Design of a Low-Cost Wind Turbine Controller for Decentralized Rural Electrification Through the Small Wind Turbine

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Abstract. This paper present the development of a low-cost wind turbine controller for decentralized rural electrification through the small wind turbine. This controller allows on the one hand protecting the battery against overcharging and deep discharge. On the other hand, it helps to protect the turbine against strong winds. It is controlled by PIC microcontroller 16F877A. This control function is performed using an algorithm that continuously compares the battery voltage to the charge and discharge thresholds, and tilting towards dissipation resistors. The control signals generated by the microcontroller are PWM (Pulse Width Modulation) type. The validation of the main functions of the controller is presented. The main advantages of this controller are the robustness, the simplicity and especially the low cost.

Keywords: Controller · Wind turbine · Microcontroller

1 Introduction

As in photovoltaic systems, wind energy applications include most often batteries for storing excess energy and feed loads low and medium powers. The batteries are weak with the phenomena of overloading and deep discharge. This adversely affects the life of the batteries and is a weak point for renewable energies. To protect the batteries and prolong their lives, a controller should be used. For photovoltaic systems, the controller can only protect the batteries. The principle often used for photovoltaic controller consists in disconnecting the PV generator from the batteries. This disconnection occurs when the batteries are fully charged or deeply discharged (Amin et al. 2008). For wind turbine applications, the same principle cannot be used. Indeed, we cannot afford to disconnect the turbine from the batteries and keep it in a vacuum which will increase the risk of its destruction by overspeed. The principle adopted for the control

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of the batteries charge/discharge for wind systems must take into account this constraint. The wind turbine must always be loaded by the batteries and/or other charges (use, discharge resistors). In addition to the batteries, the controller protects the wind turbine.

The importance of a charging/discharging controller in an autonomous system such as a photovoltaic system or wind turbine needs no more to be discussed. However, it must be done very carefully in order to meet the requirements for reliability, simplicity, portability and cost. As in the embodiment of any system, the controller also poses a number of problems related to the existence of several possible architectures for load control (Usher and Ross 1998; Koutroulis and Kalaitzakis 2004; Thiringer and Petersson 2005) (maximum charging current with control battery voltage, constant voltage charging with control current battery, charging with adjustable intensity together with control of the battery voltage, etc.) and battery discharge (Usher and Ross 1998) (direct control of the battery voltage, check the battery voltage compensated or not the discharge current, discharge control across the state of battery charge. Several solutions are possible: analog, digital or mixed.

Additional constraints imposed on the controller such as the possibility of varying the parameters of the control algorithm and display the battery charge level, increase its complexity and lead us to opt for a smart solution based on microcontrollers.

This paper presents the different development steps of a battery controller for wind turbine applications, operating under the control of the microcontroller PIC16F877A.

2 Presentation of Wind Turbine and Regulation System

2.1 Characteristics of Wind the Turbine

The wind turbine used in this work was designed specifically for the African rural context, unlike wind turbines on the market. The electromechanical conversion is ensured by a permanent magnet three-phase alternator. The characteristics of this wind turbine are as:

- Starting speed: 2 m/s
- Stall speed: 10 m/s
- Nominal Power: 500 W
- Diameter of the helix: 3 m
- Type of mast: 18 m cable-stayed
- Control mode: Erasing gravitational lateral of the rotor

The figure below (Fig. 1) shows photo of the wind turbine.

Fig. 1. Photo of the wind turbine.

2.2 Performance of the Wind-Turbine

It is necessary to know precisely the behaviour of the wind turbine according to different parameters. The figure below (Fig. 2) shows, the characteristic curves of power and efficiency according to the wind speed of the wind-turbine.

The first of the figures shows the power curve of the wind turbine as a function of the wind speed. No power is delivered for a wind speed less than 2 m/s, we are in zone 1. The higher the wind speed, the more power the wind turbine develops; this is zone 2. The nominal power of the turbine is 500 W, which corresponds to a wind speed of 9 m/s. Beyond the stall speed of 10 m/s, the nominal power is exceeded, the turbine must be stopped. The second figure shows the efficiency of the wind turbine as a function of the wind speed. The ideal wind speed is between 3 m/s and 5 m/s for a maximum yield between 25% and 27.5%.

