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DESIGN OF OPTIMUM TORQUE METHOD FOR TRACKING THE MAXIMUM POWER POINTOF VARIABLE SPEED WIND TURBINE

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ABSTRACT

Optimum torque based maximum power point tracking (MPPT) method is widely used in high power wind turbines. In this paper a proposed optimum toque method is developed and applied to the wind turbine system. The diversity of maximum power point tracking methods are developed, all those methods are vary in implementation, cost, complexity and faster tracking speed, in all of that optimum torque is the more accurate for the variable speed wind turbines. This optimum torque method involves a generator torque control system and it is responsible for tracking the reference torque given by MPPT control law. Initially optimum torque method is developed and then, proportional integral controller is used. Numerical simulations are carried out in MATLAB platform and the obtained results are of two types, the first one represents the step change in wind velocity and second represents the turbulent wind velocity.

KEYWORDS: Optimum torque, Maximum power point, Variable speed wind turbine (VSWT), Proportional integral (PI) controller.

1. INTRODUCTION

Wind energy has been one of the fastest growing energy sources in the world. In present days the wind power generation is increased because of, wind energy is plentiful, renewable, widely distributed& clean. Wind turbine can capture and convert maximum energy from the wind. Modern wind turbines are more reliable, efficient, cost effective and the pollution free when compared with the other resources.

Modern wind turbines majorly fall in to two types, horizontal axis and vertical axis. Most large modern wind turbines are horizontal-axis turbines. A variable speed wind turbine rotational speed must be adjusted when the wind speed varies but fixed speed wind turbine doesn't have arrangement of mechanical parts for the adjustable speed. VSWT have low noise level and increased energy capture when compared to the fixed speed wind turbine (FSWT). Generally VSWT system uses two-mass model of the drive train shaft.

Reported MPPT method involves different controlling techniques, namely, Tip speed ratio control (TSR), optimum torque (OT), Perturb and observes (PO) method. These two TSR &PO methods are fail to track the MPP during parameter variations caused by changes in air density, aging and blade surface contamination. OT method is suitable for variable speed wind turbines and in this method the energy gain also depends on the level of turbulence.

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2. VARIABLE SPEED WIND TURBINE SYSTEM

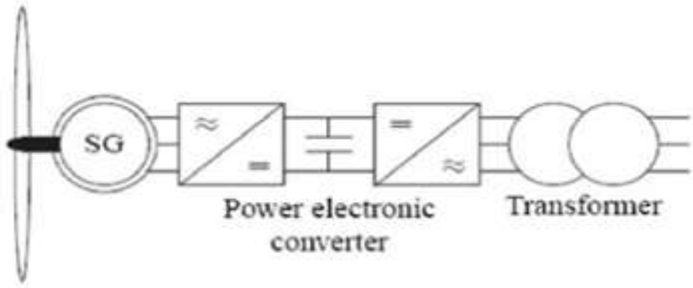

Fig.1.The configuration of the system considered.

The system considered here consists of a wind turbine with an electric generator as shown in fig.1. The generator output is connected to the grid through a power electronic converter. Generally, permanent magnet synchronous generator(PMSG) have advantages of higher efficiency and reliability. PMS generators are designed with multiple poles which imply that there is no need of gear box which further improves turbine efficiency and power output.

3. OPTIMAL TORQUE MPPT METHOD

As a function of aerodynamic efficiency C_p, the mechanical power $P_t$of the wind turbine is expressed as

$P_t = \frac{1}{2}\rho A v^3 C_p(\lambda,\beta)$(1)

$$\lambda = w_t R / v$$

Where

v = wind velocity (m/s)

ρ=air density (kg/m^3)

A = swept area of the blade (m^2)

w_t = rotational speed of the turbine (rpm)

R = radius of the blade(m)

λ= tip speed ratio

β = pitch angle

The basic power equation of the turbine (1) is modified to obtain the aerodynamic torque is given by

$$T_t = \frac{1}{2}\rho C_p(\lambda)\pi R^5 w_t / \lambda^3$$

For any wind velocity below rated value, the turbine torque that corresponds to the maximum power specified by

$$T_{to} = K w_t^2 \quad (2)$$

Eq.(2) is basic for the optimul torque MPPT and is used to set the reference value generator torque T_g , for the electromagnetic torque. The control law of the conventional optimal torque MPPT is given by

$$T_{g*} = K w_g^2 \qquad (3)$$

In steady state, under constant wind speed, the OT method ensures that the T_g becomes equal to the T_t and the system reaches maximum power point. If a positive wind perturbation is occur, the generator speed increases along the trajectory and reaches new maximum point and generator speed decreases with negative wind perturbation.

