Chapter 8: Electrical Panel Design

8.1. Introduction

After sizing and selection of conveyor motor, 3φ motor drive, stepper motors, stepper drives, power supplies, and air compressor, the electrical panel is designed to connect all loads and motors to the main grid through classical components (contactors, circuit breakers, and switches). There are three main sections to power, protect, and control conveyor motor, three stepper motors, and Air compressor. Each part is electrically protected by a circuit breaker and overload, powered by a contactor.

In this section, the types of electrical components and rating calculations for each part are examined, and then the overall panel is designed using SOLIDWORKS ELECTRICAL and SOLIDWORKS to estimate the lengths of all required wires, orientation of each component, and the overall dimensions of the panel.

8.2 Electrical Components

Indicator light

An indicator light often referred to as a pilot light, is a small electric light used to indicate a specific condition of a circuit. The green light is used to indicate that a motor is running, red is used to indicate the motor stoppage while yellow is used to indicate the motor fault.

Fig.8.1: Indicator lights (pilot)

Overload thermal protection

Overload relays which is indicated in **Fig.8.2** are used to protect motors from over-heating. When excessive current is drawn for a predetermined amount of time , the over load relay’s contacts open; removing power from the motor. Overload thermal protection consists of main contacts that sense the over-heat while N.O and N.C contacts change their state with current passing which is used in control circuit to indicate the state of relay, and most importantly trip the circuit in case of overload.

Fig.8.2: Thermal overload relay.

Contactor

A contactor is an electrical device used for switching an electrical circuit on or off. It is considered to be a special type of relays. However, the basic difference between the relay and contactor is that the contactor is used in applications with higher current carrying capacity. Contactors can be field mounted easily and are compact in size. Generally, these electrical devices feature multiple contacts, which are in most cases normally open and provide operating power to the load when the contactor coil is energized. Contactors are most commonly used for controlling electric motors. It is shown in **Fig.8.3**.

When current passes through the contactor excites the electromagnetic coil, which produces a magnetic field, causing the contactor core to move the armature. A normally closed (NC) contact completes the circuit between the fixed contacts and the moving contacts. This permits the current to pass through these contacts to the load. When current is removed, the coil is de-energized and opens the circuit.

The contacts of the contactors are known for their rapid open and close action. These contacts are implemented also in control circuit with indicator lights, or a sensor could be connected to the coil of the contactor and its contacts could be used as auxiliary contacts to the sensor or motor. [120]

Fig.8.3: AC electrical contractor.

Fuse

A fuse is a one-shot device. The heat produced by overcurrent causes the current carrying filament to melt open, disconnecting the load from the source voltage.

Circuit Breaker

Circuit breakers provide a manual means of energizing and de-energizing a circuit. In addition, circuit breakers provide automatic overcurrent protection of a circuit. A circuit breaker allows a circuit to be reactivated quickly after a short circuit or overload is cleared

Fig.8.4: Double pole circuit breaker

8.3 Electrical components' selection calculations

8.3.1 Conveyor motor

8.3.1.1 3φ induction motor

Conveyor motor is 3φ induction motor that its specifications were determined before. This motor will be driven through VFD which its input is a 1φ 220v so that double pole circuit breaker is used. However, the contactor is three phase with a proper connection of a single phase input.

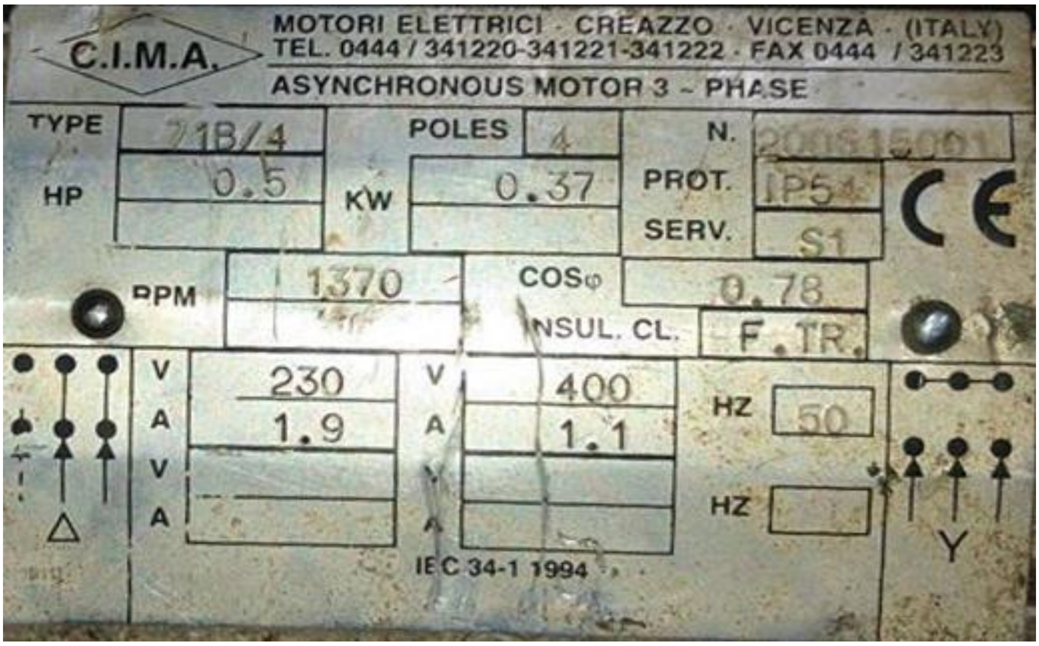

Fig.8.5: 3φ induction motor name plate

From name plate it is found that the main specifications

- Rated Power = **0.5 hp** = **0.37 kW**
- Rated current OL = **1.9 A** at **50 Hz**
- Power factor = **0.78**
- Rated speed = **1370 RPM**

