Simplifying Allen Bradley PLC Digital Logic Programming Using Boolean Algebra Theorems

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Abstract

Process Control Instrumentation is facilitated by accurate process programming. Wrong programming can damage process instruments and/or prevent attainment of desired result. Process Control Programming is performed using a Programmable Logic Controller (PLC) alongside a programming interface provided by a software. Ladder Logic (LL) is the most common PLC programming language amongst others like Function Block and Structural Test Code (STC). PLC programmers are initially faced with problem of relating the problem statement and test criteria to ladder logic which determines the blocks to use to get the desired solution.

In this paper, Boolean Algebra theorems were applied to simplify the problem definition. This was testedon asimple Compressor Control System. This involved representing the problem on a truth table and simplifying using Boolean simplification theorems.

Results showed that Boolean Algebra can be used to simplify Digital Process Control problems. All test criteria were met. For better and protective control, alarms and notifications can be added as well as other mathematical blocks. The burden of problem interpretation especially with many Inputs and Outputs (IOs) is reduced.

Keywords —*PLC, LL, Boolean Algebra, IOs, CCS.*

I. INTRODUCTION

Programmable Logic Controllers (PLCs) automate the control and monitoring of physical industrial and infrastructure processes like power generation, gas/oil pipeline, and water management [1]. A PLC is akin to electronic microcontrollers like 8085 and the Arduino microcontroller family, in terms of fundamental operation. They all have digital/analog input pins which sensors/transducers and relays connect to respectively [2]. There is a programming interface that helps the processor carry out instructions based on the states of the input(s). However, a PLC is more standardized (4 to 20mA, 0 to 10V, 3 to 15 PSI) and more rugged for harsh environmental conditions. PLCs also communicate to HMIs (Human Machine Interface) for online set point programming, storage, and process monitoring. There are different brands of PLCs like Allen Bradley, Siemens etc. and different programming modes of which Ladder Logic is the most popular owing to the resemblance with actual relay contacts and coils.

PLC can easily automate digital control circuits like traffic lights, digital temperature control systems, digital filling stations, compressor control system, and a lot more. When the inputs become scaled or analog, it becomes comparatively complex to program. The programmer is faced with the task of deconstructing the problem statement to determine when AND or OR operations are needed, and this complexity can increase as the number of IOs increase.

Boolean algebra simplification comes in handy to help take away redundant operations (after simplification), leaving simple and comprehensible easy to program (in Ladder Logic) IOs.

II. LITERATURE REVIEW

Boolean Algebra is used to express the effects that various digital circuits have on logic input and it helps in manipulation of logical variables to the end that the best and simplest expression for performing a function is used [3][4].

Boolean Algebra finds application in only digital circuits and thus can be applied to digital control circuits. Complex expression resulting from problem statement in a control problem can be reduced effectively using Boolean theorems like Morganization, De-Morganization, duality theorems, Sums-of-Products (SOP), Products-of-Sums (POS), and logical identities [3].

Simplifying logic expression can be done using the Karnaugh map or any of the logical theorems for simplification [4]. Outputs of 1's or 0's can be used to generate the logical expression for simplification depending on which has the least expression. By NOTing, Morganizing and De-Morganizing, fitting output states can be gotten whether it represents pump-on or pump-off condition.

III. CASE STUDY APPLICATION (COMPRESSOR CONTROL SYSTEM)

A. *Problem Definition and Test Criteria*

This case study involves maintaining the pressure in a receiver on a compressor application [5]. The process diagram is shown in Figure 1 below. It contains two pressure switches (pressure switch low and pressure switch high which should close at 90 and 110 PSI. The process diagram includes an indicator light which should lit when the pumpis on. A pump is included to increase the pressure when it is below limit.

depends on the number of outputs. This case study has two outputs; hence two truth tables will be used to extract the necessary expressions for simplification and Ladder Logic interpretation.Test criteria 4 has some twists to it. The programmer should be able to differentiate between drain and pump mode. This is well reflected in the truth table below.

The truth tables are shown below (Table 1 and Table 2). Table 1 shows the state interactions between the two inputs and the pump. Table 2 shows the state interactions because two inputs and the lamp.

