Sirte University Scientific Journal Vol. 16, No. 1 (2026) 183-190
Sirte University Scientific Journal (SUSJ)
Journal home page: http://journal.su.edu.ly/index.php/susj

PI Speed Control of Permanent Magnet Double-Rotor Generators for Wind Energy Applications

Hassan S. Bin Hamdin [(1)], *Eljaroshi M. Diryak* [(2)] and *Ali Algaddafi* [(3)]

[1،2]*Department of Electrical and Electronics, Faculty of Engineering, Sirte University, Libya.*

[3]*Department of Electrical and Electronic Engineering, University of Birmingham, UK.*

Correspondence: ***Eljaroshi Diryak** – ***Emd202@su.edu.ly***

DOI: https://doi.org/10.37375/susj.v16i1.4175

ARTICLE INFO:

Received 15 May 2026.
Accepted 19 June 2026.
Available online 24 June 2026.

Keywords: Permanent Magnet Double Rotor Generators, Proportional Integral Control, Wind Turbine System, MATLAB/Simulink Model.

A B S T R A C T

This paper introduces a Permanent Magnet Double Rotor Generator (PMDRG), single stator, double rotating rotors with symmetrical air-gaps machine. It is capable to deliver independently power by two generators in a single machine. The proposed study is about the circuit diagram of PMDRG model, and controlled dynamics by Proportional Integral (PI) control system and introduces the simulation by MATLAB/Simulink. The machine should be installed for wind energy application aiming a more compact and efficient power production. The PI control system is commonly used for electric machines due to its simplicity and effectiveness in eliminating steady-state error. In PMDRG system, PI controllers are naturally used to regulate their rotors speeds, which in turn controls the active power output.

التحكم في سرعة مولدات الطاقة ذات الدوار المزدوج نوع المغناطيس الدائم لتطبيقات طاقة الرياح باستخدام التحكم التناسبي التكاملي (PI)

حسن سعد بن حمدين [1]، الجروشي محمد درياق[2] ، علي ابريك القذافي [3]

[2،1]قسم الهندسة الكهربائية، كلية الهندسة، جامعة سرت، سرت، ليبيا.

[3] قسم الهندسة الكيميائية ، كلية الهندسة، جامعة برمنجهام ، برمنجهام ، بريطانيا.

المُخلص

هذا البحث العلمي يقدم الة كهربائية نوع تزامني المغناطيس الدائم وذات الدوار المزدوج كمولدات للطاقة. تتضمن هذه الالة جزء ثابت واحد وجزئين دوارين بحيث تكون الثغرة الهوائية بين الجزء الثابت وبين الجزئين الدوارين غير متفاوتة. هذه الالة قادرة ان تولد قدرة كهربائية مزدوجة من الة واحدة. الدراسة المقترحة لهذا البحث هو إيجاد نموذج رياضي لها ويمكن من خلاله محاكاته بواسطة برنامج الماتلاب والتحكم به بواسطة المتحكم التناسبي التكاملي. هذه الالة يفترض ان تكون احدى التطبيقات لاستخلاص القدرة الكهربائية من طاقة الرياح. من خلال المتحكم التناسبي التكاملي يمكننا التحكم بسرعة الدوارين وبذلك التحكم في القدرة الكهربائية المنتجة. النتائج أظهرت ان هذا المتحكم استطاع ان يتحكم في سرعة الدوارين بالرغم من تغير سرعة الرياح.

الكلمات المفتاحية: مولدات تزامنية نوع المغناطيس الدائم ذات الدوار المزدوج، نمذجة ومحاكاة الالة باستخدام برنامج الماتلاب والمتحكم التناسبي التكاملي، توربينات الرياح.

