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Optimal Torque Control Strategy for A Variable Speed Wind Turbine

P. Lakshmi Narayana* Srinivasa Kishore Babu Y* and Tripura Pidikiti**

Abstract : In this paper, an optimal torque control strategy for a variable speed wind turbine using PMSG for a standalone system is presented. By using control strategy for a generator side converter maximum power is extracted. This system is featured with output voltage controller as well as frequency controller. The system developed is suitable to handle variable load. A dump load resistor is used to dissipate the excess of power. Basically a boost converter is used to improve the dc-link voltage of this system. The results shows that the controller is successfully extracted the maximum power under variable load conditions also.

Keyword : Variable speed wind turbine, PMSG (permanent magnet synchronous generator), Diode bridge rectifier, DC-DC converter (Boost converter), Voltage and frequency controller.

1. INTRODUCTION

Basically in olden days fixed speed wind turbines are used as the years passed on variable speed wind energy is introduced which is more advantageous than the fixed speed wind turbines. Such as maximum power point tracking technique can be used, more efficient, power quality [1]. We can eliminate gearbox according to our requirement [2]. Because of the presence of gearbox regular maintenance should be done.

Now-a-days PMSG had much attention in case of wind energy conversion systems because of its advantages. PMSG is self excited, more efficient with high power factor, Direct driven system and diode bridge rectifier can be used in case of PMSG only .Optimal torque control strategy is used to achieve optimal wind energy[2]. Some of the WECS used anemometer based strategy which is more costly[3]-[7]. Mostly the control strategy based on anemometer based technology but because of those wind sensors cost of the system increases, so in this paper the control strategy is developed without using the wind sensors to reduce the cost of the system.

The ZDC control strategy is used in PMSG, in this control strategy making the direct axis current to zero to linearize the relation between the electromagnetic torque and the stator current from this we can extract the maximum power. Control strategy is used for a generator side converter by using a single active switch to improve the output of the rectifier.

Load side converter is used to control the output voltage of the inverter and to control output frequency of the system for variable load condition. Therefore to control the output voltage and frequency a vector based control strategy is used in this standalone system.

Dump load resistance is used in this system to dissipate the excess power generated in the dc-link along with a controller by using a single IGBT switch by generating pulses.

* PG Scholar, Assistant Professor, EEE Department, JNTUK University College of Engineering Vizianagaram.
** Assistant professor, EEE Department, K L University, Vaddeswaram, Vijayawada E-mail: p.l.narayana238@gmail.com.

2. FORMULATION OF THE PROBLEM

Basically the input energy is wind energy which is in the form of the kinetic energy which is converted into required mechanical energy with the help of wind turbine as follows

The power captured by the wind turbine is

$$p_t = 0.5 * \rho * A * c_p * (v\omega)^3 \quad (1)$$

$$= k_{opt} * (\omega_{m\_opt})^3 \quad (2)$$

$$k_{opt} = 0.5 * \rho * A * c_{p\_opt*} \left(\frac{r}{\lambda_{opt}} \right)^3 \quad (3)$$

Therefore, from the above equation torque can be derived

$$T_{m\_opt} = k_{opt} * (\omega_{m\_opt})^2. \quad (4)$$

Output electromagnetic torque of PMSG is given below

$$T_e = 1.5 * p * [\lambda_{iq} + (L_d - L_q) * i_d * i_q] \quad (5)$$

Our system is non-salient pole PMSG hence direct axis and quadrature inductances are same.

Therefore equation-5 is modified as shown below

$$T_e = \frac{3}{2} p_n \Psi f_{iq} \quad (6)$$

$$w_e = p_n w_m \quad (7)$$

Output voltage equations of the permanent magnet synchronous generator

Direct axis voltage of PMSG is

$$v_{ds} = (R_s + p.L_s).\ i_{qs} + w_e L_{dids} + w_e \Psi f \quad (8)$$

Quadrature axis voltage of PMSG is

$$v_{qs} = (R_s + p.L_d).\ i_{ds} - w_e L_{qiqs} \quad (9)$$

Output voltage of diode bridge rectifier is given below

$$v_d = (3 * \sqrt{3} / 3.14) * V_m \quad (10)$$

Basic equation of full power converter

$$v_d * i_d * 1.5 = v_{ds} * i_{dc} \quad (11)$$

From this we can calculate the rectifier output current.

