Appendix – A Safety Precautions and Power-Electronics-Drives-Board, CP1104 I/O Board, DS 1104 Control Board and Motor Coupling Unit, familiarization

1.1 Why is safety important?

Attention and adherence to safety considerations is even more important in a power electronics laboratory than it's required in any other undergraduate electrical engineering laboratories. Power electronic circuits can involve voltages of several hundred volts and currents of several tens of amperes. By comparison the voltages in all other teaching laboratories rarely exceed 20V and the currents hardly ever exceed a few hundred milliamps.

In order to minimize the potential hazards, we will use dc power supplies that never exceed voltages above 40-50V and will have maximum current ratings of 20A or less. We use a dc supply of 42V. However in spite of this precaution, power electronics circuits on which the student will work may involve substantially larger voltages (up to hundreds of volts) due to the presence of large inductances in the circuits and the rapid switching on and off of amperes of current in the inductances. For example in Power Electronics laboratory a boost converter can have an output voltage that can theoretically go to infinite values if it is operating without load. Moreover the currents in portions of some converter circuits may be many times larger than the currents supplied by the dc supplies powering the converter circuits. A simple buck converter is an example of a power electronics circuit in which the output current may be much larger than the dc supply current.

1.2 Potential problems presented by Power Electronic circuits

- Electrical shock may take a life.

- Exploding components (especially electrolytic capacitors) and arcing circuits can cause blindness and severe burns.

- Burning components and arcing can lead to fire.

1.3 Safety precautions to minimize these hazards

1.3.1 *General Precautions*
- Be calm and relaxed, while working in Lab.

- When working with voltages over 40V or with currents over 10A, there must be at least two people in the lab at all times.

- Keep the work area neat and clean.

- No paper lying on table or nearby circuits.

- Always wear safety glasses when working with the circuit at high power or high voltage.

- Use rubber floor mats (if available) to insulate yourself from ground, when working in the Lab.

- Be sure about the locations of fire extinguishers and first aid kits in lab.

- A switch should be included in each supply circuit so that when opened, these switches will de-energize the entire setup. Place these switches so that you can reach them quickly in case of emergency, and without reaching across hot or high voltage components.

1.3.2 *Precautions to be taken when preparing a circuit*
- Use only isolated power sources (either isolated power supplies or AC power through isolation power transformers). This helps using a grounded oscilloscope and reduces the possibility of risk of completing a circuit through your body or destroying the test equipment.

1.3.3 *Precautions to be taken before powering the circuit*

- Check for all the connections of the circuit and scope connections before powering the circuit, to avoid shorting or any ground looping that may lead to electrical shocks or damage of equipment.

- Check any connections for shorting two different voltage levels.

- Check if you have connected load at the output.

- Double-check your wiring and circuit connections. It is a good idea to use a point-to-point wiring diagram to review when making these checks.

1.3.4 *Precautions while switching ON the circuit*

- Apply low voltages or low power to check proper functionality of circuits.

- Once functionality is proven, increase voltages or power, stopping at frequent levels to check for proper functioning of circuit or for any components is hot or for any electrical noise that can affect the circuit's operation.

1.3.5 *Precautions while switching off or shutting down the circuit*

- Reduce the voltage or power slowly till it comes to zero.

- Switch of all the power supplies and remove the power supply connections.

- Let the load be connected at the output for some time, so that it helps to discharge capacitor or inductor if any, completely.

1.3.6 *Precautions while modifying the circuit*

- Switch Off the circuit as per the steps in section 1.3.5.

- Modify the connections as per your requirement.

- Again check the circuit as per steps in section 1.3.3, and switch ON as per steps in section 1.3.4.

1.3.7 *Other Precautions*

- No loose wires or metal pieces should be lying on table or near the circuit, to cause shorts and sparking.

- Avoid using long wires that may get in your way while making adjustments or changing leads.

- Keep high voltage parts and connections out of the way from accidental touching and from any contacts to test equipment or any parts, connected to other voltage levels

- When working with inductive circuits, reduce voltages or currents to near zero before switching open the circuits.

