Phase-Control Alternatives for Single-Phase AC Motors Offer Smart, Low-Cost, Solutions

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Abstract **-** Single Phase AC motors continue to be the primary solution for air-movement, pumping and compressor applications. Their low cost and availability make them ideal for low-performance systems. DC Brushless platforms attempt to address these applications but their higher cost and complexity continue to form impenetrable barriers of entry. They are viewed as overkill for most applications. Single-Phase Inverter Drives have come on the scene, making headway, but remain complex and costly. Phase-Control solutions are being revisited and upgraded to fill the void. This paper explores the performance limitations and trade-offs of the Phase-Control solution and clarifies the boundaries under which the TRIAC Phase-control is a preferred method of speed control and the improvements provided by smart phase-control.

INTRODUCTION

Variable speed motor controls have been available for many years. As technology progresses, major innovations and improvements have been made in sophisticated systems improving the motor drive performance and reducing cost and complexity of the available solutions. Thus, improvements in the performance and availability of AC inverter (Inverters) solutions as well as DC brushless drives (BLDC) and motors have brought these solution options into the market in greater numbers.

There are many articles and technical papers that address the improvements and innovations in brushless dc drives as well as improvements in AC drives. What we see little of is the improvements in the existing low-cost control techniques focusing on phase control or other low-cost AC control techniques that don't require the AC power to be converter to twice. This paper revisits the single-phase AC motor control and outlines improvements and value added features now available that make phase-control drives a viable alternative for speed control in most applications.

Of greatest interest is going back to revisit the Phase-control platform that has been around for many years and look at the innovations and improvements that are available. Comparisons will be made to the single-phase inverter designs but we will not directly cover Inverter design innovations here. Most single-phase motors are not designed to work well with high frequency inventers resulting in bearing pitting and motor performance degradation.

The results demonstrate that with careful attention to the application requirements and applying state-of-the-art technology to the basic TRIAC topology a good cost-performance solution can be provided that will allow variable speed to be incorporated into numerous applications that were not viable for the manual controlled TRIAC or the expensive Inverter solution. Upgrading the TRIAC control results in smart, performance competitive solutions at a lower cost.

SINGLE- PHASE AC MOTOR SPEED CONTROLS

The two primary ways to control the speed of a single-phase AC motor is to either change the frequency of the line voltage the motor sees or by changing the voltage seen by the motor, thereby changing the rotational speed of the motor. An Inverter will convert the AC waveform into a DC Voltage and them create a PWM signal output that will filter into a waveform with a predetermined voltage (controlling torque) and frequency (controlling speed). Figure 1 has a block diagram of the Inverter design and the various speed waveforms are shown in Figure 2.

Key Benefits: Voltage / Frequency control → Wide Speed range → low-speed / High efficiency
Key Drawback: Higher Cost → Hi-Voltage Pulses→Full Speed losses→ Motor Reliability

