A Step-By-Step Approach to Retrofit and Automation of PCB Machines Using PLC

John Nyutu Kamau, EN371-2188/2015

Msc. Student, Department of Electrical and Electronics Engineering

Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya

P.O. Box 8191 – 0100 THIKA, KENYA

Email:jnyutu@gmail.com

ABSTRACT

Abstract – Retrofitting of machine has today become very popular for manufacturing and processing in small, medium and large industries as demand for high quality, greater efficiency and automated machines increase by day. It offers numerous advantages in the area of cost effectiveness and higher productivity. Technological upgradation and refurbishing of old machine restore them close to their original performance levels, contain capital costs, add value to the process and address obsolescence. Retrofitting can be achieved through a phased approach from the perspective of comprehension or through step-by-step approach to automate, understanding the needs thus employing the best control system to achieve the desired result. Simplification of engineering practices and precision control requirements of manufacturing processes by absorbing technological changes can result in significant cost savings. The most cost-effective way which can pay rich dividends in the long run is adopting flexible automation via a planned approach towards integrated control systems. It requires a conscious effort on the part of plant managers to identify areas where automation can result in better deployment/utilization of human-machine-interface and its implementation to achieve higher productivity. This paper highlights a case study of retrofitting and automation of a Del Monte's old FMC Caser Machine (Model 7 Non Shock Caser) with a Programmable Logic Controller, PLC, based control system using a step-by-step approach for a successful performance to address problem of: obsolescence, reduced productivity, increased down time, increased repairs and increased maintenance costs.

Keywords: Electro-Pneumatics, Industrial Automation, Programmable Logic Controller (PLC), Printed Circuit Board (PCB), Retrofitting of Machine

I. INTRODUCTION

Over the years the demand for high quality, greater efficiency and automated machines has increased in the industrial sector of all kinds. They require systems with high accuracy, greater flexibility, continuous monitoring and control. But now-a-day's rapid growth in technology has come-up with different solutions such as PLC which will fulfill all the requirements of the industrial processes through automation. Simplification of engineering practices and precision control requirements of manufacturing processes by absorbing technological changes can result in significant cost savings. The most cost-effective way which can pay rich dividends in the long run is adopting flexible automation via a planned approach towards integrated control systems.

Since customers today have access to world markets due to globalization and liberalization of economies, they have at liberty to trade-off with innovative, indigenous solutions or readily available expensive solutions. The retrofit is an attempt of indigenous and innovative solution to contain the capital costs and add value to the processes by mix and match of inexpensive available technological inputs to result in improved quality at a lower price. Hence market life of products can be increased by absorbing technology through retrofits to addresses obsolescence.

Upgrading the existing machines through retrofits can bring many a benefits of new equipment at a fraction of the cost. Much of the savings depends on the application. For example, if the control circuitry and selection represents 10 to 20% of the machine value, and its replacement just would give a new-machine of same performance, the machine owner would save 80% of capital cost of new machine purchase. This justifies retrofitting the machine by changing the state-of–the-art control circuitry. Upgrading the machine for performance enhancements through retrofits is possible. These engineering solutions are ingenious and innovative which will render huge cost savings and higher productivity levels. Micro, Small and Medium Enterprises, MSME, sector will survive adapting these engineering practices wherever it necessitates to remain competitive in the era of technological revolution by remaining ingenious and innovative.

The typical examples could be reduced machine's productivity or increase in the cost of support systems would invite ingenious retrofit solutions. Another example could be increased down-time, increased repairs, increased maintenance costs and calibration costs would offer an opportunity to set right things by suitable retrofits ingeniously. Often a suitable closed loop control system can compensate for deficiency in performance [1].

Finally, a subtle factor affecting the new-versus-retrofit decision is the time needed to get a machine up and running productively and economically. It may be quicker to retrofit using off-the-shelf parts compared to typical lead times with new machine purchases. It is a good thing that innovations are happening at the start-up and MSME sector because they have to ever remain competitive.

