# System for Controlling a Wind Turbine

Corneliu Buzduga
*Stefan cel Mare University, 13 University, Suceava, Romania*

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Abstract: This paper presents the improving operating principle of a wind turbine actually achieving an optimum control of the rotation speed. This control consists in limiting the speed of rotation to a permissible maximum value based on the peripheral speed determined by tests of resistance of the materials from which the blades are made. Constructively, the whole mechanism is built from a set of interconnected functional blocks such as: the positioning system, the shaft-hub-shaft assembly, the transmission system, the blade step change system and, last but not least, the generator.

## 1 INTRODUCTION

Since the weather conditions are not constant, with slow or sudden variations in both direction and intensity of the air currents, the optimum operating point of the generator suffers permanent changes, the generator must continually adapt to environmental conditions (U.S. Energy Information Administration, 2013). Optimal position detection and adaptation go to a smart microprocessor-based system. This, according to predefined instructions, will have to interpret the data from various sensors and perform wind turbine operation corrections so that a maximum output is reported consistently at the given wind speed and safe operation of the whole assembly. The electricity produced by this wind turbine is stored in the batteries as a reserve or consumed directly (World Energy Council, 2010).

In operation, an important aspect is the height regime at which the turbine will be installed, known as the dynamics of the air currents differ at altitude, thus a height between 10 ÷ 15 meters of the tower is an economically suitable choice and aesthetically, framing the entire system in the landscape, but also places the turbine in an area of turbulent air flows due to both neighbouring constructions and tree vegetation. Another determinant factor that influences the efficiency of the turbine is its location, which often proves to be less favourable and, compared to the airflow maps of its direction and intensity, determines that the installation of a wind turbine be considered less profitable (Wagner, 2017).

Electricity is directly proportional to both the rotor speed of the generator and the mechanical power of the propeller shaft. The two parameters are dependent on each other in the sense that the mechanical power at the shaft is determined by the structural characteristics of the blades (dimensions and aerodynamics) and the maximum speed of rotation under safe conditions is determined by the diameter of the turbine. In order to eliminate this inconvenience, the solution addressed was the use of an oversized turbine, thus ensuring at the same wind speed a greater mechanical power on the turbine shaft. With this solution we succeeded in changing the operating point, the target being the production of electricity at wind speeds starting at 3,5 ÷ 4 m/s, but at the same time this solution radically changes the dynamics of operation at high speeds, which, although rare manifestation, the likelihood of occurrence during violent storms jeopardizes the integrity of the system. Under this consideration, in addition to the production of electricity, which is the main aspect to be pursued, the consideration should also be given to the protection systems of the entire device so that its operation can be safely carried out regardless of the weather conditions to which it is subjected (Jianbo and Qunyi Liu, 2017).

The protective systems must ensure continuous adaptation of the turbine to environmental conditions, and be able to react to all factors that can disrupt proper operation. Although it is a more sophisticated implementation method, the electronic control solution brings several advantages such as continuous adaptation according to a calculation algorithm,



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remote control and monitoring of operating parameters (Suaad, 2013)

# 2 SYSTEM SETUP

## 2.1 The System Components

a. THE ROTOR
The rotor or propeller consists of three movable blades around the longitudinal axes assembled on a supporting hub and represents the active element that transforms the kinetic energy of the wind into mechanical energy available on its own shaft, which rotates when the air currents is present and the turbine are aligned in their direction. The mobility of blades around their own axis is useful and necessary at the same time to change the angle of attack, known as pitch, in this way controlling the speed of rotation until it keeps the rotor at constant speed regardless of the wind speed.

A particular case is the passing of the blades in a flag step, in this way the propeller can be dynamically broken as a further protection during storms.

Figure 1: The hub and the mechanical interconnection system of the blades.

b. THE ORIENTATION SYSTEM
The orientation system is designed to position the nacelle, making a 360 degree rotation around the axis of the tower (vertically to the ground plane). The positioning is carried out by a universal DC motor, with a built-in speed reducer, controlled by the microcontroller, which has as reference the position of a wind direction sensor, called weathervane. Depending on the weather conditions, the nacelle is oriented with the rotor in the wind direction, over a minimum operating threshold, always aiming at correcting the position.

