Designing Efficient Fans

for Electronics Cooling Applications

Introduction

In modern day equipment racks, the power consumed by the cooling fans represents a significant percentage of the overall system power budget. With the advent of data centers and their large energy costs, the issue of "cooling power" is exacerbated. It is, therefore, becoming crucial to design and implement methods for reducing data centers' power consumption. As an example, a large data center contains about 400,000 servers and consumes 250 MW of power [1]. It has been estimated that about 20 % of the total power supplied to a high end server is consumed by fans.

This article presents a review of methods available for reducing energy consumption through increasing fan efficiency. Three main ways of improvement by optimization will be discussed: motor and electronic driver optimization, fan aerodynamic optimization and surrounding inlet/outlet equipment optimization.

Background

A fan is an energy converter, so its efficiency can be expressed as the ratio of input and output power [2]:

$$\text{Fan efficiency} = P_{out}/P_{in} \quad (1)$$

where Pout (W) is the fan airpower and can be expressed as:

$$P_{out} = p \cdot \dot{V} \quad (2)$$

where p is the air pressure (Pa) and $\dot{V}$ is the air flow (m^3/s) at the fan outlet.

P_{in} (W) is the fan electrical input power:

$$P_{in} = U \cdot I \quad (3)$$

where U is the voltage (V) and I (A) the current drawn by the fan.

To date, a number of power management techniques have been adopted in the electronics industry in order to achieve the desired level of cooling with minimum fan energy consumption. For example, fan speed and power are controlled to the minimum level necessary for cooling. Since fan power consumption is proportional with $(RPM)^3$, significant savings can be achieved through fan speed control. In another example, the speed of a brushless DC fan is controlled by varying the input DC voltage. Variable-speed fan controllers for computers usually use Pulse Width Modulation (PWM). An AC induction motor driven fan can be speed controlled by varying its input voltage and frequency.

Beyond fan speed control, there are more savings available through optimization of the motor and electronic driver, increased fan efficiency and proper air system design.

Motor/Electronic Driver Optimization

DC Fans

For a brushless DC motor driven fan, one way to improve efficiency is by using more complex three-phase electronic drivers and motors, replacing the industry standard two- phase design. Figure 1 presents the schematics and practical implementations for these two concepts. Component count is 2 to 3 times greater for the three-phase design, but produces significant energy savings.

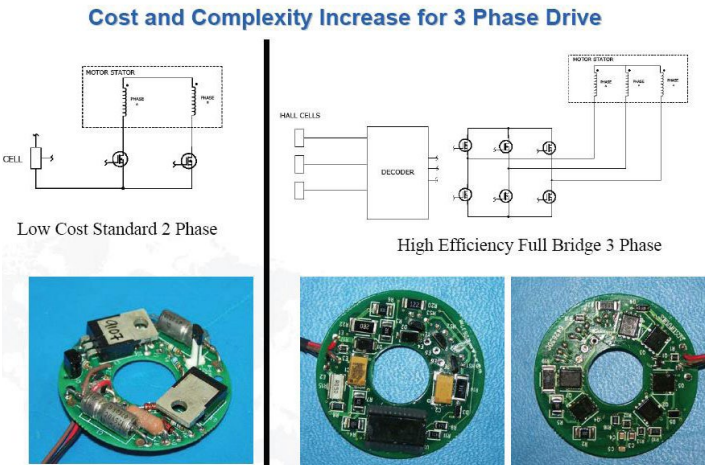

Figure 1. Standard 2-Phase and 3-Phase Driver Designs [1]

Test results comparing a 120 mm round axial fan (7.6 mm H2O, 140 CFM) equipped with a standard two phase electronic driver and a three phase driver indicate an energy savings of 9.8 W, or 30 % of the electrical input power [1]. Additionally, the reduced internal electrical losses decrease the motor temperature with a positive effect on fan reliability.

PWM heating is another source of motor losses, occurring when a DC fan is operated to its current limit as opposed to the natural commutation frequency of the brushless permanent magnet motor. This higher frequency PWM switching results in magnetic hysteresis losses which, combined with motor iron losses, can reduce overall fan efficiency by 5 to 15 %. As an example, Figure 2 compares the phase voltage and current waveforms for a fan operating under natural commutation and under PWM, while delivering the same air performance. By using PWM switching, the input power increased by 12 % (from 47 W to 53.5 W).

