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IMPLEMENTATION OF A SMALL SIZE ELECTRONIC POWER MODULE FOR MOTOR CONTROL

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Abstract
There are several speed drives and electronic devices in the market used to control the speed of ac motors. The recent invented development kit is the Microchip dsPICDEM MC1 motor control development board which is rather huge in size and bulky. In fact, it is not bringing convenience to be mobilized from one place o another. In consequence, based on the advantages brought to the world of technology by dsPICDEM, smaller equipment is designed. This compact sized development board is favourable due to its convenient size. The objective of this paper is to evaluate the process flow of the signal in the converter module and fabricate small size electronic components that obtain the same values required for motor speed control. The small driver is able to convert the input current from the humidity and temperature sensor to the motor speed in order to develop a sensitive motor with the atmosphere. Hence, senseless vector control or direct torque control can be employed in the microcontroller program to improve the performances of the development kit. This therefore, calculates speed and position of the rotor based on the feedback output voltage and current.

Keywords: Smart power module, Selin motor, Schottky diode, Op-amp

1. Introduction

The main objective of this paper is to evaluate the process flow of the digital signal of the microcontroller to the converter module through the electronic components to obtain the required analogue signal for motor speed control, and redesign a small size drive module. The whole process involved power supply, temperature and humidity sensors, microcontroller, driver module and ac motor [1, 3, 4]. The process flow is shown in figure 1.

Nowadays, there are a lot of drives in the market which is slightly larger in size and are not suitable in applying them to certain circuits. In addition, the actual components for the internal structure of the power module are large in size and are inconvenient for carrying around. For example, ABB ACS800 which control the speed of squirrel cage motor with high performance utilizing direct torque control or scalar control models and without any encoder or tachometer feedback for speed and position control is larger in size than the motor size [2].

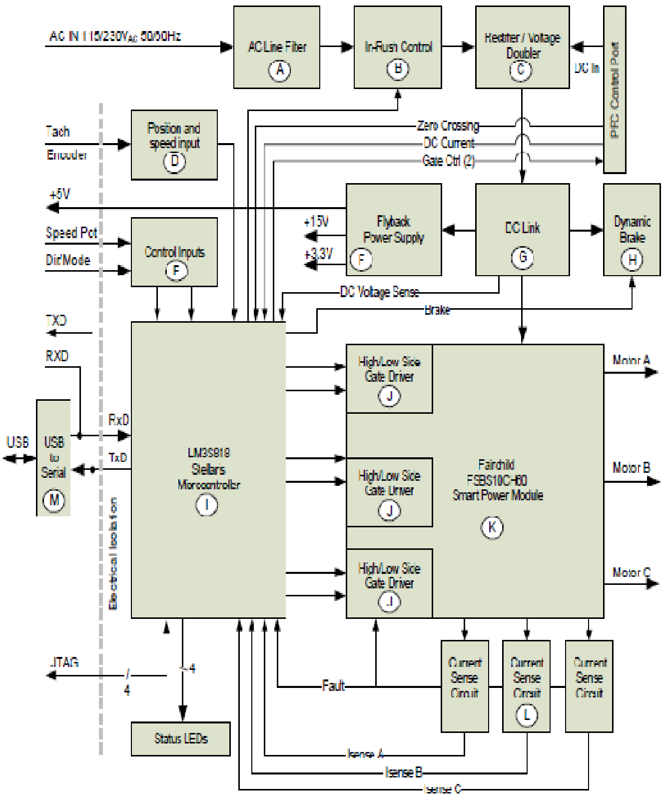


Figure 1 Block Diagram of the process flow

2. Components

The first component is the Smart Power Module SPM is usually used in inverter technology to produce high performances and cost effective. This inverter provides many benefits towards the world technology that easily to be mobilized, and less risky towards engineers. In concerning of the environment and energy conservation, SPM has established its dominant position either in compactness, functionality, reliability and ease of user interface [4, 5]. Smart Power Modules are usually used in washing machine, air conditioners, refrigerator, energy saving and noise reduction. Fairchild [5] has successfully developed a range of Smart Power Module attaching with most of the variable drives. One type of the SPM is FSBS15CH60. This is chosen for this implementation since it is fully optimized intelligent integrated IGBT inverter module and also because of its tiny size in Surface Mount Device SMD package. SMD package offers high efficiency in reducing the size of the component and still giving the same function of the component in dual-in line DIP.

