A Study on Undesirable Impacts of Implementing Frequency Support Controllers In PMSG And DFIG

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Abstract- *Although wind power as a renewable energy is assumed to be an advantageous source of energy, its intermittent nature causes difficulties especially in the islanding mode of operation. Conventional synchronous generators can help to compensate for wind fluctuations, but the slow behavior of such systems may result in stability concerns. Here, the virtual inertia method and droop method, which imitates the kinetic inertia of synchronous generator, is used to improve the system dynamic behavior. Since the proposed method focuses on short-term oscillations and incorporates no long-term power regulation, it needs no mass storage device. Thus, the method is economical. To prevent any additional cost, the rotating mass connected to the PMSG and DFIG shaft or a super-capacitor connected to the DC-link of a back-to-back inverter of a wind power generator could be used. The concept and the proposed control methods are discussed in detail. Eigen-value analysis is used to study how the proposed method improvessystem stability. The proposed approach also shows that while virtual inertia is not incorporated directly in long-term frequency and power regulation, it may enhance the system steady-state behavior indirectly.*

I. INTRODUCTION

DUE to environmental, technical and financial issues, there is unprecedented interest in effective integration of wind based energy sources. The intermittent nature of wind could be accounted as its most challenging characteristic. To extract the maximum available power from wind with fluctuating speed, variable-speed turbine is required [1]. To cope with this requirement, a doubly-fed induction generator (DFIG) and permanent magnet synchronous machine (PMSG) is commonly used in type-3 and type-4 wind turbines as it can be controlled to maximize the extracted energy using partial-scale converters with lower ratings as compared to the full-scale back-to-back converter topology used with synchronous generators. Recently, and especially after introducing the concept of micro grid to enhance supply reliability and increasing utilization of inertia-less type[2] of generation in power grids, it becomes essential for wind turbines to participate in frequency regulation. Even in the grid-connected mode, many grid codes have changed to allow or even force wind power generation to participate in primary frequency regulation [3]. Significant part of research efforts is devoted to the use of wind turbine rotating mass, whereas several proposals are made to provide this energy by deviating from maximum power extraction point. Interestingly, the use of frequency deviation, i.e., frequency droop method and virtual methods are used for frequency regulation. It is reported that this methods has more advantages however, detailed analysis was not provided to prove these arguments. Frequency regulation methods have been investigated in several studies, however, their practicality has not yet been discussed thoroughly. Recently, pointed out that the rate of change of power (ROCOP) associated with the implementation of virtual inertia can be a limiting factor. A higher ROCOP leads to higher wear and tear in a wind generator and consequently faster aging and higher maintenance cost. This is a very important factor, because it has been recently found that aging in wind power generators, even in conventional units without frequency regulation ,is faster than what was previously expected owing to mechanical breakdowns. On the other hand, effective frequency regulation performance demands a higher permissible ROCOP. The impacts of this trade-off problem and possible mitigation strategies are not deeply investigated in the current literature. Conventionally, a simple rate limiter, usually with a threshold of approximately 0.2 per-unit (pu)/s, is commonly adopted to limit the ROCOP. Even though the study addresses the importance of the ROCOP, it does not discuss owing to the lack of theoretical analysis the disadvantages and possible alternatives of the rate limiter block. Further, it does not explain why the ROCOP is not a concern in a conventional wind generator and, therefore, the rate limit constraints could be relaxed. Furthermore, a single-mass mechanical model is usually adopted in droop- or virtual inertia-related studies. Motivated by the aforementioned difficulties, this paper provides a systematic analysis of the impact of droop and virtual inertia implementation on the mechanical tensions of generatorsintypicaltype-3andtype-4windturbines.Itdiscusseswhy without implementing frequency regulation, the ROCOP, even for fast changes in wind speed, is not a serious concern. The impact of both droop and virtual inertia and effectiveness of the rate limiter method are also investigated. Finally, the paper presents a compensation method to relax the trade-off between effective virtual inertia implementation and the ROCOP limits. Motivated by the aforementioned difficulties, this paper provides a systematic analysis of the impact of droop and virtualinertia implementation on the mechanical tensions of generators in typical type-3 and type-4 wind turbines. It discusses why without implementing frequency regulation, the ROCOP, even for fast changes in wind speed, is not a serious concern. The impact of both droop and virtual inertia and effectiveness of the rate limiter method are also investigated. Finally, the paper presents a compensation method to relax the tradeoff between effective virtual inertia implementation and the ROCOP limits. Time domain simulation results based on detailed nonlinear models validate the theoretical results.

