A paradigm shift towards learning and harnessing programmable logic controllers for industrial efficiency in Papua New Guinea

Joseph Kim Suwamaru

Abstract

Programmable logic controllers (PLCs) can support improved efficiency when applied in industrial control processes in PNG. Technological advances in engineering and computing have resulted in PLCs witnessing diverse applications such as in water treatment processes, mining operations, electrical power generation systems and primary industry milling facilities with improved efficiencies and better economic outcomes. Against the backdrop of diverse computer programming languages, learning and harnessing, programming PLCs can be a fun-filled and profitable skill in PNG. This paper discusses the *status quo vis-à-vis* PLCs and pedagogical possibilities among academic institutions in PNG.

Key words: programmable logic controllers, ladder logic, I/O module, distributed control systems, SCADA, HMI and industrial control systems.

Introduction

As Papua New Guinea (PNG) witnesses increased industrialization, efforts towards efficiency in industrial control systems are being realized through the use of programmable logic controllers (PLCs). However, the knowledge and skills required to design and implement PLC systems are scarce locally requiring over reliance on foreign experts. Yet PLCs are simple enough technologies to learn and master. This paper highlights the current knowledge gap among PNG citizens concerning PLCs whilst delineating easily comprehensible concepts.

Against the backdrop of the existing gaps in expertise in PNG concerning PLCs, this paper demonstrates real world simulations that could be used in learning PLCs. The traffic light and coconut storage/dispensary simulations illustrate real world applications of PLCs relevant in pedagogical purposes. In essence, the discussions include trends in PLCs leading to industrial efficiencies with economic and environment benefits. An overview of PLCs is given of applications in processing units with a sample of languages from some manufacturers. Notwithstanding the diversified manufacturers, there are commonalities with PLCs making them convenient for pedagogical considerations. The paper uses simple real world simulations and discusses their relevance in teaching and learning. Some departing thoughts on future possibilities then are offered.

Towards PLCs

Computer science courses in tertiary academic institutions across PNG largely lean towards popular programming languages such as C++, java and python among the recent additions (Lakoa 2009). As PNG experiences increased industrialization, the use of these languages may be advantageously supplemented by PLCs to automate processes and systems. In varying industrial environments, PLC driven automation systems can offer increased efficiency for better profit margins (Siemens 2011). Unlike other programming languages having their own structure and syntax, PLCs although supplied by many vendors have commonalities lending them easy and fun to learn and use in PNG. Divine Word University (DWU) could consider offering PLC training within the computer science strand to respond to growing industry demands.

Prior to PLCs, industrial facilities used hardwired systems connecting input push-button switches, timing devices and other sensor devices feeding output units like motors, lights and heating devices among others (Okoli, Onubogu, Okezie & Okorogu, 2011). This hardwired input-output connection was inflexible and often led to time consuming trouble shooting in the midst of messy and high power consuming cables, often leading to protracted downtime, attracting economic costs (Vosough and Vosough 2011). The advent of PLCs has replaced such hardwired and inflexible control systems with convenient software driven configurations which read and assess conditions of input devices to inform output devices for appropriate actions (Bolton 2006). Applications of PLCs in PNG have increased across sectors of the economy. The resources sector has seen increases in exploration and ore production with the largest being the liquefied natural gas (LNG). The LNG plant in the Southern Highlands and the Napanapa oil refinery facility in Port Moresby both employ PLCs in their control processes (Lihai 2015). In Madang, British American Tobacco (BAT) deploys PLCs to control robots in its packaging and conveyor systems, while Islands petroleum and coconut oil production companies pose as good candidates to consider PLCs for oil storage and dispensary to customers in the value chain. Industry experiences have shown PLC based control systems to improve profits due to overall efficiencies in operations (Siemens 2011).