- BEWARE of bracelets, rings, metal watch bands, and loose necklace (if you are wearing any of them), they conduct electricity and can cause burns. Do not wear them near an energized circuit.

- Learn CPR and keep up to date. You can save a life.

- When working with energized circuits (while operating switches, adjusting controls, adjusting test equipment), use only one hand while keeping the rest of your body away from conducting surfaces.

1.4 Power-Electronics-Drives-Board familiarization

The electric machine drives board, which we use in the Electric Drives Laboratory has been designed to enable us to perform a variety of experiments on AC/DC machines. The main features of the board are:

- Two completely independent 3-phase PWM inverters for complete simultaneous control of two machines

- 42 V dc-bus voltage to reduce electrical hazards

- Digital PWM input channels for real-time digital control

- Complete digital/analog interface with dSPACE board

The basic block diagram of drives board is shown in Fig. 1 and the actual drives board is shown in Fig. 2. Please note that various components on this board are indicated in Table. 1.

1.4.1 *Description of Power Electronic Drives Board.*

The board of Fig 2 is shown with some additional labels in Fig 3. The two independent three phase PWM voltage sources labeled phases A1, B1, C1 and phases A2, B2, C2 in Fig 1 are obtained from a constant DC voltage source (as shown in Circuit in Fig 1). Hence two machines can be controlled independently for independent control variables, at the same time. A single phase motor needs only Phase A1 B1 for powering while three phase motor needs three phases A1, B1, C1.
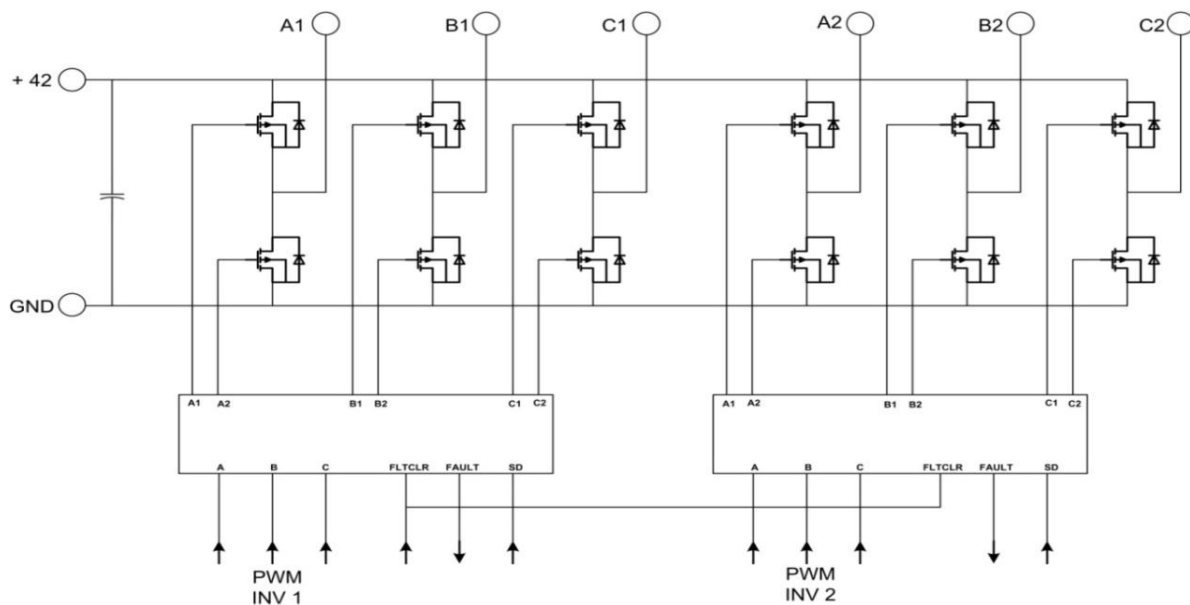

