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Design of Aero Generator Using MATLAB Simulink for Commercial Applications

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ABSTRACT

In developing countries, especially many non-grid connected rural areas are in need of reliable and low cost electrical power. To solve this problem an efficient wind power system to supply high quality electrical power for rural settlements has to be designed. This paper presents the design of aero generator for commercial applications. The wind generators are used to charge the battery banks, whilst the battery banks allow for an uninterrupted inverter-fed power supply without requiring continuous turbine operation. These aero generators are used where a grid connection would be too expensive. Here aero generator employing PMSG, pitch angle control, drive train, buck converter and inverter is designed in MATLAB simulink. A new control strategy to make the input voltage track its reference rapidly, to restrain the charging current of battery and to control the speed of PMSG is adopted in this paper.

Keywords—Aerogenerator,Rectifier,Battery,PMSG,Wind turbine,Buck converter

1. INTRODUCTION

Nowadays, electric power supply of state electricity board is very uncertain and the voltage is also unreliable. There are frequent voltage fluctuations and shutdowns without any notice to consumers. This results into stoppage of working. Also, the cost per unit is increasing day by day. In future the electrical energy is going to be more scarce and more costly. In houses and small offices/ establishments, normally generator run by petrol /diesel /kerosene is used to supply electricity when there is no grid power. The use of such appliance is not always satisfactory as it makes lot of noise and creates smoke and fumes. To overcome this problem, inverter and UPS system with batteries to give sufficient backup is provided. But, even such an arrangement fails when there is great scarcity of power as the batteries cannot get sufficiently charged due to such frequent and long duration power cuts. It is well known that solar energy with the help of photovoltaic cells can be used. But, harnessing the solar energy is very costly. So another solution is required to overcome power shortage problem.

Wind energy can be used to produce electrical energy as it is clean and renewable energy. Wind mills that are used to generate electricity have been lauded in recent years as a potential solution to the future energy needs of people all around the world. But there are significant drawbacks to wind mills that should be considered are high initial cost, unreliability, Environmental Impact, Noise, Wildlife, and Interference. Therefore, there is a dire need for a set of equipment which will generate sufficient electrical energy and eliminates power shortages.

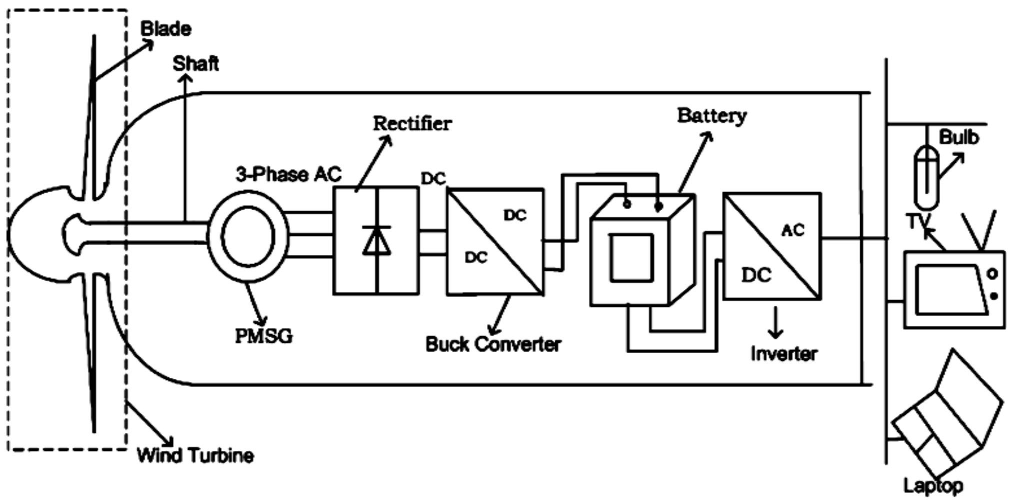

Fig1: Block Diagram of Aero Generator

This paper presents the generation of electrical power, at a reasonably low cost by the alternator driven by wind which is called aero generator. Aero-generator is an electromechanical device used to convert wind energy into mechanical energy and then into electric energy. The electric power output from aero generator can be used to charge storage batteries for energy storage and the stored electric energy can be transformed into the 230V/50Hz alternating power supply or the power supply of local voltage and frequency. The block diagram of proposed aero generator for residential applications is shown in above fig1.

