

## **A SUGGESTED CRITERIA FOR THE SELECTION OF RTUs AND SENSORS**

Blair L. Stringam<sup>1</sup>  
Paul Elser<sup>2</sup>

### **ABSTRACT**

Selecting an appropriate Remote Terminal Unit (RTU) and sensors for an automation project can be daunting. There are numerous devices available with varied capabilities and performance. Factory representatives and specifications can be misleading and confusing. Advances in the electronics industry are seeing tremendous changes and subsequently RTUs and sensors are undergoing new developments. Older models are being redesigned and in some cases losing their integrity. Efforts have been made to test various RTUs and sensors, but they have not been exhaustive and these devices will eventually become obsolete.

Considering the extensive choices that are available and the changes that are continually occurring, a criteria was developed for selecting these devices for automation projects. While basic performance criteria are important, it was concluded that consulting with individuals who have used these components is the most important.

### **INTRODUCTION**

Experts will all agree that automation helps manage and save water. There are numerous devices that have been developed which can be used to automate canal and other water resource systems. As advances are being made in the electronics industry, new devices are coming out on the market and older ones are being discontinued. As engineers undertake new projects they are faced with several questions. What capabilities are required for the project? Is there future growth that is required in the project? Will the equipment that has been used on previous projects work for the new project? Are there automation devices already in place that will have to be merged with the new system? What is the expected life of the automation equipment? Is service available for the selected equipment? How long will replacement parts be available for the new equipment? Will a large time investment be required to understand the new equipment?

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<sup>1</sup> Assistant Professor, 333 Leon Johnson Hall, Montana State University, Bozeman, Montana, 59717; telephone: (406) 994-5778; email: blairs@montana.edu<sup>2</sup> SCADA Systems Manager, Alberta Environment, Regional Services – Water Management Operations, 200 – 5th Avenue S., Lethbridge, Alberta, T1J 4L1; Phone (403) 381-5289; email: Paul.Elser@gov.ab.ca

If there is a break down in the automation system, precious time, data, energy, and water can be lost. This motivates the design engineer to error on the costly side to try to avoid expensive problems. However, expensive equipment does not necessarily mean reliable. It must also be realized that irrigation systems are harsh on equipment (Stringam 1992). There will be breakdowns (Burt and Piao 2004) and components will have to be replaced. Considering all of these factors, a criteria was developed for selecting control units and sensors.

### **Control Unit Selection**

The control unit or remote terminal unit (RTU) is the device that is placed out in the field to perform manipulations that will cause or force the system to respond in a desired manner. One must be careful when selecting these devices. They range in cost from \$100 to more than \$8,000. They have varied capabilities and different weaknesses. Some RTUs have demonstrated field problems such as unexplainable stalling when executing program code, loss of data, unexplainable breakdowns, inability to handle the environment, intermittent communication, loss of programming code, unusual sensor readings, and little or no factory support. In some cases, RTUs did not perform as claimed by factory representatives. In order to select an RTU, the control engineer obviously must understand the basic operation. They should be aware of potential problems so that they can discriminate between a reliable RTU and one that will cause problems.

As mentioned earlier, electrical control devices are undergoing change. Older devices are being discontinued and new ones are being brought on the market. In other cases, control requirements dictate that a newer device is required to properly operate the project. Control engineers are often faced with having to select new control RTUs that will handle the project requirements. There are the usual requirements like:

- How many analog inputs will the RTU accept or how many control inputs or outputs are available?
- Can the control inputs and outputs be expanded if required?
- Can the analog input capability be expanded?
- Does the RTU have SDI-12 capabilities?
- What are the communication capabilities?
- Can the RTU communicate with another RTU in the system?
- How many communication ports does the RTU have?
- What are the programming languages that are used in the unit?
- Is the RTU reliable?
- What type of warranty and service is provided by the manufacturer and the system integrator?

- How long has the manufacturer been in business and what kind of track record do they have in the industry?

All of these questions should be asked by the design engineers and the potential users of the system. The first questions are just physical capability questions. It is just a matter of looking up factory specifications. A simple question can be asked for each control site: How many sensors are required and is there a possibility that more sensors will be added in the future? The same is true for digital control outputs and digital inputs (I/O). If a control gate motor is being operated, two output I/O are required. One I/O for moving the gate up and one for moving the gate down. If a limit switch input is required, one digital input I/O is required to read it.