1 Introduction

The permanent magnet double rotor generator (PMDRG) has been widely used in different industry fields because of its higher power density, high torque, and high efficiency than the wound rotor synchronous machines [1]. Compared with the conventional PMSM, the PMDRG with dual-rotating rotors also provides features such as high efficiency, high torque capability, compact structure [2,3]. Thus, the PMDRG with dual-rotating rotors has been commonly used in various applications including wind energy, electric ships, underwater vehicles (UVs), Electric vehicles and airplane [4,5]. Usually, an electrical machine with multiple rotating rotors has multiple assembly machines in series or parallel [6,7]. For the present topology, the machine has dual-rotating rotors and a single stator. The inner rotor will rotate by the wind turbine, and by electromagnetic induction the outer rotor will rotates. in other words, the speed of the outer rotor is 1/3 of the rotation speed of the inner rotor [8]. In spite of the conventional synchronous machines, the rotor rotation speed must be synchronized with the magnetic field speed. However, for the PMDRG the inner rotor's rotation speed is not synchronized with the outer PM rotor due to slip of permanent magnet induction mechanism. For the dual rotor machines studies, Cao et al. [9] studied the decoupling analysis of a brushless dual-mechanical-port dual-electrical-port machine. This machine operates without brushes making it suitable for wind energy and hybrid electrical vehicles applications. The authors verified their theoretical results using Finite Element Analysis (FEA) and validated them experimentally. However, they did not control the speed of each rotor. Ullah et al. [10] presented and introduced a new type of dual-rotor wound-field flux switching generator for wind power applications. The proposed machine uses two rotors rotating in opposite directions i.e. (counter-rotating). Even though, the rotors speed control does not include of their study. Zhao et al. [11] presented the investigation of the magnetic coupling effect and performance characteristics of a permanent magnet dual-rotor generator for wind energy system. The proposed machine includes two coaxial rotors with permanent magnets and a shared stator placed between them. Their topology is analyzed by using FEA in order to evaluate the magnetic field distribution, torque ripple and output power production. The structure of this paper is as follows: Section 2 the two-dimensional (2D) model of the PMDRG system is presented and provides an overview of the system operation principle; Section 3 presents the mathematical model of the proposed PMDRG system; Section 4 the control system of the machine is presented and describes the block diagram of the complete model of the PMDRG; Section 5 presents and discusses the obtained simulation results to evaluate the effectiveness of the proposed control scheme; finally, section 6 presents the concluding remarks of this study are provided.

Main Contributions of This Work

1. Development of a complete dynamic mathematical model of the PMDRG in the synchronous dq reference frame, including stator, inner rotor, and outer rotor dynamics.
2. Design of a Proportional–Integral (PI) controller for controlling the inner and outer rotors speed under variable wind speed conditions.
3. Implementation of the proposed mathematical and control models in MATLAB/Simulink using fundamental simulation equations rather than predefined machine libraries.
4. Demonstration of the effectiveness of the proposed control scheme in maintaining a constant inner and outer rotors speed despite fluctuations in wind speed.

2 Two-Dimensional (2D) Model and Operating Principle

Figure 1 shows the two-dimensional (2D) model of the PM generators with dual-rotating rotors, where the two rotors are employed to drive two wind plates. the inner rotor is wound rotor whereas the outer rotor working stator since there is slip speed between them. The single stator which has the electromagnetic field in its windings speed must be synchronized with the real speed of the outer rotor. The two generators output power can be extracted from the windings of the inner rotor and the stator windings.

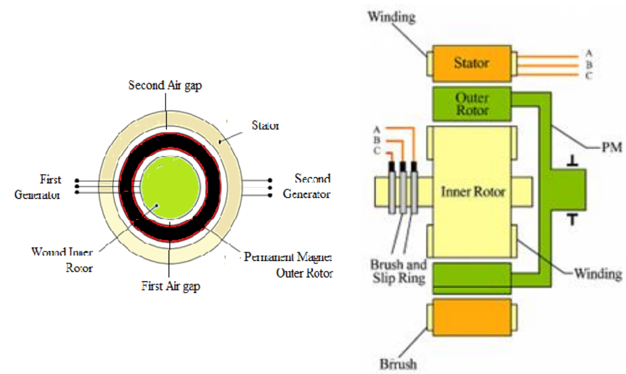

Fig.1: Overview of PMDRG Machine, (a) Front view of the Machine and (b) Side view of the Machine.

The PMDRG configuration is illustrated, where both generators are designed to produce power, the inner rotor windings to be connected into sliprings. The rotation of both rotors is in phase. Since the outer rotor is rotating according to electromagnetic induction of inner rotor and to assist its rotation there are plated can be installed as shown in Figure 2. The mathematical model of the system and description of the proposed PI control strategy are presented in the next section. Figure 2 shows the proposed installation of both plates, where the shorter one is the main plates connected to the inner rotor, while the other plates can be connected into the outer rotor.