This motor is driven by **VFD** (variable frequency drive), VFD current should be greater than rated current of motor and twice rated power of motor to guarantee safe mode to the motor. VFD acts as the motor driver to adjust the required speed of motor. Besides, it protects the motor during starting and overload condition. It also provides auxiliary relays to for general purpose, it also provides a pin that can send the current readings that the motor draws which then could be used in digital twin mode, another pin is used to switch the motor electrically which also could be use in control mode of digital twin.

8.3.1.2 VFD speed driver

The corresponding nameplate is for 1/2HP VFD (**LSIS** type).

It is appropriate but the higher rating one is chosen to ensure more safety, and it was cheaper.

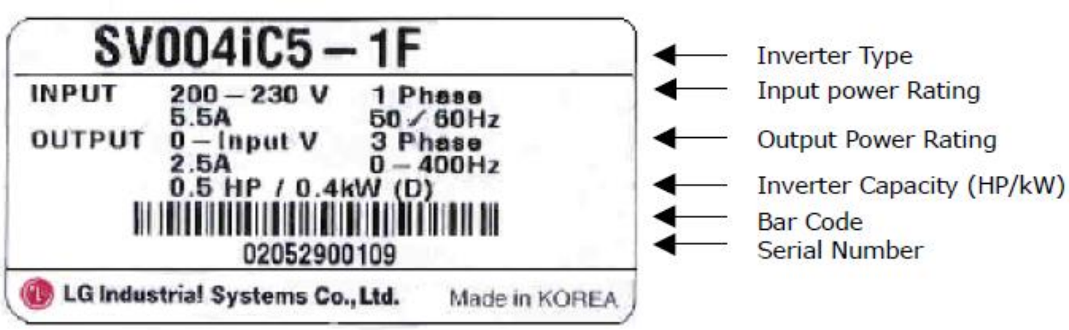

Fig.8.6: VFD (LSIS) name plate

From name plate it is found that the main specifications

- Rated Power =**1 hp** = **0.746 kW** VFD
- Rated output current = **5A**
- Output frequency = **0: 400 Hz**

As said before this drive is essential to handle the motor with different speed and torque types, as well as it protects the motor from overload or short circuit current; so, in this part there is no need for overload relay which is internally available at VFD.

8.3.1.3 Electrical components sizing

Contactor and circuit breaker feeding the VFD are to be designed

Rated current of motor = 1.9 **A**, Rated current of VFD = 5**A**,

$$\mathbf{I_{CB} = 2.5 * I_{rated} = 2.5 * 1.9 \cong 5\ A} \quad \textbf{(8.74)}$$

$$\mathbf{I_{Contactor} = 1.2 * I_{rated} = 1.2 * 1.9 \cong 2.4\ A} \quad \textbf{(8.75)}$$

Then the cross-sectional area of the required conductor = **5/4** = **1.25 mm^2**

Based on these calculations and the available cable selection tables **AWG** and breakers standards the selected rating of each components is

Conveyor motor circuit breaker = **6 A**

Conveyor motor contactor = **9 A**

For cable cross section area, it's defined in the VFD manual to use **2mm^2** cable with input and output power cables and **0.3 mm^2** cable with control cables.

Circuit breaker	Circuit breaker NB1, 2 P, 6A, B, 6kA (CHINT)
Contactor	NC1-12, 380 V (CHINT)
Power wires	AWG 11
Control wires	AWG 22

8.3.2 Delta arm

In this part there are three stepper motors with three stepper drives, and there power supplies as mentioned before the calculations for selecting the supplies each supply is 66V/6A.The three subsystems are powered through only one contactor, one thermal overload relay and one circuit breaker, besides, each supply is protected via **6 A** fuse .The design is based on supply to ensure that the drawn current does not exceed the supply current.

Power supply rated current = 6 **A**

$$\mathbf{I_{CB} = 2.5 * I_{rated} = 2.5 * 6 = 15\ \mathit{A}} \quad \textbf{(8.76)}$$

$$\mathbf{I_{Contactor} = 1.2 * I_{rated} = 1.2 * 3 * 6 = 21.6\ A} \quad \textbf{(8.77)}$$

$$\mathbf{I_{Overload} = 1.13 * I_{rated} = 1.13 * 3 * 6 = 20.34\ A} \quad \textbf{(8.78)}$$

Then the cross-sectional area of the required conductor = **15/3=5mm^2**

Based on available tables and standards of **AWG** we decided the components we need.

