PMSM/BLDC as Generators in Renewable Energy Conversion Systems

Vencislav Cekov Valchev, Plamen Valentinov Yankov and Angel Stanimirov Marinov

Abstract – **This paper studies the use of the PMSM (permanent magnet synchronous machine) generators instead of the induction based alternating current generators in renewable energy sources (wind turbines, combined heat and power, etc.). The paper considers the most significant advantages of the novel permanent magnet technology such as increased specific power, high torque, reduced maintenance costs, increased operational time.**

The paper proves that PMSM/BLDC machines tend to be the future preferable choice as generators in renewable energy systems with mechanical energy conversion.

Keywords – **PMSM, renewable energy sources, efficiency**

I. Introduction

The type of generators used in the industry driven by wind, pallets, water or in other words renewable energy sources must be up to specific requirements. Although a non-suitable generator can be used in some cases, for example synchronous instead of asynchronous machine, the efficiency of the system is reduced. The improvement of the power electronic converters and especially the switching components used in the circuitry led to the effective use of PMSM generators, which roots we can trace to 1962 [2]. In mechanical way they are similar to the AC synchronous machines. However, a sophisticated control technique has made them as controllable as brushed DC motors.

Two types of control are mainly used in the PMSM applications: sensorless Field-Oriented Control (FOC) or a simpler sensor based algorithm control type.

Manufacturers of microchips (Microchip, Infineon, and STMicroelectronics) are producing specially designed IC's to control the permanent magnet machines. BLDC control requires less computation power (for example STMicroelectronics's 8-bit controller) and in essence is a six step process. The more complicated FOC control need 16 bit controller (for example Microchip's dsPIC33FJ12MC201/203 DSC). Basically FOC is made of two algorithms: the first one is the Clarke algorithm, which converts the stator winding- phase currents from a three-axis vector to a two-axis vector, referenced to the stator; the second one is the Park transform, which then converts the two-axis currents into a rotating system, still relative to the rotor [6].

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Although at the present time there is focus at the PMSM sophisticated sinusoidal control, because of the capabilities of the control technique, there are some applications that do not require so many actions such as reversing and braking but only one of them. Then the use of the simpler trapezoidal BLDC control is more appropriate and adequate.

II. PMSM/BLDC Motor Construction Advantages

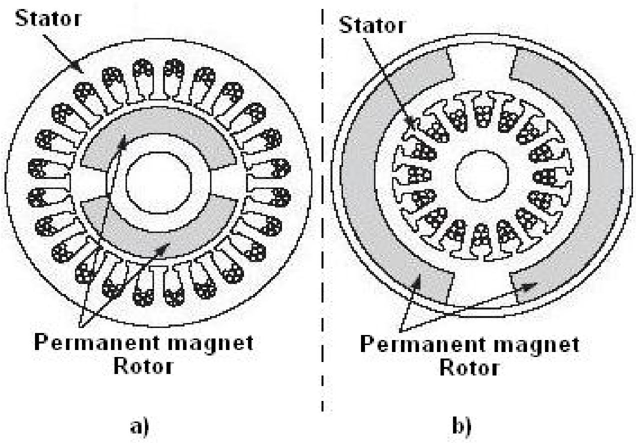

Fig. 1 PMSM/BLDC motor construction

Figure 1 shows a PMSM/BLDC witch consists of a magnetic rotor and wound stator construction [1]. There are several construction possibilities:

- The rotor is rotating inside the stator (Fig.1, a)); examples are washing machine motors, etc.
- The rotor is rotating outside the stator (Fig.1, b)); examples are personal computer fans, etc.
- "Pancake" construction – the rotor is next to the stator, [9]; Examples are the CD player motors.

