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Modern Control Approaches for a Wind Energy Conversion System based on a Permanent Magnet Synchronous Generator (PMSG) Fed by a Matrix Converter

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ABSTRACT

This "paper proposes a super-twisting adaptive Control Approaches for a Wind Energy Conversion System Based on a Permanent Magnet Synchronous Generator (PMSG) Fed by a matrix sliding mode for tracking the maximum power point of wind energy conversion systems using permanent magnet synchronous generators (PMSGs). As the adaptive control algorithm employed retains the robustness properties of classical wind energy conversion system control methods when perturbations and parameter uncertainties are present, it can be considered an effective solution; at the same time, it reduces chattering by adjusting gain and generating second-order adaptive control methods. The Egyptian power system (EPS), a three-zone interconnected microgrid (MG), and a single machine linked to the grid are only a few examples of the power systems for which this article introduces the concept of direct adaptive control (SMIB).The goal of our work is to maximize the captured power by solving a multi-input multi-output tracking control problem. In the presence of variations in stator resistance, stator inductance, and magnetic flux linkage, simulation results are presented using real wind speed data and discussed for the proposed controller and four other sliding mode control solutions for the same problem. The proposed controller achieves the best trade-off between tracking performance and chattering reduction among the five considered solutions: compared to a standard sliding mode control algorithm, it reduces chattering by two to five orders of magnitude, and steadystate errors on PMSG rotor velocity by one order of magnitude". The purpose of this article is to examine wind turbine control system techniques and controller trends related to permanent magnet synchronous generators. The article presents an overview of the most popular control strategies for PMSG wind power conversion systems. There are several kinds of nonlinear sliding modes, such as direct power, backstepping, and predictive currents. To determine the performance of each control under variable wind conditions, a description of each control is presented, followed by a simulation performed in MATLAB /Simulink. This simulation evaluates the performance of each control in terms of reference tracking, response times, stability, and signal quality. Finally, this work was concluded with a comparison of the four controls to gain a better understanding of their effects. "Moreover, it reduces the above-mentioned steady-state error by four orders of magnitude compared to a previously-proposed linear quadratic regulator based integral sliding mode control law. A dynamic model is simulated under both variable step and random wind speeds using the DEV-C++ software, and the results are plotted using MATLAB. The obtained results demonstrate the robustness of the proposed controller in spite of the presence of different uncertainties when compared to the classical direct torque control technique.

Keywords-- Wind Energy Conversion Systems, Permanent Magnet Synchronous Generators, Adaptive Control Method, Voltage-Oriented Control

I. INTRODUCTION

Permanent magnet synchronous generators (PMSGs) are now the most widely used power generating technology due to their great efficiency [1–5]. For instance, synchronous-generators (SGs) in moderate-size power marine diesel gen-sets have worse electrical efficiency than PMSGs [6]. Voltage regulation in island-operation is difficult since PMSG don't include excitation control. As temperature rises, a permanent magnet's (PM) flux density decreases, making voltage control more challenging. The high cost and handling when manufacture of PMs is some of its challenges [7]. The demand for energy is unremittingly increasing all over the world due to the rapid growth in population, the increased energy consumption per capita and the substantial industrialization that has taken place. There is a limited amount of conventional fossil fuels available on the market today [1]. As a result, there will be an increase in energy crises in the future. "There is a tremendous increase in the use of renewable energy sources, such as solar energy [2], wind energy [3], biogas energy [4], ocean energy [5], tidal energy [6], and so on. One of the most promising sources of renewable energy

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among these is wind power. It has been well known for over a millennium that wind energy has been used across the globe for a variety of purposes. As early as the days of sails on boats and rafts, as well as wind driven mills for grinding grains, wind energy has found a use throughout the ages. Wind energy has been the most abundant form of energy available in the atmospheric environment with varying air currents spread over the troposphere and stratosphere. Wind energy has been used for a multitude of purposes for thousands of years across the globe. From the use of sails in boats and rafts, to wind driven mills for grinding grains", "wind energy has found its use throughout history. Wind energy has been a staple for transportation in oceans until as recently as the 19th century. The early usage of turbines was found in the form of carousel like vertical axis turbines in Persia for pumping water and grinding food grains in a very small scale, around the 10th century [13]. Horizontal axis turbines were adopted in England, which had to be manually oriented according to the direction of the wind currents, thus giving it the name post mill. Large scale harnessing of wind energy has been implemented since the 17th century in Europe [14]. These have paved the way for the more effective and useful utilization of wind in the 21st century, with modernization in design and optimization enabling us to store energy in the form of electricity, using wind turbines [15]. The wind energy conversion system (WECS) is an integrated system comprising of wind turbines, generators, mechanisms for control and an integrating method. The turbines are responsible for converting the power of wind into mechanical power, thus harnessing the kinetic energy from the wind. The efficiency of the turbines is a function of shaft power recorded at the rotor shaft and the power available in the flow of the wind stream [16]. The mechanical components are used chiefly for the conversion to mechanical power and transmission to electrical components of the system, as well as providing support to the moving components. The amount of power that can be strained from the wind current depends upon a multitude of factors such as density of wind, shape of turbine rotor, blade measurements, wind velocity, and so on. The high power WECS are low speed, high torque at the turbine. These turbines produce power of more than 1 MW where the speed of the turbine shaft is in the range of six to twenty rpm. However, the generator shaft is that of high speed and low torque, and thus, to couple it with the rotor shaft a gearbox is added [17]. For an effective reduction in torque, a multiple stage gearbox is used in high power grid-connected WECS. A planetary gear assembly ensures even more effective reduction phase. The electrical components of the WECS mainly comprise of a generator, a controller system coupled with anemometer to detect the speed of wind available to control the operation of the turbine. Figure.1 shows our WECS configuration, which includes wind turbine, mechanical coupling parts, generator, and power converters.

