ABSTRACT

The use of the programmable logic controller has advanced tremendously since its introduction in the late 1960's. The programmable logic controller, affectionately known as the PLC in today's industries, was first introduced as an electrical control relay replacer. The purpose of this paper is to assist those who are considering the application of a PLC in their facility to better understand where programmable logic controller technology has advanced to today.

OVERVIEW

The programmable logic controller (PLC) can be considered as consisting of three main components, the first of which would be the central processing unit (CPU). The input section and output section make up the other two. Let's look at these three areas one at a time in more detail (Figure 1).

The inputs would consist of field mounted devices. These devices would normally be devices such as push buttons (either maintained or momentary), limit switches (perhaps on a conveyor),
level switches, pressure switches, etc. The devices would be wired to the input section of the PLC and may be at various voltage levels.

Outputs of the programmable logic controller would consist of those field devices that would be controlled based on logic that has been installed in the CPU. Typical output devices would be motor starters, indicating lights, or perhaps digital numerical readouts that an operator would use for status of a particular value in the process.

However, the real core of the PLC consists of the CPU or processor (Figure 2). The processor is the location that the logic is installed which will control the outputs of the PLC, depending on the status of the inputs. In the majority of PLC's available on the market today, this logic would be written in the form of ladder logic. The use of ladder logic in the majority of programmable logic controllers on the market stems from its beginning functionality as a relay replacer. However, the use of programmable logic controllers has advanced far beyond what standard hard wired relay logic can perform.

As the PLC technology advanced, the introduction of more advanced instructions such as timers, counters, and sequencers became an integral part of even the smallest available programmable logic controllers on the market. In today's market place, the definition of a small PLC is one that handles up to but not greater than 128 I/O points. Large PLC's would then be any programmable logic controller that would handle anything larger than 128 I/O points. The main point to observe, however, is that the beauty of the PLC is the logic used to control the outputs is a software logic. Prior to the introduction of the PLC, logic was done through hard wiring of devices. The only way to change these devices was to actually remove and replace wiring that took many hours for maintenance personnel to perform. Today, with the PLC, the same changes can be done through a computer interface in a matter of minutes.

HARDWARE

If we take a closer look at these three major sections of PLC system, the hardware can be broken down similarly. Typically, the hardware would consist of a chassis or rack, in which the processor may reside (Figure 3). Also in this chassis would be individual I/O cards consisting of both input cards and output cards. In more complex systems, the use of intelligent I/O modules may also be considered. These types of modules may be modules such as a basic programming module. This would contain a basic program that would be used to manipulate data outside of the processor of the PLC. As technology has advanced, modules such as bar code interface modules and vision input modules are but a few of the types of intelligent I/O modules available on the market today. However, the same basic concept does still hold. These would be considered either inputs to the PLC or outputs from the PLC in the same chassis along side of what could be considered standard I/O points.

SOFTWARE

We have all heard the term "software" used, very loosely at times, sometimes referred to as "merely software". The software makes up a very important part of the programmable logic controller system. The software is the logic that controls the outputs of your system. It also manipulates and gathers data where appropriate. As I stated previously, the logic is in the form of relay ladder logic in most PLC's on the market today (Figure 5).

Also residing in the CPU or processor of the PLC system, is the data that is also being collected and used by your PLC system. This data could be real world field values such as thumb wheel inputs or analog level signals, or they could be values that were calculated through the logic of the PLC. Regardless, the point to note is that the software in the PLC processor consists of not only ladder logic. The data tables are another important part of the PLC software. The instruction set
available in the PLC’s of today’s market are quite advanced. These advanced instructions can be math computations such as simple addition, subtraction, multiplication, and division, or they can be more complex math calculations such as square root and advanced trigonometric calculations. The results of these math computations can then be used to perform logic decisions as to whether equipment should function or not in your ladder logic (Figure 6).

Another more advanced instruction that is now being used in the programmable logic controller today is the proportional integral derivative (PID) loop control instruction. This instruction can be used to control the value of an analog output, which would be considered the control variable of a field device. Typical applications for this PID instruction would include temperature control and flow control, to name a few (Figure 7).

