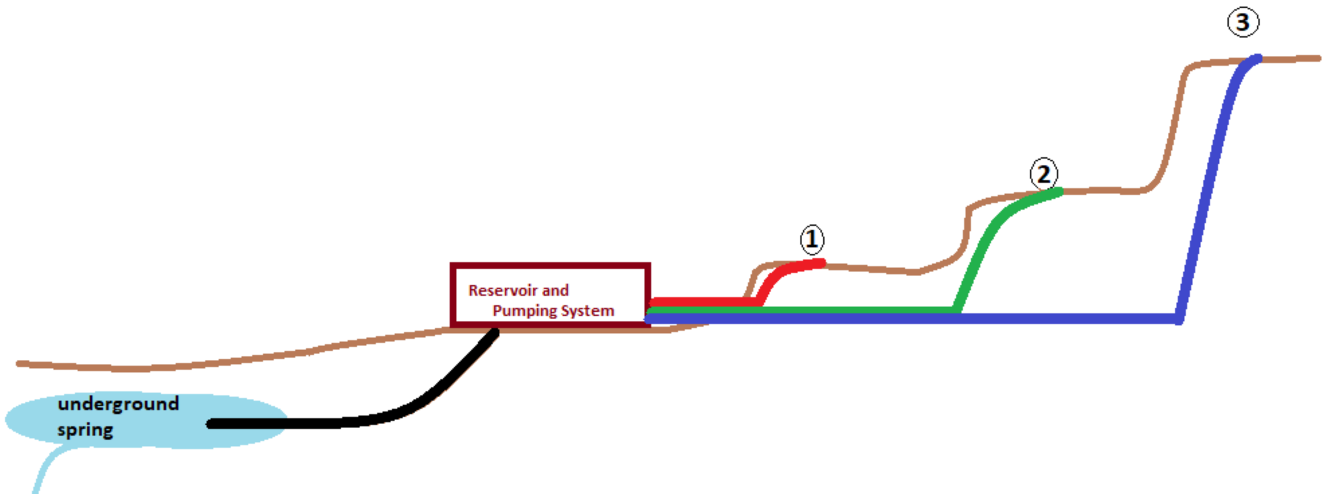
ECE-298 Embedded Project: Water Reservoir System

F2024

Project Background:

A terraced vineyard, near a community is undertaking a development that will require an **Embedded System Controller** for its irrigation system. It is to operate with energy efficiency.

A diagram below, shows the system that is already installed and what is needed is a Controller function for the system. There is a central water reservoir that is refilled with water from an INLET PIPE connected to an underground spring. A Water Depth Sensor in the reservoir is installed to sense water depth in the reservoir. When the irrigation activities occur, a single pump is used to move the water from the reservoir. A valve system is used to direct the water to each specific zone. The reservoir, pumps, pump motor and piping are already installed on the site.



The basic sequence of operation for the system is that the water reservoir is filled up with water from the underground spring overnight. Then, during the following day, the system divides the water volume in the reservoir out for distribution among the zones being irrigated.

A primary thing to keep in mind is that there are 3 different zones to irrigate and each one is at a different vertical level. This situation will require different water pressures to be applied by running pump motor with different pump speeds. A small-scale operating model is to be developed to investigate and test the system design sequencing.

EMBEDDED PROJECT DELIVERABLES:

The work to be done for the Embedded project consists of two parts. These are:

