Challenges for dynamics in future grid
and amplitude-frequency modulation dynamics

电力电子化电力系统基本挑战与幅频调制动力学

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二零一九年十一月十二日

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Dec 5 2019

Operational mechanisms and Amplitude/frequency state variables

➢运行机制与幅频调制

Fundamental challenges for controls and protections

➢控制保护问题的基础性挑战

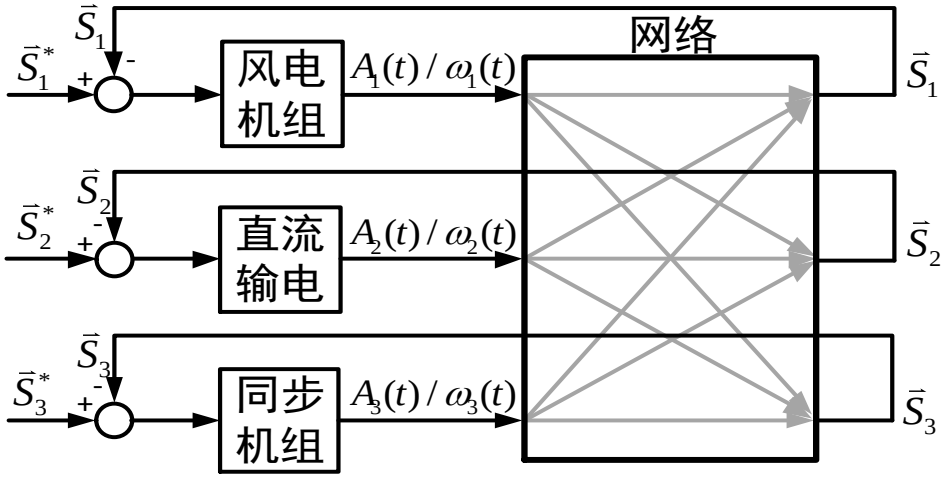
Needs for new generation of theory for dynamics

➢对新一代基础理论的创新需求

Framework of amplitude-frequency modulation dynamics

➢幅频调制动力学基本框架

运行机制与幅频调制



Time-varying amplitude/frequency AC signal concepts is fundamental to mechanisms and analytics

$$\int_{t_0}^{t} A(t)\cos\left(\int \omega(t)dt\right)dt = \int_{t_0}^{t} \frac{A(t)}{\omega(t)} d\sin\left(\int \omega(t)dt\right) = \frac{A(t)}{\omega(t)}\sin\left(\int \omega(t)dt\right)\Big|_{t_0}^{t} - \int_{t_0}^{t} \sin\left(\int \omega(t)dt\right) d\frac{A(t)}{\omega(t)}$$

Interactions between supply-demand balancing and amplitude-frequency dynamics

✓**系统有功-无功功率供需平衡与电压幅值-频率动态相互作用的运行机制；**

Power driving voltage for nodes - voltage driving power for networks and performance