Delta robot circuit breaker = **20 A**

Delta robot contactor = **18 A**

Delta robot overload =**18 A**

Circuit breaker	Circuit breaker NB1, 2 P, 20A, B, 6kA (CHINT)
Contactor	NC1-18, 380 V (CHINT)
Overload	NR2-25, 380 V (CHINT)
Power wires	AWG 11
Control wires	AWG 22

8.3.3 AIR compressor

P_{max} = 8 bar, Tank Capacity >= 15 L, Motor Power = 1 hp

It acts as single-phase motor with rating 1hp with assuming power factor is 0.78

$$\mathbf{I_{rated}} = \frac{\mathbf{P}}{\mathbf{v * pf}} = \frac{\mathbf{0.746 * 1000}}{\mathbf{220 * 0.78}} = \mathbf{4.6\ A} \quad \textbf{(8.79)}$$

$$\mathbf{I_{CB}} = \mathbf{2.5 * I_{rated} = 11.5\ A} \quad \textbf{(8.80)}$$

$$\mathbf{I_{Overload}} = \mathbf{1.13 * I_{rated} = 5.198\ A} \quad \textbf{(8.81)}$$

$$\mathbf{I_{Contactor}} = \mathbf{1.2 * I_{rated} = 5.52\ A} \quad \textbf{(8.82)}$$

Then the cross-sectional area of the required conductor = **5/4** = **1.25 mm^2**

Based on these calculations and the available cable selection tables AWG and breakers standards the selected rating of each components is

Air compressor circuit breaker = **12 A**

Air compressor contactor = **12 A**

Air compressor overload = **5.5 A**

Circuit breaker	Circuit breaker NB1, 2 P, 12A, B, 6kA (**CHINT**)
Contactor	NC1-12, 380 V (**CHINT**)
Overload	NR2-25, 380 V (**CHINT**)
Power wires	**AWG 11**
Control wires	**AWG 22**

8.3.4 Main Line

The rated current of the machine is estimated by

$$\boldsymbol{I_{rated} = 5 + 18 + 4.6 = 27.6\ A} \quad \textbf{(8.83)}$$

Then both circuit breaker and contactor could be sized

$$\mathbf{I_{CB} = 2.5 * I_{rated} = 2.5 * 27.6 = 69}\ \boldsymbol{A} \quad \textbf{(8.84)}$$

$$\mathbf{I_{Contactor} = 1.2 * I_{rated} = 1.2 * 27.6 = 33.12\ A} \quad \textbf{(8.85)}$$

Based on these calculations and the available cable selection tables AWG and breakers standards the selected rating of each components is

Main circuit breaker = **63 A**

Main contactor = **50 A**

Circuit breaker	Circuit breaker NB1, 2 P, 63A, B, 6kA (**CHINT**)
Contactor	NC1-50, 380 V (**CHINT**)
Power wires	**AWG 5**
Control wires	**AWG 22**

8.4 Panel design

After determining the ratings of each component needed in the project, then designing the Electrical panel which holds all power component is an essential step so that we estimate the size of the panel, orientation of each part in the panel, length of each type of wires; so that extra material is not purchased, and finally to ease the process of installation of components. To do so there are many software such E-Plan, AutoCAD ELECTRICAL, but SOLIDWORKS ELECTRICAL, as it is compatible with the mechanical design carried on SOLIDWORKS as well as it has simple interface that helps beginners a lot. [119]

8.4.1 Design steps

To walk through the software first the user creates a project, then it gives the user the chance to choose whether to draw single line diagram schematic, which is called wiring line diagram, or multi-line diagram, which is called scheme, after that the user is asked to draw the needed schematic with the help of symbols and wire schemes, or in some cases it allows the used to use both single line and multi-line diagram in the same field which is called mixed scheme, it also gives the user the ability to insert PCBs, PLCs, and black boxes.[117]

Another advantage of this program is, that it allows labeling to simplify the schematic, then the user is asked to link these symbols with real parts, that the manufacturers such as SIEMENS™, SCHNIEDER™ provide on Electrical Component Library online, after downloading the needed parts, which are then imported in the software, then the user is asked to fill all the missing information such as dimensions, ratings, or most importantly the symbol, footprint, and 3D part which is basically SOLIDWORKS part with some modifications using

SOLIDWORKS ELECTRICAL 3D tool to add the connection points of the component as shown in **Fig.8.7**. [118]

