INGRAM PRODUCTS, INC.

AP-1
Liquid Level Monitoring

Introduction

The monitoring and control of liquid level is a common requirement in a broad range of industrial, processing and plant management systems. In many situations, it is only necessary to ensure that a liquid does not overfill a container or that the liquid level does not drop below a prescribed minimum level. Applications include boiler low level cut-off protection and feed water level control, pump interlock and control, food and cooking equipment, dairy monitoring systems, steam cookers, water dispensing systems and moisture (leakage) detection.

There are a wide range of measuring techniques available, including ultrasonic, hydrostatic pressure monitoring, optical and simple conductive measurement. The type of measurement is often dictated by the type of fluid being monitored. Highly caustic or corrosive materials often preclude any direct contact with the liquid, necessitating indirect measurement using ultrasonics, radiometric or other non-contact techniques. In the other extreme, if the liquid is conductive a low cost probe can be used that simply measures the presence or absence of a liquid.

Table 1 provides the conductivity of many common liquids. One of the most common liquids is water, which has a conductivity of ~ 5k ohms/cm, verses open air, which is a virtual insulator with a conductivity greater than 10 mohm/cm.

As shown in Figure 1, to detect the presence of water simply requires a probe inserted into the tank. Assuming that the probe contacts are ~ 1 cm apart, if the water does not make contact the probe equivalent resistance R_e is an open circuit and R_1 and R_2 form a voltage divider. The voltage at A will be $R_2/(R_1 + R_2)$ X Va = ~ 6 volts. If the water does make contact with the probe R_2 and R_e (~ 5 k) are in parallel with a resistance of $(R_2 + R_e)/2$ = 2.5 K the voltage at point A will shift from ~ 6 volts to ~ 3 volts.

Figure 1.

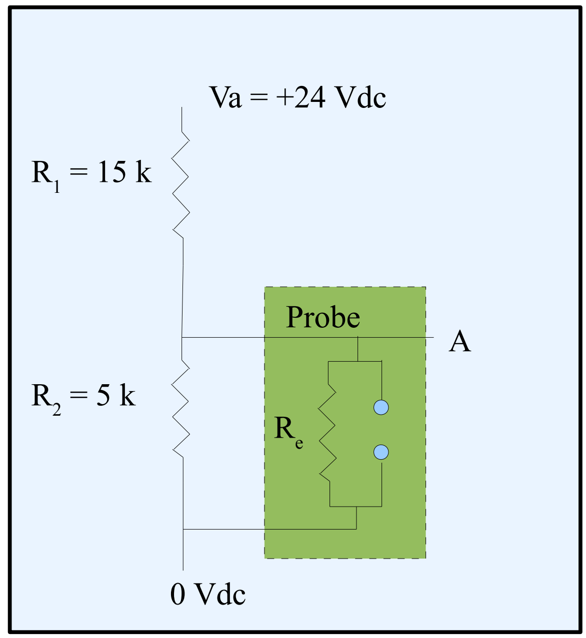


Table 1.

Liquid/Material	Ohms/cm
AIR	> 10m
Aluminum Hydroside	2.2k
Aluminum Sulfate	2.2k
Ammonia	5k
Ammonium Chloride	1k
Ammonium Hydroxide	10k
Ammonium Nitrate	18k
Ammonium Sulfate	10k
Baby Foods	1k
Barium Chloride	1k
Barium Nitrate	1k
Beer	2.2k
Black Liquor	1k
Borax (Aqueous)	10k
Brine	1k
Buttermilk	1k
Cadmium Chloride	1k
Cadmium Nitrate	1k
Cake Batter	5k
Calcium Chloride	1k
Calcium Hydroxide	10k
Catsup	2.2k
Caustic Soda	1k
Cement Slurry	5k
Coffee	2.2k
Corn Syrup	45k
Cream Corn	2.2k
Ferric Chloride	10k
Ferrous Sulfate	10k
Ink (water based)	2.2k
Jams/Jellies	45k
Juices (fruit/vegetable)	1k
Lithium Chloride	1k
Magnesium Chloride	1k
Magnesium Hydroxide	2.2k
Mayonnaise	5k
Mercuric Chloride	90k
Milk	1k
Molasses	10k
Mustard	1k
Oil – Soluble	10k
Paper Stock	5k
Photographic Solutions	1k
Plating Solutions	2.2k
Potassium Chloride	1k
Salts – chemicial	2.2k
Sewage	5k
Silver Nitrate	1k
Soap Foam	18k
Sodium Carbonate	2.2k
Sodium Hydroxide	1k
Soups	1k
Starch Solutions	5k
Vinegar	2.2k
Water – Carbonated	3k
Water – Condensate	3k
Water – Chlorinated	5k
Water – distilled	450k
Water – deionized	2.0 M
Water – Hard/natural	5k
Water – salt	2.2k
Wine	2.2k
Zinc Chloride	1k
Zinc Sulfate	2.2k

