LOAD POWER MANAGEMENT CONTROL STRATEGY FOR A VARIABLE SPEED STAND ALONE WIND ENERGY CONVERSION SYSTEM USING PMSG

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Abstract - There are many remote communities throughout the world where the grid is not available. These communities can be supplied with stand alone systems using a permanent magnet synchronous generator (PMSG). This paper presents a control strategy in order to get output voltage with a constant amplitude and frequency for a variable speed stand alone wind energy system. Here PMSG of 20 kW rated power is connected to a resistive load through a switch mode rectifier and a voltage source inverter. Battery energy storage system is used to store the excess of wind power, to meet the energy demand during shortage. Control of the load side voltage source inverter is used to regulate the output load voltage in terms of amplitude and frequency.

Keywords— DC-link voltage control, output voltage control, permanent magnet synchronous generator, standalone variable speed wind turbine

I. INTRODUCTION

Wind energy is a renewable source of energy and has many advantages like it reduces fossil fuel consumption, less air and water pollution, it helps in job creation. Nowadays, wind energy has become the fastest growing power sector in the world due to the fast increasing energy demand and accelerating depletion of the world fossil fuels. It becomes more widely adopted in the future because it is clean energy source and infinite natural resource. But the nature of wind flow is stochastic. So rigorous testing is to be carried out in laboratory to develop efficient control strategy for wind energy conversion system (WECS).

The study of WECS and the associated controllers are, thus, becoming more and more significant with each passing day. Variable speed wind energy systems have several advantages over fixed speed systems such

as yielding maximum power output while developing low amount of mechanical stress, improved efficiency and power quality. Nowadays many stand-alone loads are powered by renewable source of energy. With this renewed interest in wind technology for stand-alone applications, a great deal of research is being carried out for choosing a suitable generator for stand-alone WECS.

Permanent magnet synchronous generator (PMSG) can significantly improve the reliability of the variable speed wind energy system. PMSG has several advantages over other types of generators which are used in wind energy systems such as simple structure, operate at slow speed, self excitation capability, leading to high power factor and high efficiency operation [1]. With PMSG there is no need of a gearbox that suffers many times from faults and requires regular maintenance, which makes the system unreliable [2, 3]. Power electronics devices with variable speed system are very important, where AC–DC converter is used to convert AC voltage with variable amplitude and frequency at the generator side to DC voltage at the DC-link voltage. The DC voltage is converted again to AC voltage with constant amplitude and frequency at the load side for electrical utilization [4, 5]

Throughout a day, wind power varies continually with change in wind speed. Wind turbine can deliver maximum power when the rotor speed of PMSG varies according to the change in wind speed.

There are many remote communities throughout the world where the grid is not available. These remote communities are supplied with electrical energy which is produced by diesel generators. As is well known the conventional sources are very expensive and go to depletion; however these communities are affluent in renewable energy resources including wind energy. In this case, stand-alone wind energy systems can be considered as an effective way to provide continuous power to these communities.

It leads to a self-sufficient power generation which involves using a wind turbine with battery storage system to create a stand-alone system for isolated communities that is located far from a utility grid. Load side voltage source inverter is responsible to supply controlled output voltage in terms of amplitude and frequency to the load.

Wind energy systems are among the most interesting, low cost, and environment friendly for supply power to remote consumers. Battery energy storage system is essential for a standalone system to meet the required load power. As a variable speed wind energy system which has a fluctuating generated power due to the variability of wind speed. It can store the excess energy when the generated power from the wind is more than the demanded load power for a time when the generated power from the wind is less than the demanded load power to maintain the power balance between generated and required load power. The fluctuating power from wind energy system can be removed and the reliability of power to the load can be maximized with battery storage system. Voltage source inverter is used as an interface between DC-link voltage and the load to supply power to the consumers' load. This paper proposes a control strategy for a variable speed standalone wind energy supply system. Maximum power extraction from wind turbine is done by control of the generator side converter. DC-link voltage can be maintained at constant value and power balance of the system can be achieved by control of the DC-DC bidirectional converter

II. STAND ALONE WIND ENERGY SUPPLY SYSTEM.

Fig1. Shows the power circuit for a variable speed stand-alone wind energy supply system. The system consists of a wind turbine which is connected to a PMSG of 20 kW rated power. The PMSG is direct drive i.e. it does not have a gearbox. An uncontrolled rectifier which consists of a three phase diode bridge rectifier and DC-DC boost converter is used, and a batteries bank is connected to the DC-link voltage through a DC-DC bidirectional buck-boost converter. Additionally a voltage source converter is connected through an LC filter.

