

Telescope and Site Controlled Document

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LSST Summit Control Panel Manufacturing Guidelines

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1 Overview

This document describes the Large Synoptic Survey Telescope (LSST) requirements for the design and manufacture of electrical control panels and systems for use at the summit location. The specification is appropriate for both: in-house projects and third party contracts.

The objective is to provide a consistent set or rules to avoid essentially different builds by different vendors. The intention is also to restrict unnecessary diversity of components, interconnects and software that otherwise would negatively impact long term maintenance efforts and procurement of replacement parts. These guidelines take in consideration national and local standards for compliance with existing regulations and to ensure that safety aspects are properly observed.

These guidelines apply to all electrical and electronic equipment and their integral control systems, in particular control panel design, safety mechanisms and wiring.

For the purpose of this document, "Vendor" refers to any internal or external entity working on the design or manufacture of LSST control panels.

Document No.	Title	Author
LTS-52	Summit Support Facility Electrical Requirements	O. Wiecha
LTS-54	LSST Summit Environmental Conditions	J. Sebag
LTS-96	LSST Summit Electrical and Control Systems Standards	O. Wiecha
LTS-99	LSST Summit Safety Interlock System	O. Wiecha

2 List of References

3 Technical Specifications

3.1 Enclosures

3.1.1 Environmental Conditions

All equipment shall be capable of operation at LSST site altitude (2700 meters or 9000 ft).

All equipment shall be capable of operation at ambient temperatures between -10°C and +40°C.

All equipment shall be capable of operation at relative humidity between 5% and 90% non-condensing.

The temperature differential between the inside of the electrical enclosure and the exterior ambient temperature shall not be greater than 10 °C except when thermal management is required. See LTS-54 "LSST Summit Environmental Conditions".

3.1.2 Environmental Rating

Control panels for use indoors shall have a minimum degree of protection of IP54 (NEMA 12). Panels that are exposed to the elements shall have a minimum degree of protection of IP65 (NEMA 4).

3.1.3 Pattern

Self standing style, floor mounted with an integral plinth, or wall mounting with all the required fixing hardware.

All enclosures shall have welded, copper plated ground studs; one for the main body and one for each door. The assembly plate shall be earthed by means of rivet-nuts and serrated screws, all zinc plated.

Seismic rating and securing hardware may be required for some locations.

3.1.4 Finish

Enclosures shall have a RAL 7035 (ANSI/ASA 61) light Gray epoxy semi-gloss finish. Assembly plates shall also be finished epoxy semi-gloss color yellow orange (RAL2000) or white.

3.1.5 Access

Doors and removable access panels shall be fitted with ¼ turn, key operated fastener. Space permitting, hinged doors are the preferred option. Latches operated without the use of accessory tools or devices are also permitted upon approval.

Panels fitted with external manual disconnect switches may only be opened when the switch is in the off position so that all power is removed; this includes all control panel doors in the Observatory.

3.1.6 Assembly Plates

Assembly plates shall be drilled and tapped to accept the equipment mounting screws. Screws shall be of the appropriate length (i.e. not cut to length), which shall protrude no more than three millimeters (approximately 1/8") of thread length beyond the back plate or otherwise not interfere with equipment or structures located behind the same.

All screws shall be zinc plated steel, stainless steel or other rust free material or finish. Slotted screws are not permitted unless no other option is available as they are not well suited for installation with power tools.

4 Grounding

4.1 Main Ground

A copper earth bar shall provide grounding for electrical equipment inside the control panel. The cross sectional area shall be in accordance with the applicable wiring standards.

4.1.1 Fixing

The earth bar shall be fitted on insulated stand-offs and all equipment shall be connected directly to the earth bar. "Daisy chained" grounding shall not be permitted if continuity and integrity of the connection cannot be guaranteed under any operating or maintenance condition.

In some panels ground terminal blocks are more practical, and most electrical standards allow using DIN rails for grounding. Use rivet-nuts for improving the connection of components and parts not equipped with ground terminal.

4.1.2 Connections

Each earth conductor connected to the earth bar shall be green with a yellow stripe and identified at each end with the device identification of the component that it is bonding to facilitate identification and testing.

4.1.3 Supplementary Bonding

Braided conductors or stranded cables shall be provided for all assembly plates, hinged doors, swing panels and gland plates.

4.1.4 Conductor Size

The minimal cross sectional area of all earth bonding conductors and straps shall be related to the phase conductor size. When practicable the use of conductors the same size as the phase conductors is preferred. Refer to NFPA 70 for minimum required cross sections.

4.2 Electromagnetic Compatibility

Assemblies shall comply with current FCC rules and IEC directives on Electro Magnetic Compatibility and Interference (EMC/EMI). The magnitude of the conducted and radiated noise voltages and fields shall not exceed the limits defined in FCC part 15, class B. All off-the-shelf electronic devices shall satisfy these standards unless specifically waived. A combination of approved devices installed as intended shall be deemed compliant. Custom designed electronics shall take advantage of all reasonable good practices in design and fabrication to ensure non-interference and to ensure the design is robust against interference to itself or its neighbors. When testing in an anechoic chamber is not practical or economically viable, the use of analytical tools or comparison to similar builds is acceptable in lieu of formal FCC/IEC certification. Scientific instrumentation is potentially susceptible to EMI and the aim is to prevent such interference.

