Gi-Joon Nam, IBM Research - Austin

Sani R. Nassif, Radyalis

Opportunities in Power Distribution Network System Optimization (from EDA Perspective)

Outline

- SmartGrid: What it is
- Power Distribution Network & EDA
- Energy Analytics Planform (Our implementation)
- Energy Analytics Problem Example: Load Balancing

Smart Grid – What It Is

A smart grid is a modernized electrical grid that uses analogue or digital information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

1. From Wikipedia, the free encyclopedia http://en.wikipedia.org/wiki/Smart_grid

2. U.S. Department of Energy. "Smart Grid / Department of Energy" Retrieved 2012-06-18

Smart Grid – Goals

- A smarter grid applies technologies, tools and techniques available now to make the grid work far more efficiently…
  - –Ensure its reliability to degrees never before possible.
  - –Maintaining its affordability.
  - –Reinforcing our global competitiveness.
  - –Fully accommodating renewable and traditional energy sources.
  - –Potentially reducing our carbon footprint.
  - –Introducing advancements and efficiencies yet to be envisioned.

From The US. Department of Energy Report

Smart Grid: Technology Aspects

- GIS Data and Processes
  - GIS = Geographic Information System
  - Accurate representation is critical
    - Phase, Connectivity, Landbase, Spatial positioning etc.
- Data storage and Communication Networks infrastructure
  - Data storage, Security, Bandwidth, Robustness, Resiliency, Time Synchronization and propagation etc.
  - Big Data application
- Energy (Power) Delivery Network Topology
  - Design Practices, Alternate Paths, Substation Capacity, Circuit Capacity, Physical Field Asset Capacity, Construction Standards, Logistics
- Integration Architecture
  - Security, SOA (Service Oriented Architecture), CIM (Common Information Model)
  - Internet of Things (IoT) system
- Accommodating Legacy Systems

Big Data Perspective

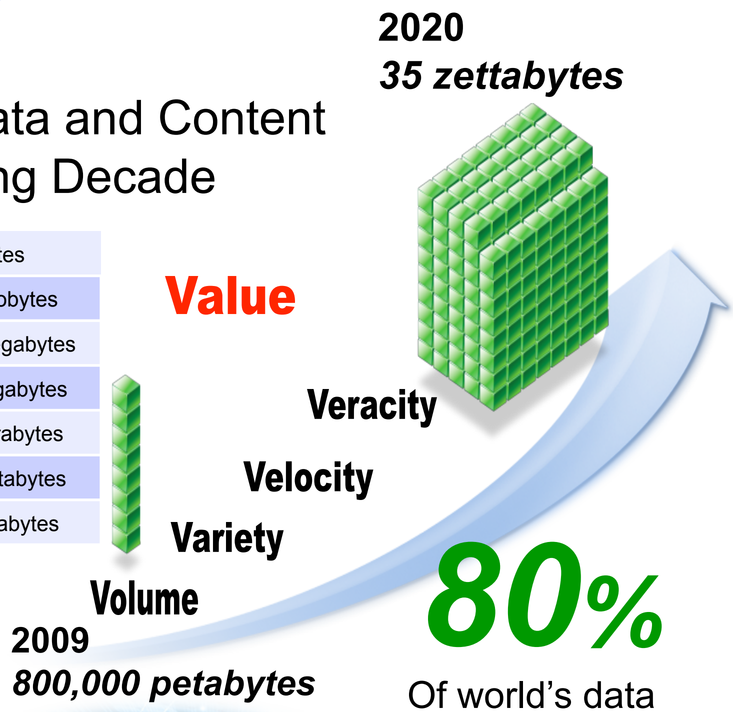
Big Data →→→ Big Value

to enterprise and society

44x

as much Data and Content Over Coming Decade

Kilobyte (kB)	1,000 Bytes
Megabyte (MB)	1,000 Kilobytes
Gigabyte (GB)	1,000 Megabytes
Terabyte (TB)	1,000 Gigabytes
Petabyte (PB)	1,000 Terabytes
Exabyte (EB)	1,000 Petabytes
Zettabyte (ZB)	1,000 Exabytes



80%

Of world's data is **unstructured**

1 in 3 Business leaders frequently make decisions based on information they don't trust, or don't have

1 in 2 Business leaders say they don't have access to the information they need to do their jobs

83% of CIOs cited "Business intelligence and analytics" as part of their visionary plans to enhance competitiveness

60% of CEOs need to do a better job capturing and understanding information rapidly in order to make swift business decisions

The resulting explosion of information (plus intermediate data) creates a need for a new kind of intelligence

Smart Grid: The First Internet of Things

IoT WORLD Increasing intelligent connections everywhere

Rich Quinnell

Smart Grid: The First Internet of Things

Rich Quinnell, Editor in Chief, 1/29/2014

Bio Email This Print Comment 12 comments

Rate It

50% 50%

Save It

With all the buzz that the Internet of Things (IoT) has been generating in the last year, it is easy to forget that the concept has been around for more than a decade. Earlier conversations also used different terms, such as machine-to-machine (M2M) and smart grid, to discuss technologies now being viewed as elements of the IoT. The history of these other technologies can provide useful insights into the way the IoT as a whole will likely evolve.

The smart grid is a particularly interesting example of IoT principles, one that has been building out for more than a decade. The "things" in this instance are smart meters, which are able to measure and store detailed information about electricity usage by a specific customer, including time of use, and communicate that information back to the utility company. In some cases, smart meters can also serve as a gateway device into smart building networks, allowing monitoring (and in some cases, control) of individual systems such as HVAC units.

