
*International Journal of Science and Technology*, 2025, 33–36

doi: 10.70728/tech.v02.i17.007
Volume 02, Issue 17
ISSN: 3030-3443
Paper

PAPER

# MATLAB/SIMULINK MODELING OF THE ABC–DQ TRANSFORMATION FOR PERMANENT MAGNET SYNCHRONOUS GENERATORS (PMSG)

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## Abstract

This study presents the theoretical foundations of transforming a three-phase (abc) system into stationary (αβ) and rotating (*dq*) reference frames and explains the advantages of these transformations in controlling permanent magnet synchronous generators (PMSG). A Park-transformation-based modeling block was developed in the *Matlab/Simulink* environment to analyze the conversion of stator voltages and currents into *dq* components and to examine their dynamic behavior in relation to the rotor angle. Simulation results demonstrate that the Park transformation significantly simplifies the mathematical model of the PMSG, enhances the effectiveness of field-oriented control (FOC) algorithms, and improves the stability of the energy conversion process. The findings are of practical importance for improving control strategies and operational performance of PMSG-based systems in renewable energy applications.

**Key words**: PMSG, Park transformation, dq coordinates, Matlab/Simulink, electrical machine modeling, vector control.

## Introduction

Permanent magnet synchronous generators (PMSG) are widely used in modern renewable energy systems due to their high efficiency, compactness, and reliability. The use of high–energy-density permanent magnets in the rotor enhances the generator's efficiency while reducing maintenance requirements. However, the analysis of electromagnetic processes in PMSG becomes complex because three-phase (abc) signals exhibit time-varying and trigonometric relationships.

Clarke (αβ) and Park (*dq*) transformations play a crucial role in overcoming this complexity. The Clarke transformation converts the three-phase system into a stationary αβ reference frame, while the Park transformation rotates these signals into the *dq* reference frame aligned with the rotor

**Compiled on:** December 16, 2025.

position, resulting in nearly constant (DC-like) quantities. This enables independent control of torque and current, the implementation of field-oriented control (FOC), and significant simplification of the mathematical model.

To investigate the practical application of these transformations, a Park-transformation-based model was developed in the Matlab/Simulink environment. The conversion of abc signals into dq components and their dynamic behavior were analyzed. Simulation results confirm that coordinate transformations simplify PMSG control and enhance system performance.

A review of the literature (Chapman [1], Krause [2], Park [5], Bose [4], Chen and Guerrero [3], and others) demonstrates the necessity of coordinate transformations for precise PMSG control and highlights the effectiveness of vector control. Local studies also provide practical insights into the design and modeling of PMSGs. Overall, although the theoretical basis of the Park transformation is well established, the practical modeling and dynamic analysis of the abc–dq transformation in Matlab/Simulink remain relevant research topics.

## EXPERIMENTAL RESEARCH

A permanent magnet synchronous generator (PMSG) generally consists of a stator and a rotor. The stator contains three-phase windings placed in a laminated iron core, with the phases spaced 120 electrical degrees apart. The main structural distinction of a PMSG is the use of high–energy-density permanent magnets such as NdFeB or SmCo on the rotor instead of a conventional excitation winding. These magnets create a strong, stable, and lossless magnetic field.

The use of permanent magnets allows the generator efficiency to reach 95–98%, which is 3–8% higher compared to traditional synchronous machines [2,6]. This advantage is especially important for ensuring stable performance in the variable-speed operating conditions typical of wind energy systems. The high energy density of rotor magnets increases the power density of the generator and contributes to a more compact overall design.

