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Power Electronic Converters and Maximum Power Point Tracking Controllers in Wind Energy Conversion System: A Review

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Abstract

This paper presents the comparison of different types of wind power converters which can be connected to induction generator. The induction generator is cost effective as compared to other generators. The power converter is used in the present system is back-to-back voltage source converters. In the proposed system the power converter is connected with Power Factor Correction (PFC) Converter and Voltage Source Converters. Thus the cost of the entire system is minimized. A vector control scheme for Pulse Width Modulation (PWM) inverters results in independent control of active and reactive power. Also different types of maximum power point tracking (MPPT) control algorithms are presented and compared by their performance. From the review of the above converters and MPPTs, it has been concluded that P&O method with PFC Converter fed Induction Generator system should be best configuration which gives better performance with low cost.

Keywords: Induction generator, PFC converter, DC-DC Boost converter, Voltage source converter, Vector control, MPPT.

Introduction

Wind power conversion is the fastest-growing energy source among the new power generation sources in the world and this tendency should remain for some time. Already now, wind energy is rapidly developing into a main stream power source in many countries of the world, with over 175GW of installed capacity worldwide.

Under an advanced wind energy growth projection, coupled with ambitious energy saving, wind power could be supplying 29.1% of the world electricity by 2030 and 34.2% by 2050 (Fig. 1) [2].

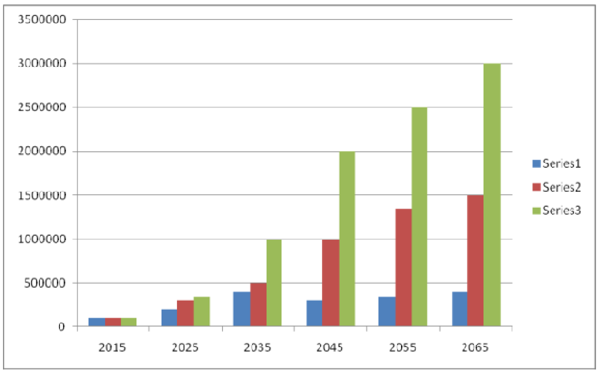

Figure 1: Global cumulative wind power capacity[2].

Wind power converters are widely used in these days. There are different converter topologies used for wind power conversion applications. The converter topologies are connected to the various generators such as induction generator, synchronous generator and double fed induction generator.

Modern Power Electronics

Today the role of power electronics in wind power applications is so important. By interfacing the power electronics in wind energy conversion system is to control the voltage, frequency, active and reactive power. The power converter is the interface between the generator and the grid is shown in fig.2. The power may flow in both directions, of course, dependent on topology and applications. Three important issues are of concern using such a system. The first one is reliability; the second is efficiency and the third one is cost. For the moment the cost of power semiconductor devices is decreasing 2-5 % every year for the same output performance and the price per kW for a power electronic system is also decreasing. A high competitive power electronic system is adjustable speed drives (ASD). Wind energy for electric power generation is an area of research interest and nowadays the emphasis is on the cost-effective utilization of this energy aiming at quality and reliability in the electricity delivery [3,4]. During the last two decades, wind turbine sizes have been developed from 1.5MW to 2MW, while even larger wind turbines are being designed. Moreover, a lot of different concepts have been developed and tested [4].Currently, variable-speed wind energy conversion systems (VS-WECS) are continuously increasing their market share, since it is possible to track the changes in wind speed by adapting shaft speed, and thus, maintaining optimal power generation. The more VS-WECS are investigated, the more it becomes obvious that their behaviour is significantly affected by the control strategy used.

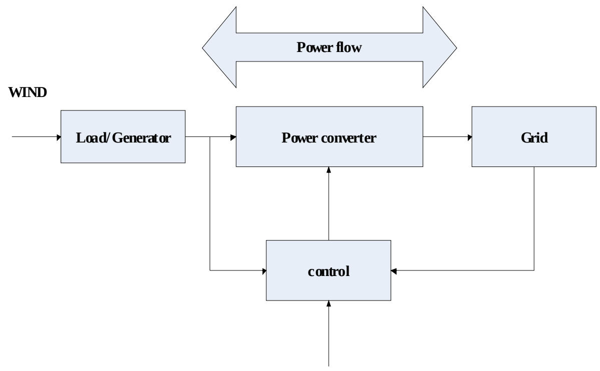

Figure 2: Power electronic system with the grid, load/source, power converter and control.