Sequential control of a system prior to the PLC was done with a hard wired device such as the drum controller switch. Today, in the PLC, this is done with one instruction, called a sequencer. This sequencer controls many outputs associated with the PLC and can sequence them on and off based on predetermined timed intervals or conditions. The flexibility of the instruction set being used in the PLC allows endless combinations for the PLC software designer. No two control software designers would sit down and write identical ladder logic for any given control situation. This point is made to help understand that the limitations of the PLC as they apply to the process control system are almost limited only by the imagination of the designer doing the system (Figures 8, 9, and 10).

COMMUNICATIONS

Once a better understanding of the hardware and software has been mastered, in most systems the need for communications to other solid state devices, personal computers or larger Distributed Control Systems (DCS) is necessary (Figure 4). The programmable controllers available today offer various forms of communications to these external devices. The method that PLC’s use to communicate directly out of a front port of the processor is affectionately known as Data Highway. Over this Data Highway, blocks of information or words of data can be transferred to other programmable logic controllers or to other intelligent higher level systems such as personal computers or mainframe computer systems. This capability of the PLC to communicate both upstream and downstream over Data Highway opens up the ability to store data or transfer data for use in other software programs, residing in these higher level computers. This can be data that would be used for historical production trending or possibly to track an order as it moves its way through a facility while it is in production (Figure 14).

If we take a closer look at the method that the PLC’s use today to communicate, some PLC’s on the market offer integral communication capabilities. That would be the ability of the processor to directly communicate out of a port available on that processor directly to these higher level systems. Other methods are available, such as modules that would slide into the chassis where the I/O is residing that would connect through hard wiring to the front of the processor and then over this Data Highway or RS232/RS422 communication protocols.

Once again, however, the point should be noted that the flexibility is available in the PLC to allow various methods of communications to external intelligent devices (Figure 13).

The trend in today’s market place is to eliminate the need for various black boxes to allow these separate intelligent devices to communicate with each other. The ability for these devices to communicate through a common backplane is the direction that PLC manufacturers are heading today. As various groups in a facility are getting more involved in these PLC applications, the need for interfacing to these higher level systems relatively easily becomes apparent. It used to be, the design engineer was the only one involved in the logic associated with the installation of a PLC. As more groups are finding out the capabilities of the programmable logic controller and how they can be applied throughout a facility, the influx of production personnel and manufacturing information
systems (MIS) personnel are getting involved in the earlier stages of a project where a PLC is involved. These groups now have input on the information that will be gathered by the PLC down at the plant floor level, rather than the PLC being considered only as a means of controlling the process. It is now the lowest level in their system for the gathering of data which will be communicated to their higher level systems. This relationship is crucial in allowing an overall plantwide strategy for a particular facility to become successful. The ability to utilize or maximize the information that is available in the PLC becomes very important in the overall production efficiency of a plant.

APPLICATIONS

As I have stated earlier in this paper, the applications that PLC’s were used in started very simply as relay and timer replacers. And even today, that is a very useful method of justifying the installation of small PLC’s. That nest of wiring and relaying existing in that enclosure mounted on a wall in the shadows of a plant that only one maintenance electrician is capable of working on because no drawings exist is still a realistic situation in many facilities. Today, that panel can be replaced by a very simple, low level PLC, capable of replacing as many as 30 timers and an associated number of relays and contacts that would be involved in that logic. Applications such as conveyor control or simple pump prioritization are just a few of these low level applications that the small PLC’s are being used in today.

Obviously, the justification for a PLC in a facility would typically grow to much larger and more complex levels. Today, the PLC is being applied as a distributed control system (Figure 4). This would be several PLC’s located throughout a plant communicating over Data Highway with each other and to a graphic operator interface terminal, usually in a control room environment. This operator interface can be an industrialized personal computer running graphic software that would give this operator a window into the process, both real time and historically, and would also include the ability for alarming and alarm summaries.

Let’s take a closer look at some real world applications that are being done today in the citrus industry.

