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Low Cost Regulation and Load Control System for Low Power Wind Turbine

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Abstract

Context: Electric power generation systems designed as a point solution to supply needs away from the power grid typically make use of the energy resources available in the area. These systems are custom designed to supply a specific need, and with high efficiency criteria in mind. A fundamental element in these systems are the batteries charge and control circuits. **Method:** The regulation system was designed for the wind turbine prototype of the Francisco Jos de Caldas District University, campus of the Technological Faculty, and considering its use in low-income housing. The module has three intermediate stages of regulation: rectification and conditioning, DC/DC regulation and battery charging, and voltage inversion. **Results:** We achieved a prototype of high efficiency, low cost and high performance in laboratory tests. **Conclusions:** The load control and regulation system is a low-cost, high-performance alternative to solve problems of supplying electric power in non-interconnected areas of the Colombian power grid.

Keywords: system, module, converter, signal, control, battery, power, programmable

1 Introduction

Currently, according to the IPSE (Institute of Planning and Promotion of Energy Solutions for non-interconnected zones of Colombia), in Colombia there is

Figure 1: Low-power Savonius wind turbine.

a deficit in the provision of electricity service because 52% of the national territory is not inside of the National Interconnected System (SIN), corresponding to 90 municipalities, 20 biodiverse and border territories, 1448 localities, 39 municipal headwaters and five departmental capitals [5]. These are very dispersed areas, with little population, the resources of these people are very limited and their energy consumption is very low.

Colombian territory has abundant natural resources such as solar, wind, water resources, coal and oil. The generation of electric energy through the use of unconventional technologies exploiting the existing resources in the areas of interest are giving solution to the problem of these communities [8]. Strategies such as MCGP (programming by goals) are used to select the most appropriate form of renewable energy, also selecting the exact location where the environmental and social impact is the lowest possible, as they are very important aspects to take into account [7].

Europe invests heavily in this type of energy solution [2, 1, 6]. Renewable energy sources are used to power the grid autonomously and thus supply electric power to remote homes. These technologies are still not very reliable because of intermittent sources. Turn them competitive like the traditional energy generation is an open research problem [4, 9, 3].

In the Technology Faculty of the Francisco Jos de Caldas District University, a low-power Savonius wind turbine has been developed for residential lighting (Fig. 1). This article documents the development of the regulation system of voltage and charge of batteries of this wind turbine for a nominal power of 120 W with autonomy of 42 minutes. The goal is to achieve a very reliable system regardless of wind strength. The generator shaft drives a chain-coupled, 48 V and 350 W three-phase brushless motor. The power converters are controlled from an embedded control unit coordinated by microcontroller.

2 Materials and Methods

The wind turbine has a transmission that moves a 350 W three-phase brushless motor that works as a generator. The generated signal is rectified and filtered for DC/DC converter power. The DC/DC converter maintains constant and continuous the output voltage. This signal then goes through the storage stage in the batteries. The system has current and voltage restrictions. Finally, the DC signal passes to an inverter for lighting circuits at 120 Vac-60 Hz, with a maximum load of 120 W.

2.1 Battery bank

Batteries are composed of different types of materials including Lead-Acid, NaS, Ni-Cd, Ni-Mh, Li-ion and others. Lead-acid batteries have been the most developed and used in power systems, and are the ones selected in this project for cost and availability. This type of battery has about 2000 charge and discharge cycles, when it does not have a discharge depth greater than 20%, its efficiency is 75%, can withstand 80% discharges and have a life of up to 15 years. These batteries are sold in groups of 12 V or 24 V.

Charging a battery is the reverse process of the discharge. In the charge the same energy that has been extracted should be returned to the battery, plus an additional percentage. The charger is designed as constant-voltage constant or constant voltage with limited current, this project uses in second scheme. The characteristics of the selected batteries are:

- Rated voltage: 12 VDC
- Rated capacity: 7 Ah
- Highly secure sealing
- 1.06 cm terminals
- Maximum temperature: 300°C

We define the energy that two batteries can provide to power a resistive load of 120 W:

$$E = V \times Ih = 12V \times 7Ah = 84Wh \tag{1}$$

$$ET = 84Wh \times 2 = 168Wh \tag{2}$$

Donde:

- E = Energy delivered by one battery

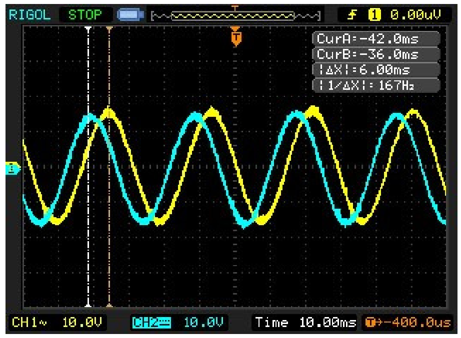

Figure 2: Signals of the ab-bc phases of the motor.