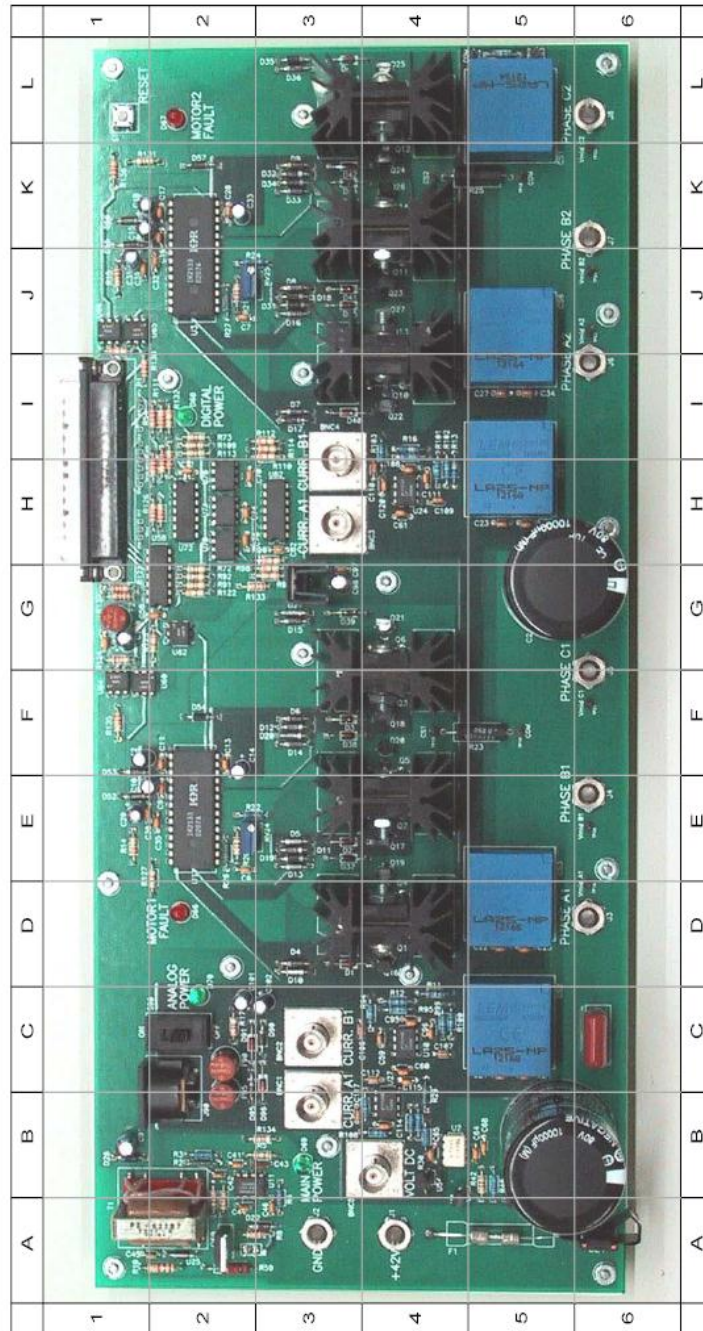Figure 1: Block Diagram of Electric Drives Board