In order to differentiate the type of SPM™, the order of each character of the model is given in Table 1. Therefore, through this order specification, it can be seen that FSBS15CH60 is under SMP3 type of ceramic material. This kind is specially designed in a compact and high performance way in ac drives which is usually used in low-power inverter-driven application. Low-power inverter-driven application includes household machines such as washing machine and air conditioner [6]. Circuit protection and low-loss IGBTs can be achieved by FSBS15CH60. However, the integrated under-voltage lock-out and short circuit protection gives the system reliability a better driver to be used. Opto-coupler-less single-supply IGBT gate driving capability is provided by the high speed built-in HVIC to reduce the overall size of the inverter system design. Meanwhile, the divided negative dc terminal can monitored the phase current of the inverter separately [6].

Table 1: Order reading of SPM

F	Fairchild Semiconductor
S	Divided N-terminal
B	A: Thermistor (SPM2) B: No-thermistor
S	M: DIP-SPM (SPM2) S: MINI-SPM (SPM3 with Ceramic) B: MINI-SPM (SPM3 with DBC)
15	Current Rating
C	Low $\frac{dv}{dt}$ type
H	High Switching Frequency
60	Voltage rating (x10)

The features of FSBS15CH60 include the three-phase IGBT inverter bridge, Breakdown Voltage: Collector to Emitter Voltage BVCES of 600V and 15A and ICs controlling for gate driving and protection. FSBS15CH60 has the divided negative dc-link terminals which can measure the values of the inverter current sensing applications. The power supply is single-grounded due to built-in HVIC. The isolation rating for this kind of smart power module is 2500Vrms/min. Ceramic substrate are used due to a very low leakage of current. FSBS15CH60 can be used for 100V to 253V three-phase ac inverter drive for most small power ac motors [6]. Its length for this smart power module is 4.4cm while the width is only 2.68cm. The advantage of the small size smart power module is to reduce the board size in order to make it into a smaller PCB board.

The second component is the Operational Amplifier is a dc-coupled high gain electronic voltage has a differential input and single-ended output. It is often used to amplify weak electrical current in certain circuits. Table 2 describes its configuration.

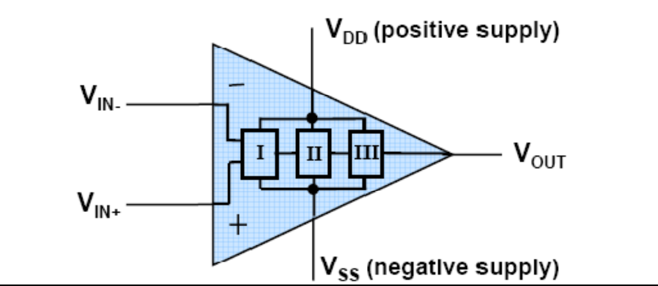
During the amplifying moment, the linearity (information carried) in the signal will not changed. The frequency of the signal will remain but the amplitude and phase will be different. Theoretically, the output voltage of op-amp is given by $V_{OUT} = (V_+ - V_-)A_{OL}$ where:

V_{OUT} = Output Voltage, V_+ = Non-inverting Voltage, V_- = Inverting Voltage, A_{OL} = Open-Loop gain of the amplifier

During the saturation, the magnitude of the Open-Loop gain of the amplifier (A_{OL}) is very large, while it will bring slight difference to the Non-inverting Voltage and the Inverting Voltage in certain circuit. Hence, the results will be either in maximum or minimum voltage set by the power supply voltages [7].