Micro-PLC Level Control

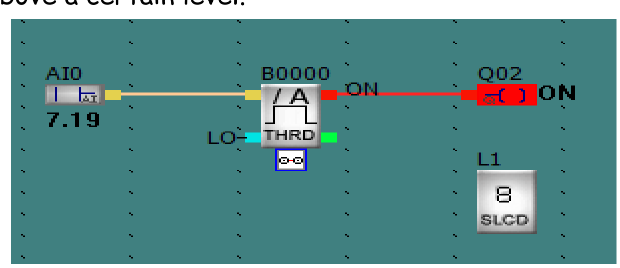
The APB family of micro-PLC's offer both analog and digital inputs and numerous analog 'function blocks' that allow the processing of signals. The extended processing capability offered by micro-PLC's allows a wide range of incremental features to be added at minimal (no) cost.

The analog inputs of the APB product provide an input impedance of ~ 50k ohms, which, in the previous example would be in parallel with the sensor probe. Since this impedance is ~ 10 X the activated probe resistance it can generally be ignored in most applications.

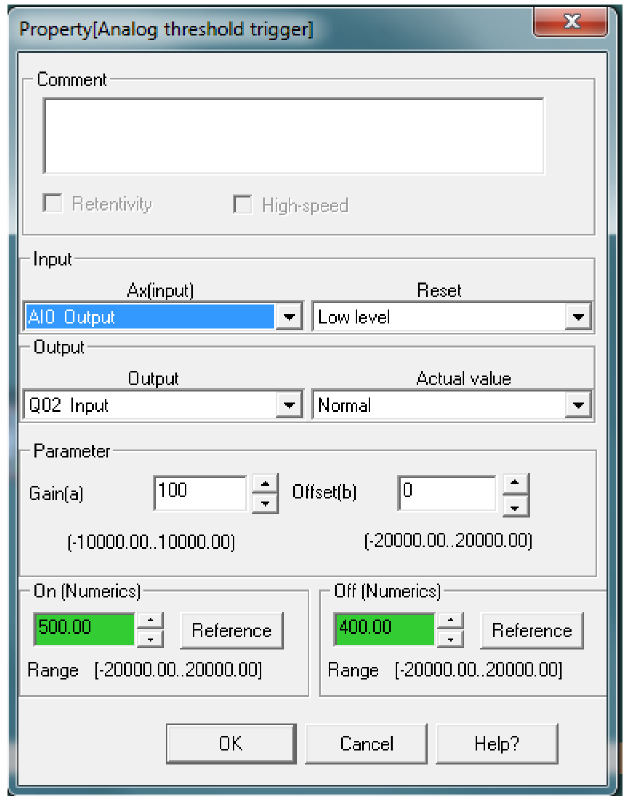
NOTE: The SR family of micro-PLC's also offer analog input capabilities but the effective input impedance is much lower, typically ~ 2k ohms. Use of the SR family with conductive probes would typically require an input buffer/amplifier.

In our previous example, it is known that if the probe is in contact with water the input voltage will shift from ~ 6 Vdc to ~ 3 Vdc. The APB controller offers an 'Analog Threshold Detect' (THRD) function ideally suited to detect this type of change.

In the following circuit analog input 0 (AI0) is connected to THRD threshold detect function block. Output 2 (Q02) will be activated if the threshold detect circuit determines that the input voltage is above a certain level.

