(19) INTELLECTUAL PROPERTY OFFICE OF SINGAPORE

(11) Publication number: **SG 184802 A1**
(43) Publication date: **29.11.2012**
(51) Int. Cl: **H02P 6/18, H02P 6/00;**

(12) Patent Application

(21) Application number: **2012073243**
(22) Date of filing: **03.05.2010**

(71) Applicant: **DELTA T CORPORATION 2425 MERCHANT ST. LEXINGTON, KENTUCKY 40511 KT US**

(72) Inventor: **NOBLE, ERNEST, JOHN 17 JALAN TR2/3 TROPICANA GCR PETALING JAYA SELANGOR 47410 MY**

(54) **Title:**
A CEILING FAN

(57) **Abstract:**

A ceiling fan comprising: an EC motor to drive a plurality of fan blades, a motor controller configured to determine the rotor position using the back EMF and configured to energise the motor according to the rotor position and predetermined instructions. Also a method of controlling a ceiling fan.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 November 2011 (10.11.2011)

PCT

(10) International Publication Number
WO 2011/138626 A1

(51) International Patent Classification: *H02P 6/18* (2006.01) *H02P 6/00* (2006.01)

(21) International Application Number: PCT/IB2010/000990

(22) International Filing Date: 3 May 2010 (03.05.2010)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **HAIKU DESIGN SDN. BHD.** [MY/MY]; B607 6th Floor Block B, Kelana Square (Dataran Usahawan Kelana), 17 Jalan SS 7/26 Kelana Jaya, Petaling Jaya, Selangor 47301 (MY).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **NOBLE, Ernest, John** [NZ/MY]; 17 Jalan TR2/3 Tropicana GCR, Petaling Jaya, Selangor 47410 (MY).

(74) Agent: **PEACOCK, Blayne, Malcolm**; Marks & Clerk Singapore LLP, Tanjong Pagar, P. O. Box 636, Singapore 910816 (SG).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK,

[Continued on next page]

(54) Title: A CEILING FAN

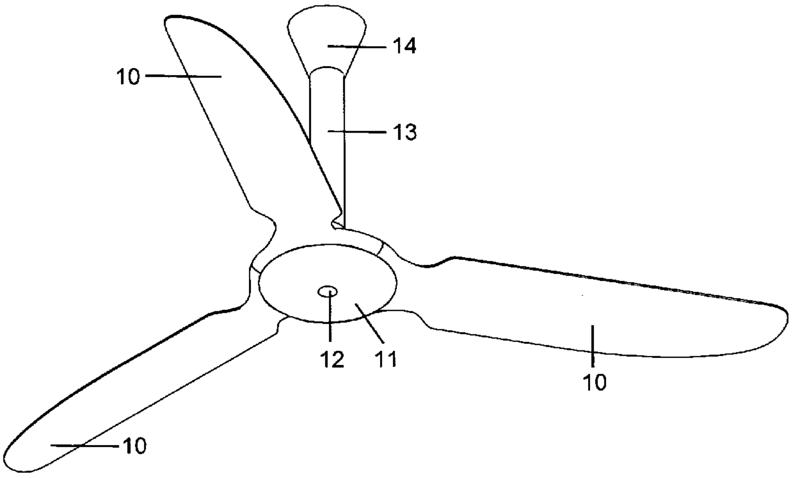

FIG. 1

(57) Abstract: A ceiling fan comprising: an EC motor to drive a plurality of fan blades, a motor controller configured to determine the rotor position using the back EMF and configured to energise the motor according to the rotor position and predetermined instructions. Also a method of controlling a ceiling fan.

WO 2011/138626 A1

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

A CEILING FAN

Field

The present invention relates to a ceiling fan, particularly though not solely to a sensorless sinusoidal ceiling fan and a method of controlling a ceiling fan.

Background

Ceiling fans are typically powered by high pole number AC induction motors, operating directly from the utility AC line voltage at high degrees of frequency slip, which makes operation very inefficient. Typical domestic ceiling fans may be optimised for low cost and long life, but not electrical efficiency. For example a typical domestic ceiling fan consumes around 75W of electrical input power, but only generates around 15W of mechanical shaft power; an efficiency of just 20%.