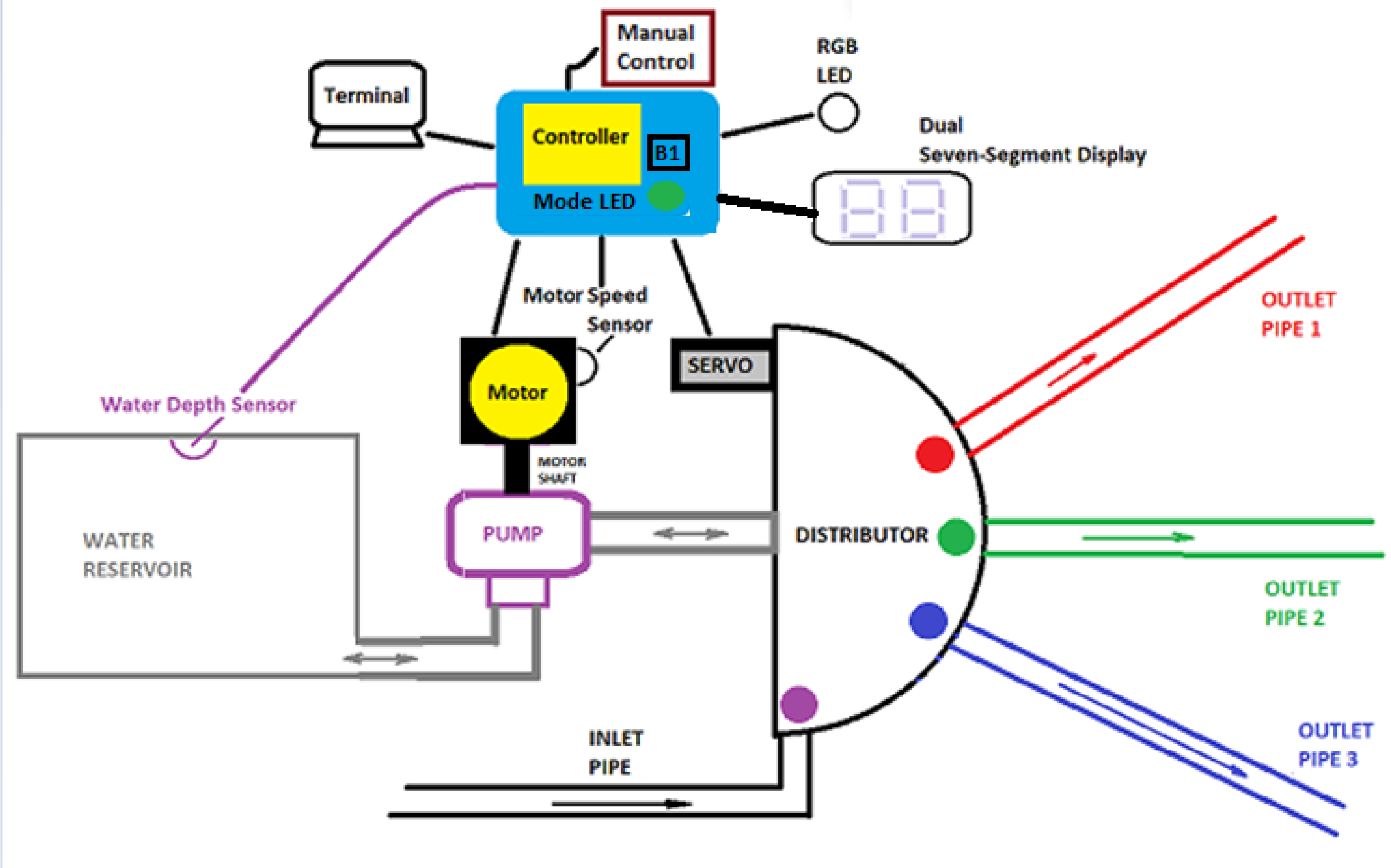
1) Team Project Demo
2) Team Project Report

The Team Project Demo will consist of developing a "final Feasibility Model" design (which will include changes from the Feasibility Model design review of a Team Feasibility Model video). All design review feedback items must be implemented on the design breadboard. This demo will also require the development of processor code to run the Embedded Project design.

The Team Project Report will consist of:

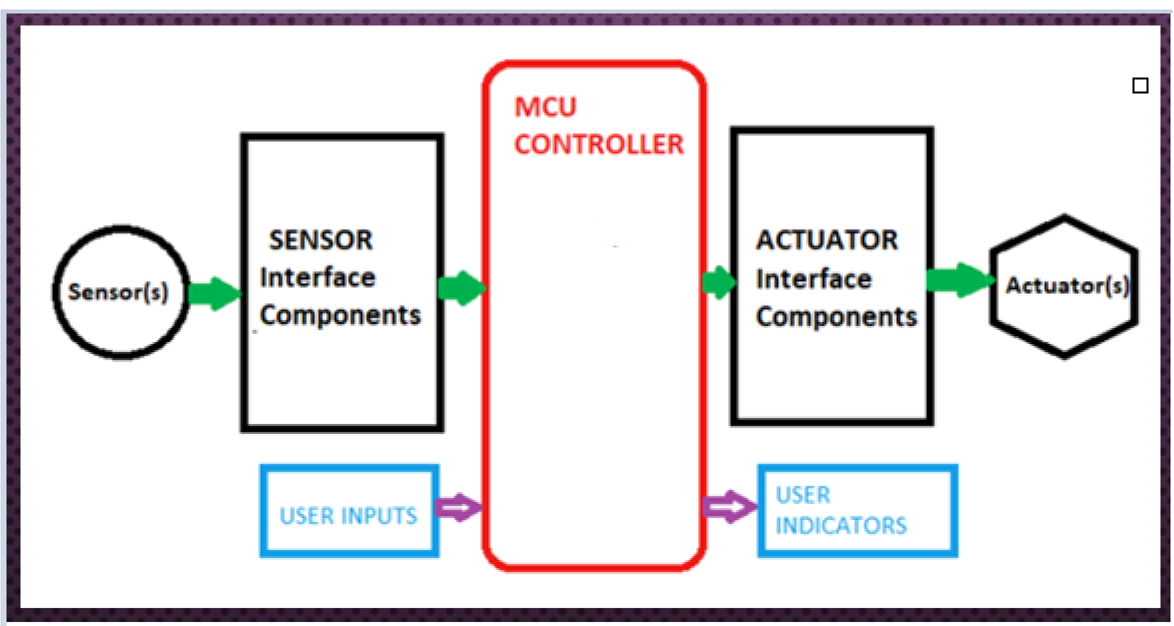
1) A Final Prototype Schematic;
2) A Final Prototype PCB Design and its associated files
3) A proposal for running the Embedded Project for minimum operating costs

