High DER/DA/Storage Architecture

Circuit structure and power flow control

Sonny/Arjun

Discussion emphasis: circuit structure with power flow control

- Feeders and feeder networks
- Structure at secondaries
- Effect on protection and control
- Effect on FLISR and DA in general
- Relationship to network mode
- Relationship to LENs
- Structure evolution/progressive deployment effects (dynamic aspects)

- Quick review of Trends/Issues
- Explore the creation of an architecture model or template (“breadboard”).. which can be customized for variety or tailored to particularity.

Some Trends (from Trends and Issues)

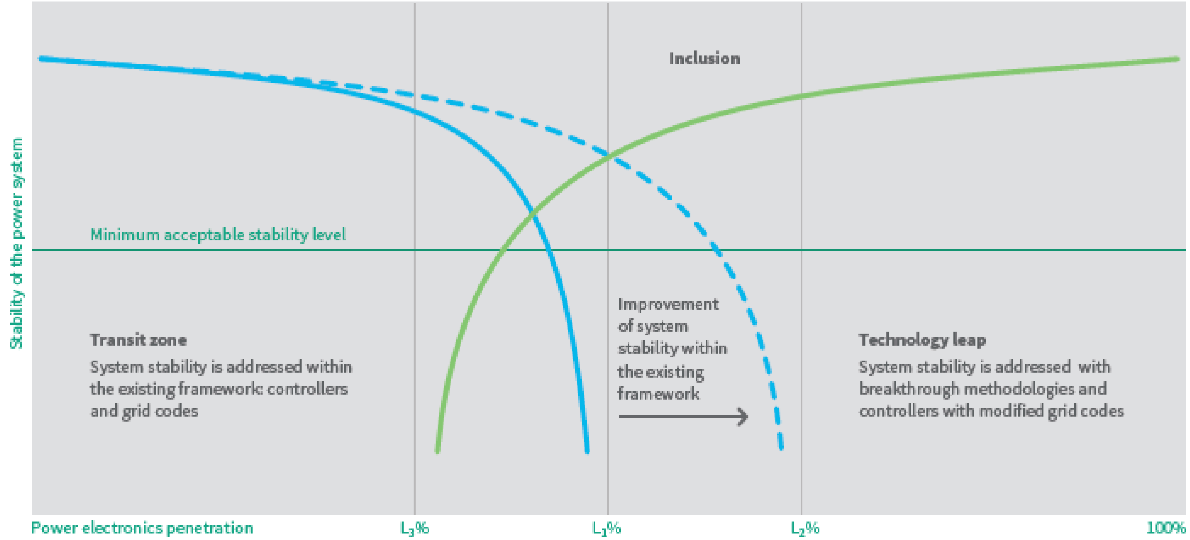
- Power industry deregulation
- State renewable portfolio standards
- Local power reliability needs
- T&D infrastructure investment deferment
- Congestion management
- Demand-side management
- Power electronics maturation
- Power flow control interest

Trends (contd.)

- Increasing penetration level
- From grid edge to MV/HV grids (new IEEE standards under development (IEEE 1547, P2800, P2030.x)
- From positive to negative generation
- Decreasing system inertia
- From centralized to decentralized
- Planned/scheduled to ad-hoc/real-time
- Coordinated to autonomous/self-optimizing
- Top-down to bottom-up
- Generation-follows-load to load-follows-generation
- Smart power electronics

Approaches - Evolutionary vs. Revolutionary

- Evolutionary
  - Situation as today (Large power plants, TD structure)
  - Hosting capacity and impact analysis
  - Grid services requirements
  - Coordinated control (may not be optimized)
- Revolutionary ("future grid")
  - Reinvent the grid and new grid architecture
  - Distributed, flatted, and networked
  - Cooperative or bio-inspired control
  - Dynamically reconfigurable for fault-tolerance and resilience



Recall there are existing future grid concepts that bring up this issue..

