

Frequency Regulation in Microgrid by Wind Turbines Operating in MPPT and Deloading Modes Using Droop Control Characteristic

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Abstract. This paper presents the frequency regulation using wind turbines in microgrid connected systems. Frequency regulation is achieved by operating the wind turbines in MPPT and deloading modes using fixed droop control. Generally wind turbines are operated at maximum efficiency which implies that there is no reserve power that can be used to regulate frequency. Deloading creates a power margin in Doubly Fed Induction Generator(DFIG) wind turbines so that they can also participate in primary frequency regulation. Frequency regulation in Maximum Power Point Tracking(MPPT) and deloading modes is simulated in this paper. The effectiveness of providing frequency regulation in both modes is discussed.

Keywords: Primary frequency regulation, MPPT, deloading, droop control, DFIG based wind turbines etc.

1. Introduction

Large integration of Wind Energy Conversion Systems into conventional generation has some issues especially with the wind energy systems because of the rapid variation of primary source, wind. High penetrations of wind energy sources into conventional systems lead to output power fluctuations. The decoupling nature of Variable Speed Wind Turbines (VSWT) like the DFIG imposes restrictions because of the power electronic interface with the grid. The VSWTs are operated to have optimum efficiency for maximum power output at any wind speed which implies that there is no reserve power which can be varied with frequency. As a result wind turbines do not have inherent frequency regulation capability. Sufficient amount of reserve margin is an important requirement for any generator to participate in frequency regulation which is absent in a Wind Turbine Generator.

Stable active power control strategies of DFIG is given based on the high, medium and low wind speed [1]. The moving-average with K deviation method is introduced to preserve a certain amount of wind power reserve. J. Morren et al. has proposed a method to let variable-speed wind turbines emulate inertia and support primary frequency control [3] from the kinetic energy stored in the rotating mass of the turbine blades. An active and reactive power control by DFIG in a wind park is proposed in [4]. For this wind turbines are operated over a deloaded maximum power extraction curve and supervisory wind farm control acts to adjust the output of wind park by a request from operator. This paper implements the primary frequency regulation in a microgrid consisting of wind turbines. Also the frequency regulation is carried out at different operating modes of the wind turbines i.e. at MPPT and deloading modes. Deloading of WTG is done to create reserve power. Simulation of both modes is done by using droop control strategy.

2. System Modeling

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2.1. Wind Turbine Aerodynamical Equations

The mechanical power output from a wind turbine is given by

$$P_m = 0.5C_p(\lambda, \beta)\rho AV_w^3 \quad (1)$$

where C_p is the power coefficient which is a function of Tip Speed Ratio(λ) and blade pitch angle(β); ρ is the air density; A is the area swept by the rotor blades; V_w is the wind speed velocity.

$$C_p(\lambda, \beta) = 0.73 \left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2 \right) e^{-18.4/\lambda_i} \quad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{(\lambda - 0.02\beta)} - \frac{0.003}{\beta^3 + 1} \quad (3)$$

Tip-speed ratio (λ) is given by

$$\lambda = \frac{w_t R}{V_w} \quad (4)$$

where w_t is the angular speed(in rpm) of the turbine rotor; R wind turbine rotor radius

2.2. MPPT and Deloading Operation of Wind Turbines

Maximum Power Point Tracking is the natural way to maximize the energy capture of a wind turbine. Such an operational strategy makes the wind turbine extract as much power as it possibly can for each given wind speed. This is the economically most beneficial method of operating a wind power plant but when grid codes begin to put requirements on wind power to help in e.g. frequency regulation, operational modes other than MPPT are required. As a frequency dip occurs, the wind turbine should be able to increase its energy capture up to the maximum available level, thereby providing as good frequency support as possible. This is possible only when the wind turbines have some reserve power in them. No reserve power can be expected from the wind turbines when they are operating at their optimum power. Operational strategies that help to create reserve power like these are commonly referred to as deloading methods[4].

