Improving Performance and Cost in Single-Phase AC Fan Systems

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ABSTRACT

Single-Phase AC motors continue to dominate the motor market and continue to grow in volume. Their low cost and simplistic design make them an ever favorite even as they are slowly displaced with more complex; more energy efficient solutions. By utilizing digital control technology to the more basic single-phase AC drive, many improvements can be made to the performance, noise and installation costs related to these motors. Fan assemblies are becoming more common in both distributed HVAC systems and Cleanroom filter systems. The low cost AC platform will continue to play a significant role and with improvements resulting from digital control we can narrow the performance gap. Thus, the AC systems will be quieter, more efficient and easier to install; extending their usefullness and competitiveness for new applications and installations.

INTRODUCTION

In previous articles[1]-[2], AC motor drive techniques were presented for driving AC motors with a digital control platform. Numerous benefits have been identified and AC solutions with digital control have been closing the gap on more sophisticated and expensive DC brushless platforms. This paper reviews some of the performance benefits highlighted preciously and expands on the additional benefits that continue to drive AC platform solutions.

The resulting controls can provide sophisticated closed loop control, provide more efficient operation and incorporate “smart” solution systems that make AC systems viable for a wider range of applications. In the end, there remain limitations and tradeoffs that even the best controllers can’t overcome. Adding these features without pricing the solutions out of the users’ price range continues to be a moving target as smarter microprocessor solutions become available at ever lower costs.

This paper reviews the numerous benefits and clarifies the present state-of –the-art in phase-control AC motor drive technology.

[1] Power Electronics Technology Conference 2004
[2] Power Electronics Technolgy Magazine June 2005

FEATURES AND TECHNIQUES

Linear Speed Regulation - One of the frustrating facets of phase-control is the non-linearity of the rpm with the linear change of the phase angle. This non-linearity is well understood and can easily be compensated for by a digital control engine. This has been reviewed previously and is the most obvious application of a digital controller in AC fan controls.

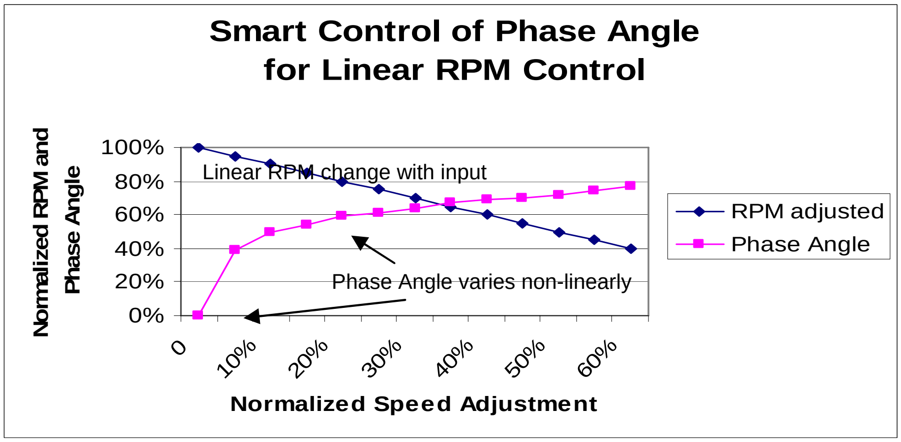

Figure 1: Linear RPM Output Using micro-control of TRIAC Phase Angle

3-Wire Configuration – Implementation of a unique 3-wire control scheme to improve the efficiency and noise of the single-phase PSC motor by using the microprocessor control. Figure 2 shows a fan being driven by a 3-wire circuit topology. The Auxiliary winding is connected directly to the AC line maintaining full voltage as the voltage across the primary is reduced.

