

## White Paper

### **VARIABLE-SPEED MOTORS IN HVAC BLOWER APPLICATIONS**

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Recently, comparisons have been made between variable-speed induction motors (VSIM) and the Electronically Commutated Motors (ECM™) widely used in heating ventilation and air conditioning (HVAC) system blowers. VSIM proponents copied some of the function and features of the already established ECM and are now claiming an advantage simply because induction motors are in widespread use. Such claims are misleading and, in some cases, misinformed.

Actually, two motor technologies are being compared to the ECM – the variable speed induction motor and the switched reluctance motor (SRM). While they make claim to some of the features and functions pioneered and patented by GE in its ECM, the inferences of superior performance or better economic value simply cannot be substantiated. Since there are few (in the case of the SRM there are no) residential HVAC blower products in the U.S. market that use them, the basis for the claims are unsubstantiated.

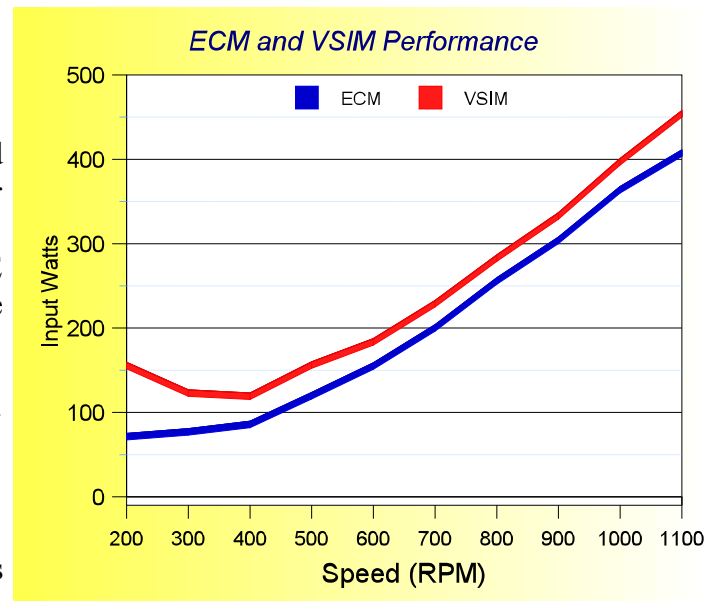
This paper highlights the advantages of blowers driven by GE's ECM and presents the facts behind the performance, cost, and operation of the various types of variable-speed motors.

### **Background**

GE pioneered the development of variable-speed technology for residential HVAC in the late 1970's. It was in 1979 that GE began studying the available technologies to determine which would provide the highest efficiency, overall performance, and economic value in residential and commercial HVAC. The study began with the induction motor and the three-phase variable-speed drive – the combination known as the VSIM. While tests proceeded with that conventional technology, efforts to develop the brushless-dc motor and methods to produce it were also underway. It was a well-known physical fact that brushless-dc motors are

more efficient than induction motors, and tests with both motor technologies in HVAC blowers and compressors were corroborating that fact.

The ECM as GE was to call their brushless-dc technology performed consistently better in those tests than variable-speed induction motors. Even efforts to improve VSIM performance using



**Figure 1**

sophisticated field-control methods could not compete with the inherent efficiency and simple operation of the ECM. To this day VSIMs do not match the ECM's efficiency and performance.

Early in the development of the ECM – in the early 1980's – there were three drawbacks to the ECM, and all needed a low-cost solution. The first was the need to use permanent magnets in the motor – and they had to be very low cost. The second required the electronics controller to know rotor position so the motor could be controlled without mechanical brushes and commutators. The last was the necessity to develop low-cost production techniques to attach the permanent magnets to the rotor. All three drawbacks were readily solved.

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GE had already developed a method that allowed the use of low-cost ferrite magnets (the type of magnet in mass production worldwide for automotive motors) that simply depended on closely tailoring the motor and control design to the characteristics of the magnets. In time, sensing rotor position was solved by using the inherent characteristics of the motor itself when one of the magnetic poles on the rotor passes by the unactivated winding of the stator (unlike an induction motor, there is always an unactivated winding), the passing pole induces a voltage in that winding. All that was needed was to sense that induced voltage and the problem of knowing when the electronics should switch (commutate) to the next stator phase winding was solved. It couldn't have been simpler; it was done without adding sensors, and GE was granted a patent on the technique..