Types of Wind Power Converters

There are some wind power converters are present. They are

1. Bi-directional Back-to-Back PWM converters
2. Unidirectional voltage source converter

These power converters are related to the partial-rating power converter wind turbine and the full rating power converter.

Bi-Directional Back-To-Back PWM Converters

The PWM VSCs is the most frequently used in three phase frequency converter. A technical advantage of the PWM-VSC is the capacitor decoupling between the grid and generator converters. This decoupling offers separate control of the two converters. The inclusion of boost inductance in the DC-link circuit increases the component count, but a positive effect is that the boost inductance reduces the demands on the performance of the grid side harmonic filter andoffers some protection of the converter against abnormal conditions on the grid. This topology is for full rating converter with squirrel cage induction generator and permanent magnet synchronous generator. The DC-link voltage is also controlled by a Proportional Integrator(PI) controller, via the grid side inverter [5,6].

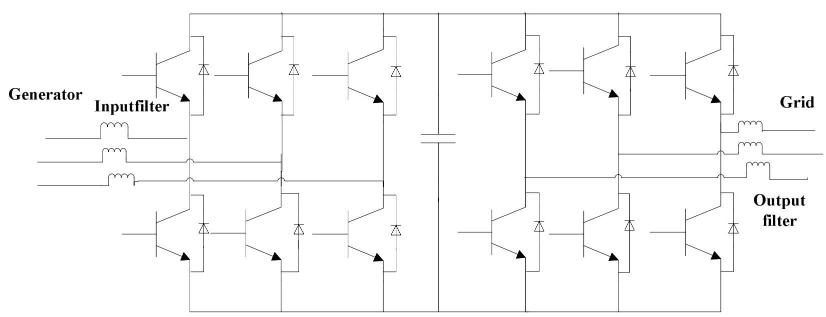

Figure 3: Structure of back –to-back voltage source converter.

Unidirectional Voltage Source Converter

The induction generator requires a simple diode rectifier for the generator side converter. The diode rectifier is the most common topology in power electronic applications. It is used in only in one quadrant and simple and there is no possibility to control it. The variable speed operation of the wind turbine is achieved by using an extra power converter which feed the excitation winding. In order to achieve variable speed operation the wind turbines equipped with a squirrel cage induction generator will require a boost DC-DC converter inserted in the DC-link, that is the same configuration of power factor corrected (PFC) converter[7]. These power converters can be used for different types of wind turbine generator. The wind turbine generator types are 1.Induction generator, 2.Double –fed induction generator, 3. Synchronous generator.

The wind turbine generators can be compared by using different combinations of power converters. These wind power converters can be controlled by some control schemes such as vector control, MPPT control and other control techniques are employed. By implementing the control techniques to control the generator side converter and grid side converter. The main purpose of these control techniques is to have control over the real and reactive power flow in the system. One option is to apply vector control to the supply-side converter, with a reference frame orientated with the d-axis along the stator voltage vector [8,9]. The supply-side converter is controlled to keep the DC-link voltage constant through regulation of the d-axis current. It is also responsible for reactive power control through alteration of the q-axis current [8,9]. As for the rotor side, the choice of decoupled control of the electrical torque and the rotor excitation current is presented [10]. The machine is controlled in a synchronously rotating reference frame with the d-axis orientated along the stator-flux vector, providing maximum energy transfer. Conversely, in [10], the rotor current was decomposed into d-q components, where the d-axis current is used to control the electromagnetic torque and the q-axis current controls the power factor. Both types of rotor-side converter control employ the use of PI controllers. PWM switching techniques can be used [10]. The comparison rotor-side converter control employ the use of PI controllers. PWM switching techniques can be used [10]. The comparison of several wind turbine generator topologies can be shown in the table I.

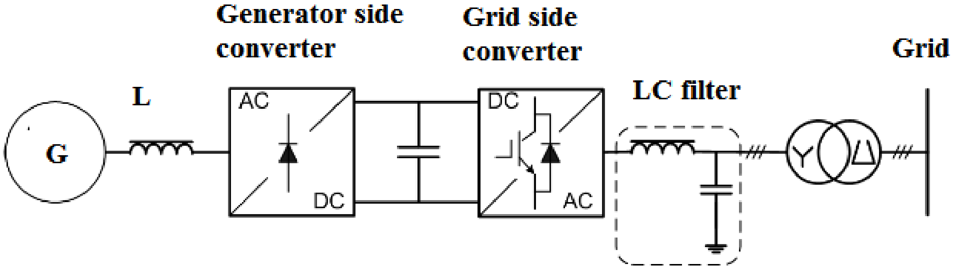

Figure 4: Variable speed wind turbine with generator and full-rating power converter.