Baically active switch used is boost converter to improve the voltage levels of the system, the output voltage of boost converter is given below

$$v_o = v_{dc}/(1 - d) \quad (12)$$

The inverter used is pwm based converter, hence here modulation index plays a crucial role

$$v_{ac} = m_a * 0.5 * v_{dc} \quad (13)$$

Direct and quadrature-axis load voltage can be calculated as shown below

$$v_{dg} = v_{d1} - R_f * i_{dg} - L_f * \frac{di_{dg}}{dt} + \omega L_f i_{qg}$$

$$v_{qg} = v_{q1} - R_f * i_{qg} - L_f * \frac{di_{dg}}{dt} + \omega L_f i_{dg} \quad (14)$$

The active and reactive power of the load can be calculated as shown below

$$p = 1.5 * (v_d * i_d + v_q * i_q)$$

$$Q = 1.5 * (v_d * i_q + v_q * i_d) \quad (15)$$

3. SOLUTION OF THE PROBLEM, NUMERICAL DISCUSSION AND ANALYSIS

The analysis is conducted to generate electricity and to distribute it to load. Using the physical parameters as given in reference [1] are taken as

Density of air = 1.225kg/m^3, Area swept = 1.06 sq.mm, Radius of the turbine blade = 0.581 meters, Optimum coefficient = 1.67*10^-3, Base wind speed = 12 m/sec, No. Of poles = 10, Rated speed = 153 rad/sec, Rated current = 12 Amps, Armature resistance = 0.425 ohms, Magnetic flux linkage = 0.433 wb, Rated torque = 40 N-M, Rated power = 6 KW, Direct axis inductance = 0.0084 H, Quadrature axis inductance = 0.0084 H, Moment of inertia = 0.01197, Friction co-efficien *t* = 0.001189.

The basic parameters of the turbine and generator are tabulated above. The power electronic converters are used and their control strategies are implemented in the simulation with the sampling time of 20 micro seconds. PI-controller is designed using Nicholas-Ziegler method.

Here basically used wind turbine is of variable speed wind turbine which changes its speed with respect to time. Initially it is at 10 m/sec then it rises to 12 m/sec then it drops to 9 m/sec and again raised to 10 m/sec.

Fig-1 says how the parameters of turbine and PMSG changes with respect to wind speed. Fig-1(*a*) explains the output torque of the turbine how it varies with respect to speed of the wind turbine. Fig-1(*b*) represents angular speed of the PMSG, Fig-1(*c*) shows the electromagnetic torque of the generator, we should recognize that the electromagnetic torque always follows the reference torque, Fig-1(*d*) shows that the dc-power of the system.

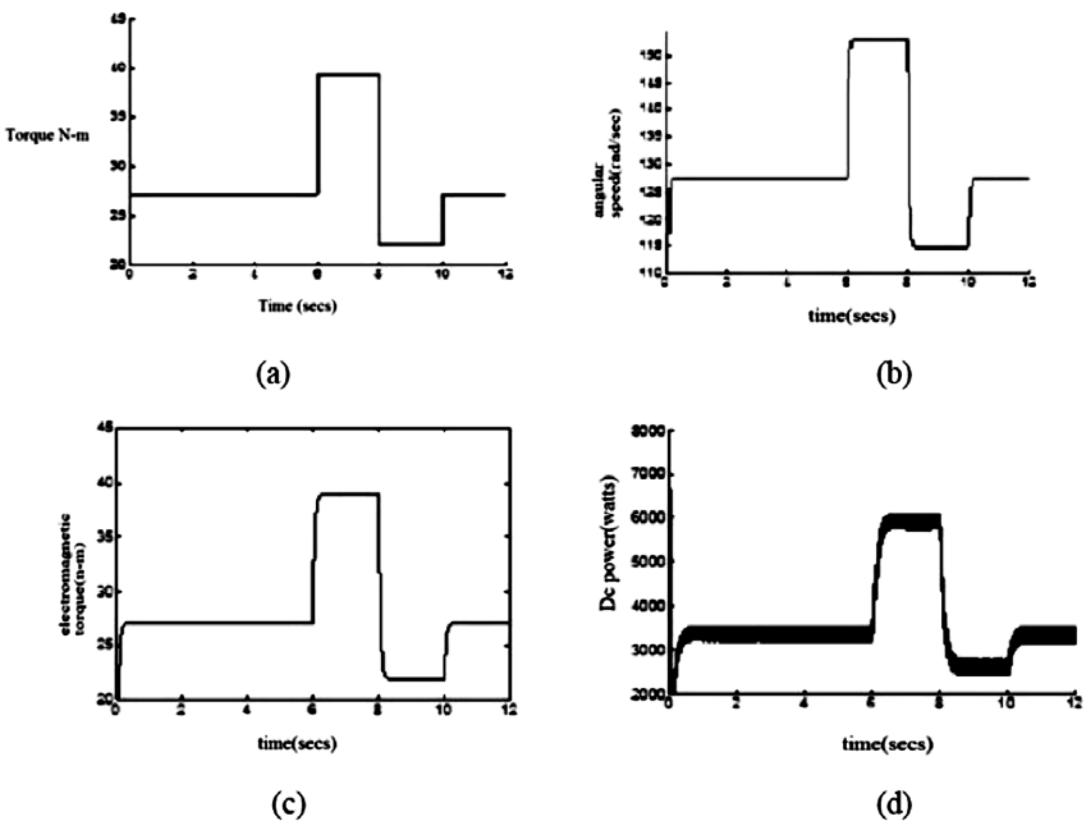

Fig. 1. (*a*) Turbine torque (*b*) angular speed in rad/sec (*c*) electromagnetic torque (*d*) dc power.

