Data Center Energy Systems: Current Technology and Future Direction

Santosh Chalise, Amir Golshani, Shekhar Raj Awasthi, Shanshan Ma, Bijen Raj Shrestha, Labi Bajracharya, Wei Sun and Reinaldo Tonkoski
Department of Electrical Engineering and Computer Science, South Dakota State University, Brooking SD
santosh.chalise@sdstate.edu

Abstract— **Data centers are becoming a significant energy consumer. Server workload, cooling, and supporting infrastructure represents large loads for the grid. This paper intends to present a comprehensive literature review that account for generation, loads, storage, and topology of data centers. It is shown that green data centers are emerging which incorporate renewable energy sources to cap their carbon footprint. Different data center metrics have been introduced which shows data center efficiency and utilization of resources. Utilization of different power supply topologies and storage to improve the availability, and how various components can play role in energy management to improve the performance of data centers are presented.**

Keywords— data center; generation mix; load; storage; topology

I. INTRODUCTION

The rapid increase in cloud-scale services is driving a growth in data centers. Resources and support-infrastructures inside these centers consume a lot of energy. It is estimated that, currently, data centers consume about 3% of the world's electricity production [1] and should double in every 5 years [2]. By 2020, data centers should consume approximately 8% of the total world's energy [3] and emit 340 metric megatons of CO_2 annually [4].

Data centers are mostly using two strategies to reduce greenhouse gases emissions [5]. First, improve energy efficiency by implementing best practices in design and operation and second, use of renewable energy sources [6, 7]. However, renewable energy sources, like solar and wind, are not predictable and cannot be relied upon. Thus, there is a challenge to integrate renewable energy sources in a cost effective way and also ensure the reliability and power quality required by data centers.

To guarantee a reliable power supply, data centers employ a variety of energy resources such as: uninterruptible power supply (UPS) systems and backup generators, to make up when the grid is not present [8]. In addition, all critical loads are dual powered. Data centers are becoming key loads in distribution systems and has various energy resources that are not being utilized often. Therefore, a lot of attention has been drawn to better integrate them in the distribution systems. Data centers are changing in various aspects such as: energy mix, efficiency, storage capacity and architecture, etc. This paper presents holistic review of data center energy supply system using information disseminated throughout the literature. The objective of this review paper is twofold. First, familiarize with the typical data system components, introduce the current trend on data center energy mix, characteristics of the load, power supply system topologies, current and future trends of storage and the metrics used to measure the data center performance. Second, introduces how the unutilized or underutilized energy resource such as storage, can be used to provide the ancillary service such as demand response.

This paper is organized as follows. Section II presents the description of the data center energy resources, energy mix and current metrics used to measure performance. Section III provides the characteristic of the typical data center load characteristics. Section IV presents the storage technologies, their comparison and use in energy management algorithms. Different topologies of data centers are discussed in Section V, followed by the conclusions in Section VI.

II. DATA CENTER ENERGY RESOURCES

Data centers in the U.S. consumed 2% of all electricity usage in 2010 [9]. Utility, as a primary source, provides electricity for data centers. Diesel and natural gas generators are employed as emergency sources during a utility power outage. Since coal and gas plants are the dominant sources of the electricity produced in the U.S., the current growth in data centers energy consumption will produce large carbon emission and incur high electricity cost. Environmental concerns, as well as energy prices, obligate companies to build green data centers, which partially or completely use renewable energy sources, such as wind and solar. Incorporating renewable sources can reduce carbon footprint, energy price, and loss, but their intermittent nature is a key challenge. New generation of data centers will be either own renewable energy sources or buy it directly from an existing off-site generation (co-location). More importantly, they will play an active role instead of being a pure consumer to the utility.

A. Data Center Platform

In small scale, researchers from University of Mass. at Amherst have built Blink [4] powered by two micro wind turbines and two solar panels, as a research platform. HP Labs has recently presented a datacenter partially powered by a PV solar array [10]. Researchers from Rutgers University have introduced Parasol, a prototype of green micro data center based on solar panels [4].

