Mechatronics

PLC Applications

Wind Turbine

Job Sheets - Courseware Sample

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
~	Alternating current
≂	Both direct and alternating current
3~	Three-phase alternating current

Safety and Common Symbols

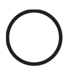
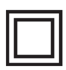
Symbol	Description
	Earth (ground) terminal
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

Table of Contents

Preface

The *Programmable Logic Controller, Basic Programming* student manual allowed the reader to become familiar with PLCs and ladder programming. This was accomplished with the help of the Programmable Logic Controller Training System (Model 3240).

The aim of the present series of PLC applications is to integrate the basic principles previously acquired by designing small-scale systems that can be found in the real world. Through practical examples, students will gain a strong knowledge of the PLC field of study.

Each manual of the PLC applications series concentrates on a specific example of PLC application that evolves along a path of increasing complexity. With each manual, new components are added to the PLC module to create different opportunities to learn.

We hope that your learning experience with the PLC Training System will be the first step of a successful career.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Programmable Logic Controllers (PLC's) represent state-of-the-art microprocessor-based electronics that make up technologically advanced control systems with applications in virtually every segment of industry where automation is required.

The present manual includes four Job Sheets that introduce students to PLC control of the Wind Turbine Training System, Model 8075-5. Throughout the manual, students will learn how to program, connect, operate, and troubleshoot a simple nacelle control unit PLC.

Prerequisite

Before performing the Job Sheets in this manual, it is recommended to review the *Programmable Logic Controller, Basic Programming* student manual, which explains how to use the programming software and the most common PLC instructions. If any difficulty is encountered while performing the exercises, the programming software's user guide and help menu can assist students in problem solving.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Control Systems can be harmful when not used properly. Before performing any of the exercises in this manual, make sure that you respect the following general guidelines:

- Put your safety glasses on.
- Avoid wearing any loose clothing (e.g., tie, long sleeves, jewelry).
- Have your hair tied out of the way if it is long.
- Clean your work area if necessary.

Remember that you should never perform an exercise if you have any reason to think that a manipulation could be dangerous to you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

Appendices

Appendix A: *List of Equipment Required*, gives the list of equipment needed to perform the exercises.

Appendix B: *Ladder Program Design*, presents two different methods that can be employed to program a PLC ladder program.

Appendix C: *Boolean Algebra and Digital Logic*, shows the logical relationships that can be employed with normally-open (NO) and normally-closed (NC) contacts.

Appendix D: *Troubleshooting Procedures*, is a set of guidelines permitting students to locate and correct PLC system failures.

Appendix E: *Glossary of Terms*, defines technical words and expressions contained in this manual.

Appendix F: *Ladder Diagram Graphic Symbols*, depicts the main symbols used in ladder diagrams.

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

The instructor should be familiar with PLCs to recognize erroneous results. It is advised that a complete run-through of each job sheet be included in the instructor's preparation for class. Each Job Sheet has several performance objectives. The instructor should ensure that each student understands them.

Sample
Extracted from
the Job Sheets Student
and the Job Sheets Instructor

Familiarization with the Wind Turbine

The energy needs of the world population are continuously increasing along with the development of new technologies and the industrialization of emergent countries. Electricity is one such indispensable resource needed in many aspects of modern life. It is usually generated in power plants of the thermal type which uses one sort or another of fuel (coal, petroleum, fissionable elements…) to cause a heat- generating reaction driving turbines to produce electricity. Each method has its drawbacks such as environmental pollution, management of dangerous waste and limited supply of fuel. Power plants using renewable resources are becoming much more prevalent as the focus is shifting towards environmentally-sound methods of electricity production. Energy produced by such plants comes from a natural resource – such as water, sunlight, wind, tide – acting as a substitute to conventional fuel in the power-generation process.