The efficiency of a ceiling fan may be greatly improved by replacing the AC induction motor with an Electronically Commutated (EC) motor, comprising a permanent magnet rotor with a plurality of alternating magnetic poles and a stator with one or more phase windings controlled by electronic switches. EC motors are typically able to achieve efficiencies of 60% or greater, so that only 25W of electrical input power is required to generate 15W of mechanical shaft power.

The use of EC ceiling fans can potentially reduce energy consumption by as much as 66% compared to typical AC motor ceiling fans. Since the use of ceiling fans is widespread throughout the worlds temperate, tropical and sub-tropical regions improvements to EC ceiling fan technology can play an important role in reducing global energy consumption and its effect on global climate change.

An EC ceiling fan requires an electronic controller to detect the position of the rotor magnetic poles and energise the stator windings so that current of the correct magnitude and polarity flows in the winding to generate motoring torque in the required Direction Of Rotation (DOR).

The winding current waveform amplitude and phasing may also be controlled in order to achieve acoustically quiet operation which may be desirable to consumers.

The electronic controller requires a means of Rotor Position Sensing (RPS) to determine the position of the rotor magnetic poles relative to the stator windings. One possibility is to use a high resolution encoder, but this is expensive. Another option is magnetically sensitive electronic hall effect switches placed in close proximity to the rotor magnets, which directly sense the magnet polarity. The outputs of these hall effect sensors can then be decoded by logic circuits or a microprocessor to determine the rotor location and therefore the timing for the winding switching pattern. However, hall effect sensors are relatively fragile electronic components and can pose reliability issues when embedded in the stator due to the device itself and its interconnection with the main controller circuit.

US patent no 7157872 discloses a ceiling fan with an outer rotor DC brushless motor with an additional magnetic ring mounted on the outside of the external rotor. This allows the hall effect devices to determine rotor position from outside of the motor. However using hall effect devices and their interconnects; may increase the mechanical complexity of the motor; and may introduce the possibility of reduced motor efficiency and increased acoustic noise due to misalignment of the secondary magnetic disk with the actual rotor poles, which may cause errors in commutation timing.

Summary of the Invention

In general terms the present invention proposes a ceiling fan using a high efficiency Electronically Commutated (EC) motor with a sensorless motor controller. The sensorless controller may have the advantage of eliminating the use of hall effect devices or encoders to determine rotor position, providing improved starting reliability and providing smooth and quiet operation.

The sensorless controller may include a PWM DC-DC converter with output filtering. For example the converter may be a synchronous buck converter. The converter may employ sinusoidal pulse width modulation (SPWM), with one or more switching configurations depending on speed. For example at low speeds the switching waveform may be largely sinusoidal with low harmonic content which may achieve very quiet operation, while at high speeds higher order harmonics may be added to the switching waveform which may improve efficiency. The output filtering and / or switching configurations may have the advantage of optimising efficiency and / or minimising noise.

The sensorless controller may include a stopping sequence which stores the position of the rotor once stopped in non-volatile program memory so that the information may be retained when the power supply is disconnected. The sensorless controller may include a starting sequence which depends on the rotor position when the fan was last stopped. This may have the advantage of improving the chance of success of the starting sequence.

The sensorless controller may employ a switching logic which results in each phase being continuously sequentially connected to the common rail for 1/3 of the electrical cycle. This may have the advantage of allowing the current to be determined based on the voltage drop across the switch, and that the current may be used during starting sequence to determine whether the starting sequence has been successful.

Additionally an AC:DC isolating power supply (SMPS) may be used to provide safety isolation from the incoming utility supply and to transform the line voltage to a level where the user is protected from electric shock by the low voltage level, such power supplies complying with IEC Safety Extra Low Voltage and/or UL1310 Class 2 limits. The power supply may be separated from the motor, in a sealed portion of the mounting tube. Alternatively the AC:DC power supply may be a non-isolated converter topology whereby the user is prevented from coming into contact with live components by constructional features of the fan. Alternatively the AC:DC power supply may be directly rectified and filtered from the incoming AC supply.

In a first particular expression of the invention there is provided a ceiling fan according to claim 1.

