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Design & Development of MPPT for Micro Wind Turbine and a review on Wind Fuel cell Hybrid System.

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ABSTRACT

Wind power generation is playing a prominent role in the recent years. Wind energy has become the least expensive source of new renewable energies that is also compatible with environment preservation programs. Many countries promote wind power technology by means of national programs and market incentives. The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator to be used for system control. During the low wind speeds, the turbine tends to stop due to the back EMF generated in the generator and during high wind speeds it has to be stopped by connecting a dump load to avoid the mechanical breakage which could result in the reduced power extraction. This paper presents a novel method to solve these problems in two sections. The first section deals with the low wind speed problems and the other deals with the high wind speed problems. During the low wind speeds, the electrical load is disconnected for a shorter duration in which the turbine gains its inertia which is sufficient to generate the maximum power. The proposed solution has been discussed in the second section to connect an electrolyzer as dump load.

Keywords: *Micro wind turbine, MPPT for wind fuel cell hybrid system, fuel cell.*

1. Introduction

Electrical energy produced by a wind turbine has many uses. Converting wind energy into electric energy enables the user to store energy in a battery, transmit it over long distances, or convert the energy into many different forms (mechanical energy, heat, etc.). In some small applications, wind turbines are operated in isolated operation. Battery charging is very popular because of its simplicity and versatility. DC or AC generators can be used for battery charging. The turbines which generate less than 1.5kW power are usually known as micro wind turbines. Micro-wind turbines have been used for many years in domestic, industrial and farming applications for both water pumping and electricity generation. The power generated and associated carbon emission reductions per turbine are relatively small, but cumulative benefits could be significant. Micro-wind turbines are likely to increase in the coming years on homes and both commercial and public buildings. An average household (with a typical wind regime) can save approximately a third of its typical energy requirement by installing a domestic micro-wind turbine. Larger micro-wind systems can provide nearly all the energy required in a home.

The power generated by the wind turbine is need to be stored in battery. The most important factor in the success or failure of any wind generation system, whether it is a commercial wind farm or small-scale battery charging, is the strength and nature of the wind resource. The average wind speed of a site is a good guide to whether it is suitable for a wind generator or not. Since the energy in the wind varies in proportion to the cube of the wind speed.

For stand-alone wind systems, where a constant supply of electricity is desirable, it is essential to have a battery to store electricity for when the wind is light. DC, or direct current, is the only type of electricity that we can get straight from batteries, and is suitable for running DC appliances. It is convenient to use DC with small wind generators for charging batteries.

On the other hand the fuel cells also have a huge capacity to produce electricity. Hydrogen today is produced from natural gas from limited markets but it can be produced from renewable sources and promises substantial contributions to the global energy supplies in the long term. Hydrogen is most abundant element in the universe, the simplest chemical fuel (essentially a hydrocarbon without the carbon) that makes a highly efficient clean burning energy carrier. It has the potential to fuel transportation vehicle with zero emissions and also provide process heat for industrial process, help produce electricity from (centralized or distributed power systems and provide a storage medium for electricity from renewable sources. Sir William Grove (1811-1896), a British lawyer and amateur Scientist, developed the first fuel cell in the year 1839. The principle was discovered by accident during an electrolysis experiment. [1]

When Sir William disconnected the battery from the electrolyzer and connected the two electrodes together, he observed a current flowing in the opposite direction consuming the gases of hydrogen and oxygen. He called this device a gas battery. It consisted of platinum electrodes placed in test tubes of hydrogen and oxygen, immersed in a bath of dilute sulphuric acid. It generated voltage of about 1 V. However, due to some problems of corrosion of the electrodes and instability of the materials grove fuel cell was not practical. But however, Bacon in the year 1950 successfully produced the first practical fuel cell which was an alkaline fuel cell. It was an alkaline electrolyte (molten KOH) used instead of dilute sulphuric acid. The electrode was constructed of porous sintered nickel powder so that the gases could diffuse through the electrodes to be in contact with aqueous electrolyte on the other side of the electrode. This greatly increased the contact area contact between the electrodes, gases and the electrolyte. Thus, increasing the power delivered by the fuel cell.

A fuel cell is an electrochemical device that converts chemical energy directly into electrical energy. Like a battery, a fuel cell consists of a pair of electrodes and an electrolyte. Unlike a battery, the species consumed during the chemical reactions are continuously replenished such that there is never a heed to recharge the cell. A fuel visually hydrogen is supplied to the anode of the full cell. At the anode, the fuel is oxidized yielding electrons, which travel through the external circuit and at the Cathode the oxidant is reduced, consuming electrodes from the external circuit. Ions travel through the electrolyte to balance the flow of electrons through the external circuit. Anode and the cathode reactions and the composition and direction of flow of the mobile ion vary with the type of fuel cell.