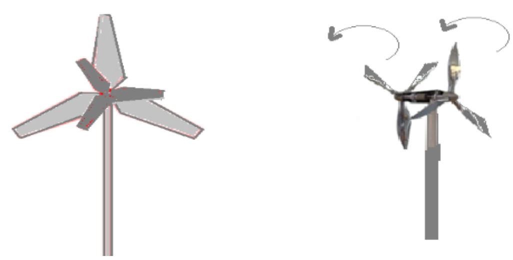

Fig.2: Dual Rotor Dual Plates of the Wind Energy.

3 Mathematical Modeling and Control Methodology

The following assumptions are made to simplify the dynamic model equations:

- Saturation effects, hysteresis, and eddy current losses are neglected in the analysis.
- The induced EMF is assumed to be a sinusoidal.
- It is assumed the inner rotor and stator winding resistances are constant and equal.

The dynamic model of the PMDRG as the other types of electrical machines is developed by writing differential equations for voltages, currents, speed, and torque. The voltage equations in the dq0 reference frame are presented below.

The stator voltage equations can be written in the dq0 reference frame as [2].

$$V_{ds} = r_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs} \quad (1)$$
$$V_{qs} = r_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s \psi_{ds} \quad (2)$$

Where V_{ds} , V_{qs} represent the stator voltages in the direct and quadrature axes. ω_s is the angular synchronous in the stator, R_s is the stator winding resistance. ψ_{ds} , ψ_{qs} are the direct and quadrature flux linkages in the dq0 frame between the stator windings and the PM outer rotor, which are given by the equations:

$$\psi_{ds} = L_{ds} i_{ds} + L_{md} i_{dir} + \lambda_{PMor} \quad (3)$$
$$\psi_{qs} = L_{qs} i_{qs} + L_{mq} i_{qir} \quad (4)$$

Where $i_{ds}, i_{qs}, i_{dir}, i_{qir}$ are the direct and quadrature currents in the stator and inner rotors windings, respectively. L_{md} & L_{mq} is the mutual inductance between the inner rotor winding and the stator windings. λ_{PMor} is the flux linkages produced by the PM-surface mounted outer rotor and the stator, and this magnet is fixed on the outer surface of the outer rotor.

The same model is obtained in the inner rotor; However, the angular speed is defined as the difference between the speeds of the two rotors. So, the inner rotor voltages in dq0 are described in equations as:

$$V_{dr} = r_{ir} i_{dir} + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr} \quad (5)$$
$$V_{qr} = r_{ir} i_{qir} + \frac{d\psi_{qr}}{dt} + (\omega_s - \omega_r)\psi_{dr} \quad (6)$$

Where the flux linkages can be defined as:

$$\psi_{dr} = L_{dir} i_{dir} + L_{md} i_{ds} + \lambda_{PMir} \quad (7)$$
$$\psi_{qr} = L_{qir} i_{qir} + L_{mq} i_{qs} \quad (8)$$

Where ω_s is synchronous speed, ω_r is the rotor actual speed, $V_{dr}, V_{qr}, \psi_{dr}, \psi_{qr}$ represent the voltages and the magnetic fields in the dq0 frame, respectively and R_r is the inner rotor winding resistance. λ_{PMir} is the flux linkages produced by the PM- surface mounted outer rotor and the inner rotor. From equations (1,2 and 5,6) the following equations can be produced.

$$\psi_{ds} = \int \left[V_{ds} - r_s i_{ds} + \psi_{qs}\omega_s\right] dt \quad (9)$$
$$\psi_{qs} = \int \left[V_{qs} - r_s i_{qs} - \psi_{ds}\omega_s\right] dt \quad (10)$$
$$\psi_{dr} = \int \left[V_{dr} - r_{ir} i_{dir} + (\omega_s - \omega_r)\psi_{qr}\right] dt \quad (11)$$
$$\psi_{qr} = \int \left[V_{qr} - r_{ir} i_{qir} - (\omega_s - \omega_r)\psi_{dr}\right] dt \quad (12)$$

Using the mathematical solution of the magnetic flux equations system, the current equations from equations (3,4 and 7,8) are:

$$i_{ds} = \frac{1}{L_{ds}}\left[\psi_{ds} - L_{md} i_{dir} - \lambda_{PMor}\right] \quad (13)$$
$$i_{qs} = \frac{1}{L_{qs}}\left(\psi_{qs} - L_{mq} i_{\mathrm{qir}}\right) \quad (14)$$
$$i_{dir} = \frac{1}{L_{dr}}\left[\psi_{dr} - L_{md} i_{ds} - \lambda_{PMir}\right] \quad (15)$$
$$i_{qir} = \frac{1}{L_{qr}}\left[\psi_{qr} - L_{mq} i_{qs}\right] \quad (16)$$