The efficiencies realized from PLC based control systems flow from savings in time and money that would otherwise have been expended for physical electrical wiring and alternations. With PLCs, amendments and alterations are a simple matter of re-coding the sequence of instructions within the memory with savings in time and money. All that is required is for the operator to key in a different set of instruments (Bolton 2006). From the environmental perspective, using PLCs rather than physical wires reduces the chance of material wastage associated with physical wires, and contributes to a greener environment in PNG.

Prior to the advent of PLCs, control systems consisted of a physical wiring scheme where configuring and troubleshooting components were often messy and time consuming. With a PLC, all wiring is implemented with coded software using easy to understand syntax. The following section explains the core elements and functions within PLCs and introduces the concept of ladder logic which forms the main PLC programming language.

Overview of PLCs

Consider first the *status quo vis-à-vis* the PLCs as implemented in PNG. An overview of PLCs and its core elements (Figure 1) show the controller playing a central role according to preconfigured instructions responding to conditions from field devices and issuing actions to output units such as motors, pumps, lights or valves depending on the nature of the control system. Figure 1 illustrates the definition of PLC as a microprocessor-based controller using a programmable memory to store instructions which implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes to achieve a desired outcome (Bolton 2006). In this paper , simple programs for control of traffic lights such as those used along Port Moresby roads and an oil storage/dispensary facility in Madang will be used to illustrate the conveniences realizable with PLC programming.

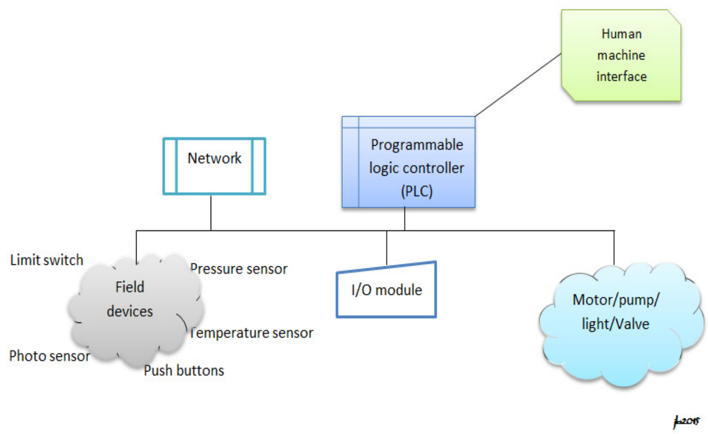

Figure 1: A generalized view of PLC design at Napanapa oil refinery, Port Moresby.

The PLC controller and the input-output (I/O) module contains the software driven instructions working together to interface with the physical world devices. Quite often, field devices are distributed in various process locations within the facility, communicating status of various sensors via the network, (sometimes referred to as a fieldbus) to the I/O module for processing by the PLC controller which then actuates the output devices such as motors, pumps, lights or valves. The human machine interface (HMI) and the program residing in the PLC should have the correct protocol drivers for efficient communication via TCP/IP enabled network (Lihai 2015). In Figure 1, the PLC unit may also be configured with appropriate software to perform as a server. The PLC monitors inputs (field devices), makes decisions based on the programs residing in the processor, and controls the outputs to automate a process or machine (Siemens 2009).

Where input or output (I/O) points are located remotely to the PLC, the connectivity between distributed I/O devices at those process locations and the PLC, together with the HMI, can be supported via an Ethernet based network. Ethernet has capacity to transport big data for process control and to integrate the process with management information systems (Collins 2007). The HMI block (Figure 1), provides a convenient operator monitoring interface for on-demand supervisory functions through timely acquisition of process control data. At Napanapa, since field devices are located in noisy locations, fiber-optic cabling is used to reduce the possibility of data corruption from interference by electrical noise (Lihai 2015). Fiber-optic has the advantage of good resistance to noise and is smaller in size, with abundant bandwidth and good flexibility (Martins et al. 2006).

