Energy Adaptive Networks

SD Power Grid to Protect Against Natural Disasters

ENERGY AND UTILITIES

CONNECTED TRANSPORT

MANUFACTURING

HEALTHCARE

BUILDINGS & INFRASTRUCTURE

OPEN INDUSTRY

ENABLING IoT

IOT SOLUTIONS WORLD CONGRESS

Energy Adaptive Networks
SDN Power Grids to Protect Against Natural Disasters

Michael Enescu
CEO & Co-Founder, EAN Corp

IoT Solutions World Congress
Barcelona, 30 October 2019

Outline

- Introduction
- Wildfires Caused by Power Grid Failures
- EAN (Energy Adaptive Networks) Technology and OpenOPF (Optimal Power Flow)
- Solutions: Open Source, IoT, data driven power grids
- Conclusion: Call to Action!

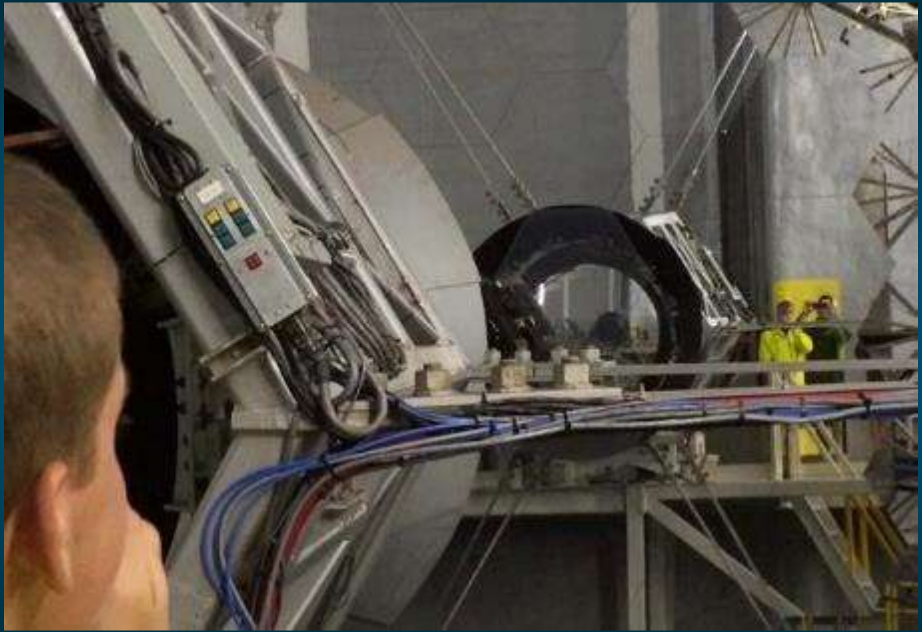
About Us

- Energy Adaptive Networks
  - “IoT will be to Electricity what the Internet was to Telephony” – EAN
  - Founded by Michael Enescu (Cisco) and Steven Low (Caltech)

- R&D supported under US Federal research grants
  - Caltech research, contributions from Berkeley, Stanford, and others
  - In collaboration with Pacific Northwest National Lab, National Renewable Energy Lab, Lawrence Livermore National Lab
  - Open Source connectivity – Cisco
  - IoT Energy Gateway - EAN

Energy Adaptive Networks Corp

Amazing “Devices” at The Outer Edge?
From “Adaptive Optics” to “Adaptive Networks”



The Mirror Barn
Keck Observatory, Mauna Kea, Hawaii 4207 meters

Keck 10m Twin Telescopes at Mauna Kea

Why Apps move to the Edge?

Data Gravity – Over 2EB per day!

80 million smart meters in the U.S alone, 2 billion data points 1TB/ day

A single consumer packaged good manufacturing machine generates 13B data samples/day

A large offshore field produces ~1TB data/week

4+ million industrial things that spin, some producing 20TB/hour

95% of the world's data created in last 3 years

40 ZB (T-GB) by 2020 – 50x since 2010, 5200GB/human on Earth

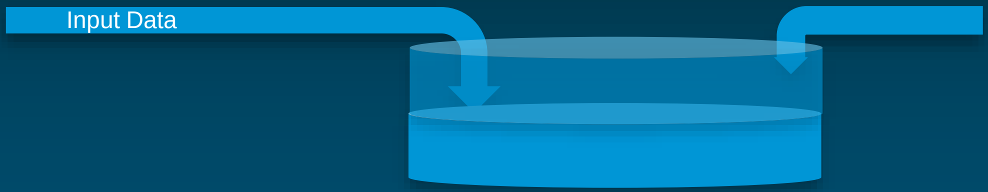
75+ Billion IoT devices by 2025 – adoption 5x faster than electricity or telephony!

What's Different Now?

IoT Systems <u>not built</u> to handle Streaming Data

<u>Traditional</u> model: Store First, Query Later

Data-base waiting for Queries



- Fetch,
- Analyze,
- Report

<u>New</u> model: Process First, Store Optional

Query-base waiting for Data

Rules can express:

- Predicates and Filters
- Contextual/Dimension Data
- Aggregations
- Pattern Matching
- Categorization & Classification
- Sub-queries …

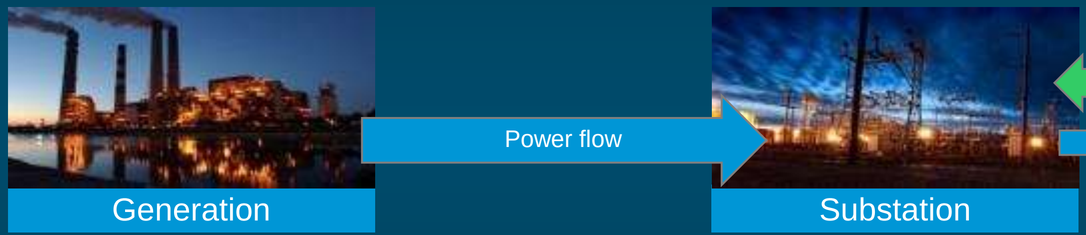
Generate Actionable Events,
Integrate with Policy/Mgmt System