- Digital grid
- Energy internet
- Intergrid
- Integrated grid
- Web of cells
- Fractal grid
- Flexible network

High DER/DA/Storage Systemic Issues

- Controlling generation complexity requires new optimization formulations
- Integrating dispatch and DG and active loads requires new technologies and components
- Modes of operation evolve
- Load prediction task is harder
- Balancing modes may need new structural agreements and methods
- There is a gap in closed-loop fine-grained control algorithms deployments.
- Current control is rigid and centralized.
- Standard contingency analysis, state determination, and balance/control flow tools are not adequate. Need to incorporate alternate paths to direct secondary load control.
- Responding to low inertia requires new technologies and methods.
- New data sources for control algorithms need to be identified and sensing/actuation mechanisms need to be established.
- Lack of control and coordination across the power delivery chain
- Existing analysis and planning methodology is inadequate for operations

High DER/DA/Storage Systemic Issues (contd.)

Vital emergent issue: lack of control and operation frameworks for dynamically adapting grid is a central problem.

- Decentralized power system needs
  - distributed computing (grid computing)
  - distributed intelligence[1] (PnP, cooperativeness, autonomy, adaptability, self-awareness)
  - distributed control
- New holonic* control architecture (similar to layered decomposition)

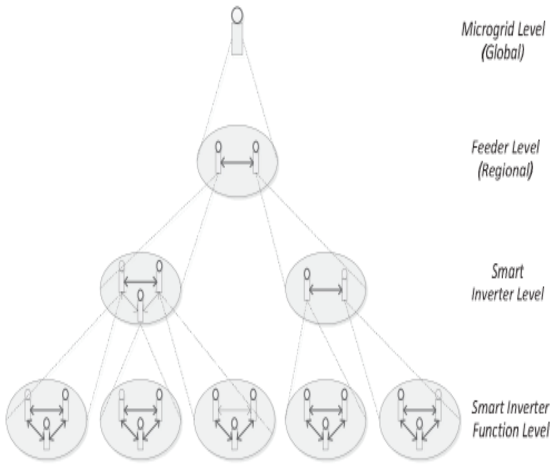


Fig. 4. Smart inverter-based holonic microgrid architecture.

[1] Y. Xue and J. M. Guerrero, "Smart Inverters for Utility and Industry Applications," *Proceedings of PCIM Europe 2015; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*, Nuremberg, Germany, 2015, pp. 1-8. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.834.418&rep=rep1&type=pdf

*A holon (Arthur Koestler 1967) is a part-whole system, with an evolving self-organizing dissipative structure, that can be seen as a component of a higher level system or as a whole composed of other holons.

Smart PE control functions

Table I. Smart inverter standards and grid codes.

Standard Type	Standards or Activities
Standard control functions	IEEE 1547-2018, EPRI smart inverter initiative, IEC 62109-2
Information & data models	IEC 61850-7-420, SunSpec, OpenADR, OpenFMB, etc.
Communication protocols	IEEE 1815 (DNP3), IEEE 2030.5 (SEP2), etc.
Grid codes	FERC, NERC, CPUC Rule 21, HPUC Rule 14H
Compliance & certification testing	UL 1741 SA, UL 62109-2, IEEE P1547.1

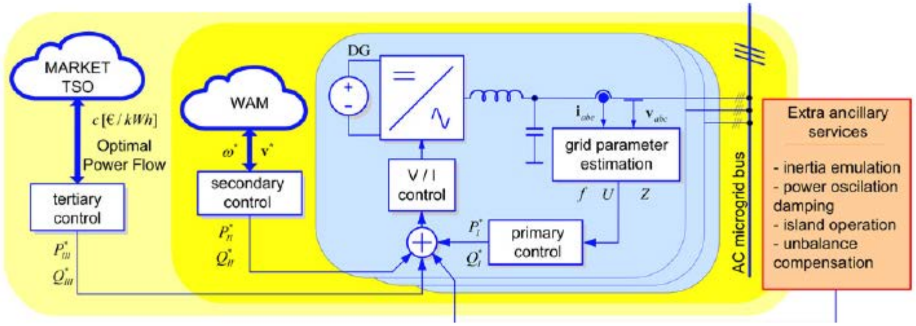
Y. Xue *et al*., "On a Future for Smart Inverters with Integrated System Functions," *2018 9th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Charlotte, NC, 2018, pp. 1-8.

