VAr Compensation Based Stability Enhancement Of Wind Turbine Using STATCOM

P. Malathy, J.Lakshmi Priya

Abstract— Maintenance of power system stability becomes vital during disturbances like faults, contingency etc. This work deals with a novel priority oriented optimal reactive power compensation of Doubly-Fed Induction Generator (DFIG) based wind turbine using Static Synchronous Compensator (STATCOM). A multi-objective problem will be formulated to maintain voltage within its tolerance levels using Voltage Severity Index (VSI) and to mitigate low frequency oscillations by using Transient Power Severity Index (TPSI) during post-fault conditions. An optimal solution to this proposed problem will be obtained using Fuzzy Logic. In order to justify the proposed methodology it is simulated and tested using 2 MW DFIG with MATLAB- Simulink.

Index Terms— stability indices; wind turbine; reactive power; fault; fuzzy logic; STATCOM.

I. INTRODUCTION

An optimal reactive power and voltage control strategy of DFIG based wind turbine using Particle Swarm Optimization (PSO) is discussed in [1]. STATCOM has been used in a wind farm associated with DFIG for real time applications [3]. In [4] application of various FACTS controller models are validated for the real and reactive power coordination problems related to power system studies. An adaptive neural network configuration has been implemented [5] to control reactive power in a grid connected wind farm. Bacterial Foraging Technique (BFT) [7] has been used to maintain a constant power output in a DFIG based wind turbine and batteries. Genetic Algorithm has been applied to mitigate voltage sag, swell problems [8] in a grid connected DFI wind generators. A modified Differential Evolution (DE) algorithm has been used to design an optimal electric network for an offshore wind farm [9].Simulated Annealing technique (SA) has been used [10] for the optimal maintenance of constant voltage and power output in a DFIG based wind turbine. Real time transient stability analysis of a fixed speed wind farm is done using STATCOM [11]. In order to solve the low voltage problems in a grid connected DFI wind generators Genetic Algorithm (GA) has been applied [12]. A multi-objective problem using decomposition based evolutionary algorithm has been used to analyze the voltage stability [13]. This work presents, a priority oriented optimal VAr compensation of DFIG based wind turbine using STATCOM. A multi-objective problem is formulated to maintain voltage within its rated limits using VSI and to mitigate low frequency oscillations by using TPSI during three phase fault conditions.

The solution for the proposed problem is optimized using Fuzzy Logic. In order to justify the proposed methodology it is modeled in a 12 bus power system with a 2 MW DFIG using MATLAB- Simulink. The system is then tested by simulating a three phase fault. The graphical results of the case study are analyzed and presented.

II. METHODOLOGY

A. Synopsis of the Proposed work

The main objective of this study is to formulate a multi-objective problem for modeling a optimal reactive power controller. Transient stability of the system under consideration is improved by reducing the voltage deviations at the Wind turbine. Fig. 1, shows the general block diagram of the proposed model.

![Fig. 1 Block diagram of the proposed control for stability improvement](image)

Fig. 1. Block diagram of the proposed control for stability improvement

![Fig. 2. Diagram of the proposed control](image)

Fig. 2. Diagram of the proposed control [15]

The next objective is to minimize the voltage deviation at the Point of Common Coupling (PCC) in the system even during fault. The next objective is to minimize the TPSI to improve the transient stability by mitigating the oscillations after clearing the fault or during post fault conditions. The DFIG based wind turbine is connected to the grid.
grid. It has been controlled by STATCOM using Fuzzy Logic Controller (FLC). The FLC is tuned offline, by a set of fuzzy rules as shown in Table I.

### TABLE I. Fuzzy Rules

<table>
<thead>
<tr>
<th>Rule No.</th>
<th>Fuzzy Input</th>
<th>Fuzzy Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>IF HIGH-HIGH THEN MEDIUM-HIGH</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>IF HIGH-MEDIUM THEN MEDIUM-HIGH</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>IF HIGH-LOW THEN HIGH-HIGH</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>IF MEDIUM-HIGH THEN LOW-HIGH</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>IF MEDIUM-LOW THEN MEDIUM-HIGH</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>IF LOW-HIGH THEN LOW-LOW</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>IF LOW-MEDIUM THEN LOW-LOW</td>
<td></td>
</tr>
</tbody>
</table>

B. The Reactive Power Control Technique

Fig. 2 shows that, there are two states for switches $S_1$ and $S_2$. During normal condition, the switches $S_1$ and $S_2$ are closed in state 1. In this state the initial reactive power limits, denoted as $Q_{RSC}^*$ and $Q_{STATCOM}^*$ are maintained. During fault condition, the switches are transferred to state 2. The Fuzzy Logic Controller (FLC) acts suddenly and provides the optimal control values namely $Q_{RSC}^*$ and $Q_{STATCOM}^*$ to control the STATCOM which in turn compensates the required reactive power in order to maintain the transient stability. The two sensitivity indices namely Voltage Severity Index (VSI) and Transient Power Severity Index (TPSI) are necessary to optimize the control parameters, through which Var compensation is achieved. The operation of FLC is based on fuzzy rules as shown in Table I. The fuzzy subsets for the input variables, $T_f$ and $T_c$ is shown in Fig. 3. The fuzzy subsets for the output variables $Q_{RSC}^*$ and $Q_{STATCOM}^*$ are shown in Fig. 4 and Fig. 5 respectively. Table II and III shows the initiating values of parameters, $m$ and $\mu$, for the input and output fuzzy subsets.