Figure 1: Single-Phase AC Inverter Block Diagram

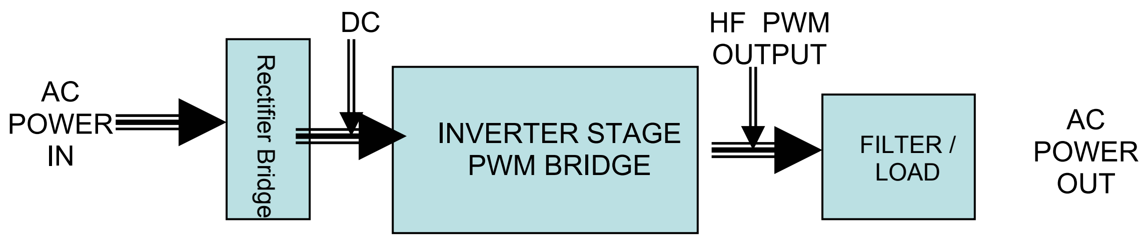
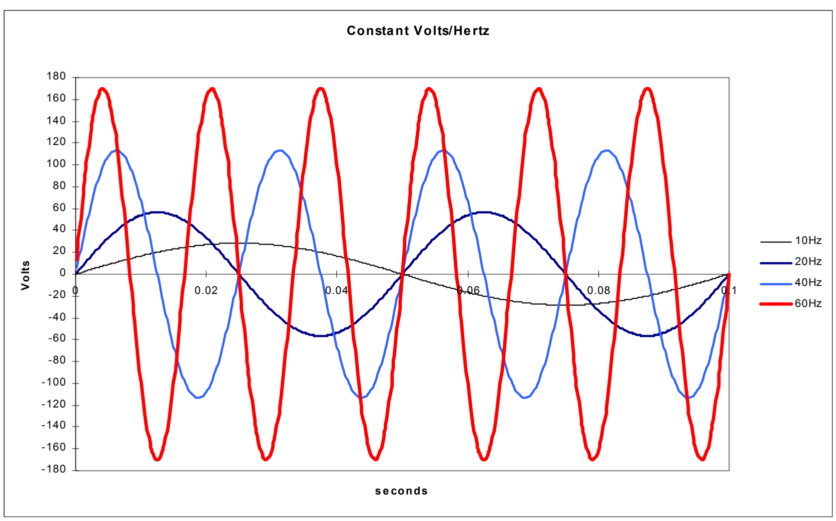
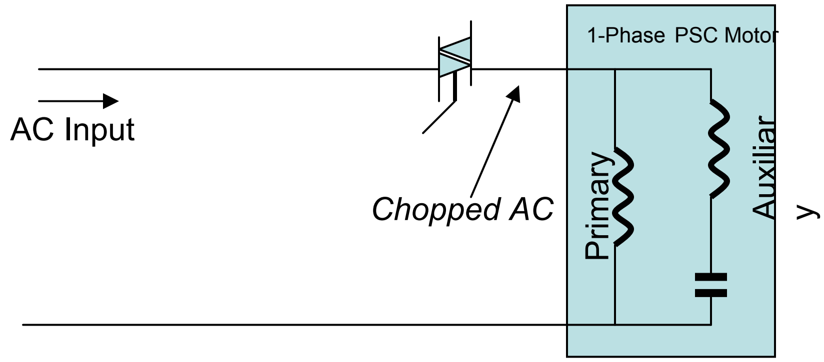


Figure 2: AC Waveforms for Inverter Drive



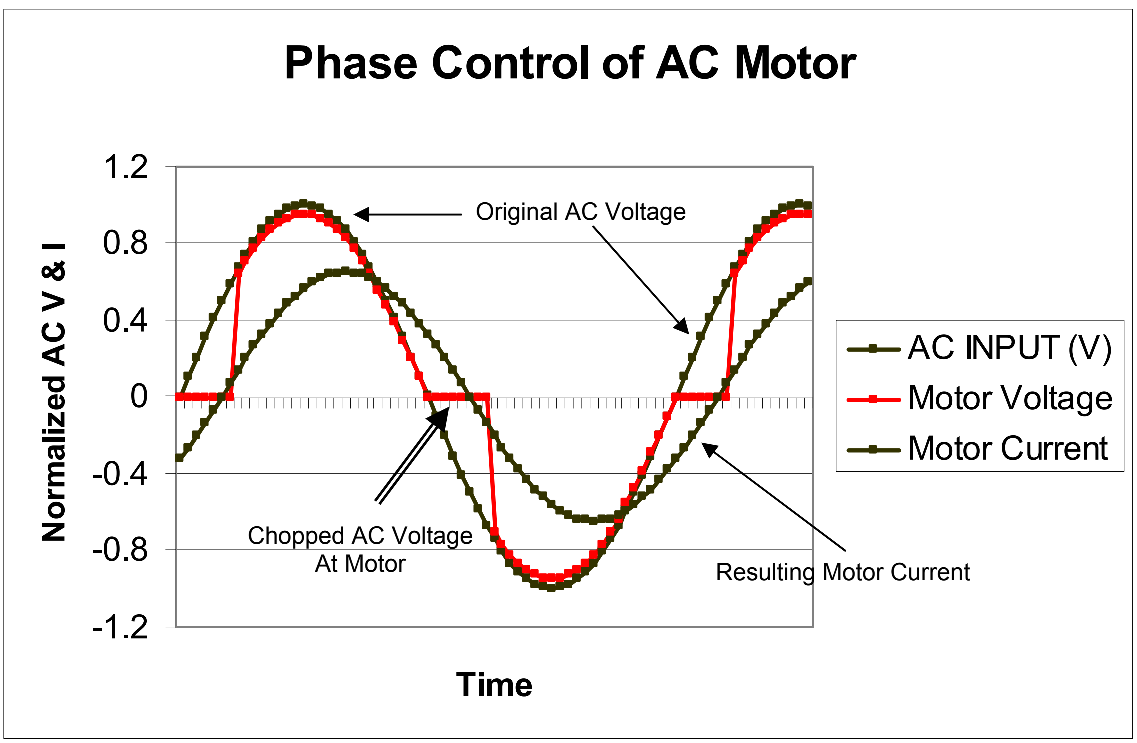
The TRIAC, Phase-Control design is simpler. There is a single switch that is in line with the AC line. It chops the AC waveform causing the power to shut off during a portion of the AC Cycle. Figure 3 shows the general schematic for a TRIAC controlled drive. The motor shown is a permanent split capacitor motor having 2 windings and a capacitor for phase shift.