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Torque equation of PMSG:

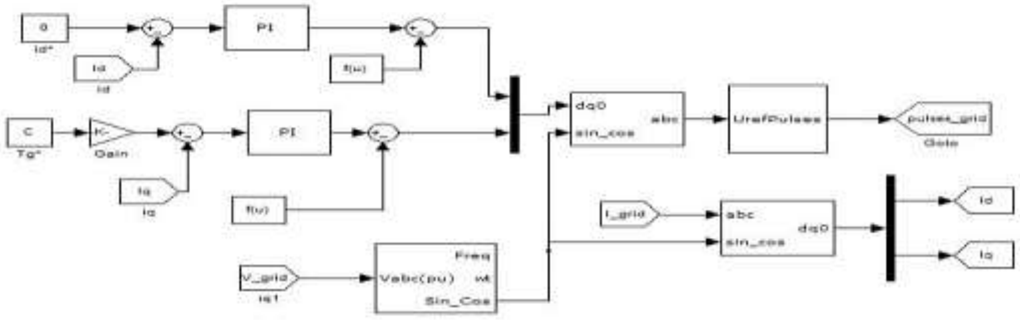

Fig.2. PMSG torque control method

Fig.2. represents the torque controlling method of the permament magnet syncronous genrator. This is used for tracking the reference torque given by the MPPT control technique. The angle between the magnetic axes of thr rotor and phase coil, is used to convert machine currents into rotor reference frame. From this i_q and i_d values are identified. For constant torque angle control technique i_d is to be zero and i_q should be proportional to the torque.The electromagnetic torque equation is

$$T_g = \frac{3}{2} P\varphi i_q = K_t\, i_q$$

Where

P is the nunber of pole pairs, φ is flux density, i_q is quadrature axis current component.

Two mass shaft model:

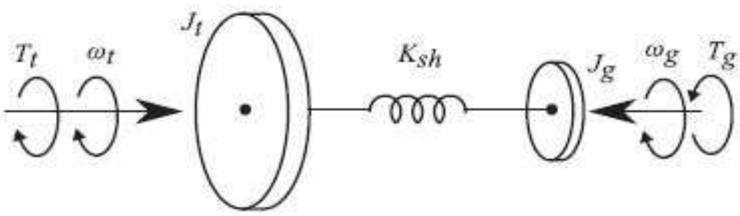

Fig.3. Two mass drive train model

Fig.3. represents the two-mass model of the shaft, considering separateinertias of the turbine and generator, connected by a flexible shaft. The state model of the drive train is given by

$$\begin{bmatrix} w^{\cdot}t \\ w^{\cdot}g \\ \theta^{\cdot}sh \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{Ksh}{Jt} \\ 0 & 0 & \frac{Ksh}{Jg} \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} wt \\ wg \\ \theta sh \end{bmatrix} + \begin{bmatrix} \frac{1}{Jt} & 0 & 0 \\ 0 & -\frac{1}{Jg} & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Tt \\ Tg \\ 0 \end{bmatrix} \qquad (4)$$

Where K_{sh} is the stiffness constant, T_g , J_g is the generator torque and inertia, θ_{sh} represents the torsional displacement of the shaft. T_t and J_t represents the turbine torque and inertia.

Starting from initial conditions $T_t = T_g = T_t$

$$w_t = w_g = w_{go}$$

By appling laplace to the Eq.3. under intial conditions,

$$T_{g*}(s) = 2Kw_{g0}w_g(s) = T_g(s)$$

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Eq.3. is used in single mass drive train models, when coming with the two mass model a possible realization would require a aaditional correction componet to the reference generator torque,there by quickening the MPPT process. This is obtained by augmenting T_{g*} with the net accelerating torque,coupled with a suitable weight, a, as From fig. 3, the accelerating torque of the turbine can be expressed as

$$T_t - T_g = T_a$$

$$T_a = J_t \frac{dwt}{dt} + J_g \frac{dwg}{dt}$$

By using second and third rows of state space model (4), the above equations can be written as

$$T_a = J_t \frac{d}{dt}\left(wg + \frac{Jg}{Ksh}\frac{d^2wg}{dt^2} + \frac{1}{Ksh}\frac{dTg}{dt}\right) + J_g \frac{dwg}{dt}$$

Considering zero intial conditions to the above equation T_a can be expressed as

$$T_a = s\left((J_t + J_g) + \frac{JtJg}{Ksh} \right) w_g(s) + \frac{Jt\, s^2}{Ksh} Tg(s)$$