The PMDRG machine has a different electromagnetic torque developed equation in flux linkage and currents. The torque equation is the electromagnetic torque generated by the stator, outer rotor, and inner rotor, and is described by the equations [12][13].

$$T_{\mathrm{e,\,stator}} = \frac{3}{2}\frac{P}{2}\left(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}\right) \quad (17)$$
$$T_{\mathrm{e,\,pm\text{-}rotor}} = \frac{3}{2}\frac{P}{2}\left(\lambda_{PMor} i_{qs} + \lambda_{PMir} i_{qir}\right) \quad (18)$$
$$T_{\mathrm{e,\,wd\text{-}rotor}} = \frac{3}{2}\frac{P}{2}\left(\psi_{ds} i_{qir} - \psi_{qs} i_{dir}\right) \quad (19)$$

The Mechanical speed equations of the inner and outer rotors are derived by equating the inertia torque to the accelerating torque.

Mechanical dynamic speed equations of the machine are given as follows:

- outer rotor speed found as:

$$\omega_{or} = \int \frac{P}{2J_{\mathrm{or}}}\left[T_{eor} + T_{mech} - T_{friction-or}\right] dt \quad (20)$$

- Inner rotor speed found as:

$$\omega_{\mathrm{ir}} = \int \frac{P}{2J_{\mathrm{ir}}}\left[T_{eir} + T_{mech} - T_{friction-ir}\right] dt \quad (21)$$

In the equation, T_{mech} is the externally applied mechanical torque acting in the direction of the rotor speed, and $T_{friction}$ represents the damping torque acting opposite to the direction of rotation.

ω_{rm} is the mechanical rotor speed, and ω_e is the electrical speed, and the relationship between them is equal to:

$$\omega_e = \frac{p}{2}\omega_{rm} \quad (22)$$

The instantaneous magnitude of the stator and inner rotor voltages, currents, and active power at the generator's terminal are calculated as [14].

$$V_t = \sqrt{V_d^{\,2} + V_q^{\,2}} \quad (23)$$
$$i_t = \sqrt{i_d^{\,2} + i_q^{\,2}} \quad (24)$$
$$\mathrm{P_t} = \frac{3}{2}\left(V_d i_d + V_q i_q\right) \quad (25)$$

4 Machine Control with PI Controllers in the dq0 Reference Frame

The control strategy is based on cascaded loops, where the outer loop controls the machine speed and the inner loop regulates the dq0 currents. All quantities are transformed into the synchronous dq0 reference frame, allowing decoupled torque and flux control.

- ***Outer Speed Loop Stator Side***

The stator synchronous speed ω_s is continuously measured and compared with the reference speed ω_s^*. The error signal $(\omega_s^* - \omega_s)$ is processed by a PI controller, and its output defines the reference q-axis stator current i_{qs}^*. This reference current is then compared with the actual measured stator q-axis current i_{qs}. The resulting error $(i_{qs}^* - i_{qs})$ is input to another PI controller, whose output produces the reference stator q-axis voltage v_{qs}^*. This voltage reference is applied to the machine to control speed and regulate torque production. Figure 3 illustrates the overall structure of the outer speed control loop and inner current control loop on the stator side.

In parallel, the d-axis stator current control is performed. A reference value i_{ds}^*, typically set to zero for maximum torque per ampere, is compared with the actual measured d-axis stator current i_{ds}. The error $(i_{ds}^* - i_{ds})$ is processed by a PI controller, generating the reference stator d-axis voltage v_{ds}^*, which is applied to maintain flux regulation.

- ***Outer Speed Loop Inner Rotor Side***

The rotor speed ω_r is measured and compared with its reference ω_r^*. The error signal $(\omega_r^* - \omega_r)$ is fed to a PI controller, and the output defines the reference q-axis rotor current i_{qr}^*.

This value is compared with the actual measured rotor q-axis current i_{qr}, and the error $(i_{qr}^* - i_{qr})$ is applied to a PI controller. The controller generates the reference rotor q-axis voltage. v_{qr}^* which contributes to rotor speed control. Figure 3 illustrates the overall structure of the outer speed control loop and inner current control loop on the inner rotor side.

