Proceeding paper

A Review of Power Converter Topologies for Applications in Wind Energy

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Abstract: The study of wind energy conversion systems (WECS) has gained attention in the field of renewable energy sources. This is partly because wind generator size has increased quickly and because power electronics have developed and can be used to extract wind energy. This article offers a thorough double fed both historical and contemporary converter topologies that are related to permanent magnet generators and doubly fed induction generators. Price, power consumption, efficiency, control complexity and the diverse generator-converter combinations are contrasted based on topology. The attributes of each generator-converter setup are considered from the viewpoint of wind turbine systems.

Keywords: WECS (wind energy conversion system); Wind energy; PMSG (permanent magnetic synchronous generator); Induction generators

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1. Introduction

Governments are focusing on producing electricity from renewable energy sources, with 239GW installed to meet three percent of worldwide demand [1].

As a green source of energy, wind energy has long attracted a lot of attention. Wind turbines are used to harvest wind energy (WTs). Today, onshore, or land-based WT dominates. From a few kilowatts to the multi megawatt methods that are set up today, WTs have grown over time [2, 3]. High and stable output power is achieved by combining and configuring generators and converters in novel and novel ways. Pitch able blades, which allow for regulation of the wind power input, are a significant advancement in WTs technologies [4, 5]. A significant amount of WT will soon be installed offshore, where the winds are sturdier and there is a requirement for WTs with greater ratings.

WT are typically set up in groups and connected to a storage system but can also be connected directly [6]. This paper examines the potential converter and generator topologies for PMSG and DFIG, as well as potential control approaches.

2. Wind Energy Background

Each wind turbine's specific power consumption is determined and controlled by.

$$P_t = \frac{1}{2}\rho A C_P v^3_w A, \tag{1}$$

Where;
Pt =turbine power,
ρ =air density,

A =swept turbine area,
C_P =coefficient of performance and
v^3_w =wind speed.

The tip-speed to wind speed ratio, or TSR, provided by a wind turbine affects the coefficient of performance of the device.

$$\text{TSR}=\frac{\omega r}{v_w} \qquad (2)$$

Where;
ω =rotational speed of turbine,
r =radius of turbine.

According to a typical relationship depicted in Fig. 1, the turbine is most effective at a particular TSR [7]. To generate the most power for all wind speeds, the TSR must be had at its ideal operating moment. The power output of the turbine can be mapped in opposition to the rotational speed of turbine for diverse wind speeds. An illustration of this is presented in Fig. 1. The slopes demonstrate that as wind speed changes over time, the maximum point of power rises and falls as well. The numerous generator-converter combinations that can produce the most power at different wind speeds is covered in the sections that follow.

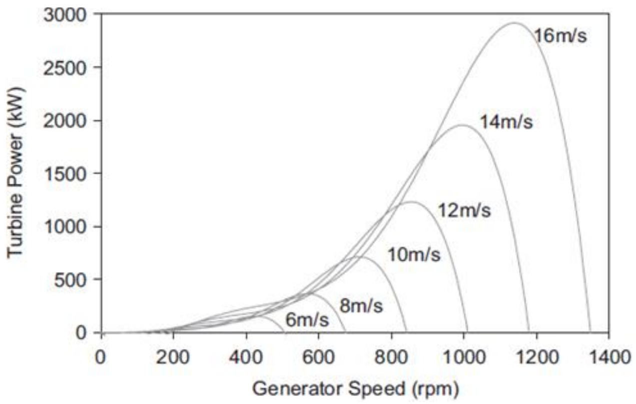


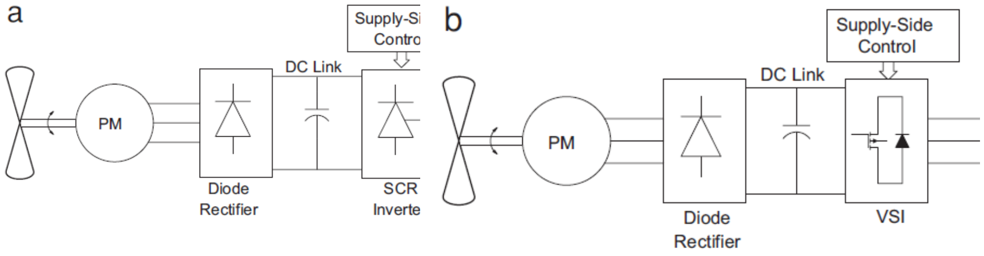
Fig. 1. Power output aspects of the turbine.

3. Permanent Magnet Synchronous Generator

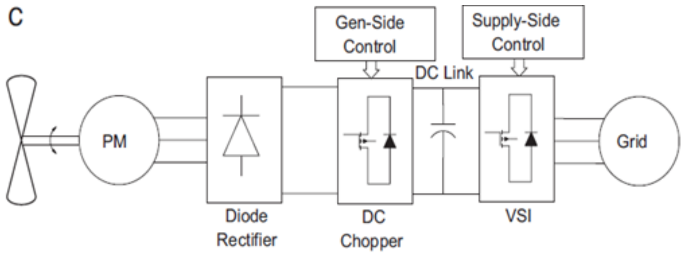
PMSG have the advantage of not needing an external excitation current, allowing for small blade diameter and increased efficiency. Larger scale designs are constrained by cost.