An array of PLCs

PLCs are available in two types of physical configurations, fixed and modular, where fixed is small and self-contained while modular comes as individual modules for assembling to specific requirements. Fixed units consist of built-in power supply, input section, processor, associated memory and the output section. Fixed units are generally used in small PLC applications controlling up to 32 I/O points, with less than 20 I/O points being the norm (Martins et al. 2006).

Modular PLC can be sourced as individual parts including power supplies, processors, input modules, individual output modules with a selection of assemblies such as racks, chassis, or baseplates and assembled to hold individual components together (Lihai 2015). By and large, the size of a PLC is determined by the processor speed and the number of I/O modules it supports. Medium PLCs are deployed in applications requiring up to 128 I/O points with analogue control, data manipulation, and arithmetic capabilities (Martins et al. 2006). Large PLCs supporting over 2048 I/O points are used in sophisticated control tasks, with extensive data manipulation, data acquisition, and reporting (Bolton 2006). These systems are more likely to be designed as distributed control systems (DCS) linking a collection of remote I/O modules interfacing with sensor devices and the processor. These systems also have HMI or Supervisory Control and Data Acquisition (SCADA) functionalities (Anderson, 2014). Typical examples of large scale PLCs in PNG are deployed at the Napanapa oil refinery, Porgera, Lihir and Tolukuma gold and copper mines (Lihai 2015).

PLC Programming formats

The original design philosophy with PLCs was to eliminate high costs associated with inflexible hardwired, electromagnetic relay controlled systems. The paradigm shift was towards programming formats that are easy to code with program reusability (figure 2). Manufacturing plants are usually maintained by engineers and technicians with limited computer programming skills, hence, PLC programming formats were designed to be easily reprogrammed when project were modified. This proved advantageous over rigid traditional hardwired connections of field devices feeding the input switches energising or de-energising the respective output device such as motors or valves in the control system.

Popular programming formats used with PLCs include ladder logic diagrams (LD), instruction lists (IL), sequential function charts (SFC) and structured text (ST). Simple examples of these are given below where discrete inputs such as push buttons or analogues inputs such as sensors, are blended in logical AND/OR, combinations to get a logical TRUE/FALSE condition energizing or de-energizing for an ON/OFF output action.

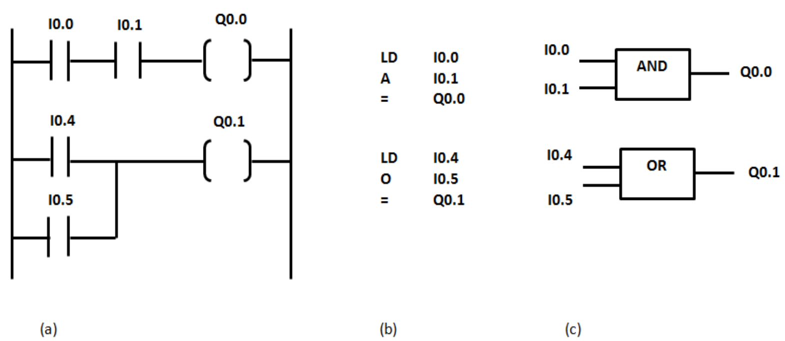

Figure 2: Programming format using Siemens PLC notation.

Figure 2a illustrates the ladder diagram with two rungs read from left to right where two relays combine to form the condition for the output actions for Q0.0 and Q0.1. In practice, Q0.0 and Q0.1 outputs can either be ON or OFF because they are controlling a pump, conveyor belt or a similar unit, in response to the condition fed to the soft switches I0.0, I0.1, I0.4 and I0.5. This is the essence of PLC based control systems. In the first rung (as in real physical ladders) a logic AND configuration will only energize the output (Q0.0) if and only if both I0.0 AND I0.1 are both TRUE.