Systems involving modulated power delivery like motor drives deserve particular attention. Valuable information regarding EMI/EMC compliant installation and best practices can be found in the industrial literature:

- Kollmorgen (kollmorgen.com): AKD[™] Installation Manual
- Lenze (lenze.de): L-force Drives 9400 Hardware Manual
- Siemens (siemens.com): Sinamics Operating Instructions

4.3 Marking

All items shall be UL marked unless they are exempt from the marking process. Certificates of Conformance shall be provided for all components that require UL marking. Certificates shall be supplied at the time of delivery. UL marking shall specifically indicate compliance with the UL 508 series of standards denoting suitability for use in electrical panels. MCBs for feeding branch circuits shall be UL listed as molded case circuit breakers (MCCB). Use RoHS compliant components whenever available.

4.4 Layout

4.4.1 Accessibility

The control panel layout shall be arranged such that components are readily accessible with no components located lower than 200 mm (8") from floor level. The handle of any supply-disconnecting device shall be located no lower than 600 mm (2 ft) from floor level.

Where reasonably practicable, components should be mounted on 35 mm symmetrical DIN rail.

Manufacturer's installation instructions regarding spacing, orientation and segregation of cabling shall be followed when installing components.

Unimpaired access shall be provided to each component and terminal to allow ease of access for maintenance and calibration without the need for removal of component wiring or the use of special tools. In the extreme case the use of special tools is required those should be provided to LSST as part of the deliverables.

4.4.2 Proprietary Equipment

Where proprietary control equipment is installed within a compartment or panel, the manufacturer's standard enclosure shall always be utilized. The installation of "stripped out" motherboards or circuit boards is prohibited.

4.5 Trunking

4.5.1 Backplates

Wiring shall be run in open slotted trunking and where wiring becomes exposed it shall be clipped neatly and supported to avoid sagging.

Distances from trunking to terminals shall be a minimum of 25 mm (1'') and such that cable marking is not obstructed and those components can be removed without removing trunking covers – check distances when planning the layout and again before cutting any cables to length.

4.5.2 **Doors**

Wiring to compartment doors, with the exception of earth wires, shall run in flexible plastic conduit or spiral wrap.

4.5.3 Capacity

Trunking shall not be filled to more than 60% of its capacity.

4.6 External Cabling

Control panels shall be provided with gland plates of sufficient size and number to gland off all cables.

Glanding facilities shall be provided for a minimum of two additional glands or 20% of the total number of cables specified whichever is the greater.

All cable glands shall be matched to the environmental rating of the enclosure. For outdoor applications use metal glands only.

4.7 Terminal Blocks

4.7.1 Application

All wiring, except specialized cabling like communications, shall enter and leave each internal enclosure via terminal blocks. Direct connection onto equipment terminals is only permitted for main circuit breakers and manual disconnect switches as well as outputs to loads where the equipment itself is intended as the terminal block or when wire continuity is crucial (e.g. soft starters, variable frequency drives and servo amplifiers).

4.7.2 Type

All terminals shall be of a type providing positive mechanical clamp-on connection, made of non-ferrous materials and protected against oxidation. Terminal blocks that allow direct contact between the screw and the wire shall be avoided, particularly with fine stranded wires, which in all cases must be terminated with ferrules. In environments prone to vibration spring terminals are preferred.

Common terminals should be linked using jumper bars of the same current rating as the terminals being used. Exposed live parts shall be protected against accidental contact.

4.7.3 Layout

One terminal block shall be provided for each incoming cable. There shall be sufficient terminals to terminate each core of the cable and all screens and drain wires. Barriers shall be used to

separate groups of terminals. Soldered pass-through terminals for cable shields are permitted when necessary.

Terminal blocks for the connection of all external cabling shall be situated near their respective gland plate or entry point.

4.7.4 Mains Terminals

All main phase terminals shall be suitably marked to ensure that the correct phase rotation is obtained when the plant is connected to the supply. Each phase stud shall be segregated by the use of phase barriers and a non conductive cover engraved in red letters "DANGER XXX V" shall cover all phase terminals, where XXX denotes the phase to phase voltage.

4.7.5 Segregation

Terminals for power, control, instrumentation and data cables shall be physically segregated from each other.

Where terminals carry 50 V or greater they shall be fully shrouded. All door-mounted terminals shall be fully shrouded.

4.7.6 Spare Capacity

Unless stated otherwise, Vendor shall ensure that, after installation, each terminal rail shall incorporate 20% spare capacity.

Where possible, no more than two wires shall be connected to any one terminal. The removal of any component shall not affect the continuity of any power, earth or signal wire shared with other components.

4.7.7 Marking

All terminal blocks shall be numbered sequentially using the snap-on numbering system provided by the manufacturer of the terminal blocks. The same number shall appear on both sides of each terminal block. A functional description is not necessary.

4.8 Labels

4.8.1 Ratings Plate

Each control panel shall be equipped with a nameplate providing current and voltage levels including short circuit rating per U.S. NEC. The nameplate shall also state the date of manufacture and the revision number of the specification and drawings to which it was built. The nameplate shall be mounted in a prominent position. Label fixing shall not degrade the enclosure ingress protection classification.

4.8.2 Component Labels

Internal labels should be provided for all components. Equipment labeling nomenclature shall comply with the approved drawings.

4.8.3 Character Size

Character size (upper case) for enclosure identification shall not be less than 5 mm (0.2") in height. Characters on device identification labels shall not be less than 3 mm (1/8") in height.

4.8.4 Material and Fixing

Exterior labels shall be of plastic sandwich material, engraved and fixed – adhesive shall be permitted only in indoor applications.