Figure 3: AC Chopper / TRIAC control of 1-Phase AC motor



The AC motor acts as a low pass filter causing the resulting current waveform to be sinusoidal at the same operating frequency with a slight lag. The lower RMS voltage created by the chopper increases the slip to the motor, thereby reducing motor speed. Essentially starving the motor of its power, the motor slows down and eventually stops because there is not enough energy to maintain rotational speed. Figure 4 shows typical waveforms; the TRIAC driven output and the resulting AC waveform that the motor sees.

Figure 4: Phase Control AC Waveforms for Single-Phase Motors

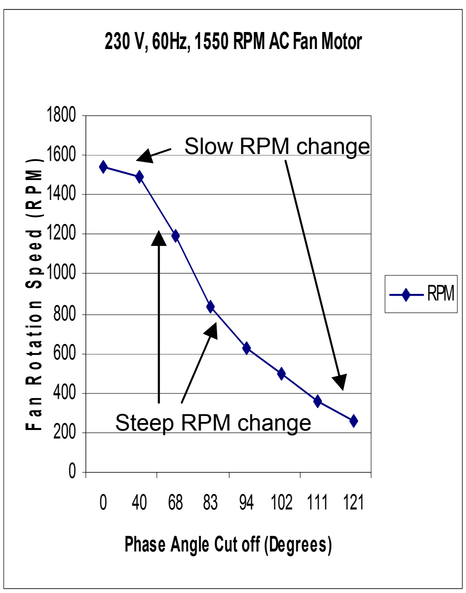


Key Benefits: Low Cost → Ease of Control → Robust & Reliable → Multi-loads
Key Drawback: Motor Speed range → Lower Efficiency → Power Factor

TRIAC CONTROLS REVISITED

A key problem with TRIAC controls is that the resulting voltage (and ultimately resulting speed) is reduced by essentially starving the motor. However, where very inefficient motors were the norm years ago, many fan applications are using more efficient and better designed motors. These motors can be driven off a phase-control scheme down to 30% of motor speed before running out of torque. The motor speed is very sensitive to small changes in the phase angle. Figure 5a depicts the RPM change by phase angle for an efficient fan motor down to 20% speed range. The result is non-linear with minimal speed change as the phase control begins and then enters a steep change mode as the phase angle increases to the heart of the sinusoidal waveform. A well known phenomenon, this characteristic is a frustrating element of existing manual controls as speed changes too fast when using a speed potentiometer. In applications such as clean rooms the constant adjustment and difficulty of setting the speed add much technician time to the set-up and recalibration process.

