A Reliability Perspective of the Smart Grid

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Introduction

Increasing complexity of power grids

- Growing demand
- Requirement for greater reliability, security, efficiency
- Environmental and energy sustainability

How to solve this problem

- Advances in communication and information technology give us a possible solution which toward a “smarter” grid is widely referred to as “smart” grid.

Introduction

What can we get from smart grid[1]:

- Better situational awareness and operator assistance;
- Autonomous control actions to enhance reliability
- Efficiency enhancement by maximizing asset utilization;
- Improved resiliency against malicious attacks
- Integration of renewable resources
- Integration of all types of energy storage and other resources
- Two-way communication between the consumer and utility
- Improved market efficiency
- Higher quality of service to power an increasingly digital economy.

Introduction

The initiatives for smart grid can be categorized into 5 trends[1]:

- Reliability
- Renewable resources,
- Demand response
- Electric storage devices
- Electric transportation.

These trends are also recognized by the Federal Energy regulatory Commission (FERC) and recent funding by the U.S. Department of Energy (DOE) [1].

Grid Reliability Challenges

Meeting reliability objectives in modern grids is becoming increasingly more challenging due to various factors such as:

- Aggravated grid congestion
- More numerous and larger transfers over longer distances increasing volatility and reducing reliability margins
- The grid being operated at its “edge” in more locations and more often
- consolidation of operating entities giving rise to larger “footprints”
- Massive utilization of distributed resources accentuating complexity and volatility of the grid.

Reliability Impacts

- Load Management/Demand Response
- Renewable Resources
- Storage Devices
- Electric Transportation

Load Management/Demand Response

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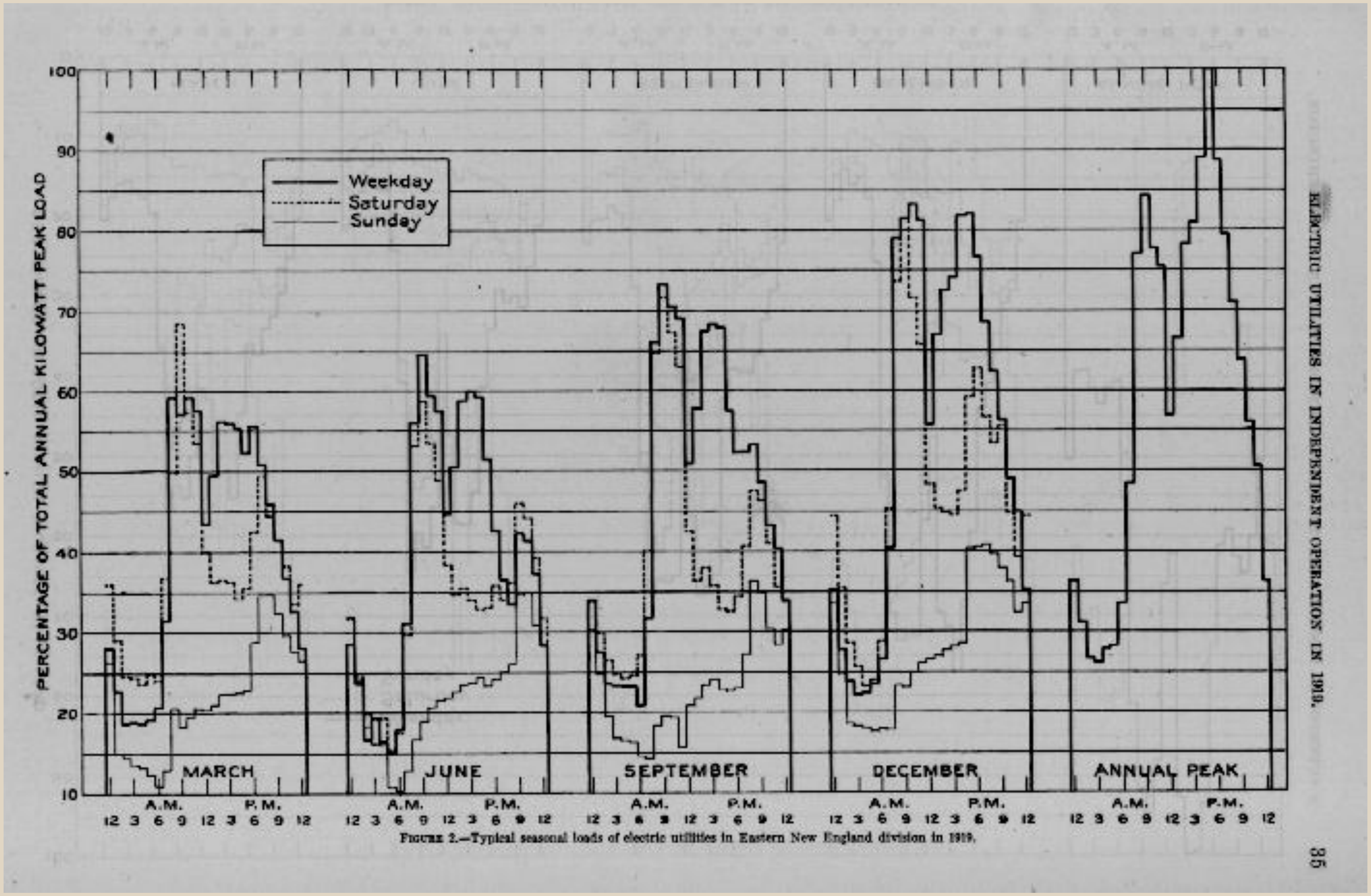
- Load management involves reduction of load in response to emergency and/or high-price conditions. Reduction initiated by the consumer is usually referred to as demand response.
- Demand response does not substantially change the total energy consumption since a large fraction of the energy saved during load curtailment is consumed at a more opportune time—thus a flatter load profile.
- Load rejection is an emergency resource to protect the grid.
- In addition to capability to flatten the load profile, demand response can serve as an ancillary resource to help reliability.

