Fault Ride Through Enhancement of DFIG using robust H-infinity Control

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1. Introduction

Wind energy is the fastest growing and most competitive form of sustainable renewable energy today. On the other hand, the high penetration WTs may bring some negative impacts on stable grid operation. For example, the simultaneous disconnection of huge number of WTs may cause a considerable impact on the stable grid operation. Different problems experienced by transmission system operators in countries with high penetration of WTs led to re-evaluation of grid code requirements for fault ride through (FRT) capability. Consequently, the immediate disconnection of wind turbines in case of voltage dips is not acceptable anymore and voltage stability support is required.

Double-fed induction generators (DFIG) are the dominant type of WT, which have gained prominence because of their active/reactive power controllability and variable speed constant frequency operation. It has been recognized that controllers have a critical impact on the stability performance of grid connected DFIGs. Several DFIG control strategies have been proposed in the literature to enhance FRT capability; however, most of these methods do not take into the consideration the inherent nonlinearity of the power system in the controller design. A linear controller does not perform satisfactorily during grid disturbances. In order to address this problem, this paper proposes a nonlinear H-infinity control scheme to enhance the FRT capability of DFIG-WTs during transient-state as per new grid code requirements.

2. System Configuration and modelling

Fig. 1 illustrates the diagram of a single machine infinite bus (SMIB) system simulated in MATLAB R2015a. A 9MW wind farm, consisting of six 1.5 MW wind turbines with DFIG system, connects to the unity bus via a 25kV 30km transmission line. The power is then exported through a 120kV grid through a feeder.

Initially, the DFIG uses the vector control strategy for active and reactive power control, in which the control function is performed by linear PI controllers. Even though simple and easy to implement, PI controllers are not ideal during grid disturbances.

In this study, these PI controllers are replaced by the proposed robust H-infinity controllers in current regulators of the vector control system as seen in Fig. 2. An appropriate controller is synthesized for the rotor side convertor because this controller is responsible for controlling the active and reactive of the DFIG. This control strategy aims to limit inrush rotor current during grid faults to protect the rotor side convertor and limit DC voltage fluctuations.

3. H-infinity Control Design

The major concern in the design of advanced control for power systems is robustness capability – ability of the control scheme to perform satisfactorily under a broad range of operating condition that may involve uncertainties. This is the basis for adopting the H-infinity controller design in this study. The main advantage is robust performance and internal dynamics stabilization. The basic concept of robust control is to allow for uncertainty in the design of the fixed controller, thus, producing a robust controller that is insensitive to parameter variations or disturbances. The major drawback is that it comes at a cost of computational burden and could be hard to realize in practice.

Fig. 3 illustrates the standard H-infinity configuration. The vectors are defined as follows: \( w \) is the exogenous input that represents the driving signals generating the disturbances and input references signals; \( u \) is the control input vector which is responsible for closed loop stability; \( z \) denotes the error (output) signal, and ideally should be zero; the observed output \( y \) is available for feedback; the vector \( x \) denotes the state variable. In this study, the
exogenous input variables are carefully selected and evaluated such that the controller performance is optimal. Another advantage of H-infinity is the minimization of noises and disturbances without making assumptions on them. The control objective is to minimize the H-infinity norm such that:

$$\|T_{zw}\|_\infty < \gamma$$  (1)

Where $T$ is the closed-loop transfer function from input $w$ to output $z$. The variables are derived from:

$$
\begin{align*}
    x &= \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix}, \\
    w &= \begin{bmatrix} i_{dr,ref} \\ i_{qr,ref} \\ v_{ds} \\ v_{qs} \\ \Delta \omega \psi_{dr} \\ \Delta \omega \psi_{qr} \end{bmatrix}, \\
    u &= \begin{bmatrix} v_{dr} \end{bmatrix}, \\
    z &= \begin{bmatrix} i_{dr,ref} - i_{dr} \\ i_{qr,ref} - i_{qr} \end{bmatrix}.
\end{align*}
$$  (2)

As mentioned, the main difficult of DFIG control during a grid fault is the system’s nonlinear behavior. It is therefore essential that this nonlinearity is considered in the controller design. In this study, the plant model is carefully linearized from nonlinear variables to incorporate the inherent nonlinearity of the DFIG electrical dynamics in the controller design. To design the H-infinity controller, first a stable and detectable state-space model for the continuous-time plant, $P$, is developed:

$$
\begin{align*}
    P : \begin{bmatrix} x \\ z \end{bmatrix} &= \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} x \\ w \end{bmatrix}, \\
    y &= \begin{bmatrix} u \end{bmatrix}.
\end{align*}
$$  (3)

The H-infinity control problem is solved by searching for a controller $K$ which internally stabilizes the closed-loop, and the Finally, the optimal H-infinity controller is designed using state-space methods:

$$
\begin{align*}
    K_K(s) : \begin{bmatrix} \dot{x}_K \\ u \end{bmatrix} &= \begin{bmatrix} A_K & B_K \\ C_K & D_K \end{bmatrix} \begin{bmatrix} x_K \\ y \end{bmatrix}.
\end{align*}
$$  (4)

The disturbance and reference variables are considered because they incorporate electrical and physical system dynamics. For example, the difference between synchronous speed and rotor speed. Rotor speed is determined by the wind speed, as a result, the operating state of the wind turbine can be properly considered in H-infinity controller design. This is unlike in PI control where the parameters are not determined based on the operating state of the system.

4. Simulation Results

The H-infinity controller was designed and implemented in MATLAB software. The parameters of the DFIG-WT remain as given in the reference model in MATLAB 2015a. Simulations were performed under the following conditions; the wind speed is kept constant at 12m/s, a 3-phase fault occurs at bus B25 with a ground resistance of 0.01 Ohms, fault is cleared after 0.15 seconds.

Fig. 4 shows the change in the terminal voltage of WT and the DC-link voltage between grid-side converter and rotor-side converter. From Fig. 4 (a) it can be seen that the PI controller results in oscillatory post-fault behavior. On the other hand, the H-infinity controller provides improved performance in terms of damped oscillations, shorter settling time and generally better damping. The voltage dip is also improved with the proposed method. The H-infinity control based ride through strategy reduces oscillations and settling time of the DFIG transient behavior and consequently enhance the DFIG voltage dip behavior. Using the proposed controller, it is again clear that the controller meets standard FRT requirements. From Fig. 2 (b) it can be seen that by using the H-infinity controller, the DC-link voltage fluctuation range is reduced. This is important in order to protect the power converters during fault conditions.

4. Conclusion

This paper presented a control design of a DFIG-WT based on H-infinity method in order to enhance FRT capability during fault conditions. This H-infinity controller has been designed in line with the new grid code requirements. From the simulation results, it is apparent that the performance of the proposed H-infinity control approach is more effective than that of the conventional PI control. The FRT of the DFIG-WT is significantly improved demonstrating the superiority of robust H-infinity control over conventional PI control. The future aim of this study is to investigate the effect of the dynamic interactions among several DFIG units.

References
