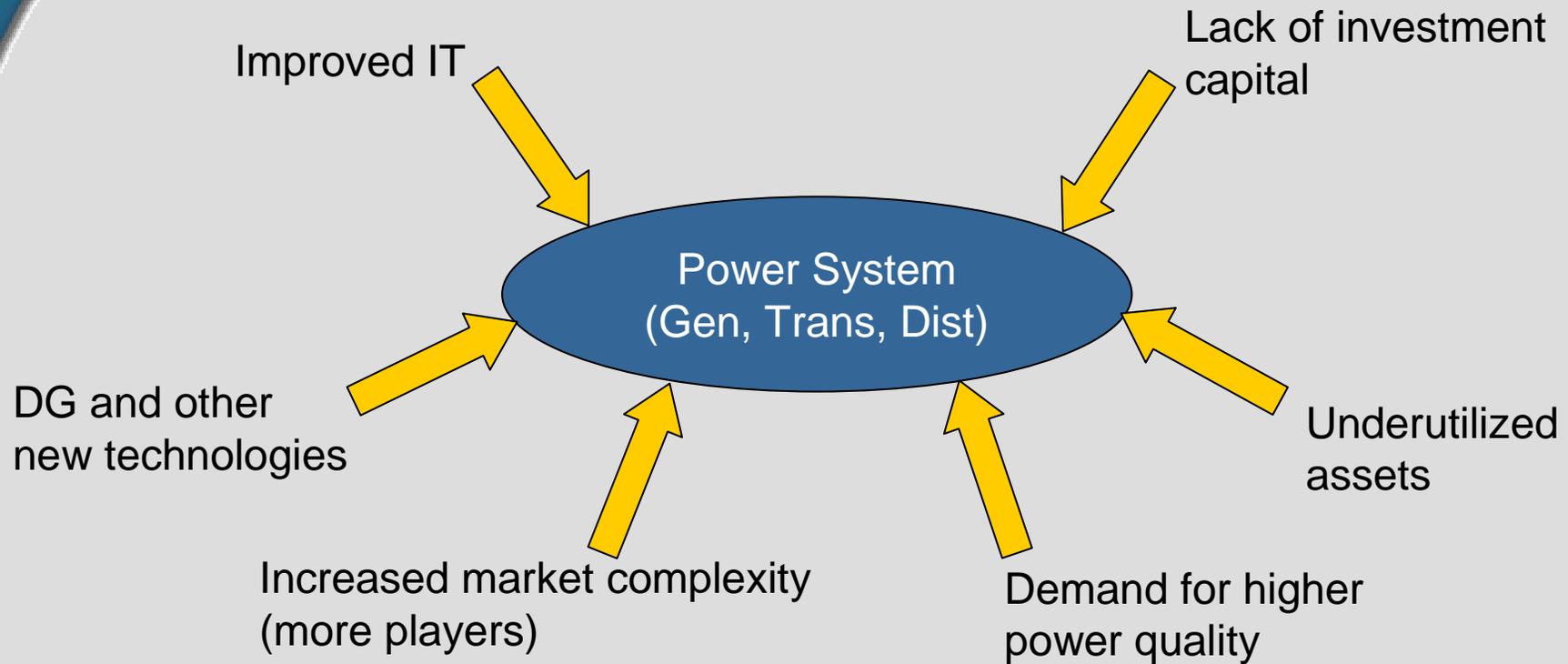


Electric Distribution Transformation Program Review FY04

Grid Friendly Appliance™ (GFA) Controller Development
Matt Donnelly, Paul Boyd, Ning Lu, Henry Huang
Pacific Northwest National Laboratory

October 28, 2003
Coronado CA

Relevance to Problems & Needs



- ▶ These forces point to need for greater flexibility/control in distribution and on the premises

Challenges

- ▶ Develop, prove and gain industry acceptance for managed loads to
 - Provide ancillary services such as feeder voltage support and spinning reserve;
 - Provide alternative to rolling blackouts;
 - Aid system restoration efforts through cold-load pickup techniques;
 - Participate in markets; and, more generally to
 - Empower the demand-side.

