

Lynx Distributed Control System (DCS)

Introduction

Willowglen wanted to create a new Distributed Control System (DCS) product that offers outstanding performance and reliability while being adaptable to many different industries and easily scalable to applications of various sizes. While designing the Lynx DCS to meet these goals, we chose to not rely on any legacy hardware or software. Everything we designed was new and specifically built to meet the rigorous requirements of the DCS market.

It was with this philosophy in mind that we decided to include the following features in the Lynx DCS:

- Rapid peer-to-peer communications between Distributed Processing Units (DPU)
- 10 millisecond system response time
- Sequence of Events (SOE) digital input modules with 1 millisecond time stamp accuracy
- 100 MB per second raw Ethernet data network
- Redundant hardware and data networks
- Clocks on all hardware synchronized to ± 50 nanosecond Global Positioning System (GPS) time
- Ability to operate in a wide range of environmental conditions
- Ability to execute user written IEC 61131 programs
- Wide range of I/O module types
- Electrically isolated channel for each point of an I/O module
- Hot swappable processors and I/O modules
- LED activity indicators for every channel on the I/O modules
- 24 VDC power - ideal for plant environments
- Interchangeable hardware

These desirable features enable the Lynx DCS to be the right control solution for almost any control application in any industry.

Willowglen built the various Lynx DCS component modules around the award winning ARM9 and ARM7 processors, which provide excellent performance and advanced features at reasonable cost. Each Lynx CPU module has one ARM9 processor, one ARM7 processor, 32 MB of RAM, 8 MB of Flash ROM, and runs the open source Linux operating system. The I/O modules are built around a single ARM7 processor. Dual redundant backplanes join the two CPU modules to the I/O modules in a metal chassis.

There are several distinguishing aspects of Willowglen's Lynx DCS, one of which is its constant use of both dual redundant data networks. Unlike other systems that employ a "hot standby" network which can be exploited in the case of a failure on the primary network, Willowglen designed the Lynx DCS to always use both networks all the time. In other words, all data is always sent on both networks all the time. There is no such thing as a primary or secondary network. If one should fail, the other continues to operate without interruption.

System Topology

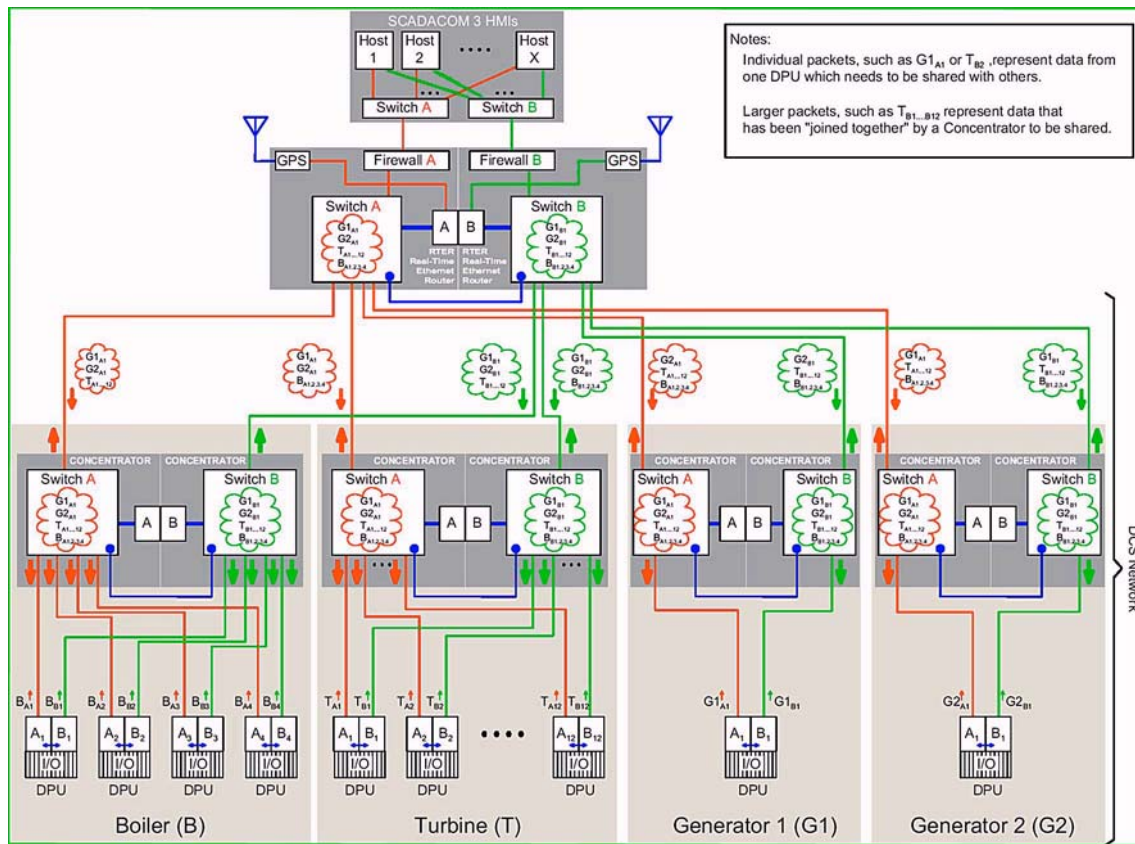
There are four types of Willowglen hardware used in a Lynx DCS. From the bottom up, they are:

- I/O modules
- Distributed Processing Units (DPU)
- Concentrators
- Real-Time Ethernet Routers (RTER)

Data is exchanged between the devices according to a very accurate 10 millisecond system heart beat. Some data is bound for (or from) the SCADACOM® Human Machine Interface (HMI), while other data is being sent entirely within the DCS network for the benefit of peer-to-peer data sharing. Standard off-the-shelf 100 MB per second Ethernet switches are used in addition to the Willowglen Lynx DCS hardware.

Willowglen chose to design the CPU module in a more generic fashion rather than in a strict purpose-built fashion, allowing us to use the same CPU module in the DPU, concentrator and RTER. This facilitates easy system setup and maintenance, requires fewer types of spares for a customer to inventory, and reduces overall system cost as our design effort was reduced.

The diagram below shows an example of a Lynx DCS hierarchy.



Following is a description of each piece of Lynx DCS hardware, and how they are connected:

I/O Modules and Distributed Processing Unit (DPU)

Looking at the Lynx DCS from the bottom up is perhaps the easiest way to conceptualize the system. At the lowest level are the I/O modules. Each is a single circuit board contained in a rugged plastic housing and is intended to perform a specific function. There are a variety of types, including the typical compliment of: analog input, digital input, SOE digital input, analog output, and relay output modules. There are also specialized modules such as: Modbus interface (master and slave), Proportional-Integral-Derivative (PID), thermocouple, Resistance Temperature Detector (RTD), and several others. The full list and a description of each is provided towards the end of this document. These modules typically have eight channels or data points, each with an LED so that some real-time assessment of signal activity can be made while examining the module. Except where noted, each channel is electrically isolated from its neighbours. The I/O modules are connected using dual redundant backplanes to a pair of CPU modules, all of which are inside a rugged metal chassis. Together, the CPU modules, I/O modules, backplane and chassis is called a Distributed Processing Unit, or DPU. A DPU is an autonomous embedded industrial computer that contains a database and I/O control instructions. The DPUs are connected to Concentrators at the next level up the DCS network.

It is possible to connect a DPU directly to the SCADACOM® HMI. The DPU is not a member of the DCS network, and as such are not aware of the 10 millisecond system heart beat, and thus are incapable of sharing data with other DPUs. This limited application of a DPU is useful in standalone applications where there are non-critical tasks to be performed.

Physically, a DPU consists of a compliment of up to 15 I/O modules, and one or two CPU modules depending on whether or not redundancy is desired. The DPU connects to a Concentrator using a standard Ethernet cable. There can be up to 250 DPUs in the system.

Concentrator

According to the system's heart beat, each DPU transmits a short data packet every 10 milliseconds. To avoid the problem of a poor packet "header to payload ratio", a Concentrator coalesces several short DPU messages from a group of DPUs into one larger, more efficient packet. Joining these data packets together is necessary because of the combined effects of frequently sending many short messages from DPUs and the fact that each Ethernet packet has 18 bytes of overhead. It is intended that clusters of 8 to 14 DPUs be joined by a Concentrator. In this way, what would have been a burst of 8 to 14 small and inefficient Ethernet packets every 10 milliseconds now becomes one larger packet with a much more efficient header to payload ratio.

A Concentrator consists of a CPU module and an off-the-shelf Ethernet router. In order to have a dual redundant network, two CPU modules, and two Ethernet routers are required. The Concentrators are then connected to the Real-Time Ethernet Routers (RTER) at the next level of the DCS network using a standard Ethernet cable. There can be up to 16 Concentrator pairs in the system.