Figure 2: The orientation system, drive motor and chassis.

As the construction number has been reduced as much as possible, the guidance system also has a secondary supporting role, being the link between the pillar and the support frame of all mechanical and electrical components.

c. THE TRANSMISSION SYSTEM
The transmission system is designed to drive the rotation movement taken from the main shaft and deliver it to the generator. By comparison, the behaviour of the transmission is similar to a gearbox of a car, but operating in the sense of increasing the rotation, with a continuous transmission ratio of 1: 1.4 to 1: 4.7, respectively the amplification follows a straight slope between the intervals minimum and maximum, there being no thresholds that can cause vibrations in the pillar when switching gears.

The transmission ratio is changed electrically by means of a universal DC motor controlled by the microcontroller, which monitors the incoming and outgoing speeds during operation of the system. In order not to force the rotor and eventually premature shutdown of the turbine, changing the ratio of the transmission to the amplification direction will be performed only after the propeller has reached a minimum threshold of 400 rpm, at which point the input shaft speed will remain at an approximate threshold constant. If the wind speed decreases in intensity and the turbine output decreases, the transmission gradually returns to the minimum threshold, with the condition that the propeller does not fall below 400 rpm and the transmission has a positive gain ratio.

d. THE POWER GENERATOR
The power generator that supplies the turbine is the result of changing a synchronous motor in the sense

that parameters such as winding conductor material and section have been changed, the number of coils and the number of paths. With the modifications we have made, we have been looking for a large voltage (about 120 V DC) and a low load current to be cut so that the winding and transport losses are as low as possible. By construction, the generator is a three-phase Y-connection with the permanent magnet rotor of the ferrous material outdoors, also acting as cooling fan, and on the inside the stator with 36 notches distributed equally to the three electric phases (Archer and Jacobson, 2012).

Figure 3: The power generator – left: assembly, centre: rotor and right: stator.

e. THE ELECTRONIC CONTROL AND COMMAND MODULE

The operating principle is based on the block diagram of Figure 4.

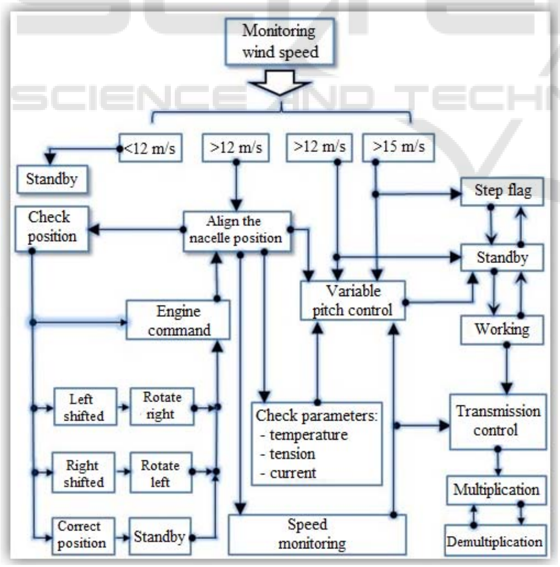


Figure 4: The block diagram; operating principle.

Running the entire system at rest has the following steps:

Step 1: The air currents are not present or their intensity is too low to justify starting the turbine. As a result of operating tests, the lower limit threshold at which it was set as starting point is 2.5 m/s, the wind speed sufficient to start and accelerate the rotor. Below this minimum threshold, although the rotor is in motion, the energy collected at the generator terminals is insignificant, resulting only in idle operation (John and Julia, 2015).