The second rung shows two contacts in an OR configuration which may energize output (Q0.1) either when I0.4, I0.5 or both are TRUE (TRUE or FALSE refer to logical 1 or 0). In these, we see that the left components in the ladder diagram representing conditions required for the output actions. The illustrations in figure 2 are really software implementations required to perform actions such as turning on/off an alarm light, a motor to drive a conveyor system, inlet/outlet valve in fluid flow control for storage tanks being examples. Figure 2b shows the same program in IL format while figure 2c shows a simple SFC notation of the program. ST uses similar format as control structures such as the IF/ELSE statements found in C++ or java or other so-called high level programming languages (Bolton 2006).

The next example will show that these programming formats are easy and fun to learn for students and professionals requiring only basic knowledge of electricity and magnetism offered in secondary schools or at preliminary university, logic gates and Boolean algebra in PNG. Whereas there are variations in these formats among manufacturers of PLC, their fundamental forms have commonalities that can be harnessed for control systems in PNG. The PLC programming formats are guided by International Electro-technical Commission IEC 1131-3 standard.

Firstly, ladder logic diagram is easier to learn than popular programming such as C, C++, python and java offered by computer science strands at DWU. Ladder logic is a graphical programming language that uses graphical symbols to provide the PLC with the logical instructions needed to perform control operations (Wysk 2009). The logical instructions use common logic gates such as AND, NAND, OR, NOR, NOT and EX-OR configured to read a condition from field devices to initiate an on/off action to control industrial machines. Blended together with control structures as those used in C, C++ or java programming languages, to add intelligence and decision making capabilities, PLCs can be designed to control virtually any kind of industrial control system (Vosough and Vosough 2011).

Pedagogical considerations

There are exciting pedagogical opportunities for PLCs in PNG where students and academics may engage with real world projects. Such pedagogical possibilities may include modelling and simulation of simple and even advanced control systems depending on the applications and objectives. In order to fully understand control systems, it is important to study them by developing models that describe the systems (Martins et al. 2006).

Interesting models that may attract the interest of students relate to PLC controlled automatic transfer unit between PNG power mains supply and generators at DWU. Considerations here would be the number and type of sensing inputs which would be read by input points (conditions), then processed by PLC program to energize or de-energize the relevant output (actions). Other models could concern counter applications to count packages on a production conveyor system and routed through a reflector to the appropriate packaging zone.

The multi-story shopping malls in Port Moresby are also seeing escalators transporting shoppers between various levels. This could be modelled and simulated using freely available PLC software such as i-Trilogi which is also used in this piece to simulate simple control systems. The i-Trilogi PLC software can be easily downloaded from the internet and used conveniently to simulate interesting control system project by indigenous students and enthusiasts. Similarly PLC based lift systems in multi-level buildings provide interesting PLC projects which can be modelled and simulated by students and academics to improve and enhance PLC skills and competence.

Traffic control system

Traffic lights have gained a central role in Port Moresby roads, directing the flow of vehicles and may soon extend to other centers in PNG. With smaller PLCs, combinations of software timers activating traffic lights following the sequence of red – orange - green – orange– red – orange- green, regulating the traffic can make roads safer. PLCs have three main types of software timers, on-delay timer, off-delay timer and pulse timer (Bolton 2006). Smaller PLCs like those used in traffic light control systems may only have on-delay timers, such as that used in this piece to simulate the red – orange - green – orange – red – orange- green sequence.