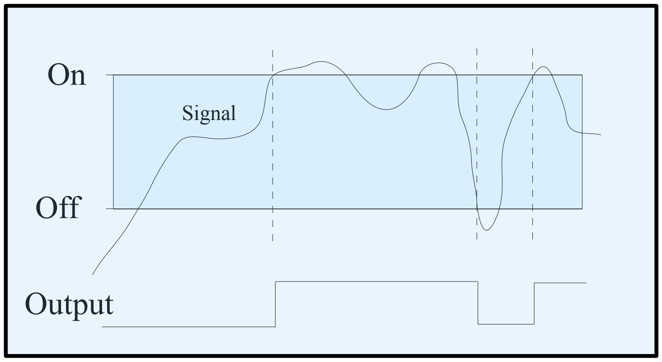


Double clicking the THRD block will display the associated parameters.



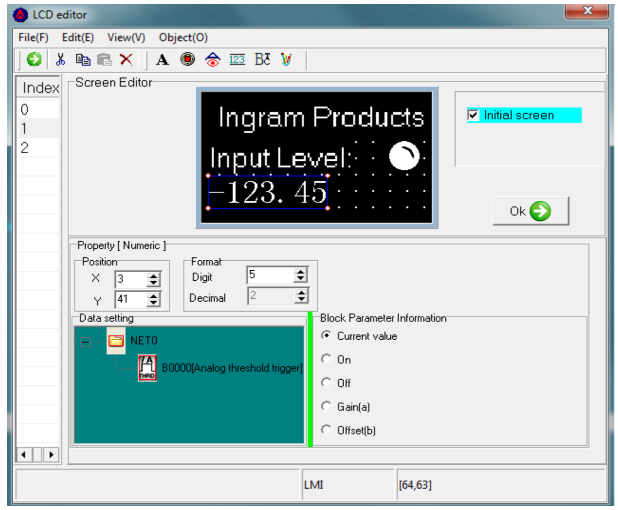
As shown, the 'On' threshold has been set to 500 and the 'Off' threshold has been set to 400.
The On and Off thresholds provide hysteresis to minimize false triggering. When the signal reaches the On level the output will be activated. It will not be deactivated until the signal drops below the Off level. Once the signal drops below the Off level, it will not activate until it reaches the On level. Signal level changes within the band defined by the Off and On levels will not change the output state.

Figure 2



The circuit shown also includes an HMI display block (SCLD). For test purposes we can configure the HMI to display the current value of the Threshold Detector and the state of the output QO2. When the program is loaded the HMI will display the current value in place of the -123.45 and the will toggle with the output state.

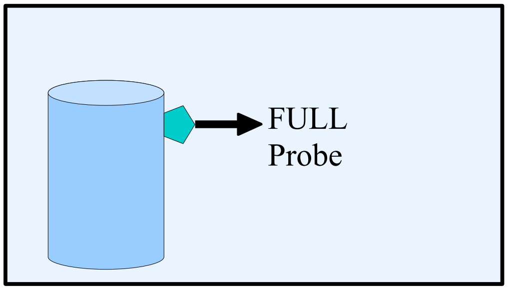
Note: The SR Quick Start Guide provides an introduction on using functional block programming with the SR family of controllers and the SuperCad software. The APB family uses a similar programming environment (APBSoftware) which may be downloaded at no cost. The APBSoftware allows you to graphically construct the application program, run the program in a simulator mode and to download the program to an APB controller and monitor the program in real time.

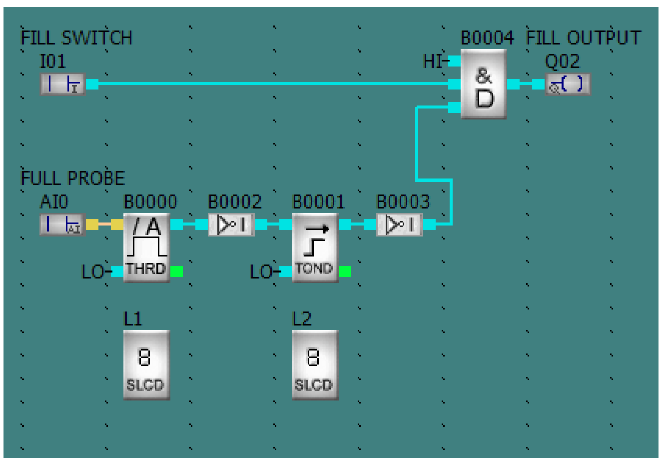


Fill/Drain Control Logic

Having established a method to detect the presence of a liquid it is now possible to implement some simple control sequences. For a simple FILL system it is necessary to ensure that the tank being filled does not overflow. A probe will be installed at the top of the tank to detect when the tank is at the FULL level. A digital input will be connected to a 'FILL SWITCH'. When activated, a 'FILL CONTROL' output relay will be activated until the probe indicates that the tank is full.