II. STEP BY STEP APPROACH METHODOLOGY

Retrofitting refers to the addition of new technology or features to older system. Principally retrofitting describes the measures taken in the manufacturing industry to allow new or update parts to be fitted to old or outdated assemblies. It offers numerous advantages in the area of cost-saving, the optimization of existing plant components, adaptation of the plant for new or changed products, as well as in maintaining a high quality [2].

A review of the relevant literature [2][3][4][5][6], one can develop a step by step approach of typical retrofitting of machine, which consists of six steps: analyze existing design and review documentation, create a new design or re-engineering design, develop Automated control program and simulate to verify functionality, build the hardware system as per the design by proper selection of equipment, validate the system through testing and demonstration for the desired automated control operation of the machine, and generate complete technical data package and manuals to support operation of the machine. All of which can be represented by the block diagram shown in Fig. 1.

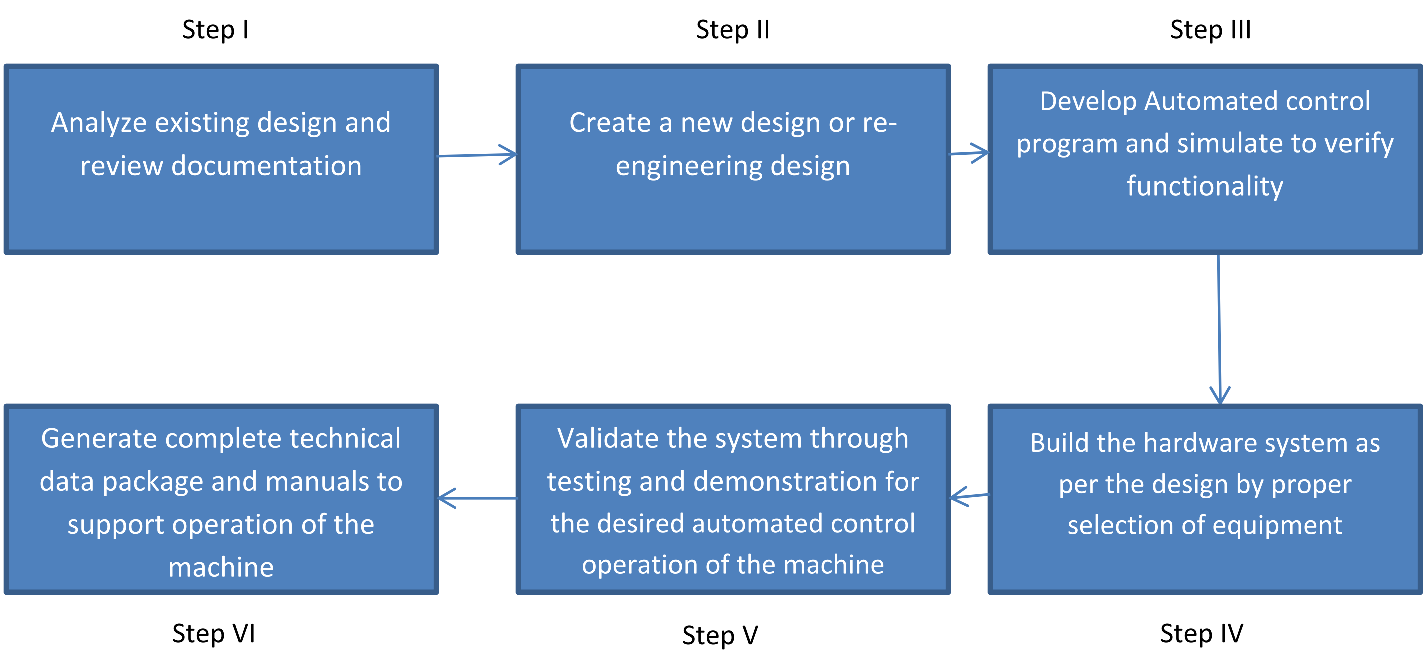

Fig.1: Step by Step Approach for retrofitting

2

III. AUTOMATION AND MODERN TECHNOLOGY ADVANTAGES

Industrial automation uses computers and controllers to control industrial machinery and processes to optimize productivity and delivery of services. Automation greatly decreases the need for human sensory and mental requirements [7]. The impact of automation in industries is as follows:

- Increase productivity and reduce cost.
- Emphasis on flexibility and convertibility of manufacturing process. Automation is now often applied primarily to increase quality in the manufacturing process, where automation can increase quality substantially.
- Increased consistency of output.
- Replacing humans in tasks carried out in hazardous environment.