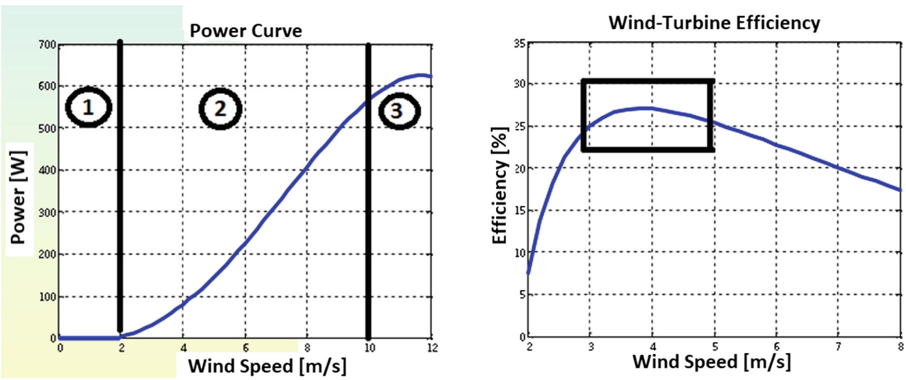

Fig. 2. Power curve and wind-turbine efficiency.

2.3 Problematic and Principle of Regulation

The voltage delivered by the turbine is three-phase, a diode bridge rectifies to provide a DC voltage at its output. This voltage will be used for battery charging. However, the wind never blows at a constant speed, so the mechanics of the wind turbine are subject to the constraints of the climate.

It is necessary to protect the battery from too high or low voltages at its terminals. Too high a voltage could cause irreversible battery destruction due to overcharging, and too low voltage could also cause irreversible destruction due to deep discharge. It will therefore be necessary to determine a high threshold and a low voltage threshold, their values are given by the manufacturer of the battery. Outside these thresholds for a long time, this can lead to the destruction of the battery.

This diagram below (Fig. 3) illustrates the configuration of the wind turbine with its regulation.

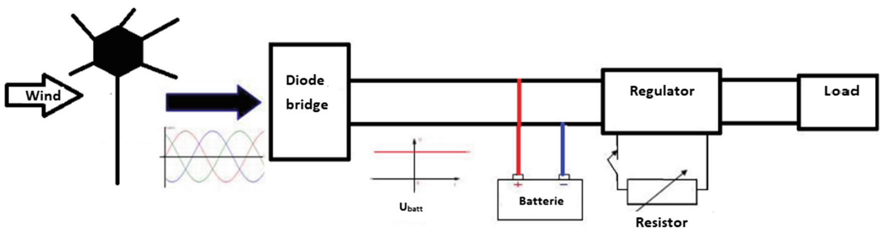

Fig. 3. Wind turbine/controller/battery/load.

The controller is placed parallel to the battery. It is accompanied by two external resistors: a resistance of use and a variable resistance of dissipation. The battery voltage will be measured permanently.

The role of the controller will be to control the connection of the control board to the two external resistors in order to protect the battery.

3 Presentation of the Regulation

This section first presents the basic block diagram of the charge controller. Then the electric diagram of the controller is presented. Finally, the flowchart that reflects the operation is presented.

3.1 Functional Blocks of the Controller

The diagram (Fig. 4) below illustrates the general operation of the controller.

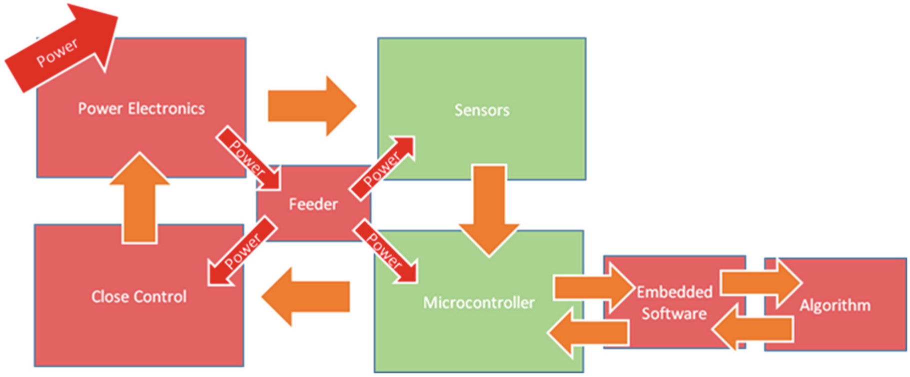

Fig. 4. Functional blocks of the controller.