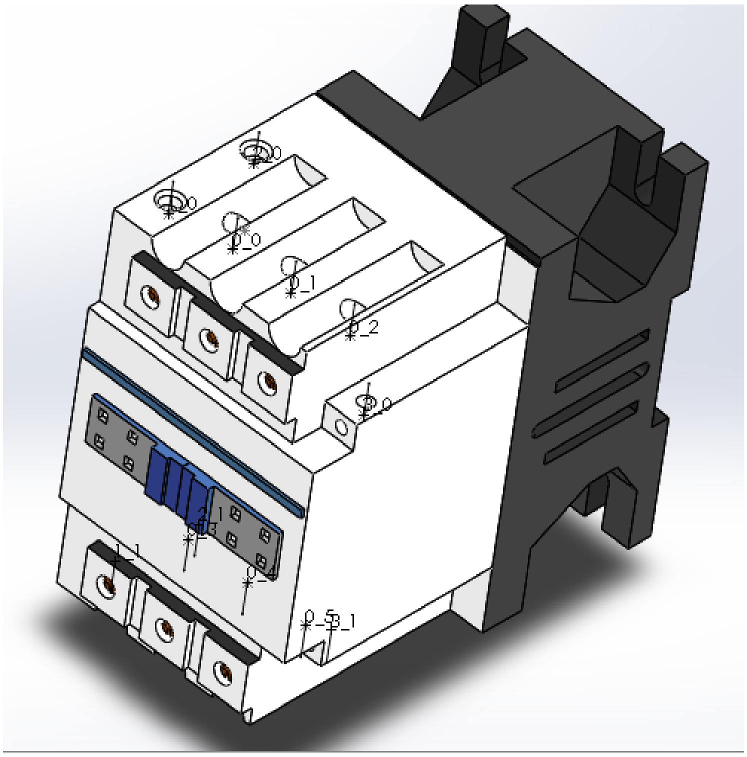

Fig.8.7: Connection Points of the main contactor

It should be also mentioned that in case of multi circuit with contactors, and thermal overload relays, which has many auxiliary contacts used in control circuits, the contact should be linked with its parent by right clicking on the symbol, then choosing “Symbol properties” then modifying “Cross reference type” to “Child”, while the contactor or thermal overload relay is set to “Parent in line”, or “Parent on table”, after that the symbol contacts besides the parent changes its color to indicate the use and unused, as shown in **Fig.8.8**.

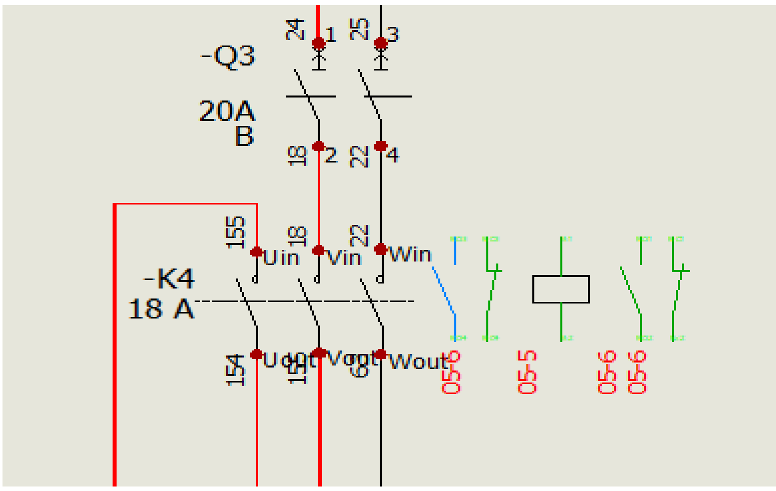

Fig.8.8: Used auxiliary contacts of a contactor in green

After linking all the part to the corresponding symbols the program asks the user to fix the auto wiring numbering scheme which is mostly not correct so with right click on any wire then choosing “Wring cabling order” and modify the numbering so that it each wire number is consecutively after the previous ones which facilitates the routing a lot and makes it looks better, as shown in **Fig.8.9**. [117]

