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AN ASSESSMENT OF POWER-USE PROFILE IN DESKTOP COMPUTERS

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Abstract- Knowing the actual power requirement of each individual component in a desktop computer is useful when sizing a power supply or when upgrading the PC. In this paper the power demand by various components within six different computer systems was investigated. Measurements of the actual current drawn from each voltage rail when idle and when in use were made and the data examined. The results obtained showed that the total power drawn at idle and on CPU load test was mainly due to the load demand on the +12V rails and this varied significantly between the computer systems; meanwhile +5V and +3.3V lines drew very little power and the total power consumed did not vary significantly between systems on idle state. The assessment revealed that it is highly unlikely that a modern computer system will ever overload either the +5V or +3.3V rails of an ATX12V 2.x compliant power supply; the +12 rails on the other hand, are very heavily used especially under load. Thus, it is very likely that the ratings for the +12V rails is more important than the total wattage rating when it comes choosing a power supply unit for a computer system.

Keywords*- sizing; voltage rail; load demand; wattage rating*

I. INTRODUCTION

Power is the life force of every computer. Each element in a computer, from hard drives and memory, to video cards, motherboards, and modems demand energy from the power supply unit (PSU) [1]. A PSU converts the electrical power available at the mains socket to the type used by the electronic circuitry and electromechanical devices inside the computer unit. It is designed to convert either 120-volt (nominal) 60Hz ac (alternating current) or 240V (nominal) 50Hz ac power into –12V, –5V, +3.3V, +5V, and +12V dc (direct current) power.

Computer power supplies are rated based on their maximum output power. The input specifications are listed as voltages, and the output specifications are listed as amps at several voltage levels [2]. Table 1 shows the rated outputs at each voltage line for supplies with different manufacturer-specified output ratings [3].

TABLE 1: PC POWER AND COOLING ATX/ATX12V POWER SUPPLY OUTPUT RATINGS

Model (Rated Output):	235 W	250 W	275 W	300 W	350 W	400 W	425 W	510 W
+3.3V	13	13	14	14	28	40	40	30
+5V	22	25	30	30	32	40	40	40
+12V	8	10	10	12	15	15	15	34
–5V	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
–12V	0.5	0.5	1.0	1.0	0.8	1.0	1.0	2.0
+5VSB	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0
Total watts (3.3+5+12)	249	288	316	340	432	512	512	707
+3.3V and +5V Max.	125	150	150	150	215	300	300	300

Typical power ranges are from 500 W to less than 300 W for small form factor systems intended as ordinary home computers; 500–800 W for gamers and high-end multimedia applications; while higher-end PCs demand from 800 W up to 2 kW powers supplies intended mainly for servers and extreme performance computers with multiple processors, several hard disks and multiple graphics card [4].

In most cases these ratings cannot be exceeded when operating under normal conditions. Problems with power supplies however do occur when expanding or upgrading the PC. This is due to power supply overload caused by filling up the expansion slots and adding more drives. Many of these add-on devices have varying degrees of current demand under different operating conditions; they have power ratings which is not officially certified but self-claimed by each manufacturer; and simply adding together the power required by each component at full load produces estimates for total system power demand that are always too high, sometimes as much as double, this is because no PC application stresses all components simultaneously to maximum load. Therefore, it is possible to overload a power supply on one voltage rail without having to use the maximum rated power [5].

In this paper, an attempt is made to determine how much power is demanded by a variety of components in a desktop computer system by measuring the actual current drawn on each voltage rail while the computer is in use. The results should bring some real empirical data to limelight, and should help determine what can and what can't be predicted about the power draw of a system.

II. METHODOLOGY

The experiment was conducted in the Electronics Lab of Electrical/Electronic Engineering Department, Federal Polytechnic Mubi. Six different desktop computer systems were configured for the testing. The systems represent a decent cross-section of PCs in use today. None of them directly compared to the others; consideration is not on differences between systems, but on general tendencies of power usage that are true for almost any configuration.

A wide variety of central processing units (CPU) and chipsets were tested, as well as several different VGA cards. Each system was powered by its own PSU; there were a variety of PSU models. All the PSUs were capable of delivering more than 15A on the 12V lines (combined). Table 2 shows the specification of each system.

