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A STAND-ALONE WIND ENERGY CONVERSION SYSTEM CONTROLLED BY PERMANENT MAGNET SYNCHRONOUS GENERATOR

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ABSTRACT

In today's world,with a competitive cost for electricity generation, wind energy conversion system (WECS) is nowadays deployed for meeting both grid-connected and stand-alone load demands. However, wind flow by nature is intermittent. In order to ensure continuous supply of power suitable storage technology is used as backup. In this paper, the sustainability of a 4-kW hybrid of wind and battery system is investigated for meeting the requirements of a 3-kW stand-alone dc load representing a base telecom station. A charge controller for battery bank based on turbine maximum power point tracking and battery state of charge is developed to ensure controlled charging and discharging of battery. The mechanical safety of the WECS is assured by means of pitch control technique.

Keywords: WECS, Wind Energy, Battery System, MATLAB, Reactive Power.

I. INTRODUCTION

Nowadays, most countries of the world are facing difficulties in using conventional sources for power generation due to exhaustion of fossil fuels and environmental issues. Wind energy, is one of the available non-conventional energy sources, which is clean and an infinite natural resource.

Variable speed wind energy systems have several advantages compared with fixed speed wind energy systems such as yielding maximum power output, developing low amount of mechanical stress, improving efficiency and power quality. Power electronics devices with a 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. The reliability of the variable speed wind energy systems can be improved significantly by using a permanent magnet synchronous generator (PMSG). PMSG has several advantages over other types of generators which are used in wind energy systems such as its simple structure, ability of operation at slow speed, self-excitation capability leading to high power factor and high efficiency operation. With low speed of PMSG operation there is no need for a gearbox which often suffers from faults and requires regular maintenance making the system unreliable. Maximum power can be extracted from the available wind power, which varies continually with change in the wind speed throughout a day, by adjusting the rotor speed of PMSG according to the wind speed variation. So, most recent papers try to achieve sensor-less maximum power extraction from available wind power because using these mechanical sensors leads to inaccurate measurements due to mechanical parts consideration. There are two common types of interfaces between PMSG and the load. The first configuration is designed as back-to-back PWM converter, the second configuration is a single switch mode rectifier and an inverter the former is commonly considered as the technical ultimate operation but may be more expensive and complex, it has a lot of switches which cause more losses and voltage stress in addition to presence of Electromagnetic Interface (EMI). The latter, which is adopted in this paper, is usually used in the stand-alone or small scale wind farms for its simple topology and control, and most importantly, low cost. There are many remote communities throughout the world where the electricity grid is not available. These communities are supplied with conventional energy sources. As it is well known, these conventional sources are very expensive and go to depletion. If these communities are affluent in wind energy, in this case, stand-alone wind energy systems can be considered as an effective way to supply power to the loads in these communities. It is one of the practicalities for self-sufficient power generation which involves using a wind turbine with battery storage system to create a stand-alone system for isolated communities located far from a utility grid. Load side voltage source inverter is responsible to supply controlled output load voltage in terms of amplitude and frequency to the load. Wind energy supply systems are among the most interesting, low cost, and environmental friendly for supply power to remote communities which are affluent in wind energy resource. Battery storage system is essential for a stand-alone wind energy supply system to meet the required load power. As a variable speed wind energy system which has 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 required load power for a time when the generated power from the wind is less than the required load power to maintain power balance between generated power and required load power. Also, it can remove the fluctuating power from wind energy system and maximize the reliability of power supplied to the load. Hence, this paper proposes a control strategy for a variable speed stand-alone wind energy supply system. Control of the switch mode rectifier at the generator side is used to achieve sensor-less maximum power extraction from available wind power. Control of the DC-DC bidirectional converter, which is connected between the batteries bank and DC-link voltage, is used to maintain the DC voltage at constant value and to meet power balance of the system. Control of the voltage source inverter at the load side is used to supply controlled output voltage in terms of amplitude and frequency to the load. Simulation results demonstrate that the control strategy performs very well in spite of wind speed and required load variation.A hybrid wind-battery system is considered to meet the load demand of a stand-alone base telecom station (BTS). The BTS load requirement is modeled as a dc load which requires a nominal regulated voltage of 50 V. The WECS is interfaced with the stand-alone dc load by means of ac–dc–dc power converter to regulate the load voltage at the desired level.

