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Design and Implementation of VFD for Speed Control of Three- phase Induction Motor

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ABSTRACT: The main aim of the project is the speed control of a three phase induction motor with energy saving. To do so, a VFD is used for controlling the speed of a three phase induction motor with variable load attached to the motor. It certainly leads to the best performance and increases the efficiency of the induction motor .In recent years the major issue is shortage of electricity, in such cases it is important to save unwanted energy. As a result, the implementation of VFD helps in saving a large amount of energy by reducing the sudden jerks occurring at the starting of the motor. An experimental set up is designed using VFD and without VFD and the outcomes are displayed to prove the concept of energy saving.

KEYWORDS: Variable Frequency Drive, Brushless DC Motor, Electric Vehicle, Direct Torque Control

I.INTRODUCTION

A Variable Frequency Drive (VFD) or adjustable-frequency drive (AFD), Variable Voltage/Variable-frequency (VVVF) drive, Variable Speed Drive (VSD), AC drive, micro drive or inverter drive is a type of adjustable-speed drive used in electro-mechanical drive systems to control the speed and torque of AC motor by varying motor input frequency and voltage.FDs are used in applications ranging from small appliances to large compressors. About 25% of the world's electrical energy is consumed by electric motors in industrial applications. Systems using VFDs can be more efficient than those using throttling control of fluid flow, such as in systems with pumps and damper control for fans. However, the global market penetration for all applications of VFDs is relatively small. Over the last four decades, power electronics technology has reduced VFD cost and size and has improved performance through advances in semiconductor switching devices, drive topologies, simulation and control techniques and control hardware and software. VFDs are made in a number of different low- and medium-voltage AC-AC and DC-AC topologies.

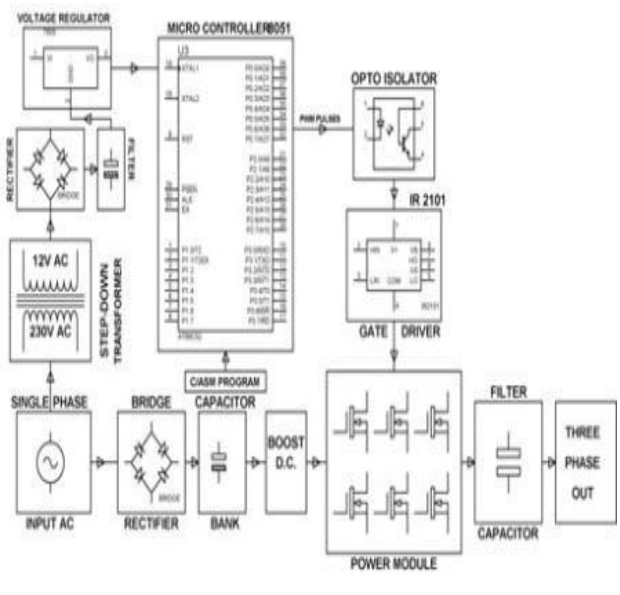

Figure 1 Block diagram of VFD

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II.SYSTEM DESCRIPTION AND OPERATION

A variable-frequency drive is a device used in a drive system consisting of the following three main sub-systems: AC motor, main drive controller assembly, and drive operator interface.

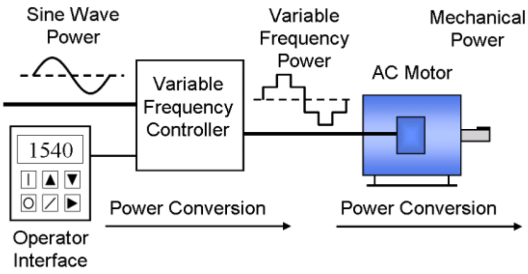

Figure 2 VFD based speed control

III.AC MOTOR

The AC electric motor used in a VFD system is usually a three-phaseinduction motor. Some types of single-phase motors or synchronous motors can be advantageous in some situations, but generally three-phase induction motors are preferred as the most economical. Motors that are designed for fixed-speed operation are often used. Elevated-voltage stresses imposed on induction motors that are supplied by VFDs require that such motors be designed for definite-purpose inverter-fed duty in accordance with such requirements as Part 31 of NEMA Standard MG-1