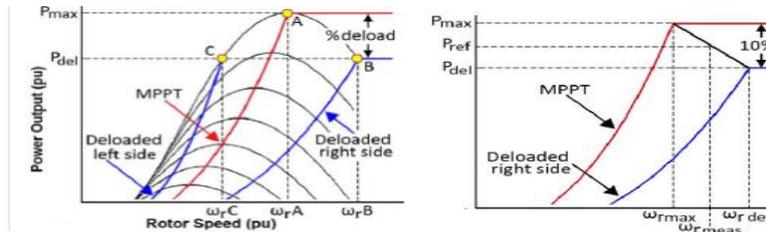


Fig. 1 (a) MPPT and deloading power curves, (b) Power reference calculation for deloading operation

In this paper deloading is done by pitch angle control. Fig 1(a) shows the MPPT and deloading curves of a wind turbine generator for different wind speeds for a 10% deloading[5]. The percentage of deloading is to be decided considering the allowable maximum limit of the DFIG rotor speed. For 10% deloading, $P_{del} = 0.9 P_{max}$. P_{ref} is the operating power reference for the DFIG wind turbine generator for any rotor speed $w_{r\ meas}$ and is given in

$$P_{ref} = P_{del} + (P_{max} - P_{del}) \cdot \left[\frac{\omega_{r\ del} - \omega_{r\ meas}}{\omega_{r\ del} - \omega_{r\ max}} \right] \quad (5)$$

where P_{max} is the maximum power [p.u.]; P_{del} is deloading power [p.u.]; $w_{r\ max}$ is DFIG rotor speed at P_{max} [p.u.]; $w_{r\ del}$ is DFIG rotor speed at P_{del} [p.u.]; $w_{r\ meas}$ is measured rotor speed [p.u.].

The pitch angle controller is used for adjusting the wind turbine blade pitch angle during high wind speeds and deloading operation. The reference speed for pitch angle controller is calculated as

$$\omega_{r\ ref} = \frac{P_{ref}}{T_{mec}} \quad (6)$$

Where P_{ref} = power reference of DFIG [p.u.]; T_{mec} = measured mechanical torque [p.u.].

2.3. DFIG modeling

In this paper a simplified model of the DFIG is considered where the converter dynamics are neglected. The generator can be modelled as a torque source, which immediately generates an amount of torque equal to the set point generated by the rotor side controller. The reduced and the detailed model of the DFIG are given in [1] and [2] respectively. The only resulting differential equation associated with the generator and the converter that remains after simplification is the equation of motion

$$\frac{dw_r}{dt} = \frac{1}{2H} (T_m - T_e) \quad (7)$$

where w_r is frequency [p.u.]; T is the torque [p.u.]; and H is the inertia constant of the rotating mass (sec). The indices m and e are mechanical and electrical, respectively.

In a conventional synchronous generator, governor droop parameter(R) is used to increase the power generated in proportion to change in frequency. The wind turbines have infinite droop because their response to frequency in this case is zero and also there is no inherent drooping feature in them. A controller is implemented in the wind turbines (Fig. 4(a)) so that they can also respond to frequency. df/dt emulates the inertial response and the signal Δf makes the signal respond to frequency changes. df/dt prevents the rate of change of frequency in the initial stage. The droop parameter of the primary speed governor of a generating unit allows multiple units to share common loads. The speed droop parameter (R) is defined as

$$\%R = \frac{\Delta f}{\Delta P} * 100 \quad (8)$$

Where Δf = Incremental change in frequency [p.u.]; ΔP = Incremental change in power [p.u.]

The grid codes of various countries stipulate governor droop settings between 3%–6%, for all units participating in the system frequency regulation. Referring to the supplementary control loop of the DFIG in Fig. 4(a), the primary frequency contribution (PFC) of the WTG to the changes in the system load demand can be computed as

$$\Delta P \propto \frac{\Delta f}{R} \quad (9)$$

where ΔP represents the individual power contribution from each wind turbine for a frequency change Δf .

3. Simulation Results

To study the proposed method, a microgrid consisting of 4 WTGs, diesel driven synchronous generator has been considered. Each WTG is of 1.5MW capacity and the synchronous machine is of 5 MVA (1 p.u.) capacity. The inertia constants of thermal unit and WTGs are 5 s and 5.04 s, respectively, on the individual machine base. On a 5 MVA system base, the WTG inertia constant reduces to 1.512 s. An integral controller is modelled in the thermal machine for the secondary frequency regulation. The governor and engine dynamics of the diesel generator (DG) has a droop setting of 6%. [5]

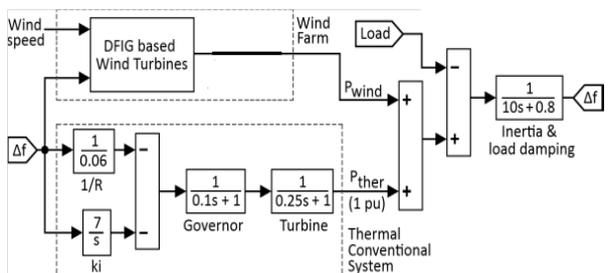


Fig. 2 Microgrid for implementation of the proposed method.