Project Objectives

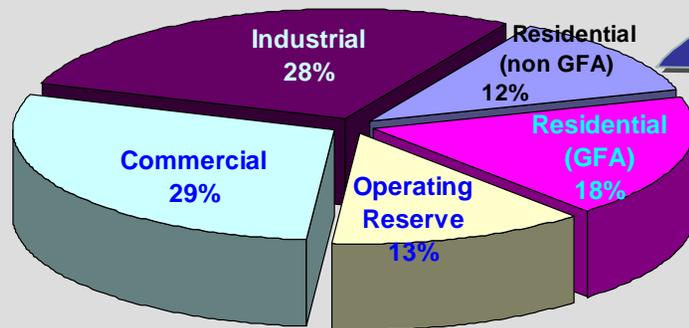
- ▶ Move the Grid Friendly™ concept to the marketplace
 - Document the magnitude of the resource
 - Demonstrate the efficacy of the concept
 - Develop the technology base
 - Begin with autonomous control
 - Move to coordinated control through advancements in IT
 - Promote the acceptance of the concept through government, industry and professional forums

Technical Approach

1. How much resource is available?
2. What kinds of control are possible?
3. Is it feasible?
4. Laboratory testing results
5. Market transformation

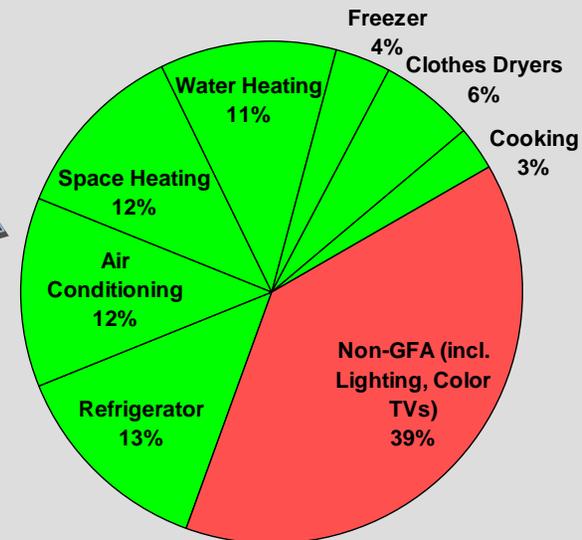
Magnitude of Resource

- ▶ 61% of residential load is GFA compatible
- ▶ Exceeds US operating reserve requirements!



Loads and Reserves on a Typical U.S. Peak Day

Expanding residential portion

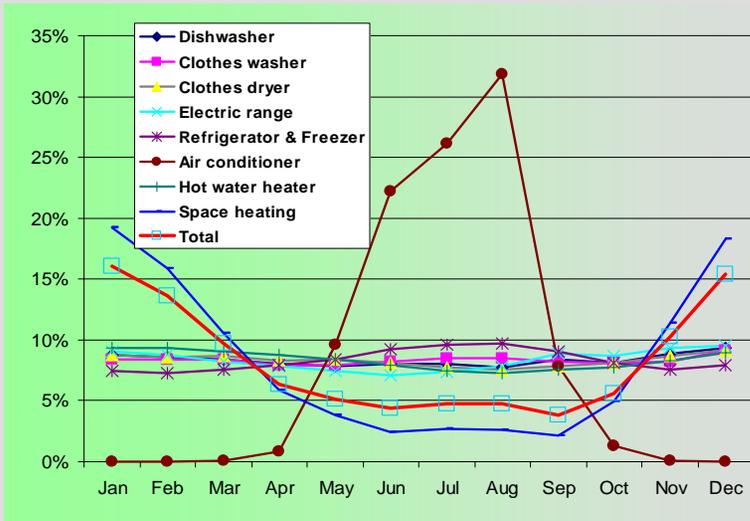


Residential Energy Consumption, 1997
Source: EIA (RECS)

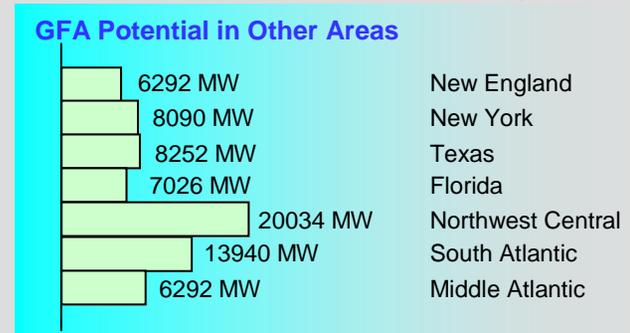
GFA Potential (per million homes)

