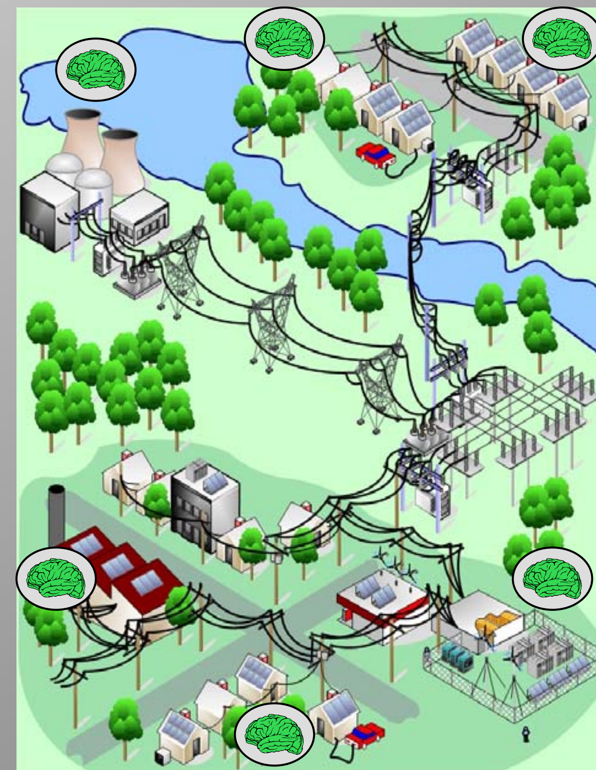
Implication of Smart-Grids Development for Communication Systems in Normal Operation and During Disasters



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Overview

- Introduction
- The smart-grid concept
  - General issues
  - Advanced controls
  - Energy storage
  - Distributed generation
  - Power architectures
- Discussion
- Conclusion

Smart-grids

• There are two similar but not equal approaches to the smartgrid concept.

• EU-led vision (customer and environmentally driven):
  • Europe's electricity networks in 2020 and beyond will be:
    • Flexible: Fulfilling customers' needs whilst responding to the changes and challenges ahead;
    • Accessible: Granting connection access to all network users, particularly for renewable energy sources and high efficiency local generation with zero or low carbon emissions;
    • Reliable: Assuring and improving security and quality of supply, consistent with the demands of the digital age;
    • Economic: Providing best value through innovation, efficient energy management and 'level playing field' competition and regulation.

•"European Technology Platform SmartGrids. Vision and Strategy for Europe's Electricity Networks of the Future" European Commission KI-NA-22040-EN-C EUR 22040

Smart-grids

- US led vision (security and consumer driven)

- US DOE goals for 2030
  - 20% reduction in the nation's peak energy demand
  - **100% availability to serve all critical loads at all times and a range of reliability services for other loads**
  - 40% improvement in system efficiency and asset utilization to achieve a load factor of 70%
  - 20% of electricity capacity from distributed and renewable energy sources (200 GW) heat and power generation.

Today's Grid	Principal Characteristic	Modern Grid
Responds to prevent further damage. Focus is on protection of assets following system faults.	**Self-heals**	Automatically detects and responds to actual and emerging transmission and distribution problems. Focus is on prevention. Minimizes consumer impact.
Consumers are uninformed and non-participative with the power system.	**Motivates & includes the consumer**	Informed, involved and active consumers. Broad penetration of Demand Response.
Vulnerable to malicious acts of terror and natural disasters.	**Resists attack**	Resilient to attack and natural disasters with rapid restoration capabilities.
Focused on outages rather than power quality problems. Slow response in resolving PQ issues.	**Provides power quality for 21st century needs**	Quality of power meets industry standards and consumer needs. PQ issues identified and resolved prior to manifestation. Various levels of PQ at various prices.
Relatively small number of large generating plants. Numerous obstacles exist for interconnecting DER.	**Accommodates all generation and storage options**	Very large numbers of diverse distributed generation and storage devices deployed to complement the large generating plants. "Plug-and-play" convenience. Significantly more focus on and access to renewables.
Limited wholesale markets still working to find the best operating models. Not well integrated with each other. Transmission congestion separates buyers and sellers.	**Enables markets**	Mature wholesale market operations in place; well integrated nationwide and integrated with reliability coordinators. Retail markets flourishing where appropriate. Minimal transmission congestion and constraints.
Minimal integration of limited operational data with Asset Management processes and technologies. Siloed business processes. Time based maintenance.	**Optimizes assets and operates efficiently**	Greatly expanded sensing and measurement of grid conditions. Grid technologies deeply integrated with asset management processes to most effectively manage assets and costs. Condition based maintenance.

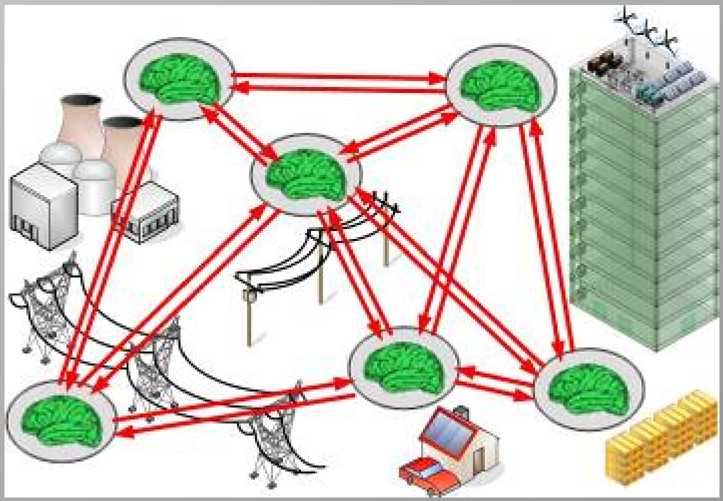
"The NETL Modern Grid Initiative A VISION FOR THE MODERN GRID", US DOE

Smart-grid concept

• There are many views of what is an smart grid.

• In reality, a smart grid is not a single concept but rather a combination of technologies and methods intended to modernize the existing grid in order to improve flexibility, availability, energy efficiency, and costs.