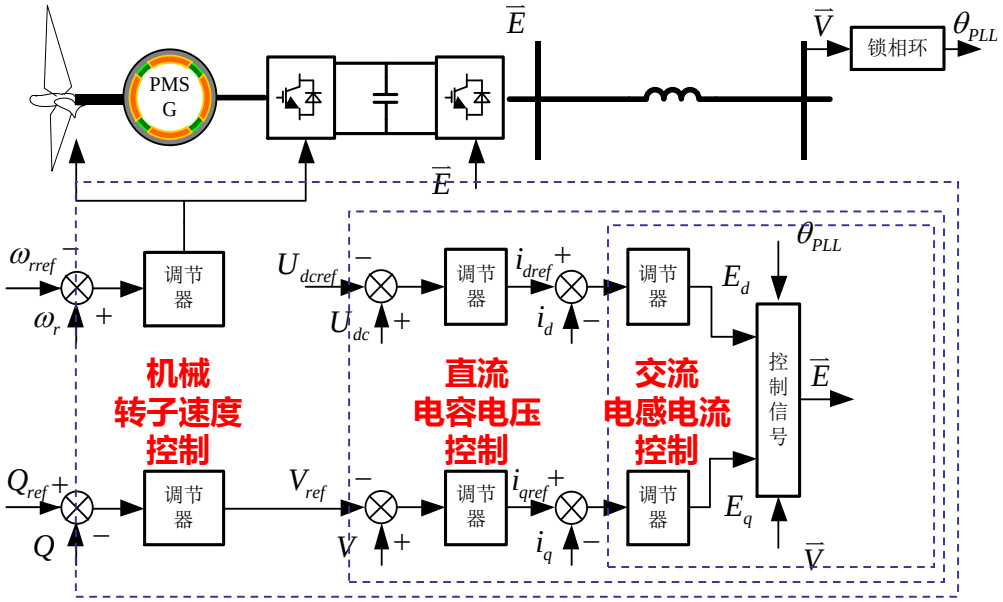
✓**节点的功率驱动内电势特性及网络的内电势驱动功率特性与系统动态行为；**

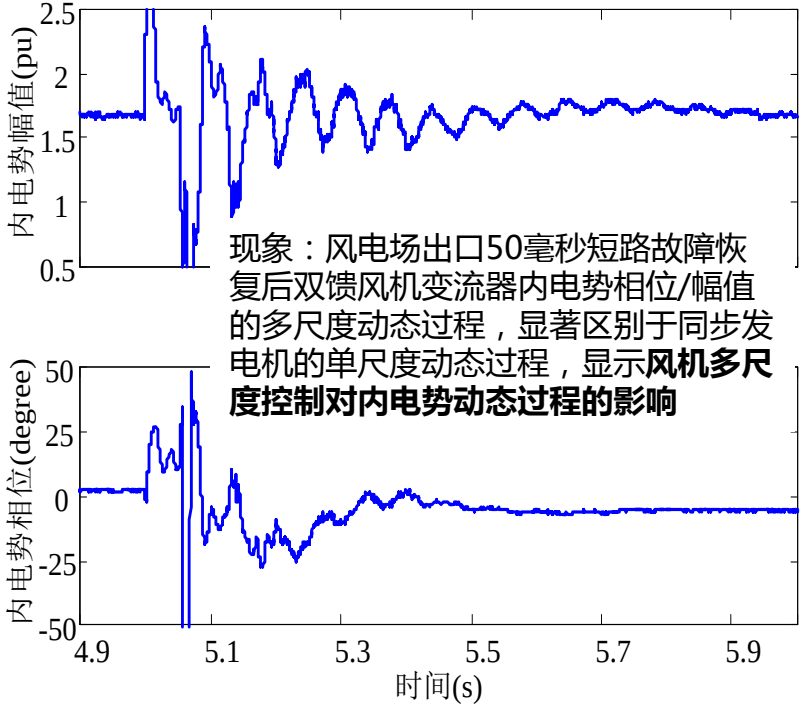
Amplitude-frequency as variables and concepts of operation points and perturbations

✓**幅频状态变量与系统运行工作点、扰动与动态过程的幅频调制本质；**

控制保护问题的基础性挑战一

典型直驱风机控制结构
（基于简化青海电网仿真系统）





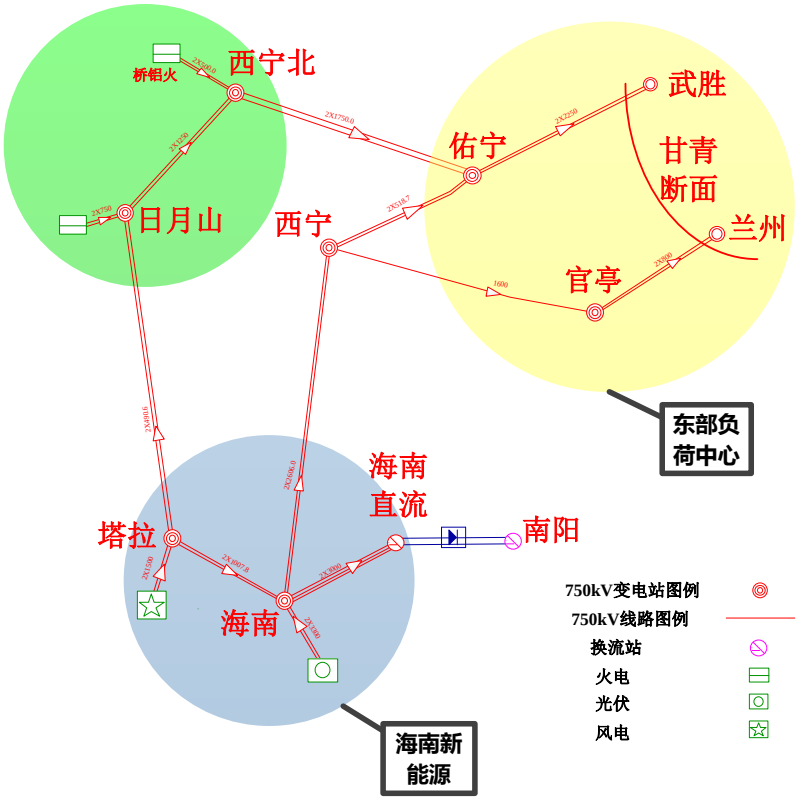
现象：风电场出口50毫秒短路故障恢复后双馈风机变流器内电势相位/幅值的多尺度动态过程，显著区别于同步发电机的单尺度动态过程，显示**风机多尺度控制对内电势动态过程的影响**