The Open-Loop gain amplifier cannot be used as a stand-alone differential amplifier since the magnitude of the Open-Loop gain cannot precisely be controlled by manufacturing process. Negative feedback must be applied in desire linear operation to enable the output voltage to be as closer as possible to the amplified voltage in order to avoid the saturation effect. If the negative feedback is used, the circuit's overall gain will become more determined. If the negative feedback is not used, the op-amp will either function as a switch or comparator. If there is positive feedback, the op-amp can be used in hysteresis or oscillation. [7]

Table 2: Op-Amp Configuration



I	Differential Input Stage: - Provides differential Inputs - Infinite input impedance (high) - Rejects signal common to input (noise)
II	High Gain Stage: - Infinite open loop gain (high) - Gains up differential input signal and conveys to output stage.
III	Output Stage: - Provides low output impedance (zero) - Delivers current to load of op-amp - Provides current limiting and short circuit protection circuitry
V_{IN+}	Non-Inverting Input
V_{IN-}	Inverting Input
V_{out}	Output voltage
V_{DD}	Positive Power Supply
V_{SS}	Negative Power Supply

The feedback components are FAN4174 (single) and FAN4274 (dual) and are ultra-low cost voltage feedback amplifiers with CMOS inputs which consume only 200µA current per amplifier. [8]. FAN4174 provides output short circuit current of ±33mA per amplifier. These kinds of CMOS amplifier are specially designed for operating 2.3V to 5V of power supplies. The common mode voltage range extends beyond the negative and positive rails [8]. CMOS type of FAN4174 amplifier is designed on a CMOS process. This process enables the CMOS amplifier to provide a 3.7MHz of bandwidth with slew rate of 3V/µs at 5V supply voltage. FAN4174 is a combination of low power, rail-to-rail performance, low-voltage operation and tiny package options in order to make this amplifier family well suited for usage in either general-purpose or battery-powered applications. FAN4174 is used in order to amplify the current of the motor. Figure 2 shows the pin configuration of FAN4174

FAN4174 can be used in daily applications; it includes portable or battery-powered applications, Personal Computer Memory Card International Association PCMCIA which is used for adding memory to PC and also for mobile communications, cellular phones, pagers, notebooks and PDAs. Besides the daily used devices, FAN4174 amplifier is also used in other driver instruments, for example, sensor interface, A/D Buffer, active filters, signal conditioning and also portable test instruments. The pin assignments are shown in Table 3

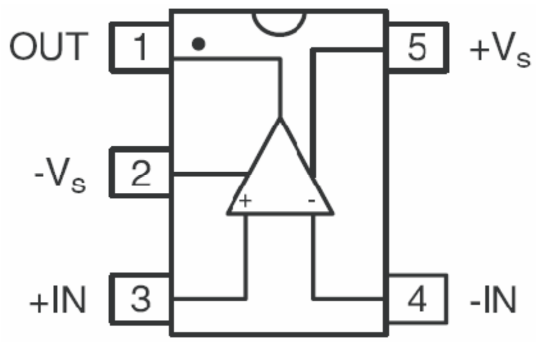


Figure 2: Pin Configuration of FAN 4174IS5X SOT23 [5]

Table 3: Pin Assignments of FAN4174IS5X [5]

Pin	Name	Description
1	OUT	Output
2	$-V_s$	Negative Supply
3	+IN	Positive Supply
4	-IN	Negative Input
5	$+V_s$	Positive Supply

In order to choose the best amplifier for usage and testing in application, the specifications of the op-amp are to be taken into consideration. Thus the higher the Gain bandwidth Product GBWP and Slew Rate SR is the better the op-amp react in frequency domain response and time domain response. In order to achieve the best result in dc performance and input characteristics, Power Supply Rejection Ratio PSRR and Common-mode rejection ratio CMRR must be low.