Consider actual load shapes for all appliances.

| 1000000 Homes | % homes with unit | # homes with unit | Annual consumption per unit (kWh) | July consumption per unit (kWh) | Average Watts per unit (W) | Sheddable power (MW) |
|------------------|----------------------|----------------------|--------------------------------------|-------------------------------------|-------------------------------|-------------------------|
| | #1 | #2 | #3 | #4 | #5 | #6 |
| Sources | AHS 2002 | #1*1000000 | ELCAP 1992 | #3 & Load shapes from ELCAP 1992 | #4/31 days /24 hours | #2*#5 |
| Refrigerator | 98% | 977740 | 3044 | 293 | 394 | 385 |
| Air conditioner | 54% | 536600 | 1014 | 265 | 356 | 191 |
| Hot water heater | 40% | 398033 | 4707 | 350 | 470 | 187 |
| Space heating | 31% | 313785 | 27298 | 744 | 1000 | 314 |
| Other sheddables | 62% | 624479 | 1760 | 130 | 175 | 109 |
| Total | | | | | | 1186 MW |



| | |
|--------------------------------------|-----------------------|
| California Peak Demand July 2001 | (61125 MW) |
| California Peak Capacity July 2001 | (54370 MW) |
| California Homes 11.5m * (1185 MW) = | GFA (13627 MW) |
| | 49% |



Benefits/Applications

Transient Stability

- Local Generation
- Bulk Power Operations

Spinning reserve

- Milliseconds to tens of minutes bandwidth

Voltage Support

- Motor starting
- Line drop compensation

Remedial action

- Load shed, etc.

