

Soft Starter for DC Shunt Motor using ATmega328P

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Abstract— The conventional methods of starting DC Shunt Motors involves introduction of resistance to limit starting current. The above forms of control results in ohmic losses by the resistor and the loading of the machine is limited by the rating of current limiting resistors. The paper introduces a technique called soft starting involving power semiconductor devices such as an IGBT. The use of soft starter improves the efficiency of the starting process.

Index Terms— Buck Converter, DC Shunt Motor, Soft Starter, IGBT, Microcontroller, PWM.

I. INTRODUCTION

The usual starting and speed control techniques of DC Shunt Motor makes use of some form of current limiting elements such as resistors. At standstill back EMF is zero and the only resistance opposing flow of current is the armature circuit resistance, which is quite small for all types of DC motor. If a DC motor is started with full supply voltage across its terminal, a very high current will flow, which may damage motor and cause heating of winding. Therefore it is necessary to limit the current to a safe value during starting.

The rheostats are introduced to limiting the starting current and to control voltage across the windings. The above forms of control results in ohmic losses by the resistor and the loading of the machine is limited by the rating of current limiting resistors during speed control operations. Soft starters provides solution to this problem by taking advantage of minimal power dissipation of power converters relative to conventional methods and smooth starting along with speed control is possible. The proposed model uses a microcontroller that generates gating Pulse Width Modulation(PWM) signals to be applied to the BUCK Converter on occurrence of an external hardware interrupt such as signal from push button.

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II. CONVENTIONAL METHODS

• Simple Resistor

To limit the starting current, a suitable external resistance R_{ext} is connected in series (Fig.1) with the armature. At the time of starting, to have sufficient starting torque, field current is maximized by keeping the external field resistance R_f to zero value. As the motor picks up speed, the value of R_{ext} is gradually decreased to zero so that during running no external resistance remains in the armature circuit. But each time one has to *restart* the motor, the external armature resistance must be set to maximum value by moving the wiper manually.

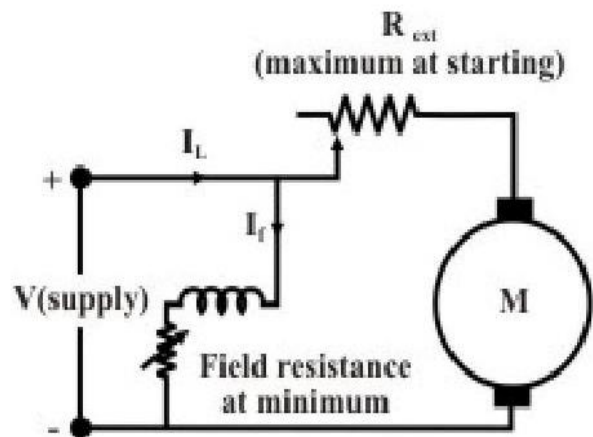


Fig.1 External Resistance maximum at start

Imagine, the motor to be running with $R_{ext} = 0$ (Fig.2). Now if the supply goes off (due to some problem in the supply side or due to load shedding), motor will come to a stop. All on a sudden, let us imagine, supply is restored. This is then nothing but full voltage starting. In other words, one should be constantly alert to set the resistance to maximum value whenever the motor comes to a stop. This is one major limitation of a simple rheostatic starter.

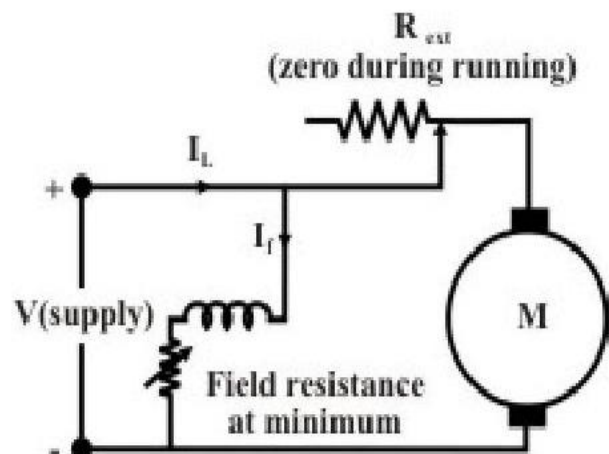


Fig.2 External Resistance zero during running condition

• Three Point Starter

It is an extensively used to start a D.C shunt motor. It not only overcomes the difficulty of a plain resistance starter, but also provides additional *protective features* such as *over load protection* and *no volt protection*. The diagram of a 3-point starter connected to a shunt motor is shown in Fig.3.

