Characterizing and Analyzing Renewable Energy Driven Data Centers

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ABSTRACT

An increasing number of data centers today start to incorporate renewable energy solutions to cap their carbon footprint. However, the impact of renewable energy on large-scale data center design is still not well understood. In this paper, we model and evaluate data centers driven by intermittent renewable energy. Using real-world data center and renewable energy source traces, we show that renewable power utilization and load tuning frequency are two critical metrics for designing sustainable high-performance data centers. Our characterization reveals that load power fluctuation together with the intermittent renewable power supply introduce unnecessary tuning activities, which can increase the management overhead and degrade the performance of renewable energy driven data centers.

Categories and Subject Descriptors
C.4 [Performance of System]: Design studies
General Terms
Design, Management, Experimentation
Keywords
Renewable energy, Data center, Power variation, Load tuning

1. INTRODUCTION

Environmental and energy price concerns have become key drivers in the market for sustainable computing. The advances of renewable technologies and continuously decreasing renewable energy costs have made renewable energy driven data centers a proven alternative to conventional utility-dependent data centers and the market is rapidly growing [1].

While there has been prior work discussing renewable energy driven data centers, the impact of renewable energy on data center design is still not well understood. To tune the load power footprint, existing practices either put servers into low power states or enforce a hard limit on server power using DVFS. Although these approaches show impressive power control capability, they sacrifice the computing throughput or response time. In addition, our characterization on renewable energy source shows that it typically takes a long time for the renewable energy generation to resume. As a result, in mission critical data centers, putting servers into low performance state and waiting for the renewable energy to resume is not wise, especially for those parallel computing systems with inter-node workload dependency.

In this study, we propose and evaluate a framework for understanding the key design considerations of wind/solar energy powered data centers. We propose *iSwitch*, a novel dynamic load power tuning scheme for managing intermittent renewable power sources. As an alternative to load power throttling, *iSwitch* intelligently shifts the load from one energy source to another to achieve best load matching. In other words, *iSwitch* dynamically allocates/de-allocates (i.e., "switch") the load power between renewable energy supply and conventional utility grid to meet the time-varying power supply.

We develop a trace-driven modeling technique that combines real-world data center traces and renewable energy resource statistics. Our experiments on *iSwitch* load tuning show the following interesting characteristics:

- Fine grained load tuning provides more accurate tracking of the variable renewable energy supply but does not guarantee high renewable energy utilization. Appropriate ratio between the renewable energy provisioning capacity and the load power consumption demand is also important.
- Load tuning should be carefully performed. Not only does too conservative load tuning miss the opportunity of utilizing precious renewable power but it is also unsustainable since we have to use large-scale battery to store the excess renewable generation. On the other hand, excessive load tuning activities will introduce unnecessary management overhead. To this end, we propose *REU* (renewable energy utilization) and switching frequency to evaluate the load tuning effectiveness.
- The renewable power variation together with the server power fluctuation introduce unnecessary and unbalanced load tuning activities which bring us little benefit on energy utilization but disturb the normal operation of server clusters and degrade the system performance.

2. POWER-AWARE LOAD TUNING

Our prior work in [2] shows that power-aware load tuning can make a difference in renewable energy driven computing systems. In this study, we propose *iSwitch*, a new data center management abstraction for handling hybrid energy source (e.g., renewable power supply plus conventional power grid). The basic idea behind *iSwitch* is *switching*, which is defined as a load tuning activity that will result in redistribution of load power between different power supplies. With *iSwitch*, the computing load is logically divided into two groups: one powered by conventional utility grid, the other powered by renewable energy generation. *iSwitch* dynamically resizes the renewable energy powered load to meet the time-varying power supply.

The implementation of *iSwitch* has many variations. For instance, at the facility level, we can switch servers between different power supplies via power transfer switch; at the system level, the switching operation can also be achieved by virtual machine migration or other data shifting mechanism.

SIGMETRICS'11, June 7-11, 2011, San Jose, California, USA.
ACM 978-1-4503-0262-3/11/06.

In this study, we consider the following two metrics for evaluating renewable energy powered data centers:

Renewable Energy Utilization: The *renewable energy utilization* (REU) is defined as $P_L / P_R \times 100\%$, where P_L is the amount of renewable power that is actually utilized by the load and P_R is the total renewable power generation.

Switching Frequency: The *switching frequency* is defined as the aggregated number of switching activities performed during a fixed duration (e.g. one day or one week). A high switching frequency may introduce more control overhead.