In large scale, ABB is working to develop a new DC data center, to be launched by the end of 2015 [11]. Apple is deploying two large solar farms (20 MW) to provide a significant amount of renewable energy for its data center in Maiden, NC. Apple also plans to power its Reno data center from 100% solar and geothermal energy. MidAmerican Energy

978-1-4673-8040-9/15/$31.00 ©2015 IEEE

announced an agreement to supply Google's Iowa data center with up to 407 MW of wind energy [12]. Facebook planned to purchase energy from a new wind project nearby its data center in Iowa. Microsoft is buying 110 MW of wind energy from a wind farm to power its San Antonio data center [13]. Table I summarizes various data center powered by 100% renewable energy [7]. For example, in Maiden NC., the apple-owned renewable sources generate nearly 167 GWh of energy per year, which exceeds the total energy consumed in fiscal 2013 [14].

TABLE I. DATA CENTERS POWERED BY 100% RENEWABLE ENERGY.

Data Center Company	Facility Location	Power Capacity (MW)	% Resource Mix of Local Utility (Natural Gas - Nuclear - Coal)	PUE
Google	Council Bluffs, IA	105	19% - 6% - 45%	1.12 [15] (Average)
	Pryor, OK	49	25% - 0% - 46%	
	Hamina, Finland	19	13% - 32% - 22%	
Apple	Prineville, OR	2	12% - 0% - 60%	1.5 (North Carolina) [16]
	Maiden, NC	19	4% - 57% - 38%	
	Newark, CA	15	27% - 21% - 0%	
	Reno, NV	5	51% - 15% - 7%	
Facebook	Lulea, Sweden	70	1% - 40% -1%	1.07 (Lulea, Sweden) [17]
	Altoona, IA	70	19% - 6% - 45%	
Microsoft	San Antonio, TX	27	37% -13% - 27%	1.125 [18]
Yahoo	Lockport, NY	23	36% - 23% - 12%	1.08 [19]

B. Data Center Power Management

Power management in green data center is critical to handle renewable sources uncertainties by intelligently managing the workloads. The location of data centers could spread over multiple geographical areas. Their computational workloads can be adjusted dynamically by shifting to the area where more renewable sources are available [20]. Adaptive power management has been proposed in [21] to minimize the total power cost under uncertainties. A workload scheduling algorithm is introduced in [22]. It can reduce the brown energy consumption up to 40% across geographically distributed data centers with renewable energy sources. GreenSlot is developed to schedule renewable source usage to lower brown energy consumption [23]. GreenSwitch can effectively reduce electricity costs and carbon footprints by managing workload, energy sources, and storages at the same time [4].

In the future, with the rapid expansion of cloud computing and their increase in energy demand, it is expected that more renewable sources will be used in data centers. Governments continue providing incentives for green energy to reduce the carbon emissions. Also, advances of new technologies with higher efficiencies will reduce the capital cost. However, there are various difficulties associated with demand and supply uncertainties needs to be addressed.

C. Data Center Effectiveness Metrics

Metrics are to measure and improve the effectiveness of the some value, function or parameter [24]. In case of data center, metrics such as power usage effectiveness (PUE), Water Usage Effectiveness (WUE), Energy Reuse Effectiveness (ERE), Data Center Compute Efficiency (DCCE), Clean Energy Index have been defined for self-improvement and for comparison with other data center. Among metrics, PUE is the simple and primarily used metrics in data centers. PUE represents how much of this power is actually used by the IT equipment, in contrast to power used by cooling, lighting and other additional plant within the data center [25] (PUE = Total Facility Power/IT equipment power). Ideally, the value of PUE should be 1, a lower PUE value indicates a more efficient data center. According to the Uptime Institute's data center survey in 2014, the global average PUE of largest data centers is around 1.7 [15]. Some of the reported large data center's PUEs are presented in Table I.

PUE is a simple metrics but it can cause significant problem when used incorrectly. One example of such incorrect use is when applied to only a section of a data center's infrastructure. Further, PUE does not handle improvements in IT efficiency properly. Therefore, its use should be focused primarily on the infrastructure and its improvements [24].

