Industrial/Appliance Consumer Ceiling Fan

Sensorless field-oriented control for ceiling fan sinusoidal BLDC motor with PFC

Introduction

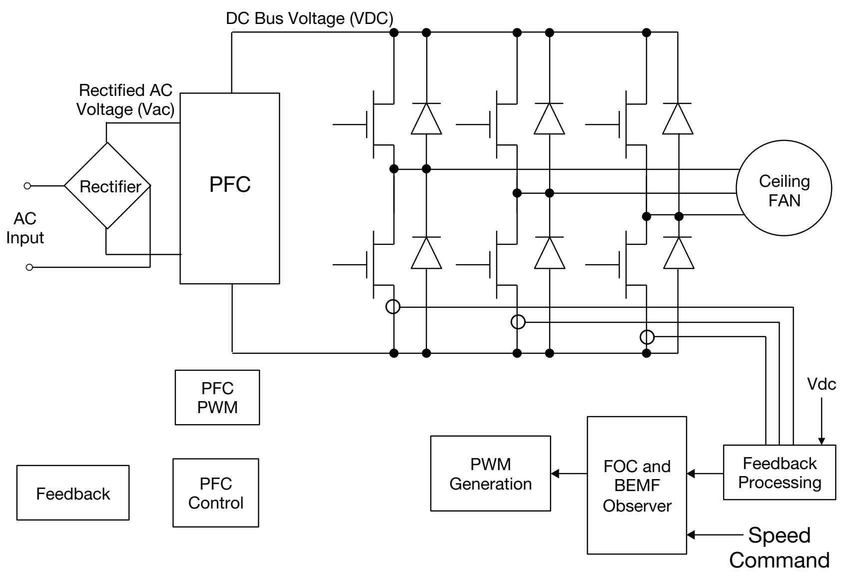
Brushless direct current (BLDC) motors are readily gaining popularity where energy savings are required. BLDC fans offer several advantages over traditional brushed DC motor and induction motors, including more torque per weight, more torque per watt (increase efficiency), high dynamic response, increased reliability, reduced noise, longer lifetime, more power and overall reduction in electromagnetic interference (EMI). This article covers a typical ceiling fan application with cost-effective smart electronics along with the advantages of BLDC motors as mentioned above. The reduced energy consumption in this application makes it an excellent choice for the energy efficiency initiative.

This article is dedicated to the sensorless sinusoidal BLDC/PMSM FOC for the ceiling fan application.

System Overview

Front-end power factor circuit (PFC) followed by three-phase inverter with Freescale DSCs is used to drive a three-phase sinusoidal back EMF BLDC/PMSM motor. The three shunt resistors cascaded in the lower leg of the inverter are required to obtain three-phase current. The power configuration is shown in figure 1. A firmware observer is applied to obtain the rotor's magnetic axis position which is crucial for the vector field-oriented control (FOC) algorithm. The sensorless vector control algorithm with 16 kHz PWM frequency and 8 kHz current control loop frequency is used to gain excellent performance, low noise and high efficiency.

Figure 1: Sensorless Sinusoidal BLDC/PMSM FOC + PFC



Features of Ceiling Fans

- Speed range 140–320 RPM
- Input power factor > 0.95 from minimum speed of 90 RPM
- Direction can be reversed when fan is running
- Start-up even if the vanes are still rotating (due to inertia)
- 45 seconds to deceleration/acceleration from 90 to 320 RPM
- 25 watt total power consumption
- Speed control in five steps through IR remote