A wind turbine is a device designed to extract the energy stored in the wind in order to convert it to electricity. The wind is naturally blowing at various speeds and from different directions as time passes. Once a location with a good wind potential has been found, a wind turbine or an array of them can be installed to harness that energy. The wind will propel the aerodynamically-designed blades of the rotor up to some angular speed thus driving a power generator inside the nacelle of the wind turbine to produce electricity.

Figure 1. A wind turbine.

The nacelle is the nerve center of the wind turbine. It typically includes all the mechanical devices (shafts, gearbox…) necessary to transmit mechanical power from the hub of the rotor to the generator. It also contains a braking system to slow or stop the rotor, a system to control the orientation of the nacelle on its yaw axis, and a control unit automating the operating procedures according to the wind conditions or the maintenance needs. Other essential parts of the nacelle are the meteorological instruments required to monitor the speed of the wind (anemometer) and its direction (wind vane).

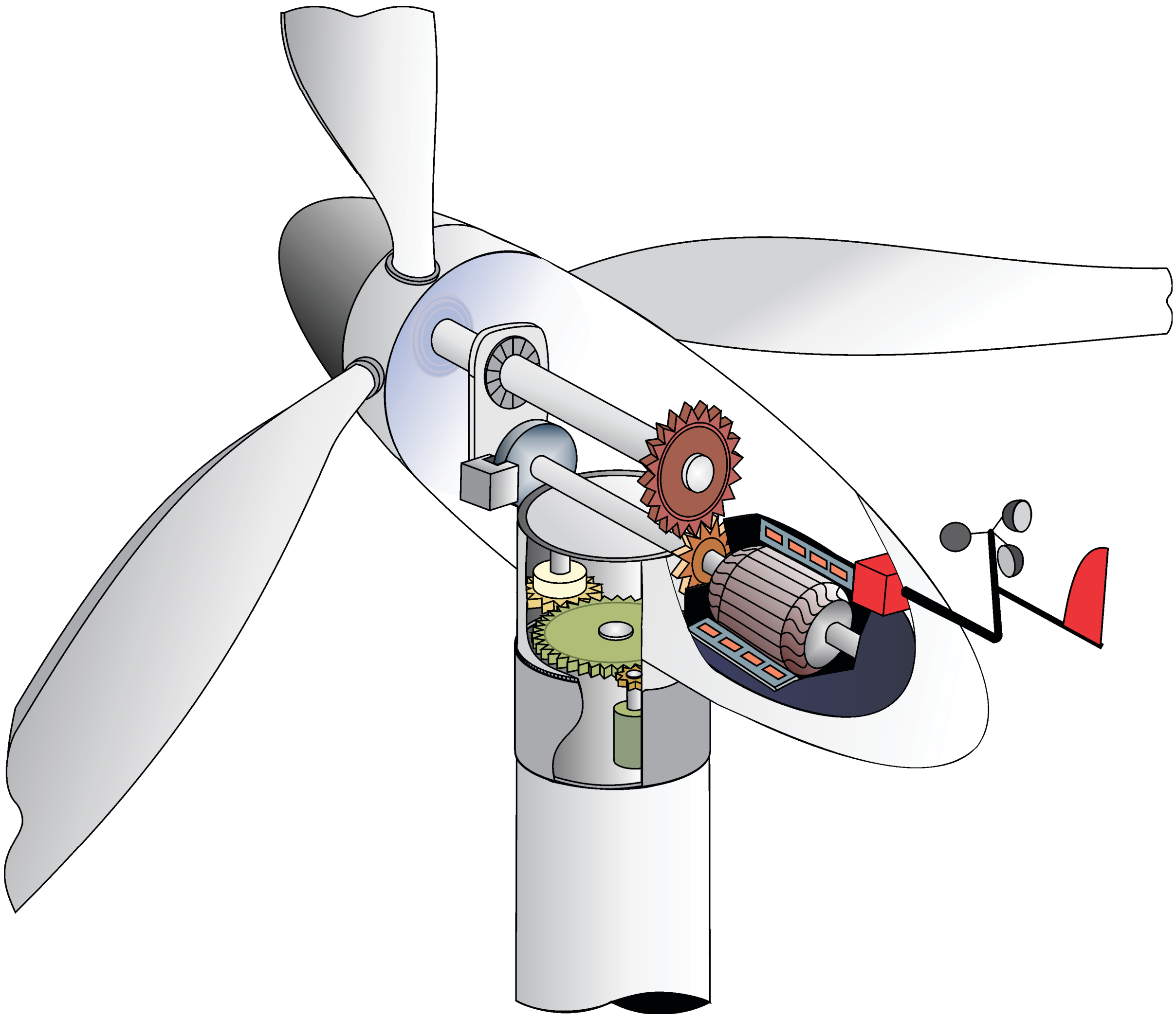


Figure 2. Schematic of a nacelle.

Wind Turbine Training System

The Wind Turbine Training System is made of two modules:

- Wind Generator, Model 3213
- Nacelle Simulator, Model 3297

Figure 3 shows the Wind Generator. It is a device used to produce a constant wind whose strength, as measured by the anemometer, can be varied simply by moving the generator towards or away from the measuring instruments of the nacelle.

Figure 3. Wind Generator, Model 3213.

1. Wind Outlet
2. ON/OFF Switch
3. 24 V DC Power Input

The Nacelle Simulator is shown in Figure 4. It is designed to reproduce the key characteristics of a wind turbine nacelle and to demonstrate the possibilities of control and automation programming.

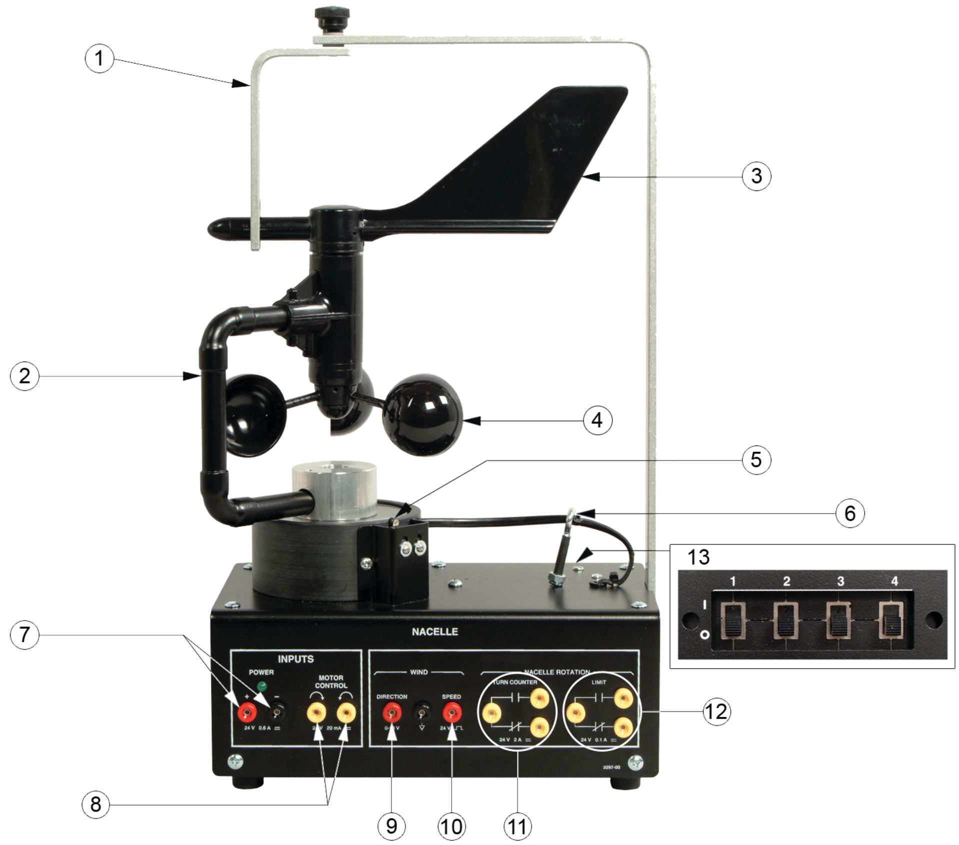


Figure 4. Nacelle Simulator, Model 3297.