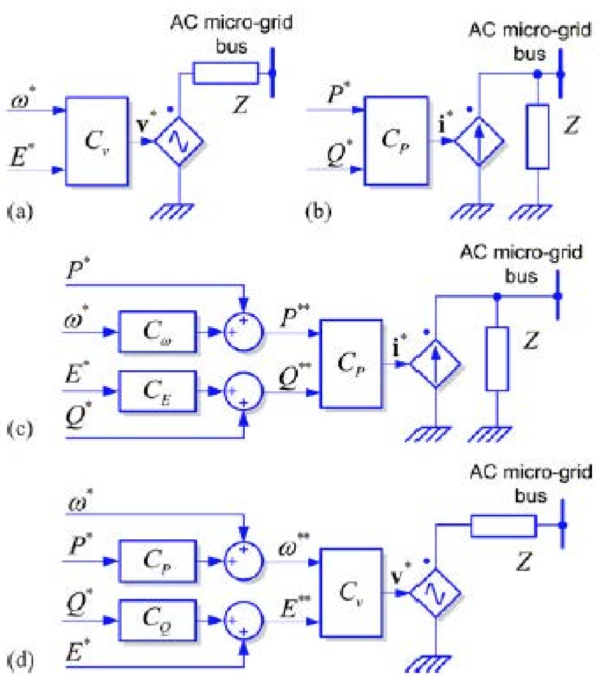
Smart Features	Possible Approaches or Control Functions
Plug-and-play	• Standardized communication protocols • Non-formation cooperative controller (distributed frequency control, parallel processing, etc.) • Communication graph (at cyber layer)
Self-awareness	• Fault diagnostics (detection, isolation and classification) • Prognostics & health management (condition monitoring and device lifetime estimation) • Self-expression with communication (alarm, status, etc.)
Adaptability	• Grid parameter estimation • Frequency-adaptive grid synchronization • Distributed anti-islanding detection and adaptive mode transfer • Real-time optimization • Fault tolerance (modular and redundant structure, fault current control, fault ride-through) • Current source/voltage source flexibility
Autonomy	• Active/reactive power flow control • Grid forming/grid following flexibility
Cooperativeness	• Dynamic grid feeding • Dynamic grid supporting • Active/reactive power and harmonic current sharing • Sub- or super-harmonic damping • Ramp rate control • Soft start • Coordinated harmonics compensation • Coordinated unbalance compensation

Fig. 1. A list of control functions and approaches associated with each smart inverter feature.

Y. Xue and J. M. Guerrero, "Smart Inverters for Utility and Industry Applications," *Proceedings of PCIM Europe 2015; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*, Nuremberg, Germany, 2015, pp. 1-8.