The régalateur uses part of the power from the battery, it is located in the ***Power Electronics block***.

In the ***Feeder block***, a voltage controller converts the battery voltage into a lower voltage suitable for powering the controller.

The ***Sensors block*** has a voltage divider bridge. Its purpose is to adapt the voltage read at the terminals of the battery, in a voltage that can be read and interpreted by the microcontroller. This will permanently read the voltage across the battery. This is why this block is assimilated to a sensor.

The ***microcontrolle***r reads a voltage adapted at the input of its analog-digital converter. It contains a program (***Algorithm & Embedded Sof***tware) and will give output instructions.

The Close Control receives instructions from the microcontroller. It keeps the battery voltage between the two thresholds, it will decide whether or not it connects the battery to the external resistors.

3.2 Electrical Diagram of the Controller

The different blocks (Power Electronics, Feeder, Sensors, Microcontroller, Close Control) have been highlighted in the electrical diagram of the controller shown in Fig. 5.

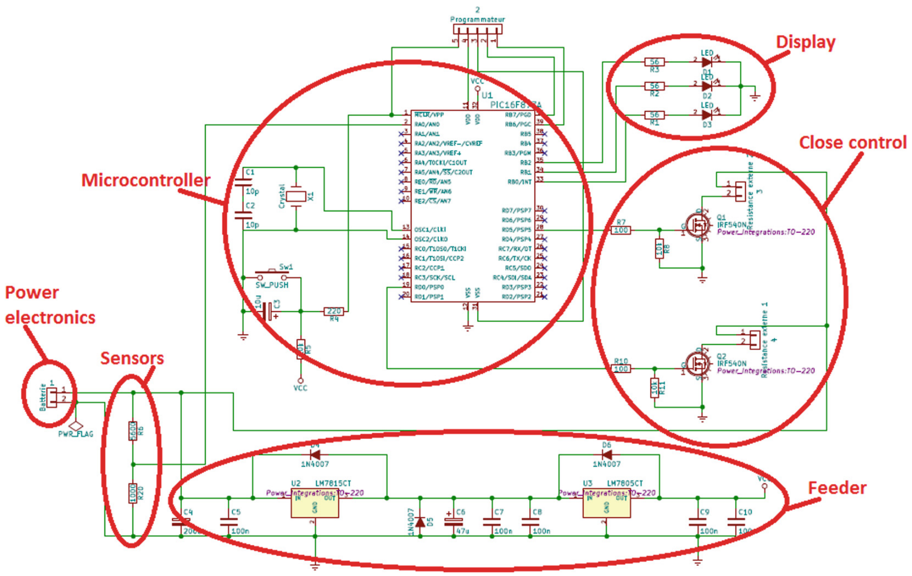

Fig. 5. Electrical diagram of the controller.

The microcontroller part contains a PIC 16F877A. It will therefore be necessary to study in detail the PIC datasheet in order to better adapt the functional blocks that surround it. In addition, this controller has a display of the status of the battery that has been called Display, via three LEDs of different colors.

3.3 Flow Chart of the Controller

The flowchart of the controller is shown in Fig. 6. It highlights the control of charge and discharge of the battery, and the visualization of the state of the battery. Note that the thresholds were determined for a 24 V battery.

The voltage (Ubatt) at the battery terminals is read continuously. Control of the charging/discharging of the battery and the display of its voltage will be a function of Ubatt.

The voltage thresholds defined for the 24 V battery are as follows:

- High threshold at 28 : Battery voltage should not rise above this threshold
- Low threshold at 24 V: Battery voltage should not drop below this threshold

Two external resistors are connected to the control board: load resistance and overflow resistance. These two resistors will be used depending on the voltage read at the terminals of the battery.

In addition, the control board allows to visualize the voltage at the battery terminals, through three LEDs. The full charge voltage is 26 V.