1	Wind Direction Selection	9	Wind Direction Analog Output (0 – 10 V DC)
2	Nacelle		
3	Wind Vane	10	Wind Speed Output (Pulse)
4	Anemometer	11	Turn Counter Output Contacts (NO / NC)
5	Turn Counter		
6	Turn-Limit Detector	12	Turn Limit Output Contacts (NO / NC)
7	24 V DC Power Input		
8	Motor Controls – Clockwise and Counter-Clockwise Rotation.	13	Fault Panel (On the back panel)

Automated control of a wind turbine

The control unit inside a nacelle is effected in the simulation by a PLC module monitoring the outputs of the instruments to control and optimize the operation of the wind turbine.

The available outputs of the nacelle module are:

- The speed and direction of the wind.

- A turn counter coupled to a limit detector.

The PLC has control over the yaw motor of the nacelle to track the wind or move away from it as the situation dictates. The different programs necessary to implement the control routines proposed in the following job sheets will have to be programmed on the PLC with the help of a computer running a ladder programming software.

Operation of the Wind speed output

The anemometer is the device measuring the speed of the wind as it blows on the wind turbine. The Wind Speed output is a frequency output, a pulse being generated every time the anemometer completes a revolution.

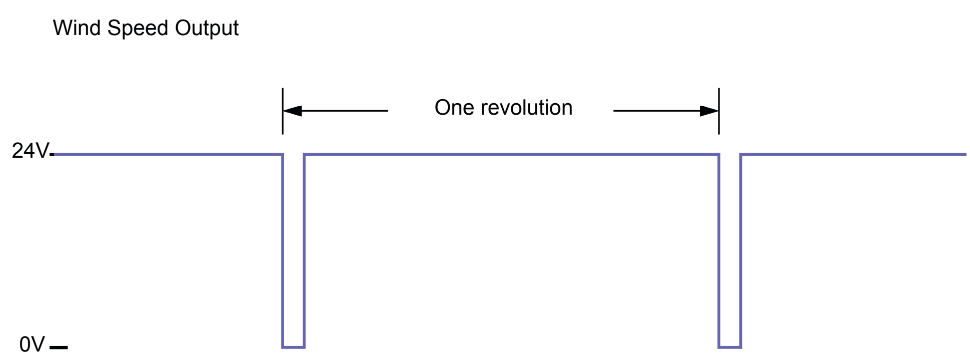


Figure 5. Time Diagram of the Wind Speed output.

In the following job sheets it will be required to evaluate the wind speed. This is of prime importance given that a typical wind turbine starts operating at a wind speed above 4 m/s (about 15 km/h – 9 mph) and has to cut-off to avoid damaging its components when the speed gets higher than 17 m/s (about 60 km/h – 37 mph). Using a timer allows for the calculation of the wind speed when a dividing component is added to the ladder logic. A counter can be added to the design if the wind speed is to be averaged over the course of a few revolutions.

Divide instruction

The Divide (DIV) instruction is a standard mathematical operation used to divide a number (Source A) by another (Source B). The result is stored in a data file (Destination), typically in the Float data file (F8). As an example, say we know the distance travelled by the anemometer to be some value X and the time it took to do so to be stored in the accumulator of a timer. The average speed can be calculated and saved in the F8 data file by using a rung similar to the one displayed in Figure 6.

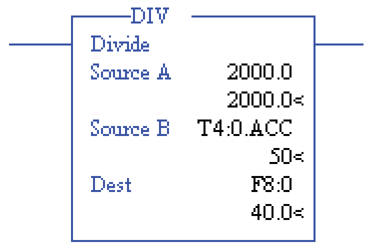


Figure 6. A typical use of the DIV instruction.

