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POWER PERFORMANCE EVALUATION OF AN ELECTRIC HOME FAN WITH TRIAC-BASED AUTOMATIC SPEED CONTROL SYSTEM

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Abstract – In order to provide a low cost system of thermal comfort, a common model of home fan, 40 cm diameter size, had its manual four-button control system replaced by an automatic speed control. The new control system has a temperature sensor feeding a microcontroller that, by using an optic coupling, DIAC or TRIAC-based circuit, varies the RMS value of the fan motor input voltage and its speed, according to the room temperature. Over a wide range of velocity, the fan net power and the motor fan input power were measured working under both control system. The temperature of the motor stator and the voltage waveforms were observed too. Measured values analysis showed that the TRIAC-based control system makes the fan motor work at a very low power factor and efficiency values. The worst case is at low velocity range where the higher fan motor stator temperatures were registered. The poor power factor and efficiency and the harmonics signals inserted in the motor input voltage wave by the TRIAC commutation procedure are correlated.

Keywords: TRIAC-based fan speed control, harmonics, power efficiency.

1. INTRODUCTION

Nowadays, small electric home fans are very common and easily found at any department store at a low price. They are basically composed of an axial fan moved by a shaded pole induction motor and a manual speed control system with four buttons, three for speed and one to start/stop control. Each speed button connects a different motor stator coil tap, thus varying power value can flow to the rotor and it can rotate at three different speeds.

The fan velocity control aims thermal comfort to the user, once this can get more air flux when feeling an uncomfortable sensation of hot. The manual system is cheap but has some inconveniences: it needs the user intervention, the control buttons are a source of mechanical failure, the stator motor coil needs to be fabricated with taps, it is insensible to room temperature changes.

Keeping the low cost of the system, a new control approach was implemented, providing to the electric home fan an automatic control based on the room temperature and the user with thermal comfort feeling. Fig. 1 shows the system block diagram and it works as follows: the temperature sensor signal inputs the microcontroller's A/D converter. By means of a PC serial communication interface, the user can store several different values of speed (for several different room temperature ranges) in the internal flash memory of microcontroller (it has an UART module too). According to the read room temperature and the respective stored velocity values, through the optically isolated TRIAC driver, the microcontroller changes the TRIAC conduction instant after the time given by the zero-crossing detector, thus, the fan speed changes to the desired value.

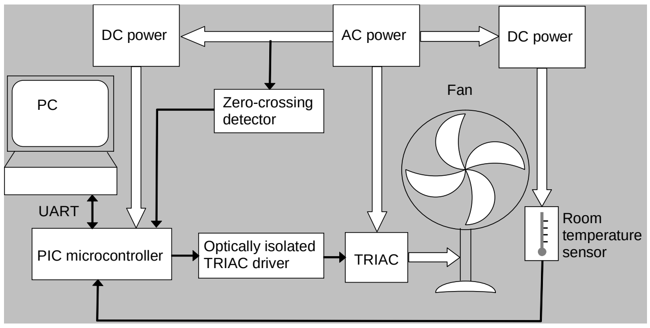

Fig. 1. Automatic shaded pole induction motor fan control system.

The TRIAC-based drive chops up the shaded pole induction motor sinusoidal input ac voltage waveform; thus, it modulates fan speed to compensate for changes in room temperature by controlling its inputting power RMS value. As the radial fan power varies as speed cubic exponent [1], it is necessary more or less RMS power when speed has to increase or decrease respectively. Unless the automatic way of working, given by the PIC and temperature sensor, this control system is similar to the dimmer TRIAC-based ones that are very popular and cheap speed controller used for permanent-capacitor induction motor of ceiling fans.

Even under sinusoidal steady-state input condition, shaded poles have a pulsating rotating stator magnetic field and are less efficient and have much higher slip than the other types of single-phase induction motors [2]. Thus its operation parameters are very dependent on harmonic components present in the chopped input voltage [3], [4].

To evaluate the effects of the TRIAC-based speed control system on the fan shaded pole motor performance, some experimental procedures were carried out in order to get fan power curve, RMS motor input values of voltage and current and frame motor temperature at several speed values when working under both speed control systems.

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2. MEASUREMENT PROCEDURE

2.1. Fan power curve determination

The fan was connected to the shaft of a permanent magnet DC motor driven by a DC adjustable voltage power supply. Its voltage, current and speed values were registered for a wide range of rotation. In order to know the no load power losses, the same procedure was performed with no fan at the DC motor shaft. Because of the very low stator wiring resistance, its ohmic loss was neglected.

