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Wind velocity and rotor position sensorless maximum power point tracking control for wind generation system

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Abstract

In order to perform maximum power point tracking control of wind generation system, it is necessary to drive windmill at an optimal rotor speed. For that purpose, a rotor position and a wind velocity sensors become indispensable. However, from the aspect of reliability and increase in cost, rotor position sensor and wind velocity sensor are not usually preferred. Hence, wind velocity and position sensorless operating method for wind generation system using observer is proposed in this paper. Moreover, improving the efficiency of the permanent magnet synchronous generator is also performed by optimizing *d*-axis current using the Powell method.

Keywords: Rotor position and speed sensorless; Wind velocity sensorless; Wind generation system; PMSG; Optimized *d*-axis current; Powell method

1. Introduction

Electric power generation using non-conventional sources is receiving considerable attention throughout the world due to exhaustion of fossil fuels, and environmental issue.

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Wind energy, which is the clean energy source and infinite natural resources, is one of the available non-conventional energy sources. In the large-sized wind generation system whose output per generator like a wind farm is about 2000 kW, there are various problems such as, restrictions of an installation place, wind conditions, and introductory cost are high. In recent years, small wind power system having output about 100 kW is in practical use. In such wind generation system, the permanent magnet synchronous generator (PMSG) is introduced because it is efficient, smaller in size, and easily controllable as compared to direct current generator or induction generator. However, wind energy has a drawback of having only $\frac{1}{800}$ density and irregularity as compared with that of water energy. It is important that how we can utilize it as high-efficient electric power energy. Because of this problem, various high-efficiencies control schemes have been reported in recent years [1–3].

Power generation using wind energy is possible in two ways, viz. constant speed operation and variable speed operation using power electronic converters. Variable speed generation for wind generator is attractive because of its characteristic to achieve maximum efficiency at all wind velocities [4]. Therefore, variable speed control of permanent magnet generator which applied vector control is needed. However, this system requires a rotor speed information for vector control purpose. Usually, an encoder or a tacho-generator is used to measure the motor speed, but the presence of these sensors increases the drive cost and reduces the robustness of the overall system. To alleviate the need of rotor speed sensor in vector control, we propose a new sensor-less control of PMSG based on flux linkage. We estimate the rotor position using estimated flux, obtained from the integration of induced electro-motive force. However, the integration generates operation error due to offset and/or input errors. Thus, we use a first-order lag compensator to obtain flux linkage. Furthermore, a wind velocity is required for optimal rotor speed determination. However, it is necessary to pay attention for the selection of sensor attachment position and wiring to controller. Moreover, removal of wind velocity sensor from the aspect of reliability and increase in cost, is desired. We estimate wind velocity and rotor speed using an observer.

In this paper, we propose the sensor-less maximum power point tracking control of wind generation system. The rotor position is estimated based on the flux linkage. The rotor speed and wind velocity are estimated by using an observer. The optimal rotor speed is determined using the estimated value obtained. Moreover, improving the efficiency of the permanent magnet synchronous generator is also performed by optimizing d-axis current using the Powell method [5]. The effectiveness of the proposed method is demonstrated through simulation results.

2. System configuration

The configuration of a maximum power point tracking wind power system is shown in Fig.1. The wind power energy obtained from a windmill is sent to PMSG through gear. PMSG measures only current by the sensor and is controlled by the PWM converter by wind velocity and the position sensor-less controller.

If all the wind power is converted to mechanical power, the input energy P_{wind} is expressed as

$$P_{\mathrm{wind}} = \tfrac{1}{2}\rho\pi R_0^2 V_{\mathrm{w}}^3, \tag{1}$$

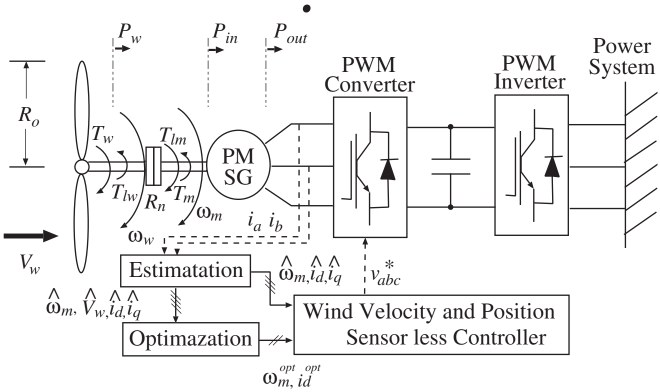

Fig. 1. Wind generation system configuration.

