International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Measuring Energy Efficiency of Cloud Datacenters

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Abstract*: *In today's technology driven world, use of cloud technology is ever increasing. To sustain the increasing demand, new data centers are coming up quite fast. Also, the equipment in these data centers is scaling up. Energy consumption by these data centers has opened a new front of research. Not only the energy consumption has to be minimized, but the carbon footprint needs to be arrested to minimize the environmental hazards. Energy usage and dissipation takes place in different forms. Customized metrics are required to evaluate the performance of these centers. We have classified the major efficiency metrics according to their importance in a given scenario. Different scenarios have been identified for the suitability of these metrics along with the formulae to calculate these metrics. Two new metrics namely Energy Eat by Servers and Switches (EESS) and Energy Eat and SLA violation Factor (EESF) have been proposed.

Keywords: Cloud computing, cloud datacenters, compute efficiency, datacenter efficiency metrics, energy efficiency metrics, and power efficiency.

I. INTRODUCTION

Cloud Computing provide all the resources on per use basis to the end users. Users need to pay only for the resources used per unit of time. With the invention of cloud computing, an organization can be spared from the installation of costly software, establishing infrastructure and constant upgradation of both software and hardware. Due to this, cloud computing has become very popular. Ever-increasing demand of cloud computing has resulted in large sized data centers. Google, Yahoo, Amazon etc. are running tremendous datacenters throughout the world. Accordingly, their energy consumption is increasing everyday [1]. These data centers pose a challenge on energy efficient utilization of resources [2]. According to a report [3], global data centers consumed 4.35 gigawatts in 2013 with annual increase rate of 15%. According to Forbes 2017, the electricity consumed by datacenters in the US is approximately 90 billion KWh. Around 34 high capacity coal-powered plants are needed to produce this amount of electricity. Globally, the electricity consumption scales up to approximately 416 terawatts. Hence, the consumption is around 3% of the total electricity consumption. As reported in [4], from 2005 to 2010 there is an increase of around 60% in the energy usage of data centers. Energy consumption takes place in different forms like computing devices, network devices and thermal heat etc. Hence diverse and comprehensive tools in the form of energy metrics are required to evaluate the performance. According to Daim et.al.[5], metrics are the tools to measure the performance of the system. Energy efficiency metrics for data centers may help in reduction of energy consumption. With the analysis of these metrics one can find, how the infrastructural or technological updation can be done in data centers so as to provide better services. A metric helps in assessing the effects of changes done in the system. A metric must be standard and globally accepted. A landmark event was conducted by US Department of Energy in July 2008 for improving the collective efforts by the IT industry and government to control the energy dissipation and related environmental hazards [6].

II. ENERGY EFFICIENCY

Energy consumption is a very important factor in setting up data center for the cloud service provider because high electricity bill decreases the profit. According to a report in [7], data centers will consume approximately 75 billion KWh by 2020 in the United States itself. In today's competitive world where everybody longs for more and more ROI (Return on Investment), it is necessary to use the resources in an efficient way. Hence, for providing better ROI, the data centers have to utilize the energy optimally. Performance of a data center regarding energy usage and dissipation can be computed as the ratio of the amount of computational work done to the amount of total electricity supplied to the data center. Resource utilization determines the energy consumption most of the time. Cloud data centers can be made energy efficient at different levels.

III. METRICS FOR ENERGY EFFICIENCY

These metrics are the tools to measure quality of the data centers for efficient utilization of energy. For promoting the efficient usage of energy, there is a requirement of benchmarking the performance. Given the huge number and type of components used in the data centers, standard and diverse set of metrics is required to measure the performance of data centers. However, there are some common characteristics required for all the metrics used. Some guidelines have been mentioned in [8] and listed as follows.

Manuscript published on 30 September 2019
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- The name used for the metric should be sensible and self-explanatory.
- Scalability is paramount i.e. it should be capable of adapting technological and environment changes.
- It must be accurate and precise.
- It must be general enough and provide data driven decisions.

Many researchers have proposed various metrics for measuring the performance of data centers for energy usage [9] [10] [11]. For the optimal ROI (return on investment) and least environmental impact, cloud service provider can use these metrics. Energy metrics are also helpful to analyze the trade-off between the productivity of the data center vis a vis consumption and dissipation of energy.

IV. METRICS CLASSIFICATION

Using the right metric for a given scenario is very important for minimizing energy consumption without compromising the optimal use of resources. We have classified the metrics available in the literature in the following categories:

- Computing Energy Metrics
- IT Equipment Energy Metrics
- Facility Energy Metrics
- Data Center Energy Metrics
- Green Energy Metrics

The classification is helpful in choosing the right category of metric in a given situation. Different metrics available for measuring energy consumption along with their method of calculation have been presented here.