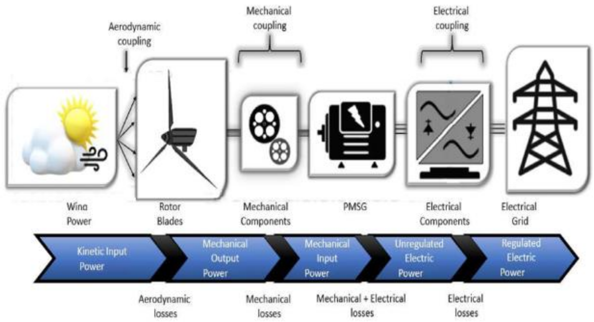

Figure 1: Typical configuration of a wind energy conversion system

1.1 Wind Energy Conversion System and its Modelling

The use of unconventional energy sources has evolved into a complement to or replacement for traditional energy sources. Wind energy offers limitless potential and benefits for the environment, making it the most widely used renewable energy source. Both fixed and variable speed WECS based on wind turbines (WT) are recognized. Fixed-speed WECS was the most popular at first. Variable speed generators are more efficient today. In comparison to other generators, PMSG is more effective and efficient and is ideally suited for WECS because of its high torque to size ratio, low maintenance needs, lack of slide rings, and lower overall price. Stator direct-flux is kept constant by using permanent magnets (PM) rather than electromagnets [40]. Here is a discussion of the modelling of a wind-based power generating system.

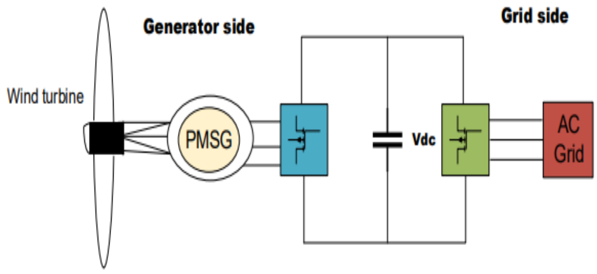

Figure 2: PMSG-based wind energy conversion

1.2 Wind Turbine Modelling

The wind's kinetic energy is transformed into mechanical energy by WT's rotor blades. When used as an electrical system, a generator converts mechanical power into electrical power. Vertical-axis wind turbines (VAWT) and horizontal-axis wind turbines are the two types of WTs often employed for WECS (HAWT). The advantages of HAWT over VAWT are stated below.

- It has adjustable blade-pitch to allow blades to function at the best angle of attack, capturing more wind energy.
- Because the blades rotate perpendicular to the wind, they efficiently catch wind energy at all times.

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- Although it is self-starting, VAWT requires a starting torque.

The turbine blade area is pierced by the kinetic energy that is captured from the wind. The greatest amount of wind energy that may be harvested is provided as [65] in accordance with the energy-mass conservation in wind theory.

$$P_{wind} = \frac{1}{2} PAV_w^3 \quad (1)$$

"Where Wv is wind velocity, ρ is density of air, A is swept-are a of turbine-blades. Cp, power coefficient is defined as the ratio of turbine power to the extracted wind power."

$$cp = \frac{Turbine\ power\ (Pturbine)}{power\ obtained\ from\ wind\ (Pwind)}$$

So, the turbine's power is provided by:

$$Pturbine = P_{wind}\, Cp = \frac{1}{2} PAV_w^3\ \ CP \quad (2)$$

The turbine-power wrt wind transients are given by

$$P_{turbine} = P_{wind} C_p = \frac{1}{2} \rho A v_w^3 C_p(\lambda, \beta) \quad (3)$$

