Descending Viewer Method for Fault Tolerant Control

K. Lenin
Prasad V. Potluri Siddhartha Institute of Technology, India

ABSTRACT

In this paper, descending viewer method (DVM) projected for finding and fault tolerant control of stator inter-turn short circuit faults in doubly-fed induction generators based in wind turbine. A process has been developed that allows the way from ostensible controllers designed for strong condition, to vigorous controllers designed for defective condition. Finally value of the rotor resistance estimated & is based on the use of the error between real and probable value of doubly fed induction generator (DFIG) in faulty condition, this will perk up the performance of this viewer. Simulation results show the reliability of the proposed DVM approach.

Corresponding Author:
K. Lenin,
Prasad V. Potluri Siddhartha Institute of Technology,
Kanuru, Vijayawada, Andhra Pradesh -520007, India.
Email: gklenin@gmail.com

1. INTRODUCTION

Now a day’s Wind energy generation is an economic & one of the alternative source energy sources [1-7]. Systems such as DFIG-wind turbine, which have non-linear dynamics, have the regulator demean during wide variations of wind speed. Many techniques do not make use of the precise nonlinear DFIG-wind turbine model in the control design. Accordingly, the acquired controllers are usually not supported by recognized stability analysis and their performance cannot be particularly enumerated. Fault exposure and localization unit notice the incidence of fault and verify its temperament [8-19]. It can be recognized by examine the transform of the rotor resistance and suitable assessment has to be proceeded i.e. admitting the evasion or else cease the machine to perform a remedial protection. In this paper, DVM projected for finding and fault tolerant control of stator inter-turn short circuit faults in doubly-fed induction generators based in wind turbine. A process has been developed that allows the way from ostensible controllers designed for strong condition, to vigorous controllers designed for defective condition. Finally value of the rotor resistance estimated & is based on the use of the error between real and probable value of DFIG in faulty condition, this will perk up the performance of this viewer. Simulation results show the reliability of the proposed DVM approach. Figure 1 shows block diagram of speed and reactive power controls of DFIG.

2. MODELLING OF DOUBLY FED INDUCTION GENERATOR

In the stator [7], [18-24] orientation frame (α-β), the mechanical/electrical energy alteration process is described by the equations [10], [16-28] of DFIG are given by:

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Stator and rotor flux equations of are defined as below:

\[
\begin{align*}
\psi_{\alpha s} &= L_s i_{\alpha s} + M_{sr} i_{\alpha r} \\
\psi_{\beta s} &= L_s i_{\beta s} + M_{sr} i_{\beta r} \\
\psi_{\alpha r} &= L_r i_{\alpha r} + M_{rs} i_{\alpha s} \\
\psi_{\beta r} &= L_r i_{\beta r} + M_{rs} i_{\beta s}
\end{align*}
\]  

(2)

Electromagnetic torque articulated by:

\[
C_{em} = p \frac{M_{sr}}{L_r} (\psi_{d*} I_{qr} - \psi_{q*} I_{dr})
\]

(3)

Figure 1. Block diagram of speed and reactive power controls of DFIG
Standard vector control with stator flux [18], [28-29] of the DFIG is shown in Figure 2. The stator flux vector will be associated on the ‘d’ axis & the stator voltage vector on the ‘q’ axis, this final restriction is complimentary to acquire an easy control model.

Figure 2. Respective position of the references (αs, βs) and (αr, βr)

In a fixed reference frame (αs-βs) [12], [14-17] DFIG electrical equations in the state-space can be articulated as below:

\[
\begin{align*}
\frac{dX}{dt} &= AX + BU \\
Y &= CX \\
\end{align*}
\]

