CHAPTER 5

Power Modules for Induction Motor Control

5.1 Motor Drive Requirements

Three-phase AC induction motor requires pulse-width modulated control of the six switches of a 3-phase inverter bridge connected to the motor's stator windings . The six switches form 3 pairs of "half-bridges", which can be used to connect the leg of a winding to the positive or the negative high-voltage DC bus. As shown in the figure, two switches on the same "half-bridge" must never be on simultaneously, otherwise the positive and negative buses will be shorted together. This condition would result in a destructive event known as "shoot-through". If one switch is on, then the other must be off; thus, they are driven as complementary pairs. It should also be noted that the switching devices used in the half-bridge often require more time to turn off than to turn on. For this reason, a minimum dead time must be inserted between the off and on time of complimentary channels. In these cases, software program develops necessary dead time between the complimentary channels. Power modules are available in wide variety of configurations that accommodate most of the common motor drive topologies.

5.2 Six-Packs Configuration

A common circuit configuration that is used for three-phase induction motor is Six-pack. Six-pack is a three-phase bridge arrangement, which consists of six transistors. The collector of upper transistors are all connected together to a common positive bus terminal, the emitters of lower transistors are connected to a common negative terminal. The positive and negative terminals are connected to a DC source. The three output terminals are connected to a three-phase motor.

A six-pack module could consist of IGBTs, MOSFETs, bipolar transistors, or any other type of power switching transistors. Large high voltage motor often use an IGBT six-pack In PWM motor drive designs IGBTS are best suited for applications that require transistors rated at 400 V or higher, while MOSFETs are most effective for applications that require transistors rated less than 100 V .

Six- pack configuration is nearly universal in its suitability for different three-phase motor drive systems. High power six-packs often have a separate emitter terminal for the gate drive connection, as shown in figure 5.1. These terminals are often called an emitter-Kelvin terminals. The effect of emitter inductance can be minimized by making use of this terminal. The large currents switched by the power devices can create large voltage transients in the stray emitter inductance. The Kelvin terminals are not intended to be used for power connections, their internal wire bonds are not designed to handle high currents.

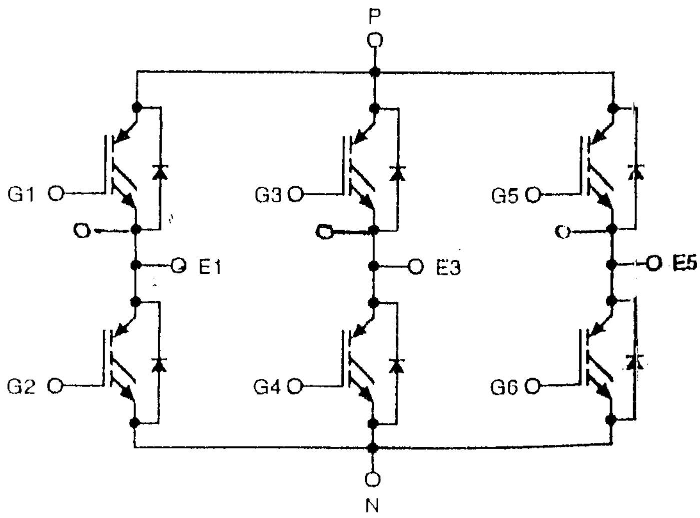


Figure 5.1 – Six-pack IGBT module with emitter Kelvins.

5.3 Gate Drive requirements

IGBTs commonly used in motor drives, UPS and converters operating at dc bus voltages up to 600VDC require voltage drive in order to achieve a saturated "ON" state condition. The drive signal must have the following characteristics

- An amplitude of 10V to 15V.
- A low source resistance for rapid charge and discharge of the gate capacitance.
- A floating output so that high side switches can be driven.

In addition to the above requirements the actual driver should be capable of driving combinations of devices in both low-side and high-side switch configurations. With this in mind the driver should also provide the following:

- Low internal power loss at high switching frequency and maximum offset voltage.
- Accept ground referenced logic level input signals.

- Protect the power switch from damage by clamping the gate signal to the low state in the event of gate under voltage or over voltage or if the load current exceeds a predetermined peak value.
- Protect the power switch by clamping the signal to the low state if the signal inputs are disconnected.

Traditionally the functions described above have required discrete circuits of some complexity but International Rectifier's IR2130 six-channel gate driver perform all the requirements for interfacing logic level control circuits to high power IGBTs in high-side/ low-side switch configurations using up to six devices.