IV.CONTROLLER

The VFD controller is a solid-state power electronics conversion system consisting of three distinct sub-systems: a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage-source inverter (VSI) drives (see 'Generic topologies' sub-section below) are by far the most common type of drives. Most drives are AC-AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three-phase, six-pulse, full-wavediode bridge. In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase-controlledcurrent-source inverter (CSI)and load-commutated inverter (LCI) drives (see 'Generic topologies' sub-section below). The drive controller can also be configured as a phase converter having single-phase converter input and three-phase inverter output. Controller advances have exploited dramatic increases in the voltage and current ratings and switching frequency of solid-state power devices over the past six decades. Introduced in 1983, the insulated-gate bipolar transistor (IGBT) has in the past two decades come to dominate VFDs as an inverter switching device. In variable-torque applications suited for Volts-per-Hertz (V/Hz) drive control, AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, for 460 V, 60 Hz motors, this linear V/Hz relationship is 460/60 = 7.67 V/Hz. While suitable in wide-ranging applications, V/Hz control is sub-optimal in high-performance applications involving low speed or demanding, dynamic speed regulation, positioning, and reversing load requirements. Some V/Hz control drives can also operate in quadratic V/Hz mode or can even be programmed to suit special multi-point V/Hz paths. The two other drive control platforms, vector control and Direct Torque Control (DTC), adjusts the motor voltage magnitude, angle from reference, and frequency[14] so as to precisely control the motor's magnetic flux and mechanical torque. Although space vectorpulse-width modulation (SVPWM) is becoming increasingly popular,[15] sinusoidal PWM (SPWM) is the most straightforward method used to vary drives' motor voltage (or current) and frequency. With SPWM control (see Fig. 3), quasi-sinusoidal, variable-pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current). Operation of the motors above rated name plate speed (base speed) is possible, but is limited to conditions that do not require more power than the nameplate rating of the motor. This is sometimes called "field weakening" and for AC motors, means operating at less than rated V/Hz and above rated nameplate speed. Permanent magnet synchronous motors have quite limited field-weakening speed range due to the constant magnetic flux linkage. Wound-rotor synchronous motors and induction motors have much wider speed range. For example, a 100 HP, 460 V, 60 Hz, 1775 RPM (4-pole) induction motor supplied with 460 V, 75 Hz (6.134 V/Hz), would be limited to 60/75 = 80% torque at 125% speed (2218.75 RPM) = 100% power.[18] At higher speeds, the induction motor torque has to be limited further due to the lowering of the breakaway torque[a] of the motor. Thus, rated power can be typically produced only up to 130-150% of the rated nameplate speed. Wound-rotor synchronous motors can be made to run at even higher speeds. In rolling mill drives, often 200-300% of the base speed is used. The mechanical strength of the rotor limits the maximum speed of the motor.

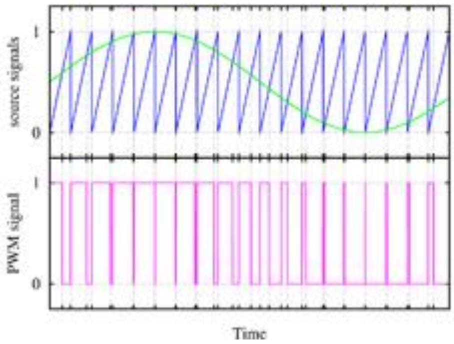

Figure 3 SPWM carrier-sine input & 2-level PWM output

An embeddedmicroprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user-inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment. The basic drive controller can be configured to selectively include such optional power components and accessories as follows:

- Connected upstream of converter -- circuit breaker or fuses, isolation contactor, EMC filter, line reactor, passive filter
- Connected to DC link -- braking chopper, braking resistor
- Connected downstream of inverter—output reactor, sine wave filter, dV/dt filter

V.OPERATOR INTERFACE

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. The VFD may also be controlled by a programmable logic controller through Modbus or another similar interface. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display or indication lights and meters to provide information about the operation of the drive. An operator interface keypad and display unit is often provided on the front of the VFD controller as shown in the photograph above. The keypad display can often be cable-connected and mounted a short distance from the VFD controller. Most are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A Serial communication port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

VI. SPEED CONTROL

There are two main ways to control the speed of a VFD; networked or hardwired. Networked involves transmitting the intended speed over a communication protocol such as Modbus, Modbus/TCP, Ethernet/IP, or via a keypad using Display Serial Interface, while hardwired involves a pure electrical means of communication. Typical means of hardwired communication are: 4-20mA, 0-10VDC, or using the internal 24VDC power supply with a potentiometer. Speed can also be controlled remotely and locally. Remote control instructs the VFD to ignore speed commands from the keypad while local control instructs the VFD to ignore external control and only abide by the keypad. On some drives the same pins are used for both 0-10VDC and 4-20mA and are selected via a jumper.

VII. PROGRAMMING A VFD

Depending on the model, a VFD's operating parameters can be programmed via: dedicated programming software, internal keypad, external keypad, or SD card. VFDs will often block out most programming changes while running. Typical parameters that need to be set include: motor nameplate information, speed reference source, on/off control source and braking control. It is also common for VFDs to provide debugging information such as fault codes and the states of the input signals.

VIII. STARTING AND SOFTWARE BEHAVIOR

Most VFDs allow auto-starting to be enabled, which will drive the output to a designated frequency after a power cycle or after a fault has been cleared or after the emergency stop signal has been restored (generally emergency stops are active low logic). One popular way to control a VFD is to enable auto-start and place L1, L2, and L3 into a contractor. Powering on the contactor thus turns on the drive and has it output to a designated speed. Depending on the sophistication of the drive multiple auto-starting behaviours can be developed e.g. the drive auto-starts on power up but does not auto-start from clearing an emergency stop until a reset has been cycled.