(4)

with

\[
X = \begin{bmatrix} i_αs & i_βs & Φ_αr & Φ_βr \end{bmatrix}^T, \quad Y = \begin{bmatrix} i_αs \\ i_βs \end{bmatrix} \quad \text{and} \quad u = \begin{bmatrix} u_αs & u_βs & u_αr & u_βr \end{bmatrix}^T
\]

\[
A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}, \quad B = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}, \quad I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad \text{and} \quad J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}
\]

with

\[
A_{11} = \begin{bmatrix} -\frac{1}{σ_r} & 0 \\ 0 & -\frac{1}{σ_τ} \end{bmatrix}, A_{12} = \begin{bmatrix} L_m \tau & wL_m \tau \\ \frac{wL_m}{σ_τ} & L_m \end{bmatrix}, A_{21} = \begin{bmatrix} \frac{L_m}{τ} & 0 \\ 0 & \frac{L_m}{τ} \end{bmatrix}, A_{22} = \begin{bmatrix} \frac{1}{σL_s} & 0 \\ 0 & \frac{1}{σL_s} \end{bmatrix}
\]

\[
B_{11} = \begin{bmatrix} \frac{1}{σL_s} & 0 \\ \frac{1}{σL_s} & 0 \end{bmatrix}, B_{12} = \begin{bmatrix} \frac{L_m}{σ_τ L_s} & 0 \\ 0 & \frac{L_m}{σ_τ L_s} \end{bmatrix}, B_{21} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \quad \text{and} \quad B_{22} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}
\]

And \( σ = 1 - L_m^2 / (L_s L_r) \), \( w = pΩ_{me} \)

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where $R_s$ and $R_r$ are the stator and rotor resistance, respectively. $L_s$, $L_i$ and $L_m$ are the stator and rotor full inductance, the magnetization inductance, respectively. The electromagnetic torque [15], [26-28] equation can be written as,

$$C_e = \frac{3}{2} p \frac{L_m}{L_r} \left( \Phi_{\alpha} i_{\beta} - \Phi_{\beta} i_{\alpha} \right)$$

(5)

An inter-turn fault for a stator phase winding is a consequence of the worsening of insulation between the individual coils. A Short circuit in stator phase winding alters the symmetrical stator current. To forecast the electrical performance from the stator supply due to an inter-turn fault, it would emerge that the impedance of the short-circuited stator winding has been diminished [5-33]. The degree to which its impedance will be diminished is depend on the rigorousness of the fault. To simulate the failure, the impedance of the stator phase winding is diminished by placing a resistor in parallel with the winding, as shown in Figure 3 [22-23]. Stator resistance matrix redrafted as follows, yet, the matrix of stator voltages unaffected.

![Stator winding configuration with the inter-turn short circuit fault in phase 'A'](image)

Figure 3. Stator winding configuration with the inter-turn short circuit fault in phase ‘A’

$$[R_s] = \begin{bmatrix}
(1-\mu)R_s & 0 & 0 & \gamma R_s \\
0 & R_s & 0 & 0 \\
0 & 0 & R_s & 0 \\
0 & 0 & 0 & \mu R_s \\
\end{bmatrix}$$

(6)

« $\mu$ » fraction of the number of shorted turns of phase « a », then we have a strong portion of a fraction $1-\mu$ of turns and the phases "b" and "c" are also strong. New inductance stator matrix [20-25] is given as follows:

$$[L_s] = L_{\mu diag} \left[ \begin{bmatrix}
(1-\mu)^2 & -(1-\mu) & -(1-\mu) & \mu (1-\mu) \\
-(1-\mu) & 1 & -\frac{\mu}{2} & -\frac{\mu}{2} \\
(1-\mu) & -\frac{\mu}{2} & 1 & -\frac{\mu}{2} \\
-\frac{\mu}{2} & -\frac{\mu}{2} & -\frac{\mu}{2} & \mu^2 \\
\end{bmatrix} \right] + M_s$$

(7)

Matrix of mutual inductances [2-30] is given as follows& Rotor inductance matrix [21], [24-25] remains equal to that of the strong cases.
3. DESCENDING VIEWER METHOD

If the system is noticeable, then the intention of the viewer is to provide the most excellent evaluation of the state variables from the measurements on the output “y” and the input “u”.