TABLE 2: SPECIFICATION OF THE SYSTEMS

	P4 Socket 478	**P4 LGA775**	**Pentium D Dual Core**	**AMD Socket A**	**AMD Socket 754**	**AMD Socket 939**
Processor	Intel Pentium 4 2.8GHz (N- Core)	Intel Pentium 670 3.8GHz	Intel Pentium D 820 2 x 2.8GHz	AMD Athlon 2500+ (Barton Core)	AMD Athlon 64 3200+ (Newcastle Core)	AMD Athlon 64 3500+ (Venice Core)
Motherboard	AOpen AX4GE	Intel D915PBL	Intel D945GTP	MSI K7N2G NForce 2	Epox EP-8KDA3+	DFI NF4 LanParty NForce 4
RAM	512 MB OCZ PC3200	512 Corsair DDR2	512 Corsair DDR2	512 MB OCZ PC3500	512 MB OCZ PC3500	2 x 512 MB OCZ PC4000
VGA Card	ATI Radeon 9600 XT AGP	AOpen Aeolus 6800GT PCIe	–	–	Matrox MX440 AGP	AOpen Aeolus 6800GT PCIe
HDD	40 GB Seagate	250 GB Western Digital	74 GB Western Digital	20 GB Seagate	80 GB Samsung	2 x 300 GB Maxtor

To measure the current on any line, a Kyoritsu Clamp Meter was used.

This is a device that measures the electromagnetic field around any wire that's carrying electricity and translates it into a current readout in Amperes.

The meter is properly scaled to indicate very low currents and specified for 1.9% accuracy. For each system the measurement procedure was the same:

The individual wires in the various cable sets from the power supply were separated and then recombined according to the voltage they carried. In this way the total current from each individual voltage line could be measured separately. The two +12V lines were also separated and measured independently.

The –12V, and +5VSB lines were not measured, as they carry so little current that they are insignificant also they are not used to power components.

Each system was measured at idle and then under load using CPUBurn (two instances were run for multi-threaded and dual core processors and the average recorded). Ambient temperature at the time of testing was 29^{o}C. The experimental setup is shown in Fig. 1.

Figure 1. Experimental setup

III. RESULTS AND DISCUSSIONS

A. Idle Power Test Results

The power distribution in the PC when the system was idle is as shown in Table 3. The systems are listed in order of increasing total power.

TABLE 3: POWER DISTRIBUTION WITHIN THE PC: IDLE

	+12V (total)	+12V1	+12V2 (CPU)	+5V	+3.3V	Total DC Power
AMD (754) Athlon 64, 3200+ (Newcastle)	0.8A	0.4A	0.4A	2.5A	2.6A	31W
Intel (478) P4, 2.8 GHz, (Northwood)	1.8A	0.9A	0.9A	1.1A	3.3A	38W
AMD (A) Athlon 2500+ (Barton)	4.6A	2.0A	2.0A	2.3A	2.0A	73W
Intel LGA775 Pentium D 820 (2x2.8GHz)	4.6A	0.5A	4.1A	3.6A	0.7A	76W
Intel LGA775, Pentium 670 (3.8GHz)	5.1A	2.3A	2.8A	2.9A	1.5A	81W
AMD (939) Athlon 64, 3500+ (Venice)	4.6A	4.0A	0.6A	3.0A	3.9A	83W

From a cooling perspective, the power draw at idle is largely irrelevant. A good cooling system must provide adequate cooling when the system is under sustained high load [6]. Any system that can handle this will automatically be cool enough at idle. The same thing applies when sizing a power supply: If it can handle the peaks under heavy load, it should have no problems supplying the power required by a system at idle.

From the standpoint of conserving power, however, the idle power draw is very important because most systems spend a vast amount of time at or close to idle. The total power draw at idle is largely determined by the load on the +12V lines. In fact, with only one exception, the relative power draw on the +12V lines was a good predictor of the total power draw.

The A64-3500+ system is arguably the most powerful system tested; it was the only system with two sticks of RAM and the only one with two hard drives. This is reflected in the relatively high current draw from both the +3.3V line (for RAM) and the +5V line (for the HDD). In fact, the combined power draw on these two lines totalled almost 30W about 50% more than the other systems, which drew 18~21W from these lines at idle. The extra RAM and hard drive obviously contribute a little, but most of the power is being drawn on the +12V1 line, so it makes sense to figure out what is being drawn from this line. The likely suspect is the high-powered 6800GT VGA card, which consumes a significant amount of power.