Team Project Demo



TEAM PROJECT DEMO HARDWARE DESIGN:

The Team Project Demo will include hardware components such as in the following sketch:

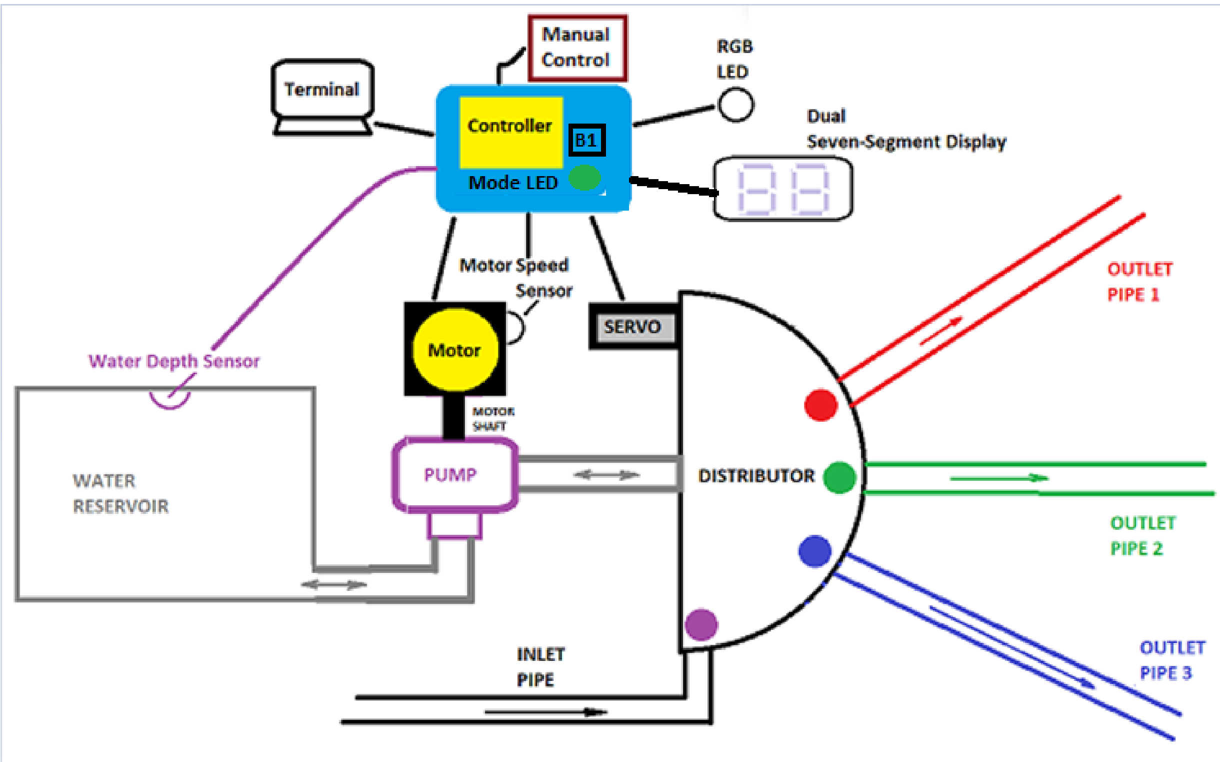


The Nucleo board will be the MCU controller, the external devices will be those components provided in the Reservoir System kit, the Lab A Timer Board, an ultrasonic Distance Sensor and the interface components and wiring implemented on a breadboard for signal and power connections. Any design review changes required for the Feasibility Model design video must also be implemented on the breadboard for full marks. The MCU interfaces required are listed below:

1) UART COMM link (to Workstation Terminal)
2) Potentiometer Analog Input (Manual Cntrl)
3) PWM signals to a motor controller for Brushed DC Motor
4) PWM signals interface for SERVO Motor
5) UART I/F or Timer I/F to ultrasonic Distance Sensor
6) Interrupt interface from RPM Sensor
7) GPIO interface to Timer Display
8) GPIO interface to RGB LEDs
9) GPIO interface for Mode LED (Nucleo LD2)
10) GPIO interface to B1 Push Button.

All interfaces must have the appropriate signal voltage translation buffers included for full marks. Refer to the information provided in the Lab Presentation slides, Lab Manuals, MCU Pin Planning spreadsheet and the device datasheets.

