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Proposed Mu2e Remote Handling Controls Panel Layout

Dave Pushka

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Contents of Panel:

- QTY 14 Servo drives, Kollmorgan AKD-00306 units, (power data excerpt on right).
  A PLC (Automation Direct Productivity 2000, extended base, multiple I/O types, DI, DO, AI, Comm)
- 24 VDC power supplies for providing 24 VDC need by the servo drives.
  - (Perhaps Automation Direct PSV24-50 units)
- An ethernet hub
  - (Perhaps an Automation Direct se2-sw18u-2g unmanaged ethernet switch)
- Some lights inside the cabinet to make it easier to work
  - (Perhaps Automation Direct 022000 units).
- Fuse holders for the 24 VDC output between the 24 VDC power supply output and the servo drives.
- Terminal blocks for instrumentation connection, AC neutrals and grounds.
- 14+ Signal conditioners for the LVDTs & torque sensors.
- Wire ducts for making the wiring neat and orderly and to provide separation between the AC and the signal or communication wiring

AKD Installation | 6 Technical description and data

6.5 Electrical Data AKD-xzzz06

Electrical Data	Units	AKD-x00306	AKD-x00606	AKD-x01206	AKD-x02406
Rated supply voltage	V	3 x 120 V to 240 V ±10% 1 x 120 V to 240 V ±10%			3x240 V ±10%
Rated supply input frequency	Hz	50 Hz to 400 Hz ±5% or DC			
Rated input power for S1 operation	kVA	1.2	2.38	3.82	7.6
Rated input current					
at 1x120 V	A	5.0	9.9	12	-
at 1x240 V	A	5.0	9.9	12	-
at 3x120 V	A	2.3	4.6	9.2	-
at 3x240 V	A	2.3	4.6	9.2	18.3
Permitted switch on/off frequency, mains	1/h	30			
Max. inrush current	A	10	10	10	20
Rated DC bus link voltage (Bus Turn on Delay 3ph 1 sec)	V	170 to 340			
Continuous output current (± 3%), single-phase or three-phase					
at 120 V	Arms	3	6	12	-
at 240 V	Arms	3	6	12	24
Peak output current (for 5 s, ± 3%)	Arms	9	18	30	48
Continuous output power @ rated input current					
at 1x120 V	VA	312.5	625	1250	-
at 1x240 V	VA	625	1250	2500	-
at 3x120 V	VA	312.5	625	1250	-
at 3x240 V	VA	625	1250	2500	5000
Peak output power (for 1 s)					
at 1x120 V	kVA	0.937	1.875	3.125	-
at 1x240 V	kVA	1.875	3.750	6.250	-
at 3x120 V	kVA	0.937	1.875	3.125	-
at 3x240 V	kVA	1.875	3.750	6.250	10
Technical data for regen circuit	—	→ p. 41			
Motor inductance min.					
at 120 V	mH	1.3	0.6	0.5	0.3
at 240 V	mH	2.5	1.3	1	0.6
Motor inductance max.	mH	250	125	100	60
Thermal dissipation, output stage disable	W	max. 20	max. 20	max. 20	max. 25
Thermal dissipation at rated current	W	31	57	137	175
Noise emission (low speed/high speed fan)	dB (A)	N/A	33/39	37/43	41/56
Aux. voltage supply (PELV)	V	24 V (±10%, check voltage drop)			
-current B, P, T types without/with motor brake	A	0.5 / 1.7	0.6 / 1.8	0.7 / 1.9	1.0 / 2.5
-current M type without/with motor brake	A	0.8 / 2.0	0.9 / 2.1	1.0 / 2.2	1.3 / 2.8

Constraints, Assumptions, & Recommendations:

- QTY 14 Servo drives, Kollmorgan AKD-00306 units:
  - Dave Peterson recommended we provide 3 phase 208 to power these drives, although they can also be powered on single phase. Vendor data on these drives recommend the maximum input circuit protection be 10 Amps
- A maximum of 8 servos will drive at any one time (Window machine). 4 driving, 4 holding.
- Need to understand if powering a servo driver is okay if the servo motor and resolver are disconnected. (Dave Peterson & George Lolov to look into this).
- Dave Peterson Recommended multiple small 24 VDC supplies in lieu of one big one
- Lighting is needed in the panel and should be permanently mounted.
- Assume 5 wire 208 is available in the room: 3 wires for each leg of the 3 phase, a neutral, and a ground. Voltage from any one leg to the neutral is 120 VAC.
  - See Slide 8 for the building electrical panel assigned circuits.
- Lighting, PLC, and 24 VDC power supplies mentioned in the previous slide all indicate satisfactory for 110 to 240 VAC input, single phase.
- AC Power (> 50 VAC) needs to be separated from DC or signal cable: Assume separate wire ducts meet this requirement. (More on this later).
- Servo drive and resolver cable can be in the same wire duct as ethernet.
- Assume an open, unmanaged ethernet switch is acceptable.
- Assume patch panel location under the desk is negotiable.

Choice of Kollmorgan servo motors and drives:

- Kollmorgan Servo Motors and Drives were selected by Mike Campbell early in the mechanical design process for the remote equipment
  - Kollmorgan bought out the Slo-Syn line from Superior Electric.
  - Slo-Syn Synchronous / Stepping Motors have been used at Fermilab for many years.
- The Kollmorgan Servo Motors include position feedback from the motor to the drive which allows closed loop control of the motor rotation.
  - Closed loop control which is only possible with feedback is better than open loop control (as is typically done with stepper motors) because it compensates for 'lost steps' which can occur with open loop control.
  - Closed loop control is important for high speed, high precision, and high accelerator applications.
  - The remote handling equipment is designed to need high precision, therefore the servo motors were chosen over stepper motors.
- The downside to servo motors is higher cost and interchangeability between manufactures.
  - Cost of the servo motors and drives are about $1900 each.
  - A small fraction of the total remote handling material cost.

Choice of Automation Direct PLC:

- PLC recommended by Dave Peterson.
  - Similar to others used by Dave
  - Relatively inexpensive (PLC cost including IO modules < $2000).
  - Quick delivery.
  - Free programming software
  - Experience with Automation Direct PLC's used by Paul Kasley's group in for NuMI LCW is good.
  - Using same PLC for other AD/TSD applications
  - Can share common spare module pool.
- Avoids License problems and annual license renewal expenses with Lab-view and similar products.

Questions to and Answer from the Electrical AHJ, Dave Mertz (Mertz's email replies in blue font):

Question 1: If 110 VAC single phase is also brought into this panel, then there are two disconnects that need to be made for LOTO. Having 2 power sources requires a written lotto procedure, right?

- If you have two sources of power, yes, you need a written LOTO procedure. However, If you bring in a 5-wire 208 3-phase supply, which includes the grounded (neutral), then you can run your 110 V loads from one phase to neutral, so you won't need the second power source unless you want to run the controls with the drive power shut off. Not sure why you'd need to do that.

Question 2: All of the equipment inside the panel besides the servo drives are listed as operating on 100 to 240 VAC. So, theoretically, one leg of the 208 to neutral could provide this power. Is this sensible?

- True, but if you're running 14 servos that (according to the table below) need up to 5 amps each on a single-phase circuit, that's 70 amps without figuring in any of the other loads. NEMA-type plugs an receptacles only go up to 50 amps.

  (Note, only use 8 drives at any one time – 4 driving, 4 holding)

Does the 208 VAC building distribution include a neutral, or just a ground?

- While I can't rule out that there might be an oddball 208V 3-phase panel somewhere on site that does not have a neutral, everything I recall seeing has a neutral. If you can check the panel you want to use, if it has any 1-pole circuit breakers it's gotta have a neutral.

  (See panel from building construction drawings later in this presentation)

Or should a separate single phase AC power source also be brought into the panel?

- As I noted in question 1, a separate single phase control power circuit is generally not necessary, unless you want to keep the controls running without any power for the drives present.

Recommendations from the Electrical AHJ, Dave Mertz:

Question 3: A disconnect for the power coming into this panel (with LOTO capability) should be provided, even if this is plug connected equipment, right?

- If you want a separate single phase control power circuit to keep the controls running without any power for the drives present, then yes. Otherwise a single cord-and-plug connection could potentially allow you to use the exclusive control of the plug exception in the LOTO program.

Question 4: Is it okay to be able to open the panel doors with AC power on for signal debugging or does the disconnect need to be disconnected to open the panel as is frequently down (and always overridden) in other installations?