Characteristics of nodes under multi-time scale controls: from single-time-scale low-order Linear continuous system to multi-time-scale high-order nonlinear discontinuous system

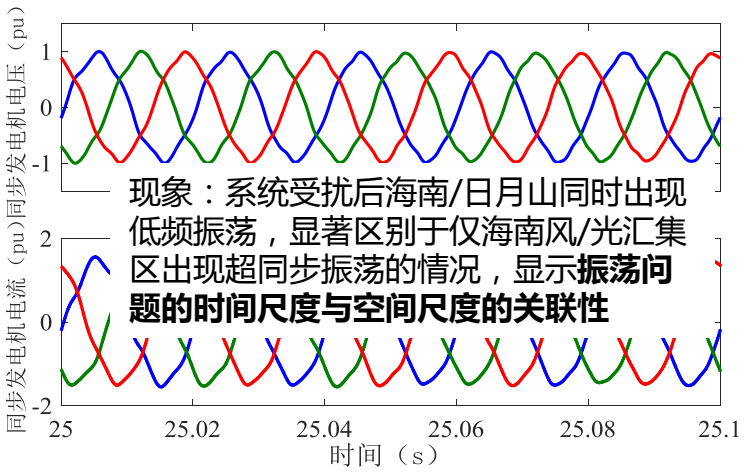
从单尺度低阶线性连续系统到多尺度高阶非线性切换系统：
多尺度控制作用下设备特性的形成机理与规律性