where R_0 is windmill blade radius, ρ is air density. The windmill input torque T_{wind} can be described as

$$T_{\text{wind}} = \tfrac{1}{2}\rho\pi R_0^3 V_{\text{w}}^2. \tag{2}$$

The motion equation of a windmill is expressed as the following equation, when windmill loss torque is set to T_f and load torque of a windmill is set to T_{lw}

$$T_{\text{wind}} = J_{\text{w}} \frac{d\omega_{\text{w}}}{\text{d}t} + T_f + T_{\text{lw}}, \tag{3}$$

where J_{w} is windmill inertia coefficient, and ω_{w} is windmill rotor speed. The motion equation of the windmill output torque that can actually be extracted from a windmill can be expressed as

$$\begin{aligned} T_{\text{w}} &= T_{\text{wind}} - T_f \\ &= J_{\text{w}} \frac{\text{d}\omega_{\text{w}}}{\text{d}t} + T_{\text{lw}}. \end{aligned} \tag{4}$$

Moreover, since the windmill loss torque T_f serves as a convex function according to wind velocity and windmill rotor speed, it can be expressed as an approximation equation like the following equation [4]

$$T_f = K_0 V_{\text{w}}^2 + K_1 V_{\text{w}}\omega_{\text{w}} + K_2\omega_{\text{w}}^2. \tag{5}$$

Here, a windmill loss coefficient K_0, K_1, and K_2 are expressed as

$$K_0 = \tfrac{1}{2}\rho S R_0(1-\gamma), \tag{6}$$

$$K_1 = -\tfrac{1}{2}\rho S R_0^2\zeta, \tag{7}$$

$$K_2 = -\tfrac{1}{2}\rho S R_0^3\xi, \tag{8}$$

where S is blade rotation area, γ, ζ, and ξ are coefficients that are determined by the size, the form of blade, number of blade, and pitch angle for the windmill. The relationship of rotor speed and torque between the windmill and the generator is expressed as the following equation by using gear ratio R_n

$$\omega_m = R_n \omega_{\mathrm{w}}, \tag{9}$$

$$T_{lm} = -\frac{1}{R_n} T_{\mathrm{lw}}, \tag{10}$$

where ω_m is generator rotor speed, and T_{lm} is generator load torque.

3. Rotor position angle estimation method

In this paper, rotor position angle is estimated from flux linkages, which is obtained by integration operation of electromotive force, because of the flux linkages on fixed stator reference frame includes rotor position angle information. The first-order lag compensator in consideration of the integration operation error is adopted to estimate the flux linkages [6].

Here, since the direction of energy is defined on the basis of an electric motor, it is considering as the generator by adding negative torque to a permanent magnet synchronous motor (PMSM) model in this paper. The voltage equation for the PMSM on the rotor reference frame (*d–q* axis) can be described as

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} pL_d & -\omega_m PL_q \\ \omega_m PL_d & pL_q \end{bmatrix} \begin{bmatrix} i_{dt} \\ i_{qt} \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_e K_e \end{bmatrix}, \tag{11}$$

$$\left. \begin{aligned} i_{dt} &= i_d - i_{di}, \\ i_{qt} &= i_q - i_{qi}, \end{aligned} \right\} \tag{12}$$

where R is armature resistance, v_d and v_q are armature voltages in *d–q* axis, i_d and i_q are armature currents in *d–q* axis, i_{dt} and i_{qt} are load currents in *d–q* axis, i_{di} and i_{qi} are iron loss currents in *d–q* axis, L_d and L_q are armature inductance, ω_e is electrical rotor speed, K_e is electromotive force coefficient, p is differential operator, and P is the number of pole pairs.

