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Variable Frequency Drives: Topology and it's Testing Procedure

Krutik Panchal[1], Rutvik Machchhar[2], Het Patel[3], Shail Rami[4], Prof. Nirav Mehta[5], Dr. Anwarul Haque[6]

UG Student, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[1]

UG Student, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[2]

UG Student, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[3]

UG Student, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[4]

Assistant Professor, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[5]

Assistant Professor, Dept. of Power Electronics, VGEC, Chandkheda, Ahmedabad, Gujarat, India[6]

ABSTRACT: Variable Frequency Drives (VFDs) are vital components in modern industrial and commercial sectors, allowing efficient control of electric motors by adjusting frequency and voltage. This paper explores VFD applications, technologies, and testing procedures. It highlights diverse applications in manufacturing, HVAC, renewable energy, and transportation, offering benefits such as energy savings and precise motor control. The underlying technologies, including pulse-width modulation (PWM), is explained along with their advantages and limitations. Emerging technologies like Direct Torque Control (DTC) and sensor less control methods are explored for improved motor performance and energy efficiency. Testing procedures are crucial for reliable VFD operation. The paper investigates pre-installation tests, commissioning tests, and routine maintenance procedures, emphasizing electrical safety checks, insulation resistance measurements, harmonic distortion analysis, and motor performance evaluation. Advanced techniques like thermal imaging and power quality monitoring are discussed for comprehensive VFD assessment. Overall, this paper provides a comprehensive analysis of VFD applications, technologies, and testing procedures, highlighting their importance in enhancing energy efficiency and operational performance across industries. Understanding these aspects aids in optimizing VFD utilization and maintenance, resulting in increased productivity and reduced energy cost.

KEY WORDS: Working Principle, components & it's topology, Applications and Requirements, Testing-Procedure.

I.INTRODUCTION

In today's industries, control panels are frequently utilised to give appropriate control for operations of any mechanical and electrical equipment. These can also be used to safeguard electrical equipment against harm caused by flaws such overload, earth leakage, and short circuit [1], [7]. Each and every panel is made to control a particular piece of equipment using a particular set of devices and equipment arrangements [2].It is more crucial than ever for technicians and maintenance staff to keep VFD installations working properly in the quickly expanding variable frequency drive (VFD) market [3]-[5]. Through adjustments to voltage and motor power frequency, variable frequency drives may alter motor speed [8]. To maintain a good power factor and lessen excessive motor heating, Volts/Hertz ratio must be kept constant [9]. The variable frequency drive's primary function is to control different motors used in innumerable process such as mains motor,cutter motor, dressing motor, blower motor, polishing motor, coolant pump etc [6], [8]. We use the Variable Frequency Drive (VFD) panel to control the speed of various motors [10].

In order to manage the speed of electrical machinery, electronic equipmentis used in the systems at different stages with various aspects.Components of a variable frequency drive includes IGBT'S, Thyristors, Capacitor bank, Bladder circuit,

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MOV circuit, Control card, Triggering card, Fuse, Display unit, Step-down Transformer, Exhaust fan, Snubber circuit etc Fig.1.

1. **Input / Output terminals of the VFD**
The VFD input terminals are L1, L2 & L3. The output terminals to the motor are U, V & W. Connect the power supply to input terminals L1, L2 & L3 only. Never connect the power supply to the U, V, and W terminals. Incorrect wiring will lead to VFD damage or fires.

2. **Noise filter**
The VFD will generate high harmonic electromagnetic noise, so using the following noise measures is recommended. Insert a noise filter on the input side of the Keep the wiring length between the noise filter and VFD to 500 mm (19.7") or less. Use a shield cable for the VFD and motor wiring and connect the screen to the VFD's terminal. When using the control circuit wiring and power circuit wiring in parallel, separate the wiring by 300 mm (11.8") or more or pass each of the wiring through separate metal conduits. If the control circuit wiring and main circuit wiring intersect, make sure that they intersect at a right angle.

