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PLC Motor Control Fundamentals and Safety Features; A Case Study

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Abstract

Electric motors are the most used final control elements / actuators in process control and automation. This include DC, Synchronous, and AC induction motors. Squirrel cage three phase induction motors are the most popular in industry as they only require one AC source, self-started, and exhibit a high degree of ruggedness. The motor speed is typically regulated using a PLC microprocessor based variable speed / frequency drives, which greatly reduce energy consumption when adequately utilized in the control. All industrial motor starters must at least contain fuses, disconnect switch, and thermal overload protective relays. They can also include protection against over load / torque and other failures or up normal conditions, which might damage the motor. PLC software must account for additional protections and adheres to all safety standards.

This paper uses a case study extracted from an actual process control implemented project to highlight PLC motor control safety and fundamentals. Real time control used in a waste water treatment facility for the processing of high flow storm rain water using the Allen Bradley (AB) SLC 500 Programmable Logic Controller (PLC). The rain water is channeled to two large wet wells, the east wet well and the west wet well. The water is pumped to the river from the two connected wells at constant rate using a predefined process sequence control. Two motor derived constant speed immersed pumps are used, one in the east wet well and one in the west wet well. Each pump is equipped with an overload alarm switch, which is used to trigger any unusual conditions such as over temperature or over load. The motors provide an input discrete signal indicating if the motor is running or not. The motors can also start by activating the Push Button located on the local panel if the AUTO/MAN switch is in Manual.

Three float switches are used to provide an accurate indication of the water level at three pre- specified critical east / west wet well. The Low-Level Float switch triggers the stopping of the running pump. The High-level Float switch triggers the starting of the scheduled pump. If the scheduled pump fails to start within 5 seconds, the second pump is selected and started. An alarm must be issued to alert the operator of any motor failure. The Very High-level float switch triggers the starting of both pumps. If either of the two pumps fails to start the corresponding alarm is activated by the control. Failure of both pumps shuts down the system.

Pumps are scheduled to run according to pre-defined calendar. This input is expected in hours of accumulated total pump run time. The two pumps must alternate while the water level is below the Very High Level and above the Low Level. The two pumps run at levels above the Very High Level and cascaded timers are not altered during this condition. This paper shows the design and implementation of the process control using an abbreviated version of the typical original system used in waste water facilities with secondary treatment and separate rain water processing.

A. Safety Precautions and PLC I / O Map

Wet well water pumps are driven by a sophisticated induction motor. They are designed to safely operate in and around water. Their secure sealing, rugged construction, and mounted protective safety monitoring instrumentation provide pump equipment long life and safe operation. In wet pit applications, submersible pump relies on the liquid in which it is submerged to dissipate the heat from the frame. If pump runs on dry or low level well, the shaft and impeller spin at extremely fast rates. With no water to transfer their rotational energy to, that energy is released as heat instead. Its moving parts will become extremely hot, causing severe damage to the pump over time and greatly limiting its service life. Also, if the pump pressure becomes too high, it can put excess stress on the sealed casing and pipes, potentially causing them to crack or even burst. Float switches used to monitor wet well level can fail or get stuck on causing pump to run dry, which will burn out the pump prematurely. All potential failures are prevented by utilizing mounted pump / motor safety features and the. redundant PLC implemented precautions discussed next.

The first step in the design of a PLC control application is the translation of the process specification to actual input / output resources. This is known as the PLC Input / Output (I/O) map. This important step lists all I/O tags, assigned PLC addresses, and description. Figure 1 lists the wet wells pump control system discrete inputs and the corresponding PLC input tags. Figure 2 shows the same process for the PLC symbol editor screen. Figure 3 and Figure 4 repeat the same process for the control system discrete outputs. Notice that none of the real analog inputs / outputs for this control process is listed. We only limited our case study to ON / OFF control based on water level simulated analog real time measurements relative to user defined set point for the wet wells.