REFRIGERATION/UTILITIES

Refrigeration is a very important part of most of the citrus processing industry. This refrigeration requires much power and energy to maintain the proper levels. Because such high levels of power and energy are used, there is obviously the ability for much waste and inefficiency if the equipment in these systems is not accurately monitored or controlled. The ability of the PLC to both control and communicate with compressors and other refrigeration associated equipment gives the capability of monitoring and very closely controlling how these pieces of equipment operate. This would include areas such as staging of compressors, monitoring of pressures and temperatures, and controlling this equipment around the desired and most efficient level. This information, once gathered by the PLC, can be logged and looked at historically to see if the most efficient methods are being used and whether different times of day affect this process.

This application of energy management is usually justified, by the savings associated with reduced power consumption and reduced down time and maintenance of critical equipment.

AIR COMPRESSORS

An application for programmable logic controllers exists in the use of air compressors at most citrus plant facilities. Today, these compressors can be many in number and be of various sizes. At many locations in the industry, these are manually operated and the plant air pressure is monitored manually by an operator. The operator watches the plant air pressure and modifies or stages
manually, individual compressors as needed. This application is perfect for the use of a PLC. What would be done in this application is that the pressure is monitored. A set point that is entered by the operator is also evaluated against the existing air pressure, and air compressors are automatically staged on-line as needed. This avoids problems with machinery and other applications using plant air and how they can be affected if air pressure drops too low or is increased to unnecessary high levels. The overall efficiency of the system is increased dramatically, in addition to the ease of operation of the overall air compressors as they apply in the plant.

**PUMP MATRIX**

The use of tanks full of product waiting to be packaged, whether it be in cartons or 96 ounce jugs, is typically fed to filling operations from one of many available tanks or sources. So, product is then moved from a source tank, sometimes very large in size, to a smaller tank or a user tank in various filling areas. This could be in a carton filling area, for example. Prior to automating this application, various methods were used to route product from one tank to the other. As can be seen through automation, a matrix can be set up where it can have many users and many sources, and through a matrix of piping and the control of various pumping and filling operations, the logic for this type of an application can be automated. As an example, in a carton filling area, the tank feeding the various fillers of these cartons, a level can be maintained by feeding it from one of various tanks or directly from the production line. The selection for this path of product from point A to point B would be done through an operator intervention, whether it be through a graphic screen or some other means of operator interface. The operator can then select which pump he would be operating, which source he would be drawing from for a particular run of product in the filling operation. This decision or logic can be based on the availability of product, whether it be form storage areas or from on-line production operations.

**PRODUCT TRACKING**

The use of PLC’s is also been heavy in the area of data acquisition in both order tracking and finished product tracking after it has been cased or packaged. There can be tremendous losses between the point of packaging and the point of transportation inside of any given facility. These losses can be reduced or accounted for, or even eliminated if closer attention is given to the location and method used to transport through a ware house. This would be done typically through the use of bar coding of packages being automatically sensed as they move down conveyor belts. This bar code data is then fed to a module existing in a PLC rack of I/O. The PLC is then connected over Data Highway to higher level computers or operator interface areas. The product is then counted for quantity and accounted for as far as destination point. So, as the product moves from point A in the warehouse to its destination (or point B), it can be monitored at various locations to confirm that it has arrived, that the proper number has arrived, and no lost product has occurred between point a and point B. This lost product can happen through the means of inadvertent diverter energizing or boxes being removed inadvertently from conveyor lines when they shouldn’t be. Therefore, overall losses of product in a warehousing operation can be reduced substantially through the use of automation equipment, such as programmable logic controllers in conjunction with bar code readers.