In the mechanization and automation of industrial processes, pneumatics has gained great significance because of the easy implementation of often-needed straight-line, back and forward motion using pneumatic cylinders; swivel motion and rotation using rotary drives; revolving cylinder engines and stepping drives [8]. Until a few years ago the compressibility of the energy carrier, i.e. compressed air, basically limited the automation of fast motion sequences to simple adjusting movements where stop points were implemented by mechanical limit stops. Electro pneumatic controls combine the best features of electronic and pneumatic controls. Such system consists of pneumatically actuated valves, electrical/electronic controllers, sensors and control systems Electro-pneumatics is used in most areas of industrial automation. Production, assembly and packaging systems worldwide are driven by electro-pneumatic controls. Electro pneumatic controllers have the following advantages over pneumatic control systems:

- Higher reliability.
- Lower planning and commissioning effort for complex controls.
- Lower installation effort.
- Simple exchange of information between several controllers

Considering the varied demand and increasing competition, one has to provide for flexible manufacturing process. One of the latest techniques in solid state controls that offers flexible and efficient operation to the user is “Programmable Logic Controller”. The basic idea behind these programmable controllers was to provide means to eliminate high cost associated with inflexible, conventional relay controlled systems. Programmable controllers offer a system with computer flexibility. Programmable Logic Control or PLC as it is universally called is the ‘work horse’ of industrial automation. It is important because all production processes go through a fixed repetitive sequence of operations that involve logical steps and decisions. A PLC is used to control, time and regulate the sequence [9].

IV. CASE STUDY

4.1 Overview of Project

The aim of the project was to retrofit a Del Monte’s old FMC Caser Machine (Model 7 Non Shock Caser) using PLC. During the preliminary phase of project, the machine controller was found to be based on an old and inflexible Printed Circuit Board, PCB, board. The board was marred with frequent breakdown and its repair was very expensive. The manufacturer, FMC, had termed the board obsolete and with no replacement. The manufacturer recommended replacement of the entire machine with a new one. Most of the pneumatic cylinders and electro-pneumatic (solenoid) valves in the machine were in good condition and required no replacement. The machine controller was to be replaced by the PLC. Also the whole automatic operation of the machine was to be maintained. With these considerations, the main objective set for the project was to design, develop and implement automated controller for the machine in order to upgrade the technology. A step by step approach was to be used to achieve the objective.

4.2 Method and Implementation

Applying the proposed approach is to take each step of retrofitting in questioning and assessment through the systematic process.

4.2.1 Step I: analyze existing design and review document

The objective of this step is to analyze existing design and reviews documentation. The machine electrical components are reviewed and their location identified and their electrical specification analyzed. Electrical and logical schematic is also reviewed and number/nature of inputs and outputs explored and investigated. The fig.2 below shows the caser machine electrical components that was reviewed in details and targeted in the retrofitting.

The electrical schematic shown in fig.3 shows the PCB inputs and outputs that were used to design the new PLC controller and determine electrical sequence of operation.