Tag Nam	Address	Comments
OFF_FLOAT	I:2/0	Off Float Switch
ON_FLOAT	I:2/1	On Float Switch
OVERRIDE_FLOAT	I:2/2	Override Float Switch
E_ROL	I:2/3	East Pump Running on Line
W_ROL	I:2/4	West Pump Running on Line
AUTO	I:2/5	Auto/Manual Selector Switch

Figure 1: Pump Station System Input

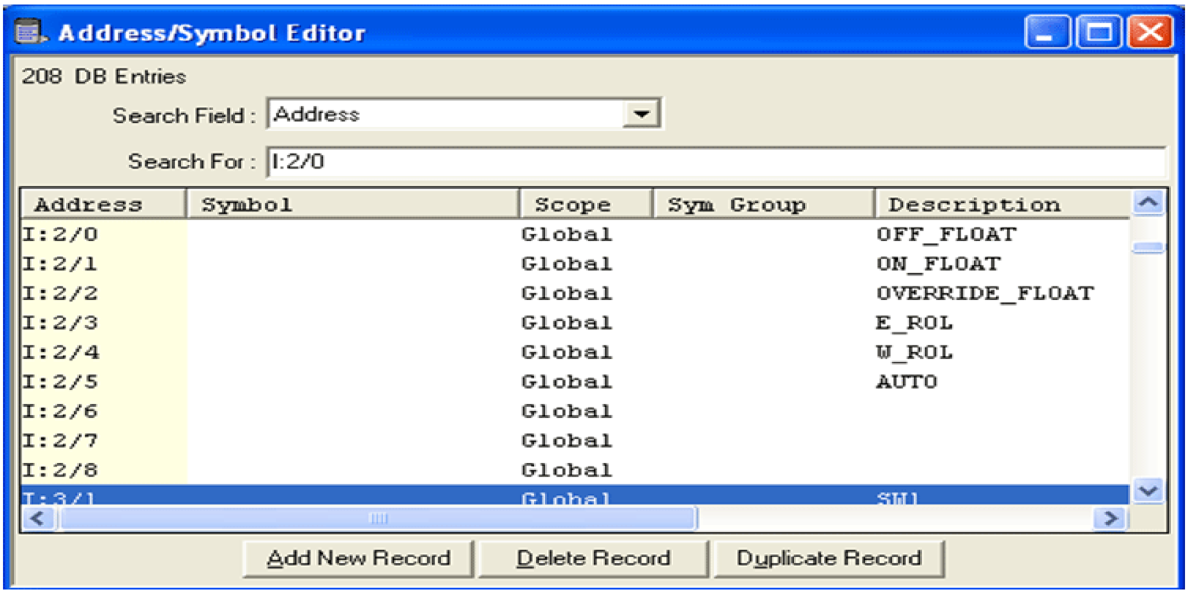

Figure 2: Pump Station System PLC Input Tags

Tag Name	Address	Comments
E_PUMP	O:3/0	East Pump
W_PUMP	O:3/1	West Pump
E_FTS	O:3/2	East Pump Fail To Start
W_FTS	O:3/3	West Pump Fail To Start
COMMON_ALARM	O:3/4	Common Alarm

Figure 3: Pump Station System Outputs

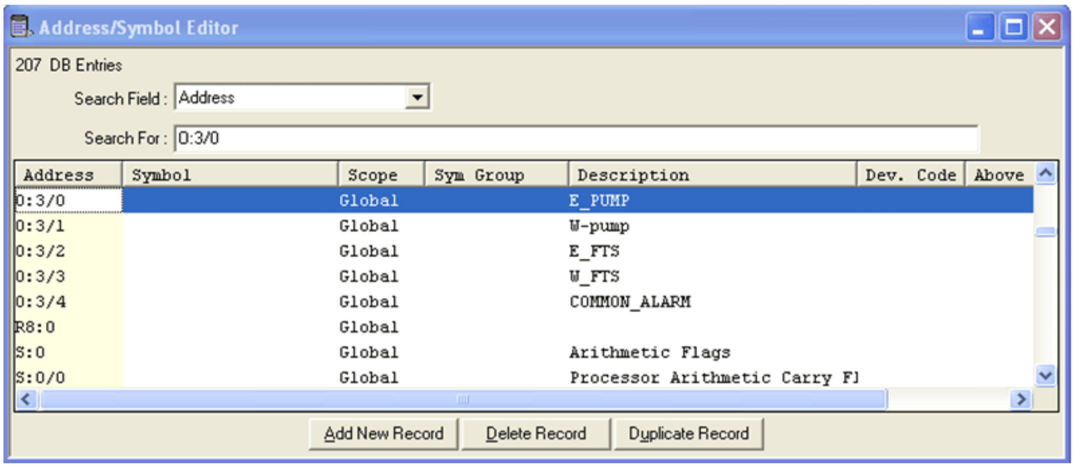

Figure 4: Pump Station PLC System Outputs Tags

B. Automated System Building Blocks

The PLC processor supports subroutines that allow an efficient program structure. File 2 (main file) define the structure of the program. Subroutine (SUB3) contains the code that corresponds to specific tasks or combinations of parameters. Each subroutine f provides a set of input and Output parameters for sharing data with the calling file. Figure 5 shows the subroutines designed and implemented for the wet well Pumping station control in the Project View. Figure 6 shows the same in the PLC Ladder View.

