Electrical Power and Energy Systems 99 (2018) 603–617

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Analysis of frequency sensitive wind plant penetration effect on load frequency control of hybrid power system

Asma Aziz[a,*], Aman Than Oo[a], Alex Stojcevski[b]

[a] Deakin University, Australia
[b] Swinburne University, Australia

ARTICLE INFO

Keywords:
Load frequency control
System bias
Area control error
DHCP model
Grid code frequency sensitive wind plant

ABSTRACT

Integration of wind penetration has moved the electricity grid in a transition phase to a new model where wind power plants are expected to participate in all levels of frequency regulation. This paper analyses the load frequency control of hybrid power system consisting of thermal, hydro and gas-based power plants in the presence of non-scheduled wind plants under different operating modes and under different penetration level. A moving average filter and dynamic dead band dependent frequency-active power controller is applied to augment the type-3 wind plant model. Simulation results presented here provides some guidance on the design parameters of frequency regulation scheme in the presence of frequency sensitive wind plant. Simulation results indicate that the penetration level up to 60% of grid code compatible frequency sensitive wind plants participating in the AGC system is a possibility in a strongly interconnected network with low load disturbance. Control area having grid code compatible frequency sensitive wind plant integrated with thermal plant presents better LFC performance than the control area having wind plant combined with gas or hydro power plant. The gas-based power plant model dependency upon fuel limitation and maximum-minimum load limitation highly affects the frequency response and makes them suitable as peak load plant only. A detailed representation of temperature control and maximum rate of fuel valve closing must be included in models to get the proper range of frequency deviations occurring in gas plant based network.

1. Introduction

Power systems around the world are undergoing the continuous shift from centrally dispatched large-scale synchronous generation towards intermittent renewable energy sources. There were 43 countries with Renewable energy target (RET) in 2005 which rose to 164 countries in 2015 [1]. This change in generation mix due to high renewable energy penetration challenges the interconnected system designs built under different network configuration, operational strategies and the regulatory framework within which it operates. The automatic generation control (AGC) problem has been extensively studied during the last four decades, and it has been one of the most highlighted issues in the design and operation of independent and interconnected power systems [2–8]. LFC is used as part of AGC to maintain constant frequency and to regulate interconnection power flows. Maintenance of system frequency within the utility prescribed tolerance band was earlier considered as the exclusive responsibility of the conventional power plants. Preponderance on renewable sources like wind energy that demand different management as compared to a conventional system has moved the electricity grid in a transition phase to a new model. These sources having new production and nonlinear control technology imply new energy management system (EMS) with AGC being one of the major units of EMS in modern power system [9]. Load Frequency Control (LFC) is used for many years as part of Automatic Generation Control (AGC) in power system around the world [10–14]. With the advances in the control techniques, wind-based power plants are also expected to participate in all levels of frequency regulation. Modern wind turbines now incorporate the possibility for their active power outputs to be controlled almost instantaneously as required by system frequency and operators command. According to the Hydro Quebec's revised grid code 2005 [15], all new wind turbines must present the capability of providing a power increment up to 6 percent of their nominal capacity for 9 s within 1.5 s during low-frequency events. Transmission operators like independent electric system operator (IESO) in Ontario [16,17] and National do Sistema Elétrico (ONS) in Brazil [18] have formulated similar grid codes requiring active power control from wind farms > 50 MW and inertial response respectively. Grid codes like that of U.K. [19,20] require a response from wind farms under normal conditions and limited up/down response under high-frequency conditions. The required power response range can be

* Corresponding author.
E-mail address: asma.aziz@deakin.edu.au (A. Aziz).

https://doi.org/10.1016/j.ijepes.2018.01.045
Received 19 November 2017; Received in revised form 20 January 2018; Accepted 28 January 2018

Nomenclature

Acronyms

LFC	load frequency control
AGC	automatic generation control
TAIPS	three area interconnected power system
VSWTG	variable speed wind turbine generators
DCHP	decentralized combined heat and power plant
MPPT	maximum power point tracking
ITAE	integral of time multiplied by absolute error
PID	proportional integral derivative
ACE	area control error
WPP	wind power plant
DFIG	doubly fed induction generator
MAF	moving average filter
p. u.	per unit
T_p	power system time constant
K_p	power system gain
ΔP_t	conventional generation units power variation
ΔP_W	wind power output
ΔP_L	load disturbance
$\Delta P_{tie,i}$	area I tie-line power variations
H_{eq}	control area equivalent inertia constant
D	load damping constant
Δf	frequency deviation
B	area bias
R	generator droop
L_p	wind penetration level
P_{INT}	wind inertial power
P_{APC}	active power setpoint
T_d	delay time
α	AGC participation factor
DB-UP	upper dead-band
DB-DN	lower dead-band

