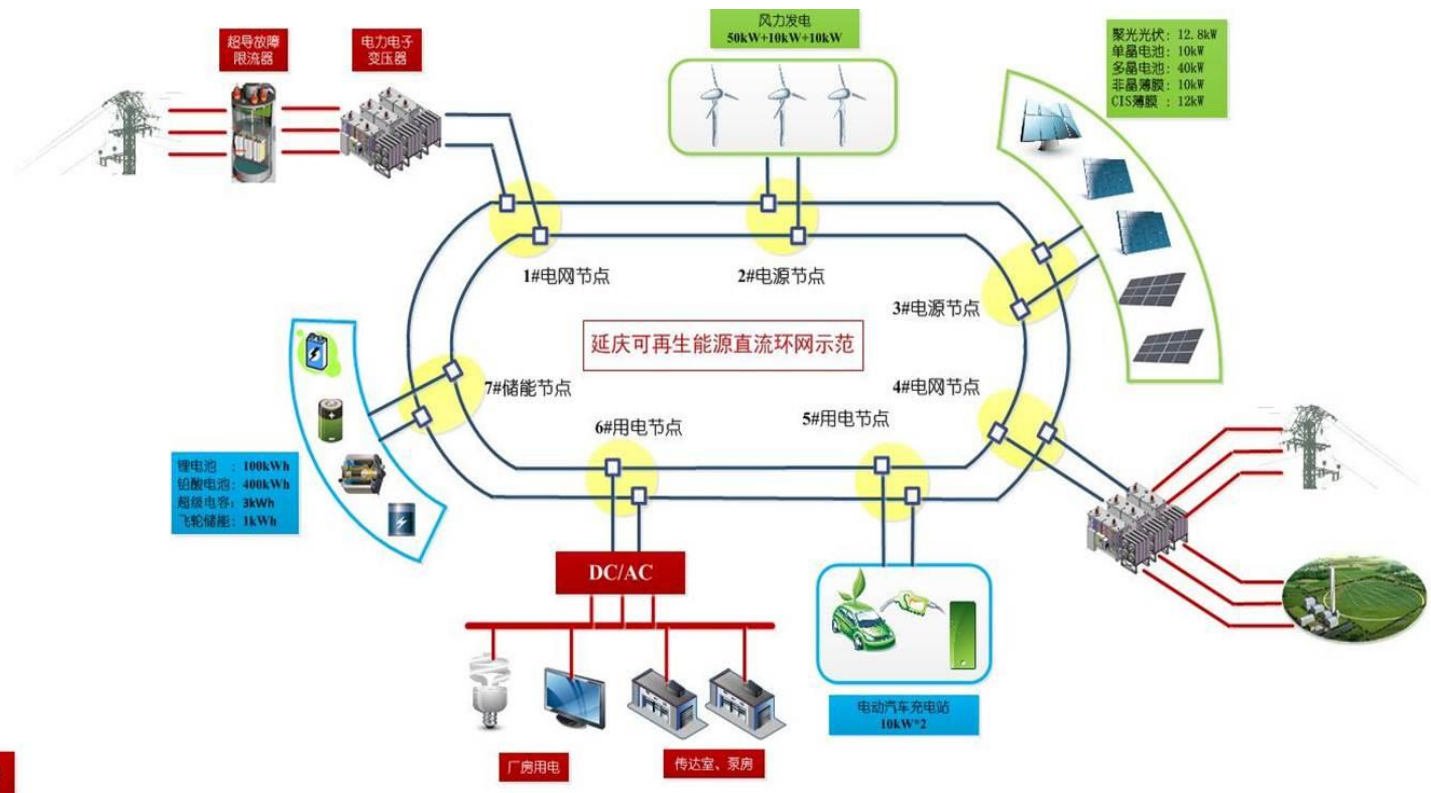


恒电流负荷比例增大时系统的稳定性能下降，但依然保持稳定

DC MG Planning

- DC Voltage level and classification.
- DC grid structure and reliability
- AC/DC connection and its operation principles.
- Islanded DC grid.
- Key equipment and functions orient.