Real-Time Ethernet Router (RTER)

At the top of the Lynx DCS hierarchy is the Real-Time Ethernet Router. It is this device that separates the scheduled 10 millisecond data flow in the DCS network from the random Ethernet communications of a company's enterprise level network, while still allowing certain data to pass between the two.

The RTER also serves as the point at which the highly accurate Global Positioning System (GPS) time signal is injected into the DCS network. An antenna positioned with good visibility of the sky and a long enough cable are required to receive the GPS satellite signal and bring it to the RTER.

The RTER consists of a CPU module, an off-the-shelf Ethernet router, a firewall, and a GPS module. As with the Concentrator, if a dual redundant network is required, two CPU modules, two Ethernet routers, two firewalls, and two GPS modules are required. There can only be one RTER pair in the system.

System Operation

The heart of the DCS network is its repeated 10 millisecond system heart beat and all the scheduled actions that occur within that time span. Each millisecond of each 10 millisecond heart beat has certain actions scheduled to take place on the various system devices.

I/O Modules and Distributed Processing Unit (DPU)

Each I/O module in each DPU periodically reads or writes data to or from its I/O channels. The data is then shared with the two associated dual redundant CPU modules using the two backplanes at scan rates selected during the system configuration: 10 milliseconds, 60 milliseconds, 120 milliseconds, 250 milliseconds, 500 milliseconds, or 1000 milliseconds. Important data is configured to be sent more often than unimportant data. All I/O module data is maintained in a database in each of the two CPU modules.

Also happening on the DPU during each 10 millisecond frame is the execution of IEC 61131 programs. These IEC programs use the live data held in the CPU module's database while executing user written algorithms. This allows the Lynx DCS to control and react to plant variables autonomously and in real-time. The IEC programs can be simple or complex, and can even use data taken from other DPUs. They can be scheduled to execute at rates of up to once every 10 milliseconds.

Concentrator

Another activity happening on the DPU every 10 milliseconds is the sending and receiving of data. When the system is configured, each data point can be marked as shared with other DPUs or not. Every 10 milliseconds each DPU sends a relatively small Ethernet packet of all the shared data on the DPU. According to the system topology described above, the packet is sent to a Concentrator. Once it arrives, the Concentrator waits for a set number of milliseconds to allow the neighbouring DPUs to send up their shared data. The Concentrator then joins all of the Ethernet packets (typically between 8 and 14 packets) into one large, more efficient packet. Later in the 10 millisecond heart beat, the large packet is sent out 2 times: once as a multi-cast for the benefit of DPUs in the Concentrator's local group and once as a broadcast up to the RTER from where it is sent to all the other Concentrators, and from there to all other DPUs. The exact same activities are occurring on all the other Concentrators in the system, so "this" Concentrator also receives the coalesced packets from all the other Concentrators.

Real-Time Ethernet Router (RTER)

At the RTER level, activities also continue according to each millisecond of the system heart beat. The RTER accepts coalesced Ethernet packets from all the Concentrators and sends each of these to the other Concentrators, which then send it to each of its DPUs. This multiplication of data is, in effect, the DPU peer-to-peer communication mechanism.

Also taking place on the RTER is the passing of data between the DCS network and the SCADACOM® HMI on the enterprise level corporate network. This important activity is more delicate than it may appear because below the RTER is the DCS Ethernet network where all communications is orchestrated to work according to the 10 millisecond heart beat. Above the RTER, standard Ethernet communications is used without any attempt at scheduling.

The random activity of the enterprise network cannot pollute the DCS network but data must still be able to pass between the two. This critical task is performed by the RTER. The SCADACOM® HMI periodically sends poll requests and sometimes commands to DPUs. The messages are intercepted by the RTER and injected into the DCS network at the appropriate millisecond of the system heart beat. Similarly, data flowing from the DPUs up to the HMI also make their way to the RTER in a millisecond scheduled fashion, and are then passed up to the HMI in the enterprise level. This mechanism allows the two networks to remain separated but maintains the ability to exchange messages between them.

A final activity occurring in the RTER is the time synchronization with the GPS receiver. The RTER receives extremely accurate timing pulses from its GPS receiver and uses these to build time synchronization packets that are distributed throughout all the Lynx DCS devices. A sophisticated algorithm is used to compensate for transmission delays introduced by the store-and-forward Ethernet switches such that each Lynx DCS device maintains an internal time that is extremely close to all other devices. This accurate system time is even sent down to the I/O modules.