For FAN4174, the acceptable value of the common mode input range should be as low as 300mV below ground to 100mV above V_s in single supply operation. However, in exceeding the limited values of the common mode input range, it does not bring any phase reversal to the circuit. Conversely, if the value exceeds by more than 0.5V, the Electrostatic Discharge ESD devices will be started, and then the output remains at the rails in this overdrive conditions. If the maximum input is exceeded to 700mV, the input current will be externally limited to ±5mA [8]. On the other hand, the maximum internal power dissipation allowed is directly linked to the maximum junction temperature. Performance degradation will occurs when the maximum junction temperature exceeds 150^{o}C. If there is non-stop degradation for an extended time, the device may fail. The overdrive of an amplifier will have recovery time based on the overdriven input or output and the range of exceeding. Normally, FAN4174 will recover in less than 500ns from an overdrive condition.

Another component used is Schottky diode or Schottky Barrier diode or Surface barrier diode or hot carrier, which is used in most electronic applications, is a semiconductor device in which the basic structure is made of a metal-semiconductor transition where the basic electronic properties are identified by this transition [9]. Schottky diode is normally used when low forward voltage drops are needed where brings more advantages than PN junction diode. PN junction diode will drop with a minimum of 0.6 volts, conversely, Schottky diode has the ability to drop from 0.1 to 0.4 volts dependently upon the current. Due to this reasons, Schottky diode can perform faster and better than normal diode in the market [10]. The characteristics of Schottky diode represented in the forward voltage, reverse leakage current, and the reverse blocking voltage [11]. It is fast in speed because when it acts as a conventional diode or when it goes through different type of region, it does not depend on either holes or electrons recombining. The current density of Schottky diode is much higher than normal PN junction, which means the low forward voltage drop enables the diode an ideal component to be used in power rectification applications. On the other hand, the reverse current of Schottky diode is comparatively high [10]. When the diode is turned on, it resembles the function of an ideal switch, where as when the diode is turned off, the reverse-recovery current which is negative will clear all the overload carriers in the diode, thus this will allow it to block a negative polarity voltage. However, the reverse-recovery current does not bring much affect in the converter's characteristic, which may indicates that the diode is ideal when it is in turn-off transient [12].

Schottky diode is operated as Rectifier in certain electronic applications. It is used as output rectifiers and in other high-speed switching applications like motor drives or switching of communication devices and electronic automations [9].

MBR0520L, Figure 3, is used as a Schottky Rectifier in this implementation which is suitable for low voltage, high frequency operation as freewheeling and polarity protection [13]. MBR0520 is a surface mounted component which brings advantages as this small size package is used when the size of application is critical or in fitting the Global System for Mobile Communication GSM and PCMCIA requirements. MBR0520 Schottky Rectifier has very low forward voltage drop, extreme fast switching, negligible switching losses and guard ring for enhanced ruggedness for long term reliability [13]. MBR0520L requires only 0.5 Ampere current to operate with a low forward voltage which is less than 385 mV. Schottky Rectifier uses the power dissipation package which only required 400 mW. This surface mounted package of MBR0520L has the same footprint as mini-meld [14].

RGF1M, Figure 4, is a fast diode acts as a fast rectifier connected to the pins of the SPM with resistors and capacitors. It is a glass passivated junction for surface mounted application. RGF1M has a very low forward voltage drop and high current capability and moreover the surge current is also of high capability [12]. Due to the convenient of size, this fast rectifier is easy to pick and place.

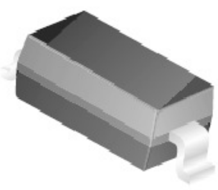


Figure 3: SOD123, MBR0520L

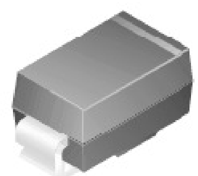


Figure 4: RGF1M

Selni Motor is the fifth component used; it is a three phase ac induction motor which is widely used in either air-conditional or washing machine. The model of the motor is shown in Figure 5. The characteristic of the motor is described in Table 4, 5 and 6.

3. Overall components of power module

Diode, resistors and capacitors plays a very important role in building the motor drive. Small size components are used for not having space consuming factor. There are two types of diode used in this module, namely: Schottky diode, and Fast diode which acts as a fast rectifier. The components name stated in table 7 indicating each placement of the components in the schematic diagram, figure 6. D1, D2, D3 is connected to the pin 11, 15, 19 of the SPM3 FSBS15CH60 with capacitors and resistors attached. D4, D5 and D6 (MBR0520L) are actually connected to the op-amp which functions as a protection to the SPM3.