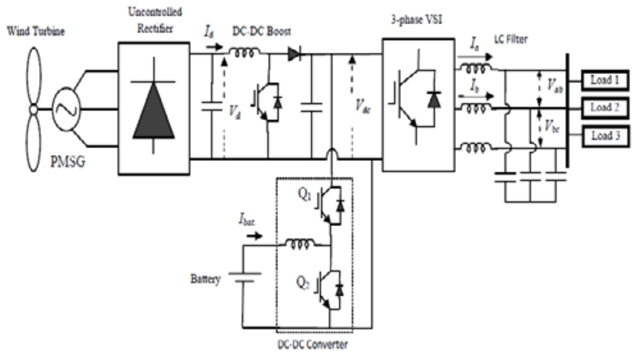

Fig1. Power circuit topology for variable speed wind energy supply system

III. WIND-TURBINE CHARACTERISTICS

The amount of power captured by the wind turbine (power delivered by the rotor) is given by,

$$P_m=0.5\rho AC_pV_w^3 \quad (1)$$

Where ρ is the air density (kilograms per cubic meter), V_w is the wind speed in meters per second, A is the blades' swept area, and C_p is the turbine-rotor-power coefficient, which is a function of the tip speed ratio (λ) and P_m is the output mechanical power from the wind turbine (Watt). ω_m = rotational speed of turbine rotor in mechanical radians per second

The mechanical rotor power generated by the turbine as a function of the rotor speed for different wind speed is shown in Fig. 2.

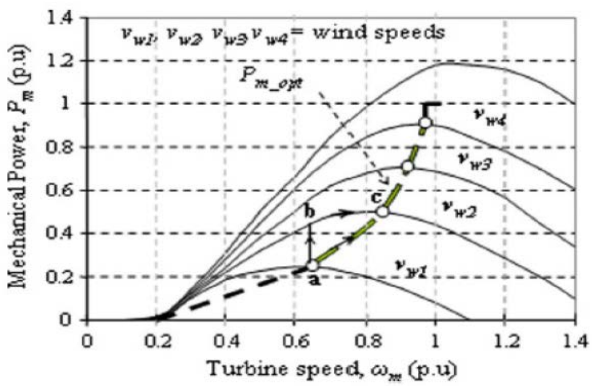

Fig 2.Mechanical power generated by the turbine as a function of the rotor speed for different wind speeds

Most recent papers try to extract maximum power from wind turbine without using mechanical sensors because using these sensors lead to inaccurate measurement as it includes mechanical parts.

IV. PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG)

Different types of generators are being used with wind turbines. Small wind turbines are equipped with DC generators of up to a few kilowatts in capacity. Modern wind turbine systems use three phase AC generators. The common types of AC generator that are used in modern wind turbine systems are as follows:

• Squirrel-Cage rotor Induction Generator (SCIG),
• Wound-Rotor Induction Generator (WRIG),
• Doubly-Fed Induction Generator (DFIG),
• Synchronous Generator (With external field excitation),
• Permanent Magnet Synchronous Generator (PMSG).

For assessing the type of generator in WECS, criteria such as operational characteristics, weight of active materials, price, maintenance aspects and the appropriate type of power electronic converter are used.
The PMSG differs from the Induction Generator as in that the magnetization is provided by a Permanent Magnet Pole System on the rotor, instead of taking excitation current from the armature winding terminals, as it is the case with the Induction Generator (IG). This means that the mode of operation is synchronous, as opposed to asynchronous. That is to say, in the PMSG, the output frequency bears a fixed relationship to the shaft speed, whereas in the mains connected IG, the frequency is closely related to the network frequency, being related by the slip.
Permanent magnet machines may be set in several categories, those with surface mounted magnets, those with buried magnets, those with damper windings, etc,
The advantages of Permanent Magnet (PM) machines over electrically excited machines are:

- Higher efficiency and energy yield.
- No additional power supply for the magnet field excitation.
- Improvement in the thermal characteristics of the PM machine due to the absence of the field losses. ƒ
- Higher reliability due to the absence of mechanical components such as slip rings.
- Lighter and therefore higher power to weight ratio.

However, PMSG machines have some disadvantages which can be summarized as follows: ƒ

- High cost of PM material,
- Difficulties to handle in manufacture,
- Demagnetization of PM at high temperature.

In recent years, the use of PMs is more attractive than before, because the performance of PMs is improving and the cost of PM is decreasing and in addition to that the cost of power electronics is decreasing, variable speed direct-drive PM machines with a full-scale power converter become more attractive for offshore wind powers[6].