III. DATA CENTER LOAD

Data centers today contribute a substantial percentage to global energy usage. As technology advances, data centers are becoming more complex, causing the amount of computational power and power density to increase drastically. With the increased power density there is need of load management in data center.

A. Data Center Load Breakdown

Data center houses a large number of heterogeneous components for computing, storage, and networking, together with an infrastructure to distribute power and provide cooling [26]. The data center load is divided into interactive (inflexible) and delay-tolerant (flexible) load [27]. The equipment that must not immediately lose power in the event of a utility outage is collectively called "inflexible load" i.e. data center server, cooling equipment for server and the other supporting infrastructure are termed as flexible load [28].

A survey by the LBNL (Lawrence Berkeley National Laboratory) presents the average load contribution of different component in data center. A benchmark for 12 data centers situated in different geographic location was developed. The average load breakdown for a typical data center is as follows: Server - 46%, Cooling - 31%, UPS - 8%, Lighting - 4% and Other miscellaneous - 11% [29].

Data centers contain extremely flexible loads. The servers and cooling loads can be adjusted significantly. The load flexibility of data centers is described in [27] and shows that energy management can be applied in data center without violating service level agreement, which are the sets of the commitment in term of service reliability done by the service provider with the consumer. The server load in data center is highly unpredictable which, depends upon the user activity and fluctuate during day. An active server, consumes on average of 50% of the rated power even when idle [30]. The ratio P_{peak}/P_{idle} is the power elasticity of the server. High elasticity means less power consumption when the server is idle [31].

The computer room air conditioning (CRAC) units chill hot air and maintain a constant temperature. The CRAC units are oriented in such a way that there are hot and cold aisles in the room and which recycles the hot air from the servers by cooling it and pumping it back into the under-floor plenum of the data center. Depending upon the server loading the cooling load also varies [32]. All other load in the data center are almost constant. The load profile of the data center depends upon the location as well. The peak load varies depending upon the weather condition of external environment. For instance, the average peak to average ratio (PAR) of data center loads is within the range of 1 to 4.

B. *Trend in Load Management and Energy Saving:*

Generally, data center servers must be provisioned to handle peak load and guarantee service availability which cost very high. In order to reduce the datacenter operating cost the following load management techniques are being used.

Demand response (DR) provides an opportunity for consumers to reduce or shift their electricity usage during peak periods. Reducing peak demand provides not only the economic benefits but also helps to reduce the carbon emission. Since data centers are highly automated, monitored and include flexible loads, they can adopt both traditional and advanced demand response strategies. According to the study performed by Lawrence Berkeley National Laboratory (LBNL) [33] in four California data centers, a demand saving of 25% at the data center level or 10% to 12% at the whole building level can be achieved utilizing various DR strategies. Two demand response schemes including workload shifting and use of local power generation have been proposed in [34]. Numerical results show that utilizing both schemes can provide 35-40% reductions of energy costs, and 10-15% reductions of emissions. Aggregation of several small data centers have a large potential to participate in DR program. The simulation result presented in [35] shows that by using DR load control method, 30% power reduction can be achieved. It is our perspective that in the future more data centers will be participating in DR program through onsite backup generators and storage, workload management, and fast load shedding (cooling and lightning loads).

Workload scheduling in geographically distributed data centers. In order to support the vast customer demands, service providers host large computer systems over a number of geographical distributed datacenters. Each may use different electricity providers (some of which may be using renewable energy resources). Throughout these different locations, the electricity costs may vary, and the locations of datacenters with lower electricity costs are favored. When there is peak load in any datacenter the server request may forward to the other locations [36]. One major drawback of using this method could be the increase in carbon footprint when the least expensive source of electricity are based on fossil fuels, thus might not be an environment friendly solution.

Pre-cooling server area. Large datacenters require massive cooling capacity to eliminate heat generated by the IT equipment. On average, for every watt of power consumed by IT equipment, data centers need another watt of power to operate the equipment needed to remove the heat. Datacenter uses the concept of pre-cooling to reduce the cooling power demand in which they lower the internal temperature of the datacenter during the off-peak hours, when energy price is cheap. This allows turns off the chiller and pumps during the peak load hour, letting the temperature vary a bit higher than usual to avoid paying the high cost of energy [37].