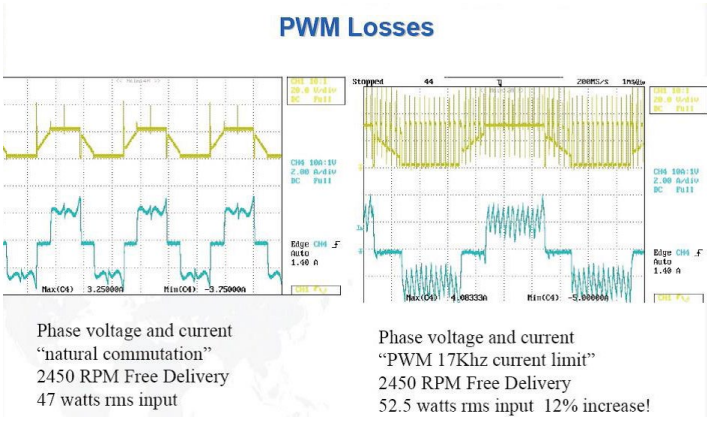

Figure 2. Phase Voltage and Current Waveforms for a Fan Operating under Natural Commutation and PWM [1]

A tradeoff should be sought between employing PWM at low voltages (and therefore achieving full performance) and operating the fan at full voltage, with the continuous associated losses. In certain cases, the use of PWM may not be justified.

AC Fans

Oftentimes, commercially available inverters are used to control the speed of an induction motor driven fan. Significant losses can result from the mismatch between the fan and the inverter [1]. Table I summarizes the performance comparison for a motor/fan operated under pure 3-phase sine wave versus with a 3-phase inverter. The inverter driven system consumes 14 % more power, mostly due to deterioration of motor efficiency. As a result, the stator temperature is 17 °C higher. The additional losses are due to harmonics contained by the distorted current waveform as well as PWM losses. An ideal inverter would synthesize a pure sine wave with no PWM imposed on the phase current waveform.

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Power Input	Amps	Watts	RPM	Stator Temperature Rise Deg. C
Inverter Drive 3 Phase 480 vac/400 Hz (PWM set to 4khz)	6.50	4120	11,035 RPM	61 Deg. C
Pure Sine Wave 3 Phase 466 vac/388 Hz	5.84	3550	11,045 RPM	44 Deg. C
Increase in Power (Electrical Losses)	0.66	570* Watts (14 %)	Equal Air Performance	17 Deg. C

Table 1. PWM and Harmonic Losses for an Inverter Driven Induction Motor [1]

Fan Optimization

Fan efficiency varies dramatically with the aerodynamic loading. Figure 3 presents a performance plot for a standard 120 mm diameter axial fan, with the efficiency curve plotted together with the usual pressure-airflow curve [2].

It can be observed that the peak efficiency occurs at a pressure value about one third of the maximum pressure. As a general rule, fan efficiency increases with blade diameter and rotational speed.

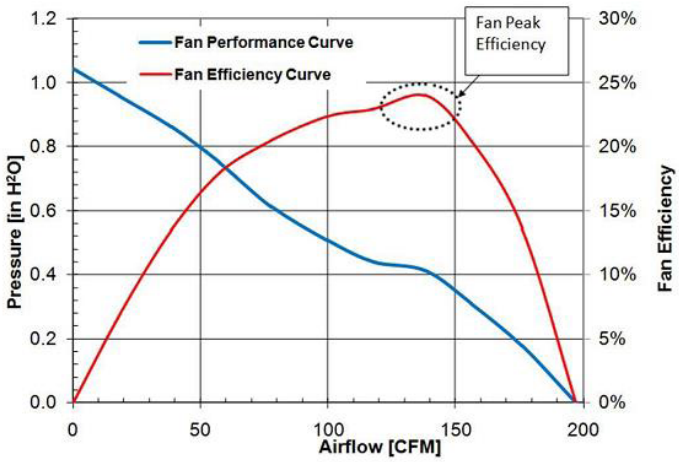

Figure 3. Pressure and Efficiency as a Function of Flow for an Axial Fan [2]

An illustration of fan optimization is offered in [1] for a standard 120 mm axial fan. The optimization is performed for the performance point of 50 CFM and 1.45 inch H_2O.

