An electromechanical approach to improve the output voltage of a DC wind turbine in low wind speed areas

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An Electromechanical Approach to Improve the Output Voltage of a DC Wind Turbine in Low Wind Speed Areas

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***Abstract*—This paper proposes a concept that can be applied to increase the output voltage of a wind turbine in low wind speed areas. A simple and cost efficient model is introduced which follows sequential procedures to amplify the minimal generated voltage. Traditional wind turbines are mostly AC generator oriented, whereas this model deals with DC wind turbine, since this technology is becoming more and more promising day by day. The approach presented in this paper illustrates the simple way of increasing the wind speed, amplifying the generated voltage of wind turbine by mechanical system, and finally stabilizing the output voltage for DC applications. To be specific, this is a nozzle augmented DC wind turbine where the nozzle is used to boost the wind speed. Then a gear coupling is being introduced in the intermediate stage to further increase the generated voltage. At the end, a DC voltage stabilizer is used prior to final usable DC output. It is expected that, this novel approach will play a vital role in improving the output voltage of a DC wind turbine.**

Keywords*—*DC voltage; nozzle; spur gear; wind turbine.

I. Introduction

Wind energy is considered as one of the most prominent renewable energy sources. Taking into account the increasing demand of electricity, wind turbine is surely a great choice to solve that crisis. But this is not the best solution if the wind turbine's output is not satisfactory with respect to the installation and maintenance cost. This problem becomes acute when the wind speed is low and varying frequently. However, if few DC applications can be performed by DC wind turbines at low wind speed areas, then a significant amount of electricity demand can be satisfied there. In this research work, focus has been given both on how the wind speed can be increased and the generated voltage can be improved.

Many researchers have attempted to improve the output voltage of wind turbines [1]. Most of them are AC voltage generation oriented. DC wind turbines are also growing in number very rapidly. Studies of DC wind turbine are mainly for series-connected types to increase the collective output [2] [3]. But improving the output voltage for a standalone DC wind turbine is quite a novel approach.

Throughout this paper, few measurements are taken and data are analyzed which leads to the direction of increasing the output voltage of a DC wind turbine. This paper is organized as: in Section II, methodology of the system is described. Section III represents the system design & experimentation. Finally, Section IV draws conclusion and proposes future scope of this research work. Since the expanse of this research work considers only unidirectional wind, throughout this paper the words speed and velocity have been used interchangeably.

II. Methodology

There are three prime segments in this paper which sequentially deal with increasing the output voltage of a DC wind turbine. These three major parts are: boosting the wind speed, increasing the rotational speed of the wind turbine and stabilizing the output voltage. Fig. 1 shows the complete sequence of generating stable DC voltage from low velocity wind source. Output voltage of a wind turbine can be amplified by both rising the wind speed and/or increasing the rotor's rpm. This observation is factual because the output voltage of a DC generator is directly proportional to the rotor's rpm [4] and the rotor's rpm is proportional to the wind speed.

$$E = \frac{P\phi ZN}{60A}, \tag{1}$$

Where E = generated voltage, P = number of poles, ϕ = flux per pole, Z = total number of armature conductor, N = Shaft Speed (revolutions per minute) and A = number of parallel paths in armature.

Rotor shaft speed is given by the following equation [5]:

$$N = \frac{60v\lambda}{\pi d}, \tag{2}$$

Where v = Wind speed, λ = Tip speed ratio and d = Turbine's diameter. Whereas, the Tip Speed Ratio is mathematically defined as [6]:

$$\lambda = \frac{r_m \omega_m}{v}, \tag{3}$$

Where r_m = the maximum radius of the rotating turbine in meter, ω_m = mechanical angular velocity of the turbine in $rads^{-1}$, v = wind speed (ms^{-1}).