DC MG Research & Demonstration Platform



- DC loop based microgrid to integrate multiple distributed power generations and EV charger station. 设计了多节点结构的直流环网，更加高效、可靠地集成大规模可再生能源；
- It can also be used for the physical simulation of high voltage DC grid. 不仅作为直流电网技术的测试、示范，还可用于直流电网动模实验；

DC MG Research & Demonstration Platform

绿色能源分布式智能电网研究示范基地

绿色电源

塔式太阳能热发电

槽式太阳能热发电

多种类型光伏电池

多种类型风力发电机

研究平台

光伏发电技术研究平台

风力发电技术研究平台

太阳能热发电技术研究平台

分布式直流电网技术研究平台

分布式智能电网动模实验系统

含大规模可再生能源电力的区域电网数模混合仿真平台

储能装置

先进储能电池

超级电容器

飞轮阵列

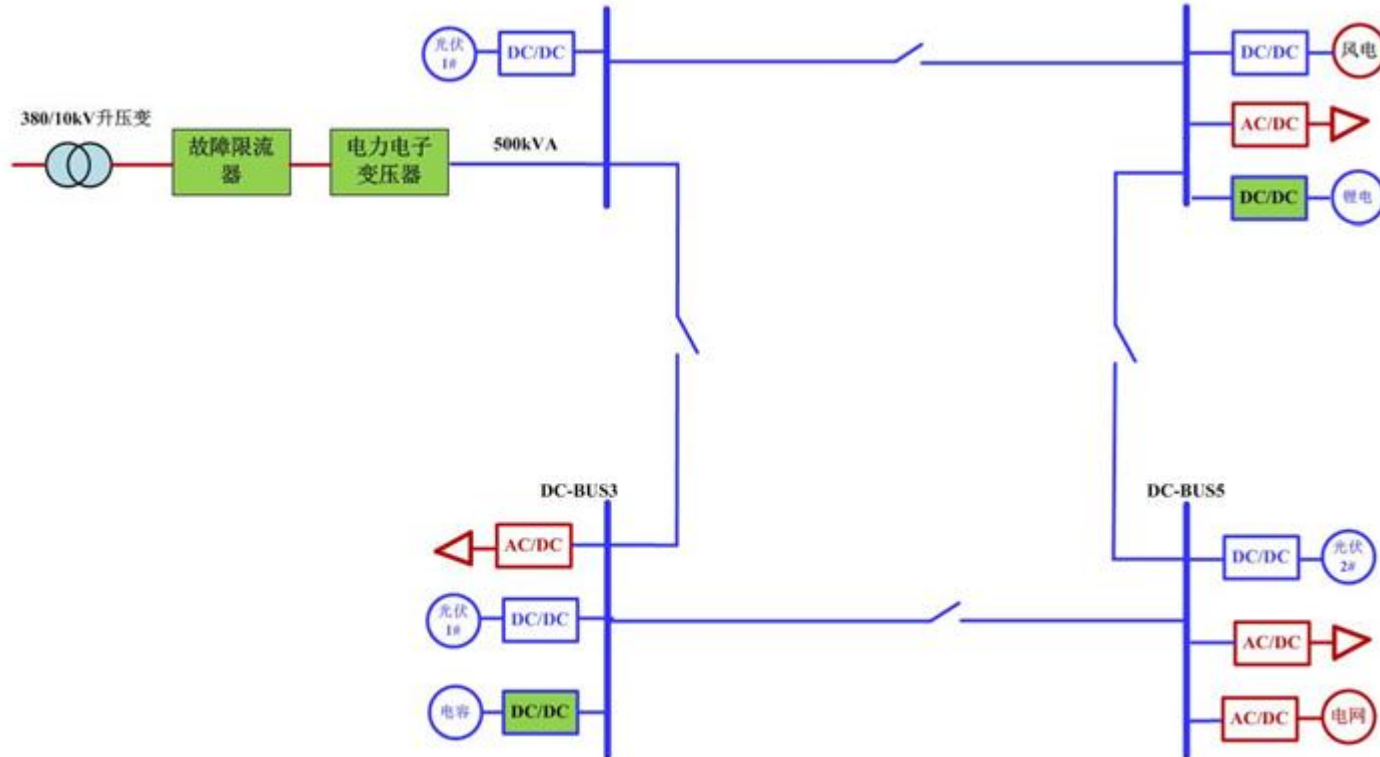
先进压缩空气储能

电动汽车充电/储能站

绿色 智能 安全 高效

中国科学院电工研究所
IEECAS

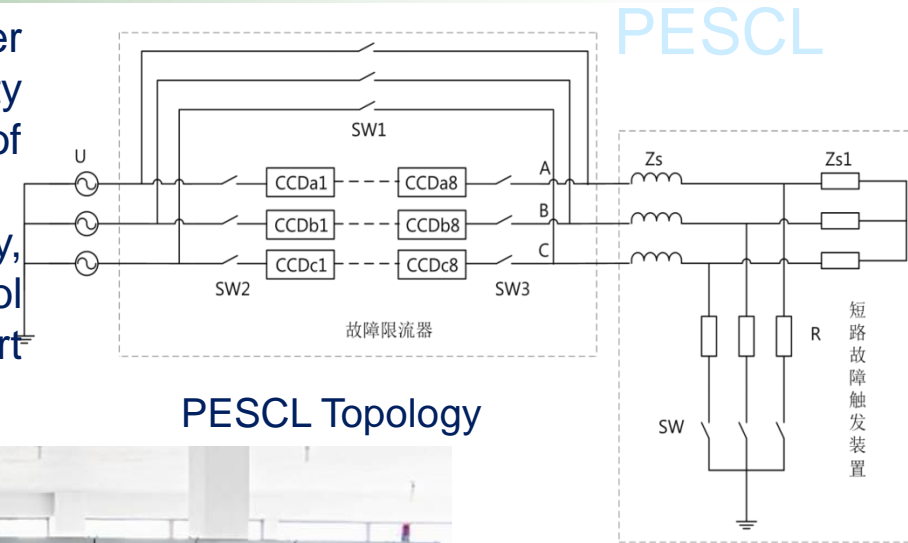