A. Computing Energy Metrics

These metrics are meant for computing resources of the data center. Using these metrics, one can optimize the utilization of computing resources. Some important computing energy metrics have been listed in table 1:

TABLE1: COMPUTING ENERGY EFFICIENCY METRICS

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
CPE[12]	0-100	Percentage	100	CPE= ITEU/PUE	Compute Power Efficiency (CPE) quantifies the fraction of total facility power used for computing. It measures the efficiency of computing resource utilization in datacenter. ITEU is IT Equipment Usage and PUE is Power Usage Effectiveness
DCcE[13]	0-1	Number	1	DCcE= $\frac{\sum_{i=1}^{m} ScE}{m}$	Data Center Compute Efficiency (DCcE) is used to measure efficiency of compute resources. It is the ratio of total server compute efficiency and number of servers. Quantifies the efficiency of all computing resources. ScE is Server Compute Efficiency and m is the number of servers.
DH-UE[14]	0-1	Number	1	DH-UE= n/m	DH-UE quantifies the chances to optimize the utilization of servers using virtualization. 'n' is the mandatorily number of servers to operate at the peak load. 'm' is the total number of servers available..
DH-UR [14]	0-1	Number	1	DH-UR=i/m	Deployed Hardware Utilization Ratio (DH-UR) measures the proportion of idle servers. i is representing the idle servers not executing any task. m is the servers deployed in total.
DWPE [15]	0-WPE	Perf/Watt	Closer to WPE	DWPE=$\frac{WPE}{sPUE}$	Data Center Workload Power Efficiency (DWPE) measures the power efficiency for a particular workload. WPE is Workload Power Efficiency sPUE is system PUE
DceP [16]	0-∞	UCU/KWh	Maximize	DceP=W/E	Data Center Energy Productivity (DceP) quantifies the computational tasks executed with respect to the energy consumed. It should be measured in contiguous time interval which is known as assessment window. W is the number of computational tasks done. E is the energy consumed.
OSEW [17]	1- ∞	OS instances /KWh	Maximize	OSEW=$\frac{Count_{OS}}{Power_{DC}}$	Operating System Workload Efficiency (OSEW) quantifies the efficiency at which data center is providing OS instances. Count $_{OS}$ is the running OS instances Power$_{DC}$ is the total power usage of the data center
ScE [18]	0-100	Percentage	100	ScE= $\frac{\sum_{i=1}^{n} P_i}{n} \times 100$	Server Compute Efficiency (ScE) help in finding out ideal or least used server with aspect of its primary service. Server with low ScE may be turned off to decrease energy consumption. *Pi is number of instances where server is providing services, primary in nature.* *n is the total number of server instances.*

B. IT Equipment Energy Metrics

IT equipment metrics represent the goodness of IT equipment including network devices in energy dissipation. Metrics are listed below in table II.

TABLE 2: IT EQUIPMENT ENERGY METRICS

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
ITEU [19]	0-1	Number	1	ITEU= $E_{IT}/E_{Itrated}$	IT Equipment Utilization (ITEU) quantifies the amount of energy saved of IT equipment due to optimized utilization. E_{IT} is the energy consumed by all the equipment $E_{ITrated}$ is the total rated power of different hardware
ITEE [19]	0-∞	Cap/KW	Maximize	ITEE=C/E	IT Equipment Efficiency (ITEE) quantifies the energy savings of IT equipment due to optimized processing capacity. C is total capacity E is the energy consumed
ITUE [20]	1-∞	Number	1	ITUE=E_{IT}/E_C	IT Equipment Utilization (ITUE) measures the IT equipment burden on computing resources. E_{IT} is the energy consumed by IT Equipment E_C is the energy consumed by Computing Equipment
H-PO [14]	1-∞	Number	1	H-POM=HL_P/HL_C	It tells how much power gets consumed by other facilities as compared to computing resources. L_P is the total hardware load at plug L_C is the total compute load in optimal usage

C. Facilities Energy Metrics

These metrics are meant for facilities used in data center like light, cooling system etc. Table 3 lists some of the important metrics.