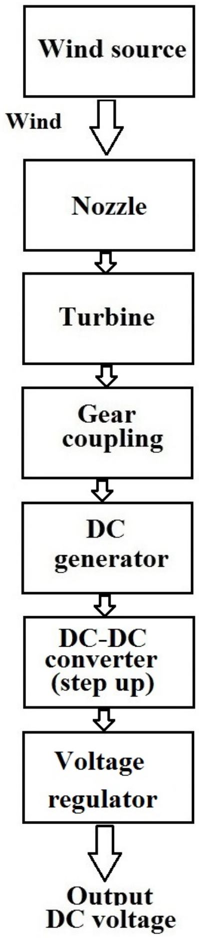

Fig. 1: Block diagram for the overall experimental setup.

A. Boosting the Wind Speed

First step of increasing the output voltage of a wind turbine is to boost the wind speed with the help of a mechanical nozzle. In order to do that, initially a mechanical nozzle is simulated and it is observed that the outlet wind speed of the nozzle is increased. After that, a mechanical nozzle is practically installed in front of the wind source. Then inlet and outlet wind speed is measured with the help of an anemometer and compared with the simulated data.

Nozzle's inlet, outlet wind flow rate can be related as [7]:

$$v_2 = \frac{{d_1}^2}{{d_2}^2} v_1, \tag{4}$$

Here, v_1 and v_2 stand for inlet and outlet wind speeds, and d_1 and d_2 denote inlet outlet diameter.

B. Increasing the Rotational Speed of the Wind Turbine

Second step is to increase the first step's rpm (as well as voltage) with a spur gear couple. For a spur gear couple, rpm of a gear is inversely proportional to its teeth number [8].

$$\frac{N_2}{N_1} = \frac{n_1}{n_2}, \tag{5}$$

TABLE I: WIND SPEEDS AND CORRESPONDING GENERATED VOLTAGES WITHOUT MECHANICAL ENHANCEMENTS

Wind speed (ms^{-1})	Generated DC voltage (mV)
1	13
1.5	15
2	91
2.5	151
3	200
3.5	239
4	289
4.5	360
5	380

Where, N_1 and N_2 denote the rpm of the large and small gear, and n_1 and n_2 indicate the number of teeth of the large and small gear respectively.

However, there are few other gear couplings available, in this research work, spur gear coupling was used, because the efficiency of a spur gear pair can be about 98% [8] and it has the simplest design.

C. Stabilizing the Output Voltage

The last and third step is to stabilize the output voltage of the DC wind turbine for DC applications. For that purpose, a voltage regulator IC is used here. In case of wind speed falls and the output voltage decreases below expected value, in order to stay on the safe side, DC-DC step-up converter can be used to uplift the voltage. Here Boost converter is a smart choice whose input and output voltage relationship with duty cycle is [9]:

$$V_o = \frac{V_{in}}{1-D}, \tag{6}$$

Where, V_o and V_in are output voltage and input voltage respectively, and D is the duty cycle of the Boost converter.

III. SYSTEM DESIGN AND EXPERIMENTATION

Only low wind speeds are considered for this research work. That's why wind speed is not taken greater than 5 ms^{-1}. For experimentation purpose, a stand fan is used here to work as the wind source. Velocity of wind, produced from the wind source is measured (in ms^{-1} unit) with the help of an anemometer. Generated DC voltages from wind turbine in response to wind speeds are listed in Table I.

The components of the overall experimental setup which include wind source, nozzle, wind turbine, gear coupling and anemometer are arranged sequentially. Since the output voltage of a DC generator is proportional to the rotor's speed, in order to increase the wind turbine's rpm, wind speed was increased with the help of a nozzle. Here, used nozzle prototype's inlet and outlet diameter were 0.5m and 0.25m respectively. As it is stated in [10] that, the nozzle length should be neither too long nor too short, the nozzle length considered here was 0.5m. Different inlet wind speeds are taken by changing the speed of the fan. These wind speeds are given as input to the real nozzle and corresponding real nozzle output wind velocities are recorded with an anemometer.