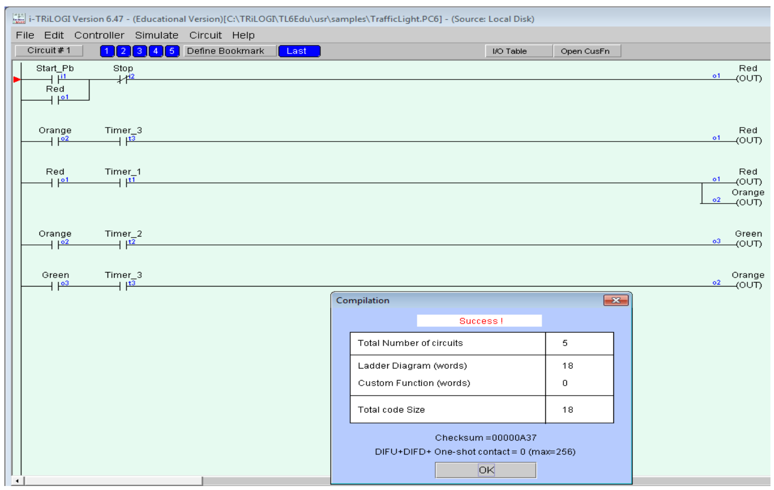

Figure 3: Red-orange – green-orange-red-orange-green simulating ladder logic diagram.

Upon a momentary pressing of Start_Pb, the red light is illuminated while latching it and setting the on-delay Timer_1 on for 60 seconds. This on-delay time lapses which turns the orange light on, which in turn sets on-delay Timer_2 for 15 seconds. After this time lapse, the green light activates also setting on-delay Timer_3 for 60 seconds, after which orange lights activates and triggers on-delay Timer_3, thereby repeating the sequence.

Ladder logic diagrams are popular programming tools in PLCs with which a wide variety of applications can be simulated emulating real world control systems (Okoli et al. 2013). In control and automation systems from simple applications such as the traffic lights in Port Moresby to complex versions like escalator supported stairways found in multilevel shopping complexes, PLCs play a central role. Lifts are another example where PLCs are used. Manufacturing and packaging systems employ PLCs for many purposes such as sorting, counting and moving physical packets from loading machine to packaging point. When an item enters conveyor belt, a contact switch senses the presence of the item and starts the conveyor belt. The motor keeps running until the package reaches the end of the conveyor belt to be packed and a switch is activated to turn off the conveyor motor until the next item is loaded onto the conveyor belt.

Coconut oil storage and dispensary

The next simulation concerns the coconut oil storage and dispensary unit in Madang (Figure 4). The coconut oil storage and dispensary facility is used to design a simple control system to improve process efficiency. This is a simple and interesting design which if implemented may improve efficiency to the processes involved in storing and dispensing coconut oil at the Madang depot.

Figure 4: Coconut oil storage and dispensary unit in Madang town.

The coconut oil storage/dispensary unit in Madang town is filled via an inlet valve operated manually after manually recording the low level in the tank by physical climbs upstairs. With the use of a dip stick, levels can be measured to take action on whether the tanks need refilling or otherwise. Customers arrive randomly and the outlet valves are opened to serve them, depending on the number of customers and frequency of arrivals, the cycle of ascertaining the oil level in the tank and refilling can consume time and energy.

A pictorial representation of the process (Figure 5) shows the high and low level sensors appropriately feeding the input of the PLC. If low level sensor detects coconut oil dropping to a low, a logical high is sent to energize an internal relay which shuts the drain outlet valve off and turns the fill motor on. This implies that the internal relay energizes the motor actuator which starts the fill motor. This motor keeps running until the input sensor detects the level of coconut oil at the high level. At this point, the fill motor is de-energized for shut down and the drain outlet is opened on demand as and when customers arrive.