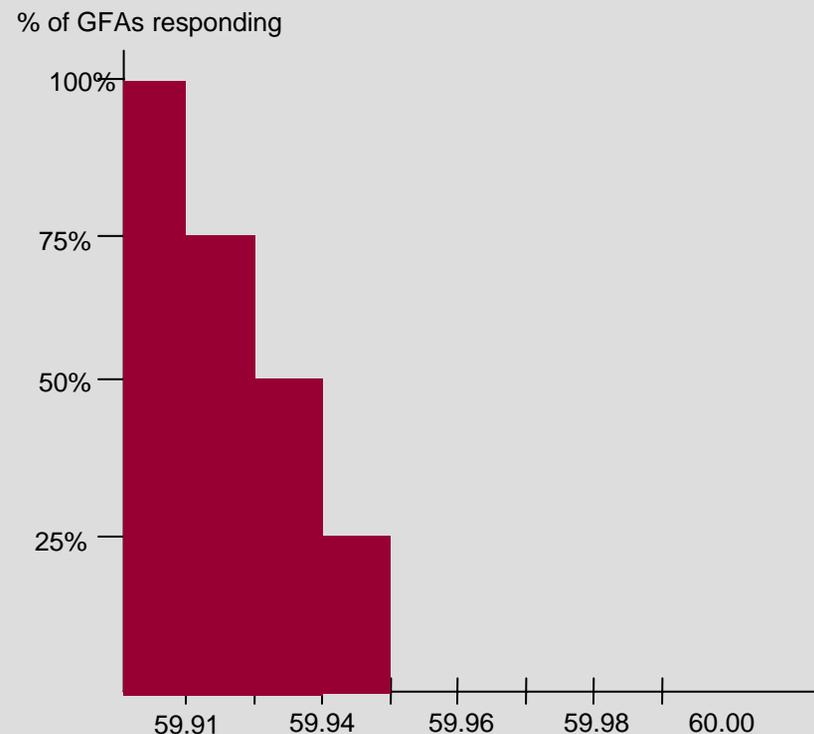
Power quality

- Sags and swells

Leads to true demand elasticity

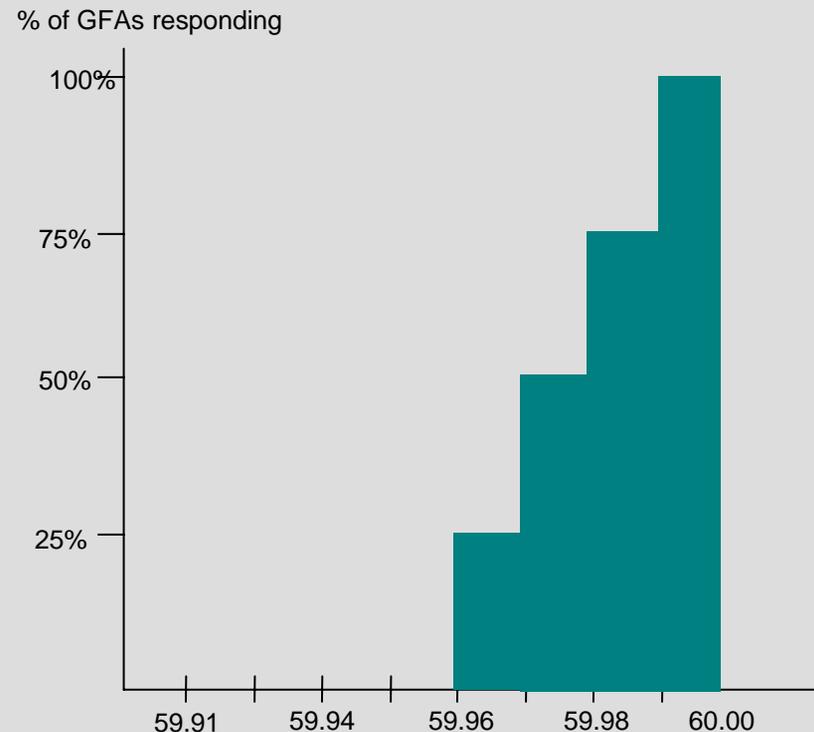
One Hypothetical Control Law

- ▶ A stair case probability distribution
 - GFA Shedding Process
 - GFA Recovering Process
- ▶ Response Time
 - Assume zero turn on/off time
 - Check frequency every 1 sec
- ▶ Response Rate
 - $P_c(t) * \text{prob}(f=f(t))$ MW/sec, where $P_c(t)$ is the available GFA capacity
- ▶ Dead band
 - 59.95 Hz – 59.96 Hz
 - Settling Frequency: 59.955 Hz