Where λ is the tip-speed ratio of the turbine:

$$\lambda = \frac{\text{rotational speed of rotor } (\omega_r) * \text{radius(r)}}{\text{wind velocity } (v_w)} \quad (4)$$

Where

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4 \right) e^{\frac{-C_5}{\lambda_i}} + C_6 \lambda \quad (5)$$

$$\lambda_i = \left(\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \right) \quad (6)$$

Power Generation Using Permanent Magnet Synchronous Generator (PMSG)"

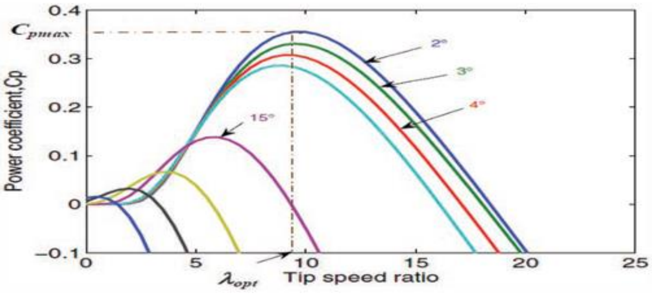

Figure 3: Power coefficient Cp (λ, β) vs tip speed ratio λ.

Where β stands for the blade pitch angle.

The coefficient C1 to C6 are: C1 = 0.5176, C2 = 116, C3 = 0.4, C4 =5, C5 =21, C6 = 0.0068. Figure 2 show the relationship between the power coefficient Cp and tip speed ratio λ the governing formula for directly-coupled PMSG for the mechanical analysis is given as,"

$$\frac{d\omega_m}{dt} = \left(\frac{1}{J}\right)(T_m - T_{gen} - B\omega_m) \quad (7)$$

$$\omega_e = P\omega_m \quad (8)$$

Also

$$\int \omega_e\, dt = \theta_e \quad (9)$$

"Where, θe = electrical angle (is required for abc↔d-q transformation), Tm = generated turbine mechanical-torque (Nm), (Tgen =Te) = generated electromagnetic-torque (Nm), P= pole-pairs ωm = the rotor mechanical speed (rad/sec), ωe= rotor electrical speed in elec. rad/sec, J = inertia-moment (Kgm2), B = viscous-friction coefficient (can be ignored for small WT)."

1.3 Modelling of the PMSG

In a permanent magnet synchronous generator, the excitation field is generated by a permanent magnet instead of a coil. Since the magnetic field is generated by a shaft mounted permanent magnet mechanism and current is induced into the stationary armature, the rotor and magnetic field rotate at the same speed. As wind energy conversion systems become more and more connected to the grid, research about dynamic models is one of the challenges to achieving knowledge for the ongoing change nowadays, wind energy is being used more and more. There is some involvement in those models in this paper, but there is also some discussion. Wind energy conversion systems consisting of wind turbines with permanent magnets Full-power converters and magnet synchronous generators (PMSG). Specifically, it focuses on In order to achieve this; models need to incorporate the dynamics of the system as much as possible In order to assert consequences on the operation of the system. In modeling the energy captured from the wind by the blades, disturbance imposed by the asymmetry in the turbine, the vortex tower interaction, and the mechanical Eigen swings in the blades are introduced in order to assert a more accurate behavior of wind energy conversion systems. The conversion system dynamic comes up from modeling the dynamic behavior due to the main subsystems of this system the variable speed wind turbine, the mechanical drive train, and the PMSG and power electronic converters. The mechanical drive train dynamic is considered by three different model approaches, respectively, two-mass or three-mass model approaches in order to discuss which of the approaches are more appropriated in detaining the behavior of the system. The power electronic converters are modelled for three different topologies, respectively, two-level, multilevel or matrix converters. The consideration of these topologies is in order to expose its particular behavior and advantages in what regards the total harmonic distortion of the current injected in the electric network. The electric network is modeled by a circuit consisting in a series of a resistance and inductance with a voltage source, respectively, considering two hypotheses: without harmonic distortion or with distortion due to the third harmonic, in order to show the influence of this third harmonic in the converter output electric current. Two types of control strategies are considered in the dynamic models of this paper,

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respectively, through the use of classical control or fractional-order control. Case studies were written down in order to emphasize the ability" "of the models to simulate new contributions for studies on grid-connected wind energy conversion systems."

