Logical Energy Networks

Concept of Operations

v0.3

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Logical Energy Network Definition

Logical Energy Networks are structures for the virtualization of distribution systems. A Logical Energy Network (LEN) is a distribution level virtual structure specified and enforced through coordination and control processes. It is a portion of a distribution system that is segmented in a way that is roughly analogous to bulk system Balancing Areas. A LEN is a virtualization of a portion of a physical distribution system, including infrastructure, loads, and DER, somewhat analogous to but not the same as a microgrid. There may or may not be underlying circuit elements (sectionalizers, boundary sensors/meters, power flow controllers) involved. LENs may be thought of as virtual microgrids except that islanding capability is optional.

LEN Structure

A LEN is a segment of a primary feeder with associated devices and loads. Ideally, each LEN has three energy sources available to it:

- Fed from two primary distribution feeders
- Some amount of DG/DS resource internal to the LEN that is utility controlled or coordinated

This structure recognizes two classes of DER:

- Edge resources (non-utility owned)
- Core resources (utility owned)

Core resources are controlled directly by the electric utility. Control of edge resources is dependent on other aspects of distribution system structure, namely the form under which T/D coordination is done[1], and the manner in which third party DER operators such as aggregators are incorporated into the mix. Some edge resources may be controlled directly by an electric utility, or may be coordinated indirectly via interaction with the DER owners or via DER operators.

Figure 1 shows an example of several adjacent LENs on a pair of interconnected distribution feeders.

[1] P De Martini and L Kristov, Distribution Systems In A High Distributed Energy Resources Future, LBNL Report No. 2, Future Electric Utility Regulation series, October 2015. Available online: https://gridarchitecture.pnnl.gov/media/advanced/FEUR_2%20distribution%20systems%2020151022.pdf