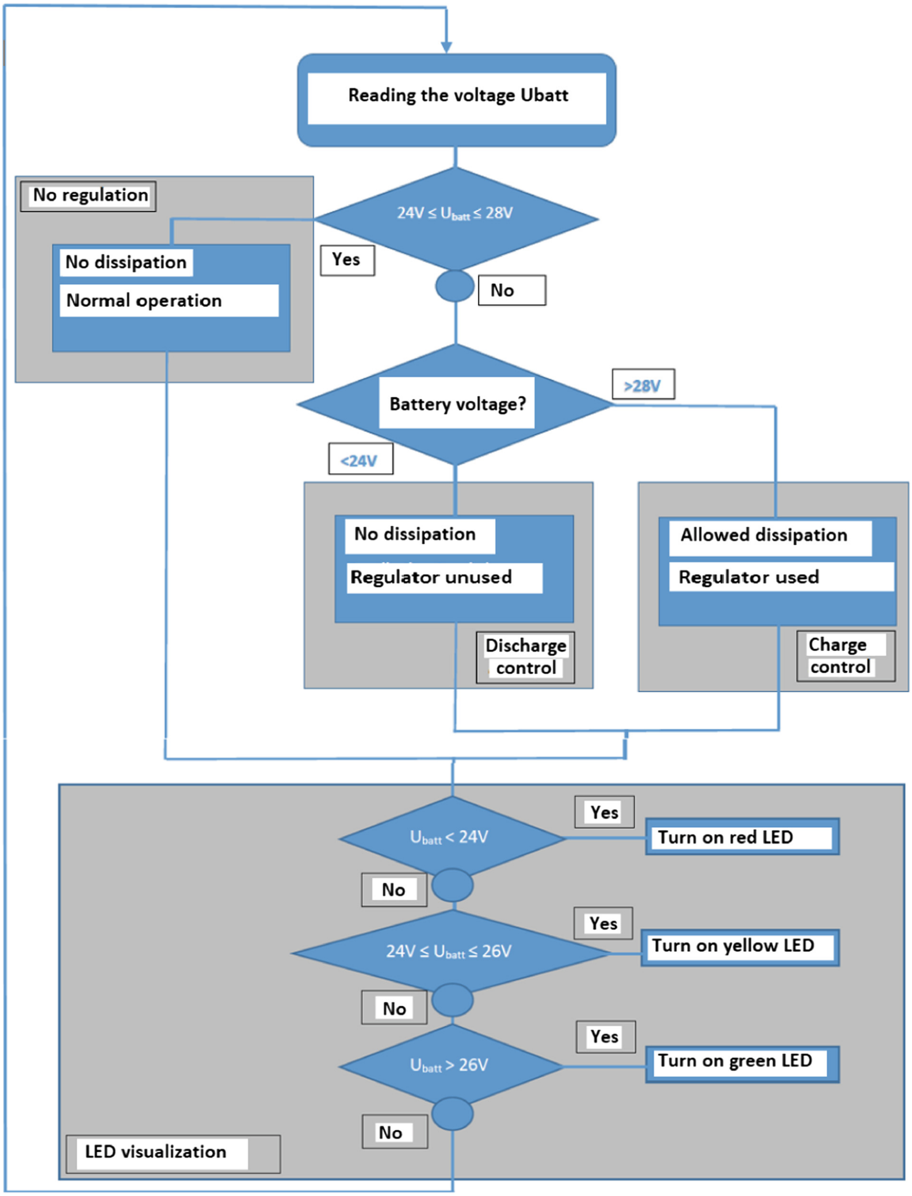

Fig. 6. Flow chart of the controller.

4 Presentation of Hardware Blocks

4.1 Power Supply Block

The input voltage of the controller is that read across the battery. The card requires a 5 V supply voltage, imposed by the microcontroller (PIC 16F877A). The purpose of the power supply is therefore to regulate the input voltage to a voltage of 5 V. The electrical diagram of the power supply unit of the control board is shown in Fig. 7.

