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Design and Performance Analysis of Brushless Doubly-Fed Machine for Wind Power Generation Using AI

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Abstract
In BDFIG whenever an inductive load is suddenly connected or disconnected from the stator power winding(PW), it would leads to large fluctuations at PCC (Point of Common Coupling). So that here we proposed a transient control phenomena of the reactive current by the Line Side Converter (LSC) control. The reactive power change of load leads to the affect of the quality of the voltage waveform at PCC. The LSC cannot work properly, when the amplitude of the PCC voltage is higher than the dc link voltage. Many control strategies such as direct voltage control, predictive control etc., are developed to supply reactive current to overcome this problem in the machine side converter. By supplying or absorbing reactive current the PCC voltage fluctuations are stabilized, this can also be achieved by the LSC. Here we analyzes the PCC voltage and the transient reactive current when is load is suddenly connected or disconnected to the stator power winding and proposed a concept for
this control which has better transient state performance. An AI- Fuzzy logic controller is developed in this paper for the better mitigation of distortion. The controllability of the LSC is analyzed whenever voltage swell occurs at PCC, when the load is disconnected from the power winding of the stator.

By using reactive current of the LSC, a high voltage ride through concept is proposed and the correctness of this method is discussed by simulation and changes in the output as compared to proposed method is observed in the results..

***Index Terms*—Brushless doubly-fed induction generator (BDFIG), reactive current compensation, stand-alone operation, transient response, Artificial Intellegence (AI) Fuzzy logic controller.**

I.INTRODUCTION

BRUSHLESS doubly-fed induction generator (BDFIG) is a new type of induction machine which has the advantages of DFIG that it only requires a low-power rating of the converter compared to the nominal power of the machine. Furthermore, the absence of brush gear and slip rings in the BDFIG can increase the system reliability and decrease the high maintenance costs [1]. With the independent control of the active and reactive power, the BDFIG as a stand-alone power generation has a wide application of variable-speed constant-frequency generator in some embedded generation systems, such as ship shaft generation systems [2], [3]. The BDFIG has two sets of three-phase stator windings. One is the stator power winding (PW) which is used for generating power and connected to the load, the other set of stator windings, called the stator control winding (CW), is supplied with a variable voltage and frequency power converter which is also connected to the stator PW [4]. The rotor winding (RW) is used to couple to the two stator windings. In the stand-alone BDFIG system, the generator should be controlled to build up a constant stator PW voltage to support the loads, but the voltage at the point-of-common coupling (PCC) will fluctuate in case of larger variations of the loads. Especially, the load is connected or disconnected from the PCC. The voltage fluctuation degrades the performance of other loads connected to the PCC and introduces torque pulsations [5]. The associated converter is composed of two back-to-back voltage-source converters with a common dc-link. Usually the machine-side converter (MSC) controls the stator CW current directly. Then, the output voltage of the stator PW can be regulated indirectly, and the line-side converter (LSC) is used to control the dc-link voltage regardless of power flow direction through the MSC [6]. The LSC can also assist in stabilizing the PCC voltage fluctuation by supplying or absorbing the reactive current. In case the inductive load is connected to the stator PW of the BDFIG, the system will generate reactive power for the load. The disadvantage of reactive power compensation based on the MSC control is the slower response compared to the LSC control because of the larger mechanical inertia. Since one end of the LSC is connected with the PCC and the other end is connected with the dc-link capacitor, the control bandwidth of the LSC is significantly higher than that of the BDFIG. So the LSC can quickly suppress the voltage fluctuation at the PCC by producing the reactive current. In addition, based on the compensation by the MSC control, the excitation current in the stator CW will also increase to supply more reactive power when the inductive loads are connected to the PCC. So it will cause more losses and reduce the efficiency of the system [7]. Based on the reactive current compensation by the LSC control, the reactive current in the LSC is injected at the PCC by using the proportional-integral (PI) controller [8]. Implementing the PCC voltage-oriented reference frame, the q-axis current can be used to control the reactive current of the LSC. The q-axis reference value is usually calculated according to the reactive component of the load current. This conventional control scheme can result in a good steady-state performance and can be easy to implement, but in the transient period of inductive load connecting to the PCC, the reactive component of the load current may not be a constant value. Because of narrow control bandwidth of the PI controller [9], if this reactive load current is directly used as the q-axis reference value, it is impossible to obtain accurate control for the oscillation quantities. This will make the PCC voltage fluctuation more serious for a long time. Another, when the load is disconnected from the stator PW, the PCC voltage will swell. Moreover, when the amplitude of the PCC voltage is higher than the dc-link voltage, the LSC cannot work normally [10]. Some methods employ extra sets of hardware appliances, such as the super conducting magnetic energy storage, the dynamic voltage restorer, and the static synchronous compensator (STATCOM), to suppress the voltage swell [11]–[13], but these methods would lead to higher costs and more complex design of the system. The high-voltage ride-through (HVRT) control for the LSC itself is proposed with adaptive adjustment of the dc-link voltage reference according to the PCC voltage or supplying the reactive current to the load [14], [15]. In order to ensure the normal operation of the LSC, the dc-link voltage which is controlled as a constant under normal operation is set to a relatively high value during grid voltage swell in [14]. However, a higher dc link voltage means that the maximum permissible voltage of the dc-link capacitors and the power semiconductor devices will increase [14]. In [15], the reactive current of the LSC is controlled on the basis of ensuring its active current control, but the relationship between the control voltage and the reactive current in the LSC is not analyzed in-depth for a given capacity constraints. According to the above analysis, the transient control algorithm of the reactive current by the LSC control is proposed in case the inductive load is suddenly connected and disconnected from the stator PW. First, the voltage drop at the PCC is analyzed using the equivalent circuit for the stand-alone BDFIG system under sudden load change. Then, the transient reactive current compensation method is proposed based on the conventional PI controller. In case of the large load disconnected from the PCC, the voltage swell is analyzed and the control method of the reactive current of LSC is given to ensure the normal operation of the LSC. Lastly, the influence of this reactive current compensation on the dynamic performance of the dc-link voltage is also analyzed. Test results during steady state and transient operating conditions are presented to demonstrate the properties and correctness of the proposed method.