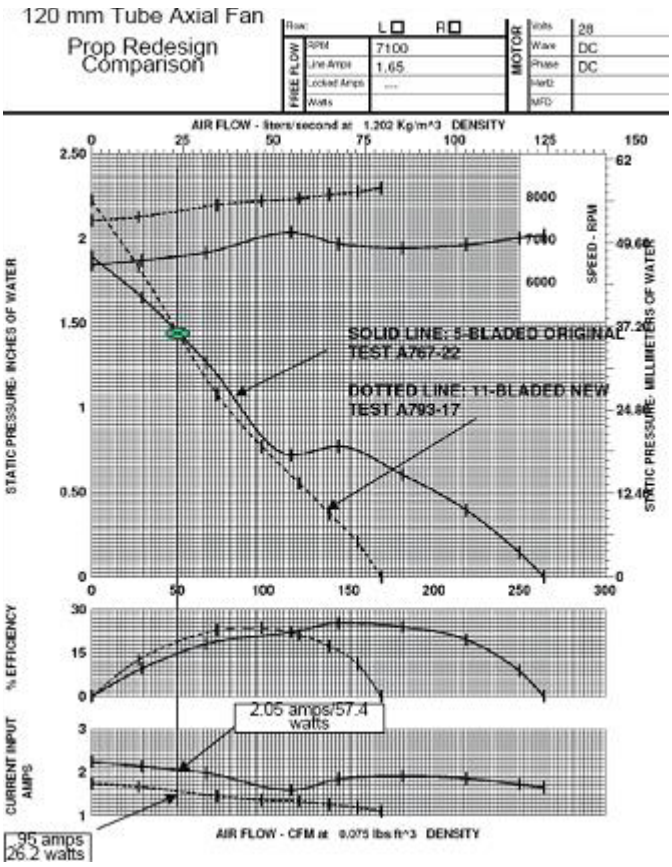

Figure 4. Performance Comparison between Standard and New Designs [1]

The optimized fan required a new propeller design with more blades, lower blade pitch and a higher operating speed. Figure 4 compares the performance of the standard fan with that of the optimized design, while Figure 5 illustrates the old and new designs, side by side.

Power consumption of the new fan at the operating point was reduced by more than 50 %, from 57 watts to 26 watts (Table II). The cost of this increase in efficiency is 6 more blades and 1000 more RPM.

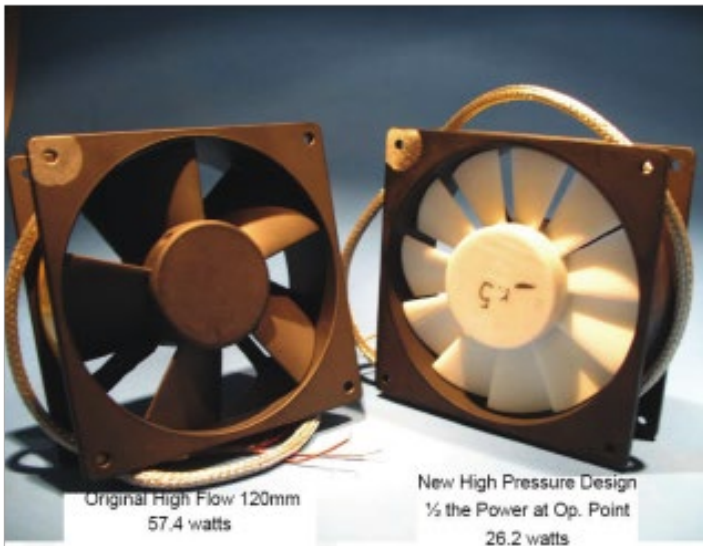

Figure 5. Standard and Optimized Fan [1]

	Original Production 120 mm Tube Axial Fan	Redesigned Propeller 120 mm Tube Axial Fan
Operating Point:	23.6 L/sec (50 CFM), 36.8 mm H_2O (1.45 in H_2O)	23.6 L/sec (50 CFM), 36.8 mm H_2O (1.45 in H_2O)
Number of blades	5	11
Pitch of blades/ Blade Depth	Hub: 38 °/ 24.13 mm (0.95") Tip: 30° / 24.13 mm (0.95")	Hub: 28° / 8.13 mm (0.32") Tip: 18° / 10.67 mm (0.42")
Power at operating point	57 Watts	26 Watts
Speed (RPM)	6700 RPM	7700 RPM

Table 2. Performance Comparison of Fan Designs [1]

Note: The basic motor design and the electronic driver remained the same.

A CFD snapshot output (Figure 6) showing velocity vectors for the two designs near the operating point also uncovers a stall region (for the standard design), just under the blade. This stall has been eliminated in the redesign process.

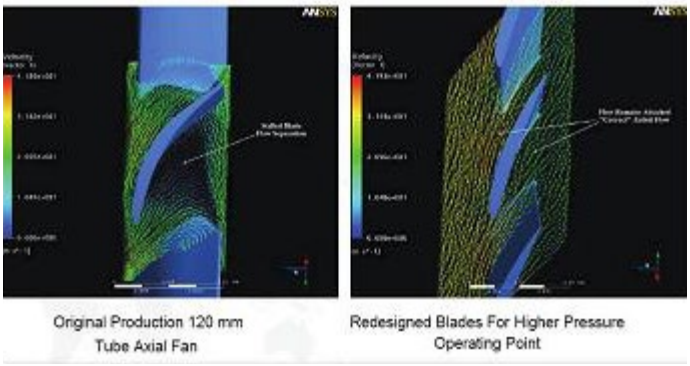

Figure 6. Results from CFD Analysis [1]

System Optimization

Additional energy savings can be gained by designing the fan within its operating environment rather than isolated, running on an air chamber. Fan performance and efficiency are both impacted by its air inlet and outlet configurations. The equivalent of inlet fairings and outlet diffusers can be built into the customer equipment to significantly boost overall air performance [1].

