

Modeling and Simulation of Wind Powered Permanent Magnet Direct Current (PMDC) Motor Using Matlab

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Abstract: This paper presents Modelling and simulation of PMDC motor fed by wind power through PMSG, Rectifier and Boost Converter. In wind energy conversion systems the interest is also focused on small units, used to provide electricity supply in remote areas that are beyond the reach of an electric power grid or cannot be economically connected to a grid. The system topology used in this paper is based on Permanent Magnet Synchronous Generator (PMSG) connected through diode bridge rectifier and boost converter to PMDC. With compare to AC application it will be cost effective to use DC appliances. It will reduce the cost of Inverter and increase the overall efficiency of the system.

Keywords: Wind Turbine, PMSG, Rectifier, Boost Converter, PMDC Motor

1. Introduction

Because of the soaring oil prices and environmental issues like global warming, pollution etc. the renewable energy considered as an option for generating clean energy technology. The wind generation system becoming more important renewable energy source, since it offers many advantages such as no fuel cost, no pollution, requiring little maintenance among the other renewable energy sources.

Wind power also offers a feasible solution to distributed generation for isolated communities where utility grids are not available. In such cases stand-alone wind energy systems can be considered as an effective way to provide continuous power to loads, the stand alone system often requires batteries to supply in exceeds the load demand and surplus can be stored in the batteries[1-2].

Synchronous machines are ac rotating machines that rotate at a speed proportional to the armature current frequency, in this case magnetic field created by the armature currents rotate at the same speed as that created by the field current on the rotor. The PMSG has widely found its application a high performance machine drive because of the ripple free torque characteristics and simple control strategies.

Compared to induction generator the PMSG has less rotor losses hence it is more efficient and some more features are as follows.

- Low reactance values
- High power density
- High peak torque capability
- It can resist repetitive torque pulsation of up to 20% of the rated torque

A major cost benefit in using the PMSG is the fact that a diode bridge rectifier may be used at the generator terminal since no external excitation current is needed. There is a

requirement of boost converter to increase the voltage so that the generated low voltage can be converted to high voltage and supply a load demand in low wind speed.

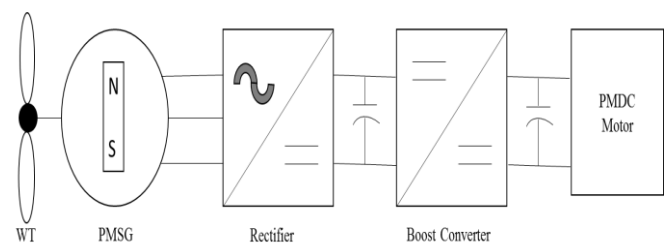


Figure 1: Block diagram of the wind powered PMDC motor

The system topology used in this paper based on a horizontal wind turbine driven PMSG connected through a diode rectifier and a boost converter to the PMDC motor shown in fig.1. The PMDC motor applications ranging from fraction to several horsepower application such as toy industries, water pump, air conditioner electric tools, vacuum cleaner, food mixer etc.

2. Modelling of The System

2.1 Wind Turbine

Assuming that the air temperature and pressure are constant, the power contained in the wind is proportional to the cube of the wind speed. The wind turbines harness the kinetic energy of the wind and convert it to mechanical energy which will be supplied to the rotate the rotor of an electric generator. The power in the air can be estimated as follows.

$$P_{wind} = 0.5\rho A v^3 \quad (W) \quad (1)$$

Where, ρ is the air density, A is the swept area by the blade (m^2) and v is the wind speed (m/s). In this simulation we assume $\rho = 1.225 \text{ kg/m}^3$

Due to the aerodynamic losses that depend on the rotor design and construction (number of blades, weight, stiffness etc.), the maximum power can be extracted from the wind is expressed as follows.

