Implementation of novel control strategy for a variable speed wind turbine using PMSG

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Abstract—This paper presents a novel control strategy for the operation of a stand-alone variable speed wind energy conversion system using permanent magnet synchronous machine. The maximum power is tracked using yaw. Yaw control is obtained by keeping a gear under the nacelle. By using a DC motor the gear is moved along the direction of wind with maximum speed which is achieved using a microcontroller. The microcontroller senses the wind speed in terms of voltage and makes the motor to rotate with respect to the wind speed sensed The proposed model of stand alone wind energy conversion system can be implemented in small scale and medium scale for power supply.

***Keywords*—permanent magnet synchronous machine, wind turbine, wind, variable speed,yaw motor.**

I. Introduction

In today's world, the massive increase in population has led to enormous energy consumption, the threat of running out of fossil fuels have added to this which has led to the era of renewable energy resources like solar, wind, hydro, ocean, tidal e.t.c. Solar energy acts as the best renewable energy resource to be used. Next to solar, wind acts as the second renewable energy resource which is used and available all over the world. Wind is widely used as it is ample, clean, zero raw materials cost, cheap, readily available no need to purchase from some other country, take up less space, can be combined with other renewable energy resources like solar, friendly to the surrounding environment. Wind turbines can be broadly classified into two types, one is horizontal axis wind turbine [1]-[4] other is vertical axis wind turbine [5]-[8]. Wind turbines can be classified based on the speed as fixed (constant) speed [9]-[10], nearly constant speed any bad variable speed wind turbines. Similarly based on size, output and utilization, wind turbines can be classified which is shown in Fig.1. The difference between horizontal and vertical axis wind turbines is shown in Table I . In this project horizontal axis wind turbine is used due to its simplicity of operation. In constant speed, constant frequency wind turbines [11]-[12], the generation scheme is based on fixed speed technology. The horizontal axis wind turbine, whose speed can be controlled by using a pitch-control mechanism, operates at constant speed and drives, through a gear box, a synchronous [13] or an induction generator [14] that is connected to the power network. A constant speed wind turbine can achieve maximum efficiency at the speed that gives the tip speed ratio the value corresponding to the maximum power coefficient. Its main weakness lies in its poor energy capture from the available wind power at other wind speeds. Moreover, a pitch control mechanism adds considerably to the cost of the machine whereas in case of near constant speed, constant frequency wind turbines ,the generators are driven by horizontal axis wind turbines but with less stringent pitch angle controller, which can maintain small values of slip. In variable speed, constant frequency wind turbines continuous operation can be achieved, reduction in size and weight of gear box, reduction in noise emission, possibility of power smoothing can be achieved but in areas where grid cannot be constructed this kind of wind turbine cannot be used but variable speed variable frequency wind turbines can be used. This variable speed, variable frequency [15]-[17] scheme employs capacitor self-excited three phase or single phase induction generators for small scale power generation as a source of isolated supply to feed frequency-insensitive loads.

The maximum power is tracked using yaw. Yaw control is obtained by keeping a gear under the nacelle. By using a DC motor the gear is moved along the direction of wind with maximum speed which is achieved using a microcontroller. The microcontroller senses the wind speed in terms of voltage and makes the motor to rotate with respect to the wind speed sensed The proposed model of stand alone wind energy conversion system can be implemented in small scale and medium scale for power supply. . Wind turbines can be broadly classified into two types, one is horizontal axis wind turbine [18]other is vertical axis wind turbine .

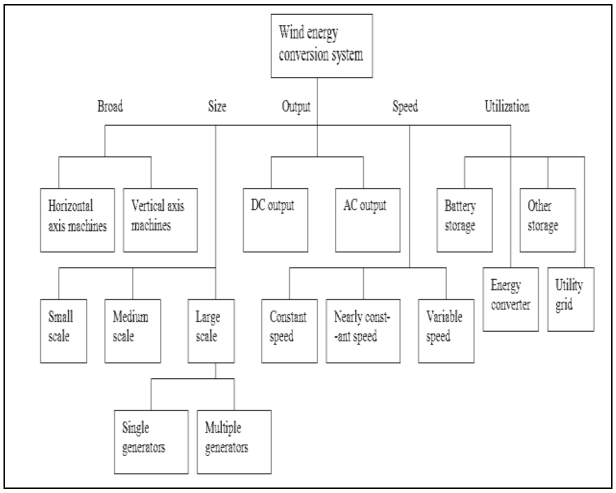

Figure 1. Classification of wind turbines

For stand alone operation [19]-[21] of wind turbines, variable speed, variable frequency wind turbines are used for industrial applications for different loads and for regions like hilly areas. PMSG has many advantages like lower operating cost, maintenance cost, very high torque at lower speeds, flexibility in design, without increasing generator size higher output can be achieved, no need for separate excitation like induction generators due to permanent magnets, no significant losses in rotor, long life of bearings but it also has disadvantages like higher initial cost, high temperature, short circuit condition, severe overloading may damage permanent magnets, use of diode rectifier in initial stage reduces overall controllability. As advantages are greater than the disadvantages PMSG is considered for operation.