Precise scaling of the anemometer is not required for the following job sheets. A value for X (see previous paragraph) must be determined such that the calculated wind speed in the strongest wind condition attainable – i.e. when the wind generator is closest to the nacelle – is about 65 km/h (40 mph).

Familiarization with the Wind Turbine

OBJECTIVE

- Become familiar with some components of the Nacelle module.
- Create and implement a ladder program using a timer to measure the wind speed.

PROCEDURE

1. The first step in using the wind turbine application is to establish the requirements of the control routine. The program to be written for this Job Sheet must allow you to perform the following tasks:

   - A toggle switch is used to manually command a rotation of the nacelle in the clockwise direction. Another one is used to perform a rotation in the counter-clockwise direction. The nacelle stands still if both switches are simultaneously activated.
   - The wind speed is calculated using a timer and a divider. A pilot light is energized whenever the wind becomes too weak to drive the wind turbine (15 km/h – 9 mph) and another one lights up if it becomes too strong (60 km/h – 37 mph).

   The ladder program uses only the following RSLogix instructions:

   XIC – XIO – OTE – TON – DIV – GEQ – LEQ – NEQ

2. Use these I/O connections:

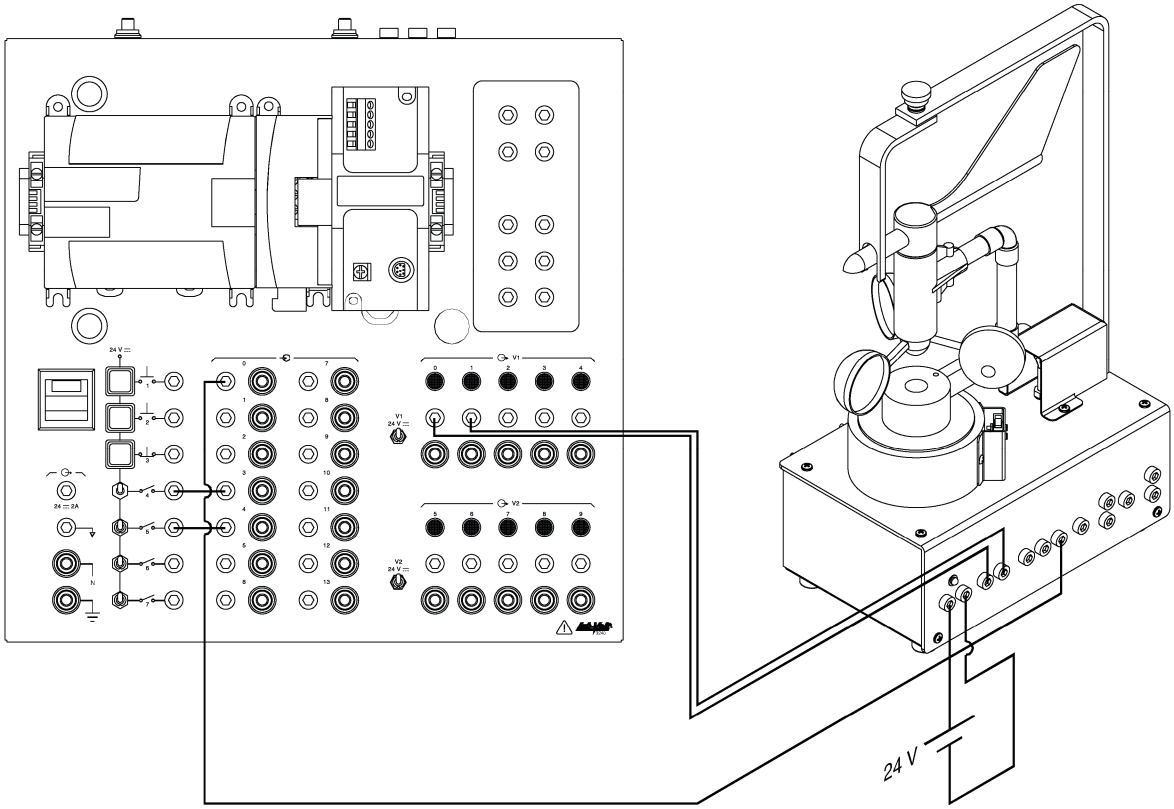


Figure 7. Interface connections for the PLC implementation.