Attaching the magnets proved to be almost as simple. Tests had proven that a reliable attachment could be made by bonding the magnets to the surface of the rotor core. High strength epoxies were more than adequate to hold the magnets at rotational velocities up to 3,000 RPM three times greater than the speeds that would be encountered in HVAC blowers. With the addition of a "cup-like" retainer over the magnets, rotational velocities up to 12,000 RPM were achieved.

Nevertheless, GE continued evaluating both VSIM and ECM technologies, competing one against the other, into the early 1980s. There was intense effort to improve the efficiency of VSIMs to enable them to offer the same or better HVAC system value. Interestingly, the key to making any improvement in the induction motor's performance depends on knowing the position of the rotating magnetic fields inside the motor. Unfortunately, such knowledge isn't as available in the VSIM as it is in the ECM. Even when costly, "vector-controlled" motors – as they are called – in which the position of the magnetic fields could be ascertained were tested, they still fell short in performance and far below the value of the ECM.

A major reason for this is fundamental to the induction motor itself; the efficiency of the induction

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motor falls off dramatically at low speeds. This characteristic seriously degrades the performance of an air conditioner or heat pump since power consumption at low load accounts for most of the operating hours and the SEER and HSPF ratings. Blower power is a major factor at low loads.

Ultimately, GE decided to market the ECM. The initial offering was a two-piece design: the motor was separated from the electronics control. Today, it is a single-piece design in which the motor and the control are integrated, and for this reason today's version is sometimes called an ICM. This product is responsible for a new standard of performance in HVAC systems and is used in the best HVAC systems in the US, Canada and Europe. ECM-driven blowers are featured members of nearly every major US manufacturer's furnace and fan coil product lines.

*The ECM is transforming the HVAC market to high product value and efficiency by providing an unparalleled combination of low operating cost, comfort, flexibility, serviceability and reliability.*

### **Simplicity**

To justify the VSIM in residential HVAC its proponents have made several erroneous claims about its simplicity. Perhaps the most inaccurate is the statement that VSIMs use residential AC voltage, but ECMs use DC voltage which doesn't exist in residences. This misleading statement belies the fact that for variable-speed operation both the ECM and the VSIM use AC power and both must convert it to DC before reconverting it to voltages and frequencies capable of being used by the motor. What is not stated is that the conversion process is much simpler in the ECM. The misinformation seems to be based in the belief that because the induction motor is commonplace, variable-speed induction motors must be simple.

### ***Motor and Control Simplicity Explained***

The induction motor may be one of the most complex machines in universal high volume use ever developed. When three-phase induction motors are

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operated at variable speeds that complexity really begins to show itself.

For maximum efficiency VSIMs must be driven from three independent sinusoidal voltages in much the same way 3-phase fixed-speed induction motors are operated from a 3-phase AC line. The frequencies of the three voltages and currents must be varied to change the motors's speed. The synthesis and processing of sine waves by the motor's control electronics add complexity and cost. A further complication is that the fidelity of the sine waves is critical, especially at the lower frequencies needed for low speed operation. Magnetic losses in the motor and poor sine wave fidelity are major reasons for the relatively poor efficiency at off-load speeds. Motor and control design can be optimized to help minimize these effects, but at the expense of even further complication that makes the motor more unlike commonplace, low-cost induction motors. Nevertheless, even an optimized induction motor cannot match the performance of the ECM without significantly increasing its size (stack) and material content.

As mentioned, for hvac applications both the VSIM and the ECM are powered from the AC line and both convert AC line voltage to DC. The VSIM must then reconvert the DC to sinusoidal variable frequency AC, while the ECM makes more efficient use of the DC voltage it develops. As a matter of fact, the more "DC-like," or trapezoidal, the ECM motor's waveforms are, the higher the torque production per delivered amp – a direct indicator of efficiency. ECM's are controlled with a simpler process with no requirement to develop three separate and distinct sinusoidal waveforms.

