Smart Metering:
IT and Power Sector Distribution –
A Techno-economic Analysis
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Talk Outline

- Metering and Control – Technologies and capabilities
- Other countries (Italy)
- India – Leapfrogging opportunity?
  - Techno-economic analysis
- Issues and Challenges
# US Industry Evolution

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Options Define Service</td>
<td>Option Consolidation</td>
<td>Separate Options</td>
<td>Integrated Options</td>
</tr>
<tr>
<td>1800s to Early 1900s</td>
<td>1920s to 1960s</td>
<td>1970s to 2000</td>
<td>After 2000</td>
</tr>
<tr>
<td>Pricing</td>
<td>Pricing End-Use Rates</td>
<td>Pricing TOU Rates</td>
<td>Pricing Real Time Pricing</td>
</tr>
<tr>
<td>Metering</td>
<td>None</td>
<td>Time Period Loads</td>
<td>Hourly Loads</td>
</tr>
<tr>
<td>Load Shape Objectives</td>
<td>Load Growth</td>
<td>Load Growth, Valley Filling</td>
<td>Preserve Electric Reliability, Customer Cost Management</td>
</tr>
<tr>
<td>Customer Involvement</td>
<td>Active, Fuel Switching</td>
<td>Passive, few options</td>
<td>Interactive Participation</td>
</tr>
<tr>
<td>Demand Response</td>
<td>Contracts for Service</td>
<td>Utility Command and Control</td>
<td>Demand Bidding, Risk Management</td>
</tr>
<tr>
<td></td>
<td>Water Heater Time Clocks</td>
<td>Curtailable, Interruptible, Direct Control</td>
<td></td>
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</table>

- **Increased choice**
- **Reduced choice**
- **Reduced choice**
- **Increasing choice**

- **Service tailored to customer needs**
- **Increasing value to customers**
- **Increasing costs**
- **Cost Volatility**

- **Declining cost**
- **Loss of control**
- **Declining value to customers**
- **Value of Information**

**Source:** *New Principles for Demand Response Planning*. Palo Alto, EPRI: 1006015
Metering Design – Function of Capabilities

- Parameters to be measured
  - kWh, peak kW, power factor, etc.
- Frequency of measurement
  - 15 minutes, 1 hour, daily, monthly, etc.
- Frequency of “uplinking”
- Sending signals downstream
  - Pricing, connect/disconnect, emergency, other
- Other capabilities
  - Demand Response/Demand Side Management
  - Home monitoring
  - Broadband
  - etc.

*Today’s focus is on IT and distribution – covers metering, Demand Response (DR), and power distribution system*
# Technologies vs. Capabilities

<table>
<thead>
<tr>
<th>Past</th>
<th>Current Efforts</th>
<th>Possible Future</th>
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</thead>
<tbody>
<tr>
<td>Past</td>
<td>Current Efforts</td>
<td>Possible Future</td>
</tr>
<tr>
<td>Electro-mechanical Meter</td>
<td>Digital (solid state)</td>
<td>Next Gen. Meter and integrated IT system (proposed)</td>
</tr>
<tr>
<td>low (has threshold issues for low usage)</td>
<td>high</td>
<td>Arbitrarily high</td>
</tr>
<tr>
<td>poor</td>
<td>Node only</td>
<td>High (network level)</td>
</tr>
<tr>
<td>expensive add-on</td>
<td>External; AMR potential</td>
<td>Built-in (on-chip)*</td>
</tr>
<tr>
<td>nil</td>
<td>Limited</td>
<td>Full (connect / disconnect); Extending signaling to appliances</td>
</tr>
<tr>
<td>Historical usage reads only</td>
<td>Real-Time control; DSM</td>
<td></td>
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</table>

*Can do much more than Automated Meter Reading (AMR) |

US AMR/Smart Metering

- Automated Meter Reading (AMR) penetration by 2002 (all capabilities/technologies):
  - 16.9% penetration by meter (Scott Report)
  - ~1/3 of utilities have some level of AMR in place
    - Public Utilities are the real laggards
  - More use of wireless than other countries

- Many Smart IT pilots/deployments in the US focused on Real Time Pricing or Demand Response
  - California
    - E.g., RTEM: 25,000 advanced meters installed – 9/01-6/02 - SCE
      - TOU pricing (with web access)
      - Consumers typically
        - Reduced peak loads
        - Reduced overall loads
        - Reduced Costs
Some countries are already implementing such systems.
Real Prospects for Smart IT System