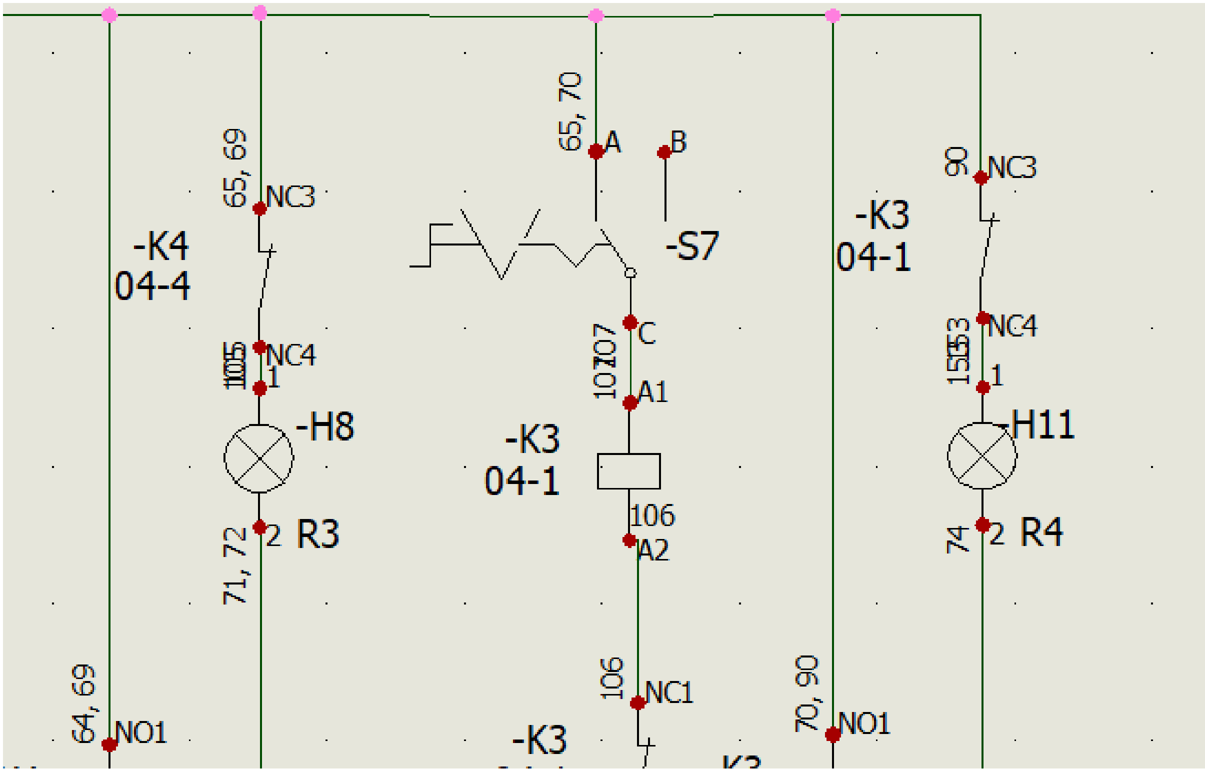

Fig.8.9: Wires numbering scheme

Then the user has the choice whether to make the panel in 2D mode or 3D mode. 2D mode offers many analytical advantages such as cable tray capacity which should not exceeds 60%, easy installations of racks and tray, but its only disadvantage that if any component is placed outside the panel it could not be connected so it was not suitable for our application where stepper motors sensors, conveyor motor, and air compressor where all out of the panel, unlike the 3D mode which, of course, gives much better looking design as well as ability to connect any component outside the panel, estimate the wire lengths required, and even the wire cuts, its only disadvantage that it is very time consuming as not all the required 3D models of electrical parts exit online so manual modeling is required most of the time, routing wires is done automatically but it takes a lot of time to repair the unwanted routes, finally after finishing routing, **SOLIDWORKS ELECTRICAL** exports files such as lengths of each wire and the total length of wire scheme chosen while drawing schematic, bill of materials that contains all the used components in the design which facilitates the purchasing process, and also list of cable and harnesses if exist.