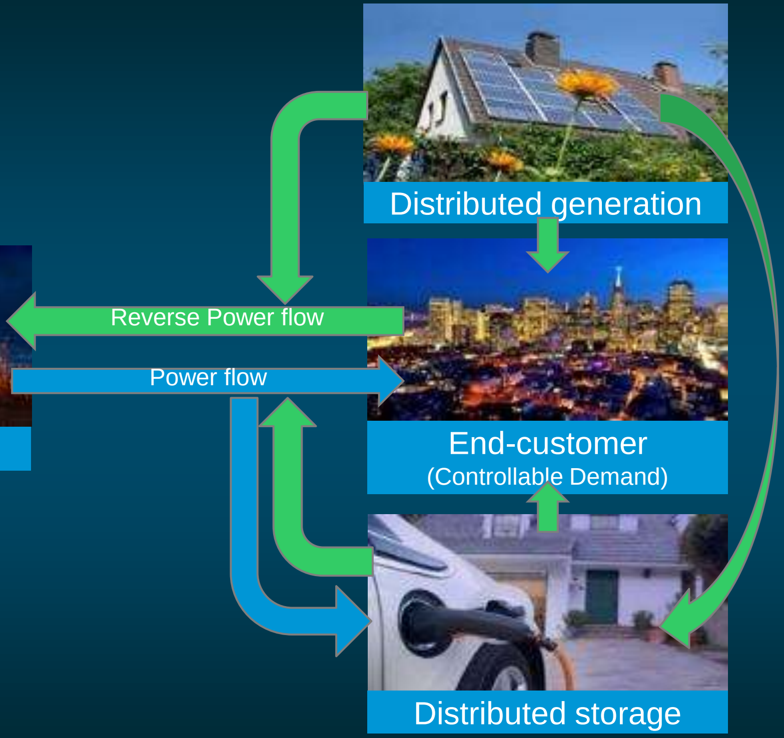
- Fetch,
- Analyze,
- Report

What’s Different Now?

Power Grid <u>not built</u> to handle Reverse Power Flows

Need for a much different Control Plane:
Communication, Remote Sensing & Control





Transmission

Distribution

Distributed Energy Resources (DER's) Problem or Opportunity?

DERs Introduce Variability

- DERs are useful
  - Local DER's avoid loss in transmission & distribution
  - Reduce peak loads
  - Reduce grid cost, wasted electricity
- DERs are unpredictable
  - Weather, clouds, wind, …
  - Rapid, random fluctuations
  - Movement, where do EV's park

What is the best configuration of millions of devices to optimize power flow?
…Such that it minimizes cost and ensures safety & reliability?
… And we need to make this decision again and again!

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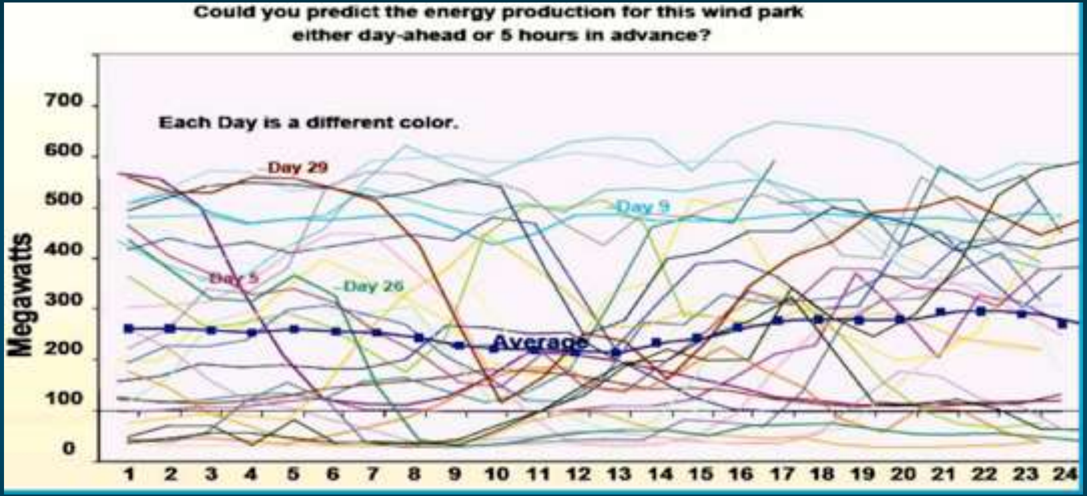
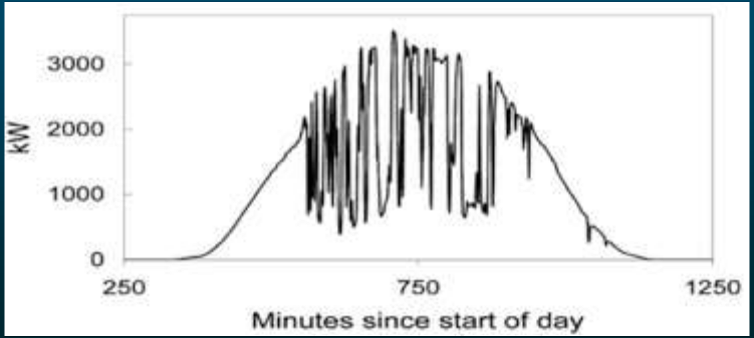
The Problem
DER's introduce fluctuations, risk, blackouts