4.8.5 Color

Prohibition labels (the action must be NOT carried out) shall be red with white engraving.

Mandatory labels (the action must be carried out) shall be blue with white engraving.

Warning labels (risk of danger) shall be yellow with black engraving.

All other labels shall be white with black engraving.

4.8.6 Visibility

Labels should be clearly visible when the compartment wiring is complete as well as any indicator light.

4.9 **Power Supplies and Power Distribution**

4.9.1 Operating Voltage

The nominal operating voltage and frequency for the control panels is TP+N 380 Vac, 50Hz; SP+N 220 Vac, 50Hz

However, due to load fluctuations, operating from standby generators and the expected voltage oscillations of the local commercial power grid, the nominal voltage may vary by up to +10/-15% and the frequency by $\pm 5\%$. Hence, all equipment shall be capable of operating without malfunction over the voltage range TP+N 324-419 Vac, 47-53Hz; SP+N 187-242 Vac, 47-53Hz.

4.9.2 Power Configuration

Control panels will be only single or three-phase, single feed. Dual feed panels may be necessary when working with energy conversion or power generators and should be clearly marked. In the case of three-phase panels preference shall be given to solutions that do not require the use of the neutral wire in order to control unbalance currents and neutral switching.

4.9.3 Manual Disconnects

Every control cabinet shall be capable of being completely disconnected from the power grid. If this cannot be made locally to the control cabinet, a durable warning notice should be provided stating the location and procedure for disconnecting. Door mounted disconnect switches are not permitted. All disconnect switches must contain terminals for the connection of every incoming power conductor. When a three-phase disconnect switch is required to break the neutral conductor, the corresponding contact shall be of the "early make" type in order to prevent applying high transient voltages to single-phase loads. In single-phase applications both conductors: phase and neutral or both phases, shall be interrupted. Protective conductors are never interrupted.

The main disconnect switch shall have the ability to be padlocked in the "OFF" position. Any door interlocked with the isolator shall be able to open only in the OFF position. Rotary isolators shall be equipped with internal rotary operating handle in order to permit operation independent of the door position without auxiliary tools as per U.S. NFPA 79, 2007 Edition, paragraphs 5.3.4 and 6.2.3.

Panels fitted with more than one power feed must exhibit a warning sign alerting about this condition.

Where practicable, the incoming supply shall terminate directly at the main disconnect switch, whose terminals shall be fully shrouded.

4.10 Uninterruptible Power Supplies

All control circuit voltages for monitoring and safety circuits shall be derived from a UPS.

The UPS shall be "on-line" type capable of providing a minimum of 20 minutes autonomy, at full load, when the main supply is removed.

The UPS shall be fitted with an alarm scheme to provide information about the battery charge.

Any single-phase UPS shall be equipped with bypass means and double-pole disconnect switch at the output, which shall be lockable in the "OFF" position by means of a padlock.

4.10.1 Control and Isolation Transformers

All transformers shall be of the double-wound, isolated, screened construction with the screen and one side of the secondary winding connected to earth, which in the case of power transformer shall be the electrical power earth bar.

Whenever possible the transformer shall have ±5% tapings on the primary side.

Any individual single-phase transformer loading shall not exceed 3 kVA. In the instance of loads exceeding 3 kVA additional transformers shall be provided.

The primary of the transformer shall be protected by:

- a suitably rated double-pole circuit breaker fed from two phases of the TP+N supply;
- a single-pole circuit breaker with switched neutral fed from one phase and the neutral of the SP+N supply.

The secondary shall be protected by a suitably rated single-pole circuit breaker.

4.10.2 Power Distribution

Whenever possible all LV power distribution shall be by means of suitably rated circuit breakers. Protection by fuses shall be avoided due to the susceptibility of their characteristics to changes in altitude and difficult remote monitoring.

One circuit breaker shall be provided for each power circuit. A tripping curve appropriate to the load to be protected shall be chosen.

Where specified on the drawings, circuit breakers shall be fitted with a potential free trip and auxiliary contacts that will be closed when the circuit breaker is not tripped.

Where the application controls Duty and Standby equipment then separate circuit breakers shall be provided for Common, Duty and Standby equipment.

4.10.3 DC Power Supplies

DC power supplies shall generally be of a switched mode, fully stabilized design.

DC power supplies associated with low level analogue signals shall be of low noise design.

Specific power supplies may be required for certain safe extra low voltage (SELV) circuits.

All power supplies shall be complete with a close fitting cover and terminal guard.

For single-phase applications, universal input power supplies rated for 100 Vac to 240 Vac nominal voltage, 50/60Hz are the solution of choice. For three-phase applications 380 to 480 Vac power supplies are commonly available, but in the case of 208 Vac to 240 Vac three-phase panels the preference is for single phase power supplies fed from two phases.

4.10.4 Mains Filters

When used, filters shall be of a metal clad, preferably two-stage design with earth line choke.

4.11 Emergency Stop and Guard Circuits

Emergency stops and guard circuits are connected to the facility interlock safety controller.

Both, emergency stop and guard circuits shall be dual channel with monitored reset.

Where there are insufficient contacts on the safety relay then the number of contacts may be expanded using relays or contactors with positively guided contacts as to maintain the specified safety category.

All emergency stop and guard circuitry shall be "fail-safe" under any operation conditions.

4.12 Programmable Controllers

4.12.1 Processors, PLCs and PACs

See list of preferred equipment.

4.12.2 I/O Modules

I/O modules shall be selected for the appropriate duty.