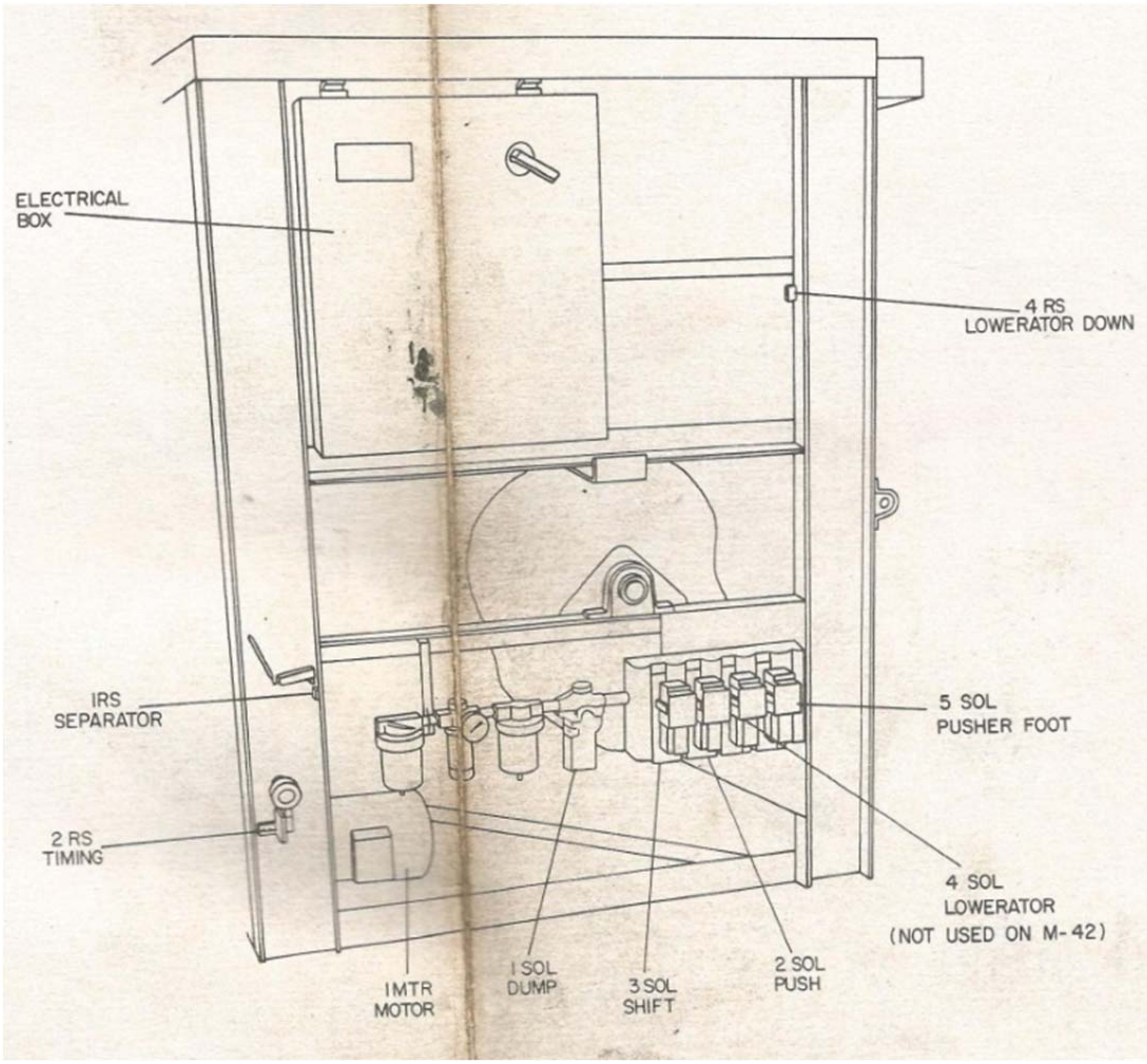

Fig.2: **Electrical component locations**

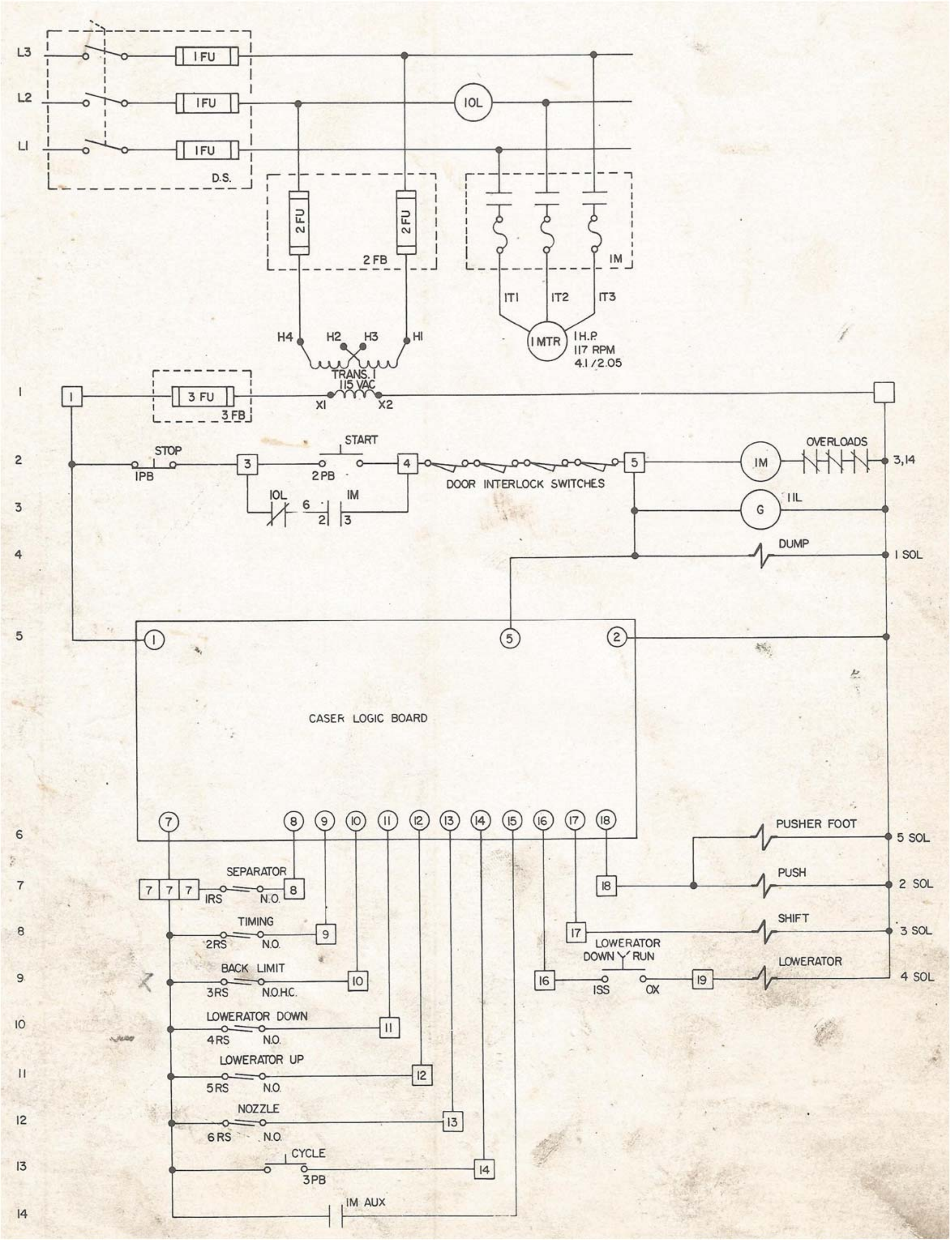

Fig.3: Electrical schematic

4.2.2 Step II: create new design or re-engineering design

Problem presented in this step is how to replace the PCB logic board with a PLC to control the machine. The purpose of this step is creates new design or re-engineering design. The existing machine is driven by a number of solenoid valves, limit switches, push button switches, and accessories. This is used in determining the number of input and output for the design of control by PLC to replace the old system. After a detailed exploration and investigation, it is found that 8 inputs and 3 outputs are required. In this stage, a PLC control is designed. The fig. 4 below show the new PLC design showing input/output relays, protection MCB and siemens Logo PLC.