5.3.1 IR2130 Block Diagram

As shown in Figure 5.2 the gate driver consists of six output drivers which receive their inputs from the three input signal generator blocks each providing two outputs. The three low-side output drivers are driven directly from the signal generators L1, L2 and L3 but the high-side drive signals H1, H2 and H3 must be level shifted before being applied to the high-side output drivers.

An under voltage detector circuit monitoring the VCC level provides an input to inhibit the six outputs of the signal generator circuits. In addition, there are individual under voltage lockout circuits for the high-side outputs should any of the floating bias supplies fall below a predetermined level.

The ITRIP signal which can be derived from a current sensor in the main power circuit of the equipment (current transformer, viewing resistor, etc.) is compared with a 0.5volt reference and is then "OR-ed" with the UV signal to inhibit the six signal generator outputs. A fault logic circuit set by the UV or ITRIP inputs provides an open drain TTL output for system indication or diagnostics. There is also an internal current amplifier in the IR2130 and IR2132 that provides an analog signal proportional to the voltage difference between VSS and VS0. Thus, a viewing resistor in the main power circuit can provide a positive voltage at VS0 and by suitable feedback resistors the current amplifier can be scaled to generate 0-5Vdc as a function of actual load current.

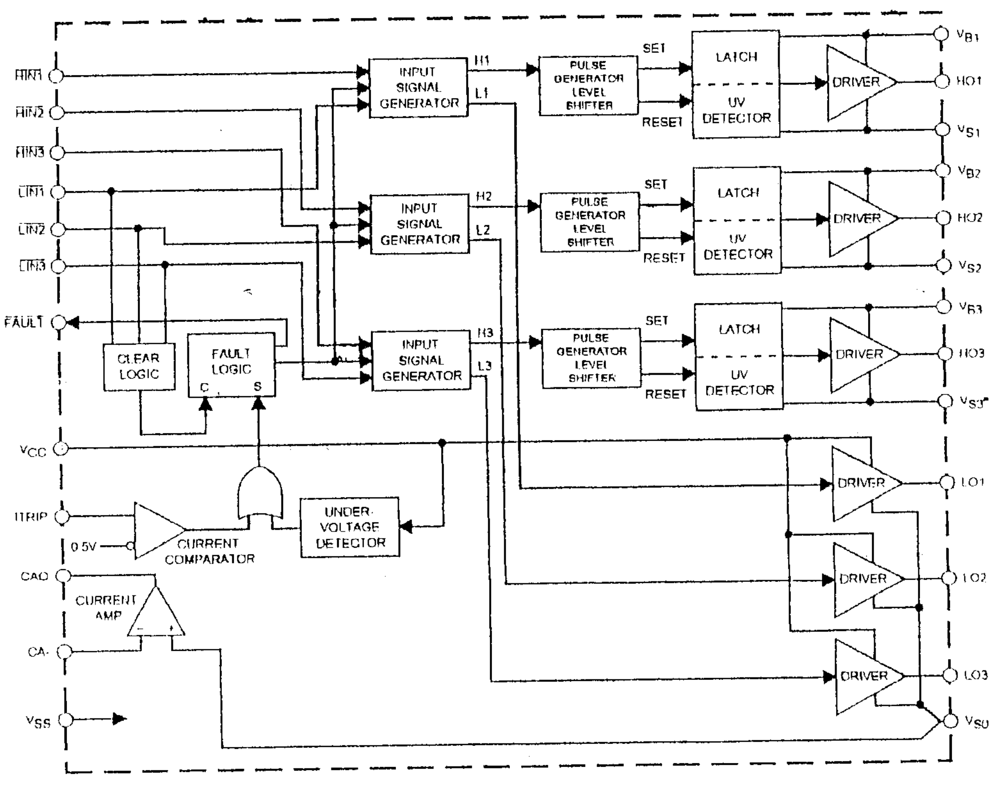


Figure 5.2 - Functional block diagram of the IR 2130

5.3.2 Protection Circuits and Fault Reporting

- **Under voltage Protection**

An under voltage condition on the VCC level, defined as less than 8.9V (as VCC is reduced) and less than 9.3V nominal (as VCC is increased) causes all outputs to shutdown With VCC at around 9 volts the drivers provide marginally adequate drive voltages to ensure full enhancement of the power switches for most applications. Separate UV lockout circuits are provided on the three high-side outputs. They also have a 0.4V hysteresis band with levels of 8.3 volts for a falling bias voltage and 8.7 volts for a rising voltage. Unlike the VCC UV circuit they inhibit only their particular high-side output and do not affect the operation of any other output.