Once the control requirements are determined, an RTU that will handle these requirements can be selected. It should be noted that it is good practice to use a device that has one or two extra analog inputs and extra I/O. There may be times where the extra sensors and I/O are required and more inputs must be used. As users of the control system become familiar with the system, they may ask for additional sensor inputs. If the RTU has expandable I/O, this is not a concern.

### **Controller Architecture**

The RTU or programmable logic controller (PLC) can be either a fixed or modular design. The fixed design is typically a single board unit that has a fixed number I/O and may or may not offer the ability to expand the I/O. The modular design typically allows for the selection of I/O modules to match the control needs fitted into a rack arrangement. In either case, the control unit usually consists of a central processing unit (CPU), analog to digital inputs (A to D), digital input and outputs (I/O), communication ports, and possibly communications devices such as radios or phone modems. Some fixed units offer an integrated human machine interface (HMI) that provide text or graphics based information and push button keys for information access and manipulation. Modular units generally require a separate HMI to be connected to one of the communications ports. All of these components must perform seamlessly with the CPU for efficient uninterrupted control of irrigation sites.

### **Analog Inputs**

The analog inputs of the controller should be able to interface with industry standard transmitters and provide a minimum of 12-bit resolution. The most readily available transmitters provide a 4-20mA output which can be converted to a voltage by using a current dropping resistor. A 4-20mA signal can be converted to 1-5 Vdc with a 250 ohm resistor and 0.5-2.5 Vdc using a 125 ohm resistor. Some controllers provide 0-5 Vdc or 0-2.5 Vdc inputs which means that the 20% of the input resolution will be lost unless the input can be adjusted to measure

over a reduced range where the bottom end is offset. It is important that the analog inputs have as close to the same span as the sensor in order to maximize the measurement resolution.

The digital resolution of the analog inputs is important to resolve the input signal to a fine enough increment to be able to perform good control. A 12-bit resolution provides for 4096 unique steps over the measuring range of the sensor. For example, 12 bit resolution provides better than 0.001 foot resolution on a transmitter with a four foot span. Controllers with 12-bit resolution are pretty common today, although 14, 15 and 16-bit resolution are also becoming more popular with the use of more powerful microprocessor units in the design of controllers.

An important consideration when assessing analog inputs is input surge protection. Analog inputs are highly susceptible to damage caused by surges typically caused by lightning. Some controllers provide a limited form of surge protection on the input circuitry, but if the input is damaged, the module or the entire controller may have to be replaced. The design of any control system should include separate lightning protection units (LPU) when there is a significant amount of cable between the control unit location and the sensor location.

### **SDI-12 Inputs**

RTUs that have SDI-12 capability can greatly expand the sensor input potential. An SDI-12 input allows for several sensors to be connected to one input port. The sensor input is fed into the RTU using a digital communication protocol that identifies each individual sensor and the sensed value. Some RTUs allow for several sensors to be connected to one port. It must be realized that if these sensors are used, there is a few second delay for each sensor reading.

### **Discrete Inputs**

Discrete inputs monitor the status of sensing devices that are either on or off, such as limit switches. Discrete inputs are designed to operate with dc voltage or ac voltage, but typically not both, and depending on the type of control application, the correct input voltage range must be selected. Discrete inputs typically have a voltage operation range with threshold levels that the controller recognizes. These threshold levels indicate the on state and off state of the device. The input voltage range is important to select depending on the voltage used to monitor and control an irrigation gate controller, however it is generally desirable to use dc voltage where practical.

The threshold value is generally not an issue when dry contact devices, such as a micro switch, provide the input status. However, when using electronic devices

such as proximity switches, the threshold value is important as proximity switches typically have an off state leakage voltage that may exceed the on-state threshold voltage of the discrete input. The selection of discrete sensors should be carefully considered when designing a control system.

### **Discrete Outputs**

Discrete outputs on controllers come in various forms and care must be taken when selecting a controller and designing the control circuitry on an irrigation gate control system. Discrete outputs are available as 5 Vdc TTL, open collector (sinking or sourcing), triac and dry contact. Care must be taken when directly driving loads to ensure that the voltage and current limitations of the output circuitry are not overloaded. TTL outputs are especially susceptible and the selection of controllers with this type of output should be avoided.

In most cases it is good design practice to utilize an interposing relay between the controller output and the field device. An interposing relay can be switched by lower voltage and current outputs and is capable of switching higher voltage and current required by the load. The biggest advantage of using an interposing relay is that the relay can be easily replaced at a lower cost in the event of a problem.