The viewer [32-33] defined as follows,

\[ \dot{x} = f(x, y, u, t) + \Lambda u \]  

A nonlinear system is considered [6-19] by the following equation,

\[ \begin{align*}
\dot{x}(t) &= f(x(t), u(t)) \\
y(t) &= C x(t)
\end{align*} \]  

Or. \( x \in \mathbb{R}^n, u \in \mathbb{R}^n \) et \( y \in \mathbb{R}^p \)

The system is noticeable, & the system (10), the viewer [3-8-11-13] is decided by descending mode by:

\[ \dot{x} = \hat{f}(x(t), u(t)) + \Lambda \hat{x} \]  

\[ I_s = Sign(S) = \begin{bmatrix} sign(s_1), sign(s_2), \ldots, sign(s_p) \end{bmatrix}^T \]  

where \( sign(.) \) is sign function and is the then slide surface is given by,

\[ S = NC \bar{x} = [s_1, s_2, \ldots, s_p] \]  

\[ \bar{x} = \hat{x} - \hat{x} \]  

\( N \in \mathbb{R}^{p \times p} \) is a matrix to be indicated.

Therefore, the dynamics of the observation error turn into as follows:

\[ \dot{x} = f(x, u) - \hat{f}(x, u) + \Lambda \hat{x} \]  

The descending surface \( S = 0 \) is striking if:
\[ S_i, S_s < 0 \text{ for } i = 1, 2, \ldots, p. \]

This circumstance describes the area for which the slip mode is present. In the duration of slip, the dynamics of the estimation error are condensed from the order \( n \) (preliminary system) to the order of \( n - p \) (condensed order equal system). Then the assets of this condensed dynamics are examined. The method of equivalent control has been utilized for the examination. The purpose of the expression of the condensed dynamic range is based on the computation of the equivalent \( \tilde{I}_s \) switching vector on the switching surface.

As of the condition of invariance \( S \equiv 0 \) and \( \dot{S} \equiv 0 \),

\[ \dot{S} = NC\tilde{x} = NC\left( f(x, u) - \hat{f}(\tilde{x}, u) + \Lambda \tilde{I}_s \right) = 0 \]  \hspace{1cm} (16)

Matrix \( NCA \) is invertible, then,

\[ \tilde{I}_s = (NCA)^{-1} NC\left( f(x, u) - \hat{f}(\tilde{x}, u) \right) \]  \hspace{1cm} (17)

The replacement of \( \tilde{I}_s \) in (15) has permitted us to acquire the condensed dynamics as,

\[ \dot{x}_{eq} = [I - \Lambda(NCA)^{-1} NC] f(x, u) - \hat{f}(\tilde{x}, u) \]  \hspace{1cm} (18)

At last, the viewer amalgamation selects the matrices \( N \) and \( \Lambda \) so as to make sure that the same time the magnetism of the sliding surface and stability of the condensed dynamic range.

4. **DVM PROJECTED FOR FINDING AND FAULT TOLERANT CONTROL OF STATOR INTER-TURN SHORT CIRCUIT FAULTS IN DOUBLY-FED INDUCTION GENERATOR**

The descending method viewer for the evaluation of the doubly-fed induction generator flows as follows,