HIGH-LEVEL PUMPING SYSTEM DESIGN



For general operation, the Reservoir must ALWAYS be filled first before any irrigation to the zones can begin.

After the water reservoir is filled, the Controller can direct water from the water reservoir to any one of the three zones for irrigation at a time.

The selection of the zone pipe connection is done by controlling the SERVO. When the SERVO has been configured for a new selection, the RGB LED is Driven to the specified colour. Note that for the INLET Pipe, the RGB colour is set for PURPLE.

The Pump is driven by the MOTOR via a PWM signal from the MCU. The RPM of the pump can be controlled by the PWM Pulse width to the Motor Controller. Note that the direction of water by the pump with the INLET is **OPPOSITE** to the water flow to the ZONES.

The depth of water in the water RESERVOIR may be determined at any time by using the Ultrasonic Distance Sensor. You should set in code, your determined limits for minimum and maximum Water Level distance values. Then your code should calculate the percentages for distance values between those limits. Note that the distance Sensor is mounted at the CEILING of the Reservoir. So as the water level rises, the distance to the sensor decreases. The Water depth must be seen on the Dual Seven-segment display on the Timer Board) and on the Terminal. The depth will be shown in percentage terms (0% to 99%). Keep in mind that when the water level is HIGHER in the reservoir, the distance measurement by the Distance Sensor will be LOWER in value. The Reservoir water level can be represented by some sort of movable barrier (such as a piece of cardboard etc.) in front of the Distance Sensor.

A Manual Control (Potentiometer) can be used to manually set the RPM value of the motor for any zone or inlet connection, if the option is chosen by the terminal, during the SETUP MODE of the embedded system. Alternatively, the RPM parameter for driving each zone or inlet pipeline connection can be set with an option chosen by the terminal in SETUP Mode.

The Terminal is configured to run with a BI-DIRECTIONAL UART connection to the embedded system. It is used to enter or display information when the embedded project is operating in each of its operating modes (SETUP or RUN).

TEAM PROJECT DEMO SOFTWARE DESIGN:

The Pump motor speed PWM for the DEMO will just use a constrained set of values (for simplicity). The TA will specify which option settings to use for your team demo. Your system is to run in a SETUP Mode and in a RUN Mode.

For specific hours of scaled time, a number between 00 and 23, inclusively speaking, may be entered at the keyboard in SETUP Mode.

1) **DEMO of SETUP MODE**: This MODE is entered by Resetting the NUCLEO MCU. **The GREEN LED on the Nucleo board is OFF while in SETUP MODE.** **NOTE: The Pump Motor MUST BE OFF in SETUP MODE**.

   The Terminal displays "SETUP MODE and then displays the message (in Part A below) to cover all of the pipeline choices. There are FOUR entries to be made for the DEMO.

   A) FIRST PIPELINE CHOICE FOR CONNECTION (SET to option 0 (for INLET) only for the Demo):
   FIRST PIPELINE CHOICE FOR MOTOR PWM (SET to option 0 (INLET) for Manual Control for the Demo):

   SECOND ZONE CHOICE FOR CONNECTION (option 1-3):
   SECOND ZONE CHOICE FOR MOTOR PWM (option 1-3):

   THIRD ZONE CHOICE FOR CONNECTION (option 1-3):
   THIRD ZONE CHOICE FOR MOTOR PWM (option 1-3):

   FOURTH ZONE CHOICE FOR CONNECTION (option 1-3):
   FOURTH ZONE CHOICE FOR MOTOR PWM (option 1-3):

   Use the following list for entering the PWM option for the MOTOR SPEED for a ZONE or INLET:

   0) Manual Control (the Potentiometer setting in Run Mode for the Inlet connection only);
   1) 70% PWM; 2) 85% PWM; 3) 99% PWM.

After all INLET and ZONE MOTOR SPEED PWM INFO is entered, the terminal then displays the messages in Part B below. The wall clock times are to be entered.

The Embedded System is to be designed to run all pumping operations within a 24-hour time period.

But because we don't have 24 hours to test each team design, we will be running the DEMO with "scaled time" operation.

An internal MCU Timer should be used to drive variables for the SCALED WALL CLOCK time values of scaled hours and scaled minutes. If we let the 24-hour cycle of WALL-CLOCK TIME be represented as 4.8 minutes in SCALED TIME. So, for a scaled running time of 1 hour, the duration in REAL TIME becomes 0.2 minutes (or 12 seconds of real time)**.** This means that the Timer must run 300 times faster than real time.

For this DEMO, BECAUSE **ONLY ONE ZONE OR INLET** CAN BE CONNECTED TO THE PUMP IN EACH HOUR, THERE CAN BE NO OVERLAP OF WALL-CLOCK ENTRIES.

