# New Technology at PJM

Carnegie Mellon
Electricity Industry Center
February 27, 2007
Ken Huber

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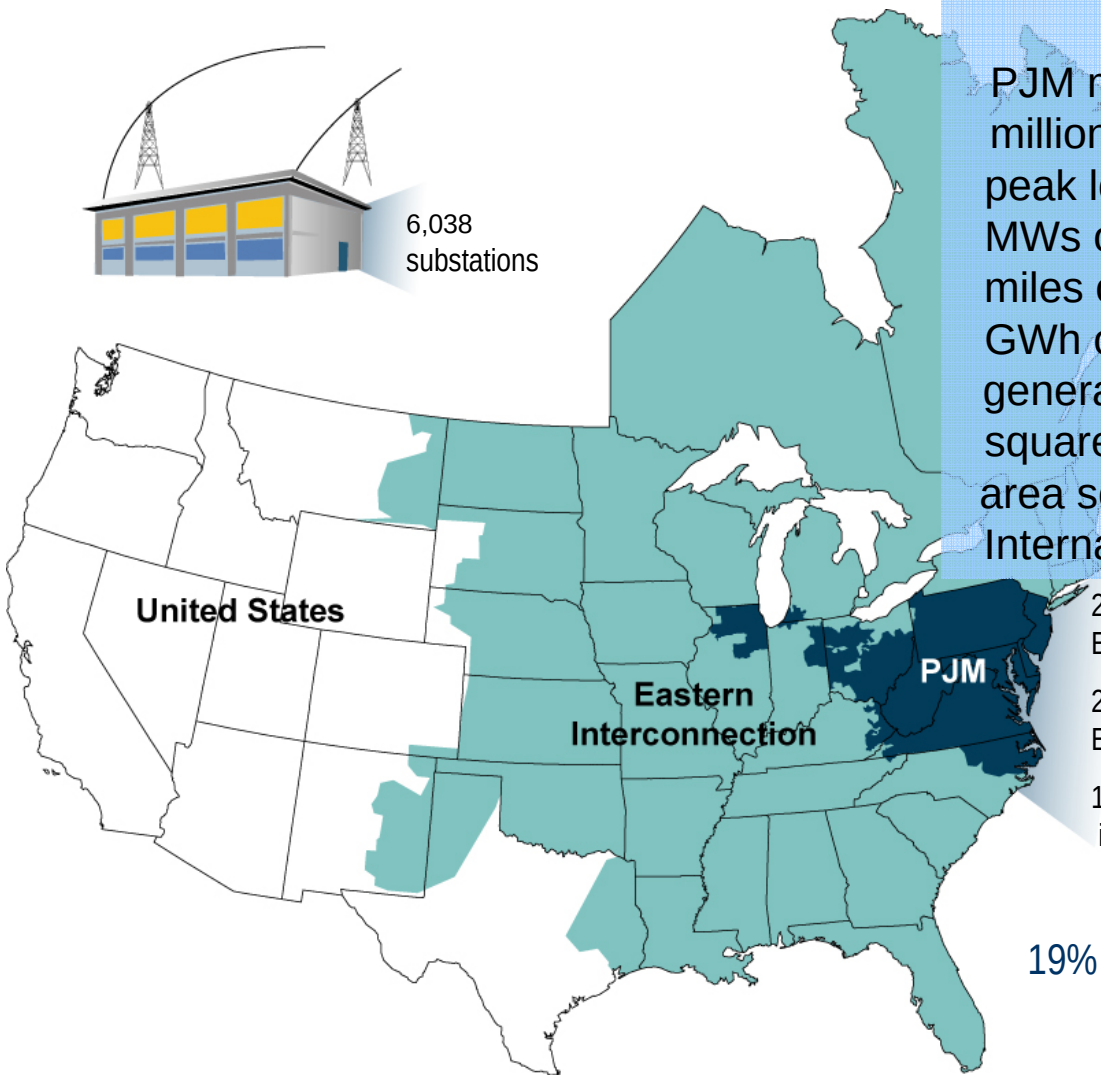
# PJM as Part of the Eastern Interconnection



6,038
substations




**KEY STATISTICS**

| | |
|---|---|
| PJM member companies | 475 |
| millions of people served | 51 |
| peak load in megawatts | 144,644 |
| MWs of generating capacity | 164,905 |
| miles of transmission lines | 56,250 |
| GWh of annual energy | 729,000 |
| generation sources | 1,271 |
| square miles of territory | 164,260 |
| area served | 13 states + DC |
| Internal/external tie lines | 247 |

26% of generation in
Eastern Interconnection

23% of load in
Eastern Interconnection

19% of transmission assets
in Eastern Interconnection

19% of U.S. GDP produced in PJM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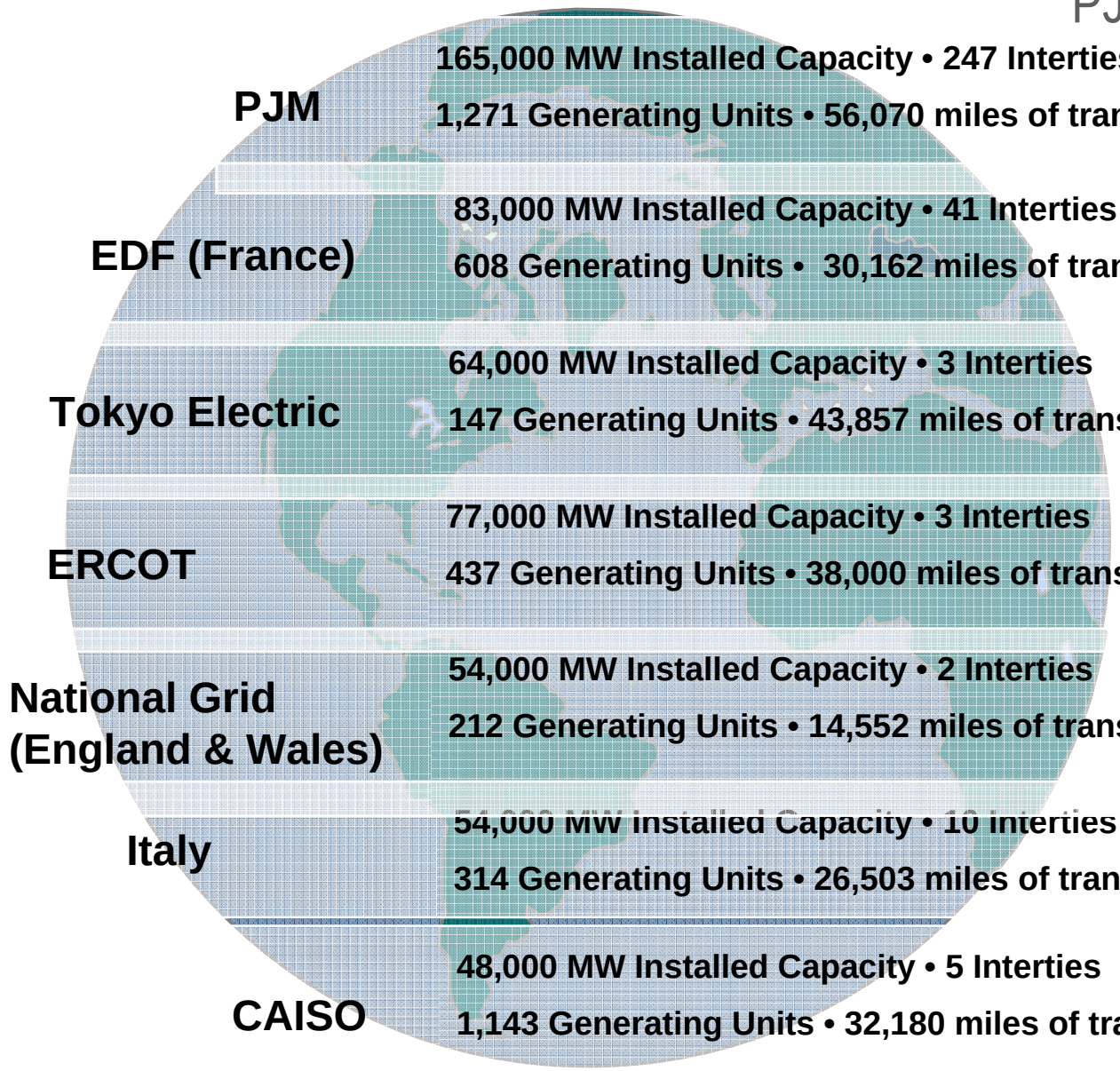
# PJM in the World



**PJM**
165,000 MW Installed Capacity • 247 Interties
1,271 Generating Units • 56,070 miles of transmission

**EDF (France)**
83,000 MW Installed Capacity • 41 Interties
608 Generating Units • 30,162 miles of transmission

**Tokyo Electric**
64,000 MW Installed Capacity • 3 Interties
147 Generating Units • 43,857 miles of transmission

**ERCOT**
77,000 MW Installed Capacity • 3 Interties
437 Generating Units • 38,000 miles of transmission

**National Grid (England & Wales)**
54,000 MW Installed Capacity • 2 Interties
212 Generating Units • 14,552 miles of transmission

**Italy**
54,000 MW Installed Capacity • 10 Interties
314 Generating Units • 26,503 miles of transmission

**CAISO**
48,000 MW Installed Capacity • 5 Interties
1,143 Generating Units • 32,180 miles of transmission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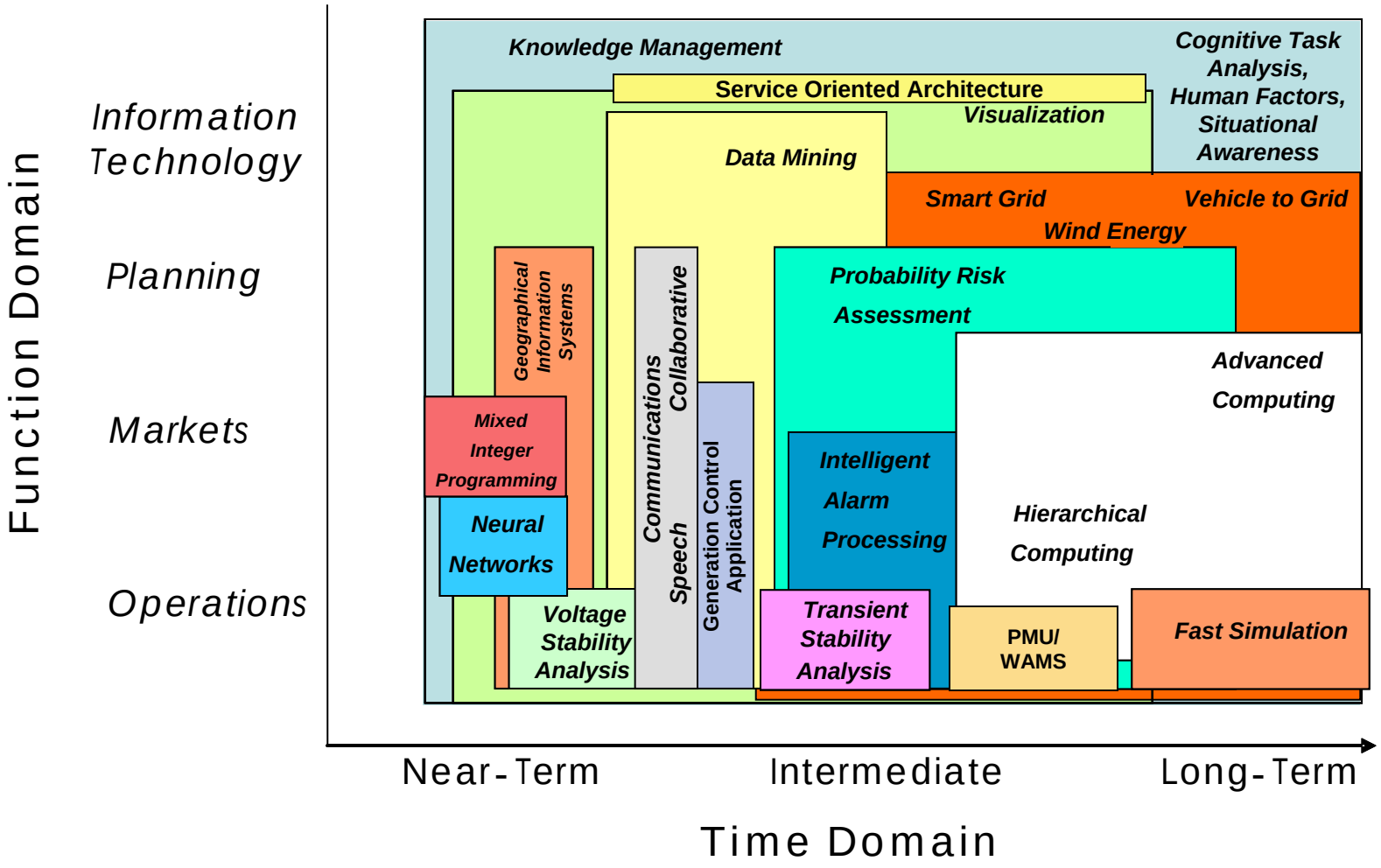
# Advanced Technology Initiatives