- ENEL (Italy) offers glimpse of possibilities
  - All users (~30 million) to be converted by 2005-06
    - ~20 million converted today; 700,000+/month
  - ~80-100$ total (avg.) cost per node, installed
    - Includes back-end
    - Total 2.4 billion Euros
  - ~4 Year payback just from operational savings
  - 2-way communications and control capabilities

- Developing Countries: hard to make apples to apples comparison
  - Utilities lack “standard” equipment required in conjunction with IT solutions
    - ARCs, Variable Transformers, etc.
### Enel System

- **Technology**
  - Hybrid wireless (GSM) and PowerLine Carrier (PLC)
  - Store and Forward architecture (not fully real time)
    - Function of when the technology decisions were made?
- **Blanket deployment – lowers costs**
  - Assumed existing meters were a sunk cost
- **Other driver(s) than typical CBA**
  - Changing load ratings (3.3 kW, 6 kW, or 9 kW) for consumers previously required truck roll
  - Deregulation by 2007
  - ~3% bad collection
- **Partnering with IBM for modifications and reselling worldwide**
The Indian Power Sector Today – Salient Features

- 112 GW capacity –
  - Per capita consumption only ~350 kWh
- Growth of 10% annually required
  - Industrial/commercial demand
  - Over ½ of rural homes not yet electrified
- Loss-making state-owned utilities (billions of $ losses)
  - High “T&D” losses
    - Theft estimated ~10-15%
  - Undergoing reforms to improve performance
    - Newest Elec. Act 2003 might give exit strategies for captive generation

Not Enough Paying Consumers: Mismatch in Consumption & Tariffs (2001-02)

Consumption ≈ 315 Billion kWh

Prices
239.9 ps/kWh (Average) ≈ 5.00 ¢/kWh

Source: Planning Commission

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The Bottom Line

- “Cost of supply” is Rs. 3.50/kWh, realization only Rs. 2.40/kWh
  - Much of the electricity is sold below cost (and some well above cost)
  - Much of it is unaccounted for
    - High T&D losses (~30%)
      - Technical – 10-15% (?)
      - “Commercial” = Theft – 15-18%

- Utilities are bleeding money
  - Returns calculated as –30 to –40% (on Net Assets)
  - Losses (excluding $1.5 B subsidy) are approximately $4 billion
IT and Power Sector in India

- IT already used* in transmission and generation (SCADA systems)
- This presentation: Distribution sector
  - Massive reforms underway
    - Technical upgrades for a lossy system
    - Metering
    - ~4+ Billion US$ earmarked annually for this (plus non-govt. funds)
Goals and Hype for IT

- Public pronouncements: IT the “silver bullet”
  - End theft
  - Improve finances, etc.
- Reality: IT can’t erase fundamentals
  - Tariff Irrationality and System Design
  - Physics of losses – quite high
    - But, IT can improve operations significantly
      - Variable Transformers, VAR compensators, etc.
IT and India’s Power Sector

  - Good introduction but incomplete vision
  - Recommendations
    - 2 “quick win” pilot projects
      - Integrated billing system for Commercial & Industrial consumers
      - Energy accounting system – mainly for MV distribution
    - “Advanced technologies” mainly looked at tamper-proof
      Automated Meter Reading (AMR)
      - Solutions seem expensive, and limited in potential

- Can we consider a new paradigm?
  - Don’t simply extrapolate
  - Leapfrogging Opportunity
Grand Vision for IT
(Way beyond AMR)

- Be able to…
  - Micromonitor and control every kWh
  - Provide improved power quality
  - Remote connect/disconnect
  - Manage loads and offer new services
  - And, of course, reduce theft

- While allowing…
  - Improved utility operations
  - Next Generation DSM
Smart IT: Techno-Economic Model

- Target specific users
  - All agricultural (almost one-third of the load)
  - All Industrial and larger commercial users
  - Only the larger-size domestic users
    - Estimated 2/3 of homes only use <50 kWh per month
- Include network nodes that need monitoring and/or control
  - Substations
  - Transformers
  - Capacitor banks (as applicable)
  - Relays (as applicable)
  - etc.
  - Excludes capital for utility equipment like transformers
- New system designs and services are not factored in
  - Pre-paid metering
  - Future interaction with smart appliances, smart home networks, etc.
  - Distributed generation
Economics of Smart IT System – (Utility Name Withheld)