3. EXPERIMENTAL METHODOLOGIES

We developed a framework that simulates dynamic load tuning and hierarchical power control in renewable energy powered data centers. We simulate the renewable power supply using models derived from commercially available wind and solar power generators. We collected real world data center traces and renewable energy source statistics as simulation inputs.

3.1 Data Center Traces

We assume a raised floor data center consisting of 4,800 HP ProLiant DL 360 G6 servers. The peak and idle power of the modeled server are 186W and 62W respectively.

We evaluate data centers with both homogeneous and heterogeneous load variations. The homogeneous configuration assumes that all the servers are running the same workload and have similar utilization levels. In the heterogeneous configuration scenario, the servers are grouped into several clusters and different clusters have different utilization profiles.

We generate the homogeneous utilization traces from the raw data provided by the Internet Traffic Archive [3]. The server utilization traces we generated represent a one-week server load variation including idle period, peak hours and daily surge. For heterogeneous utilization traces, we collected server utilization traces from a real-world academic HPC center, which has five major clusters with different service targets and loads.

3.2 Renewable Power Supply Traces

We use the sun irradiance and other meteorological data (i.e. temperature and wind speed) from the Measurement and Instrumentation Data center (MIDC) [4] of the National Renewable Energy Laboratory. We choose meteorology data from stations with different local renewable energy potentials. The raw data traces we obtained have different measurement time intervals between 1-minute to 1-hour. We generate representative power supply trace sets for different evaluation purposes.

4. RESULTS

In Figure 1 we show the renewable energy utilization (REU) obtained from different RES traces (*H1~L2*) with different provisioning capacities (*Low*, *Moderate* and *High*). *Facility* is a conventional facility-level load matching scheme.

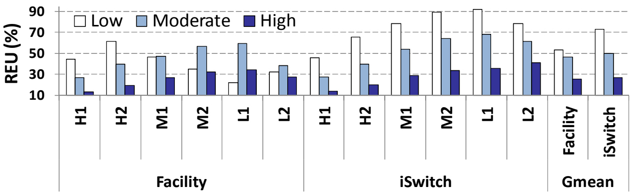

Figure 1: Renewable energy utilization

As can been seen, *iSwitch* shows better renewable energy utilization since its fine-grained load tuning provides better renewable power supply tracking. When the installed energy capacity is low, *iSwitch* improves the REU by 54% compared with *Facility*; when the installed energy is high, the improvement is only 5%. The reason is that *iSwitch* improves energy utilization but cannot absorb all the over-provisioned power. Therefore, a thoughtful capacity planning is very important for renewable energy driven data centers.

We evaluate the impact of supply/load variation on switching frequency, as shown in Figure 2. The supply/demand variation has strong influence on the load tuning activities. Low renewable supply variation and low load power variation will reduce the switching frequency significantly. A low switching frequency is always preferred since it means lower control overhead.

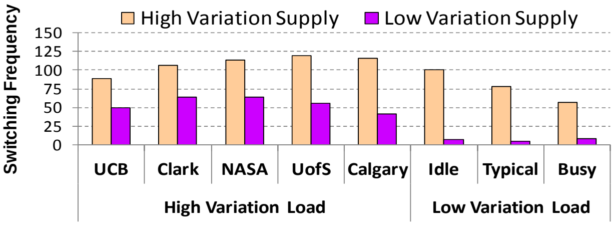

Figure 2: Average switching frequency (iSwitch)

We found that conventional power tracking schemes incur unnecessary load tuning activities. In Figure 3, we compare a conventional tracking scheme with our modified load tuning control which features a light-weight tuning mechanism. Conventional tracking schemes require significant load tuning efforts (up to 2X of our design) while receive less than 10% energy return. Therefore, we need to carefully explore the tradeoff between switching frequency and renewable energy utilization. Overly aggressive load tuning schemes introduce significant overhead (e.g., communication traffic) which may overweigh the benefit of REU improvement.

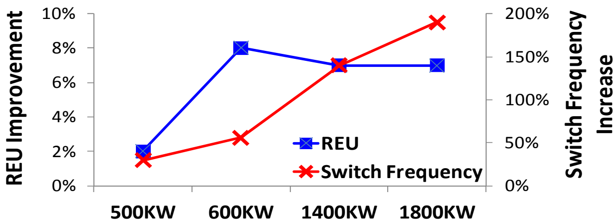

Figure 3: REU benefit and control effort of conventional design compared to iSwitch (x-axis: renewable energy capacity)

5. CONCLUSIONS

Designing renewable energy driven data centers is challenging and requires thoughtful coordination between the renewable power supply and load power. In addition, appropriate optimization is necessary to reduce management overhead.

6. REFERENCES

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