Concentrating Renewable Energy in Grid-Tied Datacenters

Nan Deng, Christopher Stewart and Jing Li
Department of Computer Science and Engineering
The Ohio State University
“We are not going to solve the climate problem via efficiency – we must move to cleaner sources of energy.”

Bill Wheil, Google Energy Czar
March 2011 at Climate One Forum on Cloud Computing
Niche market for renewable-powered computing

- 35% of the IT Managers surveyed would pay a premium for renewable-powered services. [rackspace-2009]

- Over 300,000 Facebook users petitioned for renewable-powered datacenters. [greenpeace.org-2011]

- New construction of datacenters with on-site renewable-energy sources, 7 announced in 2009 alone.

  - Renewable-energy datacenters [stewart-hotpower-2009]
Datacenters that produce renewable energy on-site should manage their renewable-powered resources.

Renewable energy is a precious resource:
- The production of solar or wind energy is intermittent
- The capacity of renewable energy sources may be less than the datacenter consumption

Datacenters should concentrate renewable-energy for targeted server workloads:
- Renewable-powered computing as a service
- Such service may attract more customers/higher prices
Concentrating Renewable Energy in Grid-Tied Datacenters

Introduction

Challenges facing renewable-energy concentration in datacenters

#1: Renewable energy is uncontrollable
#2: The servers that can use renewable energy produced on site are fixed by the power delivery system
#3: Grid-tied datacenters allow renewable energy to provide only a fraction of a server’s energy needs

Contributions

How do grid-tied datacenters distribute renewable energy?
How to measure the concentration of renewable energy?
How do different datacenter parameters affect the concentration of renewable energy?
Outline

- Background: Grid Ties and Grid-tied Datacenters
- *Renewable-Powered Instances*: A Metric for Renewable-Energy Concentration
- Study of Renewable-Powered Instances
Power delivery devices convert unstable, high voltage electricity into stable, low voltage input to servers

- Power Delivery Unit (PDU) - Distributes power from one input to several outputs.
- Automatic Transfer Switch (ATS) - Move servers to a backup if a primary fails
- Uninterpretable Power supply (UPS) - Smooths transient voltage fluctuations

The power delivery system is critical to availability and rarely changes in practice
Grid ties change on-site renewable energy into grid-compatible AC

- Inject electricity into grid powered circuits ("plug in")
- Datacenter uses a proportional mix of grid and on-site energy

Most widely used device for renewable-energy integration
- Supported by utility companies
- Grid tie failures don’t hurt DC
- All energy produced on-site is used

This grid tie in our lab accepts DC input from a programmable supply and powers laptop on a 120V AC circuit.
Where should grid ties be placed in the power delivery system?

Assumption: Injected electricity flows downstream first (power engineering principle [bialek-1996])

No assumptions about electricity that flows upstream

- High-level placement near ATS or UPS
  - More servers downstream
  - Each server receives less renewable energy
  - Upstream flows less likely

- Low-level placement in rack PDU
  - Few servers downstream
  - Renewable energy is highly concentrated
  - Hard to account for upstream flows
  - Small grid ties are more efficient
Where should grid ties be placed in the datacenter’s power delivery system?

Strategy #1: Place 1 grid tie at highest level
- Widely adopted in practice
- Simple & easy to approve

Strategy #2: 1 grid tie at lower level
- Still simple & easy to approve
- Concentration tradeoff
- Extreme: Micro grid ties (300W)
Where should grid ties be placed in the datacenter’s power delivery system?

**Strategy #3: Multiple grid ties at different levels**

- Dynamically manage concentration as energy production changes
- Requires smart PDU between grid ties (we use the lowest-level grid tie that sends no electricity upstream)
- Too many grid ties increases complexity; hard to get approved

Multiple grid ties allow for high concentration under fluctuating renewable energy production
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Compute resources (servers) separate datacenter workloads

Grid ties may distribute renewable power to servers from different workloads

**Problem**: Renewable-energy concentration is two dimensional

- Percentage of server energy needs from renewable sources
- Number of servers powered by renewable energy

**Solution**: Define a metric that counts servers with minimum renewable power

**Problem**: Renewable energy production *and* concentration changes over time

**Solution**: Study instances (not servers)

- Amazon EC2 uses a similar approach for workload changes, called *compute instances*
Renewable-Powered Instances

- **Definition:** $k$ Renewable-Powered Instance ($k$-RPI): a server that gets at least $k\%$ of its energy needs from renewable energy in a given time period $t$.

- **Operational components:** $p_i = \frac{r_i}{d_i + r_i}$, where $r_i$ is the amount of renewable energy to $i$th server; $d_i$ is the amount of grid energy to $i$th server.

- Define $k$-RPI is a server whose $p_i \geq k\%$ during $t$

- See paper for a formal description in power delivery context
Parameters that affect $k$-RPIs in a grid-tied datacenter

- Grid-tie placement: High vs low-level strategies
- Grid-tie placement: Number of grid ties
- Minimum concentration ($k$)
- Renewable energy production patterns
- Server energy needs
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- *Renewable-Powered Instances*: A Metric for Renewable-Energy Concentration

- Study of Renewable-Powered Instances
Trace-Driven Simulation

- Power consumption trace - Energy usage of rack-level PDUs in our department from Mar. to Jun. 2010
  - We linearly scaled the production trace to produce 20% of the energy used by the datacenter

- Renewable energy production trace - 1-year (2004) trace of wind energy production from Cheyenne, WY [sap-insight]
  - The site of a well-known datacenter with on-site renewable energy [greenhousedata.com]

- 500 randomly selected grid-tie placements
Higher RPI usually means more save on grid energy

Figure: CDF of the 100% 1-hour RPI

Some placements allow datacenter managers to track 499 RPI per hour while other placements can’t report any RPI. Grid-tie placement *can* affect a datacenter’s ability to concentrate renewable energy.
Multiple grid ties improved RPI

- Placing a grid tie at 2\textsuperscript{nd} level instead of top level can produce high concentration without sacrificing simplicity
- Multiple grid ties improved RPI production by 1.89X
Normalized RPI Increase (vs 100% RPI)

For $k$-RPI, decreasing $k$ improved some placements much more than others.
The use of multiple grid ties increases the disparity between grid-tie placements. The difference between the 90th percentile and the 10th percentile of placements with 3 grid ties was 388 RPI per hour, more than 2.5 times larger than the difference for placements with 1 grid tie.
Related Work

- Renewable-energy datacenters have received increased attention in (computer) systems research [stewart-hotpower-2009]

- Blink [sharma-asplos-2011] and SolarCore [li-hpca-2011] developed computer systems that adapt to intermittent outages
  - These works used ATS instead of grid tie. Resources get power from only one source at a time

- Le et al. [le-igcc-2010] and Liu et al. [liu-sigmetrics-2011] adapt to changes in the energy mix from utility providers.
  - Our work considers on-site renewable sources and datacenter design, e.g., grid-tie placement
Conclusion

- Server workloads in grid-tied datacenters are powered by a mixture of renewable and grid energy.

- Renewable-Powered Instances (RPI) measure the concentration of renewable energy powering a workload.

- Grid-tie placement can have a significant effect on the concentration of renewable energy:
  - Placing a grid tie at 2\textsuperscript{nd} level instead of top level can produce high concentration without sacrificing simplicity.
  - Multiple grid ties improved RPI production by 1.89X.