Smarter Energy:
Challenges and Opportunities in Realizing the Potential of Cyber-Physical Systems
Acknowledgements

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Why Smart Energy?
# Why Smarter Energy?

**#1 Power Cuts:** demand > capacity & price inflexibility => financial losses + power cuts. Need “de-peaking”

**#2: Rural Electrification:** Micro-grids to complement traditional grid

**#3: Large-scale grid blackouts:** wide-area situation awareness & real-time contingency analysis

**#4 Non-technical Losses (a.k.a. Theft):** reliable localization to aid enforcement

**#5 Diversifying Supply:** High-Yield Renewable Farms
Climate Change: GHG Emissions linked to fossil-fuel energy

Figure 1.9. Breakdown of world greenhouse-gas emissions (2000) by cause and by gas. “Energy” includes power stations, industrial processes, transport, fossil fuel processing, and energy-use in buildings. “Land use, biomass burning” means changes in land use, deforestation, and the burning of un-renewed biomass such as peat. “Waste” includes waste disposal and treatment. The sizes indicate the 100-year global warming potential of each source. Source: Emission Database for Global Atmospheric Research.

Note: Energy *by itself* is **not** the problem: *(Demand management and Renewable Supply are part of the long-term solutions)*
Smarter Energy & Smart Grid

- A Smart Grid manages demand/supply of high-quality electrical energy to users with low impact on the environment.

- Methods:
  - Energy Conservation & Management [DEMAND side]
  - Loss (both technical and non-technical) minimization; Robust operation/real-time view / responsiveness [Grid OPERATIONS]
  - Use renewable energy sources (eg: solar, wind etc): & integrate w/ storage & transportation (eg: plug-in hybrid vehicles) [SUPPLY side]

- Smart Grids, more broadly, enable Smarter energy choices:
  - Linkages to Transportation, Utilities optimization
Smart Energy: Load Management (Demand Side)

Goals:
(a) flatten peak demand
Peak loads: Time-shifting deferrable loads reduces peak load significantly.

A significant proportion of loads are deferrable in modern households including washing machines, water heaters, phevs, which contribute to peak demand.

Shifting deferrable loads from peak to off-peak times reduces peak load significantly.

However coordinated time shifting of user loads requires a communication infrastructure - expensive to deploy.

Electric Power Consumption in Europe’s households
[Source: Wal, Kern 2004]

Credits: Deva Seetharam, Tanuja Ganu, Vijay Arya, Jagabondhu Hazra, Rajesh Kunnath, Dr. Liya (UBD), Dr. Saiful (UBD)
Our Solution: Local sensing and decision making

- Line voltage as an indicator of grid load

\[ V_R = Z_{LD} \times I \]
\[ = \frac{Z_{LD} \times E_S}{\sqrt{(Z_{LN} \cos \theta + Z_{LD} \cos \phi)^2 + (Z_{LN} \sin \theta + Z_{LD} \sin \phi)^2}} \]

- Line frequency as an indicator of grid imbalance

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Distributed Micro-demand/response: nPlug

Key Features

- Requires **NO communication infrastructure NOR any changes to the appliance or grid**.
- It is **simple** and **inexpensive** for end consumer use. (Approximate cost 20$ in small volumes)
Experiments

- Learning Module: Inferring peak and off-peak periods

Voltage sensing data for a week

Evaluation of voltage sensing for 3 months

Off-peak time (3AM)
100% accuracy

Peak time (7PM)
95% accuracy
Experiments

- Load Scheduler: Decentralized Scheduling

Monte-Carlo Simulation with a mix of 200 deferrable appliances and uncontrolled load presenting real-world scenario
nPlug: Load Scheduler

- **Grid-Sense Multiple Access (GSMA) based scheduling**
  Multiple nPlugs continuously sense the grid and attempt to acquire service in the presence of varying uncontrolled load.

