ENERGY PROFILE OF A PERSONAL COMPUTER

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Abstract – *The personal computer is analyzed in the view of the interaction between the ICT (information communication technologies) and the electrical power production and distribution. Namely, the energy consumption of a personal computer is studied under different conditions in order to create a base for realistic estimation of the power consumption of a data-center. In the paper we will try to merge our (LEDA laboratory of the University of Niš) own results with ones available in the literature in order to give as complete a picture of the subject as possible.*

1. INTRODUCTION

Modern distribution grids are being transformed from passive to active networks in the sense that decision-making and control is distributed and the power flows bi-directionally. The function of the active distribution network is to efficiently link power sources with customer demands, allowing both to decide how best to operate in real time.

The ICT equipment in general, including the enormous number of new small electrical loads (Personal computers, chargers, rectifiers etc.), represents a new load to the electrical grid being nonlinear by nature so generating distortion, a tremendous amount of harmonics, what gives rise to interference with other devices being powered from the same source. The problem becomes serious with serious, sometimes damaging, consequences and has to be dealt with properly. In addition, when speaking on computers, the total amount of energy required to power them becomes significant imposing serious requirements to the energy supplying system [1]. The Environmental Protection Agency (EPA) released a report on energy efficiency in data centers [2]. According to the government's best estimates, energy usage at data centers has doubled between 2000 and 2006, and it was poised to double again by 2011. The government has plenty of reasons to care about this, but one of the most obvious is financial. If growth continues at current levels, the US federal government alone will be shelling out $740 million for data center electrical bills in 2011. The report was authored by researchers at the government's Lawrence Berkeley National Laboratory. The final results indicate that the US used 61 billion kilowatt-hours of power for data centers and servers in 2006. That's 1.5 percent of *all* US electricity use, and it cost the companies that paid those bills more than $4.5 billion.

Particular analyses on lower level confirm the notion that if care is taken considerable savings may be created in this area. For the beginning, Fig. 1 represents the participation of the critical loads (computers and accessories) into the complete consumption in a data center [3]. As can be seen, in average 36% of all electricity is spent for the critical loads while the main part of the energy needed stands for cooling.

Saving by critical loads, however, understandably, leads to savings in cooling.
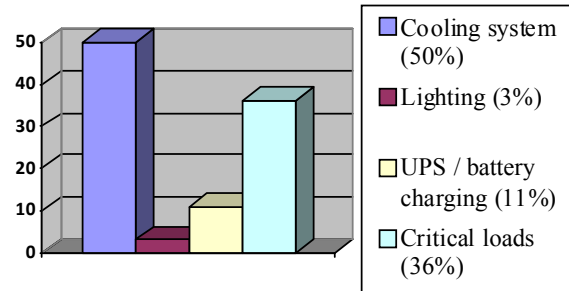

Figure 1. *Breakdown of data center electrical requirements*

Average values of consumption of the parts of a personal computer are listed in Table 1[4]. This table may be used to compute the consumption of a PC. Here we can see that, depending on the loads (working tasks), some components are spending more or less energy.

Table 1. *Power supply requirements of a PC*

Component	Requirement
AGP Video Card	30W-50W
PCI Express Video	50W-150W One power connector, 150W-300W Two power connectors
Average PCI Card	5W-10W
DVD/CD	20W-30W
Hard Drive	15W-30W
Case/CPU Fans	3W
Motherboard w/o CPU or RAM	50W-150W
RAM	15W per stick of RAM
Processor	80W-140W

That is why; there is a common opinion that savings may be achieved by controlling the working conditions of the computer. To get the feeling about the possible influence to the working condition of a computer to the power consumption two analyses will be given. In Table 2. the power consumed by a processor in three different load situations is given [5]. Namely the power consumed in standard, low power, and saving mode is used in order to estimate the maximum savings possible. For example, a savings of just 20–30 watts in power consumption translates to a savings of 60 kWh per year for a desktop system that is on 2,000 hours per year (40 hours/week, 50 weeks/year).

Similarly in Table 3. the variation of power consumption when a server is shifted from light to heavy load is given [6].

An additional aspect to introduce energy savings in a data center is introduction of time queue so relocating the noncritical jobs in time. AS can be seen from Fig. 2 the period between 10 and 19 hours is the busiest so if tasks exist that are of lower priority they may be rescheduled outside of that

time interval. That will allow the data center to avoid exceeding the power limits imposed by the utility and save considerable amount of money.