控制保护问题的基础性挑战二

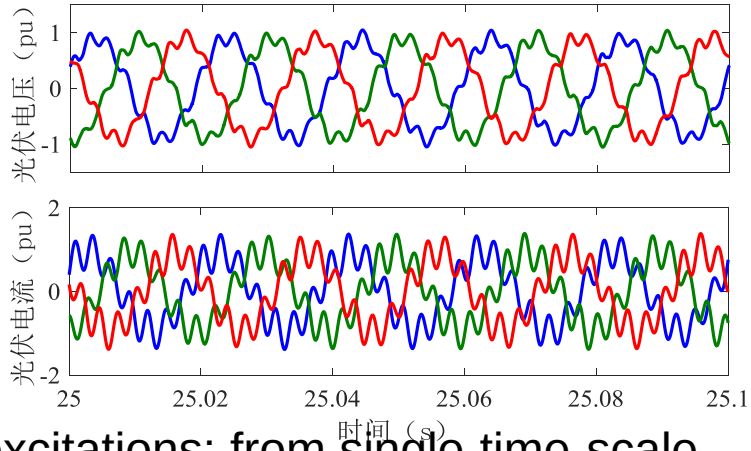
简化青海电网仿真系统



日月山火电节点电压电流波形



海南光伏发电节点压电流波形

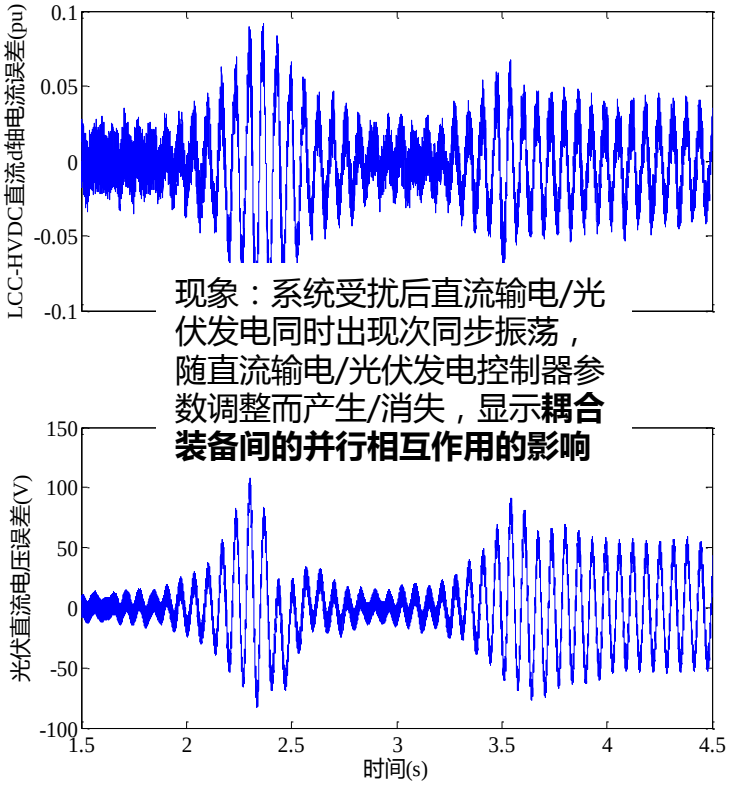


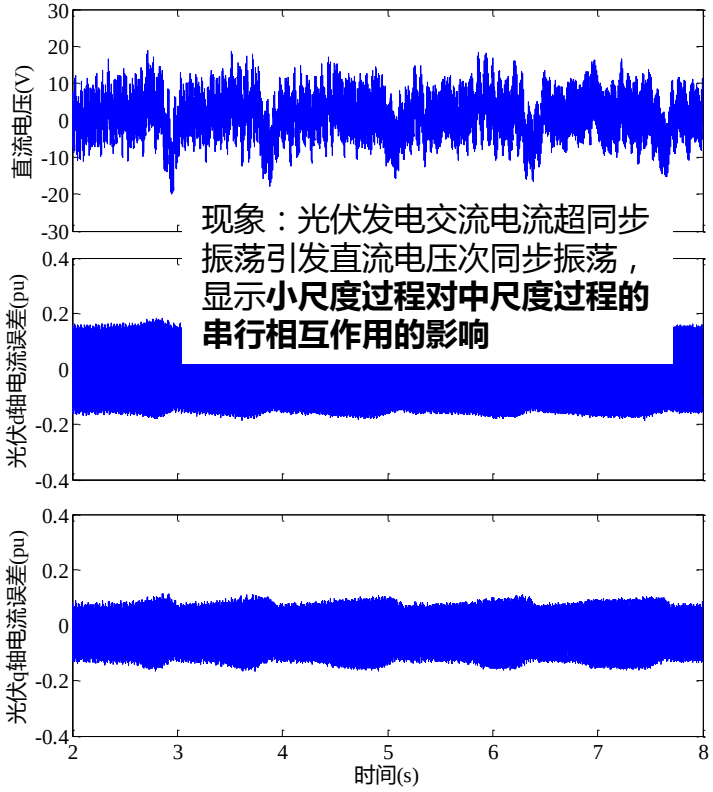
Characteristics of networks under multi-time scale excitations: from single-time-scale Constant AF excitations to multi-time-scale time varying AF excitations