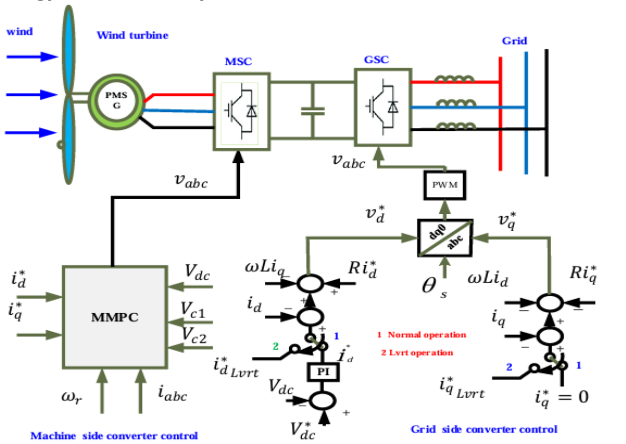

Figure 4: PMSG-WECS block schematic and control structure

They are known as synchronous generators because f, the frequency of the induced voltage in the stator (armature conductors) conventionally measured in hertz, is directly proportional to RPM, the rotation rate of the rotor usually given in revolutions per minute (or angular speed). If the rotor windings are arranged in such a way as to produce the effect of more than two magnetic poles, then each physical revolution of the rotor results in more magnetic poles moving past the armature windings. Each passing of a north and South Pole corresponds to a complete "cycle" of a magnet field oscillation. Figure 3 depicts the "Park" model for the D-Q axis. In PMSG, the magnetic field is produced by a rotor that is constructed of PM and not an external source. Therefore, it is not necessary to build a rotor voltage equation since the fluctuation in rotor flux with respect to time."

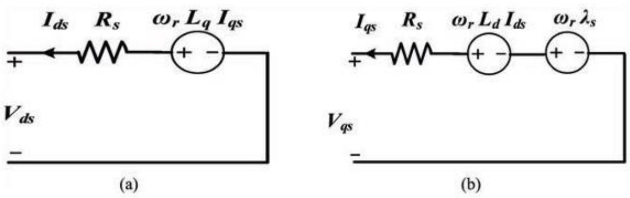

Figure 5: PMSG model(a) d (direct)-axis, (b) q (quadrature)-axis

Stator voltage I equations are as follows [65]:

$$V_{sd} = R_s I_{sd} + \frac{d\phi_{sd}}{dt} - \omega_e \phi_{sq} \quad (10)$$

$$V_{sq} = R_s I_{sq} + \frac{d\phi_{sq}}{dt} + \omega_e \phi_{sd} \quad (11)$$

The stator fluxes come from,

$$\phi_{sd} = L_d I_{sd} + \phi_m \quad (12)$$

$$\phi_{sq} = L_d I_{sq} + \phi_m \quad (13)$$

Where, Rs = stator-winding resistance, Ld = d-axis stator-inductance, Lq = q-axis stator-inductance, φm = flux linkage, Vsd &Isd = d-axis stator voltage & current, Vsq & Isq =q-axis stator voltage &current. FromEquations10–13:

$$T_e = \left(\frac{3}{2}\right) P(\phi_m I_{sq} + (L_d - L_q) I_{sd} I_{sq}) \quad (16)$$

For surface-seated PMSG, we can assume Ld = Lq. Then Te can be written as:

$$T_e = \left(\frac{3}{2}\right) P\,(\phi_m I_{sq}) \quad (17)$$

Real power Ps and reactive power Qs of PMSG are as follows under steady-state conditions:

$$P_s = V_{sd} I_{sd} + V_{sq} I_{sq} \quad (18)$$

$$Q_s = V_{sq} I_{sd} - V_{sd} I_{sq} \quad (19)$$

1.4 The History of Wind Power Technology

Wind turbines could be powered by lead acid batteries invented by Camille Faure in 1881. A few forms of horizontal axis turbines were successfully built by prominent researchers such as Professor James Blyth, and Charles Brush in the following years. The number of blades on the turbines reduced significantly during this period because fewer blades rotating faster were more efficient than more blades rotating slowly. A vertical axis turbine system was eventually developed through research. Wind capacity reached almost 300 GW worldwide in 2012, which is less than one-third the cost of electricity in the 1980s. Modern wind turbines have an efficiency of 20–30%, and more and more wind farms are being constructed. As a result of this review article, researchers will be able to select the materials that are most suitable for blades and generators. In general, HAWT and VAWT have few disadvantages in common. Due to the properties of wind at altitude, the force driving the turbine is much greater than the force opposing it, since the wind at the top is stronger. VAWTs must be installed close to the ground, while HAWTs can be installed at any height. As wind energy can be converted into mechanical energy, and ultimately electricity, it is a valuable source of electric power. It is imperative to use robust estimation methods when estimating wind speed because of its significant variability. The mechanical power of wind turbines (WTs) is estimated using input variables such as wind speed, angular speed of WT rotor, blade pitch, and power coefficient.

II. LITERATURE REVIEW

"In this paper, a number of previous research works have been overlooked, the majority of which are related to HSPMSG designs driven by wind turbine systems in this paper. A literature survey provides a necessary consideration such as the selection of the lamination material, coil construction, and thermal analysis for HSPMSG design, and how the operational efficiency of the machine can be increased by making adequate design choices as compared to other counterparts for the same rated power by making adequate design choices. The purpose of this survey is to be able to build a detailed prototype model of brushless HSPMSG and to solve the additional technical challenges associated with thermal sensitivity of the magnet material, and high-temperature design of the magnet, for example.