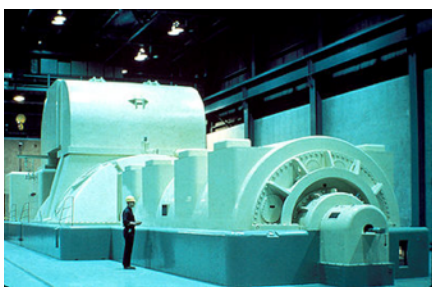
http://www.iotworld.com/author.asp?section_id=3150&doc_id=562485&piddl_msgpage=2#msgs

Outline

- SmartGrid: What it is
- Power Distribution Network & EDA
- Energy Analytics Planform (Our implementation)
- Energy Analytics Problem Example: Load Balancing

Power Distribution System

- Power Distribution Systems refer to the last part of the electricity network that connects to homes and businesses.
  - Many components, large and complex system.
  - Majority of losses and outages happen at this level.
- This domain is rapidly changing…
  - New types of loads, like electric vehicles.
  - New distributed sources of power, like Photovoltaic and Wind.


Generation


Transmission


Substation


Distribution network


Customer

Distribution System

Why Distribution Optimization "Problem"?

The US electric energy delivery market has two types of participants:

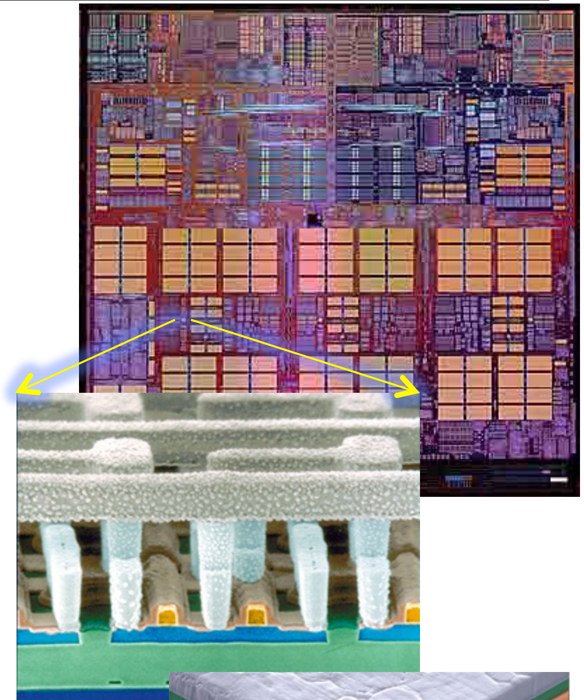
- Transmission deals with nation-wide power grids.
  - Few large companies, few large technology providers.
  - Regulated.
  - Mostly researched in "Power" Community

- Distribution focuses on "local" delivery within a geography.
  - Many small/medium companies, and small technology providers.
  - Deregulated…
  - Small companies == very limited engineering/planning/design resources

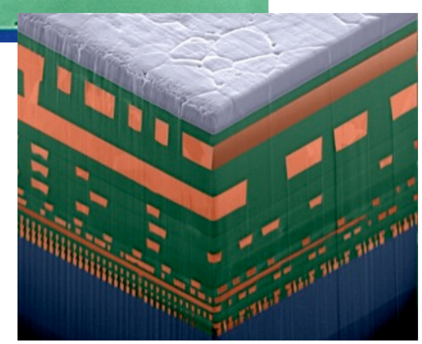
- The state of the art in this area is far behind VLSI/EDA

- There was no "Moore" in the Energy industry!

Leveraging Research in EDA



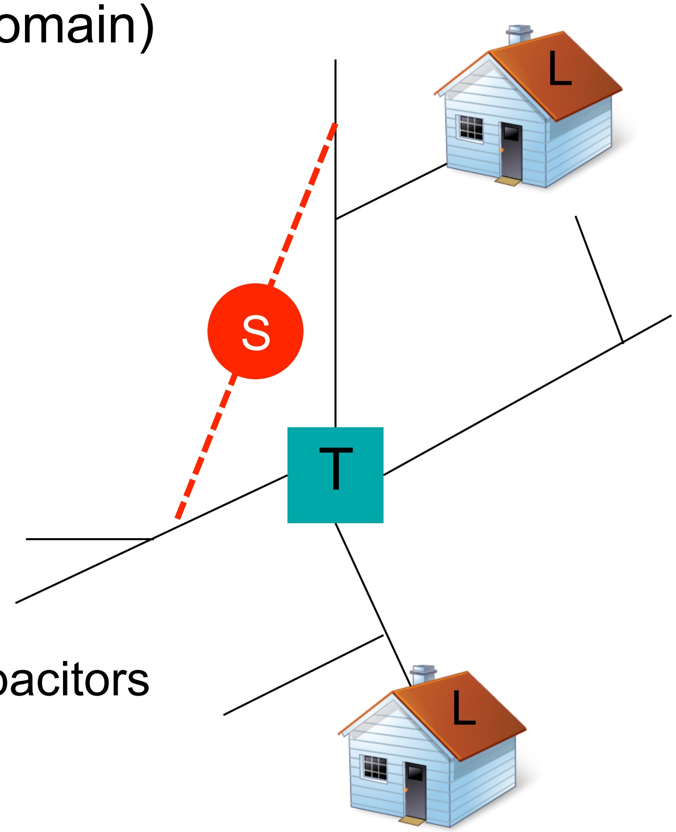
- IBM has made large investments in design automation for integrated circuits (chips).
- IBM Processor Chips contain Billions of interconnected devices and are designed using a sophisticated set of Computer-Aided-Design tools that guarantee performance and correctness.



- IBM now has a significant effort in the “Smarter Planet” arena to apply computing to real-world problems.
- These algorithms and techniques applicable to the energy distribution sector.

