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Enhancement in Primary Frequency Contribution using Dynamic Deloading of Wind Turbines

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Abstract: This paper presents a fuzzy logic based scheme to enhance the primary frequency contribution of grid connected variable speed wind turbine generators (WTGs). Deloading of WTGs from its maximum power point generates reserve margin which can be used to stabilize the power system during frequency deviations. In this paper, deloading power of WTG is adjusted continuously which increases the output power from deloaded WTG. Combination of dynamic deloading and variable droop operation of WTGs gives best performance in terms of reduction in frequency excursion and increase in output power of deloaded WTG. Extensive MATLAB results are presented by considering different cases.

Keywords: Variable speed wind turbine, primary frequency regulation, fuzzy based deloading control, variable droop operation.

1. INTRODUCTION

Nowadays, wind power is the fastest growing and most widely used renewable energy technology in power system due to clean and free fuel cost. Unlike conventional synchronous generator, WTG has no inherent inertial response with frequency variation because it is decoupled with the grid by an electronic converter. With the growing penetration of large-scale wind generation into modern power system thus may results in increased rates of frequency deviations when system event occurs such as switching ON/Off of large load, loss of generation, etc. [1]. Therefore, it may soon become mandatory that wind turbine generators (WTGs) should participate in system frequency regulation [2]. Hence, to support the frequency control in wind farms as like conventional power plants, the frequency sensitive control loops are implemented as supplementary control in the revised new grid code [2]. The frequency sensitive control loops such as droop control, kinetic energy control etc. are help to provide short term frequency support with system events. The initial response of generating units to this frequency change is termed as primary frequency response [1, 3-12]. Primary control establishes the active power balance between generation and demand by using proportional control action, also known as droop control [1, 3-5]. It is relevant to note that the initial rate of change of frequency deviation dependent on the total inertia of the power system at any system events. Higher the rotating inertia, slower is the rate of fall of frequency and vice-versa [1, 4-8].

In previous literatures, it is mentioned that the implementation of both droop control and inertia emulator improves the dynamics of the system frequency response [4-5]. Any generating unit to be used for primary frequency regulation, availability of sufficient reserve capacity is an important requirement. This is possible by shifting the operating point of WTG from its maximum tracking power to a reduced power level. This is called as deloaded operation of WTG [1, 7-16].

The deloading operation of WTG can be achieved by rotor speed control and/or pitch angle control [1, 3-15]. To avoid mechanical damage and safe operation of wind turbine blades, rotor speed of the WTG is limited by its pitch angle controller at higher wind speed [4-7]. In [7-11], authors have considered pitch angle control based deloading operation at low and medium wind speed. However, increase in pitch dynamics may affect life of the pitch controller and more maintenance cost. The mechanical damages may also cause by the frequently change of the pitch angle which increase wear-tear on the gear system. In [12-13], authors have considered fixed percentage of deloading of WTGs. However, operating with constant deloading point will reduce the generated output power of the WTGs. In [1, 14, 15] authors have developed a control strategy to modulate the primary frequency support from deloaded WTGs by varying the deloading parameter continuously. In [1, 14, 15], on power vs rotor speed characteristics the curve between MPPT point and deloading power point is assumed to be a straight line (i.e. linear relation) for different wind speeds, which is not accurate (refer Fig.1). Due to consideration of linear relationship between deloading power and rotor speed may reduce the extracted output power of the deloaded WTG with system events.

The deloaded operation reduces the output power of the WTGs, but increases the primary frequency contribution for long-term frequency deviation for any system events. However, deloading is restricted between 10-20%, which depends on rotor speed limit constraints, available wind speed and converter rating [1, 13]. Due to deloading of WTG, its output power reduces and hence the annual capacity factor (CF) of wind farm decreases. For example 10% deloading reduces the CF of wind farm by 10%.

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Proper methodology to choose the percentage deloading is not highlighted in the past literatures. In this paper, fuzzy logic based intelligent control method is implemented to calculate the non-linear deloading parameter. Hence, deloading parameter is adjusted continuously; CF of wind farm can be increased. The proposed dynamic deloading with co-ordination with supplementary controls such as droop control and inertia control give better primary frequency regulation. Moreover, modified pitch angle control is implemented to reduce the pitch dynamics of WTG. In this study, Doubly Fed Induction Generator (DFIG) based variable speed wind turbine is considered.