Reliability Impacts of Major SG Resource Types
Load Management/Demand Response



Load Curve Example [2]

Renewables

Wind

In the United States, wind is expected to grow from 31 TWh in 2008 (1.3% of total supply) to 1160 TWh by 2030 (wind energy target of 20% of total supply of 5800 TWh)[1].
The unpredictability of wind energy resources is indicated by their low capacity factors (typically 20% to 40%[1]) which are much lower than conventional generators. This creates challenging problems in the control and reliability of the power grid.

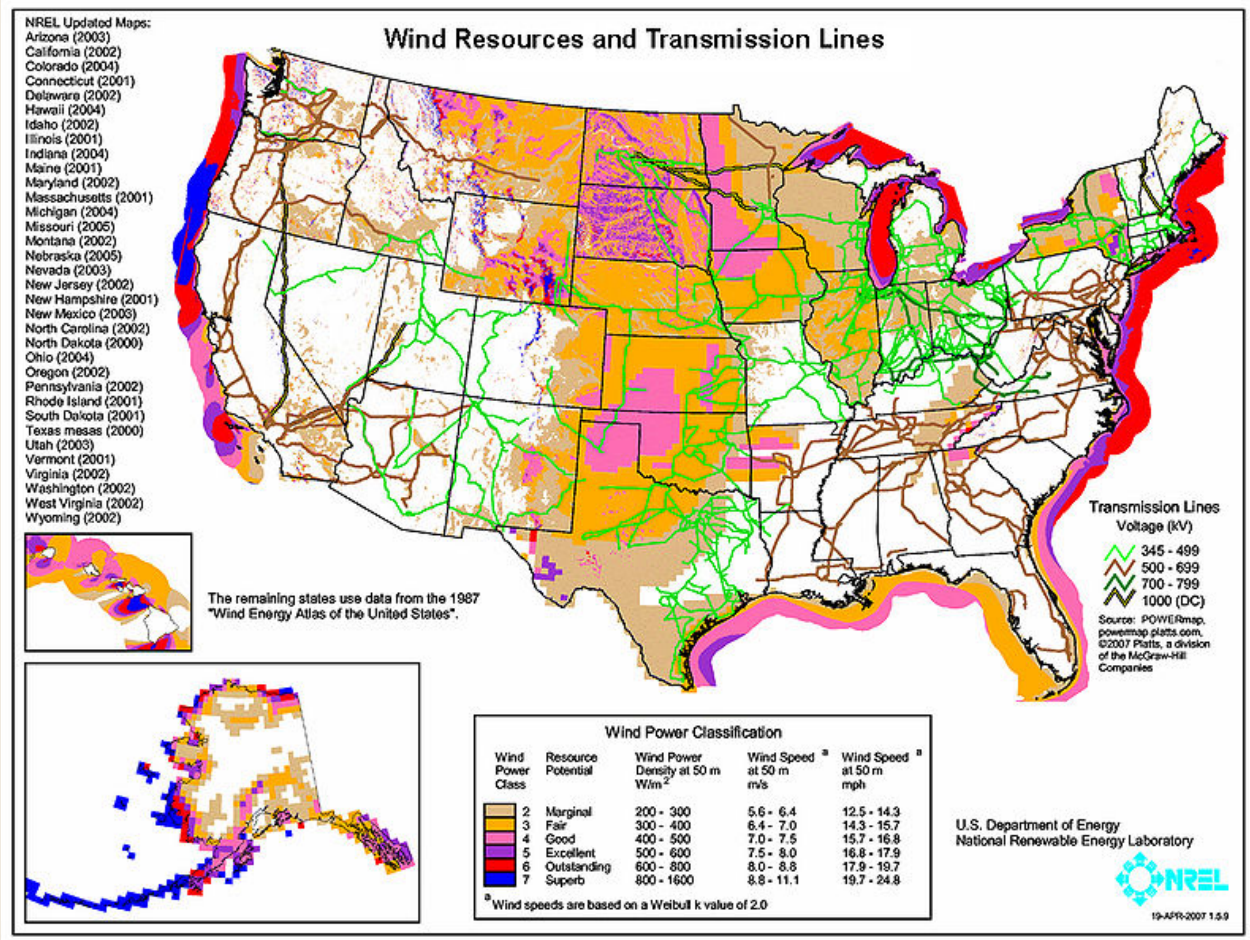
The variability of wind power is impacted by