V. DC-DC BIDIRECTIONAL CONVERTER CONTROL

Here, the batteries bank is connected to the DC link voltage through a DC-DC bidirectional buck-boost converter, the DC-link voltage can be maintained constant as a reference value, in addition to, charge/discharge current to/from the batteries bank according to the generated power from the wind and the demanded load power. This is achieved by controlling the DC-DC bidirectional buck-boost converter. The batteries bank voltage can be kept lower than the reference DC-link voltage (V_{dc_ref}) and hence less number of batteries needs to be connected in series. Thus here in the proposed system batteries bank voltage is kept at about 300V while V_{dc_ref} at 690V. The control strategy of DC-DC bidirectional buck-boost converter uses a PI controller to regulate the output DC voltage at a reference value. In this control technique the DC voltage V_{dc} is sensed and compared with the reference DC voltage $V_{dc\_ref.}$ The error signal is processed through the PI controller. The output signal is the duty cycle of the switches Q1 or Q2 according to the case of charging or discharging. The control strategy of the DC-DC bidirectional converter is shown in Fig 3. During charging, the current transfers from DC-link voltage (high voltage) to the batteries bank (low voltage). In this case the converter works as a buck converter, so, Q1 is the active switch while Q2 is kept off. On the contrary, during discharging, the current transfers from batteries bank (low voltage) to the DC-link voltage (high voltage). In this case the converter works as a boost converter, so, Q2 acts as a controlled switch and Q1 is kept off. Also, presence of the inductor at the batteries bank side results low ripple current which achieves higher efficiency and longer lifetime for the battery storage system [7].

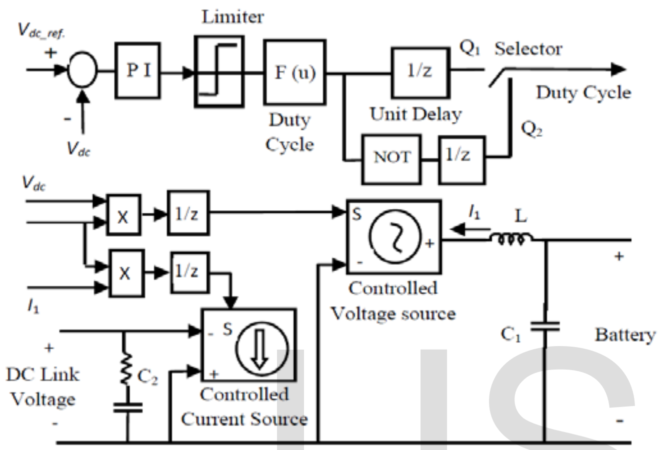

Fig3. DC-DC Bidirectional converter control strategy

If the consumers' loads is divided into three categories of load; Load 1 is important load, Load 2 is less important load and Load 3 is accessories load. Regarding to the load power management based on the instantaneous change in the State of Charge (SOC) of the battery and its value, when the generated power from wind is less than the all consumers' loads the SOC of the battery starts to decrease until it reaches at certain value. At this value the Load 3 can be disconnected to save the energy stored in the batteries bank. If the generated power from wind is still less than the required load power the SOC continues to decrease until it reaches at lower certain value. At this value the Load 2 can be disconnected. With time when the generated power from wind is greater than the Load 1, the SOC will start to increase. The Load 2 can be connected when the value of the SOC reaches at a certain value. And, if the generated power is still greater than the required load power the SOC continues to increase and the Load 3 can be connected at higher certain value of the SOC.

Fig4. Flowchart of the load power management based on the SOC

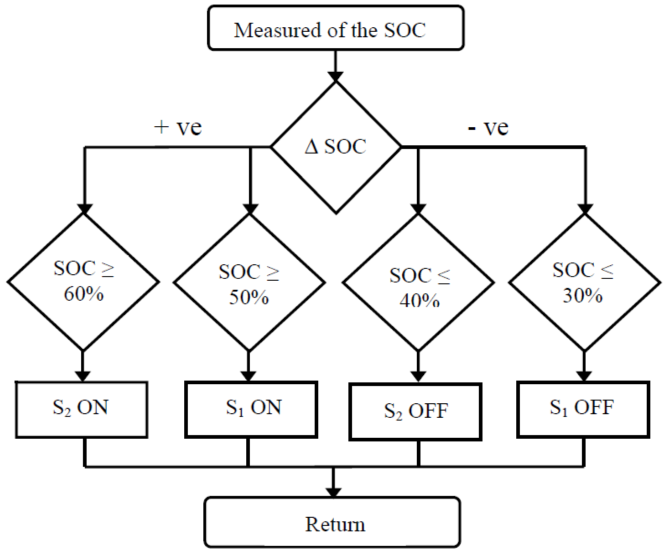

Fig4. Flowchart of the load power management based on the SOC

VI. LOAD SIDE CONVERTER CONTROL

With regard to load side converter control strategy, a three phase voltage source inverter is used as an interface between DC-link voltage and the resistive load. Unwanted high frequency harmonics are generated from the voltage source inverter based on the switching frequency. A simple passive LC filter can eliminate these high frequency harmonics to improve the power quality at the customer side. The control of the load side voltage source inverter is used to regulate the output load voltage in terms of amplitude and frequency. This control is utilized to control the output load voltage during load and/or wind speed variation. In this paper, the specified load voltage frequency and *RMS* value of output phase voltage are 50Hz and 220V, respectively. The voltages V_{ab}, V_{bc} and the currents I_a, I_b should be measured and transformed from stationary *abc* reference frame to rotating *dq* reference frame using chosen electrical load frequency. In this case V_q equals zero.