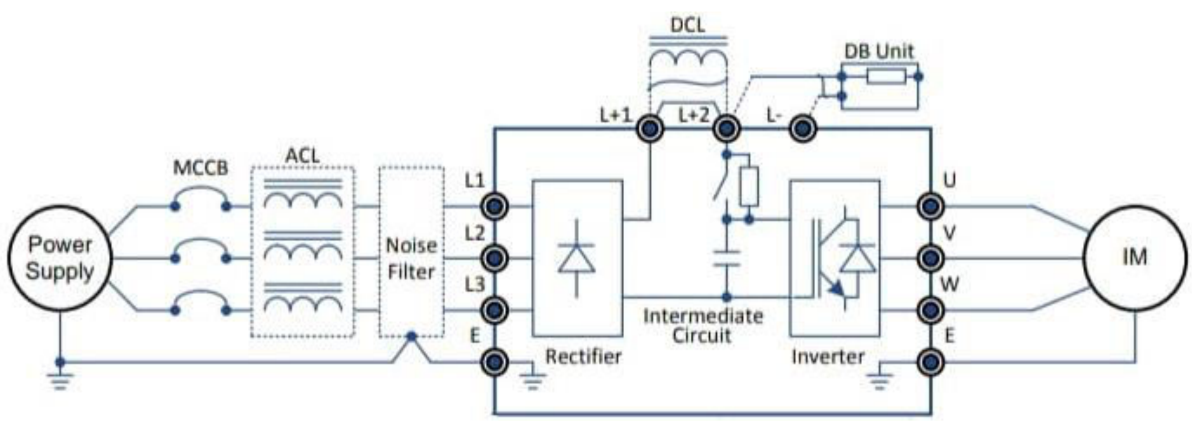

Figure 1: Block diagram of VFD

3. **Rectification section**
Rectifier circuits are used in variable frequency drives to convert AC currents to DC currents and to deliver a constant voltage output to the capacitor bank. Instead of simply using DC currents, rectifiers allow for the use of a larger variety of electric currents.

4. **Intermediate circuit**
Basically, in VFD the intermediate circuits are filter circuits basically RC filter is used in this section for storing dc voltage in the capacitor bank generated by rectifier section.

5. **Inverter section**
Direct current and voltage are changed to alternating current and voltage in this section. The IGBT switches in the inverter portion start switching once a run instruction and speed reference are supplied, resulting in the output waveform. This waveform was created using cutting-edge technology. PWM switching methods at the control card give the motor the best performance and the fewest motor losses. The programme has a variety of control modes that can be chosen depending on the performance requirements.

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6. **Grounding**
   Always ground the VFD unit according to the regulations of the current where the VFD is being used to ensure personnel safety in all circumstances, and to reduce electromagnetic emission and pickup. Make sure that grounding conductors are adequately sized as required by safety regulations. In a multiple-drive installation, connect each VFD separately to protective earth.

7. **DCL**
   DCL is an abbreviation for Direct Current Link. It refers to a design in which the VFD's rectifier component transforms incoming AC power from the mains into DC power, which is then utilised to drive the motor. The rectifier stage of a DCL VFD directly supplies DC power to the inverter portion, with no intermediary energy storage devices such as capacitors or batteries.

8. **Dynamic Braking Unit**
   A dynamic braking unit (DBU) is a device mainly used in variable frequency drive to provide a means of dissipating the kinetic energy of rotating machinery or moving loads. It is commonly employed in applications where deceleration or stopping of rotating equipment is required, such as elevators, cranes, machine tools, and locomotives, is basically protects the IGBT section in VFD. It is connected with L- and L+ terminals.

Figure 2: Basic Structure of VFD

Operation of VFD:
The three fundamental components of a VFD the rectifier unit, the DC bus, and the inverter unit is necessary to comprehend the fundamental concepts underlying in its operation Fig.2. First, the supply voltage passes via a rectifier unit, which transforms it from an AC to a DC supply. Next, the three-phase supply is supplied through a three-phase full wave diode, which converts it from an AC to a DC supply. The harmonics produced during the AC to DC conversion are filtered out in the filter section of the DC bus. The inverter part of the last component, which includes six IGBT (Insulated Gate Bipolar Transistor), converts the filtered DC power into a quasi-sinusoidal wave of AC supply that is supplied to the attached induction motor[2]. As we know that the synchronous speed of motor (rpm) is dependent upon frequency.

$$Ns = \frac{120f}{P}$$

Where:
Ns = Synchronous speed
f = Frequency of the power supply in Hz.

