A REVIEW ON SPEED CONTROL OF THREE-PHASE INDUCTION MOTOR USING VARIABLE FREQUENCY DRIVE TECHNOLOGY

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ABSTRACT

This paper describes speed control using variable frequency drive(VFD). The proposed system is a MATLAB simulink model, which is a closed loop model designed to achieve desired speed control of a three-phase induction motor to control thefrequency and thus the speed. The proposed method conformed to performance predictions and delivered by varying its frequency. The simulink model has six main blocks, namely the boost converter, 3-Phase inverter, 3-Phase squirrel cage induction motor,speed controlling feedback,driver circuit,SPWM Generator. The inverter is comprised of six insulated-gate bipolar transistors (MOSFET),which are fired by gate pulses generated by PID Generator block, filtered with gate driver circuitry along with SPWM generates. Hence, variable speed is achieved at output of induction motor. The project presents the working principle of variable frequency drive (VFD), its performance, and the use of Pulse Width Modulation (SPWM) in a three-phase inverter the desired outputs.

Keywords: Variable frequency drive, three-phase induction motor, pulse width modulation(SPWM), MATLAB R2019b software for simulation, easyEDA software for PCB design, Proteus software for circuit design

INTRODUCTION

Variable-Frequency Drive (VFD) is a type of adjustable speed drive used in electromechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage. VFDs are used in applications ranging from small appliances to the largest of mine mill drives , Electric vehicles and compressors. Over the last four decades, power electronics technology has reduced VFD cost and size and improved performance through advances in semiconductor switching devices (MOSFET), drive topologies, simulation, and control techniques, and control hardware and software. VFDs are available in several different low and medium voltage AC-AC and DC-AC topologies. Variable speed drives are used for two main reasons: to improve the efficiency of motor-driven equipment by matching speed with the changing load requirements and to allow accurate and continuous process control over a wide range of speeds. This project specifically puts emphasis on one of the various methods of speed control of induction motor that is by changing frequency. The simulation of this VFD consists of six main units namely boost converter, inverter, DC to AC converter& Filter, 3-phase Squirrel cage induction motor, PID(Proportional Integral Derivative) controller, Driver circuit with SPWM generator. In this project model, pulse width modulation technique is used to generate variable frequency.

TECHNOLOGY OVERVIEW

Electric AC motors operate at fixed speeds and are ideally suited to applications where a constant output speed is required. However, around half of all motor applications have some kind of varying speed demand. In the 1980s and 1990s, variable frequency drives started appearing on the market; these devices offer an alternative method of control. A variable frequency drive is also called a frequency inverter or adjustable speed drive. The basic working principle of such drives is adjusting the electrical supply to an AC motor with a corresponding frequency and voltage change in the motor's speed and torque output.By implementing this type of control, a very close match between motor speed and the process requirements of the machine that it is driving may be achieved.Variable frequency drive technology is now mature and is enjoying widespread adoption and use with AC motors; these drives are extremely versatile and offer a high degree of motor control, which means that motor speeds can be accurately varied from zero rpm through over 100% of the rated speed. As speed is adjusted in this way, the torque is also automatically adjusted to suit. Different options are available for different applications. Basic VFD designs are used in simple applications, such as fan and pump control, whereas more complex versions might be used for very precise speed and torque control in, for example, multiple winders or materials forming applications While there are a number of variations in variable frequency drive designs, they all offer the same basic functionality. This functionality is to convert the incoming electrical supply of fixed frequency and voltage into a variable frequency and variable voltage that is output to the motor with a corresponding change in the motor speed and torque.

Fig1. Block diagram of drive system

Figure 1 shows the complete VFD system, AC (230V) supply given to AC to DC converter(Rectifier) which converts 230V AC to 230V DC. This, DC supply is given to boost converter which converts 230V DC to 440V DC. Then, this 440V DC given to three-phase inverter, which converts it into AC.The gate pulses to MOSFETs present in three-phase inverter, triggered by driver circuit..SPWM generator which is nothing but microcontroller with supplied with SMPS which is responsible to give exact output for a system.In result, we get variable frequency and variable voltage at output to feed an induction motor. After filtering it,gate driver circuitry along with SPWMgenerates Hence, variable speed is achieved at output of induction motor.

