DIGITAL TECHNOLOGY AND ELECTRICITY: MEASUREMENTS, PROPORTIONALITY AND ENERGY EFFICIENCY

Authors and date

- Submitted on: June 30th 2021
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ELECTRICAL METRICS

In order to analyze the electrical consumption of digital equipment during the usage phase, it is necessary to operate two different metrics: electrical power and energy.

ELECTRICAL POWER

The watt (W) is the unit of measurement for electrical power. This unit matches to the rate at which energy that is produced or consumed. The name watt is a tribute to the Scottish mechanical engineer and mathematician James Watt (1736-1819) who worked on improving steam engines.

It is calculated with the following formula: P (power in watts) = U (voltage in volts) x I (current in amperes) [2] . One watt is equivalent to one joule per second.

The joule (J) is a unit for measuring energy, work and a quantity of heat[3]. The name Joule is a tribute to the English physicist James Prescott Joule (1818-1889) who, among other things, proposed the first law of thermodynamics.

- The kilowatt (kW), or 1000 watts, is frequently used for large servers or computing or storage racks.
- The megawatt (MW), or one million watts, can be used for large digital systems (such as data centers or high-performance computing centers) that can have a power of several tens of MW [1].
- The gigawatt (GW), or one billion watts, is used to qualify a massive electrical production. For example, the average power output of a French nuclear reactor is around 1 GW.
- Then come the terawatt (TW, one thousand billion watts), the petawatt (PW, ^{1015} watts), the exawatt (EW, ^{1018} watts), the zettawatt (ZW, 1021 watts), the yottawatt (YW, ^{1024}

watts).

ELECTRICAL ENERGY

The watt-hour (Wh) is a unit of energy measurement. It is used to measure the amount of work done over a given period. A Wh is the amount of energy produced in one hour by a one-watt machine or the amount of energy consumed in one hour by a system with a power of one watt.

It is calculated with the following formula: Wh: W * h

- The kilowatt-hour (kWh), or 1,000 watt-hours, is frequently used as a measure of household consumption. Your electricity meter counts kWh!
- The megawatt-hour (MWh or one million watt-hours) can be used to quantify the consumption of a digital equipment over a year. For example, a computing server that is powered continuously and has a constant power of 300 watts would use 2,628 MWh of electricity over a year.
- The gigawatt-hour (GWh or one million kWh) can be used to measure the consumption of large digital systems or the production of power plants. For example, a 1 MW wind turbine would provide an average of 2 GWh of energy over a year (2000 hours of wind per year)[4].
- The terawatt-hour (TWh) can be used to measure the production of massive power plants. For example, a French nuclear reactor produces about 8 TWh per year.

Thus

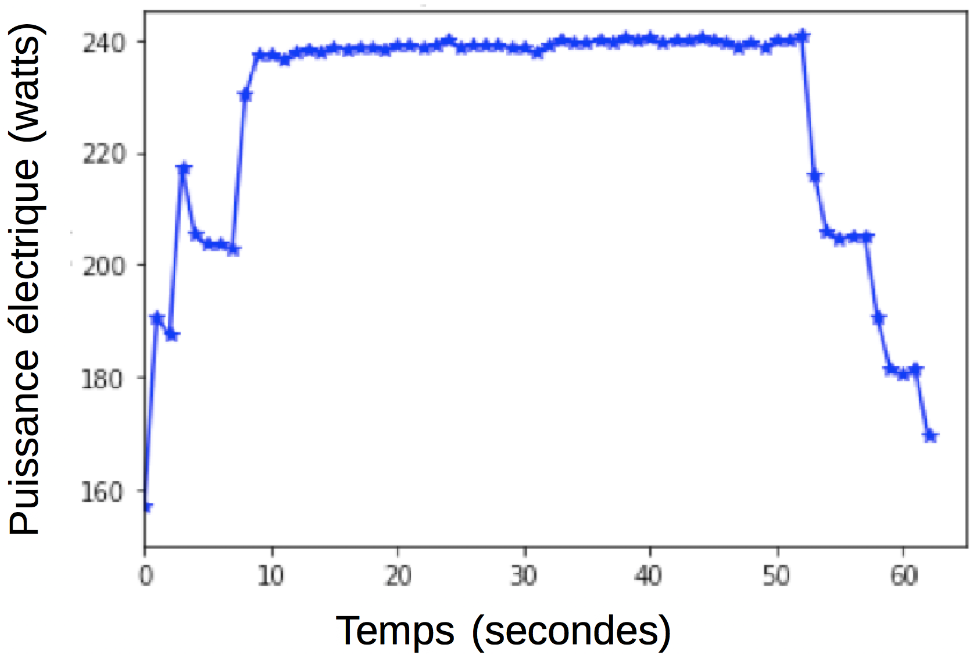
- a 60 W lamp that stays on for 1 hour consumes 60 Wh = 60 * 1 or 0.06 kWh
- a 900 W oven that runs for 5 minutes consumes 75 Wh = 900 * 5/60 or 0.075 kWh [2]

Conclusion, do not confuse the electrical power (expressed in watts) with energy (expressed in joules or Wh) [2] .