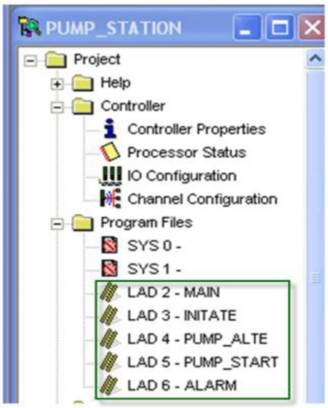

Figure 5: Pump Station System PLC Subroutines (Project View)

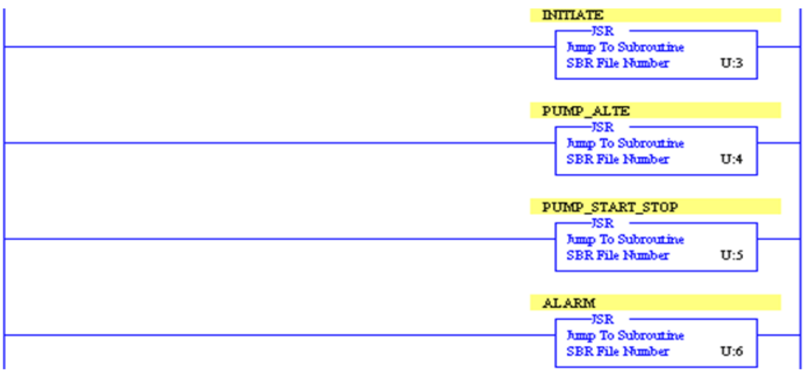

Figure 6: Pump Station PLC Subroutines (Ladder View)

C. Pumping Station Ladder Implementation

The Initialization Block "INITIATE" is shown in Figure 7. A one-shot cause this rung to execute once when selector switch AUTO/MANUAL is in AUTO.

i.Pump Alarms

The Pump Alarm Subroutine will include, eight Rungs, (Figure 8 through 10). One common alarm is dedicated for the east wet well and the other for the West wet well. A common Alarm is triggered from east pump motor fail to start, west pump motor fail to start, or emergency shutdown.