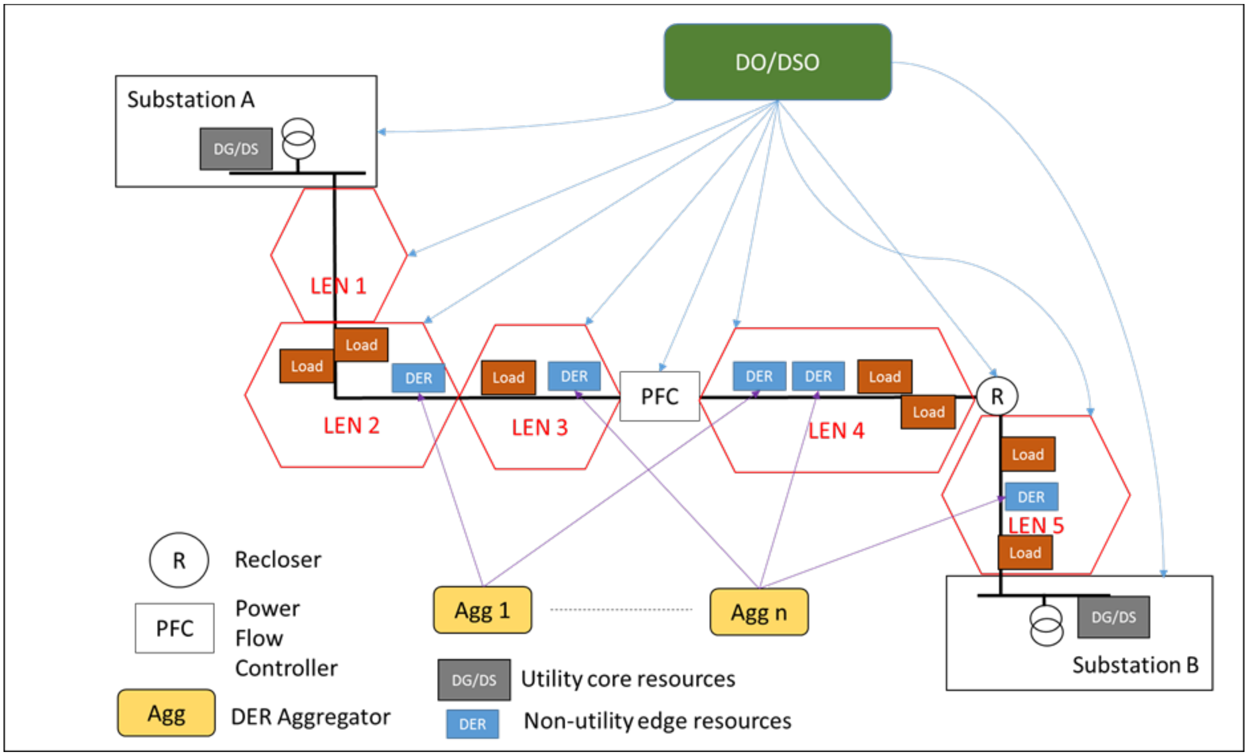

Figure 1 Example LEN Mapping to Feeders

The definition of a LEN extent is a degree for freedom for the grid designers and engineers. A LEN may be confined to a single feeder (or connected feeder pair) or may encompass multiple feeders or connected feeder pairs as needed. LEN structure is virtual and so may be imposed on the physical infrastructure in a variety of flexible ways.

LENs map to adjacent contiguous sections of infrastructure but **do not overlap**. LENs are not virtual power plants - a virtual power plant is the aggregation of Distributed Energy Resources (DER) to be treated as a single resource for bulk energy system purposes. A LEN is a virtualization of physical infrastructure and edge-connected energy assets. Physical microgrids, where they exist, are contained within LENs that include the points of common coupling.

Note that LENs are compatible with Laminar Coordination.[2] Each LEN can function as a Laminar Coordination domain and its Laminar node can coincide with and be hosted on the same computing element as the LEN logic, so the LEN may be viewed as existing within a larger Laminar Coordination framework. Both are compatible with the distributed intelligence approach of the Open Field Message

[2] JD Taft, Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes, PNNL- 25480, June 2016. Available online: https://gridarchitecture.pnnl.gov/media/advanced/Architectural%20Basis%20for%20Highly%20Distributed%20Transactive%20Power%20Grids_final.pdf .

Bus.[3,4] Figure 2 shows an example mapping of virtual to physical structure for a portion of a distribution grid. Note the Laminar node placement and Laminar Network structure in relation to the LEN structure.