Brief Description of Drawings

One or more example embodiments of the invention will now be described, with reference to the following figures, in which:

Figure 1 is a perspective view of an EC ceiling fan according to an example embodiment, viewed from below;

Figure 2 is an exploded perspective view of mounting details for the blades 10, upper cover 15, EC motor 30;

Figure 3 is a partial perspective view of the EC fan viewed from below showing EC Motor 30, Electronic Controller PCBA 351;

Figure 4 is an exploded perspective view of the EC motor 30;

Figure 5 is perspective detail of EC motor stator 350, viewed from below;

Figure 6 is an electrical block schematic of the power supply 136 and printed circuit board assembly (PCBA) 351;

Figure 7 is a graph of the voltages Abmf 420, Bbmf 421, Cbmf 422, referenced to the winding common point 413;

Figure 8 is a software state diagram of the main controller operating states;

Figure 9 is a software flowchart of STANDBY STATE operation;

Figure 10 is a software flowchart of START STATE operation;

Figure 11 is a software flowchart of RUN STATE operation;

Figure 12 is a software flowchart of RUN STATE PWM INTERRUPT operation;

Figure 13 is a graph of the voltages Aph 410, Bph411 and Cph 412 referenced to 0V;

Figure 14 is a graph of the voltage Aph 410 referenced to 0V; and

Figure 15 is a software flowchart of SHUTDOWN STATE operation.

Detailed Description

Rotor Position Sensing according to the example embodiment uses electronic sensing means (Back EMF RPS) to determine commutation timing by measuring the back EMF voltage associated with the windings, thus eliminating the hall effect devices.

The simplest Back EMF RPS method employs a 3 phase inverter controlled in a 2-ON / 1-OFF 6-Step switching pattern. In this method a 3 phase motor is driven so that at any instant 2 phases are energised and the voltage is measured on the 3rd disconnected phase which has zero current flow. This allows the controller to directly sense the back-emf voltage (Vbmf) generated in the 3rd phase by movement of the rotor magnets. The controller typically detects when Vbmf in the sensed phase crosses zero and uses this as a basis for calculating, via analogue or digital means, the timing of the next commutation instant at which point the sensed phase will turn ON and one of the energised phases will turn OFF. Motor speed is controlled either by varying the DC bus voltage, or by Pulse Width Modulation (PWM) of one or more of the inverter switching devices.

Back EMF RPS with 2-ON / 1-OFF commutation offers the advantage of simplicity, but has a major disadvantage that acoustic noise is generated at each instant when the windings are switched from ON to OFF. The noise generated may be unacceptable for ceiling fans operating in close proximity to people in household environments including bedrooms.

Optimal smoothness and low acoustic noise for a motor drive may be improved by the use of an EC motor driven with an SPWM inverter where the winding voltages or currents are also controlled to be sinusoidal and maintained in synchronism with the motor Vbmf.

Implementation of Back EMF RPS with a SPWM inverter is problematic because all windings must be continuously energised so the motor Vbmf cannot be directly measured under conditions of zero current. The terminal voltage of the motor is the applied PWM voltage and cannot be used directly to determine the Back EMF. In that case a high speed microprocessor performing advanced mathematical transformations on measured voltage and current are necessary to determine rotor position. The cost and complexity of these devices and associated support circuitry may be less desirable for ceiling fans.

According to the example embodiment Back EMF sensing is employed with a synchronous buck converter. Because the synchronous buck converter output is decoupled from the SPWM of the inverter switching devices by filer components, the winding voltages are measured to approximate the Back EMF.

This may allow for accurate sensing of rotor position in a sinewave motor, and may avoid the need for complicated calculations to determine the Back EMF.

Fan construction

Figures 1 shows an EC ceiling fan according to the example embodiment. Three fan blades 10 are mounted radially around a central tube assembly 13, with a lower cover 11 with centrally located Infra-Red LED lens 12, fitting tightly to the lower edges of the blades 10, to provide reasonable ingress protection against dust and water from below.

Figures 2 and 3 show an exploded view of the blade mounting arrangements. Blades 10 align with motor 30 blade mount webs 331, and are fastened in position by screws 312.

Figure 3 shows that the lower cover 11 raised turrets 314 can be aligned with mounting slots 315, so that the cover 11 can be pushed vertically upwards and rotated to lock into position. A motor controller PCBA 351 with InfraRed signal detector 352 is mounted in the centre of the motor 30.

Figure 4 shows an exploded view of EC motor 30, the motor is an external rotor, slotless, axial flux, double rotor configuration, commonly referred to as a TORUS motor.