IV. STORAGE

Continuous and smooth power supply system is the most basic requirement of the data center. Cost of power interruption could be very high especially for the e-commerce related business [38]. In order to provide continuous power during grid outages, data centers are provided with diesel generators and uninterruptible power supply (UPS) systems [8, 11]. UPS plays an important role in maintaining data center uptime by providing continuous power until backup generators start in the event of grid failure.

Storage is the most critical component and requires regular maintenance. Among various energy storage technologies, batteries, ultracapacitors, flywheel, compressed air energy storage, fuel cell are making their way to the data center [39, 40]. Among the aforementioned storage technologies, about 99% of the UPS manufacturers uses batteries as energy storage [11]. This is because ultracapacitors and flywheels can provide power only for a few seconds but batteries can be used for minutes to hours. In addition, lead acid is the mostly used storage technology in today's data center because of low cost per watt [40]. However, these battery have short lifetime compared to others. New battery technologies such as aqueous hybrid ion battery, fuel cell, meta-air battery are in developing phase to overcome the issue with lead-acid battery. Failure of battery is the main cause of data center power outages. The UPS battery failure cause approximately 55 percent of data center outages [38], thus there is a need of a more intelligent system and architecture to reduce the UPS equipment failures.

Use of battery is not only limited for data center power availability but also for the power quality improvement and participation in energy management. For power quality, data center's input voltage sags and swells can be compensated using storage. Typically, small data centers with less than 200 kW capacity, have about 30 minutes of battery storage, but larger data centers typically have 15 minutes of battery backup system [8, 11, 30, 40] to support the peak load. Since large data centers also consist of an emergency generator that can assume a full load within 10-15 seconds, only about 2% of battery capacity will be utilized during the transition period [41]. Therefore, the underutilized battery system can take part in the energy management scheme such as demand response [39] and peak power saving [42]. Further, use of threshold value in distributed storage, is presented in [43]. Study presents, if the power required is higher than the threshold, storage supply the power for peak shaving purpose. However, using battery in energy management can impact the battery lifetime because of frequent charging and discharging cycles and should impact the maintenance schedule of batteries.

Centralized architecture is the traditional method of using storage in data center but this is changing towards the distributed architecture in current state of the art high density data centers [39, 43]. In centralized, entire data center power either comes from the utility or from the storage. This type of architecture is suitable if the space inside the data center server rooms is limited, then, batteries can be placed outside in a separate room [39]. However, in the centralized architecture, the impact of single point failures can lead to significant loss of power and consequently outages [11].

The distributed architecture can provide higher reliability and lower losses in conversation. In this architecture, storage is distributed throughout the data center in different levels of the power supply system hierarchy (PDU - power distribution unit, rack, and server levels) [43]. Further studies to determine the type of storage and location of connection was presented in [39], including the trade-offs of placing them at different levels of the power hierarchy, and quantifying the resulting cost-benefit trade-offs as a function of workload properties. Study concluded that more we go towards the rack level, higher cost saving can be obtained. Some industry examples from the study are Facebook and Microsoft use storage in the rack and PDU levels and Google uses storage in server level in their high density data centers. Distributed architecture also possesses challenges due to the lack of heavy overprovisioning [43]. It is an open question now and need more studies to determine whether or not the hybrid architecture (centralized + distributed) provide the highest level of reliability and efficiency promoted.

V. Data center Topologies

The major concern for data centers is to ensure the continuity of energy supply and improve the energy efficiency [11]. The tier systems with different topologies contribute to improve the reliability and availability. The comparison of AC and DC energy distribution in the data center gives some guidance on the electrical configuration design.