Figure 2: Power Electronics Drives Board

Table 1: Locations of components on Power Electronics Drives board

| No.	Component	Ref. Des.	Location in Fig. 2
1	Terminal +42	J1	A-4
2	Terminal GND	J2	A-3
3	Terminal PHASE A1	J3	D-6
4	Terminal PHASE B1	J4	E-6
5	Terminal PHASE C1	J5	G-6
6	Terminal PHASE A2	J6	J-6
7	Terminal PHASE B2	J7	K-6
8	Terminal PHASE C2	J8	L-6
9	DIN connector for ±12 V signal supply	J90	B-2
10	Signal supply switch	S90	C-2
11	Signal supply +12 V fuse	F90	C-2
12	Signal supply-12 V fuse	F95	B-2
13	Signal supply LED	D70	C-2
14	MOTOR1 FAULT LED	D66	D-2
15	MOTOR2 FAULT LED	D67	L-2
16	DIGITAL POWER LED	D68	I-2
17	MAIN POWER LED	D69	B-3
18	Inverter 1		D-3 to G-4
19	Inverter 1		I-3toL-4
20	DC Link capacitor of Inverter 1	C1	B-5
21	DC Link capacitor of Inverter 2	C2	G-5
22	Driver IC IR2133 for Inverter 1	U1	E-2
23	Driver IC IR2133 for Inverter 2	U3	J-2
24	Digital Supply Fuse	F2	G-1
25	dSPACE Input Connector	P1	H-1 and I-1
26	RESET switch	S1	L-1
27	Phase A1 current sensor (LEM)	CS2	C-5
28	Phase B1 current sensor (LEM)	CS3	D-5
29	Phase A2 current sensor (LEM)	CS5	H-5
30	Phase B2 current sensor (LEM)	CS6	J-5
31	DC link current sensor (LEM)	CS1	L-5
32	VOLT DC	BNC5	B-4
33	CURR A1	BNC1	B-3
34	CURR B1	BNC2	C-3
35	CURR A2	BNC3	H-3
36	CURR B2	BNC4	I-3
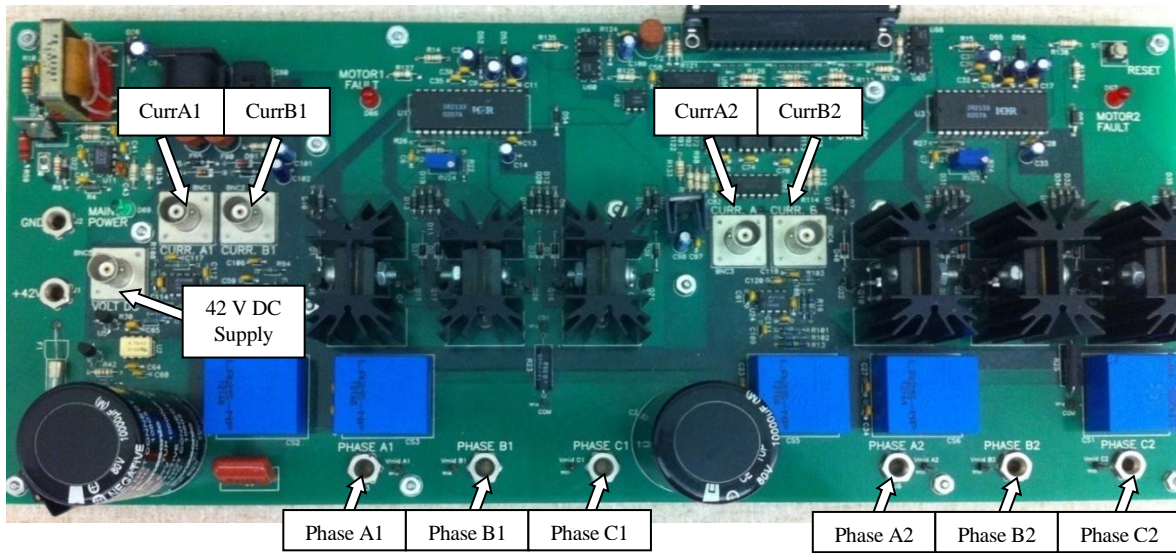
Figure 3: Power Electronics Drives Board (with key lables)

The location of some key supply and measurement points are shown with labeling in Fig 3. The board provides the motor phase currents (currA1, currB1, currA2, currB2), dc-bus voltage (shown to left of Curr A1) as in Fig 4 to control the motor for a desired speed or torque.
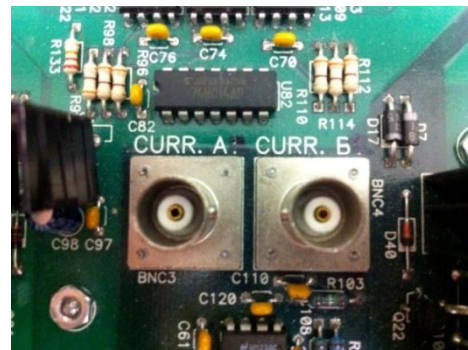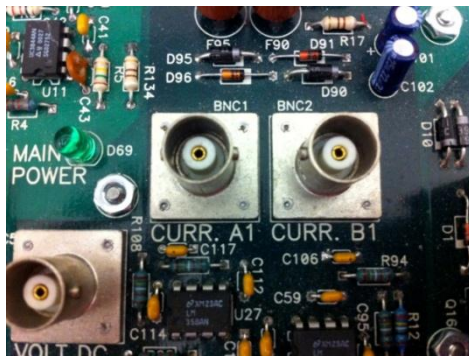