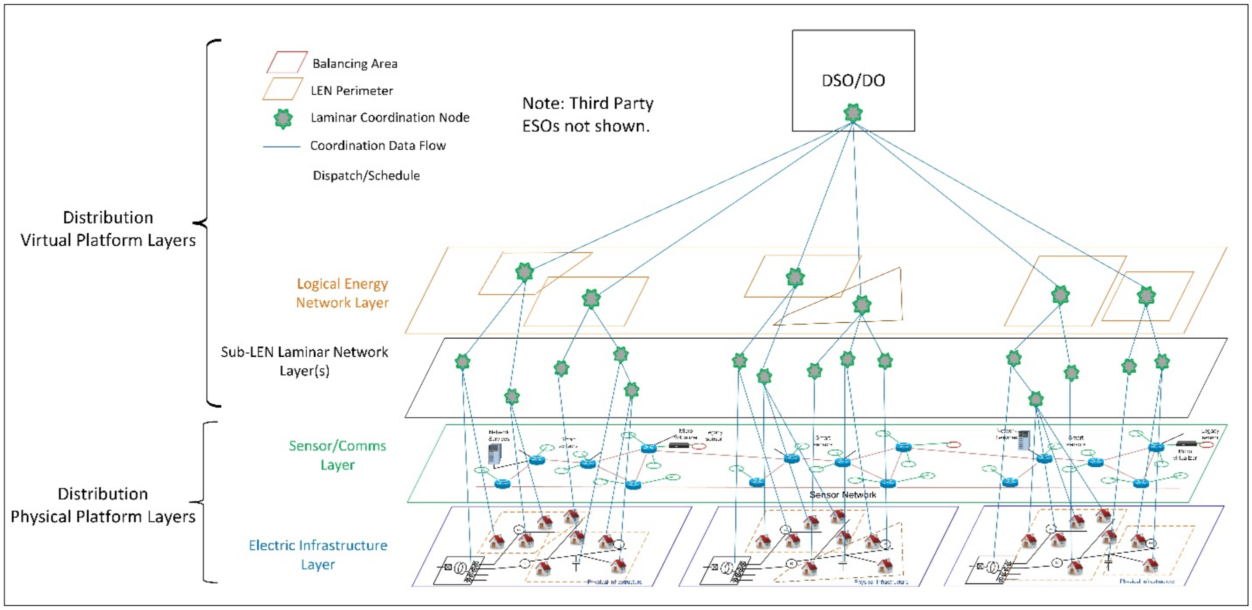

Figure 2 Example Mapping of Virtual Grid LENs to Physical Grid

<u>LEN Functions and Behavior</u>

Logical Energy Networks interact with each other (on a neighbor basis) to carry out:

- local (within the LEN) balance
- power wheeling across LENs
- interchange between LENs
- intra and inter-LEN outage support
- inter-LEN V/VAR support

Power wheeling has two aspects: pass through of feeder-supplied power from upstream LENs to downstream LENs for normal feeder operation, and sourcing or pass-through of power sourced within a LEN but sent to another adjacent LEN. Given that large amounts of DG may cause reverse power flows (from the standpoint of the distribution feeder) pass-through may also flow upstream (toward the substation). Interchange is essentially the same as for Bulk Energy System (BES) Balancing Areas – exchange of power between adjacent LENs for balance and support purposes, although the LEN does not have a system frequency-based control criterion for LEN balance.

On a larger scale, LENs are managed using Laminar Network structure to provide multi-scale coordination up to the level of the entire distribution system. Such structure provides for both local and

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[3] OpenFMB Collaboration site: https://openfmb.github.io/

[4] S Laval and B Godwin, Distributed Intelligence Platform (DIP) Reference Architecture Volume 1: Vision Overview, January 5, 2015.

global coordination, and consequent local selfish optimization within a global coordination framework. LENs may also be decomposed into Laminar coordination domains, as Figure 3 illustrates.

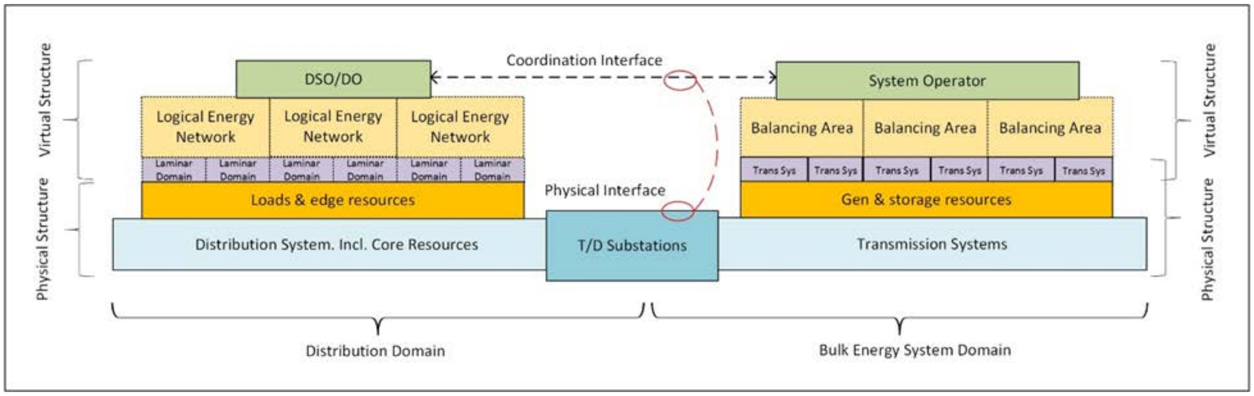

Figure 3 BES and LEN Stack Model Showing Homology

The figure shows that LENs may be considered to be homologous to BES balancing areas, which are themselves virtualizations of the BES. The functions of the LEN are similar to the functions of the Balancing Area.