Dual Redundant DCS Network

The Lynx DCS was designed from the ground up as a system intended to be operated in a dual redundant manner, but capable of operating in a simpler single unit configuration. The I/O modules each have a rear connector that joins to two DPU backplanes, and the metal chassis for the DPU has two CPU modules. However, cost sensitive customers with non-critical requirements can choose to put just one CPU module in a DPU. Similarly, in a dual redundant system where a Concentrator or RTER is required, two are supplied to facilitate the redundant A and B sides of the DCS network. If redundancy is not required, it is possible to build a system without these hardware “pairs”.

When a Lynx DCS is built in a dual redundant fashion the result is more than just a DCS network with a hot standby. Willowglen’s unique design ensures that the A and B DCS networks are both fully active at all times. There is no notion of a hot standby. In fact, this idea of two fully engaged networks has been taken further by having DPUs, Concentrators, and RTERs exchange messages between their A and B sides. This allows any one side to be aware of problems with its counterpart and to take appropriate action.

For example, if the B side CPU module in a DPU has failed, the A side Concentrator is aware of this and can compensate by replicating the missing data and passing it to the B side of the network thus allowing the B side to continue without missing data from that DPU. The importance of this is magnified in cases where data from the affected DPU is to be shared with other DPUs and used by their IEC programs.

I/O Modules

There are 12 types of I/O modules and a GPS module for the Lynx DCS. The following is a brief description of the modules:

Analog Input (Current) Module

This module accepts 0-5 V and 1-5 V voltage input ranges, and 0-20 mA, 0-10 mA, and 4-20 mA current input ranges with internal or external loop power.

Each of the eight isolated channels utilize a separate 16-bit Analog to Digital converter with an update rate of 62.5 milliseconds.

All channels in voltage input mode exhibit $\pm 0.1\%$ (full scale) accuracy over the operating temperature range. All channels in current input mode exhibit $\pm 0.2\%$ accuracy.

Analog Input (Voltage) Module

This module accepts the following bipolar voltage input ranges: -0.125 V to 0.125 V, -0.250 V to 0.250 V, -0.500 V to 0.500 V, -1.00 V to 1.00 V, -1.25 V to 1.25 V, -2.50 V to 2.50 V, -5.00 V to 5.00 V or -10.0 V to 10.0 V.

Each of the eight isolated channels utilize a separate 16-bit Analog to Digital converter with an update rate of 62.5 milliseconds.

All channels in ≤ 1.00 V input ranges exhibit $\pm 0.1\%$ (full scale) accuracy over the operating temperature range. All channels in > 1.00 V input ranges exhibit $\pm 0.2\%$ accuracy.

Analog Output Module

This module has eight isolated differential output channels support 0-20 mA, 0-10 mA, and 4-20 mA output modes.

Each channel supports internal or external loop power. Current output accuracy is $\pm 0.2\%$ (full scale). All output channels have open loop detection.

Digital Input Module

This module obtains the status of eight digital input points, each of which can be either dry contacts (not powered) or wet contacts (voltage applied).

The dry input mode supports two open contact voltages (24 V or 48 V) and the wet input mode supports four signal levels (24 V, 48 V, 72 V or 120 V). Each input mode allows for software signal debouncing. Input points can be updated as often as every 10 milliseconds.

Digital Sequence of Events (SOE) Input Module

This module obtains the status of eight digital input points, each of which can be either dry contacts (not powered) or wet contacts (voltage applied).

In addition to real-time tracking of an input status, this module also time stamps and logs input events with 1 millisecond accuracy and stores up to eight events per channel (most recent).

The dry input mode supports two open contact voltages (24 V or 48 V), and the wet input mode supports four signal levels (24 V, 48 V, 72 V or 120 V). Each input mode allows for software signal debouncing. Input points can be updated as often as every 1 millisecond.

Relay Output Module

This module contains eight SPDT (Form C) relay outputs, each of which can be configured to operate in one of several modes:

- Two-State
The state of the “Command” parameter passed to the module corresponds directly to the relay state.
- One-Shot
The relay is activated only for the period of time defined by the “PulseDuration” parameter, after which the relay is deactivated.
- Continuous Mode
The relay is continuously toggled on and off for periods of time defined by the duty cycle.
- Burst Mode
The relay is toggled on and off in the same manner as Continuous Mode, however only for a defined number of cycles.