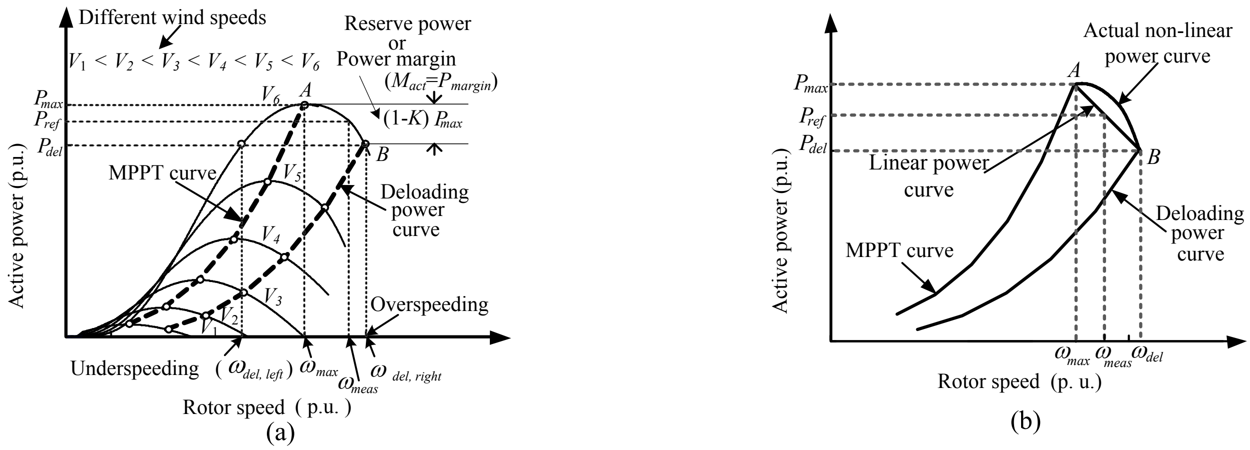

Fig. 1: (a) MPP and deloaded curve, (b) Deloaded and maximum active power curve

2. FREQUENCY CONTROLLER DESIGN FOR WTG

2.1 Deloading Operation of WTG

To participate in the primary frequency regulation, at any instant the WTGs should have sufficient reserve margin. This is possible by operating WTGs on deloading curves instead of maximum power point (MPP) as shown in Fig. 1 [1]. WTGs are deloaded by shifting the operating point on right side of curve say from point '*A*' to '*B*' as shown in Fig. 1(a). As far as DFIG is concerned, the maximum deloading is to be decided by considering the allowable maximum rotor speed i.e., 1.33 p.u. [1].

The dynamic operating reference power (P_{ref}) of the deloaded WTG for any rotor speed and the power margin of a WTG for any particular wind speed are calculated as:

$$P_{ref} = P_{del} + P_{margin}\left[\frac{\omega_{del} - \omega_{meas}}{\omega_{del} - \omega_{max}}\right] \quad (1)$$

with $P_{margin} = P_{max} - P_{del}$ (2)

and $P_{del} = K\, P_{max}$ (3)

where, P_{max} – maximum power (p.u), P_{del} – deloaded power (p.u), ω_{max} – rotor speed at P_{max} (p.u), ω_{del} – rotor speed at P_{del} (p.u), ω_{meas} – measured rotor speed (p.u), K – percentage of deloading.

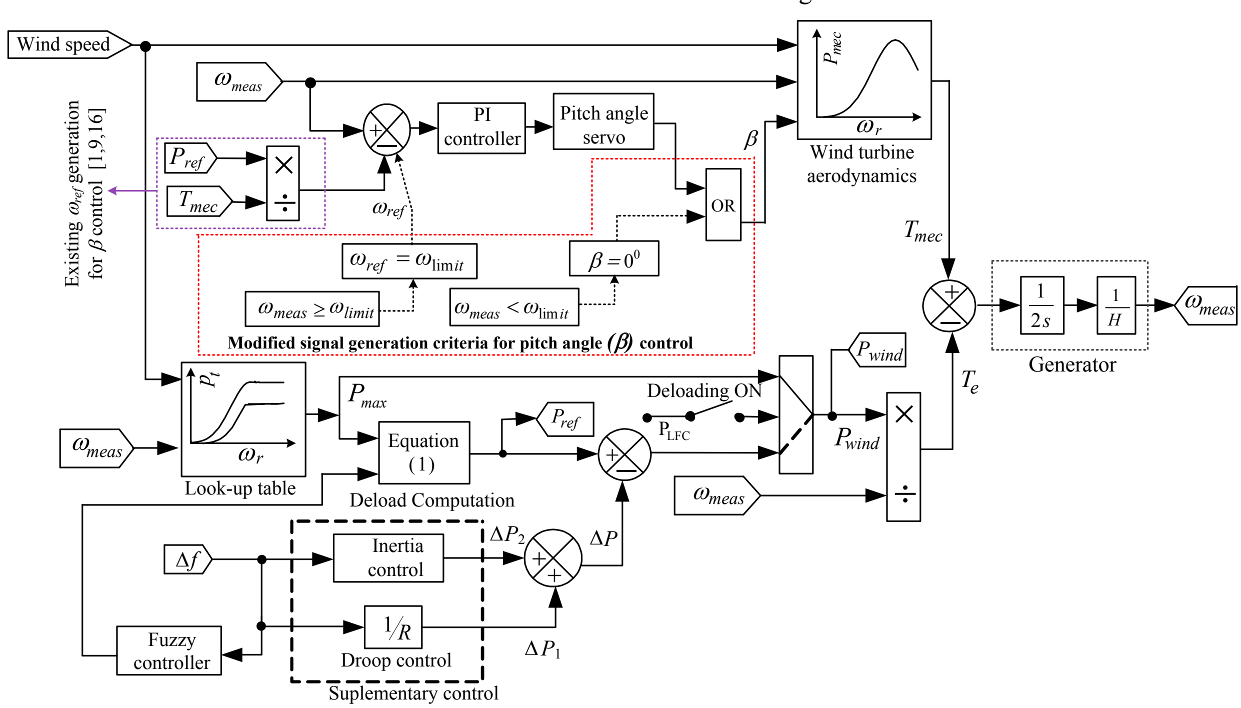

Fig. 2: Modeling of DFIG based wind turbine for primary frequency control