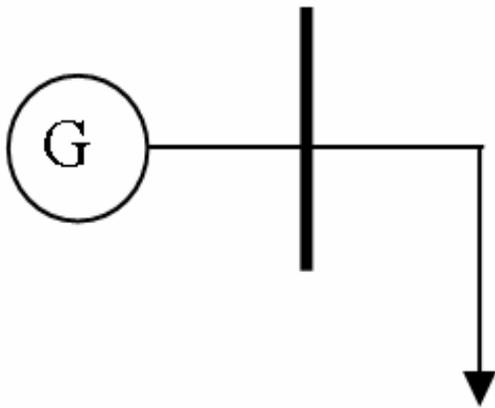


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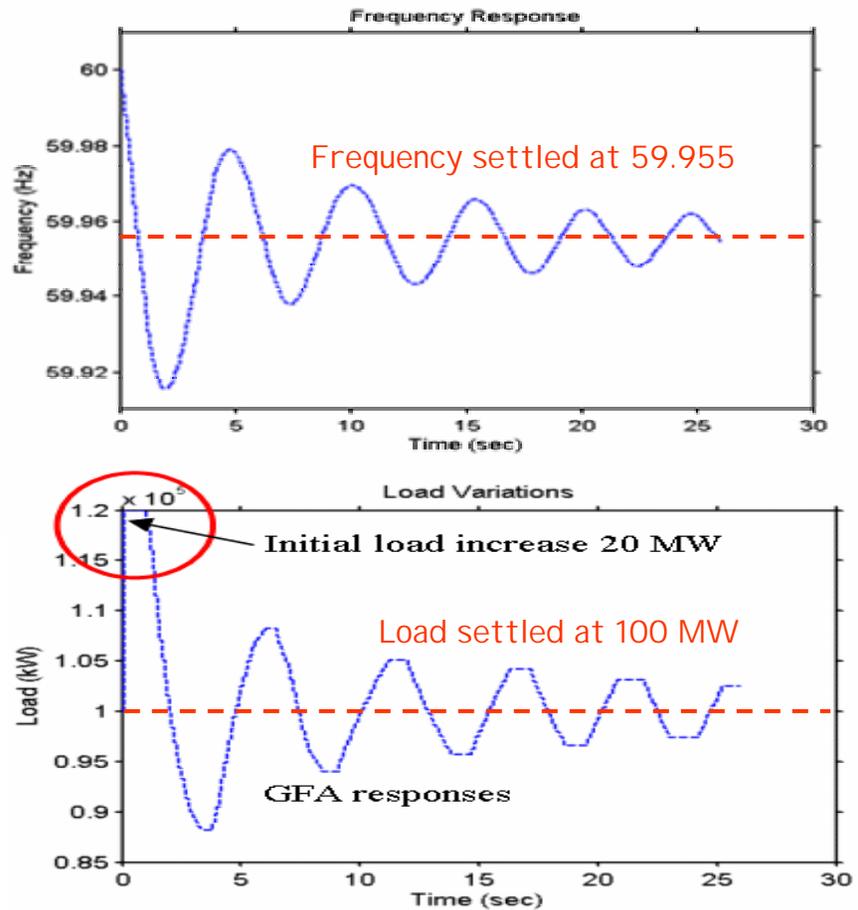
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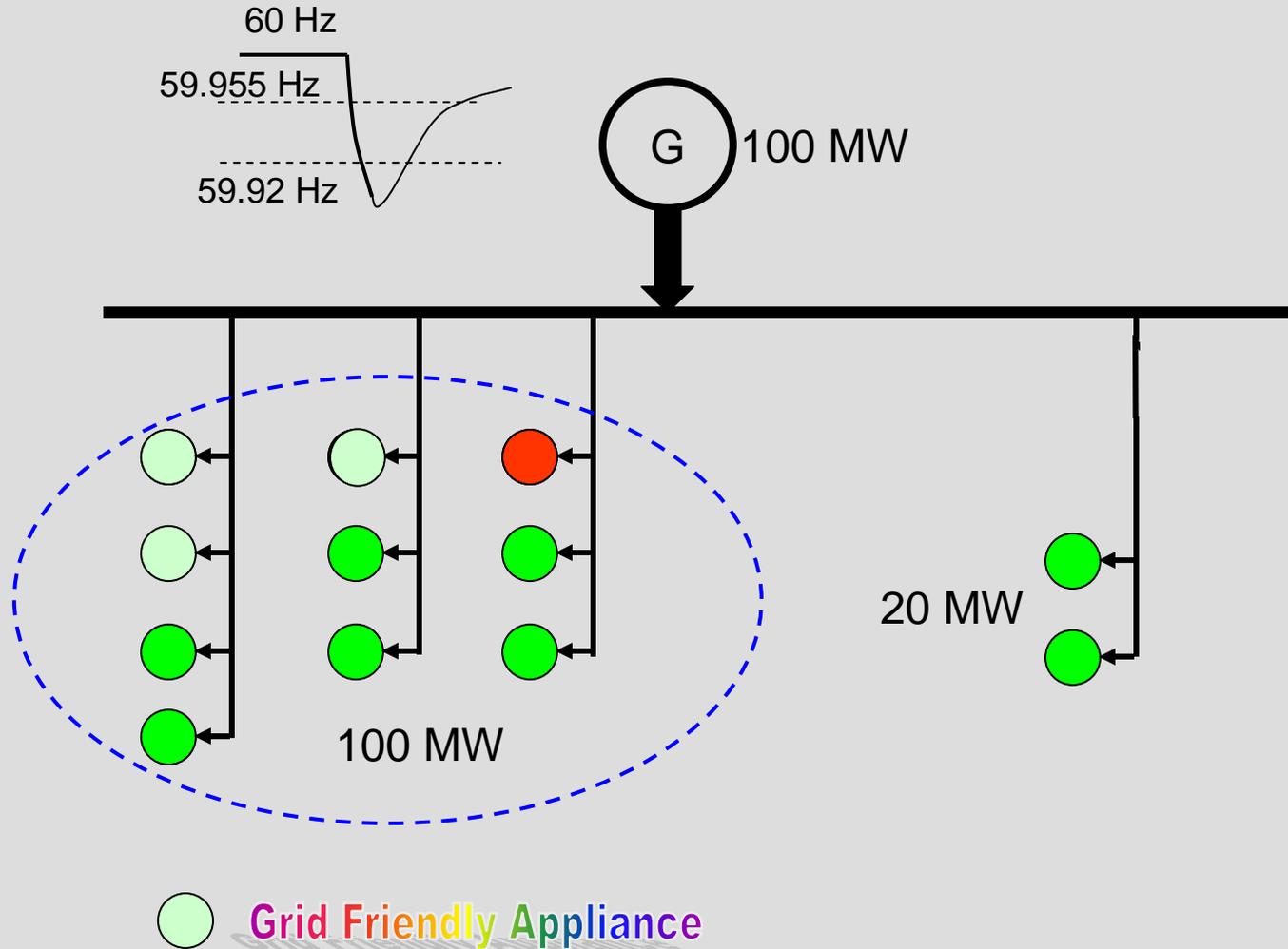
Hypothetical Control Law (cont.)