II. MODELING AND ANALYSIS OF SMAL SIGNAL

The following equation describes the wind turbine power

$$P_m = 0.5\rho C_P(\lambda,\beta)A_r v_w^3$$

where ρ is the air density; CP is the power co-efficient of the wind turbine; λ is the tip ratio; β is the pitch angle; Ar is the effective area covered by the turbine blades; Vw is the wind speed; ωg is the generator speed; and Pm is the mechanical input power. The following equation represents the desired electrical output power of the generator.

$$P_{g\text{-ref}} = K_f K_{\mathrm{OPT}}\omega_g^3 + P_{reg} + P_{ad}$$

The first term on the right side is related to the maximum power extraction, where as the second term reflects the active power needed for frequency regulation, either by droop or virtual inertia control. When droop necessitates a deviation from maximum power extraction. The desired generator power is compared to the actual one and fed to a PI power controller to generate the desired current as shown below.

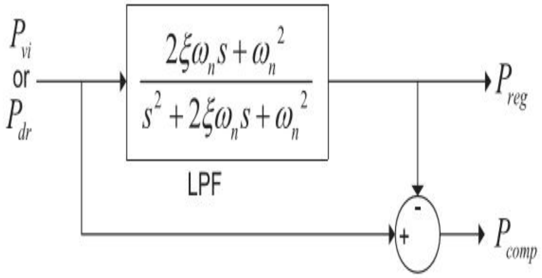
$$i_{q\text{-ref}} = (P_{g\text{-ref}} - P_g)(K_p + K_i/s)$$

$$\dot{\omega}_t = \frac{1}{2H_t}(T_t - K_s\theta - D_t\omega_t)$$

$$\dot{\theta} = \omega_B(\omega_t - \omega_g)$$

$$\dot{\omega}_G = \frac{1}{2H_g}(K_s\theta - T_g - D_g\omega_g)$$

The above equations describe the mechanical dynamics of the two mass generator-turbine system, where H, T, Ks, D, θ, and ω represent inertia constant, torque, shaft stiffness, damping factor, shaft angle, and rotating speed, respectively; and subscripts B, 0,t, and g denote base, initial, turbine and generator, respectively. The input of the filter is either the virtual inertia or droop power, where as the output is fed as Preg. The remaining power, denoted here as Pcomp, could be produced by the dc-link. Assuming that the closed-loop dc-link voltage control is fast enough, the reference value of the dc-link voltage, Vref, could be corrected as given to generate Pcomp, where Vnom and Cdc are the nominal value and the capacitance of the dc-link, respectively, and ωn and ξn refer to the cutoff and damping factor of the second-order filter, respectively. It is worth mentioning that this implementation method guarantees the restoration of the dc-link voltage to its nominal value after disturbance.



$$P_{reg} = \frac{2\zeta\omega_n s + \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} P_{vi/drp}$$

$$P_{\mathrm{comp}} = P_{vi/drp} - P_{reg}$$

$$V_{\mathrm{ref}}^2 = V_{nom}^2 + (2/C_{\mathrm{dc}}s)P_{\mathrm{comp}}.$$

III. METHODS FOR REGULATION OF FREQUENCY

A. Droop Method:

This method requires power reserve, reserve power is taken from maximum available power at wind generated by deviation. It responds to steady state behavior and it does not respond to transient state behavior. The equation for droop power is given below

$$P_{reg} = P_{drp} = \frac{m_p}{\tau_m s + 1}(\omega_{m,\mathrm{ref}} - \omega_m).$$