The motor 30 includes a rotor shell 330 which may be formed from non-ferromagnetic material of suitable strength, such as diecast aluminium or injection moulded thermoplastic, and provides blade mount webs 331 and a bearing turret 332 which provides mounting for upper bearing 324 and lower bearing 326. Alternatively, rotor shell 330 and upper cover 15 may be formed as a single integrated component.

The upper rotor 340 comprises an annular disk of ferromagnetic material, and an annular magnetic ring 341, composed of permanent magnetic material, glued into position and magnetised with 16 equispaced magnetic pole sectors facing the stator 350 upper surface. The upper rotor 340 is attached to the rotor shell 330 from the inside of the motor by 3 mounting screws 327.

The stator 350 has a plastic injection moulded core with the main motor shaft 351 pressed in to position and retained by splines 357 and circlip 358.

The rotor shell 330, fitted with upper rotor 340, bearings 324 and 326, is slid into position down shaft 351 and retained in position by circlip 322 and washer 323. Wave washer 325 provides bearing preload.

The lower rotor 342 comprises an annular disk of ferromagnetic material, with an annular magnetic ring 343, composed of permanent magnetic material, glued into position and magnetised with 16 equispaced magnetic pole sectors facing the stator 350 lower surface.

Both upper 341 and lower 343 ring magnets are preferably of ceramic magnetic material, which is widely available at low cost as used in loudspeaker ring magnets. Alternatively, a complete ring may be formed from multiple magnet segments. Alternatively rare earth Neodymium Iron Boron or other high strength permanent magnet materials may be used, either in complete rings or formed from multiple magnet segments.

Figure 5 shows perspective detail of the stator 350 lower surface, the stator 350 is toroidally wound with a 16 pole 3 phase winding, comprising 15 turns per pole of 0.9mm diameter enamelled copper magnet wire with a resistance of 0.4 ohms and inductance of 180uH per phase. Stator teeth 355 are formed from injection moulded thermoplastic material, used for the purpose of guiding the magnet wire during winding, and do not form an active part of the motor magnetic circuit.

A moulded turret 356 extends from the lower surface of the stator core, and provides a housing for PCBA 351 which is retained in position by mounting clips 354. The stator windings terminate directly to the PCBA via loom and plug 353.

Motor controller

According to the example embodiment the EC motor is energised by the motor controller 351 shown in Figure 6. The motor controller 351 is electrically connected to a 12V DC power supply 136 and motor stator windings 350.

The motor controller 351 generally includes a 3 phase synchronous buck converter 409, a microcontroller 368, a driver circuit 367 for the convertor 409, voltage sense filters 386-397 and a 3.3V power supply 381 for the microcontroller 368. The motor controller 351 is arranged on a Printed Circuit Board Assembly (PCBA).

The user provides desired control settings such as speed via the infrared transmitter 373, which are provided at the infrared receiver 352. The microcontroller 368 then measures the Back EMF from the voltage sense filters 386-397 and provides appropriate switching signals, amplified by the drivers 367, to the converter 409. Generally speaking if the fan needs to speed up the level of the applied voltage from the converter 409 is increased and vice versa for slow down. The frequency of the applied voltage from the converter 409 is always synchronised with the speed of the motor (as measured from the Back EMF).

SMPS 136 provides a 12Vdc supply to controller 351. The SMPS 136 provides output current and overload protection for the 12Vdc supply rail. A thermal switch 374 disconnects power to the motor controller 351 should internal temperature exceed safe limits, due to a motor or controller fault or excessive ambient temperature.

3.3V power supply 381 includes a voltage regulator to generate a 3.3V supply rail for microcontroller 368. Capacitors 382 and 383 provide sufficient charge storage to power the microcontroller 368 until the fan speed has reduced from maximum rpm to stationary when the AC power supply 135 is disconnected. Diode 380 isolates capacitor 382 from being discharged into the 12Vdc rail.

The 12Vdc supply rail is measured periodically by the microcontroller 368. Resistors 384 and 385 attenuate the 12Vdc supply voltage to under 3.3V to allow measurement by microcontroller 368. The attenuated supply rail voltage is connected to analogue-to-digital converter (A/D) input AN4. When the voltage drops below 9.5V microcontroller 368 goes into an ultra-low power SHUTDOWN STATE. Motor drive is reactivated when the 12Vdc rail returns to greater than 10.5V.The converter 409 includes a set of mosfet switches 361-366 to convert the 12V supply DC voltage into a three phase Pulse Width Modulated voltage. The PWM is smoothed into an approximately sinusoidal voltage (i.e. the harmonics are reduced) by filter inductors 400-402 each with a value of 50uH, and filter capacitors 403-405 each with a value of 47uF.