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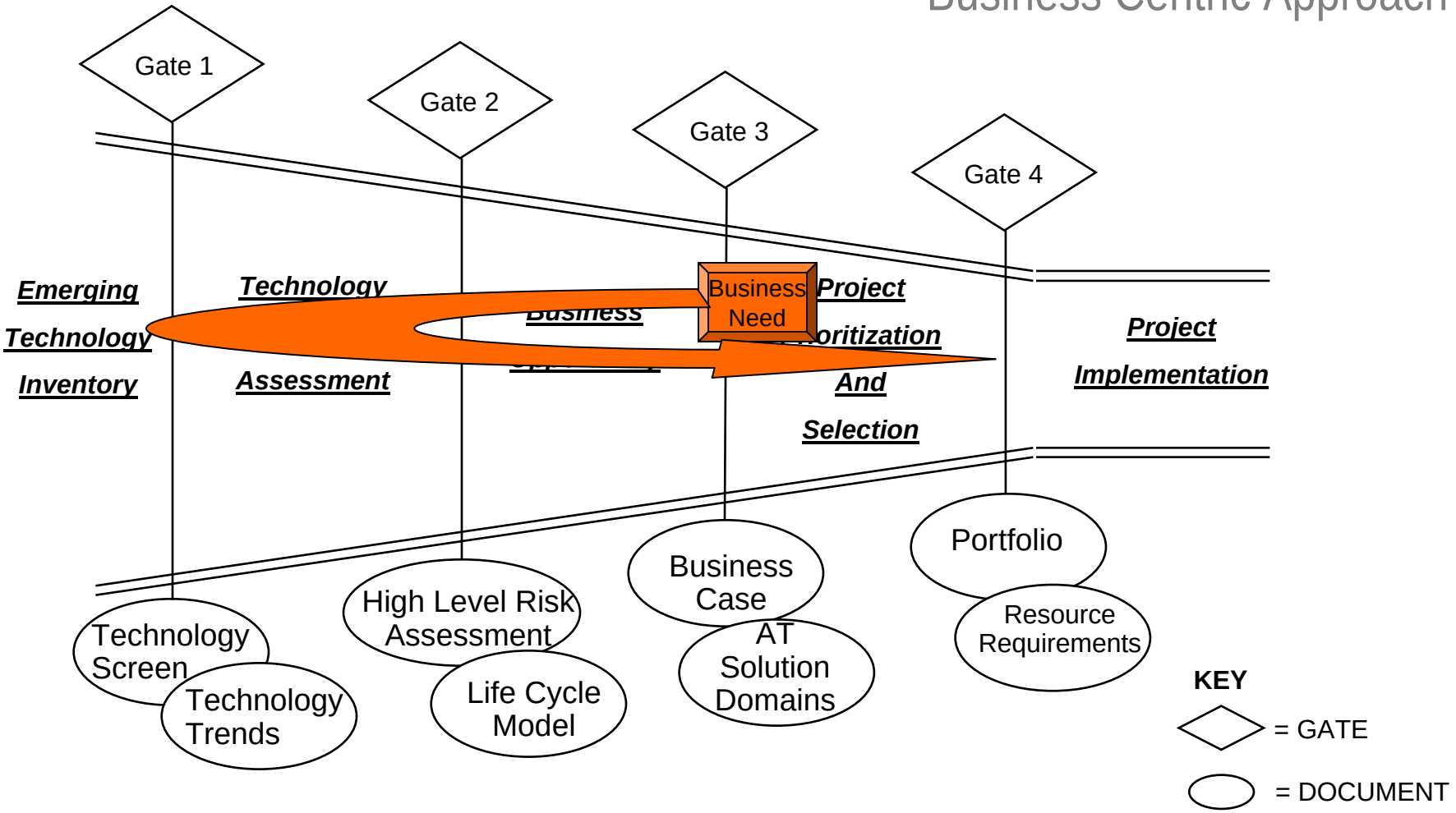
# Analysis of Emerging Technology
# Innovation Funnel
# Business Centric Approach





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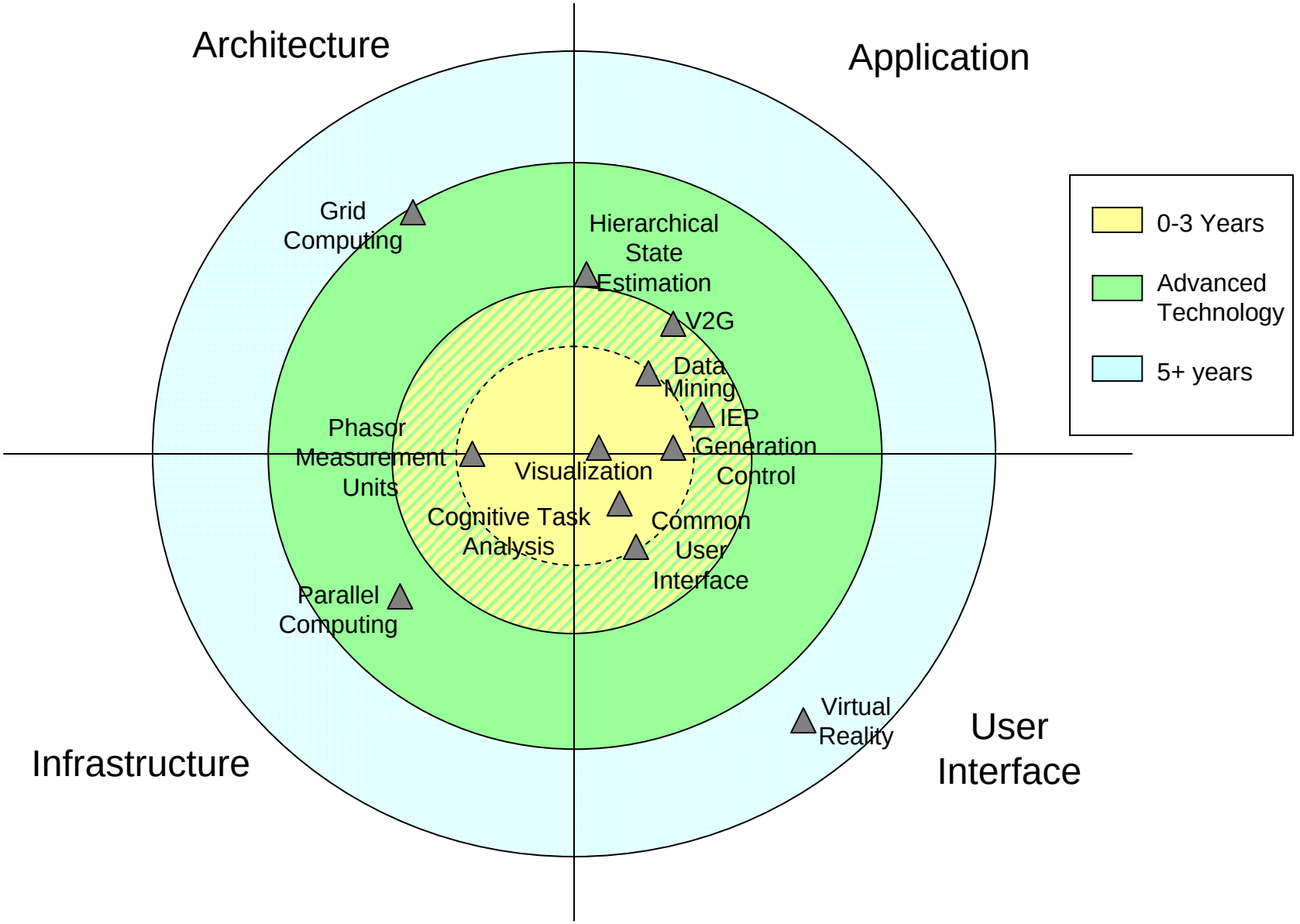
# Analysis of Emerging Technology
# Current Advanced Technology Focus





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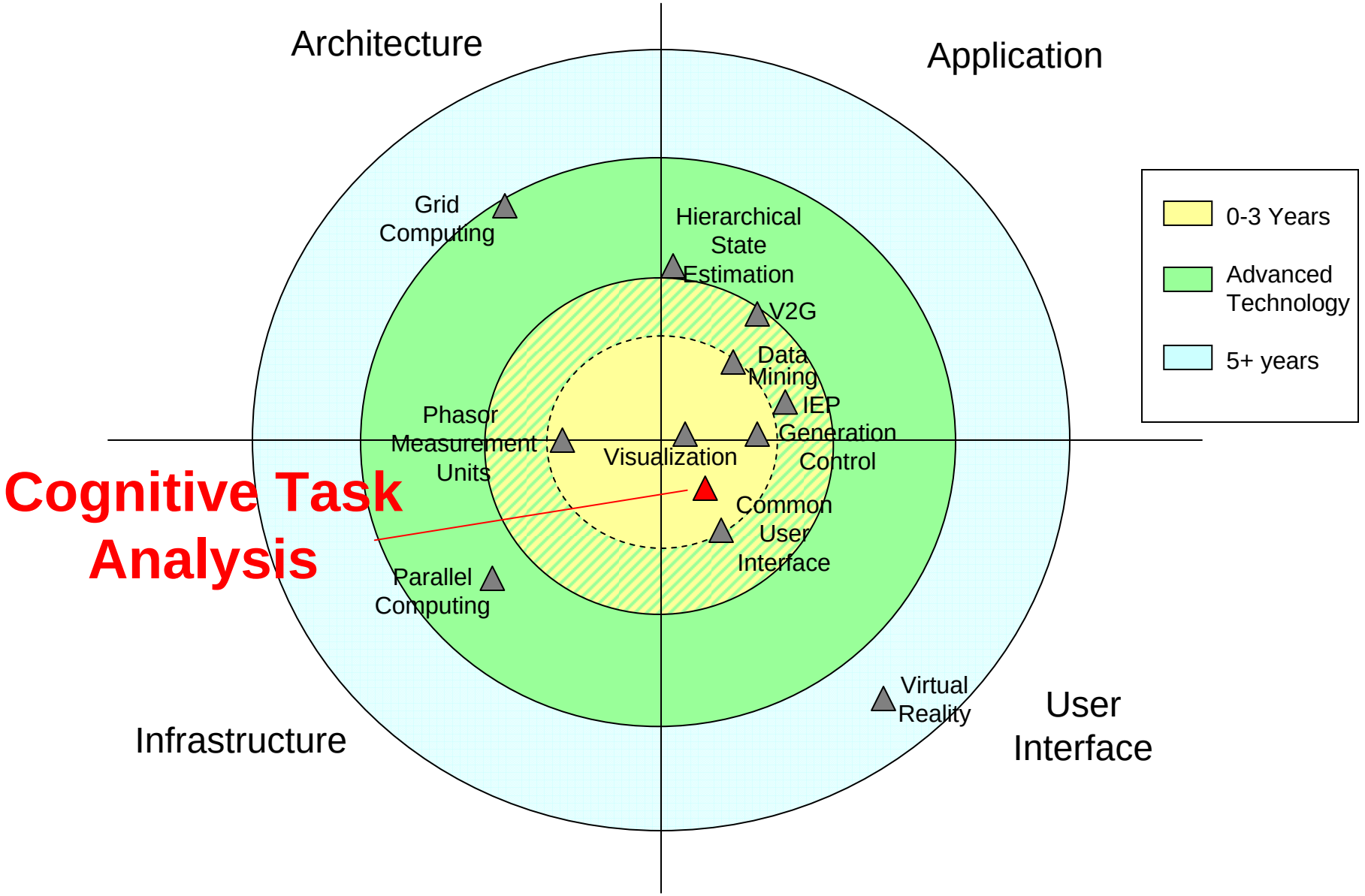
# Analysis of Emerging Technology
# Current Advanced Technology Focus





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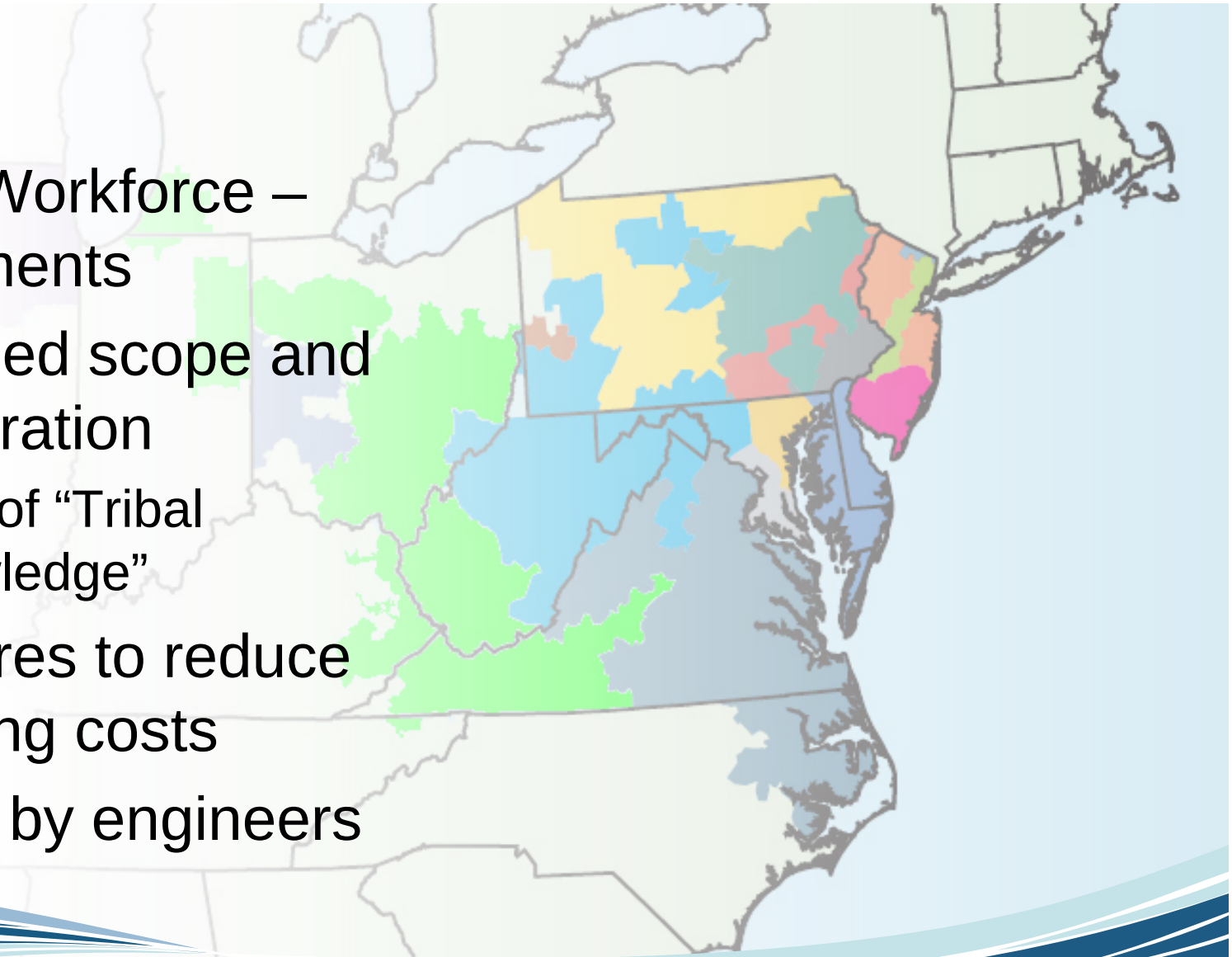
# Challenges Facing PJM