- The design of the equipment
- Their location(transmission line)
- The wind power forecasting errors
- Wind generators present problems regarding low voltage ride through (LVRT).

Wind power variability has a relatively small adverse impact on regulation requirements. The variability of wind energy has little correlation to the variability of the load and hence contributes only a little towards meeting ERCOT’s peak load despite the expected 18 GW of wind capacity.

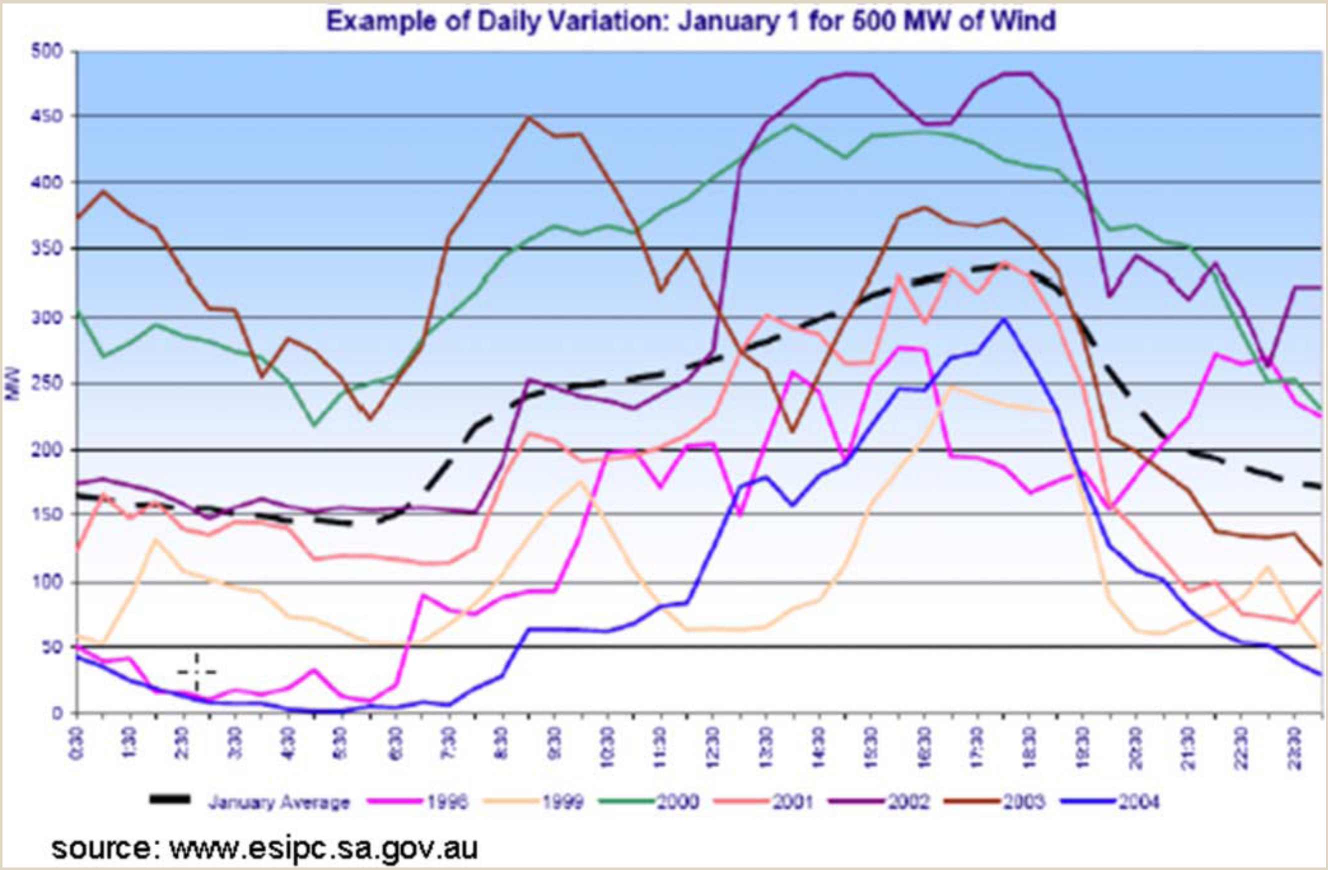
Reliability Impacts of Major SG Resource Types