The switches 361-366 are controlled to an Enhanced Sinusoidal PWM (ESPWM). In other words the PWM duty cycle varies throughout each electrical cycle approximately according to a sinusoid. The combination of filters 400-405 and ESPWM may result in near silent operation of the motor.

The ESPWM switching pattern for each electrical cycle is stored in the microcontroller 368 internal memory as a data table (WaveTablePWM). Multiple tables may be used to optimise performance at different operating speeds, for example one table optimised for low noise at low speed and another optimised for best efficiency at high speed.

According to the switching pattern, microcontroller 368 outputs Adrv, Bdrv, Cdrv, Aen, Ben, Cen are supplied to the driver circuit 367. The driver 367 then sends a drive signal to the gate of each switch according to the Mosfet drive logic shown in the following table:

Xen	Xdrv	Upper Mosfet (361-363)	Lower Mosfet (364-366)
0	0	OFF	OFF
0	1	OFF	OFF
1	0	OFF	ON

1	1	ON	OFF

Electronic protection is provided via the microcontroller software to detect motor stall or abnormal operating conditions and shutdown.

User control of fan functions is implemented via an Infra-Red remote control transmitter 373, with control signals received by Infra-Red receiver 352, mounted directly on motor controller PCBA 351. Alternatively a radio frequency (RF) remote control transmitter and input module and may be used. Alternatively a low level analogue voltage or current signal, such as 0-10V or 4-20mA, may be directly connected to the microcontroller 368 input portIRX.

Back EMF sensing

As mentioned earlier, when a synchronous buck converter is used the motor winding 350 voltage is very close to the Back EMF. Thus according to the example embodiment the three phase winding voltage is applied to filter circuits 386-397 to attenuate the signal voltage level and reduce electrical noise.

The Back EMF shown in Figure 7 has three phases that are approximately sinusoidal. The microcontroller 368 detects the zero crossings of winding voltages to determine the frequency and phase of the back EMF. By monitoring the frequency and phase of the back EMF, the PWM voltage can be applied in synchronism to ensure windings are energised in the correct sequence and in the desired direction.

Motor control strategy

The motor control strategy is generally comprised of a starting algorithm, a running algorithm and a stopping algorithm. Starting and stopping are usually at the user's activation, or may be according to stored data such as scheduled start stop times.

Figure 8 shows a software state diagram of the main controller operating states. On receiving a Power On Reset (POR) signal the controller enters a STANDBY STATE (STANDBY). On receiving a valid SPEED or ON signal from the InfraRed controller 373 the controller enters a START STATE (START) where the motor is step started until it reaches sufficient RPM to enter RUN STATE (RUN) operation. If an OFF or SPEED=0 control signal is received in START or RUN the controller returns to STANDBY. If VDC drops below 9.5V in any mode the controller enters SHUTDOWN STATE (SHUTDOWN) and can only exit by a RESET when power is reapplied and reaches 10.5V.

Back EMF sensing also faces difficulties during starting. Since the Vbmf induced in the stator winding is zero when the rotor is stationary a special starting routine is required. The simplest approach may be to energise the windings in a pre-determined sequence and periodically sample the Vbmf until the rotor speed is sufficient to detect Direction of Rotation (DOR) and allow Back EMF RPS operation. A major disadvantage of this method may be that from an unknown start position there is only a 50% chance that the rotor will start to turn in the correct direction. A ceiling fan rotor has substantial inertia due to the mass and diameter of the blade assembly, so if the first step DOR is incorrect it may take many seconds to stop the rotor and repeat the start sequence. Fan start errors are clearly visible in a ceiling fan and may be undesirable.

Other approaches include applying large current pulses to the windings to induce & detect magnetic saturation in the motor, or by injecting high frequency voltage signals and measuring the transfomer coupling between phases. However these methods may complicate the drive & detection circuitry and generate acoustic noise in the motor during the detection sequence, which may be undesirable in a ceiling fan.