Table 1. PLC I/O connections of Job Sheet 1.

PLC address	PLC Terminals	Connected to / Used as
I:0/0	Input 0	Wind Speed Output of the Nacelle
I:0/3	Input 3	Toggle Switch 4 / Used for Manual Clockwise Control
I:0/4	Input 4	Toggle Switch 5 / Used for Manual Counter Clockwise Input
O:0/0	Output 0	Motor Control of the Nacelle – Clockwise Input
O:0/1	Output 1	Motor Control of the Nacelle Counter Clock-wise Input
O:0/4	Output 4	_ / Pilot Light – Indicates Dangerous Wind Speeds
O:0/5	Output5	_ / Pilot Light – Indicates a Weak Wind

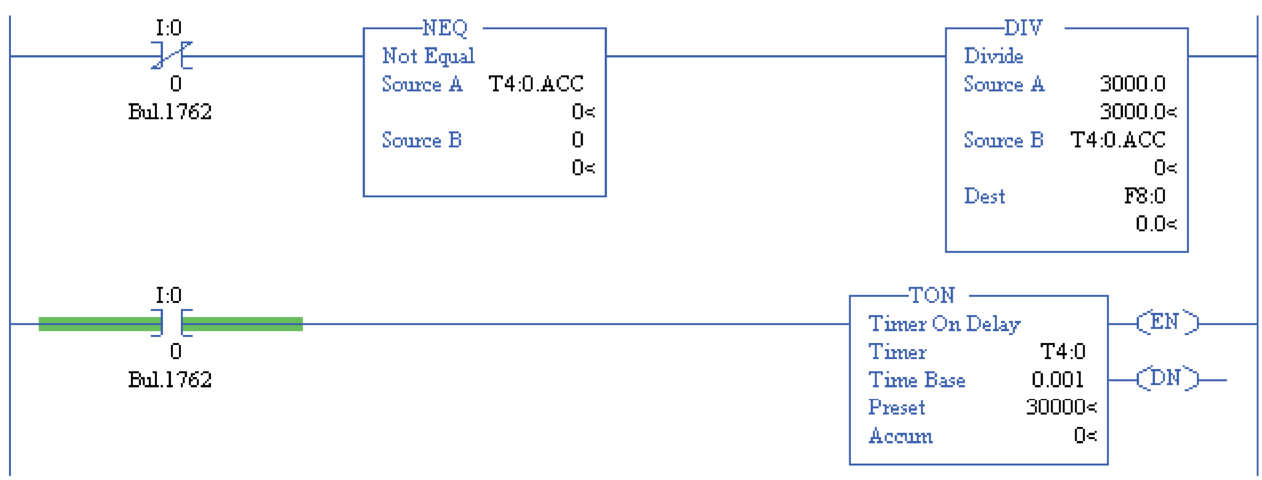
3. The manual controls of the motor must be designed in such a way as to avoid sending a contradictory signal to the motor in the nacelle, i.e. a command to turn both in the clockwise and in the counter-clockwise directions at the same time.

   What are the boolean equations preventing such a contradictory command? These equations relate outputs O:0/0 and O:0/1 to inputs I:0/3 and I:0/4. Refer to Appendix B and C if necessary.

$$O:0/0 = I:0/3 : \overline{I:0/4}$$
$$O:0/1 = \overline{I:0/3} : I:0/4$$

   A well-designed system will override illogical commands to always produce coherent results. Always strive for such designs!