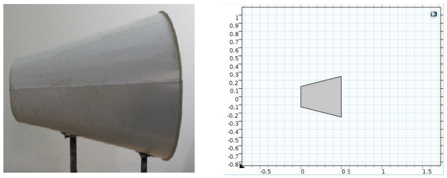

Fig. 2: Practically used nozzle and COMSOL model of the nozzle.

TABLE II: For Some Particular Inlet Wind Speeds of Nozzle, Corresponding Outlet Speeds Measured By Anemometer and Simulated in Comsol

Taken input wind speed (ms^{-1})	**COMSOL nozzle output** (ms^{-1})	**Real nozzle output** (ms^{-1})
1	1.97	2.2
1.5	2.96	3.6
2	3.94	4.32
2.5	4.93	5.23
3	5.91	6.01
3.5	6.89	6.99
4	7.88	8.8
4.5	8.86	9.4
5	9.85	10.65

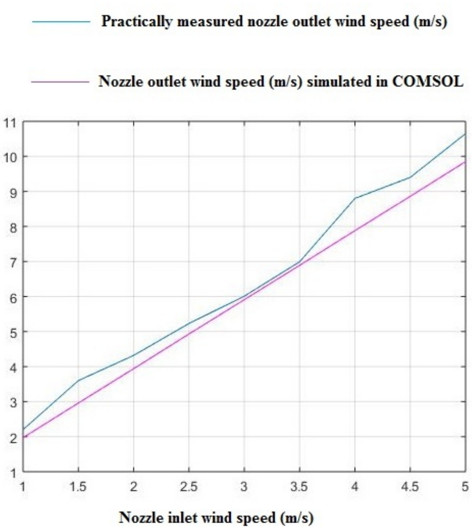

Fig. 3: For a taken wind speed, practically measured nozzle outlet wind speed and simulated outlet wind speed in COMSOL.

The real nozzle was also simulated and different outputs are measured using the similar input wind speeds in COMSOL multiphysics software. Fig. 2 shows both the practical nozzle and the simulated one. The relations between input and output wind velocities are calculated using fluid dynamics as presented in Table II.

Real nozzle output wind velocities and COMSOL simulated output wind velocities are plotted w.r.t. input wind speeds in Fig. 3. It is noticeable that despite of slight fluctuation, real values and simulated values are almost same.

The increased output wind speeds are used to rotate the DC wind turbine and generate DC voltages. Then a spur gear coupling is introduced between the wind turbine and DC generator. The large gear is attached with the wind turbine shaft

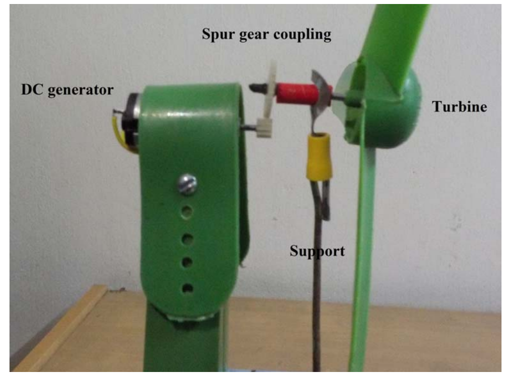

Fig. 4: Setup arrangement of the gear coupling.

TABLE III: Wind Turbine's Generated Voltage for Nozzle's Outlet Wind Speed with and without Gear Coupling

Generated voltage (mV) for nozzle's outlet wind	**Generated voltage (mV) with gear coupling**
93	107
143	172
213	266
278	361
319	424
383	513
470	644
492	659
563	976

and the small gear is attached with the DC generator's rotor. A support is required to mount the gear coupling as illustrated in Fig. 4. Here, the large gear has 24 teeth and the small gear has 12 teeth. The role of gear coupling in increasing the DC voltages is listed in Table III.