Figure 5a: RPM of motor changes non-linearly with phase angle shift
Figure 5b: RPM tracks within 6% of RPM for fan motor over high speed range



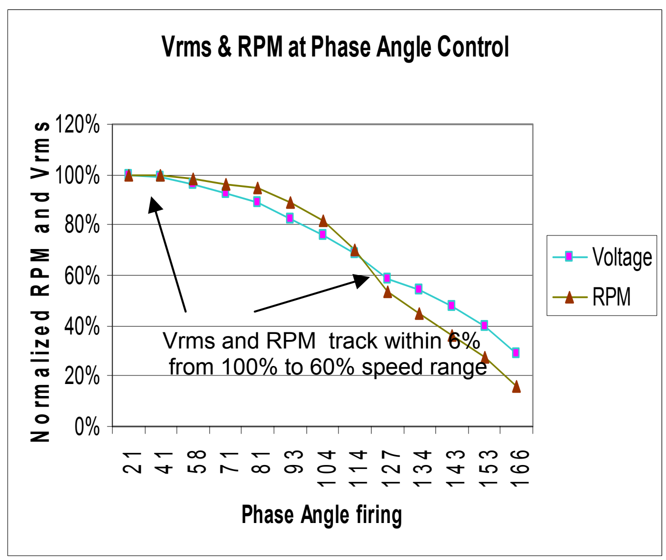
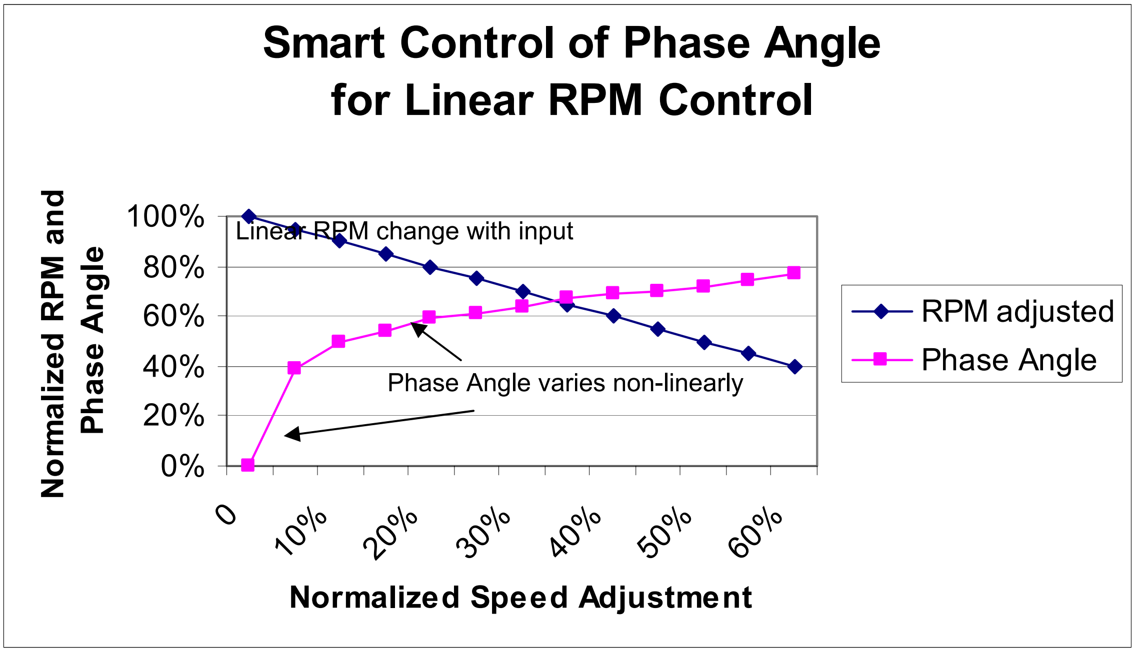


Figure 5b shows the relationship between the VRMS and RPM of a single phase motors. Surprisingly, the speed of the fan (RPM) will track with the RMS voltage across the motor. This is impacted by the loading (all the information presented is based upon fan loading). Thus, if a control methodology could be provided that will linearize the RMS Voltage as a function of controller change, the blower speed will likewise be linear.

Microprocessor control of the TRIAC drive provides this improvement. The digital control can be designed to match the loading tables of the drive, making the response of the drive to a linear input (i.e. the turning of a speed knob) or the digital input of 0-100%

controller signal (0-5 volt or 4-20 mA control signal). Thus, the microcontroller provides a non-linear phase-angle control to keep the speed changes linear. This can be seen in Figure 6 where significant phase angle needs to be transversed before the speed changes even 10%.

