A 200kW Wind Turbine Power Chain

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Abstract–This paper presents a modern configuration of the power chain for a high power wind turbine machine using permanent magnet generator. A test setup is shown and device specifications are described. Advantages of using Direct Drive Generators are also shown. The discussion on the use of SRG is proposed. It provides a low speed solution of the wind turbine power converter design.

Keywords: Wind Turbines, Vector controlled inverter, Direct Drive, Regeneration.

I. INTRODUCTION

Due to the rapidly depleting supply of non-renewable energy resources and an urgent need for sources of clean energy, the world is set to significantly expand its electricity generation from renewable resources, and for the next decade and more, wind energy will make the major contribution[1-2]. Today, most of the wind power generators are based on doubly-salient permanent [3]. Induction generator [4], doubly-fed induction generator [5] and permanent magnetic generator [6]. Grid connected wind power system is also developed [7-8]. Wind energy is by far the most efficient renewable resource available to date. However, due to the high installation and maintenance cost, it's necessary to find ways to improve efficiency and simplify the structure to make the installation simple and reliable
Different configurations of high power generator are examined for the study. A modern configuration for a 200kW permanent magnet wind turbine power generation chain is presented. Other reluctance generators based on parallel operation are also discussed.

II. TEST SETUP

Fig 1 below is shown the test setup for a 200kW wind turbine using permanent magnet motor.

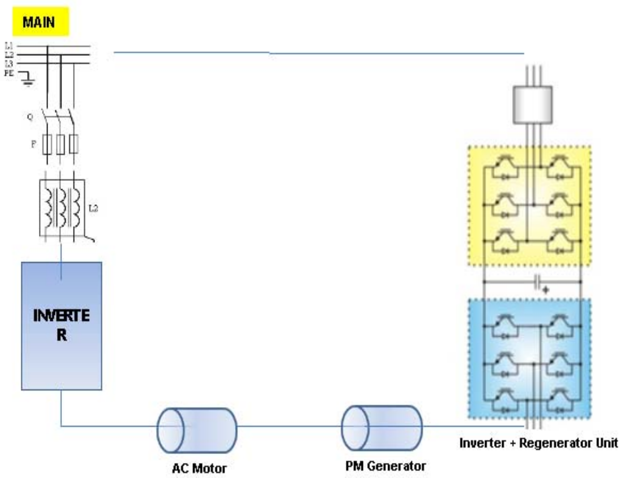

Fig 1: Permanent magnetic generator configuration

Inverter1 and the ac motor are shown here to emulate a rotating turbine blade unit. This setup can be used to test the regenerative capacity of the PM generator. They should be replaced by the actual blade units in final testings. The full power of the generator can be tested without wasting energy. With the combination of the inverter and regeneration units, power factor of the generated power can be controlled and THD maintained below 3%.

Unlike many low power turbines which use diode bridges for connection to the generator, an inverter is used instead. The advantages of using an inverter are multi-folds: it can control the amount of generated power at different wind speed. This allows a broader range of usable wind speed for power generation, and thus maximizing power generation. Efficiency can also be improved through soft-switching methods. The inverter can also provide active braking for the wind turbine in case of over speed. To put it simply, using an inverter can maximize the power output and allows more control over the machine. It could be seen that this kind of set up can also be used to drive a motor where the braking energy can be regenerated to the main grid and in fact this kind of setup has been used in driving cable cars to recover energy in a downhill situation.

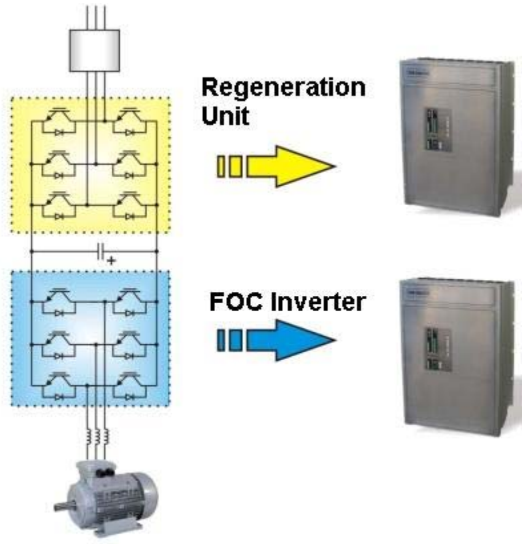

Fig 2: Regeneration and FOC units

Specifications for the Regeneration and Field Oriented Control (FOC) Inverter unit are:

Regeneration Unit Specifications:
Nominal current : 450 A rms
Peak current : 600 A rms
Peak current : 160 % of nominal for 30 sec.
PWM frequency : 1,5 kHz

Altitude : < 3000 ft>
FOC Inverter Unit Specifications :
Control Mode : Closed Loop Flux Vector
Nominal current : 450 A rms
Peak current : 600 A rms
Peak current : 160 % of nominal for 30 sec.
PWM frequency : 1.5 kHz
Altitude : < 3000 ft>

A Field Oriented Closed Loop Vector controlled is selected to control the speed of the turbine. The inverter converts the generator energy into DC and the regeneration unit converts it into 3 phase AC feeding back to the main grid. The switching frequency is chosen to be 1.5kHz to reduce switching losses. Because the response of the system is not critical such low frequency has proven to be adequate.

III. WIRING DIAGRAM

The wiring of the regenerator unit is shown in Fig 3. The legend of the system is also shown blow.

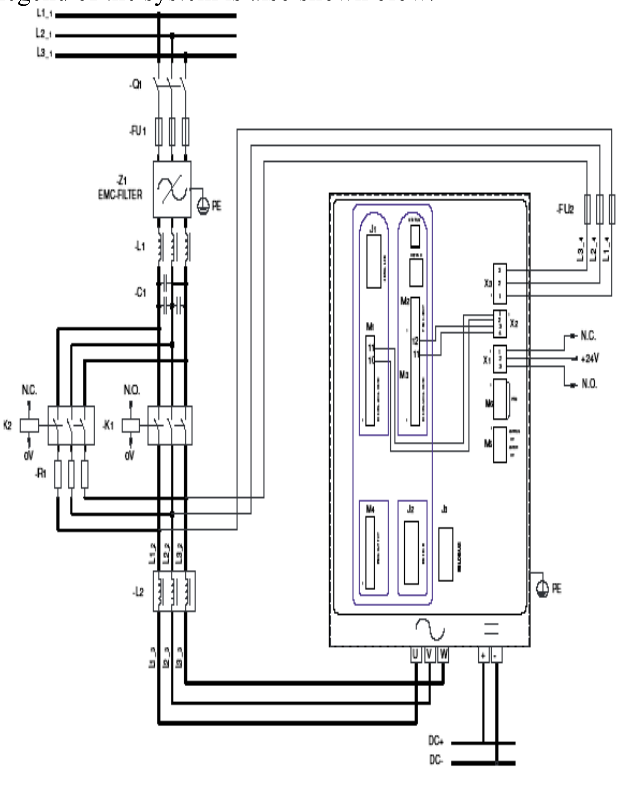

Fig 3: Regeneration Unit wiring

FU1, FU2 Line fuses
Z1 EMC filter group
L1 Line choke (if the line drop is more than 3%).
C1 Group of capacitors per Filter (500Hz/700Hz)
K1 Main contactor. It is normally open and it is closed at the end of the soft-start
K2 Secondary contactor. It is normally closed and can open only once the soft-start of the DC BUS
has been achieved. It can be controlled by the command outcoming from the RELAY RL1. K1. K2 is of contactor type AC-3.
R1 Resistors group for the soft-start of the DC BUS.
L2 Main choke.

For the regeneration unit, it's needed to precharge the DC BUS capacitor when starting. This is accomplished by the K2 contactor which connects the R1 resistor group to the DC bus. After precharging K2 is open and K1 is closed for normal operation. L2 is installed to suppress transients of the regenerated power.

Specifications for components:
Main Contactor K1
Rated Power at 400V 50Hz : 200kW
Rated Current : 400A

Secondary Contactor K2
Rated Power at 400V 50Hz : 11kW
Rated Current : 25A
Soft Start Resistor Group R1
Resistance:4ohms
Energy : 3 X 7300J
Power : 3 X 300W

Main Choke L2
Nominal Current : 370A
Inductance : 0.189mH
Saturation Peak Current : 1369.5A

Filter Capacitors C1(500Hz)
Capacitance : 91μF

Filter Inductors L1
Nominal Current : 370A
Inductance : 0.054mH
Saturation Peak Current : 1680A

IV. DIRECT DRIVE

Permanent magnet motors with gearbox have been widely used in wind turbine applications, mainly due to its wide spread availability. But it is soon found out that for high power application this is not an optimal solution because gearboxes pose a major reliability hazard to the equipment. They need constant maintenance due to the very high torque situation, and reduce efficiency of the turbine. The loss in electricity generation during downtime and cost of maintenance make people realize that an alternative solution has to be found. It is also realized that one cannot treat the wind turbine simply as blades connecting with coupling to a motor in a regeneration mode but as a system where different parts have to be integrated for improved reliability.

The solution to this is the direct drive generator/motor where the nominal speed is controlled down to around 100rpm by increasing pole count. This solution was not available previously because of technical difficulties in making such motors in very high power, not to mention the cost. But advances in motor manufacturing technologies and designs have made such motors a reality. Direct drive generators have many advantages. It is much more efficient than a motor and gearbox combination, produces less noise, and it makes the drive train simpler. Costs and size of the installation can be dramatically reduced. For that reason manufacturers of high power wind turbines are moving in such direction.

It is also changed the way the turbine is designed. Instead of putting parts from different suppliers together like toy bricks wind turbine manufacturers are now working with motor manufacturers to produce special motors where the rotor of the motor is actually the shaft of the blades. And in turn a new type of specialized machine is formed.

IV. Direct Drive

1. Direct drive

Permanent magnet generator with gearbox is to provide the improved performance of power density of the generator when it is required to work at low frequency. Because of the life time and the low frequency of the mechanical subsystem, the direct drive is preferred for many generators [9-10]. Recently there are many low speed generators available in the market. They are based on multi-pole approach that can therefore reduce the speed. The drawback is that the weight and size is considerable increased.

2. Parallel operation

Alternatively, the generator can be connected in parallel. Each phase winding should be isolated form other so that the magnetic flux is not necessary to couple to other winding. This reduces the magnetic core design. One of the methods to use is the switched-reluctance generator (SRG). Each phase of the SRG can be connected to a DC link through the single phase inverter. Fig 4 shows the phase connection of each winding.

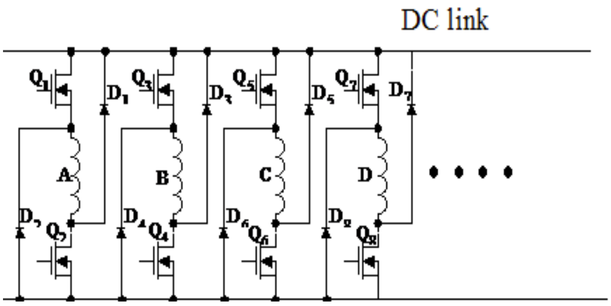

Fig 4: SRG driving circuit and the DC link

Fig 5 shows the system diagram of the parallel connection. It can be seen that the SRG converter is used to connect all the phase together. The DC link is used for the power bus. Other AC output can be connected to the DC link. The DC link may be connected with suitable battery to maintain the DC voltage. Suitable charger units can also be added between the DC link and the battery.

The transient of the wind power generation can be absorbed by the super-capacitor. A converter unit is used to capture the high frequency and transient t of the wind energy into the capacitor.

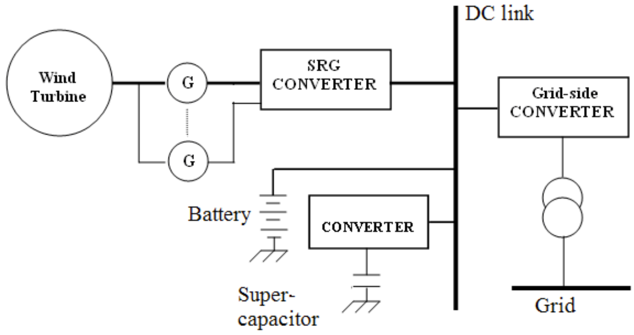

Fig 5: The overall system diagram.

IV. SRG

For a direct drive system with more conversion energy, the permanent magnet generator is the commonly used one, but it required high torque to run and expense in the material and maintenance. The investigated SRG in this project, is a possible candidate for such applications with no starting torque require, that means the required energy to overcome the cogging torque in a PM generator can be used to produce power in an SRG. Furthermore, SRG has a simplified construction with the absence of permanent magnet and windings in the rotor which leads to lower cost. Its lower inertia and wide operational speed allow the system to respond to rapid variations, extremely suitable for the rapid variation of wind speed.

Although SRG is a reliable and effective machine with high power density, the ripples of voltage, current and torque are big problems for achieving high quality power energy. To solve these challenges, a well-designed power electronics inverter is required with appropriate algorithms to control the switch angle and achieve constant power/torque. Meanwhile, there is no well-established method to model an SRG and no previous experience on applying the SRG to low speed wind generation with high performance.

Fig 6 shows the connection of different winding of an SRG. The rotors of the wind turbine are connected to the large rotational turbine. Each time when the machine rotor passed through the air-gap, electric power is generated and that produces power to the DC link. Many phases can be made parallel and connected for such arrangement. As each phase is independent from others, hence the unit can be made at very low frequency.

V. Conclusion

It is described in this paper the power train of a 200kW wind turbine. Details of the components involved are presented and the advantages of using direct drive over gearbox explained. It is for sure that further advancement will be made on wind turbine technologies, whether it's a new type of generator or enhancement on existing type. The final goal is to made wind energy more accessible to the mass market. The use of the parallel concept is designed. It allows all the winding phase can be individually controlled and parallel to the DC link. This provide an alternatively solution of the power generation and low speed application of wind turbine.

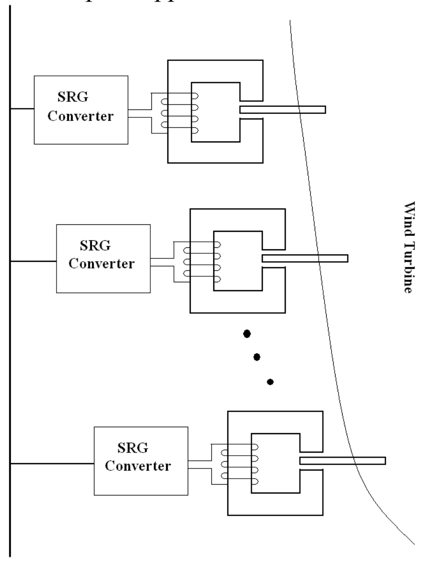

Fig 6: SRG phase winding connection illustration

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REFERENCES

[1] Akhmatov, V., Eriksen, P.B., “A Large Wind Power System in Almost Island Operation—A Danish Case Study”, IEEE Transactions on Power Systems, Vol. 22, Issue 3, Aug. 2007, pp. 937 - 943

[2] Ummels, B.C., Pelgrum, E., Kling, W.L., “Integration of large-scale wind power and use of energy storage in the netherlands' electricity supply”, IET Renewable Power Generation, Vol. 2, Issue 1, March 2008, pp. 34 – 46.

[3] Ying Fan, Chau, K.T., Ming Cheng, “A new three-phase doubly salient permanent magnet machine for wind power generation” IEEE Transactions on Industry Applications, Vol. 42, Issue 1, Jan.-Feb. 2006, pp. 53 – 60.

[4] Bueno, E. J., CÓbreces, S.; RodrÍguez, F. J.; HernÁndez, A.; Espinosa, F., “Design of a Back-to-Back NPC Converter Interface for Wind Turbines With Squirrel-Cage Induction Generator”, IEEE Transaction on Energy Conversion, Vol. 23, Issue 3, Sept. 2008, pp. 932 – 945.

[5] Gomis-Bellmunt, O., Junyent-Ferre, A., Sumper, A.; Bergas-Jan, J., “Ride-Through Control of a Doubly Fed Induction Generator Under Unbalanced Voltage Sags”, IEEE Transaction on Energy Conversion, Vol. 23, Issue 4, Dec. 2008, pp. 1036 – 1045.

[6] Zhang, J., Cheng, M., Chen, Z., “Investigation of a new stator interior permanent magnet machine”, IET Electric Power Applications, Vol. 2, Issue 2, March 2008, pp. 77 – 87.

[7] Piwko, R., DeMello, R., Gramlich, R., Lasher, W., Osborn, D., Dombek, C.; Porter, K., “What Comes First?”, IEEE Power and Energy Magazine, Vol. 5, Issue 6, Nov.-Dec. 2007, pp. 68 – 77.

[8] Andersson, D., Petersson, A., Agneholm, E., Karlsson, D., “Kriegers Flak 640 MW Off-Shore Wind Power Grid Connection—A Real Project Case Study”, IEEE Transaction on Energy Conversion, Vol. 22, Issue 1, March 2007, pp. 79 – 85.

[9] Spooner, E., Gordon, P., Bumby, J.R., French, C.D., “Lightweight ironless-stator PM generators for direct-drive wind turbines”, IEE Proceedings -Electric Power Applications, Volume 152, Issue 1, Jan 2005, pp.17 – 26.

[10] Chinchilla, M., Arnaltes, S., Burgos, J.C., “Control of permanent-magnet generators applied to variable-speed wind-energy systems connected to the grid”, IEEE Transaction on Energy Conversion, Vol. 21, Issue 1, March 2006, pp. 130 – 135.