For the rotor d-axis, the reference current i_{dr}^* is compared with the actual rotor current i_{dr}. The error $(i_{dr}^* - i_{dr})$ is processed by a PI controller, and the resulting output is the reference rotor d-axis voltage v_{dr}^*. This voltage reference is applied to regulate rotor flux.

A complete MATLAB/Simulink model of the PMDRG was developed in the dq0 reference frame. The model incorporates all the mathematical equations representing the stator and rotors dynamics, including voltages, currents, and flux linkages, as well as the implemented PI control loops for speed control. Figure 3 shows the wind turbine block diagram components.

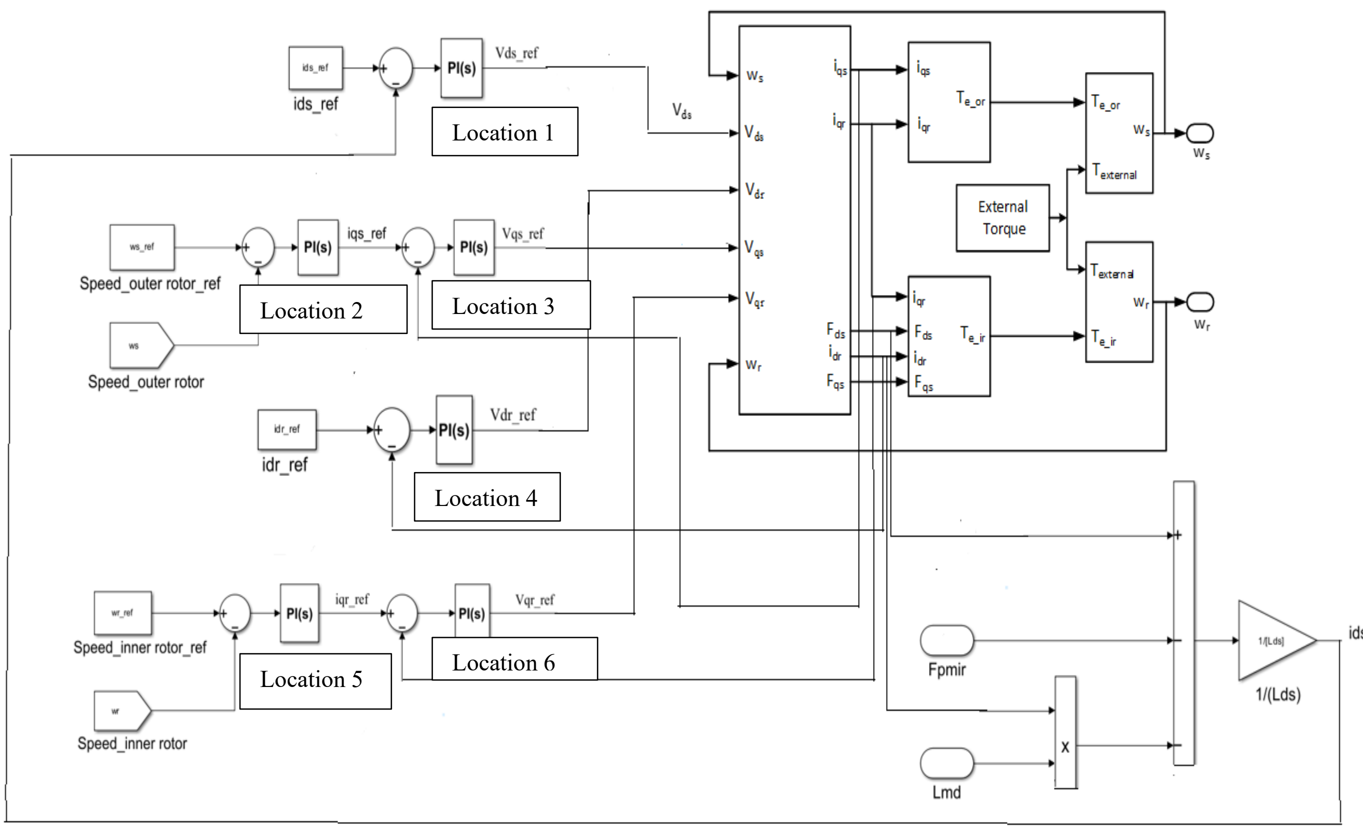

Fig. 3: Complete Block Diagram PMDRG System.