The order of wall clock selection options is listed below:

B) CURRENT WALL CLOCK TIME (SET to 00 only for the Demo):

INLET WALL CLOCK START TIME (SET to 00 only for the Demo):
INLET WALL CLOCK STOP TIME (SET to 07 only for the Demo):
The above settings allow for Manual Control Testing in scaled time operation. An object must be placed in front of the distance sensor (to represent an Inlet water fill level) before hour 07 is reached.

FIRST ZONE CHOICE WALL CLOCK START TIME (08-23):
FIRST ZONE CHOICE WALL CLOCK STOP TIME (09-23):

SECOND ZONE CHOICE WALL CLOCK START TIME (08-23):
SECOND ZONE CHOICE WALL CLOCK STOP TIME (09-23):

THIRD ZONE CHOICE WALL CLOCK START TIME (08-23):
THIRD ZONE CHOICE WALL CLOCK STOP TIME (09-23):

NOTE: WALL-CLOCK TIME is expressed in a simple 24-hour format.
The entry options are: 00 – midnight, 01 – 1:00am, 02- 2:00am….,, 12 – noon, 13- 1:00pm…. 23 – 11:00pm

The program DEMO operation ALWAYS STARTS at Clock Hour = 00 and STOPS WHEN Hour 24 is reached.

For the DEMO, when all WALL-CLOCK entries are completed in the SETUP MODE, the system then **flashes** the GREEN LED continuously on the Nucleo board while the system remains waiting at the end of SETUP MODE. The MCU is waiting for the activation of the BLUE B1 button before it brings the embedded system into RUN Mode.

When the BLUE B1 Button on the Nucleo board is pressed and released, the system goes from SETUP MODE to RUN MODE. **The GREEN LED stays ON continually for RUN MODE**.

2) **DEMO of RUN MODE**:
Set the WALL CLOCK TIME to 00 and enable it to start running.
The FIRST PIPELINE connection made to the pump is the INLET pipeline. Configure this connection by setting the Servo to the pointer position for that connection.
Set the RGB LED to indicate the INLET connection colour.
Perform a measurement for the Water Level in the Reservoir.

If it is not empty, Enable the motor to use the Manual Control to set the motor speed.
Over the first Scaled time operation make RPM measurements of the motor speed during each hour. Also make Water Level measurements during this time. Report results to the Terminal (as described below). At the end of operation (WALL CLOCK STOP TIME for a pipeline connection) shut down the motor.

The RUN Mode sequencing proceeds through the irrigation process for each ZONE (like in the above steps for the INLET connection) in their selected order, specified in the SETUP Mode, and with each one using its respective motor speed PWM setting.
KEEP IN MIND THAT THE DEPTH OF THE RESERVOIR MUST BE ALWAYS MONITORED AT LEAST ONCE PER HOUR (SEE SPECIAL EVENT BELOW).

During RUN Mode, the Terminal displays the system STATUS using a set of Column headings as shown below:

Wall-Clock Hour, Minutes optional| Zone/Inlet | Motor Speed %PWM | Motor RPM |Water Reservoir Depth |

The Timer Board must also show the Water Depth Percentage with each hourly measurement.

Updates about the system status information should displayed on ONE line per update on the terminal display. There can be multiple reports per hour, but you must include the minutes value as well.

The display gets updated on a new row of info at least once every WALL CLOCK hour. The info shown should reflect the operations of the system during that hour (typical RPM measurements have +/- 5% RPM values for any given motor speed).

The RPM values must be based on revolutions per **REAL TIME MINUTE** (not scaled time intervals).
IMPORTANT: Because of motor inertia, it is suggested that the RPM value calculation not use RPM tick counts for near the beginning of each hour when a change in motor speed is made.

