COST STUDY OF AC VS. DC DATA CENTER POWER TOPOLOGIES BASED ON SYSTEM EFFICIENCY

TECHNICAL STUDY OF SYSTEM EFFICIENCY AND FINANCIAL SAVING

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ABSTRACT

Data consumption across the globe is increasing exponentially and it has triggered massive growth in the number of data centers and their power consumption. Many businesses are looking for options to effectively implement their data centers in order to reduce their carbon footprint to be environmentally friendly and save on initial investment and capital expenditures. This is leading data center owners to invest in and explore new technologies and innovative solutions. This has reignited an interest in DC-powered data centers with various studies and research having been conducted to better understand various aspects of the power system. This paper describes a detailed technical analysis that was carried out to compare the efficiency of the equipment used in DC- and AC-powered data centers based on the current market and thereby calculate the amount of savings that can be achieved if an AC powered data center switched to DC power.

INTRODUCTION

Data centers are consuming about 3 percent of the global electricity supply and accounting for about 2 percent of total greenhouse gas emission. Based on industry studies, the consumption amounted to 416.2 terawatt hours of electricity for the year 2015 [1]. This energy consumption is expected to double every four years - a growth rate that is not proportional with the current power infrastructure growth.

These statistics have raised concerns across the globe, and relevant governing bodies are looking to optimize power consumption of existing data centers by increasing the data storage capacity per rack, decreasing the power and cooling density of the building infrastructure and other measures. In addition, this has led to many data center owners concentrating on efficiency of the power systems and other equipment used in the data center.

The cost of building a new data center is enormous and owners are reluctant to make such an investment in a volatile economy and given the current market trends. So, the focus now is on improving existing facilities either by retrofitting with high efficiency systems or by redesigning the site and adapting new technology which offers reduced footprint and high efficiency. Even those owners that do choose to build new facilities are looking for innovative approaches to achieve availability, efficiency and space saving.

This paper, then, takes a real-life approach to analyzing the costs of both AC and DC power topologies in order to help data center owners make the best decision.

AC AND DC TOPOLOGY

In our scenario, the power system under the study is assumed to have a total 800kW IT load and is served by both AC and DC power topologies. The system power supply is similar for both AC and DC before the UPS and efficiency values are ignored.

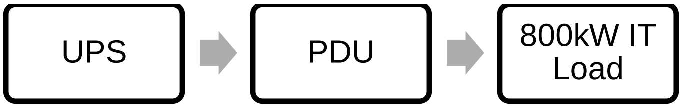

Fig.1. Power System Block Diagram

A detailed description of the power system topology is described in the section below.

A. AC Topology

The system under study is a common AC distribution system in a data center where the AC IT load power is supported by AC UPS with battery and power distribution unit (PDU). The server has a power supply unit (PSU) and voltage regulator (VR) in order to power the circuits. A detailed block diagram of the power flow is as shown below:

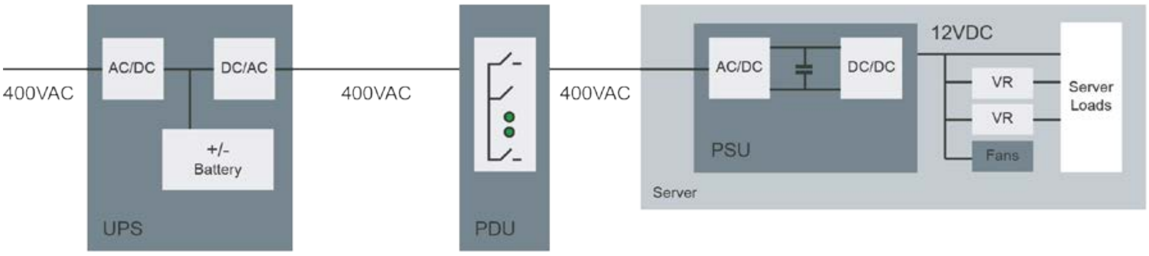

Fig.2. AC Power System Block Diagram without Transformer

The above system is not applicable for North America and Japan as the topology for data centers in these countries requires a transformer in the PDU to convert 480VAC to 208/120VAC as shown below:

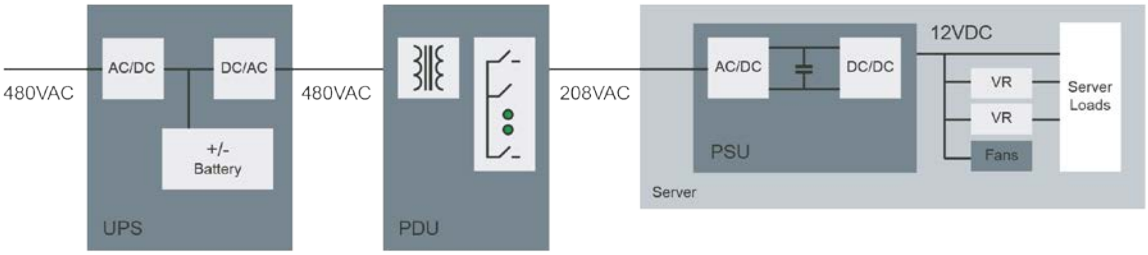

Fig.3. AC Power System Block Diagram with Transformer

Further, regions across the globe where the power grid is not stable will make use of isolation transformers in order to provide galvanic isolation, suppress noise and for other safety reasons.

B. DC Topology

The DC distribution system in a data center where the 380VDC IT load power is supported by 380V DC UPS with battery and a power distribution unit (PDU). The server has a power supply unit (PSU) and voltage regulator (VR) in order to power the circuits. A detailed block diagram of the power flow is as shown below:

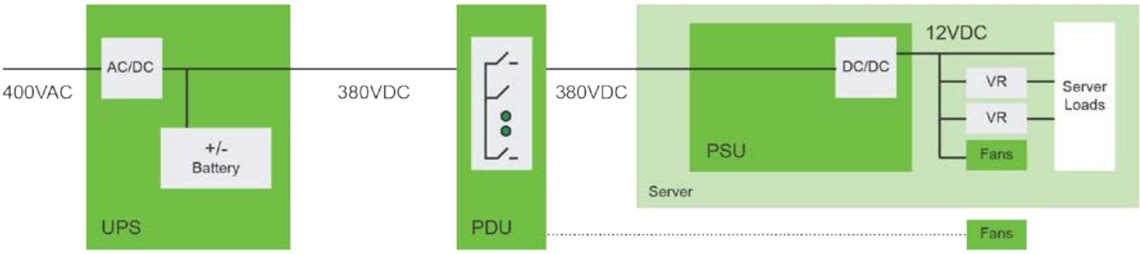

Fig.4. DC Power System Block Diagram

C. Comparing AC vs DC Topology

Based on the above topologies, the key differences are highlighted below:

- No of power conversions required from UPS to Server PSU for
  AC Topology (without transformer) = 4
  AC Topology (with transformer) = 5
  DC Topology = 2

- Elimination of components in DC topology
  DC-AC inverter in UPS
  Transformers in power distribution unit (PDU)
  AC-DC rectifier in power supply unit (PSU)

EFFICIENCY DATA FOR THE POWER SYSTEM

In order to establish efficiency data for the power path, the active load is assumed to be at 50% of total IT load of 800kW. The mechanical load and other miscellaneous items are not considered in the analysis.

The power path design is based on one UPS supplying ten PDUs and each PDU in turn support 30 IT racks. So, in total there are 300 IT racks. The distance from UPS to PDU is assumed to be 30m and from PDU to respective IT racks is 10m.

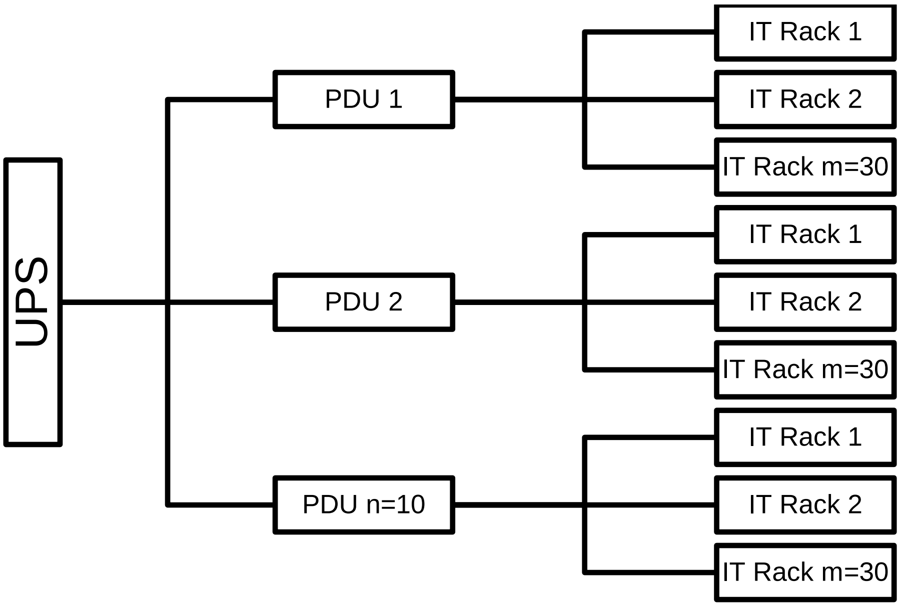

Fig.5. Power Path for Data Center

A. Efficiency of Power Supply Unit (PSU)

The calculations are shown below:

$$Total\ IT\ Load\ in\ kW = 800kW \quad (1)$$

$$Active\ IT\ Load\ in\ kW = 400kW \quad (2)$$

$$Power\ in\ kVA = \frac{Power\ in\ kW}{Power\ Factor} \quad (3)$$

$$Total\ no\ of\ PSU = 300Nos \quad (4)$$

$$Power\ per\ PSU = \frac{Power}{No\ of\ PSU} \quad (5)$$

Using (5),

$$Power\ per\ PSU = \frac{400}{300} = 1.33kW \quad (6)$$

The efficiency of the PSU is established as follows

$$Load\ 208VAC\ at\ 50\% = 93.2\% \quad (7)$$

[2]

$$Load\ 400VDC\ at\ 50\% = 95.6\% \quad (8)$$
[2]

The input power required for the PSUs is calculated based on the formula shown below:

$$Input\ Power = \frac{Output\ Power}{Efficiency} \quad (9)$$

Using (9),

$$AC\ PSU\ Input\ Power = \frac{1.33}{93.2} = 1.43kW \quad (10)$$

$$DC\ PSU\ Input\ Power = \frac{1.33}{95.6} = 1.39kW \quad (11)$$

B. Efficiency of Power Distribution Units (PDU)

The PDU efficiency can be divided into three portions which are studied in detail for the efficiency and power requirement. The cable type is assumed as single core PVC insulated copper cable, non-armored, with or without sheath type and ambient temperature 30ºC & conductor operating temperature 70ºC.

1) PSU to PDU cable loss

The cable loss from PSU to PDU, based on a distance of 10m, is calculated using code of practice for electrical installation Table 4D1A [3] and ignoring the grouping factor. For AC, 2.5mm^2 cable size is assumed to ensure <4% voltage drop [3] at full load. Based on active load, 0.5% voltage drop is calculated. For DC, using 2.5mm^2 cable amounts to 0.2% voltage drop at active load. These voltage drops will account for 0.5% power loss in AC and 0.2% power loss in DC system. The power at the output of the PDU is then calculated using (9):

$$AC\ PDU\ Output\ Power = \frac{1.43}{100-0.5\%} = 1.44kW \quad (12)$$

$$DC\ PDU\ Output\ Power = \frac{1.395}{100-0.2\%} = 1.4kW \quad (13)$$

2) PDU switchgear loss (without transformer)

The losses in the PDU are assumed to be 0.5% for both AC and DC systems. Further, the PDU supports 30 PSU units. The input power of the PDU for 30 racks of equipment is calculated using (9):

$$AC\ PDU\ Input\ Power = \frac{1.44}{100-0.5\%} \times 30 = 43.35kW \quad (14)$$

$$DC\ PDU\ Input\ Power = \frac{1.4}{100-0.5\%} \times 30 = 42.13kW \quad (15)$$

3) PDU to UPS cable loss

The cable loss from PDU to UPS based on a distance of 30m is calculated using code of practice for electrical installation Table 4D1A[3] ignoring grouping factor. For AC, we need 240mm^2 cable at full load to ensure less than 4% voltage drop [3] for single-phase voltage. The voltage drop at active load is calculated to be 0.4%. For DC, we need 150mm^2 cable at full load with 0.2% voltage drop at active load. These voltage drops will account for 0.4% power loss in AC and 0.2% power loss in DC system. The power at the output of the UPS for ten PDUs is then calculated using (9):

$$AC\ UPS\ Output\ Power = \frac{43.35}{100 - 0.4\%} = 43.52kW \tag{16}$$

$$DC\ UPS\ Output\ Power = \frac{42.13}{100 - 0.2\%} = 42.26kW \tag{17}$$

C. Efficiency of UPS

The power path considered for the analysis starts with a UPS. For the AC UPS, there are current products in the market whose performance is verifiable. As various studies have been carried out in analyzing the efficiency, we use the efficiency of AC and DC UPS's as follows:

$$Best\ in\ Class\ Double\ Conversion\ AC\ UPS = 96.3\% \tag{18}$$
[4]

$$DC\ UPS = 97.7\% \tag{19}$$
[2]