Wound stator can dissipate heat to the motor housing and the surrounding environment. In contrast, a brush motor holds the heat under a non-conductive air gap, resulting in greater efficiency and power density for the PMSM design and providing high torque-to-inertia ratios. A PMSM motor generates magnetic flux using permanent magnets in the rotors, which are driven by the stators applying a synchronous rotational field. On the other hand, the flux that is applied by the stators (the armature-reaction flux) generates torque most effectively when it is perpendicular to flux generated by the rotors. To maintain near-perpendicularity between stator flux and rotor flux, two control methods with position-speed feedback loop are popularly used for controlling a PMSM as mentioned in the introduction of the article: Field-Oriented Control (FOC) and Brushless DC Control.

The overall advantages of PMSM construction compared with conventional AC machine are:

- Removed slip-rings (there is no excitation winding)
- Reduced copper losses (there is no excitation winding)
- Less weight (there is no excitation winding)
- Less generated heat and better heat dissipation
- Reduced size (due to specific construction and permanent magnets)
- Lower Torque Ripple improves position control
- Compared to brushed motors, better EMI and reliability
- Excellent torque at low speeds

The disadvantages are the higher overall cost of the machine and the cost and complexity of the control.

Cost of the permanent magnets is key element for reducing the price. This expense may be reduced in the future when key patents expire for the underlying rare earth-based magnet technology. The cost of control can be reduced by employing low cost dsPIC Digital Signal controllers and (optionally) removing expensive sensors by incorporating sensorless control with back-EMF tracking for determining the rotor position.

III. Driving a PMSM/BLDC

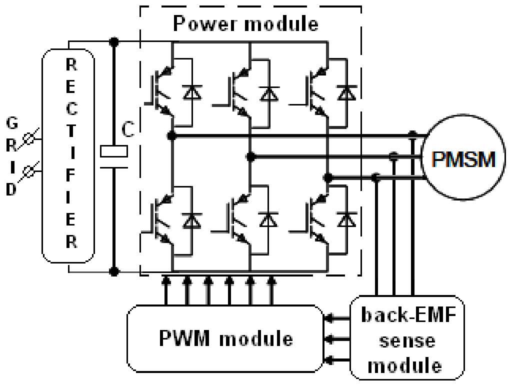

Fig. 2 Block scheme of PMSM/BLDC sensorless control scheme

PMSM/BLDC machines require a control and power schemes to run. Figure 2 shows block scheme of sensorless control. It consists of Back-EMF sensing circuit (often resistors and Analog to Digital Converter (ADC)), which detects the position of the rotor. The PWM (Pulse width modulation) module is producing the control signals, according to the previous sensor for BEMF. The signals drive the power module transistors to continue the spinning of the rotor correctly.

The most popular power devices for motor control applications are Power MOSFETs and IGBTs. A Power MOSFET is a transistor controlled with voltage. It is designed for high-frequency operation and has a low-voltage drop in forward direction, so it has low power losses. The IGBT requires low drive current, has fast switching time, and is suitable for medium to high switching frequencies. Its structure combines both bipolar and MOSFET technologies.

The control module produces signals with desired by the user frequency/speed of the machine. The shape of the control wave is dependant on the kind of control technique.

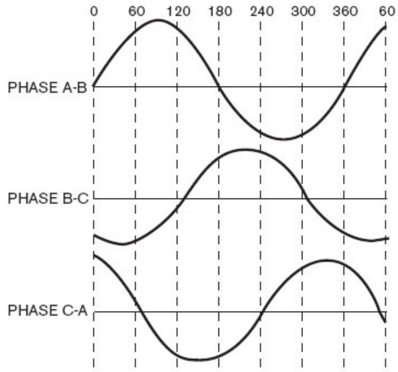

Fig. 3 Sinusoidal drive current for PMSM with an ideal torque ripple of zero

Figure 3 shows the typical signals for PMSM with field orientated control (FOC). The torque ripple of the wave is ideal with zero value.

