AUTOMATIC WEIGHT SELECTION AND ROBUST LOOP SHAPING CONTROL FOR DOUBLY FED INDUCTION GENERATOR

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ABSTRACT
Automatic weight selection to achieve maximum stability margin for a doubly-fed induction generator (DFIG) is proposed in this paper. Uncertainty and infinity norm of transfer function from disturbances to states are formulated as the objective function in our optimization problem. Although the trial and error method can be applied to specify the performance weight in robust loop shaping method; however, it is still difficult to achieve high stability margin in some cases of control design. In the proposed technique, to enhance the ability and ensure the optimal value of selected weight, Genetic Algorithms (GA) is adopted to find the weight. Robust Loop Shaping technique is then applied to design the controller. Simulation results are shown to verify the effectiveness of the proposed technique.

KEY WORDS
DFIG, Genetic Algorithms, Robust loop shaping control, Automatic weight selection.

1. Introduction
Robust control is needed to design high performance controller for a Doubly fed induction generator (DFIG); In this system, there are some disturbance from wind and mechanical system. Although many researchers try to develop the robust and high performance controllers for this system; however, this research area is still on going and requires more attention for enhancing the control system [1-4]. Robust control is one of the most interesting techniques for designing the controller for any kinds of systems. There are many schemes in robust control such as mixed-sensitivity approach, robust loop shaping control, mu-synthesis method, etc. Among them, robust loop shaping gains more attention due to its simplicity and well understanding concept. This technique requires two steps those are weight selection and controller synthesis. In weight selection process, the weight is satisfied if the performance specifications and high optimal stability margin are achieved. However, the relationship between stability margin and performance is not straightforward. Weight selection process is usually carried out by trial and error method. In addition, the success of selection depends on experience of designer and requires the knowledge of control system to adjust weight parameters. To simplify the process of weight selection, in this paper, we adopted GA to find the optimal values for weight to maximize the maximum stability margin of robust stabilization problem. Maximum stability margin obtained by solving two Ricatti’s equations is formulated as the fitness function in the proposed optimization technique. This paper is organized as follows. Section 2 describes the DFIG plant (grid side converter) adopted in this paper. Section 3 illustrates the proposed algorithms and GA based weight selection. Section 4 describes the results and section 5 concludes the paper.

2. Modeling of the grid side converter

(a)
Based on the analytical model, the grid side converter model can be expressed as:

\[
\frac{d}{dt} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} = \begin{bmatrix} -\frac{R_f}{L_f} & \omega_g \\ -\omega_g & -\frac{R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + \begin{bmatrix} -1 \\ 0 \end{bmatrix} v_{\text{convd}} + \begin{bmatrix} 0 \\ -1 \end{bmatrix} v_{\text{convq}}
\]

(1)

Where \(i_{gd}\) and \(i_{gq}\) are grid current components in \(d\) and \(q\) axes, respectively. \(L_f\) is field inductance and \(R_f\) is field resistance. \(\omega_g\) represents the grid angular frequency. \(v_{\text{convd}}\) and \(v_{\text{convq}}\) represent converter voltage components in \(d\) and \(q\) axes, respectively.

3. Proposed technique

Our proposed technique is based on the concept of co-prime factorization problem proposed by McFalane and Glover. In this technique, the pre- and post-weights, \(W_i\) and \(W_2\), can be selected by considering the conventional loop shaping technique. Normally, desired open loop shape is specified to achieve high maximum singular values at low frequency region, low minimum singular values at high frequency region and -20 dB/decade slope at cutoff frequency region (SISO case). Based on the concept of robust loop shaping, maximum stability margin is adopted to find the suitability of weight for the control design problem. To find the maximum stability margin, there is a unique method described in [5].

\[
\varepsilon_{\text{opt}} = \left( \inf_{\text{stabilizing}} \left\| \begin{bmatrix} I \\ K \end{bmatrix} (I + G_s K)^{-1} M_s^{-1} \right\|_\infty \right)^{-1}
\]

(2)

Where \(\varepsilon_{\text{opt}}\) is the optimal (maximum) stability margin, \(K\) is the controller, \(G_s\) is shaped plant which is \(W_2 G \omega_s\). \(G\) is plant and \(M_s\) is the normalized denominator of the shaped plant. Low maximum stability margin indicates low compatibility of weight with the control design problem. The \(H\) infinity controller, \(K_\infty\), can be evaluated by solving the following formula.