Figure 5: Selni Motor

Table 4: Main Characteristic of Selni Motor

Manufacturer	
Selni-Nervers-France	
Motor	
AHV 2-42-	
Main Characteristics	
Phase to phase voltage	0-190V or 0-250V
Frequency (F)	0-340Hz
Insulation Class	F
Geometry	Drawing 10102
Speed ratio	10-16
W.M. Speed	0-1800RPM

Table 5: Special Characteristic of Selni Motor

Special Characteristics	
Stack Thickness	42mm
Stator ref	Drawing 10230
Stator lamination ref	21760 (24 slots)
Winding	2 poles, embedded, real poles. R=3, 5 Ω ± 5% ph to ph at 23°C

Table 6: Special characteristic of Selni motor without thermal protector

Without thermal protector	
Rotor ref:	Drawing 10207T01
Rotor lamination ref	27525 (28 slots)
Tacho Generator	Electromagnetic T 31(2*8 poles)
Optimum slip	From 3Hz at low frequencies to 8Hz at high frequencies
Maximum torque	2-3Nm at low speed
Maximal slip	For F ≤ 5Hz → 5Hz 13 Hz→25Hz 25Hz→28Hz 25Hz→16Hz 34Hz→35Hz

Table 7: Type of diode used

Components	Recommended	Values
D4, D5, D6 (MBR0520L)	Diode Schottky 20V	500mA
D1, D2, D3 (RGF1M)	Diode Fast 1000V	1A