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P = Number of poles in the motor stator winding.

Therefore, by varying the frequency of the power supply through VFD we can control the synchronous motor speed consequently, we may conveniently change a motor's speed by adjusting the motor's applied frequency. Altering the number of poles on a motor is another option to alter its speed, although doing so would require physically altering the motor. Pulse Width Modulation Drives are used to adjust a motor's speed because they supply the output voltage and frequency required. The needed waveform is created by combining pulses of varied widths produced by a pulse width modulation (PWM) inverter [11]-14].Because the frequency may be changed more readily than the motor poles, the speed control drive is also known as a variable frequency drive (VFD).

How Drive Changes Motor Speed:

Pulse Width Modulation Drives are used to adjust a motor's speed because they supply the output voltage and frequency required. The pulse width modulation (PWM) inverter generates pulses of various widths that are combined to create the necessary waveform. Some converters employ a diode bridge to cut down on harmonics. PWM generates a current waveform that more closely resembles that of a line source, reducing unwanted heating. PWM drives have a power factor that is nearly constant and close to unity at all speeds. PWM modules may control several motors with a single drive as well.As a result, the carrier frequency is determined by how quickly a power device switch on and off. Additionally, known as switch frequency. Therefore, the resolution for PWM (Pulse Width Modulation) incorporates higher the carrier frequency. As opposed to the previous SCR-based carrier frequency, which ranges from 250 to 500 times per second, the usual carrier frequency ranges from 3 KHz to 4 KHz, or 3000 to 4000 times per second. Thus, it is evident that the resolution of the output waveform will increase with the carrier frequency. It should be noticed that the carrier frequency lowers the drive's efficiency since it causes the drive circuit to get hotter [15], [16].

II.REQUIREMENT OF VFD

The demand for effective motor control and the capability to modify motor speed and torque in accordance with particular application requirements give rise to the need for variable frequency drives (VFD).

- Speed control
- Energy efficiency
- Process optimization
- Motor protection and durability
- Noise reduction
- Reduced maintenance costs
- Flexibility
- Compatibility

III. APPLICATIONS OF VFD

VFDs have numerous applications in a variety of industries. Ithas a variety of important uses, including

- Manufacturing
- (HVAC) Heating, ventilation and Air conditioning system
- Water and waste water treatment
- Mining and Extraction
- Oil and Gas Industry
- Transportation

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IV.TESTING PROCEDURE OF VARIABLE FREQUENCY DRIVE

A Variable Frequency Drive (VFD) must undergo a number of phases during the testing process to ensure optimal functioning and operation. Here is a general VFD testing process Fig.3. The basic tools used for the testing phenomena are as under: Multi-meter, Clamp on meter, Temperature sensor gun etc.

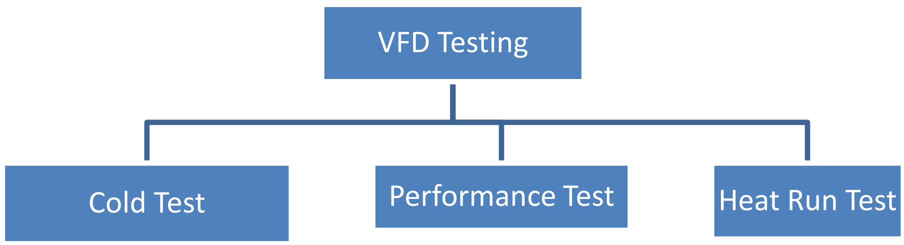

Figure 3: Testing procedure of VFD

I. Cold test

The cold test which is performed on different varieties of VFD Fig.4. In this cold test we have to perform the following steps:

1. Physical inspection

- Verify the VFD for any physical harm, loosed connections, or overheating symptoms.
- Make sure that all cables, terminals, and connections are securely fastened and in good shape.
- Check to see if the VFD complies with safety requirements and is grounded appropriately or not.
- Verify that the power supply voltage is the same as the VFD's rated voltage.
- Verify that the input power supply connectors have the correct phase and voltage levels.
- To determine the power supply's voltage and frequency, use a multi-meter or power analyser.