- I'd have review UL 508A, (unfortunately the lab's copy is out on loan to another person) to give you a definitive answer on that question. What might be of interest to you is an item in the 2018 NFPA 70E Table 130.5(C) says that there's no likelihood of an arc-flash when working on control circuits under 125 V AC or DC. **So my analysis of this is if you put use two cabinets for the controls, one with the power equipment like the drives, and the other with the PLC and instrumentation, you could open and work on the controls-only cabinet without needing arc-flash PPE (shock protection PPE still needed if voltages are over 50).You could also have a single panel with an additional removable barrier inside that would protect a control-circuit worker from an arc-flash on the power side.** The power side could still supply the control power, so this would not necessitate a second separate control power supply. If you could keep all circuits on the controls side under 50 V, then no PPE would be needed to work on the control circuits

(Bold font is my addition to high-light important words from Dave Mertz)

208 VAC source:

Circuits 49, 51, 53 and 50, 52, 54 provide 208 VAC to outlets in the remote handling room and adjacent areas. These outlets are where the remote handling panel will be located when in use.

PANEL: PP-Mu2e-A1-6-A1

MAIN BUS RATING:	225 A	FED FROM:	PHP-Mu2e-A1-6 via TR	LOCATION:	ROOM 115
MAIN BREAKER:		FEEDER SIZE:	4#4/0, 1#2G, 2 1/2"C	MOUNTING:	SURFACE
MAINS TYPE:	MLO	VOLTS:	208/120V 3PH,4W	ENCLOSURE TYPE:	Type 1
LUGS:		PHASE / WIRE:	3PH, 4W	AIC RATING:	10,000A

CKT	Circuit Description	C/B	P	A		B		C		P	C/B	Circuit Description	CKT
1	REC 208V (RM 115)	20 A	3	1911.0...	1911.0...					3	20 A	REC 208V (RM115)	2
3	–	–	–			1911.0...	1911.0...			–	–	–	4
5	–	–	–					1911.0...	1911.0...	–	–	–	6
7	REC 120V (RM115 & 105) & JC	20 A	1	900.0 VA	720.0 VA					1	20 A	REC 120V (RM115 & 105)	8
9	REC 120V (RM 115 & 105)	20 A	1			900.0 VA	720.0 VA			1	20 A	REC 120V (RM115 & 105)	10
11	REC 208V (RM115 & RM105a)	20 A	3					1274.0...	1274.0...	3	20 A	REC 208V (RM 115, RM 105a)	12
13	–	–	–	1274.0...	1274.0...					–	–	–	14
15	–	–	–			1274.0...	1274.0...			–	–	–	16
17	PWR FOR FUT. HEPA FAN 3/4HP	20 A	1					1590 VA	1440.0...	1	20 A	REC 120V + GEN REC (RM 015)	18
19	OUTDOOR GFI WP RECEPTACLE	20 A	1	180 VA	1440.0...					1	20 A	REC 120V + GEN REC (RM015)	20
21	EXTINCTION MONITOR	30 A	3			2883.0...	2883.0...			3	30 A	EXTINCTION MONITOR	22
23	–	–	–					2883.0...	2883.0...	–	–	–	24
25	–	–	–	2883.0...	2883.0...					–	–	–	26
27	REC 208V (RM 011 & 007)	30 A	3			1922.0...	1922.0...			3	30 A	REC 208V (RM 011 & 007)	28
29	–	–	–					1922.0...	1922.0...	–	–	–	30
31	–	–	–	1922.0...	1922.0...					–	–	–	32
33	REC 208V (RM 011, 005 & 006)	30 A	3			2883.0...	2883.0...			3	30 A	REC 208V (RM 011, 005 & 006)	34
35	–	–	–					2883.0...	2883.0...	–	–	–	36
37	–	–	–	2883.0...	2883.0...					–	–	–	38
39	REC 120V (RM 011, 005 & 006)	20 A	1			1260.0...	900.0 VA			1	20 A	REC 120V (LL EXIT 019)	40
41	REC 120V (RM 011, 005 & 006)	20 A	1					1260.0...	1260.0...	1	20 A	REC 120V (LL EXIT 017)	42
43	REC 208V (LL TRANSP. CORR.)	30 A	3	3844.0...	3844.0...					3	30 A	REC 208V (LL TRASNP.CORR)	44
45	–	–	–			3844.0...	3844.0...			–	–	–	46
47	–	–	–					3844.0...	3844.0...	–	–	–	48
49	REC 208V (RM 014, 015)	30 A	3	3833.0...	3833.0...					3	30 A	REC 208V (RM 014, 015)	50
51	–	–	–			3833.0...	3833.0...			–	–	–	52
53	–	–	–					3833.0...	3833.0...	–	–	–	54
		Total...		40340 VA		40880.0 VA		42650.0 VA					
		Total...		336 A		342 A		355 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Receptacle	123870.0 VA	54.0%	66890.0 VA	Total Conn. Load:	123870.0 VA
				Total Est. Demand:	66890.0 VA
				Max. Connected Amp per Ph:	355 A
				Average Est. Demand Amp per Ph:	186 A