Applications of Fuel Cells:

Fuel cells have been used extensively and successfully in spacecraft and now efforts are on to commercialize the fuel cell. They have a wide range of applications which are listed below.

i. Stationary power

- Power generating stations
- Auxiliary units
- Distributed power generation
- Residential use as combined heat and power (CHP)
- Generating station

ii. Transportation

- Airport intra terminal vehicles
- Buses and car

iii. Portable electronics

- Laptop
- Cellular phones [1]

2. Battery charger for micro wind turbines

2.1 Block diagram

This topic presents the detailed description of block diagram. It starts with the working principle of designed battery charger for micro wind turbines and the description of the main components used in the set up. The block diagram gives an insight idea of the electrical connection of wind generator and battery through a smart interfacing circuit. The circuit is designed to obtain the maximum power generated by the wind turbine.

Fig.2.1: Block diagram

The block diagram consists of 12V DC wind generator, voltage sensing circuit, ADC, microcontroller, driver IC, MOSFET, LCD and 12V battery as a load. Instead of DC wind generator AC wind generator can be used with rectifier.

2.2 Working Principle

The voltage sensing circuit is used to monitor the generator output voltage and battery voltage. The output OF sensing circuit is connected to the microcontroller through ADC0809 which converts analog voltage into digital value so that the controller can understand it easily. The output of voltage sensing circuit at battery side is directly connected to the $P_{1.0}$ pin of microcontroller. When $P_{1.0}$ receives high signal that indicates battery is fully charged. Controller sends the gate pulse to the switch (MOSFET) through driver circuit according to generator output voltage (V_g). Frequency modulation technique is used for generating the pulse. The ON period and OFF period of pulse depends on the V_g. During the low wind speed at which the turbine generates the output voltage less than 13.5V therefore the battery will be disconnected. As the V_g reaches 13.5V, the battery will be reconnected to utilize the generated power. The OFF period decreases as the V_g increases from 13.5V to 17.5V. During OFF period the turbine gains its inertia and supplies power to the battery when it is connected. As the battery voltage reaches 13.5V, it will be disconnected automatically to protect from overcharging.

3. Design of Voltage Sensing Circuit

The voltage divider circuit is used as a voltage sensing circuit. It consists of two series resisters connected in parallel to the input supply. The voltage sensing circuit is shown in Fig.3.1

Formula used for calculating the V_2 is given by

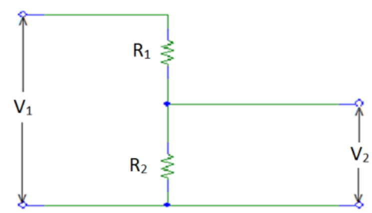


Fig. 3.1: Voltage sensing circuit

R_1 and R_2 are fixed and they are selected to get V_2 less than 5V for maximum input voltage (V_1). Two voltage sensing circuits are used in this project, one is at the wind generator side and another is at battery side.

Considering the maximum wind generator output voltage is 38V so that R_1 and R_2 are selected as 10kΩ and 1.5kΩ respectively to get V_2 less than 5V. V_2 is further connected to ADC as an input. The calculated results of V_2 are presented in below fig 3.2.

Calculated results of V_2 of voltage sensing circuit at wind generator side

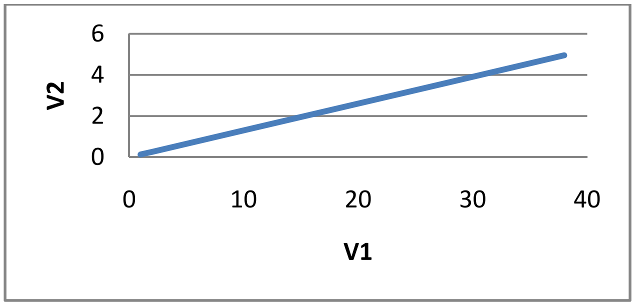


Fig 3.2: Plot of V1 to V2

The voltage sensing circuit at battery side is used to sense battery voltage. R_1 and R_2 are selected to get V_2 = 2.7 V when V_1 (Battery voltage) = 13.5 V. The output of this voltage sensing circuit is directly connected to the pin $P_{1.0}$ of microcontroller because that pin gets high signal at 2.7 V and program is written to disconnect battery when $P_{1.0}$ receives high signal. The same procedure is followed to calculate V_2 for R_1= 100kΩ and R_2= 25kΩ. V_2 is calculated only for V_1= 13.5 V is shown in below Table-3.1

Table-3.2: Calculated results of V_2 of voltage sensing circuit at battery side.

