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VARIABLE VOLTAGE VARIABLE FREQUENCY (VVVF) DRIVE BASED EOT CRANES

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ABSTRACT

Conventional DOL (Direct On Line) starter operated EOT (Electrically operated Overhead Travelling) Crane requires high starting current, power and torque. All these drawbacks are overcome by introduction of Variable Voltage Variable Frequency (VVVF) Drives in EOT Cranes. This paper details about VVVF Drive advantages, principle and the vector control techniques were explained. The Normal and Micro speeds are achieved by four motors with two gear boxes, each motor is having independent VVVF Drive, the drive has advantage of continuous speed control and speed reversals achieved by changing phase sequence through inverter, also precise positioning, energy saving and increased motor life. Motor related protections in drive were furnished. A Study has been carried out on existing EOT cranes at SDSC-SHAR and major EOT crane details are tabulated. This paper focuses on the application of variable voltage variable frequency (VVVF) drive in EOT crane applications.

INTRODUCTION

In SDSC SHAR, EOT cranes are being used for lifting and assembly of various stages of launch vehicles. EOT crane is an Electrically operated Overhead Travelling crane which is used for three operations as follows:

- Hoist travel (up-down movement).
- Long travel (to move along the length of the building).
- Cross travel (to move from one side to other side of the building).

Each travel has minimum two different speeds termed as Normal speed and Micro/Creep speed. If Normal speed is 100% and Micro speed will be 10% of normal speed. Configuration of EOT Crane is having four motors with two gear boxes. Each motor is having independent VVVF Drive, with selection of Pendant control switches., four motors configuration or two motors configuration can be operated, with four motors the speed will be 3m/Min and with two motors the speed will be 1.5m/Min. Induction motors are generally used for application of EOT cranes. Fig.1 shows an EOT Crane of capacity 450/60Ton in SDSC SHAR.

Fig.1: 450/60T x 37.5m Double Girder EOT Crane at SHAR

Earlier the motors which are used to operate these cranes were started by direct online starters (DOL starters). But they have got few limitations.

- Using DOL starters we cannot vary the speed of the motor.
- When we go for higher ratings of motor, the size of the starter also increases which in turn increases the panel space.
- The size of the contactors and cables used will also increase as they carry more current.

To overcome such limitations, VVVF drives are being used to control the operation of the induction motors in turn that of cranes.

VVVF DRIVE

A Variable Voltage Variable Frequency (VVVF) Drive, variable-frequency drive (VFD) or adjustable-frequency drive (AFD), 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 AC motor speed and torque by varying motor input frequency and voltage. The electrical energy supplied, at times for certain applications, need to be modified and controlled in a specific manner before giving it to the motor to get the desired performance from the motor. Drive is nothing but the product that takes the available electrical power, converts it into required form and then gives it to the motor and in addition to that provides required protection to the motor and the system. The electric product that gives desired power to AC motor is called AC drive. The AC drive that takes fixed voltage, fixed frequency AC supply and converts it into a variable frequency and variable voltage AC supply is called VVVF Drive as shown in Fig.2.

Fig.2: Basic VVVF Drive

VVVF Drives are used in applications ranging from small appliances to large industrial applications. About 25% of the world's electrical energy is consumed by electric motors in industrial applications. Systems using VVVF Drives can be more efficient than those using throttling control of fluid flow, such as in systems with pumps or fans. VVVF Drives are made in a number of different low and medium voltage AC--DC and DC--AC topologies.

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WORKING OF VVVF DRIVE

In VVVF drive, we need to obtain variable frequency variable voltage from a fixed frequency fixed voltage AC supply. For this first the available AC supply is converted into a fixed magnitude DC and then it is reconverted into AC of desired voltage and frequency. Any Variable Voltage Variable Frequency Drive incorporates following three stages for controlling a three phase induction motor shown in fig.3, having Fixed AC input Voltage & Frequency and producing Variable AC Voltage & Frequency at output.