<u>LEN Operations</u>

Each LEN has a local control/intelligence capability that supports local load and energy resource management. A LEN has logic that manages:

- Local balance
- V/VAR regulation (local)
- Participation in global coordination
- Grid services resource management (local)

LENs operate in a cellular fashion, functioning autonomously when necessary and coordinating globally via Laminar Coordination networks when connected for communications.

The cellular automaton capability of LENs is important for resilience purposes: under conditions of grid strain, a distribution system based on LENs can separate into segments or fragments that continue to operate without the need for either centralized or global coordination and control. This implies that each LEN must have its own internal intelligence with the capability to recognize segmentation/fragmentation conditions and act accordingly. This is the LEN generalization of microgrid islanding. Physical separation of LENS may or may not be included, depending on how circuits are configured, but for control purposes, LENS can island in a virtual fashion.

Local balance – unlike in the BES, local LEN balance cannot be measured via system frequency. Instead it is necessary to treat the LEN as a multi-port macro-node, with a set of power flows (in and out) that satisfy several conditions:

1. Power to meet the demand for all loads in the LEN, accounting for internal resources
2. Power flow-through to support wheeling, including aggregated power needed by downstream LENs

3. Upstream power flow to meet allocated grid services requirements
4. Power flows to meet nearest neighbor interchange requirements

Note that storage internal to the LEN may be acting as either load or generation and may switch operating modes on short notice. LENs require both power flow measurement at the virtual ports and power flow control, as well as information (forecasts and actual state) on demand and available DER resources.

V/VAR regulation – any given LEN may or may not have control devices for V/VAR regulation. Consequently, such regulation is a cooperative effort where some LENs may only be providing measurements whereas others may be providing control for themselves and other LENs. This implies a level of peer-to-peer communication that is supported by the Laminar Network structure but also suggests that if LENs are to operate autonomously at times, then V/VAR control devices would be needed in those that would stand alone, much like microgrids. The necessary intelligence for such control is hosted in the same computing elements that perform the rest of the LEN management and the Laminar coordination.

Participation in global coordination – LENs must be able to coordinate on various scales, from nearest neighbor, to entire distribution system. The coordination mechanism must not be centralized and must be capable of operating in various fragmented forms, with the ability to organize itself based on the communication and electrical connectivity available at any given time. Laminar Coordination frameworks and Laminar Networks can provide these capabilities, given the appropriate intelligence at the Laminar and LEN nodes.

Grid services management – combining the LEN/Laminar Network model with the Total DSO model provides the structure to disaggregate requirements for grid services down to the local DER level while maintaining distribution reliability. Combining this with aspects of the LEN load balance function described above yields a structure for systematic use of Der for both distribution level and BES level purposes without the scaling issues, cyber security vulnerabilities and tier-hopping reliability issues of past approached to DER utilization. This also points to why DER aggregators and other third parties should be participants in the Laminar Coordination framework.

<u>Summary</u>

LENs are virtualizations of physical electric distribution system infrastructure and edge-attached loads and DER. The purpose of the virtualization is to obtain the essential benefits of distributed resources and control without having to make extensive modifications to physical infrastructure (for example, creating physical microgrids). These benefits include increased grid resilience and functional flexibility in the use of new DER assets.

LEN-based virtualization can be done by the electric distribution utility with minimal changes to prosumer and third party systems and equipment (especially if the Laminar Coordination Framework approach to edge asset coordination is used). The use of the LEN approach implies a new form of distribution grid control but this can be done within the confines of the electric utility since the virtualization of the grid is an approach to utility management of the grid and connected assets. In addition, LEN structure will require levels of grid observability not presently common in distribution systems and communications network structure that supports data flows also not common in 20th Century electric distribution systems.

The LEN approach combines modularization, distributed control and coordination, and virtualization into a structure for systematic cooperative operation of extended electric grids, including edge assets.