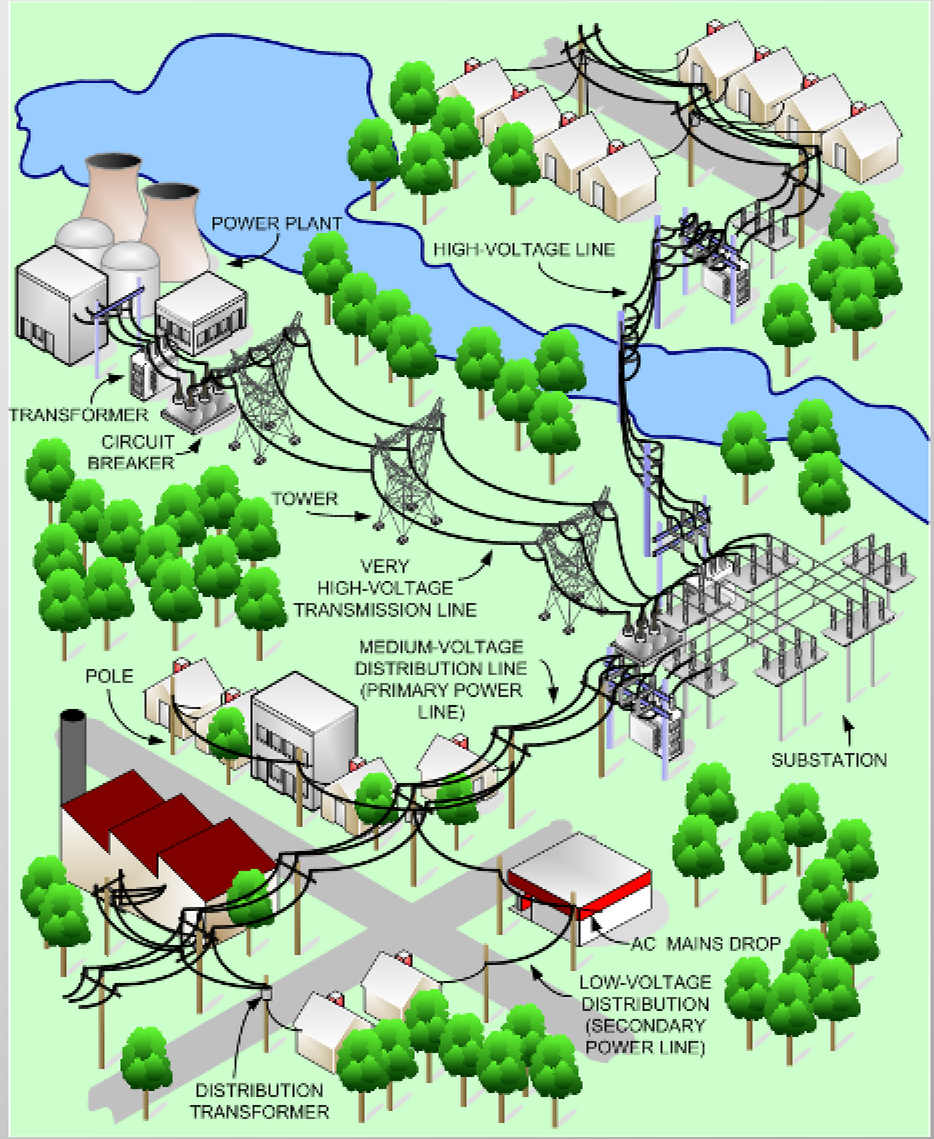
• Smart Grid 1.0:
  • Intelligent meters



• Smart Grid 2.0 ("Energy Internet" enabler):
  • advanced autonomous controls,
  • distributed energy storage,
  • distributed generation, and
  • flexible power architectures.

• Why don't address telecom power availability issues at their origin? Why don't improve grid availability instead of dealing with power plants?

The traditional dull electric grid



Traditional technology - the electric grid:

- Generation, transmission, and distribution.
- Centralized and ***passive*** architecture.
- Extensive and very complex system.
- Complicated control.
- Not reliable enough for some applications.
- Relatively inefficient.
- Stability issues.
- Vulnerable.
- Lack of flexibility.

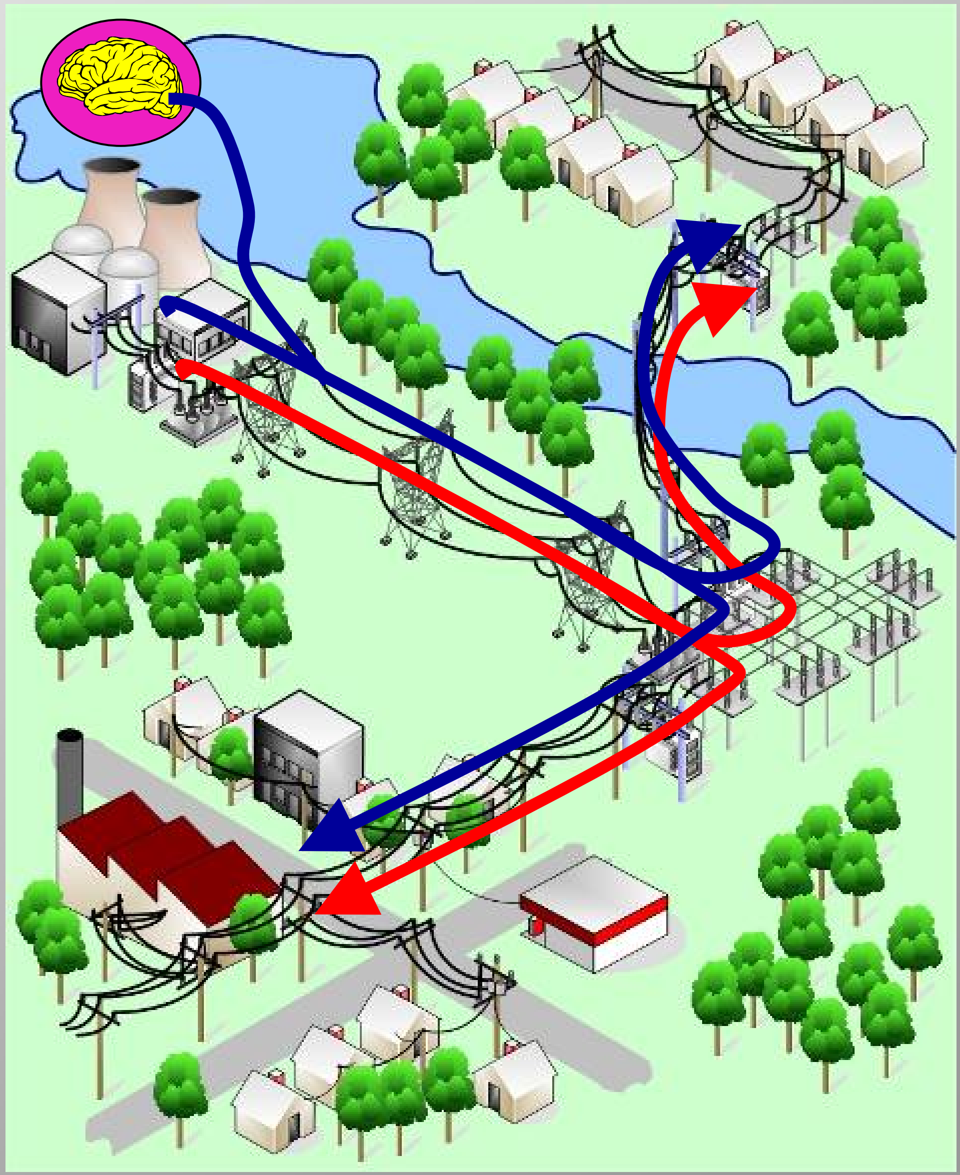
Smart grid evolution: dull past/present

- Centralized operation and control

- Passive transmission and distribution.