One of the many viable research works from the past was the observation that wind turbines can produce electricity. Researchers hypothesized early on that wind turbine generators could save energy and reduce losses by designing highly efficient ones. The reasoning for how to design a highly efficient wind turbine generator was not well understood. Using a two-blade propeller downstream system at a constant rotational speed of 28 rpm (revolutions per minute), Smith-Putnam machine built the world's first large wind turbine in 1941. A synchronous electric generator feeds the Smith-Putnam machine's wind turbine with 1,25 MW of wind electricity.

According to previous research, cogging torque and electromagnetic torque in permanent magnets are maximized by considering only radial components. This resulted in a reduction in the overall performance of the PM machine. According to Rasmussen [12], tangential components of magnetization could enhance the performance of machines by including them in field distribution calculations. The author's main objective is to present an analytical prediction of the magnetic field generated by a surface mount magnet motor. This model was used to calculate the field distribution for three different types of magnetizations: sine magnetization, radial” sine “magnetization, and radial magnetization. To measure the radial air-gap flux density, he constructed the Hall probe and encoder test setup. According to the author, the model developed and the measured results were in good agreement.

The previous methods assumed calculations of torque, back-emf, etc. across macro-elements such as air gaps with permanent magnets. [15] presents a numerical-analytical solution to the magnetic problems for slotted and PM machines with surface magnets in 2000. For overlapping sub-regions, the Schwartz technique is used to achieve fast convergence between different types of solutions when a hybrid magnetic field calculation is used. By combining analytical and numerical solutions, electric machine designers can take advantage of the symmetry, periodicity, and linear magnetic properties of air gaps and slots in PM machines to combine Fourier series, boundary integrals, and finite elements in the overlapping sub regions. Finite element analysis (FEM) and different solutions in the slot were used to validate the method.

A number of research works have examined the computational analysis of electrical machines, including experimental, analytical, and numerical methods. Modeling and predicting the performance of electrical machines has been done using these methods of analysis [17]. As an example, et al. [18] used modelling and simulation techniques to study how a micro turbine generation system behaves with a permanent magnet synchronous generator (PMSG) for isolated and grid-connected operations. A mathematical modelling method, as well as a load analysis of PMSG, are utilized in this paper in order to describe the system in a good way. Simulating the load conditions showed that the model developed met the requirements. By using MATLAB/Simulink, their work simplifies previous studies by including block diagrams describing the system with varying loads and fuel consumptions.

The winding configuration is an important factor to enhance PMSG performance, however their importance will be less pronounced without considering the stator lamination material. By using 6.5% S (Silicon Iron) lamination instead of 3% with experimental data, the iron loss can be significantly reduced. In high speed and high power PM generators, whose outputs are rectified by simple bridge rectifiers, they represented a predicted no-load and full-load stator iron losses, demonstrating the benefits of using 6.5% laminations. In large electrical machines, 3% is rarely considered due to its lower saturation flux density and higher cost. Due to its higher electrical resistivity at high fundamental frequencies, 6.5% is considered. Based on this literature survey, it is clear that several factors play a role in rotor topologies, air-gap flux density, stator winding configurations, and cogging torque.

Using computational analysis and optimization methods, it is possible to predict the output torque, the maximum efficiency, the size of the machine, etc., for the design process. Although there are numerous other factors to consider in optimizing the entire design process of HSPMSG with different prototype models of a machine, computational analyses and optimization methods still provide useful insight. In order to design high-speed machines appropriately, multiple design boundaries must be addressed simultaneously. In one example, A presented a design for high-speed permanent magnet synchronous machines, but did not analyze the rotor dynamics. Similarly, has improved design methodology, but lacks thermal analysis. There are different design methodologies presented by researchers, but no one has developed a fully integrated design that incorporates electrical, mechanical, and thermal analysis.”

“In order to meet the required output power, 660 kW is selected [24]. A generator's output power is often determined by the type of application in which it is used, as well as the preferred devices connected to the generator measured in kW power. HSPMSG brushless generators have a rated speed of 15000 rpm to achieve the required performance at high rotating speeds [25]. In the design of high-speed PM machines, the issue is reducing iron and eddy current losses due to the high frequency produced by the high speed of the generator.

2.1 Contribution of Our Work

In this study, an ST-ASMC for PMSG-based WECSs with chattering attenuation is proposed. The presence of an external pitch controller is taken into account to show the effects of the transients given by transitions between partial-load and full-load regions. The authors of focused on controlling currents on both generator and grid sides, achieving MPPT by controlling the GSC, instead of the MSC, as done in our work. Both were focused on active power coordination (rather than considering the presence of an external pitch controller as in our case).