DC MG Research & Demonstration Platform



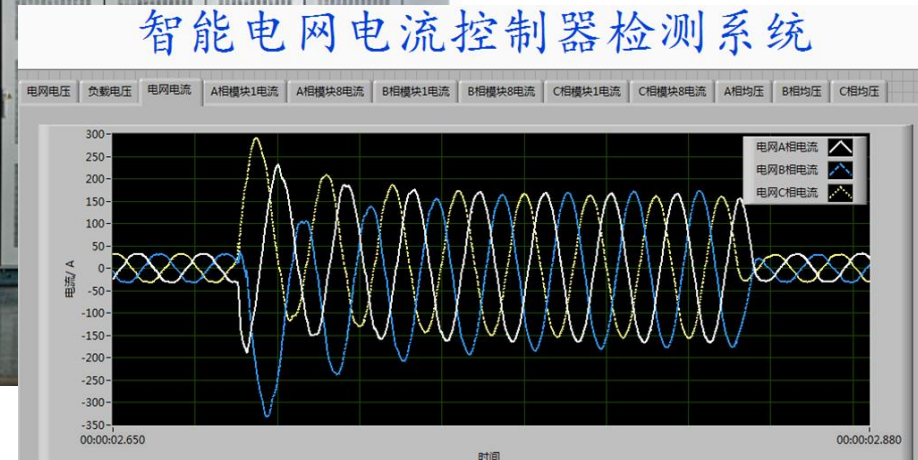
- 4 terminals is now available with Power Electronics Transformer(PET) and a AC/DC Power Flow Controller as two main power sources, and PV, wind power, energy storage and EV charger connected in the DC grid.

DC MG Research & Demonstration Platform

- Power Electronic based Short Current Limiter (PESCL) is a key equipment for the reliability operation of power system with the ability of short current limit and power flow control.
- A PESCL is developed with novel topology, on-line fault current detection and control method, which can reduce 79% of the short current.