To avoid momentary triggering of the circuit (waves etc.) a simple timer may be used. If the probe signal is activated it will start the timer. If the timer 'times out' it's output will activate. If the probe signal is removed before the timer 'times out' the timer will be reset.

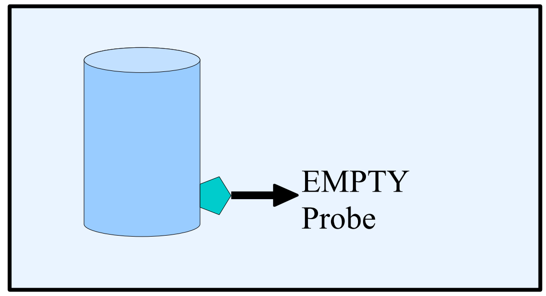




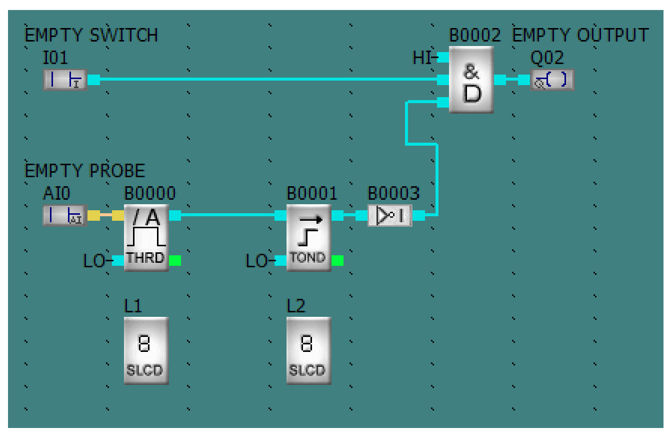
In the circuit shown, we have added a Time-On delay (TOND) block to control the output and have added an inverter block (B0002) between the threshold detector and the TOND block. When the probe signal becomes active (water detected) the timer will start. If the signal becomes inactive before the timer expires the timer resets. If the signal stays active for the full time-out delay then output Q02 will become active. A second SCLD display block has been added to give the option of observing the timer value on the HMI display.

The FILL SWITCH input and the inverted output of the timer are connected to the AND block B0004. If the FILL SWITCH is active *AND* the timer output is NOT ACTIVE the FILL OUTPUT will be active.

A similar situation may occur when ensuring that a tank has not been emptied below a minimum level. In this case an 'EMPTY' probe is installed at the lowest level of the tank.



The 'FILL' switch becomes the 'EMPTY' switch and the FILL OUTPUT becomes an EMPTY output. The Output will only become active if the EMPTY probe detects that liquid is available, avoiding emptying a tank below a safe level.

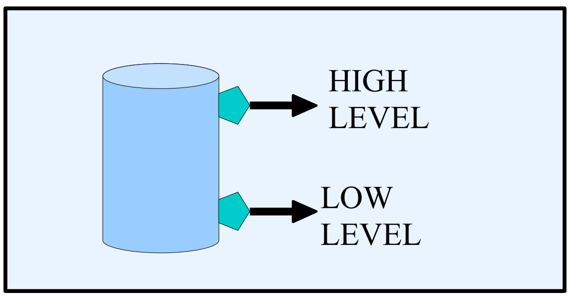


The only change required is the removal of the B0002 inverter. The probe signal now must be present to allow the empty process to proceed. Previously, the probe signal (FULL) had to be absent to allow the fill process to proceed.

Automatic Level Manager

The FILL and EMPTY examples may be easily combined to provide a controller that ensures that the liquid remains above the LOW level and below a HIGH level.