Figure 6: Linear RPM Output Using Micro-control of TRIAC Phase Angle

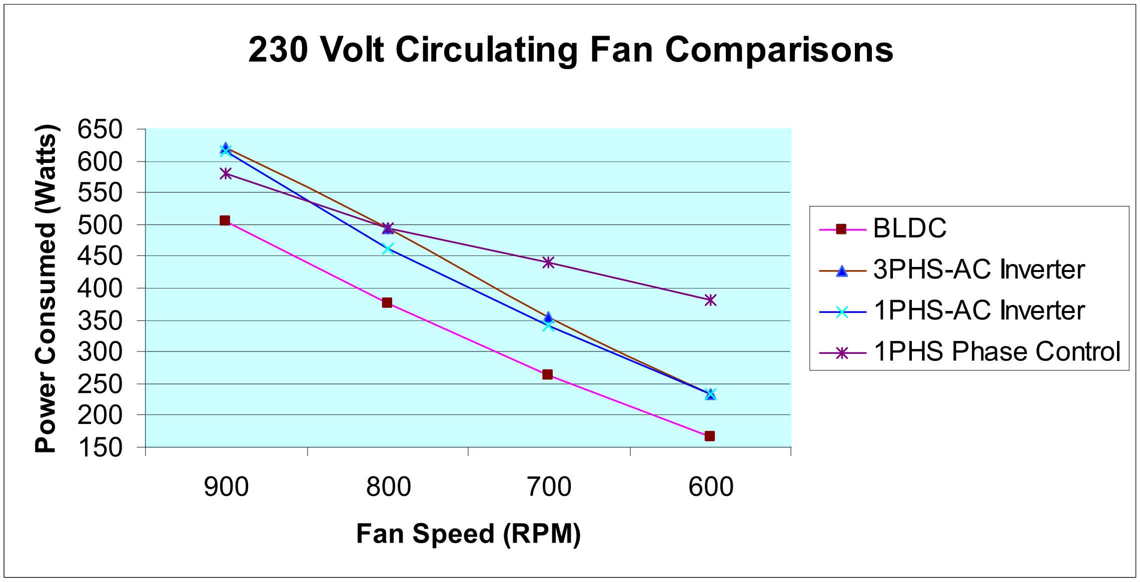


EFFICIENCY REVIEW

No evaluation of the TRIAC Phase-control is complete without discussing the main reason to NOT use TRIAC controls. Other than the limitation of speed range we already covered, the biggest reason cited for not using TRIAC controls is the poor efficiency of this approach. Although there is less energy consumed when the drive runs at lower power, alternate approaches save more energy. In a semiconductor cleanroom facility where you may find thousands of fans, the extra 20% or more energy savings add up and can be used to offset the significantly higher investment in more energy efficient motors and drives. Figure 7 shows a ¾ HP blower being driven by several technologies:

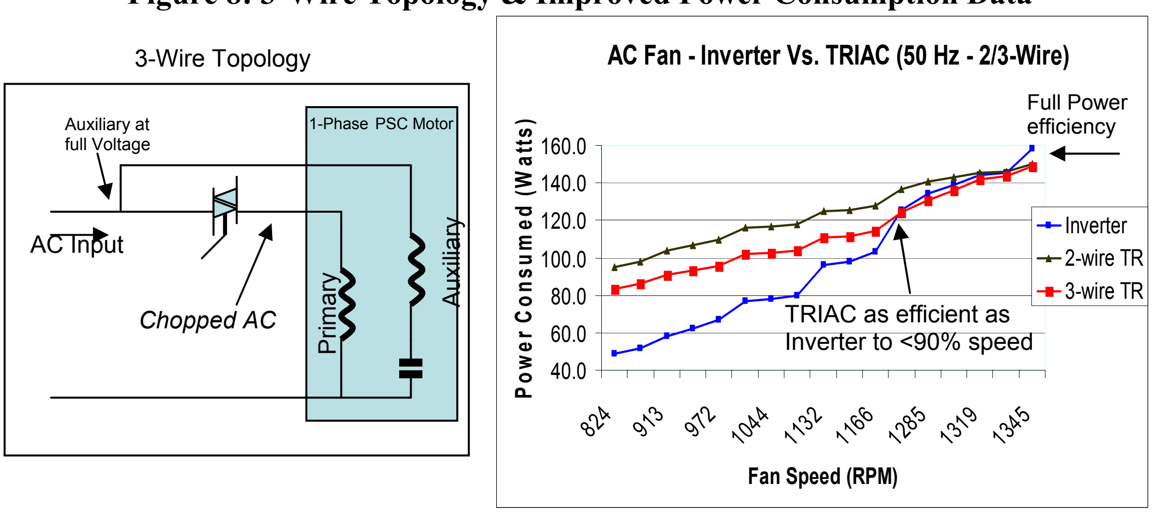
BLDC – Highest efficiency motor – uses >100 watts less at full power. Best power consumption alternative at highest cost.
3 Phase AC – motor is comparably efficient to the single phase choice. Notice how the power consumed is higher than TRIAC at 95-100% speed.
1 Phase AC – PSC motor – power consumption is slightly more efficient than 3-Phase but that seems to be more attributed to the motor differences than the drive. At 95-100% speed the double power conversion shows the inherent inefficiency of this at full speed
1 Phase TRIAC Phase Control – Energy saving at lower speeds do not compare to the other options as power savings is less as the speed reduces.