### **Communications**

Communication capabilities are becoming the most important feature in a control system. The ability to communicate remotely with an irrigation control site reduces travel and discovery time, and allows an entire system to be operated more efficiently. Generally, a control unit should have a minimum of two communications ports for connection of a local HMI and remote communication device. These ports should provide access to both the data area and program areas of memory. This allows the local and remote interfaces to view operational data, manipulate set point data, and to also make programming changes.

Generally, control units should support a communications protocol that enables multiple units to communicate within a system. A protocol is a language that control units will understand and respond to when a message is addressed for a specific unit. Today there are many different protocols that can be classified as “open” or “proprietary” protocols. The selection of an open protocol generally allows the data area of different control units to be read from and be written to but doesn’t necessarily allow the program area to be modified. Today, open protocols are generally supported by many different brands of control units and allow control units from multiple vendors to be purchased and implemented in an overall control system. This offers some flexibility to the end user especially down the road when a control unit needs to be upgraded or when the vendor no longer manufactures the control unit or has gone out of business.

Proprietary protocols are typically developed by the vendor and are only supported by control units they manufacture. For the end user who is developing a telemetry network, this means they must buy from the same vendor so that new control sites are compatible with existing sites. As long as the control units are cost effective, reliable, and meet the design specification, standardizing on one controller can simplify design, implementation and maintenance of a control system.

Modbus is currently considered an industry defacto open serial communications protocol. Many control unit manufacturers purport to supporting Modbus protocol and most do in fact faithfully implement the protocol as laid out in the protocol manual available from Modicon. However, there are different variations of Modbus that have been developed in the past few years and some are not compatible with standard communications drivers used for remote telemetry applications. The authors are aware of one RTU device that was advertised to have Modbus communication capability, but when an RTU was purchased and tested, it was discovered that the device would not communicate with other devices using Modbus. When tech support was contacted, the response was that the manufacturer was not responsible for the problem and the system integrator would have to find a solution.

Other serial protocols, such as Allen-Bradley DF1, are also supported by a few vendors and there are many communications products available today that can be configured to convert one protocol to another. Serial communications are not the only mode available today, although they are considered to be a very secure method of transferring data. The advent of wireless Ethernet radios has thrust TCP communications into the limelight in recent years, and many controller vendors are offering an Ethernet port as standard. Ethernet is regarded as a good choice due to its inherent peer-to-peer communications capabilities, although with radio communications it is the radio equipment that defines the communications flexibility. With the right radios even Modbus, traditionally considered a master-slave protocol, can be implemented as a peer-to-peer network.

### **Human Machine Interfaces**

The human machine interface (HMI) provides the ability for the operator to interface with the control unit to monitor current status and modify set points as required. Including a local HMI as a part of the control system design, either as a built in feature or as a stand-alone device is highly beneficial. HMI's can be as simple as a single line display of 10 characters and a couple of pushbutton keys, or as elaborate as a color touch screen with graphics capabilities.

The selection of an HMI is dependent on the type of control unit selected and the complexity of the process being controlled. A simple upstream level control gate with only one level transmitter connected would probably operate satisfactorily

with a simple text-based HMI, where as a multiple gate check structure providing upstream level control with high and low flow over rides would benefit from the additional features afforded by a graphical interface. The power source for a site will also dictate this selection because a power hungry graphical display may not be a good choice for a solar powered gate site.

### **Controller Programming**

Control units are programmed using many different types of logic including BASIC or a vendor specific form of BASIC, compiled C, ladder logic, both compiled C and ladder logic, Graphset and IEC-1131-3. In most cases, vendors usually provide compatibility for using program logic in all controllers in a product family, but programs from one brand of controller cannot be directly used in another brand. Programs will always have to be re-written and tested for the target controller.

IEC-1131-3, a graphical and function block oriented programming language, was originally conceived to be the one programming language that would allow programs from one platform to be used in another. However, vendors have developed extensions of the language specific to their control units and the ability to convert programs directly is not currently available.

Learning to become proficient in a new computer language is time consuming. It is not just a matter of becoming familiar with the programming language, there are often unique functions that make programming more efficient. Considering that there are many choices in RTUs, it is recommended that an RTU is selected that uses a language that the programmer is familiar with. This reduces development time and cost. Technical support for the controller hardware and its programming language should be carefully considered when selecting a control unit.

There is an RTU that is presently on the market that is difficult to program because of the programming language that it uses. This device was given poor ratings in a report by the ITRC (1999). The authors of this paper agree that it is a difficult device to program however, they have found it to be an extremely reliable and durable device.

