2012 IEEE International Conference on Power Electronics, Drives and Energy Systems
December16-19, 2012, Bengaluru, India

Efficient Data Center design using Novel Modular DC UPS, Server Power supply with DC voltage and Modular CDU cooling

Subrata Mondal, Member IEEE
Inertech, Danbury, CT, 06810, USA
Subrata.Mondal@inertechsystems.com

Earl Keisling
Inertech, Danbury, CT, 06810, USA
Earl.Keisling@inertechsystems.com

***Abstract* - An efficient cost effective novel modular scalable Data Center topology using Direct Current Uninterruptible Power Supply (DC UPS), server power supply with DC input and Cooling Distribution Unit (CDU) for IT load incorporating hybrid (both AC and DC voltage) distribution has been proposed in this paper. There is mismatch of infrastructure (both mechanical and electrical) capability and IT load in the existing Data Center. It takes years to reach equilibrium when IT load is balanced with infrastructure load capabilities. Major energy efficiency improvements and technological innovation of the Data Center industry had not been achieved for both electrical and mechanical infrastructure in the past, even as computing hardware and software follow Moore's law and has become efficient. A detailed analysis of the topology is presented to validate effectiveness of the proposed topology. Efficiency improvement and cost reduction of the proposed Data Center topology is found to be quite significant.**

Keywords – DC UPS, Server Power Supply, IT load, Data Center, CDU, PUE, Modular, Efficiency.

I. INTRODUCTION

With the emergence of massive Data Center growth, coupled with evolving IT loading requirements comes the need to provide more reliable and flexible cooling and electrical infrastructure, that mirrors the elasticity of the IT load that it serves. The increase in demand for Big Data is due to the enormous growth of Web-2.0-enabled business world viz. financial, e-commerce, pharmaceutical, and multi-media initiatives world wide. The system platforms rely on computer processing, storage and routing capabilities. This equipment consumes an enormous amount of energy as well as requires sophisticated support cooling infrastructure. Most current Data Centers are supported by inefficient cooling and electrical systems. They were not designed to be flexible and or elastic to the varying IT loads that they handle. Rather, in most cases they were designed to be highly reliable with emphasis on redundancy. This paradigm led to overbuilding and stranding of under-utilized power and cooling capability. The market trend caused an explosion in building (CAPEX) and operating (OPEX) cost associated with over built, under utilized expensive equipment, hardware, and systems. This inefficient infrastructure represents significant Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) cost problems for businesses. Data Centers and businesses with mission critical digital data storage needs a high efficient and reliable infrastructure systems solution to reduce overall Total Cost of Ownership (TCO). It has been measured that digital storage market demand doubles every 18 months, indicating market Compound Annual Growth Rate (CAGR) of ~20% for the next 5 years. It is calculated that ~820 MW of new IT demand exists in the US market for 2012, indicating that there is large opportunity for revenue as it is a sizeable market of ~$9.84 billion assuming typical traditional Data Center Capex is $12 million per MW.

Fig. 1 shows the existing Medium Voltage (MV) Data Center topology with traditional centralized on-line double-conversion AC UPS, server power supply with AC input voltage and standard Computer Room Air Conditioning (CRAC) IT cooling method to remove heat from IT space. Regular CRAC units are not efficient and use lots of water. MV distribution (e.g. 13.8 kV) provides cost effective Data Center design as it reduces copper conduction cost greatly in comparison to conventional