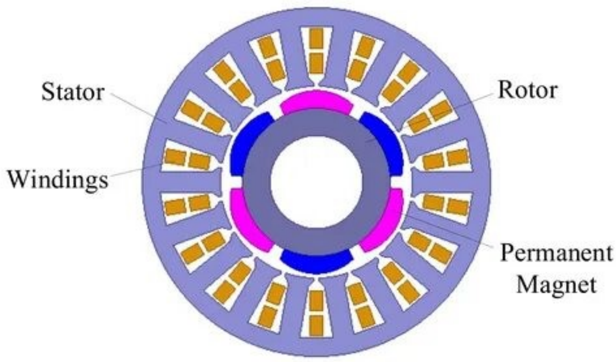


**Figure 1.** Cross-sectional view of the PMSG construction

### Mathematical Model: Stator Equations

The time-domain equations of the three-phase stator voltages are expressed as follows:

$$v_a = R_s i_a + \frac{d\psi_a}{dt},\quad v_b = R_s i_b + \frac{d\psi_b}{dt},\quad v_c = R_s i_c + \frac{d\psi_c}{dt}. \tag{1}$$

In a PMSG, the rotor flux is produced by the permanent magnets, therefore:

$$\psi_f = \text{const} \tag{2}$$

and, depending on the rotor angle, it is induced in the stator phases as follows:

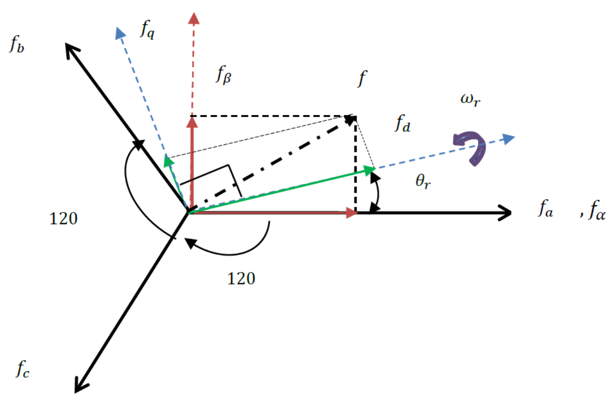


**Figure 2.** Combined stationary and rotating reference frames for a three-phase system.

### Park Transformation

The Park transformation is widely used in the analysis of permanent magnet synchronous machines. The novelty of Park's work lies in its ability to convert any set of machine equations with time-varying coefficients into another set of equations with time-invariant coefficients [7].

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \triangleq \begin{bmatrix} \cos(\theta_r) & -\sin(\theta_r) \\ \sin(\theta_r) & -\cos(\theta_r) \end{bmatrix} \begin{bmatrix} f_d \\ f_q \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = [\text{Park matrix}] \begin{bmatrix} f_d \\ f_q \end{bmatrix} \tag{4}$$

Where:

$$[\text{Park matrix}] \triangleq \begin{bmatrix} \cos(\theta_r) & -\sin(\theta_r) \\ \sin(\theta_r) & -\cos(\theta_r) \end{bmatrix} \tag{5}$$

As shown in Figure 2, the resultant physical quantity obtained from the (d–q) representation is:

$$f = \sqrt{f_d^2 + f_q^2} \tag{6}$$

## RESEARCH RESULTS

Development and Simulation of an abc–dq Transformation-Based Mathematical Model in Matlab/Simulink. In control systems for permanent magnet synchronous generators (PMSG) and motors, the trigonometric relationships of voltages or currents given in the three-phase a,b,c coordinate system complicate the calculation process. Working with three-phase sinusoidal signals is particularly challenging when developing real-time control algorithms. One of the most effective methods to overcome this issue is the Park transformation, which converts a static three-phase system into a rotating (dq) reference frame.

Using a model built in the Matlab/Simulink environment, the process of first converting three-phase signals into dq coordinates and then transforming them back into the abc frame is analyzed. The overall structure of the model is shown in Figure3.