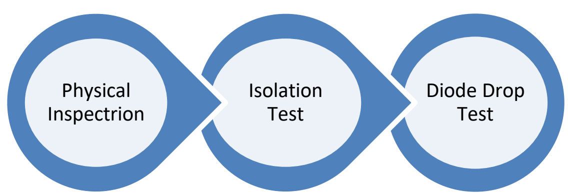

Figure 4:Procedure for cold test

2. Isolation test

Isolation test includes certain steps such as measuring resistance, continuity and diode drop

➢ **Resistance test**

A resistance test, often known as an ohmmeter test, is a method of determining the resistance of a component or circuit. It aids in the identification of broken or damaged components, the measurement of resistor resistance, the verification of appropriate continuity, and the troubleshooting of electrical systems. To do a resistance test, you will need a multi-

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meter that can measure Resistance between the input terminals of the VFD (L1, L2, L3) and the output terminals of the VFD (U, V, W) is measured in the resistance test as required by the VFD ratings.

- **Continuity test**

  A continuity test is a fundamental electrical test that determines whether or not there is a continuous channel for electric current flow in a circuit. It aids in the detection of open circuits, short circuits, and defective connections in a circuit or device. A multi-meter, which is a multifunctional electronic measuring tool, is commonly used to perform the test.Continuity test is conducted between the input's terminal of VFD (L1, L2, L3) & the ground & output terminal of VFD (U, V, W) with reference to ground.

3. ***Diode drop test***

The term "diode drop test" refers to a procedure used to measure the forward voltage drop across a diode under specified conditions. It is primarily conducted to determine the functionality and characteristics of the diode.During the diode drop test, a voltage source is connected in series with the diode, and a load resistor is placed in parallel with the diode. The voltage source is typically set to a specific value, such as 0.7 volts for a standard silicon diode. The diode is forward-biased, meaning the positive terminal of the voltage source is connected to the anode of the diode, and the negative terminal is connected to the cathode.By measuring the voltage drop across the diode using a voltmeter, the forward voltage drop of the diode can be determined. This voltage drop is a characteristic property of the diode and depends on its material composition and other factors.The Diode drop first we have to put negative probe of multi-meter on the positive terminal of VFD and positive probe is on to the output or input where we have to check the diode drop.