Hierarchical control





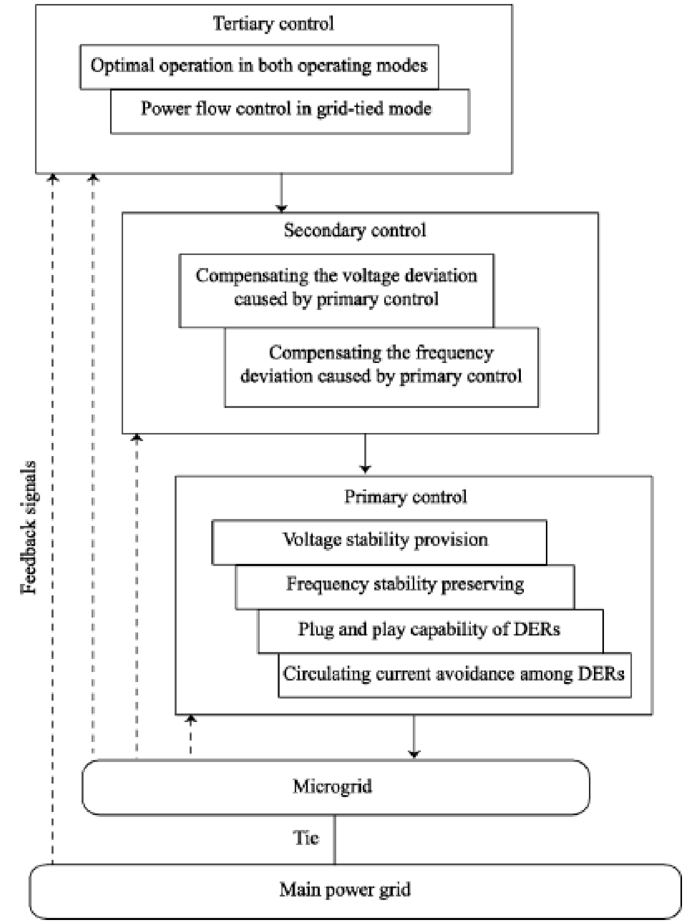
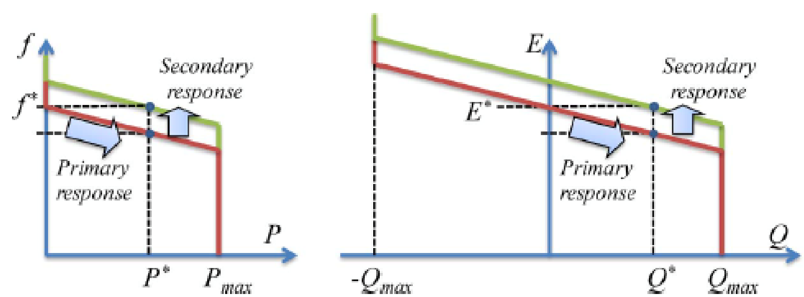
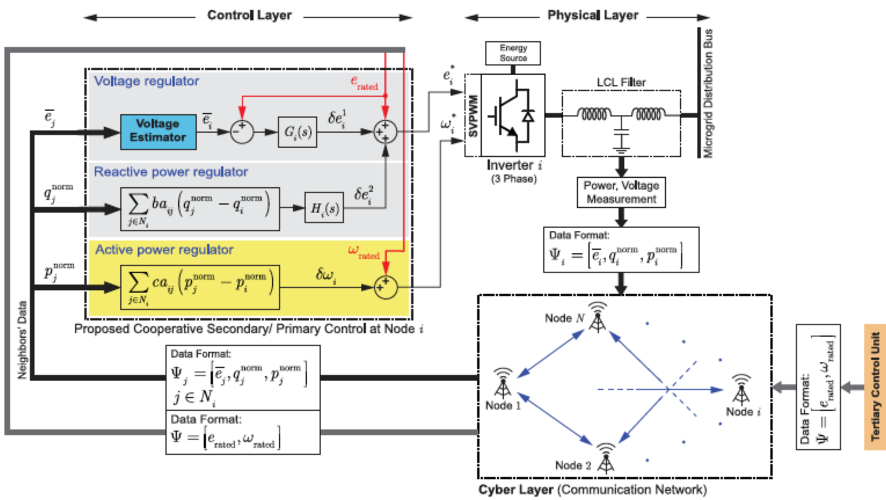
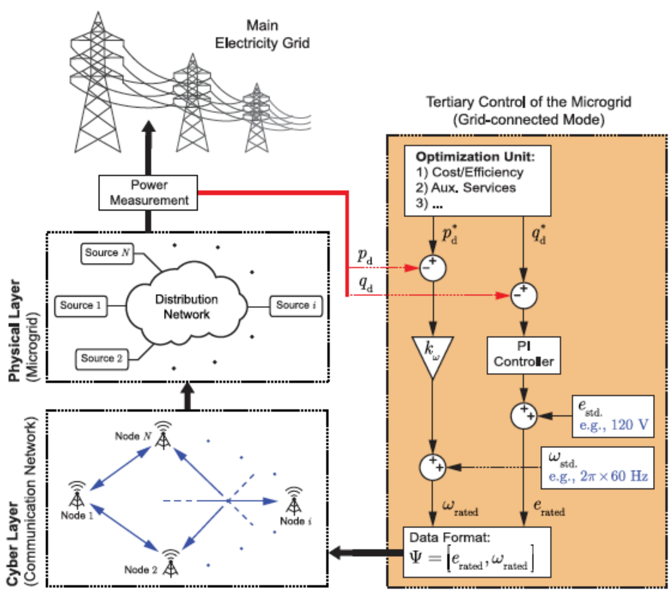