II WIND ENERGY

It is defined as the system in which the kinetic energy of the wind is converted to mechanical energy which in turn is used to generate electrical energy. The machines which are used to convert the kinetic energy of the wind into mechanical energy usually consist of sails, vanes or blades radiating from the hub or the central axis. The axis can be horizontal in most of the cases or vertical in some cases. When the wind hits the blade it rotates around the axis and the motion of the blades can be put to useful work .The devices which are used in wind conversion system are known as wind turbines because they convert the kinetic energy of the wind into the rotational energy and the device used for this is known as rotor. These wind turbines are connected to electrical generator to the required electrical energy and the connection of these two devices is known as aero generator. A transmission system is usually used to increase the speed of the rotor with the help of gear system. Wind mills are in the usage for more than dozen centuries for grinding grain and pumping water and now scientists are looking to generate electricity in large quantity with the help of wind turbines and interest in this field is increasing .Wind energy system can play an important role in reducing the energy crises of the world and can be used to produce efficient energy in remote areas. The wind speeds in India usually remain in between 5 to 20 km/hr. There are usually three factors which determine the output of the electrical energy generated from the wind energy, wind speed, cross section of wind swept by rotor, the conversion efficiency of the rotor, transmission system and the generator. There is no device designed to extract all the wind energy because the wind will be brought to rest and this would prevent the passage of wind into the rotor. An efficient aero generator can only extract 60% of the total energy present in the wind into the mechanical energy. The available wind power is directly proportional to the square of the diameter of the horizontal axis of the wind turbine and the velocity of the wind speed as it passes though the rotor. The wind energy conversion system components are aero turbine, gearing, coupling, electrical generator.

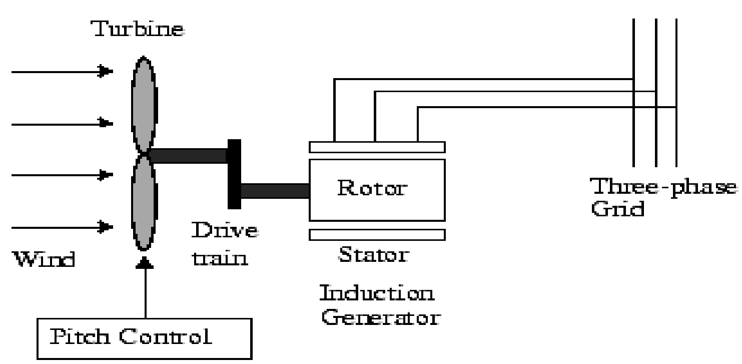

Figure 2: Wind Energy System.

The permanent magnet synchronous generator

1. **Types of Rotor**

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a. Salient pole SG

The rotor windings are placed as a concentrated coil around the pole shoe. This causes a different magnetic resistance (reluctance) in the rotor oriented d- and q-axis, which results in different machine reactancesxd and xq (xd>xq). A damper winding is placed in the pole shoe. Built with 8…16 poles and a respective speed of 750...375 rpm this kind of synchronous generator is generally used in hydro power plants, rotating with lower speed than round rotor SGs

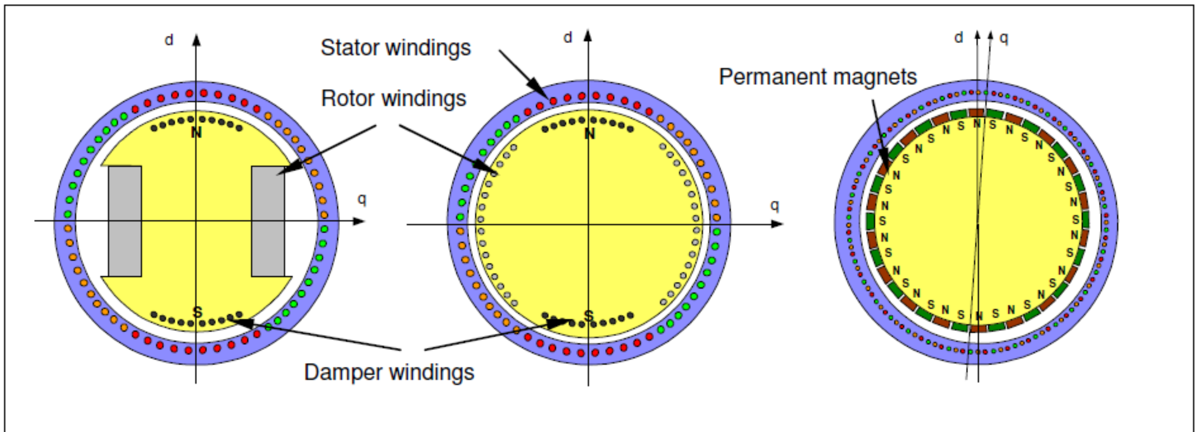
b. Round rotor SG

The rotor windings are equally distributed in the rotor slots, which results in an equal reactance in d- and q-axis (xd = xq). 2-pole or 4-pole round rotor SGs are used in thermal power plants operating at very high speed (3000 rpm, 1500 rpm).

c. Multipole permanent magnet SG

In order to operate with low speeds, e.g. at 20 rpm, a high number of poles is used in PMSG wind turbines. Instead of electrical DC excitation the magnetic rotor field is provided by permanent magnets.

