Electrical Power and Energy Systems 55 (2014) 420–428

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Developing the full-field wind electric generator

Chen-Ching Ting [a,*], Li-Yu Yeh [b]

[a] Dept. of Mechanical Engineering, National Taipei University of Technology, Taiwan
[b] Institute of Mechatronic Engineering, National Taipei University of Technology, Taiwan

ARTICLE INFO

Article history:
Received 17 January 2013
Received in revised form 3 September 2013
Accepted 25 September 2013

Keywords:
Wind electric generator
Normal rated power
NRP
Working efficiency
Full-field wind electric generator
Multi-layer magnetic cutting electric generator

ABSTRACT

A conventional wind electric generator generally works with a fixed normal rated power (NRP). Moreover, a gearbox for providing such generator the quasi-constant rotational speed to reach its maximum working efficiency is required. It is well known, an electric generator with large NRP also receives relatively small working efficiency while the input power is too small due to it needs gearbox with relatively larger speed ratio to reach the required rotational speed. In general, the larger the speed ratio of gearbox, the larger the transmission loss. In other words, if the mechanical resistance is considered, the conventional wind electric generator actually loses a lot of energy in the slow wind speed field. To avoid the use of gearbox with large speed ratio in the slow wind speed field, a special generator with changeable NRP should be used. This work presents a special wind electric generator using the multi-layer magnetic cutting electric generator, which effectively works in full wind field with the help of the changeable NRP and is already patented by our CCT laboratory. The developed multi-layer magnetic cutting electric generator is the so-called disk or axial flux permanent magnet electric generator with multi-layer structure, which is mainly composed of the rotational axis, the rotational magnet frameworks, and the fixed electric coil frameworks. In process, the numbers of the active fixed electric coil frameworks are changeable due to the different numbers of the active fixed electric coil frameworks has the different NRP. In other words, the developed multi-layer magnetic cutting electric generator can automatically adjust its NRP to match various wind speeds and always reach the maximum working efficiency in the full wind field. The results show that the total working efficiency of the developed full-field wind electric generator has increased ca. 3%.

1. Introduction

It is well known, wind energy is eco-friendly and huge green energy from the nature, but its unstable property yields great difficulty for developing the required harvesting technique [1]. The conventional wind electric generator generally works with a fixed normal rated power (NRP) and is the electromagnetic induction generator, whereas an electric generator with large NRP also receives relatively small working efficiency while the input power is too small [2]. Moreover, an optimum rotational speed is always requested by an electromagnetic induction generator, e.g. a diesel electric generator is ca. 3600 rpm, an exciting electric generator is ca. 1800 rpm, a permanent-magnet wind generator is ca. 300–600 rpm, a disk or axial flux permanent magnet electric generator is ca. 100 rpm [3–8], and so on. In general, an electromagnetic induction generator cannot reach maximum working efficiency and even goes down rapidly while the rotational speed leaves its required optimum value, whereas electric generators with different NRPs have unfortunately their own optimum rotational speeds. Figs. 1 and 2 show an experimental data of working efficiency vs. rotational speeds and working efficiency vs. circuit loads for the wind electric generator [9]. The high rotational speed requirement of an electromagnetic induction generator has already limited its applications and also caused its extra energy loss during speed-up. The conventional wind electric generator with fixed NRP actually loses large energy, especially in the slow wind speed field.

To convert the unstable wind energy to more stable output electricity, the doubly-fed induction generators (DFIGs) are widely used in wind turbines today, which use some control strategies to allow the output voltage with constant amplitude and frequency. The DFIGs can therefore be directly connected to the alternating current (AC) power network. There are already many different control schemes and strategies presented in wind turbine applications, such as vector control [10], direct power control [11] and robust power control [12,13]. Due to the DFIGs have variable speed operation ca. ±33% around the synchronous speed, its brush and slip-rings must be maintained constantly. Moreover, the stators of DFIG connecting to the power network directly will cause transient current to affect the DFIG while the power network is failed. In order to avoid harming generators, the control schemes

* Corresponding author.
E-mail address: chchting@ntut.edu.tw (C.-C. Ting).
URL: http://cct.me.ntut.edu.tw/ (C.-C. Ting).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.09.030

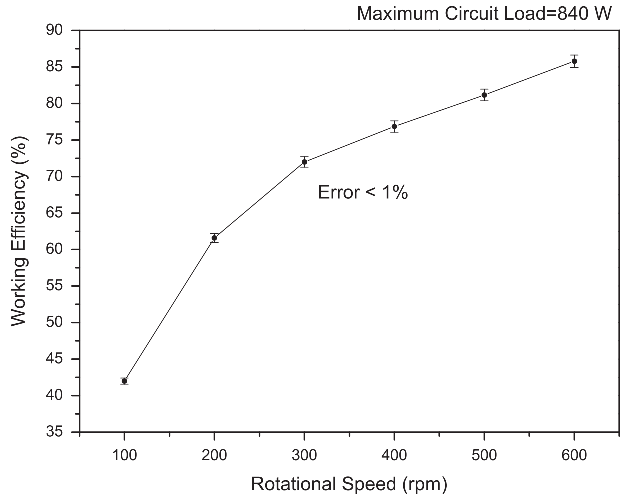

Fig. 1. Relationship of rotational speed vs. working efficiency for the wind electric generator [9].

and strategies of DFIGs are more complicated [14]. In addition, the DFIGs are not developed for full wind field energy harvesting.