- **Algorithm – Probabilistic Negative Linear Back-off (PNLB)**

  \[ n = \frac{(E_t - S_t)}{\tau}, \quad D = \frac{d}{\tau}, \]

  **Step 1 – Contention Window**

  \[ w_c(t) = \max \left\{ 1, \frac{n - t}{D} \right\} \]

<table>
<thead>
<tr>
<th>Length of Contention window at time t</th>
<th>Available time slots</th>
<th>Duration</th>
<th>Current time</th>
</tr>
</thead>
</table>

  **Step 2 – Consumption Probability**

  \[ p = \begin{cases} 
  0 & \text{if } v_c < V_l \\
  1 & \text{if } v_c > V_u \\
  \frac{v_c - V_l}{V_u - V_l} & \text{otherwise} 
\end{cases} \]

<table>
<thead>
<tr>
<th>Voltage at time t</th>
<th>Voltage lower threshold (safe operating threshold)</th>
<th>Voltage upper threshold</th>
</tr>
</thead>
</table>

  - Represents current load on the grid
  - Represents remaining capacity on the grid
  - Voltage lower threshold, \( V_l = 210\text{V} \)
  - Voltage upper threshold, \( V_u = 250\text{V} \)
  - Voltage at time t, \( V_c \) (varies)

  \( V_u = 250\text{V} \)
  \( V_c = 220\text{V} \)
  \( V_l = 210\text{V} \)
Smart Energy: Energy Efficiency & Conservation (Demand Side)

Goals:
(a) reduce total demand
Managing TOTAL demand

- **Thermal loads: Heating / Cooling:**
  - Reduce *average temperature difference*:
  - Reduce *building leakiness*:
  - Increase *efficiency of heating system*:

  - Thermal *Storage* for buildings/residential blocks: convert electricity to heat when cheap, and store heat.
  - **Solar Thermal:** Solar energy for heating water, cooking etc (especially in India etc).

- **Appliance demands:** Electricity demand is decentralized: distributed amongst a set of appliances:
  - Energy-efficient appliances
  - Fine-grained management of appliances
  - Efficiency involves behaviors & needs of humans

  **Theme 1:** Reduce Physical Sensing via Soft sensors

  **Theme 2:** Fine-grained local demand & supply management / matching (a.k.a. micro-grids)

\[
\text{power used} = \frac{\text{average temperature difference}}{\text{leakiness of building}} \times \frac{\text{efficiency of heating system}}{\text{...}}
\]
SoftGreen: System Overview

- **SoftGreen**\(^1,2\): Leverages pre-existing opportunistic context sources (*soft sensors*) in a commercial building to determine occupancy

- *Soft-sensors* to get cues about an employee’s location
  - Wi-Fi based indoor localization
  - System activity
  - Inbuilt accelerometer
  - Calendar entries
  - Ethernet location

- Other potential sources
  - Access keycards, webcams, VoIP phone etc.

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[1]: SoftGreen: Towards energy management of green office buildings with soft sensors – E6 workshop, IEEE COMSNETS 2012 (Best Paper Award)
Pilot Overview: Context data, ground truth and environmental data

- **Context data**
  - A software service collected data on WiFi access points, calendar, accelerometer, inbuilt accelerometer, and system activity

- **Ground truth data**
  - Installation of RF readers and tags
  - Carried by users to establish ground truth to measure SoftGreen accuracy

- **Environment data**
  - Floor temperature, aggregated occupancy, light details at several locations on the floor

- **Total 9938 person hours** of data collected with ground truth
Pilot overview: Floor map

- 97 RF readers, 230 PIR sensors, 34 network switches, 97 temperature and light sensors
- Figure depicts the location of each sensor
  - Empty boxes represent areas which were not covered
  - The boxes on the right and bottom are meeting rooms
- Each cubicle, sensor, reader, HVAC vent, volunteer location, room is a point \((X, Y)\) on the floor map
SoftGreen evaluation: Occupancy inference with the RFID tags

- A location on the floor is represented as an X-Y coordinate
  - A volunteer carrying an RFID tag is detected by nearby readers
  - Readers log reader id, tag id, signal strength every ten seconds with a timestamp
  - Tag’s location is fixed at the reader which logs the highest signal strength
  - Reader’s X, Y coordinates are marked as volunteer’s coordinates

![Diagram showing how RFID tags are used to infer occupancy]

Breaks, left the floor
SoftGreen is evaluated as an area occupancy prediction system. Accuracy is measured as its ability to find if the cubicle is occupied (presence) or unoccupied (absence).
SoftGreen evaluation: Accuracy