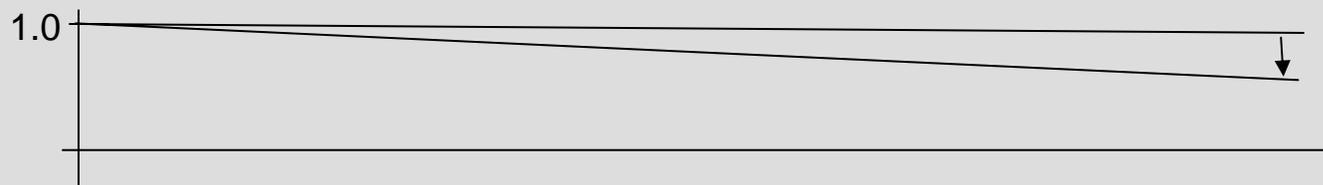
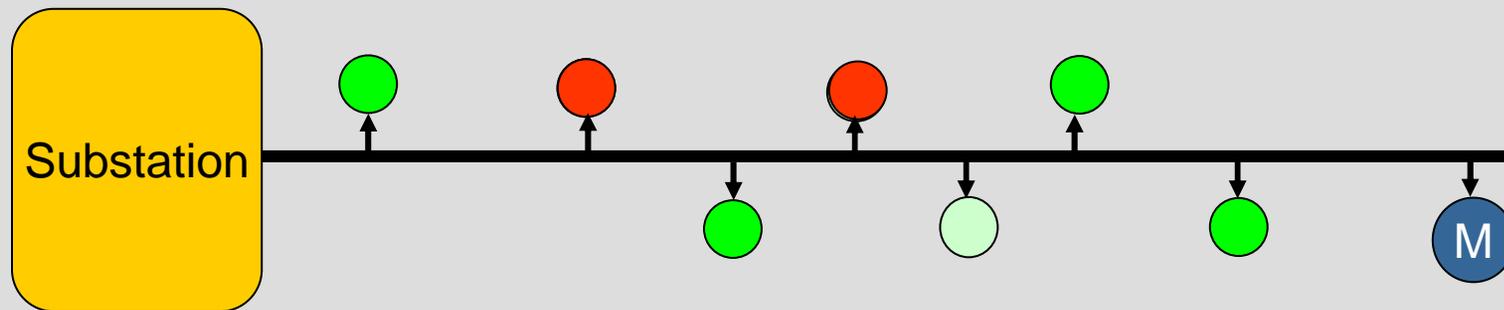
Initially, a generator is serving 100 MW load.
A sudden load increase of 20 MW drags the frequency down to GFA response range.