- ET = Total energy for the two batteries

To extend the life of the battery, only 50% will be discharged, so of the 168 Wh, only 84 Wh can be used. With this we proceed to calculate the autonomy that will have the system when the wind is not enough to turn the blades of the wind turbine.

$$A = \frac{E}{Pd} = \frac{84Wh}{120W} = 0.7h = 42min \tag{3}$$

Where:

- A = System autonomy
- E = Energy delivered by batteries
- Pd = System power output

The batteries feed a resistive load of 120 W for 42 minutes.

2.2 Rectifier

The signals produced by the motor are sinusoidal waves. The motor has three stator windings offset 120° (Fig. 2). Nosotros utilizamos un rectificador trifsico no controlado con diodos.

The output voltage of the rectifier is:

$$Vdc = \frac{1}{\pi/3} * \int_{\pi/6}^{\pi/2} \sqrt{3} * Vfase * \cos(\omega t) d\omega t \tag{4}$$

$$Vdc = \frac{3 * \sqrt{3}}{\pi} * Vfase = \frac{3 * \sqrt{3}}{\pi} * 48V = 79.4V \tag{5}$$

$$IDC = \frac{P}{V} = \frac{120W}{79.4V} = 1.51A \tag{6}$$

Where:

- Vdc = Output voltage
- IDC = Output current

The current in each diode is:

$$IDCdiode = \frac{IDC}{3} = 0.50A \tag{7}$$

Where:

- $IDCdiode$ = Current in each diode

The diodes must have a voltage greater than 80 V and a current greater than 0.5 A.

2.3 DC/DC Converter

We chose a Buck converter for the design. The input voltage can vary in the range of 0 V to 30 V. The output voltage should be regulated to 15 V for the batteries and the inverter. For the design we assume:

- Vin = 30 V and $Vout$ = 15 V
- $Imax$ = 8 A and $Imin$ = 800 mA
- Δ $Vout$ < 150 mV
- f = 180 kHz

For a 50% duty cycle:

$$D = \frac{Vo}{Vi} = \frac{15V}{30V} = 0.5 \tag{8}$$

The chokue is calculated in continuous mode for the most unfavorable condition:

$$Lc = \frac{(1-D)*Vout}{2fIo_{min}} = \frac{(1-0.5)*15V}{2*180kHz*800mA} = 26.06\mu H \tag{9}$$

We use a safety margin of 25%, so we define a critical inductance value of $Lc = 32\mu H$.

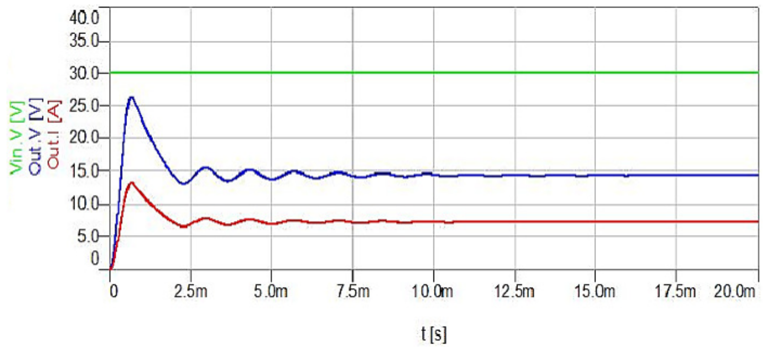

Figure 3: Buck converter startup with high wind.

$$C > \frac{(1-D)*Vout}{8Lf^2\Delta Vout} = \frac{(1-0.5)*15V}{8*47\mu H\ (180kHz)^2*0.15V} = 12.6\mu F \qquad (10)$$

The Fig. 3 shows the expected behavior of this controller at startup with high wind.