从单尺度恒定幅频信号激励到多尺度时变幅频信号激励：多尺度信号激励下网络特性的形成机理与规律性

控制保护问题的基础性挑战三

（基于简化青海电网仿真系统）



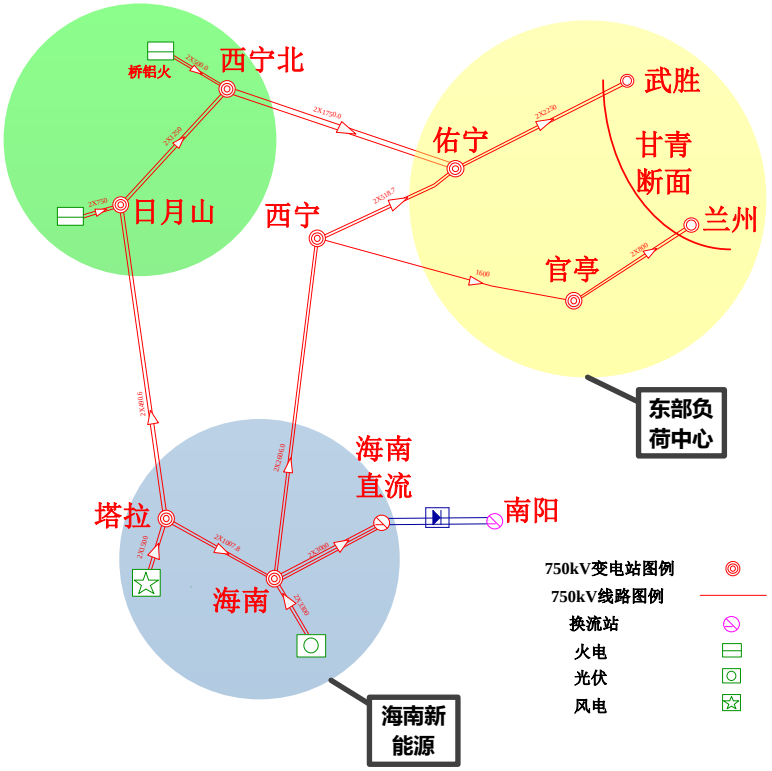


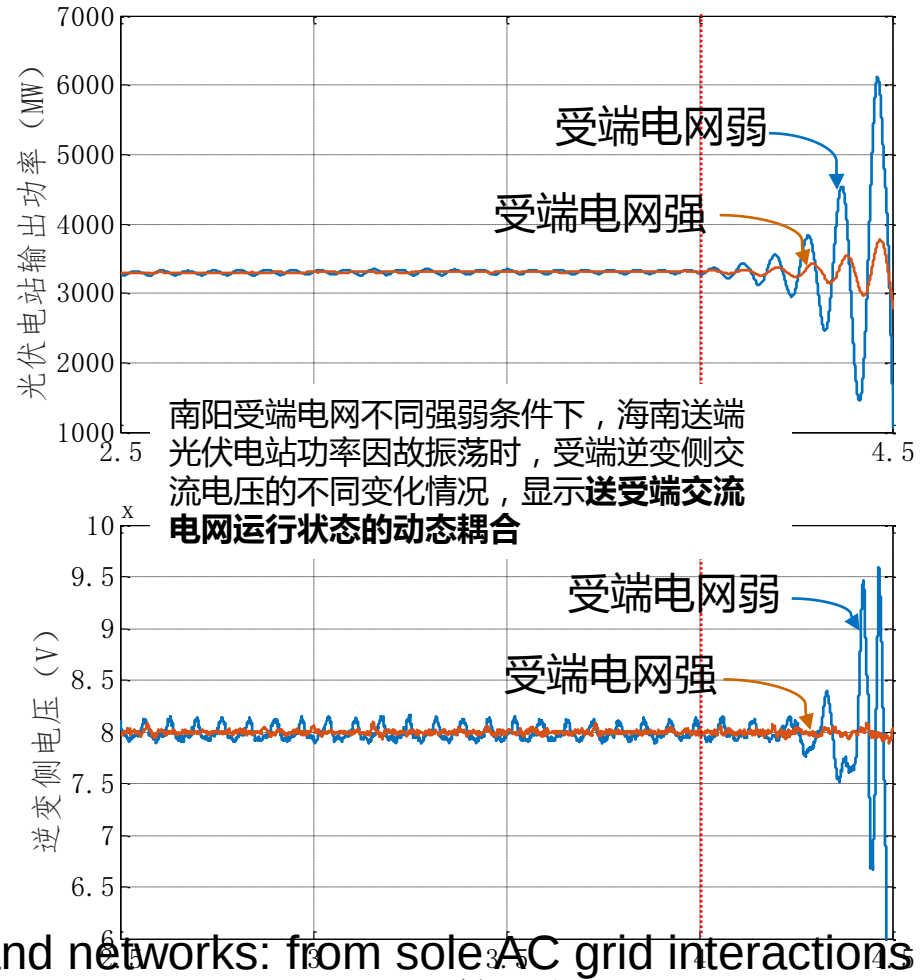
Dynamical interactions among nodes and networks: from sole parallel interactions to Combined series-parallel interactions