The voltage equation on the fixed stator reference frame, which is obtained by coordinates transformation of (11), is expressed as

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = R \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + p \begin{bmatrix} \Psi_{ds} \\ \Psi_{qs} \end{bmatrix}, \tag{13}$$

where v_{ds} and v_{qs} are armature voltages in *ds–qs* axis, i_{ds} and i_{qs} are armature currents in *ds–qs* axis, Ψ_{ds} and Ψ_{qs} are flux linkages in *ds–qs* axis.

The flux linkages in (13) can be expressed as

$$\begin{bmatrix} \Psi_{ds} \\ \Psi_{qs} \end{bmatrix} = L_q \begin{bmatrix} i_{dst} \\ i_{qst} \end{bmatrix} + K_e \begin{bmatrix} \cos\theta_m \\ \sin\theta_m \end{bmatrix}, \tag{14}$$

where i_{dst} and i_{qst} is load current in *ds–qs* axis. Moreover, it is confirmed that it includes the rotor position information $\cos\theta_m$ and $\sin\theta_m$. Therefore, if the estimated value of the flux linkages is set to $(\widehat{\Psi}_{ds}, \widehat{\Psi}_{qs})$, the estimated value of a rotor position can be obtained as the following equations:

$$\cos\widehat{\theta}_m = \frac{\widehat{\Psi}_{ds} - L_q i_{dst}}{\widehat{\Psi}_s}, \tag{15}$$

$$\sin\widehat{\theta}_m = \frac{\widehat{\Psi}_{qs} - L_q i_{qst}}{\widehat{\Psi}_s}, \tag{16}$$

where

$$\widehat{\Psi}_s = \sqrt{(\widehat{\Psi}_{ds} - L_q i_{dst})^2 + (\widehat{\Psi}_{qs} - L_q i_{qst})^2}. \tag{17}$$

Consequently, the stator position angle $\widehat{\theta}_{es}$ can be obtained as

$$\widehat{\theta}_{es} = \arctan\frac{\sin\widehat{\theta}_m}{\cos\widehat{\theta}_m}. \tag{18}$$

It can be seen from (13) that integration of the electromotive force $(v_{ds} - Ri_{ds})$ may provide the flux linkages. However, integration error occurs due to drift with analog integrator, particularly in the low-frequency range. To avoid this, we adopt first-order lag compensator to estimate the flux linkage. Thus, as shown in (19), the estimated *ds*-axis flux linkage can be obtained from the first-order lag compensator using the *ds*-axis electromotive force e_{ds} and the *ds*-axis flux linkage reference as inputs to the estimator

$$\begin{aligned}\widehat{\Psi}_{ds} &= \frac{T_c e_{ds} + \Psi^*_{ds}}{1 + T_c s} \\ &= \Psi_{ds} + \frac{(\Psi^*_{ds} - \Psi_{ds})}{1 + T_c s},\end{aligned} \tag{19}$$

where T_c is time constant of the first-order lag compensator, s is Laplace operator, and superscript "*" denotes the reference value. The flux linkage reference can be obtained as the following equation by transforming those on the rotor reference frame

$$\begin{bmatrix}\Psi^*_{ds} \\ \Psi^*_{qs}\end{bmatrix} = \begin{bmatrix}\cos\widehat{\theta}_m & -\sin\widehat{\theta}_m \\ \sin\widehat{\theta}_m & \cos\widehat{\theta}_m\end{bmatrix}\begin{bmatrix}L_d i^*_{dt} + K_e \\ L_q i^*_{qt}\end{bmatrix}. \tag{20}$$

The estimated *qs*-axis flux linkage can also be obtained in the similar manner as (19).

4. Rotor speed estimation method

Since the estimated value of rotor speed can be obtained by differentiation operation of the estimated rotor position angle obtained by the technique of the Section 3, a position and speed sensorless control can be attained. However, it can be considered that the estimated error at a low speed becomes large or exposed to noise. Therefore, a speed observer is used for estimation of rotor speed in this paper. Furthermore, the windmill output torque observer for estimating wind velocity is also performed.

We consider the equivalent dc motor as a vector-controlled PMSG. The motion equation of the PMSG and the windmill and relations are explained.