4.12.3 Distributed I/O

Distributed I/O shall be implemented preferably using Ethernet I/O modules.

4.12.4 I/O Module Wiring

I/O modules shall be provided with an adequate cable support system to avoid strain on the termination headers. Means shall be provided to prevent termination headers being accidentally disconnected. Latched or screw-lock connectors are preferred.

The I/O wiring shall be loomed to allow for the removal of the individual I/O module header complete with the attached wiring. For each I/O module, the header shall be clearly identified as to which module it relates.

Each wiring termination between I/O modules and incoming/outgoing terminals shall be identified with the relevant alphanumeric I/O address. A short functional description should also be considered.

Where high-density modules are used, the manufacturer's multi-core cable may be used.

Where digital outputs switch DC inductive loads, they shall be fitted with diodes that protect against back electromagnetic force (back EMF). These diodes shall be fitted as close to the load as practicable.

Where digital outputs switch AC inductive loads, they shall be fitted with arc surge suppression devices. These devices shall be fitted as close to the load as practicable.

Diodes and surge suppression devices shall not be fitted to the termination headers of I/O modules.

After the design of the complete scheme has been finalized, 10% spare capacity or one spare module of each type utilized, whichever is the greater, shall be provided, within each enclosure, for inputs and outputs.

4.13 Human Machine Interfaces (HMIs)

HMIs shall be selected for the appropriate duty.

Panel mounted workstations shall be installed in the doors of panel such that the horizontal centre line of the display is 1,5 m (5 ft.) above finished floor level. All internal communications and connecting cables shall be suitably installed to prevent damage or interruption to operation during panel access.

Facilities shall be included to allow the adjustment of control and other parameters from the workstation. Such facility shall be multi-level password protected to provide varying levels of access.

Where more than one type of operator is connected to the same controller provision shall be made to prevent conflicting control data from multiple sources.

Where multiples, such as networked computers and a local HMI terminal, have access to control data a hierarchical structure shall be defined with password access for data changes from either source. Normally this structure shall allow default access via the computer with secondary control from the local HMI.

4.14 Utility Outlet

A metal-clad, surface-mounted, dual-switched, RCD (GFCI) protected socket outlet shall be installed within each controller panel for use with a portable programmer and test equipment.

A label shall be affixed adjacent to the socket indicating "Test Equipment Use Only".

The socket outlet voltage and format shall match the Chilean standard.

4.15 Relays and Timers

All relays shall be clearly identified and grouped according to plant usage.

4.15.1 Interface Relays

Control interface relays shall be of the miniature NO-NC type, complete with a 24 Vdc operating coil and status indicator.

4.15.2 Timers and Monitoring Relays

Time delay and monitoring relays shall be of the DPDT or 4PDT, multi-range electronic type. The ranges shall be selectable using DIP switches or similar. Case necessary each range shall be fully adjustable by means of a front mounted graduated potentiometer or otherwise electronically programmable.

4.15.3 Relay Bases

Relay bases shall be 35 mm DIN rail mounting type with spring release tab and relay retention clip.

4.16 Motor Starters

4.16.1 Cage Induction Motors

Electric motors with a rating not exceeding 3 kW (4 HP) can be operated using DOL starters. Motors exceeding 3 kW (4 HP) shall be operated using an electronic soft start unit or VFD.

4.16.2 Protection

Where practicable, motor starters shall be implemented using "compact starters" that comprise isolation, thermomagnetic tripping and switching functions in a single unit. Preferably the unit selected would have at least two NO-NC contacts for alarm and signaling functions or network connectivity.

4.16.3 Construction

Groups of multi pole circuit breakers (MPCBs) shall be connected using the manufacturer's standard busbars. The contactor shall be closely coupled to the MPCB using the manufacturer's connecting module.

Contactor pairs used in star-delta starters or automatic transfer switches shall incorporate electrical and mechanical interlocking to prevent both contactors closing simultaneously. An electronic star-delta timer module shall be used to sequence the switching of the contactors.

4.17 Pushbuttons and Selector Switches

Pushbuttons fitted to the control panel shall be spring return shrouded type, and each shall have a label indicating its function. Emergency stop buttons shall be monoblock construction or equally resilient to accidental disassembly, mushroom head, with latch-in/twist-to-release or key release depending upon the application.

Color	Function	Usage
White	Initiate Action	Start-up (the legend on the button should be 'I').
Black	Terminate Action	Shut-down (the legend on the button should be '0').
Gray	Non Specific	General usage.
Blue	Mandatory	Acknowledge a mandatory condition e.g. acknowledge a change of mode.
Green	Normal	Initiate a normal condition, e.g. enable or arm a system.
Yellow	Abnormal	Suppress an abnormal condition e.g. alarm reset, restart after an abnormal condition.
Red	Emergency	Initiate a stop condition (as emergency logic must be hardwired, this color should not appear on screen based controls).

Colors of any additional pushbuttons shall be as detailed in the drawings.

Selector switches fitted to the control panel shall be lever operated, stay put type unless otherwise specified in the drawings.

4.18 Pilot Lamps

Access to lamp shall be from the panel front.

Color	State	Function	Usage
White	Steady	Neutral	Other condition e.g. power on
Blue	Steady	Mandatory	Indication of any condition that requires mandatory action by the operator e.g. change mode.
Green	Steady	Normal	Normal condition e.g. motor running, pressure ok, etc.