Table 2. *Power consumed by a microprocessor*

	Sockets	Speed (GHz)	Standard (W)	Low (W)	Saving (W)	(1) − (2)	(1) − (3)
			(1)	(2)	(3)	[%]	[%]
AMD	1	1.8-2.6	103	65	38	37	63
AMD	2	1.8-2.6	95	68	27	28	72
Intel	2	1.8-2.6	80	50	30	37.5	62.5

Table 3. *Dynamic power variation of actual servers*

Platform	Processor	Light load	Heavy load	Varia-tion
Dell PowerEdge 1150	Dual Pentium III - 1000	110 W	160 W	45. 5 %
Intel Whitebox	Pentium 4 - 2000	69 W	142 W	106 %
IBM BladeCenter HS20 Full chassis – 14 blades	Dual Xeon 3.4 GHz	2.16 kW	4.05 kW	87.5 %
HP BladeSystem BL20pG2 Full chassis – 8 blades	Dual Xeon 3.06 GHz	1.55 kW	2.77 kW	78.7 %

Having all that in mind one comes to the conclusion that by proper monitoring and control of the power consumption within a data center significant savings may be achieved. In a study reported by Google, the savings may reach up to 50% of the energy required for powering the data centers [7].

In order to establish a control algorithm one needs a figure of merit to optimize and a measurement procedure to get data. In the next we will first introduce the Power Usage Effectiveness (PUE) as a figure of merit that is commonly used. Then we will describe our own measurement procedure which was implemented for measurement for small nonlinear loads. Measurement results will be presented related to a PC. The data given in Table 1 and Table 2 will be confirmed. Doubts will be introduced as to how to take into account the distortion power which is usually neglected (as it was done in Table 1 and Table 2).
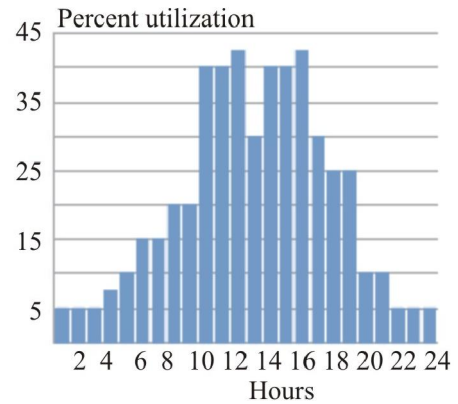

Figure 2. *Daily utilization of a typical business data center*

2. POWER USAGE EFFECTIVENESS (PUE)

Power Usage Effectiveness (PUE) is the recommended metric for characterizing and reporting overall data center infrastructure efficiency. The task force [8] strongly recommends annual energy consumption (kWh) for all energy types as the unit of measure for PUE calculation. However an entry level measurement category has been included in the recommendations to allow operators that do not have consumption measurement capability to utilize demand based power readings. PUE is defined by the following formula:

PUE = (Total data center energy consumption or power / IT energy consumption or power)

The following sections detail boundary considerations for both Dedicated Data Centers and Mixed-Use Data Centers, describe the four recommended PUE categories for data centers, and address calculation details associated with proper accounting of all fuels and on-site systems.

The task force recommends four measurement categories for the measurement of PUE within a data center:

PUE Category 0
This is a demand based calculation representing the peak load during a 12-month measurement period. IT power is represented by the demand (kW) reading of the UPS system output as measured during peak IT equipment utilization. Total data center power is measured at the data center boundary (e.g. point of electric feed for Mixed-Use Data Centers or utility meters for Dedicated Data Centers) and is typically reported as demand kW. As this is a snapshot measurement, the true impact of fluctuating IT or mechanical loads can be missed.

PUE Category 1
This is a consumption based calculation. The IT load is represented by a 12-month total kWh reading of the UPS system output (or sum of outputs if more than one UPS system is installed). This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points.

PUE Category 2
This is a consumption based calculation. The IT load is represented by a 12-month total kWh reading taken at the

output of the PDU's supporting IT loads. This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points. The total energy is determined in the same way as Category 1. This measurement method provides additional accuracy of the IT load reading by removing the impact of losses associated with PDU transformers and static switches.

PUE Category 3

This is a consumption based calculation. The IT load is represented by a 12 month total kWh reading taken at the point of connection of the IT devices to the electrical system. This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points. The total energy is determined in the same way as Category 1. This measurement method provides the highest level of accuracy for measurement of the IT load reading by removing all impact of losses associated with electrical distribution components and non-IT related devices, e.g., rack mounted fans, etc.

Implementation of Category 3 PUE enables continuous monitoring of the energy dissipate and dynamic control of the energy consumption.

A prerequisite for implementation of this concept is use of measurement devices connected to all consumers within the data center. For that purpose usual metering devices may be applied. Related to that two aspects are to be considered. First, since large number of metering devices is to be implemented one should use as a chip device as possible. Dedicated and simplified devices may be much chipper than commercially available power meters. Secondly, the electronic equipment seen as a load to the grid is, in general, a nonlinear two terminal network. In conventional metering devices, however, the readings for the power does not carry information about the distortions and the distortion power factor. Harmonics, being transferred back by the neutral line usually does not cancel and a large high frequency current is heating both the neutral line and the appropriate transformer.