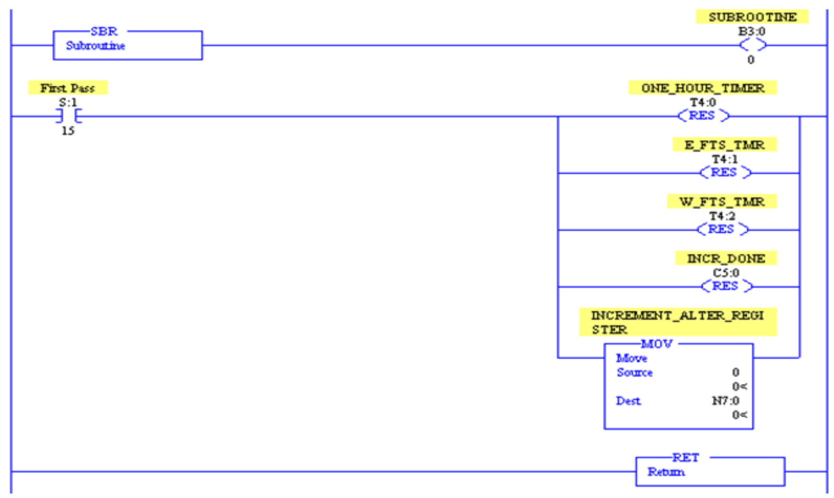

Figure 7: Initialization Subroutine Rungs

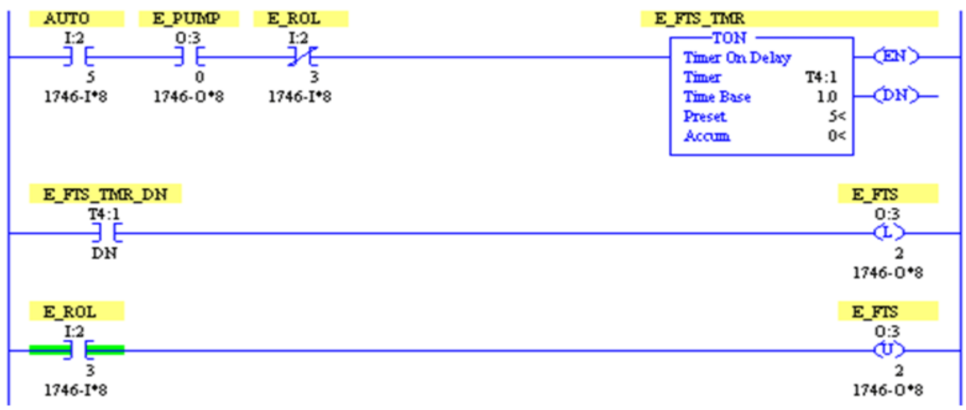

Figure 8: East Pump Failed To Start Rung

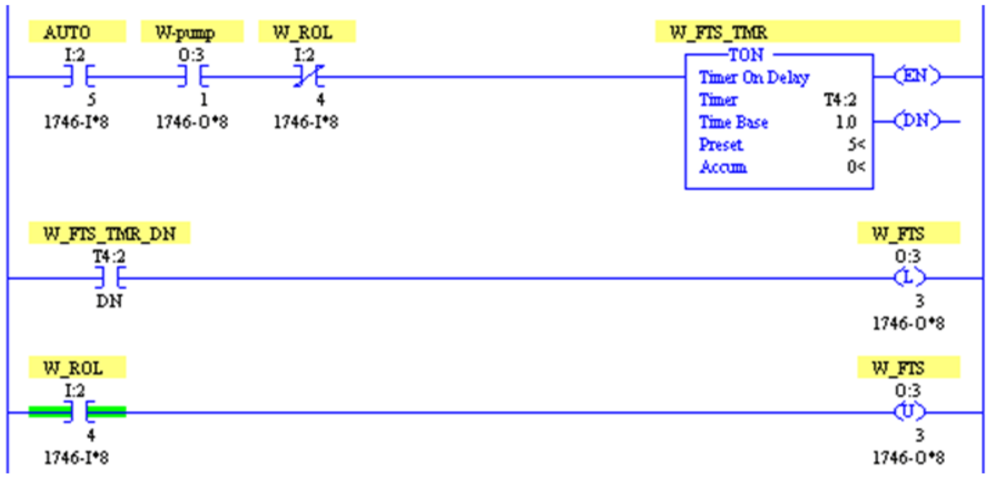

Figure 9: West Pump Failed To Start Rung

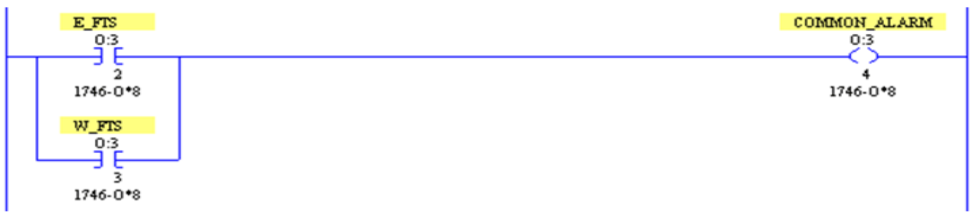

Figure 10: Common Alarm Rung

- The East Pump fail to Start is ON, If Motor running input is not received within 5 seconds from the initiation of the rung command.
- An alarm is issued once the selected pump fails to start. The operator is expected to attend to this failure and clear the cause to allow and enforce the pump alteration calendar. Having a situation where both pumps failing to start can constitute an emergency condition and must be eliminated. A third stand by pump and the manual control system can eliminate this problem. The latch for the fail to start is used because the same condition is used to allow the pump output.
- West pump Fail to start is ON if the Motor running input is not received within 5 seconds from the West Pump motor run output command. The latch for the fail to start is used because the same condition is used to allow the pump output.
- The Common Alarm goes ON if either of the East Pump fail to Start or the west pump fail to start or Emergency Shutdown (ESD) is triggered.

ii. Pumps Alteration

- The two pumps alteration follows a defined calendar based on scheduled run time in hours (simulated by 60 seconds). An ON Delay Retentive timer shown in Figure 11 is configured for one hour Preset Value (T4: 0.ACC). The Done bit of this timer is used to trigger an up counter, which is configured to implement the desired pump schedule calendar Figure 12.
- The Pump Calendar is initialized by the operator in hours, which indicate the time intervals for the two pumps alterations. The Up counter shown in Figure 13 is used to keep track of the accumulated pump run time in hours. The counter is incremented every hour of operation.
- A memory word (N7:0) as shown in Figure 13 is used to select one of the two pumps to run and is named Increment register (INCRM).