Using *dq* transformation, the active and reactive powers are given by:

$$P = 1.5V_dI_d \quad (2)$$

$$Q = 1.5V_dI_q \quad (3)$$

Thus by controlling the direct and quadrature current components the active and reactive power can be controlled respectively. Also, in the case of a resistive load V_d* can be governed by:

$$V_d^* = \sqrt{2}Vrms \quad (4)$$

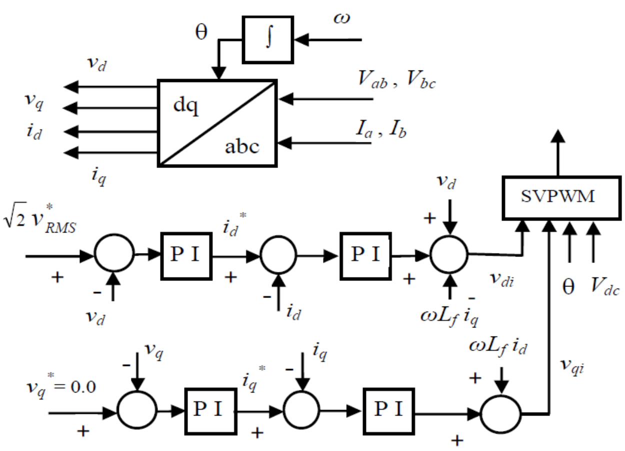

Fig5. Voltage source inverter control.

Where *Vrms* is the *rms* value of the output phase voltage. The PI controllers are used to regulate output load currents in the inner control loops and to regulate the output load voltages in the outer loops. Compensation terms are added as shown in Fig. 5 to compensate the cross coupling effect due to the output filter in the rotating reference frame.

Space vector PWM technique is used in the controller, as it increases the fundamental output load voltage and reduces the harmonic contents of the output load voltage.

VII. CONCLUSION

A control strategy for a standalone variable speed wind turbine using direct drive PMSG has been presented in this paper. Here it is discussed as to why the PMSG is preferred as compared to other induction generators and the study shows the control strategy of the dc-dc bidirectional converter and the voltage source inverter which essentially helps to conclude that although there is wind speed variation, the output voltage obtained is controlled in terms of amplitude and frequency. Simple sensor less maximum power extraction control, using generator side switch mode rectifier, is also described here

REFERENCES

[1] T. F. Chan and L. L. Lai, "Permanent-magnet machines for distributed generation: a review", Power engineering society general meeting, IEEE Conf., Tampa, FL, pp. 1-6, June 2007.

[2] A. J. G. Westlake, J. R. Bumby, and E. Spooner, "Damping the powerangle oscillations of a permanent magnet synchronous generator with particular reference to wind turbine applications". IEE Proceedings, Elec. Power Appl., vol. 143, No 3, pp. 269 – 280, May 1996

[3] H. Polinder, F. F. A. Van der Pijl, G. J. de Vilder, and P. J. Tavner, "Compaison of direct-drive and geared generator concepts for wind turbine, " IEEE Trans. Energy Conversion, vol. 3, no. 21, pp. 725-733, Sep. 2006.

[4] T. Ackerman and L. Soder, "An overview of wind energy status 2002,"Renewable and sustainable energy reviews, vol. 6, no. 1-2, pp. 67-127, April 2002.

[5] J. A. M. Bleij, A. W. K. Chung, and J. A. Rudell, " Power Smoothing and Performance Improvement of Wind Turbines with Variable Speed", Proc. of 17th British Wind Energy Assoc. Conf., Warwick, UK, pp. 353-358, July 1995.

[6] R. Mittal, K. S. Sandhu, and D. K. Jain, "Battery energy storage system for variable speed driven PMSG for wind energy conversion," International Journal of Innovation, Management and Technology, vol. 1, no. 3, pp. 300-304, Aug. 2010.

[7] M. M. Hussein, T. Senjyu, M. Orabi, M. A. A. Wahab, and M. M. Hamada, "Control of a variable speed stand alone wind energy supply system"