According to the example embodiment the last position of the rotor is stored when the fan is stopped. This position may be used to improve the chance of success in the starting sequence. This is done in STANDBY and SHUTDOWN by measuring each phase Vbmf at microcontroller 368 inputs AN0-2 and determining the phases with the highest (Vbmf(max)) and lowest, (Vbmf(min)) Vbmf measurement. A 10 bit A/D converter in the example embodiment has a resolution of around 3.2mV/bit when referenced from a 3.3V supply rail. Allowing for A/D conversion errors and signal noise this allows for reliable Vbmf measurement down to around 10mV. In the preferred embodiment an EC ceiling fan motor designed for operation from 12Vdc has a peak winding voltage coefficient of 28V/1000rpm. Therefore the lowest rpm which can be reliably detected is given by 28V/10mVx1000rpm = 0.36 rpm, or 2.7 minutes per revolution. This is sufficiently slow so that the rotor-fan assembly does not continue to rotate sufficiently far beyond the last valid Vbmf measurement to invalidate starting performance.

In order to ensure valid readings the peak-peak Vbmf voltage (Vbmf(pp)) is calculated and minimum valid Vbmf (Vbmf(valid)) amplitude specified, so that

Vbmf(pp) = Vbmf(max) – Vbmf(min), and;

Vbmf(valid) <Vbmf(pp) to ensure the readings are reliable.

There are 6 possible valid combinations listed as follows with the maximum Vbmf first: AB, BC, CA, BA, CB, AC. The last measured combination is saved as variable VBMFSTATE and used during the starting procedure to determine which phases to energise to ensure the start direction is correct.

During SHUTDOWN, VBMFSTATE is monitored and when a contiguous number of readings are made without VBMFSTATE changing state the rotor is regarded as stationary and the final VBMFSTATE value is saved to EEPROM memory for recall when power is reapplied. SHUTDOWN mode places the microcontroller 368 into an ultra-low power operating mode so that capacitors 382 and 383 hold sufficient charge to power the controller until the fan has become stationary. Alternatively a standby battery supply may be used to allow continuous monitoring of rotor position when the AC supply 135 is disconnected.

Since ceiling fan rotor-blade assemblies have relatively high mass and inertia they are not prone to turning due to air movement over the blades while power is disconnected, so saving the last known rotor position provides an effective means of improving step starting reliability.

In the event that the rotor is moved when the controller 3.3V supply has dropped below the minimum required for operation then the controller automatically recovers on the first restart by following a standard open loop step pattern.

Figure 9 shows a flowchart of STANDBY operation. On the first entry to STANDBY after a power on reset, variables VBMFSTATE and SPEED are recalled from EEPROM memory. VBMFSTATE now contains the last known rotor position during the previous SHUTDOWN. If the recalled SPEED value is non-zero the controller starts immediately.

STANDBY continually polls the InfraRed control input 352, VDC input on AN4, Vbmf inputs on AN0, AN1, AN2 and updates VBMFSTATE. On receipt of a valid SPEED input or turn ON request from InfraRed remote control transmitter 373, the controller exits to START. If VDC drops below 9.5V the controller exists to SHUTDOWN.

Figure 10 shows a flowchart of START operation. Software checks motor rpm to determine whether the motor is stationary or already rotating. If stationary, the DC:DC converter outputs are energised according to VBMFSTATE and an open loop stepping pattern is initiated to sequentially energise the phases from the VBMFSTATE start position. After the start sequence the DC:DC converter outputs are disabled and motor Vbmf measured. If the motor has reached sufficient rpm so that Vbmf(run)<Vbmf(pp) then the controller exits to RUN. If Vbmf(pp)<Vbmf(run) the controller continues pulsing the windings according to

the VBMFSTATE pattern until the Vbmf(run)<Vbmf(pp) or a restart timeout occurs, where the entire START routine is repeated.

Figure 11 shows a flowchart of RUN operation. RUN continually polls the InfraRed control input 352, VDC input on AN4, Vbmf and lower mosfet 364-366 Vds voltage on AN0, AN1, AN2, and updates VBMFSTATE. While the motor is running Vbmf detection for DC:DC converter output waveform timing does not require a high sensitivity A/D reading, so the inputs AN0-AN2 are multiplexed to comparators 406-408 for simple level detection referenced to the motor winding Common connection Com 413.