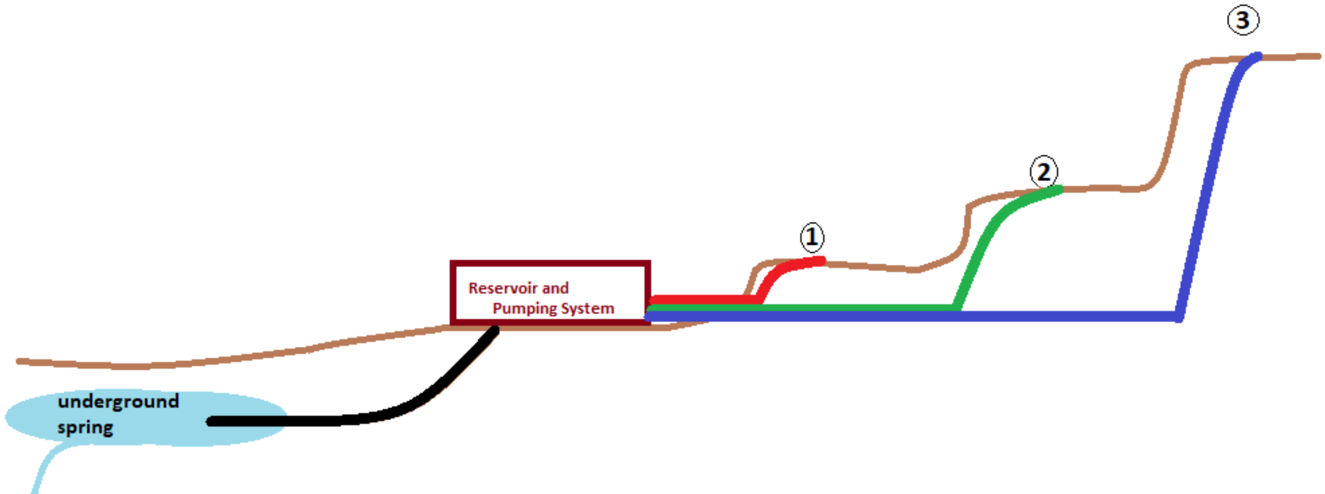
SPECIAL EVENT

A special Event is detected if the Water Reservoir ever reaches **ZERO depth %** during its 24-hour operation. The embedded system then turns OFF the MOTOR ~~immediately~~ within the hour. The Terminal display indicates that the RESERVOIR IS EMPTY and the RGB LED sequentially displays a FLASHING WHITE COLOUR. THE GREEN LED on the Nucleo board is Turned OFF.

The system should stop and then should wait for a RESET.

FOR THE Prototype Report:

You will be required to submit a Prototype schematic and a Prototype PCB design. You can use the resources on Learn to use the Proteus tools for these items. Also required will be an operational 24-hour plan for the client that will show settings to run the Embedded system with minimal operational costs.



A BASIC PUMP SYSTEM PARAMETER TERM --- HEAD:

A parameter that is used in pumping system design is a term known as HEAD. It's unit of measure is based on vertical distance. This parameter is a much "handier" unit for general performance requirements since it conveys the capabilities of a water system design in general terms. It is proportional to a pump's ability to create water PRESSURE.

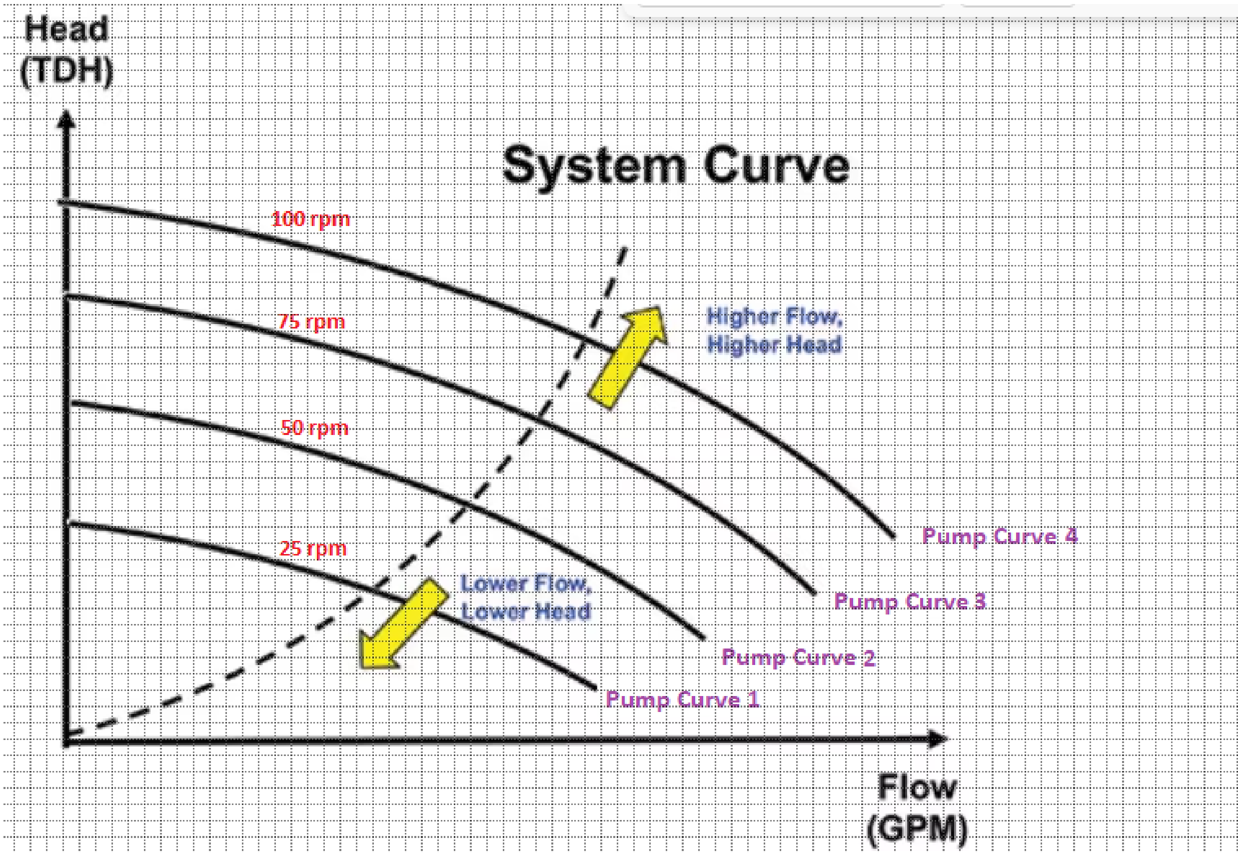
The height to which a pump can move a fluid, is generally given in HEAD terms (feet, metres etc.) because it is more intuitive for determining if a pump can perform sufficiently for a specific application. With everything then being in HEAD units (feet, meters etc.), one can use simple arithmetic calculations to develop the system design.