- Lack of flexibility

- Vulnerable



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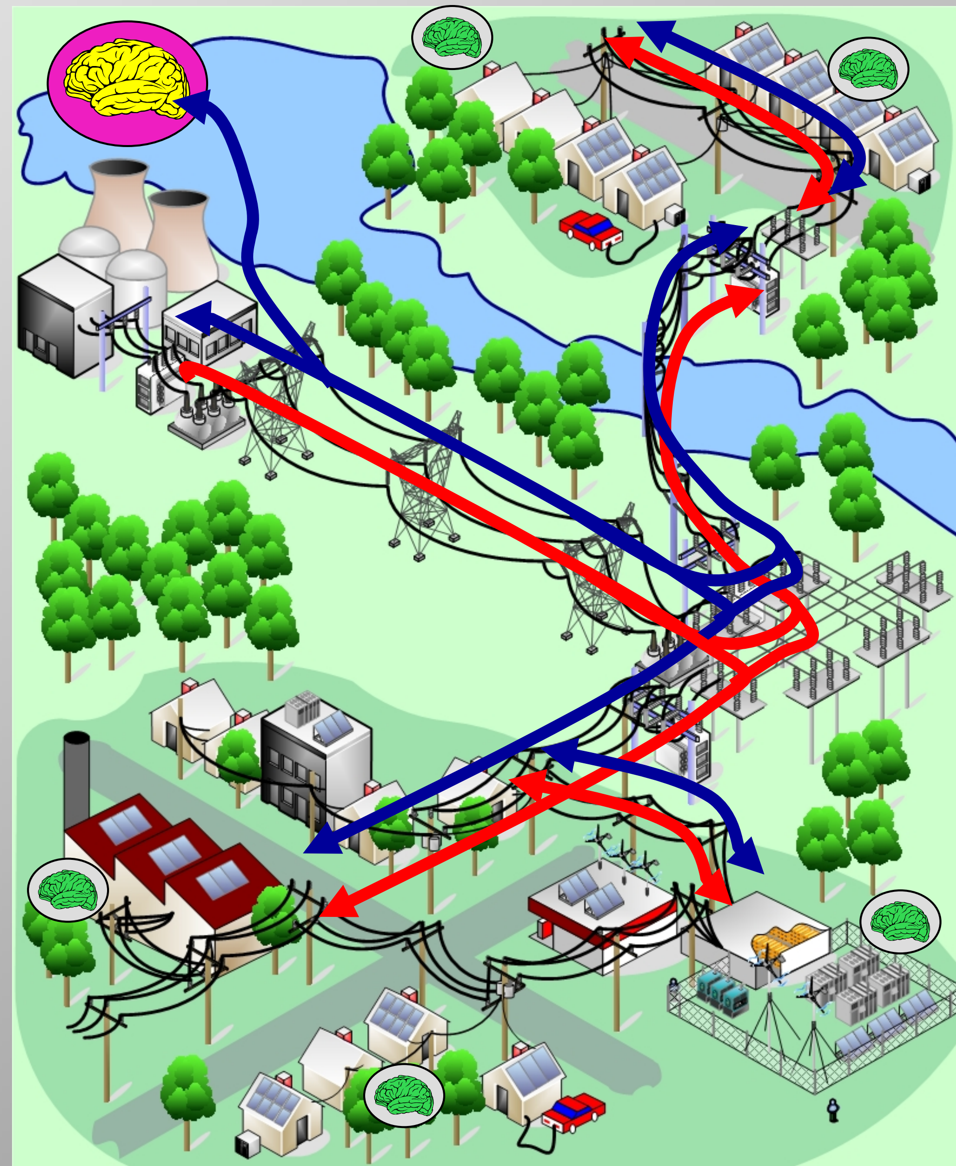
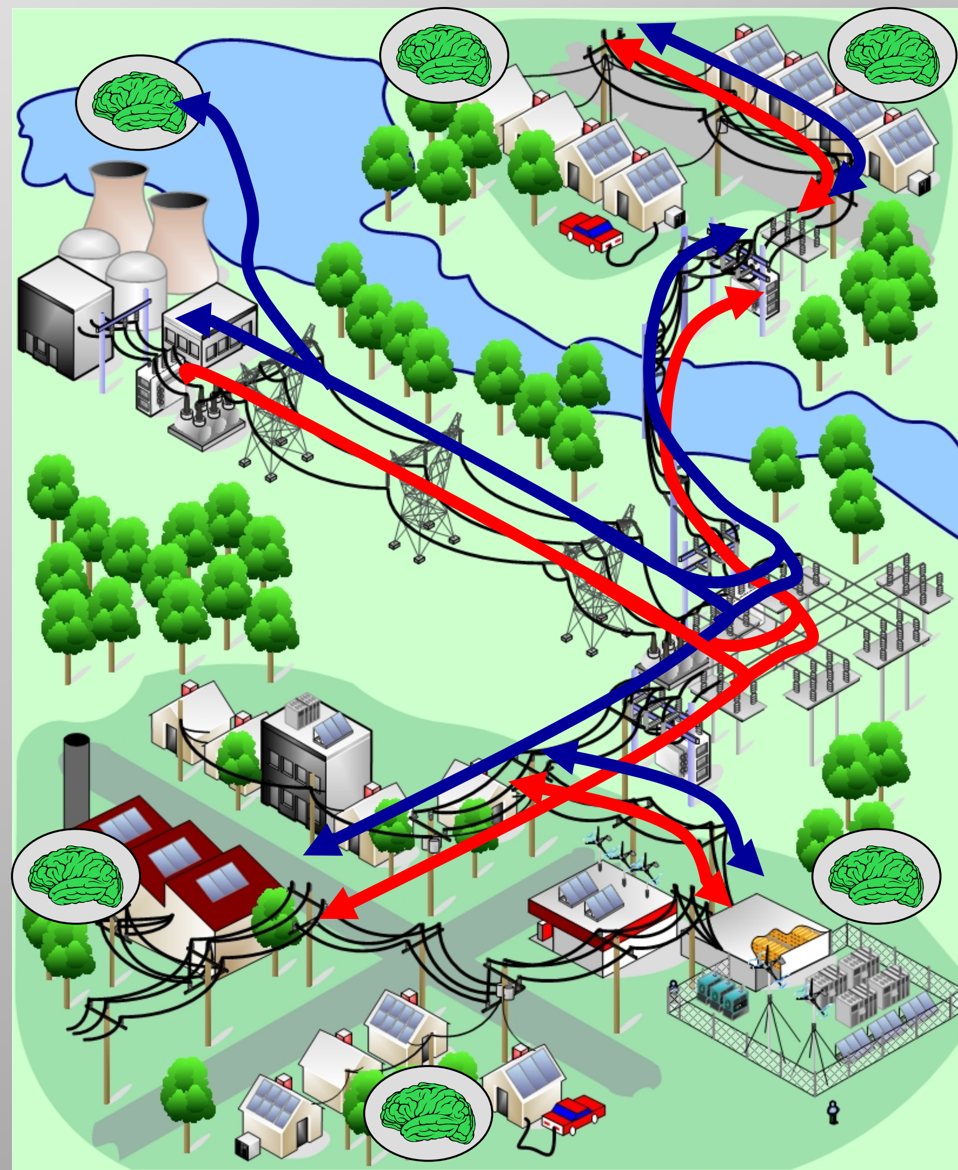
Smart grid evolution: present/immediate future