TABLE I. COMPARISON OF HORIZONTAL AND VERTICAL AXIS WIND TURBINES

Horizontal axis wind turbine	Vertical axis wind turbine
the blades rotate around the horizontal axis.	the blades rotate around the vertical axis.
HAWT cannot be located near the ground due to its blades	VAWT Can be located near the ground
High efficiency	Low efficiency
Requires additional yaw control to make the blades face the wind	No need of yaw control
Tall tower allows access to stronger winds	Small tower allows access to lower winds
Massive tower construction required to support blades, gear box and generator.	Tower construction is comparatively simpler
Difficult to maintain	Easy to maintain

II. Comparative Performance of Different Types of Wind Energy Conversion Systems (WECS)

There are again different ways to classify wind energy conversion systems. Five major configurations are possible:

- Type-A WECS-constant speed (1% to 2% variability) with squirrel cage induction generator (SCIG).
- Type-B WECS-Narrow range variable speed (0% to 10% variability) with wound rotor induction generators (WRIG).
- Type-C WECS-Limited range variable speed (-40% to 30% variability) with doubly-fed induction generator (DFIG).
- Type-D WECS-Wide range variable speed (2.5 times the rated speed) with wound rotor synchronous generator (WRSG).
- Type-D WECS-Wide range variable speed (2.5 times the rated speed) with permanent magnet synchronous generator (PMSG).

In TABLE II Comparative Performance of Different Types of Wind Energy Conversion Systems has been discussed. We can come to a conclusion that PMSG has better performance comparatively to other types of wind turbines. Therefore PMSG is chosen here.

III. System Overview

Fig.2 shows the basic block diagram of PMSG based wind turbine which consists of wind turbine, PMSG, three phase diode bridge rectifier, three phase voltage source inverter, battery storage and controller.

TABLE II. COMPARATIVE PERFORMANCE OF DIFFERENT TYPES OF WIND ENERGY CONVERSION SYSTEMS

Parameter		Type-A	Type-B	Type-C	Type-D with WRSG	Type-D with PMSG
Construction complexity		Least	Less	High	Highest	Higher
Size(similar capacity)		Small	Large	Larger	Largest	between C & D
Aerodynamic efficiency		Least	Better	Best	Best	Best
Drive Train efficiency(app.)		89%	89%	89%	90%	93%
Top Head Mass(THM)		100%	100%	100%	150%	130%
PEC cost		Less	More	High	Most expensive	Most expensive
Manufacturing cost(app.)		100%	102%	103%	110%	105%
Voltage control		Poor	Marginally better	Much better	Best	Best
Reactive Power control		Poor	Poor	Good	Best	Best
Noise from blades		Controlled	Controlled	Controlled	Controlled	Controlled
Energy efficiency	Variability of speed	Poor	Improved	Better	Best	Best
	Gear box	Poor	Improved	Best	No need	No need
	Generator	Good	Better	Best	Best	Best

	Power electronics	Hardly any losses	Less losses	More losses	Most losses	Most losses
Reliability and maintenance	Slip ring and brushes	Most reliable	Less reliable	Less reliable	Less reliable	Most reliable
	Heavy gear box	Less reliable	Less reliable	Less reliable	No need	No need
	Mechanical stress	More	More	Less	Least	Least
	Heavy and large generator	Large	Large	Large	Larger	Larger
	Complexity of generator	Most simple	Little complex	More complex	Most complex	More complex
Grid power	Flicker	Yes	Yes	No	No	No
Quality	Grid voltage and frequency control possibility	No	No	Yes	Yes	Yes
	Harmonics	No	No	Not much	Not much	Not much
Grid faults	Supplies fault currents	No	No	Yes	Yes to some limit	Yes to some limit
	Restores voltage	No	No	Yes	Yes	Yes

Wind is sensed using wind turbine. With respect to the wind speed, PMSG rotates along with the wind turbine the output is fed to the rectifier which is rectified and fed to the inverter to produce a three phase output for industrial load.

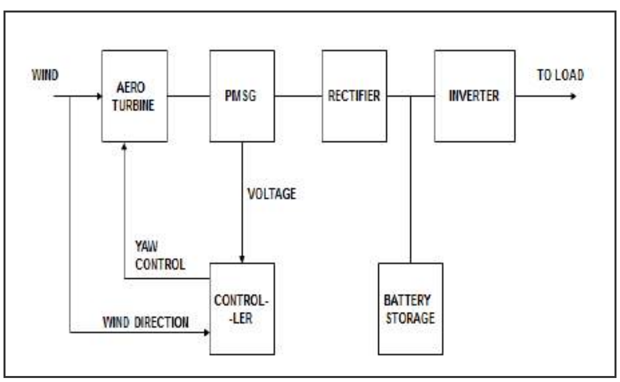

Figure 2. Block diagram of the proposed PMSG wind energy conversion system

The output from the PMSG is also fed to a microcontroller, the microcontroller converts the generator speed from analog value to a digital value and displays it in LCD. By using lookup table, the microcontroller rotates the nacelle using dc motor which is connected using two relays. The two relays are operated using two transistors. The wind turbine is allowed to rotate by 180 degree.