For example, if a pump has a Total Dynamic Head value (TDH) of 30 feet, then that means that the pump can lift, by the pump's water pressure, a fluid by 30 feet when operating at a specific rpm. But this parameter is usually specified for a water flow of ZERO. So, if your water pumping application requires a Head of 40 feet, then right away, one can know if the pump must be made to run faster to provide water flow at that height. Typically, the pump performance curves (pump curves) for a particular pump are provided by the pump manufacturer. They show a pump's TDH vs FLOW.

The PUMP CURVES and SYSTEM CURVE:

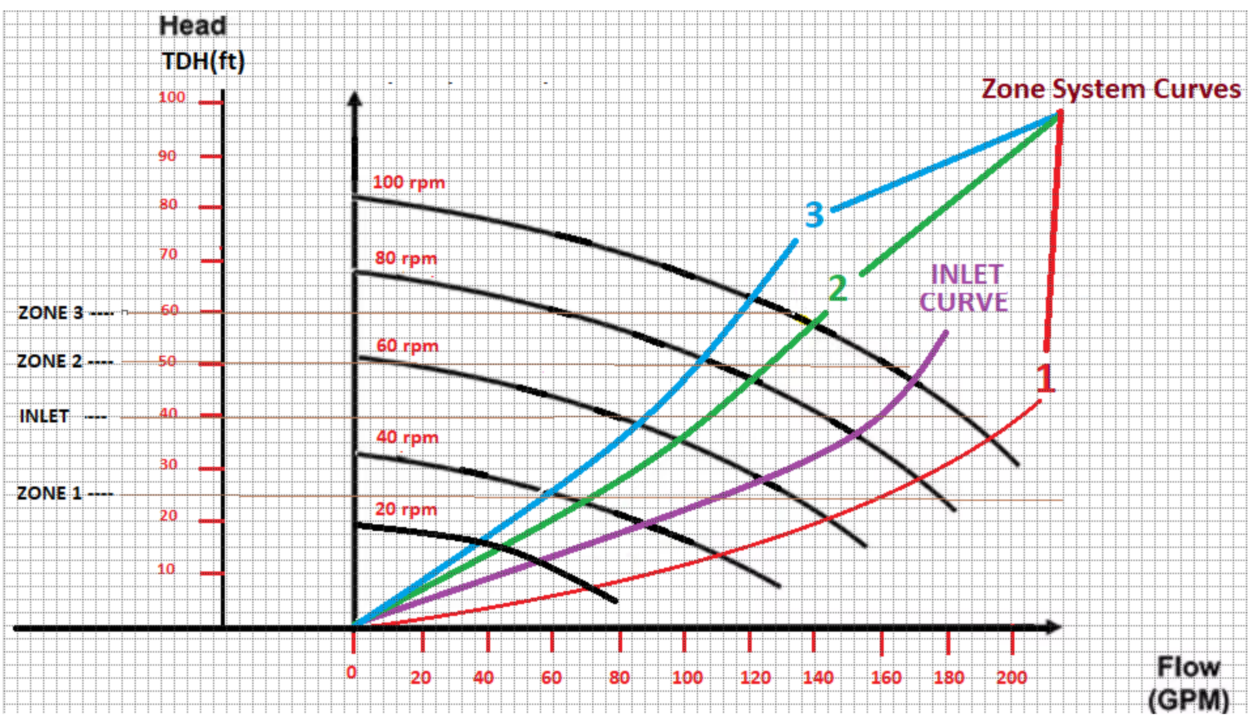
Another characteristic of a Pumping System is the System Curve. This is established by the **piping system design and pipeline layout at the customer site**. The System Curve is used as an overlay over the Pump Curves to establish how a pump will perform at the customer site for various pump parameters such as revolutions per minute (RPM).

