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Intelligent frequency regulation in the wind integrated control area☆

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ABSTRACT

Reduction in system inertia due to the higher levels of wind plants in a power system inherently necessitates the frequency regulation investigations and motivates new opportunities for the improvement of active power control techniques. This paper focus on the load-frequency regulation analysis of a control area in the presence of a proposed wind energy technology. The proposed variable speed wind turbine generator model incorporates a dynamic dead-band and moving average frequency filter-based algorithm to provide grid-code compatible power-frequency response. The proposed wind plant model provides better frequency response and increased electrical power generation in comparison to the other frequency responsive wind turbine generator models. This paper also highlights the superiority of gain scheduling concept in fuzzy logic controllers as an improved alternative to various other load frequency controllers under the stochastic conditions in a wind integrated control area.

1. Introduction

Continuous balancing of load-generation in a power system control areas (CA) is substantially based upon the frequency regulation schemes. The active power output of various generators within a CA can be regulated through load frequency control (LFC) which is the first level of frequency regulation scheme known as automatic generation control (AGC) [1]. Frequency regulation in a CA is conventionally provided through the governor-turbine response of synchronous generators. Inertial and primary frequency response enables automatic power delivery in response to the area frequency deviation within a specified time frame and ramp limit, but this dependency is changing under the increased integration of renewable energy.

Wind power plants with improved technology at the reduced cost are now considered as a significant contributor to the stable and secure energy future. The increased penetrations of wind power plants have brought a severe challenge in real-time frequency regulation. Deteriorating system security due to the low system inertia can pose a risk of severe economic impacts. Large-scale load shedding is one of the recommended mitigation methods for frequency control when there is a severe contingency event like system outage [2]. However, load shedding is not an acceptable mitigation method for high wind penetrated control area which may have high-frequency excursions. The impending system inertia reduction due to the increased integration of non-synchronous wind power plants has necessitated the formulation of new rules known as grid-codes for the network operation. Transmission system operators (TSO) currently advocate the enactment of these

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List of acronyms

CA	Control area
LFC	Load frequency control
AGC	Automatic generation control
TSOS	Transmission system operators
VSWTG	Variable speed wind turbine generators
PID	Proportional integral and derivative
ITAE	Integral of time multiplied by the absolute error
ISE	Integral of the Squared Errors
ACE	Area control error
WTG	Wind turbine generator
DFIG	Doubly fed induction generator
NEM	National electricity market
FGS-PID	Fuzzy gain scheduled proportional integral and derivative
pu	Per Unit

operation rules from wind farms in a big interconnected electrical network. Operation of the variable speed wind turbine generators (VSWTGs) in maximum power tracking mode results in zero spinning reserve for utilization in frequency ancillary services. VSWTG models must incorporate advanced active power control algorithms to provide extra active-power support. Advanced controllers may improve the VSWTG plant life by avoiding turbine over speeding and unnecessary starting and shut down of the plants [3]. Most of the VSWTG models discussed in literature utilize an auxiliary power command based on a fixed droop which may not essentially provide a grid-code compatible response. Given the mandatory grid-code frequency response requirements, proposed VSWTG model incorporates a moving averaged frequency filter and dynamic dead-band based active power control algorithm to support better grid-code compatible frequency regulation services.

Application of various control strategies to achieve a proficient frequency regulation in a unified electrical network have received substantial focus from research community since last four decades. From the manual operation [4] to the robust digital operation [5,6], LFC has advanced to the contemporary smart control system [7]. Conservative LFC controllers are more model specific failing to provide a satisfactory response in case of a sizeable non-linear system with stochastic parameters. A degrading performance was observed from the proportional-integral (PI) LFC controller under the effect of increasing wind penetration [6]. On the other hand, robust and dynamic LFC controllers involve complex control structures which are not very much preferred in industrial practices. Intelligent fuzzy logic controllers are widely popular due to their capability to handle imperfect information and inherent uncertainties [8] but basic fuzzy logic based LFC lacks reliability in diminishing the steady state errors to zero [9]. Although the proportional integral and derivative (PID) controller gain tuning methods are extensively developed for linear time-invariant systems [10,11], further research is required for nonlinear as well as stochastic systems like wind integrated nonlinear systems. With changing power system scenario, there is a need for a load frequency controller whose parameters gains can be adjusted continuously on-line and can handle any non-linearity or parameter uncertainties arising due wind plant penetration in the electrical grid. In view of the above discussions, the objectives of the current paper are as follows:

1. To present a grid frequency processor scheme based on dynamic dead-band around moving averaged frequency instead of conventional static dead-band for generation of continuously varying, frequency sensitive active power reference set point for VSWTG and its corresponding effect on system frequency control.
2. To discuss frequency sensitive response through dynamic dead-band concept and non-symmetrical droop for electrical power variation at wind turbine level.
3. To highlight the integration of knowledge representation of Gain scheduled rule-based fuzzy controllers with simplicity of PID controllers to achieve an improve frequency response from a stochastic system in comparison to other LFC controllers.
4. To present the improvement in system frequency in a low inertia system in presence of grid code sensitive wind plant participation in frequency control.

The brief outline of the paper is as follows:

Section 1 of the paper presents the load frequency control system modeling. Section 2 presents the frequency sensitive active power control modeling in wind power plant through dynamic dead-band and non-symmetrical droop concept. Including the proposed active power-frequency grid-code compatibility in VSWTG modeling enables additional electrical power support during frequency disturbances for a longer duration. Fuzzy gain-scheduled load frequency controller is discussed in the third section while the simulation results for the intelligent LFC controller performance in the wind penetrated control area is discussed in the last part of the paper.