I. MATLAB/SIMULINK MODEL OF VFD SYSTEM WITH SOFTWARE RESULTS:

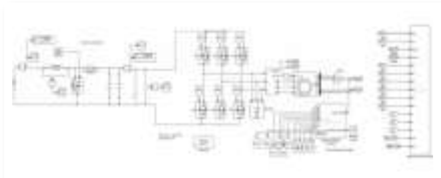

Fig2. Complete MATLAB/Simulink model of VFD

a) THREE-PHASE INVERTER: The inverter converts the rectified and conditioned DC back into an AC supply of variable frequency and variable voltage. This is normally achieved by generating a high frequency pulse width modulated signal of variable frequency and effective voltage semiconductor switches are used to create the output; different types are available, the most common being Metal-Oxide Semiconductor Field Effect Transistor (MOSFET).

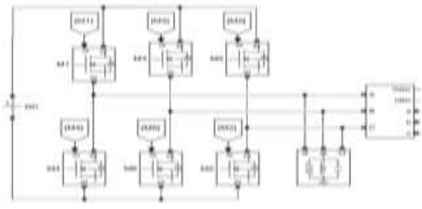

Fig3. Simulink model of 3-Phase two level inverter

Fig4. Output Voltages of inverter circuit

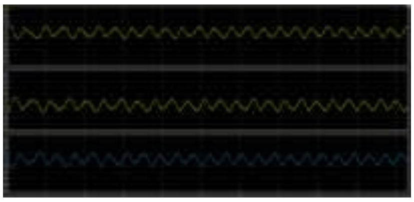

Fig5. Output currents of inverter circuit

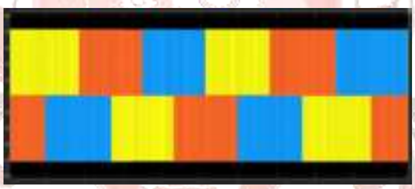

Fig6. Output Line to Neutral Voltages of inverter circuit

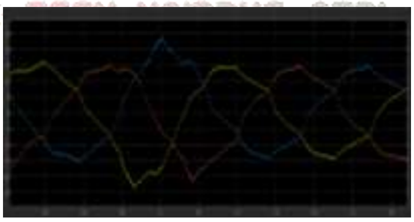

Fig7. Three phase output Line to Line Voltages of inverter circuit

b) AC to DC CONVERTER: The working principle of a converter is changing the incoming 230V alternating current (AC) supply to 230V direct current (DC). Different designs are available and are selected according to the performance required for the variable frequency drive. The rectifier design will influence the extent to which electrical harmonics are induced on the incoming supply. It can also control the direction of power flow.

c) BOOST CONVERTER (230V to 440V): Induction motor needs 415V supply so that inverter has to convert this voltage from DC. Available main supply is 230V AC. It needs to convert from AC/DC and then DC/DC 440V including all losses with required voltage. Therefore boos converter is required. The key principle that drives the boost converter is the tendency of an inductorto resist changes in current by increasing the energy stored in the inductor magnetic field. In a boost converter, the output voltage is always higher than the input voltage.

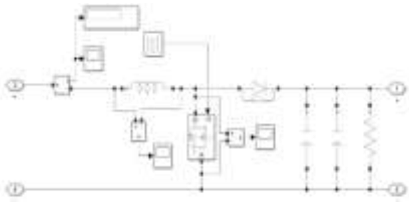

Fig8. Simulink model of boost converter (230V to 440V)

d) DRIVER CIRCUIT:

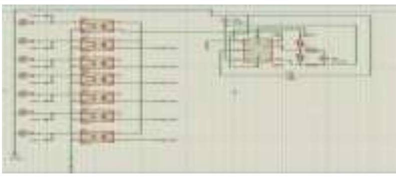

Fig9. Proteus Model/Circuit Diagram of driver circuit

Driver circuit is nothing but operation with optocouplers. There are four pins of optocoupler 1st is connected with arduino, 2nd is connected with ground , 3rd is connected MOSFET of inverter and 4th is connected to power circuit with boost 24V.resistor is used as a current sink register to make MOSFET 0. Driver circuit is used especially in trigger the MOSFETs of inverter and make a control on it.