Green	Flashing	Normal	Change of condition e.g. starting-up/shutting down/mechanism in transit.
Yellow	Steady	Abnormal	Non-critical alarm e.g. an alarm that does not stop the system from operating.
Yellow	Flashing	Abnormal	Critical alarm e.g. an alarm that prevents the system from operating.
Red	Flashing	Hazardous	Emergency condition e.g. Emergency stop operated/Guard open.

Colors of any additional lamps shall be as detailed in the drawings.

4.19 Audible Alarms

The control panel shall incorporate an audible alarm device with a sound output of at least 100 dB at 1 m.

The alarm shall sound when the panel is in LOCAL mode and a new alarm occurs. Hardwired facilities for muting the alarm shall be provided. The alarm shall be disabled when the panel is in REMOTE mode.

4.20 Internal Wiring

4.20.1 Type

Power, hook-up and lead appliance wiring material shall be stranded copper, UL 1581 AWM style 1015 compliant or equivalent:

- rated for 600 Vac, 750 Vdc, -20 °C to 105 °C;
- rated 2500 Vdc peak for electronic circuits;
- passes VW-1 vertical wire flame test;
- tinned conductors to prevent oxidation;
- oil resistant;
- preferably with oxygen free copper and halogen free PVC.

4.20.2 Color Coding

Below there is an excerpt from the applicable electrical codes that deal with wiring color codes for control panels.

4.20.2.1 NFPA 70, 2011 Edition

The U.S. National Electrical Code mostly applies to building wiring and does not address wire colors except to identify ground, neutral, the highest voltage lead of a three phase delta 4- wire system and intrinsically safe conductors. Article 409, Industrial Control Panels, refers to UL 508A in this matter.

Article 100.15 – Orange: to identify higher phase voltage on 4-wire delta connected systems.

Article 200.6 – Insulated grounded conductor (neutral):

- 1) white insulation;
- 2) gray insulation;
- 3) three white stripes on other than green insulation.

Article 250.119 – Green or green with one or more yellow stripes: to identify equipment grounding conductors.

Article 504.80(C) - Light blue: to identify intrinsically safe conductors.

4.20.2.2 NFPA 79 Electrical Standard for Industrial Machinery, 2007 Edition

Section 13.2 Identification of Conductors:

- green with or without one or more yellow stripes: strictly reserved for the equipment grounding conductor where insulated or covered;
- white, gray or three continuous white stripes on other than green, blue or orange insulation along its entire length: AC circuit grounded, current-carrying conductor;
- white with blue stripe: grounded, current-carrying, DC circuit conductor;
- white with orange stripe: grounded, current-carrying, AC circuit conductor, which remains energized when the main supply circuit disconnecting means is in the OFF position;
- orange: only to identify ungrounded conductors that remain energized when the main supply circuit disconnect is in the OFF position;
- black: for ungrounded AC and DC power conductors;
- red: for ungrounded AC control conductors;
- blue: for ungrounded DC control conductors.

The NFPA 79 standard does not apply to wiring outside industrial machinery.

4.20.2.3 UL 508A Industrial Control Panels, 2007 Revision

Section 66.5.3, Internal Wiring – Power Circuits:

- black all ungrounded control power circuit conductors regardless of voltage;
- white, gray or three continuous stripes on other than green, blue, orange or yellow grounded AC current-carrying conductor regardless of voltage.

Section 66.9, Internal Wiring of Control Circuit:

- black all ungrounded control circuit conductors operating at the supply voltage;
- red ungrounded AC control circuits operating at a voltage less than the supply voltage;
- blue ungrounded DC control circuits;
- yellow or orange ungrounded control circuits or other wiring that remain energized when the main disconnect is in the OFF position;
- white, gray or three white stripes on other than green, blue, orange or yellow grounded AC current-carrying control circuit conductor regardless of voltage;

- white with blue stripe grounded DC current-carrying control circuit conductor;
- white with yellow stripe or white with orange stripe grounded AC control circuit current-carrying conductor that remains energized when the main disconnect is in the OFF position.

The UL508A standard does not apply to wiring outside the industrial control panel.

4.20.2.4 Wiring Color Code Disambiguation

While there are no contradictions between the codes above, there is not enough guidance for a successful practical implementation in a modern control panel. It is necessary to clearly identify AC and DC power and controls at the different voltage levels. Also it is important to consider Chilean wiring standards availability of the different color insulations. Bearing in mind that a structured control panel design will usually contain an AC power section, single or three-phase, and a 24 V control section, AC or DC and sometimes both, the wiring color code shall be as follows:

- building power AC wiring is 220/380 V, 50 Hz, 3-phase, 4-wire, labeled black, red, blue with white neutral;
- control panel AC power wiring is black and shall be identified as L-N or L1, L2, L3-N or R, S, T-N on the supply side and T1, T2, T3-N or U, V, W-N on the load side;
- orange shall be used only to identify ungrounded conductors that remain energized when the main supply circuit disconnect is in the OFF position;
- yellow means a power source derived from another location and it is only yellow outside its place of origin;
- red is for less than 50 V AC power or control circuit ungrounded conductor;
- blue is for less than 50 V DC power or control circuit ungrounded conductor;
- white is for 50 V or above AC power or control circuit grounded, current-carrying conductor;
- gray is for less than 50 V AC power or control circuit grounded, current-carrying conductor;
- white with blue stripe is for less than 50 V DC power or control circuit grounded, current-carrying conductor;
- white with orange stripe identifies a grounded, current-carrying, AC circuit conductor, which remains energized when the main supply circuit disconnecting means is in the OFF position;
- white with yellow stripe identifies a grounded, current-carrying, AC circuit conductor for a power source derived from another location;
- green with optional one or more yellow stripes is used to identify ground wires, shields and screens in AC and DC circuits independently of voltage.