**MAINTENANCE**

The programmable logic controller did originate, as I mentioned earlier, as a relay replacer. Therefore, the use of relay ladder logic was very crucial to its overall acceptance into the industrial plant environment. The typical electrical maintenance personnel would understand the use of relay ladder logic. Therefore, the overall acceptance by these maintenance personnel in these various applications as they are used in the plant has been very good. Some training is always recommended and is usually necessary based on the technical expertise of the maintenance personnel in a given facility.
The ability to view the relay ladder logic while it is on-line and running opens up tremendous new avenues of troubleshooting techniques for the maintenance personnel (Figure 9). While viewing the ladder logic as it’s running, energized inputs and outputs appear on a monitor or computer screen. They will appear as highlighted or bold faced to indicate that they are energized at a given moment in time. Taking this one step further, if a particular output does not energize as expected, e.g. a motor does not start when it is being told to, maintenance personnel can easily pull up that rung of logic that should be starting and stopping that particular motor and very quickly get an indication of which contact or which permissive input is not allowing that motor to start. They then direct their attention to that input, which might be a limit switch or a start push button or an auxiliary contact on a starter, and can usually isolate the problem in a fraction of the time it would take on a hard wired system using a voltmeter (Figure 12). One method I have seen used in various facilities as they become more advanced is, the Data Highway is being run not only for the use of data acquisition at control rooms, but another leg of this Data Highway is being run back to the electrical maintenance shop area. This allows the maintenance personnel to get on-line with all of the programmable logic controllers that are connected to that highway, and without leaving the shop can diagnose problems or monitor the logic while they are on-line and running. This can substantially reduce the time necessary to respond to a trouble call as they arrive in a maintenance area. The use of identical hardware in various operations or applications also enhances or adds tremendous value to the use of programmable logic controllers. The same hardware can be used in all of these applications that I mentioned earlier. However, the logic that resides in the processor would be different. Therefore, from a maintenance perspective, the stocking of spare components is narrowed down tremendously.

CONCLUSION

The advancement of programmable logic controllers has opened up endless flexibility in the area of process control. Not only is the engineering department seeing the advantage of the use of PLC’s, but MIS and production are also realizing its advantages in the area of real time and historical data acquisition. The advantages to maintenance groups are also numerous. The use of the same hardware in many applications throughout an entire facility is but one of these advantages. The ability to take real time data and move it from the plant floor upward through an organization relatively fast and easily opens up tremendous efficiency and opportunity for a more reliable process.
FIGURE 1

PLC – 5 Family of Programmable Controllers

- PLC – 5/12
- PLC – 5/15
- PLC – 5/25

FIGURE 2
I/O Scanner Mode

FIGURE 3
Distributed PLC Processing

FIGURE 4
Relay – Type

- Monitors input signals and controls outputs

![Figure 5](image_url)

FIGURE 5

Timers and Counters

- Measure time from 0.01 seconds to 32,767 seconds (over 9 hours)
- Count from $-32,768$ to $+32,767$
- Measure longer periods or increase counts by cascading successive timers or counters

![Figure 6](image_url)

FIGURE 6
**PID Control**

- Single instruction performs proportional, integral and derivative control of a closed-loop process

![PID Control Diagram](image)

**FIGURE 7**

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**PLC - 5 Instruction Set Summary**

- PID control
- Compute
- Data transfer
- Comparison
- Sequencer
- Shift register
- Diagnostic
- Relay-type
- Timers and counters
- Program control
- Immediate I/O

**FIGURE 8**
Comprehensive Programming Language

- Powerful instruction set ideally suited to both sequential and process applications

![Control and Information Processing Flexibility](image)

- Closed-loop PID control
- Relay ladder logic
- Floating point and integer math instructions
- Data file management
- Time-based interrupts

![FIGURE 9](image)

![FIGURE 10](image)
System Building Blocks

- Control and information processing ability
- Integral communication alternatives
- Advanced programming tools
- System diagnostics and troubleshooting

FIGURE 11

System Diagnostics and Troubleshooting Capabilities

- Comprehensive hardware diagnostics
- Built-in diagnostic instructions and program routines
- On-line editing and program documentation

FIGURE 12
Arteries of Data Communication

Ethernet or Broadband

Information network

RS-232

KF2

Data Highway

DH+

PLC

RIO

SLC

I/O

I/O

Drive

I/O

PLC

I/O

I/O

I/O

I/O

I/O

RediPanel

PanelView

I/O

I/O

I/O

I/O

I/O

PLC

I/O

I/O

I/O

I/O

I/O

Drive

IMC

Multiple Drives

PLC

I/O

I/O

I/O

I/O

I/O

I/O

I/O

Remote I/O

SLC-500

FIGURE 14
I/O Trends

- Lowest denominator diagnostics
  - machines down
  - rack failed
  - limit switch 3 jammed
  - output fuse 3L blown