2. MODELING OF AERO GENERATOR

In this paper an aero generator employing PMSG is designed which produces AC power and a rectifier is used to rectify the output voltage of PMSG. The three-phase-three-wired PWM converters with three arms and six switches are mainly adopted in the conventional wind power stations. However, the reduction of cost is of much importance in this paper, so the six-switched converter is not appropriate and a diode rectifier is used. Working at the rated speed of the PMSG, the DC voltage of the diode rectifier will remain at a certain level higher than that of the battery, so a DC-DC buck converter is necessary which is used to decrease this rectified voltage to that of battery. As wind speed varies all the time energy storage device is necessary. So Battery is utilized among all the energy storage devices, which is of low cost. An inverter which is required to convert energy stored in battery to AC to supply power to home and an industry is designed.

A. Wind Turbine

A wind turbine is a machine for converting the kinetic energy in the wind into mechanical energy. Turbine consists of blades and rotor. When the wind blows over the blades, the rotor turns, causing the rotation of the drive train and generator.

The wind power is given by $P_w = E_C = {}^1/_2 m v^2 = {}^1/_2 \rho s v^3$ (1)

Where m is air mass, v is wind speed, ρ is air density and s is covered surface of the turbine

The mechanical torque of turbine can be calculated from mechanical power at the turbine extracted from wind power. However wind turbine cannot convert all wind energy to mechanical power. The coefficient of power of a wind turbine is a measurement of how efficiently the wind turbine converts the energy in the wind into electricity.

The rotor power coefficient is given by $C_P = \frac{\text{Extracted power}}{\text{power in wind}} = \frac{P_{rotor}}{P_{wind}} = \frac{p_m}{p_w} < 1$ (2)

Where Pitch angle is angle of turbine blade whereas tip speed ratio (TSR) is the ratio of rotational speed and wind speed which is given by $\lambda = \frac{W_{rotor}}{V_{wind}} * R_{rotor}$ (5)

Where W_{rotor} is rotor angular speed [rad/s], R_{rotor} is rotor radius[m] and $V_{wind}$is wind speed [m/s]

The mechanical output power of the turbine is given by $P_m = C_p(\lambda, \beta)\ {}^1/_2 \rho s v^3$ (6)

The mechanical torque is given by $T_m = \frac{P_m}{w}$ (7)

B. Drive Train

The mechanical model is realized by means of a two mass and damper model connected via a flexible shaft in order to get accurate response from generator. The drive train of a wind turbine system shown in below fig2 consists of a hub with blades, a rotor shaft and a generator. The drive train model presented in this paper includes the inertia of both the turbine and the generator. The moment of inertia of the wind wheel (hub with blades) is about 90% of the drive train total moment, while the generator rotor moment of inertia is equal to about 10%.

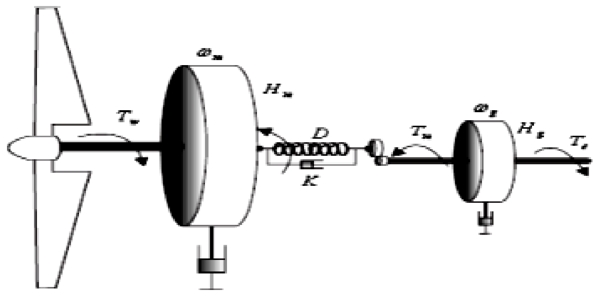

Fig2: Drive Train Dynamics

The equation of motion of the generator is given by $2H_g \frac{dw_g}{dt}=T_e+\frac{T_m}{n}$ (8)

Additionally, since the wind turbine shaft and generator are coupled together, the wind turbine shaft system should not be considered stiff. To account for the interaction between the windmill and the rotor, an additional equation describing the motion of the windmill shaft is adopted which is given by

$$2H_m \frac{dw_m}{dt}=T_w-T_m \quad (9)$$

The mechanical torque T_m is given by $T_m=k.\frac{\theta}{n}+D\frac{w_g-w_m}{n}$ (10)

$$\frac{d\theta}{dt}=w_g - w_m \quad (11)$$

where n is the gear ratio, θ is the angle between the turbine rotor and the generator rotor, w_m, w_g , H_m and H_g are the turbine and generator rotor speed and inertia constant, respectively, K and D are the drive train stiffness and damping constants, T_w is the torque provided by the wind and T_e is the electromagnetic torque.