The motion equation of PMSG is expressed as the following equation using the damping coefficient D_m, the inertia coefficient J_m, and generator load torque T_{lm} of PMSG:

$$T_m = J_m \frac{\mathrm{d}\omega_m}{\mathrm{d}t} + D_m \omega_m + T_{lm}. \tag{21}$$

The motion equation of a windmill and the expression of relations with a generator can be expressed as the following equations from Section 2:

- The motion equation of a windmill

$$T_{\mathrm{w}} = J_{\mathrm{w}} \frac{\mathrm{d}\omega_{\mathrm{w}}}{\mathrm{d}t} + T_{\mathrm{lw}}. \tag{22}$$

- The expression of relationship of the rotor speed for the PMSG and the windmill

$$\omega_m = R_n \omega_{\mathrm{w}}. \tag{23}$$

- The expression of relationship of the load torque for the PMSG and the windmill

$$T_{lm} = -\frac{1}{R_n} T_{\mathrm{lw}}, \tag{24}$$

where $T_m = K_e P i_q$. As mentioned the above, a state equation and an output equation are derived as shown the below. However, that $\mathrm{d}T_{\mathrm{w}}/\mathrm{d}t = 0$ is adopted for simplification

$$\dot{x} = \begin{bmatrix} \dot{\theta}_m \\ \dot{\omega}_m \\ \dot{T}_{\mathrm{w}} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & a & b \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta_m \\ \omega_m \\ T_{\mathrm{w}} \end{bmatrix} + \begin{bmatrix} 0 \\ c \\ 0 \end{bmatrix} i_q^*, \tag{25}$$

$$y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta_m \\ \omega_m \\ T_{\mathrm{w}} \end{bmatrix}, \tag{26}$$

where $a = -D_m R_n^2/(J_{\mathrm{w}} + J_m R_n^2)$, $b = R_n/(J_{\mathrm{w}} + J_m R_n^2)$, and $c = R_n^2 K_e P/(J_{\mathrm{w}} + J_m R_n^2)$.

The full-order observer is expressed as

$$\begin{bmatrix} \dot{\widehat{\theta}}_m \\ \dot{\widehat{\omega}}_m \\ \dot{\widehat{T}}_{\mathrm{w}} \end{bmatrix} = \begin{bmatrix} -G_1 & 1 & 0 \\ -G_2 & a & b \\ -G_3 & 0 & 0 \end{bmatrix} \begin{bmatrix} \widehat{\theta}_m \\ \widehat{\omega}_m \\ \widehat{T}_{\mathrm{w}} \end{bmatrix} + \begin{bmatrix} G_1 \\ G_2 \\ G_3 \end{bmatrix} \widehat{\theta}_{es} + \begin{bmatrix} 0 \\ c \\ 0 \end{bmatrix} i_q^*, \tag{27}$$

where G_1, G_2 and G_3 are the observer gains, γ_1, γ_2 and γ_3 are the observer poles, $G_1 = -(\gamma_1 + \gamma_2 + \gamma_3 - a)$, $G_2 = \gamma_1\gamma_2 + \gamma_2\gamma_3 + \gamma_3\gamma_1 - a(\gamma_1 + \gamma_2 + \gamma_3) + a^2$, and $G_3 = -\gamma_1\gamma_2\gamma_3/b$, $\widehat{\theta}_{es}$ are estimated rotor position.

5. Estimation of wind velocity

By substituting the windmill input torque T_{wind} from (2), and the loss torque T_f from (5) into (4), the estimated equation of wind velocity can be derived as

$$\widehat{V}_{\text{w}} = \frac{-K_1\widehat{\omega}_{\text{w}}}{2(1/2\rho\pi R_0^3 - K_0)} + \frac{\sqrt{(K_1\widehat{\omega}_{\text{w}})^2 - 4(1/2\rho\pi R_0^3 - K_0)(-K_2\widehat{\omega}_{\text{w}}^2 - \widehat{T}_{\text{w}})}}{2(1/2\rho\pi R_0^3 - K_0)}. \tag{28}$$

Wind velocity is estimated by using the windmill rotor speed and windmill output torque as input which are obtained from the proposed observer, into (28).