2.4 Voltage inverter

Design considerations according to the final load are:

- Input voltage in normal operation will be in the range of 12 to 15 Vdc. The output voltage must be in the range of 110 V to 127 Vac.
- With low wind the inverter will have an input voltage of 12 Vdc and an output voltage of 120 Vac, until the battery reaches 50 % of load, then the module is deactivated.
- Vin_max: 15 Vdc and Vout_max: 127 Vac
- Imax: 1.5 A and Pmax: 150 W
- f: 20 kHz
- Waveform: Square

We design an inverter with Mosfets in configuration push-pull, on a 150 W step-up transformer with central tap in the primary. Fig. 4 shows the output voltage under normal operating conditions.

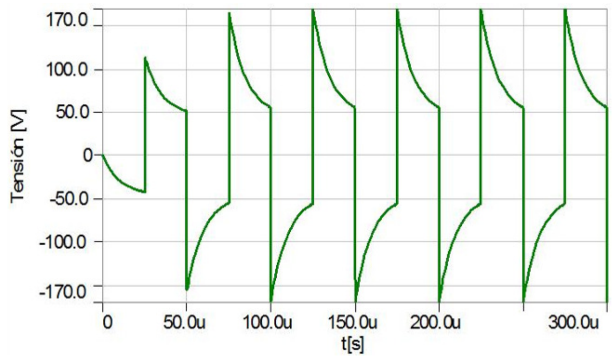

Figure 4: Inverter startup under normal operating conditions.

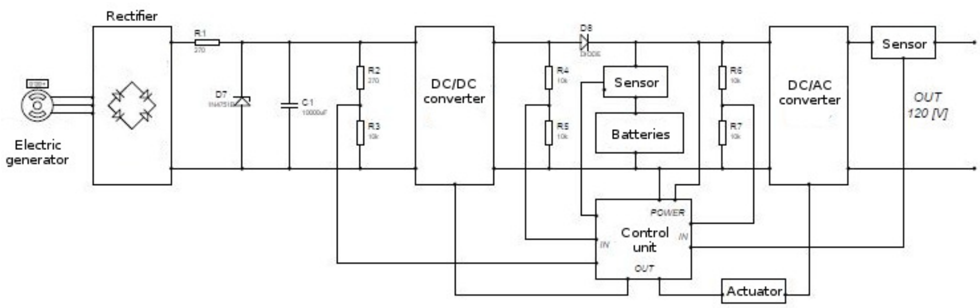

Figure 5: Power circuit of the proposed regulation system.

2.5 Control unit

The voltage and current (input and output) are sensed in each of the stages of electric power conversion, this information is necessary for both control and protection. Fig. 5 shows the power circuit of the system. There are two important restrictions to protect electronic components and batteries, the first is that batteries can not be discharged beyond 50% to ensure their life, and the second is that the output current does not exceed 1 A (this is the maximum design value of the inverter circuit transformer and the electronic components).

The control unit has an 8-bit microcontroller. This microcontroller reads the signals from the sensors and determines the outputs according to the control algorithm. The outputs correspond to the PWM signals for the Buck converter and the inverter, and the trigger and alarm signals in case of failure. It also coordinates the registration functions on a microSD memory, on-screen display and user input via keyboard.

Table 1: Battery charge test with the proposed system

Current [mA]	Time [min]
1412	0
924	30
689	50
395	70
194	130
87	240

3 Results and Discussion

Different laboratory tests were performed on the system. The most important test is the battery charge test from the DC/DC converter. After performing a 60% battery discharge, it was connected to the system to verify both the load control and circuit protections. Table 1 shows the results of one of these tests. In 50 minutes the charge current dropped to half its initial value. After four hours the current dropped to 0.1 A. The autonomy of the system was assessed over several discharge tests on luminaires with an average current of 1 A. These tests also corroborated the design parameters.

4 Conclusions

This paper documents the development of a low cost regulation and load control system for a low power wind turbine. The system is integrated with the Savonius wind turbine prototype that has been developed by the District University to solve lighting problems in low-income and isolated from the power system housing. These characteristics are taken into account in the design, which allows to achieve a small, robust, economical system easy to implement and with a very high performance. One of its most important characteristics is its microcontrolled control unit, which together with a custom DC/DC converter guarantees the battery life. Laboratory tests confirm the high performance of the prototype.

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