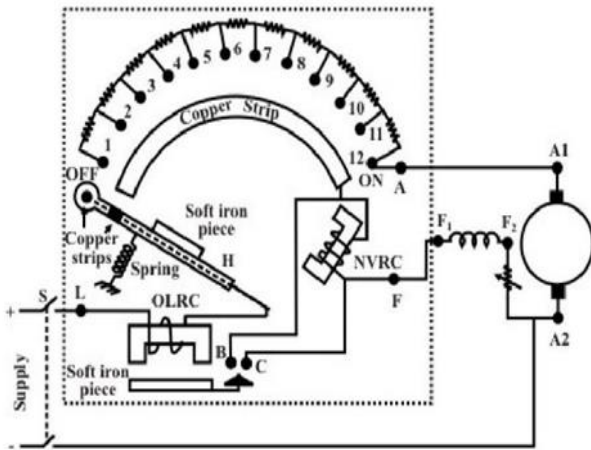


Fig.3 3 Point Starter

Initially the handle is in the OFF position. Neither armature nor the field of the motor gets supply. Now the handle is moved to stud number 1. In this position armature and all the resistances in series gets connected to the supply. Field coil gets full supply as the rectangular strip makes contact with arc copper strip. As the machine picks up speed handle is moved further to stud number 2. In this position the external resistance in the armature circuit is less as the first resistance is left out. Field however, continues to get full voltage by virtue of the continuous arc strip. Continuing in this way, all resistances will be left out when stud number 12 (ON) is reached. In this position, the electromagnet (NVRC) will attract the soft iron piece attached to the handle.

Three point starter has one disadvantage. If we want to run the machine at higher speed (above rated speed) by *field weakening* (i.e., by reducing field current), the strength of NVRC magnet may become so weak that it will fail to hold the handle in the ON position and the spring action will bring it back in the OFF position. Thus we find that a false disconnection of the motor takes place even when there is neither *over load* nor any *sudden disruption of supply*.

III. INSULATED GATE BIPOLAR TRANSISTOR

The Insulated Gate Bipolar Transistor(IGBT) is a three terminal power semiconductor device controlled by application of voltage at “Gate” terminal with respect to “Emitter” of the device. The gate terminal is separated from the substrate by in between SiO₂ layer providing isolation from the power circuit justifying the name Insulated Gate Bipolar Transistor. Three are named as Collector , Gate and Emitter. The device combines the best features of Bipolar Junction Transistor which has low On resistance and MOSFET capable of fast switching.IGBTs are mainly used in power electronics applications, such as inverters, converters

and power supplies, were the demands of the solid state switching device are not fully met by power Transistors and power MOSFETs. High-current and high-voltage BJTs are available, but their switching speeds are slow, while power MOSFETs may have higher switching speeds, but high-voltage and high-current devices are expensive and hard to achieve.

Because the IGBT is a voltage-controlled device, it only requires a small voltage on the Gate to maintain conduction through the device unlike BJT’s which require that the Base current is continuously supplied in a sufficient enough quantity to maintain saturation. It is an unidirectional device, meaning it can only switch current in the “forward direction”, that is from Collector to Emitter unlike MOSFET’s which have bi-directional current switching capabilities (controlled in the forward direction and uncontrolled in the reverse direction).

The main advantages of using the IGBT over other types of transistor devices are its high voltage capability, low ON-resistance, ease of drive, relatively fast switching speeds and combined with zero gate drive current makes it a good choice for moderate speed, high voltage applications such as in pulse-width modulated (PWM), variable speed control, switch-mode power supplies or solar powered DC-AC inverter and frequency converter applications operating in the hundreds of kilohertz range.