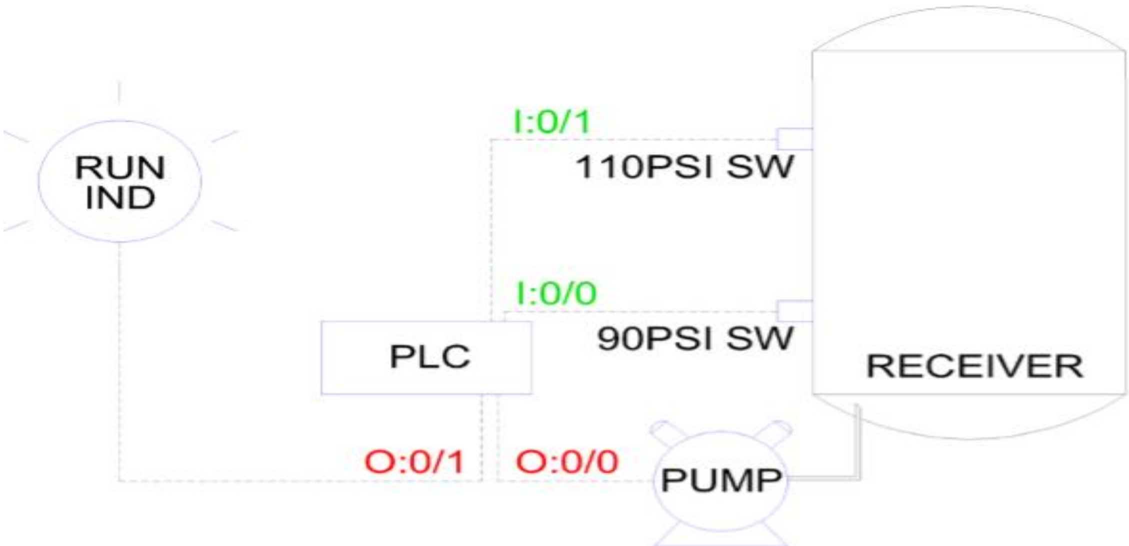

Figure 1: Process Diagram

For the test criteria (which will inform the logic table formulation), it is expected that:

1) When initially powered-on, the pump should start immediately but the light should be off.
2) The pump and the light should be energized when the low-pressure switch is on.
3) With the low pressure switch on, and the high-pressure switch on as well, the pump should de-energize and the light should remain energized.
4) With the low-pressure switch forced on and the high-pressure switch forced off, the pump should remain de-energized and the light should remain on.
5) With both pressure switches forced off, the pump should be energised, and the light should go off.

B. *Process Interpretation and Truth Table Formulation*

A study of the process diagram reveals that four (4) IOs are involved – 2 inputs (Pressure Switch Low – PSL, and Pressure Switch High – PSH) and 2 outputs(Pump and Lamp). The number of truth table

Table 1: Pump Truth Table

A (PSL)	B (PSH)	C (PUMP)
0	0	1
0	1	PSL ERROR
1	0	INDETERMINATE
1	1	0

Table 2: Lamp Truth Table

A (PSL)	B (PSH)	C (LAMP)
0	0	0
0	1	PSL ERROR
1	0	1
1	1	1

Two exceptions are evident from Tables 1 and 2 above. The pressure-high switch cannot be TRUE when the pressure-low switch is FALSE; this only reveals error in the pressure-low switch and must be investigated.

The indeterminate case seen on Table 1 above is not an error as the case of PSL ERROR. However, the truth table is not able to give a defined state for that condition as it can either be TRUE of FALSE depending on the previous state(s) of PSL or PSH. If PSH memory state value was TRUE and PSL has not been FALSE, then the mode defined is drain mode (C = 0), if PSL has gone false, then the mode defined is fill mode (C = 1).

C. Boolean Expression and Simplification

When choosing the expression for simplification, the programmer has the choice of using either FALSE outputs or TRUE outputs depending on the simplicity of evolving variables. Whether a TRUE or FALSE choice is made, Morganization comes in to get any desired output state if the reverse was chosen.