978-1-4673-4508-8/12/$31.00 ©2012 IEEE

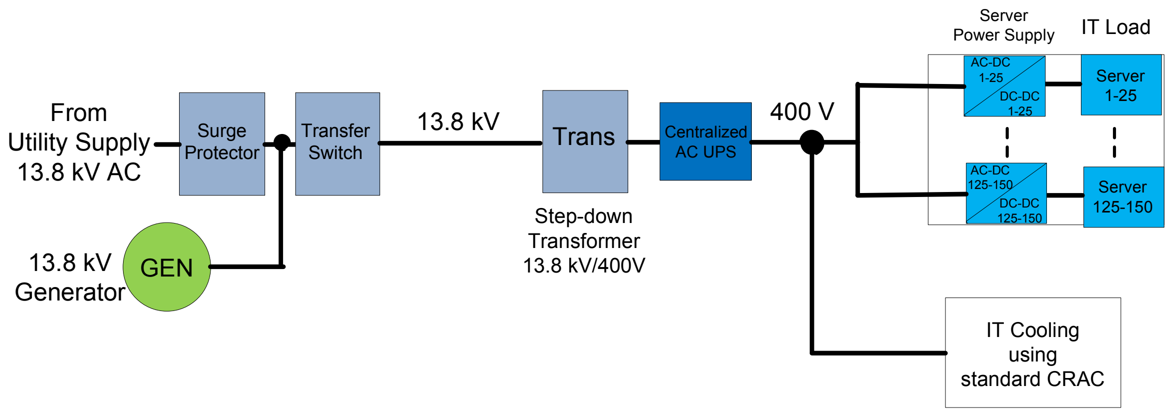

Figure 1. Data Center topology with Centralized Double conversion AC UPS & IT server power supply with AC Distribution

low voltage AC distribution (e.g. 480 V). IT and mechanical loads of Data Center are powered by utility supply via UPS. Generator starts once the utility disturbance is greater than few seconds. During transition, load is still powered by the UPS module via its storage battery and DC-AC inverter section. Once generator has reached its reference speed and stabilized, the transfer switch shifts the primary utility power source to generator source. Thereafter, load is entirely powered by the generator via on line UPS. Load is shifted to the battery of UPS system from the generator once utility disturbance is no longer present. Later transfer switch shifts the primary power source to the utility feeder via on-line UPS.

Efficiency of Data Center is measured by using Power Usage Effectiveness (PUE) metric as shown in the following equation.

$$PUE = (\text{Total Watts In}) \div (\text{IT equipment Power}) \quad (1)$$

Double (AC-DC and DC-AC) conversion AC UPS is shown in Fig. 2. It consists of three sections viz. AC-DC converter section, DC-AC inverter section and storage battery (low density shorter life cycle lead-acid battery) with or without DC-DC converter section. Converter section converts 3-phase input AC voltage to intermediate high DC voltage. Inverter section converts intermittent DC voltage back to 3-phase AC voltage. Double conversion of UPS increases overall losses and PUE of the Data Center.

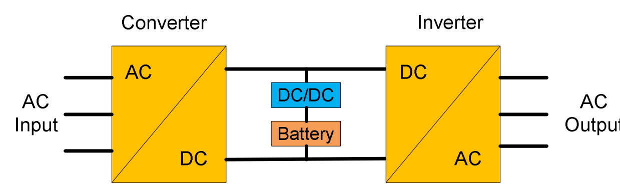

Figure 2. Block Diagram of Double Conversion AC UPS

Fig. 3 shows existing Data Center server power supply with single-phase AC input voltage. It consists of two sections viz. AC-DC section and DC-DC section. AC-DC section converts input AC voltage to intermediate DC voltage. DC-DC section converts intermediate DC voltage to multi output DC voltages (like 3.3 V DC, 5 V DC, 12 V DC and -12 V DC) to IT server computer load. Double conversion of server power supply with AC input voltage increases overall losses and PUE of the Data Center.

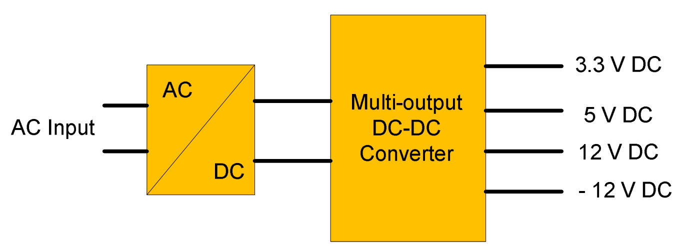

Figure 3. Block Diagram of Double Conversion IT Server power supply with input AC voltage