Figure 7: Power Consumption Comparisons of Motor/Drive Combination



One other note with regard to the TRIAC Drive consumption. The performance can be enhanced by moving to a 3-Wire approach. Figure 8 shows a small fan being driven by a 3-wire circuit topology. The Auxiliary winding is connected directly to the AC line maintaining full voltage as the RMS voltage across the primary is reduced.

Figure 8: 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.

SIMPLE GUIDELINES FOR PHASE-CONTROL

After the above overview it is useful to define the preferred boundary conditions to expedite a decision if the TRIAC phase-control is a viable alternative and the criteria that lend themselves to a smart-phase-control system solution.

To summarize the above evaluation there are a few well defined issues to consider:

1) **Existing System** – many existing systems use a single-phase motor for their needs. Adding speed control can add to their performance. Taking a manual speed control and adding smarts or network communications (needing smarts) are reasons to consider a TRIAC phase control solution.
2) **Motor Reliability-** AC motors are not designed to stand up well under inverter high frequency, high-voltage spikes. Motors today are specially designed "inverter ready" or having isolated bearings to avoid pitting. If motor reliability is an important criteria the reduced efficiency may be a worthwhile tradeoff against reduced motor life.
3) **Speed Range** – If the speed range needed is within the capabilities of the chosen AC motor, the phase-control approach is viable.
4) **Speed Accuracy** – Phase-control is not traditionally an "accurate" speed controller. Slip, loading and numerous factors contribute to the actual speed as the drive is usually an open-loop controller. "Smart phase-control" will close the loop giving full, accurate speed control. The added smarts will allow for added features to be added at low cost.. still maintaining a low cost power platform.
5) **Efficiency** – As discussed, if power consumption and efficiency are critical elements of the system design, there are better methods using more efficient motor and drive technologies. Here, the bigger issue is the AC motor inefficiencies, more so than the drive inefficiency.
6) **Cost** – The phase control power and control platform are low cost. Adding smarts, feedback, and network communications add cost at the same rate as the other topologies, however, the basic power and control platform is a fraction of the cost of rectification and inverter stages. The AC motor is also a less expensive product than alternative motors and will stay that way for foreseeable future.
7) **Robust & Reliable** – most of the electronic drives have significant sensitivity to voltage spikes, temperature swings, and current increases. The results in inverter drives is to do major de-rating to protect the product. Over-design can add 20-30% to the unit cost. The phase control drive provides additional current and voltage buffers at a fraction of the cost.

CONCLUSION

Phase Control has been making great strides by adding smarts, improving performance and adding microcontrollers and network communications to make them viable and useful tools in today's systems. Added to their robust design and low cost (power platform) these systems will continue to grow as viable alternatives when requiring variable speed control to enhance system performance.

BLDC, Inverter Drives and new system topologies will continue to make great strides in reducing cost, improving performance and closing the higher cost gap with phase control will continue. The inertia of significant volumes of single-phase motors will continue to pose barriers of entry to these solutions beyond unit-to-unit cost comparisons. In non-critical applications where the higher performance is not necessary, "smart phase-control" will evolve to be the platform solution of choice.

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