Due to the equal distribution of the surface mounted magnets and a permeability of the magnet material µm approximately as big as the airgap permeability (µm @ µ0) the reactances in d- and q-axis differ by only a few percent, so that surface mounted PMSGs can be considered as round rotor machines (xd = xq). Because the multipole PMSG is a converter connected low speed application (in contrast to high dynamic drives) no damper winding is necessary.



Salient pole SG	Round rotor SG	Multipole permanent magnet SG

Fig 2 Cross section of different synchronous generator types

Direct drive wind turbines, characterized as high efficient and low maintenance solutions, offer high potentials for future applications, especially offshore.In order to eliminate the gearbox the generator must be built for low speeds (max. 15-20 rpm). The generator needs thus a large rotor diameter for the high wind turbine torque and a large number of poles in order to get a suitable frequency at low speeds. As asynchronous generators cannot be built for low speeds (a small pole pitch together with a large air gap yields a too big reactive power demand of asynchronous generators) synchronous generators are required for low speed wind turbine applications. In a synchronous generator the magnetic field is provided by the rotor excitation. The excitation can either be provided by DC excitation or by means of permanent magnets.In case of DC excitation, the power factor of the machine can be adjusted so that operation with unity power factor becomes possible and the converter rating is reduced to the generator´s active power value. However, the use of permanent magnets eliminates the DC excitation system, which means a reduction of losses (high field ampere turns in multi-pole generators) and the omission of slip rings and thus maintenance requirements.

III WIND ENERGY CONVERSION SYSTEM (WECS)

The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. PMSG does not need a gear box and hence, it has high efficiency with less maintenance .The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation. In the present trend WECS with multibrid concept is interesting and offers the same advantage for large systems in future. Multibrid is a technology where generator, gearbox, main shaft and shaft bearing are all integrated within a common housing. This concept allows reduce in weight and size of generators combined with the gear box technology. The generators with multibrid concept become cheaper and more reliable than that of the standard one, but it loses its efficiency.

It is the equipment that converts and then stores or transfers energy from the wind into usable forms of energy and includes, but not limited to, base, blade, foundation, generator, nacelle, rotor, wind tower, transformer, turbine, vane, wind farm collection system, meteorological towers, communications facilities, electrical cabling or other components related to the system.

IV SIMULATION MODEL

4.1 DC to DC Conversion (chopper)

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. In this circuit the transistor turning ON will put voltage Vin on one end ofthe inductor. This voltage will tend to cause the inductor current to rise.

When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor providethe inductor current is continuous.

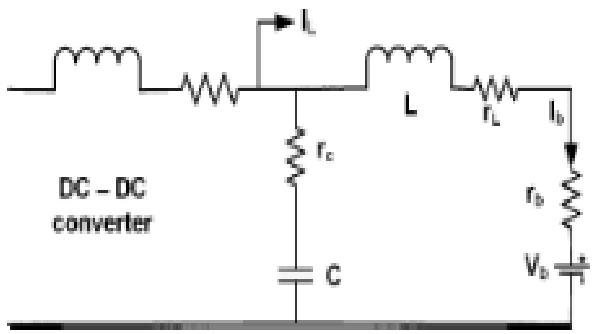


Fig.3 Circuit representation of buck converter output.

The transfer function can be computed from above ckt 6.2.2.3

$$\frac{I_b(s)}{I_L(s)} = \frac{r_c C s + 1}{LCs^2 + (r_L + r_c + r_b) C s + 1}.$$