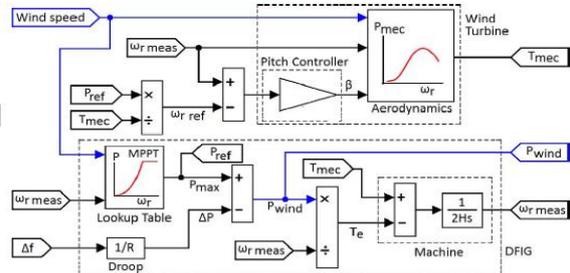


Fig. 3 Modeling of the individual WTG for frequency study in MPPT mode

The wind turbine generator also has a droop setting of 6%. The wind turbines in the farm are distributed in such a way that the k th WTG output differs from that of the $(k-1)$ th WTG by the time delay it takes the wind to cross the distance separating them. Due to this time delay, no two WTGs will see the same wind speed pattern at the same instant. Fig. 2 shows the microgrid used for implementing the proposed strategy and the individual WTG arrangement for frequency study is shown in Fig. 3. Here WTGs are operated in MPPT mode. Whenever a frequency dip occurs, the K.E. of the wind turbine blades is used to increase the

power output of wind turbine in the MPPT mode resulting in the decrease of the turbine rotor speed. But if at all, additional power is required for frequency compensation, reduction in the rotor speed of the wind turbine is detrimental, resulting in the stalling of the wind turbine. It has been observed from Figures 7 & 8 that providing frequency regulation in MPPT mode leads to power output exceeding the rated power of the wind turbine.

To avoid such a situation, adequate reserves are created by deloading the wind turbines. Fig. 4(a) shows the modeling of the deloaded WTG for frequency study. Fig. 4(b) shows the wind speeds at each wind turbine of the microgrid. Switching from MPPT to deloading mode is done by using a switch which is ON at 25sec. Figures 5&6 shows the MPPT and deloading power curves using the wind turbine aerodynamical equations. From these graphs lookup tables are formed consisting of deloaded power and MPPT power for a particular wind speed. Fig. 9 shows the variation in frequency of microgrid for a change in load in the deloading mode.

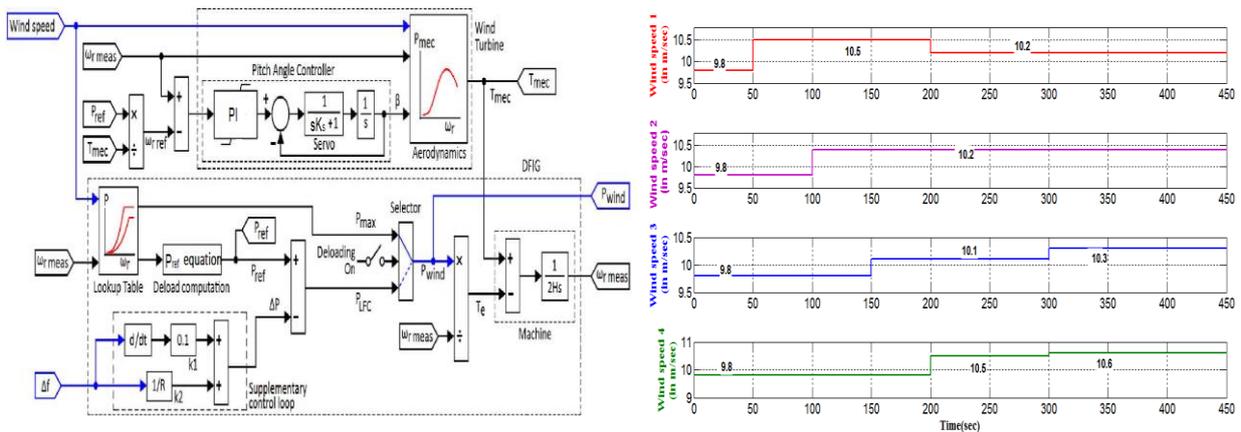


Fig. 4(a) Modelling of the individual WTG in deloading mode (b) Wind speed at each wind turbine