4. Think of an efficient ladder design to calculate the speed of the wind. You should be able to write a program with as few as two rungs using only XIC, XIO, NEQ, DIV, and TON instructions. The NEQ (Not Equal) instruction is necessary to avoid division by zero. Such an undefined operation results in a computational error and must be avoided. The speed value should be stored in a file as a Float by choosing destination F8:0. Sketch this ladder program in the space provided.



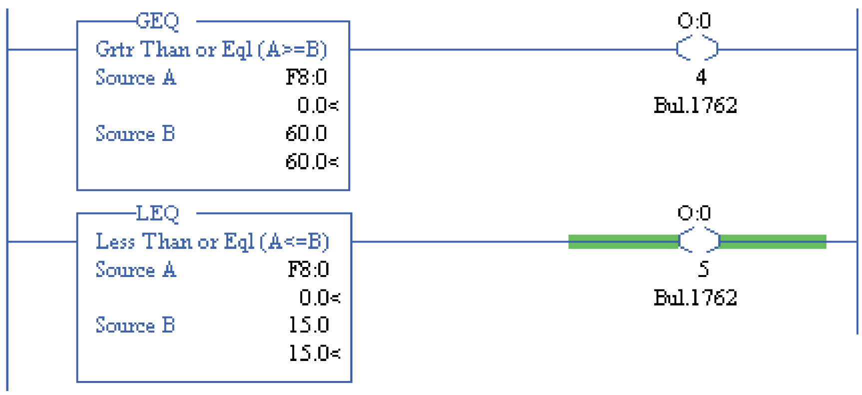
Measurement of the Wind Speed.

5. Two pilot lights are used to indicate if specific wind conditions are met or not. Using comparator logic, translate those conditions into a short ladder program which you can draw in the space provided.

Reminder:

O:0/4 is lit if the wind speed is greater or equal to 60 km/h (37 mph). O:0/5 is lit if the wind speed is lower or equal to 15 km/h (9 mph).

Can you think of another indicator which might be useful in the context of a wind turbine operation? How would you proceed to implement it?