II. BASIC PRINCIPLE AND CONFIGURATION OF THE BDFIG

The BDFIG comprises two electrically separated stator windings, called the stator PW and stator CW. The stator PW produces a p_p pole-pair field rotating at speed of ω_p and the stator CW produces a p_c pole-pair field rotating at speed of ω_c [16]. The RW is specially designed to couple to the two stator windings. The BDFIG is normally operated in the synchronous mode, called doubly-fed mode as well, as shown in Fig. 1 [3].

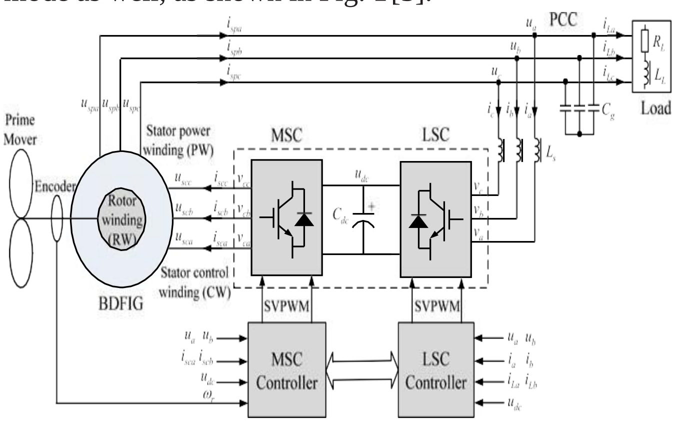


Fig. 1. Configuration of the stand-alone BDFIG system feeding resistive–inductive load.

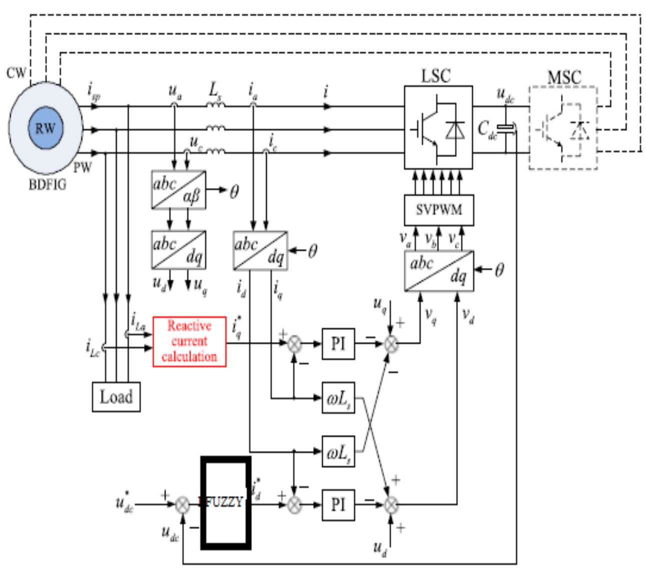


Fig. 2. Control diagram of the LSC with reactive current compensation principle.

III. CONTROL TECHNIQUES:

Control of MSC:

The main purpose of MSC is to extract maximum power with independent control of active and reactive powers. Here, the RSC is controlled in voltage-oriented reference frame. Therefore, the active and reactive powers are controlled by controlling direct and quadrature axis rotor currents (*idr and iqr)*,respectively. Direct axis reference rotor current is selected such that maximum power is extracted for a particular wind speed. This can be achieved by running the DFIG at a rotor speed for a particular wind speed.