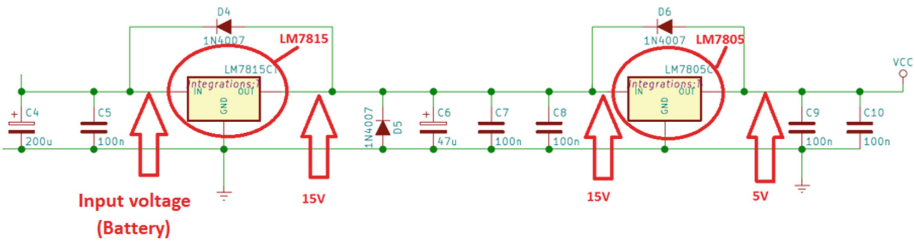

Fig. 7. Electrical diagram of the power supply.

The power supply unit consists of two series-connected voltage controllers, LM7815 and LM7805 respectively. These controllers have a maximum input voltage threshold and have fixed output voltages imposed by the manufacturer. These are linear type controllers, their disadvantage is that their efficiency is very low.

4.2 Analog to Digital Conversion

The voltage read at the terminals of the resistor R20 is connected to one of the analog inputs of the PIC. The PIC 16F877A has an 8-bit analog-to-digital converter, so $2^8 - 1 = 255$ values are possible. It can read only voltages between 0 V and 5 V, so it will read the voltage from the upstream divider bridge with a ratio of 6.6.

The following table (Table 1) shows the correspondence between the voltage at the terminals of the Ubatt battery, the voltage read at the analog input of the PIC and its digital image Vbat.

Table 1. Analog-digital conversion table.

Battery Volage U_{batt}	Voltage read after the divider bridge - at the analog input of the PIC	V_{batt}, Digital image of the battery voltage
33 V	$\frac{33V}{6.6} = 5.0V$	255
0 V	$\frac{0V}{6.6} = 0V$	0
24 V	$\frac{24V}{6.6} = 3.64V$	175
28 V	$\frac{28V}{6.6} = 4.24V$	204

Maximum value that can be read by the PIC

Minimum value that can be read by the PIC

Respectively the high threshold and the low threshold of the battery

5 Presentation and Test of the Controller

5.1 Presentation of Controller

The realization of wind turbine controller took place at the International Center for Training and Research in Solar Energy (ICTRSE) of Dakar University. As mentioned earlier, this controller consists of a power unit, a display unit of battery charge level and a control block around the PIC microcontroller.

Figure 8 shows the two sides of the controller board.

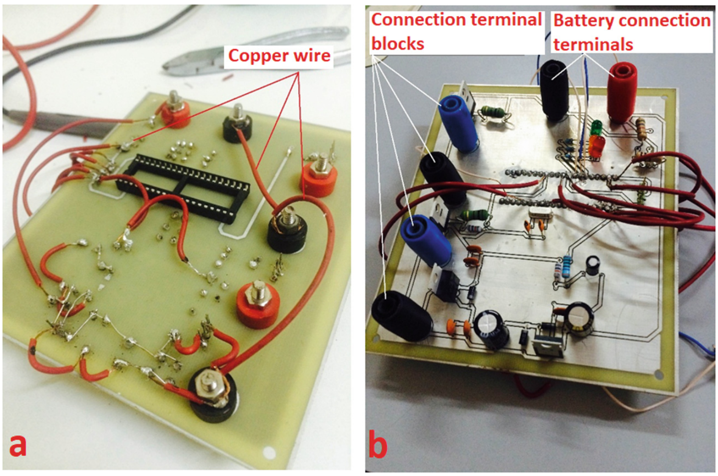

Fig. 8. Front (a) and rear (b) faces of the controller board.

5.2 Test Results

5.2.1 Visualization of the Battery Charge Level

The test validated this block. Indeed, the red LED lights for a voltage lower than 24 V, the green lights for a voltage greater than or equal to 26 V; the yellow LED lights up between 24 V and 26 V. We also verify that only one LED is active at a time. Figure 9 shows the results.

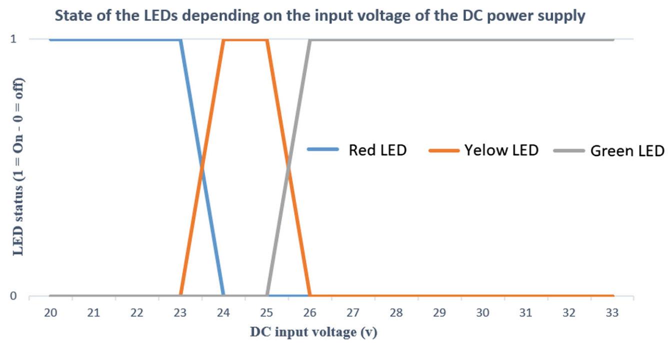

Fig. 9. State of the LEDs depending on the input voltage of the DC power supply.