\[
\left\| \begin{bmatrix} I \\ K_\infty \end{bmatrix} (I + G_s K_\infty)^{-1} M_s^{-1} \right\|_\infty \leq \varepsilon^{-1}
\]

(3)

Finally, the final controller, \(K\), can be determined by

\[
K = W_i K_\infty W_2
\]

(4)

To reduce the complexity of weight selection process, in the proposed technique, \(\text{GA}\) is adopted to find the optimal value of weight which maximize the optimal stability margin obtained by solving equation (2). When the optimal weight is obtained, the proposed technique adopts this weight to design the robust loop shaping controller. Since the weight is satisfied for the problem, the designed \(H\) infinity controller can guarantee the robustness because of high stability margin. In addition, the difficulty of weight selection process is reduced.

\(\text{GA}\) is one of the most popular search techniques that can be used to deal with both linear and non-linear optimization problems. There are many applications adopted \(\text{GA}\) to solve the problems [5-7] and the results showed the effectiveness of using \(\text{GA}\). In addition, several researchers adopted the \(\text{GA}\) [5-7] to find the optimal controllers. In the proposed technique, our optimization problem can be stated as following:

Find the weight parameters, \(x\), in \(W_i(x)\) to maximize

\[
\text{fitness} = \varepsilon_{\text{opt}}
\]

(5)

Based on the concept of loop shaping, in the proposed technique we specified the structure of weight as:

\[
W_i(x) = \begin{bmatrix} \frac{x_2 s + x_2}{s + 0.0001} & 0 \\ 0 & \frac{x_2 s + x_4}{s + 0.0001} \end{bmatrix}
\]

4. Simulation results

The parameters of DFIG (grid converter model) adopted in our study are shown in appendix A. Before adopting \(\text{GA}\), the \(\text{GA}\) parameters are set as follows: mutation probability = 0.1, cross-over probability = 0.6, \(x_2-x_4 \in [-100, 100]\). When running \(\text{GA}\) to find the optimal weight
parameters, the following optimal weight is found. Optimal stability margin obtained by this weight is 0.707.

\[
W_{opt} = \begin{bmatrix}
5.90s + 27.52 & 0 \\
0.0001 & 0 \\
7.53s + 12.85 & 0.0001
\end{bmatrix}
\]

The singular values plot of the shaped plant is shown in Figure 2. As seen in this figure, based on the concept of loop shaping, the maximum singular values at low frequency region and the minimum singular values at high frequency region are satisfied.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{plot1.png}
\caption{Singular value plots of plant and shaped plant}
\end{figure}

Next, we adopted this weight to design the robust loop shaping controller. When applied the robust loop control design technique, the 4th order robust controller is achieved. State space model of robust loop shaping controller is shown in Appendix B. Figure 3 shows the singular values plots of the shaped plant and open loop gain with H infinity loop shaping controller. As seen in this figure, the designed controller can achieve the good performance specified by the shaped plant.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{plot2.png}
\caption{Singular values plots of shaped plant and the sigular values plots of open loop transfer function of controlled system}
\end{figure}

5. Conclusion

In this paper, the design of H infinity loop shaping controller with automatic weight selection by GA has been proposed to control the DFIG. The results show that the designed system achieves the desired open loop singular values profile. The future work of this research is to apply the proposed technique to the real DFIG system.

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Appendix A

\[L_f = 0.002H\]
\[R_f = 0.8Ω\]
\[ω_g = 100π\]

Appendix B

Designed H infinity loop shaping controller:

\[
A_c = 1 \times 10^7 \begin{bmatrix}
0.00000 & 0.0000 & 0.0020 & 0.0000 \\
0.00000 & 0.0000 & 0.0000 & -0.0014 \\
-0.0031 & 0.0000 & -1.387 & 0.0006 \\
0.00000 & -0.0021 & 0.0003 & -1.7698
\end{bmatrix}
\]

\[
B_c = 1 \times 10^5 \begin{bmatrix}
-0.0095 & 0.00000 \\
0.00000 & -0.0051 \\
-5.3720 & 0.0019 \\
0.00150 & -5.3761
\end{bmatrix}
\]

\[
C_c = 1 \times 10^3 \begin{bmatrix}
-0.0052 & 0.0000 & -2.361 & 0.0001 \\
0.00000 & -0.004 & 0.0001 & -3.0111
\end{bmatrix}
\]

\[
D_c = \begin{bmatrix}
0 & 0 \\
0 & 0
\end{bmatrix}
\]

References