April in Golden Hills, Tehachapi, California



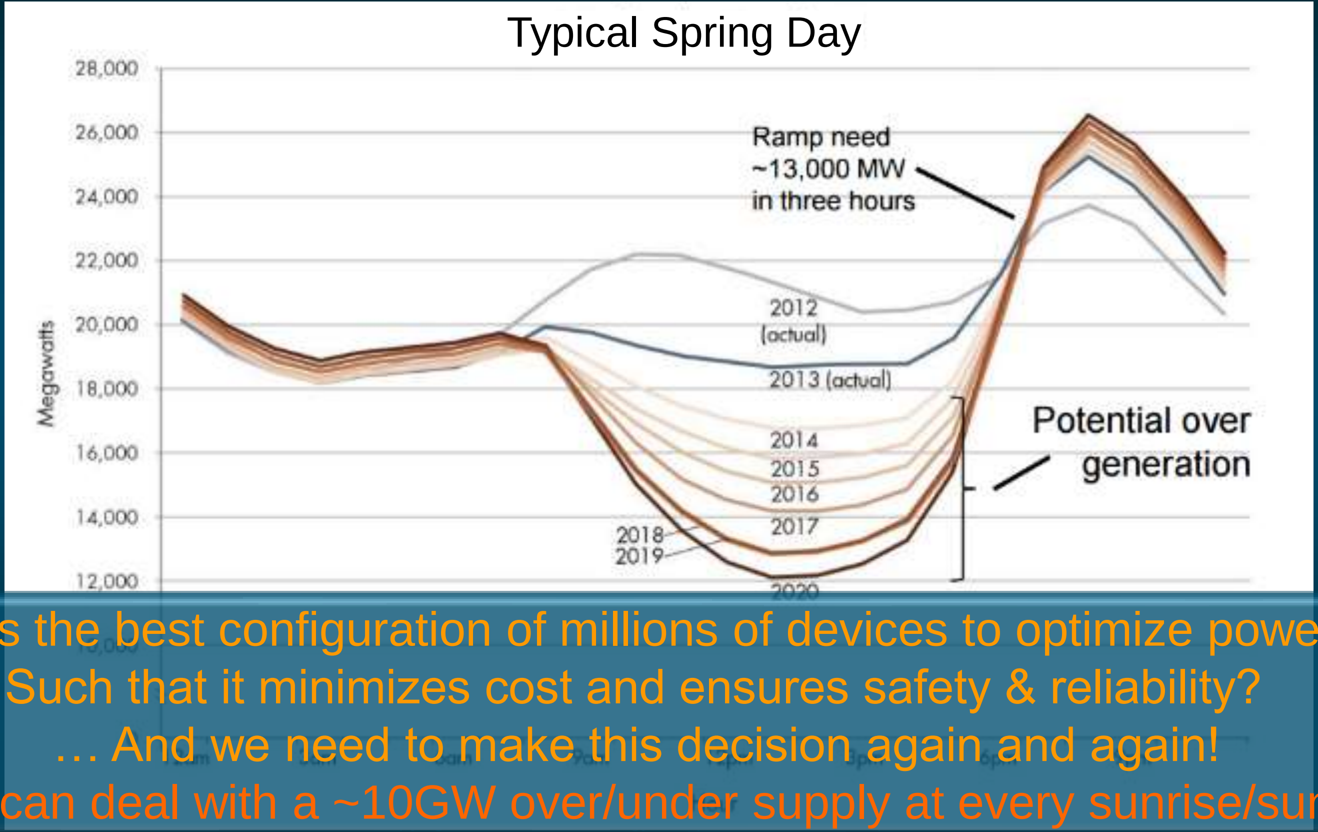
DERs are both the solution & the problem!
ubiquitous, fast-acting, distributed



Imagine when we have over 50% renewable generation
as required in CA by 2025 and trending virt everywhere

What's Different Now: California "Duck" Curve

Millions of active DER's introduce rapid, random fluctuations



What is the best configuration of millions of devices to optimize power flow?

…Such that it minimizes cost and ensures safety & reliability?

… And we need to make this decision again and again!

And can deal with a ~10GW over/under supply at every sunrise/sunset?

A Tale of Two Decisions:
Power Grid <u>not built</u> to handle Reverse Power Flows

Get it right	**Get it wrong**
Capture full benefits of the smart grid	Risk of Catastrophic Failure

Reducing waste

Improving Reliability

Reducing Investment

Reducing Emissions

When the Power Grid is not Energy Adaptive California Wildfires

12 Northern California wildfires sparked by PG&E power lines, investigators say

By Kurtis Alexander Updated 10:45 am PDT, Saturday, June 9, 2018

2018 Inverse Condemnation Information

During the 2018 Legislative Session, CSAC successfully supported keeping the inverse condemnation standard, a utility liability law, in place despite efforts to make changes. In addition, CSAC was actively involved in the negotiation of SB 901 (Dodd). SB 901 was a comprehensive piece of legislation that covered several wildfire related topics.

Ignition Points – Avoiding Natural Disasters

PG&E Caused California's Deadliest Wildfire

A new report officially points the blame for the Paradise fire at the utility's electrical transmission lines

PG&E admits its equipment likely sparked California's most destructive wildfire

THE WALL STREET JOURNAL.

