

# Reducing power consumption of blowers in emergency ventilation by field weakening

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*Abstract: Field-weakening is an established technique for exceeding motor base speeds while maintaining constant input power. To improve energy efficiency of emergency ventilators, this paper presents a methodology for reducing torque to lower the input power of brushless DC (BLDC) motors during phases of constant pressure. Using the Clarke-Park transformation, the operating point is obtained by minimizing the voltage and then applied as phase-advance angle and modulation index in the voltage model. A proof-of-concept experimental setup yields power savings of up to 40% using field-weakening compared to conventional field-oriented control approaches, demonstrating its feasibility for energy savings in BLDC motors.*

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## I. Introduction

Ventilation devices are required in situations when patients need assistance in breathing, either partially or completely [1]. For emergency situations, ambulances are equipped with portable respiratory devices, as developed by Weinmann EMT GmbH. As rapid response is critical in these scenarios, portability and efficiency are essential design criteria. Modern ventilators rely on motor-driven blowers to generate ventilation pressure, yet doing so requires substantial energy. Since the battery is a primary contributor to the overall weight, improving its energy efficiency is vital, allowing for size and weight reduction.

In this paper, we address this challenge by designing a field-weakening-based control system for brushless DC (BLDC) motors to minimize their energy consumption and, consequently, offering a solution that improves portability of emergency ventilation systems.

### I.1. Principles of field weakening

Field weakening is a known technique to operate motors above base speed by reducing torque while keeping input power constant [2]. It is based on field-oriented control (FOC) using the Clarke-Park transformation, which expresses motor currents in a  $dq$ -coordinate system [3, 4]. For non-salient motors, maximum torque occurs for  $i_d = 0$ , aligning the current vector with the counter electromagnetic force (EMF) [5]. Meanwhile, field weakening is implemented by applying a negative direct-axis current  $i_d$ , introducing a phase angle  $\phi$  between the current vector and counter EMF, as depicted in Figure 1. Consequently, mean torque  $T$  and input power  $P$  are reduced, as indicated by the power equation [6, 7]:

$$P = T \cdot \omega = i_a \cdot e_a + i_b \cdot e_b + i_c \cdot e_c, \quad (1)$$

which relates the motor's mechanical power to the electrical power delivered through the three phases.

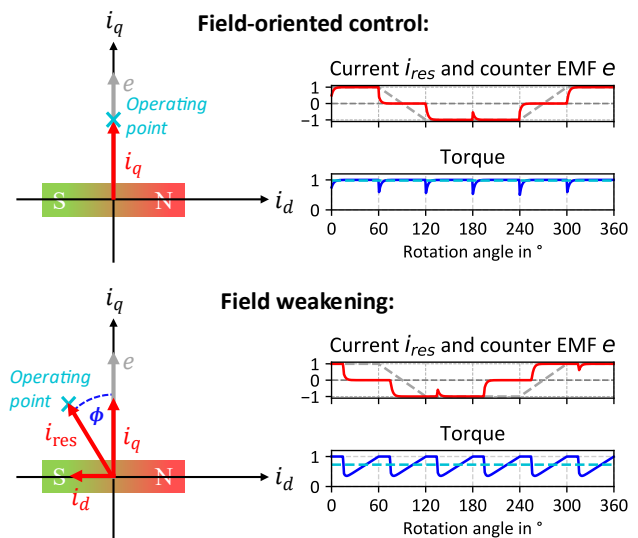


Figure 1: Conventional FOC aligns the current with the counter EMF to maximize torque ( $i_d = 0$ ), whereas field weakening uses  $i_d < 0$  to introduce a phase shift and thereby decreases torque.

## II. Concept

The employed field-weakening methodology is based on the idea of increasing the commutation angle, thereby elevating motor speed and therefore enabling operation at a reduced voltage for a constant speed. To achieve this, a controller continuously minimizes the torque, resulting in reduced power consumption as described in (1). The method then determines the optimal operating point in the current plane ( $i_d^*, i_q^*$ ) by minimizing the voltage ellipse

$$v_d = R_s i_d - \omega L_q i_q, v_q = R_s i_q + \omega(L_d i_d + \Psi_{PM}) \quad (2)$$

$$\text{subject to } \sqrt{v_q^2 + v_d^2} \leq V_{max}, \quad (3)$$

to intersect with the torque hyperbola

$$T_{ctrl} = \frac{3}{2} P \cdot \left( i_q \cdot \Psi_{PM} + i_d \cdot i_q \cdot (L_d - L_q) \right). \quad (4)$$

Here,  $P, R_s, L_d, L_q$  and  $\Psi_{PM}$  are motor properties,  $\omega$  is the measured motor speed and  $T_{ctrl}$  the torque coming from the controller. This approach, shown in Fig. 2, generates operating points on a trajectory similar to the maximum torque per voltage strategy [5], as indicated by the orange dotted line.