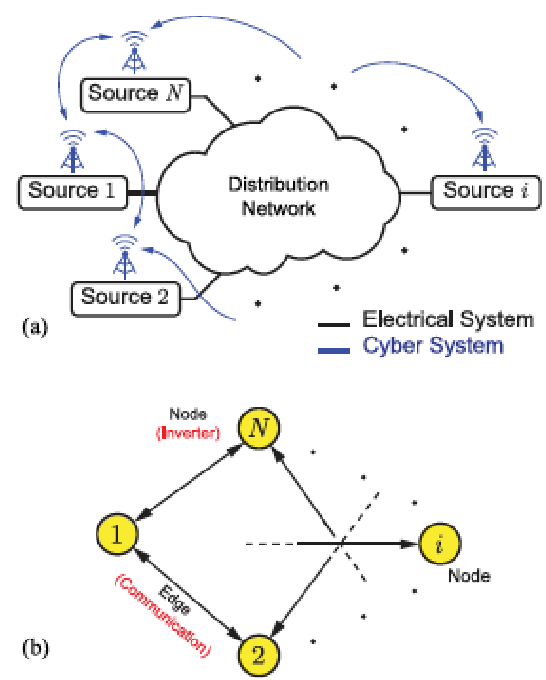
Fig. 1. Hierarchical control levels of a microgrid.