C. Generator

The mechanical output from wind turbine need to be converted to electrical output. In electricity generation, a generator is a device that converts mechanical energy to electrical energy. Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of various turbines into electrical power. Hence from numerous types of motor or generator that exists, permanent magnet synchronous generator (PMSG) is chosen to be used in this paper. PMSG provide full speed operation and ensure higher energy output. As the direct driven technology eliminates gear there is much reduction in overall weight of the system. The PMSG does not need a power converter for field excitation. The use of permanent magnets eliminates rotor windings and brushes and hence maintenance costs come down considerably. So the mechanical output from wind turbine is converted to electrical energy by using PMSG. PMSG outputs three phase sinusoidal output.

D. Diode Rectifier

PMSG outputs three phase sinusoidal voltage while the battery can only work under DC condition, so a converter is necessary. A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. Compared with the three-phase PWM rectifier, the uncontrolled diode rectifier is much cheaper and so it is adopted in this paper. So the three phase sinusoidal output voltage obtained from PMSG is converted to DC by using diode bride rectifier.

E. DC-DC Converter

Working at the rated speed of the PMSG, the DC voltage of the diode rectifier will remain at a certain level higher than that of the battery so a DC-DC converter is necessary. Buck converter is a voltage step down and current step up converter. It accepts a DC input voltage and produces a DC output voltage. So the DC output voltage obtained from rectifier is given as an input to buck converter. Buck converter converts higher output obtained from diode rectifier to lower output that can be stored in battery.

The inductor value of buck converter is given by $L=\frac{(V_{in}-V_{out})D}{LIR.I_{outmax}f_{SW}}$ (14)

The capacitor value of buck converter is given by $C=\frac{LIRI_{outmax}}{8.f_{SW}.CVR.V_{out}}$ (15)

The duty cycle of buck converter is given by $D = \frac{V_{out}}{V_{in}}$ (16)

Where LIR is inductor current ripple ratio=0.3, f_{SW} is switching frequency of converter and CVR is Capacitor Voltage Ripple Ratio = 0.04

F. Battery

Since the availability of wind and the wind speed is very much fluctuating, the electricity generated needs to be stored to prevent power shortage. So Battery is utilized among all the energy storage devices, which is of low cost. From the battery DC voltage can be used to run DC appliances and also DC voltage can be converted to AC to run AC appliances. The advantages with the battery are no need to be connected to grid, no power shortage and batteries can be easily replaced as they are not much costly.

G. Sinusoidal Pulse Width Modulation Inverter

Energy stored in batteries is available as DC power. Any electrical appliance in your home, however, must use AC power. So a converter is required to convert DC power from battery to AC power. An inverter converts the DC power in the battery to AC power. SPWM or sinusoidal pulse width modulation is adopted in this paper to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches.

3. DC-DC CONTROL OF BUCK CONVERTER

For a buck converter, traditionally the input voltage is constant and the output voltage can be controlled by adjusting the duty-cycle of the switch, while the output voltage is constant in this system and the input voltage should be adjusted. The voltage of the battery will remain at a certain level under normal condition, so it can be considered that the output voltage of the buck converter is constant and then the input voltage can be controlled by adjusting the duty-cycle of the switch. At the same time, the output voltage of the PMSG is proportional to its speed and the output voltage of the diode rectifier is directly proportional to its input voltage. If the input voltage of the buck converter which is also the output voltage of the diode rectifier varies by means of controlling the switch duty-cycle, the operation speed of the generator will change correspondingly, which means the speed of the generator can be controlled by controlling the switch.