Step 2: Once the minimum wind speed is exceeded, the turbine switches to two-stage operation:

- detecting the wind direction and the aligning wedge to appropriate position. A particular aspect is that the platform is given a degree of freedom of ± 5 ° geometric to the actual direction, thus avoiding the scenario in which the position correction is continually attempted during turbulent air streams. This is more likely to be the case that, as soon as the nacelle has moved in one direction for correct alignment, at the smallest deviation of the steering sensor, the positioning motor is restarted for a new adjustment, after which the cycle resume.
- checking and adjusting if necessary the blade step. As a result of the operating tests, in addition to the two positions, respectively the working position and the flag step corresponding to the heads of the race, it was also required to declare an intermediate step, which I called a standby position. The insertion of this intermediate position produces a positive contribution at the moment of the rotor start, and after the main shaft exceeds 60 rpm, corresponding to the propeller, the blades are switched to the working position where acceleration to the maximum required by the conditions forecasts.

Step 3: After the start, the turbine is only allowed to operate with wind direction correction, monitoring the input and output speed of the transmission block until the propeller reaches a set speed of 400 rpm. From this point the transmission ratio starts to change in the direction of the increase or decrease as the case may be, the modification being made gradually and without the propeller decreasing its speed below the set limit. In the case of wind gusts that can cause sudden accelerating, the speed will be automatically controlled, limited to 450 rpm, by a centrifugal mechanical system. The wind turbine will be left to operate in this way as long as the wind speed does not exceed an alert threshold of 12 m/s (Jacobson and Archer, 2012).

Step 4: Is a procedure to protect the turbine from any possible storms. Once the warning threshold of 12 m/s is exceeded for more than 60 seconds, the blade step will be changed to reduce aerodynamic performance, being switched to the standby position where the turbine will continue to operate but the propeller speed will be reduced. In the same way, if a 15 m/s alert threshold is exceeded, the propeller will pass the flap, the tube will enter dynamic braking where this time the air currents will block the rotation of the propeller until it stops completely (Bie and Zhang, 2012).

The engine control system is built around a microcontroller that, according to initial instructions, has the task of modifying or correcting the current status of the entire system. We can say about the microcontroller that its functions are divided into two main categories, namely the command function that uses the output signals, the final result being the motors' operation as the case may be, and the monitoring function which, by means of some sensors and transducers, interprets the operating parameters.

The monitoring function pursues:

- direction and speed of the wind;
- aligning the platform in the direction of the air currents;
- propeller and generator shaft speed;
- operating parameters of the generator: voltage, current, temperature;
- maintaining self-regulation systems at work intervals (race limits).

## 2.2 The Sensors Used in System Design

a. THE WIND SENSOR
For wind speed monitoring, a digital unit incorporating the anemometer and weathervane was used on the market under the name of TX20 SENZOR model developed by La Crosse Technology Ltd.

Figure 5: The wind sensor.

The sensor will transmit the data every 2 seconds as long as pin 3, DTR, is connected to GND. The data chart contains 41 bits divided into 6 data sections. The transmission is for 49.2 ms, the duration of one bit being 1.2 ms.

b. THE POSITION SENSOR
The role of this sensor is to align the propeller in the wind direction. It is also a wind sensor, i.e. a weathervane, but in which the output signal is analogous, used in a particular way in that the mounting base is movable to the ground. The Weathervane is mounted on the platform body, which in turn is movable around the axis of the tower. In the correct alignment position, the mobile element must be aligned halfway through the time the sensor can detect wind direction deviations. A deviation in either direction from this position will detect what triggers the rotation of the platform as well as the base of the sensor, the mobile element being maintained in the wind position. In this way, the weathervane returns to the correct position by turning the nacelle off. The phenomenon is repeated whenever position corrections are needed. The type of sensor used is a weathervane, known as wind wane model NRG # 200P.

Figure 6: The weathervane NRG model # 200P.

The mobile element of the weathervane operates an internal potentiometer in a complete rotation of 360 degrees and can be deflected by winds at speeds of 1 m/s.