$$P_{mech} = 0.5 \rho A v^3 C_p \quad (2)$$

Where C_p is the power coefficient of the rotor or the rotor efficiency, in this paper following power coefficient analytical function is used to model the turbine:

$$C_p(\lambda, \beta) = c_1 \left(c_2 \frac{1}{\lambda} - c_3 \beta - c_4 \beta^x - c_5 \right) e^{-(c_6 \frac{1}{\lambda})} \quad (3)$$

Where λ is the tip speed ratio (TSR), it is the ratio between tip speed of the blade ($\omega_{blade} \cdot R_{blade}$) and wind speed (v). β is the blade pitch angle it will increase when high wind speed is occurred to turn out the blade from facing the wind hence there will be damage in wind generator can be avoided. The coefficient of c_1 - c_6 and x can be different for various turbines. They depend upon the wind turbine rotor and blade design. The parameter $1/\lambda$ is defined as:

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08\beta} \frac{0.035}{1 + \beta^3} \quad (4)$$

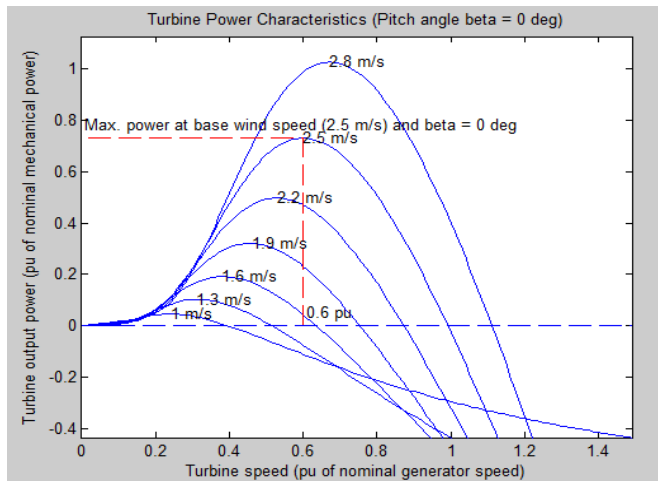


Figure 2: Wind Turbine Power Characteristics

The coefficients C_1 to C_6 are: $C_1=0.5176$, $C_2=116$, $C_3=0.4$, $C_4=5$, $C_5=21$, $C_6=0.0068$. For the value of pitch angle zero and TSR is 8.1 the maximum power coefficient 0.48 can be achieved. As scientist betz derived the betz limit is that theoretical value 59.3% of wind power can be extracted, but in case practical design maximum achievable C_p is between 0.4 and 0.5 for high speed two blade turbines and 0.2 to 0.4 for low speed turbines with more blades. Assuming the wind speed and blade pitch angle are constant, then power coefficient (C_p) becomes the function of rotor speed (ω_r) hence for each wind speed there is one rotor speed that will yield maximum power, making the system monotonic. The wind turbine characteristic shown in fig.2 hence the mechanical torque of the wind turbine can be calculated as follows.

$$T_{mech} = \frac{P_{mech}}{\omega_r} \quad (5)$$

Where T_{mech} is the mechanical torque in the rotor and P_{mech} and ω_r are rotor mechanical power and angular speed respectively.

2.2 PMSG

In PMSG power is not required for the field excitation purpose hence high efficiency is expected. as the electromotive force is proportional to the rotational speed generated. The equivalent circuit and phasor diagram for one phase are represented in fig.3

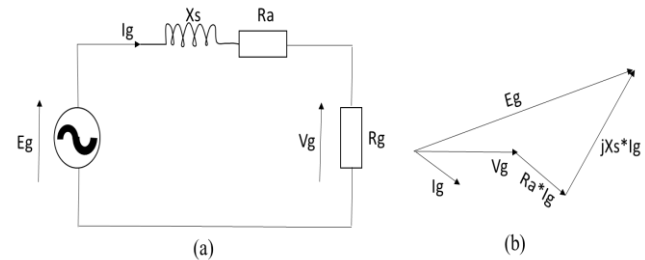


Figure 3: (a) Equivalent circuit per phase and (b) the phasor diagram for a synchronous generator

When line current of the generator is defined as I_g , the terminal voltage V_g of the generator is given by follows.