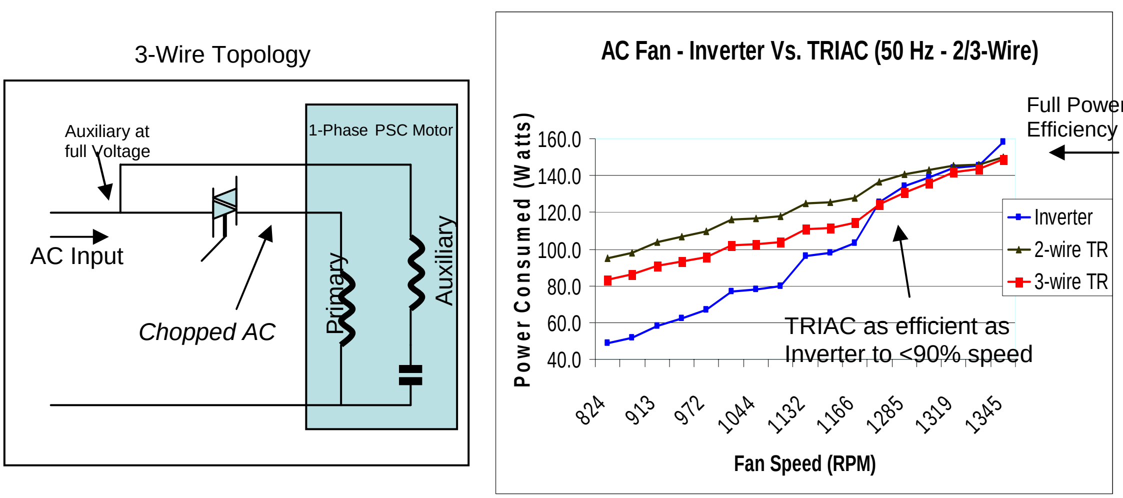

Figure 2: 3-Wire Topology & Improved Power Consumption Data

As can be see by the above, the efficiency of the TRIAC control is improved and is competitive with Inverter solutions down to almost 90% of speed and continues to provide efficiency improvements through the normal operating range of fan control.

Noise Reduction – Mechanical Hum and Harmonic Distortion – One of the effects of using a phase-control on a single-phase AC motor is the resulting noise that emanates from the motor. A distinctive “hum” can be noted from the fan as the speed is reduced. A result of the 3-wire implementation is a reduction of the "hum". This results from improved phase angle between the primary and auxiliary winding as voltage is reduced, affecting the slip effect of the motor. The reduction in circulating currents within the motor is apparent in the reduced current draw from the line, resulting in reduced hum and heating in the motor. Additionally, the motor runs at a lower current for a given RPM. The result is that harmonic distortion is reduced at the given fan speed. Figure 3 below shows the impact of harmonic distortion for a traditional 2-wire and the improved 3-wire topologies.

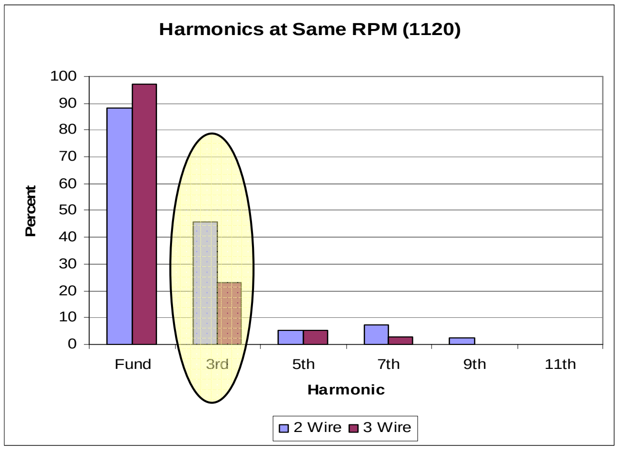

Figure 3: Harmonic Distortion for identical fan running at reduced speed

Soft-Start Implementation - With a smart controller, one can create a "controlled" delay to allow the phase to go to full throttle more slowly, giving the motor time to gain "back EMF" and reduce the current drain. Controllers can be designed so that one can customize the ramp-up period for the type of motor and system being driven (we have found significant differences between the performance of an external rotor motor and a traditional internal rotor motor during start-up). Figure 4 provides an example of an uncontrolled and smart-controlled start-up.

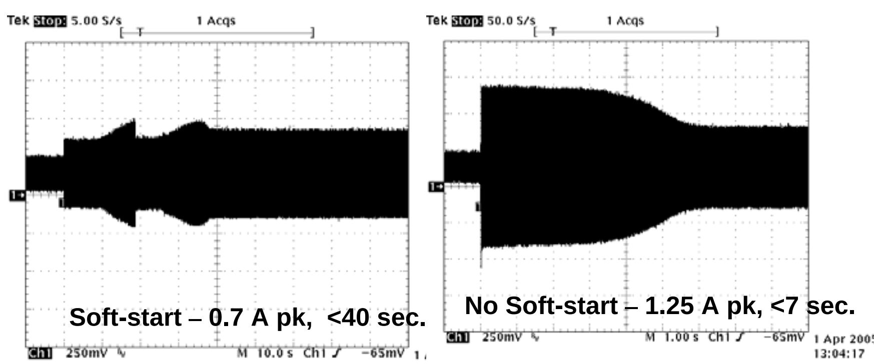

Figure 4: Smart Control for start-up - 277V, 0.65A rated motor/fan

With soft-start the peak current is reduced from 2-2.5x the rated motor current to slightly over 1.0x the rated current. The time scales on the above graphs are different (soft-start extends the time to reach full speed from less than 7 seconds to over 30 seconds).