1. POWER CIRCUIT FOR DRIVER CIRCUIT (12V to 24V):

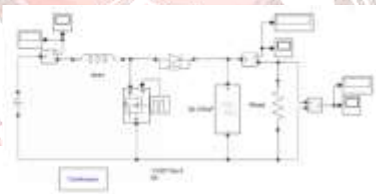

Fig10. Simulink model of power circuit for driver circuit

In this power circuit, 12V 18A SMPS we used as a external power supply. By using boost converter 12V to 24V convert the power supply and give to the driver circuit. Current is flowing through inductor when MOSFET is ON triggered by NE555 with 55% duty cycle. When MOSFET gets OFF that energy stored in inductor conduct the diode with capacitor and likewise voltage get boost up.

e) SQUIRREL CAGE THREE-PHASE INDUCTION MOTOR: A squirrel-cage rotor is the rotating part of the common squirrel-cage induction motor. It consists of a cylinder of steel laminations, with aluminum or copper conductors embedded in its surface. In operation, the non-rotating stator winding is connected to an alternating current power source; the alternating current in the stator produces a rotating magnetic field. The rotor winding has current induced in it by the stator field, like a transformer except that the current in the rotor is varying at the stator field rotation rate minus the physical rotation rate. The interaction of the magnetic fields of currents in the stator and rotor produce a torque on the rotor))Squirrel cage 3-phase induction motor: A squirrel-cage rotor is the rotating part of the common squirrel-cage induction motor. It consists of a cylinder of steel laminations, with aluminum or copper conductors embedded in its surface. In operation, the non-rotating stator winding is connected to an alternating current power source; the alternating current in the stator produces a rotating magnetic field. The rotor winding has current induced in it by the stator field, like a transformer except that the current in the rotor is varying at the stator field rotation rate minus the physical rotation rate. The interaction of the magnetic fields of currents in the stator and rotor produce a torque on the rotor.

Table1. Name plate ratings of squirrel cage 3-phase induction motor

Voltage Rating	415V
Current	4.4A
Phase	3 Phase
Speed	1410 R.P.M.
KW	2.2
H.P.	3.0
Insulation Type	B class

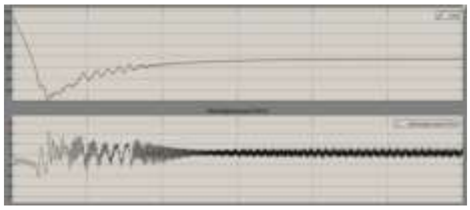

Fig11: Torque and Speed of induction motor

f) SPEED CONTROLLING FEEDBACK**:** The output of the system is feedback to the input.In closed loop system controls the electrical drive, and the system is self-adjusted. Speed controlling Feedback in an electrical drive provided to satisfy the following requirements. Enhancement of speed of torque to improve steady-state accuracyProtection.PWM output then give to the gate terminal of MOSFET.

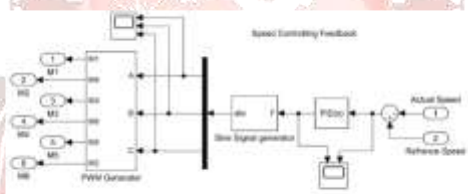

Fig12. Simulink model of speed controlling feedback

1. PID Controller:PID controller consists of three terms, namely proportional, integral, and derivative control. The difference between the setpoint and feedback is called the error ε. The job of the controller is to eliminate the error.

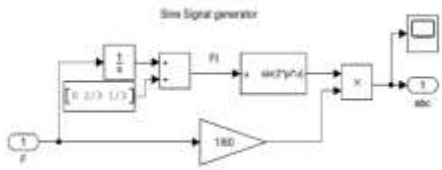

Fig13. Simulink model of PID controller

2. Proposed Model of Sinusoidal PWM generator:The triangular carrier signal is compared with the sinusoidal modulating signal. A Pulse Width Modulation (PWM) signal generator works by varying the duty cycle of a square wave while keeping the period fixed.