Conclusions

Fan power consumption is traditionally reduced by controlling the motor speed to produce only the airflow required for adequate cooling, rather than operating continuously at full speed. Significant energy savings can be achieved beyond this technique through fan efficiency increase. Optimizing the motor and electronic driver, increasing fan aerodynamic efficiency through careful redesign, and optimizing fan-system integration are three ways of achieving this. Additionally, using high efficiency fans has a positive cascade effect on the entire system design.

Power supplies can be reduced in size and the fans' power loss can be minimized. Also, the load and losses for power conversion equipment (AC to DC) are reduced.

Despite these advantages, high efficiency fans can be costlier than older fan types, a significant economic deterrent. Also, it should be mentioned that any fixed-geometry fan has a single peak efficiency point. In practice, the system operating point must fall within fan's high-efficiency operating range [3].

References:

1. **Smith, N.," High Efficiency Electronic Cooling Fans", 25th IEEE SEMI-THERM Symposium, 2009.**

2. **http://www.nmbtc.com/fans/white-papers/Fan_Efficiency_Important_Selection_Criteria.html.**

3. **Lawless, P.B., "Advanced Aerodynamics for Electronics Cooling Fans", Electronics Cooling Magazine, February 2013.**

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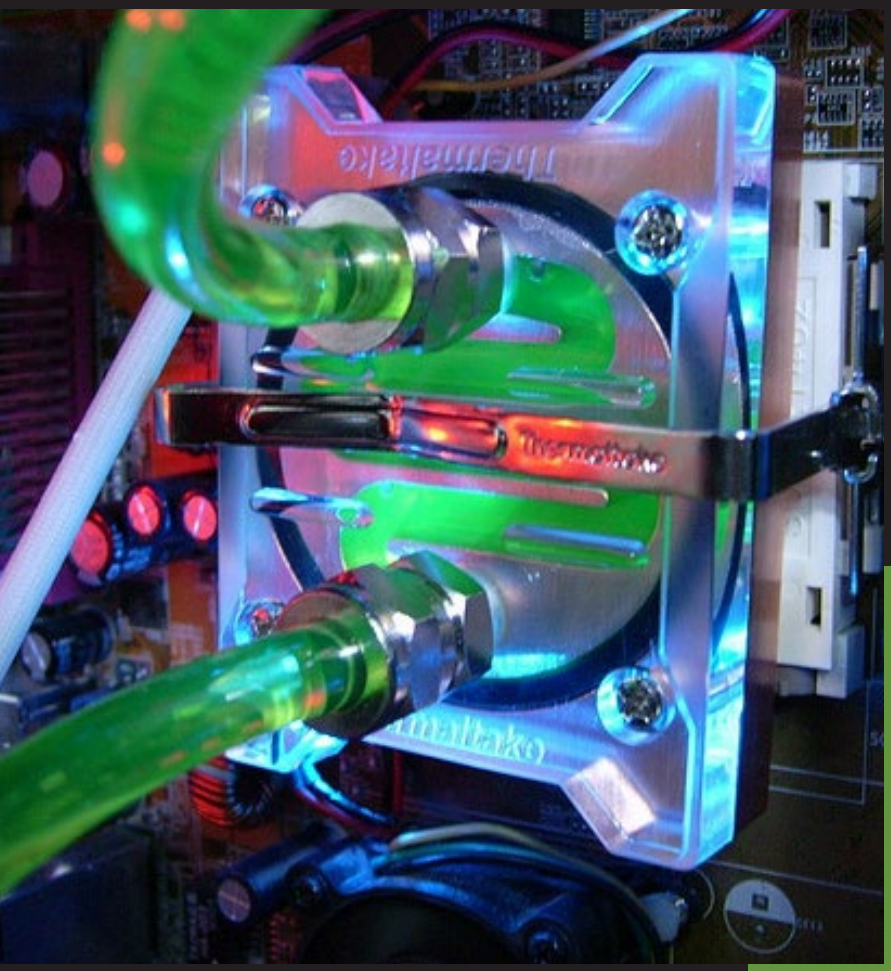

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