In this example, our switch input acts as a 'SYSTEM ON' switch. When activated, the system will attempt to maintain the level between the LOW and HIGH levels.

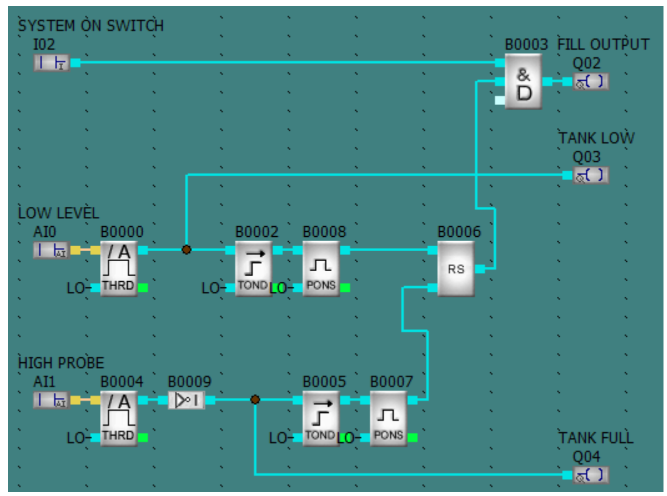


The output will control the filling of the tank by opening a valve or activating a pump. The outflow from the tank is not directly controlled, but a relay output will be provided to indicate when the tank level is below the LOW level.

In the circuit shown we have replaced the inverter on the output of the TOND blocks with a programmable one shot (PONS) block. This block will generate a single pulse (in this case 100 msec) when the input transitions from off to on. The outputs of the two PONS blocks are used to toggle a set/reset latch RS latch (TPBL) B0006. When the LOW level probe detects the absence of liquid it sets the latch ON. When the FULL level probe detects liquid it sets the latch OFF.

If the latch is ON *AND* the SYSTEM SWITCH is ON the FILL OUTPUT will be active, allowing the tank to fill.

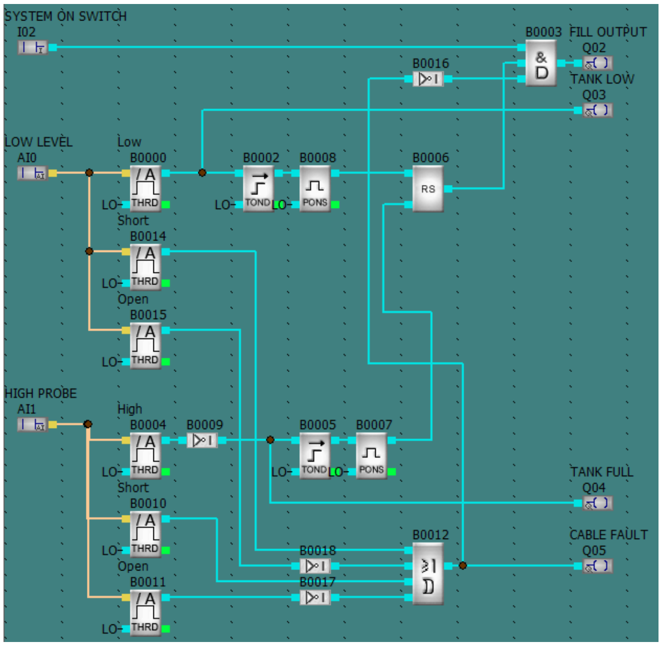
Once the tank starts filling it will continue until the HIGH level probe turns off the latch. The FILL output will not turn on again until the liquid has dropped below the LOW level probe.