TABLE 3: FACILITIES ENERGY METRICS

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
EES [21]	0-1	Number	1	EES= $(E_{DCbase}-E_{DC\ cur})/E_{DC\ base}$	Energy ExpenseS (EES) is used to know the effect of DC equipment upgradation on energy expense. E_{DCbase} is the baseline energy consumption i E_{DCcur} is the energy consumption in baseline configuration of data center.
EWR [22]	0-∞	Number	0	EWR=E_{NW}/E_{DC}	Energy Wasted Ratio (EWR) tells about the amount of energy getting wasted in heat etc. E_{NW} is the energy consumed for non-significant work $E_{DC}$is the total energy consumed
EER[23]	0-∞	BTU/Wh	Maximize	EER=CP/E_c	Energy Efficiency Ratio (EER) measures the efficiency of cooling devices CP denotes cooling performance and E_c is the energy consumed by cooling system
SEER [23]	0-∞	Number	Maximize	SEER=ACP/AE_c	Seasonal Energy Efficiency Ratio (SEER) measures annual energy efficiency of cooling system. ACP is the annual cooling performance and E_c is the energy consumed annually cooling system
WUE [24]	0-∞	Litre/KWh	Minimize	WUE=W_{DC}/E_{DC}	Water Usage Effectiveness (WUE) is used to get amount of water used for cooling. W_{DC} is the water consumed for cooling the equipment E_{DC} denotes total energy consumed

D. Data Center Level Metrics

Sometimes a more holistic view of the performance is required rather than specific equipment's performance. The data center level metrics indicate the performance of all the facilities used in the data center. A summary is presented in table 4 below.

TABLE 4: OVERALL DATA CENTER ENERGY EFFICIENCY METRIC

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
APC [21]	0-1	Number	1	$APC=1-\frac{\sum_{i=1}^{n} [K_{APC}*E_{pi}-E_{DCi}]}{\sum_{i=1}^{n} E_{DCi}}$ $K_{APC}=\frac{\sum_{i=1}^{n} E_{DCi}}{\sum_{i=1}^{n} E_{Pi}}$	Adaptability Power Curve (APC) indicates flexibility of datacenter. It is a quantitative measure of EE. n is the size of the sample and i denotes time interval. E_{DCi} is energy consumed and E_{pi} is the planned energy consumed.
CADE [25]	0-100	Percentage	100	CADE= Facility Efficiency× Asset Efficiency	Corporate Average Datacenter Efficiency (CADE) is used to measure efficiency of corporate or public sector's data centers individually or combined. It takes care of GHG's emission too.
DCIE [12]	0-100	Percentage	100	$DCIE=E_{IT}/E_{DC}$	Data Center Infrastructure Efficiency (DCIE) help in improving the data center design or modifying IT equipment to make it more energy efficient. It is the ratio of the IT equipment energy consumption to the total energy consumed..
DPPE [19]	0-1	Number	1	DPPE= ITEU × ITEE × (1/ PUE) × (1/(1-GEC))	Datacenter Performance per Energy (DPPE) measures the efficiency of the four phases of the data center. Hence it is a combination of four sub-metrics. It helps in finding out loophole anywhere in datacenter.
DCLD [9]	0-4	kW/ft^2	4	$DCLD=LP_{DC}/A_{DC}$	Data Center Lighting Density (DCLD) estimates the average light used against the total area. LP_{DC} denotes the lightning power of data center A_{DC} denotes the total area
DCPD [26]	0-50	kW/Rack	8	$DCPD=E_{DC}/n\_racks$	Data Center Power Density (DPCD) removes the ambiguity of earlier methods i.e how the power consumed and total area is calculated. n_racks is the number of racks.
DCPE [27]	1-∞	UW/Power	Maximize	$DCPE=P_{SWD}/P_{F}$	Data Center Performance Efficiency (DCPE) is long term metric and an extension of PUE and DCE. P_{SWD} is power consumed for specific work and P_F is total facility power.
DC-FVER [28]	1-10	Number	1	$DC\text{-}FVER= 1 + E_{Fixed}/ E_{Variable}$	Data Center Fixed to Variable Energy Ratio (DC-FVER) estimates the amount of power used for idle resources.
PUE[29]	1-4	Number	1	$PUE=E_{DC}/E_{IT}$	Power Usage Effectiveness (PUE) is used to represent the overall data center performance in terms of energy.
PUEr[30]	0-1	Number	0	$PUE_{r}= PUE_{TARGET}/PUE_{CURRENT}$	PUE ratio (PUE_r) tells how much optimization is required in order to reach to target PUE from the current status.
pPUE [13]	1	Number	1	$pPUE= (E_{DC}/E_{IT})_{boundary}$	While PUE is meant for the whole data center, Partial Power Usage Effectiveness (pPUE) denotes the power efficiency of particular facility.
sPUE [15]	1-∞	Number	1	$sPUE= 1+ Overhead_{PDCL} + \sum_{k=1}^{n} \left(w_k + \frac{1}{COP_k}\right)$	System PUE (sPUE) denotes the efficiency of a particular high performance system in the data center.
TUE [20]	1-∞	Number	1	TUE=ITUE× PUE	It calculates the energy efficiency and count for thee power wastage which is not considered in PUE.