Cooperative control with consensus algorithms



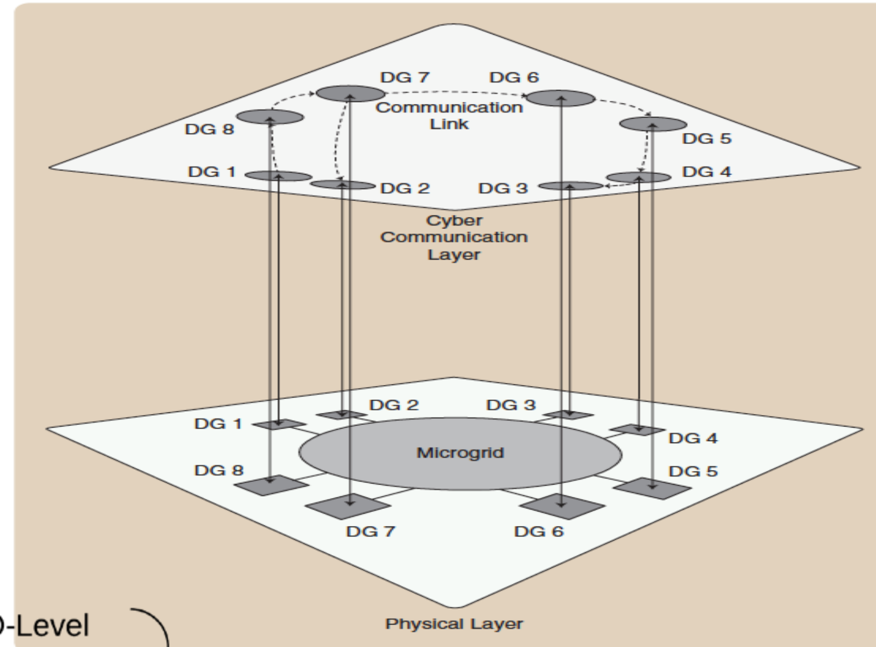


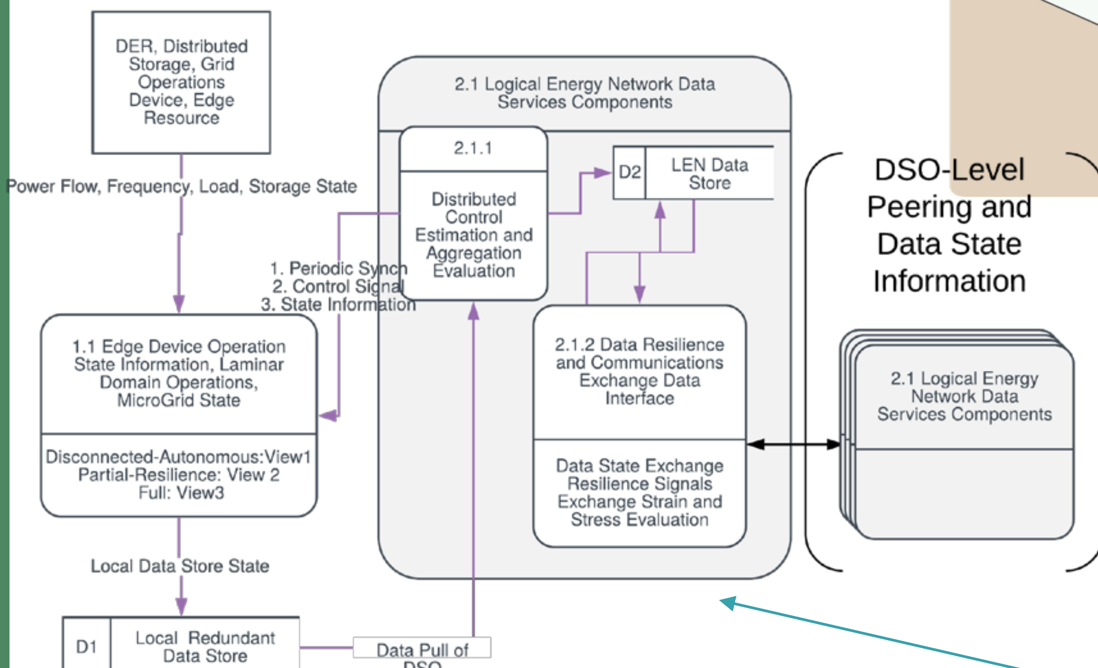


To fill in attributions yet..

Requires a formulation of Connected Controller Network (CCN)?
(aka "breadboard")