$$V_g = E_g - jX_s I_g - R_a I_g \quad (6)$$

Where R_a is the winding resistance per phase and X_s is the synchronous reactance per phase. From equation (6) we can estimate the line current as follows

$$I_g = \frac{E_g}{(R_a + R_g) + jX_s} \quad (7)$$

$$|I_g| = \frac{|E_g|}{\sqrt{(R_a + R_g)^2 + X_s^2}} \quad (8)$$

The generated output power is

$$P = 3|I_g||V_g|\cos\phi = 3R_g|I_g|^2 \quad (9)$$

$$P = 3R_g \frac{E_g^2}{(R_a + R_g)^2 + X_s^2} \quad (10)$$

2.3 Diode Rectifier

The diode rectifier is the simplest, cheap and rugged topology used in power electronics applications. The only drawback is that it is disabling to work in bidirectional power flow. The generator is connected with uncontrolled diode rectifier which converts ac power into dc as shown in fig.4 with having phase voltages V_a , V_b , V_c and inductance L_s .

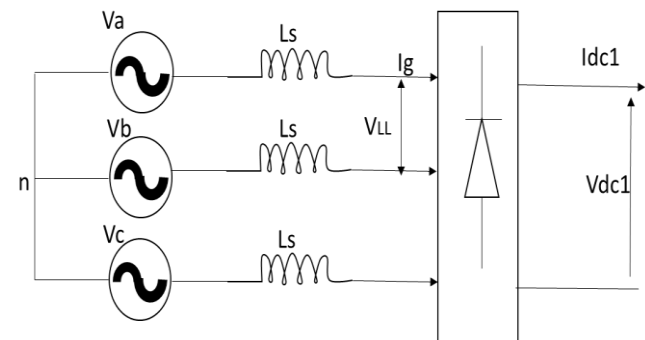


Figure 4: Three phase full-bridge diode rectifier

The mean value of the DC voltage is shown in the following.

$$V_{dc1} = \frac{3\sqrt{2}}{\pi} V_{LL} = 1.35 V_{LL} \quad (11)$$

Where, V_{dc1} is the output dc voltage, V_{LL} is the phase-to-phase voltage, X_s is the synchronous reactance and I_{dc1} is the output dc current.

In practice L_s is non-zero therefore, the current through the outgoing diode will decrease gradually and the current through the incoming diode will build up gradually. It is unable to control the dc voltage and creating current spikes on AC sides so, with a finite L_s there is a voltage drop in positive commutating diode group during the commutation interval so the average dc output voltage becomes,

$$V_{dc1} = 1.35V_{LL} - \frac{3}{\pi}X_s I_{dc1} \quad (12)$$

2.4 Boost Converter

The boost converter performs a function of converting the unregulated voltage which causes fluctuation in the line to regulated dc output with increase voltage level. It is used in switch mode power supply and in dc motor application. The circuit follows boost operation will be as given in fig.5

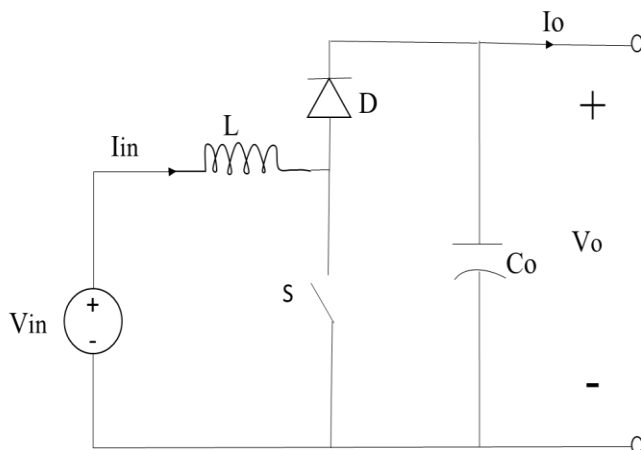


Figure 5: The boost (step up) converter

The circuit function is that when the switch is closed, the input voltage is applied across the inductor, causing the current through the inductor to ramp up which will increase the energy stored in an inductor. Opening the switch force the inductor current to flow through the diode and some of the energy stored in the inductor transferred to the output filter capacitor and the output load so the output voltage will be more than the input voltage [3-4]. Switch may be the IGBT, MOSFET, GTO etc. can be used which having their own power capability and switching speed as shown in table.1
 Table 1: Semiconductor devices with their power capability and switching speed