IV. Yaw control in Hardware and component features

A 8 bit micro controller is used for yaw control, due to the features like 256 x 8 internal RAM, 32 programmable I/O lines and three 16-bit timer/counters AT89C52 is used. From PMSG, the generator output voltage is converted to digital value using a 8 bit A/D and D/A converter as micro controllers use only digital value. As PCF8591 has features of single power supply, low standby current, operating supply voltage 2.5v to 6v, auto-incremented channel selection, on-chip track and hold circuit, 8 bit successive approximation A/D conversion, PC8591 is used. By I^2C bus data input/output through 9^{th} pin (SDA) of PC8591, the output voltage from the generator is fed to PCF8591. Through pins, 1 and 2, the converted values are fed to the microcontroller. The microcontroller accepts the converted values through read and writes pins 16 and 17which is alternate function of port 3. Using port 0 pins, the sensed value of generator output voltage is displayed in LCD. The variable resistor connected at LCD pin 3 (VD) and ground, controls the LCD display contrast. LCD's with extended temperature range (negative °C) can need a negative voltage at the VD pin (3), so the variable resistor need to be connected in a different way - the center tap goes to pin 3 (VD), one side to +5Vdc, while the other goes to a negative voltage around -3Vdc or more. To reduce power consume over this trim pot, resistor value greater than 10kohms can be used. When a resistor or a variable resistor to VD, a small current flows through and a voltage develops over the resistor, normally this voltage is small between zero and 1 Volt. The crystal connected at AT89C52 pins 18 and 19 needs the capacitors (33pF) connected to ground. Several microcontrollers' works well without the capacitors, but some of them have intermittent clock "no-start" or "stop oscillation" problems. To avoid problems the capacitors are installed. The microcontroller reset pin receives a resistor (10kohms) to ground and an electrolytic capacitor (10mF) connected to VCC. At power up, the capacitor is discharged, so current flows from ground to +Vcc via the resistor and the capacitor, until it charges the capacitor. This time can be calculated as approx.; time = 1 / R x C or 10milliseconds. The CMOS versions don't need the 10k resistor, but the books say it doesn't harm to install it. To install a "reset" button, the switch is installed in parallel with the capacitor, so when pressing the key it will apply +Vcc to the Reset pin, also discharging the capacitor. The knob to select the voltage level at which the blades must face is connected to the pins 0 and 1 of port 1, here they are configured as timer input pins. By port 2, DC motor is connected through 2 relays and 2 transistors. BC547 transistors and RW relays are used.

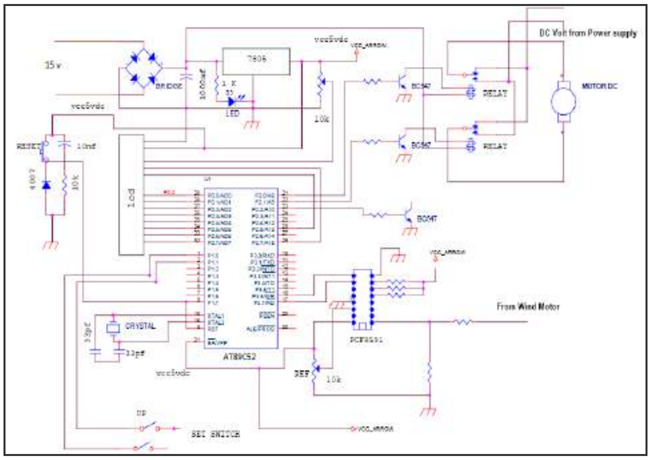

Figure 3. Hardware structure of the prototype developed

V. Simulation Results

The proposed system has been simulated for different wind speeds like 12m/s, 25 m/s and the output of the corresponding PMSG, rectifier, inverter has been displayed in Fig. and Fig. .Using MATLAB software the simulation has been worked out. For the wind turbine, generator speed, wind speed is taken as inputs and the mechanical torque is taken as output which is fed to the PMSG. From the PMSG, the rotor speed is fed back to the wind turbine; electromagnetic torque is also taken from the PMSG. The output of the PMSG is connected to the three phase diode bridge rectifier; the output is rectified and fed to the three phase IGBT inverter. In inverter the gate pulses are provided by comparing a sinusoidal wave with a triangular wave. In a single leg, the gate pulse of the upper switch is reversed and fed to the lower switch, similarly for the other two legs also the gate pulse is provided. The output of the inverter is fed to loads.

VI. Conclusion

A novel control strategy for a direct-drive stand-alone variable speed wind turbine with a PMSG has been presented. To extract maximum power, a simple yaw control is discussed here. Using MATLAB software, the simulation is implemented. For varying wind speeds also, the output remains constant. The load side inverter is controlled by varying the gate pulse using PWM. The load voltage is maintained constant at varying load conditions. The proposed model of stand alone wind energy conversion system can be implemented in small scale and medium scale for power supply. The output waveforms and the hardware results show that the yaw control is good at steady state and dynamic performance.

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