- Aging Workforce – Retirements
- Increased scope and configuration
  - Loss of “Tribal Knowledge”
- Pressures to reduce operating costs
- Design by engineers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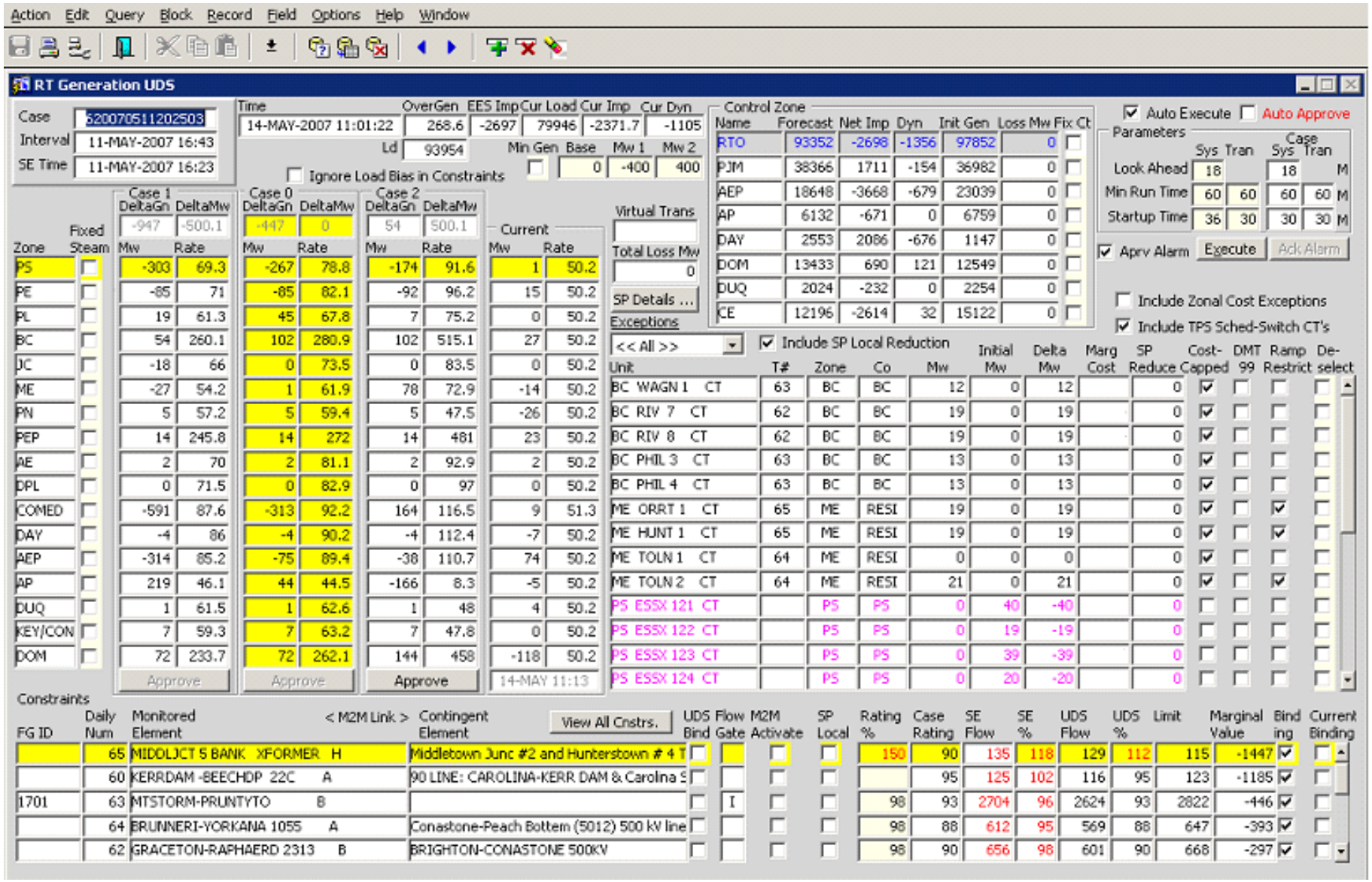
# UDS Inputs: User Interface





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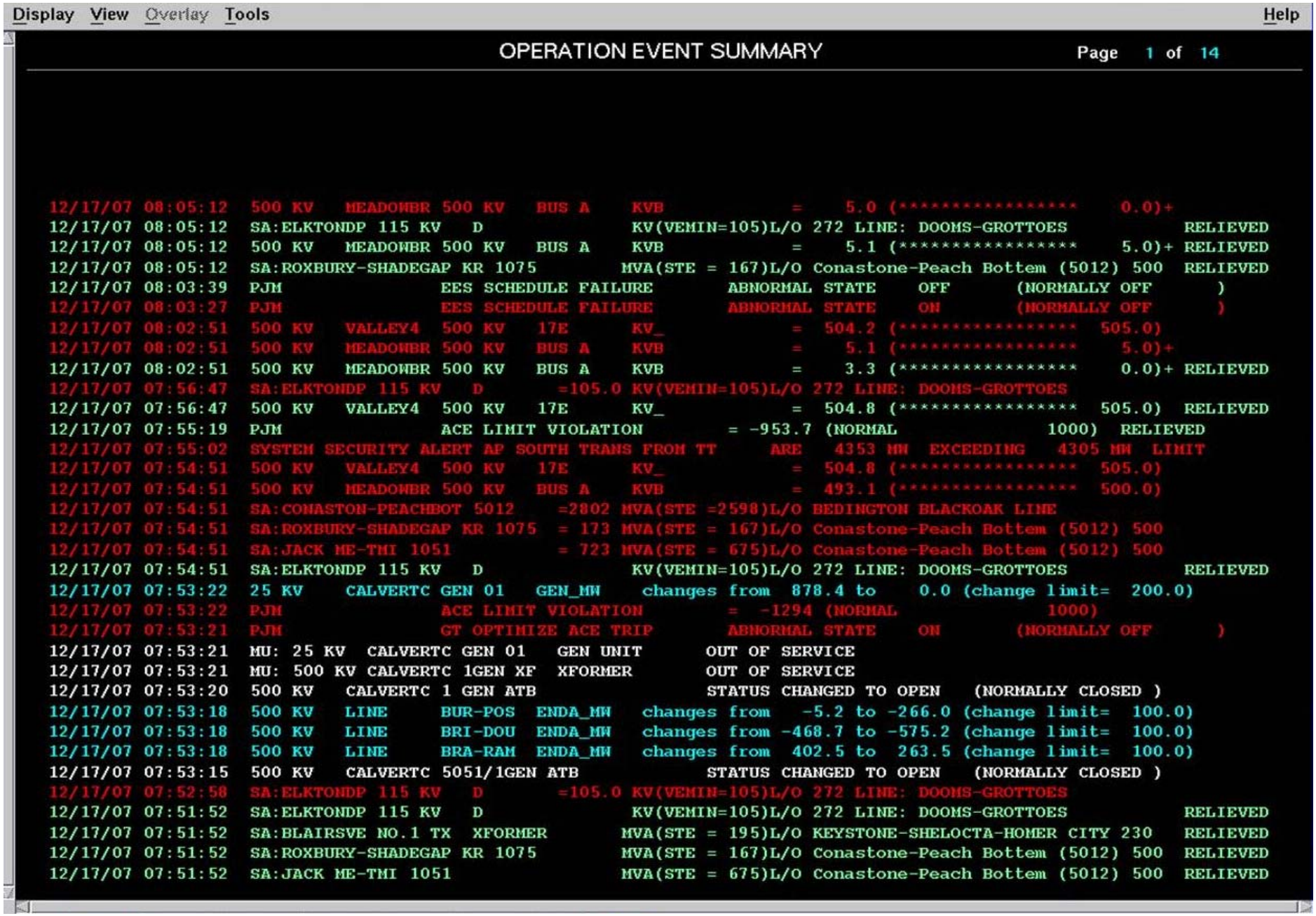
# Event Summary