Device	Power Capability	Switching Speed
BJT	Medium	Medium
GTO	High	Low
THYRISTOR	High	Low
MOSFET	Low	High
IGBT	Medium	Medium

The relation between the input and output voltage and current of the boost converter is expressed by the following equations.

$$V_{in} = \frac{1}{(1-D)} V_o \quad (13)$$

$$I_{in} = (1-D)I_o \quad (14)$$

From equation (13) it can be seen that the voltage gained will always be more than one and that by controlling the duty cycle D we can regulate the output voltage.

2.5 PMDC Motor

A permanent magnet dc motor converts the electrical energy provided by a voltage source to the mechanical power provided by spinning the rotor by means of magnetic coupling. The field flux is produced by permanent magnet so the no external supply is needed and losses associated with the circuit can be reduced this will rise the efficiency. The motor voltage equation is given by

$$V = E + IR + V_b \quad (15)$$

Where, V is the applied voltage, E is the motor back e.m.f., I is the armature current, R is the armature resistance and V_b is the brushes voltage drop. The torque is produced by interaction between axial current-carrying rotor conductors and the magnetic flux produced by the permanent magnets. The equivalent circuit for the PMDC motor is shown in fig.6

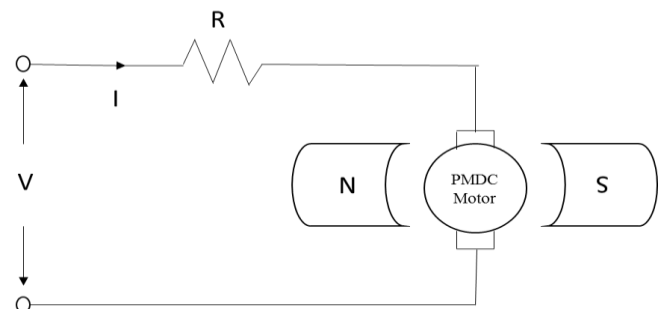


Figure 6: Schematic of PMDC motor

In PMDC motor, flux ϕ is constant

$$E = K_e N \quad (16)$$

$$\tau_e = K_t I_a \quad (17)$$

Where, $K_t = k\phi$ is called speed-voltage constant or torque constant. Its value depends upon the number of field poles armature conductors etc. the motor shaft torque can be expressed as

$$T = \tau_e - T_o \quad (18)$$

Where, T is the motor shaft torque, τ_e is the electromagnetic torque and T_o is the torque representing the mechanical (friction and windage) and iron losses.

If we assume armature losses and brush losses neglected so that motor shaft output power is expressed as $P = T\omega$, and it can also be written as

$$P = K_t(I - I_o)\omega \quad (19)$$

Using the fact that the $K_e = K_t$, the constants for the above model are obtained from the manufacturers rated data and I_o from no load test.

3. Simulation and Results

The overall simulation model of Permanent Magnet direct current (PMDC) motor power wind power is shown in fig.7.

The voltage from uncontrolled rectifier which fed through wind turbine generator is unregulated and it is in less value. It is increased to a required level by means of boost converter. In this Simulink model we used wind turbine block from library with having base wind speed is 2.5 m/s, base generator speed is 0.6 p.u. and pitch angle zero. The permanent magnet synchronous generator block used for rating nominal mechanical power of 200W and having stator phase resistance $R_s=0.18\Omega$ and armature inductance $L_a=0.000835H$ and $p=4$. For the measurement of 3-phase generated power, the three phase measurement block used from Simulink library. Universal diode bridge rectifier for the conversion of ac to dc is used with having $R_{on}=0.001$ and boost converter is design using the Mosfet as a switch and other values are $L1=0.005H$, $C1=C2=0.000090F$.