Figure 4(a): DC Bus   CURR A1 CURR B1   Figure 4(b): CURR A2   CURR B2

To generate the controlled PWM voltage source, this board requires various digital control signals. These control signals dictates the magnitude and phase of the PWM voltage source. The DS1104 R&D Controller board inside the computer generates them.

1.4.2 *Inverters*

Each 3-phase inverter uses MOSFETs as switching devices. The 3-phase outputs of the first inverter are marked A1 (D-6 in Fig. 2), B1 (E-6 in Fig. 2), C1 (F-6 in Fig. 2) shown with labels at bottom of Fig 3, and those of the second inverter are marked A2 (I-6 in Fig. 2), B2 (K-6 in Fig. 2), C2 (L-6 in Fig. 2).

1.4.3 *Signal Supply*

±12 volts signal supply is required for the isolated analog signals output from the drives board. This is obtained from a wall-mounted isolated power supply, which plugs into the DIN connector J90 (B-2 in Fig. 2). Switch S90 (C-2 in Fig. 2) controls the signal power to the board. The green LED D70 (C-2 in Fig. 2) indicates if the signal supply is available to the board. Fuses F90 (C-2 in Fig. 2) and F95 (B-2 in Fig. 2) provide protection for the +12 V and −12 V supplies respectively. Please note that the green LED indicates the presence of only the +12 V supply. Please note that turning off S90 will not stop the PWM signals from being gated to the inverters. The power supply for the 3-phase bridge drivers for the inverters is derived from the DC Bus through a flyback converter (A-2 in Fig. 2).

1.4.4 *Voltage Measurement*

Test points are provided to observe the inverter output voltages. BNC connector VOLT DC Fig 5 and (located at B-4 in Fig. 2) has been provided to sense the DC bus voltage. To measure the DC bus voltage,

- Connect a BNC cable to VOLT DC BNC connector.

- The scaling factor of input voltage is 1/10.

1.4.5 *Current Measurement*

LEM sensors are used to measure the output current of the inverters. Only A and B phase currents (CURR A1 and CURR B1) are sensed. The C phase current can then be calculated using the current relationship $I_a + I_b + I_c = 0$, assuming that there is no neutral connection for the machines. The calibration of the current sensor is such that for 1A current flowing through the current sensor, output is 0.5 V. The current measurement points are shown in Fig. 4.

To measure the output current of phase A of inverter 1

- Connect BNC connector to CURR A1 (B-3 in Fig. 2).

To measure the output current of phase B of inverter 1

- Connect BNC connector to CURR B1 (C-3 in Fig. 2).

To measure the output current of phase A of inverter 2

- Connect BNC connector to CURR A2 (H-3 in Fig. 2).

To measure the output current of phase B of inverter 2

- Connect BNC connector to CURR B2 (I-3 in Fig. 2).

1.4.6 *Inverter Drive Circuit*

The inverters (Fig 1) are driven by 3-phase bridge drivers (IR2133). The PWM inputs are isolated before being fed to the drivers.

1.4.7 *PWM / Digital Signals*

PWM and other digital signals for the board are to be given to the 37-pin DSUB connector in Fig 6 (and located at H-1 in Fig. 2). For pin-out description of this connector, see Table 2.

1.4.8 *Fault Protection*

Shown in Fig 7, the Drives Board has over-current protection for each inverter. An over-current fault occurring on inverter 1 is indicated by red LED "MOTOR FAULT 1" (D-2 in Fig. 2), while that of inverter 2 is indicated by red LED "MOTOR FAULT 2" (L-2 in Fig. 2). Each time a fault occurs, reset the fault using the "RESET" switch (L-1 in Fig. 2) on the board. The switch resets all the faults.