The Sine Wave blocks generate the phases in the following sequence, representing the three-phase voltages or currents in the PMSG stator. The

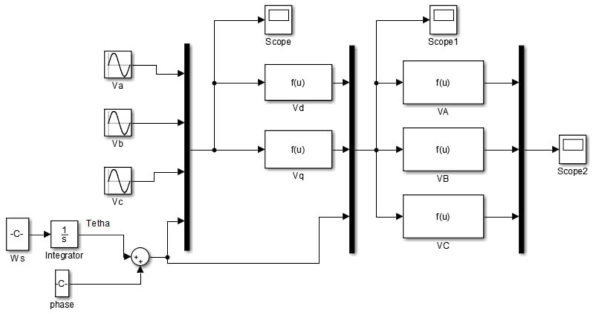


**Figure 3.** Park transformation model developed in Matlab/Simulink

Integrator and ω blocks generate the rotor angle (θ). The value of $W_S$ (ω) at the lower section is passed through the integrator to obtain θ.

$$\theta(t) = \int \omega \, dt + \text{phase} \tag{7}$$

The rotor angle is generated. **abc → dq (Park Transformation) Block**

The first functional part of the model converts the three-phase signals into the rotating reference frame. Each f(u) block performs the corresponding mathematical operations.

he general equations of the Park transformation are:

$$\begin{aligned} v_d &= V_\alpha \cos\theta + V_\beta \sin\theta, \\ v_q &= -V_\alpha \sin\theta + V_\beta \cos\theta. \end{aligned} \tag{8}$$

Thus, the three-phase sinusoidal signals are transformed into two-axis (d and q) components.

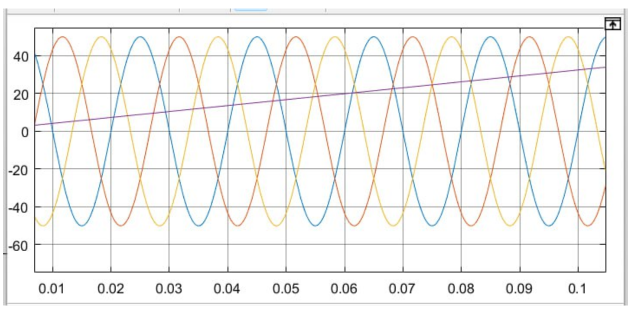


**Figure 4.** abc input signals

Three sinusoidal signals in the abc coordinate system have a 120° phase shift and equal amplitudes, forming perfectly sinusoidal waveforms. This represents a classical three-phase alternating current system.

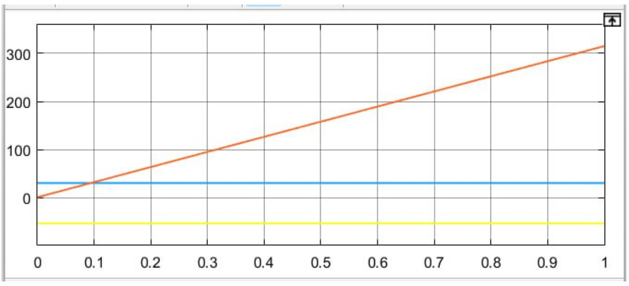


**Figure 5.** dq signals

In the dq coordinate system, the d-axis (Vd) signal approaches a nearly constant value because this axis is aligned with the rotor magnetic field. The q-axis (Vq) signal retains a sinusoidal shape. This transformation simplifies the control system, as the complex three-phase sinusoidal signals are converted into two simple functions.

When three-phase sinusoidal signals are transformed into dq coordinates, the d-axis component remains almost constant, reflecting the steady flux of the rotor magnetic field. The sinusoidal nature of the q-axis component corresponds to the generation of the electromagnetic torque in the generator.

Furthermore, during the abc → dq → abc sequential transformation, the reconstructed abc signals match the original input signals, confirming the correct operation of the model. This transformation simplifies the complex trigonometric relationships of the generator and facilitates the implementation of control algorithms.

## CONCLUSION

The analysis of the abc–dq coordinate transformation-based model implemented in Matlab/Simulink demonstrates that the Park transformation significantly simplifies the three-phase electromagnetic processes in permanent magnet synchronous generators (PMSG). Simulation results show that the d-axis component remains nearly constant, confirming its alignment with the rotor magnetic field, while the sinusoidal oscillation of the q-axis component corresponds to the generation of electromagnetic torque. The successful execution of the abc → dq → abc conversion verifies the correct operation of the model. This approach provides a reliable methodological basis for analyzing the dynamic behavior of PMSGs, developing vector control algorithms, and implementing them effectively in real energy systems.

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