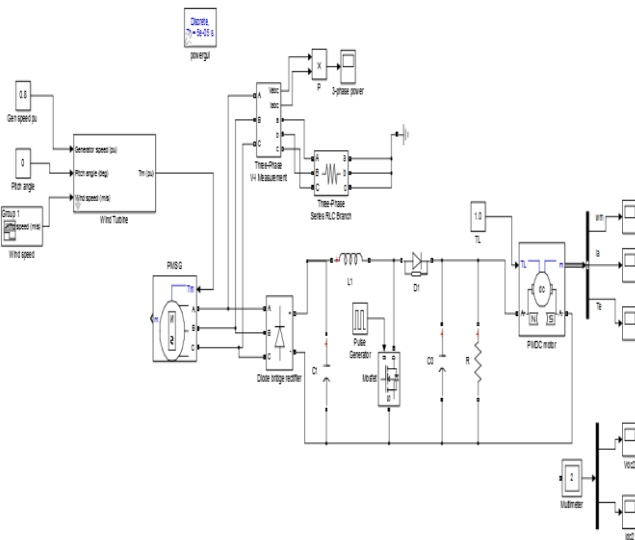


Figure 7: Simulink model of wind powered PMDC motor

Then the output of boost converter is fed to the PMDC motor having armature resistance and inductance is 0.6 ohm and 0.0012 H respectively. The Simulink model is simulated for 0.2 sec using solver method ode45 backward Euler and results are plotted as follows. Fig.8 shows the wind speed profile for the Simulink model is simulated with having the span of 0.2 sec.

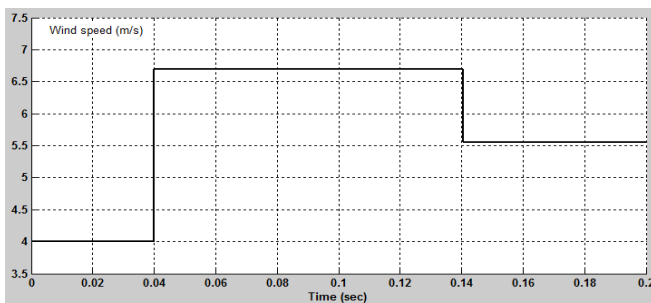


Figure 8: wind speed profile

The generated three phase power output from PMSG is shown in fig.9

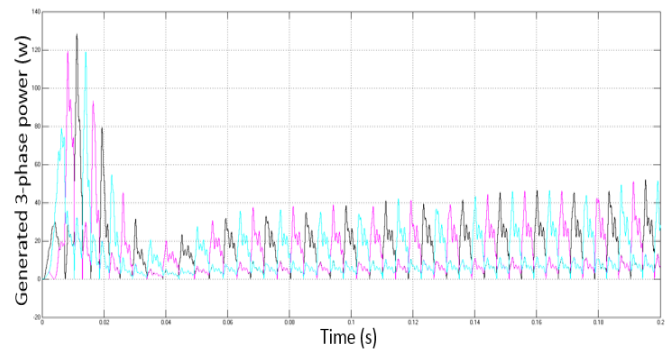


Figure 9: The generated 3-phase power from PMSG

The boost converter output voltage and current which boost up to 2 to 2.5 times the input voltage and current is shown in fig. 10 and 11 respectively