6. Optimization of operating point

6.1. Optimization of rotor speed

Since the windmill output P_{w} in a steady state is $P_{\text{w}} = T_{\text{w}}\omega_{\text{w}}$, a windmill output serves as the cubic function of windmill rotor speed ω_{w}, which is described as

$$\begin{aligned} P_{\text{w}} &= T_{\text{w}}\omega_{\text{w}} \\ &= (T_{\text{wind}} - T_f)\omega_{\text{w}} \\ &= (\tfrac{1}{2}\rho\pi R_0^3 - K_0)V_{\text{w}}^2\omega_{\text{w}} - K_1 V_{\text{w}}\omega_{\text{w}}^2 - K_2\omega_{\text{w}}^3. \end{aligned} \tag{29}$$

We can obtain the optimal windmill rotor speed $\omega_{\text{w}}^{\text{opt}}$ as the local maxima of the following equation due to $\mathrm{d}P_{\text{w}}/\mathrm{d}\omega_{\text{w}} = 0$.

$$\frac{\mathrm{d}P_{\text{w}}}{\mathrm{d}\omega_{\text{w}}} = (\tfrac{1}{2}\rho\pi R_0^3 - K_0)V_{\text{w}}^2 - 2K_1 V_{\text{w}}\omega_{\text{w}} - 3K_2\omega_{\text{w}}^2 = 0, \tag{30}$$

$$\omega_{\text{w}}^{\text{opt}} = \frac{-K_1 V_{\text{w}} + \sqrt{(K_1 V_{\text{w}})^2 - 3K_2(\frac{1}{2}\rho\pi R_0^3 - K_0)V_{\text{w}}^2}}{3K_2}. \tag{31}$$

6.2. Optimization of *d*-axis current

On PMSG, we usually obtain excitation from permanent magnet. Thus, there is some degree of flexibility at a setting of d-axis current. Since an iron loss will decrease if d-axis current is controlled to weaken the flux linkage due to permanent magnet, efficiency can be improved [6]. The relationship between input and output of PMSG is described as

$$\begin{aligned} P_{\text{w}} &= P_{\text{in}} + D_m\omega_m^2 \\ &= P_{\text{out}} + P_c + P_i + P_v \\ &= P_{\text{out}} + P_{\text{loss}}. \end{aligned} \tag{32}$$

Here, PMSG output P_{out} and total loss of PMSG P_{loss} is described as

$$P_{\text{out}} = -(v_d i_d + v_q i_q), \tag{33}$$

$$\begin{aligned} P_{\text{loss}} &= P_c + P_i + P_v \\ &= R(i_d^2 + i_q^2) + R_i(i_{di}^2 + i_{qi}^2) + D_m\omega_m^2. \end{aligned} \tag{34}$$

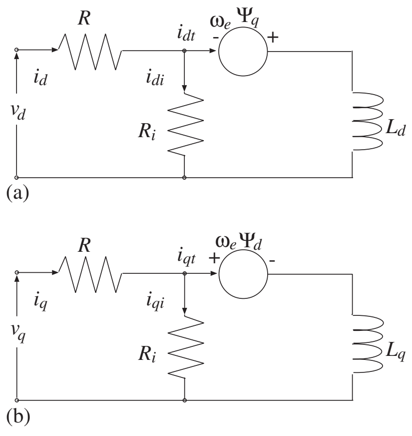

Fig. 2. d-axis current versus windmill output power characteristics. (Wind velocity : 8 m/s constant).

The total loss of PMSG when varying d-axis current from 0 to -6 A in wind velocity 8 m/s is shown in Fig. 2. From this figure, it observed that the efficiency of PMSG is improved by optimizing d-axis current so that P_{loss} could become the minimum. However, since P_{loss} is nonlinear function of (i_d, i_q), it is difficult to solve analytically. Consequently, the optimal d-axis current i_d^{opt} is numerically determined using the Powell method [5] which is one of the methods of optimizing non-linearities. The evaluation function, which is minimized by the Powell method and constraint are expressed as

$$\begin{aligned} f(x) &= P_{\text{loss}} \\ &= R(i_d^2 + i_q^2) + R_i(i_{di}^2 + i_{qi}^2) + D_m\omega_m^2, \end{aligned} \tag{35}$$

$$c(x) = P_{\text{w}} - P_{\text{out}} - P_{\text{loss}} = 0, \tag{36}$$

where the evaluation function, $f(x)$, is the total loss of PMSG, constraints $c(x)$ denotes restrictions for the energy conservation law from a windmill output P_{w} to a PMSG output P_{out} (This expresses that the input to PMSG is equal to the sum of PMSG output and total loss of PMSG.) Moreover, in this paper, since the system is sensorless, actual d–q axes currents are undetectable—therefore, the estimated values $(\hat{i}_d, \hat{i}_q)$ and $\hat{\omega}_m$ are used.