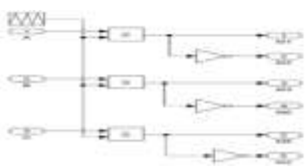

Fig14. Simulink model of SPWM generator

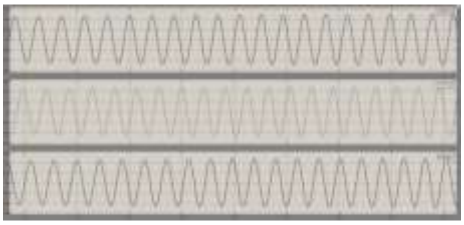

Fig15. Three-phase reference sine waves

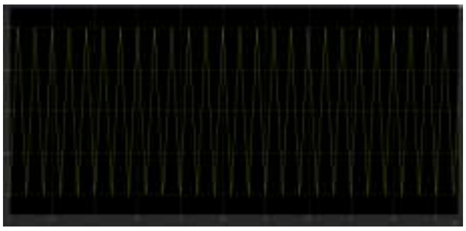

Fig16. Tringular carrier wave

Fig17. Output of PWM generator (Sine and carrier wave comparison)

Here, SPWM generator is nothing but µcontroller (Arduino UNO) .It is connected with optocoupler and feedback system.

- When arduino gives high pulse to optocoupler ,its 3rd and 4th pin gets shorted.Then, it will connect to MOSFET of inverter.Due to the high pulse inverter MOSFET gets ON.
- When arduino gives low pulse to optocoupler ,its 3rd and 4th pin gets open.Then, resistor will ground the terminals and it will disconnect to MOSFET of inverter.Due to the low pulse inverter Mosfet gets OFF.

A Hall effect sensor (or simply Hall sensor) is a type of sensor which detects the presence and magnitude of a magnetic field using the Hall Effect. The output voltage of a Hall sensor is directly proportional to the strength of the field.Hall sensor has three pins one is connected to +VCC of 5V supply. Second one is ground. 3rdpin is digital which is connected with shaft of the induction motor.This detects the magnetic field around the shaft.

Hall Effect Sensors are devices which are activated by an external magnetic field. The output signal from a Hall effect sensor is the function of magnetic field density around the device. When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage.

II. VFD HARDWARE DESIGN AND RESULTS:

In hardware design of variable frequency drive, we convert software part into hardware in four steps namely as

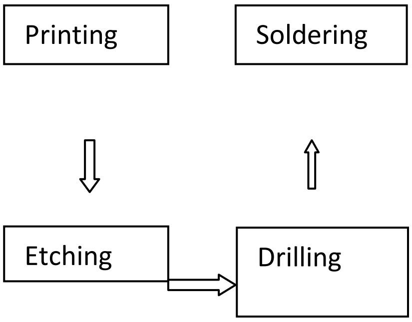

Fig18. Software to hardware process

Firstly, EXTREMELY careful & cautious while performing this steps.

1. **Printing** :This step is perform to Print easyEDA software design PCB on EHP paper.Using that ink side will print on copper cad with appropriate technique.

2**. Etching:**while performing this step ,PCB will dip into the Etching solution (Ferric chloride solution, $FeCl_3$) with shaking solution around copper cad. Using this PCB on copper cad will fix and ready for putting components.

3. **Drilling** : It is important part when components have to place on PCB. Its simply drill components holes on PCB carefully and use nail polish remover to clean the surface.

4. **Soldering** : It is when we have to fix components at their place with soldering material using soldering equipment.

PCB Design of Hardware circuits The PCB (Printed Circuit Board) designing of this project is done in software easyEDA. Three circuits are printed namely driver circuit, three phase inverter and boost converter.

a. Following is the PCB design in easyEDA and PCB component layout of gate driver circuit with components: Ceramic Capacitors 102 and 104 ,Optocouplers (7), 1K resistor(7), Preset (Variable resistor (0-100 ohm)), Timer IC, Zener diode (1N4148).