- Still primarily centralized control.
- Active distribution network (distributed local generation and storage).
- Addition of communication systems
- Advanced more efficient loads
- Flexibility issues
- Somewhat more robust



Smart grid evolution: Future

- Distributed operation and control
- Active distribution network (distributed local generation and storage).
- Integrated communications
- Advanced more efficient loads
- Flexible
- More robust



Smart grid concept

- Technologies and concepts:
  - Distributed energy resources (generation and storage) are fundamental parts. They provide the necessary active characteristics to an otherwise passive grid.
  - Advanced and distributed communications. All the grid components are able to communicate. The grid operates like a power-Internet (distributed, multiple-redundant, interactive and autonomous).
  - Intelligent metering.
  - Policies and regulatory actions. Necessary to achieve integration of all the parts.
  - Grid modernization.

Advanced communications and controls

• Present view: Centralized.

• Smart Grid view: Distributed and autonomous. Reality: still centralized

• Distributed and autonomous controls allow for local optimized operation. These controls are also fundamental for disaster resiliency.

• Eventually, agents in autonomous controllers will incorporate availability predictor modules that will monitor system and environmental conditions to optimize operation for availability. Data from different sites using the same hardware could be shared to update reliability data without RMA processes.

• Paradox in centralized control: reliable power supply is a fundamental need for communication systems and reliable communications is a fundamental need for smart grids with centralized architectures.

Energy Storage

- Two main uses of energy storage devices in micro-grids:
  - Power buffer for slow, bad load followers, DG technologies. Power to compensate short term power generation shortages usually occurring in intermittent/stochastic sources (e.g. solar panels or wind generators)
  - Energy supply for long-term stochastic generation profiles (e.g. solar power during night).

- Power delivery profile: short, shallow and often energy exchanges.
  - Flywheels
  - Ultracapacitors

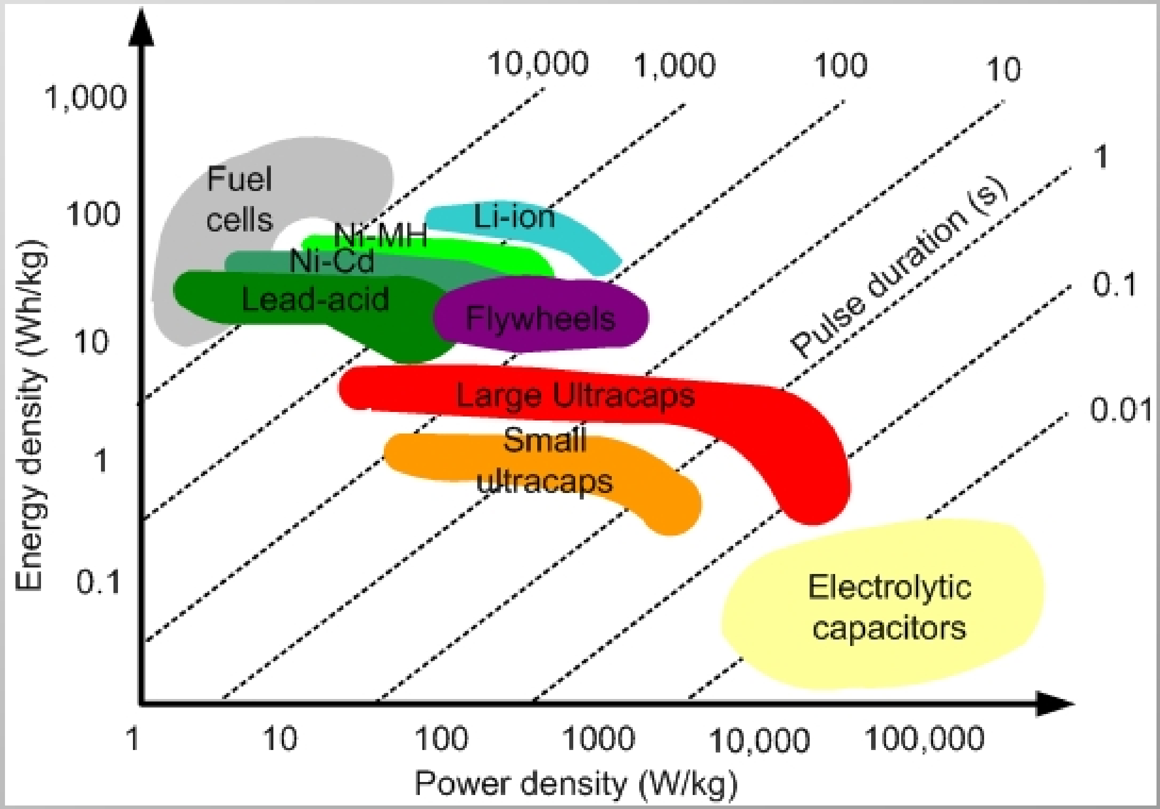
- Energy delivery profile: long, deep and infrequent energy exchanges.
  - Batteries
  - Batteries can be used in power delivery profile applications but they need to be significantly oversized in order to avoid shorter life due to continuous deep cycling.