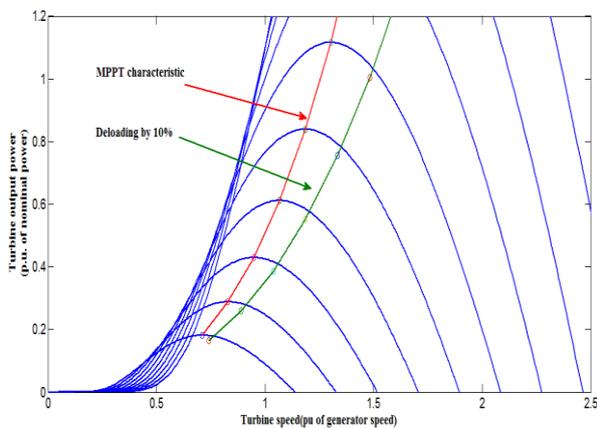


Fig. 5 MPPT and deloading power characteristics

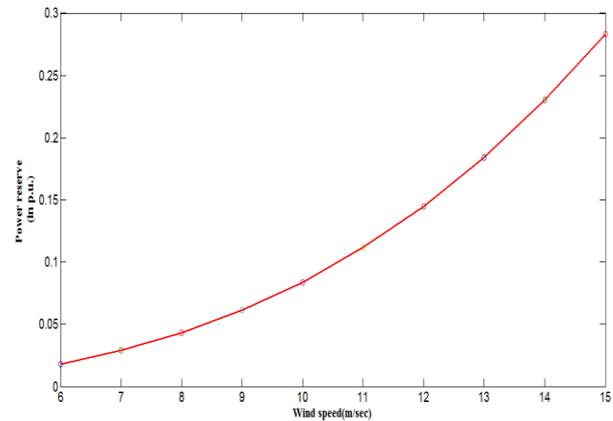


Fig. 6 Power reserve available at each wind speed

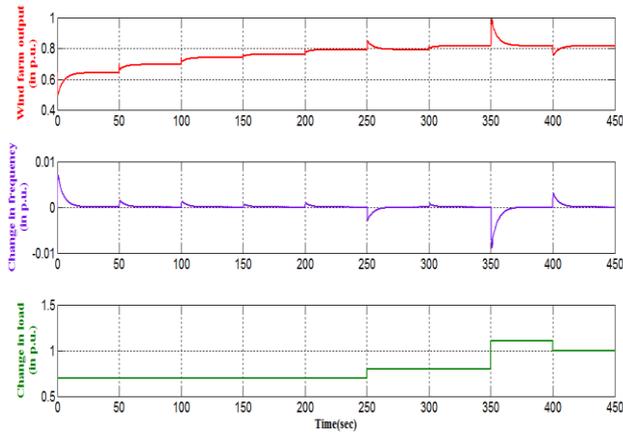


Fig. 7 Wind farm output and frequency change in MPPT mode

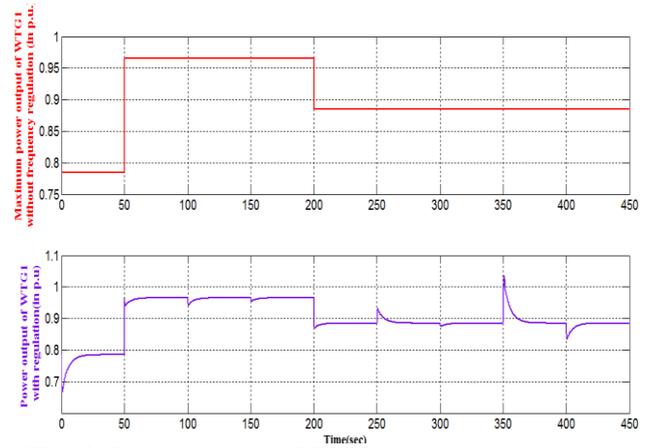


Fig. 8 Power output of WTG1 with and without frequency regulation in MPPT mode.