PG&E Caused Fire That Killed 85, California Concludes

Investigators find company's equipment sparked deadliest fire in state history after PG
probably the cause

Paradise Lost

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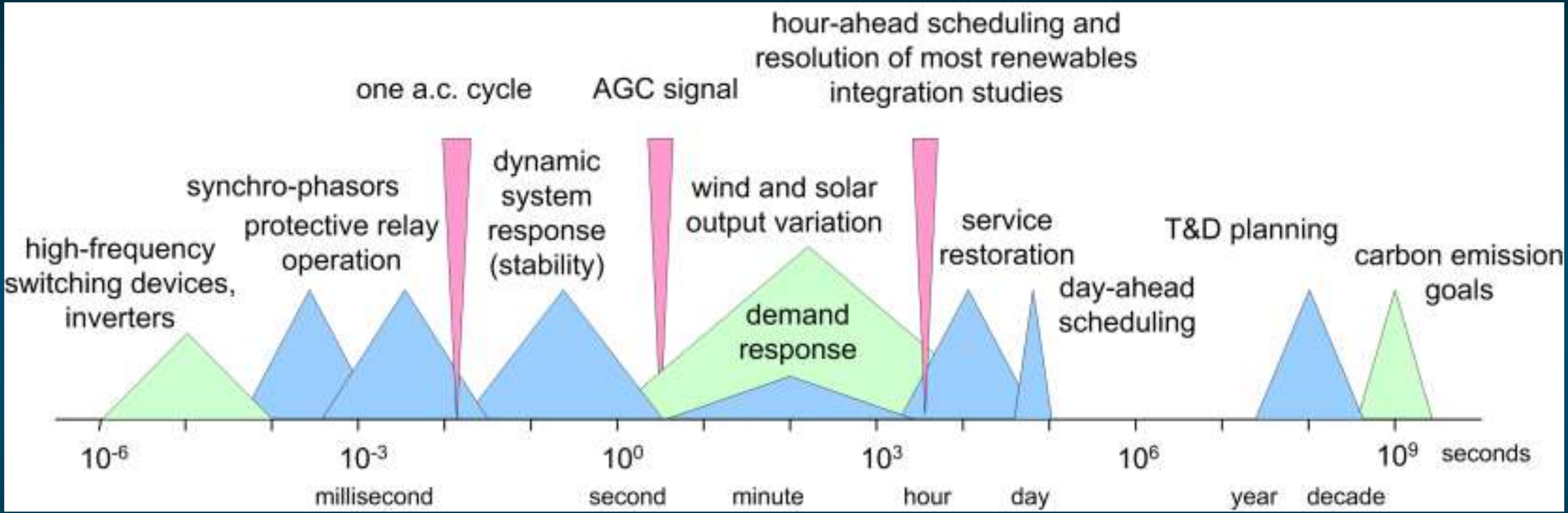
EAN Technology

- Based on Caltech research on Optimal Power Flow (OPF)
- OPF & Frequency control algorithms, using non-convex relaxation
- Fast, accurate, efficient, distributed
- Leverages IoT penetration and Open Source

Caltech EAN Energy Adaptive Networks Corp

Different Timescales – Different Models



Dynamic models
(differential equations)

Power Flow models
(algebraic equations)

Optimal Power Flow & Frequency Control

OPF is solved routinely for

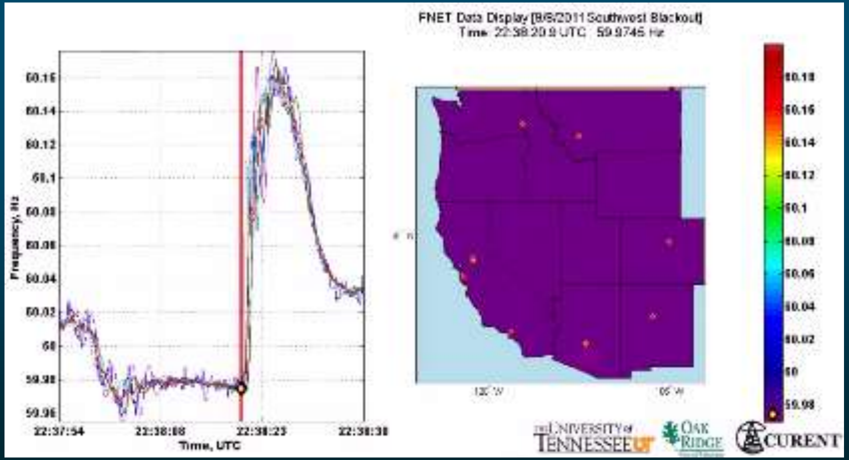
- Network control & optimization decisions
- Market operations & pricing
- Timescales of minutes, hours, days, …

Non-convex and hard to solve

- Huge literature since 1962
- Common practice: DC power flow (LP)
- Also: Newton-Raphson, interior point, …

Caltech Optimization Algorithm

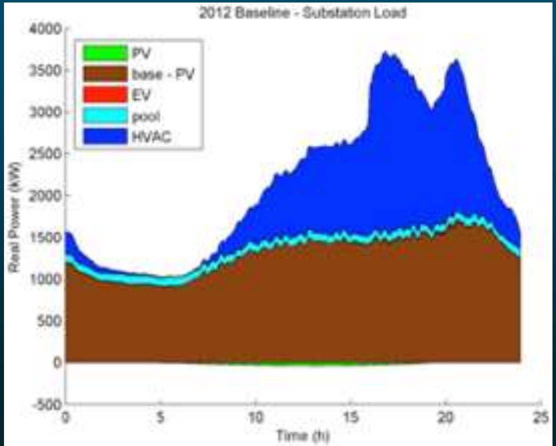
- Idea: use grid as implicit power flow solver
- All busses synced at nominal frequency
- Supply-demand imbalance => frequency fluctuation
- Load side frequency control (5 patents)



