Analysis Of DFIG Based Wind Integration In Conventional Thermal Power System For Frequency Regulation

S. Chaine*, S. Bhuyan

Abstract: A goal is to establish improvement in the system frequency profile for the power system. The analysis of the dynamic participation of doubly fed induction generator (DFIG) in existing frequency regulation mechanism is presented. The modified inertial control scheme, takes advantage of the fast response capability associated with electronically- controlled variable-speed wind energy conversion systems (WECS), allowing the kinetic energy stored by rotational masses to be partly and transiently released in order to provide earlier frequency support.

Index Terms: WECS, DFIG, AGC, CSA

1. INTRODUCTION
With ever increasing power demand, global warming and wide varieties of constraints, the capacity expansion of existing power system has created the need of integrating renewable energy with conventional power grid. A suitable renewable source should be non-pollutant and be available in abundance so that substantial amount of power can be generated at an acceptable cost. One of the more promising resources in this regard is the wind energy generating power through wind energy conversion systems (WECS) discussed earlier. However, with the increase of wind penetration levels (LP) in the system, the generated power from wind resources fluctuate affecting the frequency deviation of power system.

Author details: For a secure and stable operation of interconnected power system, frequency control is an essential need. By utilizing the decoupled inertia of large numbers of rotating wind turbines in a wind farm, additional power demand for the system can be made available for the purpose of frequency regulation [1], even though the wind generators do not have natural inertial response. A supplementary doubly fed induction generator (DFIG) control can significantly improve the turbine response by introducing emulsion of inertia [2]. In all cases, uniform wind speed across all wind turbines in the wind farm is assumed. The wind turbines have comparable levels of rotational kinetic energy stored in its rotating bodies, almost comparable with that of conventional generators [3]. The effective utilization of this stored energy in providing primary frequency control support to the grid in the event of a load/generation mismatch is a good alternative strategy which attracted considerable interest. The control structure of DFIG based WECS has been modified to introduce inertial response to it, even though the response is often advised for the initial temporary period of power requirement due to the prevailing mismatch. With the proposed control system [4], the DFIG based wind farms can supply considerably greater kinetic energy than a fixed-speed based wind farms.

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A closer understanding of the concept proposed in literature [5,6] needs to be reviewed here. The control strategy is influenced by the following two important features of WECS.
- There is no control over the primary power source, since it depends on the wind.
- The active power injected by nonconventional generators can vary almost instantly.

The first point is an important observation, as that would put a binding constraint which cannot be ignored in the design of a control strategy. The absence of control over the primary power source prevents any possibility of maintaining an arbitrary power output in a continuous manner. If a thermal plant is replaced by wind generation then fewer conventional units will be available to share the operating reserve burden [7-9]. On the contrary, in the case of conventional generators like steam and hydro units, a perfect control over the primary power source is possible even in a continuous manner. Some earlier reported works [10] have not been able to exploit the advantage of WECS mentioned in the second point while utilizing the same in problems of frequency regulation of the system. In this regard, the impact of increased penetration of DFIG based wind turbines on transient and small signal stability of a large power system is analyzed in [11,12]. The rest of the paper is organized as follows: in Section 2 the power system model used for frequency regulation tests is presented; then, Frequency control aspects of DFIG, which is one of the most suitable control methods for this application, is described in Section 3. The control strategy proposed is described in Section 4. Simulation and Results are shown in Section 5; finally, conclusions are given in Section 6.

2 TWO AREA THERMAL SYSTEM
The Linearized model of two-area interconnected power system for the load frequency control is considered [13,14]. It is a combination of conventional thermal power generating units and DFIG-based wind turbine generators. In normal conditions, the power electronic converter enable the variable-speed wind turbines to capture wind energy over a wide range of wind speeds and extracts the maximum amount of generated power by following the principle of MPPT. During intermittent wind conditions and after any disturbance in the grid, the controllers for both the converters achieve a fast control of active and reactive power output by following suitable control strategies. In transient conditions, additional controllers installed for the converters or inertial controllers
facilitate a fast active power control. However, the electronic converter is able to control the generated active power output as per the requirement, almost instantly by utilizing the kinetic energy stored in the rotational masses. The real power control capacity of DFIG makes it suitable for its use in frequency regulation of the system. For a given step change in the load $\Delta P_L$, the inertial contribution from the wind farm can be suitably increased by imposing a proportional power step rise beyond the steady state power setting. The corrected power setting can be fed to the controller of the grid side converter of DFIG to extract more rotational energy from the rotor blades [15]. Wind energy penetration is the fraction of energy produced by wind compared to the total generation. It is defined as wind penetration level ($L_p$) that is the percentage of wind power with respect to the total power generation in the system. In the power system penetrated by wind power, when the penetration levels of WECS increase then the operation and control of power system is affected.