4.1 Wind Turbine Model

The wind turbine acts as the main source of mechanical energy in the proposed wind energy conversion system. It transforms the Kinetic energy available in the wind into mechanical power required to drives the generator. The mechanical power extracted from the wind can be expressed as:

$$p_m = \frac{1}{2}\pi\, \rho\, C_p\, (\lambda, \beta)\, r^2 v^3 \quad (26)$$

Where ρ is the air density (k_g/m^3), C_p is the coefficient of power conversion, r is the blade tip radius (m), λ is the tip speed ratio (TSR), and β is the blade pitch angle in degrees.

The mechanical torque developed by the wind turbine is given by [15][16].

$$T_m = \frac{P_m}{\omega_m} \quad (27)$$

Where:

p_m : Generated power.

ω_m : Mechanical speed.

T_m : Represents the driving torque generated by the wind turbine (N·m).

Figure 4 shows the Simulink block of the wind turbine aeromechanical.

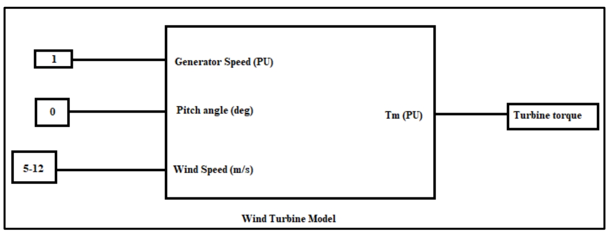

Fig. 4: Wind Turbine Block Diagram.

5 Simulated Results and Analysis

Table 1 presents the electrical parameters of the PMDRG used in the Matlab/Simulink as follows [2].

Table 1: PMDRG Main Parameters

Symbol	Unit	Inner Rotor	Inner rotor & Stator Interaction	Stator	Outer Rotor
λ_{PMir}	Wb. turns	15.915			
λ_{PMor}	Wb. turns				15.92
R	Ω	0.02		0.035	
L_d & L_q	mH	3/4.5		9/15	
L_{md} & L_{mq}	mH		0.5/1.5		
J	Kg/ m^2	0.89			0.83
B	N.m. s/rad	0.10			0.10
pole pairs (P = 2)					

To evaluate the results of the mentioned mathematical model in section (3), simulation process of the PMDRG model was carried out with the given data in Table 1. The results of modeling the depends on the wind speed ranges from 5 to 12 m/s. The simulation modeling carried out with PI control gains given in Table 2. These gains were obtained using the time-domain pole placement method [17][18].

Table 2: PI Control Gain's

PI location	K_P	K_I
Location 1	7.83	3549.56
Location 2	0.26	1.8125
Location 3	13.18	5915.93
Location 4	2.62	1184.35
Location 5	3.52	78.387
Location 6	3.94	1777

Figure 5 shows the inner rotor speed response at a wind speed varied from 5m/s to 12 m/s. The rotor accelerates rapidly and reaches a peak speed of approximately 990 rpm before settling at the reference value of 900 rpm. The settling time is about 0.183 s, indicating a fast dynamic response.

The PI controller effectively eliminates the steady-state error and maintains stable operation under wind conditions.

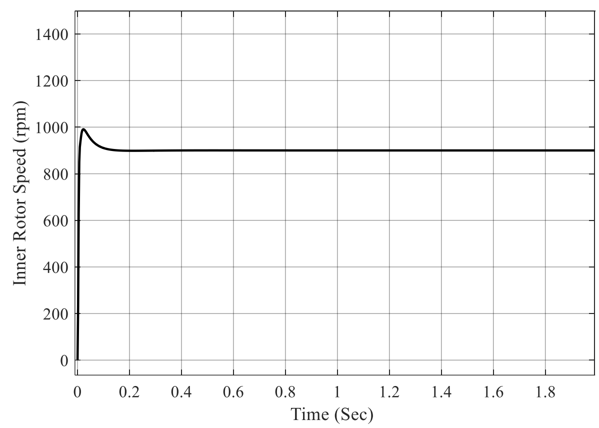

Fig. 5: Inner Rotor Speed Response.

Figure 6 shows the outer rotor speed response at a wind speed varied from 5m/s to 12 m/s. The rotor accelerates rapidly and shows a transient overshoot before settling at the reference speed of 300 rpm. The settling time is approximately 0.62 s. Despite the initial oscillations, the PI controller effectively eliminates the steady-state error and maintains stable operation at the desired speed.