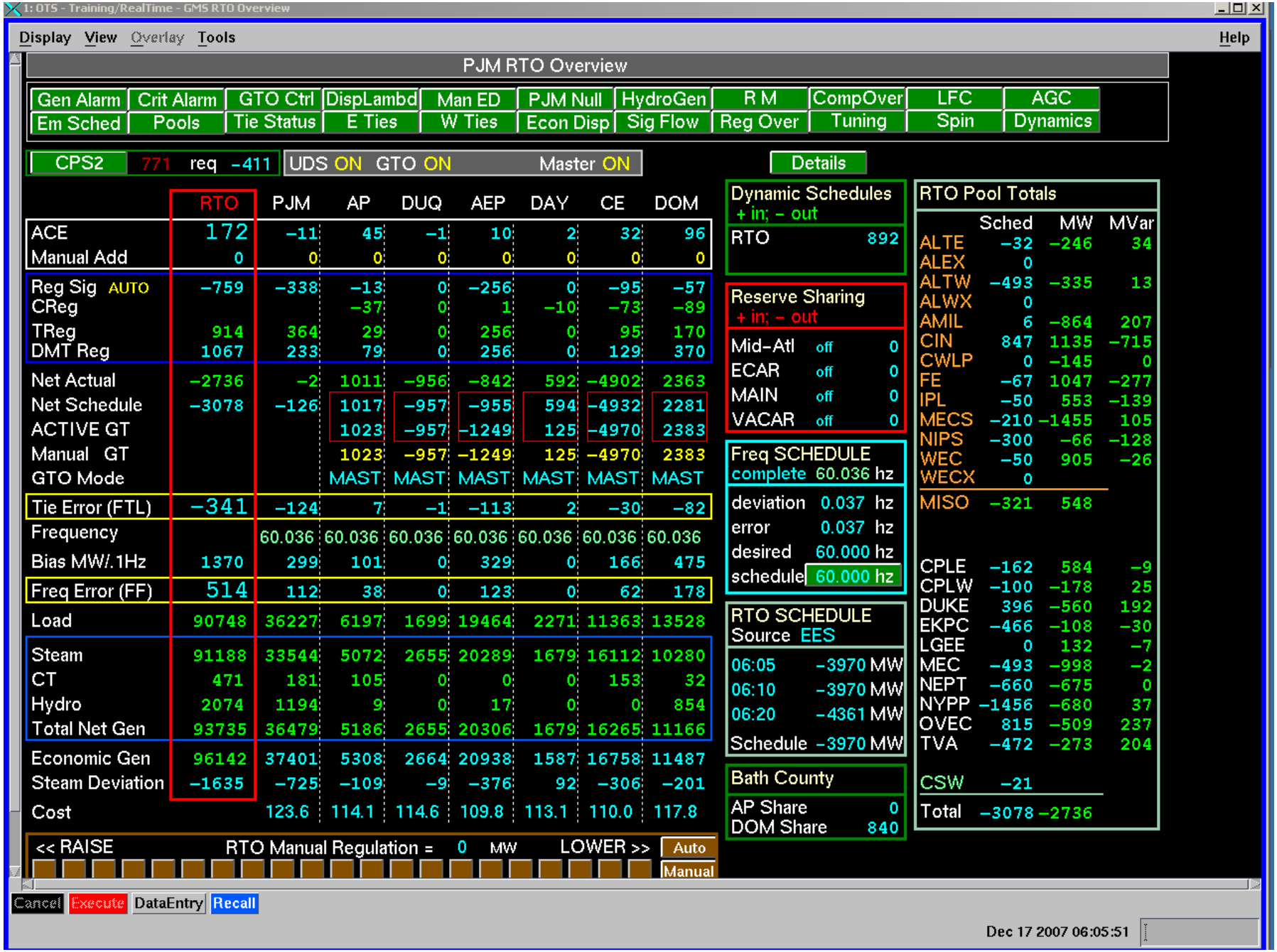


Display View Overlay Tools Help

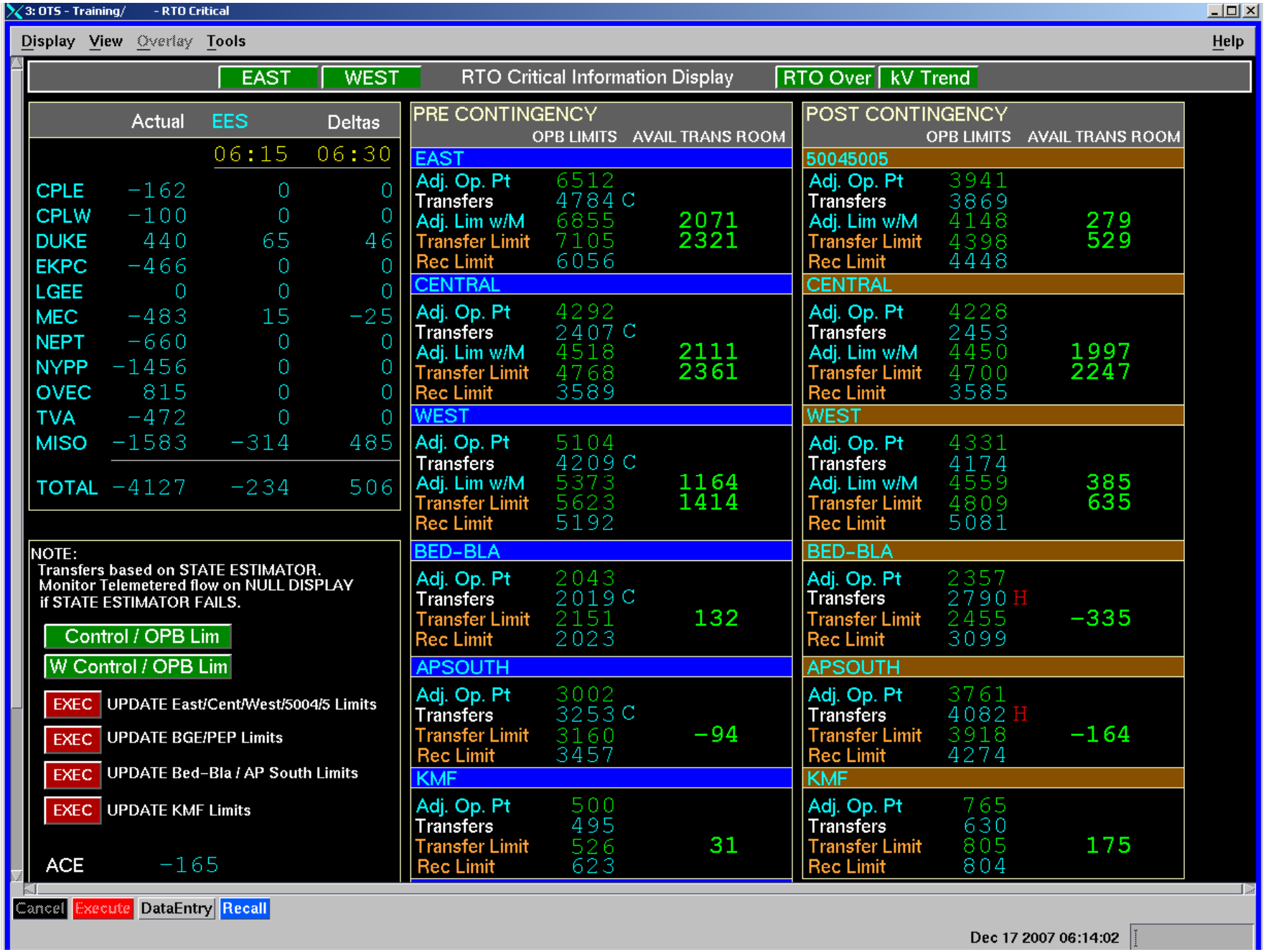
OPERATION EVENT SUMMARY Page 1 of 14

```
12/17/07 08:05:12  500 KV   MEADOWBR 500 KV   BUS A    KVB            =    5.0 (*****************    0.0)+
12/17/07 08:05:12  SA:ELKTONDP 115 KV   D              KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES          RELIEVED
12/17/07 08:05:12  500 KV   MEADOWBR 500 KV   BUS A    KVB            =    5.1 (*****************    5.0)+ RELIEVED
12/17/07 08:05:12  SA:ROXBURY-SHADEGAP KR 1075        MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500  RELIEVED
12/17/07 08:03:39  PJM              EES SCHEDULE FAILURE      ABNORMAL STATE    OFF      (NORMALLY OFF      )
12/17/07 08:03:27  PJM              EES SCHEDULE FAILURE      ABNORMAL STATE    ON       (NORMALLY OFF      )
12/17/07 08:02:51  500 KV   VALLEY4  500 KV   17E      KV_            =  504.2 (*****************  505.0)
12/17/07 08:02:51  500 KV   MEADOWBR 500 KV   BUS A    KVB            =    5.1 (*****************    5.0)+
12/17/07 08:02:51  500 KV   MEADOWBR 500 KV   BUS A    KVB            =    3.3 (*****************    0.0)+ RELIEVED
12/17/07 07:56:47  SA:ELKTONDP 115 KV   D       =105.0 KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES
12/17/07 07:56:47  500 KV   VALLEY4  500 KV   17E      KV_            =  504.8 (*****************  505.0)  RELIEVED
12/17/07 07:55:19  PJM              ACE LIMIT VIOLATION       = -953.7 (NORMAL              1000)  RELIEVED
12/17/07 07:55:02  SYSTEM SECURITY ALERT AP SOUTH TRANS FROM TT     ARE   4353 MW  EXCEEDING   4305 MW  LIMIT
12/17/07 07:54:51  500 KV   VALLEY4  500 KV   17E      KV_            =  504.8 (*****************  505.0)
12/17/07 07:54:51  500 KV   MEADOWBR 500 KV   BUS A    KVB            =  493.1 (*****************  500.0)
12/17/07 07:54:51  SA:CONASTON-PEACHBOT 5012    =2802 MVA(STE =2598)L/O BEDINGTON BLACKOAK LINE
12/17/07 07:54:51  SA:ROXBURY-SHADEGAP KR 1075  = 173 MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500
12/17/07 07:54:51  SA:JACK ME-TMI 1051          = 723 MVA(STE = 675)L/O Conastone-Peach Bottem (5012) 500
12/17/07 07:54:51  SA:ELKTONDP 115 KV   D              KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES          RELIEVED
12/17/07 07:53:22  25 KV    CALVERTC GEN 01   GEN_MW    changes from  878.4 to    0.0 (change limit=  200.0)
12/17/07 07:53:22  PJM              ACE LIMIT VIOLATION       =  -1294 (NORMAL              1000)
12/17/07 07:53:21  PJM              GT OPTIMIZE ACE TRIP      ABNORMAL STATE    ON       (NORMALLY OFF      )
12/17/07 07:53:21  MU: 25 KV  CALVERTC GEN 01   GEN UNIT      OUT OF SERVICE
12/17/07 07:53:21  MU: 500 KV CALVERTC 1GEN XF  XFORMER       OUT OF SERVICE
12/17/07 07:53:20  500 KV   CALVERTC 1 GEN ATB              STATUS CHANGED TO OPEN   (NORMALLY CLOSED )
12/17/07 07:53:18  500 KV   LINE     BUR-POS  ENDA_MW   changes from   -5.2 to -266.0 (change limit=  100.0)
12/17/07 07:53:18  500 KV   LINE     BRI-DOU  ENDA_MW   changes from -468.7 to -575.2 (change limit=  100.0)
12/17/07 07:53:18  500 KV   LINE     BRA-RAM  ENDA_MW   changes from  402.5 to  263.5 (change limit=  100.0)
12/17/07 07:53:15  500 KV   CALVERTC 5051/1GEN ATB           STATUS CHANGED TO OPEN   (NORMALLY CLOSED )
12/17/07 07:52:58  SA:ELKTONDP 115 KV   D       =105.0 KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES
12/17/07 07:51:52  SA:ELKTONDP 115 KV   D              KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES          RELIEVED
12/17/07 07:51:52  SA:BLAIRSVE NO.1 TX  XFORMER       MVA(STE = 195)L/O KEYSTONE-SHELOCTA-HOMER CITY 230   RELIEVED
12/17/07 07:51:52  SA:ROXBURY-SHADEGAP KR 1075        MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500  RELIEVED
12/17/07 07:51:52  SA:JACK ME-TMI 1051               MVA(STE = 675)L/O Conastone-Peach Bottem (5012) 500  RELIEVED
```

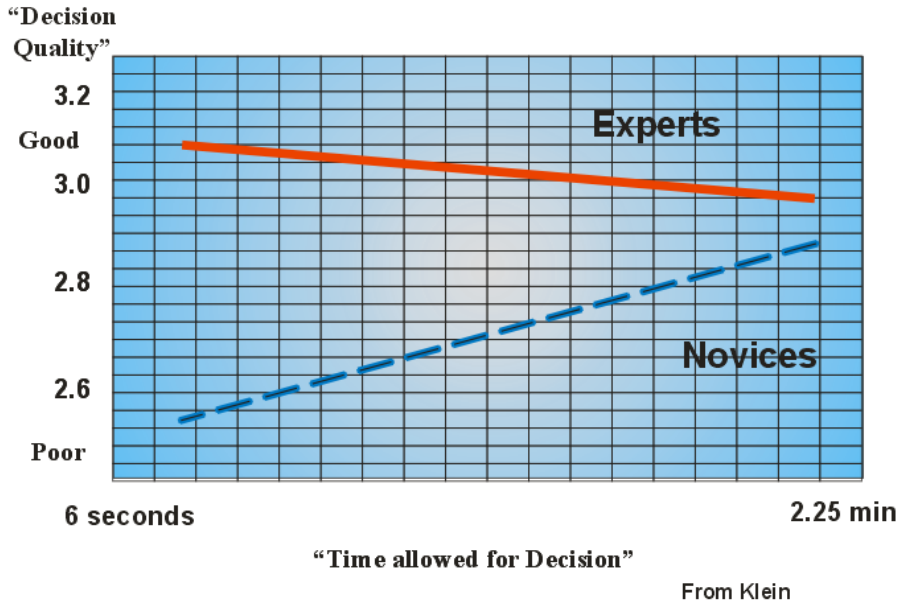
# Situational Awareness?



# Good Human Factors?



# Designing for the Novice and Expert




From Klein

- Novice
  - Lives in the moment
  - Can't recognize complex relationships
  - Produces limited options

  Routine Expert
  - Great at everyday stuff
  - Strong procedural knowledge
  - Runs into trouble when problems are ill-structured or novel
- Adaptive Expert
  - Deep comprehension of conceptual structure of the problem domain

Source: Liz Quoetone WTDB/NSSL and Dr. Gary Klein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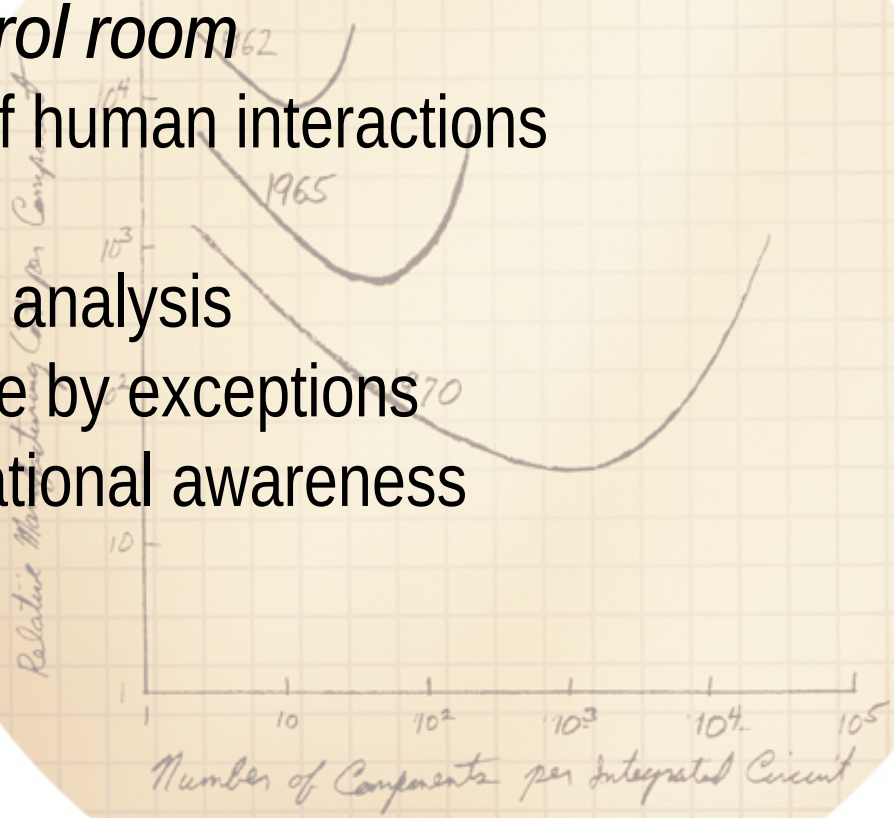
*Early adopter of human factors and cognitive task analysis in power grid control room*

- Increased understanding of human interactions
- User-centered applications
- Reduce cognitive load and analysis
- Reorganize data to manage by exceptions
- Provide current/future situational awareness





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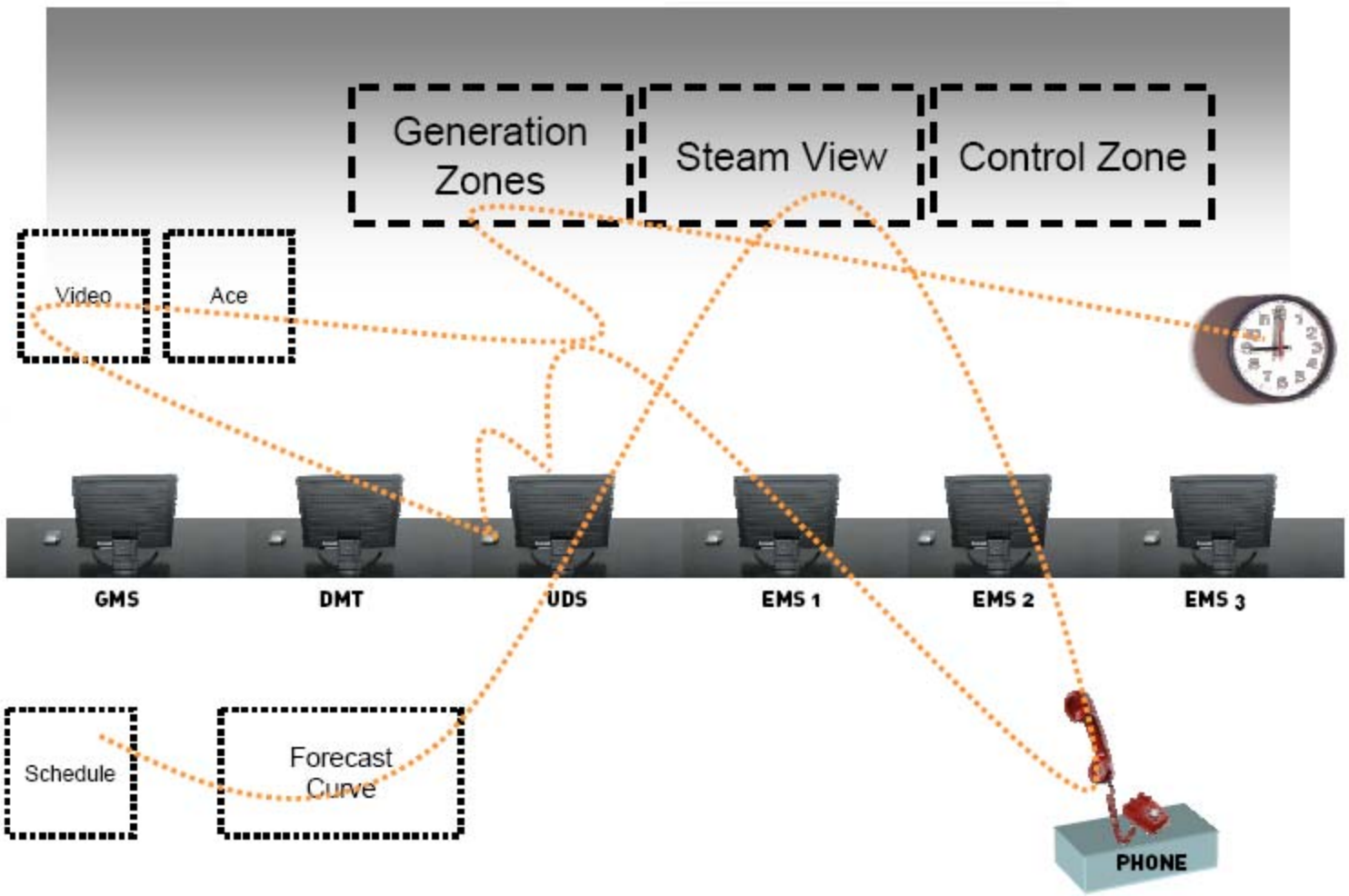
# User Centric Design - Discovery