From the foregoing discussion on the relative time scales of the shaft speed and generator torque is expressed as

$$T_a = G_1(s)\, w_g(s) + G_2(s)\, T_g(s)$$

The above trnasfer function is improper, because it does not offer a realizable function of T_g^*. Hence a function of H(s) is considered which is third degree polynomial

$$H(s) = \left(1 + \frac{s}{a2\varrho}\right)\left(1 + \frac{s(\zeta)}{a1\varrho} + \frac{s^2}{a1^2\varrho^2}\right)$$

The first term in H(s) ensures a band-limited differentia-tor component, while the second introduces a complex or real pole-pair, based on the damping coefficient, ζ. A un damped resonator (ζ = 0) is not considered to avoid internal instability. The proposed control law for the reference generator torque is obtained as

$$T_{g*} = Kw_g^2 - a\, G(s)\, w_g(s)$$

G(s) is third degree polynomial which is transfer fuction

$$\frac{1}{\left(1 + \frac{s}{a2\varrho}\right)\left(1 + \frac{s(\zeta)}{a1\varrho} + \frac{s^2}{a1^2\varrho^2}\right)}$$

where
a1=0.463
a2=0.292 and
ϱ=0.0051
ζ = 0.59

4. CONTROLLERS

A controller is a device which is used to modify the error signal and prodece a control signal and it modifies the transient response of the system. There are different controllers are present

i. Proportional controller

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This controller produces a control signal, proportional to the error signal.

ii. Integral controller
It produces a control signal which is integral of the error signal.

iii. Proportional integral controller
This controller performs both the actions of proportion and integral controllers. It produces a output signal which is proportional and integral to the error signal.

iv. Proportional derivative controller
It produces a control signal which is proportional plus derivative of the error signal.

v. Proportional integral derivative controller
It performs all three actions of proportional, integral & derivative of the error signal.

PI Controller:

The proportional controller amplifies the error signal and increases the gain of the system. This leads to steady state tracking accuracy, decrease in sensitivity of the system to parameter variations, disturbence signal rejection and stability. The main drawback of this controller is that it produces a constant steady state error and negative impact on the speed of the response, overall stability of the system. By augmenting the optimum torque with the PI controller will gives the steady state results .

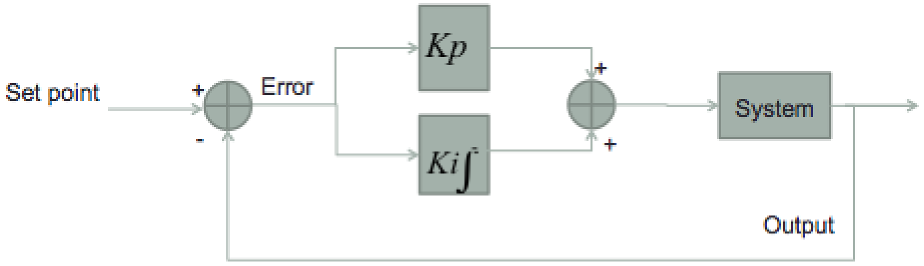

Fig.4. Basic diagram of PI controller

PI controller introduces a zero in yhe system and increases the order by one. This results in a reducing the steady state error due to integral acontroller. In the figure K_p and K_i are the proportional and integral constants and corresponding values are taken as 0.1 and 1. A combintion PI and proposed controlling technique are used to get the desired outputs.

5. SIMULATION RESULTS

Simulation results are presented in two subsections, the first deals with the step change in wind speed and second deals with turbulent wind speed which is realistic.

Step wind speed change:

A positive step in the wind speed from 9 m/s to 10 m/s is applied at 30 s and the reverse step applied at 70 s. The corresponding simulation results are shown in the fig.5. Before and after the wind speed steps, both algorithms ensure that C_p attains its maximum value 0.45 in steady state.

Fig.5.a.Step wind speed

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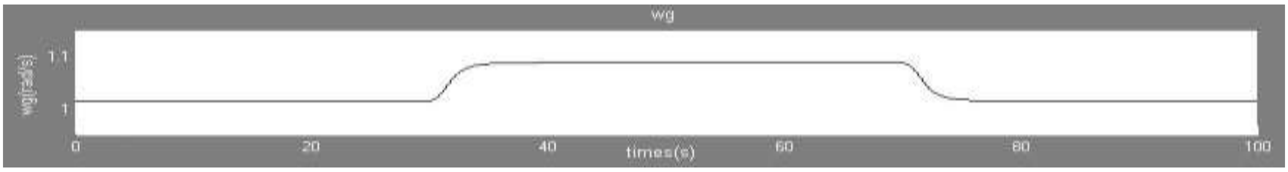