7. Sensorless drive system

The system configuration of the proposed sensorless operation system is shown in Fig. 3. The parameter of the windmill used for the simulation is quoted from [4]. Moreover, the PMSG parameter is quoted from [7]. Wind velocity and a position sensorless control system are configured using the proposed technique. We determine reference torque T_m^* as follows from PI controller, which uses the deviation of a speed reference value and a speed estimation value

$$T_m^* = k_{P\text{w}} e_{\text{w}} + k_{I\text{w}} \int e_{\text{w}}\, \mathrm{d}t, \tag{37}$$

where $k_{P\text{w}}$ is the proportional gain for speed controller, $k_{I\text{w}}$ the integral gain for speed controller, and $e_{\text{w}} = (\omega_m^* - \hat{\omega}_m)$ the speed error. Therefore, the torque current reference

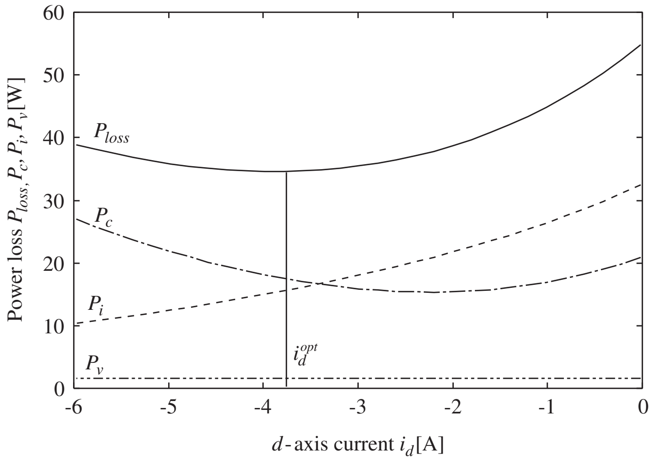

Fig. 3. Control system.

value is given as

$$i_q^* = T_m^*/P\{(L_d - L_q)i_d^* + K_e\}. \tag{38}$$

However, it is considering as $i_d^* = 0$ control.

Furthermore, d–q axis reference voltage is determined as the following equation by a PI controller using the current reference value

$$v_d^* = k_{Pi}e_{id} + k_{Ii}\int e_{id}\,\mathrm{d}t - \omega_e L_q i_q, \tag{39}$$

$$v_q^* = k_{Pi}e_{iq} + k_{Ii}\int e_{iq}\,\mathrm{d}t + \omega_e(L_d i_d + K_e), \tag{40}$$

where k_{Pi} is the proportional gain for current controller, k_{Ii} is the integral gain for current controller, $e_{id} = i_d^* - \widehat{i}_d$ is the d-axis current error, $e_{iq} = i_q^* - \widehat{i}_q$ is the q-axis current error. The estimated flux linkages can be obtained by the flux linkage estimator using the measured currents. The rotor position estimator calculates rotor position from the estimated flux linkages. However, the time constant of the first-order lag compensator is set to $T_c = 0.008$. Then, the rotor position, the rotor speed and windmill output torque can be obtained from the full-order observer using q-axis current reference and estimated rotor position. Additionally, wind velocity can be obtained by the wind velocity calculator using estimated rotor speed and windmill output torque. Wind velocity and position sensorless control of a wind power system are achieved by the above proposal technique. In addition, generator may avoid the electric power loss by executing motor operation for tracking to reference value, and an over-current may occur for motor operation. Hence, a restriction of $-20 \leqslant i_q^* \leqslant 0\,\mathrm{A}$ is adapted in q-axis current reference value, i_q^*.