- Overcoming the variable switching frequency of the three-level converter problem by designing a modulation algorithm that obtains a fixed switching frequency, where a cost function algorithm with a time pattern to make the switching frequency of the converter constant has been proposed.
- The application of the novel cost function aids the control algorithm to operate at a certain extent low switching frequency and keeping dc-link capacitor voltages balanced.
- A comparison between the classical FCS-MPC and Modulated Model Predictive control (MMPC) techniques to show the contribution of the MMPC in the performance of WECS.
- A LVRT technique has been applied to enhance the system's stability during symmetrical and asymmetrical grid faults.

III. SYSTEM MODELLING

Wind energy conversion system converts kinetic energy of the wind to mechanical energy by means of wind turbine rotor blades then the generator converts the mechanical power to electrical power that is being fed to the grid through power electronic converters. The WECS under study, described in Figure. 5, consists of two main parts.

(a) Mechanical parts: include the aerodynamic system with the rotor blades and the drive train system (if existed).

(b) Electrical parts: comprised of the PMSG and the back to-back converter set [16]."

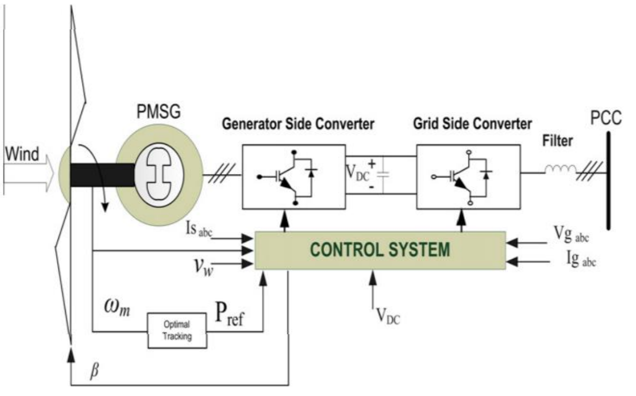

Figure 6: PMSG based wind turbine configuration

3.1 PMSG Modelling

Aerodynamic system mechanical power is transformed into ac electrical power by PMSG, which is subsequently transformed into dc power with the aid of an IGBT pulse width modulation (PWM) converter with a dc connection attached to its dc port. The control is given to another IGBT pulse width modulation via the grid the (PWM) inverter The surface-mounted PMSG's electrical model has have been created in [2,4]. Typically, the dq is where it is implemented. rotating frame of reference. The PMSG's corresponding circuits In Figure 6., the direct and quadrature axes are shown. 6. The d-q reference frame's stator voltage equations, Vsd and Vsq, are the following:"

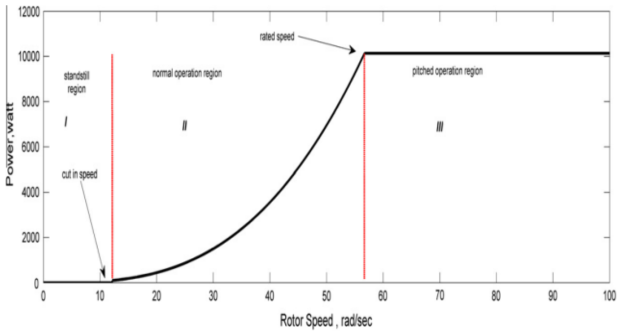

Figure 7: Turbine operating region

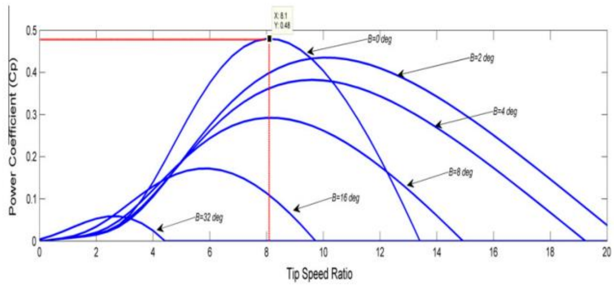

Figure 8: Cp–γ curves for different values of the pitch angle, β

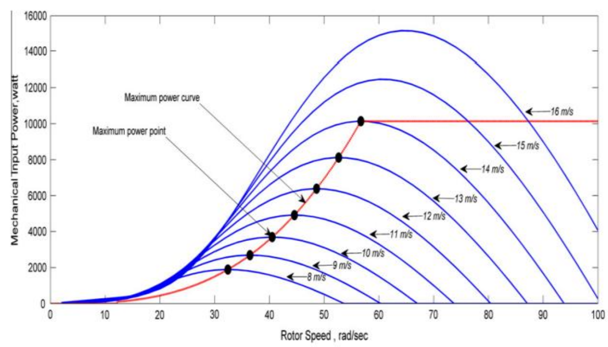

Figure 9: The power characteristic of the wind turbine used in this study

3.2 The Proposed Sensor Less Control Algorithm

The WECS is a complicated coupled system that converts kinetic energy into electrical [24]. The powertrain consists of a wind turbine, an electrical generator, a transmission system, and a number of

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inverters and converters [25]. Figure 9 depicts a WECS diagram, while depicts a WECS interconnection. The WECS generator might be a DFIG, a PMSG, or a caged induction generator. A PMSG was chosen for this study due to its high power density and direct-drive capability."