From the DC motor with fan test data one can deduct no load test data and thus determine the fun power curve.

2.2. Fan tests using shaded pole motor

With the fan connected to the motor shaft, driven through the original four buttons control system, for three different speed values, the shaded pole motor values of RMS input voltage, RMS input current, frame temperature, and speed were registered. Similar procedure was performed to the shaded pole motor when driven by the automatic TRIAC-based control system under four different speed values.

Using measured data from both control approach tests and the fan power curve, apparent power values and (efficiency) × (power factor) product were calculated for each measured rotation speed of the shaded pole induction motor.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 2 shows the results of the tests carried out for the fan power speed curve determination.

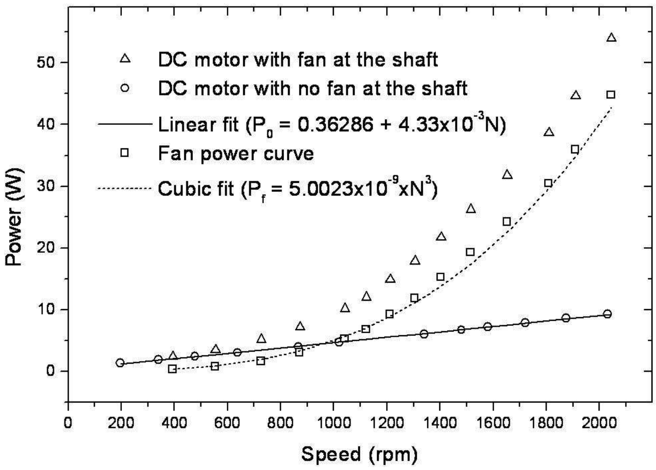


Fig. 2. Power input versus speed for DC permanent magnet motor at no load and connected to the axial fan.

The open triangle marks in Fig. 2 are the measured DC motor inputting power when moving the fan. The open circle marks are the measured inputting power of the DC motor running at no load, and show a very good agreement with the linear fit given in (1).

$$P_0 = 0.36286 + 4.33\times10^{-3} N \qquad (1)$$

where P_0 is the no load power in W and N the speed in rpm.

The linear correlation of P_0 with N (1) shows a constant torque load independent of speed. It is caused by the magnetic tractive force between stator permanent magnets and the rotor.

From (1) P_0 values were calculated for each triangle marked point and then subtracted from the upper curve. The difference is the fan power speed curve that is shown as the open square curve in the Fig. 1. As expected, the dashed line shows that the curve has a good cubic exponent fit (2).

$$P_f = 5.0023\times10^{-9} N^3 \qquad (2)$$

where P_f is the fan power in W.

Fig. 3 shows the test results for the fan moved by the shaded pole motor. Despite the required fan power variation, the apparent motor inputting power has no significant variation when driven by the TRIAC-based control system. For both control cases the motor demands a bigger apparent power compared to the required fan power.

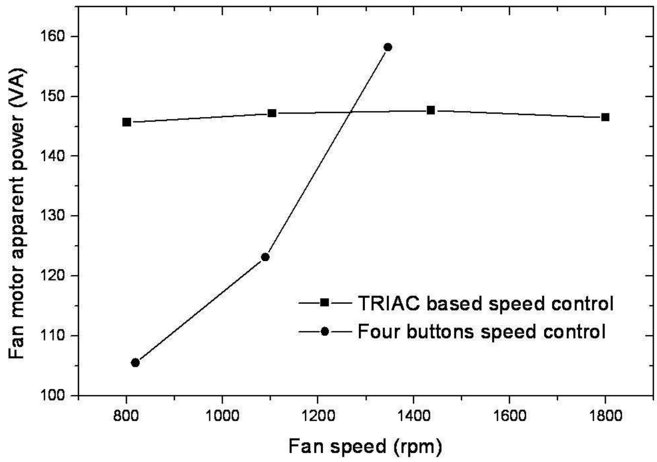


Fig. 3. Apparent power input versus speed for shaded pole induction motor moving the fan under two speed control system.