*Simply because the induction motor is the most common motor, does not mean variable-speed induction motors are simple.*

### Constant Airflow

The ECM can be programmed to adjust its speed and torque to deliver constant air flow into a wide range of restriction in the air distribution system. HVAC experts measure this restriction as a pressure

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drop and call it external static pressure. On Feb. 21, 1989 GE-Motors was issued patent # 4,806,833 which discloses how a motor could be made to adjust torque and speed in a blower to hold the air flow constant across a wide range of external static pressure without the use of an external airflow sensor. This is accomplished by first testing an ECM in a blower cabinet and then programming the test results speed and torque over a range of static pressure into the motor. The microprocessor in the motor then uses the data to determine how to adjust the blower speed and torque to control the airflow over that very wide range of airflow restriction.

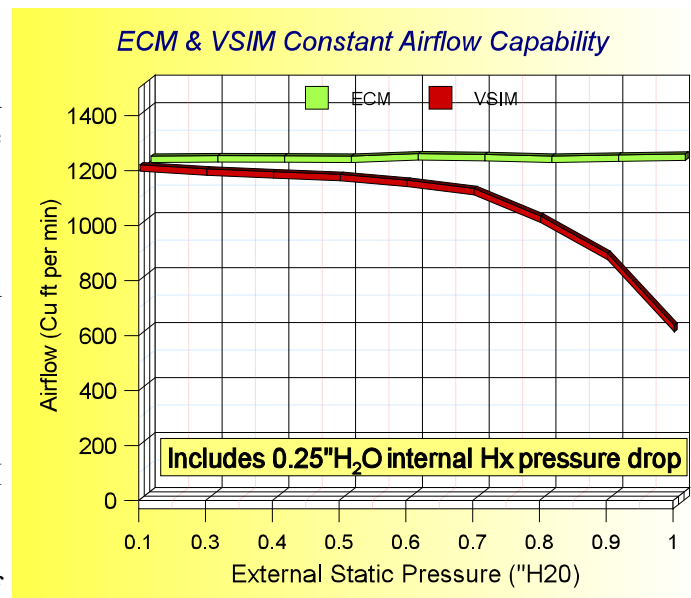


Figure 2

Why is constant airflow an advantage? Residential and light commercial HVAC blowers are applied in a wide range of products that are applied across a wide variety of duct-work, each with its own wide range of restriction at different airflows. Also, variation in restriction can be expected as filters load. Restrictions causing pressure drops as low as 0.0" of water – free discharge – and up to one inch of water are common. A standardized product cannot perform optimally across that range of application variation.

A conventional blower driven by non-variable-speed motors can't deliver as much air as the pressure on the blower builds. Since the motor can't speed up

enough to let the blower push more air faster, the motor unloads and power falls. Of course, if the airflow is to be held constant as the static pressure increases, the amount of work the motor has to do also increases.

The ECM's efficiency permits more incremental power to be delivered to speed up the blower – more than can be economically and safely delivered to a variable-speed induction motor. In other words, another ECM advantage is its “marginal” power handling. **Figure 2** shows data from a ½ hp ECM and a ½ hp VSIM. Both are applied in the same 1200 cubic feet-per-minute blower. The chart shows two significant items. The first is the excellent speed and torque control the ECM has to deliver virtually constant airflow. It also shows the dramatic airflow reduction from a blower driven by a VSIM as external restriction increases above 0.6" of water. This is the direct result of poor marginal power handling capability above its ½ hp rating.

### **Afford ability**

The cost of variable-speed technology is dominated by the cost of converting, controlling and delivering power to the load. The power delivered at the shaft necessary to rotate a blower wheel to deliver a specific airflow into the static pressure of the air distribution system is the same no matter which type of motor is driving the blower wheel. However, any undelivered power - that is, power not delivered to the shaft but consumed as losses in the motor, in the controls or elsewhere in the process – must still pass through the electronics. *Stated simply, inefficiency of the motor adds to the cost of the electronics.* Value therefore depends on the motor and control having the highest practical efficiency and is the fundamental reason why the ECM is a better choice – its efficiency reduces the cost associated with handling the power needed to operate the load.