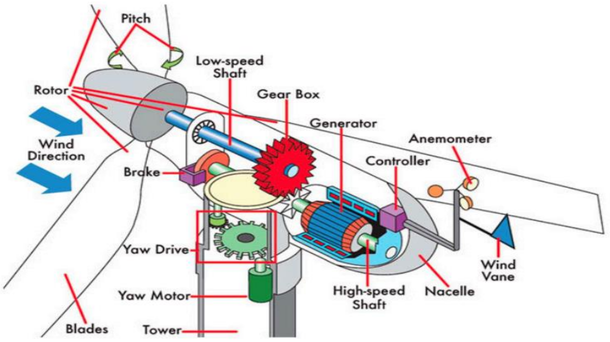

Figure 9: Components in a wind energy conversion system [26]

IV. SIMULATION RESULTS

The MATLAB/SIMULINK simulation results for a direct drive, multi-pole PMSG wind turbine are provided to validate the suggested DTC method. Table I lists the PMSG parameters. The PMSG power rate is 10 kW, and the sampling frequency of the PMSG control system is 0 I-ls. Wind turbine λ0p t is computed as 0.08; blade radius is R=2m; and air density is p =1.08 Kg/m3. (2) Models the turbine power coefficient, where C1=0.517, C2=1l6, C3=0.4, C4=5, C5=21, and C6=0.0068; the greatest value of Cp in this work is Cp mux=0.48 for /3=0 and 2=8.1. The bandwidths of the torque and stator flux hysteresis controllers are 5% of the rated torque and 2.5% of the stator rated torque, respectively.

Table 1: Parameters of the PMSG

Number of pole pairs	P	3
Magnet Flux Linkage	Ψm	0.98wb
Stator Resistance	RS	0.097Ω
d-axis inductance	Ld	0.021
q-axis inductance	Lq	0.012mH

The system dynamic performance is initially examined under wind speed variation in two phases, with wind speed starting at 9.6/mls and increasing to 12/ mls at 1.2 s. It then accelerates to 10.8/ mls in 1.8 seconds. Figure 10 depicts the At these two wind speeds, the electromagnetic torque changes. As demonstrated, the torque command varies as the wind changes and is used in the system as the rotating shaft speed MPP tracking torque reference Figures 11 and 12 also show The magnitude of the stator flux with its d-q-axis components and its d-q-axis current components, respectively."

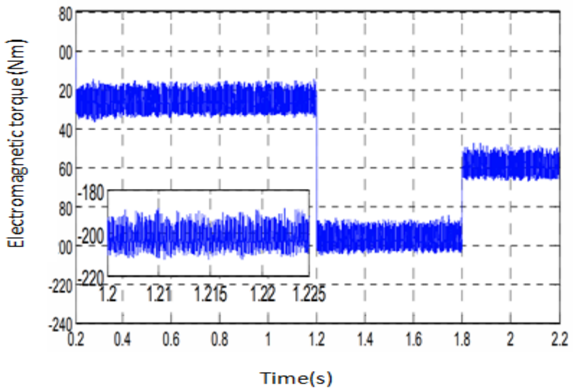

Figure 10: Shows the electromagnetic torque produced by the proposed DTC-MC

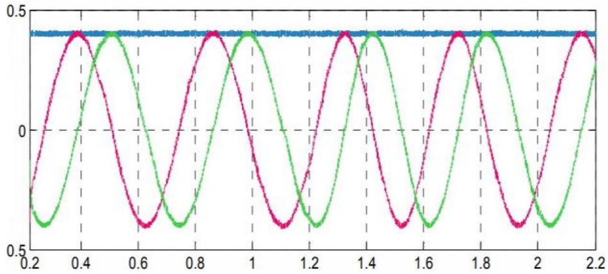

Figure11: Stator Flux using the proposed DTC-MC

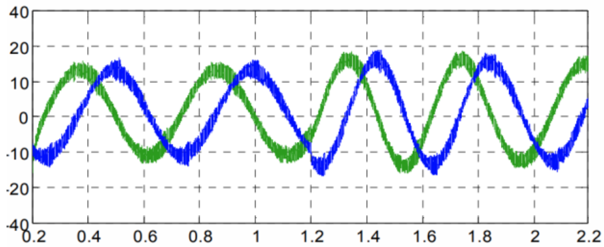

Figure 12:. Estimated d-q-axis PMSG Currents

Peak to peak maximum ripple torque in the proposed DTC-MC technique is always less than 20 Nm (10% of the rated torque), as shown in Figure 13. 9, and stator flux peak to peak ripple equals 0.02 V.S (5% of the rated flux), as shown in Figure 14. The d-q-axis stator flux components, IJfsd and IJfsd, demonstrating that DTC-MC achieves minimal distortion and well-adjusted stator flux.