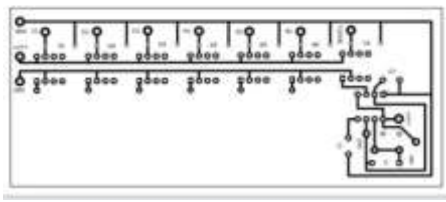

Fig19: PCB Layout of driver circuit

Fig20: PCB Layout of gate driver circuit with components placed

In power circuit of driver circuit components used are inductor 8mH, schottky diode(20A,50V),capacitor (470µF, 35V)(3), NE555 IC(55% duty cycle), preset 2 K-ohm and 3 K-ohm, Ceramic capacitor 102 and 104 and SMPS 12V 18 A.

b. Following is the PCB design in easyEDA and PCB component layout of three phase inverter circuitwith components: 2SK1118 Power MOSFETs (6), NE555 IC , capacitors and Fuses.

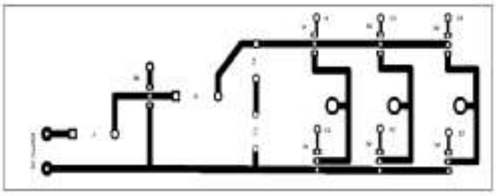

Fig20. PCB layout of three-phase inverter circuit

Fig21. PCB design of three-phase inverter circuit with all components

c. Following is the PCB design in easyEDA and PCB component layout of boost converter with components: Inductor 8mH, 47 µF 250V capacitor, 2SK1118 Power MOSFET, NE555 IC.

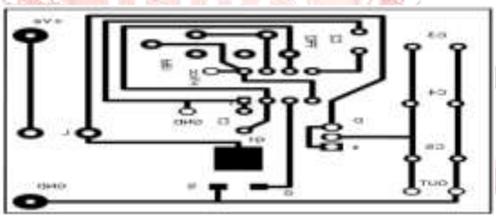

Figure 22: PCB Layout Of Boost Converter

Figure 23: PCB design boost converter circuit with all components

Boost converter is used in two conversion one 12V to 24 V in power circuit of driver circuit which is given to driver circuit and another is in 230V to 440V which is given to three phase inverterNow, three-phase inverter gives a variable frequency and variable voltage at its output. Finally, this variable frequency, variable voltage output is given to three-phase induction motor whose speed is variable at the end achieved.

RESULTS

Motor Speed $(R.P.M)$ and Motor Torque(Nm)

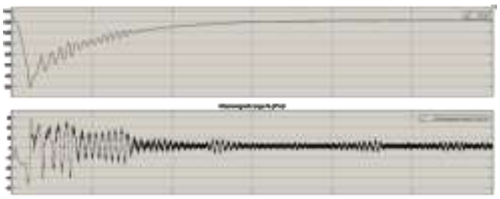

Fig24: MATLAB Simulink Result with Reference speed 1430 R.P.M.

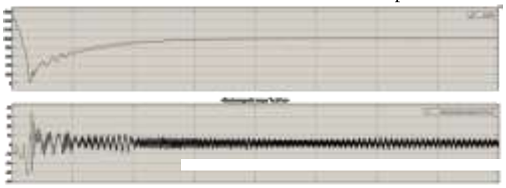

Fig25: MATLAB Simulink Result with Reference speed 1000 R.P.M.

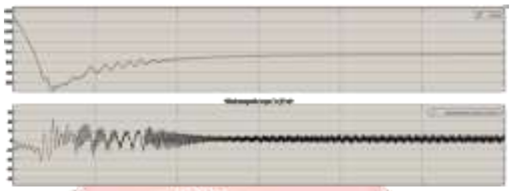

Fig26: MATLAB Simulink Result with Reference speed 750 R.P.M.

CONCLUSION

This paper analyzes one of the methods of speed control of a three-phase induction motor that is using variable frequency. We were able to achieve desired speed using MATLAB Simulink model where we have used different control units and power electronic devices. The output waveform of speed is our desired result, which shows that the control system tries to reach the desired or entered value of speed in the reference block. Upon completion of this project, it is concluded that, the design of VFD using SPWM technique is proved to be energy efficient and the most reliable way to control the speed of three-phase squirrel cage induction motor along with smooth starting and energy saving benefit . Even in the applications where high performance and high efficiency are the most concerned factors VFD is the proven system like in AC motors, like conveyor systems, blower speeds, pump speeds, machine tool speeds, & other applications that require variable speed with variable torque. By using the VFD, we can control the speed as per load requirement due to which energy consumption is reduced. It provides control over the starting and stopping of motor. Thus, for efficient speed control.

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