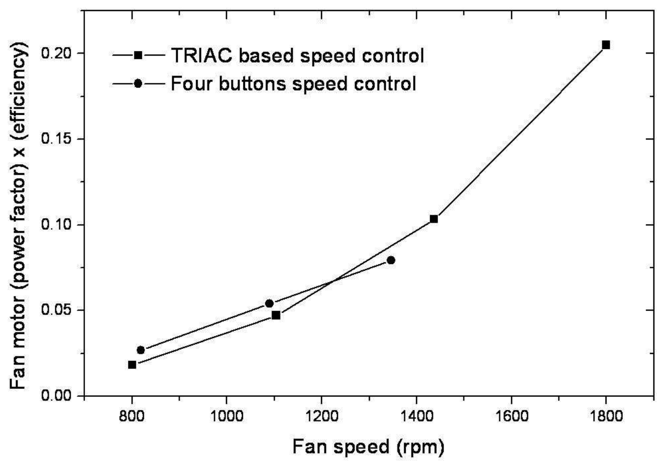


Fig. 4. Real/apparent input power ratio versus speed for shaded pole induction motor moving the fan under two speed control systems.

Fig. 4 shows the (power factor)×(efficiency) product of the shaded pole induction versus speed. These values were computed by dividing the measured motor input apparent power by the corresponding fan power (from (2)) at the same speed. In both cases, the (power factor)×(efficiency) product increases with the speed, but it is much more evident for the TRIAC-based control case.

The motor frame temperature versus speed (Fig. 5) shows that, for the TRIAC-based control, the frame is hotter at low speed and becomes colder as the speed increases.

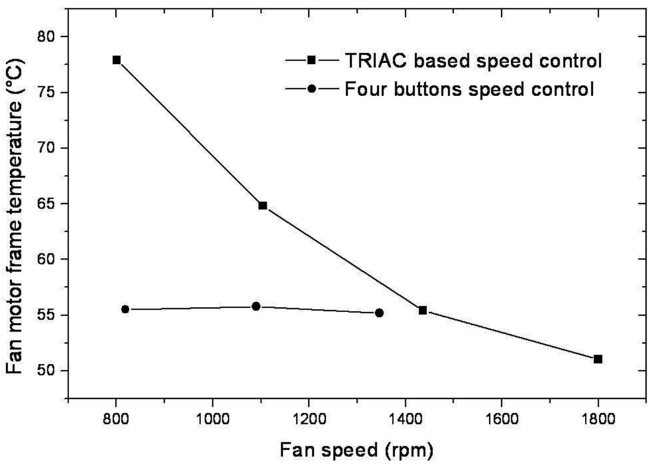
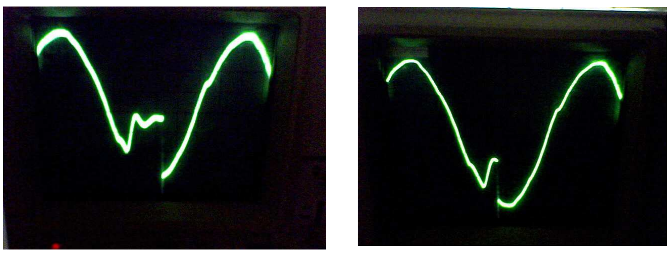


Fig. 5. Shaded pole motor frame temperature versus speed when it is moving the fan under two speed control systems.

Fig. 6 shows the voltage waveform imposed by the TRIAC at the shaded pole motor input when it is running at lower (Fig. 6a) and higher (Fig. 6b) speed. At the instant of waveform registrations, the electric power system voltage was 220 V RMS. Fig. 6(a) and Fig. 6(b) have 206 V and 215 V RMS respectively. As the waveform is more chopped for the lower speed, it has stronger harmonics components than for higher rotation speed [5].



(a) (b)

Fig. 6. Shaded pole motor input voltage waveforms (a) for the lower, (b) for the higher speed, controlled by the TRIAC-based system.

The effects of the harmonic components presence are evident in Fig. 4. In the TRIAC-based curve, at lower speed, where harmonic components are stronger, the (power factor)×(efficiency) product is very small and increases very quickly with the speed. This result was expected since harmonic components decrease the efficiency and the power factor of the electrical machines [2], [5].

The effects of the harmonic components on the motor efficiency are evident in Fig. 5. The TRIAC-based curve shows the temperature decreasing with the speed. At the lowest speed the motor frame temperature is 48 % higher than when at highest speed. The TRIAC-based system decreases the speed converting electrical energy into heat.

4. CONCLUSIONS

Measurements have been carried out in two widely spread methods to control the speed of home fans, namely the four-buttons- and TRIAC-based control methods, in order to determine their relative efficiency. Results made it clear that despite the appealing characteristic of automatic control of the latter technique (adjusting the fan rotation to compensate room temperature change, and eliminating mechanical parts and motor winding taps), the energy efficient and power factor product is dramatically degraded, due to this harmonic generation of this technique. This should be a concern, from the energy quality viewpoint, given the massive use of fans worldwide.

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