Improving the LVRT Capability of the DFIG-Based Wind Turbines during Fault

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Abstract

According to the coordination control of a dynamic voltage restorer (DVR) and an inductive fault current limiter (FCL), this paper proposes an efficient low-voltage ride-through (LVRT) scheme for a doubly fed induction generator (DFIG) based wind turbine. The DVR is located to the DFIG's stator circuit for stabilizing the terminal voltage and decreasing the generator current. The inductive FCL is connected to the DFIG's rotor circuit for suppressing the rotor overcurrent and protecting the converter. Theoretical discussions on structure, principle and scale criterion of the combined DVR-FCL are conducted, and simulation analyses of the proposed approach to handle symmetrical and asymmetrical faults are done in MATLAB/Simulink. In this study, the dynamic characteristics of the DFIG during the faults are analyzed from multiple aspects, and a detailed comparison of the proposed approach and the single action of DVR or FCL is carried out. From the simulation results, the effectiveness and superiority of the proposed approach are well demonstrated.

Keywords: Wind turbine, DFIG, Grid faults, Crowbar protection, Backstepping control, Low-voltage ride through

I. Introduction

In recent years, the contradiction between the increase of energy demands and the shortage of fossil fuels has been more and more serious, and to achieve sustainable socio-economic development, promoting the penetration of renewable energy (RE) in power systems has been regarded as a critical solution. In a sense, to construct a smart energy city, the application of micro-grids can contribute to accommodating more various RE sources and decreasing their adverse effects caused by uncertainties. As a representative of RE, wind energy has obtained the fastest growth, and the cumulative installed capacity of wind power generators all over the world may be more than 800 GW by 2021. Note that, energy quality is a significant feature to affect the stability and security of electric power systems, and it is very crucial to stabilize wind power generators under short-circuit faults. Wind turbines (WTs) should keep the grid-connected status for a certain time, and

it is very crucial to stabilize wind power generators under short-circuit faults. Wind turbines (WTs) should keep the grid-connected status for a certain time, and this condition depends on the severity of faults or level of voltage sags to meet specific code demands, so called as low-voltage ride-through (LVRT) operation. As the most widely WT, doubly fed induction generator (DFIG) has obtained considerable attention, and many different measures regarding the LVRT enhancement of DFIG have been suggested. Generally, the existing methods are classified as software and hardware approaches. The software solution is regarding an improved or updated control strategy with less cost, but it is just suitable for handling moderate fault conditions. The hardware solution is to apply one or more devices with cost investment, and it has a good ability to deal with serious shortcircuit faults. The literature review is presented as follows.