V_1 (V)	R_1 (kΩ)	R_2 (kΩ)	V_2 (V)
13.5	100	25	2.70

3.2 Analog to Digital Conversion

8-bit ADC is used to convert analog signals from voltage sensing circuit to digital values. For 8-bit ADC, the digital values can be calculated using the successive approximation method.

Consider minimum voltage of analog signal is 0 V and maximum voltage is 5 V.

Let V_{max} = maximum voltage of the analog signal

A = analog value

n = number of bits for digital encoding

2^n = number of digital codes

M = number of steps ($2^n - 1$)

D = digital value

$$D = A \times \frac{M}{V_{max}} \cdots\cdots\cdots\cdots\cdots\cdots \cdot (3.2)$$

Digital values for corresponding analog voltages are calculated using the formula 3.2 for n = 8 and M = $2^n - 1 = 2^8 - 1$ = 255. The calculated results are shown in below Fig.3.2.

The step size or resolution of ADC is given by

$$\text{Resolution} = \frac{V_{max}}{M} \cdots\cdots\cdots\cdots\cdots\cdots \cdot (3.3)$$

$$\text{Resolution} = \frac{5}{255} = 0.02\frac{\text{volts}}{\text{bit}} \ldots\ldots\ldots\ldots\ldots 3.2$$

The digital values for selected analog voltages are given in Table-3.2

Table-3.3: Analog to Digital conversion.

V_g (V)	Analog voltage	Digital value
13.5	1.76	90
14.5	1.88	96
15.5	2.02	103
16.5	2.14	109
17.5	2.27	116

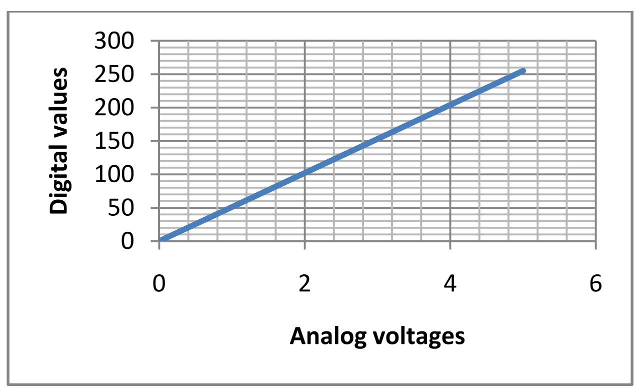


Fig. 3.2: Plot of digital values V/s analog voltages

Step 1: Measure generator output voltage (V_g) and battery voltage (V_b)

Step 2: If V_g < 13.5 V or V_b > 13.5 V, disconnect battery else connect battery

Step 3: If 13.5 V ≤ V_g < 14.5 V, generate gate pulse with 1s-ON and 4s-OFF

Step 4: Else if 14.5 V ≤ V_g < 15.5 V, generate gate pulse with 1s-ON and 3s-OFF

Step 5: Else if 15.5 V ≤ V_g < 16.5 V, generate gate pulse with 1s-ON and 2s-OFF

Step 6: Else if 16.5 V ≤ V_g < 17.5 V, generate gate pulse with 1s-ON and 1s-OFF

Step 7: Else if V_g ≥ 17.5 V, generate gate pulse with full ON

Step 8: Else go to measure V_g and V_b

This loop will be continuing repeatedly and depends on the status of V_g and V_b, the controller generates the gate pulses to the switch.

3.4 Circuit Diagram of the work done

The below figure 3.4 represents the complete connections of each component used for designing the smart charger between the micro wind turbine and battery. Interfacing between microcontroller (P89V51RD2BN), ADC0809CCN and LCD are presented with pin numbers. Two voltage dividers are used as voltage sensing circuits for monitoring the generator output voltage and battery voltage. ADC converts analog voltages into digital signals and these digital signals or digital values acts as an input to the microcontroller. N-channel MOSFET is used as a switch which operates with respect to the gate pulse generated by the controller given through the driver circuit. LCD displays generator output voltage and switching mode of the switch. P89V51RD2, ADC0809CCN and LCD require 5 V DC supply and driver IC requires both 5V and 12 V DC supply. The photograph of designed experimental setup is shown in below Fig. 3.5