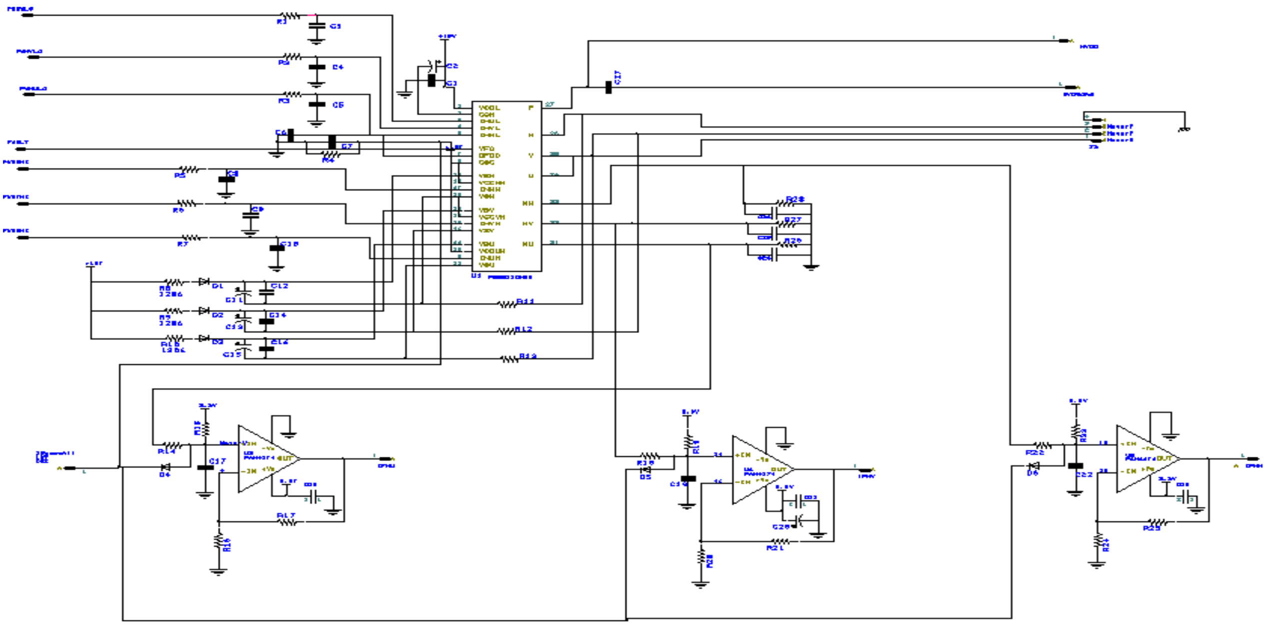


Figure 6: Schematic design of the Smart Power Module

There are many types of capacitor need to be used for different usage in this small electronic drive module. The values and the type of capacitor used are shown in Table 8. The capacitors name stated in the table designate which capacitor used in the schematic for not messing up with the arrangement and not placing wrong values and types of capacitors in the indicated circuits. Most of the capacitors are in the size of 0805.

Resistors are required in all electronic circuit boards. Table 9 shows the resistors used, with the type and values of each resistor. Resistor plays different role in the electronic circuit board with different components and depends on their connections. The sizes of the resistors are mostly of 1206 which is SMD type without space consuming.

Table 8: Type of capacitors used

Capacitors	Recommended	Values
C1, C6, C12, C14, C16	Capacitor 0805, 50V, 5%	0.1uF
C2, C11, C13, C15, C20	Capacitor, 25V, SMT	10uF
C18, C21, C23	Capacitor, 16V, 0805	1uF
C3, C4, C8, C9, C10, C17, C19, C22, C24, C25, C26	Capacitor, 50V, 10%	1000pF
C27	Capacitor, 400V polypropylene film	0.1uF

Table 9: Type of resistors used

Resistors	Recommended	Values
R1, R2, R3, R5, R6, R7	Resistor 5% 1206	100Ω
R14, R18, R22	Resistor 1% 1206	1.82KΩ
R8, R9, R10	Resistor 5% 1206	15Ω
R4, R17, R21, R25	Resistor 1% 1206	100KΩ
R11, R12, R13	Resistor 5% 1206	5.6Ω
R26, R27, R28	Resistor 1% 1W	0.04Ω
R16, R20, R24	Resistor 1%	10KΩ

4. Implementation Analysis

4.1 Smart Power Module

The flow of Smart Power Module is shown in Figure 7. It seen that the microcontroller will generate PWM to the smart power module FSBS15CH60. Thus, there is one switching speed control in the smart power module to control the motor speed. Furthermore, the phase current monitoring function is also controlled by FSBS15CH60. The current will flow to the current sense circuit in order to amplify it into a readable and acceptable value for microcontroller. The results will then be sent to the microcontroller to generate analogue signal of the phase current [4].

4.1.1 FSBS15CH60

The Schematic of FSBS15CH60 is shown in Figure 8, each pin is connected to different circuits with different functions. The speed of the motor is controlled by FSBS15CH60 power module which will be further discussed in section 4.1.3. For pin 8, there is an input signal for the short circuit protection.

FSBS15CH60 is SPM3 with ceramic material which is built up by six IGBTs with forward junction, three high voltage ICs, and one low voltage ICs, Figure 9. IGBTs are important in FSBS15CH60 as it is the hybrid transistors combination of the function of MOSFET and Bipolar Transistors. The current density of IGBT is much greater than a power MOSFET with the forward voltage drop reduced [15]. It is used to control the high power and high switching speed configurations. Thus in this SPM, pin W, pin V and pin U are used as voltage output to control the speed of three phase induction motor, where switching speed circuit is also linked to these three pins. The turn-on speed of the IGBT can be controlled by the rate of change of the gate-source voltage.