Fig-2(*a*) shows that the load voltage of the system in per unit, Fig-2(*b*) shows the line current of the system in per unit, base values of the system is considered according to the rated values of the system. Fig-2(*c*) represents the rms voltage of the system similarly Fig-2(*d*) represents rms current of the system. Fig-2(*e*) shows the modulation index of the pwm inverter, all the above outputs are obtained when the load is constant.

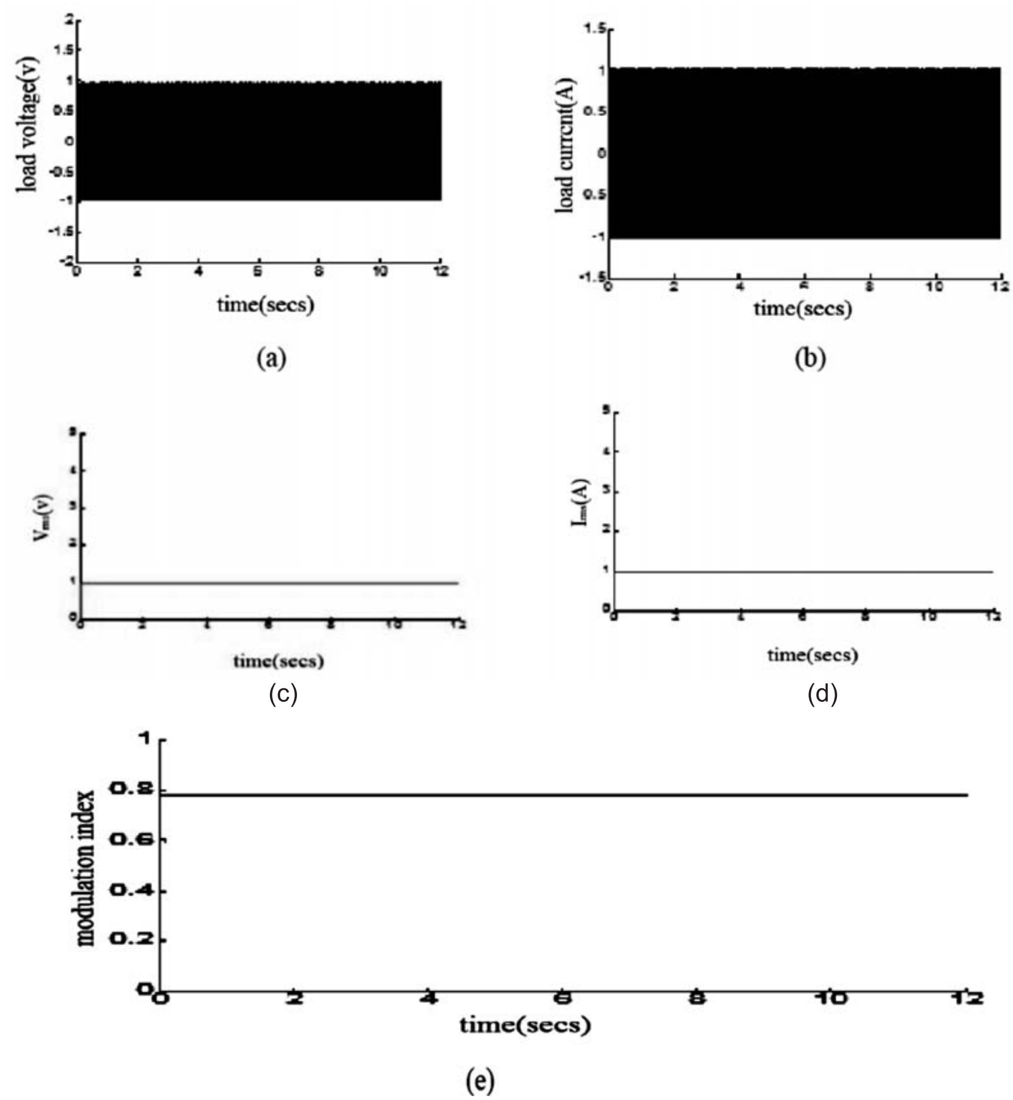

Fig. 2. **(*a*) Load voltage p.u, (*b*) load current p.u, (*c*) load voltage rms, (*d*) load current rms, (*e*) Modulation index.**