- Energy storage location: customer side vs utility side. Increased existance of geographically movable energy storage (in PHEV).

Energy Storage

• Energy storage for a smart grid acts as data buffers in the Internet.

• Micro-grids typically require power deliver profile devices. Batteries may or may not be necessary.



Distributed generation (DG)

• Smart grid planning for disaster resiliency must consider disaster impact on lifelines. During disasters special attention should be paid to dissimilar ways in which disasters affect different DG technologies.

• Renewable sources do not have lifelines but they are not dispatchable, they are expensive, and they require large footprints.

• Most DG technologies have availabilities lower than that of the grid.

• DG needs diverse power supply in order to achieve high availabilities.

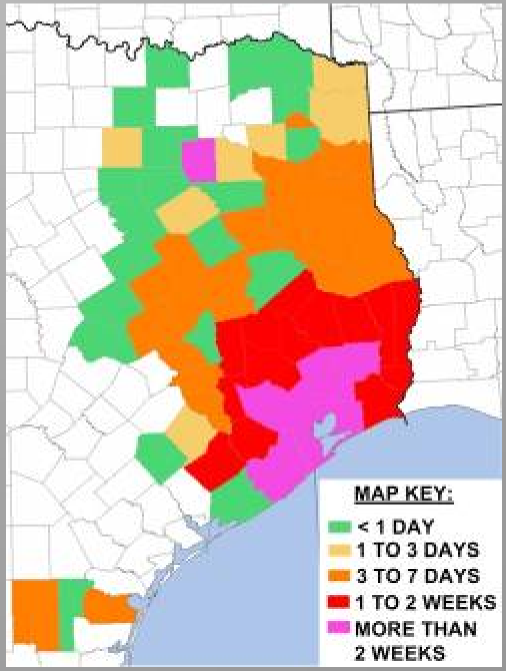
• DG provides a technological solution to the vulnerable availability point existing in air conditioners power supply.

•DG provides the active component to grid's distribution portion, essential for advanced self-healing power architectures.

Grid's behavior during disasters

» Power supply issues during disasters is a grid's problem transferred to the load.

» Power grids are extremely fragile systems.



Grid's behavior during disasters

» Common concept of damage to the electric grid during disasters:

» Real sustained damage in more than 90 % of the area:

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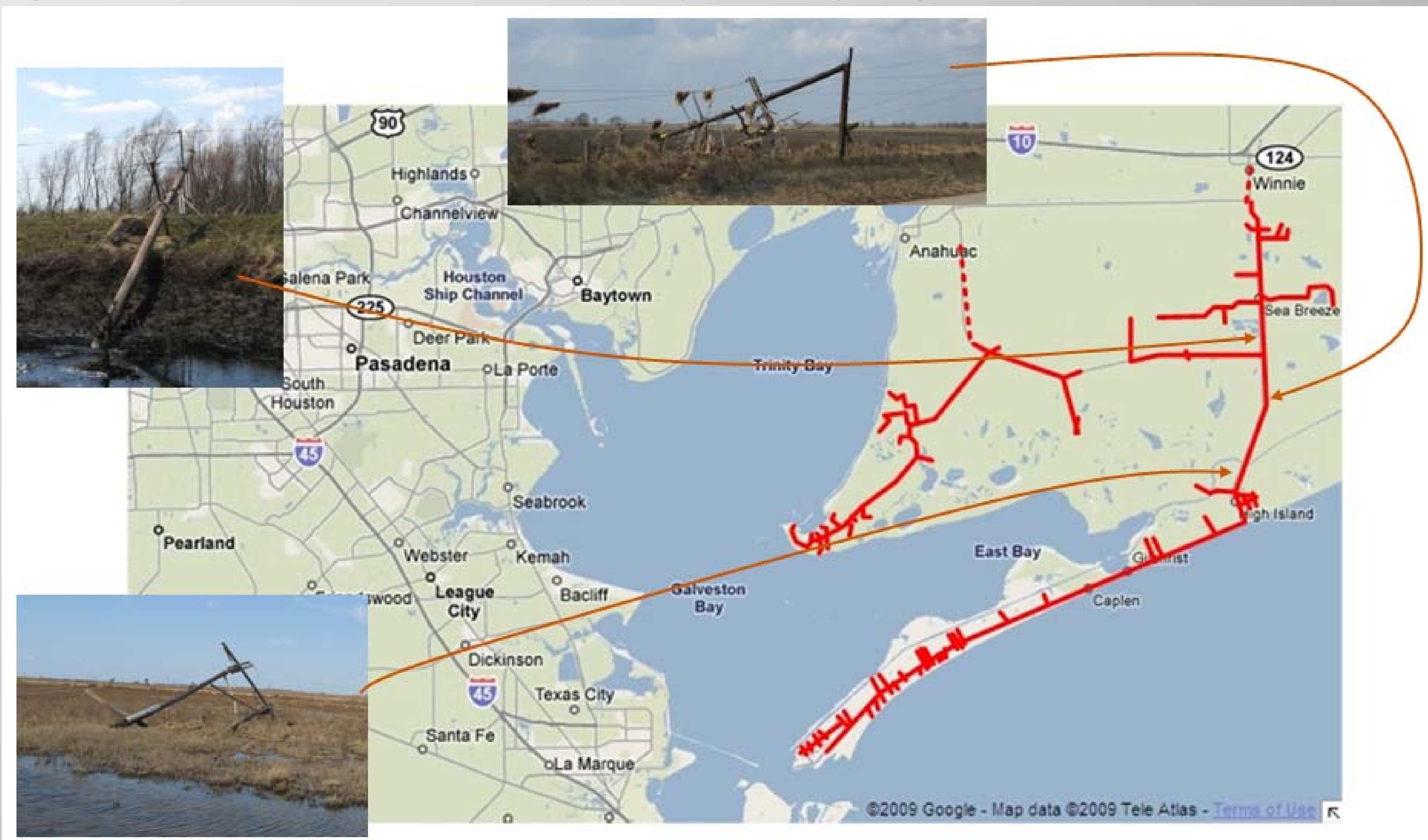
Conventional grid redundancy

• Redundancy is not common in distribution and sub-transmission portions because redundancy may be very expensive.