Energy Distribution from an EDA Viewpoint

- Alternating Current: AC (vs. DC and Time Domain)
- Geographically distributed (Km vs. μm).
- Radial (tree) or Mesh (grid).
- Source: “substation” = transformer.
- Sink: “load” = home = power drain.
- A typical scale: 10K elements.
  - Transformers (T).
  - Wires.
  - Switches (S), Safety devices, Regulators, Capacitors
  - Loads (L).



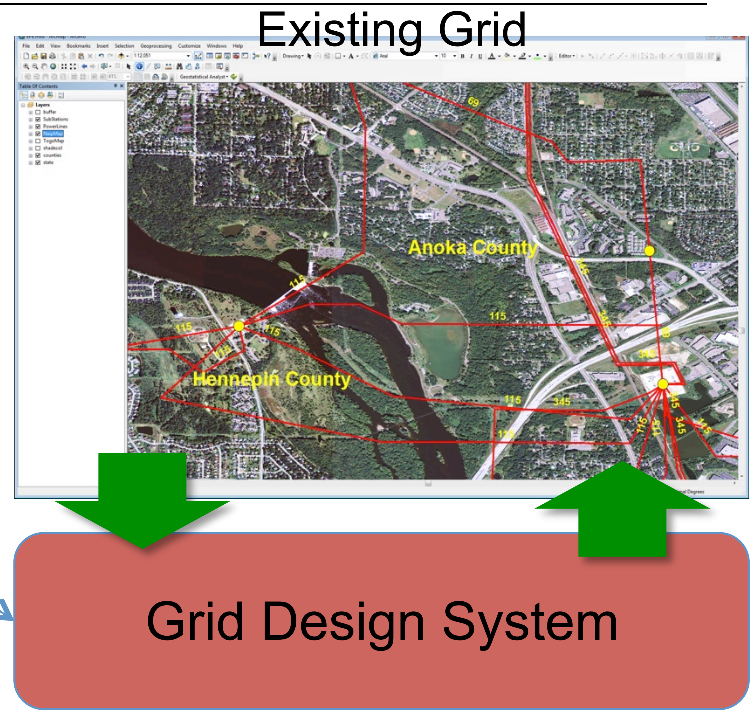
- This looks a lot like a typical VLSI design, major differences in the Language and in the need for Geospatial and Temporal Awareness.

Outline

- SmartGrid: What it is
- Power Distribution Network & EDA
- Energy Analytics Planform (Our implementation)
- Energy Analytics Problem Example: Load Balancing

A Typical Energy Analytics Problem

- Given an existing grid, one might need to make changes to accommodate:
  - A new load (e.g. a large industrial plant).
  - Anticipated growth (over time).
  - A new source (e.g. a wind farm).
  - Etc…



- The new solution needs to satisfy constraints on cost, reliability, geography, performance, and many others.
  - This is where we are getting domain help from the consulting company.

- Our goal is not just to do things incrementally better, but to fundamentally change how this industry does design.

Energy Analytics Platform

1. Data Prep for Grid Optimization

2. Netlist Extraction for Simulation

3. Simulation and Compliance Checking

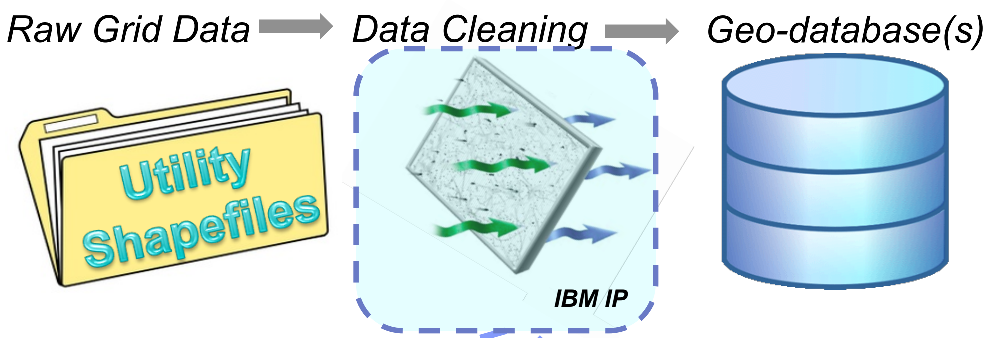
4. Optimization Engines

(1) Data Prep for Grid Optimization

- Utility distribution grid data needs to be cleaned to insure valid electrical networks. (VERY DIRTY in raw form!)

- Cleaning process closely resembles automated DRC and LVS checking that is used to validate VLSI designs.

Data Warehousing



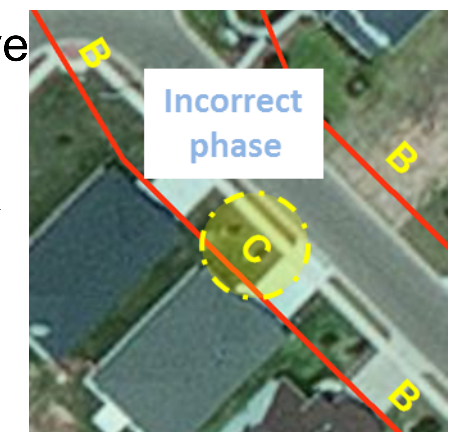
DRC Checking

- Power line objects are required to be spatially correct

- Grid snapping used to insure spatial correctness.