The control block diagram of the buck converter is shown in below Fig5, the feedback control is realized by a PI controller and the d selection part is to limit the charging current. Because the wind speed varies all the time, the referenced input DC voltage of the buck converter should be frequently changed to adjust the operating speed of the PMSG. In the below figure v_{in}^* stands for reference voltage, $\frac{v_{out}}{v_{in}^*}$ stands for the duty cycle value of the switch. PWM is the main part in designing a buck converter. By using pulse-width modulation (PWM) control, regulation of output voltage is achieved by varying the duty cycle of the switch. If output voltage of rectifier decreases due to reduction of PMSG speed then v_{in}^* is increased there by duty cycle decreases and then input of buck converter increases maintaining output voltage of buck converter constant and controlling speed of PMSG and operation will be vice versa if input voltage of rectifier is greater than .

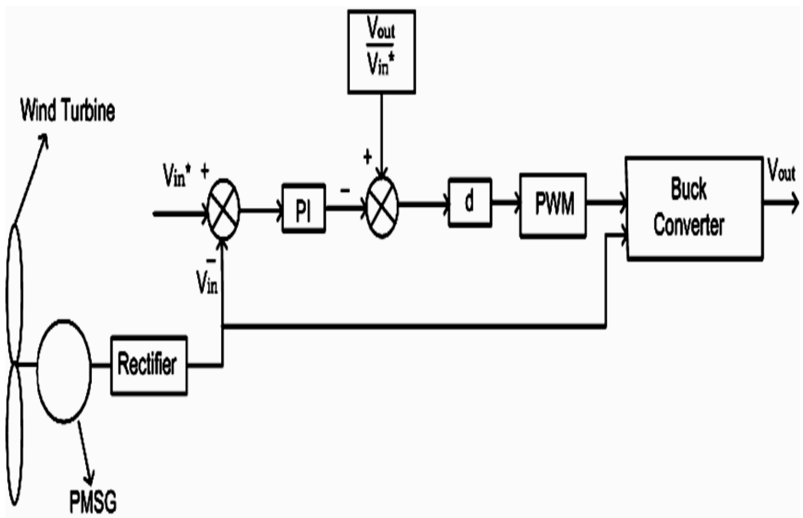

Fig3: DC-DC Control of Buck Converter

4. SIMULATION RESULTS

Aero Generator for Residential Application is shown in below fig4. This aero generator can be used for all residential applications like TV, fans, bulbs, washing machines etc., and the maximum capacity of this model is 3KW.

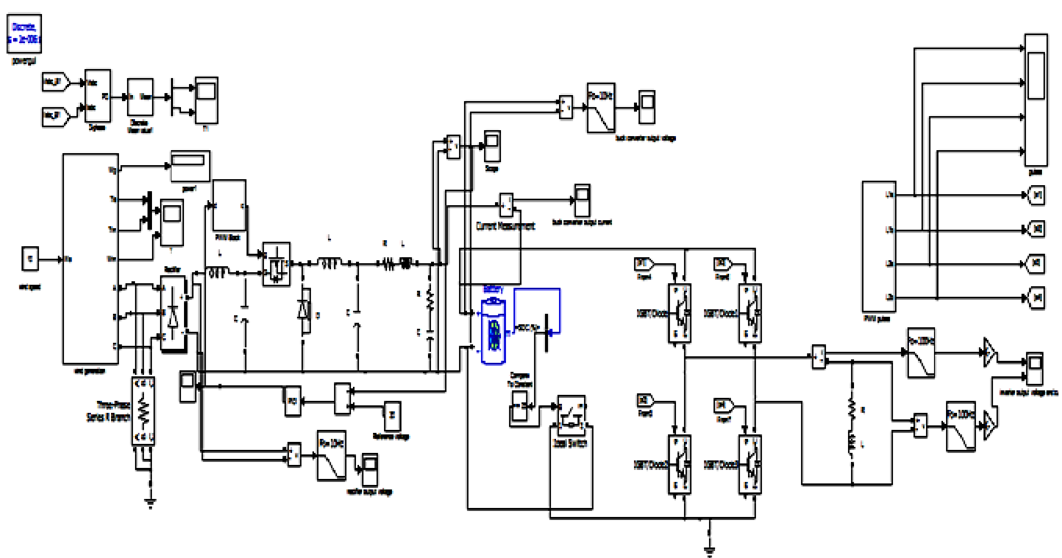

Fig4: Simulation Model of Aero Generator for Residential Applications

The output voltage of buck converter is shown in below fig5 which is battery voltage.