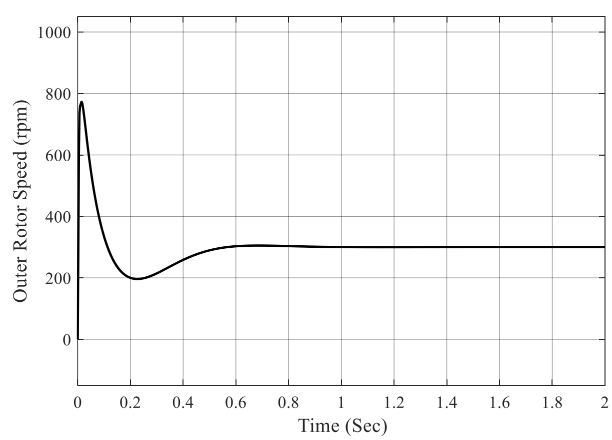

Fig. 6: Outer Rotor Speed Response.

Figure 7 illustrates the inner rotor three-phase voltages at a wind speed varied from 5m/s to 12 m/s. The voltages are balanced and sinusoidal with a phase shift of 120° between phases, confirming proper machine operation. After a short transient period, the voltages reach a stable steady-state peak value of about ±1000 V, showing the effectiveness of the control system and the stability of the generated output.

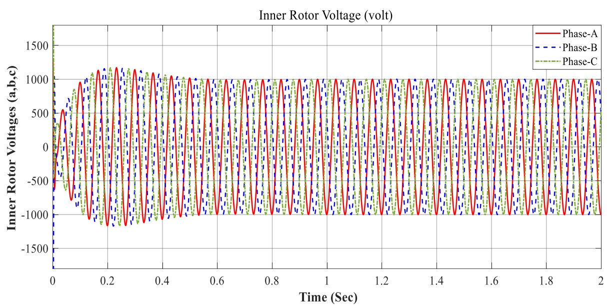

Fig. 7: Output Voltage from the Inner Rotor.

Figure 8 illustrates the inner rotor three-phase voltages at a wind speed varied from 5m/s to 12 m/s. The voltages are balanced and sinusoidal with a phase shift of 120° between phases, confirming proper machine operation. After a short transient period, the voltages reach a stable steady-state peak value of about ±500 V, illustrating the effectiveness of the control system and the stability of the generated output.

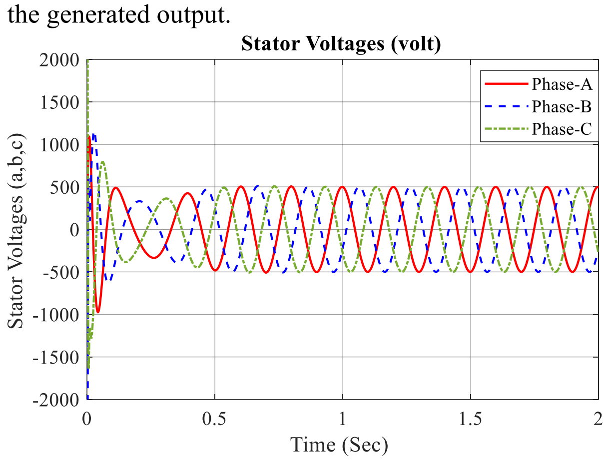

Fig. 8: Output Voltage from the Stator of PMDRG.

6 Conclusions

In this paper, the double rotor double plates wind turbine drives PMDRG system to produce dual, independent, voltage sources using a compact machine with a single stator and windings and two different rotors one rotor is PM rotor (outer rotor) and wound rotor (inner rotor) has been introduced in terms of complete model, PI control system. The PI control for the independent rotors is presented and proven to be effective to fix the speed of inner rotor to be 900 rpm and the outer rotor to be 300 rpm even the wind speed is varied. In addition, the stator and inner rotor voltages are simulated to provide independent voltage sources from a single machine. Future work will include finite element analysis, experimental prototype validation, converter modelling, and comparison with advanced control strategies.

Acknowledgements

The authors would like to thank everyone who supported this work. No external funding was received for this study

Conflict of interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

M. A. Rahman and T. A. Little, “Dynamic performance analysis of permanet magnet synchronous motors,” IEEE Transactions on Power Apparatus and Systems, no. 6, pp. 1277–1282, 2007.