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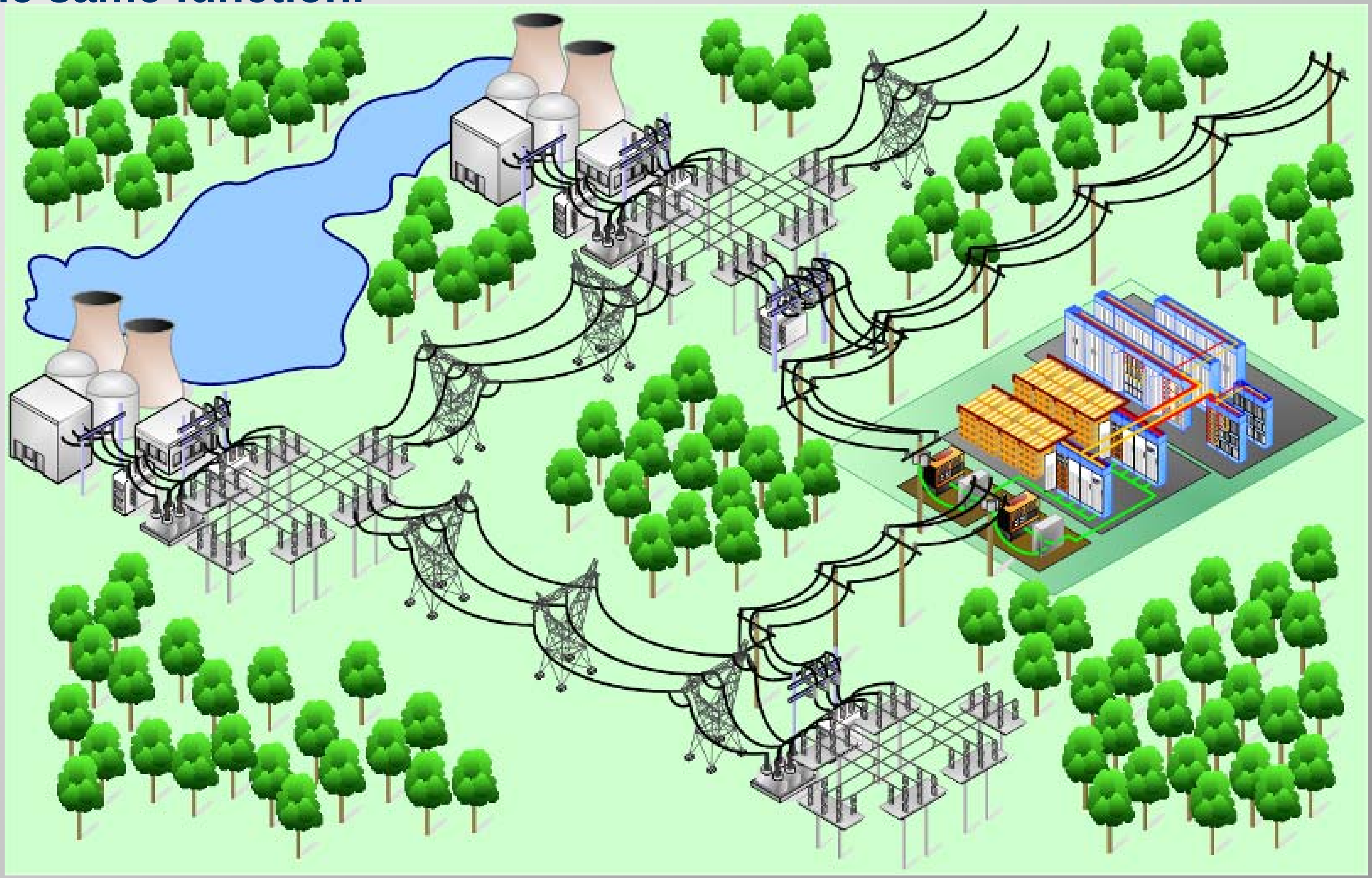
Conventional grid diversity

- Diversity implies more than one different components performing the same function.



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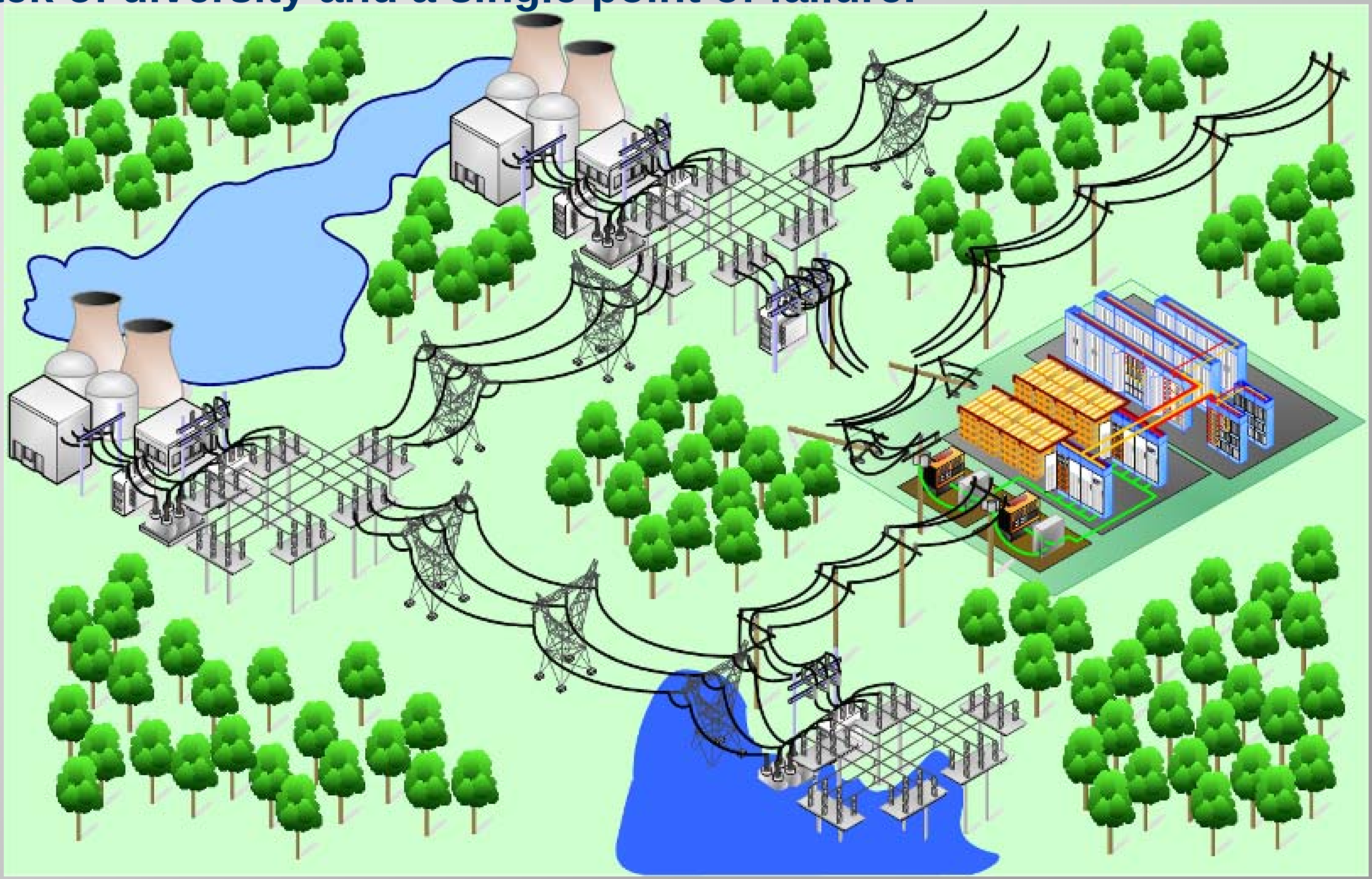
Traditional Electricity Delivery Methods: Reliability