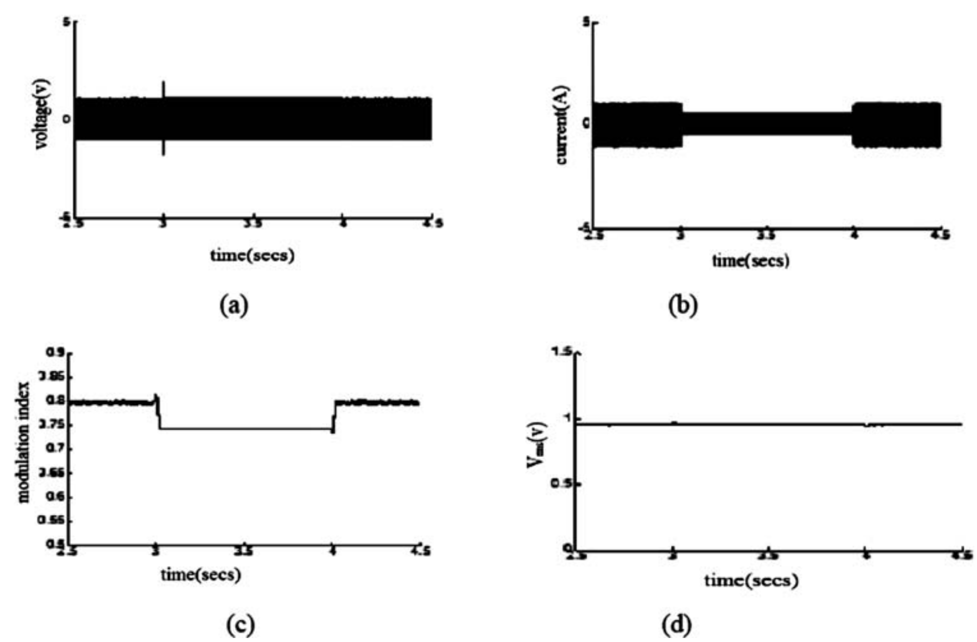

Fig. 3. **(*a*) Load voltage in per unit, (*b*) Load current in per unit, (*c*) Load voltage in rms, (*d*) Modulation index.**

Fig-3 shows how the outputs of the system changes when load is switched to 50% from 3-4 secs and again switched to full load at 4 secs. Fig-3(*a*) represents the load voltage and we can recognize the transients obtained when the load is switched. Fig-3(*b*) represents the load current in per unit and we can observe the current is reduced to 50% when the the load is switched to 50% and again reached to normal position when load switched to full load, Fig-3(*c*) shows the modulation index of the pwm inverter, Fig-3(*d*) shows the rms value of the load voltage.

4. CONCLUSION

Optimal torque control strategy for a variable speed wind turbine using PMSG is presented in this paper. Control strategy for a rotor side converter is implemented to extract the maximum power. In the same manner vector control strategy is implemented to load side converter to maintain the load voltage and frequency constant. Basically, controller is used to maintain the load voltage and frequency during the constant load as well as variable load. These proposed strategies can be used in islands, hilly areas, remote locations where grid accessibility is not available.

5. NOMENCLATURE

p_t		Turbine output power,
ρ		Density of air,
A		Area swept by wind turbine,
c_p		Power co-efficient,
v_ω		Wind speed,
k_{opt}	=	Optimum power coefficient,
ω_{m_opt}		Optimal angular speed,
r		Radius of wind turbine,
C_{p_opt*}		Optimal power co-efficient,
λ_{opt}		Optimal tip speed ratio,
T_e		Electro magnetic torque,
L_d		Direct axis inductance,
L_q		quadrature axis inductance,
i_d		Direct axis current of PMSG,
i_q		Quadrature axis current of PMSG,
p		Number of poles,
p_n		Number of pole pairs,
λ_{iq}		Magnetic flux linkage,
v_{ds}		Direct axis PMSG voltage,
v_{qs}	=	quadrature axis PMSG voltage,
R_s		Stator resistance,
L_s		Stator inductance,
i_{ds}		Direct axis stator current,
i_{qs}		Quadrature axis stator current,
v_{dc}		Rectifier output voltage,
v_s		*rms* voltage
i_{dc}		Rectifier output current,
v_o		Chopper output voltage,

d	Duty cycle,
m_a	Modulation index,
L_f	Filter inductance,
v_{dg}	Load side direct axis voltage,
v_{qg}	Load side quadrature axis voltage,
i_{dg}	Load side direct axis current,
i_{qg}	Load side quadrature axis current.

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