8.4.1 Schematic of power circuit

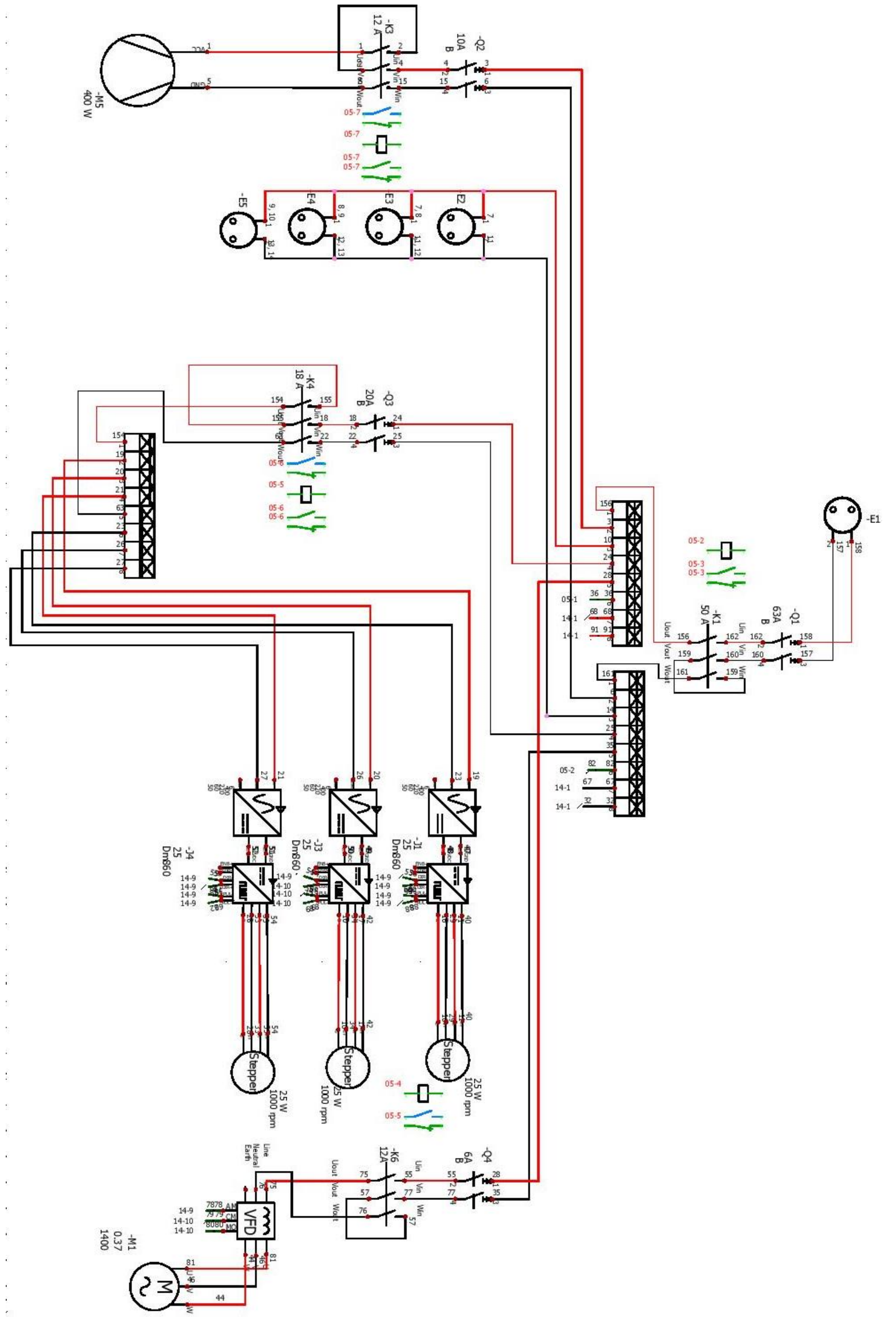

Fig.8.10: Power circuit schematic

As shown in this scheme each load is protected against short circuit via circuit breaker and against overloading conditions via thermal overload and operated via contactor except the conveyor motor which is driven by VFD so we didn't need thermal overload as VFD has its functionality of doing this overload tripping internally. While in Delta arm protection we use one contactor with one thermal overload and breaker for all delta components not for each branch because if one gets in fault, we want all the system to be stopped not only this branch. However, a 6A fuse is inserted for each branch to guarantee that each supply does not exceed their rating current. Finally, in air compressor protection we use overload and breaker with contactor safely rated on calculations we did previously besides we added four electrical bays for the design.

8.4.2 Schematic of control circuit

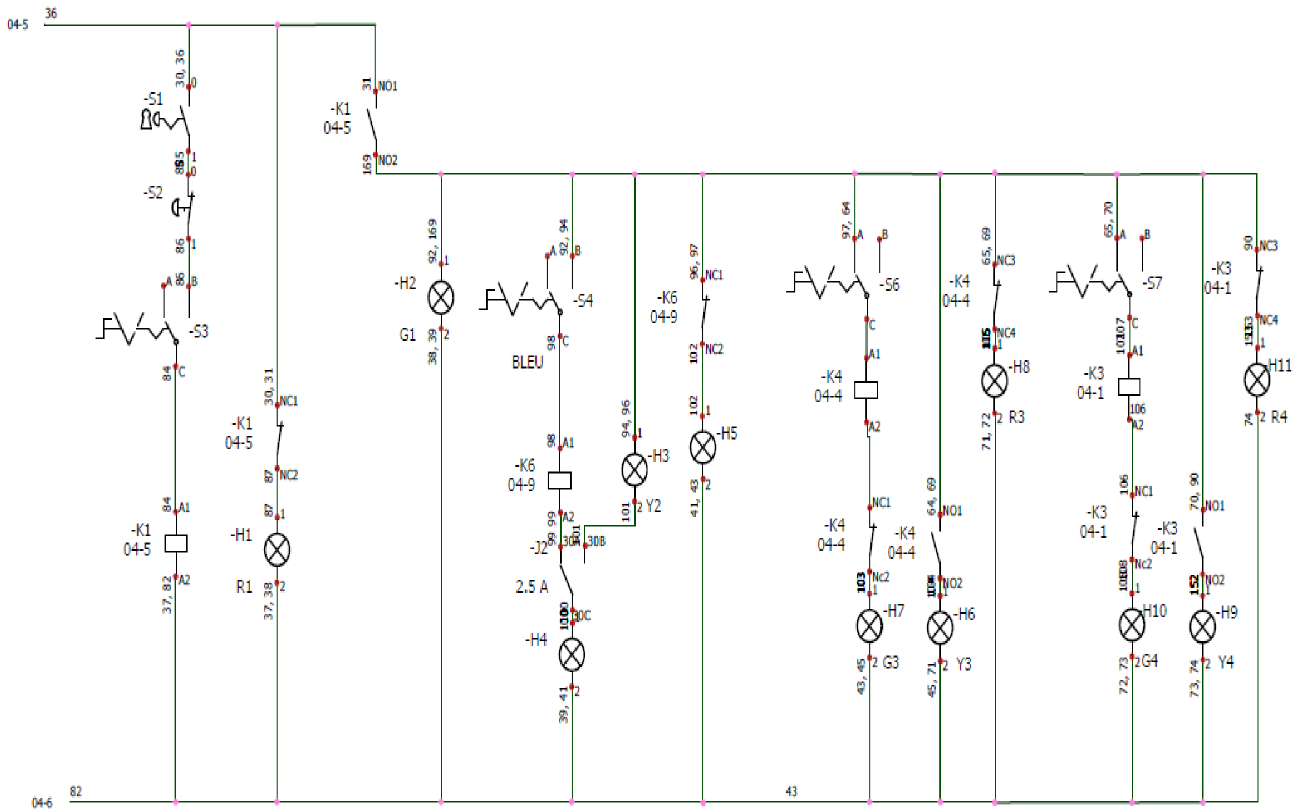

Fig.8. 11: Control circuit schematic

An isolator switch as a main switch of the panel with emergency stop, then to make it more simple we use a toggle switch as an on-off switch of the main contractor, accompanied with two indicator lamp for the main line; red-one for off-condition and green-one for on-condition. All other loads are connected through the line of the main contactor then each part has to be operated through its own toggle switch (on/off) with having three indicators lamps; green-one for on-state, red-one for the off-state, and yellow-one for fault state.