(1) Lamp Logic Expression and Simplification

The resulting expression from the lamp's TRUE output (Table 2 above) is easier to simplify.

$$C = A\bar{B} + AB \qquad [1]$$

Simplifying yields:

$$C = A(\bar{B} + B)$$

$$C = A$$

(2) Pump Logic Expression and Simplification

The resulting expression from the pump's TRUE output (Table 1 above) is easier to simplify.

$$C = \bar{A}\bar{B} \qquad [2]$$

$$If\ \bar{A}\bar{B} = TRUE\ (indeterminate)\ then$$

$$C = A\bar{B} \qquad [3]$$

D. Boolean to Ladder Logic Interpretation

Translating simplified Boolean expressions to Ladder Logic is relatively simple bearing in mind the information in Table 3 below. The ladder instructions in Table 3 below are from Allen Bradley Rs Logix software.

Table 3: Boolean to Ladder Logic Interpretation

Boolean	Ladder
$\bar{A}$	Examine if Open (XIO) contact
A	Examine if Closed (XIC) contact
OR (+)	Parallel connection
AND (.)	Series connection

E. Ladder Logic Program

The ladder logic in Figures 2 and 3 below are the direct implementation of Equations 1,2, and 3. Figure 2 is the IOs bitwise addressing and Figure 3 shows the control ladder logic containing the Boolean to ladder simplified expression upon close examination.

IV. DISCUSSION

A careful study of Figure 3 below reveals an additional Timer block in the Ladder Logic. Timers are not captured in Boolean expressions likewise notifications, alarms, and other safety controls needed to protect sensitive equipment. Boolean to Ladder tackles only the logic leaving the programmer with the duty of intuition to choose timers, alarms etc. where necessary. Boolean to Ladder assumes an ideal system performance where there are no cavitation, frictions, or process level perturbation. Whether ideal or no ideal case, Boolean theorems come in handy to reduce programming complexities in digital logic programming problems.

V. CONCLUSION

Boolean algebra theorems can be helpful to simplify process digital logic programming problems using Karnaugh map or Boolean simplification techniques. It involves getting truth tables from the process diagram or problem statement (depending on the number of outputs) and extracting Boolean expressions from the logic table. These expressions can be simplified using Boolean simplification theorems and subsequently converted to Ladder Logic for the PLC to interprete and automate the given process.

This paper exemplified this on a given digital logic compressor control problem. All tests conditions were met.

For more protective control, additional monitoring blocks can be added if necessary.

VI. REFERENCES

[1] I. Ahmed, S. Obermeier, S. Sudhakaran and V. Roussev, "*Programmable Logic Controller Forensics*", *IEEE Security & Privacy*, vol. 15, no. 6, pp. 18-24, 2017. Available: 10.1109/msp.2017.4251102.

[2] F. Petruzella, *Programmable logic controllers*, 4th ed. United States: McGraw-Hill, 2011, pp. 1-14.

[3] P. Scherz, "*Practical Electronics for Inventors*", Fourth Edition. USA: McGraw-Hill Professional, pp. 325-334.

[4] J. Gupta, "*Electronic devices and circuits*", 4th ed. New Delhi: S.K. Kataria& Sons, 2011, pp. 824-835.

[5] P. Lynn, "*Practical PLC Programming (PLCII)*". 2020, pp. 1-2.