Example of GFA Frequency Response



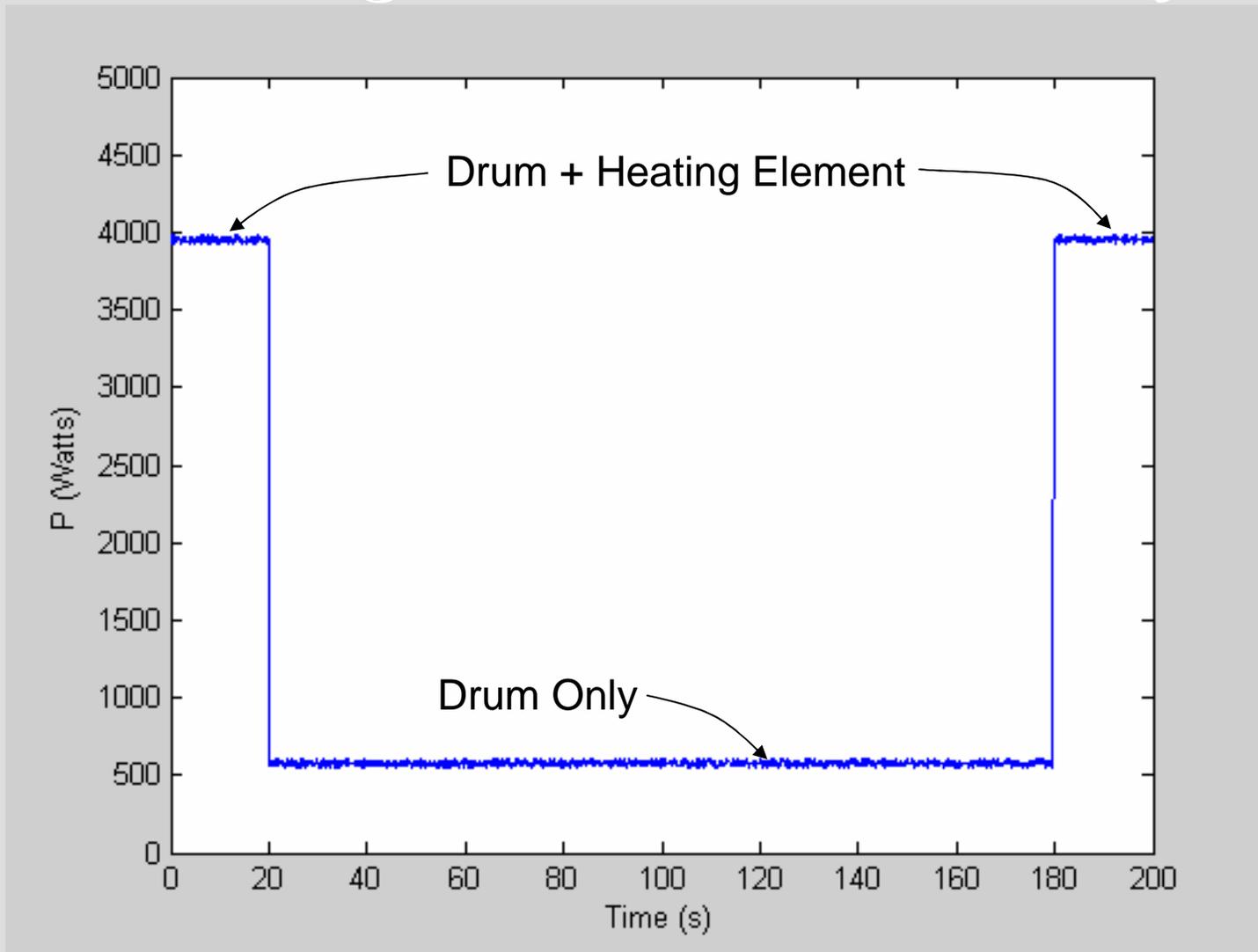
Example of GFA Voltage Response



Voltage Profile (per unit)