Renewables



Wind Energy [3]

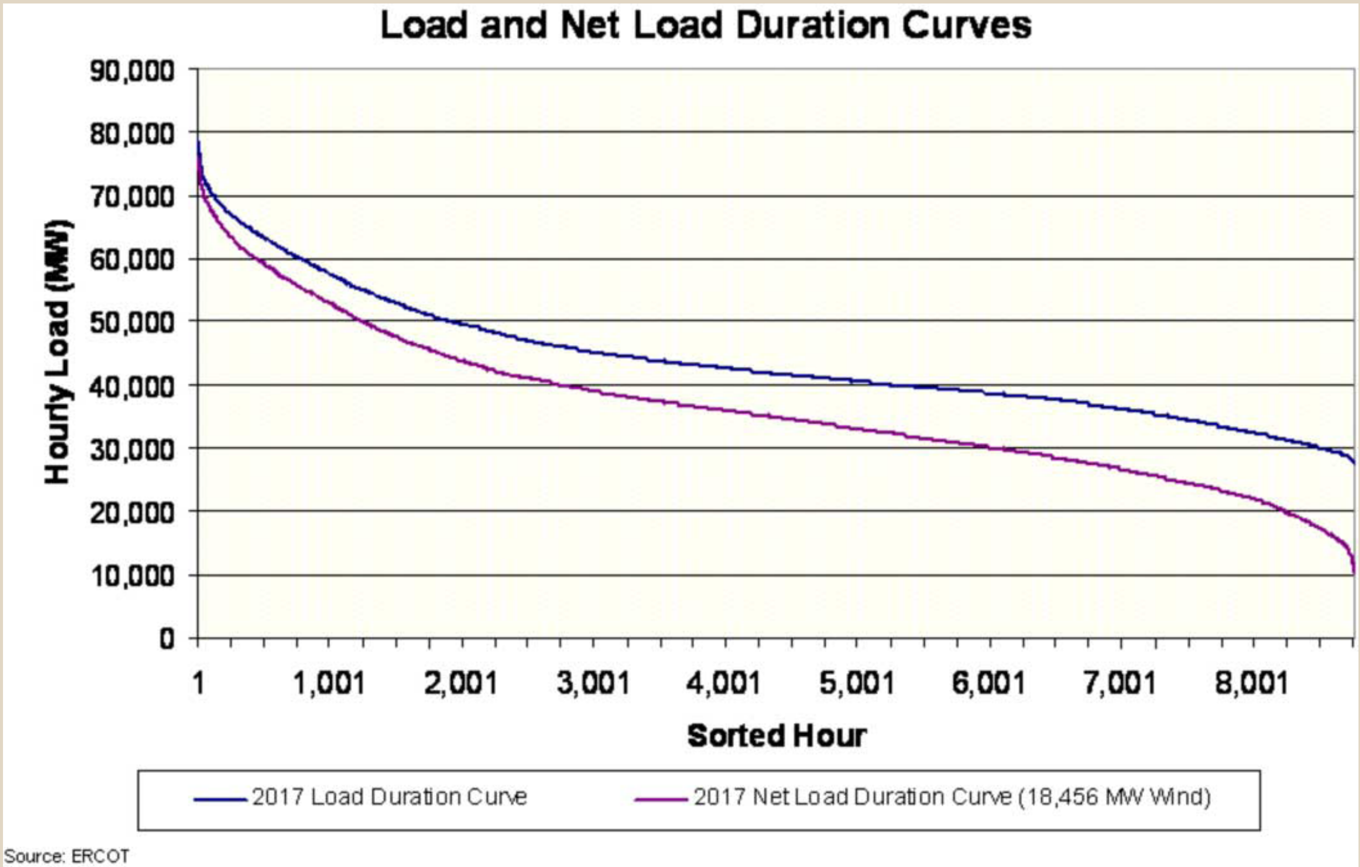
Reliability Impacts of Major SG Resource Types
Renewables