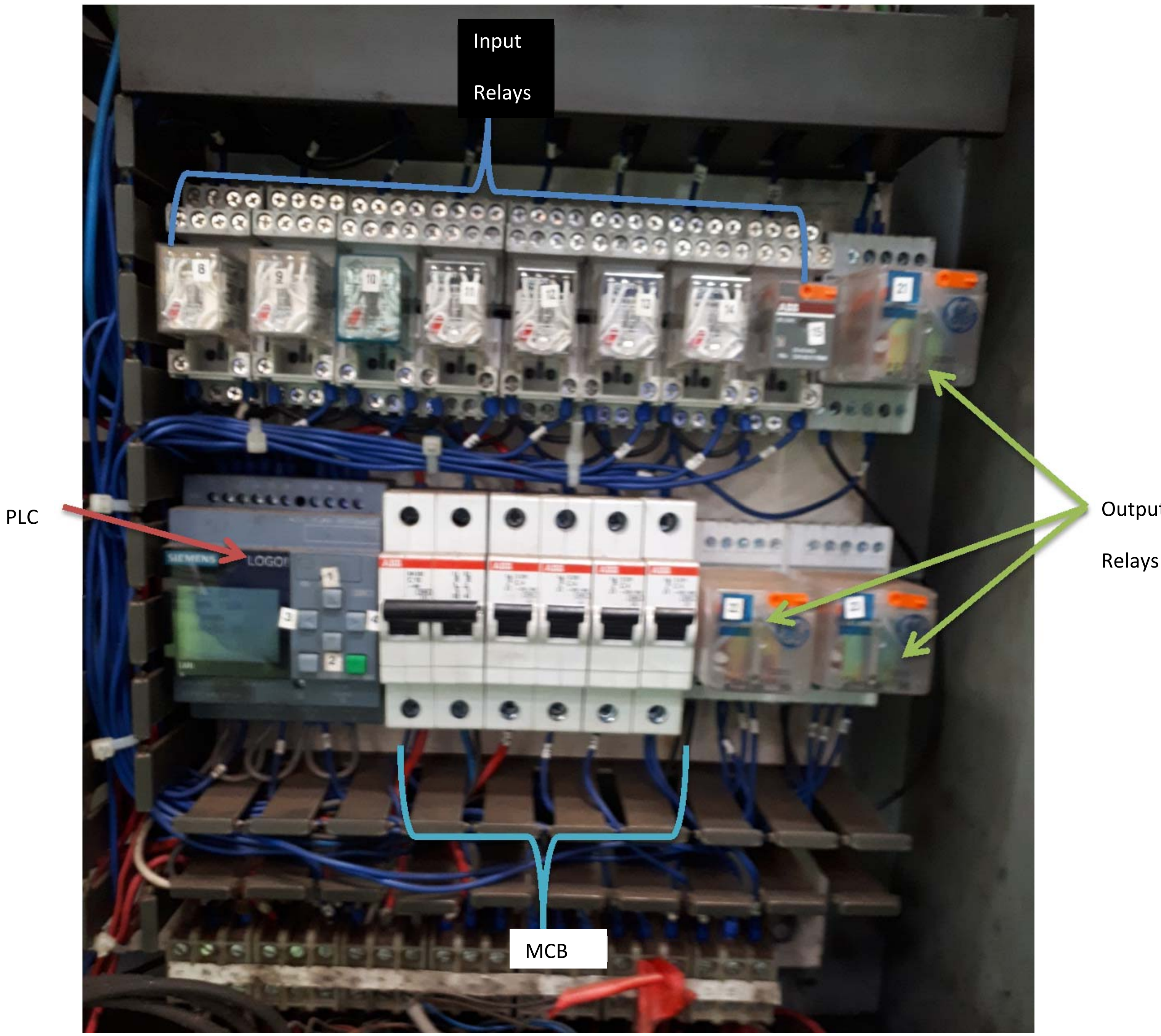

Fig.4: new design

4.2.3 Step III: Develop automated control program and simulate to verify functionality

Problem presented in this step is how one would know the machine functions as it should. The objective of this step is to develop a PLC program and simulate it to verify functionality. The Siemens logo software comfort version 8.1 was used to simulate the program. By simulating manual cycling as given by the manufacturer, one would ascertain a perfect electrical sequence of operation and functionality. The manual cycling is performed as follows: pushing cycle push button (3PB) with the nozzle reed switch (6RS) actuated, will cycle machine at any time. Without 6RS actuated, the cycle button will only cycle machine until push sequence is scheduled to occur. At this point 6RS must be actuated to make the cycle button operative.