A. Tier Classifications

The Uptime Institute defines four tier system topologies for describing the availability of system as shown in the Fig.1 [11, 44]. It can be seen that the difference between Tier I and Tier II is the number of generator and UPS. In Tier II, additional generators and UPS provide backup for the most critical components. The significant difference between Tier II and Tier III is the number of delivery path. In Tier III, the alternative power from a second utility provides the parallel power support for the critical IT load, in case of power failure of the primary path. However, there is no requirement to install UPS in the passive path. Therefore, Tier III system is vulnerable to utility conditions. Tier IV provides a complete redundant system by adding two active power delivery paths. It can enable dual systems to run actively in parallel. In both power paths, it contains N+1 UPS and generator sets. The comparison of performance in different Tier systems is shown in Table II. It shows that higher level of Tier system has greater system availability.

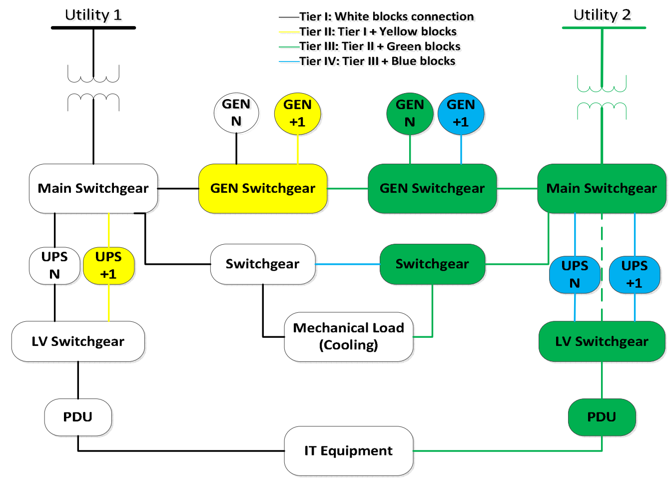

Fig.1. Topologies of different Tier systems.

TABLE II. Comparison of Tier Systems

	Tier I	Tier II	Tier III	Tier IV
Number of Delivery Path	Only 1	Only 1	1 Active and 1 Passive	2 Active
Annual IT Downtime	28.8 hr	22 hr	1.6 hr	0.4 hr
Site Availability	99.67%	99.75%	99.98%	99.99%
Practice Example	NA	TTB, Target	Gold Camp, State of CA	Lone Mountain, Via Vest

B. AC and DC Energy Distribution in Data Centers

Typically the discussion of AC versus DC in the data center starts with efficiency. Since a data center draws a significant amount of power, a relatively small increase in efficiency can lead to a reduction in operating costs. The advantages of DC datacenter over AC are energy efficiency, reliability, smaller carbon footprint, lower installation and maintenance costs, scalability, easier integration of renewable energy, utility rebates and credits, and safety. Total energy savings can reach upward of 30% for both mechanical and electrical power savings [45]. Because of this efficiency, DC systems can use various utility rebates and credits available for corporations. There are fewer power components in a DC system, making it more reliable than an AC system. With fewer power conversions, there is also less heat to affect the electronic equipment. It is because every conversion wastes energy and produces heat. And while any single conversion may be in the mid 90 percent range, they don’t add together, they multiply [45]. When energy to remove the heat is considered, it is only about 50% of the energy that actually gets used by the processors in the servers.

VI. Conclusion

This paper presented a comprehensive review of the previous research works and the future trends of data center energy infrastructure. The integration of renewable sources in data centers will be an active area of research in the future mostly dominated by solar and wind. With new sophisticated power management algorithms, problems of variability and uncertainty in power generation by renewables could be reduced. New energy storage technologies such as Li-Ion battery, fuel cell etc. are making their way to replace low efficient and short life lead-acid batteries. Not only the technologies, but also the traditional centralized storage architecture is changing. However the advantages of going towards the distributed architecture has not been fully understood. Demand response approaches are expected to play an important role to either shift or shave peak data center workload. Future data centers will be more energy efficient due to the advancement of new technologies and power management algorithms.

ACKNOWLEDGMENT

The authors would like to thank Microsoft Inc. and South Dakota Board of Regents (SDBoR) for their financial support.

REFERENCES

[1] A. Rallo. (2014, 15 November). *Industry Outlook: Data Center Energy Efficiency*. Available: http://www.datacenterjournal.com/

[2] D. Shaw, "EPA's 2007 Report on the Environment: Science Report (SAB Review Draft)," 2005.