E. Green Energy Metrics

As the size of the data centers is growing day by day, their environmental impact is also increasing. Hence it has become very challenging to optimize the productivity of data centers because it is associated with carbon foot- prints too. With the help of green metrics, the cloud service provider can minimize the CO_2 emission of the data center by keeping the margin of profit reasonable. Summary of the metrics is presented in table 5.

Retrieval Number: B3548078219/2019©BEIESP
DOI:10.35940/ijrte.B3548.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

TABLE 5: GREEN ENERGY METRICS

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
CUE [31]	0-∞	kilogramCO_2/ KWh.	0	CUE=CO2 Emission $_{DC}$ /E_{IT}	Carbon Usage Effectiveness (CUE) measures the CO_2 emission per unit of total energy consumed. Using this one can manage energy, societal, sustainability and environmental parameter in better way.
ERF [32]	0-1	Number	1	ERF=E_{RE}/E_{DC}	Energy Reuse Factor (ERF) tells the proportion of energy reused as compared to total energy.
ERE [32]	0-∞	Number	0	ERE=(E_{DC}-E_{RE})/E_{IT}	Energy Reuse Effectiveness (ERE) quantifies the energy exported outside for reuse.
GEC [19]	0-1	Number	1	GEC=E_G/E_{DC}	Green Energy Coefficient (GEC) Higher the value of GEC more energy resources are green.

F. SLA Aware Energy Metrics

Although reducing energy consumption is very important, it cannot be done by compromising the quality of services beyond a point. So, it is important to have some metrics to measure the energy efficiency and SLA violation trade-off. Table 6 summarize the important metrics to measure the optimization between energy efficiency and SLA violation

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TABLE 6: SLA AWARE ENERGY METRICS

Metric	Value Range	Unit	Optimal Value	Formula	Description and use
ESV [33]	0-∞	Number	Maximize	ESV=Energy * SLAV	This metric deal with the SLA violation and energy consumption trade-off.
E_E [34]	0-∞	Number	Minimize	E_E= 1/(p_{power}* SLA)	Energy efficiency metric is to be maximized to make data center energy efficient.
ESM [35]	0-∞	Number	Maximize	ESM = Energy * SLAV * MigrationsCount	Energy SLA migration metric takes care of three different parameters.
Pertric [36]	0-∞	Number	Maximize	Pertric= Energy * ASLAV* NHS	This metric consider number of hosts shut down along with average SlA violation and energy consumed.

V. PROPOSED METRICS

To the best of our knowledge, all existing metrics consider energy consumption by physical machines only. Switches in the network of data center consume a considerable amount of energy. Hence, more inclusive energy consumption metric will be helpful to present better picture. A metric that will consider the energy consumption by both servers and switches has been proposed. The metric is named as EESS i.e. **E**nergy **E**at by **S**ervers and **S**witches. The metric can be calculated as follows.

$$EESS= \sum_{i=1}^{m} E_{PM_i} + \sum_{j=1}^{n} E_{Switch_j}$$

where E_{PM_i} is the energy consumed by physical machine i, E_{Switch_j} denotes energy absorbed by switch j and m, n are the number of PMs and switches respectively.

As we know that mere reduction in energy consumption of devices is not enough. There must be a balance between energy efficiency and SLA violation to maintain the quality of service. Another metric has been proposed to account the trade-off between the EESS and the SLA Violation (SLAV) known as EESF i.e. **E**nergy **E**at and **SLA** violation **F**actor which can be calculated as follows.

$$EESF= EESS \times SLAV$$

VI. CONCLUSION

Energy metrics are important tools to benchmark the performance of data centers with respect to different components they use. Using right metric in a given scenario is very important to measure the efficiency of the system. A comprehensive classification has been presented to use the energy metrics in different scenarios. Two new metrics have been proposed to give further insights to energy consumed in network and trade-off with SLA violation. However, there are challenges to calculate the metrics accurately due to ambiguities in the parameters used. As far as facility like cooling system is concerned, it's not easy to measure the work efficiency in case of change in environment or data center's updation. Same is the case with green energy metrics, which are also season dependent. Some metrics use work done by computing resources though there is no standard way of doing it. Energy metrics play important role due to the enormous size of data centers. These are helpful in increasing ROI for the cloud service provider. Energy consumption in cloud has environmental impact too where these metrics can help a lot. A large variety of these metrics are available, so there was a requirement to categorize these metrics for the ease of use. Based on their area of usage, we have categorized these metrics. As already discussed, it is not easy to calculate these metrics due to involvement of different parameters. So, there is a need of automated method to calculate them. Moreover, there is requirement of more sophisticated metrics to make them practically useful.

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