LVS Checking

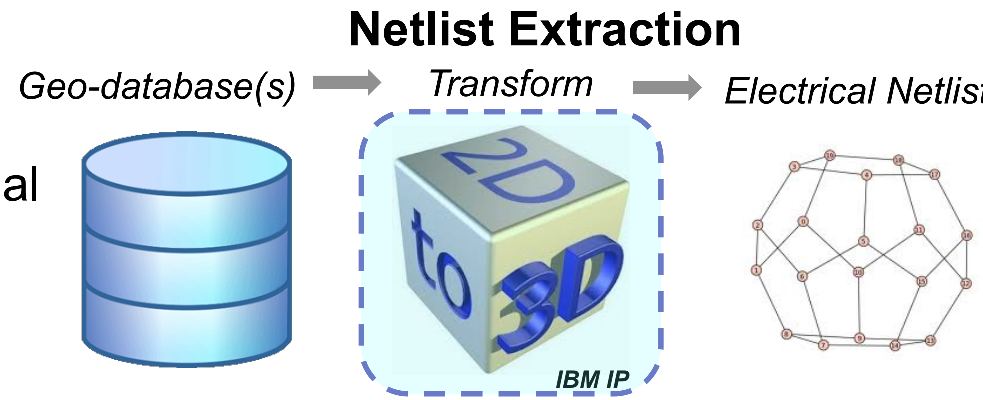
- All grid objects have attributes that described their logical connectivity (schematic).

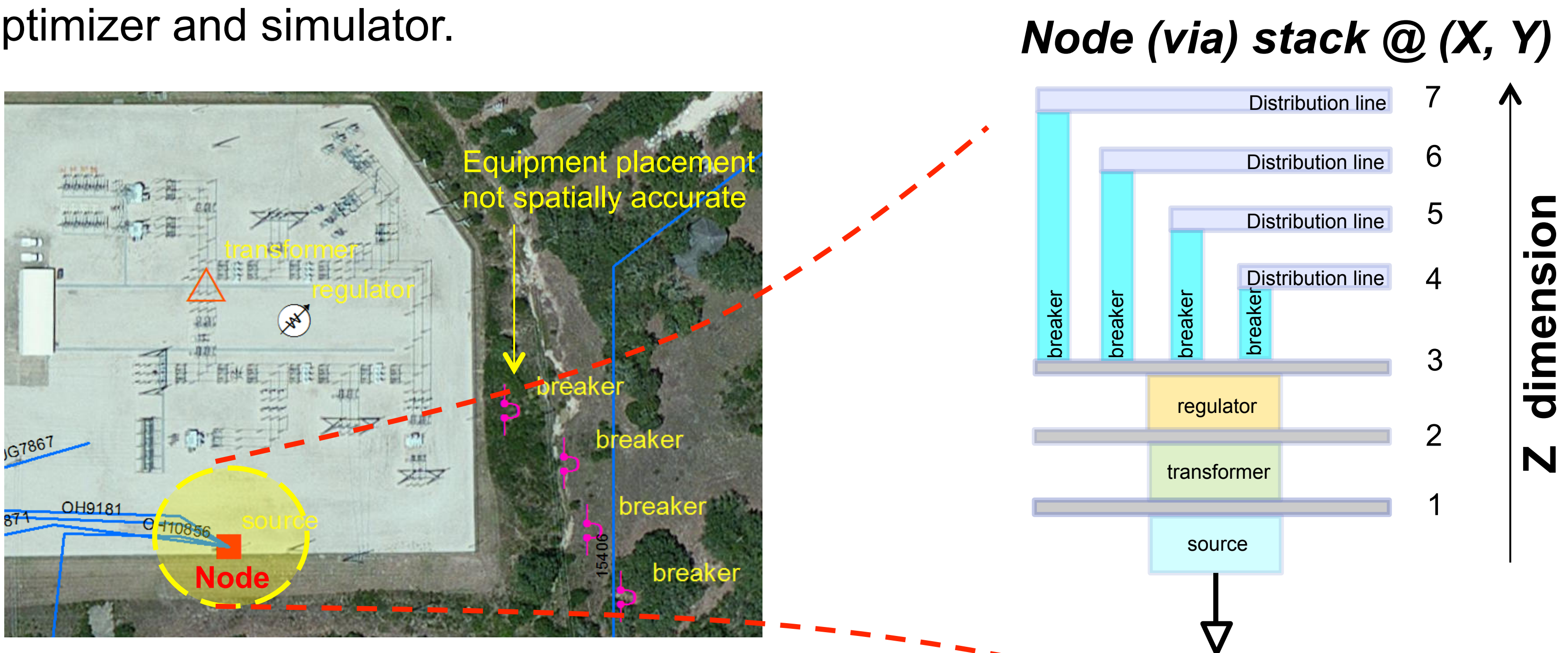


(2) Netlist Extraction for Simulation

- Utility grid distribution lines are represented spatially in 2D while equipment and loads have no spatial representation.

- Transferring grid into 3D preserves the sequencing of the objects in the optimizer and simulator.