- Accuracy for different volunteers
  - Number of instances inferred correctly over a day per volunteer
- A box represents distribution of accuracy numbers per volunteer
  - Mean value is marked with the red dot
  - First and third quartiles are the edges of the box
- Most volunteers with more than or equal to 80% mean accuracy
Around 60 HVAC vents on the floor
- Red square marks vent locations for a section of the pilot location
- Each covers 8-10 feet area around it, which usually has 4-6 cubicles (marked by a green square)
SoftGreen application: Real time vent control

- Combined view of all the vents at a given time on the floor
- Comparison of temperature and occupancy values around the vents

![Graph showing temperature and occupancy values around vents]

- The **radius of the circle** is proportional to the temperature value.
- The **square size** is proportional to the occupancy, red represents an empty section.
Smart Energy: Grid Operations

(Smart meters are just the beginning!)

**Goals:**
(a) Improved observability in under-sensed systems
(b) Asset lifetime & yield optimization
(c) Efficiency: Reduce wastage, losses & theft
(d) Grid robustness, blackout avoidance
A blackout refers to the total loss of power to an area and is the most severe form of power outage that can occur. Blackouts which result from or result in power stations tripping are particularly difficult to recover from quickly. Outages may last from a few minutes to a few weeks depending on the nature of the blackout and the configuration of the electrical network.

Typical stages of blackout

- Initiating event
- Steady state progression
  - System becomes stressed due to overload on lines, transformers and generators
  - Successive trappings occur with inter-event intervals
- Transient progression
  - System suffers from under-voltage/under-frequency
  - Many components begin tripping quickly
  - Uncontrolled islanding and blackout
### A Brief History of Major Blackouts

<table>
<thead>
<tr>
<th>Blackout</th>
<th>Date</th>
<th>Location</th>
<th>Millions affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East Blackout</td>
<td>9/11/1965</td>
<td>North America</td>
<td>30</td>
</tr>
<tr>
<td>Southern Brazil Blackout</td>
<td>11/3/1999</td>
<td>South and South-Eastern Brazil</td>
<td>75</td>
</tr>
<tr>
<td>Italy Blackout</td>
<td>28/09/2003</td>
<td>Italy</td>
<td>55</td>
</tr>
<tr>
<td>North East Blackout</td>
<td>14/08/2003</td>
<td>North America</td>
<td>55</td>
</tr>
<tr>
<td>Java-Bali Blackout</td>
<td>18/08/2005</td>
<td>Indonesia</td>
<td>100</td>
</tr>
<tr>
<td>Brazil and Paraguay</td>
<td>10/11/2009</td>
<td>Brazil and Paraguay</td>
<td>60</td>
</tr>
</tbody>
</table>
Blackout statistics

At least 1,000,000 person/customer hours of disruption


### US blackout statistics

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of blackouts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-1995</td>
<td>41</td>
</tr>
<tr>
<td>2001-2005</td>
<td>92</td>
</tr>
<tr>
<td>2006</td>
<td>36</td>
</tr>
</tbody>
</table>

Source - CNN News 9th Aug., 2010
Current blackout prediction methods

- Monte Carlo Simulation
- Importance Sampling
- Self-organized Criticality
- Exhaustive contingency analysis

Shortcomings
- Lack of computational resources and efficient algorithms are the major obstacles for studying large blackouts.
- Monte Carlo simulation and Importance Sampling techniques are not efficient algorithm for the simulation of hidden-failure chains because of large computational requirement and the need to simulate each sample blackout more than once.
- Exhaustive contingency analysis method is faster than Monte Carlo/Importance Sampling as it avoids simulating the same path repeatedly, but still it is very difficult to simulate all the possible contingencies due large number of components of the power system.
- Even with contingency analysis approach, execution time for a small system is of the order of days.
GridPulse approach

1. Power network is represented as a graph consisting of nodes and branches
2. Each node represents state of the system whereas each branch represents a contingency i.e. tripping of line/transformer or generator
3. Starting from a single event possible cascading paths are identified using event tree approach
4. Consecutive events are assumed to be dependent on previous events and based on this assumption, a region of vulnerability is defined for each contingency
5. From each node, next possible paths i.e. contingencies are selected from a region of vulnerability
6. For each node a risk index i.e. severity*probability is calculated
7. To reduce computational complexity, low risk nodes are discarded and only high risk nodes are selected and explored for the next layer
8. Equipment failures including hidden failures of protection system are modeled in this approach
9. At least 10% load loss is assumed as catastrophic
10. As cascading paths are relatively independent, high performance computation technique has been used
### Simulation results for serial implementation (IEEE 14 bus system)

