Speed Observer Design Description

SWP Report

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Contents

Appendices

A.

Rev. no.	*Rev. date*	*Changes*	*Resp.*
1	2014/06/10	Add enhancement for removing harmonic and negative serquence of EBEM	Heng Deng

This document presents the preliminary design of position/speed/flux/torque observer for direct drive permanent magnet generator. The rotor position observer is based on the closed-loop observer of the extended back emf of PMSG in stationary $\alpha-\beta$ frame. The diagram is shown in Figure 1 as below.

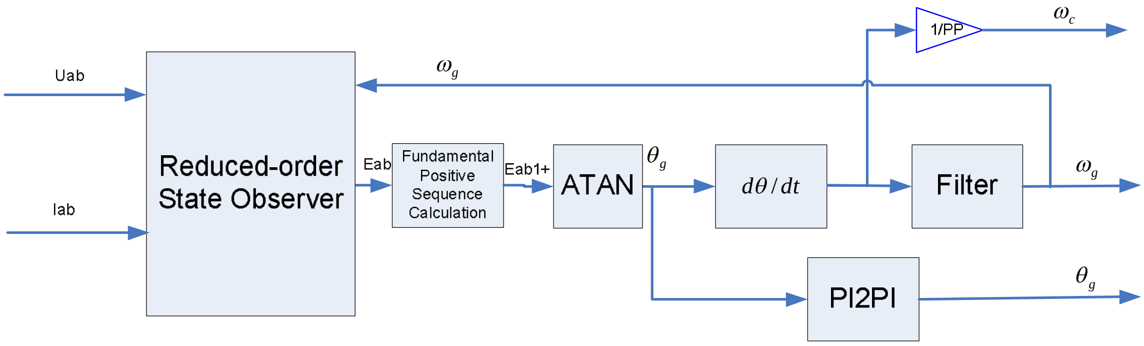

Figure 1 Speed/position/flux observer

1 PMSM Model in Stationary $\alpha-\beta$ Frame

PMSG model in d-q frame:

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R_s + pL_d & -\omega_{re}L_q \\ \omega_{re}L_q & R_s + pL_d \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \{(L_d - L_q)(\omega_{re} i_d - \dot{i}_q) + \omega_{re}K_E\}\begin{bmatrix} o \\ 1 \end{bmatrix}$$

It can be transformed to stationary frame as below.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} R_s + pL_d & 0 \\ 0 & R_s + pL_d \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \begin{bmatrix} 0 & \omega_{re}(L_d - L_q) \\ -\omega_{re}(L_d - L_q) & 0 \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix}$$

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \{(L_d - L_q)(\omega_{re} i_d - \dot{i}_q) + \omega_{re}K_E\}\begin{bmatrix} -\sin\theta_{re} \\ \cos\theta_{re} \end{bmatrix}$$

Defined the extended emf as above. It includes EMFs generated by both permanent magnet and rotor saliency. And it is the only term containing position information in the model.

The above equation can be changed to state-space model as below.

$$\frac{d}{dt}\begin{bmatrix} i \\ e \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ o & A_{22} \end{bmatrix}\begin{bmatrix} i \\ e \end{bmatrix} + \begin{bmatrix} B_1 \\ o \end{bmatrix} u + \begin{bmatrix} o \\ W \end{bmatrix}$$

$$i = [i_\alpha \quad i_\beta]^T, u = [v_\alpha \quad v_\beta]^T, e = [e_\alpha \quad e_\beta]^T$$

$$A_{11} = (-\frac{R_s}{L_d})I + (\frac{\omega_{re}(L_d - L_q)}{L_d})J$$

$$A_{12} = (-\frac{1}{L_d})I \text{ , } A_{22} = \omega_{re}J \text{ , } B_1 = (\frac{1}{L_d})I$$

$$W = (L_d - L_q)(\omega_{re}\dot{i}_d - \ddot{i}_q)\begin{bmatrix} -\sin\theta_{re} \\ \cos\theta_{re} \end{bmatrix}$$

$$I=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix},\ J=\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}$$

W is considered as disturbance to the linear system.

2 Reduced-order State Observer for Extended Back EMF

The reduced-order observer for the back EMF is designed as below.

$$\begin{cases}\dot{\hat{i}}=A_{11}i+A_{12}\hat{e}+B_1u\\ \dot{\hat{e}}=A_{11}Gi+(A_{22}+A_{12}G)\hat{e}+B_1Gu-G\dot{i}\end{cases}$$

$G=aL_dI+(\omega_{re}-b)L_dJ$, $a=v\omega_{re}$, $b=\omega_{re}$.

The closed-loop poles of the observer are $-v\omega_{re}\pm\omega_{re}j$.