Variability of wind resource output[1]

Reliability Impacts of Major SG Resource Types

Renewables



Impact of 18 GW of wind power capacity[1]

Reliability Impacts of Major SG Resource Types

Renewables

Solar

- Cumulative installed solar capacity is expected to reach 16 GW by 2020[1].
- The two prevailing technologies to harness this energy: photovoltaic and thermal.
- The variability of solar resources is very much impacted by climate and sunlight availability.
- The capacity factors for photovoltaic are typically 10% to 20%. For solar thermal plants with storage, this may reach over 70%[1].
  - Large scale solar resources could be far away from loads and consequently face various transmission limitations. However, solar resources have a positive correlation with day-time loads.

PV[4]

Solar thermal[4]

Renewables

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From the reliability perspective, renewable resources such as geothermal and biofuels behave similar to conventional generation. In contrast, wind and solar generally have adverse impact on grid reliability due to:

- Variability and low capacity factors;
- Low correlation with load profiles especially for wind;
- Relatively larger forecast errors for longer horizons;
- Transmission congestion due to large installations;
- Distribution congestion due to dispersed resources;
- Operational performance issues such as voltage and regulation.

Storage Devices

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Most of the existing storage resources are hydro and pumped storage. However, growth potential for these resources is much smaller than the need for storage necessary to counter growing net demand variability presented by new wind and solar resources.

Various storage technologies are emerging to fill the gap. Battery storage appears to be most promising due to improvements in technology as well as economies of scale.

Storage tends to make the net demand profile flatter and, as such, is expected to improve reliability. In addition, most battery storage devices can respond in subsecond time scales. Storage of various sizes can be distributed throughout the grid ranging from end-use customer premises to major substations and central power stations. This can alleviate congestion in both transmission and distribution.

Reliability Impacts of Major SG Resource Types

Electric Transportation

Electric vehicles (PEV, eCAR, etc.) continue to become more popular as environmental concerns increase. They are a significant means to reduce reliance on fossil fuels and emission of greenhouse gases (GHG).