![Fig. 1. Control scheme for frequency support in DFIG based WECS.](image)

Since change in penetration level changes some parameters value, therefore the value of these parameter obtained for different penetration level are depicted as in Table no.1. On increasing penetration level the performance of the DFIG system increases up to certain limit i.e. 20% penetration level. Beyond this, the performance of system diminishes as in fig.2

### 3 Method of Optimization and Objective Function Formulation

The optimization problem aims to optimize the controller gains of both the DFIG and AGC systems simultaneously so that they coordinate with each other. The objective function is made as a single objective, by combining the performances indices obtained from both time and frequency domain responses of the integrated system. The objective function $J$, is formulated by using the values of ITSE, total $T_1$ of both the area frequency and tie line power deviations ($\Delta f_1$, $\Delta f_2$ and $\Delta P_{tie}$), and the minimum damping ratio (MDR) of the eigenvalues of the system, as defined in (1).

$$J = \text{max} (|\text{ITSE}|, \text{max} (|X_1|, |X_2|))$$

### Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>5% $L_p$</th>
<th>10% $L_p$</th>
<th>20% $L_p$</th>
<th>50% $L_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>2.5263</td>
<td>2.6667</td>
<td>3.0000</td>
<td>4.8000</td>
</tr>
<tr>
<td>$H$</td>
<td>4.9361</td>
<td>4.8669</td>
<td>4.7104</td>
<td>4.0153</td>
</tr>
<tr>
<td>$T_s$</td>
<td>19.7442</td>
<td>19.4677</td>
<td>18.8415</td>
<td>16.0611</td>
</tr>
<tr>
<td>$B$</td>
<td>0.4042</td>
<td>0.3833</td>
<td>0.3417</td>
<td>0.2167</td>
</tr>
</tbody>
</table>

### 3.1 Cuckoo Search Algorithm (CSA): An Overview

CSA is an evolutionary algorithm that is inspired by the brood parasitism found in the breeding behaviour of some commonly found species of cuckoos. The algorithm in its structure
incorporates the mathematical model of the behaviour of Lévy flight found in some birds and fruit flies \[16-18\].

As far as applying the algorithm is concerned, three simplifying assumptions described below have been used in this work.

i) Each cuckoo lays one egg at a time which it dumps in a randomly selected nest.

ii) The best nests having better quality eggs, are retained for subsequent generations.

iii) Keeping the total numbers of host nests as constant, an egg laid by a cuckoo could be detected by the host bird with a probability (P_a) of 0.1.

4 SIMULATION AND RESULTS

The simulations are performed in the two area system mentioned earlier using MATLAB/Simulink. Further, the study assumes that the size and capacities of the converters and the controllers of both areas DFIG, driving wind turbines are identical. The local factors and disturbances related to each area do not affect the other in any condition. In many previous researches related to this work, the practice has been to give 20% of wind power support replacing equivalent amount of thermal powers [3] from the systems.

For optimizing the objective functions each of the three parameters integral controller (K_i) in AGC loop of the conventional generating units and K_pf, K_{df} are randomly initialized in suitable ranges and the parameters evolve through successive generation giving the optimum results at the end. K_{pf} and K_{df} are the proportionality constants of the frequency deviation and its derivative respectively. The control parameters of the CSA like numbers of nest (n), the probability (P_a) of detecting a laid egg by host bird and the number of optimising variable (n_d) are chosen after successive runs of the algorithm.

A comparison between CSA and other widely accepted optimization techniques like Linear Programming (LP), Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) can be done here. Table 2 depicts the parameter values of the three optimized gains, obtained with the above discussed single objective based optimization techniques.

The time domain responses of frequencies (\(\Delta f_1, \Delta f_2\)), of both the areas and the tie line power deviations (\(\Delta P_{tie}\)), using the optimized controllers for all the above optimization techniques, are

<table>
<thead>
<tr>
<th>Optimisation method</th>
<th>Controller parameters</th>
<th>(T_S)</th>
<th>MD R</th>
<th>ISTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA</td>
<td>(K_i: 0.72) (K_{pf}: 0.25) (K_{df}: 0.097)</td>
<td>70.90</td>
<td>0.29</td>
<td>0.0069</td>
</tr>
<tr>
<td>LP</td>
<td>(K_i: 0.51) (K_{pf}: 0.31) (K_{df}: 0.195)</td>
<td>78.91</td>
<td>0.17</td>
<td>0.0106</td>
</tr>
<tr>
<td>PSO</td>
<td>(K_i: 0.54) (K_{pf}: 0.27) (K_{df}: 0.290)</td>
<td>84.31</td>
<td>0.17</td>
<td>0.0109</td>
</tr>
<tr>
<td>GA</td>
<td>(K_i: 0.60) (K_{pf}: 0.34) (K_{df}: 0.197)</td>
<td>73.66</td>
<td>0.28</td>
<td>0.0085</td>
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</table>
Step load perturbation causes a substantial frequency fall, the traditional units and the DFIG wind farm would start to provide additional generation for frequency support. The response of DFIG is considerably better than that of the equivalent conventional generation shown in Fig 4-6.

Fig. 3. $\Delta f_1, \Delta f_2$ and $\Delta P_{tie}$ for a 1% SLP in the 1st area obtained with different schemes of controllers.

Fig. 4. Change in frequency of 1st area for 1% load change in 1st area.

Fig. 5. Change in frequency of 2nd area for 1% load change in 1st area.

Fig. 6. Change in Tie line power for 1% load change in 1st area.

It can be observed from the Fig. 4-6, that the dynamic performance in terms of the frequency and tie line power deviations of both the areas are better with the presence of DFIG compared to the case of only conventional unit.

5 CONCLUSION

The fast response capability associated with electronically-controlled PD control loop of DFIG based WECS is utilized to
improve the transient performance of frequency regulation of power system. Integrated with thermal systems, a coordinated tuning of the PD controllers along with those of integral controllers of AGC in a two area is found to be beneficial. The controllers tuned with CSA are found to be better compared to similar controllers optimized with some well known conventional and heuristic optimization techniques i.e., LP, GA and PSO, in terms of their control performance and robustness.

REFERENCES