However, this does not explain why the Pentium 670 system with the same VGA card draws so much less current from the +12V1 line. Perhaps the power regulation circuitry on the LGA775 motherboard is more efficient, or maybe the nForce4 chipset for the AMD system is especially power hungry. It may also be that the onboard video based on the GeForce 4 MX might be drawing additional power.

Despite all of these minor differences, the general trend was quite clear: The +5V and +3.3V lines draw very little power. Furthermore, the total power required by these lines does not vary much between systems. Building a system that draws less power at idle seems to rely mainly on keeping the power draw on the +12V line as low as possible.

B. CPU Load Power Test Results

The power distribution in the PC on CPU load is as shown in Table 4.

TABLE 4: POWER DISTRIBUTION WITHIN THE PC: CPU ON LOAD

	+12V (total)	+12V1	+12V2 (CPU)	+5V	+3.3V	Total DC Power
AMD (A) Athlon, 2500+ (Barton)	5.4A	2.3A	3.2A	2.3A	1.8A	82W
AMD (754) Athlon 64, 3200+ (Newcastle)	5.2A	1.8A	3.4A	2.5A	2.6A	83W
Intel (478) P4, 2.8 GHz (Northwood)	6.5A	0.9A	5.9A	1.2A	3.7A	96W
AMD (939) Athlon 64 3500+ (Venice)	7.8A	3.9A	4.0A	3.8A	3.8A	125W
Intel LGA775 Pentium D 820 (2x2.8GHz)	11.5A	0.5A	11.0A	3.5A	0.6A	155W
Intel LGA775 Pentium 670 (3.8GHz)	13.7A	2.2A	10.7A	2.8A	1.6A	183W

In each system, the CPU load resulted in increased current draw on the +12V2 line. For the most part, none of the other lines were affected by the CPU load. Once again, exceptions were seen in the AMD based systems.

As expected, the Socket 754 system saw an increase of 3.0A on the +12V2 line. However, the current on the +12V1 line also rose by 1.4A; this increase was not seen on any other system. This suggests that the CPU in this system was drawing current from both +12V lines. Likewise, the Socket 939 system also drew primarily from the +12V2 line, but power draw also increased by 0.8A on the +5V line. Generally, this increase is barely significant, but it does show that a given load on one system may not produce the same load pattern on a different system.

Also, the total system power ranking order changed. There's no question here that under high CPU load, the Intel systems are the power hogs. The lower end AMD systems didn't even get close. Only the AMD A64-3200+ system exceeded the power draw of any Intel system, in this case, the much less capable P4-2.8.

Power demand on the +5V and +3.3V lines varied widely between different motherboards and chipsets. Only the combined power draw of the two lines stayed fairly consistent. Regardless of platform, whether at idle or at full CPU load, the combined power draw for these two lines almost always stayed in the 20-30W range. Once again, the amount of power drawn on the +12V line almost invariably determines the total system power draw.

Table shows the load on each individual line as a percentage of the total load.

TABLE 5: POWER DISTRIBUTION BY PERCENTAGE: CPU ON LOAD

	+12V (total)	+12V1	+12V2 (CPU)	+5V	+3.3V
Intel (478) P4, 2.8GHz (Northwood)	81%	11%	73%	6%	13%
Intel LGA775 Pentium 670 (3.8GHz)	90%	14%	70%	8%	3%
Intel LGA775 Pentium D 820 (2x2.8GHz)	88%	4%	85%	11%	1%
AMD (A) Athlon 2500+ (Barton)	79%	34%	47%	14%	7%
AMD (754) Athlon 64 3200+ (Newcastle)	75%	26%	49%	15%	10%
AMD (939) Athlon 64 3500+ (Venice)	75%	37%	38%	15%	10%

The most evident trend is that the vast majority of the power is drawn from +12V2 line. This is because the CPUBurn stresses the CPU almost exclusively, so it makes sense that the CPU voltage line dominates power needs.

It is also interesting to note the differences between the AMD- and Intel-based systems. The AMD systems drew about 75% of their power from the +12V lines. This is a lot of power, but not as much as the Intel systems, which drew as much as 90% of their total power from these lines. This difference reflects the higher power demand of Intel CPUs, especially the newer ones. The older Northwood-core P4-2.8 drew much less power than Intel's newer CPUs, and consumed proportionally less power.