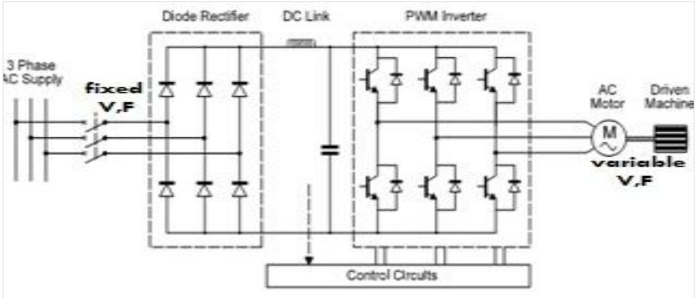

Fig.3: VVVF Drive

Rectifier stage:

In order to obtain the variable frequency, variable voltage from a fixed frequency, fixed voltage AC supply. For this first the available AC supply is converted into a fixed magnitude DC using rectifier circuits.

Inverter stage:

An inverter refers to a power electronic device that converts power in DC form to AC form at the required frequency and voltage output. Presently most of the voltage source inverters (VSI) use pulse width modulation (PWM) because the current and voltage waveform at output in this scheme is approximately a sine wave. These Power Electronic switches, switch the DC voltage at high speed, producing a series of short-width pulses of constant amplitude.

Control stage (Pulse Width Modulation):

Its function is to control output voltage i.e. voltage vector of inverter being fed to motor and maintain a constant ratio of voltage to frequency (V/HzAs the output we get is a quasi-square output from the inverter which is AC but not sinusoidal and this output will add harmonics in the supply line. These harmonic currents produce extra current in the motor and other connected devices and affect them which are not at all desirable. Hence we go for PWM (pulse width modulation) voltage output waveform. Pulse width modulation (PWM) is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts.

VVVF Drive Features:

- Speed control with & without encoder.
- Free blocks like Logic gates, timers, counters, etc., available for making the different types of logics.
- Communication capability.
- Different operating stations for control, i.e., VVVF drive Panel, Terminal and through communication like Profibus (process field bus), etc.

Merits of VVVF Drives:

- Smooth operation and Energy conservation.
- Precise speed and torque control.
- Increased reliability and availability.

- High power factor.
- Extended Machine Life and Less Maintenance.

Disadvantages of VVVF Drives:

- High Initial cost.
- Harmonics generation
- Expertise is required for programming during commissioning and for rectifying faults.

Applications of VVVF Drives:

1. They are mostly used in industries for large induction motor (dealing with variable load) whose power rating ranges from few kW to few MW.
2. VVVF Drives are used in traction systems. In India it is being used by Delhi Metro Rail Corporation.
3. They are also used in modern lifts, escalators and pumping systems.
4. Nowadays they are being also used in energy efficient refrigerators, AC's and Outside-air Economizers.

INDUCTION MOTOR SPEED CONTROL

The most widely used AC motor is the 3 phase squirrel cage induction motor because its robustness, small size and weight, negligible maintenance, low cost etc. In SDSC SHAR, the three phase squirrel cage Induction Motors are used for total EOT Crane operations. For a specific purpose of operations specific rated motors with drives are used and each motor has one encoder to obtain the data from the motor shown in Fig.4. The EOT Crane has following specifications

- For Main Hoist(M-H) 450T, Four motors of 3phase, 415V, 50Hz, 200kW, 380A, 1000rpm rating and each motor has separate Drive for operation and control and a Gear system. It has main speed of 100% and micro speed of 10%.
- For Auxiliary Hoist(A-H) 60T, One motor of 3phase, 415V, 50Hz, 90kW, 178A, 1465rpm rating and it has two Drives for operation and control and a Gear system, one of the drive is working and other is in standby mode. It has main speed of 100% and micro speed of 10%.
- For Long Travel(L-T), Four motors of 3phase, 415V, 50Hz, 15kW, 32A, 1000rpm rating and each motor has rating of 2.2kW, 4.99A with Drive for operation and control and a Gear system, two motors are in working state and other two are in standby mode.
- For Cross Travel(C-T), Two motors of 3phase, 415V, 50Hz, 11kW, 25A, 1000rpm rating and each motor has rating of 3.7kW, 8.25A with Drive for operation and control and a Gear system, one motor is in working state and other is in standby mode.
- The flux magnitude and angle is achieved by imposing a slip frequency derived from rotor dynamic equations with monitored rotor speed using external sensor such as Encoder.