<table>
<thead>
<tr>
<th>Seq.</th>
<th>All possible cascades</th>
<th>Probability</th>
<th>Identified by GridPulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-2</td>
<td>$0.50 \times 10^{-3}$</td>
<td>1-2</td>
</tr>
<tr>
<td>2</td>
<td>3-4-7</td>
<td>$0.50 \times 10^{-3}$</td>
<td>3-4-7</td>
</tr>
<tr>
<td>3</td>
<td>3-6</td>
<td>$0.29 \times 10^{-3}$</td>
<td>3-6</td>
</tr>
<tr>
<td>4</td>
<td>1-7</td>
<td>$0.25 \times 10^{-3}$</td>
<td>1-7</td>
</tr>
<tr>
<td>5</td>
<td>2-3-4-5</td>
<td>$0.21 \times 10^{-3}$</td>
<td>2-3-4-5</td>
</tr>
<tr>
<td>6</td>
<td>1-15</td>
<td>$0.50 \times 10^{-4}$</td>
<td>1-15</td>
</tr>
<tr>
<td>7</td>
<td>2-4-5-6</td>
<td>$0.50 \times 10^{-4}$</td>
<td>2-4-5-6</td>
</tr>
<tr>
<td>8</td>
<td>4-6-7-8</td>
<td>$0.29 \times 10^{-6}$</td>
<td>4-6-7-8</td>
</tr>
<tr>
<td>9</td>
<td>4-6-7-11</td>
<td>$0.29 \times 10^{-6}$</td>
<td>4-6-7-11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77</td>
<td></td>
<td>$0.56 \times 10^{-14}$</td>
<td>13-12-15-10-1-5-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>2-5-6-7-10-12-1</td>
<td>$8.95 \times 10^{-20}$</td>
<td></td>
</tr>
</tbody>
</table>

- All possible cascades are identified using exhaustive search method. For IEEE 14 bus system 118 cascades are identified.
- Serial implementation could catch only 77 cascades (out of 188) as low risk paths are discarded during exploration.
- However cumulative risk of 77 cascades is around 90% of all possible cascades.

**Shortcomings**

> Real time implementation is difficult as execution time exponentially increases with the size of the system.
As cascading paths are independent to each other, distributed architecture could be implemented to search the independent cascades in parallel which is expected to be useful in predicting cascades in real time.

Contingency analysis is naturally a parallel process because multiple contingency cases can be easily divided onto multiple processors and therefore, cluster-based parallel machines are well suited for contingency analysis.

Each contingency analysis may require different number of iterations and thus take different time to converge. The variations in execution time result in unevenness, and hence computational power is not fully utilized as many processors are idle while waiting for the last one to finish.

The challenge in parallel contingency analysis is not on the low-level algorithm parallelization but on the computational load balancing to achieve the evenness of execution time for multiple processors.
Comparison of execution Sequential v/s the Parallel Strategy

Test system: 39 bus system

<table>
<thead>
<tr>
<th>Contingency</th>
<th>Number of contingencies</th>
<th>Execution time (Serial Implementation)</th>
<th>Execution Time (Parallel Implementation on 512 nodes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-6</td>
<td>1,24,67,220</td>
<td>6.92 hr</td>
<td>0.39 seconds</td>
</tr>
<tr>
<td>N-7</td>
<td>7,53,58,719</td>
<td>1.74 days</td>
<td>0.48 seconds</td>
</tr>
<tr>
<td>N-8</td>
<td>38,98,16,214</td>
<td>9.02 days</td>
<td>0.79 seconds</td>
</tr>
<tr>
<td>N-9</td>
<td>2 728 713 498</td>
<td>order of months</td>
<td>1.33 seconds</td>
</tr>
</tbody>
</table>
Smart Energy: Supply Side Renewables & Storage

Goals:
(a) Maximize operational yield of renewable farms or distributed renewables
(b) Orchestrate storage, renewables (“matching”, “smoothing”)