II. PHILOSOPHY AND CONCEPT OF DEVELOPED TOPOLOGY

There is mismatch of infrastructure (both electrical and mechanical) capability and IT load in the existing Data Center. Efficiency improvement of Data Center is possible by using modular scalable on-line double conversion AC UPS in place of centralized double conversion AC UPS and modular CDU as shown in Fig. 4. Six modular AC UPS (UPS 1 to UPS 6) are needed for 2 MW IT load. Each modular AC UPS is rated at ~400 kW to match IT kW cooling capacity of individual CDU. Efficiency of modular UPS is higher due to higher loading factor in comparison to large centralized UPS (Fig. 1) where initial IT loading factor is not high. In traditional Data Center, UPS capacity is selected based on future IT load requirement. In the beginning, centralized UPS is loaded lightly and hence UPS efficiency is much less. It takes years to reach equilibrium when IT load is balanced with infrastructure load capabilities. With modular UPS design, it is possible to add UPS in steps based on future IT load demands. Data Center Capex cost is also low due to minimum investment in infrastructure.

Server racks are placed in rows separated by alternate hot and cold isle assembly. The primary heat rejection cooling coils reside in a contained hot aisle assembly. The hot aisle coils receive refrigerant coolant fluid from CDU. The heat is transported to the CDU where it is exchanged and transported to an outdoor heat rejection cooler unit. A hot aisle assembly can range from as few as four racks to as many as forty racks per assembly. The kW output density can also vary from relatively 2 kW low density heat output to over 50 kW. A rack assembly can be fed from a single CDU or multiple CDUs. It depends upon rack density as well as redundancy requirements. The average CDU is rated for an IT cooling capacity of approximately 250-350 kW each. The cooling cycle operates in an optimized state at all times in response to the load (IT heat output) as well as in response to the environmental conditions. The CDU system is multiple times more efficient as it uses less energy (82% less than conventional Data Center installation [1]) to maintain a lower temperature than standard Data Center cooling systems like traditional CRAC method. CDU has low mechanical PUE at light load as well as under extreme IT load condition. There is also significant drop (average 80% reduction) of water usage by CDU with WUE of 0.58 [1].

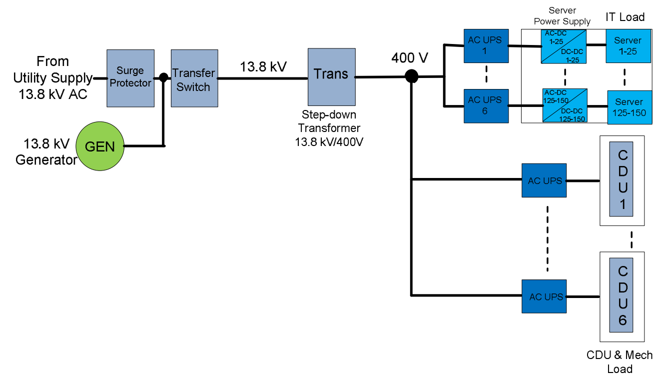

Figure 4. Data Center topology with modular scalable Double conversion AC UPS & IT server power supply with AC Distribution

Further efficiency improvement of Data Center is possible by connecting modular scalable UPS in Energy Saver (ES) mode as shown in Fig. 5. In ES mode, utility power is supplied directly to critical IT load and mechanical/CDU load during normal operation. Line filtering is done using existing filter circuits of UPS. The effective UPS efficiency in ES mode is around 99%. It is to be noted that UPS efficiency in double-conversion mode is around 94%-96% at nominal load. Therefore, overall efficiency improvement of UPS in ES mode is around 3 to 5%.

The paper proposes high efficient Data Center design solution using single conversion modular DC UPS and single conversion server power supply with DC input voltage using hybrid distribution [2] along with ultra-efficient modular CDU cooling as shown in Fig. 6. Output of each modular DC UPS is rated at ~250-350 kW. DC UPS output is connected to multiple server power supplies (250-350 kW IT loads). Server power supply is connected to server computer IT load. UPS for mechanical/CDU load are connected in ES mode as shown. Reliability of the proposed modular DC UPS design (250-350 kW IT loads) is high and overall cost is low. The proposed design eliminates inefficiency issue of the existing Data Center with AC UPS, server power supply with AC input voltage and server cooling using standard CRAC.