2D Utility grid data

3D representation

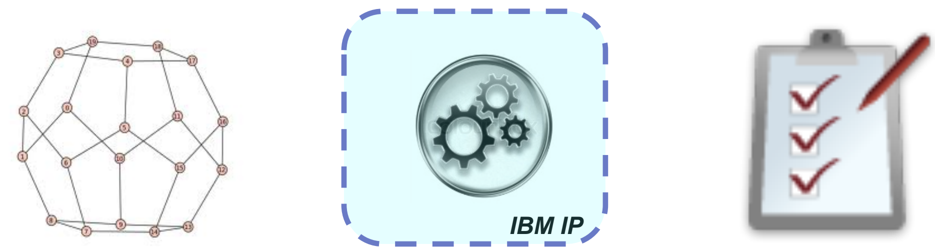
(3) Simulation and Compliance Checking

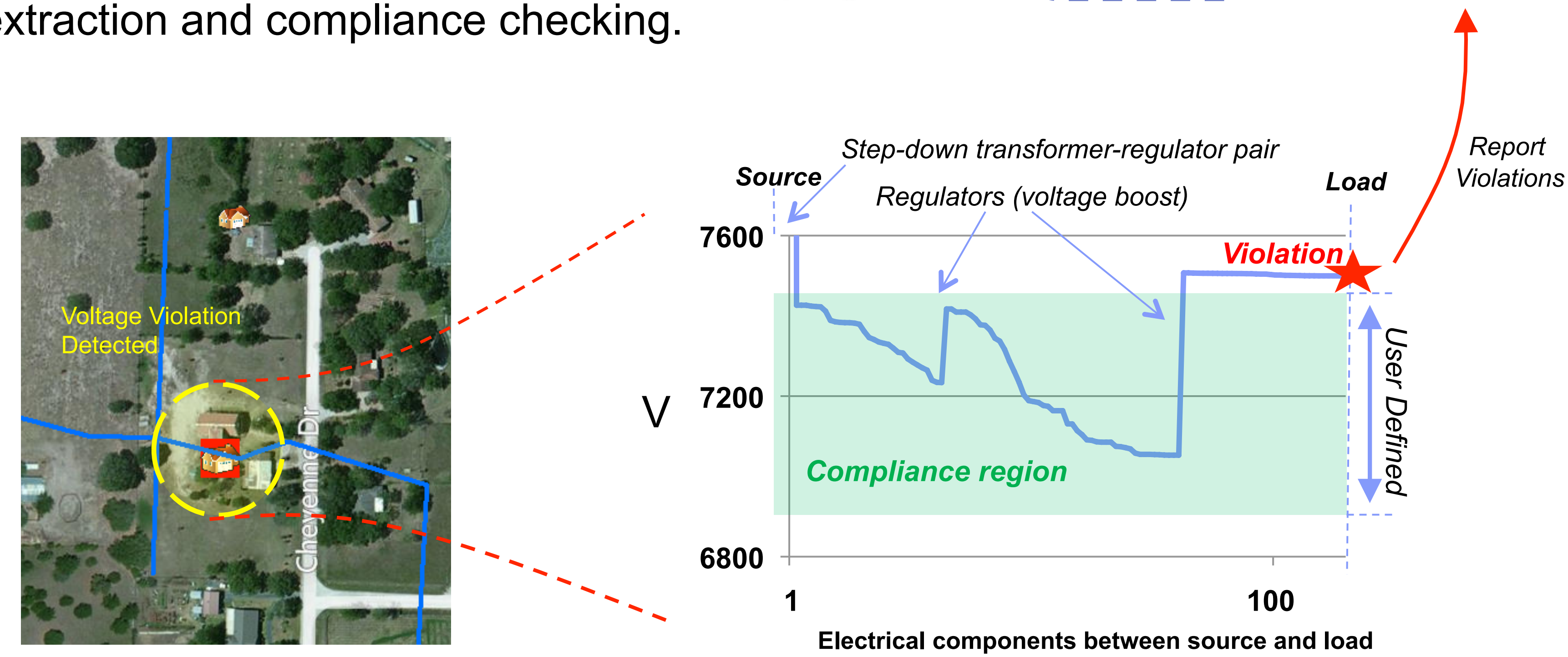
- Simulator optimized to support the types of equipment used in distribution grids, e.g. transformers, switches, reclosers, regulators, etc.

- Tight integration with netlist extraction and compliance checking.

Simulating Power Grid

Electrical Netlist → *Simulator* → *Compliances*



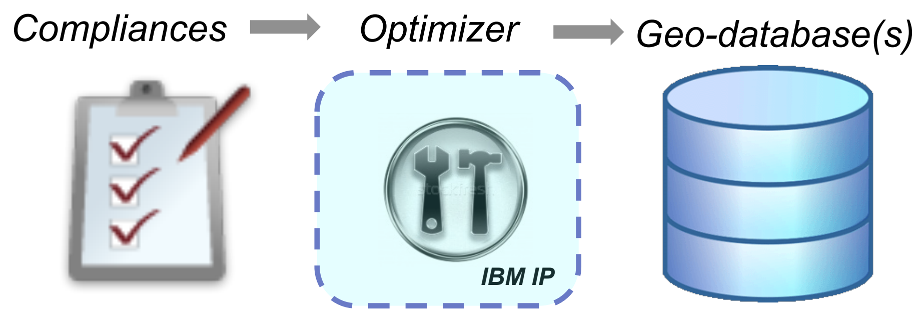


(4) Optimization Capabilities

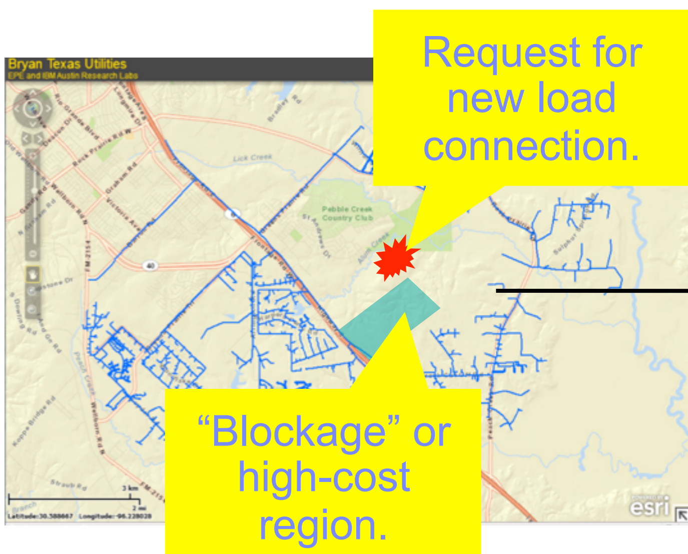
- Current capabilities …
  Load balancing, optimal load shifting for outage management, and automated fixes to thermal overloads. More to come related to growth planning and grid design.