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Background

- Distributed Energy Storages (DES) are becoming more common as the storage technologies are becoming cheaper.
- KEMA predicted that, in next 5 years 55% of total investment will be on storage.
- Energy storage systems show promise of savings for both the utility and the customer.
- In common scenarios of load fulfillment in electrical networks, an emerging concept is to fulfill the demand shortage via judicious use of batteries/inverters (external storage) in order to enhance supply.
- The need of the hour is to effectively utilize these distributed storage devices so as to lower operating costs while offering aforementioned services.
Main idea

- We observe that currently, most power companies have their own batteries/storage to augment power generators.
- In current technology, the transfer of power happens between battery to the grid or the grid to the battery.
- One specific way for augmenting supply that was absent before is to allow batteries to charge other batteries.
- The concept of energy delivery network (EDN) considering battery-to-battery charge transfer is inspired by content delivery networks (CDN).
- Battery-to-Battery energy transfer is useful for instance in scenarios when generators cannot be run for certain reasons, or that it might cause too much load on the network, if the storage devices were to be charged directly from the power grid.
CDN Vs EDN

- The goal of a CDN is to serve content to end-users with high availability and high performance.
- CDNs also offload the traffic served directly from the content provider’s origin infrastructure, resulting in cost savings for the content provider.
- Battery networks, like CDNs, can alleviate congestion in power networks and the load on generators during the peak hours.
- However, there are a few fundamental differences between the two types of delivery networks:
  - Unlike content, stored charge can’t reused
  - While there is no loss associated with writing and reading content, storing and retrieving energy suffers from significant conversion and storage losses
  - While lifetime of CDN servers usually are not impacted by read and write operations, the batteries have a limited number of charge/discharge cycles
  - The rate of reading and writing content has no impact on the amount of data recalled.
A toy example
Energy loss without B-B charge transfer

Thus, for one hour peak period and one hour off-peak period, the cumulative energy loss [network+battery loss(5%)] can be calculated as:

Cumulative Loss in one hour = 2+8+4×0.05 = 10.2 MWh
Energy loss with B-B charge transfer

\[ \text{Loss}_{\text{offpeak}} = i^2 \times R = 14^2 \times 0.02 \Omega = 3.92 \text{MW} \]

\[ \text{Loss}_{\text{peak}} = i^2 \times R = 16^2 \times 0.02 \Omega = 5.12 \text{MW} \]

Cumulative Loss in one hour = 3.92 + 5.12 + 0.05 \times (4+4+4) = 9.64 \text{ MWh}

It is instructive to see that, even though battery loss becomes double, B-B charge transfer has caused the total loss to reduce significantly, from 10.2 MWh to 9.64 MWh. This example clearly shows the potential of B-B charge transfer in smart grid.
Problem formulation

The overall objective of the SEMS problem is to minimize the total cost of operation of the generators, along with attempting to minimize the total charging and discharging costs of the batteries, while allowing charge transfers between batteries.

Objective

\[
\sum_{t=1}^{T} \left[ \sum_{i=1}^{NG} (F_i(P_{i,t}) + S_i(u_{i,t}) + H_i(u_{i,t})) + \sum_{i=1}^{nb} (F(C_{i,t}) + F(D_{i,t})) \right]
\]

- \( F_i(.) \): generation cost function for generator \( i \);
- \( NG \): number of generators;
- \( nb \): number of batteries;
- \( P_{i,t} \): power generated by \( i^{th} \) generator at time \( t \);
- \( a_i, b_i, c_i \): cost coefficients of generator \( i \);
- \( u_{i,t} \): unit on/off status at time period \( t \);
- \( S_i(.) \), \( H_i(.) \): are start-up cost and shut-down cost, respectively for generator \( i \);
- \( C_{i,t}, D_{i,t} \): are charging and discharging costs, respectively for battery \( i \) at time period \( t \).
Constraints

- Load and Generation Balance
- Upper and Lower bounds on Generation
- Ramp up, ramp down
- Minimum up time and down time
- Start up and shut down indicators
- Battery Charging/Discharging
- Network Flow constraints
Proposed Architecture

- Power Source Characteristics
- Demand Profile
- Battery Characteristics

Data Collection

Optimization Engine

Output
Optimization Engine

- Load prediction
- Generation prediction
- Generator cost curves
- Upper & Lower bound of generators
- Ramp up & down constraints
- Minimum up & down time
- Start up and shut down costs
- Network topology
- Network flow constraint
- Storage information