5.2.2 Charge/Discharge Control

Now, the load and discharge control is tested. A DC voltage is applied at the input. Following the flowchart presented in Sect. 3.3, the voltage VGS of the transistor is checked; then the connection of the board to the external resistors, by raising the voltage at their terminals as shown in Fig. 10.

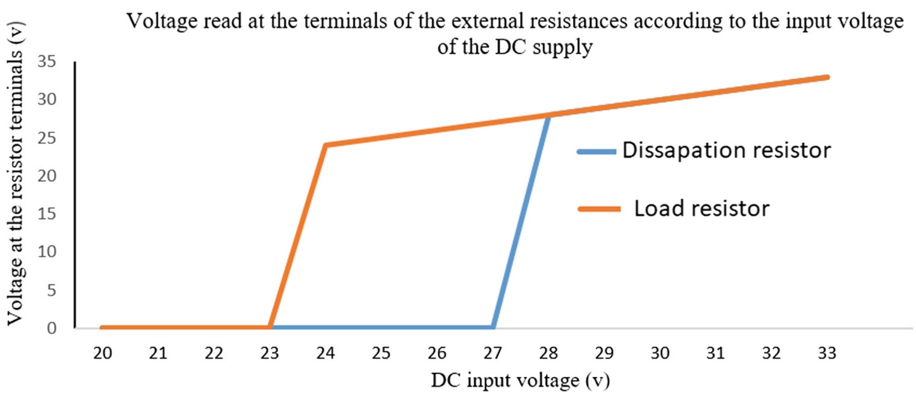

Fig. 10. Voltage read at the terminals of the external resistances according to the input voltage of the DC supply.

5.2.3 Power Budget

The characteristic curve of the power consumed by the resistors as a function of the input voltage of the DC supply is shown in Fig. 11. Remember that the nominal power of the wind turbine is 500 W. We observe that when a resistor is connected, we find the voltage of the battery at its terminals. First the utilization resistance is connected for a voltage across the battery between 24 V and 28 V, dissipating between 168 W and 196 W, i.e. between 34% and 40% of the rated power of the battery. Then the two resistors are connected simultaneously for a voltage across the battery greater than or equal to 28 V. Between them, they consume between 392 W and 490 W, or between 79% and 92% of the rated power of the wind turbine for input voltages between 28 V and 33 V.

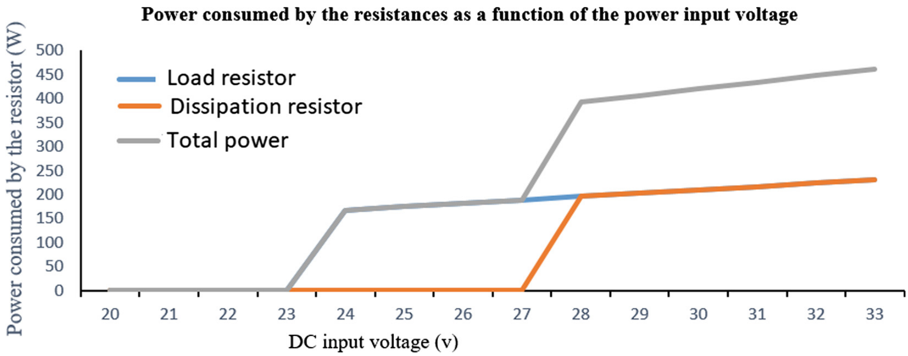

Fig. 11. Power consumed by the resistances as a function of the power input voltage.

6 Conclusion

The objective of this work was to develop a of a low-cost wind turbine controller for decentralized rural electrification through the small wind turbine. The architecture proposed and realized around the PIC16F877A microcontroller. This choice is justified by its robustness and its low cost. At this stage of the work, different blocks are tested and validated. A first prototype is developed. This will be improved and optimized with the integration of functionality according to the installation area of the wind turbines. This work comes within the framework of a project of realization of small low-cost wind turbines intended for the rural areas deprived of electricity in Senegal.

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