从单一并行相互作用到串并行联合相互作用：设备间及其与网络间多尺度动态相互作用机理与规律性

控制保护问题的基础性挑战四

简化青海电网仿真系统

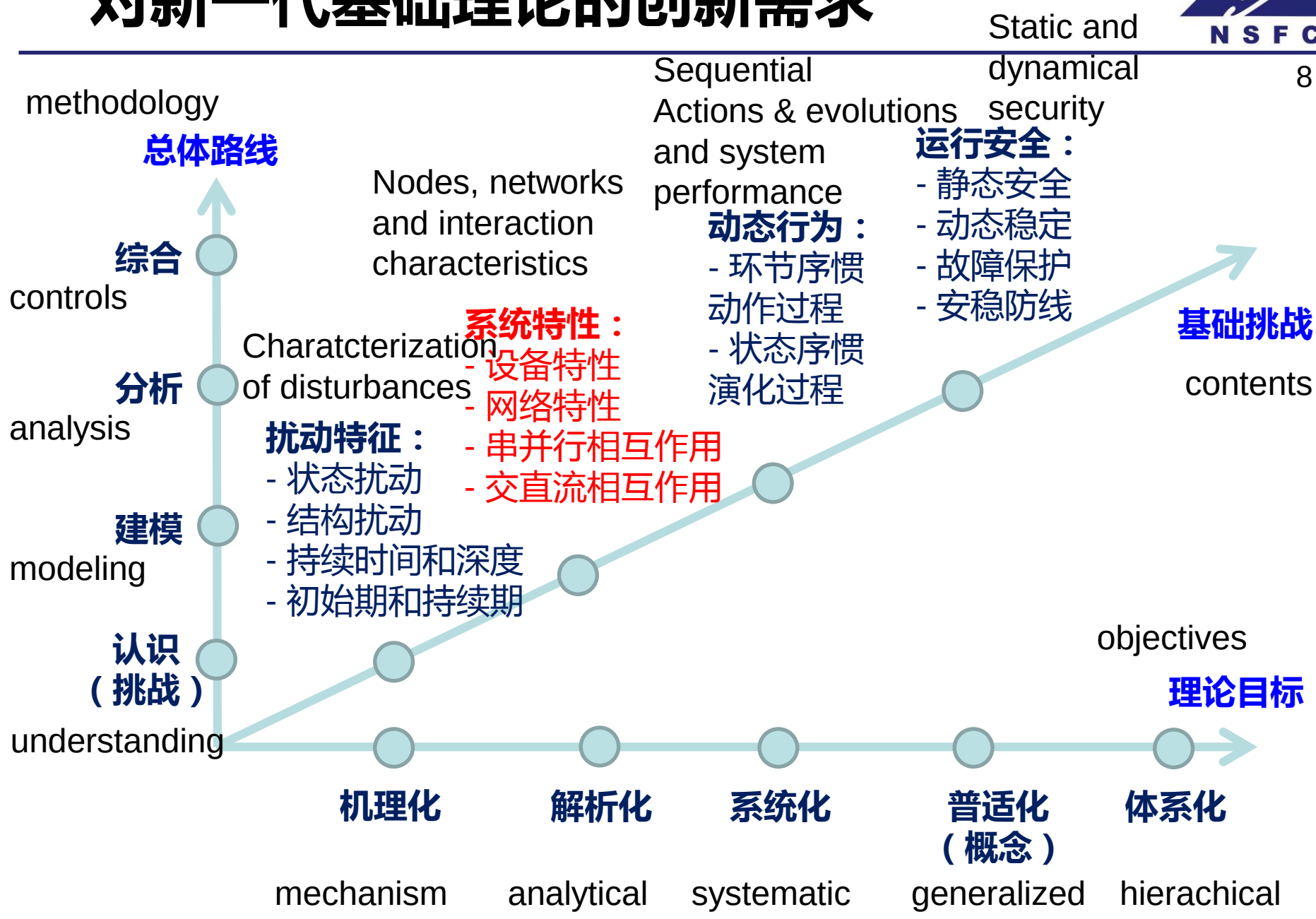




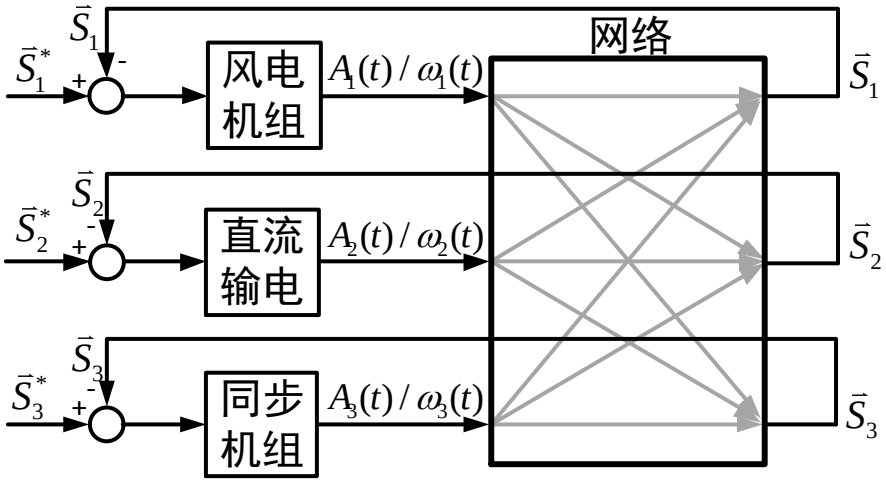
Dynamical interactions among nodes and networks: from sole AC grid interactions to hybrid AC-DC grid interactions (from among demands to among supplies and demands)

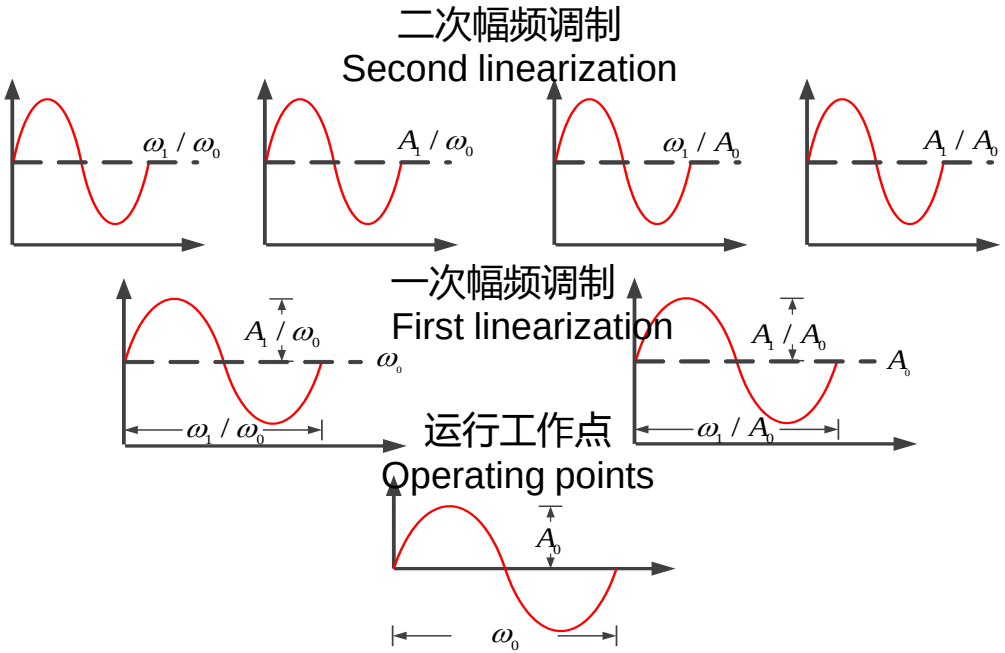
从网中相互作用到网间相互作用（从需求间到供需间）：设备间及其与网络间多尺度动态相互作用机理与规律性

对新一代基础理论的创新需求



幅频调制动力学基本框架





Casual mechanism and AF modulation

✓因果机制与幅频调制

AF motion equations nodes

✓设备幅频运动方程

AF motion equations networks

✓网络幅频运动方程

Characterization of interactions

✓相互作用自稳-致稳性

Sequential actions and evolutions

✓序惯动作与演化

Iterated AF modulation

✓迭代幅频调制

结论

New paradigm properties in nodes, networks and interactions drive needs for new generation of theory for system dynamics

- **系统节点、网络、相互作用特性变革与动态过程基础理论创新需求**

Multi-timescale power/internal voltage casual principle of system dynamics and roles of nodes, networks and interactions

- **动态过程的多尺度功率/内电势因果循环本质与节点、网络、相互作用的角色**

Time-varying AF as nature of signal dynamics and AF modulation based linearization and nonlinear mathematics

- **交流信号的时变幅频本质与基于幅频调制的线性化和非线性解析分析方法**