### **Sensors**

The field sensors that are connected to the control unit allow it to retrieve information about the outside world. There are many types of sensors that are available, but this paper will focus on sensors used in canal automation. An understanding of some of the common sensors will help to limit the errors that can occur. The most common sensors connected to an irrigation gate control system are water level and gate position.

Every sensor has limitations. There are applications where they perform well and others where they are constrained. In order to select the right sensor, some of the following questions need to be asked:

- What is the usual life span of the sensor (be honest)?
- What type of installation is required for the sensor?
- What type of environment will the sensor be exposed to?
- What is the required measurement range?
- Is the sensor signal compatible with the control unit?
- What is the power requirement for the sensor?

Life span is always a concern. As mentioned earlier, an irrigation environment is harsh on sensors. A system integrator is often faced with the decision of selecting a longer life less precise sensor or vice versa. Individuals who have struggled with maintaining an instrumentation system in an irrigation environment are usually willing to sacrifice some precision for reliability.

### **Water Level Sensors**

Water level can be measured using float and pulley sensors, float and cable-extension-spring-return sensors, submersible pressure transducers, ultrasonic sensors and bubbler systems. In all types of water level sensors, an analog signal proportional to the water level is transmitted to the control unit.

Float and pulley type sensors are probably the simplest and most reliable sensor to utilize and are very easy to calibrate. The float and cable-extension-spring-return sensors are also reliable and easy to calibrate, but are more expensive than the float and pulley type due to the mechanical requirements. Pressure transmitters are becoming quite common and more cost effective to install, however, the accuracy of the electronics needs to be carefully considered when selecting one. Ultrasonics have also become very popular but installation considerations including stilling well size and potential air temperature gradients must be carefully considered in the design. Bubbler systems are considered highly accurate and have been used for many years but are complicated.

Float based sensors tend to have the longest life. It is believed that there are three reasons for this. First, the sensors are out of the water and this prevents water from getting into the electrical portion of the sensor. Second, they are electrically non-contacting making them less susceptible to damage from lightning, and third is that the sensors are simple and rugged. Whether this type of sensor is a float and pulley type or a spring loaded type, a float is required to transfer a water level via a cable to the potentiometer unit. This means that a stilling well is required to keep the float from moving down stream. When this sensor is placed in a stilling well, cobwebs and other things can interfere with the sensor. One note of caution

when using spring loaded type float sensors is that linearity is affected by the spring rate of the sensor whereby the float will actually become more buoyant as the cable is extended.

Submersible pressure transducers seem to have the shortest life span. They are in the water and have problems with water leaking into the electronics or condensation running down the vent tube to the electronics. Even the newer transducers where manufacturers claim to have eliminated these problems fail. These sensors are very convenient to install. They may be simply hung off an irrigation structure into the water, or an open ended pipe can be fastened to the structure and the transducer can be hung inside the pipe. A special effort must be made to make sure that the transducer does not stretch out the cable over time and change the base reading. Many experienced instrumentation people will mention phantom measurements that occur with these transducers. This measurement occurs when a transducer makes consistent “reasonable” measurements for an extended period of time then there is a sudden drastic change. This value will differ from the previously measured values by several feet. Then the transducer will return to making normal measurements. If this is understood, the RTU can be programmed to compensate for these strange readings. There are many manufacturers of submersible pressure transducers and the cost is typically proportional to the accuracy available.

Some may argue that bubbler based sensors are also out of the water and should subsequently have a long life, but they are more complicated and have more things that can go wrong. They are usually made up of a pressure sensor, a pump or gas mechanism, a regulator, and a device that controls the sensor operation. They can be mounted in an instrumentation enclosure and have a small pipe that extends down to the water where air or gas can be bubbled out. The span on many of these sensors can be adjusted for optimal operation. If this device uses a compressor, it requires much more power to operate than other sensors.

Ultrasonic sensors are also mounted out of the water and have shown that they can be very reliable. They can be placed over a water surface and determine the water level by sending out a sound wave that bounces off the water surface and back to the sensor. The sensor can determine the depth by measuring the time it takes for the sound wave to leave the sensor until it returns. These devices do not require a special installation platform except that they need to be placed over a calm water surface. They must also have a clear path to the water surface through the entire measuring range so that false echoes are not created by objects in the sensors beam path. The sound waves are affected by temperature and humidity, so if there is a temperature/humidity gradient between the sensor and the water surface, there can be an error in the reading. Some of the ultrasonic sensor manufacturers try to compensate for these gradients with varied results. If the sensor can be placed over a water surface where there is free air movement, the sensor is supposed to perform better. These sensors tend to draw more power

than a pressure transducer and a potentiometer, but less than a bubbler that has a compressor.