![Fig. 3. Fuzzy input subsets of $T_f$ and $T_c$](image)

![Fig. 4. Fuzzy output subsets of $Q_{RSC}^*$](image)

### TABLE II. Parameters to Initiate Sigmoidal Membership for Input Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Low Subset</th>
<th>Medium Subset</th>
<th>High Subset</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_f$</td>
<td>[1, 2]</td>
<td>3</td>
<td>5.5</td>
<td>7</td>
</tr>
<tr>
<td>$Q_{RSC}^*$</td>
<td>0.3-1.5</td>
<td>0.75</td>
<td>0.45</td>
<td>0.9</td>
</tr>
<tr>
<td>$Q_{STATCOM}^*$</td>
<td>0.5-1.275</td>
<td>0.75</td>
<td>0.225</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### TABLE III. Parameters to Initiate Sigmoidal Membership for Output Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Low Subset</th>
<th>Medium Subset</th>
<th>High Subset</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{RSC}^*$</td>
<td>0.15-0.45</td>
<td>0.75</td>
<td>0.15</td>
<td>0.3</td>
</tr>
<tr>
<td>$Q_{STATCOM}^*$</td>
<td>0.225-0.45</td>
<td>0.75</td>
<td>0.225</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### III. Problem Formulation

A. Objective Function

The objective function is to minimize Voltage Severity Index (VSI) and Transient Power Severity Index (TPSI) given by equation 1 to 3. The objective function is subjected to both linear and non-linear constraints which are discussed in detail in the next section.

\[
VSI = \sum_{i=T_f}^{T_p} \Delta V_{PCC, i}^T \tag{1}
\]

\[
\Delta V_{PCC, i}^T = \begin{cases} 
\frac{V_{PCC, i}^T - V_{PCC, i}^0}{V_{PCC, i}^0} & \text{if } V_{PCC, i}^T - V_{PCC, i}^0 \geq \alpha \\
0 & \text{otherwise}
\end{cases} 
\tag{2}
\]

\[
TPSI = \frac{\sum_{i=1}^{N} \sum_{t=T_c}^{T_p} \left( \left| P_i^t - P_i^0 \right| / P_i^0 \right)}{N \times (T - T_c)} \tag{3}
\]

where

- $V_{PCC, i}^T$ - Voltage at PCC at time, $T=0$
- $V_{PCC, i}^t$ - Voltage at PCC at time, $T=t$
- Voltage change outside the specified limits ($\pm 5\%$)
- $N$ - Number of buses
- $T_c$ - Fault clearing time
- $P_i^0$ - Real power during pre-fault condition
- $P_i^t$ - Real power at time, $T=t$
B. Constraint

The linear constraints are the real and reactive power balance given by equations 4 and 5.

\[ P_L - P_e - P(V, \theta) = 0 \]  
(4)

\[ Q_L - Q_e - Q(V, \theta) = 0 \]  
(5)

The non-linear constraints are denoted by set of equations in 6, which includes, apparent power limit (S), Voltage Limit at various buses (V, \( \theta \)), limits of real and reactive power of generators, reactive power limits of STATCOM

\[ S(V, \theta) \leq S_{\text{max}} \]

\[ V_{\text{min}} \leq V \leq V_{\text{max}} \]

\[ P_{G \text{ min}} \leq P_G \leq P_{G \text{ max}} \]

\[ Q_{G \text{ min}} \leq Q_G \leq Q_{G \text{ max}} \]

\[ Q_{\text{STAT min}} \leq Q_{\text{STAT}} \leq Q_{\text{STAT max}} \]

The non-linear constraint also consists of change in rotor angle given by equation 7.

\[ [\max(\Delta \delta \_i\_j)] - \beta \]  
(7)

By using the fuzzy logic controller, the control variables (Q\_RSC and Q\_STATCOM) are adjusted with the help of the two parameters namely y\_1 and y\_2.

\[ 0.3 \leq Q_{\text{RSC}} \leq 2 \text{ MVar} \]

\[ 0.5 \leq Q_{\text{STAT}} \leq 2 \text{ MVar} \]

\[ 0.7 \leq y_1 \leq 0.8, 0.7 \leq y_2 \leq 0.8 \]

To begin with the solutions for the control variables represented by, \( X = [Q_{\text{RSC}}, Q_{\text{STATCOM}}] \) and adjusting parameters of FLC, denoted as, \( Y=[y_1, y_2] \) are initiated using equation 9 to 11 respectively.

\[ X_{\text{new}} = X_{\text{iter}} + (X_{\text{max}} - X_{\text{iter}}) \cdot \text{rand}(0,1) \cdot \exp(-\text{iter}/\text{max iter}) \]  
(9)

\[ Y_{\text{new}} = Y_{\text{iter}} + \text{rand}(-0.5,0.5) \cdot \left(\frac{y_{\text{iter}}}{\text{y}_{\text{initial}} + T_2}\right) \]  
(10)

\[ Y_{\text{new}} = Y_{\text{iter}} + \text{rand}(-0.5,0.5) \cdot \left(\frac{y_{\text{iter}}}{\text{y}_{\text{initial}} + T_2}\right) \]  
(11)

The change in control variables are denoted as \( \Delta \_1 \) and \( \Delta \_2 \) are shown in equations 12 and 13 respectively which contributes for the final objective functions

\[ \Delta \_1 = f_1^\text{norm}(Q_{\text{RSC}} - Q_{\text{RSC}}^\text{new}) - f_1^\text{norm}(Q_{\text{RSC}} - Q_{\text{RSC}}^\text{iter}) \]  
(12)

\[ \Delta \_2 = f_2^\text{norm}(Q_{\text{RSC}} - Q_{\text{RSC}}^\text{new}) - f_2^\text{norm}(Q_{\text{RSC}} - Q_{\text{RSC}}^\text{iter}) \]  
(13)

IV. THE CASE STUDY USED FOR SIMULATION

The power system considered for the study consists of 12 buses and 4 generators. The same simulated using MATLAB_SIMULINK with a wind turbine and a STATCOM controller, located at the Point of Common Coupling which is at bus 6 is shown in Fig. 6. The system is divided into three areas. The first area consists of generators G1 as well as G2. Generator G3 is in the load side which forms the second area. Doubly-Fed Induction Generator (DFIG) based wind turbine which under consideration for the study proposed, is rated at 2 MW and a 2 MVAr STATCOM, are associated with the third area. The speed of the rotor is 1.2 p.u. A transformer, rated at 0.69/25 kV is used to connect the DFIG to the grid. A three phase PWM converter is used to supply the rotor. A transformer rated at 13.8/25 kV is used to connect the STATCOM at the bus 6 which is the Point of Common Coupling. The system is simulated for the most sever symmetrical type of fault namely the three phase fault between bus 1 and bus 6. The time of fault simulation is enoted as, \( T_f = 50 \text{ s} \) and the time of fault clearing is represented as, \( T_c = 200 \text{ ms} \).

V. RESULTS AND DISCUSSION

The graphical results of a 12 bus power system consist of a DFIG based wind turbine, equipped with a fuzzy logic based STATCOM controller, simulated with a three phase symmetrical fault are shown in Fig. 7 to Fig. 10. The rate of change of voltage magnitude at the point of common coupling during the fault is shown in Fig. 7. The transient voltage stability of the power system is optimally maintained, after clearing the fault through reactive power compensation offered by the STATCOM. It is clearly depicted in Fig. 8 that the low frequency real power oscillations are mitigated by the intelligent behavior of FLC based STATCOM controller during post fault conditions. The variations of control variables namely \( Q_{\text{STAT}} \) and \( Q_{\text{RSC}} \), with respect to time are clearly depicted in Fig. 9 and 10 respectively.

![MATLAB_SIMULINK output for voltage at PCC during 3 phase fault](image1)

![Active power oscillations at the wind turbine during three phase fault](image2)
VI. CONCLUSION
This work presents a VAr compensation strategy of DFIG based wind turbine using STATCOM. A multi-objective problem will be formulated to improve the voltage stability by maintaining within its rated limits using VSI and to mitigate low frequency oscillations by using TPSI during three phase fault conditions. The solution for the proposed problem is optimized using Fuzzy Logic. In order to justify the proposed methodology it is modeled in a 12 bus power system [15] with a 2 MW DFIG using MATLAB-Simulink. The system is then tested by simulating a three phase fault. The graphical results of the case study are analyzed and presented. It is inferred from the results, that the fuzzy based reactive controller is effective in optimizing the power flow even during fault conditions.

In future, this work can be extended by using other types of FACTS controllers like SVC, TCSC, etc. The same work will also be implemented for higher bus power systems like IEEE 30, 57, 118, 300 buses. The same problem can also be studied by simulating various unsymmetrical faults, like, single line to ground (LG), double line to ground (LLG) and double line (LL) faults.

REFERENCES