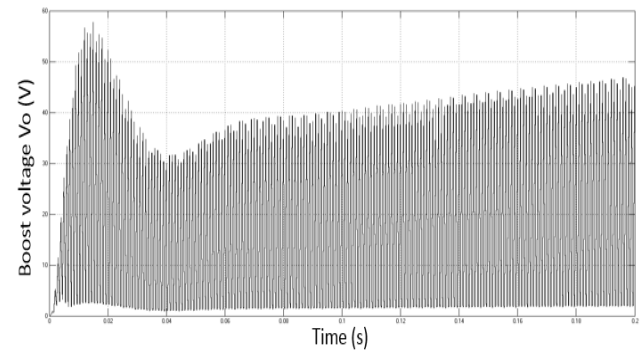


Figure 10: Boost converter output voltage

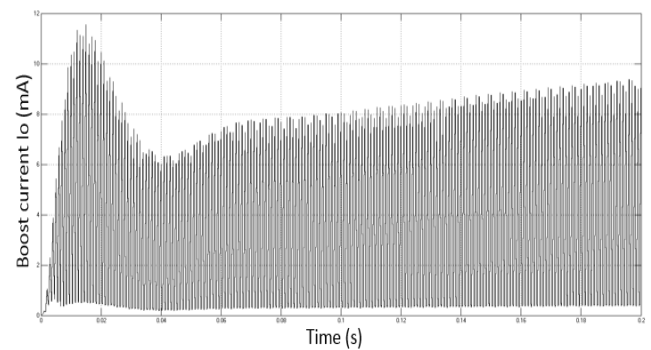


Figure 11: Boost converter output current

And finally the PMDC motor speed, armature current and electromagnetic torque variation with time are shown in fig.12, 13 and 14 respectively.

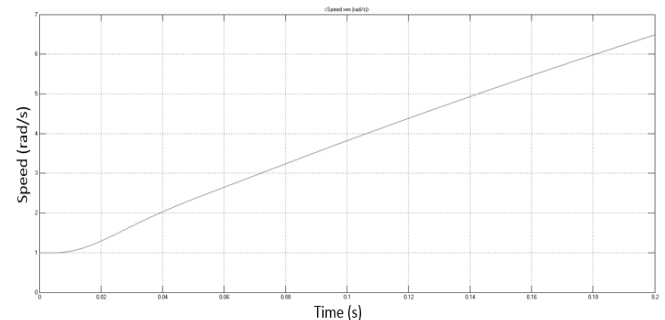


Figure 12: PMDC motor speed variation with time

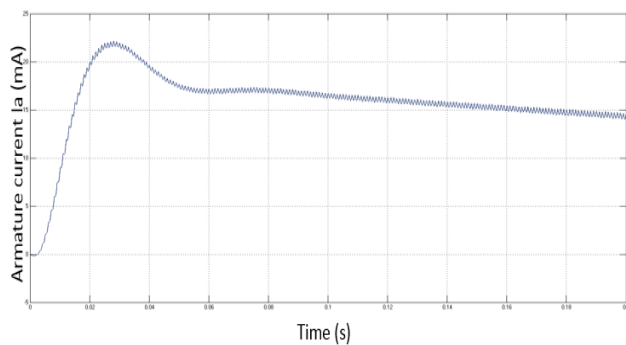


Figure 13: PMDC armature current variation with time

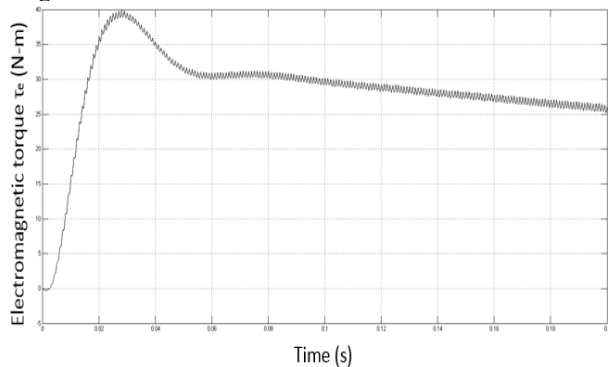


Figure 14: PMDC motor electromagnetic torque variation with time

4. Conclusion

This paper presents a modelling and simulation of wind powered PMDC motor. The above simulation and results have been shown that variation of PMDC motor parameter and efficiency can be improved. This system can be extended for the application of water pumping with the advantages of PMDC motor and inverter cost will be reduced if we used PMDC motor directly to run Centrifugal pump.

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