IX. DRIVE OPERATION

Referring to the accompanying chart, drive applications can be categorized as single-quadrant, two-quadrant, or four-quadrant; the chart's four quadrants are defined as follows

- Quadrant I - Driving or motoring, forward accelerating quadrant with positive speed and torque
- Quadrant II - Generating or braking, forward braking-decelerating quadrant with positive speed and negative torque
- Quadrant III - Driving or motoring, reverse accelerating quadrant with negative speed and torque
- Quadrant IV - Generating or braking, reverse braking-decelerating quadrant with negative speed and positive torque.

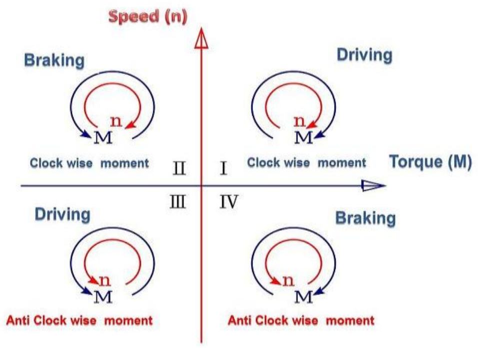

Figure 4 Four quadrant operation of drives

Most applications involve single-quadrant loads operating in quadrant I, such as in variable-torque (e.g. centrifugal pumps or fans) and certain constant-torque (e.g. extruders) loads. Certain applications involve two-quadrant loads operating in quadrant I and II where the speed is positive but the torque changes polarity as in case of a fan decelerating faster than natural mechanical losses. Some sources define two-quadrant drives as loads operating in quadrants I and III where the speed and torque is same (positive or negative) polarity in both directions. Certain high-performance applications involve four-quadrant loads (Quadrants I to IV) where the speed and torque can be in any direction such as in hoists, elevators, and hilly conveyors. Regeneration can occur only in the drive's DC link bus when inverter voltage is smaller in magnitude than the motor back-EMF and inverter voltage and back-EMF are the same polarity. In starting a motor, a VFD initially applies a low frequency and voltage, thus avoiding high inrush current associated with direct-on-line starting. After the start of the VFD, the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low-speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low-speed operation with significant torque is not usually possible without separately motorized fan ventilation.With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. A small amount of braking torque is available to help decelerate the load a little faster than it would stop if the motor were simply switched off and allowed to coast. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy. With a four-quadrant rectifier (active front-end), the VFD is able to brake the load by applying a reverse torque and injecting the energy back to the AC line.

X. BENEFITS: ENERGY SAVINGS

Figure 5 VVVF used on train

Many fixed-speed motor load applications that are supplied direct from AC line power can save energy when they are operated at variable speed by means of VFD. Such energy cost savings are especially pronounced in variable-torque centrifugal fan and pump applications, where the load's torque and power vary with the square and cube, respectively, of the speed. This change gives a large power reduction compared to fixed-speed operation for a relatively small reduction in speed. For example, at 63% speed a motor load consumes only 25% of its full-speed power. This reduction is in accordance with affinity laws that define the relationship between various centrifugal load variables. In the United States, an estimated 60-65% of electrical energy is used to supply motors, 75% of which are variable-torque fan, pump, and compressor loads. Eighteen percent of the energy used in the 40 million motors in the U.S. could be saved by efficient energy improvement technologies such as VFDs. Only about 3% of the total installed base of AC motors is provided with AC drives. However, it is estimated that drive technology is adopted in as many as 30-40% of all newly installed motors.An energy consumption breakdown of the global population of AC motor installations is as shown in the following table:

	Small	**General Purpose - Medium-Size**	**Large**
Power	10 W - 750 W	0.75 kW - 375 kW	375 kW - 10000 kW
Phase, voltage	1-ph., <240 V	3-ph., 200 V to 1 kV	3-ph., 1 kV to 20 kV
% total motor energy	9%	68%	23%
Total stock	2 billion	230 million	0.6 million

Table 1 Energy consumption breakdown of AC Motor Installations

XI. CONTROL PERFORMANCE

AC drives are used to bring about process and quality improvements in industrial and commercial applications, acceleration, flow monitoring, pressure, speed, temperature, tension, and torque. Fixed-speed loads subject the motor to a high starting torque and to current surges that are up to eight times the full-load current. AC drives instead gradually ramp the motor up to operating speed to lessen mechanical and electrical stress, reducing maintenance and repair costs, and extending the life of the motor and the driven equipment. Variable-speed drives can also run a motor in specialized patterns to further minimize mechanical and electrical stress. For example, an S-curve pattern can be applied to a conveyor application for smoother deceleration and acceleration control, which reduces the backlash that can occur when a conveyor is accelerating or decelerating. Performance factors tending to favour the use of DC drives over AC drives include such requirements as continuous operation at low speed, four-quadrant operation with regeneration, frequent acceleration and deceleration routines, and need for the motor to be protected for a hazardous operation.

XII. CONCLUSION

Hence the modern world which seeks a renewable energy source for the electricity requires the concept of power which can be achieved using the concept of VFD control for speed control of three phase induction motors.A VF solution can be implemented using variable frequency drive.

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