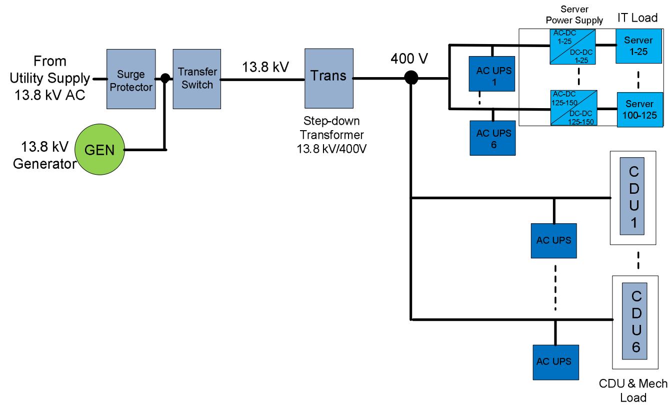

Figure 5. Data Center topology with modular scalable AC UPS in ES mode and IT server power supply with AC Distribution

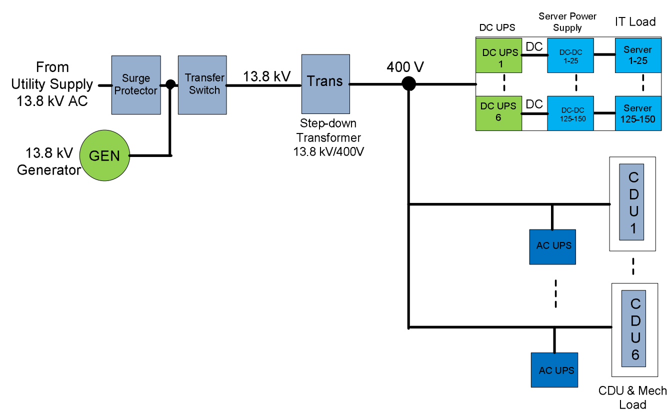

Figure 6. Proposed Data Center topology with modular scalable Single conversion DC UPS and IT server power supply with Hybrid Distribution

Block diagram of DC UPS is shown in Fig. 7. Converter section converts 3-phase AC input voltage to required DC voltage. DC UPS loss is reduced by 2 to 3% due to single stage conversion. DC UPS cost is also less due to single stage conversion. Storage battery is connected across DC output voltage. DC UPS uses high density longer life cycle 24/48 V Li-ion battery in lieu of high voltage lead-acid battery as in AC UPS (Fig. 2). Modular DC UPS has higher load utilization factor. It provides higher UPS efficiency and lower capital cost. The developed UPS system occupies less floor space due to its modular design and single stage conversion.

Server power supply loss for IT load is also reduced by 4 to 6% due to single stage conversion and use of Zero Voltage Switching (ZVS) technique with super compact high frequency (HF) high efficient Planer transformer as shown in Fig. 8. Cost of power supply is also less due to single stage conversion. MOSFETs are used due to high switching frequency operation (80 to 100 kHz). Filter circuit requirement is also minimized due to HF operation.

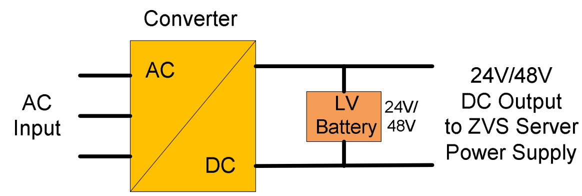

Figure 7. Block Diagram of Single Conversion DC UPS

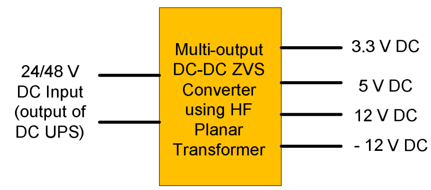

Figure 8. Block diagram of isolated ZVS based DC-DC IT Server Power Supply with input DC voltage

A DSP based 1-line diagram of ZVS strategy for IT server power supply [3] is shown in Fig.9.