From the UPS efficiency, the input power of the UPS is calculated for ten PDUs using (9):

$$AC\ UPS\ Input\ Power = \frac{43.52}{96.3\%} x10 = 452kW \tag{20}$$

$$DC\ UPS\ Output\ Power = \frac{42.26}{97.7\%} x10 = 433kW \tag{21}$$

From (20), (21) and (2), the overall AC and DC power system efficiency is calculated using (9):

$$AC\ Power\ System\ Efficiency = \frac{400}{452} = 88.5\% \tag{22}$$

$$DC\ Power\ System\ Efficiency = \frac{400}{433} = 92.5\% \tag{23}$$

EFFICIENCY TO SAVINGS

From the above efficiency calculations for an 800kW system operating at half the capacity, the amount of energy cost expenditure can be derived from kilowatt hour (kWh) consumption and cost per kWh.

The energy for the AC and DC is calculated from the power input of the respective UPS's:

$$Energy\ Consumption\ (kWh\ per\ day) = Power \times 24 \tag{24}$$

Using (24),

$$AC\ kWh\ per\ day = 10847\ kWh/day \tag{25}$$
$$DC\ kWh\ per\ day = 10392\ kWh/day \tag{26}$$

The average cost per kWh is based on the data [5] as shown below as US$0.2 per kWh.

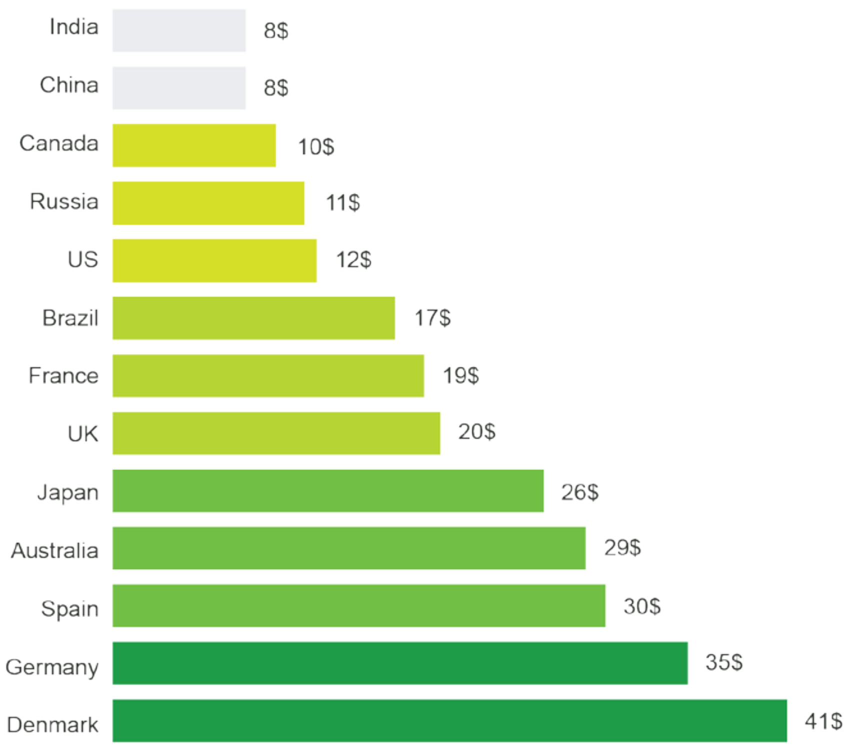

Fig.6. Average national electricity prices in US cents/kWh (2011)

The cost of energy consumption for DC and AC UPS is calculated as below:

$$Cost\ per\ year = \frac{kWh}{day}\ x\ US\$\ per\ kWh\ x\ 365 \tag{27}$$

Using (27) and (25),

$$AC\ Power\ System\ Cost\ per\ year = US\$\ 791{,}831 \tag{28}$$

Using (27) and (26),

$$DC\ Power\ System\ Cost\ per\ year = US\$\ 758{,}616 \tag{29}$$

The difference in energy consumption cost between AC and DC power systems will account for **US$ 33,215 per year savings** if a DC power infrastructure is utilized and results in **4.2% per annum** savings.

In data centers where the AC power topology requires an isolation transformer, then the saving from using a DC power system will be around **6.1% per year** which amounts **US$ 49,484 per year.**

CONCLUSION

This paper was written to provide an insight into data center efficiency, with a comparison between DC power topology and traditional AC topology. With rapid technology development in electronics, DC power systems can be optimized further in order to achieve better performance and efficiency. The savings accounted for are based solely on the efficiency of the different power equipment topologies and ignores other factors like savings in cables, more available floor space, removal of additional equipment, reduction in cooling requirements, etc. which will also contribute to CAPEX and OPEX savings for the customer using DC data center.

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