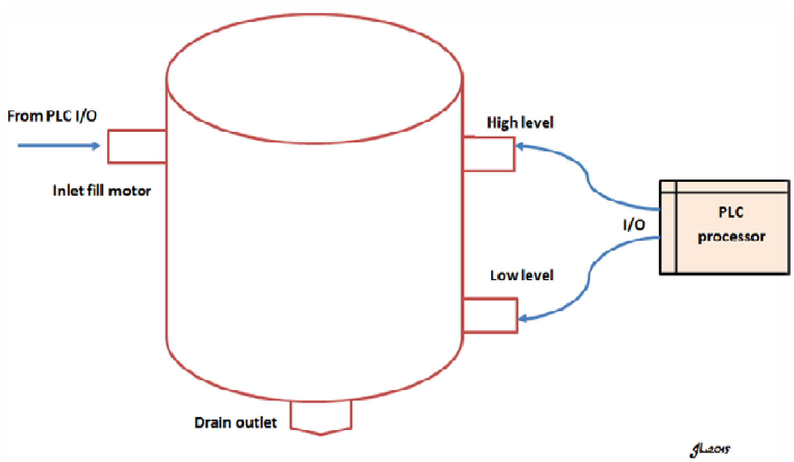

Figure 5: The PLC controlled oil storage/dispensary unit.

The ladder logic diagram (Figure 6) shows a simplified simulation. There are three input devices, a low level sensor, a high level sensor and the internal relay which also acts as an input to the motor actuator. Notice that the internal relay and motor actuators are software functions rather than physical devices. It is these software functions that send the ON/OFF signal to start or shut-down the physical motor.

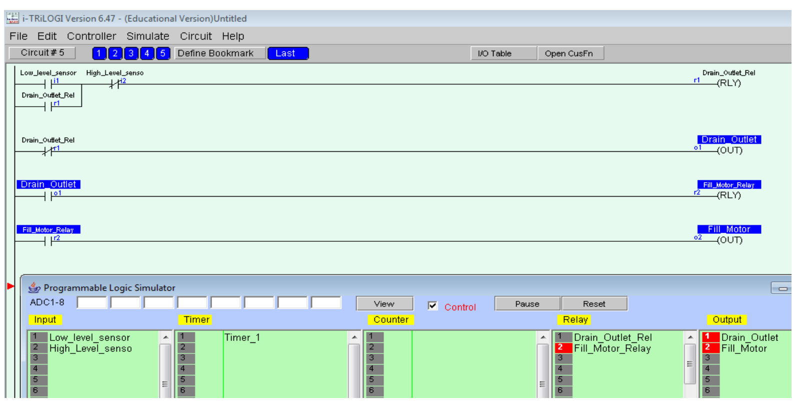

Figure 6: Simulation of coconut oil storage and dispensary facility

The ladder logic diagram used in this paper for the traffic light and coconut storage and dispensary simulation, comply with IEC 1131-3 standard (Bolton 2006). The I/O points indicated in figure 5 form the interface by which the sensor devices are connected to the PLC controller for appropriate processing and action. The ladder diagram language is a symbolic set of instructions, easy for students to learn which are used to construct the control program, which upon compilation is translated into the machine language. The ladder instructions are arranged guided by a flowchart to obtain the desired control logic which is entered into the memory of the PLC (Sharma et al. 2011).

PLCs will continue to find increased use in PNG as this simple simulation has shown and where the benefits are recognized. There are definitely savings in time and money that can be realized by implementing PLCs for the intended purposes.

Fun and profit reasons

PLCs have diverse applications across all sectors of the economy and PNG will benefit greatly when indigenous Melanesians take a paradigm shift towards learning this fun-filled and profitable language. Currently most of the expertise on PLCs is sourced from overseas and many manufacturing companies in PNG rely heavily on this expertize (Hayu 2015). Mining companies and PNG Power are some of the companies that rely on overseas expertize to the extent that in the event of faults, expert labor is often flown into PNG from overseas (Lihai 2015). With easily accessible software such as Trilogi, a wide range of real world simulations can be learned to provide local expertise.

Those who can build competence levels can easily find themselves employed in industrial control systems or can even operate and run their own companies. Currently there is only one fully locally owned national company (GMT automation systems) which has secured contracts from mining companies and PNG power to manage the Moitaka turbine driven power generation in Port Moresby (Lihai 2015). More indigenous Melanesians need to look at the opportunities associated with learning and designing PLC based automation systems.