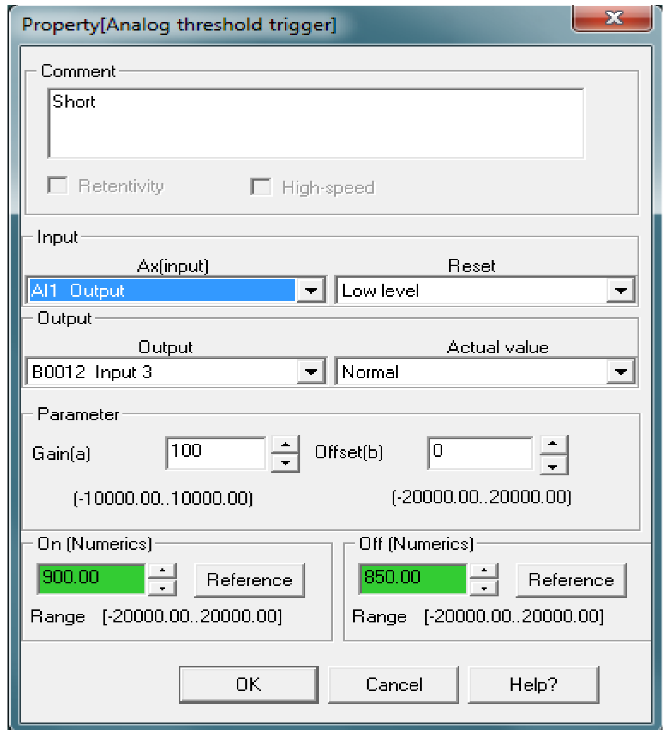


Cable Integrity

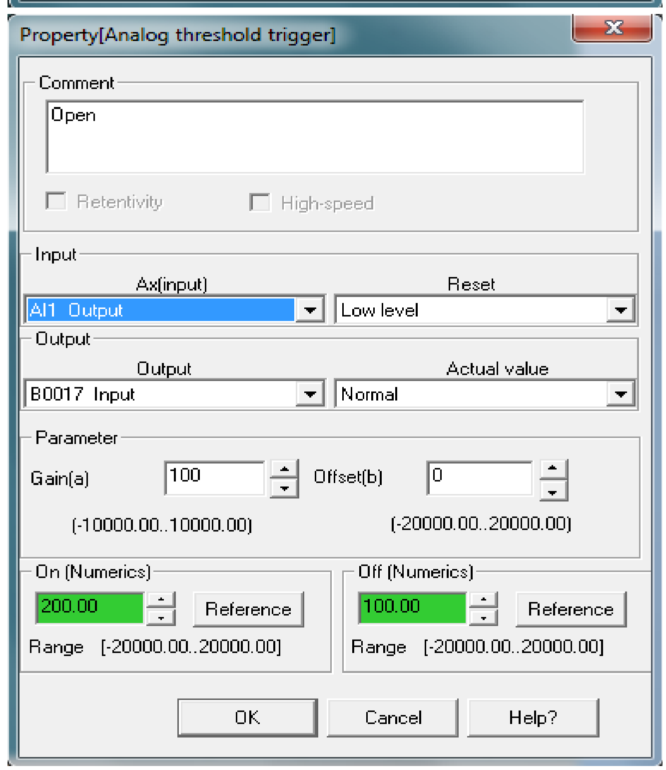
Cable integrity can be a major source of concern in systems where peripheral damage may occur. In our previous example, if the cabling to the LOW probe shorts the controller will see the signal as if the sensor has detected liquid even if the tank is empty. No signal is available to turn off the pump which may lead to catastrophic pump failure. Similarly, if the cabling to the HIGH sensor is open (disconnected) the controller will not sense that the tank is full, allowing the tank to be overfilled.

These cases may be addressed by adding additional Threshold detectors to determine if the signals are within a valid range.





Threshold detectors B0010 and B0014 detect when the cable is shorted. Threshold detectors B0011 and B0015 detect when the cable is open. These signals are fed to an OR block B0012 that will activate the CABLE FAULT output if any inputs are out of the acceptable range.



The CABLE FAULT state is inverted and connected to the FILL OUTPUT control AND block B0003 to ensure the fill output is deactivated in the case of a fault.

The parameter configuration for the Open/Short detectors show that the On/Off values have been set outside the range of the normal signals.

Multi-Stage Monitoring

In the previous examples one or two simple conductive probe devices have been used to illustrate low cost FILL/DRAIN and LEVEL control applications. The requirement was to detect when a liquid was at an extreme level – either the tank was 'full' or the tank was 'empty'. In some applications it may be desired to add additional sensors to provide a finer 'granularity' of the measurement.