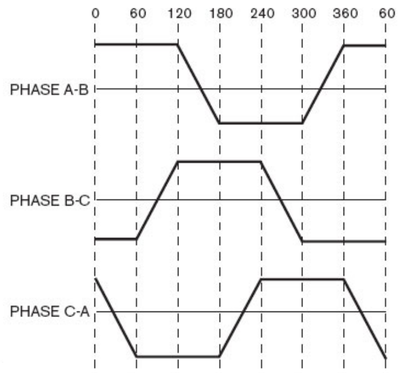

Fig. 4 Trapezoidal drive current for BLDC with an ideal torque riplle of zero

Figure 4 shows the typical signals for PMSM with brushless DC control (BLDC). The torque ripple of the wave can be expected and is possibly as much as 13%.

Sensorless control is used in areas that need reliable protection for the shaft of the motor from dust or other chemical intruders.

The information from back-EMF zero crossing is used to determine the rotor position for proper commutation and to determine which power transistors to turn on to obtain maximum motor torque. The sensorless control is efficient and implies synchronization between the phase BEMF and the phase supply so that the BEMF crosses zero once during the non-fed 60° sector. As only two currents flow in the stator windings at any one time, two phase currents are opposite and the third phase is equal to zero. Knowing that the sum of the three stator currents is equal to zero (star-wound stator), the anticipated instantaneous BEMF waveforms can be calculated. The sum of the three stator terminal voltages is equal to three times the neutral point voltage.

Sensored control structure can be used in applications that are with no specific demands for the machine. With this type of control phases are commutated once every 60° electrical rotation of the rotor. This implies that only six commutation signals are sufficient to drive a BLDC motor. The Hall sensors are used to make these signals. However they are adding to the cost of the final product.

IV. DIRECT DRIVE WIND ENERGY SOLUTIONS WITH PMSM/BLDC

Wind turbines convert aerodynamic power into electrical energy. In a wind turbine two conversion processes take place. The first converts the aerodynamic power that is available in the wind into mechanical power. The next one converts the mechanical power into electrical power. Wind turbines can be either constant speed or variable speed.

The mechanical power produced by a wind turbine is proportional to the cube of the wind speed, the full equation (Eq. 1) for the power that can be obtained from the wind is:

$$P = \frac{1}{2} S \rho V^3 \alpha \text{, [W]} \qquad (1)$$

In this equation P - power in watts; V – wind speed in meters per second; S – surface of the rotating blades in square meters; α – an efficiency factor determined by the design of the turbine; ρ - mass density of air in kilograms per cubic meter.

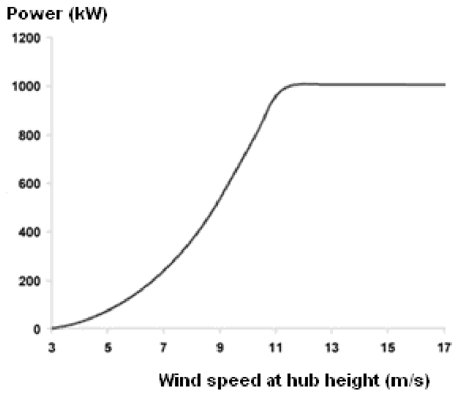

FIG. 5 WIND POWER-SPEED CURVE

Variable speed design requires producing machine witch can obtain maximum power from different wind speeds (Fig. 5). Therefore variable speed operation is necessary to maximize the energy yield.

As can be seen on the power-speed curve, there is a maximum power that is reached at certain wind speed. The nominal rotational speed and nominal power as well for a wind turbine is almost in the middle of the cubic line excluding the maximum power section. The power-speed (power-frequency) curve of the wind turbine should be as close as possible to the ideal cubic one for best obtained power.

The shaft of the blades rotor is usually connected through a gear/gearbox or in some cases for smaller wind turbines belt to the generator. The reason is that every wind turbine is produced for certain part of the wind power speed curve. The rotating of the blades (70rpm) of large wind turbines is not enough to produce large amount of power in conventional induction motors if it is connected directly. So it is needed a gear with certain ratio to make the generator spin faster. Even the smaller wind turbines require a gearbox.

The PMSM/BLDC offers a solution that will remove all gears and will make the mechanical conversion more efficient [3], [4]. The specifically produced permanent magnet generators work nominally at low rotational speeds and are connected directly to the shaft of the blades (Fig. 6).