- **Current Trip**

In the event of a shoot-through current or an output overload it is desirable to terminate all the output signals from the driver. This is accomplished through a current comparator circuit which monitors the voltage drop across a low side viewing resistor and compares it with a 0.5 volt reference level. The current comparator output is "OR-ed" with the VCC under voltage circuit output so that a fault condition of either type causes the fault logic circuit to actuate.

- **Fault Logic**

This circuit consists of a latch which is set by the conditions described incurrent trip and is reset by holding all three low-side inputs high for more than 10 microseconds or by recycling the VCC bias supply. When the fault latch is set it produces two output signals. One is used to inhibit all three input signal generator circuits thus inhibiting all six outputs. The other output signal appears as a fault indicator which goes low in the presence of a fault condition. The active low condition can drive an LED fault indicator or external logic circuit.

- **Current Sensing in IR2130**

Using the same current viewing resistor the current sense voltage of 0-0.5V is amplified in the current amplifier to generate a 0-5V analog function for processing in an external control circuit. In actual operation the voltage difference between the Vso and Vss pins forms the input voltage for the non inverting amplifier although only the positive current is measured. Two resistors Rf and RIN set the gain of the amplifier as shown in Figure 5.3. Actual voltage gain is given by the relationship

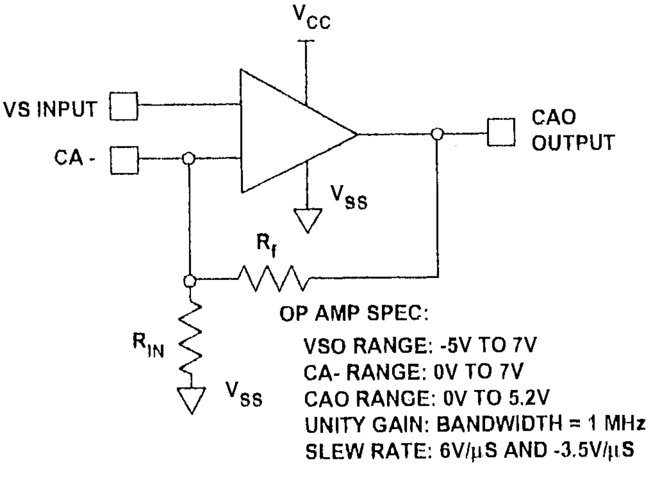


Figure 5.3 - Block diagram of the Current Sensing amplifier

$$A = \frac{R_f + R_{IN}}{R_{IN}}$$

for a gain of 10 with R_{IN} = 1k

$$10 = \frac{R_f + 1\,k}{1k}$$

$$R_f + 1\,k = 10\,k$$

$$R_f = 9\,k$$

Power for the current amplifier is supplied from VCC.

5.4 Heat Sink Calculation for IGBT module

Selection Details of Heat Sink

Thermal resistance of IGBT (TRG4 PC 30 KD)

Junction to Case thermal resistance of IGBT ($R_{\theta jc}$) =1.2 °C/W

Case to Sink, flat, greased surface thermal resistance ($R_{\theta cs}$) =0.24 °C/W