C. Power Demand of Individual Components

In addition to looking at differences in power consumption between idle and load, we also looked at how idle power consumption changed when individual components were added or removed from a system. This allowed us to judge roughly the power overhead for various components. Several different parts were tested: Two different kinds of RAM, two different video cards, a PCI Ethernet card, and an optical drive. Hard drives were not tested, since a reliable method of determining their power consumption already exists.

For each component, the power consumption on each voltage line was measured with the system at idle. These measurements were then compared to the relevant idle measurements without the component installed. The results below represent the net change between these two measurements. Differences of 0.2A or less were assumed to be within the margin of error of the testing equipment, and are therefore not included in the results below.

a. Power Consumption: RAM

Two types of RAM were tested: Regular PC3200 DDR and 533 MHz DDR2. In each case, a single 512 MB stick of RAM was added to an existing system configuration. The P4 Socket 478 system was used to test the PC3200, and the Pentium D Dual Core system was used to test the DDR2.

To stress the RAM modules while we measured them, Memtest86 was used to drive the power consumption up [7]. Because Memtest86 runs under its own OS not Windows a new idle baseline was needed for accurate comparison. Measurements for each type of RAM, at idle and under load, are given on Table 6.

The total power draw of the system is only given for the 512 MB configuration at idle. All other configurations are given as differences in power relative to this baseline. The power consumption for the +12V2 line was not listed; because the CPU the only load on the +12V2 line and therefore not used by the RAM.

TABLE 6: POWER CONSUMPTION: RAM

RAM Type	Size	Load	+12V1	+5V	+3.3V	Rise from Base
PC 3200 DDR	512 MB	Idle	0.5A	0.6A	3.0A	n/a
		M86	No Change	No Change	+0.7A	+2.3W
	1GB	Idle	No Change	No Change	+0.6A	+2.0W
		M86	No Change	No Change	+1.0A	+3.3W
533	512 MB	Idle	0.5A	3.6A	+0.5A	n/a
		M86	No	+0.4A	No	+2.0W

MHz			Change		Change	
DDR2	1GB	Idle	No Change	No Change	No Change	No Change
		M86	No Change	+0.9A	No Change	+4.5W

The total power draw of the system is only given for the 512 MB configuration at idle. All other configurations are given as differences in power relative to this baseline. The power consumption for the +12V2 line was not listed; because the CPU the only load on the +12V2 line and therefore not used by the RAM.

The power consumption of a single 512MB stick of RAM either regular DDR or DDR2 was too small for the resolution of the clamp meter. The largest measured increase was only marginally larger than the potential error in the system: 0.2A x (12V + 5V + 3.3V) = 3.9W. It is statistically possible that the total power consumption decreased for almost every test case a result that should be impossible given proper test conditions. Therefore, the fact that potential for error is high implies that the power required by RAM is basically insignificant. Even in the worst possible case, DDR2 under load, the total increase over the baseline measurement remains under 10W.

b. Power Consumption: PCI Ethernet Card

The P4-2.8 GHz system was used as a baseline for comparison. There were no identifying marks on the card itself, but the controller chip was marked "RTL8139B", which identifies RealTek as the OEM. Table 7 shows the power used.

TABLE 7: POWER CONSUMPTION: PCI ETHERNET CARD

	+12V1	+5V	+3.3V	Net Change in Power Draw
Idle	No Change	No Change	+0.5A	1.6W
Network Data Transfer	n/a	n/a	+0.6 - 0.8A	2 - 2.6W

Like the RAM test, only a small change in the load on the +3.3V line was observed after the Ethernet card was installed. The net increase was ~2W: Barely significant.

An attempt was made to measure the power consumption during a sustained data transfer. This produced a small increase on all voltage lines, but it is unlikely that the increases on the +12V and +5V lines could be attributed to the PCI card itself. Most likely this power was needed by the hard drive to copy the data used during the transfer. Hard drives do not consume power from the +3.3V line, so it seems safe to attribute this increase to the add-in card.

c. Power Consumption: Optical Drive

The baseline system is completely irrelevant to the measurements of the optical drive (Creative Labs 52x CD-ROM). Because the optical drive is powered by an individual IDE power connector, the current through these wires could be measured directly. See Table 8.