Figure 5: Main DC power input and main power indicator
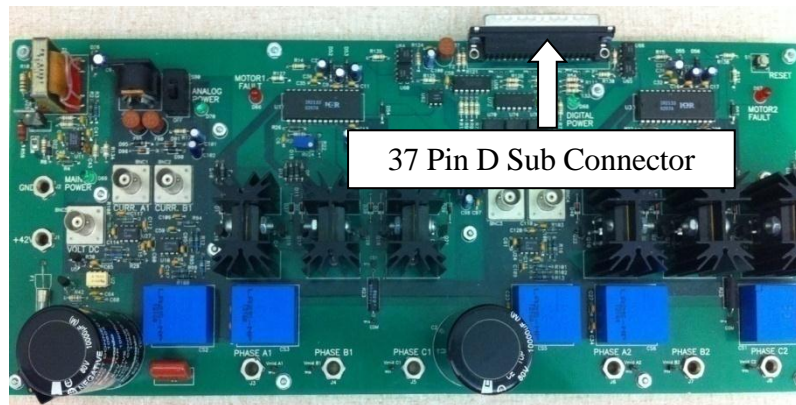

37 Pin D Sub Connector

Figure 6: D SUB Connector

Figure 7(a): Motor-1 Fault Indicator   Figure 7(b): Motor -2 Fault and Reset Switch

Table 2: 37-pin DSUB Connector (located at H-1)

No.	Pin Number	Description
1	GND Digital	Digital ground
2	FAULT 1	Inverter 1 Fault output. Fault Signal high
3	NC	Not Connected
4	GND Digital	Digital ground
5	NC	Not Connected
6	GND Digital	Digital ground
7	PWM A1	A phase PWM signal of Inverter 1
8	PWM B1	B phase PWM signal of Inverter 1
9	PWM C1	CphasePWMsignalofInverter1
10	PWM A2	A phase PWM signal of Inverter 2
11	PWM C2	C phase PWM signal of Inverter 2
12	GND Digital	Digital ground
13	GND Digital	Digital ground
14	GND Digital	Digital ground
15	GND Digital	Digital ground
16	$\overline{SD1}$	Shutdown signal for Inverter 1
17	$\overline{FLTCLR\text{-}IN}$	Clear Fault signal
18	VCC	
19	VCC	
20	GND Digital	Digital ground
21	FAULT 2	Inverter 2 Fault output. Fault Signal high
22	NC	Not Connected
23	NC	Not Connected
24	NC	Not Connected
25	GND Digital	Digital ground
26	NC	Not Connected
27	NC	Not Connected
28	NC	Not Connected
29	PWM B2	CphasePWMsignalforInverter2
30	GND Digital	Digital ground
31	GND Digital	Digital ground
32	GND Digital	Digital ground
33	GND Digital	Digital ground
34	NC	Not Connected
35	$\overline{SD2}$	Shutdown signal for Inverter 2
36	GND Digital	Digital ground
37	GND Digital	Digital ground

1.5 DS1104 R&D controller Board and CP 1104 I/O board

In each discrete-time-step, the DS1104 R&D controller board (fitted as an add-on card in computer) takes some action to generate the digital control signals. The type of action is governed by what we have programmed in this board with the help of MATLAB-Simulink real-time interface. This board monitors the input (i.e. motor current, speed, voltage etc) with the help of CP1104 I/O board in each discrete-time step. Based on the inputs and the variables that need to be controlled (i.e. motor speed or torque); it takes the programmed action to generate the controlled digital signals.