At all times during RUN one of lower mosfets 364-366 will be fully ON and the mosfet drain-source voltage (Vds(on)) can be measured at the corresponding A/D input AN0-AN2. Since mosfet 364-366 drain-source resistance (Rds(on)) and filter inductor 400-402 resistance (Rf) is known, this allows an estimation of the associated motor winding current, given by Iw = Vds(on)/(Rds(on)+Rf). This allows excessive winding currents to be detected, identifying overload or erroneous operating modes where winding currents are higher than experienced in normal RUN operation.

Figure 12 shows a flowchart of RUN mode synchronisation of the DC:DC output waveform with motor Vbmf, and PWM signal generation for creating the desired output waveform. In the preferred embodiment this is an Interrupt Service Routine (ISR) triggered by the PWM counter/timer. Alternatively it could be triggered from an independent timer or polled.

When comparators 406-408 detect a motor winding voltage 410, 411, 412 crossing the motor Com 413 the associated comparator output changes state and a Vbmf zero-crossing (Vzx) event is detected.

The time between successive Vzx events can be referred to as the Step Time and corresponds to 60 electrical degrees of the motor back-emf waveform.

The duration of the Step Time is measured by a StepTimer incremented by the microprocessor 368 internal clock. At each Vzx event the current StepTimer value is saved to variable Tstep and the StepTimer is reset to time the next Step period.

WaveTablePWM data is indexed by variable WaveAddress, which must be continually updated by the PWM ISR and synchronised to the motor Vbmf waveform.

WaveTablePWM data is divided into 128 increments per Step with 7 bit amplitude resolution. This may give a good compromise between low acoustic noise, motor rpm range, microprocessor clock speed and PWM peripheral specifications. Alternatively greater or lesser resolution may be employed to suit different microprocessor hardware platforms and different motors or operating conditions.

PWM frequency is 125kHz with an interrupt occurring every 5 PWM periods, giving a PWM interrupt rate of 25kHz.

The motor is a 3 phase 16 pole machine having 48 steps or 6144 WaveTablePWM increments per revolution.

Maximum rpm is limited by the maximum WaveTablePWM update frequency, which is 25kHz/6144 increments x 60sec = 244rpm. This is adequate for a ceiling fan where rpm is typically limited to around 200rpm for safety reasons.

Vbmf comparators 406-408 are polled during the main RUN routine and update VBMFSTATE. If a change in VBMFSTATE is detected on entry to RUN PWM ISR, the Step Timer is saved to Tstep before being reset, and all PWM outputs are set to the correct WaveTablePWM values for the new VBMFSTATE.

If the DC:DC output voltage waveform at 410, 411, 412 is lagging the actual motor Vbmf's 420, 421, 422, then the motor Vbmf causes the DC:DC output to advance, triggering the next Vzx event earlier, which reduces the subsequent Tstep and reduces the phase lag error.

If the DC:DC output waveform at 410, 411, 412 is leading the actual motor Vbmf's 420, 421, 422, then the motor Vbmf places additional load on the converter output, causing it to delay the next Vzx event, and increase the subsequent Tstep which reduces the phase lead error.

If the DC:DC converter output waveform and Vbmf are out of synchronism by a fraction of an electrical cycle less than 60degE then the electrical load placed on the DC:DC converter output by the motor Vbmf shifts the timing of the subsequent Vzx event to move the system back into synchronisation. Due to the high inertia of the fan, motor rpm does not change significantly over one electrical cycle so the Vzx detection routine is able to continually correct errors in synchronisation.

Filter inductors 400-402 and capacitors 403-405 decouple the DC:DC output waveform at 410, 411, 412 from the SPWM inverter switch 361-366 outputs allowing the motor Vbmfs 420, 421, 422 to influence the Vzx event detection timing, allowing SPWM modulation of the motor windings to be used in conjunction with Back EMF RPS detection.

After Tstep is updated the period of each WaveTablePWM increment for the next Step is calculated as:

Tinc = StepTimer/128

For the first increment:

Tinc->Tupdate

At every PWM ISR the StepTimer is checked to determine whether to increment WaveAddress.

When Tupdate<StepTimer the WaveAddress is incremented and Tupdate is increased by Tinc.

If WaveAddress is updated, the WaveTablePWM data for that value is retrieved from memory, is scaled by the set Speed value, then used to update the actual DC:DC converter PWM duty cycle registers.

The resulting voltage applied to the motor windings is an analogue version of the digitised WaveTablePWM data, synchronised to the motor Vbmf voltage with overall amplitude proportional to the Speed control signal.