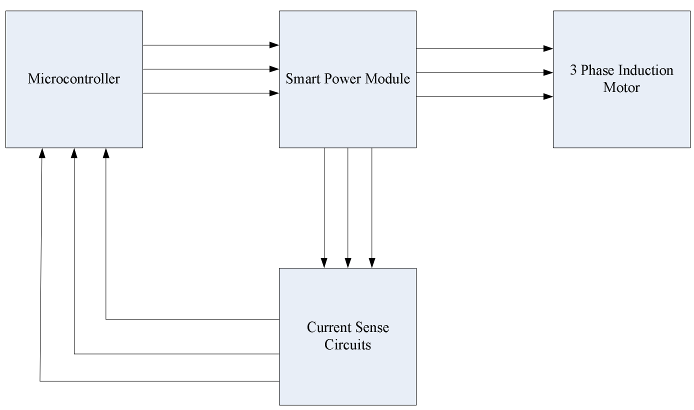


Figure 7: Block Diagram of the flow of Smart Power Module

4.1.2 Current Sense Circuit

The flow between Smart Power Module, microcontroller and current sense circuit is clearly identified. Current Sense Circuits is built up by several electronic components while the majorities

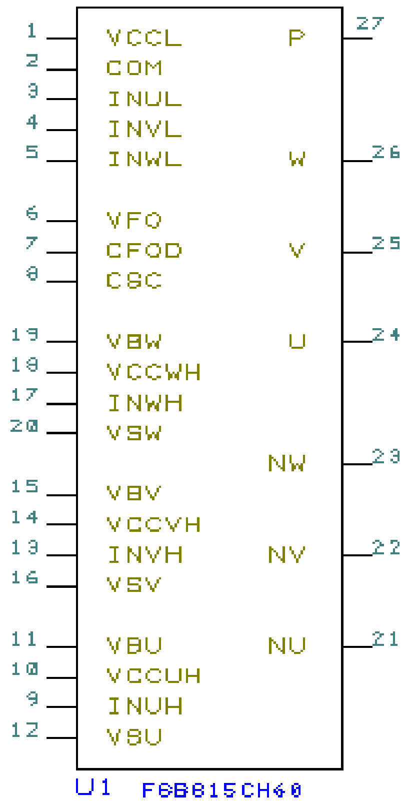


Figure 8: Schematic diagram of SPMTM FSBS15CH60

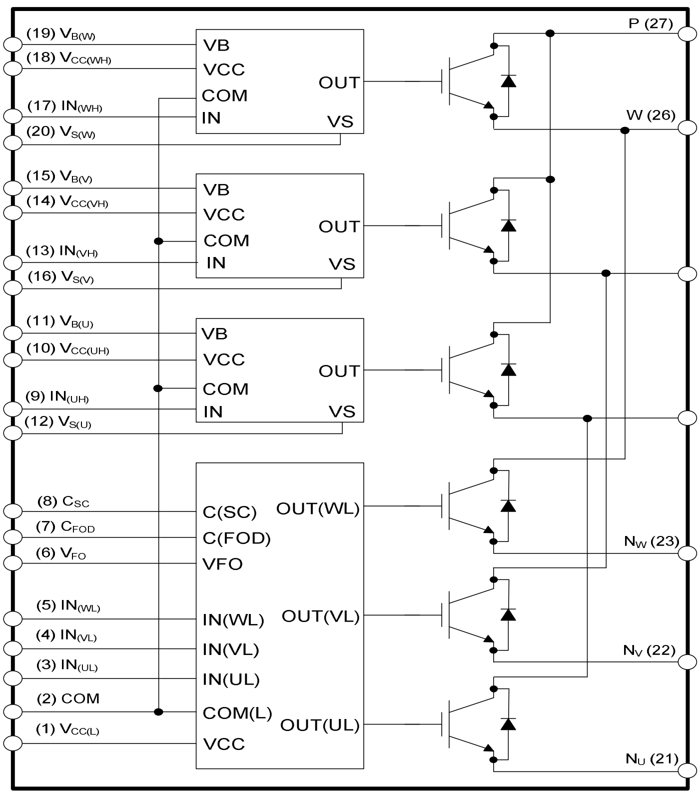


Figure 9: Inner Schematic of FSBS15CH60

are op-amp (FAN4174), diode (MBR0520), resistors and capacitors. Figure 10 shows the schematic diagram of one of the three current sense circuits which are used in measuring and monitoring the phase current of the three phase induction motor. The op-amp (FAN4174) is used to amplify the current emitted from the SPM to current sense circuit before sending the current back to microcontroller in order to produce analogue signal. Three of this current sense circuit will receive different currents from SPM FSBS15Ch60 through negative dc-link input pin 21