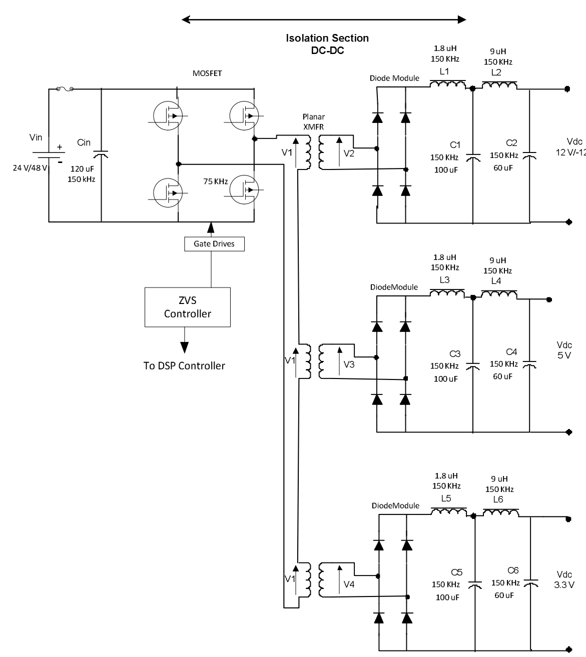

Figure 9. 1-line diagram of isolated ZVS based DC-DC IT Server Power Supply

Data Center design by using modular DC UPS, server power supply with DC input voltage and modular CDU cooling for IT load provides higher efficiency, lower capital infrastructure investment, lower operating energy cost and smaller foot print. Modular topology (both UPS and CDU) is easily scalable based on future load demand. Proposed design can be modified for Tier-2, Tier-3 and Tier-4 in N+1 configuration.

III. ANALYSIS

Processor manufacturers keep up with Moore's law. Therefore, server computing performance increases by a factor of 3 in every 2 years. Energy efficiency of server also increases by a factor of 2 in every 2 years. Therefore, power consumption and hence heat generation of IT load increases by a factor of (27/8=) 3.375 in 6 years span. In real life, server power consumption has increased by a factor of 4 [4] in 6 years span.

Table-1 shows site electric cost has increased from 10% to 158% of server IT budget in 12 years span (year 2000 to 2012). This reinforces the importance of effective and efficient IT cooling and heat rejection/transportation of heat energy to outside of Data Center. It is assumed that IT server budget is fixed at $4 million during this period (2000-2012).

In 2006, a 1U server cost was $4 K and actual power consumption was 0.5 kW [5]. Therefore, 2 MW IT servers cost $4 million in 2012. Similarly, Table-1 shows TCO has increased from 38% to 606% of server IT budget in 12 years span (year 2000 to 2012). Therefore, cost of infrastructure (Electrical, Mechanical and facilities) required to operate these servers' increases dramatically. It is assumed that the server life is 3 years and site infrastructure life is 15 years. Site Opex ($3237/year/kW) includes electricity, site technicians needed to operate and maintain power and cooling equipment and external maintenance and repair costs for site infrastructure equipment and systems [4].

Table-2 shows the overall efficiency at rated load considering only the main electrical components assuming Data Center is fully loaded. Efficiency would be lower if Data Center is not fully loaded. Table-2 clearly shows that there is definite overall efficiency improvement of 11.84% if DC UPS and server power supply with DC input are used in place of AC UPS in on-line double conversion mode and server power supply with AC input. Similarly, overall efficiency improvement of 6.78% is possible if AC UPS in ES mode are used in place of AC UPS in on-line double conversion mode.