- Estimated System
  - 96 Consumers (all classes) per Distr. Transformer
  - 163 Distribution Transformers per Sub-Station
  (Averages only)

- ~5% of India in population;~ 6% in power consumption
  (2001 estimates)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Number</th>
<th>Equipment cost ($)</th>
</tr>
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<tbody>
<tr>
<td>LT - Dom. (Applicable 20%)</td>
<td>1,654,000</td>
<td>70</td>
</tr>
<tr>
<td>LT - Comm.</td>
<td>988,000</td>
<td>70</td>
</tr>
<tr>
<td>LT - Agri</td>
<td>1,396,000</td>
<td>80</td>
</tr>
<tr>
<td>Industry - LT</td>
<td>231,000</td>
<td>80</td>
</tr>
<tr>
<td>HT (all)</td>
<td>5,089</td>
<td>100</td>
</tr>
<tr>
<td>Other (utility nodes)</td>
<td>100,000</td>
<td>200</td>
</tr>
<tr>
<td>DTRs</td>
<td>130,000</td>
<td>600</td>
</tr>
<tr>
<td>Substations</td>
<td>800</td>
<td>7,000</td>
</tr>
</tbody>
</table>

Other IT and infrastructure (capitalized) 20,000,000

419,208,900

Needed Savings 14.9% <-annualized rate

65,388,885 US$ to justify the investment

22,625,000,000 kWh sold annually

0.08 Avg. cost/kWh 3.60

1,810,000,000 gross costs (not revenue as collection/tariffs are low)

13.01 Paise/kWh GROSS cost of system

3.61% need improvements worth
# System-wide implications – Smart IT

<table>
<thead>
<tr>
<th></th>
<th>Ultimate Potential</th>
<th>Plausible</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td><strong>Savings</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theft Reduction</td>
<td>35</td>
<td>8.8</td>
<td>1/3 of thieving load on system</td>
</tr>
<tr>
<td>Freeing up capacity</td>
<td>18.1</td>
<td>9.1</td>
<td>Limited Peak shifting (short term) -- 3%</td>
</tr>
<tr>
<td>Avoiding shortfalls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of catastrophic failures</td>
<td>0.4</td>
<td>0.4</td>
<td>1 major failure in 15 years avoided</td>
</tr>
<tr>
<td>Improved GDP impact</td>
<td>3.3</td>
<td>1.4</td>
<td>conservative est. pro-rata</td>
</tr>
<tr>
<td>Operational Improvements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRM benefits</td>
<td>0</td>
<td>0</td>
<td>Assume really cheap labor in India</td>
</tr>
<tr>
<td>Load Planning</td>
<td>6.3</td>
<td>3.1</td>
<td>Better supply portfolio (existing only) - excl. “peak” pricing</td>
</tr>
<tr>
<td>Technical losses and failures</td>
<td>0.108</td>
<td>0.1</td>
<td>3% operational potential</td>
</tr>
<tr>
<td>DTR failure reduction</td>
<td>1.5</td>
<td>0.8</td>
<td>~10-15% failure rate today!</td>
</tr>
<tr>
<td>Consumer benefits</td>
<td>1.2</td>
<td>0.6</td>
<td>Lower DTR failures and downtime, equipment</td>
</tr>
<tr>
<td>Improved power quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural alone</td>
<td>25</td>
<td>8.3</td>
<td>1/3 of potential is realized</td>
</tr>
<tr>
<td>Industrial</td>
<td>2.4</td>
<td>1.2</td>
<td>Based on capital stock and one-time 1% incr. equip.lifespan</td>
</tr>
<tr>
<td><strong>TOTAL Benefits (paise/kWh)</strong></td>
<td>93.3</td>
<td>33.7</td>
<td></td>
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</tbody>
</table>

Reasonably conservative assumptions
-- Cost per node assumed several % higher than ENEL’s project (which was blanket deployment)
-- Only includes benefits where IT could play a role even within “Ultimate Potential”
– Excludes trickle down/multiplier effects or +ve externalities like higher industrial growth