Fig.5.b.Turbine speed with OT control law

Fig.5.c.Turbine speed with PI controller

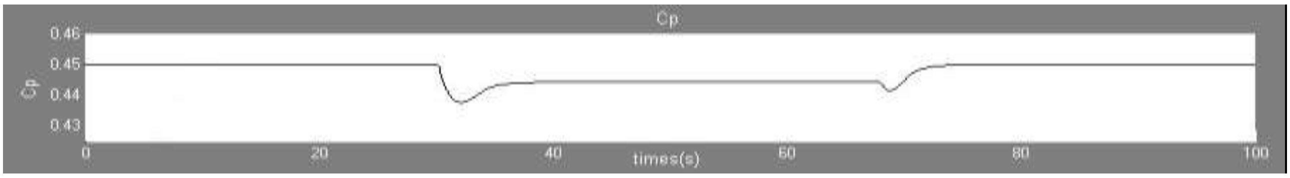

Fig.5.d.C_p profile with OT control law

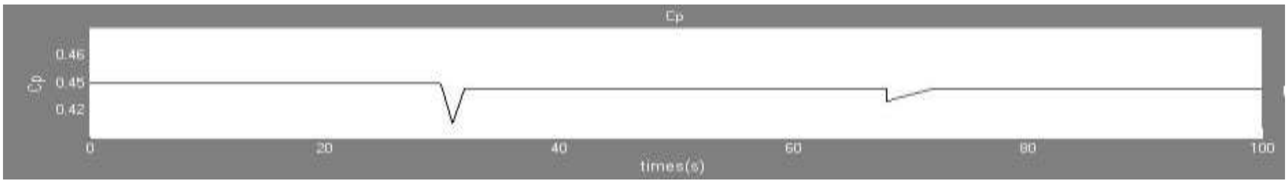

Fig.5.e. C_p profile with PI controller

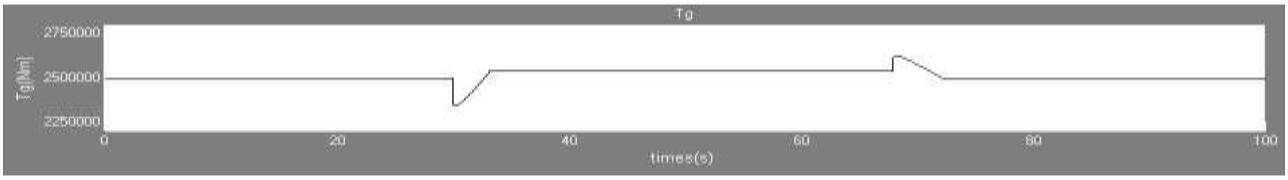

Fig.5.f. Electromagnetic torque with OT control law

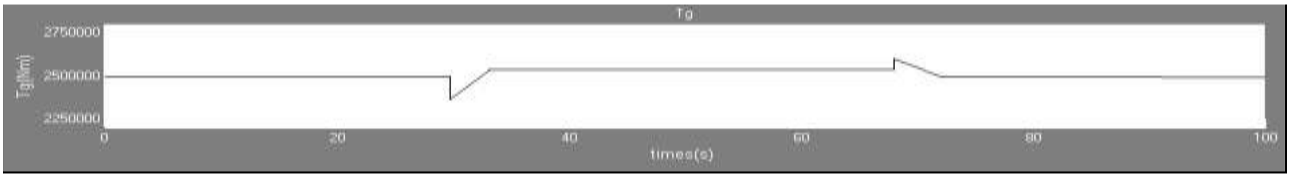

Fig.5.g. Electromagnetic torque with PI controller

Turbulent wind speed:

To test the performance of these algorithms under realistic turbulent conditions, a wind profile with stochastic variations around an average wind velocity is generated. Simulation results for the turbulent wind speed are shown in the fig.6.

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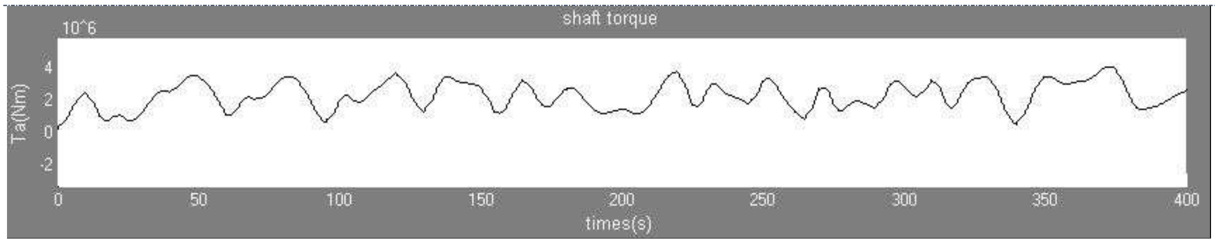