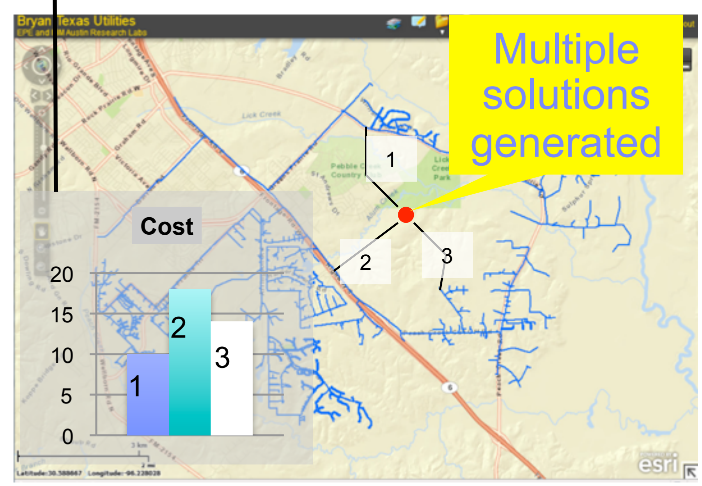
- Grid optimization closely resembles VLSI placement & routing where placement is pre-defined by environment conditions represented as raster layer cost functions.

Optimizing the Power Grid

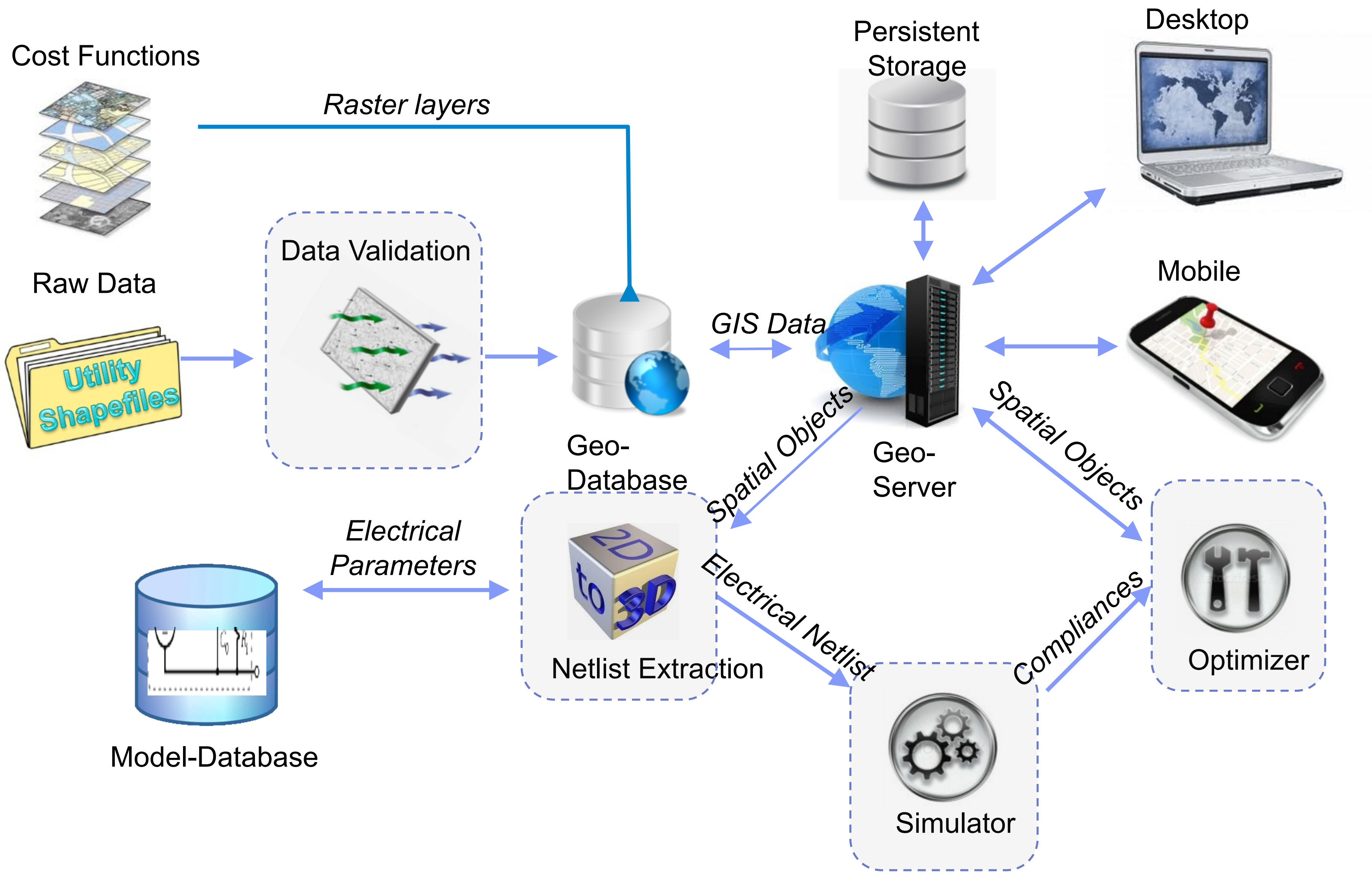


Business Decision:
We have developed tools and algorithms that can explore many design options and give the decision maker the best possible choices in terms of cost, reliability and performance