Minimize
[Generation cost + startup cost + shutdown cost + charging cost + discharging cost]

Subject to
all constraints

Unit commitment schedule
MW dispatch schedule
Optimal use schedule of storage

IBM ILOG CPLEX OPTIMIZER
Three lithium-ion batteries (of 5MWh each) were placed at bus 15, bus 19, and bus 24, respectively. Maximum charging and discharging current limits of each battery were assumed as C/2 and C/5, respectively. Batteries were assumed to operate for 30000 cycles for an average depth of discharge (DoD) of 30%.
Case studies

We consider and compare three scenarios:

- When batteries are not present
- When batteries are present, but the only charge transfers allowed are between battery and grid
- When batteries are present, and charge transfers are allowed between battery and grid, and between batteries.
Simulation results

BES reduced start up and shut down cost by minimizing on/off of generators

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Gen</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G1</td>
<td>1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>2</td>
<td>G1</td>
<td>1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>3</td>
<td>G1</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>1</td>
<td>G2</td>
<td>1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1</td>
</tr>
<tr>
<td>2</td>
<td>G2</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1</td>
</tr>
<tr>
<td>3</td>
<td>G2</td>
<td>1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

Start up and shut down cost

- Scenario 1: $3300
- Scenario 2: $2300
- Scenario 3: $1200

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Charging/discharging schedules

Within battery 15 and 19 charge transfer happened in between 1-2, 6-7, 11-12 and 17-18 hours. Similarly, between batteries 15 and 24 charge transfer happened in between 5-6 and 7-8 hours. Between batteries 19 and 24 charge transfer happened during 21-22 hour.
For scenario 2, cost got reduced compared to scenario 1 because batteries were charged from available cheaper generators during off-peak period and discharged the energy during peak period which helps in purchasing power from costly generators. In scenario 3, cost got further reduced because inter-battery charge transfer within the battery network has reduced the network power loss and start-up shut-down cost of generators.
Smart Energy: Microgrid

( Smart meters are just the beginning ! )

Goals:
(a) Electrification in remote areas
(b) Backup for unreliable grids
Electricity Supply Chain

Hierarchical Traditional Grid

Disadvantages

At least 1,000,000 person/customer hours of disruption

Decreasing Reliability Polluting Peak Load Shortage
Option 1: Extending the Grid

- Expensive.
  - $8,000-$10,000 per kilometer.
- Low population density
- High transmission and distribution losses.
- Insufficient generation

Option 2: MicroGrids

- Local renewable generation.
- Increased reliability
- Increased user involvement
- More independent operation.
- Reduced network losses and theft.
What’s a Microgrid?

- Microgrids are necessary under three conditions:
  - Offline microgrid - When there is no grid connectivity
  - Online microgrid - When peak hour grid electricity prices are much higher than off-peak prices
  - Backup microgrid - When sufficient power or power quality is not available from main grid

[Platt, et. al. Smart Grid: Integrating Renewable Distributed and Efficient Energy 2011]
Conventional Microgrids

- Expensive and Cumbersome
  - Difficult to integrate disparate components
  - System Designed for trained operators
  - No consumer participation

IBM Approach

- Hassle-free Installation
- Flexible to Change
- IBM YouGrid Operating System
  Abstraction, analysis, control
- Easy to use
- Efficient Load Management
- Security
- Optimal Use of Battery
- Optimized Energy Sources

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Getting to the Rainforest

A 30 - 150 min boat ride
KBFSC Problems

No direct grid connection

3 diesel generators (DGs) for 5 building blocks

DG hours: 6-9am and 4-11pm (~10 hrs)

DG consumption: ~30 L/day

Transporting diesel is difficult, 30-150 min long boat ride
Our Objectives

Increase Power Availability

Reduce Diesel Consumption
Renewables

Only about 2-4 hrs of direct sunshine per day
Wind speed too low

Micro Hydro
River too shallow, dam would affect ecology

In a valley with heavy foliage
DG Optimization

![Mean Daily DG Power (kW)]

- **R phase**
- **Y phase**
- **B phase**

- Loaded 20% to 50% of capacity

![DG Efficiency Curve (Cummins C38 D5)]