3.1. Supply-Side Inverter for Thyristors

Grid-side inverters based on thyristors have lower cost and higher power ratings but require an active compensator to handle harmonic distortion and reactive power demand. [7].



(**a**) (**b**)



(c)

Fig. 2. PMSG with options for a diode rectifier.

3.2. Supply-Side Inverter with Hard Switching

This converter is subject to several control strategies, such as adjusting the reference sinusoidal signal fed to the modulation index of the PWM generator, using a derivative control on the stator frequency, and using an anemometer, fixed-voltage system, and wind estimation control system. The least effective stable voltage scheme was used as the benchmark when comparing the four control strategies. The MPPT with setup of anemometer produced better results, while the sensor-less control strategy came close behind [8].

3.3. The Mid-Stage DC/DC Converter

The DC/AC inverter has the capacity to regulate the active and reactive power transferred to the grid, allowing for deviation of the switching ratio, selective harmonic elimination, and more elastic control [9, 10, 11].

Software phase lock loop (PLL) is applied to a d-q synchronous reference to determine the utility's phase angle. The duty ratio of the chopper switch can be analyzed for any specific ideal point using the voltage equation controlling an increase DC/DC chopper and a PI controller. The efficiency loss of the control system at high speeds is caused by the phase lag between the duty ratio and DC. A higher sampling rate would aid in fixing this issue [12, 13].

3.4. PWM Back To Back Converters

Two 6-converters with hard switches and a capacitor in a DC-link [14] are used to adjust the generator side rectifier to produce the most electrical torque with the least amount of current. The grid side inverter uses a hysteresis controller to regulate the line current and a PI controller to regulate the voltage of DC-link. A more recent converter was developed using two capacitors and two B-4 converters. MPPT measures the voltage and current of DC-link to determine the generator's output power and adjusts the operating point by varying the magnitude of the reference current. A PLL is applied to each side of the system to maintain the unity power factor [15].

(**a**) (**b**)

Fig. 3. PWM converter back-to-back schemes for PMSG.

3.5. Unconventional Schemes

The PMSG-based scheme uses a rotary phase shifter (RPS) as a power stabilizer and flywheel with an unlimited lifespan [16]. To solve DC-link shortage issues, switches are alternately turned on and off to ensure system symmetry and raise voltage. To ensure unidirectional energy flow, a diode is added between the inverter and capacitive DC-link [17, 18].

4. Doubly Fed Induction Generators

DFIG and induction generators have the capacity to output more power than specified without overheating, and work well for MW-scale high power applications.

4.1. SCR Converter And Static Kramer Drive Techniques

The static Kramer drive is a line commutated inverter coupled to the supply side and a diode rectifier on the rotor circuit [19]. It allows for the development of a sliding mode control that offers a good balance between torque oscillation smoothing and conversion efficiency [20, 21]. Other approaches to the issue substitute other thyristor rectifiers for the diode rectifier. Optimizing the gear ratio when attached to a wind turbine produces the best results. Both super synchronous sub-synchronous modes can generate the most power between 7.5 and 8.5 m/s.

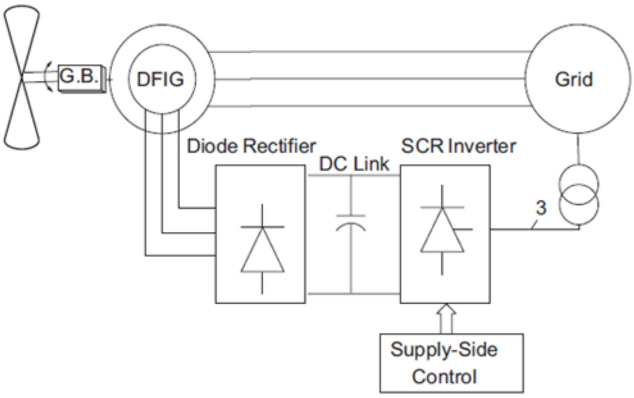


Fig. 4. DFIG with a static Kramer drive.

4.2. PWM Back To Back Converters

Back-to-back converters have been used to create a more contemporary method, with significant differences in complexity and control strategy [21-25]. Supply-side converters use vector control or stator voltage vector parallel to d-axis of reference frames, while rotor-side converters use decoupled rotor excitation current control and torque. Control schemes often employ rotor speed encoders for excellent tracking results. The most important details in this text are that the supply-side converter regulates the flow of real power between the battery and grid, and that voltage space vectors (VSV) theory can be used to speed up the rotor flux [22] and boost the stator's active power output. To identify which of the six sectors the controller is going to control using the direct power control method, a set of tables is needed.