4.2 PITCH controller

The WT power output is proportional to the cube of windvelocity. Generally the cut-off wind speed of a modern WTis much higher compared to the rated wind speed. If theWT is allowed to operate over the entire range of wind speedwithout implementation of any control mechanism, the angularspeed of the shaft exceeds its rated value which may lead to damage of the blades. So, it is very much essential to control the speed and power at wind speeds above the rated wind speed.This is achieved by changing the pitch angle of the blade. Such a mechanism is referred to as the pitch control of WT.The power coefficient(Cp) versus TSR (λ) characteristics of the WT considered in this study for different pitch angles. As examined from the characteristics, in a pitch angle of zero degree the value of Cpis maxima. Butthe optimum value of power coefficient reduces with increase in a pitch angle. This happens because with increase in blade pitch the lift coefficient reduces which results in decreasing the value. So, the pitch control mechanism controls the power output by reducing the power coefficient at higher wind speeds. Below the rated wind speed the blade pitch is maintained at zero degree to obtain maximum power. The pitch controller increases the blade pitch as the WT parameters exceed the rated value. The reduction in the value of C of Cp by pitching compensates for the increase in WT power output under the influence of higher wind speeds. Apart from regulating the WT parameters, it is also essential to control the output voltage of the ac–dc rectifier to avoid overvoltage condition in the WECS. Hence, the pitch controller ensures that with desirable pitch command, the WT parameters and the rectifier output dc voltage are regulated within their respective maximum allowable limits to ensure safe operation of the WECS.

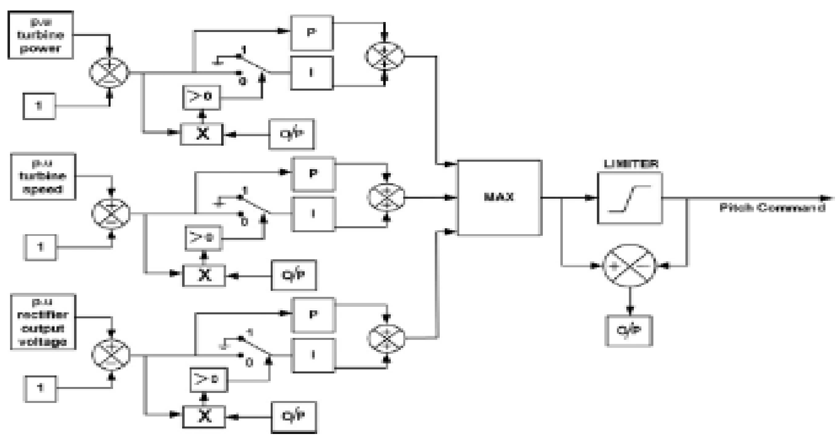


Fig.4 Pitch control scheme for a stand-alone WECS.