Use Case – DER Management System

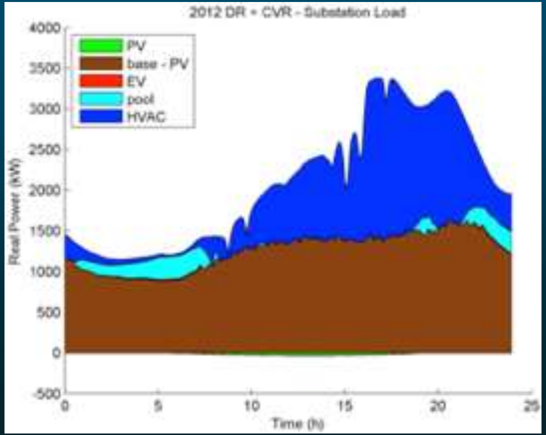
Slow timescale OPF:

- As DER penetration continues, the need for DER co-optimization increases
  This includes capacitor banks and tap changers on the grid and inverters and smart appliances at end user (more IoT devices)
- Co-optimization captures values to both utility and to users



Baseline

Optimized

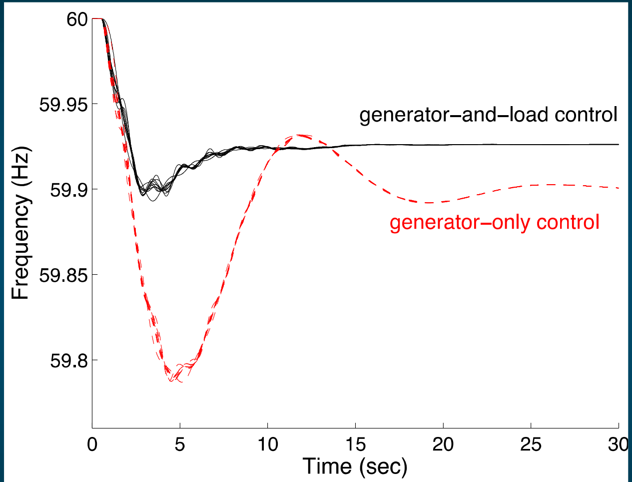


Peak load reduction: 8%
Energy cost reduction: 4%

Use Case – Frequency Control

Fast Timescale Frequency Control:

- Frequency regulation is traditionally implemented on generator side
- As DER penetration continues, the need and the ability for loads to participate increases
- Ubiquitous, continuous, fast-acting and distributed load-side participation in frequency regulation provides multiple benefits
- Caltech has developed distributed algorithms for this application



Legend
--- Current state
--- Caltech EAN technology

EAN OPF Simulator – Slow Timescale

$$\min_{V \in \mathbb{C}^n} \quad \mathrm{tr}\left(CVV^H\right)$$ min generation cost, network loss

$$\text{s. t.} \quad \underline{s}_j \le \mathrm{tr}\left(Y_j^H VV^H\right) \le \overline{s}_j$$ generation limits

$$\underline{v}_j \le \left|V_j\right|^2 \le \overline{v}_j$$ voltage constraints

$$C,\ Y_j \in \mathbb{C}^{n \times n},\quad \underline{s}_j, \overline{s}_j \in \mathbb{C},\quad \underline{v}_j, \overline{v}_j \in \mathbb{R}$$

power flow equations: $s_j = \mathrm{tr}\left(Y_j^H VV^H\right)$ for node j

- Y_j^H describes network topology and impedances
- s_j is net power injection (generation) at node *j*
- “power balance at each node *j*” (Kirchhoff’s law)

EAN Frequency Control – Fast Timescale

$$\dot{\theta}_i = \omega_i$$

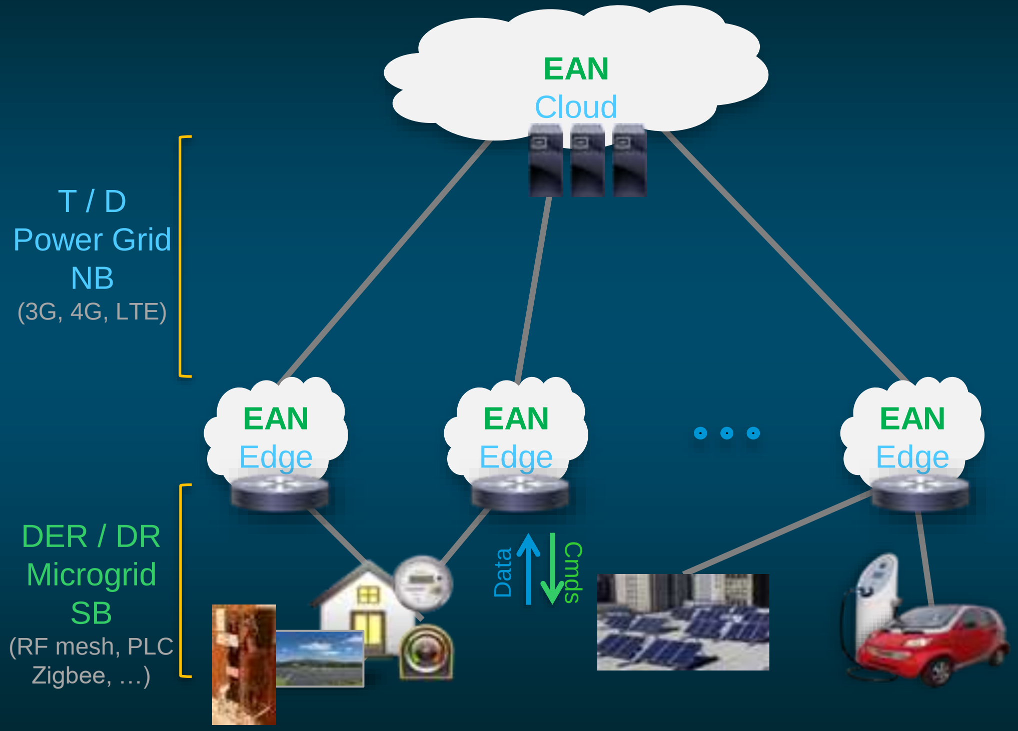
$$M_i \dot{\omega}_i = -D_i \omega_i + p_i - \sum_e C_{ie} P_e$$

$$P_{ij} = b_{ij} \sin(\theta_i - \theta_j) \qquad \forall\ i \to j$$

Objectives:

- Rebalance power & stabilize frequency – Caltech research
- Restore nominal frequency – Caltech research
- Stay within scheduled inter-area flows
- Stay within time limits

Project EAN Optimal Power Flow



- **EAN optimization**
  - Caltech OPF Algorithm
  - Optimal DER placement
  - P2V microgrid virtualization, analytics
  - ISO sensitivity to peak loads
  - Asset optimization
- **EAN enabled control**
  - Frequency Control
  - DER co-optimization
  - Real time optimization

The Missing Link – Open Ecosystem

Old – Closed:

- Aging old power grid can't handle reverse power
- Centralized
- Difficult to change or accepting innovation
- Proprietary vendor lock-in
- Evidence: No Accountability, Existential Dilemma of the old utility model
- Support: None, difficult interoperability between vendors

New – Open:

- IoT grid can solve reactive power grid problems
- Decentralized, distributed control
- Embracing innovation
- No vendor lock-in
- Evidence: 5 new open source projects, massive decentralization, DER adoption
- Support: multiple Labs, Open Source projects, collaborative ecosystem

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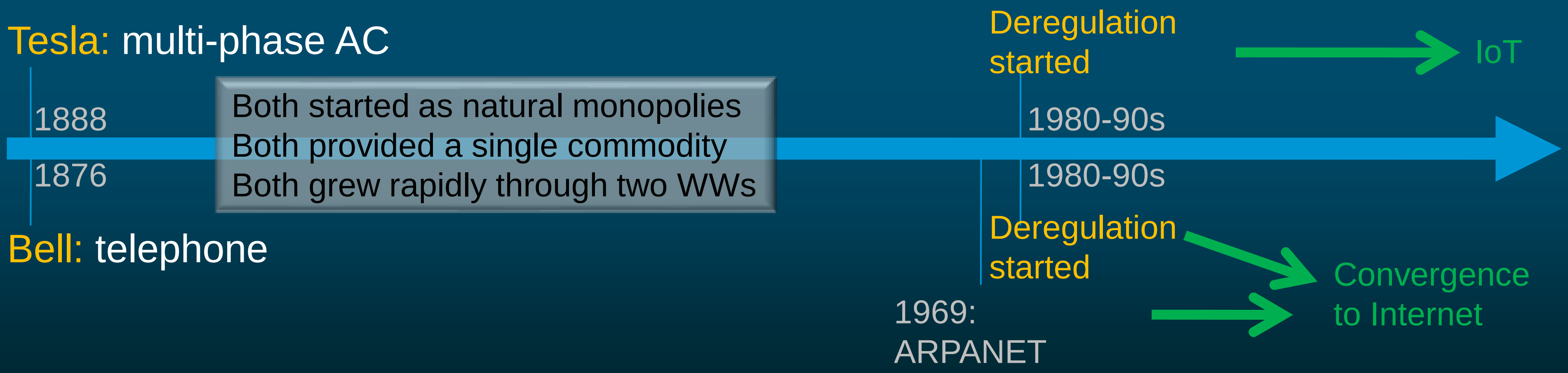
Smart Energy Opportunity:
IoT will be to Energy what the Internet was to Telephony

- Power networks will undergo similar architectural transformation as phone network went through in the last decade
- IoT adoption is 5x faster than electricity or telephony



Open OPF Simulator

Grid visualization

- Time series data collected in real time
- Network topology and power flow

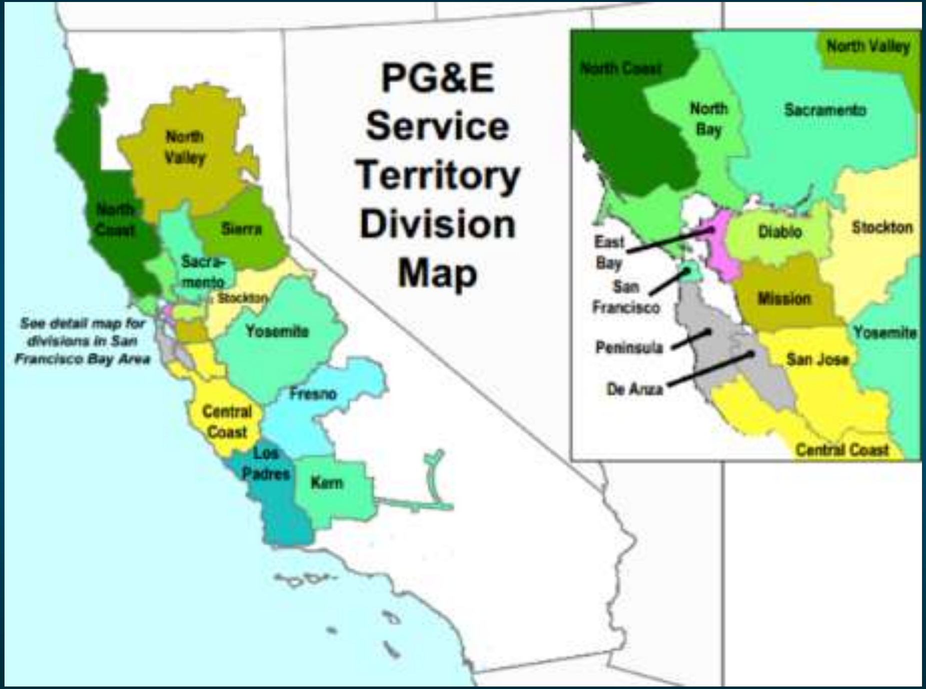
Grid management

- Data computed in real time (local min/max V(q))
- Open OPF: np hard -> np complete
- Allows for optimal device placement
- Allows for optimal device control (DR/DG)

Zero Net Energy community

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

The Way Things Were: Macro Level Planning

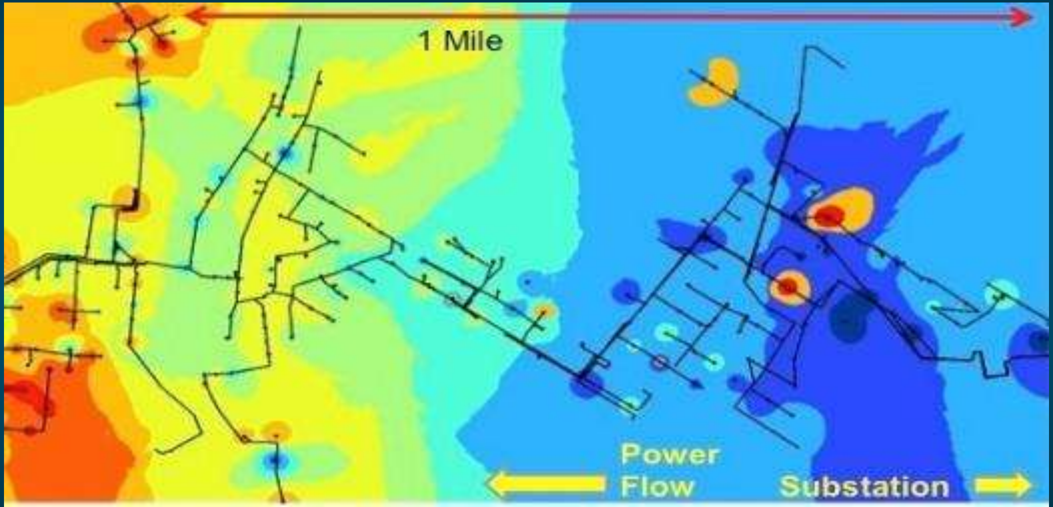


PG&E Distribution Planning

SC Edison Distribution Planning

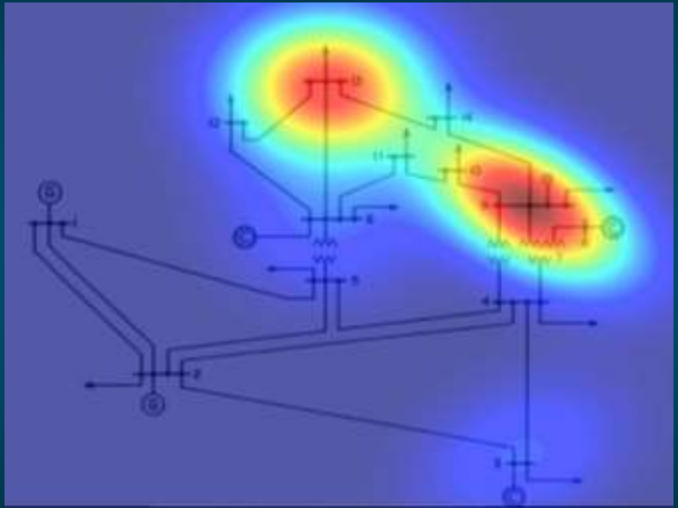
The Way Things Evolve: Microgrids

Distributed Marginal Price signal
4-5pm on a Western US Utility Feeder



Fine grain maps – DMP pricing

The picture changes throughout the day



Fine grain real-time optimization

What If Connected Microgrids Could Solve Both Generation and Distribution Everywhere?

Energy: Most Important Factor in Poverty

Remember the disappearance of the "digital divide" due to mobile Internet access?

With rapid DER penetration

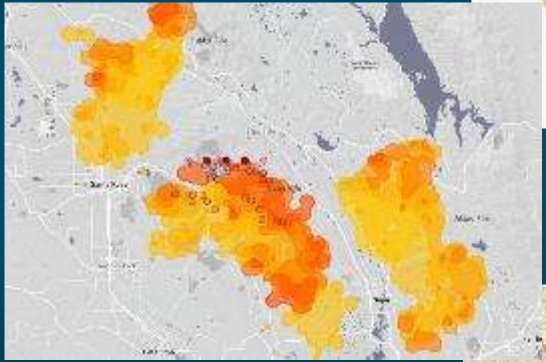
… and local / edge control

Access to Energy would follow suit when Microgrids deploy

The future is already here, it is just not very evenly distributed – W Gibson

What do we need to form such “Planetary Skin”?