10kV PESCL

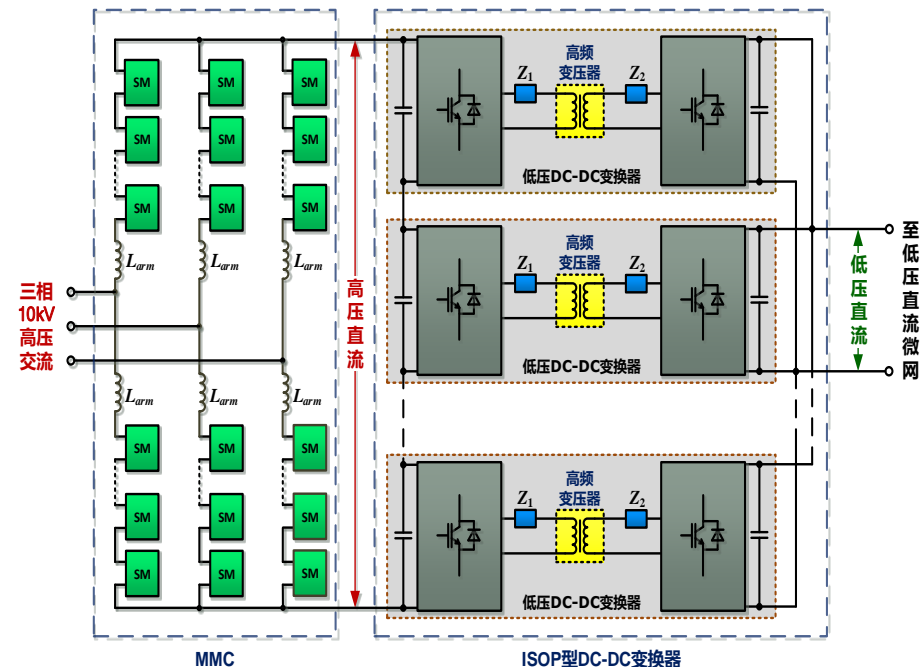


DC MG Research & Demonstration Platform



10kV Power Electronic Transformer

- PET is a key equipment in distributed smart grid with the functions of electrical isolation, voltage transform and reactive power compensation.
- A 1MVA PET is developed based on Modular Multi-level Converter (MMC).



Main Circuit Topology

DC MG Research & Demonstration Platform



AC/DC Power Flow Regulator (500kVA)

- AC/DC Power Flow Regulator(PFR) acts as an interface to regulation the power flow between AC and DC. It is bi-directional, and can be controlled to support DC voltage or active/reactive power control.
- When works with PET, PFR is current controlled to provide certain active or reactive power from AC side, while PET is voltage controlled to support DC voltage at certain level.

DC MG Research & Demonstration Platform



PV & Wind Power



DC PV Converters



DC Wind Power
Converters

- Multi-type of PV units and wind turbines are connected directly to the DC microgrid with DC-interfaced converters.

DC MG Research & Demonstration Platform

DC Loads?

DC MG Research & Demonstration Platform



DC MG EMS

EMS contains multi-DG Coordination Module, AC/DC Coordination Module, and Load Shift Module, with the objective of optimum the hybrid AC and DC operation both on grid connected and islanded mode.

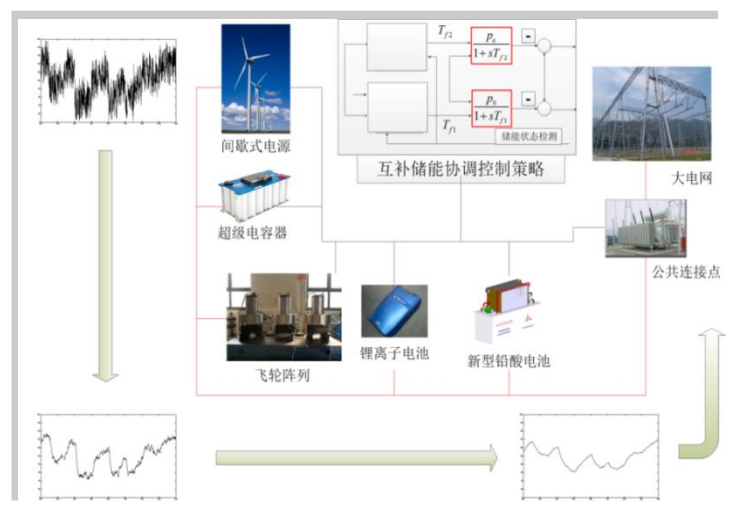
能量管理实现交直流混合配电系统中交直流能量变换、协调运行等功能，包含交直流混合配电网多源协同调度模块、直流电网/交流电网相互支持控制模块、交直流混合配电网负荷均衡与转移控制模块，完成交直流配电网中交直流接口装置、分布式电源、储能、电动汽车充电装置等在正常运行与故障情况下的运行控制与调度优化。