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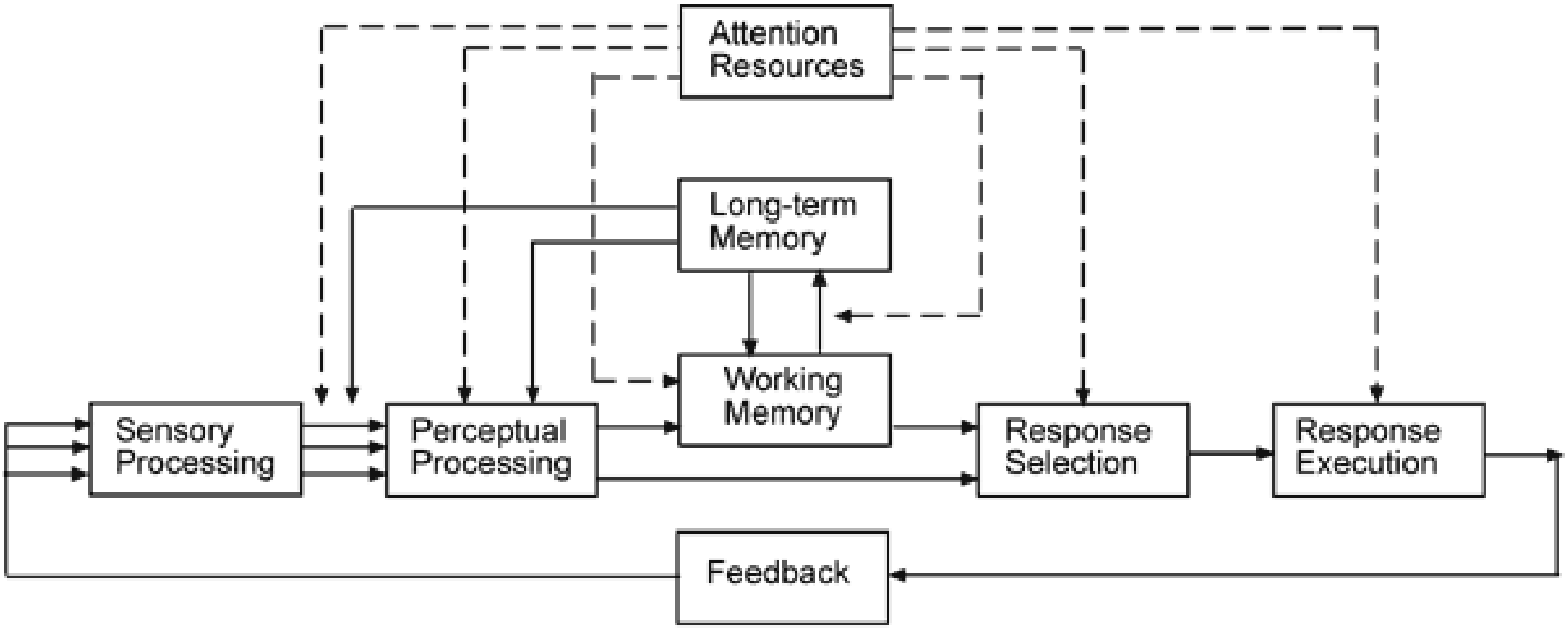
# User Centric Design - Approach





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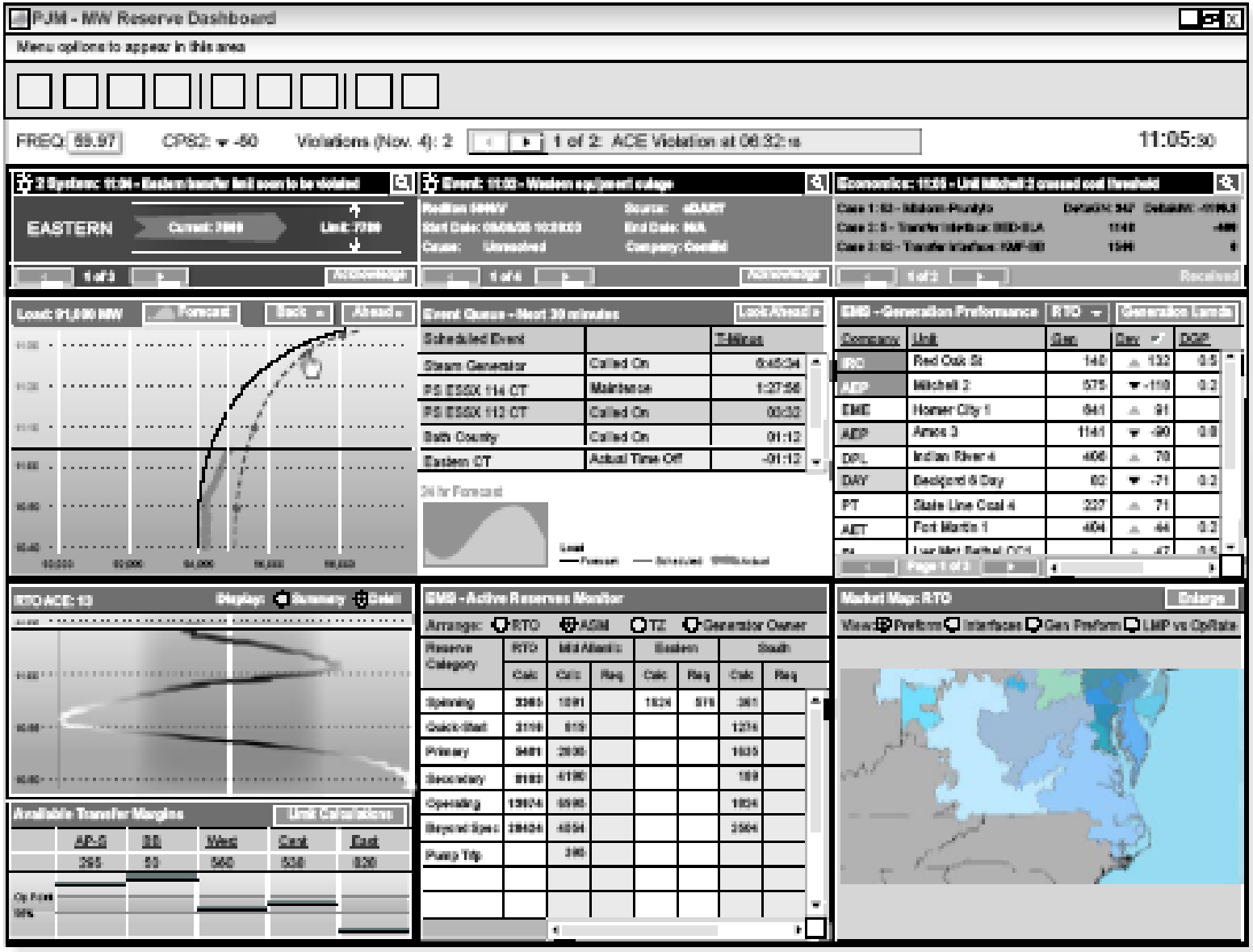
# Dashboard – Prototype Wireframe, End-User in the Loop



# Dashboard – Final Design

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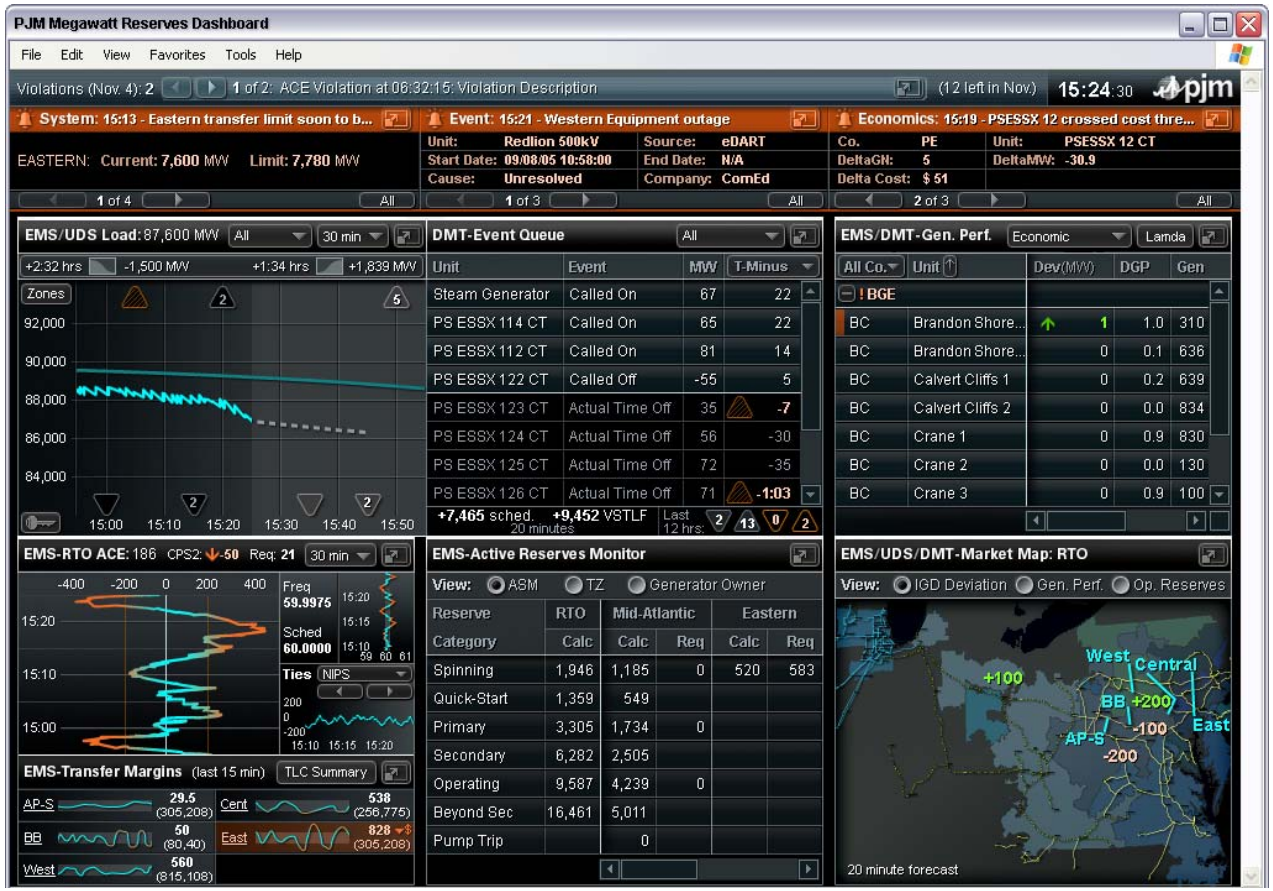
# User Interface Framework and Visualization

- Dashboard Goals
  - Minimize Visual Travel Time
  - Minimize Number of Displays
  - Reduce Cognitive load & Analysis
  - Provide Situational Awareness
  - Reorganize data to “Manage by Exception”
  - Create Data Visualization Standards





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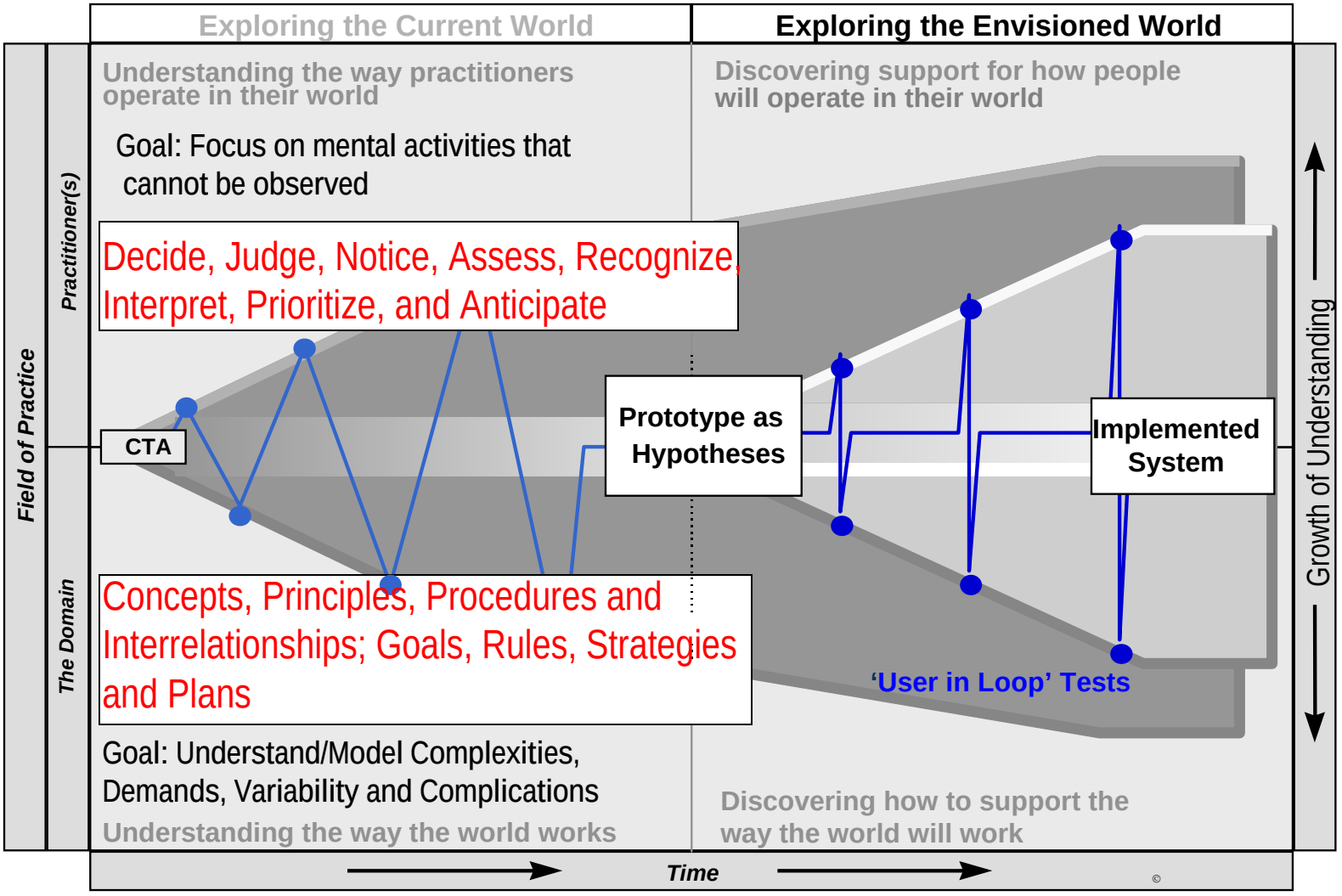
# Cognitive Task Analysis