Pulse Input Module

This module is designed to count a wide variety of pulse and frequency input waveforms.

Each input channel supports DC signal levels from 10 mVPP to 30 VPP, AC signal levels from 10 mVP to 5 VP, or up to a 30 V relay contact. The module has three input channels.

RTD Input Module

This module accepts an RTD resistance value on each of its four input channels. The RTD resistances are obtained in 3-wire or 4-wire connection modes, and undergo a linearization of RTD resistance signals to temperature values for Pt DIN, Pt IEC, and Cu RTDs.

The supported RTD types are 100 Ω Pt DIN, 10 Ω Pt DIN, 100 Ω Pt IEC, 10 Ω Pt IEC, 100 Ω Cu, 50 Ω Cu, and 10 Ω Cu. All linearization is compliant with the DIN and IEC RTD standards.

Each RTD input has a $\pm 0.2\%$ measurement accuracy for all RTD types over the full temperature range. Each channel uses a separate 16-bit Analog to Digital converter with an update rate of 62.5 milliseconds.

Thermocouple Input Module

This module accepts bipolar analog thermocouple voltage signals on each of its eight isolated differential input channels. Each channel utilizes a separate 16-bit Analog to Digital converter to digitize its inputs, with a data update rate of 62.5 milliseconds.

The module performs on board linearization of the signals to temperature values, and supports internal or external cold-junction compensation. Supported thermocouple types are J, K, T, E, R, N, B, and S.

The type T thermocouple has $\pm 0.3\%$ temperature measurement accuracy. All other thermocouple types have $\pm 0.2\%$ temperature measurement accuracy over the full temperature range. All linearization is compliant with the ITS-90 thermocouple standard.

PID Module

This module is designed to accept as input and also output voltages and/or currents to implement a closed-loop proportional, integral, differential controller. The module includes two analog inputs, two analog outputs, and two firmware-based controllers capable of executing PID algorithms. These components can be connected in arbitrary configurations to create multi-input, multi-output, and multi-stage control loops.

The PID control firmware uses a proprietary bumpless algorithm with integral-term antiwindup. Independent and variable P, I, and D gains are used, with deadband support. Scaled feed-forward values are also supported. When configured correctly, the PID continues to operate correctly when a CPU module loss occurs without affecting closed-loop stability.

Modbus Interface Module

This module is used to communicate with third-party devices using the Modbus Communication Protocol as either the Master or Slave, as determined by the firmware on the module.

When acting as a Modbus Master, the module can reference any slave address, and when acting as a Modbus Slave the module can act as one or more Modbus slaves using multiple addresses. Modbus ASCII and RTU modes are both supported. Communication is possible using a wide variety of RS-232 baud rates as well as many parity and stop bit settings.

Multi-Function Module

This module has 12 I/O channels:

- 1 analog current output
- 1 analog current/voltage input
- 7 digital voltage/contact inputs
- 3 relay outputs

The points are not all electrically isolated due to the limitation of 24 I/O pins on the front of the module. What makes this module unique is that it contains a user programmable processor that can run an arbitrary algorithm using the 12 I/O channels. Once running, the module only needs power, and it can continue to operation even if both CPU modules are not responding. In a sense, this module is in itself a tiny plant controller.

GPS Module

This module uses a 12 channel “Lassen IQ” GPS unit to obtain a time pulse and then communicates the pulse and time value through two RS-232 output ports. This signal is designed to provide the RTER with a ± 50 nanosecond time reference for use by all the Lynx DCS system devices.

System Sizes

As with any system design, the Lynx DCS has limits as to how large it can grow:

There is a maximum of 1024 database points for any DPU. A database point is either a physical I/O point such as an analog input point, or a virtual point like a value calculated as the result of an IEC program. Additionally, there is a limitation of 16,384 total database points in the system.

There can be up to 250 DPUs in the system.

There can be up to 16 DPUs per concentrator, and a total of 16 concentrator pairs in the system. A concentrator pair is one A side network concentrator and one B side network concentrator.

There is always only one RTER pair in the system.

As for physical distances between DPUs and Concentrators and RTERs the limitations are those imposed by the Ethernet technology and the switches used. Typically these limitations are: 100 metres for a CAT-5 cable and 2000 metres for a full duplex fiber-optic cable.

For additional information on specific configurations and pricing, please contact Willowglen Systems Inc.
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