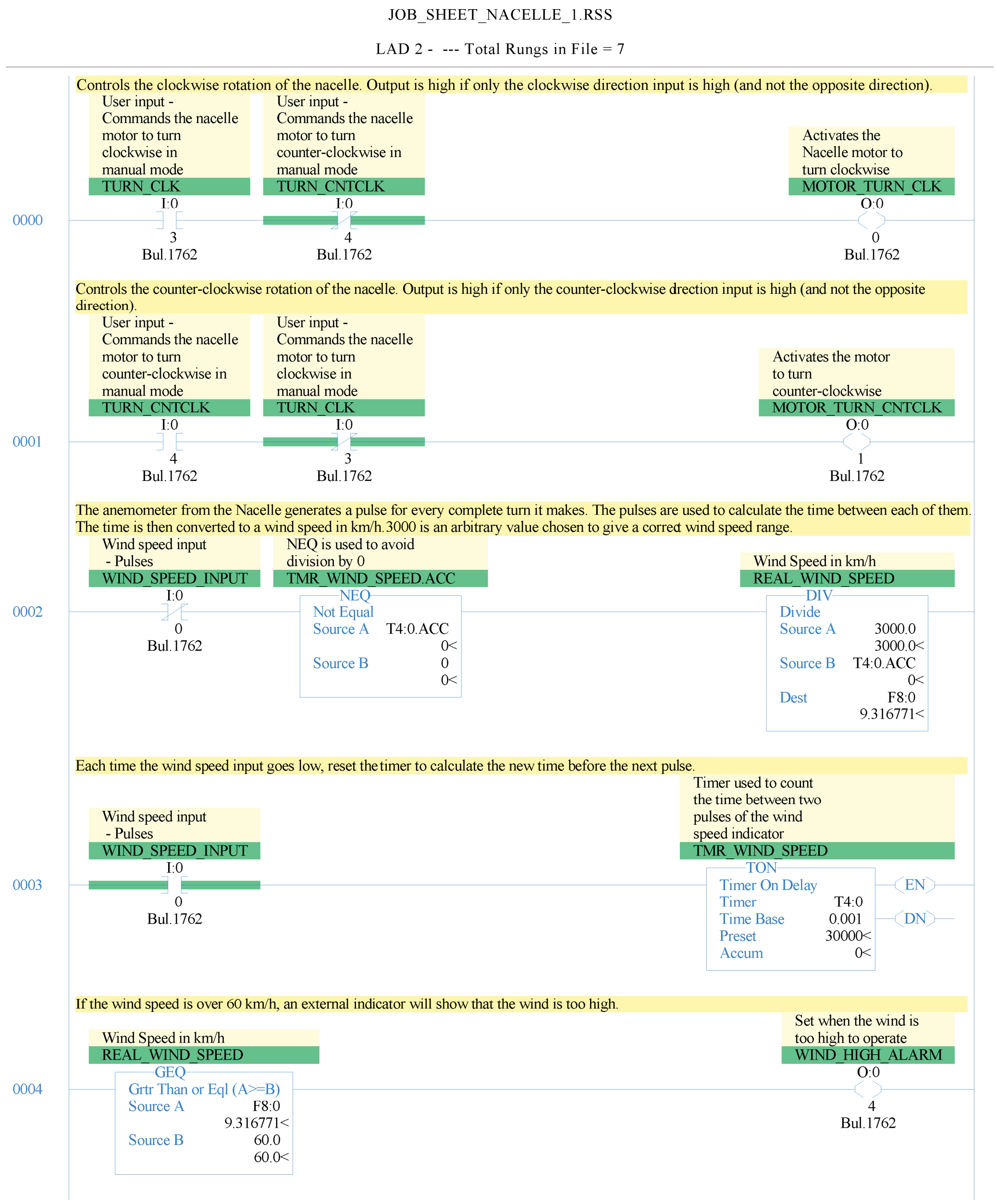


Comparator logic.

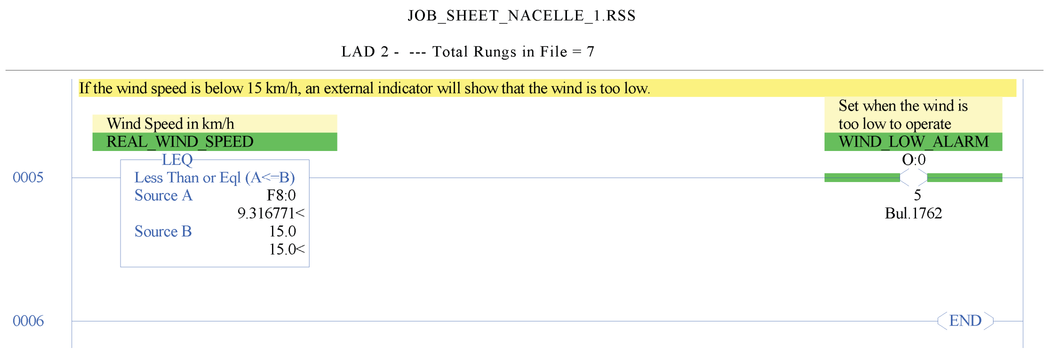
There are many other indicators which can be of interest. Among them are:

- A pilot light indicating an unsteady wind (wind speeds must then be compared over time)
- A pilot light indicating the wind is in the normal operating range.
- A pilot light indicating a command is contradictory (such as asking for clockwise and counter-clockwise rotations at the same time).
- Etc…

6. Start *RSLogix Micro* and compile all the results obtained so far in a single ladder program.



Ladder program of Job Sheet 1 (part 1).



Ladder program of Job Sheet 1 (part 2).

7. Test and comment your ladder.

8. Demonstrate the operation of your program to your instructor.

9. Print your ladder program.

10. Close *RSLogix Micro* and turn off the PLC. Disconnect and store all leads and components.

Name: ______________________________ Date: ____________________

Instructor's approval: ____