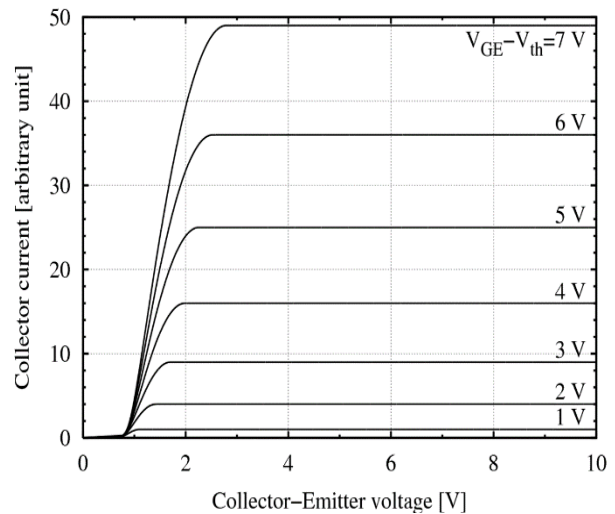


Fig.4 IGBT Output Characteristics

IV. BUCK CONVERTER

A chopper is a static power electronic device which converts fixed dc input voltage to a variable dc output voltage. It can be step up or step down. It is also considered as a dc equivalent of an AC transformer since they behave in an identical manner. Chopper systems offer smooth control, high efficiency, faster response and regeneration facility. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, BJT, MOSFET, IGBT and GTO.

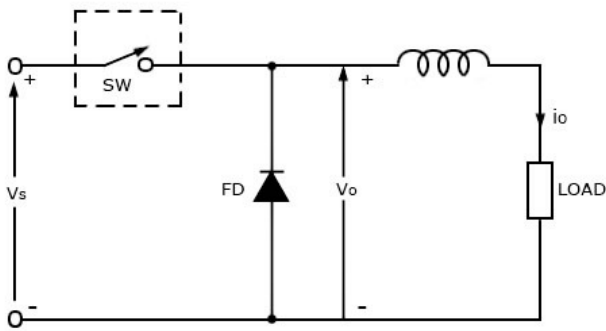


Fig.5 Buck Converter

When the switch is OFF, no current will flow. Current flows through the load when switch is ON. The power semiconductor devices have on-state voltage drop of 0.5V to 2.5V across them. During the time period T_{on} the chopper is turned on and the load voltage is equal to source voltage V_s . During the interval T_{off} the chopper is off and the load current will be flowing through the freewheeling diode FD. The load terminals are short circuited by FD and the load voltage is therefore zero during T_{off} .

Thus, a chopped dc voltage is produced at the load terminals. We can see from the graph that the load current is continuous. During the time period T_{on} , load current rises but during T_{off} load current decays.

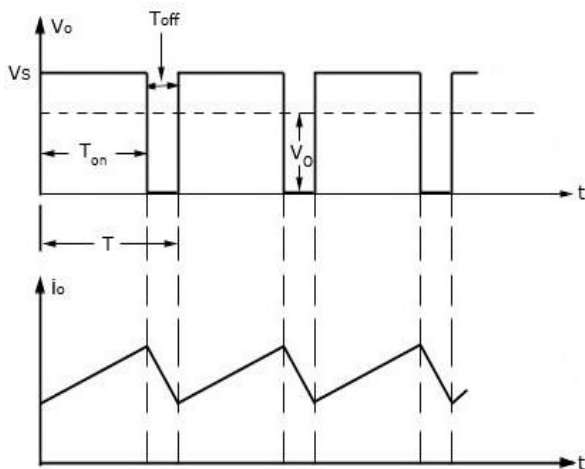


Fig.6 Output Voltage and Current Waveforms

Average load Voltage V_o is given by

$$V_o = (T_{on} / (T_{on} + T_{off})) V_s$$

$$= (T_{on} / T) V_s$$

$$V_o = D V_s$$

Where,

T_{on} : on -time

T_{off} : off- time

$T = T_{on} + T_{off} =$ chopping period

$D = T_{on} / T =$ duty cycle

So we know that the load voltage can be controlled by varying the duty cycle D. Above equation shows that the load voltage is independent of load current it can be also written as

$$V_o = f \cdot T_{on} \cdot V_s$$

$$f = 1/T = \text{chopping frequency}$$

V. MICROCONTROLLER

Arduino is an open-source single-board microcontroller, descendant of the open-source Wiring platform, designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open hardware design for the Arduino board with an Atmel AVR processor and on-board input/output support. The software consists of a standard programming language compiler and the boot loader that runs on the board. Arduino

hardware is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications and a Processing-based integrated development environment.