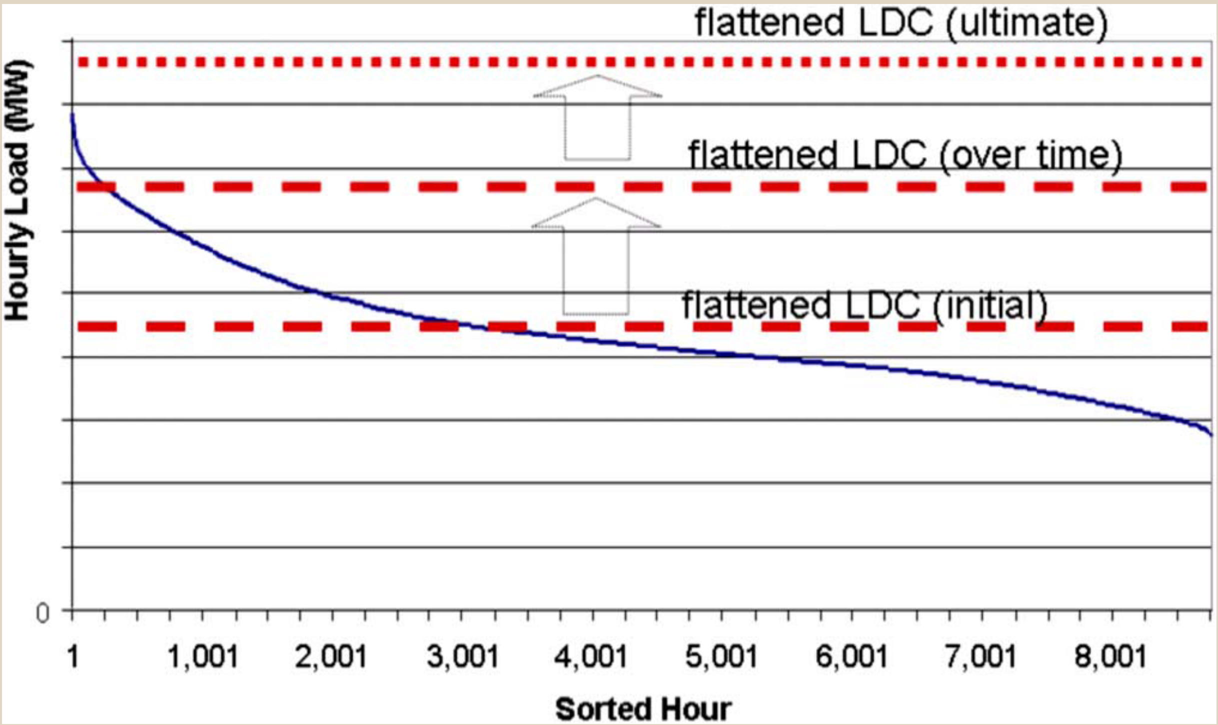
They will be a major factor in load growth with a potential to eventually Consume 600 TWh/year. This estimate assumes 30 kwh for a 100-mile trip[1], and 10 000 miles per year for 200 million vehicles in the United States.

From a purely reliability viewpoint, electric vehicles have features similar to both demand response and storage resources. However, as a significant factor of load growth, PEVs can aggravate demand variability and associated reliability problems depending on the charging schemes and consumer behavioral patterns. Long recharge times lead to unacceptable vehicle unavailability and short recharge times have potential to increase congestion at the distribution level.

Electric Vehicle[6]

Ultimate Reliability Impact of SG Resources Assessment

Under ideal conditions, demand response, storage, and electric vehicles will be closely coordinated with all other resources such that the net load profile would be nearly flat.



Ultimate reliability impact of SG resources[1]

IT Infrastructure for Smart Grid

The Instantaneous bidirectional communications among all devices ranging from individual loads to the grid wide control centers including all important equipment at the distribution and transmission levels. This involves processing a vast number of data transactions for analysis and automation.

Managing the communication burden and resulting data latency is essential for efficient analysis and fast control responses and calls for distribution of intelligence throughout the infrastructure, since centralized systems are too slow for this purpose. A distributed system enables local data processing and minimizes the need for massive data exchanges.