[3] N. Deng, C. Stewart, and J. Li, "Concentrating renewable energy in grid-tied datacenters," in *Sustainable Systems and Technology (ISSST), 2011 IEEE International Symposium on*, 2011, pp. 1-6.

[4] Í. Goiri, W. Katsak, K. Le, T. D. Nguyen, and R. Bianchini, "Parasol and greenswitch: Managing datacenters powered by renewable energy," in *ACM SIGARCH Computer Architecture News*, 2013, pp. 51-64.

[5] A. SCHWARTZ. (2013). *Does Amazon Have A Renewable Energy Problem?* [Online]. Available: http://www.fastcoexist.com/

[6] L. Zhao, J. Brouwer, J. Liu, S. James, J. Siegler, A. Kansal*, et al.*, "Fuel Cells for Data Centers: Power Generation Inches From the Server."

[7] Greenpeace.org, "Clicking Clean: How Companies are Creating the Green Internet," April 2014.

[8] R. A. Jouneghani, M. Pipattanasomporn, and S. Rahman, "Flywheel Energy Storage Systems for Ride-through Applications in a Facility Microgrid," *IEEE Transactions On Smart Grid,* vol. 10, 2012.

[9] A. Rahman, L. Xue, and K. Fanxin, "A Survey on Geographic Load Balancing Based Data Center Power Management in the Smart Grid Environment," *Communications Surveys & Tutorials, IEEE,* vol. 16, pp. 214-233, 2014.

[10] M. Arlitt, C. Bash, S. Blagodurov, Y. Chen, T. Christian, D. Gmach*, et al.*, "Towards the design and operation of net-zero energy data centers," in *13th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, 2012, pp. 552-561.

[11] ABB. (2013). *ABB Review: Data Centers*. Available: http://www.abb.com/abbreview

[12] MidAmerican Energy. (2014, April 22). *Google and MidAmerican Energy Company Announce Renewable Energy Agreement in Iowa* [Online]. Available: http://www.midamericanenergy.com/

[13] Reuters. (2013, November 4). *Microsoft to buy wind power for data center in Texas* [Online]. Available: http://www.reuters.com/

[14] Apple Inc., "Environmental Responsibility Report," 2014.

[15] Google Inc (2014). *Efficiency: How we do it*. Available: http://www.google.com/about/datacenters/efficiency/internal/

[16] C. R. Chowdhury. (2013, May 28). *Cloud Computing Has Green Appeal* Available: http://www.enterprisetech.com/

[17] Facebook Inc. (2013, June 12). *Luleå goes live*. Available: https://www.facebook.com/

[18] Microsoft. (2014, November), Microsoft's Cloud Infrastructure: Datacenters and Network Fact Sheet.

[19] Vertatique. (2015, January 13). *Mega Data Centers*. Available: http://www.vertatique.com/mega-data-centers-boom-or-bust

[20] S. Bird, A. Achuthan, O. Ait Maatallah, W. Hu, K. Janoyan, A. Kwasinski*, et al.*, "Distributed (green) data centers: A new concept for energy, computing, and telecommunications," *Energy for Sustainable Development,* vol. 19, pp. 83-91, 2014.

[21] R. Kaewpuang, S. Chaisiri, D. Niyato, L. Bu-Sung, and W. Ping, "Adaptive Power Management for Data Center in Smart Grid Environment," in *Parallel and Distributed Processing with Applications (ISPA), 2012 IEEE 10th International Symposium on*, 2012, pp. 119-126.

[22] B. H. Changbing Chen, Xueyan Tang "Green-AwareWorkload Scheduling in Geographically Distributed Data Centers," *Cloud Computing Technology and Science (CloudCom), 2012 IEEE 4th International Conference on,* pp. 82-89, 2012.

[23] Í. Goiri, R. Beauchea, K. Le, T. D. Nguyen, M. E. Haque, J. Guitart*, et al.*, "GreenSlot: scheduling energy consumption in green datacenters," in *Proceedings of 2011 International Conference for High Performance Computing, Networking, Storage and Analysis*, 2011, p. 20.