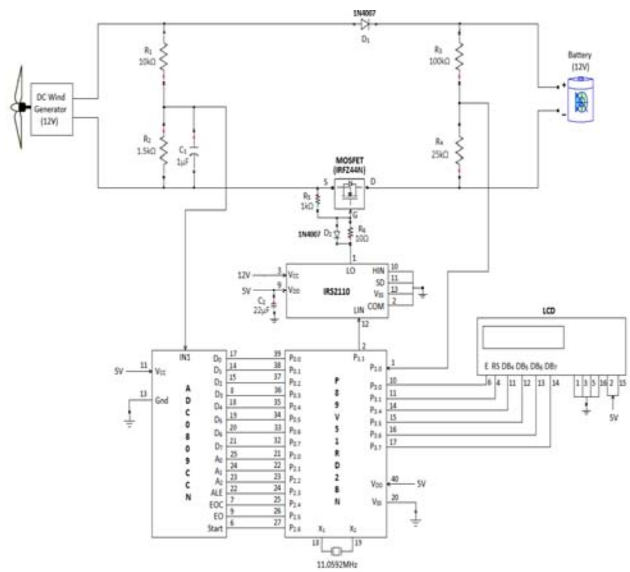
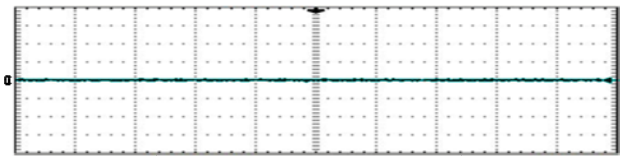


Fig. 3.4: Detailed Circuit Diagram

4. Results and discussions

The results obtained from the designed charger circuit for micro wind turbines are illustrated in this topic. Instead of wind turbine, a 24V DC power is converted by single phase AC using rectifier had been used for testing the circuit. By varying the input DC voltage using potentiometer, the gate pulses generated by the controller for different voltage ranges are observed and those are found to be correct. 12V, 7.2Ah sealed lead-acid battery was used for testing and it was found that when the battery voltage reaches 13.5 V, it will be disconnected means the switch will be opened. The generation of pulse is mainly achieved by the frequency modulation technique. Here ON time is maintained constant as 1 second and only OFF time is varied according to the requirements resulting in the change in frequency.

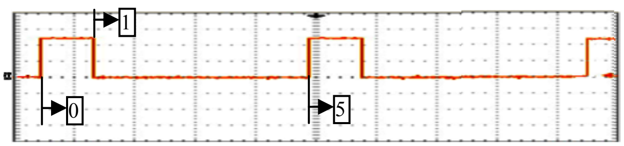
The gate pulses generated by the controller for different wind generator output voltage ranges from 13.5 V to 17.5 V are shown in below figures from Fig. 4.1 to Fig.4.6 respectively. All the results has been recorded and extracted by the use of cathode ray tube.



Time (sec)

Fig. 4.1: Gate pulses for $V_g < 13.5V$ or $V_b > 13.5V$

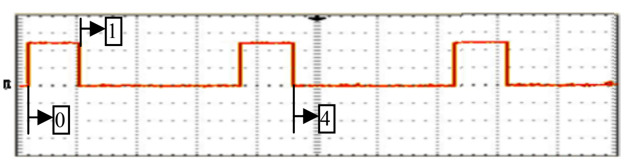
Fig. 4.1 shows the gate pulses generated by the controller when either $V_g < 13.5$ V or $V_b > 13.5$ V. The switch will be OFF until the wind generator output reaches 13.5 V and battery voltage should be less than 13.5 V.



Time (sec)

Fig. 4.2: Gate pulses for $13.5V \le V_g < 14.5V$

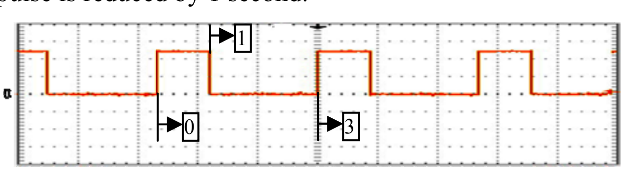
Fig. 4.2 shows the gate pulses generated by the controller when V_g lies between 13.5 V and 14.5 V. Observed that, it is1 second ON and 4 second OFF with a frequency 200 mHz.