NOTE: BREAKERS FEEDING DOUBLE DUPLEX RECEPTACLES IN POWER RECEPTACLE BOX SHALL BE TIED WITH HANDLE AS DESCRIBED IN LEGEND ON POWER PLANS (TYPICAL).

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

Mu2e CONVENTIONAL FACILITIES ELECTRICAL PANELBOARD SCHEDULE SHEET 2 OF 3

DRAWING NO. **6-10-2** **E-19** REV. **AB**

F.I.M.S. No. 270

Decisions based on Dave Mertz Guidance:

- Use one panel and include an arc flash panel over panel portions with Potentials over 50 volts.
  - 1/8 clear plexiglass has been proposed, with small holes to allow access to drive adjustments and to re-set breakers. Mertz has agreed this is okay.
  - Allows use of $2400 panel ordered in summer 2019
  - Requires perforated sheet metal separator to separator the upper and lower portions of the panel. Mertz has given guidance on the separator material.
- Locate AC and V > 50 in upper half of the panel
- Locate PLC and signal in the lower half of the panel
- Include a single point disconnect switch on panel exterior.
- Bring in 3 phase 208, supply to 3 phase 10 amp breaker (QTY = 7) for supplementary protection and supply 2 servo drives from each breaker.
- From other 10 amp 3 phase breakers (Qty = 3) Peel off 1 phase and supply to the 24 VDC supplies. Use two remaining legs on 3rd breaker to supply 110 to power PLC and panel lighting.

Proposed Layout of the 5 foot square, 8 inch deep panel:

Legend:

Red = 208 AC 3 phase breakers and wire duct

Pink = 120 AC 1 phase breakers

Gold = 24 VDC Power Supplies, fuse holders and wire duct

Magenta = Servo Drives

Purple = Servo wire Duct

Bright Green = PLC

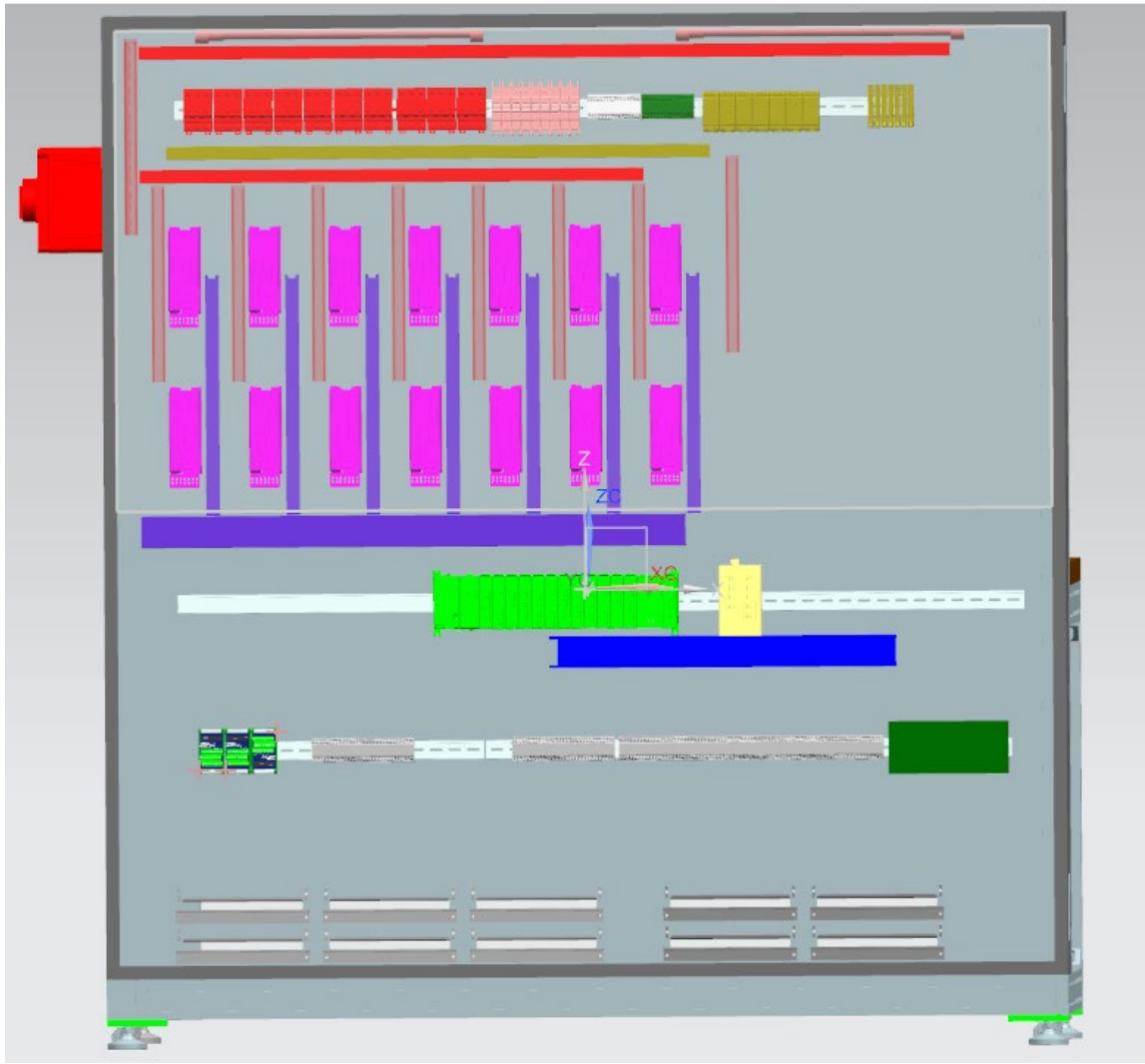
Dark Green = LVDT Signal Conditioners & wire duct

