A new control strategy of WFSG-based wind turbine to enhance the LVRT capability

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ABSTRACT

This paper proposes a competent and effective scheme to enhance the low voltage ride through (LVRT) capability of wound field synchronous generator (WFSG) based wind turbines (WTs) under unbalanced voltage dip conditions. A technique for grid synchronization against voltage excursions, i.e., a PLL using positive grid voltages with a high selectivity filters (HSFs) is utilized to extract a robust grid voltage synchronization signal irrespective of the mains condition to enhance the overall system performance. Besides, a new controller (adaptive fuzzy RST) for both the stator side converter (SSC) and grid side converter (GSC) current regulation are employed to further improve dynamic performance. Also, a reactive power support scheme to manage the WFSG reactive power during contingencies and fulfill the grid codes obligations is presented. Moreover, an additional device such as braking chopper (BC) circuit is used in the DC-link circuit for stable operation of the wind energy conversion system (WECS) underline fault. Effectiveness of the proposed control strategy is verified by the numerical simulations.

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Introduction

Among renewable energy sources, wind energy generation has been noted as the most rapidly growing technology; being one of the most cost-effective and environmental friendly means to generate electricity from renewable sources. The increasing penetration level of wind energy can have a significant impact on the grid, especially under abnormal grid voltage conditions [1]. In order to avoid this problem, an increasing number of power system operators have implemented technical standards known as grid codes that wind turbines (WTs) must meet when connecting to the grid [2,3]. Generally, these grid codes requirements cover many topics such as voltage operating range, power factor regulation, and frequency operating range, grid support capability, and low fault ride-through (LVRT) capability. Indeed, grid codes dictate fault ride-through (FRT) requirements. LVRT capability is considered to be the biggest challenge in (WTs) design and manufacturing technology [4]. LVRT requires (WTs) to remain connected to the grid in the presence of grid voltage sags.

Variable-speed wind energy systems are currently preferred than fixed-speed (WTs) due to their superior wind power extraction and better efficiency. Differently from the doubly fed induction generator (DFIG) wind systems, a (WECS) based on wound field synchronous generators (WFSGs) with a full power converter has a lot of advantages such as high power density, because it employs the whole stator current for the electromagnetic torque production [5], provides more extensive speed operating range, and full decoupling between the generator and the grid, which results to enhanced capability to fulfill the LVRT requirement. These properties make this implementation interesting [6].

Quite a few studies have been carried out to improve the LVRT capability for WT systems. Among the available approaches, protection devices such as energy storage system (ESS) or flywheel systems are required to mitigate the output power fluctuation [7–9]. Using the external devices increases the cost of the whole system. With the ESS added to wind generation systems, not only the power smoothening but also FRT can be achieved effectively [8,9]. However, the cost of the ESS is too high to solve this problem practically. One of the simplest methods for an LVRT is to apply a braking chopper (BC) [10,11]. However, it is impossible to improve the output power quality of the WT systems since the BC just dissipates the power and cannot return it to the grid.

A control scheme to improve LVRT capability of the variable speed WT under the unbalanced and distorted grid voltages is presented in this paper. Many kinds of methods for LVRT under the distortedly unbalanced grid voltages have been presented. PLL using positive grid voltages to control the grid side converter

(GSC) under the unbalanced grid voltages [12], PLL using 120 Hz Notch filter to filter the negative current components [13], and dual currents controller which controls each positive components and negative components of the currents [14] belong to this. But, the major disadvantages of dual sequence control include its extensive measurements, complicated computation for the reference current values and the usage of low pass filters (LPFs) for sequence component separation. These filters contribute excessive time delays and can deteriorate the control performance [15].

In this work, PLL using positive grid voltages to control the GSC under the unbalanced grid voltages is proposed. In this novel scheme the high selectivity filters (HSFs) have been utilized instead of the classical extraction filters, e.g., LPFs. Moreover, this algorithm works effectively not only under balanced supply voltages, but also under distorted or unbalanced conditions.

To improve control dynamic response, proportional integral (PI) plus resonant (R) current regulator [16] and proportional resonant (PR) current regulator [17] are employed in a stator stationary reference frame. But, this kind of control could be easily saturated when dealing with substantial sag. Moreover, they are sensitive to the generator parameters and other phenomena such as disturbances and unmodeled dynamics [18]. Therefore and in this particular context, this paper proposes the use of adaptive fuzzy RST controller as an improved solution that handles the classical controllers.