DC MG Research & Demonstration Platform

- Li+ battery and EDLC can be controlled complementarily to smooth the power unbalance between generation and consumer. Model Prediction Control(MPC) method is used in the process to optimize the operation of ESSs. 通过模型预测控制技术，有效平抑网内发电、用电的不平衡。



Li+ Battery and EDLC

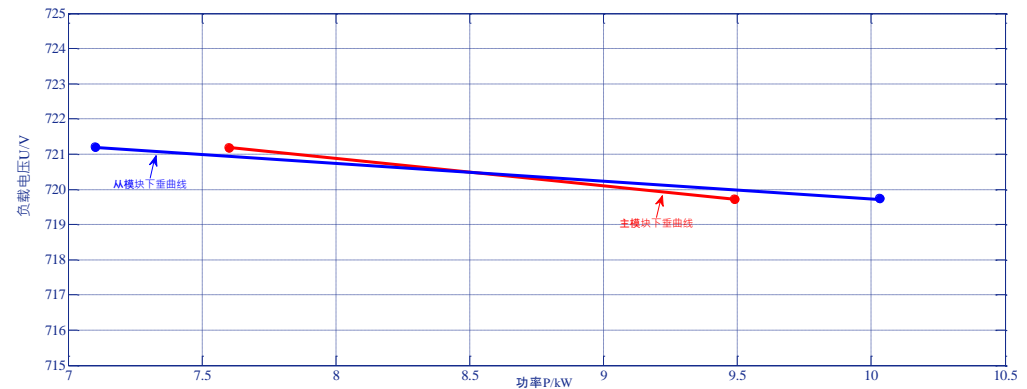


储能系统运行建议	储能系统容量配置
超级电容器和锂电池系统配置 若电网波动频率较小且功率波动小，超级电容器和锂电池系统配置 若电网波动频率较大且功率波动大，超级电容器和锂电池系统配置	超级电容器容量： 12221568.5001元

Coordinated control of multiple energy storages for fluctuations suppression

DC MG Research & Demonstration Platform

- For islanded operation, energy storage can be used for voltage support. A novel DC grid voltage based on Master/Slave Droop control method is presented, which can make the voltage regulation more precise and reliable.



Voltage Controlled Droop:

$$U_2 = U_{2ref} - K_v i_0$$

$$K_v = \frac{U_{2ref} - U_2}{i_0}$$

Current Controlled Droop:

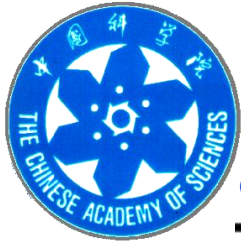
$$i_0 = (U_{ref} - U_2) K_i$$

$$K_i = \frac{i_0}{U_{ref} - U_2}$$

DC Voltage Regulation Based on Master/Slave Droop control
The operation process with load variation of Master unit based on Li+ battery and Slaver unit based on EDLC

Future Work

- The effect of DC grid or hybrid AC/DC has to be explored through lots of analysis and experiments such as its convenient for intermittent sources and pulsed loads.
- The topology and control method of DC grid interfaces for distributed generations, energy storages and loads. The contradiction of electrical isolation and efficiency is a problem.
- DC breaker is key for line protection, however, the road is still long.



中国科学院
Chinese Academy of Sciences

Thanks for your attention!