FIG.6 DIRECT-DRIVE WIND TURBINE

Simplifying the nacelle system increases reliability and efficiency by avoiding gearbox issues. A general trend towards direct drive systems has been evident for some years, although there are considerable challenges in producing technology that is lighter or more cost-effective than the conventional geared drive trains.

The technology is tested mainly on smaller wind turbines and an exception is only the turbines of Enercon [8], which have long supplied direct drive generators employing a synchronous generator and having an electrical rotor with windings rather than permanent magnets. Direct drive designs that are based on PMG (Permanent Magnet Generator) technology, using high-strength neodymium magnets are installed in July 2008, by Siemens. The machines are two new 3.6 MW direct drive turbines. They will answer the question whether direct drive technology is competitive with geared machines for large turbines. The two turbines have rotor diameters of 107m [7].

The overall advantages of direct drive technology with PMSM compared with conventional geared wind turbines are:

- Reducing the size of the nacelle
- Reducing the weight that must be installed and then supported by the tower
- Avoiding gear issues
- Better overall efficiency

V. PMSM/BLDC IN COMBINED HEAT AND POWER SOLUTIONS

Another application of PMSM/BLDC motors, concerning renewable energy is in micro Combined Heat and Power (µCHP) systems. µCHP is relatively new concept that revolves on simultaneous generation of thermal and electric power for domestic needs – of single or multiple households.

Currently the electrical energy in the µCHP systems is generated with non-variable speed generators or with variable speed AC machines. PMSM/BLDC however can prove a better solution in this application, as it main advantages are as follows:

- Reducing the size and weight – a very important asset as µCHP systems are for indoor installation and usually take space in basement, garage or other small premises.
- Improved efficiency - PMSM has significantly improved efficiency over other generator types which is a must for renewable energy systems where conversion losses should be kept at a minimum.
- Robust, low maintenance requirement – sensorless PMSM/BLDC machines are highly reliable and durable, furthermore they can be hermetically sealed in oil container along with the other mechanical moving parts to further increase durability. This aspect is of great matter since service in private households is often inconvenient.

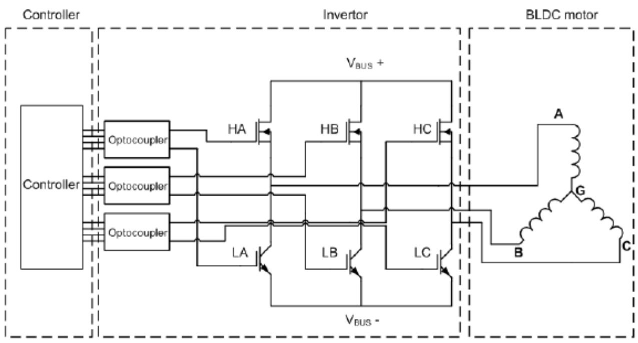

FIG.7 PMSM/BLCD SENSORLESS GENERATOR CONTROL FOR MCHP SYSTEMS

Figure 7 shows a PMSM/BLCD sensorless generator control for µCHP systems where a three phase PMSM/BLDC machine is controlled with an improve inverter. The flexibility of PMSM/BLDC allows for different driving structures as the one used in figure 7 where the PMSM/BLDC machine is controlled with improved MOSFET – IGBT combination

VI. CONCLUSION

The use of PMSM/BLDC generators becomes more popular today. The clear advantages of the construction of the machines determine the need of these types of motors/generators in future. Different applications use nowadays this advanced technology: air conditioning and compressor applications; a PMSM/BLDC is an excellent alternative in domestic application; renewable energy sources. Progress in the field of power electronics and microelectronics enables the application of PMSMs for high-performance drives, where, traditionally, only DC motors were applied; etc. Robustness and reliability are the main goals to be achieved with PMSM like the direct-drive wind turbine solution.

Because of their outstanding qualities PMSM/BLDC machines become more and more popular as generators in Renewable Energy Systems.

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