Application Concept

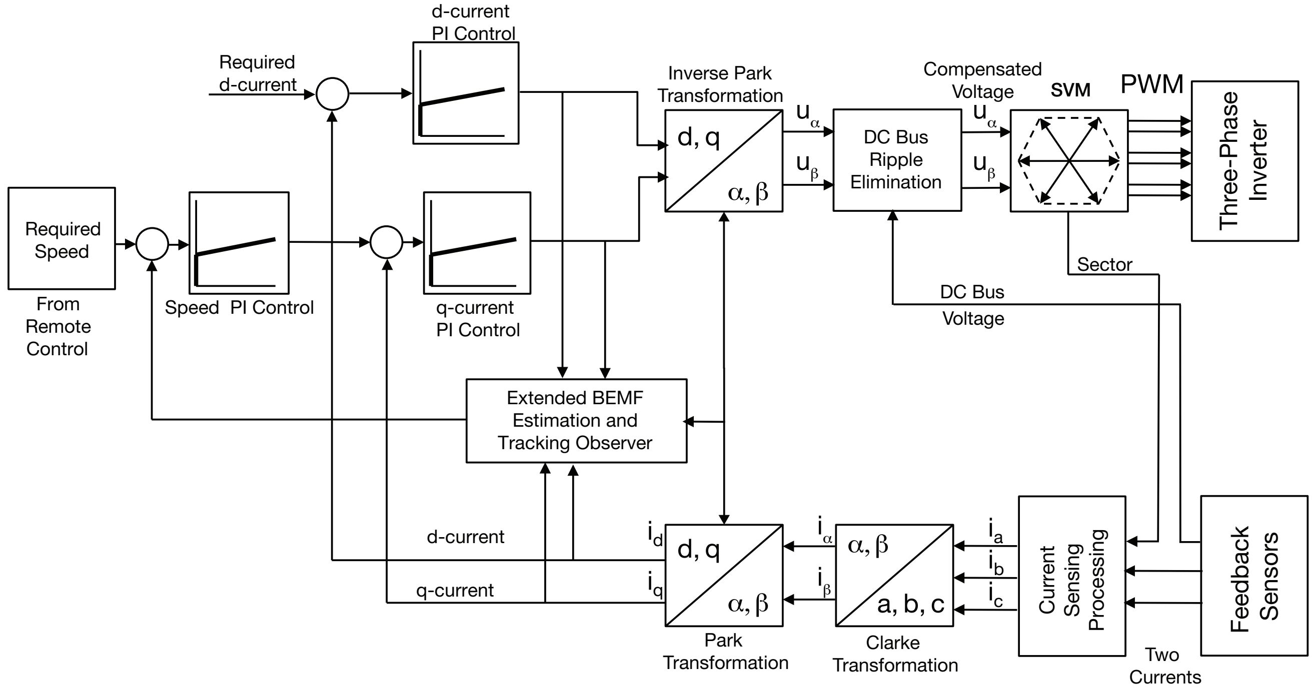
FOC

In order to run the motor properly, five stages are taken to start the fan, including sector detection, start, open loop, merge and closed loop.

Sector detection stage: The motor must start with a relatively large initial torque rotor position, otherwise there will be oscillation or failure when starting the fan. Consider dividing the rotor position of 0–360 electrical degrees into six sectors, and the sectors can be identified using stator magnet's B-H characteristics.

Start stage: Because there are current pulses in the windings when detecting the rotor's initial position, these current pulses may cause a bit of mechanical vibration. This stage is designed

Figure 2: Sensorless Sinusoidal BLDC/PMSM FOC, Software Blocks



to add some delay before actually starting the fan.

Open loop stage: When the rotor's magnetic axis has been detected, the open loop control for speed is used. During open loop operation, the observer for position and speed estimation is enabled and the speed loop is also enabled to obtain reference IQ which will be used in the close loop.

Merge stage: Once a desired speed is achieved, the control transfer from speed open loop runs to speed close loop. In close loop, the estimated rotor position is used to perform park and inverse park transformation and use the speed loop's output as the quadrature current reference. There could be a shift between the estimated position and simulated position during open loop running.

Closed loop stage: Since the rotor's position used in the algorithm has been transferred from simulated rotor position to estimated rotor position smoothly in the merge stage, now the output of the speed control loop is used as IQ reference instead of using a given reference value.

PFC Control

Boost circuitry in a discontinuous conduction mode is used to implement the PFC inner current mode control. Outer voltage loop controls the DC bus and provides constant voltage with input and speed of fan changes. Inner current loop controls the input current and corrects the input power factor > 0.95 and input current THD.

Software Design

The software is designed using a state machine so that the software is easy to understand and control. The fault task deals with overcurrent, overvoltage and undervoltage. The initial task initializes all variables used in the algorithm. The calibration task gets the DC offset of currents passing through the three shunt resistors cascaded in the lower legs of the inverter. When calibration is complete, the stop task then positions the detection task to be executed. The position detection task is intended to realize the function mentioned in the sector detection stage. The start stage realizes the function mentioned in the start stage and the run state realizes the functions mentioned in the open loop stage, merge stage and close loop stage.

Sensorless Driving with PFC

To read the speed and position in sensorless control, it is necessary to know the motor parameters well to calculate its model observer. The parameters are programmed into the BEMF observer algorithm. This observer's function is to calculate the position of the BEMF, which is needed to drive the motor. The position is then passed through the tracking observer to be filtered, and as a side product, determines the actual speed. The PFC current loop algorithm is three times faster than FOC and the voltage loop is at much lower speed.

At this point, we see that this solution requires a powerful controller from the Freescale 56800E/Ex family of DSCs.

Implementation

Freescale offers a selection of DSCs for this important task. The following is a list of what is mandatory for such an application:

- PWM: Two PWM configurations
    - One for FOC should offer a center-aligned mode, complementary switching capability with the deadtime insertion, and three-phase orientation
    - One for PFC and PWM synchronization with the ADC
- ADC: Simultaneously measures two FOC currents and PFC current, with two channels working in parallel
- SCI: Necessary for the communication with FreeMASTER to allow application debugging
- Interrupt controller: Must be priority controlled to avoid disintegrity of the control technique. The interrupt latency should be short.
- Core: Must have great computation potential in terms of mathematical operation

Performance

The application uses two system control loops.

FOC: Has two main control loops: current and speed loops. The current loop is critical and is calculated on the PWM frequency at 16 kHz. The loop has several tasks:

- Reading of measured currents and voltage, and reconstruction of the current from two values into three
- BEMF + tracking observer
- Clarke and Park transformation
- D and Q current controllers and their limitation depending on the DC bus voltage
- DC bus ripple compensation
- Space vector modulation
- PWM update of three-phase inverter
- ADC configuration for the next step

PFC: Has two main control loops: current and voltage. The slow moving voltage loop keeps the DC bus voltage constant. The current loop is critical as it controls the input current waveform.

Freescale Enablement

- Application based on FSLESL **freescale.com/motorcontrol**
- Embedded software and motor control libraries **freescale.com/fslesl**
- FreeMASTER visualization tool **freescale.com/FreeMASTER**
- Application support from Freescale motor control experts

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