Component/Architecture View

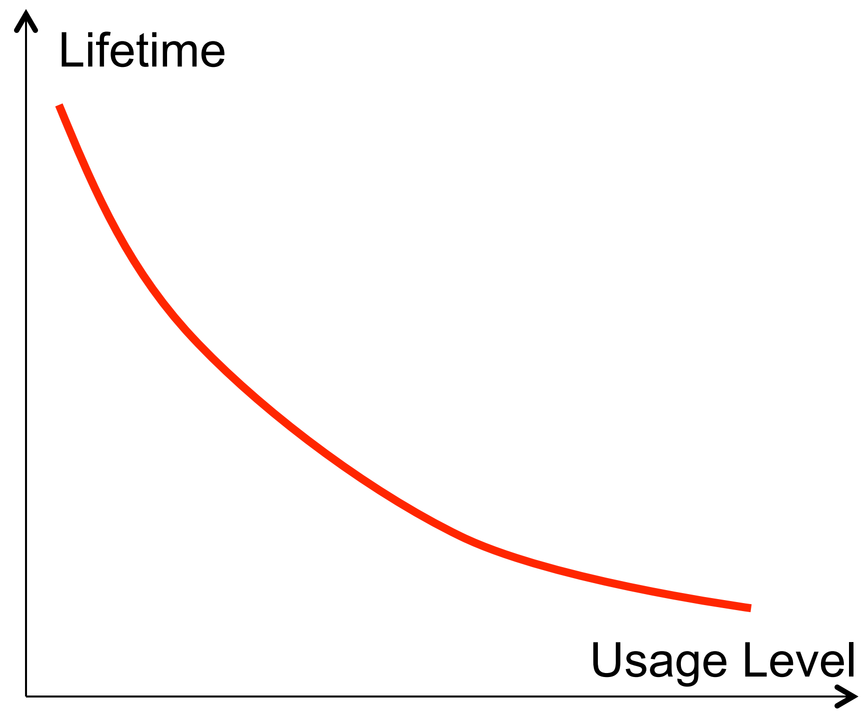


Outline

- SmartGrid: What it is
- Power Distribution Network & EDA
- Energy Analytics Planform (Our implementation)
- Energy Analytics Problem Example: Load Balancing

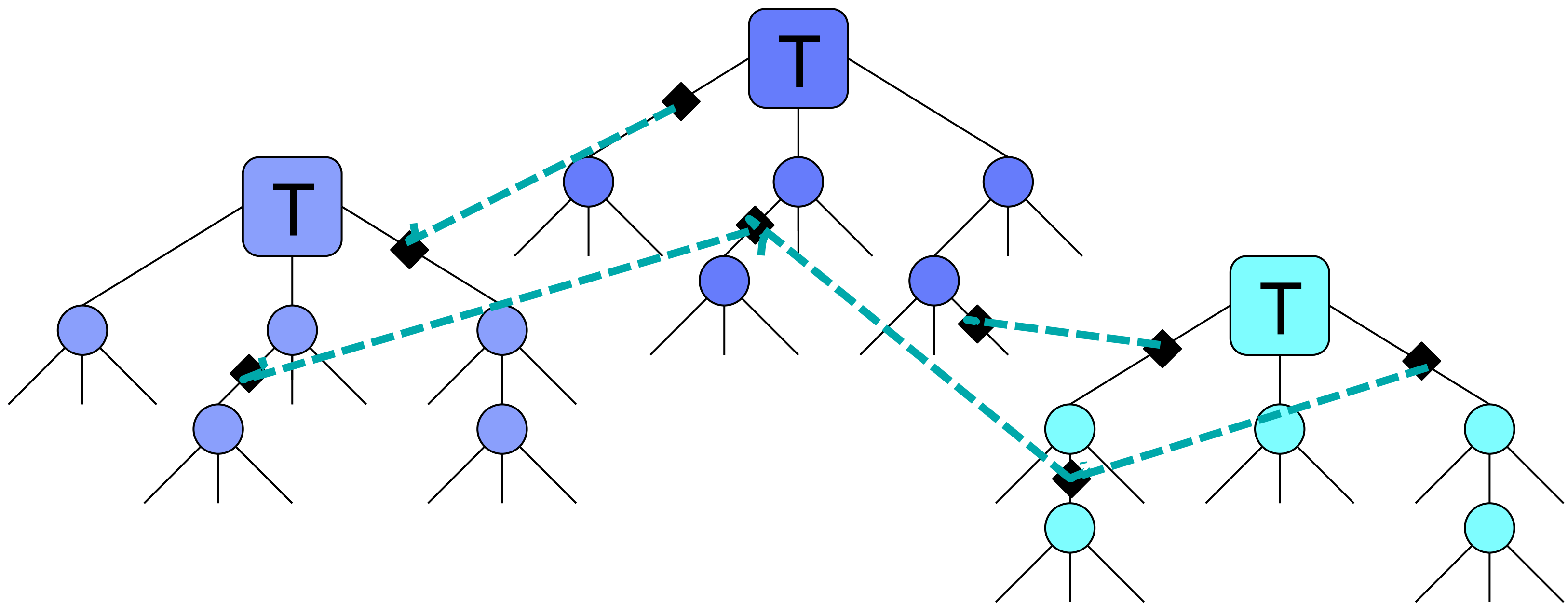
Component Lifetime (Transformers)

- Transformers are basic and costly elements of power distribution networks.
  - Lifetime of transformer depends on “stress” level, i.e., level of power transferred relative to rating.
- In order to maximize lifetime, we would like to operate components at the minimum usage level possible.
- So… if we have multiple components, we want them at the same % usage level !



Load Balancing in Power Distribution Networks

- Network consists of multiple sub-networks, connected with switches and extra wires in order to provide redundancy in the case of outages.
  - Use these switches/wires to balance load across the various components.



ASP-DAC 2014 paper (Nassif, Nam etc..)