 Grid Friendly Appliance

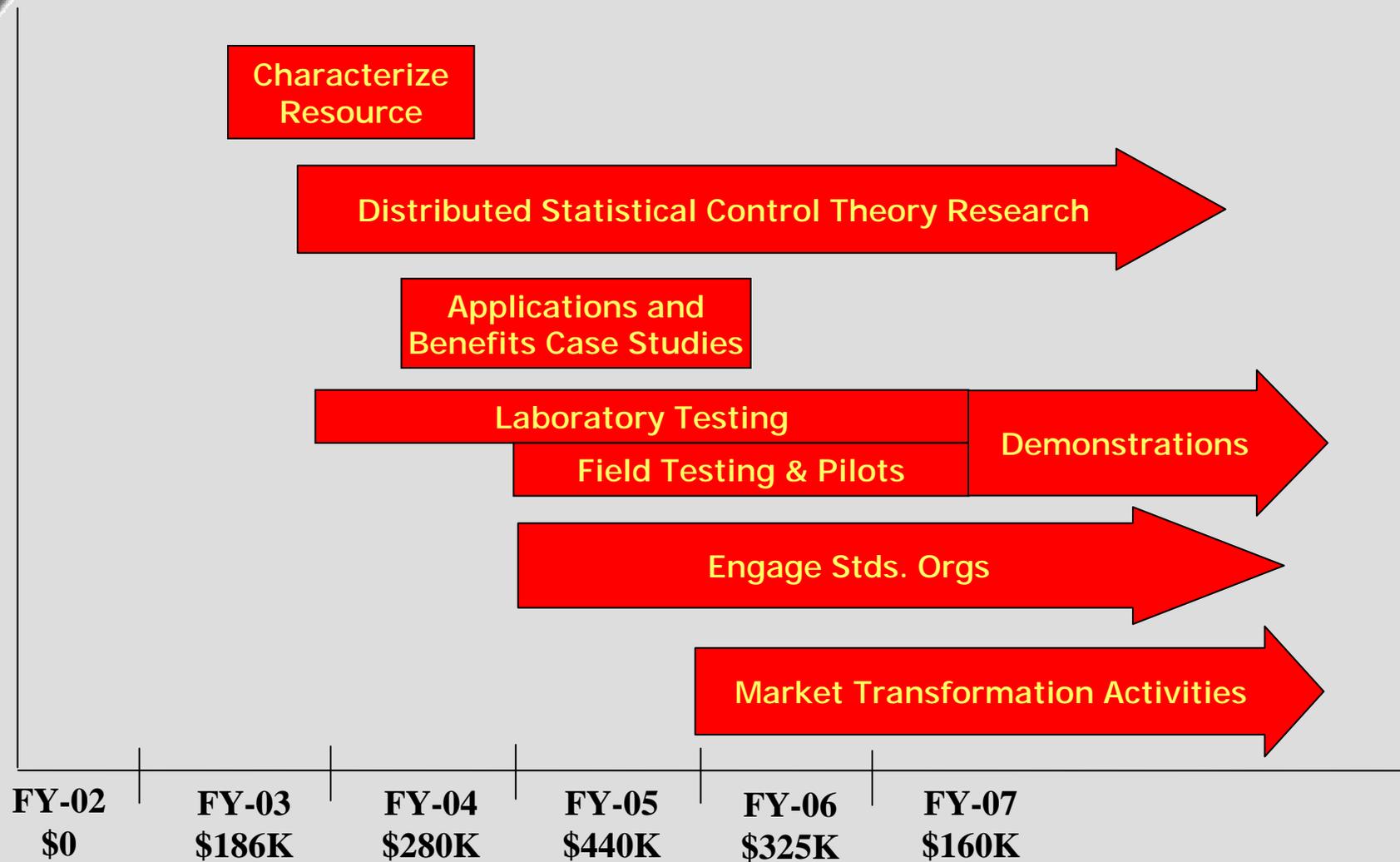
Testing Results – Clothes Dryer



Testing Results (cont.)

- ▶ For clothes dryer,
 - 88% reduction in load
 - ~2 ½ minute duration
 - no noticeable impact on user (clothes still tumbling)
- ▶ Other GFA-capable residential appliances
 - Water heater, dishwasher, heating, cooling,

Life-Cycle Project Timeline



FY03 Progress and Accomplishments

- ▶ Control law development from inertial model
- ▶ Lab testing of FPGA device
- ▶ Appliance modifications and testing
 - Clothes dryer
 - Water heater
- ▶ Limited to frequency algorithms

Planned Activities for FY04

- ▶ Frequency algorithm refinement
- ▶ Lab testing for frequency control
- ▶ Catalog expected benefits
- ▶ Professional society activities

Summary of Outyear Activities

- ▶ Voltage algorithm development/testing
- ▶ Control theory extensions
- ▶ Market transformation activities
- ▶ Professional society activities

Impacts and Benefits

- ▶ Two impediments to efficient power markets:
 - Lack of demand elasticity
 - Inability to enforce bilateral contracts

- ▶ GFAs are deployable now and may serve to pave the way to true demand elasticity

- ▶ Immediate impacts are:
 - Deferral of feeder upgrades
 - Improve reliability
 - Lower cost of production

Interactions & Collaborations

- ▶ Appliance manufacturers
- ▶ Electrical equipment/device manufacturers
- ▶ Utilities and system operators

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