\[
\begin{align*}
\dot{x}_1 &= -a_1 x_1 + \frac{R_s L_m}{a L_r} \hat{x}_3 x_3 + \frac{L_m}{b} \hat{x}_4 x_4 + \frac{1}{\sigma L_s} v_{\alpha r} + \frac{L_m}{b} v_{\alpha r} + \lambda^s_1 I_s \\
\dot{x}_2 &= -a_2 x_2 - \frac{L_m}{b} \hat{x}_3 x_3 + \frac{R_s L_m}{a L_r} \hat{x}_4 x_4 + \frac{1}{\sigma L_s} v_{\beta r} + \frac{L_m}{b} v_{\beta r} + \lambda^s_1 I_s \\
\dot{x}_3 &= \frac{R_s L_m}{L_r} x_1 - \frac{R_s L_m}{L_r} x_1 - \frac{R_s}{L_r} x_3 + \frac{1}{\sigma L_s} v_{\alpha r} + \lambda^s_1 I_s \\
\dot{x}_4 &= \frac{R_s L_m}{L_r} x_2 - \frac{R_s}{L_r} x_2 + \frac{R_s}{L_r} x_3 + \frac{1}{\sigma L_s} v_{\beta r} + \lambda^s_1 I_s \\
\dot{x}_5 &= d \left( \hat{x}_3 x_2 - \hat{x}_4 x_1 \right) - \frac{T_r}{J} x_5 + q_i \left( x_5 - \hat{x}_5 \right) + \lambda^s_1 I_s \\
a &= \frac{1}{\sigma L_s} \left( R_s + \frac{L_m^2}{L_r} \right), \quad b = \sigma L_s L_r, \quad \sigma = 1 - \frac{L_m^2}{L_s L_r}
\end{align*}
\]
With \[ \hat{x} = \begin{bmatrix} \hat{i}_{as} \\ \hat{i}_{bs} \\ \hat{\Phi}_{as} \\ \hat{\Phi}_{bs} \\ \hat{w}_r \end{bmatrix}^T \text{ and } \hat{y} = \begin{bmatrix} \hat{i}_{as} \\ \hat{i}_{bs} \\ \hat{w}_r \end{bmatrix}^T \]

\[ I_s = \left[ \text{sign}(S_1) \text{ sign}(S_2) \right]^T \]

and

\[ S_1 = x_1 - \hat{x}_1 \]
\[ S_2 = x_2 - \hat{x}_2 \]

\( S_1 \), \( S_2 \) symbolize the descending surfaces.

The increase: \( q_1 \), \( \Lambda_1^T \), \( \Lambda_2^T \), \( \Lambda_3^T \), \( \Lambda_4^T \), \( \Lambda_5^T \) are computed to guarantee the asymptotic convergence of the error estimation & given by:

\[ \begin{bmatrix} \Lambda_1^T \\ \Lambda_2^T \end{bmatrix} = D^{-1} \begin{bmatrix} \delta_1 \\ 0 \\ 0 \end{bmatrix} \quad \text{and} \quad D = \frac{1}{\left( a^2 + (kpx_3)^2 \right)} \begin{bmatrix} a & -kpx_5 \\ kpx_3 & a \end{bmatrix} \]

\[ \begin{bmatrix} \Lambda_{41} & \Lambda_{32} \\ \Lambda_{41} & \Lambda_{42} \end{bmatrix} = \begin{bmatrix} -c & -px_3 \\ px_3 & -c \end{bmatrix} \begin{bmatrix} q_1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \delta_1 \\ 0 \\ 0 \delta_2 \end{bmatrix} \quad \text{(20)} \]

\[ \begin{bmatrix} \frac{\Delta_{31}}{\delta_1} \\ \frac{\Delta_{32}}{\delta_2} \end{bmatrix} = d \begin{bmatrix} x_2 - \hat{x}_1 \end{bmatrix} \]

such as:

\[ \begin{cases} \delta_1 > \left| \varepsilon_3 \right|_{\text{max}} \\ \delta_2 > \left| \varepsilon_4 \right|_{\text{max}} \end{cases} \quad \text{and} \quad \begin{cases} q_1 > 0 \\ q_3 > 0 \\ q_4 > 0 \end{cases} \]

The residual signal is computed as follows, \( r = [y - \hat{y}] \) & \( r_0 \) as the detection threshold (lower limit), which is defined according to several pre-specified system performance. The object is to find out the mechanism of adjustment of the speed and the resistance of the rotor. The viewer structure is based on the DFIG model in the stator reference.