- Communication map of Data Plane to Physical Plane connections



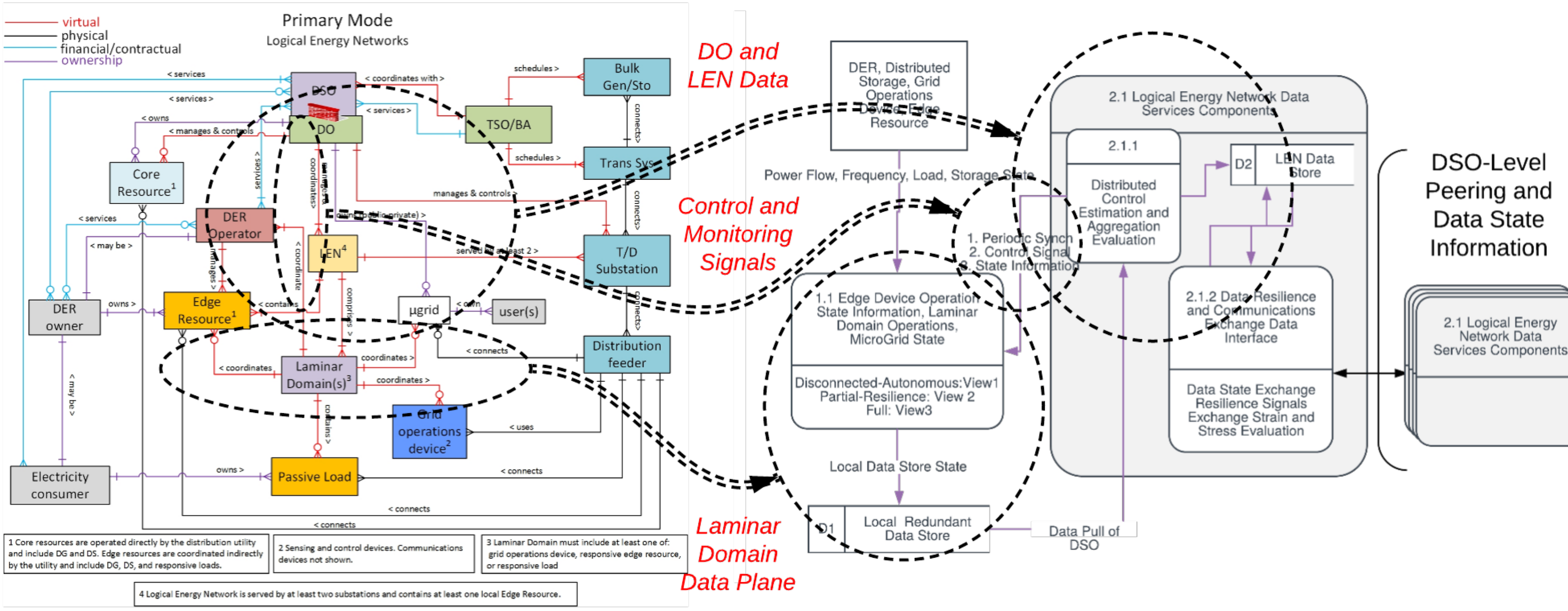


Perhaps modify this..

Inputs and Outputs

- Potential Inputs:
  - New load requirements and load profile;
  - Planned automation, storage, profile;
  - New DER profile;
  - Relevant geographic expanse/properties
- Outputs
  - Connectivity/topology recommendations;
  - range parameters over time; flexibility allowed; uncertainty projections
  - PFC structural recommendations;
  - Power Electronics interface options/recommendations;

Reviewing the data mapping for the CCN (like we did for High-Resilience Arch.)



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Control/Stability and Evolving Networks.. obviously still an active area of research

- Power Generation/Distribution Control Systems Topology Selection Based on Robustness Evaluation; Jozef B. Lewoc, Antoni Izworski, Slawomir Skowronski, Antonina Kieleczawa and Georgi Dimirovski (c. 2009)
  - The problem of the data acquisition/control system topology for distributed control systems in big power plants and/or power distribution centres is usually solved in a rather arbitrary way. The paper presents some reasonable approached based of evaluation of the system robustness, using the μ function as the measure or robustness. The paper proposes a method feasible for actual system designers since computational effort is rather low for communication systems described with time-delay members only.

- Issa, Walid & Elkhateb, Ahmad & Anani, Nader & Abusara, Mohammad. (2017). Smooth Mode Transfer in AC Microgrids during Unintentional Islanding. Energy Procedia. 134. 10.1016/j.egypro.2017.09.592.

- M. J. Hossain, J. Lu, M. A. Mahmud and T. Aziz, "Advanced decentralized DER control for islanded microgrids," 2014 Australasian Universities Power Engineering Conference (AUPEC), Perth, WA, 2014, pp. 1-5. doi: 10.1109/AUPEC.2014.6966534

- G. Li, J. Ding, C. Wen, L. Wang and F. Guo, "Controlling Directed Networks With Evolving Topologies," in *IEEE Transactions on Control of Network Systems*, vol. 6, no. 1, pp. 176-190, March 2019. doi: 10.1109/TCNS.2018.2803444
  URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8283730&isnumber=8667750
  - *"In this paper, we address an important issue regarding how the network topologies affect the cost of controlling directed networks. We have proposed a matrix function optimization model to address how the network* topology evolves for achieving more efficient control of the networks. To our best knowledge, this problem has never been addressed by existing literatures." ! [sic]

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