One might ask if it is possible to raise the VSIM's efficiency to avoid the penalty. The answer is yes, but raising a variable speed induction motor's efficiency generally means employing a longer stator stack, using higher grade steel, or tooling special stator laminations. These improvements drive the

cost to greater than the ECM's. The disadvantage the VSIM has because of its relative inefficiency more than offsets the added cost of the only unique elements in the ECM – its magnets.

In preparing this paper, a thorough cost analysis of a VSIM intended for HVAC application was conducted and shows the VSIM's electronic control is significantly more expensive than the ECM's. The motor itself is of comparable cost. There simply is no cost advantage.

*An HVAC manufacturer's long-term product plans that are based on VSIM short-term market penetration pricing strategies will be disappointed when they find “buy-in” level pricing cannot be profitably sustained.*

### **Reliability**

The only variable-speed motor capable of making field reliability claims is the ECM. Its operation in HVAC products in the field spans three generations of improvement over more than eleven years. Proponents of VSIMs (and the untested, untried switched reluctance motor) claim high reliability, yet no field data exists to substantiate the claim. Given the complexity of the electronic drives used in less efficient VSIMs, and the stresses the electronics control experiences at any load (which are above the ECM's stress at the same load), it is unlikely that VSIM motor drive reliability can approach the reliability of the ECM.

It has been stated that the ECM should be less reliable than the induction motor because of the magnets on its rotor which might come loose. The claim stems from speculation that the magnets must be prone to detaching themselves from the rotor. Neither that imagined failure mode, nor any other motor failure, are significant factors in failure rate.

By far, the dominant factor in improving failure rate is experience. The ECM is the only variable-speed motor with experience in the many adverse environmental operating conditions of residential and commercial HVAC. On the other hand, the VSIM and switched reluctance motors simply do not

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have the relevant application breadth nor the volume to adequately understand their failure modes. They have many lessons yet to learn before reaching acceptable failure rates.

*The ECM's greatest asset is its volume base in actual residential and commercial HVAC applications. Volume fuels multi-generation product design and reliability improvement that further reduce cost .*

### Serviceability

Blower motors that use “dip-switches” or jumpers located on the motor make service or adjustment a time-consuming nightmare. They force servicemen to remove the motor or blower housing so that initial set-up and minor adjustments can be made to a furnace or air handler. Present-day ECMs are “partitioned” so that all of the necessary system adjustments can be easily accessed behind the front access panel of the furnace or fan coil.

*The ECM design is partitioned so that the control can be removed from the motor without taking the motor out of the blower assembly. This simple arrangement facilitates service and minimizes replacement cost.*

Diagnostic indicators are great help during installation and service but only if they are located in the conventional service locations and can be easily accessed. The ECM's partitioning permits displaying the system's status from the residential thermostat or from the system's controls. It provides “CFM” and “RPM” outputs so that servicemen can actually see if proper airflow is being delivered. Most OEMs supply some form of indicators on their interface boards so that servicemen can make quantitative and qualitative assessments of system operation. Diagnosis of the air distribution system, humidity or comfort control, and even the applied efficiency of the system can be done using those indicators. Armed with such tools, the ECM's application flexibility can be used to correct a wide variety of problems not addressable in systems driven by conventional induction motors and other variable-speed motors.

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### Other Operational Issues

Several other factors must be considered for complete compatibility with the operational demands and economic requirements of HVAC systems. Variable-speed motors must give better performance than single-speed motors to help justify their added cost – all variable-speed motors do not provide those benefits at the same cost.

### Sound level

Low noise is a primary marker of equipment quality and is becoming a major HVAC sales feature. Air noise is by far the largest part of the overall noise level made by the indoor blower of an HVAC