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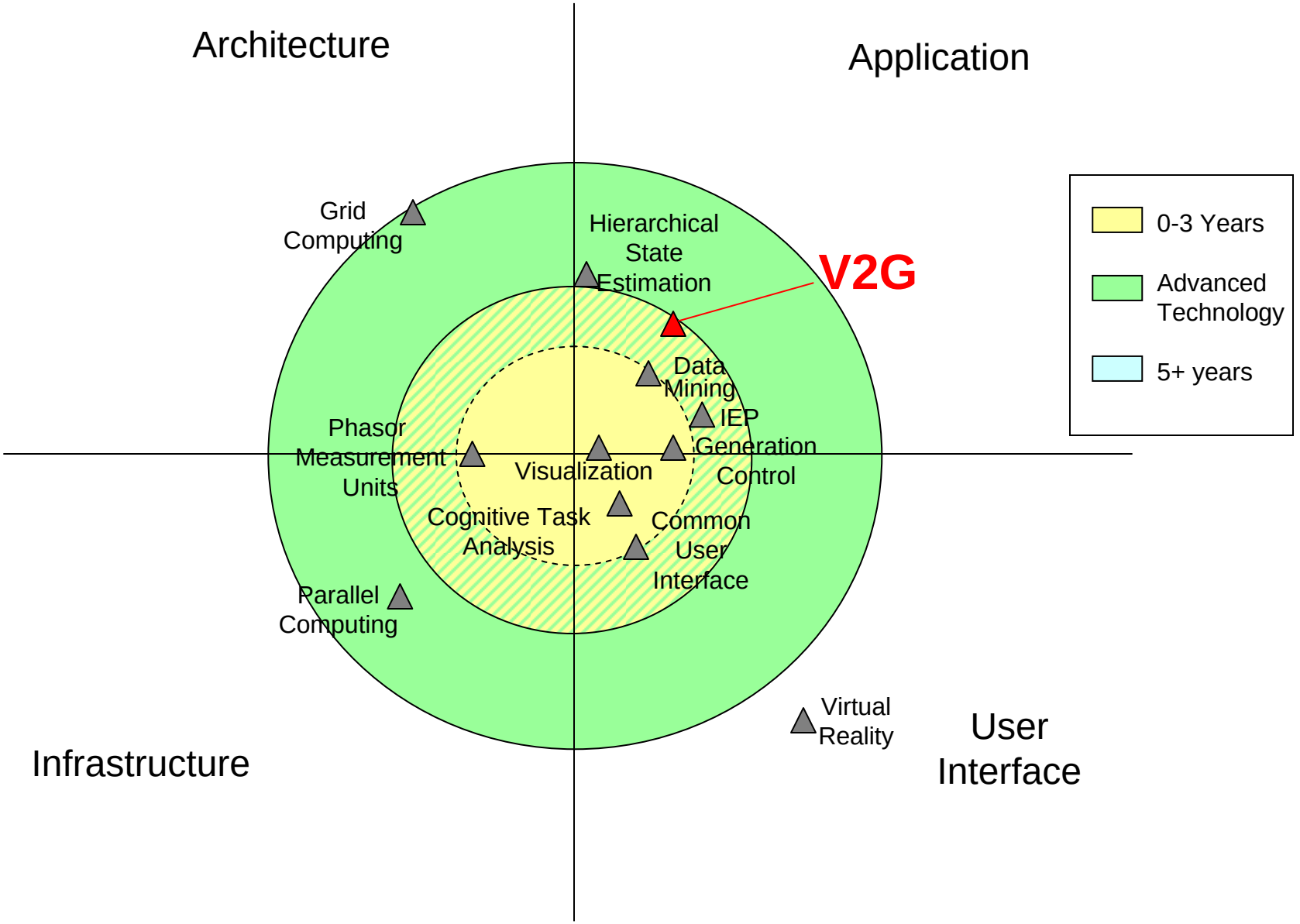
# Analysis of Emerging Technology
# Current Advanced Technology Focus





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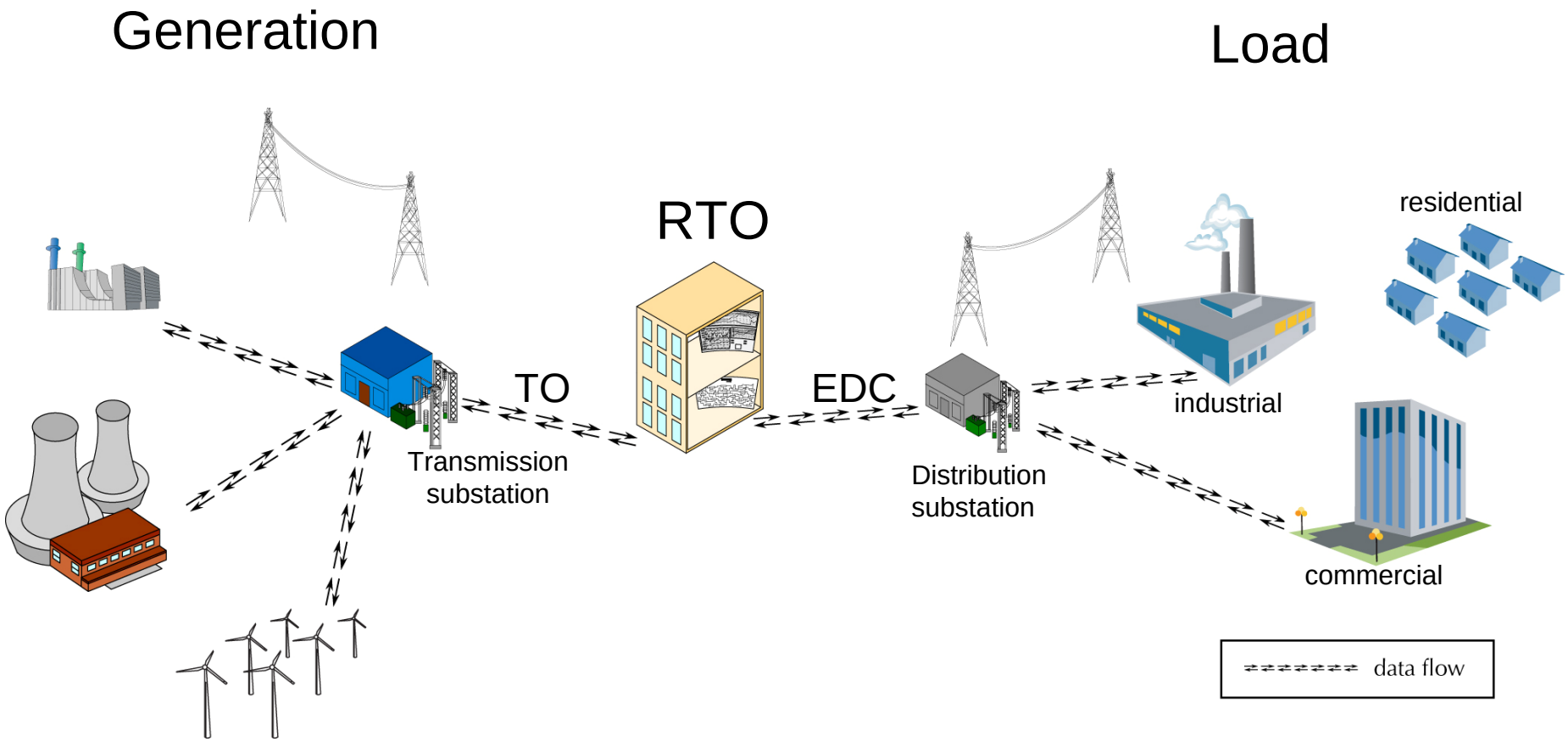
# Information Flow for Today's Grid





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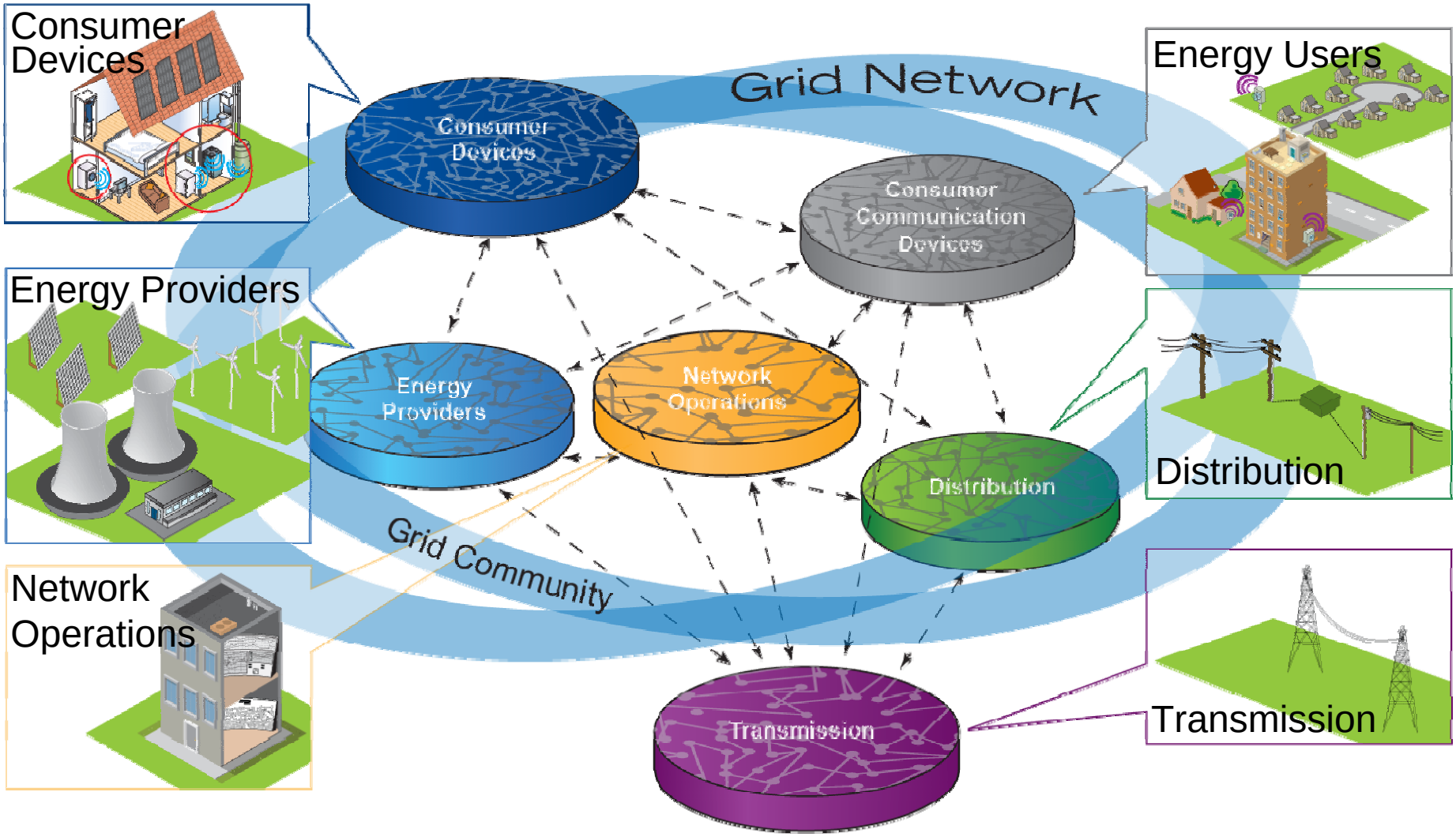
# Smart Grid