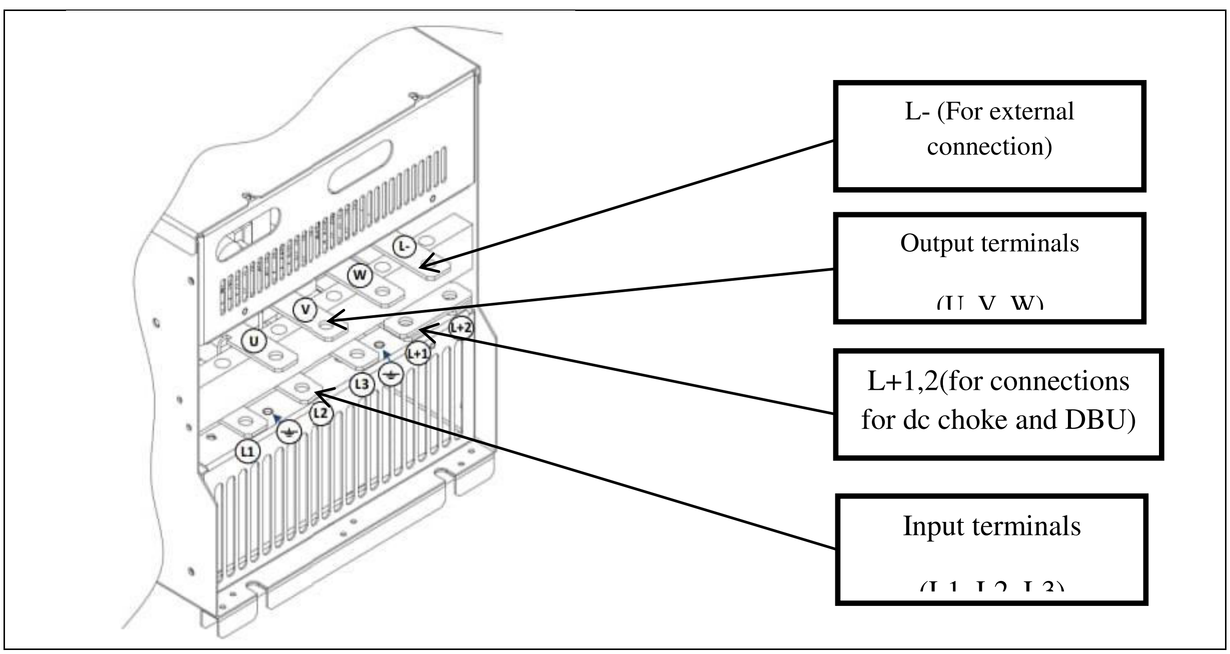

Figure 5: VFD Terminals

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II. Performance Test

The calibration test is divided into two parts:

1. *No load tests*

In the no load test the input terminal of VFD (L1, L2, L3) is connected with the input supply R, Y, B after switching on the input supply we have to feed some parameters to the VFD at first we will make the VFD in default state by going to make the default after these the DC voltage between the L+ and L- are measured with the help of multi-meter and also the upper DC voltage and lower see voltage are also measured after the we have to measure the DC voltage of digital input and digital output after measuring all these DC voltage we have to measure the AC voltage at the output terminal of VFD (U, V, W) at 10 Hz frequency and then again output AC voltage is measured at 50 Hz frequency the output AC voltage between UV, UW & VW between 80 to 84 at 10 Hz and should be between 400 TO 415 AT 50 Hz Fig.5.

2. *Full load test*

Full load test is conducted where the output terminal of the VFD is connected to the motor terminal R, Y, B and then the DC voltage between l Plus and minus is checked when the motor is started if the DC voltage between 1+ and 1– is same as that of DC voltage source in display the motor run test is done Fig.5.

III. Heat run test

The main purpose of the heat run test is to flow full current fromthe output of the VFD (U, V, W). In this test the VFD is loaded on output choke. Choke will be selected depending upon the rating of VFD like if there is 225 ampere drive so we have to connect this way to 160 kW is available there.

Other main purpose of this test is to check whether the IGBT used in VFD is working in proper condition or not yet and test take minimum 2 hour maximum 4 hours depending on the rating of the VFD.

In the heat run procedure the serial communication process is as follow while the heat run is going on Series VFD is equipped with a serial communication function using RS485 as a Standard Fig.6. It acts as a Modbus slave in the network. The unit can be controlled with a host computer (master) using this function.