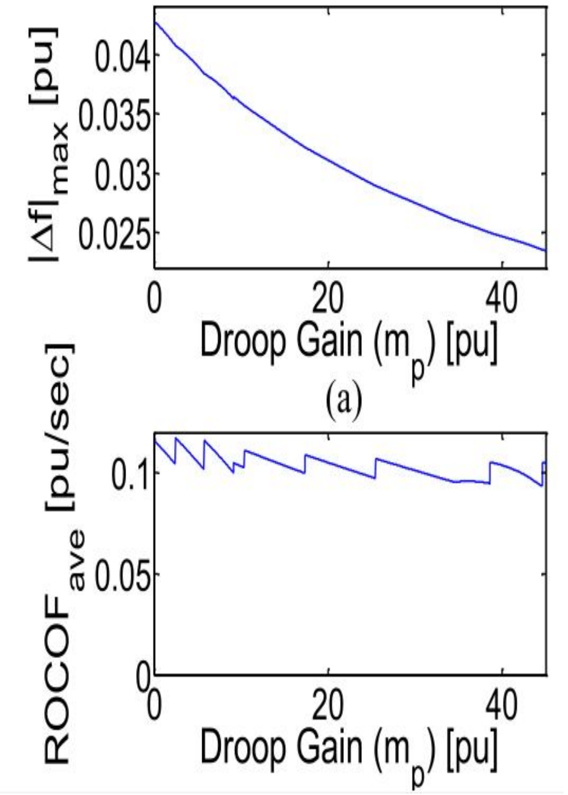


Fig 1: Droop gain Vs rate of change of frequency and ROCOF

As droop gain increases change in frequency decreases and rate of change of freq decreases but rate of change power increases, which leads to wear and tear of machines.

B. Virtual Inertia:

It does not require reserve power, it responds to transient behavior. By using this method rate of change of frequency decreases where as power increases. The equation for this method is given below:

$$P_{reg} = P_{vi} = -\frac{M_{vi}s}{\tau_{vi}s+1}\omega_m .$$

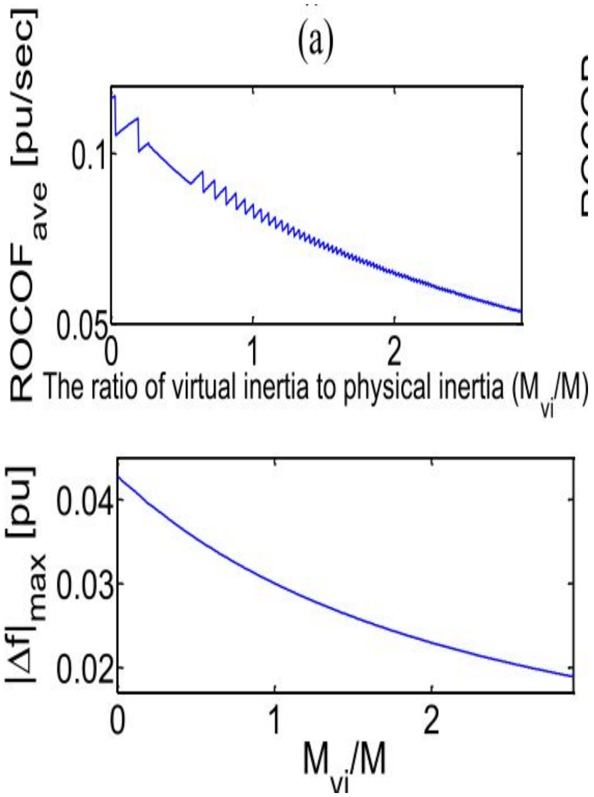


Fig 2: Virtual inertia gain Vs change in frequency and rate of change of frequency

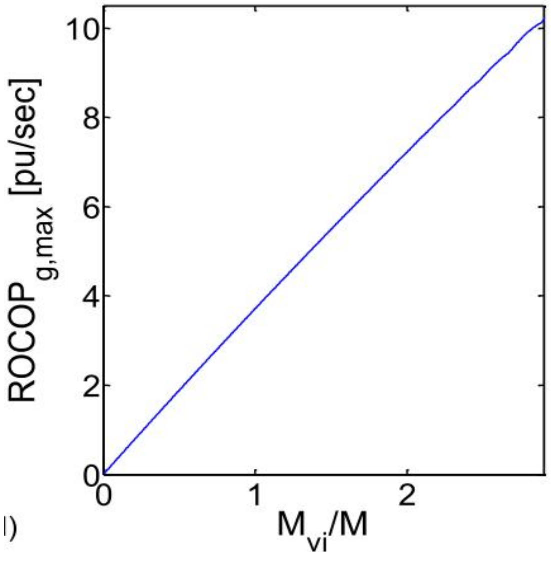


Fig 3: Virtual inertia gain Vs rate of change of power

IV. SOLUTIONS AND TIME DOMAIN RESULTS

In order to reduce the rate of change of power and to control the frequency regulation we use the ramp rate limiter and dc-link method. By using these methods we can control the frequency with the required limits. This methods is used for both virtual and droop methods of PMSG and DFIG.