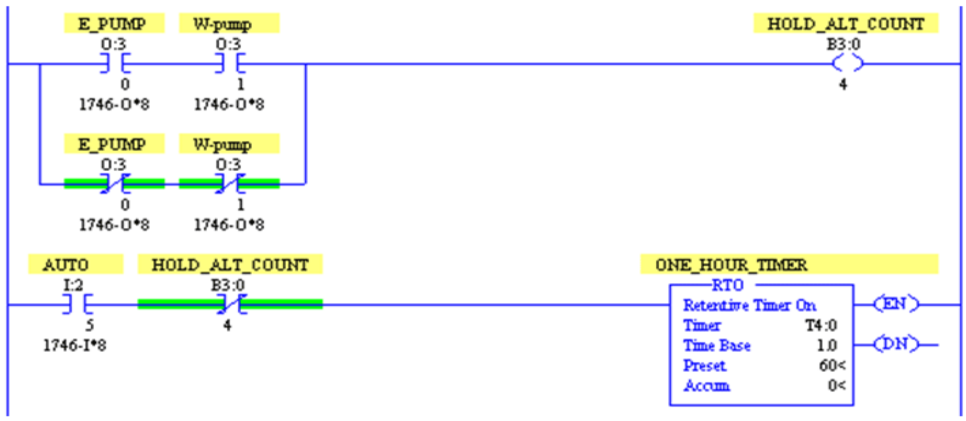

Figure 11: Pump Station One Hour Timer Rung

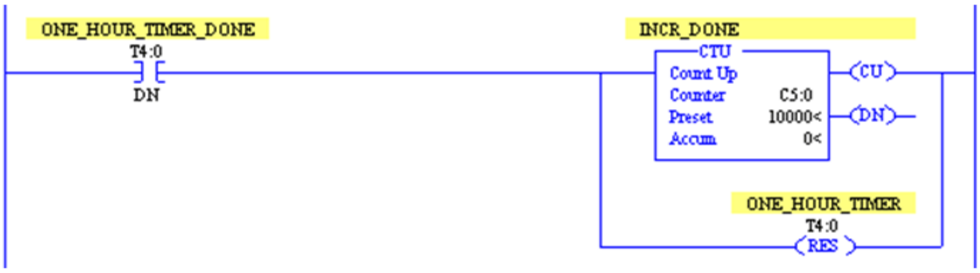

Figure 12: Pump Station Counter Rung

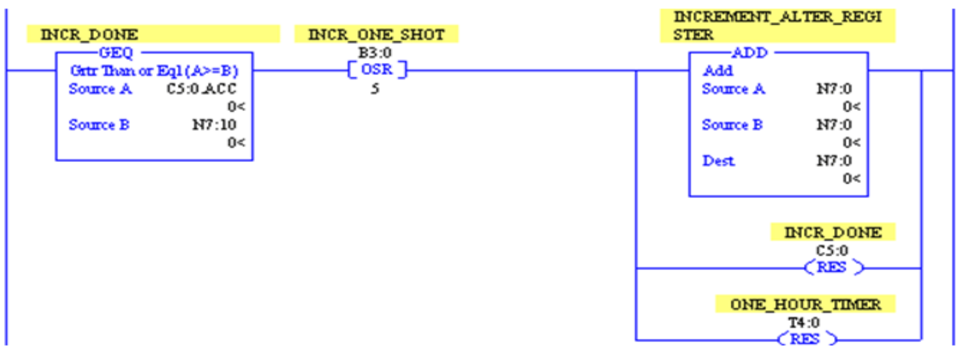

Figure 13: Pump Station ADD Rung

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iii. Pumps Selection

- The increment (INCRM) register will increment every time the user calendar expires. The even values of this register (N7:0/0 is False) will be used to select and start the East pump. The odd values of this register (N7:0/0 is True) will be used to select and start the West pump. Figure 14 and Figure 15 implement this logic.
- If system is placed in AUTO and the Wet Will water level exceeds the High limit, the scheduled pump will be selected and run. If the selected pump fails to start, an alarm is issued, and the other pump is selected and started. If the water level exceeds the High High limit, both pumps are selected and started regardless of the defined calendar.
- The Override float switch ON status will override the selection process and run both two available pumps, otherwise the scheduled pump will rum.
- The Off-float switch will cause the running pump to stop when the switch gets activated. Pumps cannot run on empty or law level well.
- Once a pump is done with its calendar before the off switch becomes active and while the on float goes off, the other pump must run to help reduce the wet level to the low value, which triggers the Off-float switch. This action is triggered by the done bit shown in the first rung of the ladder