Wire color coding does not apply to multi-wire cables.

4.20.3 Rating

Cross sectional areas of conductors shall be selected taking into account the rating of the protection device, wire bundle and altitude of the installation. Wire sizes depend on the actual current they carry as well as on the length between the source and the load and the way the wire is laid out (free air, tray, conduit, etc.) Only the maximum current carrying capacity of the wire shall be derated. It is recommended using no more than 50% of the rated current capacity at sea level. The minimum wire size for AC and DC power circuits on cable trays and conduits shall be 1.5 mm² (AWG 16). It is Vendor's responsibility to check each and every conductor.

4.20.4 Identification

All wiring shall be identified at both ends in accordance with schematic diagrams using printed wire labels. The label on each wire shall unequivocally identify the device and the specific terminal to which it belongs. Cables shall be identified on both ends with the name of the device and connector where they connect.

4.20.5 Termination

Wires shall be terminated using insulated crimp terminals (which crimp the insulation and the conductors), ferrules, or lugs of the correct size.

Insulated Tin-plated Copper with PVC insulation				
Insulation Color	Cable Size [mm ²]	Cable Size [AWG]		
Yellow	0.2 - 0.34	24 – 22		
Red	0.5 – 1.5	20 – 18		
Blue	1.5 – 2.5	16 - 14		
Yellow	4 – 6	12 – 10		
Red	10	8		
Blue	16	6		
Yellow	25	4		
Red	35	2		

Table 1: Sizes of Insulated Crimp Terminals

errules shall be made to DIN 46228-4 standard and of the proper length for the corresponding terminal block. Color coding of insulated ferrules also shall follow the DIN standard since Weidmüller and Telemecanique (French standard NF C 63-023) color codes use green for several wire sizes, which by NEC is exclusively reserved for identifying ground wires.

Bear in mind that the plastic collar of the ferule and insulated terminals has voltage and temperature ratings. To match the requirements of UL 1581 AWM style 1015 the voltage rating must be 600 Vac and the temperature rating must be at least 105°C.

The first step in selecting a ferrule is to identify the conductor size and if the application requires a single or twin wire ferrule. Ferrules are made to metric wire sizes and there may be a need to determine the metric equivalent of AWG sizes. Twin wire ferrules are available only in insulated versions and are designed to accept only two wires of the same size. To determine the correct size of the ferrule it is necessary to add the cross section of all the wires and compare with the wire capacity of the ferrule.

The next step in selecting a ferrule is to determine how long the barrel should be. There are several lengths available depending on the wire capacity of the ferrule. Most applications require the most common length; however ferrules with longer and shorter barrels are available in most sizes.

Ferrules were developed for metric wire sizes, and although some manufacturers have created ferrules for some AWG sizes, the ultimate test is to physically check how the wire fits in the ferrule and the quality of the crimp. For instance, 4 AWG wire corresponds to 21.2 mm², and depending on the crimping tool the 25 mm² ferrule may not the best choice and the 2 x 10 mm² twin ferrule should be used instead.

Crimps shall be applied by means of a crimping tool using the correct size of die. Point to point wiring in continuous lengths shall be utilized. Intermediate extensions (butt splicing) are not permitted – when needed use terminal blocks.

Size		DIN
mm²	AWG/MCM (mm ²)	Color
0.14*	26 (.129)	Gray
0.25*	24 (.205)	Purple
0.34*	22 (.326)	Turquoise
0.5	22 (.326)	White
0.75	20 (.518)	Gray
1	18 (.823)	Red
1.5	16 (1.31)	Black
2.08*	14 (2.08)	Yellow
2.5	14 (2.08)	Blue
4	12 (3.31)	Gray
6	10 (5.26)	Yellow
10	8 (8.37)	Red
16	6 (13.3)	Blue
25	4 (21.2)	Yellow
35	2 (33.6)	Red
50	1 (42.4)	Blue
70	2/0 (67.4)	Yellow
95	3/0 (85)	Red
120	4/0 (102)	Blue
150	300 (152)	Yellow

Size		DIN	
mm ²	AWG	Color	
2x0.5	2x22	White	
2x0.75	2x20	Gray	
2x1	2x18	Red	
2x1.5	2x16	Black	
2x2.5	2x14	Blue	
2x4	2x12	Gray	
2x6	2x10	Yellow	
2x10	2x8	Red	
2x16	2x6	Blue	
Table 3: Twin Wire Insulated			
Ferrules			

* Denotes sizes not in the DIN standard – color is most common choice among manufacturers.

Table 2: Single Wire Insulated Ferrules

4.20.6 Segregation

Control and supply voltage wiring shall be segregated for added safety and to avoid cross coupling of noise.

4.20.7 Accessories

All wiring accessories of plastic material, such as cleats, conduits, strapping, etc., shall be resistant to flame propagation.

4.21 Temperature Monitoring

Each enclosure shall be fitted with a thermostat whose contacts shall open when the ambient temperature within the enclosure exceeds the lowest upper operational limit for their components. In exterior panels under temperature shall also be monitored. The thermostat contact shall be connected to a monitoring device and shall generate both: local and remote alarms.

When used, enclosure heaters and coolers shall have their own temperature control. Depending on the type of enclosure, breather kits may be necessary for humidity control and pressure equalization.