- With disasters affecting large areas, grid interconnection implies lack of diversity and a single point of failure.



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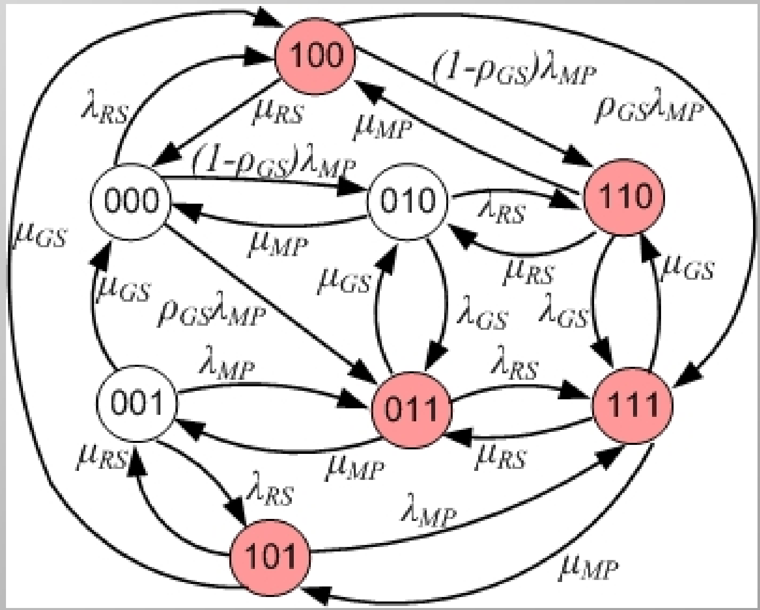
Telecom sites power supply availability

- Binary representation of Markov states:
  - 1st digit: rectifiers (RS)
  - 2nd digit: ac mains (MP)
  - 3rd digit: genset (GS)
- System reliability equation:

$$\dot{\mathbf{P}}(t) = \mathbf{A}^T \mathbf{P}(t)$$



where

$$\mathbf{A} = \begin{pmatrix} -(\lambda_{MP}+\lambda_{RS}) & 0 & (1-\rho_{GS})\lambda_{MP} & \rho_{GS}\lambda_{MP} & \lambda_{RS} & 0 & 0 & 0 \\ \mu_{GS} & -(\mu_{GS}+\lambda_{MP}+\lambda_{RS}) & 0 & \lambda_{MP} & 0 & \lambda_{RS} & 0 & 0 \\ \mu_{MP} & 0 & -(\lambda_{GS}+\mu_{MP}+\lambda_{RS}) & \lambda_{GS} & 0 & 0 & \lambda_{RS} & 0 \\ 0 & \mu_{MP} & \mu_{GS} & -(\mu_{GS}+\mu_{MP}+\lambda_{RS}) & 0 & 0 & 0 & \lambda_{RS} \\ \mu_{RS} & 0 & 0 & 0 & -(\lambda_{MP}+\mu_{RS}) & 0 & (1-\rho_{GS})\lambda_{MP} & \rho_{GS}\lambda_{MP} \\ 0 & \mu_{RS} & 0 & 0 & \mu_{GS} & -(\mu_{GS}+\lambda_{MP}+\mu_{RS}) & 0 & \lambda_{MP} \\ 0 & 0 & \mu_{RS} & 0 & \mu_{MP} & 0 & -(\lambda_{GS}+\mu_{MP}+\mu_{RS}) & \lambda_{GS} \\ 0 & 0 & 0 & \mu_{RS} & 0 & \mu_{MP} & \mu_{GS} & -(\mu_{GS}+\mu_{MP}+\mu_{RS}) \end{pmatrix}$$

- Failure probability (in time) $P_{PPf}(t) = \sum_{S_i \in F} P_{S_i}(t) = 1 - \sum_{S_i \in W} P_{S_i}(t)$

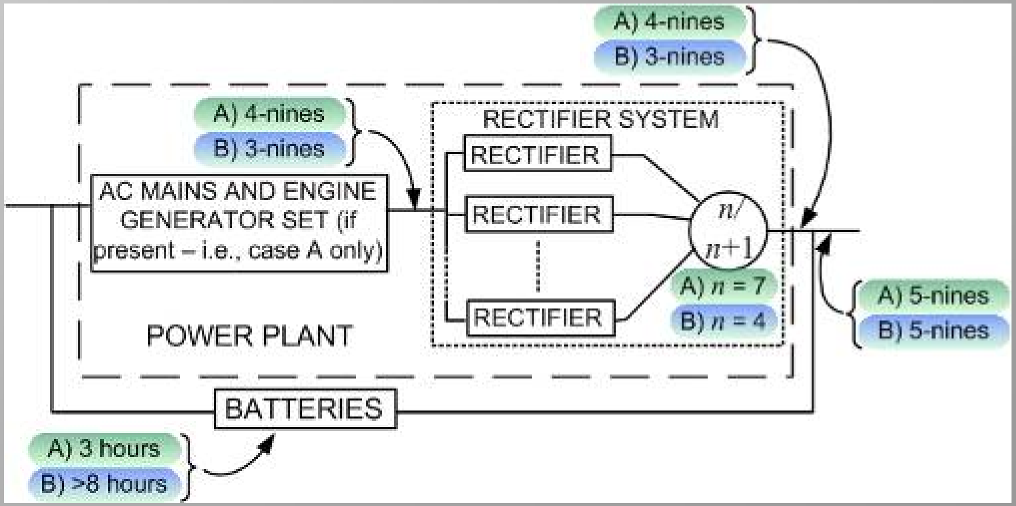
Telecom sites power supply availability

- System unavailability or outage probability:

$$P_O = e^{a_F T_{BAT}} \lim_{t \to \infty} P_{PPf}(t) = U_a e^{a_F T_{BAT}}$$

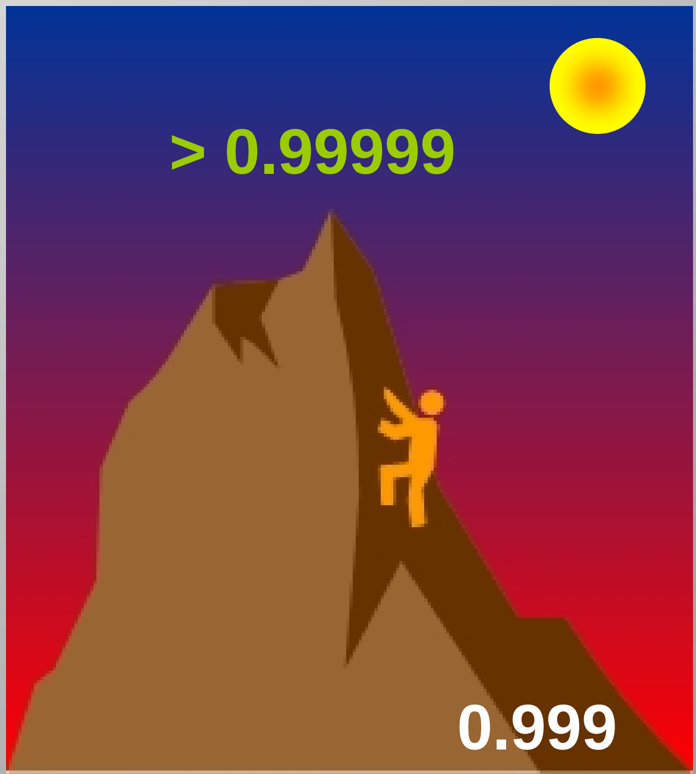
where $a_F = -(3\mu_{RS} + \mu_{MP} + \mu_{GS})$

- Two cases are calculated:
  - Case A: CO with a permanent genset.
  - Case B: DLC without genset (no air conditioning either so battery life is often reduced).



Telecom sites power supply availability

- The story behind telecom power plants design and evolution:
  To overcome the relatively low grid availability of 3-nines and bring it up to telecom standards of 5-nines or more.



- Smart grids may shift the paradigm of focusing on the load side in order to improve availability by focusing on the grid side
- Due to economics of scale, focus on the grid will facilitate integrating renewable sources that do not require lifelines… Hence, a good alternative during disasters.

Value of stored energy at telecom sites

• Smart grid development creates a impact power supply in two ways: from the grid side and from the load side. Smart grid benefits for the load have already been mentioned.

• The smart grid can utilize telecom sites stored energy to improve performance, particularly to deal with semi-dispatchable renewable sources.

• There are at least about 57,200 MWh of stored energy in batteries in the US telecom sites and data centers. But, this energy is unevenly geographically distributed and using this energy will reduce telecom sites availability.

• One option is to reduce battery backup time by increasing diesel energy storage. Then

$$U_{SYS} = P_{S_2} e^{a_D (T_D + T_{BAT})} + U_a e^{a_F T_{BAT}} \quad \text{where} \quad a_D = -(\lambda_{RS} + \mu_{MP} + \lambda_{GS})$$

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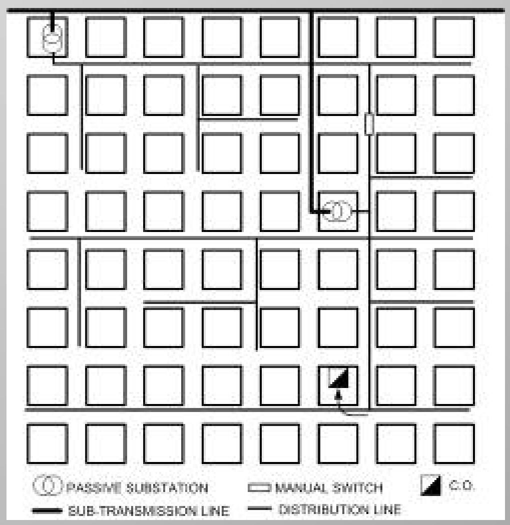
Additional smart grid effects on telecom power

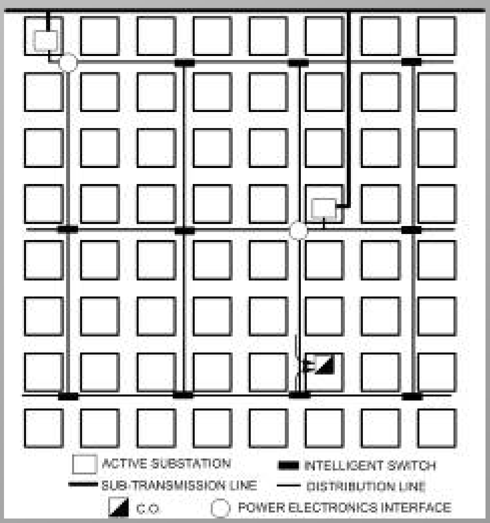
- Grid availability improvement may address power supply limitations in outside plant sites and wireless base stations. These sites are usually the weakest in terms of power supply during disasters.

- Smart grid enables new services that allow electric utilities to transition from energy sellers to service sellers (e.g. NTT-Facilities Sendai trial).

- One particular interesting service is the possibility of providing circuits with different power quality levels in hybrid ac/dc systems.

- Smart grids allow for new self-healing distribution architectures for high availability.





Conclusions

- True smart grids will convert the distribution portion of the grid from a passive element into an active element through DG and energy storage.
- In terms of power supply resiliency to disasters, smart grids creates a paradigm shift in improved availability by shifting the focus from the load side into the utility side. It will be easier to address weak points, such as air conditioners and DLC remote terminals.
- New services will be enabled.
- Telecom stored energy has value.
- There are still many unknowns on how smart grids will be developed.

THANK YOU VERY MUCH

QUESTIONS?