M. Ghanaatian and A. Radan, “Application and simulation of dual-mechanical-port machine in hybrid electric vehicles,” *International Transactions on Electrical Energy Systems*, vol. 25, no. 6, pp. 1083–1099, 2015.

S. A. Mirnikjoo, F. Asadi, K. Abbaszadeh, and S. E. Abdollahi, “Effect of Rotor Topology on the Performance of Counter-Rotating Double-Sided Flux Switching Permanent Magnet Generator,” *IEEE Transactions on Energy Conversion*, vol. 37, no. 1, pp. 65–74, Mar. 2022.

Barrero, F.; Duran, M.J. Recent Advances in the Design, Modeling, and Control of Multiphase Machines—Part I. IEEE Trans. Ind. Electron. 2016, 63, 449–458.

Sayed, E.; Abdalmagid, M.; Pietrini, G.; Sa’adeh, N.M.; Callegaro, A.D.; Goldstein, C.; Emadi, A. Review of Electric Machines in More-/Hybrid-/Turbo-Electric Aircraft. IEEE Trans. Transp. Electrif. 2021, 7, 2976–3005.

Zhitong Ran, Z.O. Zhu, and Dawei Liang, "Comparative Study of Dual-Rotor Permanent Magnet Machines with Series and Parallel Magnetic Circuits", World Electric Vehicle Journal, December 2024, 16(1):12, 1-24

Zhao Feng, Wen Xuhui, Chen Jingwei, Modeling of PM-PM Dual Mechanical Ports Electric Machines, IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics, 1251-1256.

E. Diryak, A. Algaddafi, and M. Abougharsa, “Improvements of Wind Turbine Power Efficiency by Using Four-Ports Machine Structure and Phased Rotating Plates,” *International Journal of Engineering Research*, vol. 1, no. 1, pp. 46–55, 2022.

L. Cao *et al.*, “Analysis of Contra-Rotating Brushless Integrated Flux-Modulation Machine with Open-Slot Structure for Wind Power Generation,” *IEEE Transactions on Industrial Electronics*, vol. 70, no. 12, pp. 11934–11947, Dec. 2023.

W. Ullah, F. Khan, U. B. Akuru, and M. Yousuf, “Magnetic Coupling Effect and Performance Analysis of Dual Rotor Permanent Magnet Flux Switching Generator for Counter Rotating Wind Power Generation,” *IEEE Transactions on Energy Conversion*, vol. 38, no. 4, pp. 2895–2908, Dec. 2023.

H. Zhao, C. Liu, Z. Song, S. Liu, and T. Lubin, “Analytical model for magnetic-geared double rotor machines and its d-q-axis determination,” *IET Electr Power Appl*, vol. 14, no. 2, pp. 175–183, Feb. 2020.

L. Xu, “A new breed of electric machines-basic analysis and applications of dual mechanical port electric machines,” in *2005 International Conference on Electrical Machines and Systems*, IEEE *Conf*, vol.1, pp. 24–31, 2005.

L. XU, “Dual-mechanical-port electric machines-concept and application of a new electric machine to hybrid electrical vehicles,” Industry Applications Magazine, IEEE, vol. 15, no. 4, pp. 44–51, July 2009.

Chee-Mun Ong., “Dynamic simulation of electric machinery: using MATLAB/SIMULINK, “Upper Saddle River, NJ, USA: Prentice Hall PTR, Ch. 7, pp. 309–323. 1998.

A. E. Awwad, “Dynamic performance enhancement of a direct-driven PMSG-based wind turbine using a 12-sectors DTC,” World Electr. Veh. J., vol. 13, no. 7, Jul. 2022, Art.no.123.

C. A. Obiora-Okeke, D. C. Oyiogu, U. E. Anionovo, H. N. Ogboke, K. C. Obute, and C. J. Ofuase, “Control of permanent magnet synchronous generator for wind power systems,” Int. J. Eng. Res. Develop., vol. 20, no. 4, pp. 41–48, 2024.

R. Krishnan, Permanent Magnet Synchronous and Brushless DC Motor Drives. Boca Raton, FL, USA: CRC press, 2017, ch.6, pp. 379–399.

N. S. Nise, Control Systems Engineering, 6th ed. Hoboken, NJ, USA: John Wiley & Sons, Inc., ch.4, pp.173–212, 2011.