[24] Y. Joshi, P. Kumar, B. Sammakia, and M. Patterson, *Energy Efficient Thermal Management of Data Centers*: Springer, 2012.

[25] C. Belady, A. Rawson, J. Pfleuger, and T. Cader, "Green grid data center power efficiency metrics: PUE and DCiE," Technical report, Green Grid2008.

[26] G. Chen, W. He, J. Liu, S. Nath, L. Rigas, L. Xiao*, et al.*, "Energy-Aware Server Provisioning and Load Dispatching for Connection-Intensive Internet Services," in *NSDI*, 2008, pp. 337-350.

[27] A. W. Z. L. I. Liu and H. Mohsenian-Rad, "Opportunities and Challenges for Data Center Demand Response," 2014.

[28] Z. Liu, I. Liu, S. Low, and A. Wierman, "Pricing data center demand response," in *Proc. ACM Sigmetrics*, 2014.

[29] Lawrence Berkeley National Laboratory. *Benchmarking: Data Centers - Case Study Reports [Online]*. Available: http://hightech.lbl.gov/

[30] V. Kontorinis, J. Sampson, L. E. Zhang, B. Aksanli, H. Homayoun, T. S. Rosing*, et al.*, *Battery Provisioning and Associated Costs for Data Center Power Capping*: Citeseer, 2012.

[31] M. Ghamkhari and H. Mohsenian-Rad, "Data centers to offer ancillary services," in *Smart Grid Communications (SmartGridComm), 2012 IEEE Third International Conference on*, 2012, pp. 436-441.

[32] A. Dhesikan, "Data Center Energy Efficiency: Power vs. Performance," 2012.

[33] G. Ghatikar, "Demand response opportunities and enabling technologies for data centers: Findings from field studies," 2012.

[34] Z. Liu, A. Wierman, Y. Chen, B. Razon, and N. Chen, "Data center demand response: Avoiding the coincident peak via workload shifting and local generation," *Performance Evaluation,* vol. 70, pp. 770-791, 2013.

[35] C. J. Tang, M. R. Dai, C. C. Chuang, Y. S. Chiu, and W. S. Lin, "A load control method for small data centers participating in demand response programs," *Future Generation Computer Systems,* vol. 32, pp. 232-245, 3// 2014.

[36] R. Y. Alawnah, I. Ahmad, and E. A. Alrashid, "Green and Fair Workload Distribution in Geographically Distributed Datacenters," *Journal of Green Engineering,* vol. 4, pp. 69-98.

[37] C. Pfeiffer, P. MALTBAEK, and E. Kulali, "System and method for using data centers as virtual power plants," ed: Google Patents, 2013.

[38] Ponemon Institute LLC, "2013 Cost of Data Center Outages " 2013.

[39] D. Wang, C. Ren, A. Sivasubramaniam, B. Urgaonkar, and H. Fathy, "Energy storage in datacenters: what, where, and how much?," *ACM SIGMETRICS Performance Evaluation Review,* vol. 40, pp. 187-198, 2012.

[40] S. McCluer and J.-F. Christin, "Comparing data center batteries, flywheels, and ultracapacitors," *White Paper,* vol. 65, 2008.

[41] HITEC Power Protection. (2014). *Kinetic Energy Storage VS Batteries in Data Center Applications [Online]*. Available: http://www.datacentre.me/

[42] S. Govindan, A. Sivasubramaniam, and B. Urgaonkar, "Benefits and limitations of tapping into stored energy for datacenters," in *Computer Architecture (ISCA), 2011 38th Annual International Symposium on*, 2011, pp. 341-351.

[43] V. Kontorinis, L. E. Zhang, B. Aksanli, J. Sampson, H. Homayoun, E. Pettis*, et al.*, "Managing distributed UPS energy for effective power capping in data centers," in *Computer Architecture (ISCA), 2012 39th Annual International Symposium on*, 2012, pp. 488-499.

[44] W. P. Turner IV, "Tier Classification Define Site Infrastructure Performance."

[45] G. AlLee and W. Tschudi, "Edison's Data Center: 380Vdc brings Reliability and Efficiency to Sustainable Data Centers."