The PWM converter framework's final control strategy determines the wind speed, and the turbine output power is determined by the turbine output power. The brushless

DFIG provides cheaper prices compared to machines with slip rings and brushes [26].

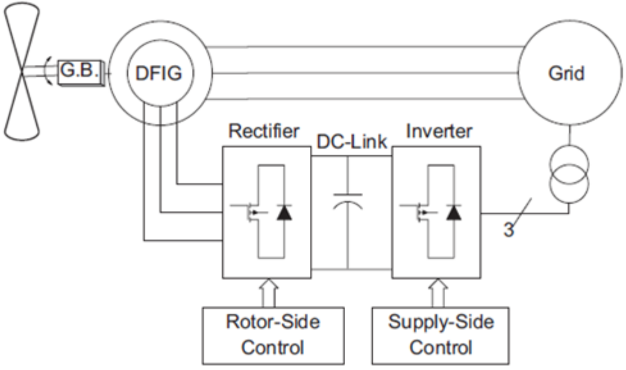


Fig. 5. DFIG with PWM back-to-back converters

4.3. Matrix Converter

The matrix converter is a topology that converts the generator's varying AC into grid-ready constant AC. It eliminates the need for a DC-link and a sizable energy storage system, as only one converter needs to be controlled. Nine switches have bi-directional configuration, enabling any input stage to be coupled to any output stage at any time. However, the cost of converter semiconductors increases due to the need for 18 switches. Permanent magnet excitation is typically used in smaller-scale wind turbine designs due to its smaller blade diameters and increased efficiency [27, 28].

Larger scale designs have been considered, but their practical use has been constrained by the cost of employing many permanent magnet modules. Generator-converter topologies can convert wind energy, but the power converter's price rises, and the complexity of the controller scheme has an impact on the controller's cost. At a small cost premium, adding a DC boost phase makes it easier to control the grid inverter.

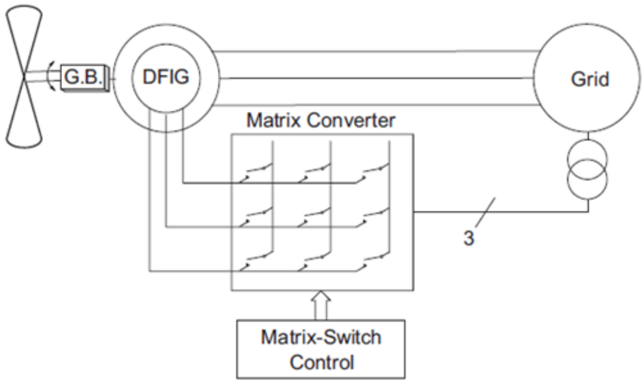


Figure 6. Matrix converter for DFIG.

5. Results

The generation of wind energy has attracted a lot of research. Through this research, a succinct review of many WECS has been accomplished. In-depth descriptions have been provided of the converter topologies used in conjunction with PMSG and DFIG as well as various control schemes. Every control strategy described aims to maximize the amount of energy that is transferred from the windmill to the grid.

To find a financially viable solution to the growing environmental problems, efforts are ongoing to improve converter and control schemes. With the advancement of power electronic technology, wind power generation has increased alarmingly in the last ten years and thus will keep doing so.

6. Discussion

A systematic formula for deficit utilizing quadrature-direct axis current and speed is proposed, along with an evaluation of the loss model of high-speed PMSG. A power-control method for WECS based on PMSG is recommended, and three current control methods are introduced. A feed-back-linearization based Partial Swarm Optimization (PSO) is created to assess new controllers, and a Vienna rectifier oriented MPC is used to measure the rectifier's potential eight voltage vectors. Coordinated control of the WT's pitch-angle and the voltage of DC-link is suggested to smooth output power in low- and high-frequency regions. The most important details in this text are the proposed processes for controlling voltage and frequency, predictive-current-control, sliding-mode-observer (SMO), output power control based on combined high order sliding mode (HOSM) controller, fuzzy, adaptive, and control method of PID, PMSG-control relying on dc-vector-control-process for MSC & GSC, integrated power-control for WECS based on PMSG, and a technique for 20-kW for higher power tracking mechanical sensor less prototype.

The DFIG (Double-Fed Induction Generator) is a cutting-edge generator technological innovation in the wind energy conversion system (WECS). It has gained recognition due to its cost-effective operation, ability to regulate at sub-synchronous or super-synchronous speeds, and decoupled control of power. This work develops a novel adaptive step size based HCS controller to address the shortcomings of the conventional HCS algorithm. Additionally, an adaptive back stepping founded nonlinear control (ABNC) scheme is developed with an iron-loss reduction algorithm to achieve both decreased power loss and enhanced dynamic performance. Simulator models are created using MATLAB/Simulink to test the efficacy of the suggested control schemes.

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