II. LITRATURE SERVEY

In, an advanced current tracking controller is applied in the rotor-side converter (RSC). Scholars discuss how to determine a proper tracking coefficient for the controller, and the results show the transient fluctuations in the RSC can be well constrained. In, an available (generator side converter) GSC voltage is utilized to conduct the voltage compensation, and the DFIG's transient flux is controlled to obtain a desirable fault current limitation. In, a linear-quadratic regulator is implemented in the DFIG. This regulator serves as the supplementary control to prevent converter saturation. In , an optimal hierarchical control structure is proposed. The primary and secondary control levels are designed, and it is found that active and reactive power oscillations in the generator can be favorably mitigated. In, two improved controllers basing fuzzy logic are used in the RSC, and the key functions of the proposed controllers are to decrease the rotor current and inhibit the DC-link voltage. In, scholars investigate an analytical method to determine the control parameters of the DFIG subject to the capacity limit of the RSC. On the whole, the transient stability support from the software solutions towards the DFIG may be relatively moderate, and the improvements of optimizing current reference and introducing over-modulation could be appreciatively done. In the following, the hardware solutions based on chopper circuit, voltage compensator/ restorer and FCL are reviewed. In, the efficacy of a DC-link chopper on diminishing the DC overvoltage is validated, nevertheless it fails to assist the demagnetization of the electrical machine post-fault. In, scholars propose a modified DC chopper that can be inserted in a DFIG basing series or parallel connection. Although the modified structure makes certain improvements, the rotor current is still around its safety limit (2.0 pu). In , a minimized series voltage compensator is applied. Since the stator flux is well controlled, the generator is allowed to ride-through the grid disturbances. In, scholars prove that a DVR is better than a crowbar circuit to handle the transient fluctuations of a DFIG. When the DVR is to solve serious voltage decline with a longer duration, it is needed to consider sufficient energy support. To deeply explore the potentials of the DVR, an enhanced voltage control basing the combination of feed-forward and feedback is proposed in, and an improved topological structure is discussed in. Using the DVR can offer flexible transient- and steady-state response for the DFIG. On the premise of meeting the DFIG's LVRT capability, it is recommended to reduce the DVR rating for making the solution be more practical. From this perspective, introducing a device with better economic performance to decrease the DVR rating might be an appropriate option. Regarding the application of a FCL in a DFIG, studies focus on bridge-type and superconducting-type FCLs.In, a bridge-type FCL with bypass resistor is applied in a DFIG. The research results confirm its positive effects on reducing the flux and electromagnetic torque oscillations. In, the efficacy comparison of a bridge-type FCL and a seriesdynamic braking resistor is carried out. It is illustrated that the FCL owns better suitability than the braking resistor in stabilizing a DFIG. In, a nonlinear control-based modified bridge-type FCL is presented. Owing to the structure improvement, the proposed FCL outperforms the conventional bridge-type FCLs to support the LVRT operation and has quicker withdrawal action. In, scholars propose a capacitive bridge-type FCL to increase the grid side voltage, and a discharging resistor is configured to dissipate excess power for protecting the RSC. In, an active-type SFCL and a flux-coupling-type SFCL are installed at the stator of a DFIG, and the two SFCLs both appear hybrid current-limiting impedance to suppress the transient fluctuations. Although an effective reduction in the stator current is realized, there is room for mitigating the rotor current. In, the contributions of the resistive SFCL in the DFIG rotor are evaluated. The stability of the RSC is strengthened, and the DC-link overvoltage is clearly alleviated. However, it is not good at enhancing the terminal voltage, and the heat accumulation in the resistive SFCL may cause a long quench recovery time. In, the scheme design and assessment of a modified flux-coupling-type SFCL for medium-scale wind plants with multiple DFIGs are studied, and the results imply that reducing the operation loss and cumulative heat of the SFCL is of significance. From this perspective, using an inductive current-limiting device is an alternate solution. It is worthy to state that, a few preliminary studies on the coordination control of a fault current limiter and an energy storage device for stabilizing a DFIG have been reported. It is revealed that the combined utilization of two devices with different functions can bring more contributions in enhancing the transient characteristics of a DFIG. In a sense, developing this kind of study and exploring a novel combination scheme with preferable potentials are of significance.

