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A Survey on Power Generation in Wind Turbines by PMSG Generator

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***Abstract:* This paper mainly describes about the survey of power production in wind turbines by using permanent magnet synchronous generator. For this a different schemes of wind turbines are considered.**
***Keywords:* PMSG (permanent magnet synchronous synchronous generator), Boost converter, neutral-point-clamped (NPC) converter, low voltage ride-through (LVRT), Direct-drive wind turbine, direct-torque control (DTC).**

I. INTRODUCTION

In recent years, the electrical power generation from renewable energy sources, such as wind, is increasingly attraction interest because of environmental problem and shortage of traditional energy source in the near future. The wind power mainly depends on geographic and weather conditions and varies from time-to-time. Therefore it is necessary to construct a system that can generate maximum power for all operating conditions.

Recently, permanent magnet synchronous generator (PMSG) is used for wind power generating system because of its advantages such as better reliability, lower maintenance, and more efficient etc. The generator is actually dedicated to a vertical axis wind turbine. Using a diode rectifier simplifies the structure and reduces system cost (no position sensor and low-cost converter without control). An optimal energetic behavior is obtained if the excitation field of the synchronous generator can be tuned.

II. POWER MAXIMAISATION

This study presents the wind turbine converts the power in the wind to mechanical power in the rotor shaft; the mechanical power in the shaft is then converted to electricity using a permanent magnet synchronous generator (PMSG). The voltage generated by the permanent magnet machine is rectified using a three-phase passive rectifier, which converts the AC voltage generated by the PMSG to a DC voltage. The schematic diagram of control system of a permanent magnet generator directly driven by wind turbine is shown in Fig.1.

The main circuit composition of generators and boost chopper, etc. was replaced in the equivalent circuit in order to theoretically analyze this wind generator system. Characteristics such as generated output power and DC output voltage were expressed in functions of duty ratio of the boost chopper and the generator rotational speed.

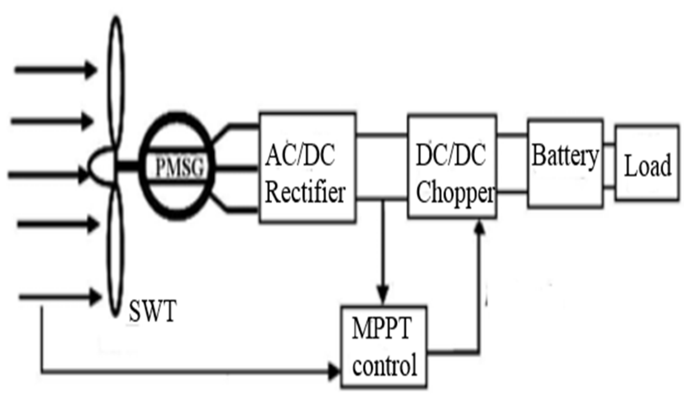

Fig 1. Schematic diagram of control system of a permanent magnet generator directly driven by wind turbine

A. *Permanent Magnet Synchronous Generator Model*

Since the power for excitation source is not required for the permanent magnet synchronous generator, high efficiency is expected. And, since the electromotive force in proportion to rotational speed is generated, it is possible to take out the generated output in the easiness.

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B. Three-Phase Diode Bridge Rectifier
The diode rectifier is the most simple, cheap, and rugged topology used in power electronic applications. The drawback of this diode rectifier is its disability to work in bi-directional power flow. The generator is connected with rectifier circuits like the below Fig.2.

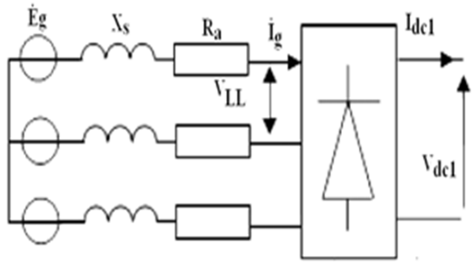

Fig 2. Connection diode rectifier circuits to the generator

C. Dc/Dc Converters
The DC-to-DC converters are often used in regulated switch-mode dc power supplies and in dc motor drives applications. Frequently, the input to this converter is an unregulated dc voltage which can be obtained by rectifying an ac voltage source. This unregulated voltage will fluctuate due to changes in the line. In order to control this unregulated dc voltage into a regulated DC output we need to use a DC-to-DC converters. In this model, the boost converter has been controlled to yield constant output DC voltage level.

D. MPPT Condition
Two types of tracking algorithms (MPPT) exist, namely: methods based on the knowledge of the Cp(λ) characteristic and methods that allow seeking the optimal operation without knowing the turbine characteristics. Some control strategies are based on the power coefficient curve (Cp), eg. λ control method, which modifies angular speed of wind rotor for maintaining an optimum λ value and consequently a maximum power coefficient (Cp) for all wind speeds. The wind turbine, when operating at maximum Cp, produces maximum mechanical power on shaft. To the small wind turbine used as reference on this work the angular speed (Ω) for maximum mechanical power points do not coincide with angular speed for maximum electrical power points, so this strategy is not recommended.

III. FAULT RIDE-THROUGH CAPABILITY
Recently, many researchers have addressed the FRT methods for the wind farm connected through the voltage source-converter (VSC)-based high voltage dc transmission (HVDC). However, in the proposed CSC-based offshore wind farm, the long distances between generator- and grid-side converters cause a grid voltage dip that cannot be identified at the same instant by generator-side controller. In addition, the dc-link inductance in the CSC-based system is normally smaller (0.7 to 1.0 pu) compared to the dc-link capacitance (3 to 5 pu) of the VSC-based counterpart. This exerts significant challenges for the FRT capability of a CSC-based system, and therefore, recently proposed FRT methods for a VSC-based counterpart in cannot be adapted or made suitable for the proposed system. In order to overcome this problem, a novel FRT method using inherent short-circuit operating capability of the CSC is developed.

IV. CHALLENGES IN EXISTING FRT METHODS FOR THE PROPOSED WIND FARM
The Proposed system configuration of cascaded CSC-based offshore wind farm and their block diagram is shown in Fig. 3 & Fig. 4.

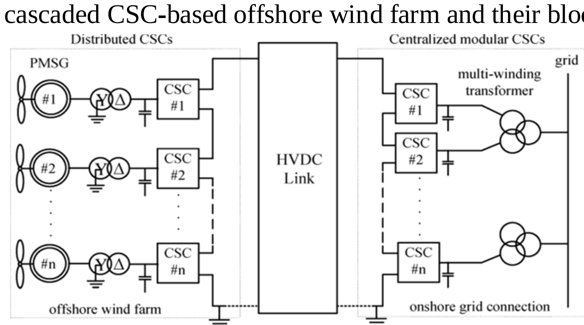

Fig 3. Proposed system configuration of cascaded CSC-based offshore wind farm

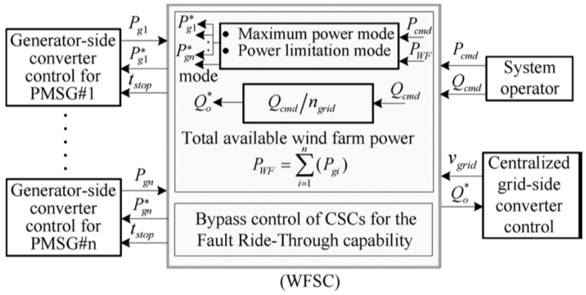

Fig 4. Block diagram

Besides the grid fault, the other technical challenge for the cascaded CSC-based wind farm is to ensure continuous operation of the wind farm when one or more turbines fail to operate. This issue is not critical for the VSC-HVDC-based wind farm, where wind generators are parallel connected. Various recent studies have adopted a wind farm with series interconnection of wind turbines but this issue has not been researched. In this paper, a flexible operation is proposed which enables the isolation of the faulty turbine-generator unit from the cascaded system without affecting the operation of other series interconnected wind turbines. The control module consists of the wind farm supervisory controller (WFSC), turbine-generator control units, and centralized grid-side converter control.

V. NORMAL OPERATION MODE

According to the system operator’s demand, the WFSC operates the wind farm in two active power control modes, namely maximum power mode and power limitation mode (e.g., for network frequency regulation In maximum power mode, all the wind turbines operate with their own maximum possible power. In contrast, WFSC generates the active power references for each turbine-generator controller in power limitation mode.

The speed controller receives the reference speed from the maximum power point tracking (MPPT) algorithm and regulates the PMSG speed accordingly. The output of the generator speedregulator gives the reference to the torque producing current (q -axis component of generator current). The zero–axis current control is applied to the generator. After capacitor current compensation, the converter reference current is used to obtain the modulation index and firing angle for the generator-side CSC#n. The gating signals are then generated using space vector modulation (SVM).

A. FRT Operation Mode

Due to the low dc-link inductance, the CSC-based system needs a fast FRT capability.

VI. THREE-LEVEL BOOST AND NPC CONVERTER BASED PMSG WIND TURBINE

A predictive control scheme is proposed for the low voltage ride-through enhancement of direct driven permanent magnet synchronous generator base Megawatt-level wind turbines. The proposed method uses the turbine-generator rotor inertia to store the surplus energy during the grid voltage dips. The power conversion system is realized using three-phase diode-bridge rectifier, three-level boost converter and neutral-point-clamped (NPC) inverter. The wind turbine requirements, such as maximum power point tracking, net dc bus voltage control, balancing of the dc capacitor voltages, and reactive power generation, are modeled as the reference control variables.

The generator- and grid-side cost functions are defined to deal with these control objectives. During each sampling interval, the control goals are achieved based on minimization of cost functions. The coordination of boost and NPC converters and the exchange of reference control variables during normal and low voltage ride-through operation is formulated such that the power converters operate in a safe mode while meeting the grid code requirements.

The power conversion system for the direct-driven PMSG based WECS is shown in Fig. 6. It consists of three stages: ac/dc, dc/dc and dc/ac, and they are implemented using diode rectifier, three-level boost converter and NPC inverter, respectively. The active switching devices in the TLB-NPC converters are realized using MV-IGBT/IGCT, and they operate at few hundred Hertz to decrease the switching losses. The diode rectifier features series connected diodes due to the MV generator. The output of the diode rectifier, v in remains unregulated but is limited by the rated speed of the turbine, which defines the voltage rating of the capacitor.

The TLB converter enables MV operation for the dc-dc stage. The output of the TLB fits directly the two dc-link capacitors of the grid-tied NPC inverter.

This second dc-link provides decoupling for the generator- and grid-side converters and thus it provides better capability for the LVRT enhancement. The NPC multilevel and MV operation at grid-side improves the power quality and efficiency of the system. The Configuration of three-level boost converter and NPC inverter based MW-MV PMSG-WECS is shown in Fig.5.

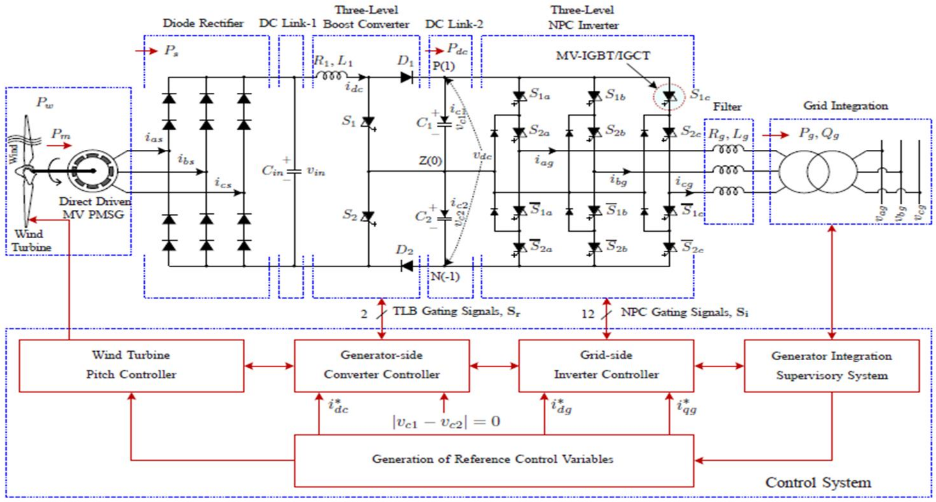

Fig5. Configuration of three-level boost converter and NPC inverter based MW-MV PMSG-WECS.

The pitch control system regulates the output power of the turbine when the wind speed is above its rated value. The magnitude, phase and frequency of the grid voltages are monitored by the grid integration supervisory system. It sends appropriate control signals to the references generation system in the event of grid faults. During the normal and LVRT operation, with the help of the references generation system, the reference inductor current is generated for the TLB converter, while the reference dq-axis currents are developed for the NPC inverter.
The control objectives for the power converters include:

A. *TLB Converter*

1) Regulation of inductor current, *i dc*

a) To achieve maximum power point tracking (MPPT) during normal operation

b) To store the surplus active power in the turbine generator rotor inertia during LVRT operation

2) Balancing of dc capacitor voltages during all operating conditions to maintain semiconductor device voltage stress within safe limits NPC Inverter:

3) Regulation of *d*-axis grid current

a) To maintain net dc-bus voltage, *vdc* at its reference value during normal operation

b) To limit the active power output, *Pg* during LVRT operation

4) Regulation of *q*-axis grid current to generate reactive power to the grid

VII. SPACE-VECTOR MODULATED SENSORLESS DIRECT-TORQUE CONTROL FOR DIRECT-DRIVE PMSG WIND TURBINES

This method proposes a space-vector modulation (SVM)-based direct-torque control (DTC) scheme for a permanent-magnet synchronous generator (PMSG) used in a variable-speed direct-drive wind power generation system. A quasi-sliding-mode observer that uses a relatively low sampling frequency, e.g., 5 kHz or 10 kHz, is proposed to estimate the rotor position and stator flux linkage based on the current model of the PMSG over a wide operating range. The optimal torque command is obtained directly from the estimated rotor speed for the DTC by which the maximum power point tracking control of the wind turbine generator is achieved without the need of wind speed or rotor position sensors. Compared to the conventional DTC, the proposed SVM-DTC achieves a fixed switching frequency, greatly reduces the flux and torque ripples, while retaining the fast dynamic response of the system. The effectiveness of the proposed SVM-DTC scheme is verified by simulation studies on a 1.5-MW PMSG wind turbine and is further verified by experimental results on a 2.4-kW PMSG with a 10 kHz sampling frequency.

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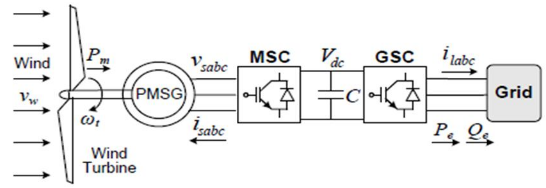

Fig 6. Configuration of a direct-drive PMSG wind turbine connected to a power grid.

The configuration of a direct-drive PMSG wind turbine is shown in Fig. 6, where the wind turbine is connected to the PMSG directly. The electrical power generated by the PMSG is transmitted to a power grid and/or supplied to a load via a variable-frequency converter, which consists of a machine side converter (MSC) and a grid-side converter (GSC) connected back-to-back via a DC link.

This paper proposes an improved SVM-based DTC scheme for direct-drive PMSG wind turbines, where the MPPT control is realized without the measurements of wind speed or generator rotor position, leading to a position/speed sensor less control for the WTG systems. The optimal torque command generated by the MPPT algorithm can be applied directly to the DTC system, which eliminates the commonly adopted outer speed control loop in the vector control systems. To minimize the CPU loading in the practical system implementation, a quasi-sliding-mode stator-flux observer is proposed, which uses a lower sampling frequency, normally lower than 10 kHz, to achieve high-accuracy stator flux observation over a wide speed range of the PMSG. By adopting the proposed DTC scheme, the flux and torque ripples are reduced while using a fixed and lower switching frequency and retaining the fast dynamic response of the system, when compared with the conventional DTC scheme. The proposed DTC scheme is validated by simulation for a 1.5-MW direct-drive PMSG wind turbine and experimental results for a 2.4-kW direct-drive PMSG wind turbine.

VIII. PROPOSED SVM-BASED DTC

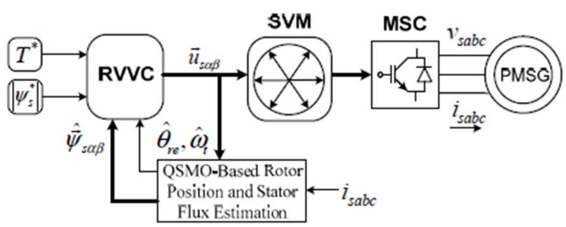

Fig 8. Proposed system

The schematic of the proposed SVM-DTC for a non-salient pole PMSG WTG is shown in Fig. 8, where *T** and *ψs* are the reference torque and stator flux magnitude, respectively.

$\hat{\vec{\psi}}_{s\alpha\beta} = [\hat{\psi}_{s\alpha}, \hat{\psi}_{s\beta}]^T$ and $\vec{u}_{s\alpha\beta} = [u_{s\alpha}, u_{s\beta}]^T$ are the estimated stator flux linkage vector and the resultant stator voltage space vector in the stationary *αβ* reference frame, respectively. From Fig. 8 it can be seen that the proposed SVM-DTC scheme retains the advantages of the conventional DTC, such as no coordinate transformation, no current control, etc. However, instead of adopting a switching table and hysteresis comparators, a reference voltage vector calculator (RVVC) is designed to determine the desired voltage vector *→us αβ*. The Experimental Setup is shown in Fig. 9.

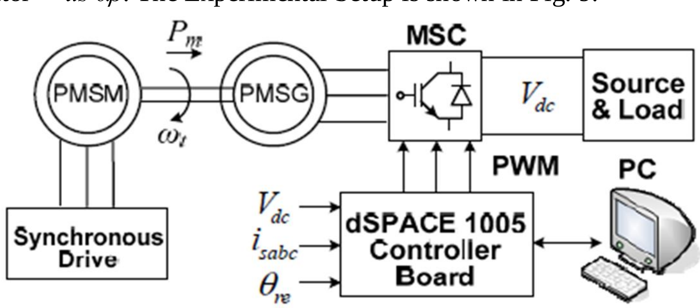

Fig 9. Experimental setup

A. Control Issues in PMSG-Based Small Wind-Turbine Systems

In the field of wind energy generation particular interest has been focused in recent years on distributed generation through small wind-turbines (power unit 200 kW) because of their limited size and lower environmental impact. The field of small generation was dominated by the use of asynchronous generators directly connected to the grid, while recently permanent magnet synchronous generators (PMSG) with power converter, either partially or fully controlled, became popular. This paper reviews the control issues related to these small wind-turbine systems: generator torque control, speed/position estimation, pitch control, braking chopper control, dc/dc converter control, and grid converter control. Specific issues for small wind-turbines arise in the wind energy extraction optimization and limitation and in the innovative concept of "universal" wind-turbine operation, that leads these system to operate grid-connected, standalone or in load supporting mode.

Fig. 10 shows the small wind-turbine market segmentation: the maximum number of manufacturers in Europe corresponds to stand alone wind applications with a max wind-turbine size of 20 kW, but the average wind penetration rate is maximum in the pumping field.

It is possible to observe that the maximum wind-turbine size increases in the case of wind diesel system with battery, and the maximum wind-turbine size increases in case of grid connection. The field of small generation was dominated by the use of asynchronous generators directly connected to the grid/load and more recently by Permanent Magnet Synchronous Generators (PMSG) with a diode rectifier, boosts converter and inverter.

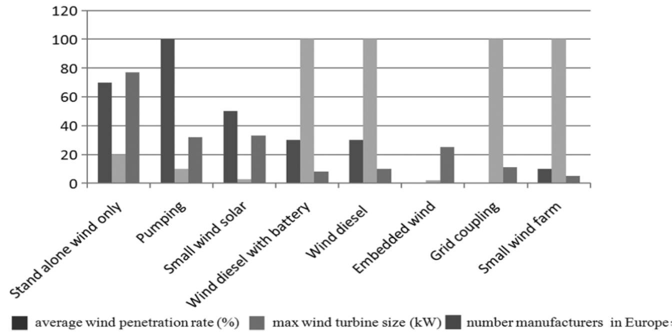

Fig 10. Small wind market segmentation

The use of an high number of pole pairs allow the PMSG to operate at low speed without decreasing the efficiency, thus allowing to avoid the gearbox. The use of a diode bridge reduces cost and control algorithm complexity. Moreover the well-known six-pulse dc-voltage waveform allows implementing a simple estimator of the rotor speed. The generator low frequency harmonics (5th and 7th) can be reduced thanks to the dc-inductor that unfortunately has a negative effect on the power factor. Moreover, the extracted power decreases as the wind speed increases due to the major effect of diode commutation and at low speed due to possible discontinuous operation of the dc/dc converter. Hence, for power levels in the order of tens of kW, these generators will use a back-to-back converter leading to a 5%–15% more power. Besides the choice of the power converter configuration, the control issues in PMSG-based small wind-turbine systems are many.

IX. WIND-TURBINE SYSTEMS TOPOLOGIES

Several types of generators can be adopted in wind power turbines: dc and ac types, parallel and compound dc generators, permanent magnets or electrical field excited, asynchronous or synchronous generators. The right choice depends on the primary source, the type of load and the speed of the turbine. Besides, systems differ with respect to their applications, whether they are standalone or connected to the grid.

From Fig.11 & Fig. 12 the most adopted wind-turbine generator for medium power systems is the doubly fed induction generator (DFIG) that could be used even in standalone operation. However, typically in small WTS for standalone applications, the choice is between variable speed asynchronous and synchronous generator. Variable speed asynchronous generators can easily operate in parallel with large power systems, since the utility grid controls voltage and frequency, while static and reactive compensating capacitors can be used for correction of the power factor and harmonic reduction. Abrupt speed changes due to load or primary source changes are easily absorbed by the solid rotor of the asynchronous generator, and current surges can be effectively damped without demagnetization issues.

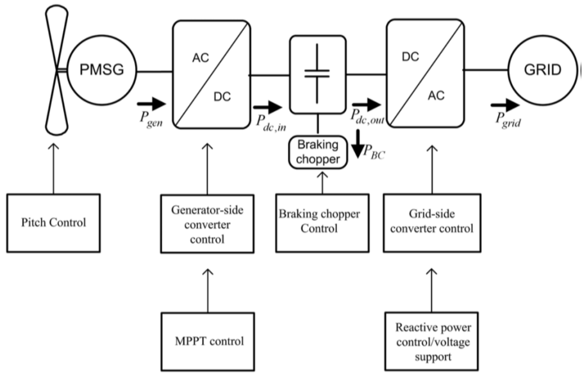

Fig 11. Control issues in PMSG-based small wind-turbine systems.

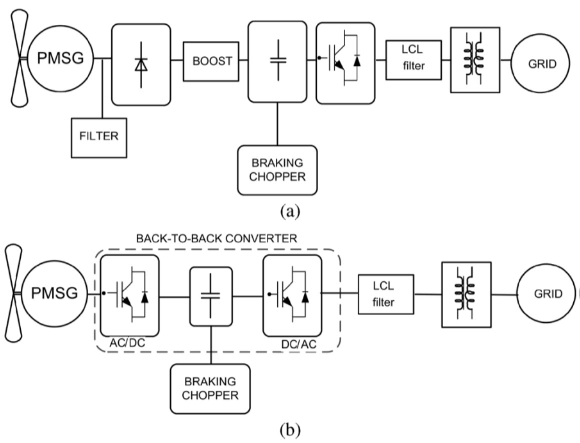

Fig. 12. Wind-turbine system. (a) Diode-bridge rectifier and boost converter. (b) Back-to-back converter.

X. RESULT AND CONCLUSION

Thus the survey about the power generation of wind by permanent magnet synchronous generator is studied with different techniques. Out of these the most convenient technique is by using maximum power point tracking method. In this method the losses are reduced and the efficiency is increased.

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