One approach is to move towards a more expensive sensor technology. Optical and ultrasonic sensors will accurately measure levels to within millimeters. Radiometric techniques allow measuring levels in extremely caustic, corrosive or extreme temperature conditions. Unfortunately, these advance technologies all carry addition costs.

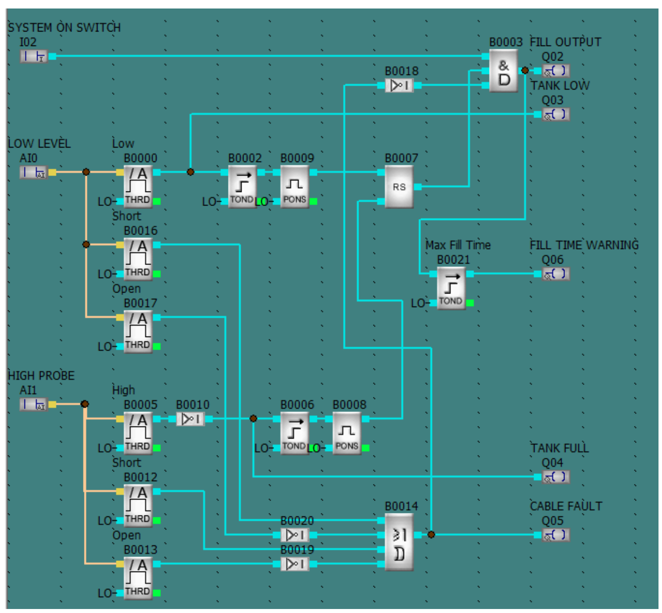
The APB-22MRD controller provides a total of 14 inputs and 8 outputs. Twelve of the inputs may be used as analog inputs so in low cost applications 12 different 'levels' may be easily detected and acted upon. For example, a 'light tree' could be attached to the controller showing 8 different levels.

In other applications, several sensors may be added to provide a rough 'inventory' measurement system. Straight forward logic coupled with the ease of use of the integrated LCD display screen allows displaying the inventory levels and possibly triggering warning/alarm signals if the level falls below preset minimums.

Time Monitoring

In any material handling system a constant concern is when the inflow or outflow of material is blocked. The APB product family offers an range of timer functions that may be used to add protection against these situations.

In the circuit below, an additional TOND timer has been added, activated whenever the FILL OUTPUT is activated. If the HIGH Level sensor is not triggered within the prescribed time, indicating a problem with the inflow of material, the FILL TIME WARNING output will be activated.



Energy Wise Control

With the ever increasing cost of energy most utilities have migrated towards 'demand based' billing which often reflects surcharges based on the time of day.

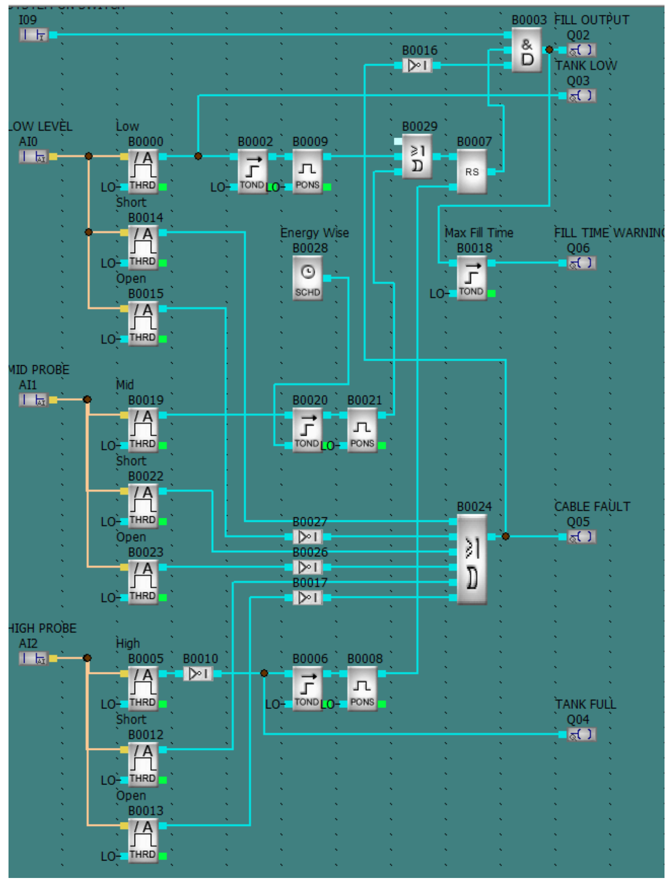
Assume that our automatic level manager described above is in fact in place to maintain levels within large reservoirs. In the assumed scenario three detectors are in use: a HIGH sensor, a LOW sensor and a mid-point HALF-FULL sensor. It is also assumed the the fill/empty cycle extends over several hours or days depending on the demand and that electrical kwh costs approximately double during the peak hours of 6:00 AM and 8:00 PM.