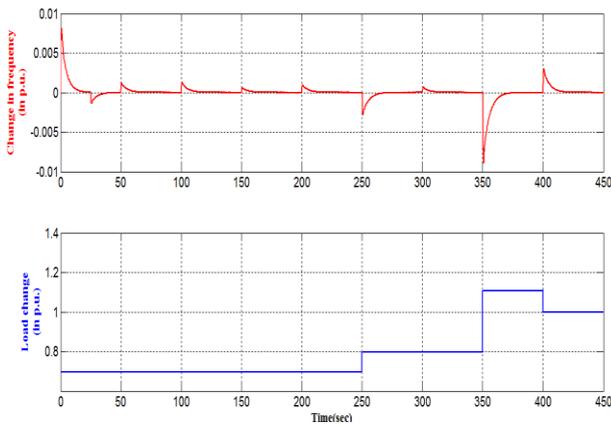


Fig. 9 Change in frequency for load and wind speed changes in deloading mode.

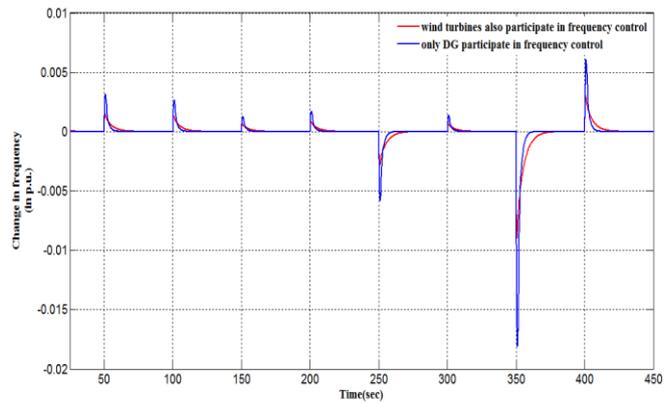


Fig. 10 Frequency variation of the microgrid with and without participation from wind turbines.

The results from deloading operation of wind turbines are shown in Figures 11 & 12. Pitch angle also varies during deloading. When all the units in the microgrid participate in frequency regulation, the deviation of frequency from nominal is less as observed in Fig. 10.

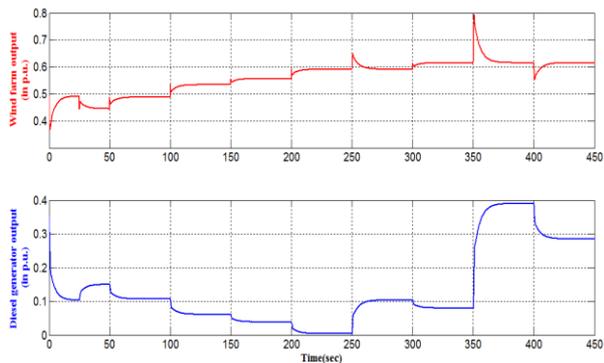


Fig. 11 Wind farm output and DG output in deloading mode.

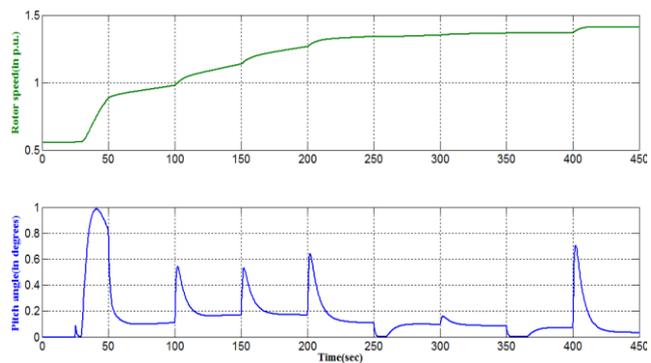


Fig. 12 Rotor speed and pitch angle variation in deloading mode

4. Conclusion

Frequency regulation in a microgrid connected system using wind turbines is discussed. This is achieved using droop control characteristics implemented both in MPPT and deloading operating modes of the wind turbines. From the results it is observed that the deloaded mode of operation of wind turbines is better than the MPPT mode in primary frequency regulation. The stable operation of the DFIG is ensured even during high wind speed, mainly possible due to the availability of power reserve margins in the deloaded mode of operation. It also prevents the stalling of wind turbines during large frequency dips.

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6. References

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