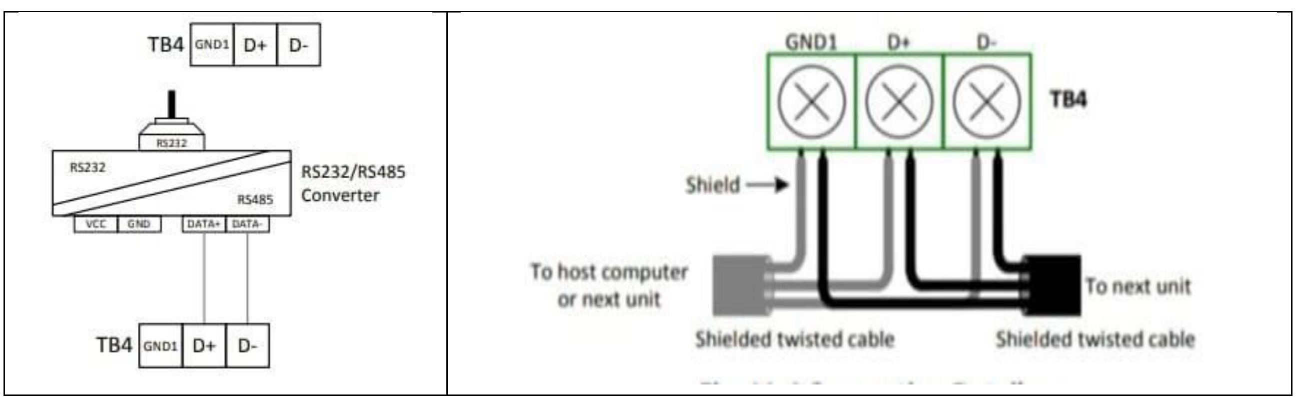

Figure 6: External communication cable RS485 cable wiring

Many parameters should be maintained while performing the heat run test such as Default load, Local set frequency, stop mode, Base voltage, Motor frequency, DTC gain, Current limit, Ramp up, Station number, etc.These parameters are described in the below table:

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Sr. no.	Name of Parameter	Description
1	Local set frequency	Sets all parameters to default values according to ratings of VFD.
2	Motor frequency	Sets maximum output voltage available at Base Frequency. This is percentage of Rated Motor Voltage.
3	DTC gain	DTC gain" refers to the control parameter used in Direct Torque Control (DTC) algorithms. DTC is an advanced control technique employed in VFDs to achieve precise control of motor torque and speed.
4	Current limit	Current limit is a percentage of motor rated current for normal running Condition. The default value is 105% for no overload duty, 125% for normal duty and 155% for heavy duty mode. Set to 300% to Disable this feature in any VFD.
5	Stop mode	The "Stop Mode" parameter in a Variable Frequency Drive (VFD) refers to the setting that determines how the motor stops or comes to a halt when the VFD command or control signal indicates a stop condition.

Basic Faults Occurs while testing VFD

There are some faults are observed when the testing of the VFD is running. The faults are tabledas shown in the below table:

Sr. No.	Fault
1.	U-phase Overcurrent Fault / V-phase Overcurrent Fault / W-phase Overcurrent Fault / Overcurrent Fault
2.	Adjustable Overcurrent Fault
3.	Undercurrent Fault
4.	Drive Overload Fault
5.	Motor Over Load Fault
6.	Charging Fault
7.	Over speed Fault
8.	EEPROM Fault
9.	Communication Loss
10.	Panel Temperature Fault

V. REPORTING AND ACTION

Keep a record of the test results, including the insulation resistance values that were measured, the testing tools that were used, and any observations or anomalies.

Consult the VFD manufacturer or a licenced electrician if insulation problems are discovered so we can identify the root of the problem and take the necessary corrective steps. To guarantee continuous insulation integrity, we should repeat the insulation test on a regular basis as part of normal maintenance or as advised by the manufacturer.

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VI. CONCLUSION AND FUTURE WORK

VFDs, which offer effective and precise control over motor speed, torque, and acceleration, have emerged as crucial components in a variety of energy sectors. VFDs are used in a variety of fields, including manufacturing, HVAC, renewable energy, transportation, and more. Energy savings, better process control, lower maintenance costs, and increased system performance are all made possible by VFDs. Itprovides advantages like energy effectiveness, adaptability, motor safety, and environmental sustainability. Visual inspection, power supply verification, control signal testing, motor operation testing, protection and safety testing, performance measurement, and documentation are all part of the testing process for VFDs. A crucial step in confirming the quality of the electrical insulation inside the VFD is isolation testing.To further enhance their capabilities and meet new problems, VFDs can be the subject of different future studies and developments. Future research should focus on advanced control, strategies for integrating renewable energy systems, harmonic mitigation and power quality, and compatibility with emerging motor technologies.

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