III. METHODOLOGY

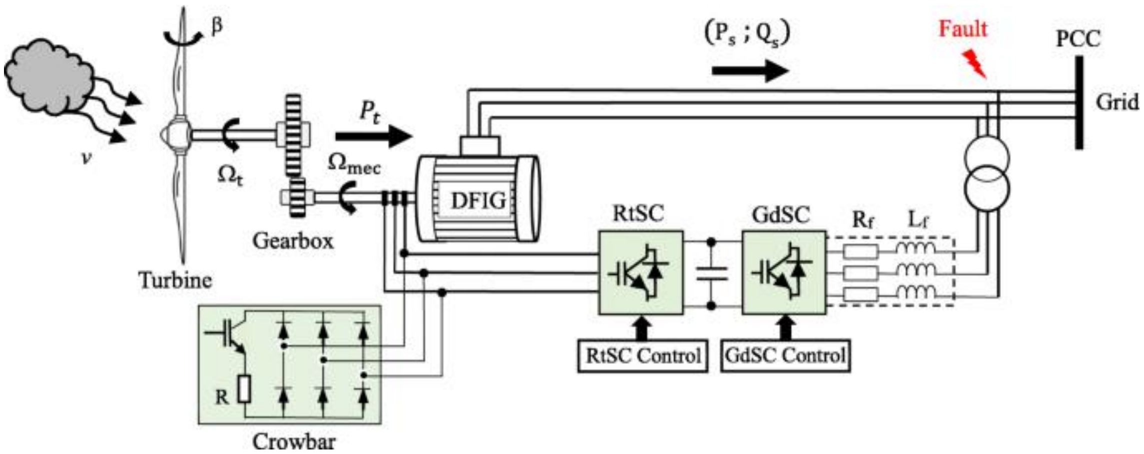

Fig. 1Block Diagram of DFIG based WT with the crowbar installed

A. *Description of proposed method:*

The basic configuration of DFIG based wind turbine is shown in Fig. 1. The electrical generator mounted to the shaft of the gearbox is a wound rotor induction machine, with its stator windings directly connected to the network and rotor windings linked to the grid through a set of back-to-back converters that consist of a rotor side converter (RSC) and a grid side converter (GSC).

The DFIG can be modeled in a rotating park reference frame using the following set of Equations [3]:

$$\begin{cases} v_{sd} = R_s i_{sd} + \dfrac{d\phi_{sd}}{dt} - \omega_s \phi_{sq} \\ v_{sq} = R_s i_{sq} + \dfrac{d\phi_{sq}}{dt} + \omega_s \phi_{sd} \\ v_{rd} = R_r i_{rd} + \dfrac{d\phi_{rd}}{dt} - \omega_r \phi_{rq} \\ v_{rq} = R_r i_{rq} + \dfrac{d\phi_{rq}}{dt} + \omega_r \phi_{rd} \end{cases} \quad (1)$$

$$\begin{cases} \phi_{sd} = L_s i_{sd} + L_m i_{rd} \\ \phi_{sq} = L_s i_{sq} + L_m i_{rq} \\ \phi_{rd} = L_r i_{rd} + L_m i_{sd} \\ \phi_{rq} = L_r i_{rq} + L_m i_{sq} \end{cases} \quad (2)$$

Moreover, the electromagnetic torque is given by:

$$T_{em} = p \frac{L_m}{L_s} \left(\phi_{sq} i_{rd} - \phi_{sd} i_{rq} \right) \quad (3)$$

Finally, the active and reactive power can be determined
By

$$\begin{cases} P_s = R_e\{v_s i_s\} = \left(v_{sd} i_{sd} + v_{sq} i_{sq} \right) \\ Q_s = I_m\{v_s i_s\} = \left(v_{sq} i_{sd} - v_{sd} i_{sq} \right) \end{cases}$$

The crowbar is activated only after the appearance of the voltage dip to protect the back-to-back converters by providing an alternative path for the fault current induced in the rotor circuit. The crowbar circuit employs a diode bridge assembled with a dissipation resistance via a Gate Turn-off Thyristor (GTO) or an insulated gate bipolar transistor (IGBT) as shown in Fig. 1. However, the use of GTO or "Insulated Gate Commutated Thyristor" (IGCT) is more advantageous than IGBT for this application because GTO and IGCT are normally designed to withstand higher overcurrent than IGBTs.

Conclusion

This paper proposes an efficient LVRT scheme based on the coordination control of a DVR and an inductive FCL for a DFIG. Theoretical investigation and simulation analysis are done to validate the effectiveness of the proposed scheme. The combined DVR-FCL can powerfully decrease the fault currents in the DFIG stator and rotor, and perform visible voltage stabilization on the generator terminal and the DC-link. Additionally, the combined DVR-FCL enables to well strengthen the DFIG power stability and suppress the electromagnetic torque within the safety limit. In consequence, the risks to cause damage of the converters are avoided, and an adequate LVRT operation is realized for the DFIG under symmetrical and asymmetrical faults.

In the near future, the follow-on tasks for the proposed approach will be carried out, and they include parameter optimization, economic evaluation and prototyping test of the combined DVR-FCL in the DFIG. The specific research schemes and results will be addressed in other reports.

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