8. Simulation results

The control parameters and machine parameters are listed in Tables 1 and 2, respectively. The effectiveness of the proposed method is demonstrated through simulation

Table 1
Controller parameters and observer poles

Sampling period T_s	0.2 ms
Proportional gain for speed controller k_{Pw}	0.5
Integral gain for speed controller k_{Iw}	1.0
Proportional gain for current controller k_{Pi}	5.0
Integral gain for current controller k_{Ii}	50.0
Observer poles $\gamma_1 = \gamma_2 = \gamma_3$	-43

Table 2
Windmill and PMSG parameters

Windmill parameters	
Blade radius R_0	0.95 m
Inertia coefficient J_w	0.312 N m s^2/rad
Air density ρ	1.204 N s^2/m^4
Gear ratio R_n	3.0
Windmill loss coefficient	
K_0	1.610319
K_1	-0.07617
K_2	0.00997
PMSG parameters	
Armature resistance R	0.57 Ω
Iron loss resistance R_i	240 Ω
d-axis inductance L_d	7.73×10^{-3} H
q-axis inductance L_q	2.28×10^{-2} H
Electromotive force coefficient K_e	1.08×10^{-1} V s/rad
Inertia coefficient J_m	1.15×10^{-4} N m s^2/rad
Damping coefficient D_m	1.00×10^{-4} N m s/rad
Numberof pole pairs P	4

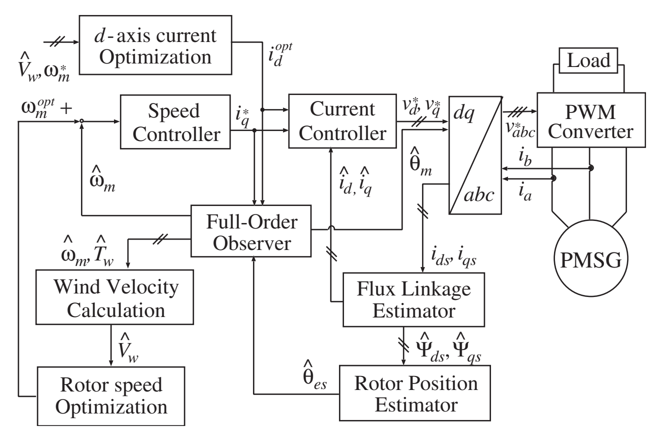

Fig. 4. PMSG output power versus wind velocity.

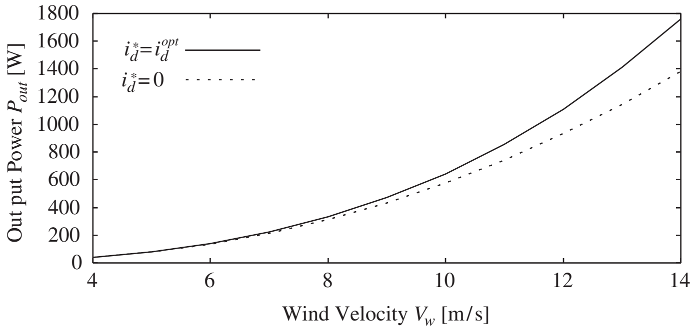

Fig. 5. Wind velocity versus PMSG output power.