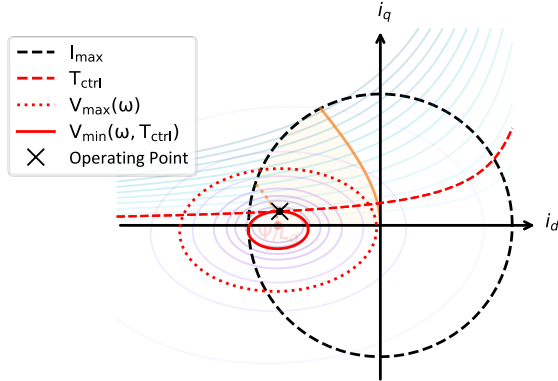


Figure 2: For the proposed field-weakening strategy the voltage ellipse (red, dotted) is minimized to the point where it intersects with the torque hyperbola (red, dashed).

### II.1. Controller design

The core control objective is operating the ventilator on reference speed while minimizing motor torque to the minimum needed, thereby optimizing energy usage. A proportional-integral speed controller is employed in a closed-loop system, using Hall sensor feedback to accurately compute rotor position and speed. The minimum necessary torque  $T_{ctrl}$  is continuously calculated and used to determine the optimal operating point in the current plane  $(i_d^*, i_q^*)$ , as described above. Phase voltages are then modulated using the modulation index and phase advance angle, as in [6]. The controller applies field weakening only when maximum torque is not required, while full torque is maintained during acceleration as in conventional FOC.

### III. Results and discussion

To experimentally validate the effectiveness of the proposed control methodology, a proof-of-concept setup is designed, featuring a state-of-the-art blower (U65HN, Micronel AG, Lindau, Switzerland) with three Hall sensors for speed feedback. Sinusoidal motor voltages are generated by a microcontroller, incorporating 10μH inductances serving as a choke module for field-weakening calculations. The controller is implemented on a real-time computer (MicroLabBox, dSPACE GmbH, Paderborn, Germany) running a Simulink (The MathWorks, Natick, USA) script. Power is supplied by a dual-voltage source, with an interconnected resistor for power measurement. Signal processing, including the acquisition of input power, Hall sensor signals, and output pressure data, is managed in Simulink. The setup allows for a direct comparison of power consumption between FOC and the proposed field-weakening strategy across different motor speeds.

The results obtained in the experimental setup are shown in Figure 3 as the average absolute and relative input power over motor speeds ranging from 250 to 1600 rad/s. The proposed field-weakening method  $FW_{minV}$  shows lower power consumption of up to 40% compared to standard FOC, with > 20% savings across the whole speed range.

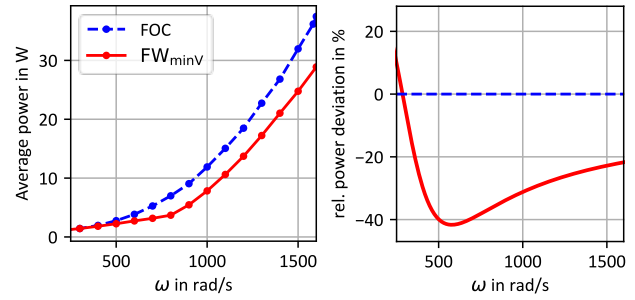


Figure 3: Comparison of average (left) and relative (right) input power across motor speeds for FOC and the proposed field-weakening method, demonstrating power savings of up to 40%.

In practice, this method is most effective for constant pressure ventilation modes, such as continuous positive airway pressure. In dynamic modes, energy savings mainly occur during hold phases, making low frequency ventilation more beneficial than ventilation under high frequencies.

Despite the encouraging results achieved in reducing input power consumption, some limitations were encountered during the experimental validation. The microcontroller's input power limitation restricts motor speed and prevents the replication of realistic ventilation pressures. Upgrading the hardware is therefore necessary for validation under realistic conditions. Additionally, in the present setup, both controllers struggle to track fast speed changes. Future work should explore faster hardware implementations and more advanced control strategies, such as model predictive control, to further improve rise time and energy efficiency.

### IV. Conclusions

This study successfully introduces a novel approach to field weakening, focusing on its potential for energy savings in motor-driven applications, demonstrated through a proof-of-concept implementation. The technique is easy to implement in software, particularly benefiting portable ventilation devices by increasing the runtime or enabling more compact designs. The approach is also applicable to other motor-driven systems with holding phases at high speed, such as drones and household appliances. While results are promising, optimizing both hardware and controller design is essential for full practical application.

#### AUTHOR'S STATEMENT

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