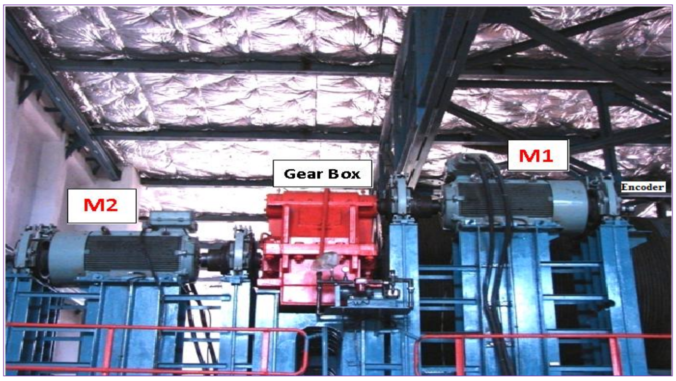

Fig.4: Crane motors with Gear & Encoders at SHAR

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The speed of the rotor of an induction motor depends on synchronous speed (speed of the rotating magnetic field produced by current in motor winding) and slip (the difference in synchronous speed and the actual rotor speed). The synchronous speed is determined by the frequency of supply and the no. of poles for which the motor is wound.

$$Ns= (120\times f)/P$$

where f is frequency in Hz and P is the no. of poles for which the motor is wound.

It should be noted that the rotor always rotates at a speed little lower than the synchronous speed, generally less by around 4%. The slip is always expressed in percentage and is given by

$$\%slip= (Ns-Nr)/Ns\times 100$$

The percentage of slip value depends upon the load on the motor but one can assume it to be around 4-5% at full load. Now, to electrically vary the speed of the motor two methods are available.

1. Vary the frequency of supply given to the motor.
2. Change the number of poles for which the motor is wound.

The first method will provide step-less variation whereas the latter will provide variation is steps. Also through second method, generally 2 to 4 speeds are only feasible. Hence the motor speed is varied electrically by varying the frequency as the synchronous speed and hence the rotor speed depends on frequency.

VECTOR CONTROL TECHNIQUE

Along with variable frequency AC inverters, induction motors are used in many adjustable speed applications which do not require fast dynamic response. The concept of vector control has opened up a new possibility that induction motors can be controlled to achieve dynamic performance as good as that of DC or brushless DC motors. The v/f control principle adjust constant volt-per –Hertz ratio of the stator voltage by feed foreword control. It serves to maintain magnetic flux in the machine at desired level. The vector control is also known as decoupling, orthogonal, or trans-vector control because of the separately excited DC motor like performance. Vector control (or field oriented control) offers more precise control of AC motors compared to scalar control. They are therefore used in high performance drives where oscillations in the air gap flux linkages are intolerable. The vector control techniques are as follows:

Direct Field Oriented Control (DFOC):

The Hall sensors are mounted in the air gap to measure the machine flux and therefore to obtain the flux magnitude and flux angle for field orientation. Field orientation achieved by direct measurement of the flux is termed as Direct Flux Orientation Control.

Indirect Field Oriented Control (IFOC):

Achievement of flux orientation by imposing the slip frequency derived from the rotor dynamic equations with monitored rotor angle using encoder. This alternative, consisting of forcing field orientation in machine is known as Indirect Field Orientation Control. This indirect method is highly dependent on machine parameters.

Sensorless Field Oriented Control (SFOC):

The method which does not require any sensor for estimation of flux magnitude and position is Sensor-less Field Oriented Control. In SFOC technique, due to the negligible stator voltage drop the air gap flux will remain constant. This condition is satisfied near rated motor frequency. As the frequency is reduced, IR drop is a larger portion of the terminal voltage. This problem is resolved by implementing a terminal V/f characteristic in which the voltage is boosted above its frequency-proportional value at low frequencies in order to compensate for the stator IR drop.