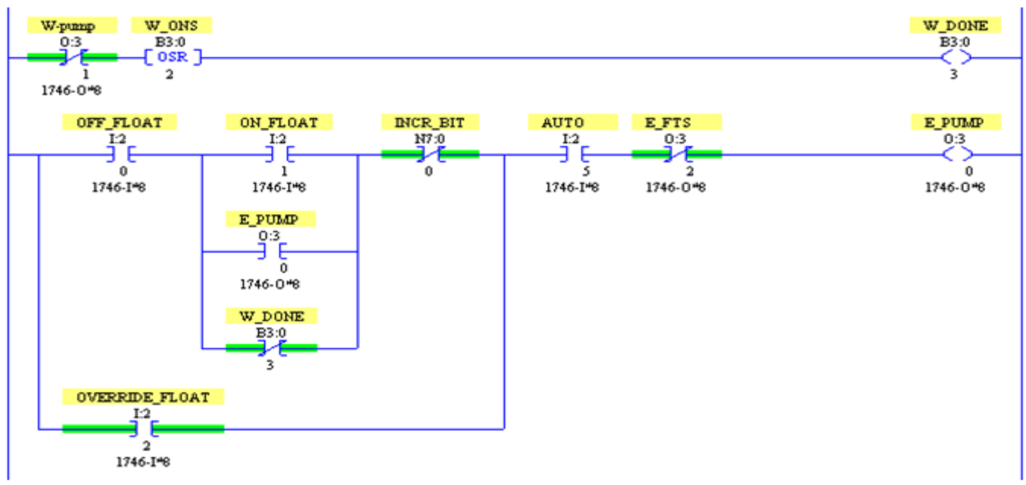

Figure 14: East pump rungs

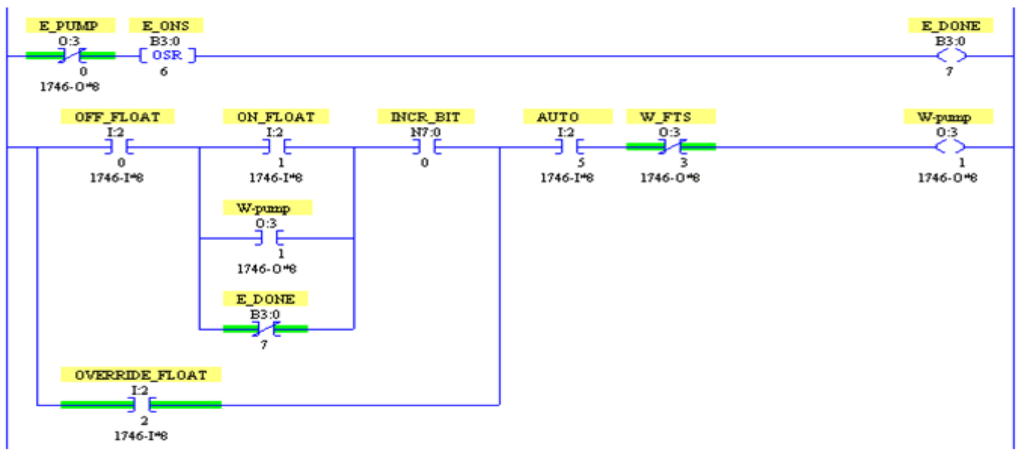

Figure 15: West pump rungs

Conclusion

This paper offers readers an insight to PLC programming with focus on real industrial process automation applications and immersible motors / pumps safety control features. Rockwell Allen Bradley SLC-500 PLC hardware configuration and the AB RSLogix 500 software were used for this implementation and final commissioning. LogixPro 500 simulation software was also used initially to implement and test the required process control before any need for the real PLC hardware and physical field instrumentation. The case study selected for this paper can serve as a cap stone project encompassing most of the concepts covered in PLC process control and industrial automation. The project is part of larger waste water treatment control process, which was implemented by the authors several years ago and documented in a recently published text book. The abbreviated part included in this paper deals with a common process control task in the Waste Water Treatment industry, which has to do with the pumping station control. The coverage in this paper is simplified to one site and can be easily transformed to an equivalent implementation using the Learning Pit LogixPro 500 simulation software.

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