For any known System Curve, a pump's RPM value will affect the operating point of a system along its System Curve.



CUSTOMER SITE SYSTEM CURVES FOR THE PROJECT:

At the customer site for this project, there are four, already installed pipeline. For these, there are three system curves for the zones and one inlet system curve for drawing water to fill the water reservoir to consider. Each system curve is based on different tubing pipe diameters and/or routing on the property.



Each system curve above shows the operating points of the system for each zone or inlet pipeline connection.

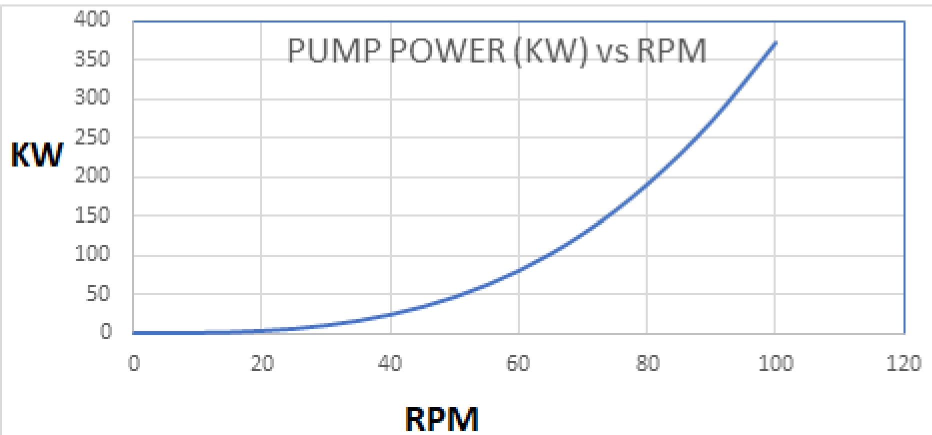
For example:

Zone 1 is at an elevation of 25 feet above the elevation of the water reservoir.

The system curve for the pipeline to **zone 1** shows that the pump will provide water to zone 1 when it is running with at least a TDH that is sufficient for zone 1. This requires a minimum rpm of 70 rpm (with a resulting flow of 160 GPM) and up to a maximum of 100 rpm (with about 193 GPM).

The system curves for the remaining two zones can be determined from the graph using the minimum TDH value to reach the zone and the range of rpm values. Intermediate values of rpm between the pump curves can be estimated.

PUMP POWER CONSUMPTION:



The pump that is installed at the customer site, has the power requirements (KW) based on RPM. The total energy, in Kilo-Watt-Hours (KWH), is the KW power times the runtime in hours to run the pump at each RPM.

SMALL BUSINESS PRICING:

TOU Price Periods	Summer (May 1 – October 31)	TOU Prices (¢/kWh)
Off-Peak	Weekdays 7pm – 7am Weekends and holidays all day	7.4
Mid-Peak	Weekdays 7am – 11am and 5pm – 7pm	10.2
On-Peak	Weekdays 11am – 5pm	15.1

Ultra-Low Overnight (ULO)

ULO Price Periods	All Year	ULO Prices (¢/kWh)
Ultra-Low Overnight	Every day 11pm – 7am	2.4
Mid-Peak	Weekdays 7am – 4pm and 9pm to 11pm	10.2
On-Peak	Weekdays 4pm – 9pm	24

IRRIGATION REQUIREMENTS (Different for Each Team)

The Water Reservoir will have the same capacity value for each team.

INLET Water Source (Underground Spring) used to fill the reservoir:

The HEAD from the spring to the reservoir is 40 feet.

Reservoir capacity: 94000 gallons in total. All the water in the reservoir is consumed with irrigating all 3 zones every 24 hours.

However, the distribution of that water from the reservoir to the three zones will be randomly assigned to each team.

HEAD to zone 3 is 60 feet

HEAD to zone 2 is 50 feet

HEAD to zone 1 is 25 feet

The volumes of water (in Gallons) will be during to each Lab Session for each team.

Your team's set of details for running the Embedded System for the client requirements must include the following:

- Table Format for your Embedded Project system operating details over a 24-hour cycle.
  Include Pipeline Name; Pipeline Start/Stop Times; Motor RPM; Gallons of Water transferred; Energy used (KWH); Energy cost ($) during pipeline run time; Choose the running operations for MINIMAL cost.
- THE **FIRST PIPELINE** CONNECTION LISTED MUST BE THE INLET (FOR RESERVOIR FILLING. For your report the INLET connection may use any desired RPM value from the graphs.
- After the end of the table: CALCULATE THE TOTAL ENERGY CONSUMED(KWH) AND TOTAL ENERGY COST FOR RUNNING THE 24-HOUR OPERATION.