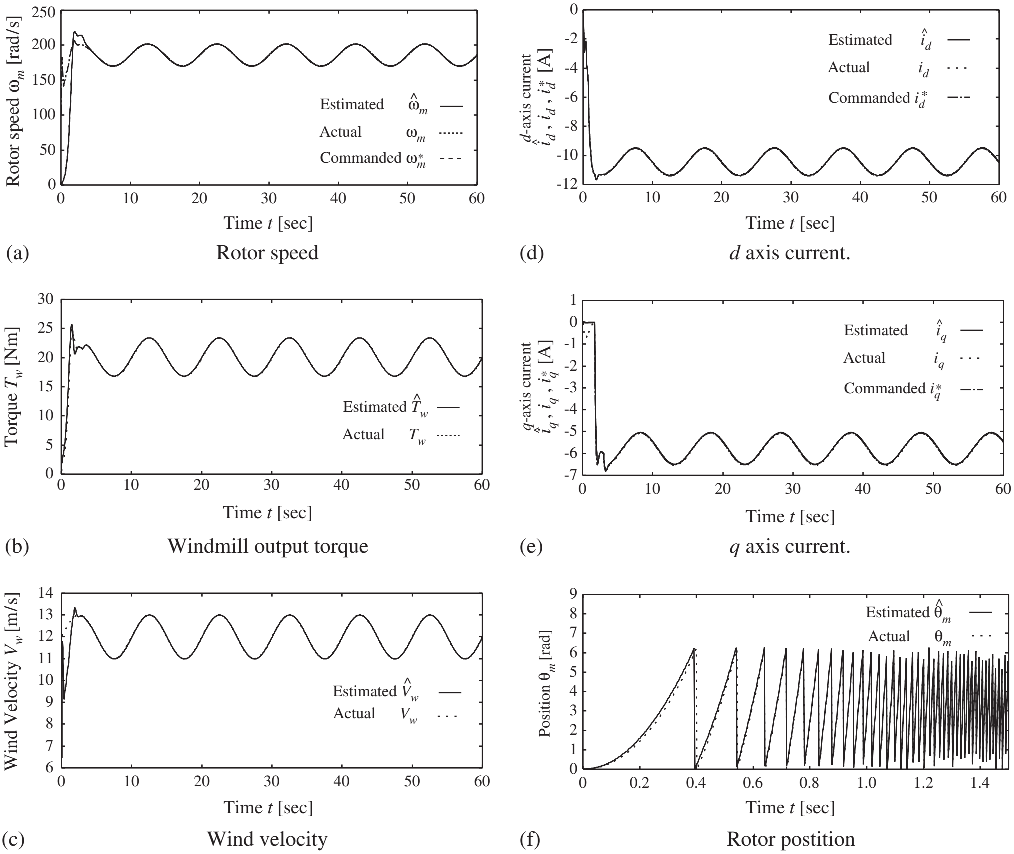

Fig. 6. Simulation result for sinusoidal wind change: (a) rotor speed, (b) windmill output torque, (c) wind velocity, (d) d axis current, (e) q axis current, (f) rotor position.

results. The simulation result of the wind velocity versus PMSG output characteristic at the proposed maximum power point tracking control and $i_d^* = 0$ control is shown in Figs. 4 and 5. However, this result is operated at the optimal rotation speed, and note that only the influence of an improvement of the efficiency of PMSG by optimization of *d*-axis current is shown. From this figure, it confirms that the better output is obtained by using the proposed method. The above effect becomes large as wind velocity becomes large.

The rotor speed is shown in Fig. 6(a) where $\widehat{\omega}_m$ shows the estimated rotor speed, ω_m^* expresses the reference speed, and ω_m expresses the actually rotor speed. We can see the good tracking performance and good estimation. Figs. 6(b) and (c) show actual and estimated windmill output torque and wind velocity. From these figures, it is observed that the windmill output torque and wind velocity are well estimated using the proposed scheme. As can be seen in Figs. 6(a) and (b) the better results are obtained in *d*-axis current and *q*-axis current, respectively. Finally, we can verify from Fig. 6(f) that good estimation ability for rotor position is achieved. The obtained results validate the proposed method. Hence, by applying the proposed method, wind velocity and position sensorless maximum power point tracking control for wind generation system can be well achieved.

9. Conclusions

Wind velocity and position sensor-less operation for wind power generation system have been presented in this paper. We estimate the rotor position from flux linkages using the first-order lag compensator to avoid the drift with analog integrator. Moreover, estimation of a rotor position, rotor speed, and windmill output torque is executed using the full-order observer. Wind velocity is estimated using these. Additionally, the optimal rotor speed and the optimal *d*-axis current are determined using the estimated value. In order to show the validity of this technique, the simulation of a wind generation system is executed. From the simulation results, it is confirmed that increase in the ratio of output power to input power is achieved by using the proposed method as compared with conventional method. Furthermore, it is confirmed that estimation of a rotor speed, wind velocity, windmill output torque, and *d*–*q*-axes currents, and rotor position could be well estimated from the simulation result, and the sensorless maximum power point tracking control of a wind power generation system could be well achieved by using the proposed technique.

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