The CP1104 I/O board (Fig 8) is an input-output interface board between the Power Electronics Drives Board and DS1104 controller board. It takes the analog signal motor current, dc-voltage etc. from the Power Electronics Drives Board in its ADC ports and also, speed signal (from encoder) at its INC ports from motor coupling system, to the DS1104 controller board. In turn, the controlled digital signals supplied by DS1104 controller board are taken to the Power Electronics Drives Board by CP1104. It also has 8 ADC ports to accept analog signals, 8 DAC ports to output analog signals and other digital I/O connectors as in Fig 9.
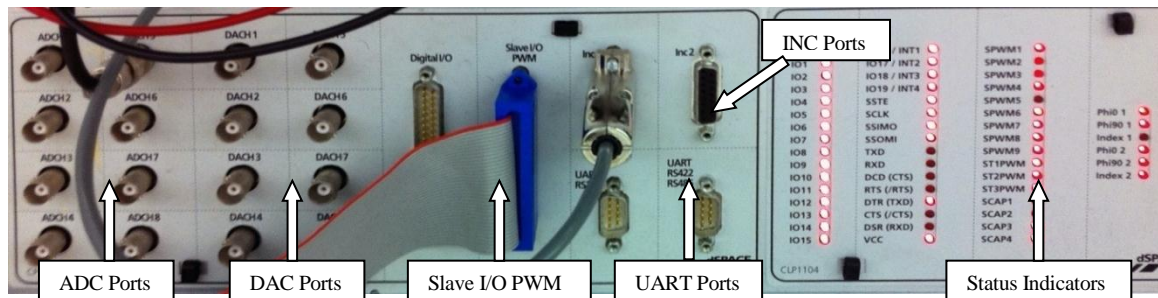

Figure 8: CP 1104 Board

Figure 9(a): CP1104 ADC and DAC Ports　　　Figure 9(b): PWM port, INC for Encoder

1.6 MATLAB Simulink and Control-desk (Programming DS1104 and control in real-time)

Simulink is a software program with which one can do model-based design such as designing a control system for a DC motor speed-control. The I/O ports of CP 1104 are accessible from inside the Simulink library browser. Creating a program in Simulink and procedure to use the I/O port of CP 1104 will be detailed in future experiments. At this stage, let us assume that we have created a **control-system** inside the Simulink that can control the speed of a DC motor. When you build the Simulink **control-system** (CTRL+B) by using real-time option, it implements the whole system inside the DSP of DS1104 board, i.e. the **control-system** that was earlier in software (Simulink) gets converted into a real-time system on hardware (DS1104). Simulink generates a *.sdf file when you build (CTRL+B) the **control-system**. This file gives access to the variables of **control-system** (like reference speed, gain, tuning the controller etc) to separate software called Control-desk. In this software a control panel can be created that can change the variables of **control-system** in real time to communicate with DS1104 and hence change the reference quantities such as the speed or torque of the motor.

1.7 Motor coupling system

This system has a mechanical coupling arrangement to *couple two electric machines as* shown in Fig. 10. It also has an *encoder* mounted on the machine that is used to measure the speed and for close loop feedback speed-control of the motor. The motor that needs to be characterized or controlled is mounted in this system. The motor under test MUT whose speed/torque needs to be controlled, could be either a DC motor or three-phase induction motor or three-phase permanent-magnet AC (PMAC) motor. The motor demands a controlled pulse-width-modulated (PWM) voltage generated by Power Electronics Drives Board.
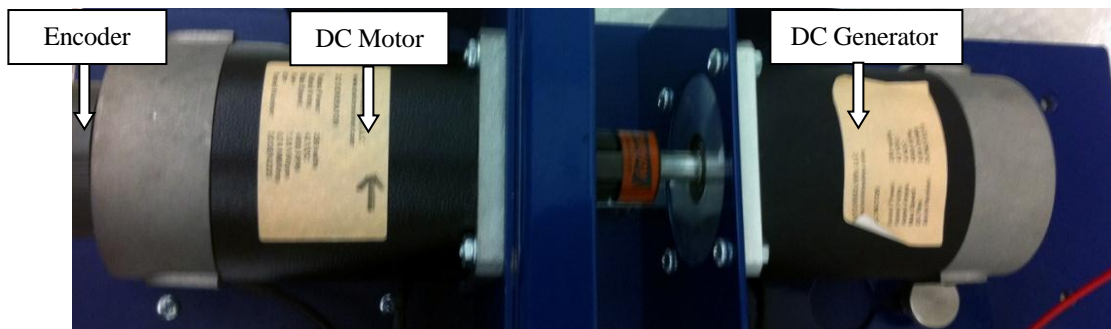

Figure 10: Motor Coupling System showing DC Motor, DC Generator and Encoder