Figure 13 shows the DC:DC converter output drive voltage waveforms 410, 411, 412 and the winding common point 413 referenced to the 0V rail with the lowest phase Vbmf switched to 0V in each period

Figure 14 shows detail of the Aphase 410 inverter output drive voltage waveform only.

From Figure 13 it can be seen that Aphase 410 voltage is lower than Bph 411 or Cph 412 during the period 210-330 degE. From Figure 14 it can be seen that this translates to the Aphase lower mosfet 364 being energised continually to pull the Aph 410 output to 0V during this period. In fact the voltage is slightly above zero due to the voltage drop across the switch and filter inductor. This can be used to determine a reasonable estimate of the phase current since the switch on resistance and filter inductor resistance are known. This may be used for monitoring purposes, to determine fault conditions (instability or oscillation during starting or drop out of synchronism during running), to log or display actual power use or to more accurately control the motor..

Figure 15 shows a flowchart of SHUTDOWN operation. SHUTDOWN is triggered from all states when VDC drops below 9.5V.

All microcontroller 368 peripherals and I/O are set to minimum current drain states and the current SPEED value is saved to EEPROM, before entering a low power SLEEP mode.

On SLEEP wakeup the microcontroller 368 A/D is re-enabled and reads VDC input on AN4, Aph 410, Bph 411 and Cph 412 inputs on AN0, AN1, AN2 and updates VBMFSTATE.

If VDC rises above 10.5V SHUTDOWN exits and RESETs.

When VBMFSTATE has remained unchanged for a number of cycles the rotor is considered to be stationary and VBMFSTATE is saved to EEPROM memory to be recalled at the next power on reset.

Whilst exemplary embodiments of the invention have been described in detail, many variations are possible within the scope of the invention as claimed as will be clear to a skilled reader.

CLAIMS

1. A ceiling fan comprising:

an EC motor to drive a plurality of fan blades,

a motor controller configured to determine the rotor position using the back EMF and configured to energise the motor according to the rotor position and predetermined instructions.

2. The fan in claim 1 wherein the controller includes a DC-DC converter with an output filter.

3. The fan in claim 2 wherein the output filter is a multiphase LC filter.

4. The fan in claim 2 or 3 wherein the converter is a Synchronous Buck convertor.

5. The fan in any one of the preceding claims wherein the controller is configured to determine the rotor position based on the zero crossings of the motor terminal voltage.

6. The fan in claim 4 wherein the output filter decouples the converter switched PWM output voltage from the motor windings.

7. The fan in any one of the preceding claims wherein the predetermined instructions includes a stopping sequence which stores the rotor position once stopped.

8. The fan in claim 7 wherein the predetermined instructions includes a starting sequence which depends on the last stopped rotor position.

9. The fan in any one of the preceding claims wherein the predetermined instructions include at least one SPWM switching configuration.

10. The fan in claim 9 wherein the predetermined instructions include at plurality of SPWM switching configurations, the controller configured to select a switching configuration based on the speed.

11. The fan in any one of the preceding claims wherein the predetermined instructions include a shutdown state based on one or more fault conditions.

12. The fan in claim 11 wherein the fault conditions include low input voltage, over temperature and high starting current.

13. The fan in claim 12 wherein the high starting current is determined based on the voltage of a single phase of the motor, when that phase is sequentially continuously connected to a negative DC supply rail.

14. The fan in claim 5 further comprising an attenuation and filter circuit to supply the motor terminal voltage to the controller to determine the Back EMF.

15. The fan in claim 8 wherein the starting sequence has a better than 50% chance of success.

16. The fan in any one of the preceding claims wherein the predetermined instructions including an ultra low power standby state.

17. The fan in any one of the preceding claims wherein the motor is a 3 phase motor and the controller is a 3 phase controller.

18. A method of controlling a ceiling fan comprising:

determining the Back EMF of an EC motor,

energising the motor to drive the fan based on the Back EMF and predetermined instructions.

19. The method in claim 18 wherein the predetermined instructions include one or more SPWM switching configurations

20. The method in claim 18 or 19 further comprising output filtering a synchronous buck converter to energise the motor.

21. The method in any one of claims 18 to 20 further comprising stopping the motor and storing the location of the rotor once stopped.

22. The method in claim 21 further comprising starting the motor based on the last stopped rotor position.