Control of LSC:

The novelty of this work lies in the control of this LSC for mitigating the harmonics produced by the nonlinear loads. The control block diagram of LSC is shown in Fig. 2. Here, an indirect current control is applied on the grid currents for making them sinusoidal and balanced. Therefore, this LSC supplies the harmonics for making grid currents sinusoidal and balanced. These grid currents are calculated by subtracting the load currents from the summation of stator currents and LSC currents. Active power component of LSC current is obtained by processing the dc-link voltage error (vdce) between reference and estimated dc-link voltage (V ∗ dc and Vdc) through PI controller

ADVANTAGES

* Total harmonic can be reduced.
* Reactive power can be compensated by local loads.
* Efficiency of the system is improved.

1V. AI-FUZZY CONTROLLER

AI techniques such as machine learning (ML), neural networks (NN), and optimization algorithms (like genetic algorithms, particle swarm optimization, etc.) can be used to enhance fuzzy control by optimizing fuzzy rules, membership functions, or adjusting control parameters based on real-time system feedback. AI-based techniques, including machine learning, neural networks, and optimization algorithms like genetic algorithms and particle swarm optimization, can be integrated into fuzzy logic controllers (FLCs) for doubly-fed induction generators (DFIGs). These AI methods can enhance fuzzy control by optimizing the fuzzy rules, membership functions, and control parameters in real-time based on system feedback.

AI-based fuzzy control for doubly-fed induction generators (DFIGs) offers robust performance in the face of uncertainty. Compared to traditional controllers like PI, these systems better handle fluctuations in wind speed and grid conditions.The AI component of these fuzzy controllers can dynamically adjust the fuzzy rules and parameters in real-time. This ensures optimal performance as DFIG system conditions change over time Improved Stability. AI-based fuzzy controllers for DFIGs are typically evaluated in simulation environments like MATLAB/Simulink or PSCAD. This allows modeling of diverse wind and grid conditions to validate the robustness and efficiency of the control system.

V. SIMULATION DESIGN AND RESULTS

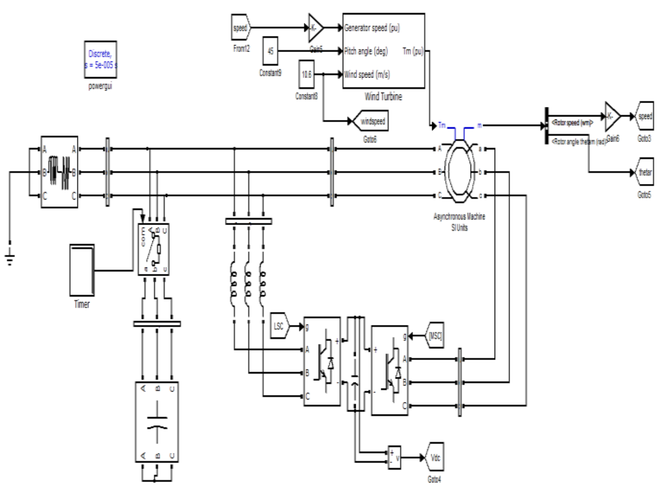


Fig4:Simlation Block Diagram

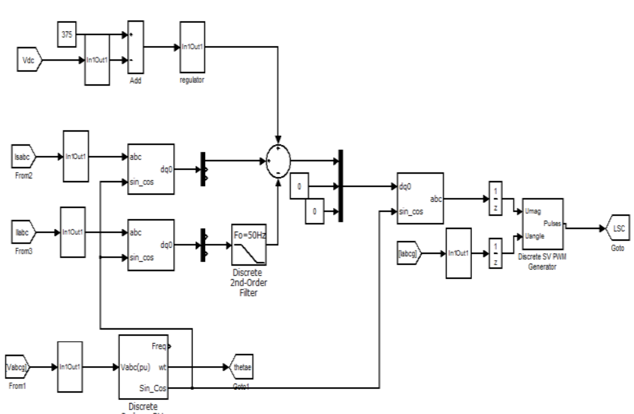
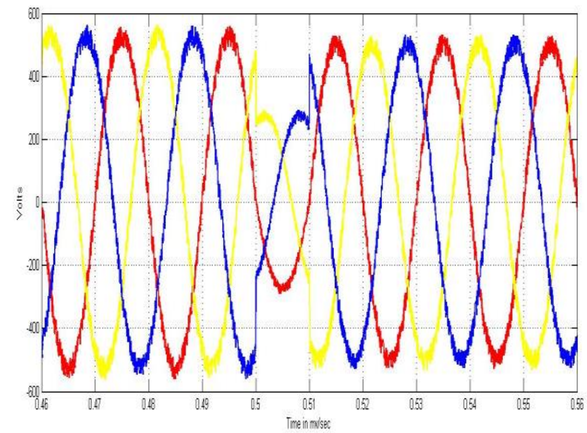
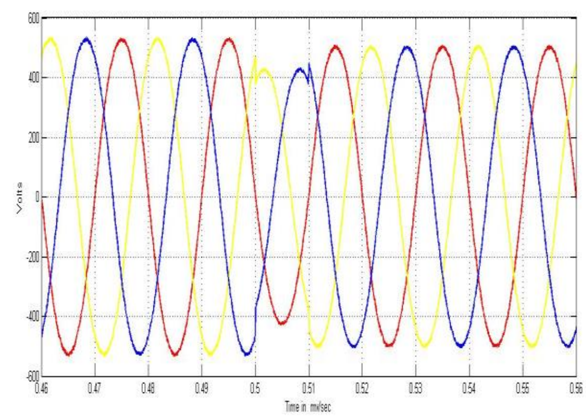