Here, since the number of teeth of large gear was double of the small gear, the generated voltage at the gear coupling's end should be around twice of the input voltage of the gear coupling. But due to improper placement of the gears and other losses (e.g. friction and vibration) the measured values slightly differs from the theoretical values. A plot of voltage increase due to gear coupling can be observed in Fig. 5.

Finally, the increased voltage can be stabilized to a certain specific level for some particular applications. For example, a desired stable 12V DC can be achieved with the help of voltage regulator IC uA7812. If a DC voltage greater than 12V is applied between pin 1 and pin 2 (ground) with the circuit arrangement shown in Fig. 6, then a constant 12V DC output is found between pin 3 and pin 2 of uA7812 IC [11].

The DC generator used in this research work generates voltage in mV range. If a DC generator (and associated nozzle, turbine and gears) with larger capacity can be used, then it will produce the desired DC voltage (above 12 V). Above comparisons show that, output voltage of a DC wind turbine can be increased by mechanical means (nozzle and gear coupling). Fig. 7 illustrates the comparison of increased voltage and the voltage without any enhancements.

IV. Conclusion and Future Work

In this paper, a simple but effective method is proposed to improve the output voltage of a DC wind turbine in low wind

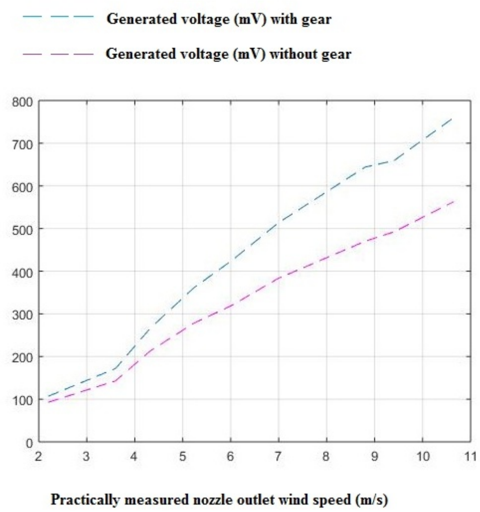

Fig. 5: Nozzle outlet wind speed vs wind turbine's generated voltage with and without gear.

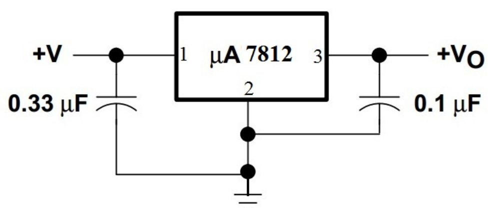

Fig. 6: Fixed 12V DC output using μA 7812 IC.

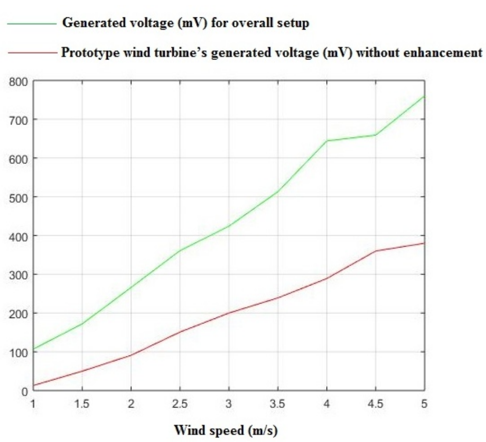

Fig. 7: Wind turbine's generated voltage for particular wind speeds without enhancement and increased generated voltage with overall setup for same wind speeds.

speed areas. From the experimental observations, it can be said that the above stated setup can increase the output voltage of a DC wind turbine to a reasonable amount with only some rare exceptions. Even, the generated voltage can be almost doubled using the electromechanical enhancements. In addition to that, the voltage stabilizer worked successfully too.

In future, more than two gears can be connected together to further increase the rpm of the wind turbine. Wind turbine's blades can be drawn under design consideration too. Finally, a feedback based intelligent DC-DC converter can be used to electrically increase the wind turbine's generated voltage in a proportionate way.

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