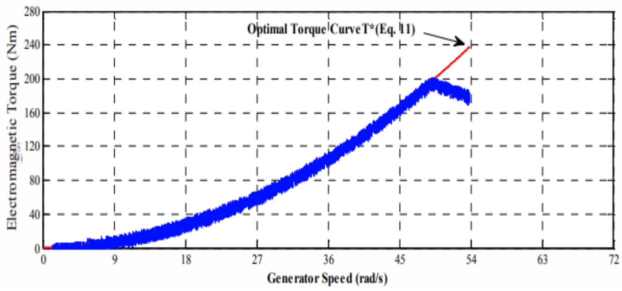

Figure 13: Torque trajectory of PMSG

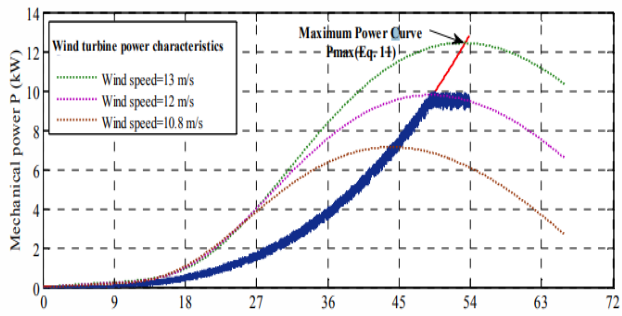

Figure 14: Mechanical power trajectory

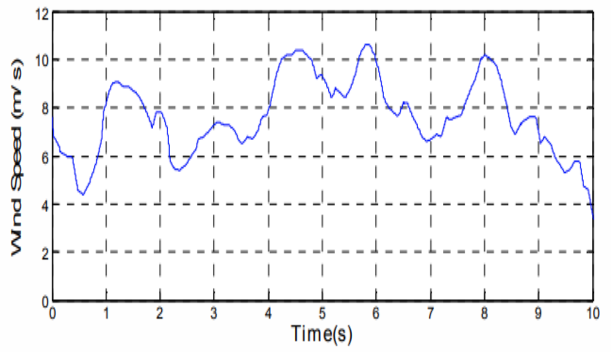

Figure 15: Wind speed (mls)

The trajectory of the predicted torque follows the ideal torque curve to harvest the most power from the wind.

In order to validate the performance of the maximum power control method, the trajectory of the mechanical power produced by wind turbine 170 as well as wind turbine power characteristics. As seen in Figure 15, the wind speed varies by 3m/s around the average wind speed of 7m/s. In such a case, the best torque reference is determined by (11). To improve generator efficiency, the stator flux magnitude is also calculated using a reference torque based on the maximum torque per ampere (MTP A) curve. The findings of analytical and material analysis modelling and simulation provide a number of output design parameters that are critical in the design of HSPMSG. However, in order to compute machine p, we must still estimate the values of output design parameters for the fundamental electrical model of a machine. All of the output design parameters are divided into eight machine elements or divisions. Among all the parts and sections, the "stator windings" contribute significantly to the fundamental electrical modelling of a machine. The parameters predicted for stator windings should not be taken too seriously, because the values anticipated for phase must be kept within a certain range in order to achieve excellent machine performance and efficiency."

V. CONCLUSION

This research developed a matrix converter-based DTC for driving wind turbine PMSG directly. Using the DTC-MC method, maximum power point tracking (MPPT) and higher system efficiency were obtained, as well as decreased flux and torque ripples. Implementing the DTC-MC method fulfils all of the benefits of the conventional DTC method; however, it uses a matrix converter, which is a single stage AC-AC converter between generator and grid, rather than back to back converters, which typically have high losses due to the bulky 171 reactive elements in the dc link. However, because matrix converters create greater voltage vectors than back to back converters, it is possible to reduce torque and flux ripples as well as switching frequency when utilising DTC with MC. The total DTC-MC method is resistant to changing machine settings and does not require a wind speed sensor or PI controllers. The efficacy of the DTC-MC method on a 10 kW direct-drive wind turbine PMSG was validated using simulation data obtained using MATLAB/SIMULINK .

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