Yellow = Ethernet Switch

Light Blue = Digital Output duct

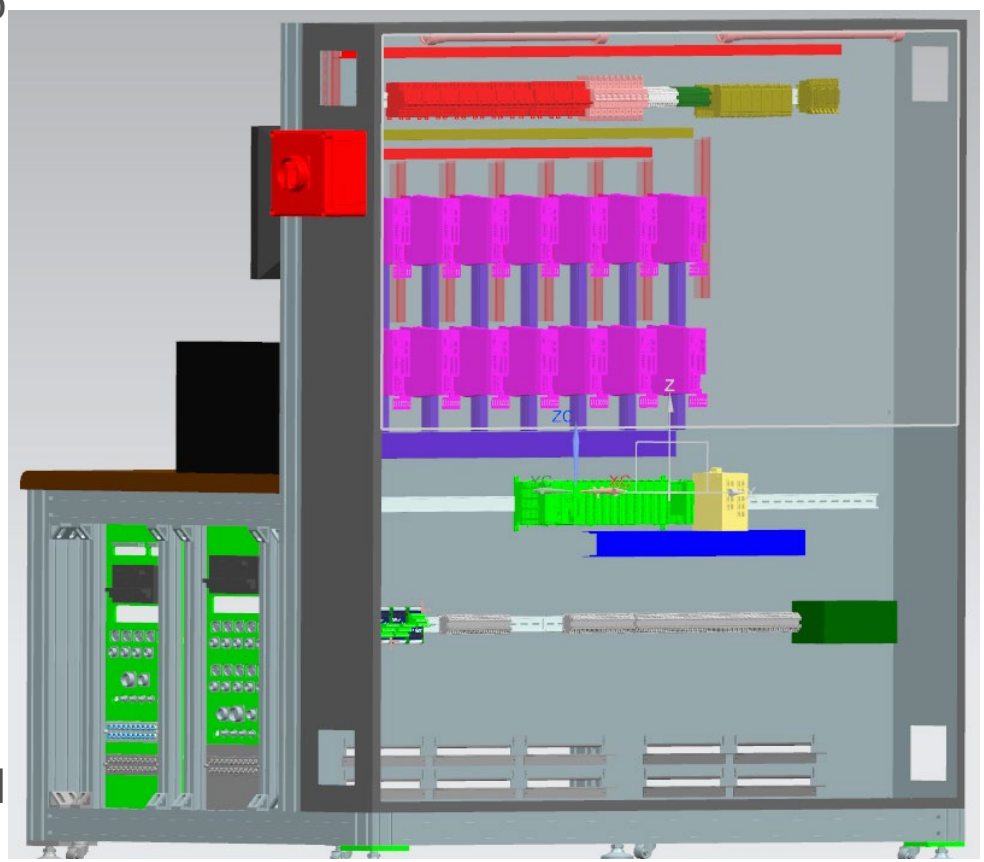
Dark Blue = Digital Input wire duct

Gray = Digital I/O terminal blocks (will be color coded)



Considerations:

- Locating the connections to the servo drives and resolvers on the left hand side of the panel to eliminate the circuitous route under the desk top.
- Moving the Digital inputs via ribbon cable should to the left hand side of the panel as much as is possible.
- Re-Ordering the PLC modules would make it easier to route the digital I/O for the solenoid valves to the right hand side of the panel, closer to where the solenoid valves are located.
- Cover over upper portion of the panel to isolate the V > 50 V as pointed out by Dave Mertz:



To David R. Pushka
Cc Eric D McHugh; Eric Schlatter; David W Peterson
You replied to this message on 1/20/2021 8:02 AM.

Dave, your plans look good. I think the materials you suggest will be adequate to stop the amount of energy an arc-flash in a 120/208V panel at 2225 A would deliver. The perforated aluminum sheet should be in the range of 20% or less hole area. Small holes in the polycarb to insert a screwdriver to prod the breakers are not a problem.

Dave

AC Electrical Load for the panel:

- 8 Servos drives operating at full 2.3 A (at 240, 3 ph) = 18.4 A
- Assume qty = 9 units of 24VDC
  - (PSV-24-50 power supplies each drawing < 1.0 A at 115 VAC or < 0.6 A at 230 VAC.)
  - 3 power supplies on each leg of the 208 to N
  - 3 amps per leg at 120 VAC
- PLC Power supply (productivity 2000) has an input power of 37 W. (at 120 VAC, current draw is > 0.5 A)
- Panel board indicates 30 A service available.
- Total 3 phase draw is about 22 amps.
- Conclusions: One 30 A 208VAC 3Ph circuit can power this panel. Likely do not want to go much higher in current.
- Put cameras and monitors (located outside this panel) on a separate power source.

Proposed Power Wire sizing:

- 208 VAC From Building Outlet thru the disconnect switch, to input side of 3 phase, 10 amp UL 1077 supplementary breakers:
  - Use 8 gauge THHN stranded based on voltage drop @ 30 amps for 15 feet.
- 208 VAC From Output of 10 amp breakers to the Servo Drives
  - Use 14 gauge THHN stranded based on voltage drop @ 10 amps for 5 feet.
- 208 VAC From Outlet of 3 phase breakers to input of 24 VDC supplies:
  - Use 14 gauge THHN stranded based on voltage drop @ 3 amps for 5 feet.
- 24 VDC From Outlet of 24 VDC supplies to fuse block (fuse at 3 amp):
  - Use 14 gauge THHN stranded based on voltage drop @ 3 amps for 5 feet.
- From Outlet of 24 VDC fuse block to the Servo Drives 24 VDC power input
  - Use 14 gauge THHN stranded based on voltage drop @ 3 amps for 5 feet

Plan Forward:

1. Arrange for a technical review of this proposed design with electrical experts including someone from Chris Jensen's dept, maybe someone from Paul Kasley's group.
2. Modify layout to based on recommendations from this group of reviewers; create version 3.0
3. Move version 3.0 assembly into TC.
4. Commence assembling the panel based on the version 2.0 layout.
   - Option A is to turn over solid model version 3.0 to Keith
   - Option B is to have 2D layout drawings created using design drafting
     - This will take more time

5. Re-start work on the single line drawings (schematics) using excel spread sheet to list all of the components, patch panels, cable segments, wire colors, plc inputs / outputs addresses, etc.