4.2.4 Step IV: Build the hardware system as per the design by proper selection of equipment

Problem presented in this step is how would you know that system that you designed is workable reality. The objective of this step is building the control panel to verify design. In the hardware part, overall component such as PLC, relays, transformer and switchgear circuit will be integrated to form the complete control circuit. The detailed list of all the hardware used in the project is listed in Table 1 below:

Table 1. List of hardware used in the project

NO	**Hardware Description**	**Make**	**Rating**	**Qty**
1	LOGO! 8 Logic Module	Siemens	230 Vac, 8 x Input, 4 x Output With Display	1
2	11 PIN RELAY	ABB	120VAC, 3PCO, 10A	3
3	14 PIN RELAY+LED	ABB	24VAC, 10A 4PCO	8
4	Miniature Circuit Breaker S201-K1	ABB	1P K 1A 480Y/277 SUPP	3
5	Miniature Circuit Breaker S201-K4	ABB	1P K 4A 480Y/277 SUPP	1
6	Miniature Circuit Breaker M202-10A	ABB	M202- 10A MCB OM 10A,2P	1
7	Control transformer	RTR energia	200VA, 50Hz, 0-240V, 0-24v	1
8	Control transformer	RTR energia	100VA, 50Hz, 0-240V, 0-110v	1

4.2.5 Step V: validate the system through testing and demonstration for the desired automated control operation of the machine

Problem presented in this step is how would you know that the machine is running according to function correctly. The purpose of this step is to validate through testing and demonstration of machine. The machine was tested through the entire electrical sequence of operation.

Electrical sequence of operation (as shown in fig.3):

- Depressing start button (2PB), energizes 1M motor starter through 1PB, 2PB and the four door interlock switches. If any of the door interlock switches are not closed, 1M cannot energize and machine will not start. When 1M starter energizes, an auxiliary contact of 1M will close energizing the 1M input of the caser logic board. When the 1M input of the logic board is energized, the remaining inputs and the three outputs will become operative.
- The 1M input must be energized for the logic board to function.
- Placing a case on the nozzle actuates the lowerator up reed switch (5RS). When 5RS is actuated, the caser logic board energizes the lowerator air solenoid (4SOL) causing the lowerator chair to rise. As lowerator rises, the nozzle reed switch (6RS) is actuated.
- As incoming cans fill the individual lanes of the caser, the separator reed switch (1RS) actuates. The caser logic board will energize the shifter air solenoid (3SOL), when both 1RS and 6RS are actuated. When 3SOL is energized, the shifter assembly blocks cans entering the separator and actuates an air limit switch mounted above the shifter.
- Actuating this air limit switch causes the main drive shaft to rotate by triggering a single revolution wrap spring clutch brake. As main drive shaft rotates, the timing reed switch (2RS) is actuated momentarily.
- When 2RS actuates, the logic board will de-energize the shift air solenoid (3SOL) after an adjustable time delay. A logic board mounted potentiometer marked “SHIFT RETURN” controls the amount of time the shifter assembly remains in the shifted position after 2RS is actuated. This time is adjustable from 0 to 0.4 seconds.
- The timing reed switch (2RS) also registers one count in the internal counter of the caser logic board. The logic board will energize the push air solenoids (2SOL, 5SOL), when 2RS actuates.
- Energizing 2SOL and 5SOL causes the pusher feet to drop and the pusher cylinder to extend. As the pusher cylinder extends, the lowerator down reed switch (4RS) is actuated. When 4RS actuates, the logic board will immediately de-energize 4SOL and after a time delay, will de-energize 2SOL and 5SOL. This time delay is adjustable by means of a potentiometer marked “FORWARD LIMIT”.
- This potentiometer is mounted on the caser logic board and is adjustable from 0 to 0.2 seconds. When lowerator air solenoid (4SOL) de-energizes, the filled case is lowered from nozzle area. When push air solenoids (2SOL,5SOL) de-energizes, pusher feet raise and the pusher cylinder retracts. When the pusher cylinder is fully retracted, the back limit reed switch (3RS) actuates. The back limit reed switch (3RS) must be actuated before the next cycle may begin.
- In 2,3,4 and 5 tier operation, the sequence is identical to one tier with the exception of the push cycle. The push cycle will not occur until a sufficient number of tiers have been lifted to the tiering chamber. This is accomplished by the internal counter of the caser logic board.