MEASURING THE CONSUMPTION OF A DIGITAL EQUIPMENT

If we want to observe and analyze the electrical consumption of computer equipment, we can not be satisfied with measurements of type electrical meter (which gives us kWh). It is necessary to profile the electrical consumption during a period of time (depending on the service provided). This measurement must be fine and precise enough to reproduce the variations due to the use of the equipment.

For example, we can observe the consumption of a desktop computer during the launch of an intensive application. The figure illustrates this energy profile of the computer by displaying the electrical power (watts) and the time (seconds). We can observe that this computer is in standby mode at the beginning of the experiment and uses an electrical power of about 160 watts. Once the application is started, its consumption increases during the loading time and then settles around 240 watts.



Power consumption of a desktop computer (Zoom)

This profiling can be done using two types of tools:

- hardware tools of the wattmeter type: which measure the consumption on the electrical outlet
- software tools: which estimate the power consumption of applications according to the use of internal resources (number of calculation operations, number of memory accesses, number of inputs/outputs, etc.) or using internal sensors.

ENERGY PROPORTIONALITY

We could observe in the server consumption profiling that this consumption varies between 160 watts (when the server is powered, the operating system is active, but no application is executed) and 240 watts (when an intensive application is being executed on the server). This variation reflects a certain energy proportionality that varies according to the use of the computer resource. The more the server is used, the more the electrical power that is used increases.
Unfortunately, when the workload decreases, this electrical power does not tend towards zero watts but towards a rather high value (160 watts in our example). In 2007, Luis André Barroso [5] observed the consumption of servers in a Google datacenter and realized that this consumption with a workload close to 0 tends towards 50% of the server's electrical peak.

This bad energy proportionality comes from the types of consumption that exist in a digital resource:

- static power consumption: which is used by everything that is powered in a fixed way in a digital equipment: motherboard, fans, magnetic hard drives...
- dynamic power consumption: which depends on the use of the equipment caused by the software executed: operating system, protocols, services, applications...

There are some cases where the power consumption is almost constant regardless of the use of the computer equipment (for example, wired network equipment such as network switches).

ENERGY EFFICIENCY

Observing the energy consumption of a piece of equipment is not enough; it is necessary to relate this consumption to the application service provided. This is what we call energy efficiency. Energy efficiency is measured in terms of resource usage (number of inputs/outputs per second, number of calculations per second, number of requests processed per second) per unit of electrical power used or energy consumed.

For example, in the world of high-performance computing centers, the volume of calculations performed on real numbers per second (*floating point operation per second: flops*) is the main performance indicator. The more flops a system supports, the faster it is and the higher its performance is theoretically. Thus the Top500[6] lists the 500 largest high-performance computing centers every 6 months. The comparison metric is the number of flops. For example, in the June 2021 Top500[6], the largest machine is the Japanese supercomputer Fugaku, which uses 7 million computing cores and has a sustained performance of 442 Petaflops. This list does not reflect the service rendered by these machines in relation to their energy consumption. Thus the Green 500 list[7], proposes to sort the 500 largest systems according to an energy efficiency metric: flops per watt. In the June 2021 list[7], the top Green 500 machine is the MN-3 machine. It uses 1664 compute cores, is 335 th in the Top 500 and achieves 1.8 Petaflops of computation. This machine has the best energy efficiency. For each watt of electricity used by this machine, 29.7 Gflops of computation are achieved.

SOURCES

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1. Patrick Eustache and Robert Ferret. Electricité: bases et aplications aux datacentres, Course conducted for ANF EcoInfo training, September 2014 url ↩
2. Des astuces pour convertir les watts en KWh, Engie, url ↩ ↩ ↩
3. Definition of Joule Wikipedia ↩
4. Jean-Marc Jancovici. Pourrait-on alimenter la France en électricité uniquement avec de l'éolien ?, July 2014, url ↩
5. Luiz André Barroso and Urs Hölzle. The Case for Energy-ProportionalComputing, IEEE Computer, Vol. 40, No. 12, December 2007 url ↩

6. Top 500: the 500 largest computing systems sorted by computational performance, June 2021 list url ↩ ↩
7. Green 500: the 500 largest computing systems sorted by energy efficiency, June 2021 list url ↩ ↩