The disk or axial flux permanent magnet electric generator changes operating mode of the traditional electric generator, which uses powerful magnets, generally Neodemium–Iron–Boron (NdFeB), as rotors and electric coils as stator. The disk or axial flux permanent magnet electric generator increases rotational diameter of the powerful magnets and successfully reduces its optimum rotational speed. Moreover, the disk or axial flux permanent magnet electric generator removes the iron core in coils to reduce energy loss and receives a relatively high working efficiency of ca. 95.7% [15]. However, the disk or axial flux permanent magnet electric generator successfully reduces its optimum rotational speed and receives a relatively high working efficiency, but it still exists the requested optimum rotational speed. In general, the conventional wind electric generator uses transmission to stand the output rotational speed in connection with the fixed NRP electric generator including the disk or axial flux permanent magnet electric generator. Constant output rotational speed controlled by transmission often causes large energy loss, especially in the low wind speed field. Unfortunately, most of studies in this field until now focus on improving efficiencies of the transmission and the electric generator separately [16–18].

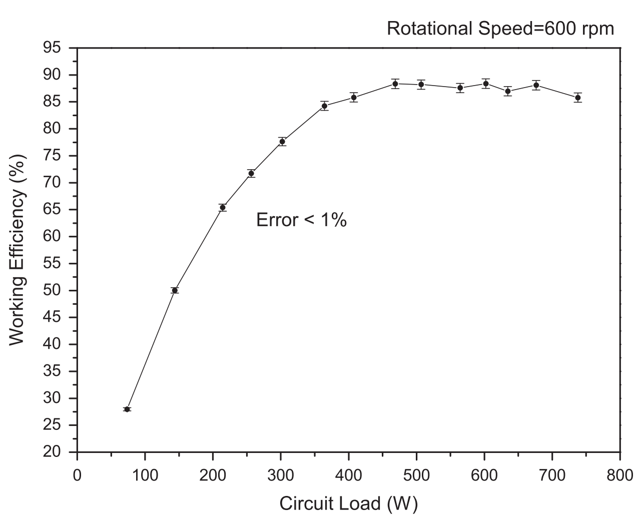

Fig. 2. Relationship of the output power vs. working efficiency of the wind electric generator [9].

Our CCT laboratory has begun to develop harvesting techniques and applications of wind energy since 2005. Discovering new applications of wind energy and improving total working efficiency of the windmill system are our two essential studying topics. In 2008, we first presented the new application of wind forced chiller [19], which first connected the windmill to the air-conditioning field. Three years later, we further presented the dual system of wind chiller integrated with wind generator to enlarge total working efficiency of the windmill system due to the compressor needs relatively large torque for effective working [6]. The integrated wind generator can capture the wind energy while the wind energy cannot effectively drive the compressor. Even so, the integrated wind generator is with fixed NRP and also requires the optimum rotational speed. That is, the wind energy which cannot effectively drive the compressor is small and can also not reach the high working efficiency for electric generation with fixed NRP electric generator. Up to this time, a new question appears, how to keep the maximum working efficiency in the full wind field? Using the multiple electric generators integrated with the windmill gives the answer. That is, using different electric generators with different NRPs to match the input wind energy can receive the maximum total working efficiency of the windmill system.

This article presents a special wind electric generator using the multi-layer magnetic cutting electric generator, which effectively works in full wind field and is already patented by our CCT laboratory. The developed multi-layer magnetic cutting electric generator is the so-called disk or axial flux permanent magnet electric generator with multi-layer structure, which is mainly composed of the rotational axis, the rotational magnet frameworks, and the fixed electric coil frameworks. In process, the numbers of the active fixed electric coil frameworks are changeable. The multi-layer magnetic cutting electric generator can automatically adjust its NRP to match various wind speeds and reach the maximum working efficiency. The results show that the total working efficiency of the full-field wind electric generator has increased ca. 3%.

2. Basic theory

An electromagnetic induction generator is often applied to convert the wind energy to the electricity due to it has relatively high working efficiency and long lifetime. This work presents the full-field wind electric generator using the multi-layer magnetic cutting electric generator which is the so-called disk or axial flux permanent magnet electric generator with multi-layer structure, where its fixed electric coil frameworks are the stators and its rotational magnet frameworks are the rotors. The working principle is detailed in the subsections.

2.1. Multi-layer magnetic cutting electric generator

The multi-layer magnetic cutting electric generator is mainly composed of the rotational axis, the rotational magnet frameworks, and the fixed electric coil frameworks. Fig. 3 shows schematics of the multi-layer magnetic cutting electric generator and Fig. 4 is its photo. The electric coil frameworks are fixed as the stators and the rotational magnet frameworks are the rotors. In process, the active numbers of the fixed electric coil frameworks are adjustable for fitting different wind speeds, i.e. different input wind energies. In other words, the NRP of the developed multi-layer magnetic cutting electric generator is changeable. In general, the higher the wind speed, the larger the active numbers of the fixed electric coil frameworks due to an electric generator with larger NRP also requires larger input power for effective driving. A