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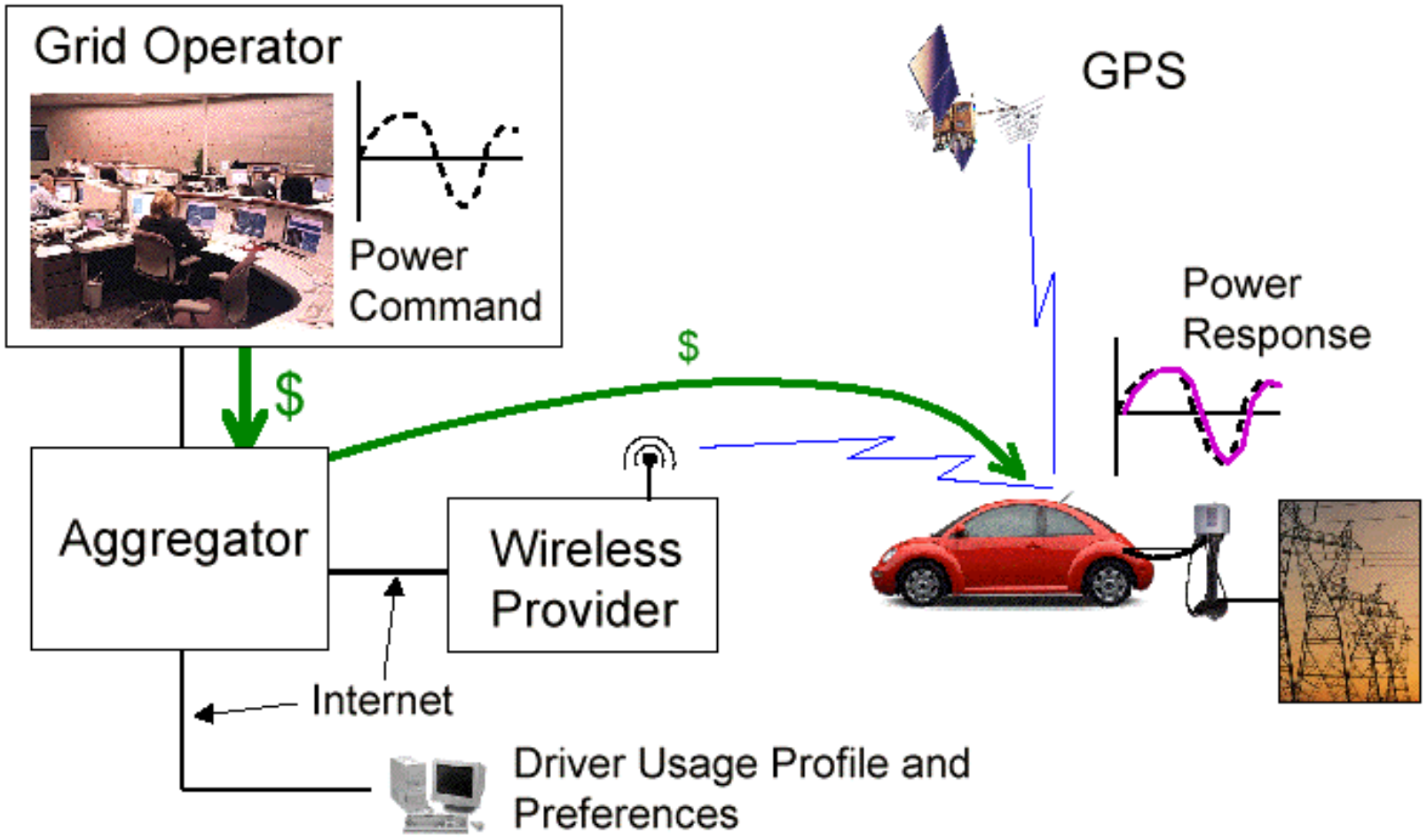
# Components of the V2G system





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**The Vehicle to Grid (V2G) concept is aimed at developing a vehicle that can plug into and interact with the power grid**

- Plug-in rechargeable vehicle with relatively high capacity battery (vs. hybrid vehicles)
- Vehicle can communicate with the power provider
- Vehicle can provide two way power. Acts as generator or load as required
- Vehicle can participate in markets (such as regulation)
- New aggregation business function to provide interface between regulation signal and vehicles.


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# eBox V2G Capable Scion Conversion from AC Propulsion

eBox by AC PROPULSION

Urban Utility Vehicle
Spacious, efficient, comfortable, unique, sporty, versatile, fun, zero emission, no gas.
All Electric.

| Vehicle Performance | |
|---|---|
| Range | 120 – 150 miles |
| Acceleration | 0 to 60 ~ 7.0 secs |
| Top Speed | 95 mph |
| Charge rate | 30 minutes for 20 – 50 miles |
| Full Charge | 2 hrs (fast), 5 hrs (normal) |
| Curb Weight | 2970 lbs |

Test track photo

| Electric Propulsion | |
|---|---|
| Drive system | 120 kW, 220 Nm, 13,000 rpm, regenerative braking |
| Battery | Li Ion, 35 kWh, 600 lb |
| Charger | Onboard, plug in anywhere, up to 18 kW |
| | |
| Vehicle to Grid | |
| Power converter | Bi-directional (charge or discharge) up to 18 kW |
| Communication | Secure, wireless |
| Battery management | Integrated control of battery voltage, state of charge, and temperature |

# EBox?
# How about a Tesla!

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# V2G Basic Math

- Average car driven 1 hour/day, thus, time parked is 23 hours/day; Daily average travel: 32 miles, storage for 100 - 250 miles
- Practical power draw from car: 10 - 20 kW
- US power: generation=978 GW; load=436 GW avg (EIA)
- US 241 million cars (FHWA 2005) x 15 kW = 3,615 GW, thus...
- **Power of fleet is >3x generation; >8x load!**


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- Initial markets (high value, low impact on battery, no system changes):
  - Regulation (“Frequency regulation”)
  - Spinning reserves

- Larger but more challenging markets
  - Peak power
  - UPS for the distribution system


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# Vehicle Revenue Estimates

Vehicle owner's annual net profit from V2G; these are representative midrange figures extracted from full analysis in the report. Key: $net (revenue – cost).

| | **Peak power** | **Spinning reserves** | **Regulation services** |
|---|---|---|---|
| **Battery, full function** | **$267 (510 – 243)** | **$720 (775 – 55)** | **$3,162 (4479 – 1317)** |
| **Battery, city Car** | **$75 (230 – 155)** | **$311 (349 – 38)** | **$2,573 (4479 – 1906)** |
| **Hybrid, Gasoline** | **$322 (1500 – 1178)** | **$1581 (2279 – 698)** | **$-759 (loss) (2567 – 3326)** |

Source: "Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California", June 2001


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- Mid-Atlantic Grid-Interactive Car (MAGIC) Consortium led by Pepco Holdings, Inc.
  - Pepco Holdings, Inc. - Delmarva Power & Light
  - Atlantic City Electric - PJM
  - Atlantic Counties Utility Authority - AC Propulsion
  - Comverge, Inc. - University of Delaware
- MAGIC in first of three project phases
  - ✓ Phase I : Phase I: ~5 cars + one bus, V2G directly from PJM regulation signal
  - Phase II: Prove business model; ~300 cars, aggregator between PJM and cars
  - Phase III: Realize a self-sufficient V2G program within OEM vehicle manufacturers, aggregators, and ISO/RTOs.


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# FERC Demonstration

- FERC Demonstration October 24, 2007
- Chairman Kelliher, Commissioner's Wellinghoff (host), Kelly, Mohler
- Briefing by MAGIC, Tesla Motors, A123 Systems
- Used PJM’s real-time regulation signal

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# What is PJM's Role in V2G

- Technology Enabler
  - PJM is **Not** intending to control hundreds or thousands of individual cars!
  - PJM is involved to help customer prove the technology can work
- PJM is working with other customers with technology initiatives that have the potential to improve Grid Reliability and/or enable greater PJM Market Participation
  - Battery to Grid (B2G)
  - Fly Wheel to Grid
  - Landfill Gas
  - Solar Voltaic


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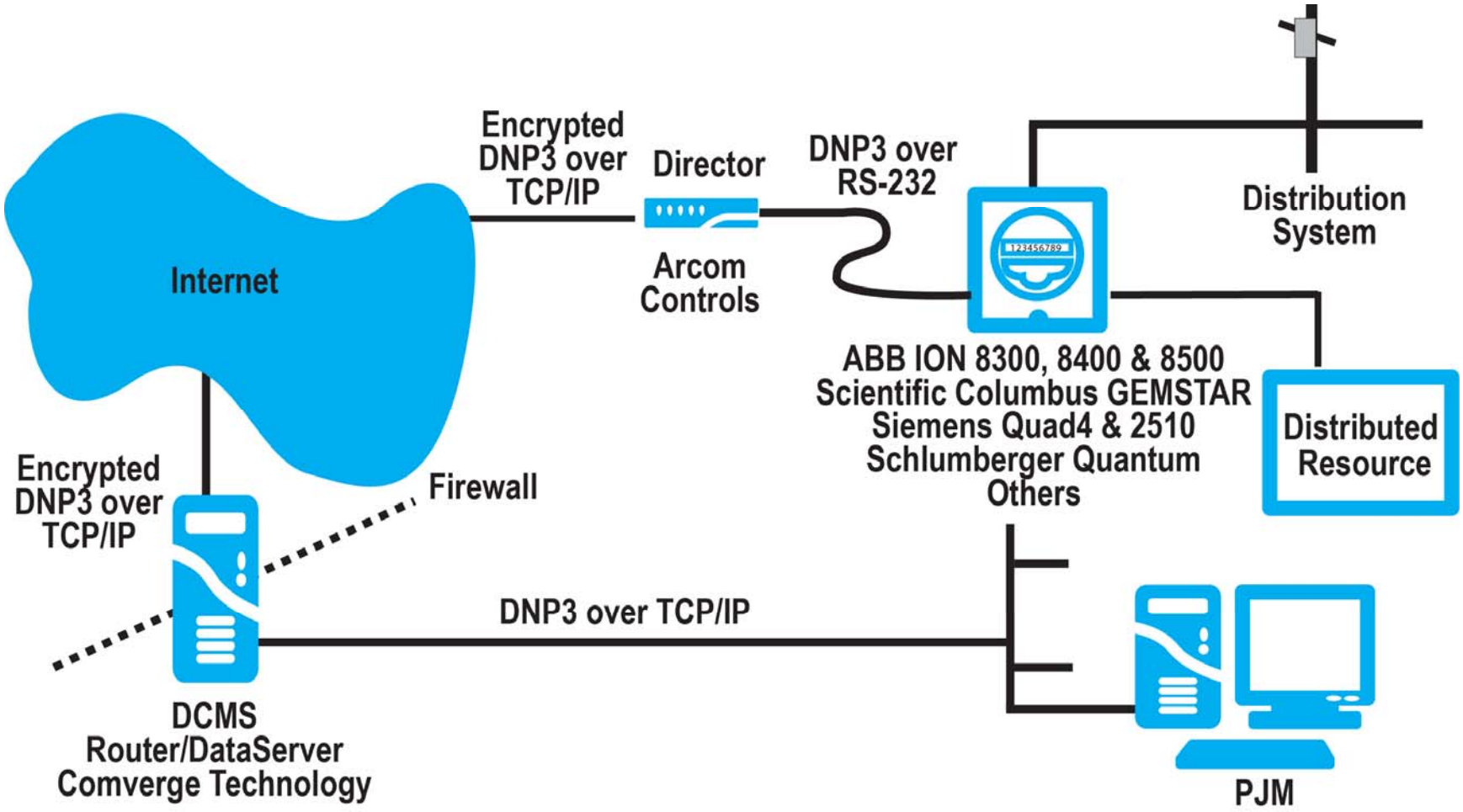
# PJM's Already Existing Internet Communications





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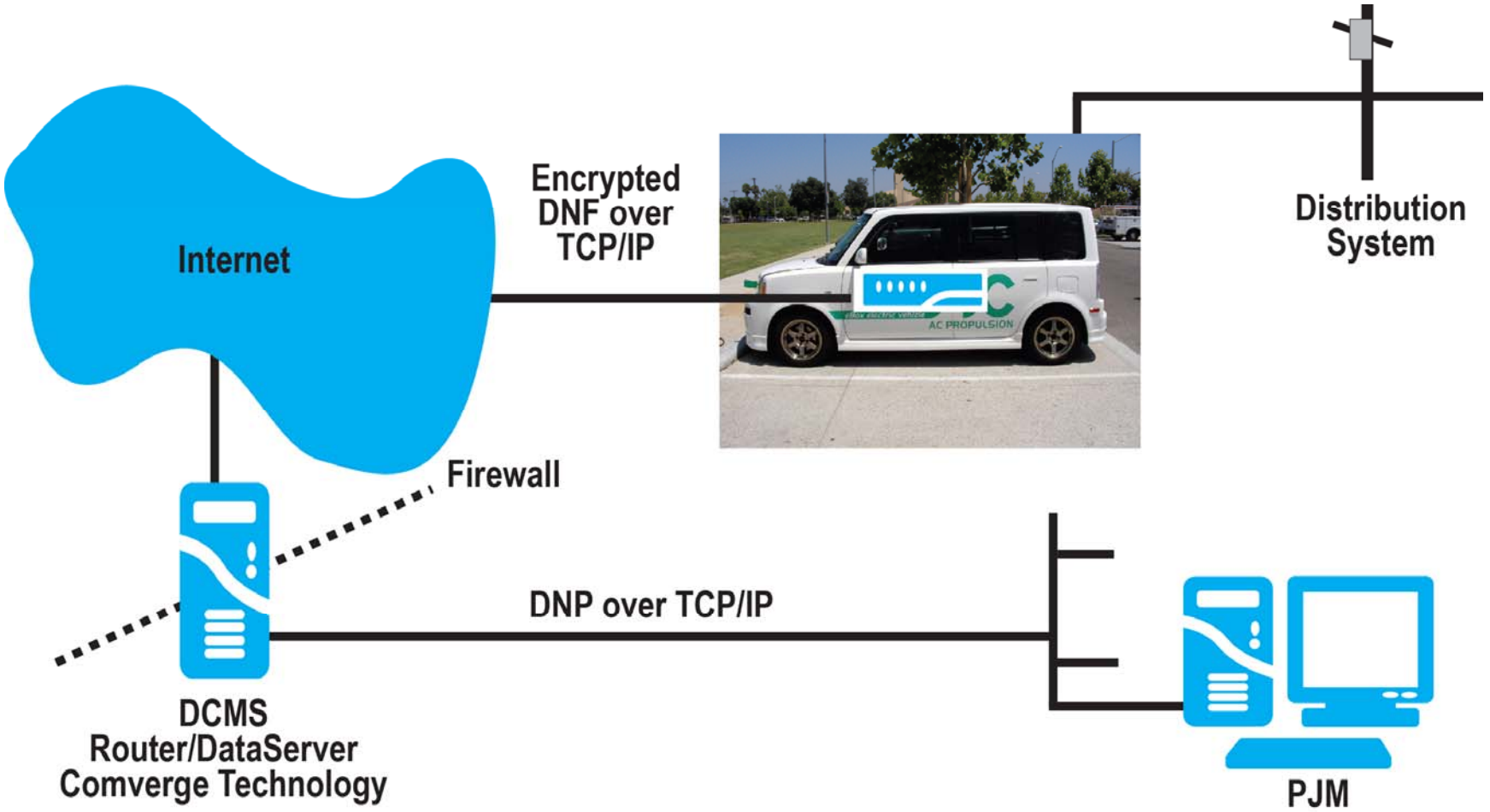
# Application of  Existing Internet Communications to V2G