- Efficiency (kWh/L)
- Load (kW)

- 20 to 40% savings

![Total Fuel Consumed (L)]

- Charging Power (kW)
- Battery Optimized DG
- Direct DG
Battery Optimized DG

Charge Controller

Primary Appliances

Secondary Appliances

YouGrid Operating System

Optimal charge/discharge decision taken based on current load profile, fuel efficiency and battery state

Power for large appliances when DG is running

Power for primary appliances always available*
Optimization

Original Scenario

Optimized Scenario

Fuel Use
- DG Max
- DG
- Sec. App A
- Sec. App B
- Primary App. A

Less Fuel Consumption

High Power Availability
The YouGrid Operating System

- Sensor Interface Layer
- User Viz. Interface
- Model Learning
- Optimization
- Visitor/ Admin Kiosk

YouGrid Engine

Data Storage
Bringing Humans in the loop

Schedule appliances for DG run hour reduction and improving fuel conversion efficiency of the DG through optimal loading
Microgrid State of the Art

SUPPLY OPTIMIZATION

HIGH POWER AVAILABILITY

ASSUMPTION: APATHETIC CONSUMERS

YouGrid

MICROGRID OPERATION

YouGrid Operating System

REALITY: MOTIVATED CONSUMERS
Home Screen

Today’s DG timing

Admin login

Current DG status

SELECT A TASK TO START WITH

Schedule Your Usage
Scheduling your electricity usage lets us know your requirements and we optimize the diesel generator timings to increase the efficiency. Tap to schedule now.

Diesel Generator
View information about the fuel consumption, energy consumption and the diesel generator efficiency in the past.

Overall Energy Statistics
View the energy consumed by the rooms, labs and the appliances inside them.

About KBFSC
Get to know more about KBFSC. You can also learn how this energy management system works.
Power Flow/Usage Visualization

Tree diagram of all appliances. Select a “Node” to view data.

Date, Week and Month Selector

OVERALL STATISTICS
Tap a node to view its details.

Can view bar graph in Stacked or Grouped view

To select/deselect data points

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Visitor’s UI

Select an activity to schedule its usage

Efficiency

Green area shows recommended timings. The handle bars allows choosing any time.

Auto-update based on selected time

Your diesel contribution
Admin can use handle-bars to select any timing, and accordingly see the scheduled appliances and ALLOT that time for running the generator.

Based on the selected timing using the handle-bar, the graph dynamically shows the load on the generator and fuel required, with total numeric values (including primary loads).

Green region showing the selected timings, which is also listed here.
Deployment Phases at Site

River

Diesel Water Pump

Pre-Filter Tank

Post-Filter Tank

Water Pump

Diesel Generator

Diesel Fuel Monitor

YouGrid Operating System

WiFi Network

Server Network

Solar Panel

VSAT

Backup Power

Backup Power

Backup Power

WiFi Battery State of Charge Sensing

Solar Powered Motion Controlled LED Walkway lights

Wired Energy Meter

jPlug: WiFi energy meter and power switch

24x7 Power for Lights, Fans and Sockets

jPlug controlled Battery Charger

jPlug controlled Inverter

High Efficiency LED lighting

Washing machine

Oven

Water heater

User scheduled appliances, jPlug enabled
Summary

- Energy ecosystem accounts for 74% of GHG emissions:
- Smarter energy => manage growth of energy demands while reducing GHG
- Smart grid: efficient electricity, minimal environmental impact

**Demand-side Goals:**
- Reduce total demand, while economy expands (efficiency, conservation)
- Flatten peak demands (defer capex/opex investments, reduce power deficits/power cuts)
- Incentivize ergonomic practices to identify and use appliances efficiently
- Distributed renewables & Micro-grids

**Operations (Txn & Distribution) Goals:**
- Minimal sensing: fusion of incidental data, tomography techniques to fill in missing data
- Phase identification, phase balancing, asset optimization,
- Robust operations: blackout prediction/avoidance, wide-area situational awareness

**Supply-side & Storage Goals:**
- Supply transformation to renewables – high yield renewables or large-scale farms + HVDC
- Renewables integration – forecasting, economic dispatch
- Virtual power plants
- Batteries – including electric vehicles as a component of the smart grid.
Thank You!
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