Fig.6.a. Turbulent wind speed

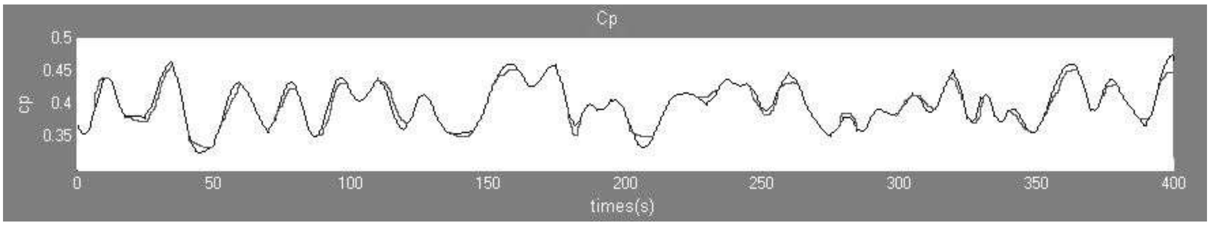

Fig.6.b. C_p profile

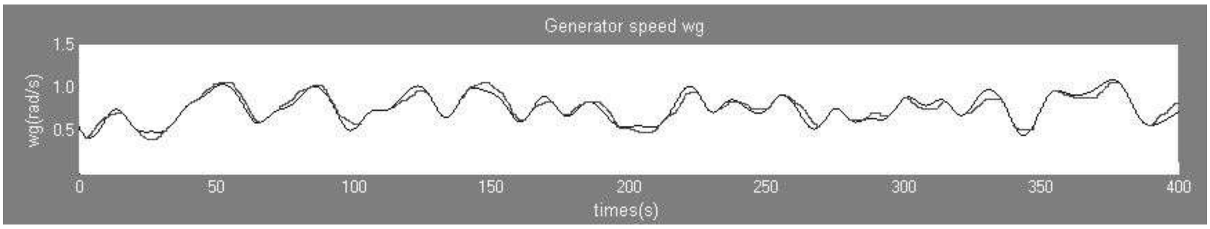

Fig.6.c. Generator wind speed

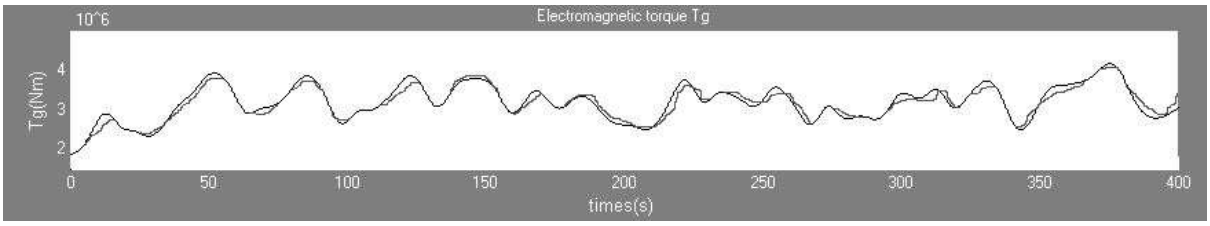

Fig.6.d. Electromagnetic torque

6. CONCLUSION

This paper focuses on neglected aspect of shaft flexibility in large wind turbines, in the context of MPP tracking performance. A control laws is developed with torque reference frame. All results are validated through simulation of the system and a realistic situation of stochastic wind velocity profile was considered. All units are to be taken in per unit system. For step input wind speed there is steady state performance occurring in presence of PI controller but coming to the turbulent speed changes there is no such variations occur. Only negligible amount of variation occurs with the PI controller. In future scope different controllers are used in place of PI controller and controlling techniques are varies depend on the type of systems (generator, wind turbine) used.

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APPENDIX:

PMSG PARAMETER & WEIGHTING FUNCTIONS

PMSG Parameter	Value
Rated generator power	5MW
Rated rotational speed	12.1 RPM
OC terminal voltage at rated speed	750V
Number of pole pairs	64
Reactance	0.62pu
Resistance	0.05pu

DRIVE TRAIN PARAMETERS:

Parameter	Value
J_t	35328141kg.m^2
J_g	5024406 kg.m^2
K_{sh}	867637000N.m./rad
Rated rotor speed	12.1 rpm
Rated power	5MW

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