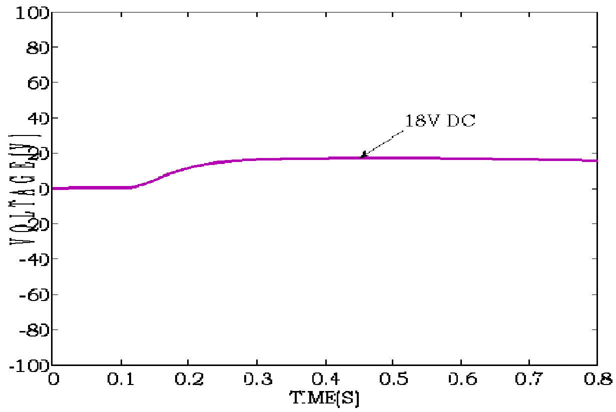

Fig5: Battery Voltage

The output voltage and output current of single phase inverter is shown in below fig6 & fig7.

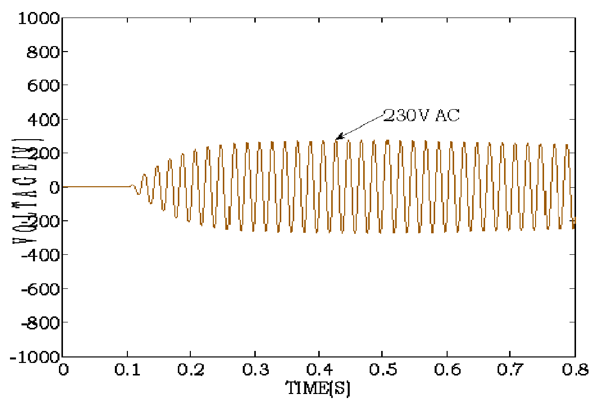

Fig6: Inverter Output Voltage

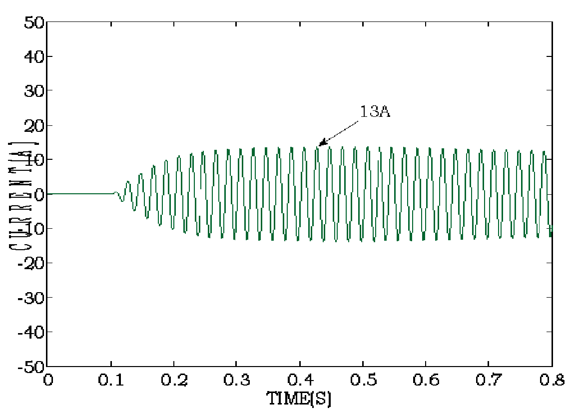

Fig7: Inverter Output Current

Design specifications

S. No.	PARAMETER	VALUE
1.	Rated power	3KW
2.	Rated wind speed	10m/s
3.	Max Line-line voltage of PMSG	300V AC
4.	Pole Pairs of PMSG	5
5.	Output voltage of Rectifier	300V DC
6.	Output voltage of Buck Converter	17V DC
7.	Output current of Buck Converter	2.8A
8.	Battery capacity	12V
9.	Inverter	single phase SPWM
10.	Output voltage of Inverter	230V AC
11.	Output current of Inverter	13A

Table1: Design Parameters

5. CONCLUSION

In this paper aero generator for commercial applications is designed using MATLAB simulink .In this project wind turbine, pitch angle control, drive train, buck converter and inverter are designed using MATLAB simulink. This project also includes the equations that form the wind turbine, drive train. A new control strategy to make the input voltage track its reference rapidly, to restrain the charging current of battery and to control the speed of PMSG is adopted in this paper.

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