Algorithm Load Balancing via Tieline

```
▷ Input: Power Graph PG with Transformer X_i ∈ X
repeat
    Let X_s be X_i with max DOWN(X_i)
    Let X_t be X_i with min DOWN(X_i)
    δ = DOWN(X_s) - DOWN(X_t)
    S = ∅; T = ∅
    for each vertex v ∈ X_s sub-tree
        if(DOWN(v) ⩾ δ)
        then Add v to S
    for each vertex v ∈ X_t sub-tree
        if(SLACK(v) ⩾ δ)
        then Add v to T
    Find a pair (s ∈ S, t ∈ T) with the shortest distance
    Add a tieline between (s, t)
until No further improvement
```

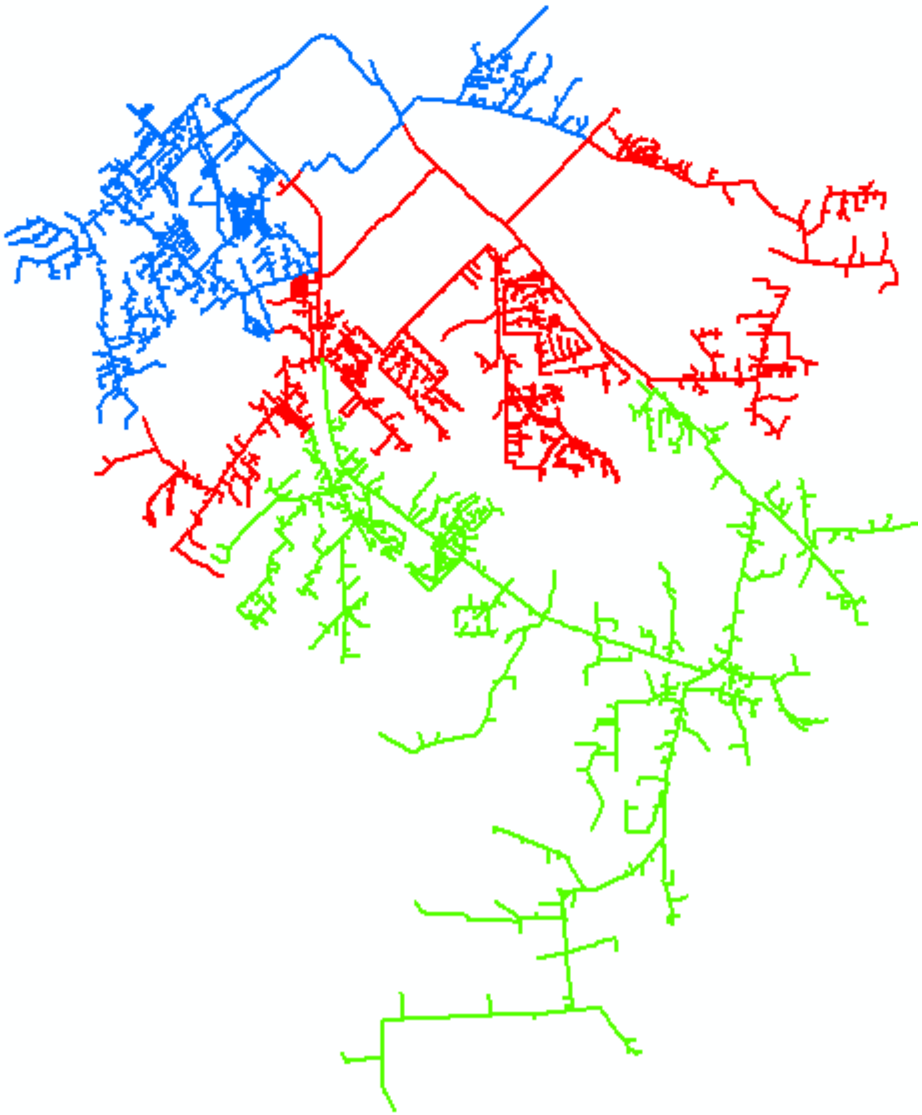
B. Load Balancing via Switch Reconfig.

Algorithm Load Balancing via Switch reconfiguration

$\triangleright$ Input: Power Graph PG with Transformer $X_i \in X$

repeat
Let X_s be X_i with $max\ DOWN(X_i)$
$\delta = DOWN(X_s) - DOWN(X_t)$
$C = \varnothing$
for each vertex $v \in X_s$ sub-tree
if($DOWN(v) \geqslant \delta$
and there is a open switch sw_i connected to $X_i \neq X_s$
and there is a closed switch sw_j between v and X_s)
then$\delta_i = DOWN(sw_i)$
Add (sw_i, sw_j, δ_i) to C
for each $(sw_i, sw_j, \delta_i) \in C$
Let p be a parent of sw_j
if($SLACK(p) \geqslant \delta_i$)
then Add v to T
Let c be the best candidate $\in C$
From $c = (sw_i, sw_j, \delta_i)$, turn on sw_j, turn off sw_i
until No further improvement

B. Load Balancing via Switch Reconfig.



Before   After

Summary and Future Works

- Smart Grid: Transforming the energy value chain
  - Transform the utility network
  - Improve generation performance
  - Transform customer operations
- Ample opportunity from advanced VLSI/CAD area
- "Operation Management" focused research activity
  - More opportunity in Design Planning Phase

Design Planning	Operation Management
▪ Manage equipment lifetime.	▪ React to outages.
▪ Plan for outages.	▪ Monitor/adjust power quality.
▪ Plan for growth.	▪ Monitor/adjust equipment.
▪ Fault-Tolerance	▪ Ensure billing accuracy.

Summary and Future Works

- Situation-Awareness is the key for success.
- Big Data & HPC
  - “Wide-area situation-awareness”
  - More analytics and optimization with available data
  - Real time monitoring and simulation for reliability
- Closely related topic to “Internet of Things” (IoT)
  - IOT starts from Smart Grid !
- ASPDAC 2014 paper titled “Applying VLSI EDA to Energy Distribution System Design”
  - Nassif, Nam, Hayes (IBM) and Fakhouri (UC Irvine)