Having all that in mind we propose a more complex measurement that may be performed by a simple equipment as described in [9].

3. MAIN METERING DEFINITIONS AND METERING SETUP

The average of the instantaneous power over a cycle:

$$P = \frac{1}{T} \int_{t_0}^{t_0+T} v(t) \cdot i(t) \cdot dt \qquad (1)$$

where t_0 is arbitrary time (constant) after equilibrium, and T is the period (20 ms in European and 1/60 s in American system, respectively).

The apparent power is the product of the root mean square value of current times the root mean square value of voltage:

$$S = V_{RMS} I_{RMS} \qquad (2)$$

In the presence of nonlinear loads, however, the system no longer operates in sinusoidal condition and use of fundamen-

tal frequency analysis does not apply any more. The non-sinusoidal voltage and current are expressed by Fourier series:

$$v(t) = V_0 + \sum_{k=1}^{+\infty} \sqrt{2} V_{k,RMS} \cos\left(k\omega_0 t + \theta_k\right)$$

$$i(t) = I_0 + \sum_{k=1}^{+\infty} \sqrt{2} I_{k,RMS} \cos\left(k\omega_0 t + \psi_k\right). \qquad (3)$$

where $V_{k,RMS}$ and $I_{k,RMS}$ represent RMS values, and θ_k and ψ_k phases for k-th harmonic of voltage and current, respectively. V_0 and I_0 represent DC values.

The instantaneous power $p(t)$ calculated by equation (1) can be represented as Fourier series:

$$p(t) = P + \sum_{k=1}^{+\infty} P_k \cos\left(k\omega_0 t + \zeta_k\right) \qquad (4)$$

However, expressing components of instantaneous power (P_k, ζ_k) as function of voltage and current spectral components $(V_0, I_0, V_{k,RMS}, I_{k,RMS}, \theta_k$ and $\psi_k)$ in non-sinusoidal conditions is not an easy procedure. These are thoroughly discussed and formulas are given in [10]. Definitions are given in [10] for all quantities describing power and distortions.

The measurement and calculation of quantities are performed by measurement setup consisting of signal acquisition modules – acquisition subsystem and software support– virtual instrument.

The acquisition and conditioning of the electrical quantities is performed by the acquisition subsystem. It is connected to the power grid from one side, and transfers the power to the load while sampling the values of three voltage and four current signals (Fig. 3). The modules for signal conditioning of the voltage and current waveforms provide attenuation, isolation and anti-aliasing.
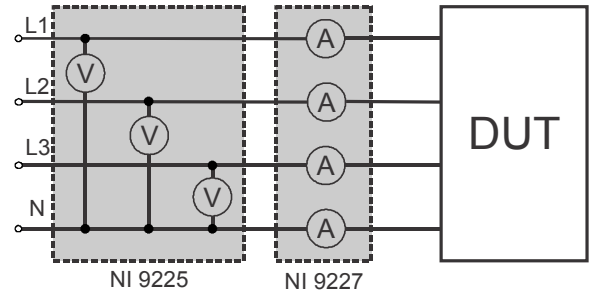

Figure 3. *Connection diagram*

The acquisition is performed by National Instruments cDAQ-9714 expansion chassis, providing hot-plug module connectivity. The chassis is equipped with two data acquisition modules: NI9225 and NI9227. Extension chassis is connected to PC running virtual instrument via USB interface. NI9225 has three channels of simultaneously sampled voltage inputs with 24-bit accuracy, 50 kSa/s per channel sampling rate, and 600 V_{RMS} channel-to-earth isolation, suitable for voltage measurements up to 100th harmonic (5 kHz). The 300 V_{RMS} range enables line-to-neutral measurements of 240 V power grids. NI9227 is four channels input module with 24-bit accuracy, 50 kSa/s per channel sampling rate, designed to measure 5 A_{RMS} nominal and up to 14 A peak on each channel with 250 V_{RMS} channel-to-channel isolation. The virtual instrument is

realized in *National Instruments* LabVIEW developing package (Fig. 4), which provides simple creation of virtual instruments. Virtual instruments consist of interface to acquisition module and application with graphic user interface.
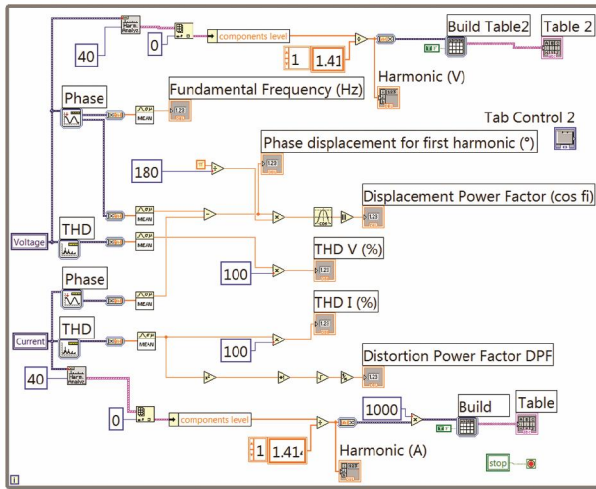