Time (sec)

Fig. 4.3: Gate pulses for $14.5V \le V_g < 15.5V$

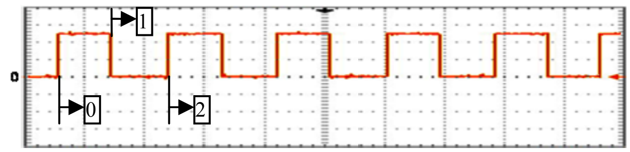
Fig. 4.3 shows the gate pulses generated by the controller when V_g lies between 14.5 V and 15.5 V. Observed that it is 1 second ON and 3 second OFF with a frequency 250 mHz. Compared to the Fig. 4.2 the OFF period of the gate pulse is reduced by 1 second.



Time (sec)

Fig. 4.4: Gate pulses for $15.5V \le V_g < 16.5V$

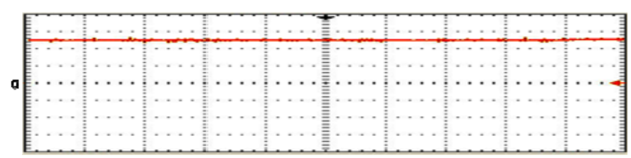
Fig. 4.4 shows the gate pulses generated by the controller when V_g lies between 15.5 V and 16.5 V. Observed that it is 1 second ON and 2second OFF with a frequency 333 mHz. Compared to Fig. 4.3 the OFF period of the gate pulse is reduced by 1 second.



Time (sec)

Fig. 4.5: Gate pulses for $16.5V \le V_g < 17.5V$

Fig. 4.5 shows the gate pulses generated by the controller when V_g lies between 16.5 V and 17.5 V. Observed that it is 1 second ON and 1 second OFF with a frequency 500 mHz.



Time (sec)

Fig. 4.6: Gate pulses for $V_g \ge 17.5V$

Fig. 4.6 shows the gate pulses generated by the controller when V_g exceeds 17.5 V. Observed that it is fully ON means battery is connected continuously.

It is observed that the OFF period of gate pulse decreases as the generator output voltage increases from 13.5 V to 17.5 V. Increase in voltage indicates that the wind speed is increased so the turbine will be rotating finely at high wind speeds therefore the OFF period of the switch is reduced as the voltage increased. In OFF period the turbine gains its inertia and it supplies power to the battery in 1 second ON period. By keeping ON period constant and varying only OFF period of the pulse with respect to the generator voltage, the turbine can be made to run even for low wind speed along with the battery charging.

4.1 Proposed block diagram

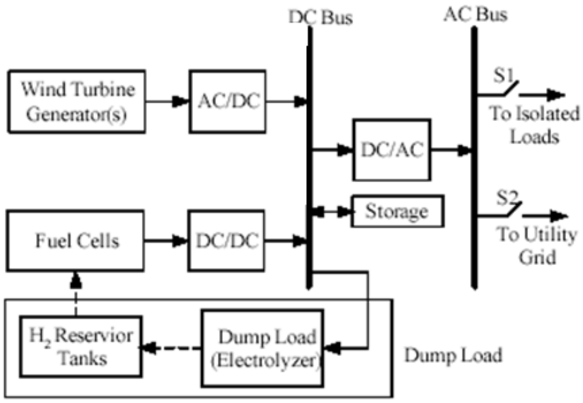


Fig. 4.7: Block diagram of the proposed set up

Conclusions

The proposed charging circuit of battery using micro wind turbine has been designed, fabricated and tested. The results obtained are found to be correct and the test results and observations revealed that, by controlling the connection of battery, the turbine can be made to run even for low wind speed. Battery can be charged linearly and it can be protected from overcharging. It helps to extract maximum power from the wind and to increase the efficiency of turbine. Obviously, a complete hybrid power system of this nature may be too expensive and too labor intensive for many Industrial Technology Departments. In this hybrid system with using fuel cell is more efficiency, long life and cheapest compare to hybrid system with using battery. The enhancements to instruction, especially in making electrical power measurements more physical, intuitive, and real-world are substantial and the costs and labor involved in some adaptation of the ideas in this paper to a smaller scale setup are reasonable. The use of solar/wind & FC hybrid power generation is an especially vivid and relevant choice for as these are power sources of technological, political, and economic importance in their state. In other places, other power sources could be used. For example hybrid combinations of wind power, solar power, geothermal power, hydroelectric power, tidal power, biomass generated power, power from incineration of solid wastes, and many other technologies could be considered depending on local interests and resources.

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