Fig5:Control Diagram



(a)



(b)

Fig. 6. Simulation results of the PCC voltage for three reactive current control methods: (a) PCC voltage without compensation, (b) PCC voltage with fully compensation.

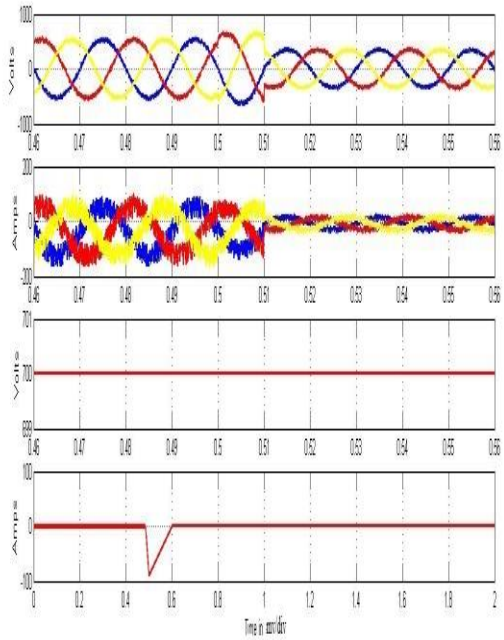


Fig7:Simulation results for proposed control

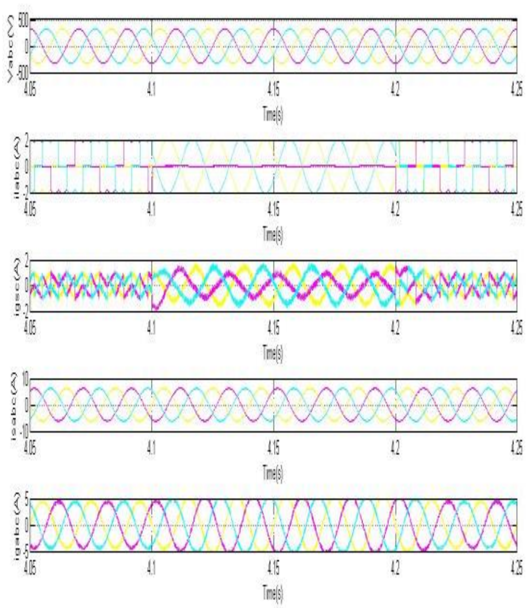


Fig8: Dynamic performance of BDFIG-based WECS for the sudden removal and application of local loads By using fuzzy logic controller

CONCLUSION

This paper proposed a transient reactive current control technique for reactive current of the LSC, for a stand-alone BDFIG system to improve the performance of the PCC voltage and the stability of the system. The stator PW current and the voltage at the PCC are disturbed and leads to several disturbances, when the resistance–inductance load is suddenly connected to the BDFIG. It results in the voltage drop and distortion at the PCC. By using the positive-sequence fundamental reactive load current only is used as the reference value of the q-axis current control loop in the LSC, the stator voltage can be compensated very significantly. Another, the controllability of the LSC with limited rating considered during the PCC voltage swell is analyzed. A HVRT control strategy of the LSC is proposed by using the reactive current of the LSC, and it also improves the fast response of the system compared to MSC the dc-link voltage in the transient region. AI-based fuzzy control for DFIGs demonstrates better responsiveness to grid disturbances, voltage fluctuations, and wind gusts, enhancing overall system stability. It control the better results with less harmonic distortion so the simulation results indicate that the compensation method performs well and can be used in regular practices in wind generations.

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