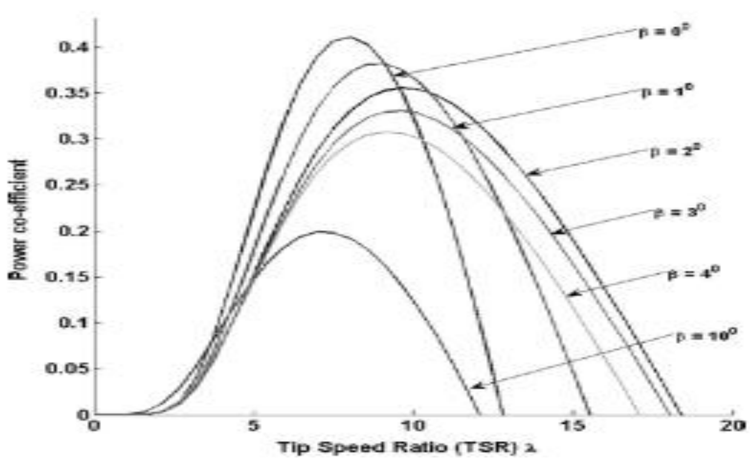


Fig.5 Cp-λ characteristics of the WT for different pitch angles

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4.3 Simulation Design

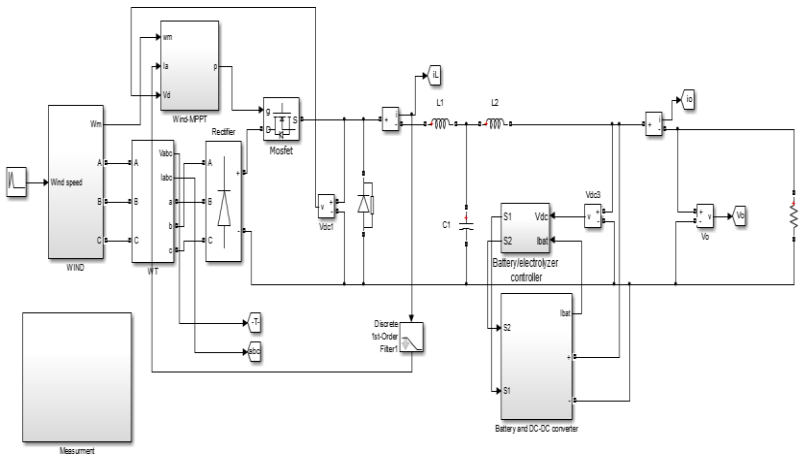

Fig.6Simulink Model Of Stand Alone WECS

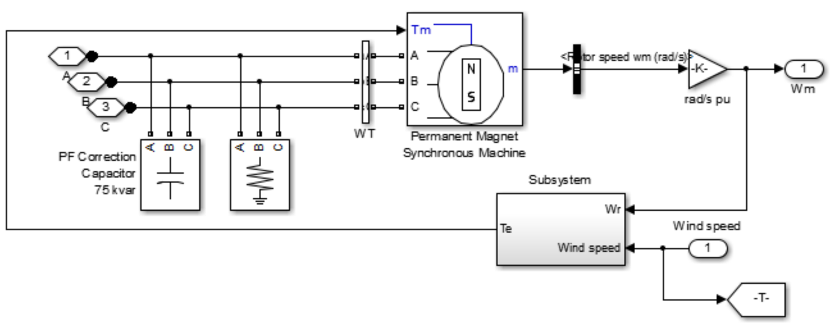

Fig.7 Wind Turbine Block With PMSG

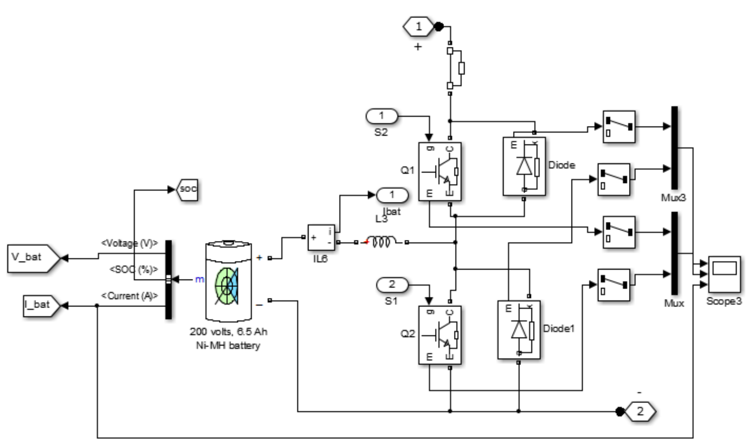

Fig.7 Battery and DC-DC Converter

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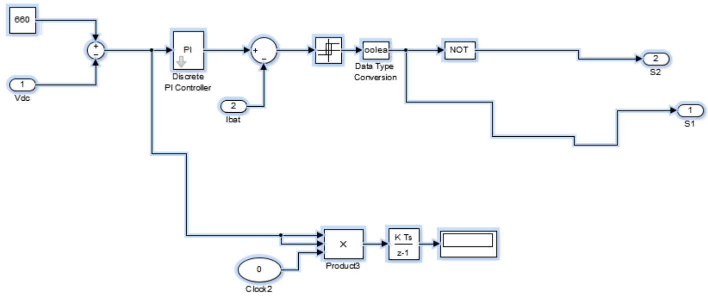

Fig.8 Battery Controller

V RESULT

The output of the above explained simulation mode are shown below

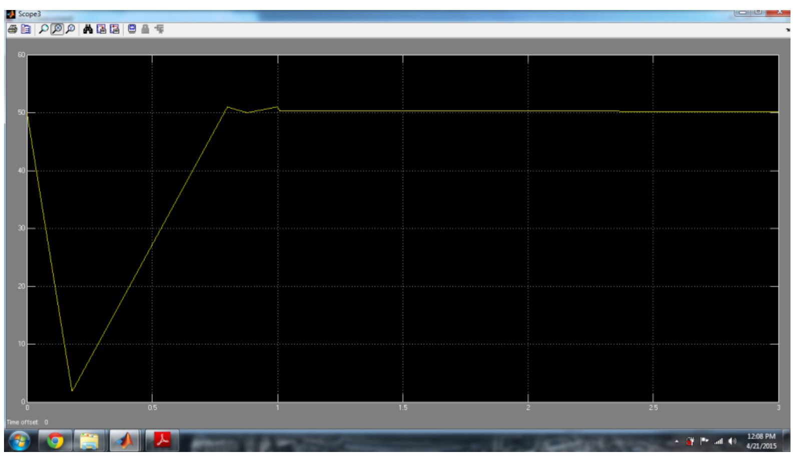

Fig.9 Output battery voltage stored by the help of WECS

Fig.10 Output battery current stored by the help of WECS

VI CONCLUSION

This type of system will be very helpful in the region where grid supply is not available. We can establish small wind energy based plant and store the generated voltage in controlled battery system for longer and further usage.

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