The machine was run in production process for three months. During this time the PLC program was modified many times in response to the user feedback.

4.6 Step VI: generate complete technical data package and manuals to support operation of the machine

The problem presented in this final step is how the operator and maintenance team would use/maintain this machine. The purpose of this step is to generate complete technical data package and manuals to support successful operation and maintenance of the machine.

V. RESULTS AND DISCUSSION

5.1 Retrofitting of machine

The results of retrofit show that engineers in the industry can successfully replace PCB controller by a PLC and upgrade an obsolete machine to give it a new-machine performance at fraction of its cost.

5.2 Production achievement

Once the machine was retrofitted and objective achieved, the company addressed the problem of obsolescence, reduced productivity, increased down time, increased repairs and increased maintenance costs. It was costing the company kshs.200,000 per month on outsourced repair of control PCB board and kshs.500,000 on loss of production. The retrofit only cost kshs.100,000 and has been working well for the last six months. Thus the retrofit and automation of the machine paved the way for increasing the productivity and reliability, time saving and PLC display enables the operation of machine easier for non-skilled labors too. Also the machine operation had good quality of product. As the project focuses on the closed loop control of the process, this will fulfill all the requirements of the industry with good levels of accuracy and repeatability thereby yielding a more robust system.

VI. FUTURE WORK

Since the benefit acrued with the retrofit is immese, it is therefore recommended that the retrofit be applied to the other two caser machines, which are still running on the old PCB board.

REFERENCES

[1] J.Hyung, Kim Harms, R. Seliger and G. Dept. of Assembly Technol. & Factory Manage., Tech. Univ. Berlin, "Automatic Control Sequence Generation for a Hybrid Disassembly System", IEEE Transaction on Automatic Science and Engineering, Volume: 4, Issue: 2 on page(s): 194-205**.**

[2] Possibilities and Advantages of Retrofit, Sitola GmbH & Co. KG, (2008).

[3] The Retrofit Advantage, FANUC FA America, (2011).

[4] Custom Retrofitted Machinery to Full Automation, http://www.rebuildersunlimited.com

[5] K. Ivan, K. Marian, and J. Frantisek, "Reverse engineering as an education tool in computer science," in Proc. the 9thIEEE Conf. on Emerging eLearning Technologies and Applications, pp. 123-126 (2011).

[6] S. Frederic, M. A. Nicolas, and V. Philippe, "Collaborative reverse engineering design experiment using PLM solution," Int. J. of Engineering Education, vol. 27, no. 5, pp. 1037-1045 (2011).

[7] O.Masao and H.Yutaka, "Recent Developments on PC+PLC based Control Systems for Beer Brewery Process Automation Applications", SICE-ICASE International Joint Conference 2006 Oct. 18-21, 2006 in Bexco, Busan,.

[8] A.Gabor, Biacs, S. Milan and Adzi "PLC Control for a Rotating Ironing Press**",** Intelligent Systems and Informatics, 2008. SISY 2008. 6th International Symposium on Publication Date: 26-27 Sept. 2008.

[9] J. J. Harris, J. D. Broesch, and R. M. Coon, "A combined PLC and CPU approach to multiprocessor control," *in Proc. 16th IEEE/NPSS Symp.Fusion Engineering*, vol. 2, 1995, pp. 874–877.