Fig.7 Arduino Uno Board

Power:

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable.

The recommended range is 7 to 12 volts. The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source
- **5V.** This pin outputs a regulated 5V from the regulator on the board.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.
- **IOREF.** This pin on the Arduino board provides the voltage reference with which the microcontroller operates.

Memory:

The *ATmega328* has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output:

Each of the 14 digital pins on the Uno can be used as an input or output, They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- **TWI: A4 or SDA pin and A5 or SCL pin.** Support TWI communication using the Wire library.
- **AREF.** Reference voltage for the analog inputs.
- **Reset.** Bring this line LOW to reset the microcontroller.



Fig.8 Block Diagram

Communication:

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer. The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

VI. MOTOR RATINGS

H.P. rating	– 5 HP (3.7 kW)
Voltage	–220 Volts
Rated Speed	– 1500RPM
Current Rating:	
Rated current	– 20A
No load current	– 1.2A
Winding Resistance:	
Field Resistance	– 208 Ω
Armature Resistance	– 1.1 Ω

VII. PROPOSED MODEL

Basically the microcontroller generates the Pulse Width Modulation (PWM) signal which drives the IGBT in the Buck converter. The pulse width modulation speed control works by driving the motor with a series of “ON-OFF” pulses and varying the duty cycle(Fig.8), the fraction of time that the output voltage is “ON” compared to when it is “OFF”, of the pulses while keeping the frequency constant. The power applied to the motor can be controlled by varying the width of these applied pulses and thereby varying the average DC voltage applied to the motors terminals. By changing or modulating the timing of these pulses the speed of the motor can be controlled, ie, the longer the pulse is “ON”, the faster the motor will rotate and likewise, the shorter the pulse is “ON” the slower the motor will rotate.

In other words, the wider the pulse width, the more average voltage applied to the motor terminals, the stronger the magnetic flux inside the armature windings and the faster the motor will rotate and this is shown below.

The Fig.8 depicts the block diagram of the proposed model. External Hardware Interrupt generates the interrupt signal. The interrupt is triggered with the help of a push button. Series RC circuit is used for debouncing and signal is conditioned using a Schmitt trigger. The IGBT works at a higher voltage and needs a greater voltage for the device to be turned on. In contrast, the control circuits operate at relatively lower voltage. The electrical isolation is provided by the opto-coupler and the gate of IGBT is driven by switches operating at 12V. The pulse from the gate driver is applied to the gate terminal. The power circuit operates at 220Vdc and the output of the converter is fed to the armature windings of the DC shunt motor. The field winding is directly connected to the DC supply.

When the user presses the button a pulse is generated and initiates Interrupt Service Routine. The microcontroller begins to output PWM signal starting from zero percent i.e. the average output voltage applied to the armature terminal is zero to maximum value i.e. the average output voltage is equal to the applied voltage with an increment of 5% of input voltage at every second until the maximum is reached. The results are depicted in the Fig.9 and Fig.10 below.

VIII. ADVANTAGES

- Effectively reduces the inrush current at start-up moment.
- It also provides the speed adjustment and can be further implemented with the speed regulation and the over-current protection.
- The IGBT based circuit gives smoother control over the entire speed range as compared with the SCR based circuit. The power loss with electronic starter is very less as compared to conventional starter.