5. SIMULATION STUDY

5.1. Phase I strong operation

To illustrate the performance of the projected control, several modes of operation have been viewed Figure 4 and 5. The primary mode match up to the over speed operation. Then it treated as the strong functioning. Finally, the study bang of the following disturbances: variation of the rotor resistance and stator inter-turn short circuit fault.

![Figure 4. Rotation speed and electromagnetic torque of the DFI](image-url)
Figure 5. Active and reactive stator power with variation of wind speed

Figure 6. Rotor currents ($i_{rd}, i_{rq}$) with variation of wind speed

Figure 7. Stator currents ($I_{sα}, I_{sβ}$) with variation of wind speed

5.2. Process with stator inter-turn short circuit fault and for variation of the rotor resistance

Figures 8, 9, 10, 11 indicates the stator inter-turn short circuit fault and rotor resistance variation. Figure 12 shows principle of an adaptive descending viewer method.

Figure 8. Rotation speed and observed rotor resistance of the DFIG
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Figure 9. Active and reactive stator power

Figure 10. Park’s rotor currents ($i_{rd}, i_{rq}$)

Figure 11. Stator Current ($I_{sα}, I_{sβ}$)

Figure 12. Principle of an adaptive descending viewer method
The current rotational speed of the ripple relative to the strong operation is noted, and in accumulation it is not affected by the variation of the rotor resistance. The active and reactive stator power, direct, quadrature rotor currents and the stator phase current have oscillations of elevated amplitudes than those corresponding to the strong operation. This augment is due to the stator inter-turn short circuit fault. As following, the control with descending viewer method has high-quality performances of heftiness and accuracy of function in dilapidation against stator inter-turn short circuit fault and the rotor resistance variation.

6. CONCLUSION

In this research paper, descending method viewer method applied to DFIG, based on the assessment of the value of the rotor resistance. The assessment of the rotor resistance is based on the use of the error between real and estimated value of DFIG in flawed condition & it need to perk up the performances of this viewer. In flawed conditions, the machine is unbalanced and noteworthy augment of stator and rotor currents is formed. In the proposed control system, the speed remains equal to its reference value and the overshoot currents cannot be evaded. When the current is not beyond the tolerable level, the DFIG prolong to activate with besmirched performance until its revamp. So, it’s constantly obligatory to accomplish early on fault detection to control the damage. The universal control scheme introduces elevated performances of heftiness and steadiness with accuracy. The rotor resistance R_estimated with little error & the estimation of rotor resistance can be helpful for improving the vibrant characters of controller by the adaptive descending viewer method.

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APPENDIX

| Table 1. Different Parameters for Model of the DFIG |
|---------------------------------------------------|
| **Electrical** | **Index** | **Value** |
|---------------------------------------------------|
| Rated power | $P_r$ | 7500W |
| Stator resistance | $R_s$ | 0.440 $\Omega$ |
| Rotor resistance | $R_r$ | 0.59 $\Omega$ |
| Stator leakage inductance | $L_s$ | 0.0072 H |
| Rotor leakage inductance | $L_r$ | 0.0079 H |
| Magnetizing inductance | $L_m$ | 0.0079 H |
| Number of pole pairs | $P$ | 2 |
| Inertia | $J$ | 0.31102 kg. m$^2$ |
| Viscous friction | $f_v$ | 0.00654 kg.m$^2$.s$^{-1}$ |
Table 2. Variation of Wind Speed

| t (s) | V(m/s) | Qref (var) |
|-------|--------|------------|
| 0     | 10     | 0          |
| 4     | 12     | 0          |
| 7     | 14     | 0          |

Table 3. The Degree of Short-circuit

| t (s) | \( \gamma \) (%) |
|-------|------------------|
| 0     | 0.10             |
| 0.9   | 4                |

Table 4. Change in \( R_{r1} \)

| t (s) | \( R_{r1}(\Omega) \) | \( R_r \) | \( R_r + 50\% R_r \) |
|-------|-----------------------|----------|---------------------|
| 0     | 1.29                  |          |                     |