TABLE 8: POWER CONSUMPTION: OPTICAL DRIVE

	+12V1	+5V	Total Power Draw
Idle	0.0A	0.3A	1.5W
Typical Read	0.3A	0.4A	5.6W
Full Speed	1.1A	0.5A	15.7W

At lower speeds, the power draw for the optical drive was fairly small, but at full speed and spin-up the sustained power draw was about 15W, mostly from the +12V line. This is worth considering when sizing a power supply.

d. Power Consumption: VGA Card

Three different video cards were also tested: Matrox G550, ATI Radeon 9600XT and AGP. The AGP cards were tested on the P4-2.8 socket 478 system and the AOpen Aeolus 6800GT PCIe card was tested on the Intel Pentium D dual core system. Only differences at idle were examined, as trying to gauge differences at load proved to be near impossible because other components are brought into play (particularly the CPU). The results are presented on Table 9.

TABLE 9: POWER CONSUMPTION: VIDEO CARDS

Video Card	+12V (total)	+5V	+3.3V	Change in Power
Maxtrox G550	No Change	+0.3A	+1.7A	+7.1W
ATI Radeon 9600XT	+0.3A	+0.4A	+0.3A	+6.6W
Aeolus 6800GT	+3.0A	No Change	No Change	+36.0W

The Matrox and the ATI both drew less than 10W at idle. The Matrox card drew most of its power from the +3.3V line, while the Radeon seemed to draw power from all three main voltages.

The Aeolus 6800GT, on the other hand, drew much more power at idle about five times as much. All of the power came from the +12V line; neither of the other two lines were affected. To put it in perspective, the entire A64-3200+ socket 754 system used less power at idle than this video card.

Although the 6800GT uses a PCIe connector to draw power directly from the power supply, most of its power seemed to be coming through the PCIe slot on the motherboard. Of the total 3.0A load on the +12V line, 2.1A was drawn through the motherboard, and 0.9A came from the direct connection to the power supply. Note that this is only at idle; it may change during high load.

From the measurements presented here, it is hard to generalize about the power consumption of video cards. The power requirements for each card are unique; there do not seem to be any similarities between the models we examined.

It is well known that the most powerful (and recent) cards draw power from the +12V line. This can be seen by examining the external PCIe connector: It has only +12V and ground wires. It is important to remember that, while this generalization might be true for powerful cards, the more mainstream cards do not necessarily echo this power profile.

IV. CONCLUSIONS

It is important to keep in mind that the measurements presented here are continuous loads. Our test equipment does not have the resolution to measure peaks, which may last for 10 ms or less and may be much higher than the continuous load. Most power supplies are rated for a continuous load with allowances for higher peaks, but the internal protection circuits may still be tripped by an exceptionally high peak. It is wise to leave headroom for peaks perhaps 30% when sizing a power supply.

With these caveats, some broad, predictable conclusions can be drawn:

1) It seems to be highly unlikely that a modern system will ever overload either the +5V or +3.3V lines of a ATX12V 2.x compliant power supply. In our systems, neither of these lines ever drew more than 5A under any circumstance, and many power supplies rate them above 20A. The power draw on these lines tended to be quite stable and did not fluctuate much with load.
2) The +12V lines, on the other hand, are very heavily used, especially under load. For Intel-based systems with no external VGA card, this power comes almost exclusively from the +12V2 line. Adding a high powered VGA card may add some load to the +12V1 line, although not all cards use +12V. The systems with AMD CPUs tended to draw power more evenly across the two +12V lines, mainly because they do not consume as much power as Intel CPUs.
3) Looking at the total power draw alone, it would appear that all of our systems could easily be handled by a 300W power supply. Given that as much as 90% of that power comes from the +12V lines, it is likely that that the ratings for the +12V lines matters more than the total wattage. If these lines are inadequate, the power supply may not provide enough power even if its "wattage rating" exceeds the total power draw of the system. It would be wiser to qualify our statement thus: When it comes to adequate power delivery, all of our test systems could easily be handled by a 300W power supply that conforms to ATX12V v2.xx. Conversely, an older PSU rated honestly for 300W output may not be adequate for the most powerful system examined here because of the much lower 12V current capacity on models that comply with v1.3 and earlier versions of the ATX12V spec.

From the above conclusions it is important to note that power delivery alone is not the only criteria by which a PSU should be chosen. Other factors such as noise, efficiency, cooling, and voltage regulation are critical when choosing a power supply.

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