5 Quality Control

5.1 General

5.1.1 Access by LSST

Vendor shall give reasonable access to LSST engineers and inspectors during manufacture so build quality and progress can be monitored.

If LSST identifies defects in either the manufacturing processes or the equipment under construction these shall be reported to Vendor immediately and confirmed within seven days. Vendor shall advise LSST of the course of action that will be taken to mitigate the defects.

5.2 Procurement

Vendor shall purchase all equipment and parts for the construction of the control panels except for specific parts explicitly provided by LSST.

5.2.1 Inwards Inspection

Vendor shall inspect every component that is delivered for use in LSST control panels to ensure that it complies with the purchase order requirements and that no component is damaged and there are no missing parts.

Warranty periods shall be also verified, as well as validity or manufacturing dates of components with limited shelf life like batteries and bulk wires and cables.

5.2.2 Storage

All equipment purchased for use in LSST control panels shall be stored in a clean, dry, dust free environment. Storage temperature variations shall not exceed the manufacturer recommended conditions. All equipment shall be clearly labeled with relevant information.

5.2.3 Exclusive Use

Once marked and stored, equipment identified for LSST projects shall not be used on any other projects that Vendor may be undertaking for other customers.

5.2.4 Test and Calibration Certificates and User Manuals

Vendor shall ensure that any test and calibration certificates and user manuals delivered with any equipment are safely preserved. These documents shall be delivered to LSST with the completed control panels within which the equipment is fitted.

5.2.5 LSST Issued Equipment

Where items of equipment are issued to Vendor by LSST, the equipment shall undergo the same goods inwards inspection procedures and shall be stored under the same conditions as components purchased directly by Vendor.

5.3 Manufacture

5.3.1 Care of Equipment

During manufacture Vendor shall take care to ensure that components and assemblies are not damaged. Particular care shall be taken to ensure that front panels are protected against marking and scratching.

5.3.2 Tooling

Vendor shall ensure that the proper tools are used in the manufacture of the control panels and that these tools are kept in good condition.

5.4 Inspection

Upon completion of manufacture each control panel shall be inspected to ensure that it complies with the manufacturing drawings and that the quality of the build is satisfactory.

5.4.1 General

- There shall be no mechanical damage to any assembly or component.
- All of the components used shall match the Bill of Materials or approved substitution.
- All of the components shall be correctly labeled with the part numbers shown on the schematics.
- Trunking routes shall not be overloaded (less than 60% of maximum capacity) and all lids shall be fitted.
- Flexible conduit shall be used to protect all wiring onto the doors of enclosures.
- The control panel shall be free of all manufacturing debris.

5.4.2 Electrical

- All wiring shall be point-to-point tested to ensure that it complies with the circuit schematics;
- Each conductor shall be sized and colored in accordance with the Wire List;
- All shields and drain wires shall be terminated or insulated in accordance with the circuit schematics;
- All power wiring shall be tested with an insulation tester to ensure that the core-to-core and core-to-earth insulation is greater than $1 G\Omega$. The test voltage shall be appropriate to the voltage rating of the cable being tested;
- All metal enclosure components shall be earth bonded and tested for continuity. The maximum impedance from the main earth bar on the panel to any metal component shall be 0.1 Ω .

5.4.3 Cables and Connectors

Each connector shall be inspected to ensure that:

- it is the correct gender;
- the shells have been correctly oriented and polarization pins have been fitted;
- all cable restraining hardware has been fitted and that the restraints are correctly sized;
- no cable cores or shields are visible.

5.4.4 Supply Compatibility

Every voltage sensitive component shall be inspected to ensure that voltage selectors have been set to match the specified supply voltage and frequency when applicable.

All relays and contactors shall be inspected to ensure that the coil voltages and frequencies match the specified supply or control voltage.

All indicator lamps shall be LED and inspected to ensure that they are of the correct power and voltage.

5.4.5 Protections

Every fuse and circuit breaker shall be inspected to ensure that the rating and curve match the circuit schematics.

All protective relays shall be inspected to ensure that the setting matches the circuit schematic.

All components shall be inspected to ensure that live parts are shrouded to prevent contact with other live parts.

The control panel shall be inspected to ensure that all warning and safety labels have been fitted.

5.5 Testing

5.5.1 General

Prior to delivery the completed control panel shall be tested at the Vendor's shop to ensure that it is fully operational. These tests shall be carried out by Vendor and witnessed by LSST.

No item of equipment shall be delivered to site without inspection having been carried out except when waived by LSST.

Vendor shall give LSST five business day notice of any tests.

Test personnel shall be fully conversant with the particular manufacturer's equipment, which is to be tested.

Minor faults may be corrected during the tests, but any major faults will result in the tests being abandoned and resumed at a later date.

Vendor shall update all software, drawings and documentation after completion of the shop tests and before shipment to site.

5.5.2 Test Schedule

Vendor shall produce a test schedule for each control panel that will verify correct operation.

All tests shall be arranged to represent the working conditions as closely as possible.

All tests shall be carried out at the rated supply voltage and frequency; AC voltage waveforms shall be approximately sinusoidal with less than 5% THD.

Tests shall include the setting up and adjustment procedures for all equipment according to manufacturer's instructions to ensure conformity with all specifications stated by the manufacturer.

The means to load, dump, initialize and auto restart following a power failure to recover the system shall also be tested.

5.5.3 Test Instrumentation

Vendor shall supply all equipment necessary to test the control panels. When necessary this equipment should include proprietary diagnostic equipment and simulators.