In addition four electrical bays for chargers are implemented that are needed for micro-controllers, router, and Kinect camera, besides, two power supplies were added; one of them is 12V, 8.3A for DC fans that will be on the sides of the panel for ventilation, rotary encoders, and for the solenoid valve for air compressor, the other one is 5V, 6.3A for sensors and two ESPs modules.

8.4.3 Schematic of DC circuit

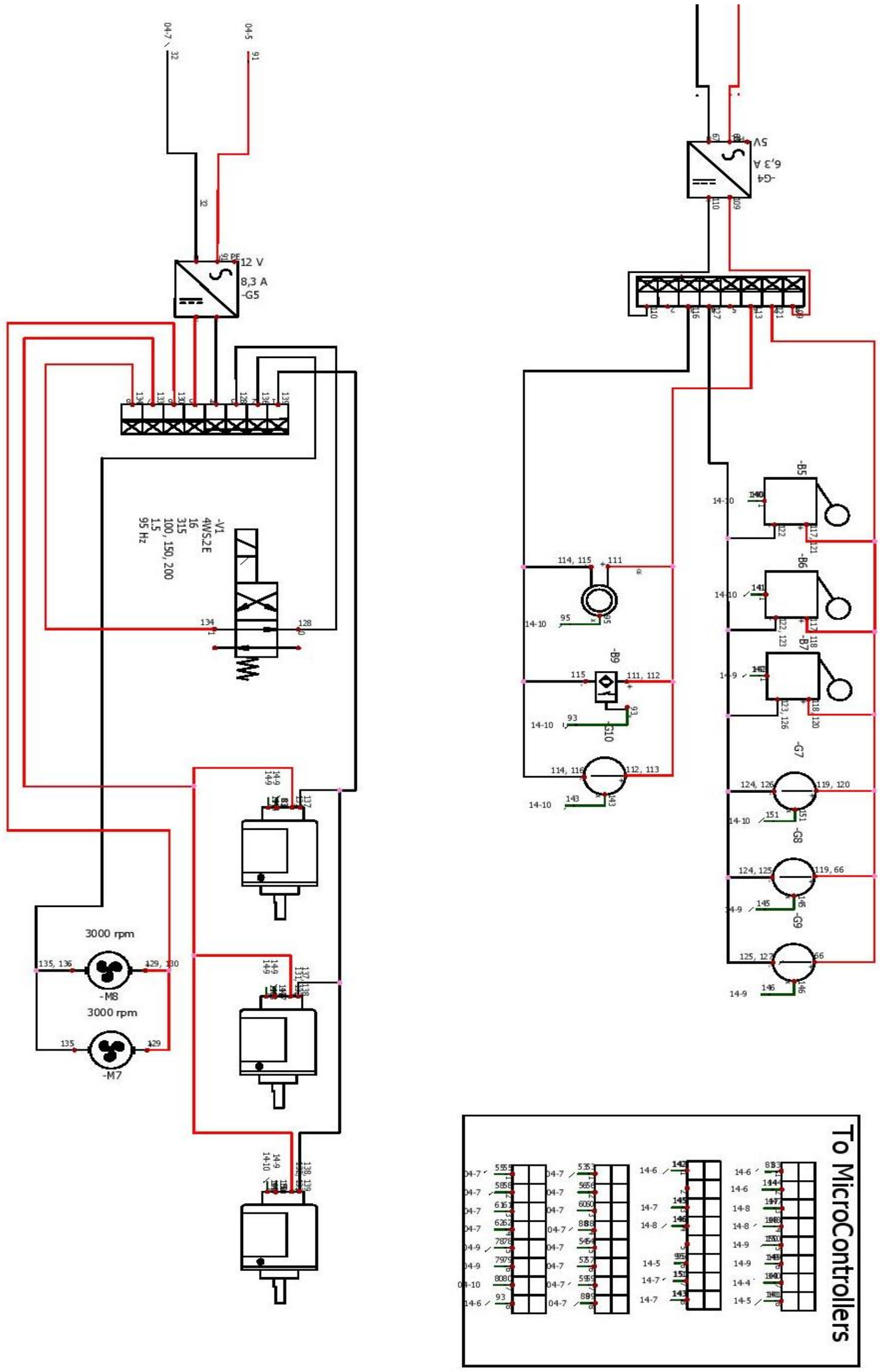

Fig.8.12: DC circuit schematic

After modeling all of these components with their real dimensiosn it is found that the suitable size of the panel that would satisfy all the criteria of VFD, and other components is (1000*800*250 mm) with considering that drive's length is 150 mm and needs 100 mm above and below for ventilation and the rack that will contain the other component takes 400 mm. SOLIDWORKS gives the user comfort to orient the components without any limitations, so we put in the lower section all robotic arm components and the VFD whether in higher section we put the other components in the rack as shown in **Fig.8.13**.