This observer includes the differentiation of the current, which is not easy to get. So the intermediate variables as below are used in implementation.

$$\xi=\hat{e}+Gi,\ \dot{\xi}=\dot{\hat{e}}+G\dot{i}.$$

So the real implementation is as below.

$$\dot{\xi}=(A_{22}+A_{12}G)\xi+G(A_{11}-A_{12}G-A_{22})i+B_1Gu$$

$$\hat{e}=\xi-Gi$$

With the observed extended back EMF, flux and torque can be calculated straight forward. This will be implemented to the DDG full order model soon.

3 Position Estimation

With the estimated back EMF, the rotor position is directly calculated as below.

$$\theta_g=\tan^{-1}\left(\frac{-\hat{e}_{\alpha1+}}{\hat{e}_{\beta1+}}\right)$$

4 Speed Estimation

Speed is calculated by filtering derivation of the estimated position as shown in Figure 2.

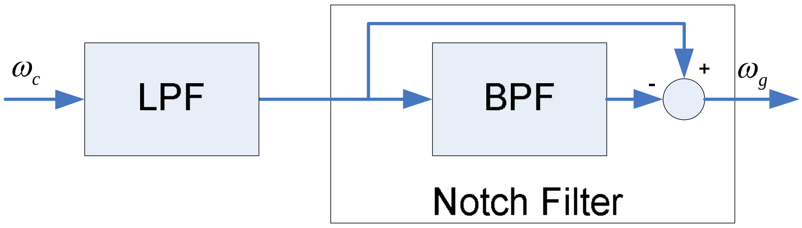

Figure 2 Speed filter

$$\omega_c(k)=\frac{\theta_g(k)-\theta_g(k-1)}{T_s}$$

Here T_s is the sampling/switching period of generator controller.

The low pass filter is as below.

$$LPF(z) = \left. \frac{4\pi^2 f_L{}^2}{s^2 + 4\pi f_L \xi_L s + (2\pi f_L)^2} \right|_{s=\frac{2}{T_S}\frac{z-1}{z+1}}$$

where $f_L = 10Hz$, $\xi_L = 1$, and T_s is the sampling/switching period of generator controller.

The band-pass filter BPF is not a filter with fixed parameters. Its parameters are updated on-line with varying rotor speed. One possible discrete implementation of the band-pass filter BPF is shown as below.

$$BPF(z) = \left. \frac{4\pi f \xi S}{s^2 + 4\pi f \xi s + (2\pi f)^2} \right|_{s=\frac{2}{T_S}\frac{z-1}{z+1}}$$

$$= \frac{a_2 z^2 + a_1 z + a_0}{z^2 + b_1 z + b_0} = \frac{a_2 + a_1 z^{-1} + a_0 z^{-2}}{1 + b_1 z^{-1} + b_0 z^{-2}}$$

$$a_2 = -a_0 = \frac{8\pi f \xi}{\frac{4}{T_s} + 8\pi f \xi + 4T_s \pi^2 f^2}$$

$$a_1 = 0$$

$$b_1 = \frac{-\frac{8}{T_s} + 8\pi^2 f^2 T_s}{\frac{4}{T_s} + 8\pi f \xi + 4T_s \pi^2 f^2}$$

$$b_0 = \frac{\frac{4}{T_s} - 8\pi f \xi + 4\pi^2 f^2 T_s}{\frac{4}{T_s} + 8\pi f \xi + 4T_s \pi^2 f^2}$$

where $f = 6\frac{\omega_g}{2\pi}, \xi = 0.7$.

5 Fundamental Positive Sequence Calculation

With PMG, there are both harmonic and negative sequence components in estimated extended back EMF. In this case, electrical angle of generator is determined only by fundamental positive sequence component of estimated extended back EMF. A block called Fundamental Positive Sequence Calculation is added to extract fundamental positive sequence component of estimated extended back EMF. The detailed diagram of the block is shown in Figure 3.

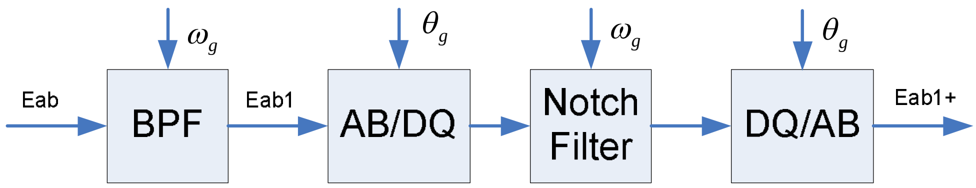

Figure 3 Fundamental positive sequence calculation

In stationary frame, a band-pass filter for fundamental frequency is used to extract fundamental component from estimated extended BEMF. After the band-pass filter, all harmonics in estimated extended BEMF are attenuated. After the band-pass filter, the output is converted to rotating frame in which negative-sequence component is at two times electrical frequency. In the rotating frame, a notch filter at two times electrical frequency is used to eliminate negative-sequence component. After the notch filter, the output is converted back to stationary frame. Fundamental positive sequence calculation is finished.