The potentiometer has an internal resistance of 10 KΩ and can be directly supplied to a voltage in the range of 1 ÷ 15V DC, the output signal being a voltage proportional to the wind direction. From constructive limitations and because a degree of freedom of 360 degrees is desired, for an interval between 8 ÷ 10 geometric degrees the sensor output is null, in this area the potentiometer cursor does not have a conductive film continuity. This is an impediment if the output signal is to be interpreted directly by a microprocessor; in the possibility that the potentiometer cursor would be in the area called dead band, the output signal is missing, which may cause operating errors. Although the probability of error is small, the dead band has a range of approximately 8 ÷ 10 geometric degrees, which means 2.75% of the measurement range, they must be eliminated or reduced as much as possible (Al-Muhaini and Heydt, 2013).

c. THE SPEED SENSORS

Changing the transmission ratio and the variable pitch of the propeller is determined by the rotation speed of the propeller shaft and the generator. In this respect, the speeds of the two shafts must be monitored throughout the turbine operating mode. There are several types of sensors specifically developed to determine the speed of rotation of the trees, among them, those with the longest use being non-contact sensors. According to the output signal type, the sensors can be classified into capacitive, inductive or Hall Effect sensors. For slow speed shafts, rotation speed detection sometimes uses reed relays, but the blades of the contact are subject to premature aging due to the large number of triggers to which it is subjected. The types of sensors used are produced by Honeywell under the SS411P encoding.

To trigger the sensor we used permanent magnets, four of which are fixed to a disc mounted on the shaft for which the speed is determined. Magnets are fixed to the disk table at equal distances with alternating poles. During rotation of the shaft and the magnets, they will enter the sensor trigger area, the output signal becoming a rectangular signal that will have two periods during a complete rotation. The frequency of the output signal is directly proportional to the rotation speed of the shaft, so its mathematical computation can be determined by the formula:

$$n = \frac{f}{2} \cdot 60 \qquad (1)$$

where f is the signal frequency and n is the speed

Figure 7: The propeller shaft switch disk.

Similarly, the rotation movement of the drive motor of the transmission mechanism is detected, indicating that this time the sensor is of the unipolar type and on the disk mounted on the shaft are diametrically opposed on the circumference only two magnets with the same pole magnetically pointing towards the sensor. Thus, every half-turn is sensed by a low level of the output signal.

The same model of the unipolar Hall sensor, in the same configuration, is used to detect positions where the blades are in the position we named above the standby position and the alignment of the platform to a reference point. For the interpretation of output signals, it should be noted that they are at a low level when they are at points of interest and at a high level in the rest (Conti and Rizzo, 2015).

d. THE TEMPERATURE SENSOR

Over a long period of operation, the internal temperature of the generator may reach critical values that may result in its destruction. To avoid possible damage or troubleshooting due to a high temperature regime, it is preferable to switch the temperature generator above the threshold. Thus, the stator temperature should be monitored throughout the operation.


Figure 8: The temperature sensor. Model DS18B20.

Variants of temperature-sensitive elements that are compatible with the microcontroller and without the need for complex processing of signal processing are the thermistor, analogue sensor LM35 or DS18B20 digital sensor, the latter being the one to be used. The main advantage is that for communication with the microprocessor, data transmission from the device is done on a single wire (and mass, GND).

e. THE CURRENT SENSOR

Electrically operated mechanisms have an average degree of complexity, and for undesirable reasons, malfunctions may occur, resulting in an increase in engine current absorbed above the normal operating range. These situations would be likely to cause blockage, defeat limiters or a high degree of wear on the engine. Maintaining under voltage at currents well above normal operating limits would cause excessive engine heating leading to irreparable damage, and other elements in the supply circuit may be affected.

Elimination of these possible situations is accomplished by monitoring the current in the motor circuits, in this sense, by introducing a current sensor into the circuit. For easy deployment, we used a sensor model built on an integrated circuit developed by Allegro MicroSystems, under ACS712 encoding. It is an SMD small integrated circuit in the SOIC8 capsule, the current detection being based on the linear Hall Effect. The sensor is invasive, requiring interruption of a supply line, and can detect current in both AC and DC circuits.