Vendor shall supply a list of all test equipment and instruments before commencement of testing. Vendor's test equipment shall be of satisfactory quality and condition.

All key instrumentation used by Vendor in the testing of control panels shall have a valid test and calibration certificate. The calibration standards used by the testing authority shall be traceable to national standards. No test shall be carried out involving electronic equipment that requires a certain warm up time until such warm up time has elapsed.

5.5.4 Spares

All spares shall be tested and available throughout the testing process.

6 Manufacture Only Contracts

6.1 Information Supplied by LSST

6.1.1 General

LSST will provide Vendor with a complete information pack for each control panel. The information pack comprises:

- document index;
- circuit schematics;
- wire lists;
- panel layouts;
- terminal plans;
- parts list;
- bill of materials.

Vendor shall not make any changes to these documents without prior consent from LSST.

6.1.2 Document Index

The document index provides a list of all documents in the information pack.

6.1.3 Circuit Schematics

A fully detailed set of circuit diagrams is provided for the control panel.

6.1.4 Wire List

The wire list provides every wire number on the schematics and lists the wire color, size, type and length.

6.1.5 Panel Layouts

Fully detailed general assembly drawings supplemented by cut out and label details.

6.1.6 Terminal Plans

The terminal plans detail the layout and composition of each and every terminal block within the control panel.

6.1.7 Bill of Materials

The bill of materials is a sorted part list that provides the following purchasing information:

• part number / device ID;

- quantity;
- description;
- manufacturer;
- supplier if applicable.

6.1.8 Alternative Suppliers

Where a component manufacturer or supplier has advised Vendor that a component which appears on the LSST Bill of Materials is discontinued, has changed in specification or that delivery is protracted, Vendor may recommend an alternative component or source. However, no component shall be substituted without prior consent from LSST.

6.2 Conformity

Vendor shall manufacture the control panels in strict accordance with the drawings and documents supplied.

6.3 Errors, Discrepancies or Missing Information

Vendor shall inform LSST immediately of any errors or issues with the information supplied so they can be corrected before manufacture proceeds. Vendor shall not make any changes to the design without prior consent from LSST.

6.4 Information to Be Supplied by Vendor

Vendor shall supply the calibration and test certificates of key equipment that may affect performance of the system.

7 Applicable Standards

This list is for reference only; see LTS-96 "LSST Summit Electrical and Control Systems Standards" for additional information.

7.1 Chilean Standards

• NCh Elec 4/2003, Instalaciones de Consumo en Baja Tensión

7.2 International Standards

- ISO 10218-1, Robots for industrial environments Safety requirements Part 1: Robot (includes Technical Corrigendum 1)
- ISO 9283:1998, Manipulating industrial robots Performance criteria and related test methods
- ISO 13849-1:2006, Safety of machinery Safety-related parts of control systems Part 1: General
- principles for design (includes Technical Corrigendum 1)
- ISO 13849-100:2000, Technical Report Safety of machinery Safety-related parts of control systems Part 100: Guidelines for the use and application of ISO 13849-1

- ISO 13849-2:2003, Safety of machinery Safety-related parts of control systems Part 2: Validation
- ISO 13850:2006, Safety of machinery Emergency stop Principles for design
- ISO 13855:2002, Safety of machinery Positioning of protective equipment with respect to the approach speeds of parts of the human body
- ISO 14121-1:2007 Safety of machinery Risk assessment Part 1: Principles
- ISO 14121-2:2007 Safety of machinery Risk assessment Part 2: Practical guidance and examples of methods
- IEC 60204-1:2009, Safety of machinery Electrical equipment of machines Part: 1 General requirements
- IEC 61000-6-2, Electromagnetic compatibility (EMC) Part 6-2: Generic standards Immunity for industrial environments
- IEC 61000-6-4, Electromagnetic compatibility (EMC) Part 6: Generic standards Section 4: Emission standard for industrial environments

7.3 U.S. Standards

- ANSI/ASSE Z244.1, Control of Hazardous Energy Lockout/Tagout and Alternative Methods
- ANSI/ISO 12100-1:2007, Safety of machinery Basic concepts, general principles for design Part 1: Basic terminology, methodology
- ANSI/ISO 12100-2:2007, Safety of machinery Basic concepts, general principles for design Part 2: Technical principles
- ANSI/RIA R15.06-1999, Industrial Robots and Robot Systems Safety Requirements
- ANSI/RIA/ISO 10218-1-2007, Robots for Industrial Environment Safety Requirements Part 1 – Robot
- FCC Rules, Part 15.
- NFPA 70: National Electrical Code 2008
- NFPA 70B: Recommended Practice for Electrical Equipment Maintenance
- NFPA 70E: Electrical Safety in the Workplace
- NFPA 72: National Fire Alarm Code
- NFPA 75: Standard for the Protection of Electronic Computer/Data Processing Equipment
- NFPA 77: Recommended practice on Static Electricity
- NFPA 79: Electrical Standard for Industrial Machinery
- NFPA 780: Standard for the Installation of Lightning Protection Systems
- OSHA Part 1920 of Title 29 of the Code of Federal Regulation: Safety Standards for Machinery
- RIA TR R15.206-2008, Technical Report for Industrial Robots and Robot Systems Safety Requirements Guidelines for Implementing ANSI/RIA/ISO 10218-1-2007
- UL 508: Standard for Industrial Control Equipment
- UL 508A: Standard for Industrial Control Panels

- UL 508C: Standard for Power Conversion Equipment
- UL 924: Standard for Emergency Lighting and Power Equipment.