NU, 22 NV, 23 NW. This current sense circuit is specially designed for amplifying large phase current

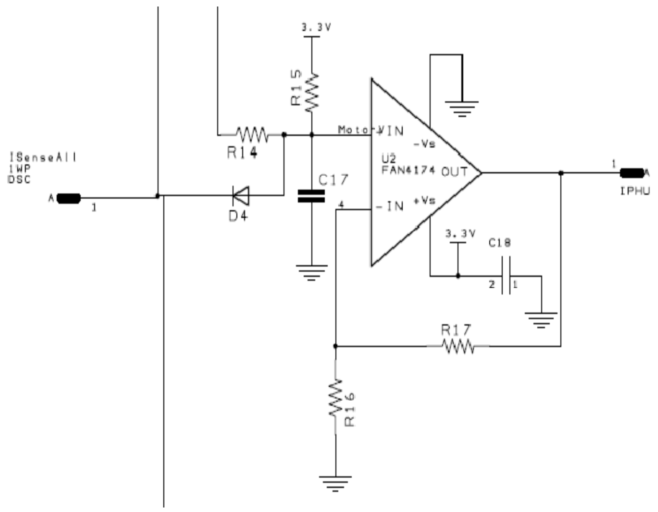


Figure 10: Schematic diagram of Current Sense Circuit

4.1.3 Three Phase Induction Motor

The switching speed control function in Smart Power Module is used to control the speed of the motor. There are four connections for the motor itself. Three of the connection is connected to different pin of the SPM, while the last wire connection which is green in colour is connected to the ground as can be seen in Figure 11 and schematic Figure 12. The switching speed control function will be connected with resistor R11, R12 and R13 and to the connection from pin W, V, U that link to the three phase ac motor.

Figure 11: Wire connection of the motor

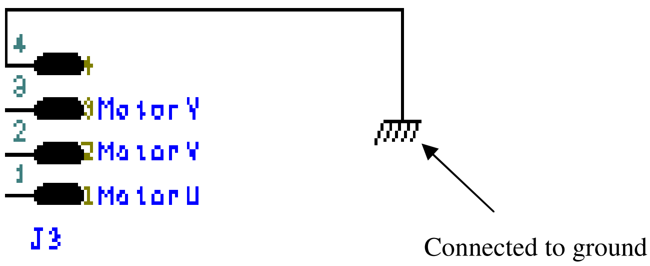


Figure 12: Connection of three phase ac motor

5. Recommendation

There are various kinds of Smart Power Module to be used in different electronic circuit applications this century. Therefore, FSBS15CH60 can also be replaced with a better Smart Power Module with lower thermal resistance and higher rate current flows. FSBB30CH60 is basically DCB (Direct bonded copper) substrates which is commonly used in Smart Power Module due to the good thermal conductivity. FSBB30CH60 allows 30 Ampere current and 600 V to pass through, and it has a three phase IGBT inverter bridge which is used to control the ICs for the gate driving as well as for protection. In addition, it has some similar function in comparing with FSBS15CH60 that has been used in this application. Negative dc-link terminals are also provided for inverter current sensing applications. The isolation rating for FSBB30CH60 is 2500 Vrms/min. This tiny SPM can be used in three phase inverter drive for small power ac motors and also home appliances applications [16]. The thermal resistance for FSBB30CH60 is the lowest, and it allows more current flowing than FSBS15CH60.

6. Conclusions

The design of small electronic drive is theoretically achieved and technically investigated and implemented in hardware. Smart power module chosen for this purpose is FSBS15CH60 due to the higher current storage and SPM3 family. Components such as op-amp (FAN4174), diode (MBR0520L and RGR1M), capacitor and resistors used are in SMD package as they are small in size and not space consuming. There are plenty other option for replacing the smart power module while the recommended one for future usage is FBB30CH60 due to its low thermal resistance and supporting high current.

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