Table I: Comparison of Different Types of Wind Turbibe Generators.

Generator (power range)	Converter options	Device count (Semiconductor cost)	Control scheme
PMSG(Kw)	Diode Bridge/SCR Inverter/Compensator	DC-Link Cap. 12 Controllable Switches (Moderate)	Simple Firing Angle Control of One Converter
	SCR Rectifier/SCR Inverter	DC-Link Cap. 12 Controllable Switches (Moderate)	Simple Firing Angle Control of Both Converters
	Diode Bridge/Hard-Switching Inverter	DC-Link Cap. 6 Controllable Switches (Low)	Power mapping technique including stator frequency derivative control MPPT, wind prediction control
	Diode Bridge/DC Boost/Hard-Switching Inverter	DC-Link Cap. 7 Controllable Switches (Low)	Vector control of supply side inverter DC Voltage control via chopper duty ratio
	Back-to-Back Hard-Switching Inverters	DC-Link Cap. 12 Controllable Switches (Moderate)	MPPT, Vector control of both converters
	Back-to-Back Hard-Switching Inverters (Reduced Switch)	2 DC-Link Caps. 8 Controllable Switches (Low)	Generator controlled through MPPT Inverter current controlled through PI controllers
DFIG (KW-MW)	Diode Bridge/SCR Inverter	DC-Link Cap. 6 Controllable Switches (Low)	Sliding Mode Control
	SCR rectifier / SCR inverter	DC-Link Cap. 12 Controllable Switches (Moderate)	Dual thyristor firing angle control
	Back-to-Back Hard-Switching Inverters	DC-Link Cap. 12 Controllable Switches (Moderate)	Vector control of rotor and supply side Space Vector Modulation or PWM MPPT, Space Vector Control

	Matrix Converter	18 Controllable Switches (high)	Vector control of rotor and supply side Double Space Vector PWM switching
IG (KW-MW)	Back-to-Back Hard-Switching Inverters PFC Converter	DC-Link Cap. 12 Controllable Switches (Moderate)	Vector Control, MPPT Controllers Use rotor slot harmonics and model reference adaptive system
SG (KW-MW)	Diode Bridge/DC Boost/Hard-Switching Inverter	DC-Link Cap. 7 Controllable Switches (Low)	Phase angle displacement control Supply voltage control
	Back-to-Back Hard-Switching Inverters	DC-Link Cap. 12 Controllable Switches (Moderate	Supply real and reactive power control Generator electromagnetic torque control

Maximum Power Point Tracking (MPPT) Algorithm

In wind generator applications capturing the maximum available wind power is essential. Regarding that, it has been shown that variable-speed (VS) configurations generate more total annual energy at any wind speed than constant speed configurations [15-18] becoming more and more attractive in low power applications. VS configurations the WG's rotating speed is changed guiding the aerodynamic system to operate at the maximum power point (MPP) for every wind speed. The latter is usually achieved through the generator's load variation by means of power converters. The MPP tracking (MPPT) methodologies consisting of both deterministic approaches such as the optimal power versus speed characteristic trackers (OCT) and more abstract approaches such as fuzzy logic or neural networks. The OCT is one of the most common MPPT control techniques [15-18,19] and uses the lacks inapplicability and is furthermore subject to imprecision resulting from mechanical deteriorating or parameter miscalculation[9].

Optimal Characteristic Tracking Controller

Optimum characteristic tracking controller: This can be a quite simple and robust method although it optimum power versus speed characteristic of the wind generator. A more flexible MPPT technique is the Perturbation and Observation (P&O) of the WG's output power [15-18], which throws out the need for a predefined characteristic.

Pertubration and Observation Controller

The MPPT controller's dependence on a predefined optimal characteristic presents certain disadvantages. Firstly, the characteristic may be degraded due to mechanical aging of the system [18] while on the other hand it being optimal depends on the precision of the initial calculations. Due to the latter drawbacks, approaches to MPPT controllers operating independently from a predefined characteristic have been reported [18- 19]. In such applications the controller performs constant perturbations and observations (P&Os) of the output power in search of the MPP.

The P&O controller algorithm used in this case is shown in Fig.5. After initialization the voltage and current on the DC side Vdc and Idc are measured and actual output power Pt is calculated. Pt is compared to the previous value Pt-1. If Pt is greater than Pt-1, then the sign of ΔD is unchanged, ΔD is added to Dt and the process is repeated. Otherwise the sign of ΔD is changed and the process continues. In each case, if maximum or minimum values of D, Dmax and Dmin respectively, are exceeded the sign of ΔD is also complemented.

The P&O process main concept, as a general rule, states that in order to achieve MPP the duty cycle is changed towards a specific course (increase or decrease) until actual power decreases and the course is reversed. However, the authors have observed that the typical algorithm, such as in [5], may indeed change the sign of ΔD as a result of a recorded power decrease, yet, when the P&O slow dynamic response of the system, the effect of this change may fail to yield a power increase, process is rapidly repeated and due to the relatively consequently the sign of ΔD is erroneously re-complemented on the next cycle and the system is disorientated.

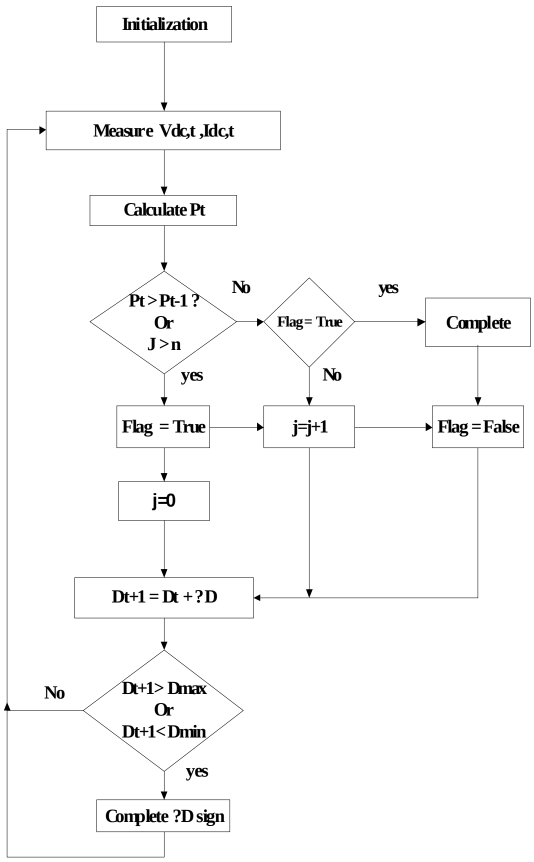

Figure 5: P&O algorithm.

Fuzzy Logic Controller

Applied method	Average Po value (case1)	Average Po value (case2)
Optimum characteristic	520 w (463 w)	382 w (379 w)
P&O	475 w (419 w)	305
Fuzzy logic	512 w (476 w)	512 w (476 w)

While the P&O controller achieves control independence from a predefined characteristic without lacking in simplicity, it can suffer from errors under specific conditions. Initialization of parameters as well as step size and timings are crucial to the system's overall performance [18]. Cases where the P&O controller has failed to function properly under rapid wind changes as a result of improper initialization have been observed [18]. In an attempt to counter such difficulties the application of fuzzy logic on the P&O concept can be applied[19]. The FL controller (FLC) uses the same philosophy as the P&O controller meaning that it performs constant perturbations of the duty cycle in order to track the MPP.

Aero Dynamic Coefficient (Cp) Average Values and Response Times

Table III: Output Power (Po) Average Values.

Applied method	Average value (case1)	Response Time (case1)	Average Value (case2)	Response Time (case2)
Optimum characteristic	0.499	6.15 sec (4.8sec)	0.486	9.88 sec
P&O	0.492	35sec (22 sec)	0.44	66 sec
Fuzzy logic	0.429	2.4 sec (3.8 sec)	0.492	2.24 sec

Conclusion

This paper shows the different topologies of wind power converters used in wind energy conversion system and also various control algorithms for tracking the maximum from the power converters. Three different Maximum Power Point Tracking (MPPT) controllers have been analysed and compared on their tracking performance. It shows that the Fuzzy Logic(FL) controller managed to perform adequately being the fastest in terms of step response, regardless of initial parameter set-up while on the same time disposing of the need for a predefined steady state characteristic. However, the optimum characteristic tracker remains the least computational demanding method yielding almost the same maximum average power provided that the steady state characteristic used is optimum. The P&O controller, while easier to implement than its fuzzy logic equivalent, faces problems associated with parameter tuning.

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