between 2% and 10% of nominal power rating [21]. While frequency response capability offered by a conventional plant can be counted on with good assurance once the appropriate control modes are on, the response capability of a wind plant will always be conditional on the statistics availability of the wind. Past studies raised the concerns that the integration of wind energy systems at large penetration level will have widespread technical impacts on power system stability and reliability. Studies showed that wind energy integration effects on system frequency and power fluctuation are nonzero and become more significant at higher sizes of penetrations [22–26]. Load frequency analysis in the presence of wind energy is discussed in several academic literatures with the significant focus on the effect of wind intermittency, low system inertia, frequency deviation. DFIG based wind farm integrated with thermal energy system is investigated in [27]. This study shows that operational impacts of the wind power fast fluctuations are primarily absorbed by the thermal unit's substantial mechanical and thermal time constants as well as control dead-bands. 5% of rated plant power can be accepted as perturbation power by thermal plants, without exceeding the frequency deviation margin. Another study indicates that AGC control standards CPS1 & CPS2 deteriorate with increasing wind penetration and this effect is observed more for large interconnected systems [26]. Wind power as a negative load was applied to examine the impact on inertia, regulation, tie-line flow at different penetration level. A coordinated control strategy for the AGC between combined heat and power plants (CHPs) and wind plants is presented in [28] to enhance the security and the reliability of a power system operation in the case of a substantial wind power penetration. Proposed control strategy shows that the wind plant can actively help the AGC, and reduce the real-time power imbalance in the power system, by downregulating their production when CHPs are unable to provide the required response. A droop control based wind turbine model for emulated inertial response is integrated into a multi-generational system for LFC analysis [29]. This study concluded a lagging AGC performance from wind integrated system in comparison to conventional systems. Wind farm participation in AGC can introduce uncertainty due to change of weather conditions. With the changing wind, VSWTG operation varies from command mode to maximum power tracking mode resulting in uncertain participation. Robust stability analysis of LFC system under wind penetration with uncertain participation in AGC is investigated in [30] through edge theorem. It was concluded that wind plant could contribute effectively to AGC and respective power system remains stable for all participation factors and transitions in them. In [31], multi-area LFC system is proved to be stable under load and system parameters uncertainty through theoretical and simulated results. All of these previous studies lack the frequency response analysis of grid code compatible wind energy system on the interconnected network. Increased penetration of wind generation in interconnected power system and impending requirements to follow grid codes thus intrinsically calls for AGC analysis for frequency regulation with present and future wind technologies in a hybrid power system with multi-generational sources.

Dynamics of different combinations of turbine-generators have different effects on system frequency maintenance [32]. Generation technologies are dispatched by their capability of responding to variations in demand and fuel type. A steam turbine converts the potential energy of high temperature and pressure steam into mechanical (rotating) energy, which then is converted into electrical power in the generator. Compared with steam turbines, hydro turbines are easier and cheaper to control, while gas turbine model is quite complicated concerning earlier two as this system must take care of different control loops and actuate only one control as per requirement. The study of a gas-based power plant in AGC is essential from the viewpoint that gas-based plants are increasingly being added to the grid system and gas turbines construction and dynamics are very different from hydro and steam turbines. The generators are of round-rotor type, have relatively low inertia compared to hydraulic units, and they spin at higher speeds. The hydropower systems have the relatively large inertia of the water being used as the source of energy which causes a significantly more considerable time lag in response to changes of the prime mover torque, due to changes in gate position. Also, the response may contain oscillating components caused by the compressibility of the water or by surge tanks. Following a sudden load rejection event, a low inertia machine can experience excessive over-speed, which can be harmful if over speed protection fails to operate.

Modern WTGs have inertia constants which are comparable to those of conventional turbine-alternators. The single wind turbine has inertia constant value in the range of 4–6 s which is comparable to hydro and fossil steam based plants in similar MVA rating range [33,34]. Also, VSWTGs can operate in a wide range of speed changes. The VSWTG generator speed can drop to as low as 0.7 p. u. speed [35], while the conventional generating unit speed can only fall to as small as 0.95 p. u. speed [36,37]. Wind kinetic energy could be utilized to provide temporary frequency control support to the grid in the event of a load/generation mismatch. However, the power is limited by the operating conditions and the power rating of the VSWTG.

Given the above discussion, the prior art of load frequency analysis is extended in this study through following contributions:

1. Frequency response analysis and comparison of three different fuels based power plants with and without wind energy integration.