Table-3 shows other benefits when overall efficiency is improved by 11.84% using DC UPS and server power supply with DC input for 2 MW IT load. It shows overall energy cost savings of $746,772.48 in 3 years. Total energy savings is 7467.72 MWhr in 3 years. Therefore, IT cooling system needs to dissipate 7467.72 MWhr of less heat and hence reduces overall cooling infrastructure cost. Also, Data Center claims 5376.76 metric ton of carbon credit (720 grams/kWhr of CO_2 emission for coal based generation) benefit in 3 years.

TABLE 1

Site TCO and Electric cost with fixed $4 million (example) rate of 1U Server Spending @ PUE 1.2								
2 MW IT load in 2012								
Year	**Compute units per $4M (Yr. 2000=1)**	**1U Server spend ($, M)**	**Total Server kW**	**Site CapEx ($, M)**	**3 year Site Electric cost ($, M) @ PUE 1.2**	**3 year Site Electric cost/Server Spend (in %)**	**3 year Site TCO ($, M)**	**3 year Site TCO/Server Spend (in %)**
2000	1	4	125	2	0.39	10	1.51	38
2003	5	4	250	3	0.79	20	3.03	76
2006	27	4	500	6	1.58	39	6.06	151
2009	140	4	1000	12	3.15	79	12.11	303
2012	729	4	2000	24	6.31	158	24.22	606
Energy cost ($) increased from 0.39 million in 2000 to 6.31 million in 2012. So, energy efficency is very important								
Energy cost ($/kWhr) : 0.1								
Site Capex ($) : 12 million per MW								
Opex ($) : 3237/year/kW								
TCO ($) : Opex + Amortized Capex (20% of Initial Capex)								
In **2006**, a 1U server cost $4K and power consumption 0.5kW								

TABLE 2

at Rated Load	AC UPS in on-line mode & Server power supply with AC input : (Fig. 4)	AC UPS in ES mode & Server power supply with AC input : (Fig. 5)	DC UPS & Server power supply with DC input : (Fig. 6)
UPS Crictical	95%	99%	97.50%
UPS Mechanical	95%	99%	99.00%
PS - AC/DC Section	94%	94%	
PS - DC/DC Section	93%	93%	94%
Overall Efficiency	78.90%	85.68%	90.73%
Efficiency Improvement		6.78%	11.84%

TABLE 3

Critical IT load (kW)	2000.00	
Input Power in kW @ 1.2 PUE	2400.00	
Power save in kW @ Efficiency gain of 11.84%	284.16	
Energy savings (MWhr) in 3 years	7467.72	**Cooling system dissipates 7467.72 MWhr of less heat**
Energy cost ($/kWhr)	0.10	
Energy cost savings ($) in 3 years	746,772.48	
CO_2 savings (metric tons) in 3 years	5376.76	**Carbon credit**

IV. CONCLUSION

The paper has described an efficient cost effective modular Data Center topology with hybrid (both AC and DC voltage) distribution using DC UPS, server power supply with DC input voltage and CDU cooling for IT server load. Proposed modular scalable topology provides high efficient cost effective sustainable Data Center topology. The applicability of the developed topology has been validated by means of extensive analysis.

ACKNOWLEDGEMENTS

The authors wish to thank Jakob Carnemark of SKANSKA, USA and Gerry McDonnell of Inertech for their support and encouragement.

REFERENCES

[1] Lee Kirby, "The Next generation Modular Data Center: Efficient, Agile, Sustainable" Published in Mission Critical – Digital Edition, September/October 2012.

[2] Subrata K Mondal, "A Modular Direct Current (DC) Uninterruptible Power Supply (UPS) and Server Power Supply with a DC Input Voltage" US Provisional Patent Application No. 61/671,641, July 2012.

[3] Subrata K Mondal, "Evaluation of Novel Analog Bi-Directional ZVS controller for High Frequency Isolated DC-DC Converters" Published in IEEE IECON 2008, pp. 743-748.

[4] Kenneth G Brill, "The Invisible Crisis in the Data Center: The Economic meltdown of Moore's law" White Paper, Uptime Institute, 2007.

[5] Belady L Christian, "In the Data Center, power and cooling costs more than the IT equipment it supports" Electronics Cooling, Vol. 23, No. 1, February 2007.