IT Infrastructure for Smart Grid

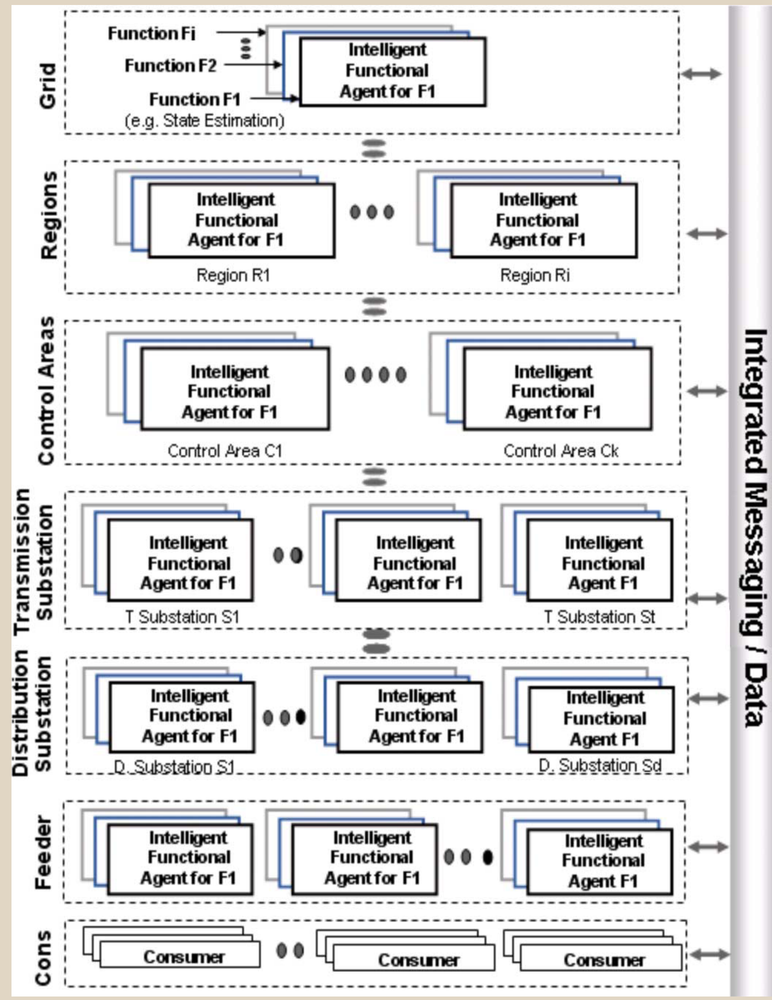
The addressed architecture calls for distribution and coordination of the necessary functional tasks in a virtual hierarchy in three dimensions:

- Organizational/control (grid, region, control area, zone/vicinity, transmission substation, distribution substation, feeder, customer (load, generation, storage), etc., representing operational responsibilities;
- Geographical area (region 1 j, substation 1 n, etc.);
- Functions (forecasting, alarming, voltage control, etc.).

Autonomous intelligent agents are deployed, as needed, throughout a grid-wide computing infrastructure to provide services

Necessary for the functional tasks in the areas of:

- Data acquisition and model management;
- System monitoring (e.g., state estimation, security analyses, look-ahead/forecasting);
- Performance enhancement (e.g., efficience enhancement, corrective/preventive actions, security constrained dispatch);
- Control (e.g., AGC, automatic emergency controls, special protection schemes).