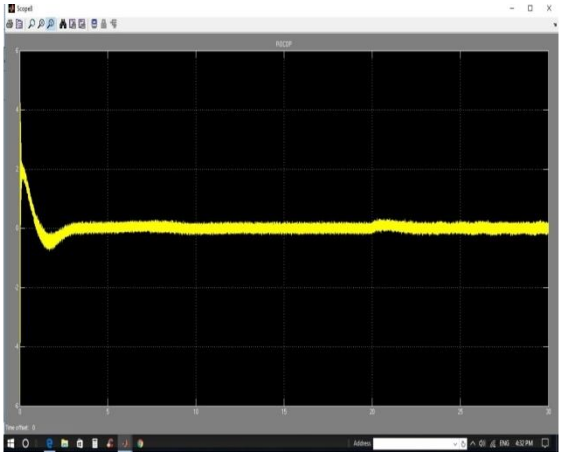


Fig 4: ROCOP WITH DROOP METHOD

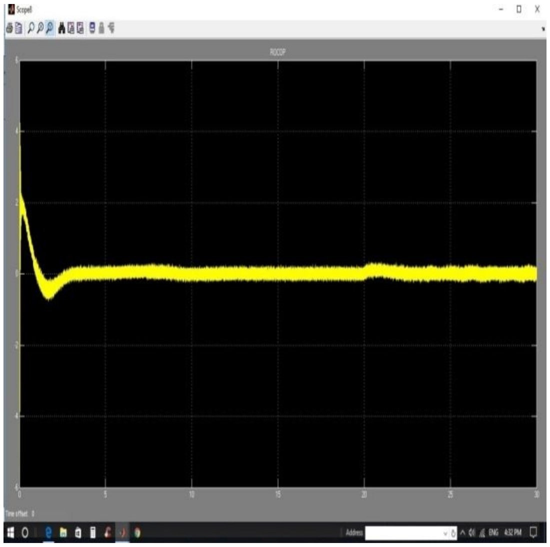


Fig 5: ROCOP WITH VIRTUAL METHOD

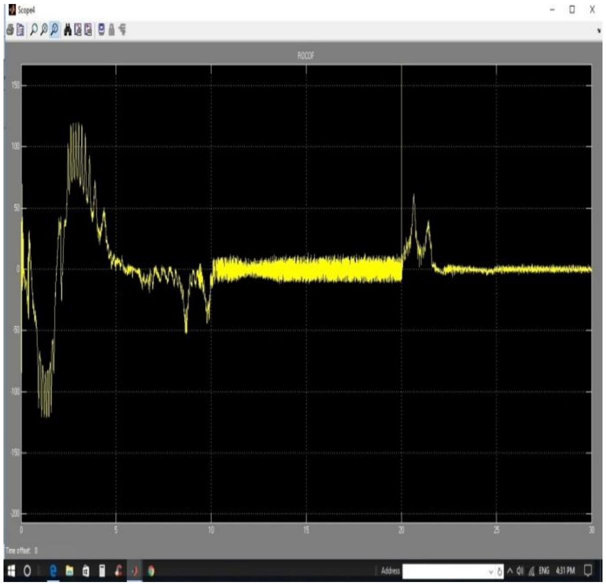


Fig 6: ROCOF WITH DROOP METHOD

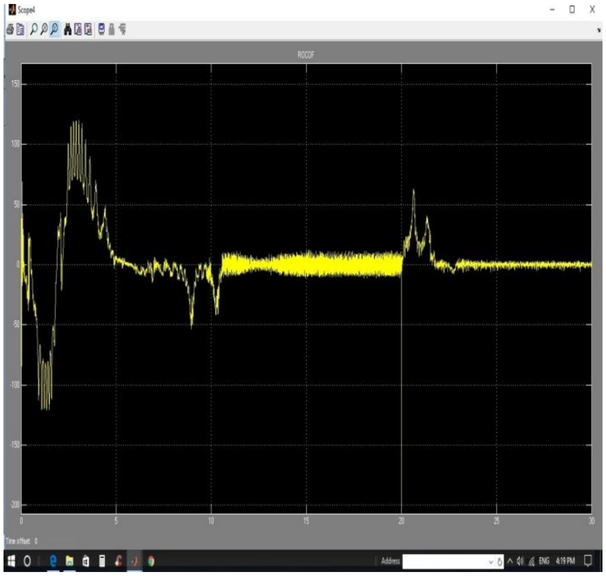


Fig 7: ROCOF WITH VIRTUAL METHOD

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