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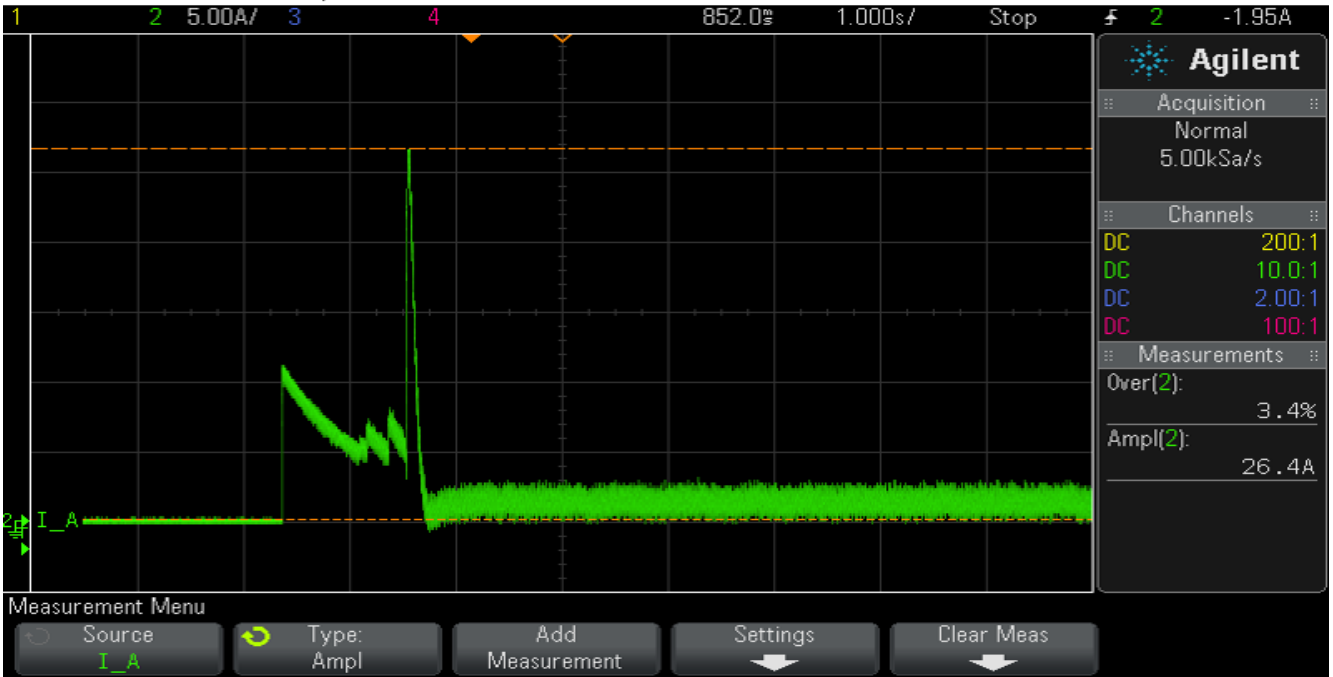


Fig.9 Starting current for Conventional starter.