Graduates who master the art of PLC programming knowledge are on high demand in PNG (Lihai 2015). Introductory PLC courses were offered by UNITECH in Lae, using a PLC programming language called square D but the present status on this training is unknown. DWU could do well to explore PLC as a pedagogical package in the near future. Sewerage and water treatment plants in PNG many also use automated operations using PLCs. These present interesting job opportunities for indigenous people with the right skills.

Academic institutions such as DWU can play indispensable roles in competence and skill building in PNG. Currently, PLCs are unknown at DWU and a quick search at the library revealed absence of related literature. Attempts to order some books through the library were questioned but in fact PLCs are equal to or highly relevant to be taught in either the information systems or the mathematics and computing departments. PLCs are increasingly being used in mining, breweries, cement production processes and packing control systems in PNG. PLCs far outweigh the use of python or java programming languages in PNG so some attempts should be made to equip students with such skills for the real world.

Concerning PLCs, there remain gaps in competencies in PNG but PLCs are not any more difficult than learning hypertext mark-up HTML or similar mark-up languages. In fact PLCs were originally designed to be an easy to use electricians' language. However with increased adoption of computer aided industrial control systems, PLCs have found widespread applications creating employment opportunities for information systems graduates. The few PLC competent workers interviewed for this paper possess no more than a diploma in electronics from Unitech, in Lae. These individuals are engaged by Puma energy and Porgera mining companies to design and install PLC based distributed control systems (DCS). They receive remunerations which are comparably attractive to other professions in PNG.

Future possibilities

PNG's future looks set to experience increased industrialization, in particular led by the mining and resource sector. Whilst these resource sector project developments involve multinational companies, the overall impact sees an expanding PNG economy bringing along more investments. Accompanying these investments will be increased infrastructure growth such as real estate of all manner demanding automation systems which are likely to use PLCs.

With the expanding PNG economy, there will be increased demand for electrical power therefore there will be need for energy generation services to effective to meet the growth in demand. For effective generation, the use of PLCs will be necessary. A wide range of applications in the industry stand to be enjoyed and for academic institutions, there are possibilities to introduce PLCs onto their pedagogical menu.

Conclusions

This paper introduced the PLC, a simple and easy to learn programming language for indigenous Melanesians with prerequisite knowledge of basic electricity and electromagnetic theory. With such basic knowledge and a good understanding of Boolean algebra, it is easier to learn PLC than C++ and java programming languages. Moreover, PLCs have gained a dominant position in control systems and as PNG enters the industrialization phase, PLCs will become indispensable for industrial automation systems. There is over reliance on foreign PLC experts, hence a call is made for indigenous expertise.

Based on ladder logic diagram, instruction lists and sequential function charts, indigenous students and professionals may find PLCs fun to learn with flow-on economic benefits. PNG currently relies heavily on foreign experts insofar as PLCs are concerned, therefore the time is right to promote PLC training in university curriculums including those offered by DWU. Two simple applications have been used in this paper to illustrate the simplicity of simulating real world control systems using Trilogi PLC software. The time is right and the future looks bright to nurture and grow indigenous PLC experts.

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Author

Joseph Kim Suwamaru (PhD) is from Siwai in South Bougainville. He earned his PhD for research on ICTs in PNG. Prior to the PhD, he earned a Master of Engineering Science from Queensland University of Technology (QUT) and a Master in Business Administration (MBA) from DWU. He is senior lecturer with DWU information systems department where he teaches structured and object oriented programming languages. Joseph also serves as a director on the board of DATACO, a state owned enterprise.

Email: jsuwamaru@dwu.ac.pg or pengtel@hotmail.com

Glossary

PLC - Microprocessor-based programmable logic controller performing logic, sequencing, timing, counting and arithmetic to control machines in an industrial process.

Ladder logic – Programing format used to represent switching operations involving logic functions.

I/O module – Main interface between the PLC system and the environment being controlled.

Distributed control systems (DCS) – Control systems with multiple disparately located I/O modules to access distantly located field devices.