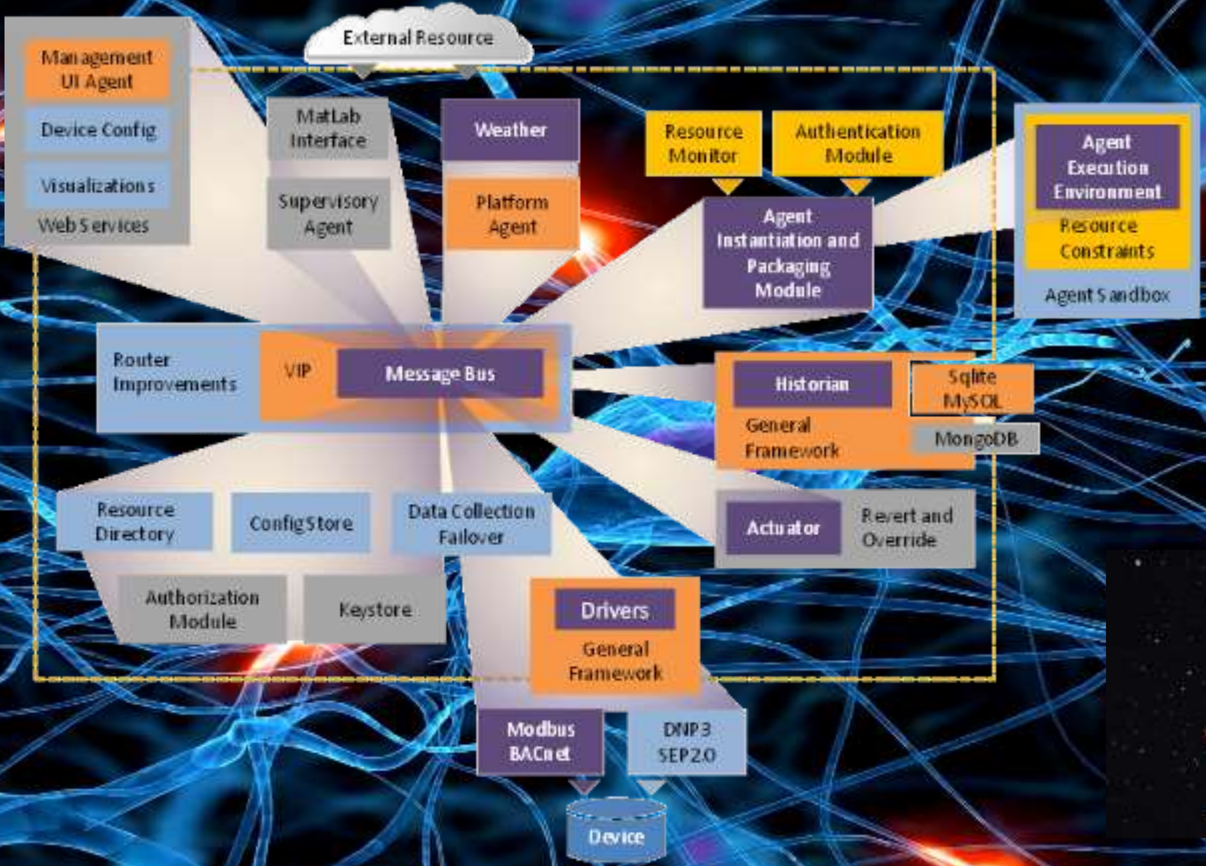
- ✓Hardware/Infra: Adoption of DER’s at scale, IOT
- ✓Software: Free and open source software to connect them
- ✓Public Good Policy: Develop an appreciation of shared value of IoT data at scale
- ✓Software: Free and open source software to compute on that data to optimize against reverse power flows
- ✓Ecosystem that does not stifle innovation



4 of 5 are only possible in Open Source!

Open Source Collaboration
Eclipse Volltron

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



Open Source Collaboration – Eclipse Volttron

Pacific Northwest National Laboratory
Virginia Tech
Case Western Reserve University
transformativewave
ACE IoT Solutions
Siemens
Energy Analytics & Consulting
University of Maryland
Drexel University
University of Wyoming
Emerson Climate Technologies
8minutenergy
UTSA University of Texas at San Antonio
Montana State
Johnson Controls
MelRok
Bosch
University of Victoria
State University of New York at Binghamton
The University of Toledo
PacStar
The University of Texas at San Antonio
I State
Purdue University
Fresno State
connect intwine
Southern Company
Intellimation
SES Consulting
SkyCentrics
Ecorithm

Open Source Collaboration

GridLAB-D

LF ENERGY

LF ENERGY RIAPS

GridAPPS-D

LF ENERGY OPERATORFABRIC

Zephyr

LF ENERGY POWSYBL

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Call to Action

1. Take advantage of IoT penetration and Open Source innovation
2. Lower your R&D costs by instrumenting your IoT devices with commercial Open Source software
3. Avoid proprietary/closed systems ~~difficult~~ impossible to interoperate
4. Embrace the shared value of IoT data, build your edge system where it belongs, at the Edge
5. Learn from the lessons learned in the 2018 wildfires
6. Join and collaborate in the Open Source Community started from Caltech and EAN

Open Source Resources

- OpenOPF Visualizer available:
  https://github.com/peterenescu/OpenOPFV
- Eclipse Volttron:
  https://github.com/volttron/VOLTTRON
- Linux Foundation Energy Summit:
  Next Tuesday (Nov 5) in Paris

Conclusion

- The century old power grid not built to handle reverse flows
  - Cannot support clean energy
  - Cannot protect
- Energy adaptive, fast time scale is needed
  - We saw this in multiple places, most recent in California Wildfires
  - Open OPF simulator validates research findings, identifies forward path
- Use Open OPF for grid visualization, optimization
  - For large scale systems to identify “hot spots” where fast time scale, energy adaptive technologies can be deployed to solve reactive power problems
- Use Open OPF for DER management
  - With IoT open source projects Volttron, Zephyr, RIAPS

Questions?

Thank You!

The future is already here – it is just not very evenly distributed

enescu@Caltech.edu
@michaelenescu