Figure 4. *The G code of virtual instrument*

Interface to acquisition module is implemented as device driver. cDAQ-9714 expansion chassis is supported by NIDAQmx drivers. All the measurements are performed using virtual channels. A virtual channel is collection of property settings that can include name, a physical channel, input terminal connections, the type of measurement or generation, and scaling information. A physical channel is a terminal or pin at which an analogue signal can be measured or generated. Virtual channels can be configured globally at the operating system level, or using application interface in the program. Every physical channel on a device has a unique name.

Table 4. *Measured consumption of a PC*

State	V (RMS)	I (RMS)	TPF (%)	THDI (%)	P (W)	QB (W)	U (W)	D (W)
Hibernation	217.5	0.090	5.29	18.4	1.04	-19.3	19.6	3.3
Standby	218.7	0.093	12.4	32.2	2.53	-19.3	20.4	6.
Idle	217.8	0.339	88.5	16.4	65.4	-31.9	73.9	12.6
High load (Video)	218.0	0.348	89.1	16.2	67.7	-32.3	76.0	12.1
High load (Simulation)	217.6	0.537	95.0	13.0	111.	-32.1	117.	18.3

The user interface of the virtual instrument consists of visual indicators. It provides basic functions for measurement. For better performance, the main application has been separated into two threads. The first thread has functions for file manipulation and saving measured values. All measured values will be saved in MS Excel file format.

All measured values are placed in a table, and after the measurement process in appropriate file. User interface also provides controls for data manipulation and saving measured values.

4. MEASUREMENT RESULTS AND CONCLUSION

The measurement setup presented in [9] was used for data center consumption characterization (PC DELL optiplex 980). All measured results are given in Table 4. for different working condition of the PC. The high load (simulation) is related to implementation of the Linear technology LTspice IV simulator for simulation of a ΣΔ modulator.

The measured results indicate that power usage of single PC is related to CPU and I/O load. This conclusion hold for the computer cluster, as well as whole data center [2,3].

5. ACKNOWLEDGEMENT

REFERENCES

[1] Dimitrijević, M., Milojković, J., Bojanić, S., and Litovski, V., "ICT and Power: Synergy and Hostility", Proc. of the 10th Int. Conf. on Telecommunications in Modern Satellite, Cable and Broadcasting Services, TELSIKS 2011, Niš, pp. 186-194, Invited paper.

[2] EPA: "Power usage in data centers ", http://arstechnica. com/old/content/2007/08/epa-power-usage-in-data-centers-could-double-by-2011.ars

[3] Sawyer, R.L., "Calculating Total Power Requirements for Data Centers", Schneider Electric white paper library, http://www.apcmedia.com/salestools/VAVR-5TDTEF_R1_EN.pdf

[4] -, http://computer.howstuffworks.com/power-supply3. htm

[5] -, "Energy Logic: Reducing Data Center Energy Consumption by Creating Savings that Cascade Across Systems", A White Paper from the Experts in Business-Critical Continuity, http://www.cisco.com/web/partners /downloads/765/other/Energy_Logic_Reducing_Data_ Center_Energy_Consumption.pdf]

[6] Spitaels, J., "Dynamic Power Variations in Data Centers and Network Rooms", Schneider Electric white paper library, http://www.lamdahellix.com/%5CUser Files%5CFile%5Cdownloads%5C43_whitepaper.pdf

[7] -, „Data center efficiency", http://www.google.com/ about/datacenters/inside/efficiency/#

[8] -, "Recommendations for Measuring and Reporting Overall Data Center Efficiency, Version 2 – Measuring PUE for Data Centers", 17 May 2011, http:// newavenergy.com/blog/2011/05/new-recommendations-for-measuring-and-reporting-overall-data-center-efficiency-2/]

[9] Dimitrijević, M., and Litovski, V., „Power Factor and Distortion Measuring for Small Loads Using USB Acquisition Module", J. of Circuits, Systems, and Computers, Vol. 20, No. 5 (August 2011), pp. 867-880.

Dimitrijević, M., and Litovski, V., "Quantitative Analysis of Reactive Power Calculations for Small Non-linear Loads", *Proc. of The 4th Small Systems Simulation Symposium, Niš, 2012, pp. 150-154.*