Closed loop vector control:

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Nowadays, there are a number of applications that inherently require tight closed-loop control, with a speed regulation better than 0.01% and a dynamic response better than 50 rad/sec. This dynamic response is about 10 times better than that provided by standard V/f drives. This high performance vector control AC drive system is essentially a cascaded closed-loop type with speed and torque control loops.

PROTECTION OF EOT CRANE

The most adaptable and the most widely used type of power driven crane for indoor/outdoor service is undoubtedly the three motion EOT crane. The three motions of such crane are the hoisting motion, long Travel and the cross Travel motion. Each of the motions is provided by electric motors. In short in all industries, wherein heavy loads are to be handled, EOT crane find its application. Fig.5. shows EOT Crane system with control & protections at SHAR.

Fig.5: 450/60T EOT Crane at SHAR

The EOT crane has following safety & protective schemes,

- ❖ Fire Detection and Alarm (FDA) system for protection and intimation against occurrence of fire or short circuit faults.
- ❖ Rotary limit sensor to move the hooks of hoists at specified ranges over top and bottom of the areas.
- ❖ Gravity limit sensor, incase of failure of rotary sensor it actuates and protects the crane.
- ❖ For cable layout, Chain Drag System is used to move the cables with crane without any disturbance or damages.
- ❖ Lubrication pump provided for regular lubrication of system over protection of system from rope cutouts, noise, sparks, etc..
- ❖ Still there are many protections for EOT Crane to operate safely by means of satisfying and fulfill the requirements.

EOT Crane Specifications:
In SDSC SHAR, the Double girder EOT Crane has following specifications,

1. Two Bridges for Crane travel through the building from one end to other. It has at least four wheels.
2. Two Trolleys with auxiliary hoist, at least four Wheels of Trolley to move along length of building.
3. Hoisting machinery set for lifting and holding.
4. It has a Bottom Block with auxiliary hoist.
5. Two Lifting hooks of 450T & 60T.
6. Two Rails on the gantry girder for crane movement.
7. Two Rails on the bridge for Trolley movement.
8. A Control room with panel boards, breakers, changeover switches, isolators, reactors, protective relaying systems, display devices, dynamic braking resistors(DBR's) and all controls and operatives of Crane system.

9. The crane can be operated either from the master controller or from a remote transmitter receiver unit.

Pendant:

Cranes and other overhead lifting devices typically use a pendant for inputting hoist, trolley, crane and any other controls into the system. It is a device used to operate and control this EOT Crane. Pendant Stations or Pendant Controls are a series of simple switches that control much larger electrical loads through various means. Most often, pendant stations are used to control large industrial cranes and hoists. They are also able to be used as the remote control for industrial machines to operate the cranes at different speeds and different operations.

PROBLEMS IN EXISTING SYSTEM

The problems in previous systems are,

- The Previous System has no Protection under Free-Fall and Breakdown of crane due to any failure such as Breakdown in Various Gear Over-Speed due to failure in various stages of Speed Reduction.
- The System is Operator Dependent & There is a Time-delay in the System.
- Caliper Brakes needs actuator signal from the Operator which is time delayed.
- The Failure due to any of the above reasons, will lead to Free-Fall of any metal from such height due to its own weight. Thus it results in disaster; Evenly Everything will turn into Ashes.

PROPOSED SYSYEM

The Proposed new system has,

❖ VVVF Drive with Multi-function programmable controller system.
❖ Inductive Proximity Sensor (Encoder) for feedback/control.
❖ Vector control for precise speed and torque variations.
❖ Operation from Remote location by Pendant.
❖ Smooth operation, huge energy savings and increased motor life.

CONCLUSION

A VVVF Drive based crane control system has been developed and its performance was demonstrated in one of the EOT Cranes in SDSC SHAR. The system consists of Variable Voltage Variable Frequency AC Drive for MH, AH, LT and CT operations and a Programmable Controller to realize the crane functions. The system is also having facility to operate from remote location by Pendant. Huge energy savings and the associated reduction in environmental emissions are possible through the massive application of VVVF drives in a wide variety of loads in the different sectors of the economy. Especially in EOT crane use of VVVF drives significantly improve the performance at creep/micro speeds, precise speed control can be achieved and same can be varied later without much mechanical modifications and by simply changing the parameters in drive unit.

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