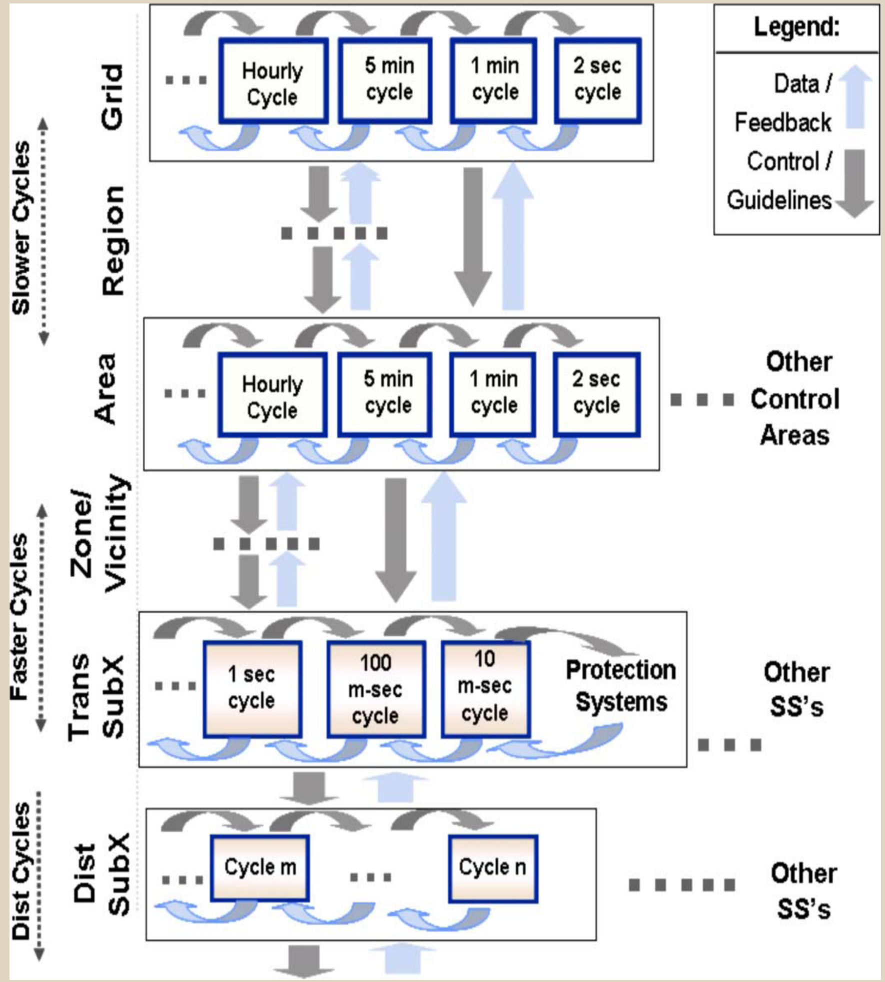


Hierarchical architecture for smart grid[1]

IT Infrastructure for Smart Grid

These functional tasks potentially apply to every level, from customer resource, feeder, and substation to the entire grid. It can respond to steady-state and transient operating conditions in real-time more effectively than conventional offline solutions.

The agents operate at different time scales ranging from milliseconds to hours corresponding to the physical phenomena of the power grid. Their actions are organized by execution cycles. An execution cycle refers to a set of related functional tasks performed in a temporally coordinated manner.



Temporal coordination by execution cycles[1]

IT Infrastructure for Smart Grid

Adaptive Model Updates

- The access to accurate global data synchronized to a microsecond presents a challenge to adaptively identifying there quire models and data for analysis in each hierarchical level and execution cycle .

Power Quality

- In addition to reliability and efficiency issues, power quality issues will assume importance at the distribution level.

Cyber-security in a Grid-wide Infrastructure

- A distributed cyber-security system monitors security throughout the architecture to maintain data integrity, confidentiality, and authentication
- Data critical for grid reliability and efficiency is delivered only to authorized agents, preventing unauthorized modifications, and guaranteeing that delivered information is authentic while it traverses through the infrastructure.

Technical Feasibility

- The data exchange volumes at various levels of the infrastructure are entirely feasible with contemporary technologies.
- Benefit models quantify selected significant benefits: energy cost savings and value of reduction of service interruptions.
- The results indicate that the benefits significantly outweigh the costs. The costs of subsequent implementations are of the same order of magnitude as for conventional control centers.

Synergies with Current Practices

The proposed architecture is in synergy with current industry practices. Many of the smart grid technologies are already in place in various ad hoc implementations.

- Wide-area monitoring and control has been gaining worldwide interest.
- Special protection/remedial action schemes (SPS/RAS) are proliferating.
- State estimation provides reliable knowledge of the current state of the power system for use by the operator and other analytical functions as needed
- Demand and resource forecasting is usually done at a macroscopic level such as control area and load zone.

Conclusion

- Based on a critical review of the reliability impacts of these resources, it is concluded that an ideal mix of the smart grid resources leads to a flatter net demand that eventually accentuates reliability issues further. Thus, the Centrality of meeting reliability challenges in the realization of the smart grid is underscored.
- This architecture supports a multitude of fail-proof geographically and temporally coordinated hierarchical monitoring and control actions over time scales ranging from milliseconds to operational planning horizon. The architecture delivers high performance through a virtual hierarchical operation of a multitude of software agents and services in organizational, geographical and functional dimensions.

Assessment

Positive

- Very great review the reliability of impacts
- Proposed the 3D IT infrastructure gives the opportunities for more function explosion.
- Transforming the power grid to a “smart grid” as the transforming the phone to smart phone

Negative

- Ideal condition for flatter load duration curve is hard to be realized.
- Cost estimation for renewable energy, storage, electric vehicle does not been included.

References

[1] Khosrow Moslehim, Ranjit Kumar, A Reliability Perspective of the Smart Grid, IEEE TRANSACTIONS ON SMART GRID, VOL. 1, NO. 1, JUNE 2010

[2] http://en.wikipedia.org/wiki/Load_curve

[3] http://en.wikipedia.org/wiki/Wind_power

[4] http://en.wikipedia.org/wiki/Solar_power

[5] http://en.wikipedia.org/wiki/Solar_thermal

[6] http://en.wikipedia.org/wiki/Electric_vehicle

Questions?

Thank you!