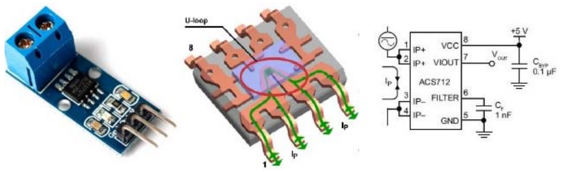


Figure 9: The current sensor. Model ACS712.

f. THE VOLTAGE SENSOR

For complete monitoring of the entire system, it is necessary to interpret the electrical parameters of the generator. If the implementation of the output current detection function is somewhat considered to be easy, with different variants of inversion or non-invasive AC sensors, measuring output voltage of the generator with a microcontroller imposes certain restrictions precisely because of the operation. The output voltage is a variable signal in both amplitude and fecundity, the maximum values being considered dangerous to be detected directly. Thus, during operation, when weather conditions allow, at the terminals of the three-phase generator, for current configuration of connections, weights can be recorded in the range 0 ÷ 90 V AC with frequencies proportional to the voltage in the range 0 ÷ 400 Hz. The maximum possible voltage is high enough to reach values considered dangerous, which is why indirect measurement is recommended to determine its value. Due to the variable frequency, it is not possible to use a low voltage transformer to obtain a low level signal so that it can be processed by the microcontroller, the frequency variation limits cause them to malfunction, being well above tolerances.

The voltage collected from the generator terminals is rectified and filtered, then applied to a resistive divider dimensioned so that for the maximum possible applied value, the divider's mean point does not exceed the 12 V DC threshold. However, there is a possibility that, due to the lack of a consumer, the tension will increase much, even beyond the limit. To avoid damaging the circuit caused by an accidental voltage, even if there is an increase above the 12V level, it will be stabilized by a Zenner diode.

Taking into account the fact that, in order to be interpreted by the microcontroller, the input signal can be a DC voltage, for detecting the voltage level of the generator we proposed and implemented the following scheme:

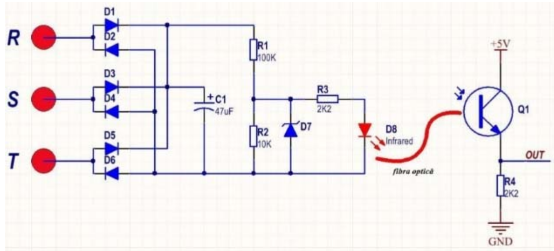


Figure 10: The voltage sensor. Electronical scheme.

The method has the advantage of galvanic separation of power circuits from signal circuits and prevents the destruction of the microcontroller if the turbine enters the operating mode in the absence of the supply voltage of the microcontroller by introducing external voltages on the signal port.

g. THE MICROCONTROLLER

The Arduino Mega 2560 development board has 54 digital input / output pins (of which 14 can be used as PWM outputs), 4 UART serial ports, 16 analog inputs, a USB connection, a 16 MHz quartz crystal oscillator, a power jack and a reset button.

The 54 digital pins can be used as outputs or inputs with the digitalRead (), digitalWrite () and pinMode () functions. These digital pins use the digital signal in which the 0 logic is represented by the absence of voltage and 1 logic having the voltage level of 5V. Analog pins provide a resolution of 10 bits meaning 1024 different values. These pins measure voltages between 0V and 5V.

Arduino Mega 2560 has facilities for communication with a computer, other microcontrollers or other Arduino cards. The Arduino software includes a serial monitoring that allows simple textual data to be received or sent to the development board.

The microcontroller is programmed to take data from the sensors to display them using the LCD module. As an example, see figure 11.

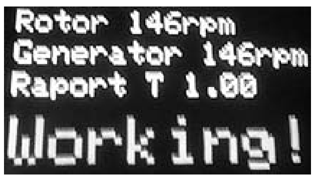


Figure 11: Display data taken from sensors.

## 3 CONCLUSIONS

The system was tested under real conditions with good results for initial tests under laboratory conditions. At the same time, a second electronic module was developed to complement the system, its functions being communication, the data taken being processed and displayed on a display. The results are promising, so we can consider the test period ended after the entire system is tested under realistic conditions in a time frame that includes both a cold season and a warm season.

The wind turbine will be used to provide the electricity needed for a home or small production hall.

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