Substantial savings may be realized by avoiding the activation of the refill pumps during peak hours. At the same time, the reservoir cannot be allowed to fully empty. The pumps must activated if the level drops below the LOW sensor.

The APB controller supports a scheduler function block (SCHD) that implements a time of day scheduler. Each scheduler block may be triggered at 32 unique 'event times' based on the time, day-of-week, month, and year. In this case, it is only required that the scheduler turns ON at 6:00 AM and turns OFF at 8:00 PM.

The previous Level controller may be augmented by adding a third input probe to detect when the level is at or above the 'mid-point' and a SCHD block to provide the time based scheduling control.

In the circuit shown below a 'MID' level sensor has been added (B0019 – B0023). The Cable Fault OR gate has been expanded to accept 6 inputs to include the MID sensor cabling. The SCHD, B0028 has been programmed to turn ON at 6:00 AM each day and to turn OFF at 8:00 PM. The output of the scheduler is connected to the RESET input of the MID level TOND Timer Delay block B0020. When the scheduler is ON the output holds the TOND in the reset state, preventing it from activating the RS latch.



In operation, if the water level is below the LOW level sensor the FILL OUTPUT will be activated regardless of the time-of-day. If the MID level sensor is activated between 8:00 PM and 6:00 AM the FILL output will activate, allowing the pumps to operate using lower cost energy.

Summary

Industry standard 'conductive probe' technology provides a reliable, low cost solution for applications requiring the monitoring and control of liquid levels. The technique relies on the conductivity of the liquid (material) to be measured and translates into a change of voltage when the probe is connected to resistive divider.

The APB micro-PLC product family has integral support for analog signals, allowing conductive probes to be connected directly to the micro-PLC inputs.

The APB products are programmed using functional blocks in which each processing element is represented as a block that performs a specific operation on the input signals. Programming the device is simply a case of connecting the blocks and specifying operating parameters such as gain or elapsed times. An APB controller will support up to 320 functional blocks.

The APB controller family is provided with an integral HMI device that allows the user to display and change program parameters.

For advanced plant management a Modbus adapter is available allowing centralized monitoring and control.

APB-22MRD (14 Inputs, 8 Outputs)

The analog and timer blocks available on the APB family provide powerful building blocks to address Level monitoring and similar control applications. A 'threshold detection' block provides signal offset and gain adjustment, threshold detection and hysteresis within a single control block. When coupled with an On-Delay timer simple FILL/DRAIN control relays may be easily implemented offering time integration of the signal and signal hysteresis to minimize false signaling.

The true power and flexibility offered by a micro-PLC implementation is realized when additional features are to be added. The simple FILL/DRAIN applications were 'combined' to provide a functional level control system that will automatically maintain the level of a liquid between a low and high sensor level.

This application was further expanded by adding open/short cable detection, again at no incremental cost, that protects against potentially costly peripheral equipment damage in cases where the installed sensors or cabling fail.

This fail-safe approach was further developed by adding a timer to offer a warning if the fill operation was not completed within a prescribed time period, possibly indicating a material leak or clog in the inflow subsystem.

Finally, a third sensor was added, coupled to a time-of-day scheduler, that will minimize power consumption during peak billing hours by only activating the pump subsystem if it is absolutely necessary.

These incremental features, which differentiate the solution from standard moisture sensing relays were all added to the APB controller with no additional hardware costs and minimal software efforts. The final solution used less than 10% of the available functional blocks (30 blocks out of 320 available).

The integral HMI further enhances the device by allowing the display of status information and allowing the operator to change specific set-points as required.

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