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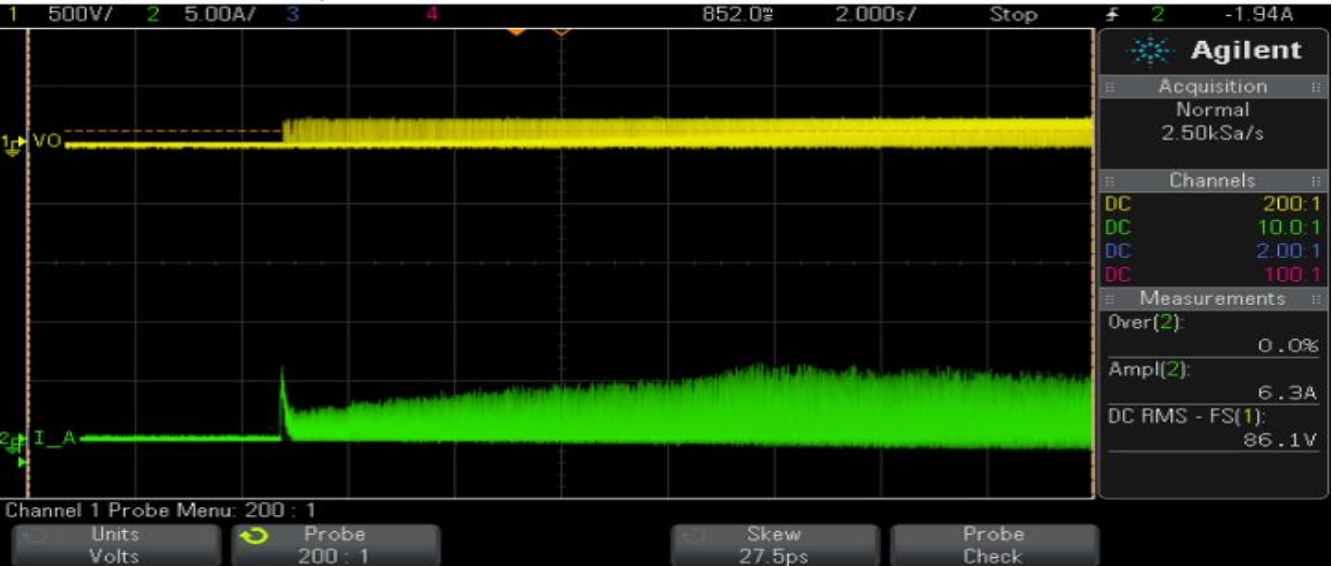


Fig.10 Starting current waveform for Starter

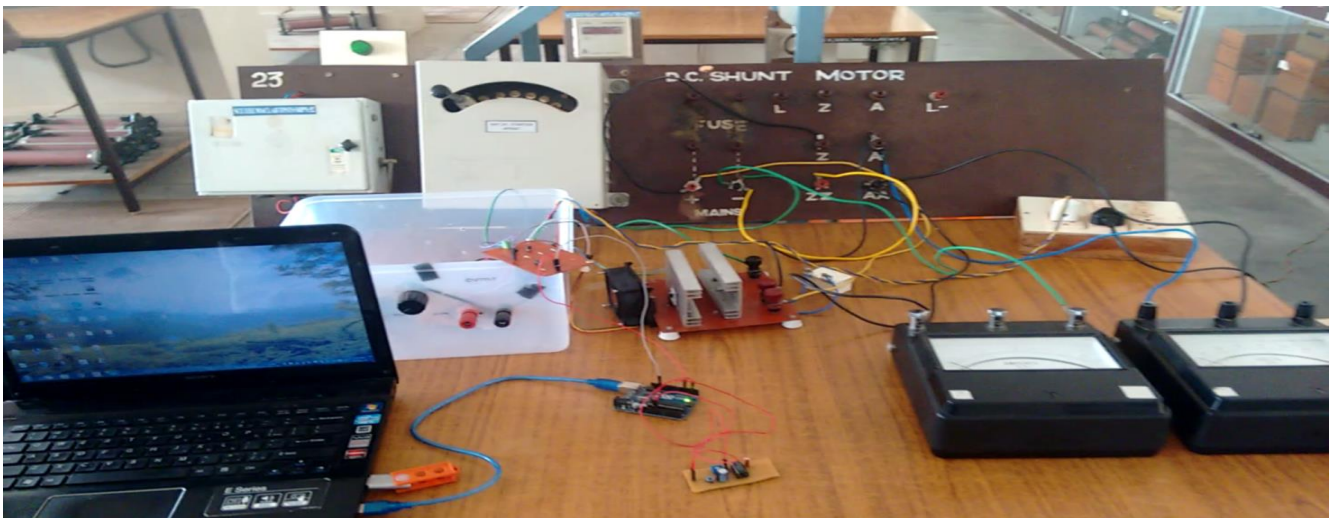


Fig.11 Project Setup

IX. CONCLUSION

The Fig.9 and Fig.10 shows the starting current trend when motor is started with the conventional starter and the proposed model. The waveform records a peak current of 26.4A which is well over the rated current specified for the motor in the nameplate when started with conventional starter. The starting process with proposed model depicts that peak starting current recorded is 6.3A significantly lesser than the conventional methods and the maximum current ratings of the motor.

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