### **Gate Position Sensors**

Measuring gate position is entirely dependent on the type of gate being used. Gates that use a rotating shaft to operate the gate can be fitted with a rotary type of sensor. Gates that have a vertically rising stem can use a spring-return-cable-extension or a continuous chain drive connected to the stem to convert linear motion into rotary motion.

In all types of gate position measurements, it is important to protect the electronic components and the small mechanical devices to ensure that position sensing is reliable and repeatable. It is extremely important to design and install a well protected and rugged gate position sensing system when flow measurement and control is based on gate position.

### **Sensor Signal Outputs**

Sensors are available with a number of different signal output options including voltage, current, digital and serial. The selection of the type of sensor must be carefully considered in the design stage to ensure that the signal reaching the control unit is not affected by outside interference and truly represents the measurement.

Transducers that have a current output are probably the most common type of sensor available today and offer the best performance characteristics for the cost. Typically these transducers, or transmitters as they are generally referred to, are of the 2-wire or 3-wire type. Two-wire or loop-powered transmitters include R-to-I cards connected to potentiometers, pressure transmitters and some ultrasonic transmitters. The R-to-I card type transmitters can be found in float type sensors or used in rotary gate position sensing when coupled to a rotating shaft. 3-wire transmitters include some types of pressure transmitters and ultrasonic transmitters as well as some encoder based rotary sensors. Current transmitters will typically operate with a dc power supply between 15 and 30 Vdc, however the lowest voltage required for the loop is based on the loop resistance and these transmitters generally operate best with a potential of at least 18 Vdc. Loop powered transmitters are the preferred type of transmitter as the maximum current draw is 20mA whereas 3-wire transmitters can require several times that amount to power the electronics and provide the current signal. Again, it is important to use lightning protection with analog sensors transmitting signals over significant cable lengths.

Another output option becoming more common in recent years is the digital encoder, which can provide either an incremental or absolute signal output. Encoders, which can be used on any type of rotary sensor, are considered digital

because they use discrete outputs connected to discrete inputs on the control unit. This makes them virtually immune to electrical interference (noise). Incremental encoders provide two signal lines that provide switching signals that are ninety degrees out of phase, thus allowing control unit programming to be developed to sense movement and direction based on which input is leading the other. Absolute encoders typically provide multiple discrete lines connected to multiple discrete inputs which can be directly decoded by the control unit as a binary pattern.

Serial interface sensors come in many different forms including SDI-12, DeviceNet, Profibus, Interbus and simple ASCII. These sensors are usually considered “smart” in that serial communications is bi-directional and sensor parameters are set-up by writing to the sensor and then sensor readings are read from the device. Typically, these sensors are more expensive than traditional voltage and current input sensors due to the intelligent aspect of them, but they provide a direct digital reading of the signal that can be communicated to the control unit. Depending on the number of sensors on the communications bus and speed of the communications, there can be a delay in retrieving information from the sensors, which needs to be considered when programming an automated control system. In addition, as these devices are connected using cables, it is important to protect the sensors and control unit input with appropriate surge protection units.

## CONCLUSIONS

Much of the selection of RTUs involves the basic exercise of determining system needs, then selecting the device that meets those needs. RTUs should be selected with an adequate number of analog inputs and digital inputs/outputs that meet the requirements of the system. There should be additional analog inputs and inputs/outputs available for future expansion, or the RTU should have expansion capability. The RTU must perform its programmed operations without stalling. Where ever possible, the system integrator should not have to learn a new programming language. The RTU should satisfy all the communication requirements and it should perform communications successfully. It is best if the RTU can communicate using an industry standard such as Modbus.

When selecting sensors, the sensor signal should match the analog input on the RTU. In other words, if the RTU has a sensor input range of 0 to 5 Vdc, the sensor should have the same output range. If the RTU had an input range of 0 to 2.5 volts, and the sensor signal varied from 0 to 5 volts, half of the sensor range is useless.

For what ever reason, factory representatives/salesman do not fully understand the automation requirements of your canal system. They may be trying to give you honest advise, but there is a tremendous difference between the performance of

their RTUs or sensors in a factory compared to an irrigation canal. It is best to talk with other technicians and engineers who have extensive field experience to determine the best device for your application. Manufacturers can also be asked for a list of companies that use their instrumentation device. In most cases, these people are aware of good and bad points of the device.

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