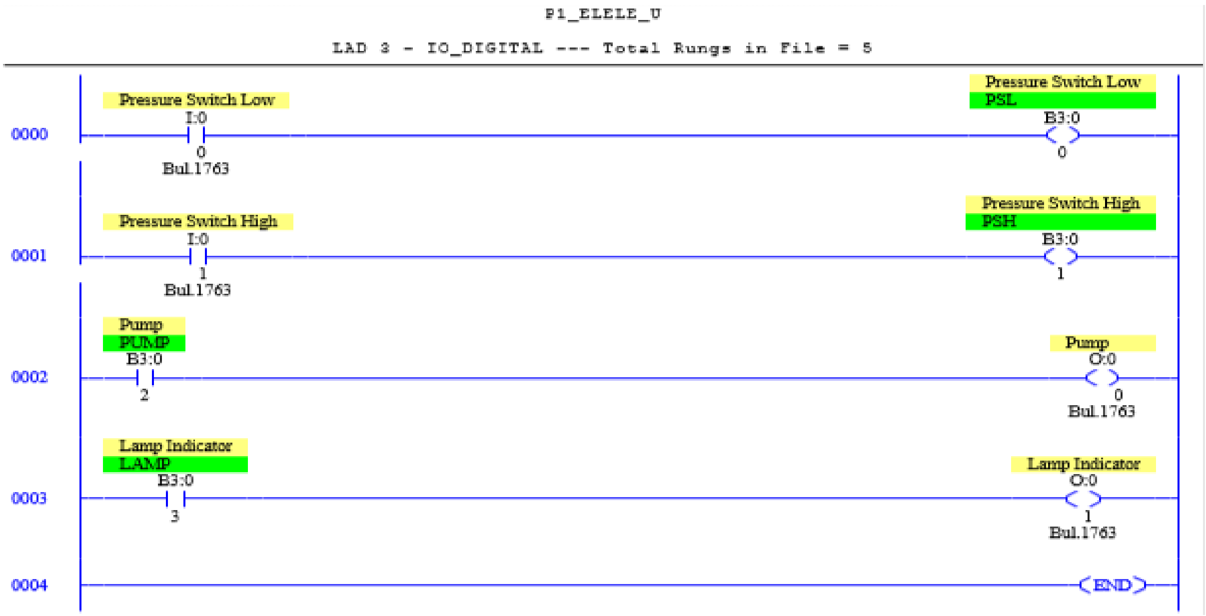

Figure 2: Ladder IOs Bitwise Addressing

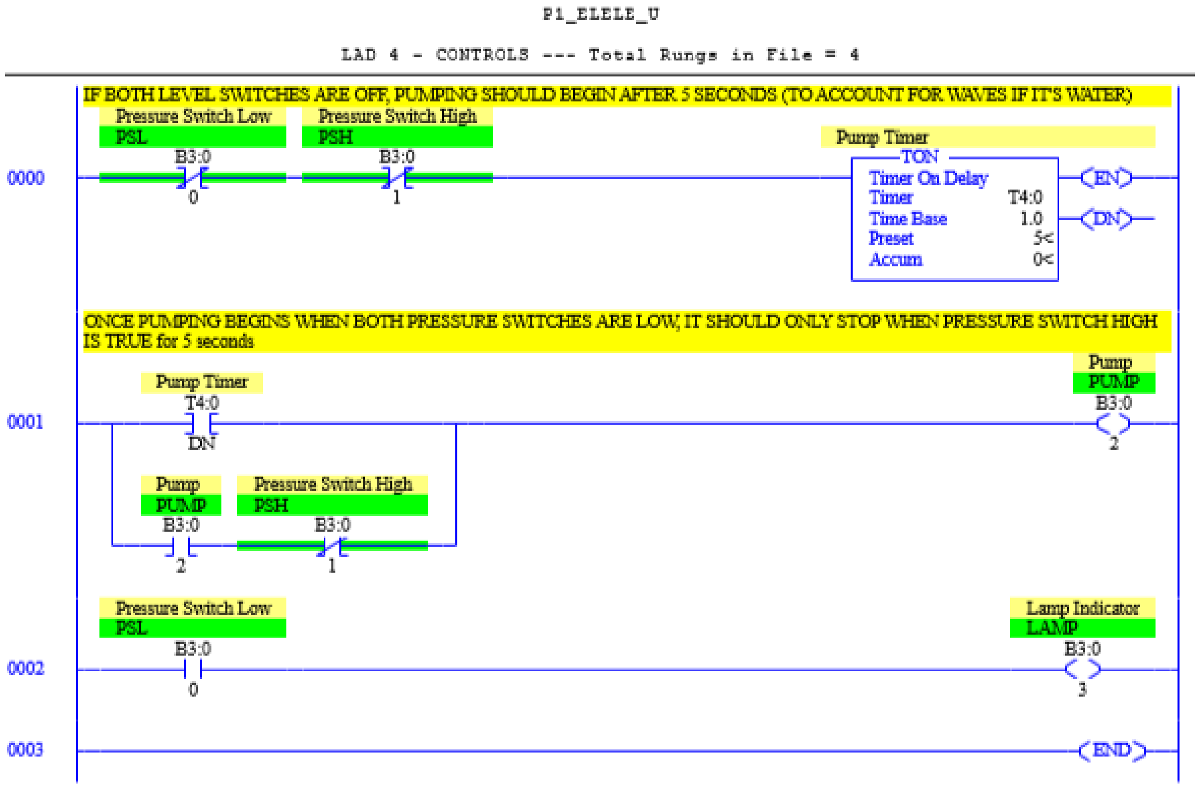

Figure 3: Boolean to Ladder Implementation