100 paise = 1 Rupee (Rs.)
1 US$ = ~ 45 Rs. (2004)
US Industry Experience

Own-Price Elasticities
California SPP vs. Nationwide Historical Results

Source: Predicting California Demand Response, Chris King and Sanjoy Chatterjee, Public Utilities Fortnightly, July 1, 2003.
Implementation of Smart IT in India: General Barriers

- Financing
  - Funding likely available (internal + external)
- Lack of technology/R&D savvy
  - Tenders for equipment lead to poor outcomes
- Real-time pricing
  - How much to propagate this through?
Implementation of Smart IT: Organizational Barriers

- “Inertia” of some utility ground-staff
  - Reduces their extra income (theft connivance) or local standing
- Bad decisions carry some irreversibility
  - E.g., reintroducing meters for the 12 million+ pumpsets is very hard
  - Half-way measures for Digital Metering ($100s of millions at a state level)
Today’s Inertia: (Simply) Digital Metering Solutions

- Simply move to Digital Metering, down to DTR level
  - Driven by “mandate” for “universal” metering
  - Mainly for historical (accounting) purposes
    - ToD usage recorded but read infrequently
  - Using “standard communications” won’t work or scale
    - Modems can not offer (near) real-time control
    - 5 min. intervals: > 100,000 reads annually

- Cost-Benefits of simply Digital Metering
  - Expensive meters yet limited capabilities
    - $20+ for low end up to ~ $200 for 3 phase at 11 kV level
  - Still costs about 1/3, and no metering for agriculture
  - Only benefits: some theft reduction, marginal operational improvements
  - Estimated costs ≈ benefits if lucky

*Incremental* costs for a Smart IT can be v. low (< ~$5–15/node)
Implementation of Smart IT: Agricultural Barriers

- Incorporating agricultural users
  - They (violently) resist Metering
  - Without Agriculture
    - Lose perhaps 2/3 of anti-theft benefits, much of the shiftable load
      - But residential/commercial peaks remain

- Consider: Smart System BUT Dumb Agriculture
  - Similar to Smart System but sans agriculture
  - Costs are ~ 50 – 70% of Smart IT (depending on depth into rural areas)
  - Benefits 2-3 times that of simply digital metering
    - Still covers
      - Industrial/commercial users
        - Paying 2/3+ of revenues
      - Residential+Commercial Consumers – responsible for the peak
  - Allows migration to full Smart IT solution including agriculture
Implementation Strategies and Research

- Political Needs
  - State by State
  - National Standards
  - Interaction with Private utilities

- Technical Needs
  - Scalable, modular design
  - Open, scalable standards
    - Prevent technology/design lock-in
    - Increase competition
  - Bringing down costs
  - Demonstration

*Prove system design and convince stakeholders*
Role of Standards: US Refrigerator Standards

Source: www.standardsasap.org
Opportunity and Need

- Help move the Indian power sector towards **viability** and **sustainability**
  - Leapfrogging
  - Prevent lock-in/lock-out
- Spur structural and operational shifts
  - Enforce against human failings
- Indian IT capabilities available to be harnessed
  - Global opportunity potentially
- Some willing utilities
  - Testbed for new ideas
- Research on technology in the context of political economy
General Issues

General Questions
- Technical Viability – does it work?
  - Function of capabilities and budget
- Financial Viability – does it save money?
  - Who gets the benefits? Externalities?
- Political Viability – can this be implemented and integrated?
  - Regulators – what innovative/pass-through pricing will they allow?
    - Complexity (critical peak, day before, etc.)
    - Sending the right signals
Design Issues

- Questions of Design
  - Time frames for implementing – waiting for “right” technologies
  - Directionality of information flow
    - Interim for DR: why not use digital radio for announcing “peaks”?  
  - Is the WAN the bottleneck? Use of complementary infrastructure (e.g., broadband)
  - Real Time Pricing plans
  - Modularity and scalability for implementation and realizing benefits

- Demand Response and DSM
  - Short Term vs. Long Term abilities to shift loads
    - Human Intervention vs. passive
  - New technologies for the home (e.g., smart refrigerators)
  - Standardization and new standards
    - 802.15.4 (“Zigbee”) – changes the consumer side?