Thermal resistance of Mica sheet + Thermal compound = 1.6 °C/W

Switching Loss of IGBT (@ I=8A, Tj =120 °C) = 0.5 mJ

Total switching loss at 5 kHz $= 0.5 \times 10^{-3} \times 5 \times 10^{3}$

$= 2.5$ W

Total heat generated by 8 nos. of IGBTs (Pd) = 20 W

By Considering, surface Area of Heat Sink = A m^2

Thermal resistance of heat sink ($R_{\theta sa}$) =0.08/A

Maximum operating temperature of junction (T_{jm})=150 °C

Maximum ambient temperature (Ta) = 30 °C

$$(T_{jm} - T_a) = (R_{\theta jc} + R_{\theta cs} + R_{\theta sa}) \times Pd$$

$$(150 - 30) = (1.2 + 0.24 + 0.125/A) \times 20$$

$$A = 0.0274 \ m^2 = 274.00 \ cm^2$$

Therefore Heat sink area should be more than the 274.00 cm^2

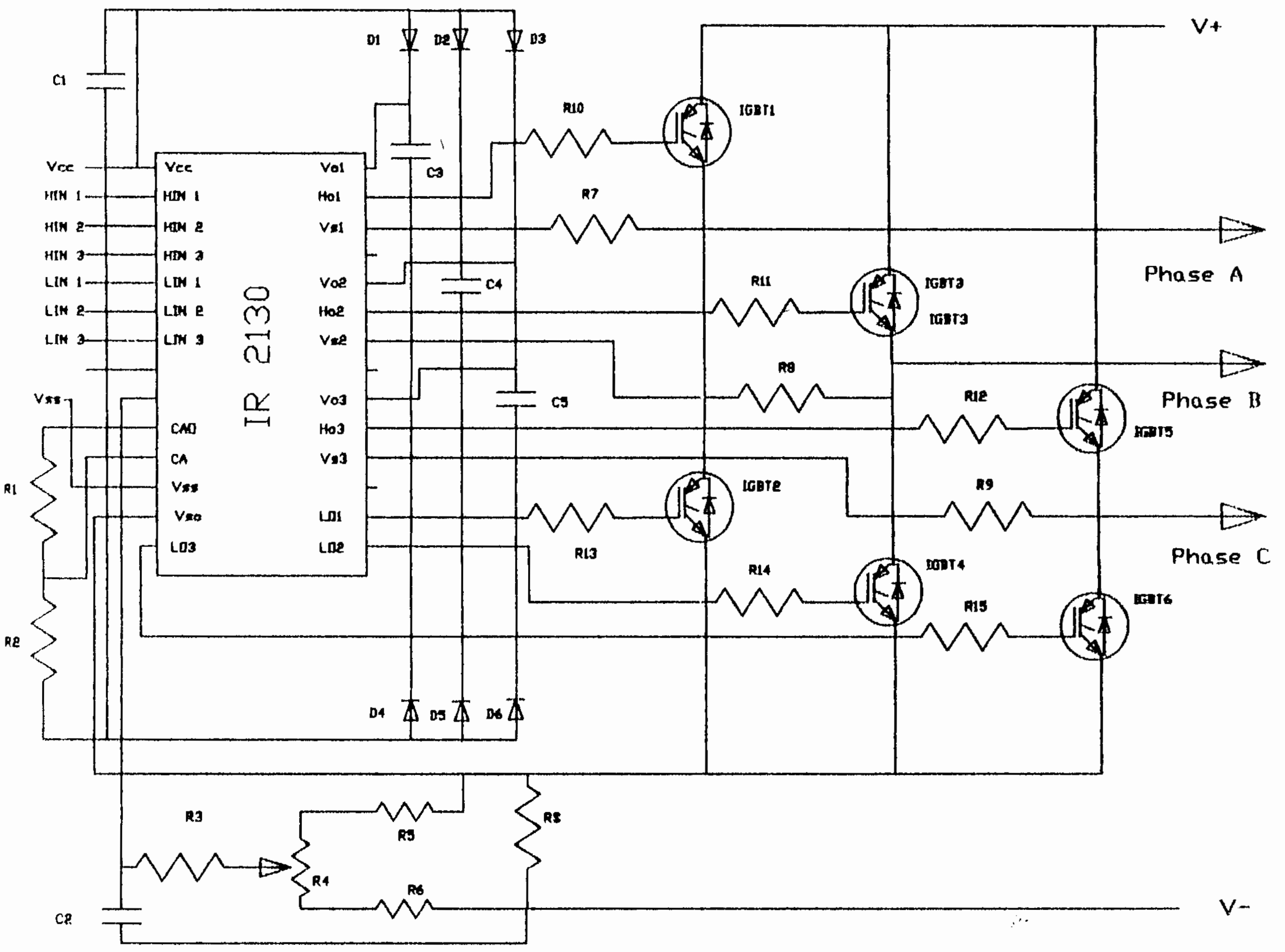
Selected Heat sink has area of 667 cm^2

Then operating junction temperature Tjo

$$(T_{jo} - T_a) = (R_{\theta jc} + R_{\theta cs} + R_{\theta sa}) \times Pd$$

$$(T_{jo} - 30) = (1.2 + 0.24 + 0.125/0.0667) \times 20$$

$$T_{jo} = 96.28 \ °C$$



IGBT1-6 –IRG4PC30KD
R1 - 9.0 kΩ, 1W
R2, R3 – 1 kΩ, 1W
R4 – 50 Ω Trimmer type
R5, R6 – 10 Ω,1W
R10,R11,R12,R13,R14,R15 -100 Ω, 1W
R7,R8, R9 - 47 Ω, 1W
RS - .1Ω, 16 W
D0,..,D6 -10DF6 ,Ultra fast recovery diode
C1,C3,C4,C5 – 0.1 μF,50V, Ceramic capacitor
C2- 1 nF, 50 V, Ceramic capacitor

Figure 5.4 – Circuit diagram of IGBT driver & IGBT Power module