To check the overall control strategy ride-through performance, simulations using MATLAB/SIMULINK on a 7.5 kW WFSG-based WT are carried out in case of varying wind speed and unbalanced voltage sags. Simulation results demonstrate that the presented WFSG-WT model possesses desirable capabilities of operation at the maximum power point. The DC-link overvoltage protection method is effective in protecting the converter from over voltage damage and thus enhancing the LVRT capacity under the grid fault condition as well. And reactive power support can also act as a desirable means to enhance LVRT capability by enhancing the grid voltage during the grid fault event.

Wind conversion system description

A simplified diagram of the power system based wind power generation is illustrated in Fig. 3. It consists of a WT, a gearbox, a WFSG, and back-to-back (B2B) converters. The rotor winding of the WFSG is connected to DC bus by DC/DC converter, whereas the stator winding is fed by B2B bidirectional the Pulse Width Modulation Voltage Source Converter (PWM-VSC). The B2B converter contains a stator side converter (SSC) and a GSC, which are connected by a DC bus. A BC is connected in parallel with the DC-link. The BC will be activated to dissipate the excessive power in case of deep voltage sags. The control system of the WECS consists of the generator-side control sub-system and a grid-side control sub-system. The Maximum Power Point Tracking (MPPT) algorithm is based on fuzzy logic and controls the generator side converter. The GSC controller maintains the dc-link voltage at the desired value by exporting active power to the grid and it controls the reactive power exchange with the grid. The SSC controls the power flow from the WFSG to the grid via the control of the stator currents of the direct and quadrature components of the WFSG stator current to achieve decoupled control of the active and reactive powers. The quadrature component controls the active power, whereas the direct component controls the reactive power.

LVRT requirement

Among the different grid codes of LVRT, the most widely adopted one is the E.ON code which is proposed by Germany
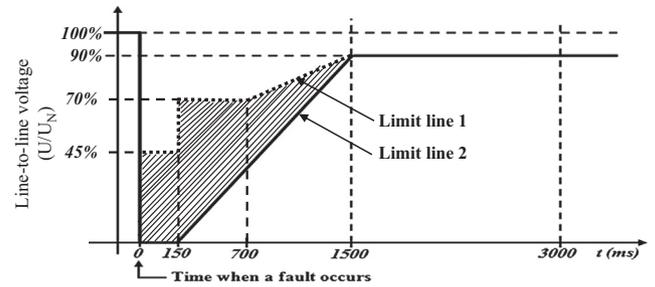

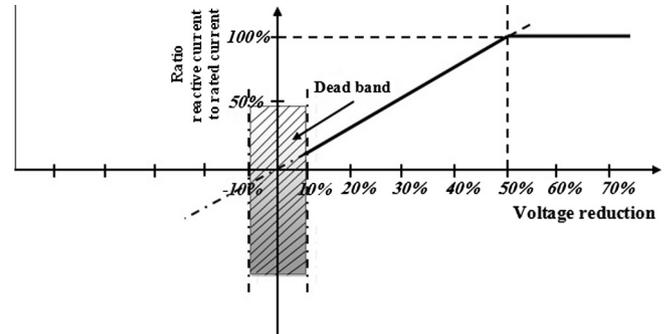**Fig. 1.** Voltage limits curves to allow generator disconnection.

Fig. 2. Reactive current to be fed under a voltage dip.

[19,20]. E.ON introduces a voltage profile and the limiting curves and regions defining the LVRT requirement as shown in Fig. 1. Accordingly, when the grid voltage is within the shaded area and above the limit line 2 in Fig. 1, LVRT is required for remain the power generation plant connected to the grid. But in case of instability a short term interruption (STI) is allowed. Below the limit line 2 in Fig. 1, no LVRT is required and STI from the grid is always permissible. Moreover, the WECS has to provide the amount of reactive current specified in Fig. 2, to support the grid voltage recovery during voltage dips. According to this figure, it has provided 2% of the reactive current for each 1% of the voltage dip, when the grid voltages are in the range of 50–90%, and has provided 100% of the reactive current when the voltage falls below 50%.

Control of machine-side converter

Wind turbine modeling

In the WT model, the aerodynamic power output is given as [21].

$$P_a = \frac{1}{2}\rho\pi R^2 V_w^3 C_p(\lambda, \beta). \tag{1}$$

where ρ is the air density; R is the WT blade radius; V_w is the wind velocity (m/s), and C_p is called the power coefficient, and is given as a nonlinear function of the tip speed ratio (TSR) λ with

$$\lambda = \frac{R\Omega_t}{V_w}. \tag{2}$$

where Ω_t is the turbine speed. C_p is a function of the TSR λ and the blade pitch angle β, and is general defined with

$$\begin{cases} C_p = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{-\frac{18.4}{\lambda_i}} \\ \lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3 + 1}} \end{cases} \tag{3}$$