Analog or Network Communications/Control – The most common set point positioning technique is by providing an analog voltage or current to the drive. To this end, with nominal interface circuitry these options are easily created. Another option is to enable the drive to be interconnected into a communication network. Most commonly accepted networks require additional communication wiring. The market is filled with numerous acceptable platform options of network interfaces.

An interface that offers an analog control (in our case we provide a 5 volt reference voltage so a simple three-terminal potentiometer can provide an input signal) provides a simple, low-cost solution. Sophisticated "systems" requiring a number of units being controlled to a greater specification (i.e. a fan system in a cleanroom environment) benefit from a cost effective network interface.

Many products today offer both (Figure 5)to be available, either selectable by hardware changes or software selections. We have found a good combination to be an analog option (i.e. 0-5 volt) along with a network solution (MODBUS RTU) that can be implemented at low cost.

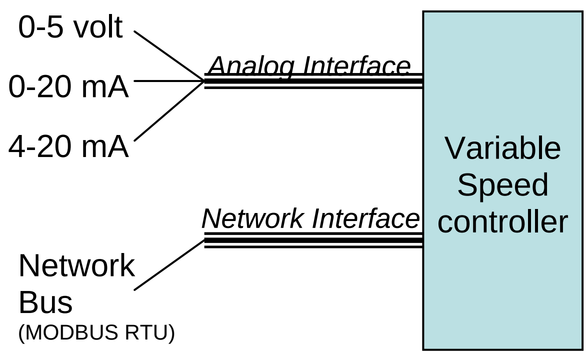

Figure 5: Interface Control – Analog, Network or "other"

Closed Loop Regulation and Control - With most low-cost microcontrollers, the key ingredients of a closed loop control system can be implemented. They are closed-loop feedback algorithms (i.e a PID control loop), a second feedback node to compare the external error signal to the desired set point and the availability of external sensors that can provide the error signal in the appropriate form needed by the controller (i.e. 0-5V, 4-20 mA etc.). Figure 6 is a simple block diagram of the desired system.

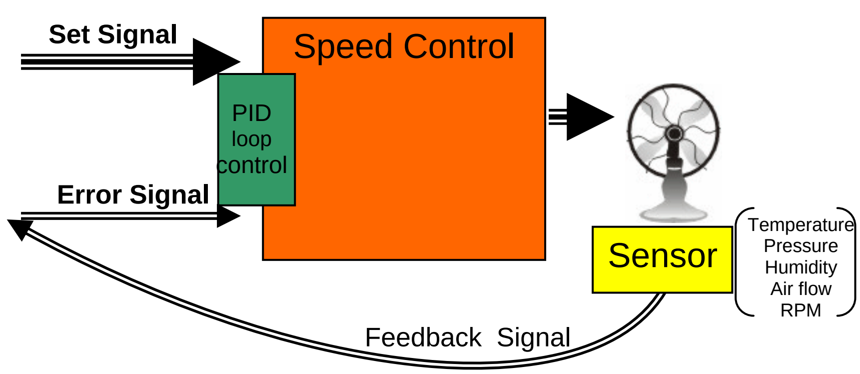

Figure 6: Close Loop Control Using External Sensors

A unique feature of digital implementation is that a number of different control modes can be incorporated into the same unit. A solution set we have offered provide 3 operating modes that can be engaged through software selection. The three modes are:

1. *Lowest cost – open loop speed control*
2. *closed loop speed control through rpm counter (hall sensor, slotted switch)*
3. *closed loop control using analog feedback from sensor (flexible set/control feature)*

CONCLUSION

Single phase AC motors (permanent split capacitor – PSC) have traditionally been controlled by low-tech, basic function elements. The higher functional requirements have been delegated to the more sophisticated and more complex motor drive platforms (3-phase, DC brushless etc.). These platforms, however often add cost that have eliminated them as viable options for most cost-sensitive applications. The availability of low-cost digital controllers allow for a myriad of features and benefits that can be incorporated into the phase-control platform without significant cost adders. Improved efficiency, start-up controls, closed loop feedback and network interfaces are all viable and practical with the new tools available to the designer.

The future holds much promise. We can create improved performance solutions for the low-cost, basic, single-phase AC motor, as we have shown above. Continued improvements and techniques will close the gap between the "inefficient" AC single-phase motor and the more sophisticated platforms.

The key to providing best-case solutions revolves around the ability to identify and implement the "necessary" features and benefits required by the application. Additionally, the single-phase AC motor has limitations that can not be overcome with technology innovation (i.e. low speed-high torque), and pushing the technology beyond its useful limits is unwise. To the consternation of those pushing the higher end motor/drive solutions, the gap in performance has definitely been closed, making the Single-Phase AC motor a viable (and still lowest cost) solution for many applications.