Research article

Maximum power extraction under different vector-control schemes and grid-synchronization strategy of a wind-driven Brushless Doubly-Fed Reluctance Generator

Mohamed G. Mousa *, S.M. Allam, Essam M. Rashad

Department of Electrical Power and Machines Engineering, Faculty of Engineering, Tanta University, Egypt

A R T I C L E   I N F O

Article history:
Received 15 May 2017
Received in revised form 22 August 2017
Accepted 6 October 2017

Keywords:
Brushless Doubly-Fed Reluctance Generator
Wind energy conversion system
Grid-synchronization strategy
Vector control
Soft starting
Maximum wind-power extraction
Unity power factor
Minimum converter current

A B S T R A C T

This paper proposes an advanced strategy to synchronize the wind-driven Brushless Doubly-Fed Reluctance Generator (BDFRG) to the grid-side terminals. The proposed strategy depends mainly upon determining the electrical angle of the grid voltage, \( \theta_v \), and using the same transformation matrix of both the power winding and grid sides to ensure that the generated power-winding voltage has the same phase-sequence of the grid-side voltage. On the other hand, the paper proposes a vector-control (power-winding flux orientation) technique for maximum wind-power extraction under two schemes summarized as: unity power-factor operation and minimum converter-current. Moreover, a soft-starting method is suggested to avoid the employed converter over-current. The first control scheme is achieved by adjusting the command power-winding reactive power at zero for a unity power-factor operation. However, the second scheme depends on setting the command d-axis control-winding current at zero to maximize the ratio of the generator electromagnetic-torque per the converter current. This enables the system to get a certain command torque under minimum converter current. A sample of the obtained simulation and experimental results is presented to check the effectiveness of the proposed control strategies.

© 2017 ISA. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Due to the cost increase, limited reserves, and adverse environmental impact of fossil fuels [1,2], the development of renewable energy sources has been attracting a great attention from researchers [3,4]. Wind Energy Conversion System (WECS) is one of the top growing renewable energy technologies in the world [5]. The wind energy has proved to be a clean, abundant, and completely renewable source of power. Therefore, it is economical to use the wind energy in producing electric power especially in rural areas [5].

The wind turbine is a very effective component in WECS that converts the wind kinetic-energy into mechanical energy that can be used to drive an electrical generator. The wind-turbine generator converts the output mechanical energy of the wind turbine into electric power and can be connected either to stand-alone loads or connected to the utility grid. The squirrel-cage induction generator, doubly-fed induction generator and synchronous generator are the most common generators that have been used in WECS [1]. Wind turbines can be classified into fixed-speed and variable-speed turbines. The main drawback of fixed-speed turbines is that the maximum power-conversion efficiency can be achieved only at a certain wind speed. However, variable-speed wind turbines can achieve maximum power-conversion efficiency over a wide range of wind speeds, since the turbine can continuously adjust its rotational speed according to the wind speed [1]. In order to make the turbine speed adjustable, the wind-turbine generator is normally connected to the utility grid through a power electronic converter. The power rating of the converter is normally the same as that of the generator. This results in increasing the overall system cost [6].

Brushless Doubly-Fed Machine (BDFM) is a special form of slip recovery machines that reduce the capacity of the required converter to be used if the required speed-control range is limited. This will lead to a significant reduction in the drive-system cost [7]. Therefore, the use of this type of machines would be a cost-effective one that should be used in variable-speed WECS. The Brushless Doubly-Fed Induction Machine (BDFIM) and the Brushless Doubly-Fed Reluctance Machine (BDFRM) are the two main competitors attracting most of the attention from researchers [8]. The rotor design of both BDFIM and BDFRM ensures robustness,
reliability, and maintenance-free operation. However, the efficiency of the BDFRM is expected to be superior to the BDFIM due to the lack of rotor copper losses [8]. Therefore, the Brushless Doubly-Fed Reluctance Generator (BDFRG) is found to be the most attractive one for variable-speed WECS.

The background and fundamental structure of the BDFRM was described in [9,10]. In addition, the machine dynamic model has already been established in [10] based on the space-vector theory. On the other hand, some research works have concentrated on the development of BDFRG in WECS [11,12]. Moreover, in order to extract the maximum power from the wind turbine, different control techniques are proposed [13,14]. Among them, the vector-control technique which is considered to be one of the most favorable control strategies for high performance operation [15,16]. This control technique offers the control of both the electromagnetic torque and the reactive power of the generator in a completely decoupled fashion [15].

Generally, a soft and fast synchronization process is an important issue, as it enables the wind–turbine generator to be connected to the utility grid with a minimum impact on the WECS and the grid [17]. In spite of the number of papers related to the grid-connected wind-driven doubly-fed induction generators, there are relatively few publications describing the synchronization process of the doubly-fed induction generator to the utility grid [18]. Furthermore, the grid-synchronization process of a wind-driven BDFRG system has not recorded any attention from researchers until to date.

The aim of this paper is to propose and implement an algorithm that can be used to synchronize the adopted wind-driven BDFRG system to the grid-side terminals. In addition, the vector-control technique is suggested in this paper to extract the maximum power from the wind turbine under two different control schemes namely; unity power-factor operation of the generator power-winding and minimum converter current. A full comparison between the two control schemes is presented. Furthermore, a soft starting method is also introduced to avoid the converter over-current.

2. Main construction of BDFRM

The BDFRM has two stator windings with different number of poles in order to avoid direct transformer coupling between the two windings. In addition, the stator windings pole-pairs must differ by more than one to avoid unbalanced magnetic pull on the rotor [8]. The primary winding (called the power winding with \( P_p \) pole-pairs) is directly connected to the grid and the secondary winding (called the control winding with \( P_c \) pole-pairs) is connected to the grid through a bi-directional ac–dc–ac converter. The conceptual diagram of the BDFRM is shown in Fig. 1.

The number of poles of the reluctance rotor is governed by the summation of the pole-pairs of the two stator windings in order to get a rotor position dependent mutual coupling between the two stator windings. The resultant mutual inductance variation with rotor position causes a change of co-energy as well as torque production [8]. The electro-mechanical energy conversion can occur only at a particular speed [9]. This speed is given by:

\[
\omega_{\text{om}} = \frac{2\pi(f_p \pm f_c)}{P_p + P_c}
\]

The ‘+’ signs denote the same (+ve. sign) and opposite (-ve. sign) sequence of the control winding with respect to that of the power winding respectively.

3. Grid-connected wind-driven BDFRG system

Fig. 2 illustrates a simple configuration of the proposed grid-connected wind-driven BDFRG system. The wind turbine is mechanically coupled to the rotor shaft of the BDFRG through a step-up gearbox. Due to a reduced power rating of the control winding converter, the starting current of the control winding should be limited below the rated value of the used converter. In order to achieve a good soft starting, the BDFRG is started as an induction machine by closing the auxiliary switch \( S_1 \), shown in Fig. 2, while \( S_2 \) is kept open until

![Fig. 1. Conceptual diagram of the BDFRM.](image-url)
دریافت فوری
متن کامل مقاله
امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات