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Power Electronics and Electrical Drives for Wind Turbine Applications

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Abstract: **-- This paper presents a review of different solutions for small wind turbines of the order 2-50kW, designed for wind energy harvesting applications. Because the power characteristic of wind turbines is not linear, there are several topologies and control strategies for maximizing machine output power. In addition, the efficiency of the entire system depends on the type of the electrical machine that is used. The development of new designs of electromagnetic machine exhibiting good power density within a low-cost constraint, coupled with appropriate power electronic control strategies, can improve overall system efficiencies.**

I. INTRODUCTION

Wind generation of electrical energy is one of the most promising future energy resources due to its sustainable nature and very low net carbon impact. OVER the last ten years, the global wind energy capacity has increased rapidly and became the fastest developing renewable energy technology. The early technology used in wind turbines was based on squirrel-cage induction generators (SCIGs) directly connected to the grid. Recently, the technology has developed toward variable speed. The controllability of the wind turbines becomes more and more important as the power level of the turbines increases. Power electronic, being the technology of efficiently converting electric power, plays an important role in wind power systems. It is an essential part for integrating the variable-speed wind power generation units to achieve high efficiency and high performance in power systems. Even in a fixed-speed wind turbine system where wind power generators are directly connected to the grid, thyristors are used as soft starters. The power electronic converters are used to match the characteristics of wind turbines with the requirements of grid connections, including frequency, voltage, control of active and reactive power, harmonics, etc. The ongoing challenges introduced by the use of small wind turbines include both economical and technological aspects. The price is fairly high and potential users face obstacles in financing, permitting, and installing small wind energy systems. In addition, the overall system is still struggling to improve its reliability and efficiency. design techniques and control algorithms do not rely on known analytical models, which is the case with more conventional electrical machines and drive technologies.

II. WIND TURBINE CHARACTERISTICS AND MAXIMUM POWER POINT TRACKING ALGORITHMS

Wind turbines are generally characterized by two parameters: tip speed ratio (λ) and power coefficient (Cp). Tip speed ratio is defined as:

$$\lambda = \frac{R \cdot w}{v} \qquad (1)$$

where R stands for length of the blade, w is rotational speed of rotor, and v presents wnd linear velocity.
Total harvested power of a wind turbine (P_{total}), in terms of power coefficient (Cp), can be calculated as:

$$P_{total} = \frac{1}{2} \rho \cdot R^2 \cdot \pi \cdot v^3 \cdot C_p(\lambda) \qquad (2)$$

where ρ is the global air density at the turbine. The power coefficient (C_p) depends on the specific design of the wind turbine ,For a particular wind turbine the power coefficient, C_p, basically depends on the tip speed ratio, λ, and the blade pitch angle, i.e. the angle between the surface of the blades and wind direction.
Figure 1 shows that optimal operation of wind turbine (maximal power for C_{pmax}) depends on tip speed ratio of the machine (λ_{opt}). In order to get maximum possible power out of a wind turbine at a certain speed, the operating point of the turbine must be kept in the λ***opt*** area, Fig 1. Therefore a Maximum Power Point Trucking (MPPT) algorithm is required to control the rotational speed of the turbine rotor, keeping it at the maximum power.

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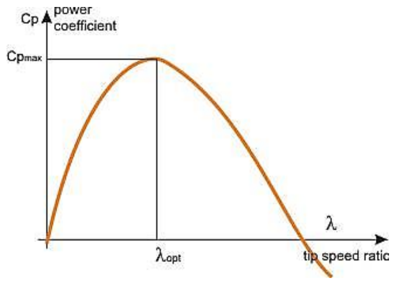

Fig. 1. Wind power curve showing power efficiency factor which depends on tip speed ratio of the electrical machine

III. DIFFERENT TOPOLOGIES OF A SMALL WIND TURBINE SYSTEMS

The two different electrical generators are used for Small Wind Turbine applications: induction generator and Brushless DC (BLDC) generator because they do not need complex control to generate energy and are inexpensive. If induction generator is applied for the wind energy harvesting, it is working at a speeds that are higher than synchronous speed, because that's the operation area of induction generator. Rotation speed of turbine is couple of hundred rpm, so gear-box needs to be attached to the turbine in order to increase the speed of induction generator. However, induction machines are not efficient, although they are inexpensive and robust. In addition, gearbox is not reliable component in the system, and has certain mechanical losses and required maintenance from time to time.

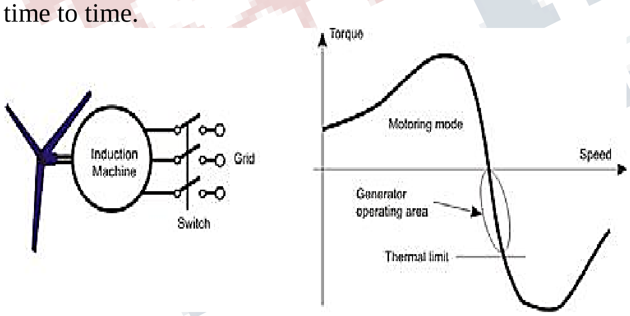

Fig. 2. Induction machine in wind turbine applications

When induction generator in wind applications is connected to the grid can work only for narrow speed range, as can be seen from the Figure 2. So, although induction machines are not expensive, in order to control them in wide speed range (variable speed) encoder is needed, which can increase small wind turbines system cost and make control more complex. Much less expensive solution for small wind turbines is Brushless DC (BLDC), which is more efficient than induction machine. In order to work as a generator, it can be controlled in wide speed range. When BLDC is connected to diode rectifier, DC voltage is generated on the terminals advantages of BLDC and diode rectifier is the simplicity of operation. Because of diode bridge, phase current and voltage are in the phase resulting the unity power factor. Output voltage of BLDC connected to diode rectifier is increasing with speed. So, both, stand alone and grid connected systems tend to have constant DC link voltage. In stand alone systems, wind turbines are charging the batteries, so by controlling DC link voltage, it is possible to control battery charging. In grid tied systems, rectified voltage from generator is feeding voltage for inverter, and should be constant.

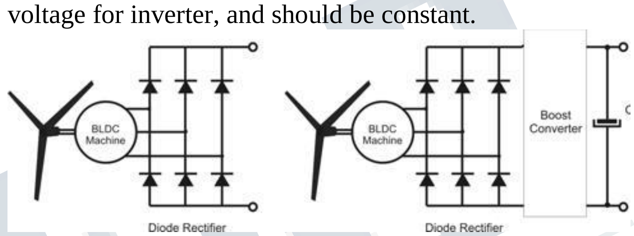

Fig. 3 BLDC generator connected to diode bridge, and connected to diode bridge and boost DC/DC converter (step-up chopper)

So, for both applications DC/DC chopper is used to keep DC link voltage constant. It is usually boost converter, which step-up rectified input voltage. The topology of BLDC with diode rectifier and chopper is shown in the Figure 3.

IV. DIFFERENT ELECTRICAL MACHINES AS WIND TURBINE GENERATORS

Wind turbines capture power from wind by means of turbine blades and convert it to mechanical power. It is important to be able to control and limit the converted mechanical power during higher wind speeds. Based on prime mover, namely high speed gas turbines or diesel engines (fixed speed), or low speed wind turbines (variable speed), there are several different electrical machine technologies . Small Wind Turbine applications: induction generator and Brushless DC (BLDC) generator and induction generator.

V. MODERN POWER ELECTRONICS

Power electronics has changed rapidly during the past years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. For both

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cases, the performance is steadily increasing, and at the same time, the price of devices is continuously falling. In order to improve reliability and reduce cost, the number of components is going down by a higher level of integration. The power electronic device technology is still undergoing important progress, including some key self-commutated devices, such as insulated gate bipolar transistor (IGBT), MOSFET, integrated gate commutated thyristors (IGCT), MOS-gate thyristors, and silicon carbide FETs.

VI. DIFFERENT CONTROL STRATEGIES FOR MAXIMIZE POWER OUTPUT OF SMALL WIND GENERATOR SYSTEM

A. Use Diode bridge rectifier:

Most of the wind turbines with BLDC machines use diode rectifiers. There are several reasons for that. First is, that such topology does not require rotor sensor for AC-to-DC conversion, which makes whole system less expensive. So, after rectification stage, the dc output voltage is regulated using a boost chopper that is feeding the battery (stand-alone systems) or capacitor DC link (grid- tied systems). This is the most common configuration of small scale wind turbines. In order to maximize the overall output power on the generator terminals, different Maximum Power Point Tracking (MPPT) techniques are developed and proposed in research papers. As presented at the Figure 6, if the maximum power needs to be generated out of the turbine, the operating point must be kept in the λopt area. So, one way to do MPPT is to know the turbine characteristic (power coefficient in respect of tip speed ratio curve). Rotational speed of the generator can be controlled by controlling the terminal voltage, which will also control the current, therefore the torqueAt every speed, there is certain terminal voltage and speed where generator has maximum power output. So, by making look up table, for every speed, voltage can be controlled in order to get maximum power, as shown in the Figure 7.

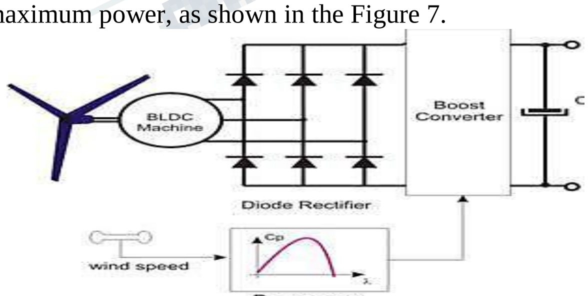

Fig. 6. MPPT using wind speed and power curve information

The system presented in is connected to the grid via current controlled inverter. The presented MPPT strategy is known as "Limited-Cycle", and is based on combination of

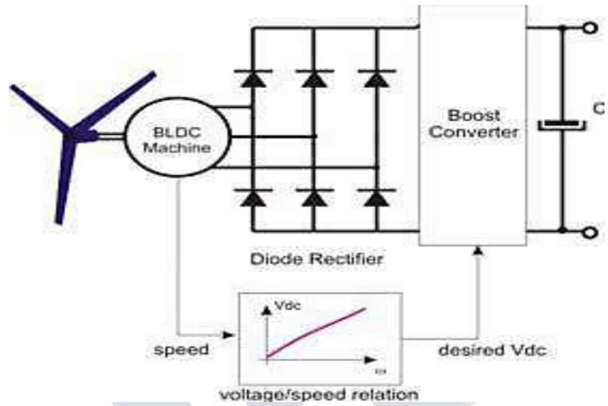

Fig. 7. MPPT using generator terminal voltage vs speed relationship

voltage and current controllers by sustaining oscillation at the steady state – so called "limit-cycle" phenomena. For rotor speeds where output power is still below maximum power limit, boost converter keeps DC link voltage at constant level using PI controller current controller to decrease reference value of the current demand. This is called "limit-cycle" moment, when system oscillates in between boundary of equilibrium/non-equilibrium states and the power flow is in its maximum power operating point. reference speed of the rotor will be increased if:

• speed is increased and if generated power Pg increases and rotor speed stays the same or increase, or both Pg and rotor speed decreases. On the other hand, the reference speed of the rotor will be decreased if:

• Decrease the rotor speed if generated power Pg decreases while rotor speed stays constant or increases, or PG increases while rotor speed decrease. This is very well known method from MPPT for controlling solar panels output power

VII. CONCLUSIONS

This paper has reviewed the power electronic applications and electrical machines for wind energy systems. Also Various wind turbine systems with different generators and power electronic converters are described. Different types of wind turbine systems have quite different performances with controllability. The electrical topologies of wind Farms with different wind turbines are described . It has been shown that the wind farms consisting of different turbines may need different configurations for the best use of the technical merits. Furthermore, the possible methods of improving wind turbine performance in power systems . While the wind turbine market continues to be dominated by conventional gear-driven wind turbine systems, the direct drive or one-stage gear, so-called multibrid-type wind system, is attracting attention. Variable-speed operation has many advantages.

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