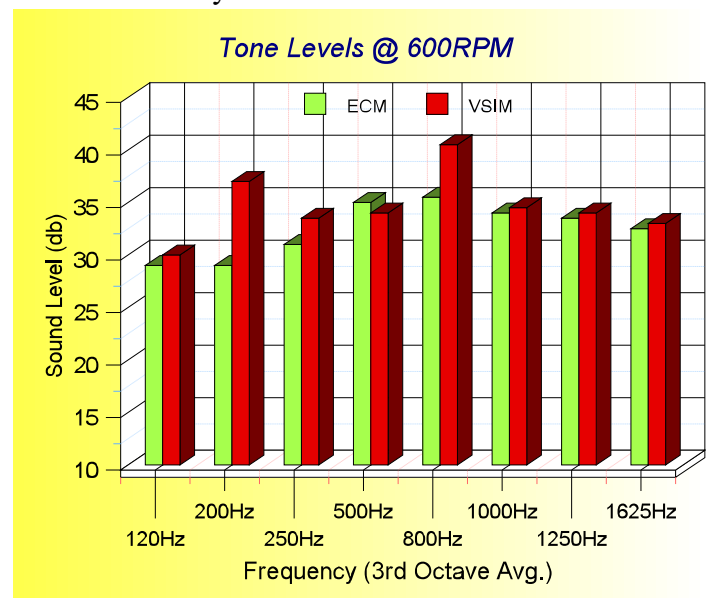


Figure 3

system.. Therefore, the quality of the air distribution system, i.e. the duct work, registers and diffusers, must be kept high and air velocities must be kept low if the background noise in a home or business is to be kept at acceptable levels. Motor noise itself, while seldom a complaint in single-stage, high velocity systems, can be a problem in multi-stage systems and under low airflow continuous-fan conditions. Nuisance sounds, such as high-pitched whistles, “wowing” and motor tones are especially troublesome during the night when background noise is very low.

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Single-speed, tapped or phase-controlled induction motors are notorious for their high sound levels for two reasons. First, they start and stop abruptly, dramatically changing the ambient noise level, giving increased perception of being noisy. Secondly, the motor can make its own electrical and magnetic noises, especially when low speed taps are selected or when operated from a phase or slip controller.

Both the ECM and VSIM can slowly ramp up to speed when activated, thus reducing the abrupt change in sound level when the system cycles on and off. They both are able to adjust airflow so that air noise itself is reduced at lower airflow. Comparison tests of the two motors in the same blower at the same RPM show comparable sound levels. However, differences become apparent at low speed – the tests show VSIMs operating at low speeds produce annoying noises.

The tone projections above the background level are shown in figure 3 for both motor types operating at 600 RPM (approximately 600 CFM). Notice the sound peaks in the VSIM data at 200 Hz and 800 Hz. They are caused by small variations in the induction motor's air-gap, by magnetic effects, and by the high frequency current switching through the motor that is necessary to maintain a nearly sinusoidal waveform. These pure tones reduce the sound quality of VSIM-driven system for two reasons: first, they occur in a very sensitive range of human hearing, and second, air noise is low at low motor RPM and cannot mask them.

The ECM does not suffer from single frequency pitches since air gap variation is not a problem. *The effective air gap is twenty to thirty times the gap needed for the proper operation of an induction motor.* Small variations have no significant effect. Furthermore, every GE ECM blower motor uses resilient rings to isolate the rotor from the shaft. The rotor is attached to the shaft through rubber rings which absorb high frequency torque ripple and keep it from coupling into the shaft. The most frequent praise given ECM-driven blowers by customers is how quiet they are.

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### **Electronic noise (EMI)**

Any electronically-driven motor must contend with electromagnetic interference, EMI, primarily caused by the switching of the high currents into the motor. The “noise” created by the switching must be kept out of the wiring of the home where it can and will cause TV and radio interference.

The ECM has an advantage here, too. It's efficiency is higher than the induction motor so it operates at lower currents to deliver the same power at the shaft. That advantage translates to a cost advantage in the filters needed to keep switching frequencies from the AC power lines. Nevertheless, a blocking filter is always necessary in a variable-speed blower motor. The amount of filtration is critical, however, and all filters are not equally effective. Data taken on VSIM and ECM motors intended for 1200 CFM blowers show that only the ECM meets FCC Class B conducted emissions requirements.

### **Conclusion**

Today, ECM-driven blowers are in widespread use in heating, ventilation and air conditioning. Besides the well-known residential furnace and heat pump air handler applications, they are in a period of very rapid growth in commercial packaged units, variable-air-volume terminal boxes, unit ventilators, fan coils, and heat recovery ventilators.

*No other variable-speed technology can claim the capability, flexibility and performance of the ECM. No other variable-speed technology has the experience gained from multi generational product improvement, application in high volume, and breadth of product application that would substantiate credible claims of greater service, reliability, value, or performance.*