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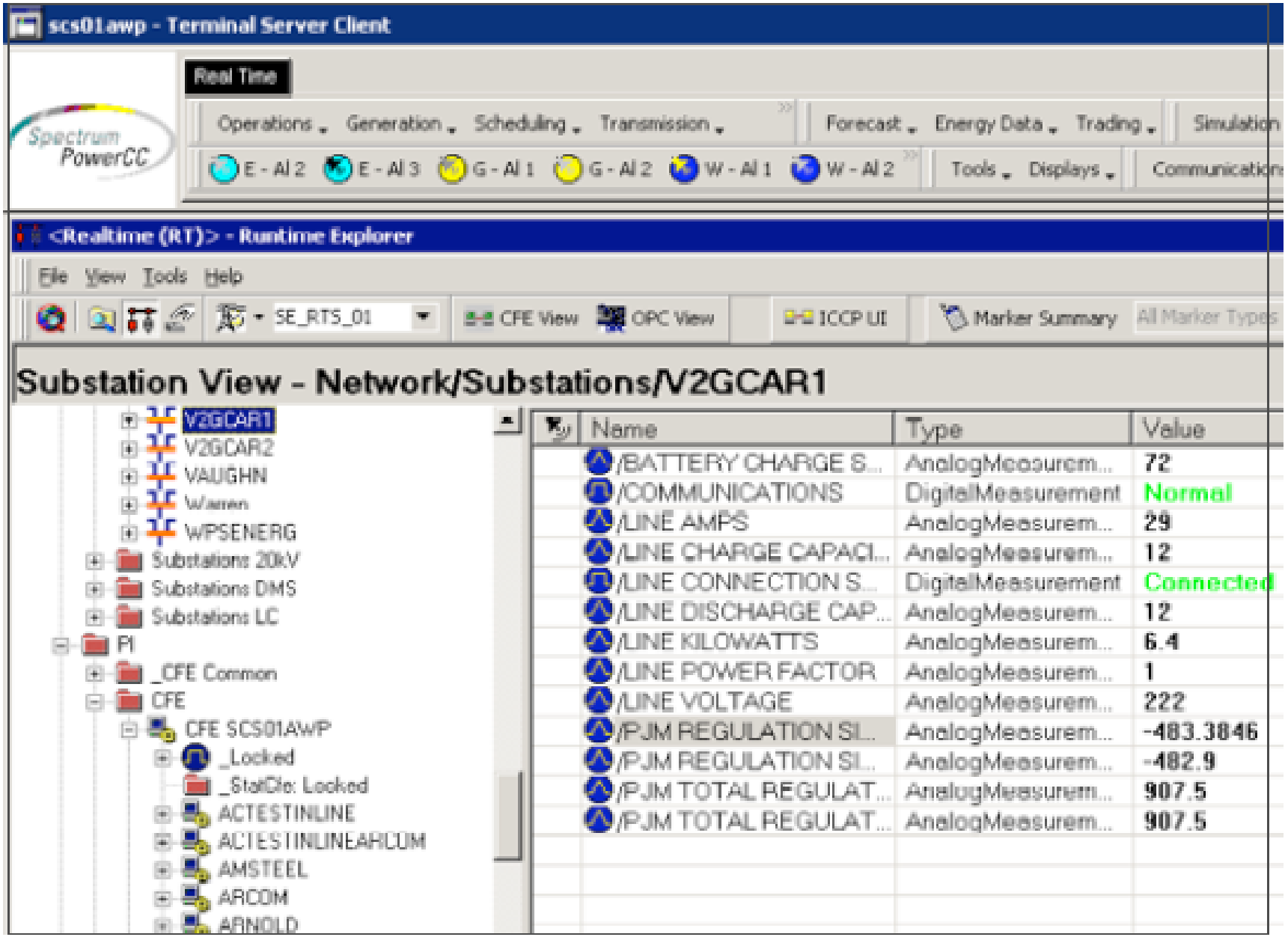
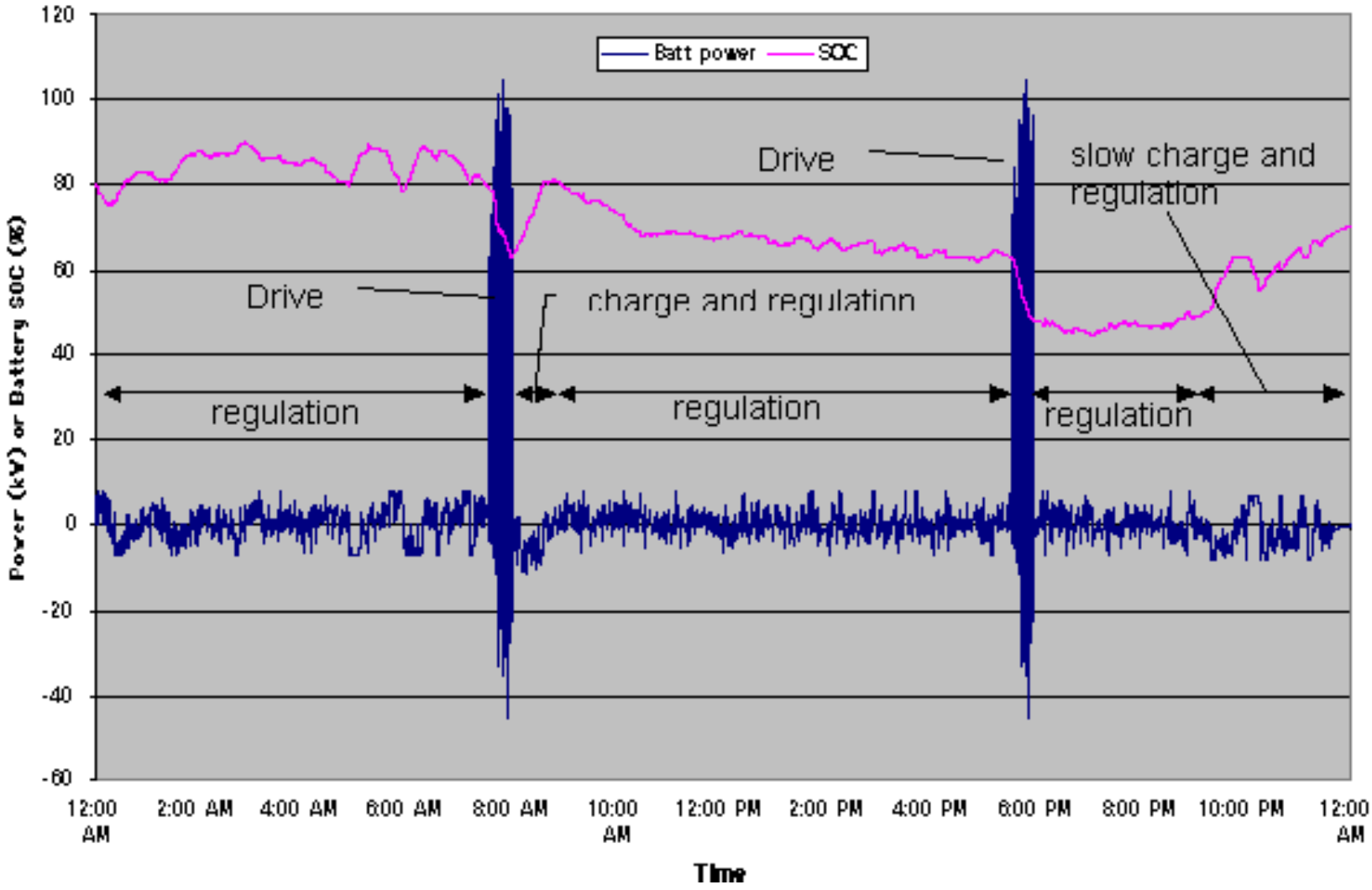
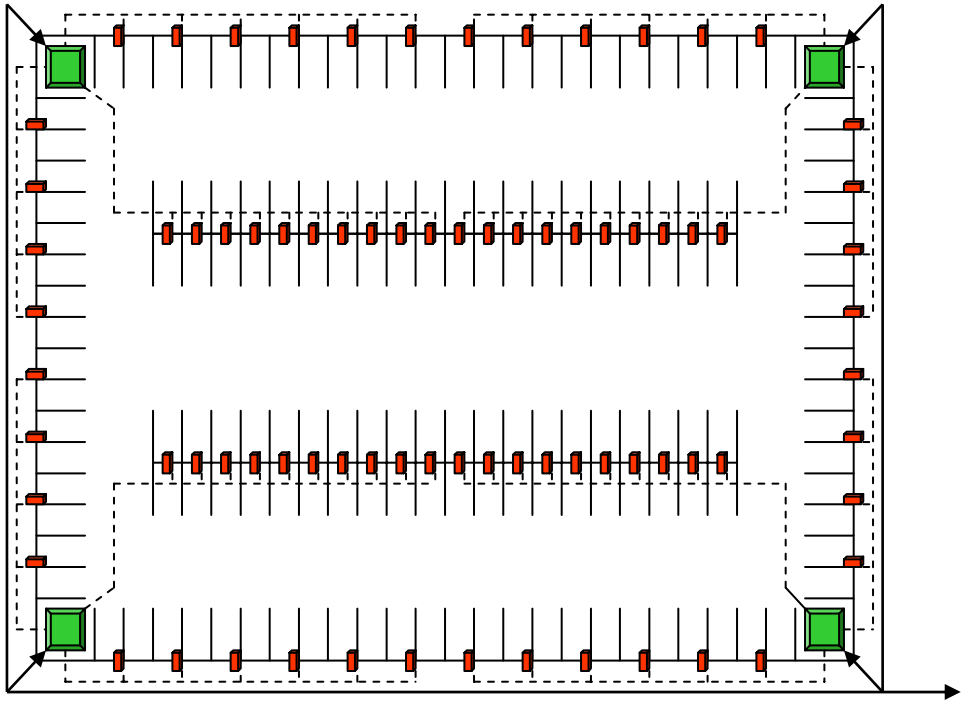
# 2-Way Communications



# A Day in the Life …



- 32A 230V 3ph service per park
- Allows 23kW peak
- One floor = 160 cars = 3.7 MW!
- Dedicated 1MVA padmount txfmrs
- Dedicated cabling

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# V2G Vision

- One-half vehicle fleet is electric drive (BEV + PHEV). National security & environment benefits.
- Lots of storage on the electric system, near loads. Electric system storage is dispatchable by ISO/TSO and/or load serving entity.
- Electric grid is more stable and reliable, Auxiliary Service is abundant and less expensive.
- Intermittent renewables can be a much higher fraction of the US generation mix.


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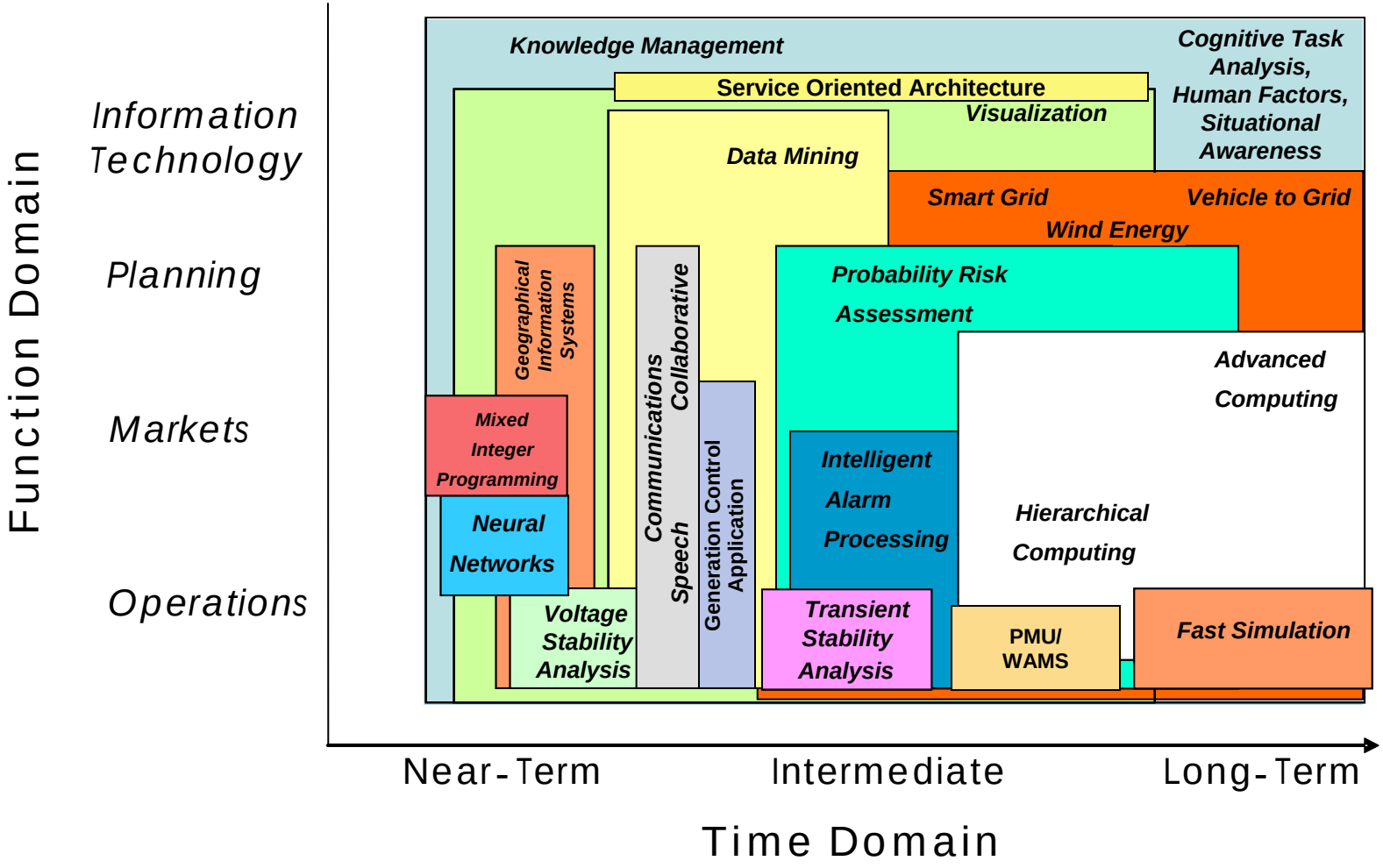
# Advanced Technology Initiatives




**Actively seeking university partnerships for research projects and graduate student engagements.**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