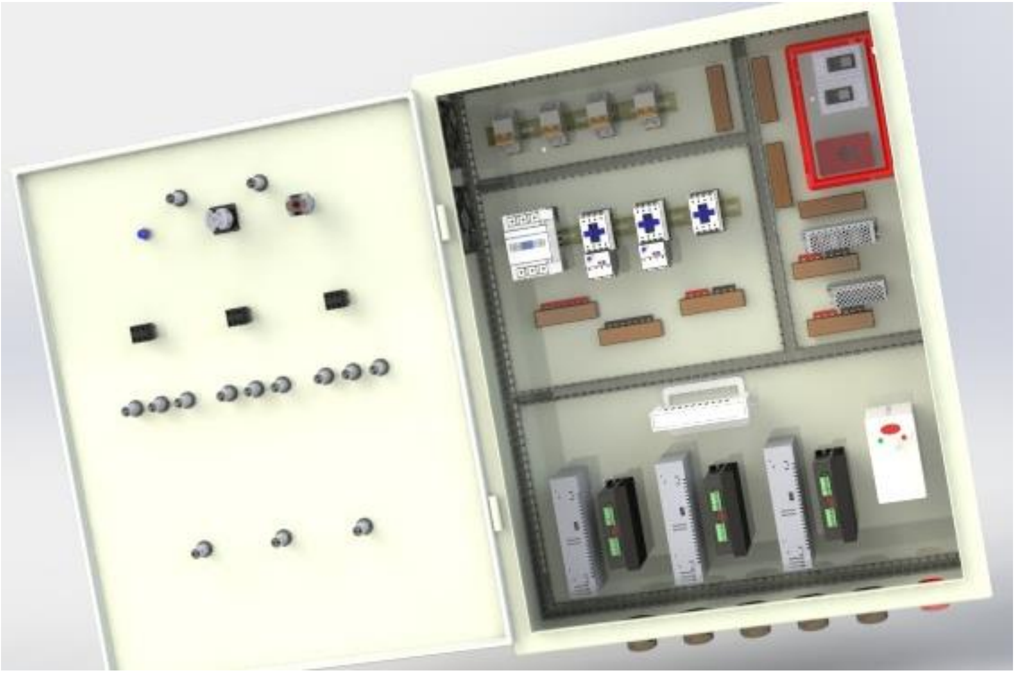

Fig.8. 14: Electrical panel inner view unwired

Fig.8.13: Electrical panel outer view

As shown in Fig (8.14) the cover of the panel there is the main switch and the emergency stop switch then each part has their switches and lamps while using the toggle switch as the on-off switch for each part. After that, routing is done automatically choosing the best suitable path between components with the help of the user 3Dsketcehed paths to reduce routing time, then giving you in details all need wires and cables length.

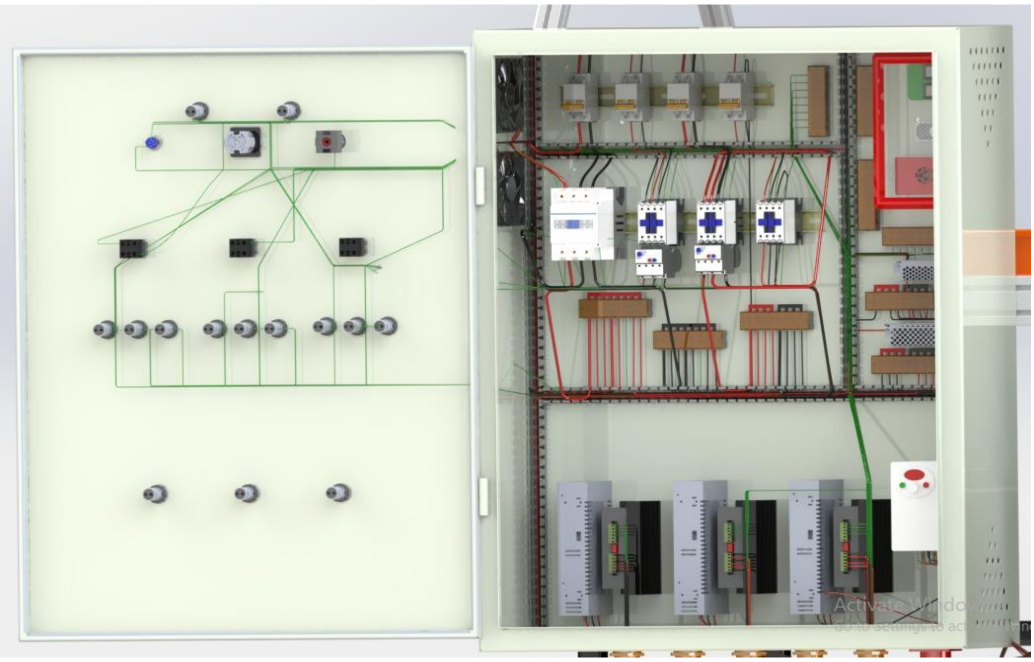

Fig.8.15: Electrical panel inner view wired

Based on excel sheet that giving us all length and based on AWG tables that available in markets we find that wires we need are:

- AWG (5)16.8 mm^2: 10m black and 10m red
- AWG (22)0.3 mm^2: 100m green
- AWG (11)4.2 mm^2: 90m black and 90m red

As we used red wires for line and black for neutral while green is for control circuits.

Fig.8.16: Full project 3D model

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