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Speed Control of Induction Motor Using DTC-SVM & Monitoring Using PLC with Motor Protection

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Abstract: **This paper examines the speed control of induction motors and monitoring of its parameters along with overload and overcurrent protection; proposing a single unit to execute the mentioned functions. The speed control of induction motors is necessary to reach the best efficiency of high speed electric drives besides its robustness and cheapness. Monitoring presents the result of complicated analysis to the user in a simple way by providing detailed diagnostic information for overload and overcurrent protection. Speed control is done using Direct Torque Control Space Vector Modulation (DTC-SVM) and monitoring using Programmable Logic Control (PLC). This paper provides a vectorial representation of speed control algorithm using SVM and a high accuracy monitoring control system by PLC incorporated with overload and overcurrent protection. This proposed system increases the versatility of existing conventional systems.**

Index Terms— **DTC, SVM, Voltage vectors, PLC, H-Bridge.**

I. INTRODUCTION

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With the continuous developments in the industrial sector, AC motors have now become a pre-requisite for most applications. On such AC motor is the induction motor which is widely used nowadays due to is numerous advantages like simple and extremely rugged construction, low cost, high reliability, minimum maintenance costs, and high efficiency. But the main disadvantage that promoted the use of DC motors, despite their demerits in comparison with induction motors in the olden days was that, the speed control of induction motors had to be done at the cost of efficiency. Also, its speed decreases with the increase in load. Induction motors are commonly known as constant speed motors and hence its speed control is in fact inevitably significant.

The equation governing the speed of an induction motor is given by,

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

Where, 'Ns' is the synchronous speed of the machine
'f' is the supply frequency and,
'P' is the number of poles.

The methods to control speed of induction motors may be mainly grouped as follows:

1. Control from stator side:
(a)By changing the applied voltage
(b)By changing the applied frequency
(c)By changing the number of stator poles
2. Control from rotor side:

(a)Rotor rheostat control
(b)By injecting an emf in the rotor circuit
(c)By operating two motors in cascade

But these conventional methods of speed control are less efficient and quite difficult. The factors that must be taken into account for choice of new methods of speed control are:

1. Affordable cost
2. Improvement in efficiency
3. Ease of implementation
4. Adaptability to incorporate complex algorithms

The advancement in the power electronics field increased the availability of thyristors, power transistors, IGBTs and GTOs which in turn gave better chances of inventing effective speed drives for induction motors. The speed control algorithm presented in this paper is Direct Torque Control Space Vector Modulation (DTC-SVM) which will be discussed in detail later on.

It is not just necessary to employ speed regulation in motors but also make sure that the system operates efficiently at all times. This can be achieved by real time monitoring of the parameters of the induction motor like speed, temperature, motor current, motor voltage etc. The monitoring system aids in the prevention of problems and keeps track of the operations that are performed by the system.

Several applications utilize sequential industrial processes that depend on use of relays, stepping drum, timers and controls. But considerable difficulties are experienced in reprogramming necessitated, due to change in the nature of production. Often the whole system has to be redesigned as required. To overcome these problems, Programmable Logic Control (PLC) System was introduced.

II. DIRECT TORQUE CONTROL (DTC)

The torque control of induction motor was presented by I. Takahashi and T. Noguchi as *Direct Torque Control* andproved to be a promising method of speed control offering simple structure and good dynamic behavior. As discussed earlier, the speed of the induction motor can be maintained at a constant value as long as the magnitude and frequency of the voltage driving the induction motor is modified accordingly. This modification should be a function of the error between the actual motor speed and the desired motor speed.

A.Overview of the System

From fig.1 it can be seen that the main elements of a DTC system are as follows:

(a)Flux Estimator

The stator flux varies with the change in applied stator voltage with time. Therefore, the stator flux maybe controlled if a proper choice of the stator voltage is made. The estimated stator flux is decreased or increased to be made equal to the desired or reference stator flux. The flux error which is the difference between the estimated and desired stator flux is fed to the hysteresis comparator which in turn produces the flux error status.

(b)Torque Estimator

The instantaneous value of torque is a sinusoidal function of the angle between the stator and rotor fluxes given by the relation,

$$T \propto \emptyset . I_2 . Cos\theta$$

Where, ‘T’ is the torque of the motor

$'\emptyset'$ is the stator flux

$'I_2'$ is the rotor current at standstill and,

$'\theta'$is the angle between stator and rotor fluxes.

This angle will change to a great extent, if the stator flux changes quickly, causing a large variation in the output torque. Thus, the voltage vectors of the inverter must be properly chosen in order to obtain a constant speed so that the desired performance is achieved. Similar to the flux control, torque is controlled within the tolerance band.

(c)Voltage Source Inverter

A voltage source inverter (VSI) converts the DC to AC through power electronic devices such as an IGBT. In order to get the desired stator flux, the technique of space vector modulation is applied. It is this inverter that carries out the command from the switching algorithm to vary the stator voltage as required in order to control the speed

The value of stator flux and torque calculated are compared with the desired values in the hysteresis comparators. This output is then fed to a switching table to select an appropriate voltage vector at the inverter. The switching table determines the voltage vector to be applied, which depends on the required changes in stator flux and torque. The selected voltage vector will be applied to the induction motor to run the machine at the required speed.

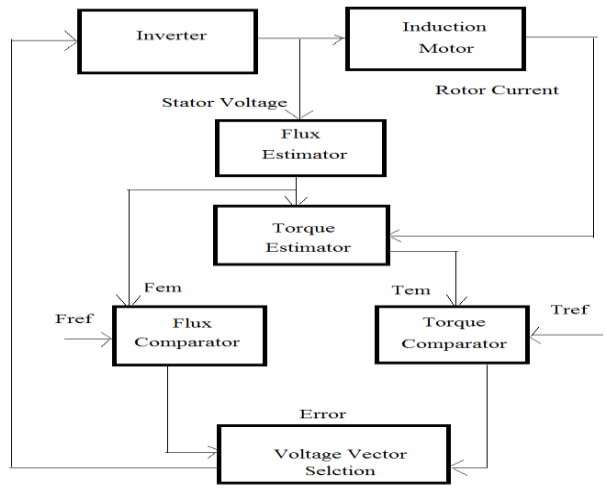

Fig.1. Block Diagram of DTC Method

B.Main Features of DTC

- Direct control of flux and torque.
- Indirect control of stator currents and voltages.
- Approximately sinusoidal stator fluxes and stator currents.
- High dynamic performance even at standstill.

C.Why DTC Alone Is Not Sufficient

- In the basic form of DTC, only one vector is applied for a particular sampling period. This may cause the stator flux and torque to go beyond their tolerance limits which introduces high torque ripples and distortions in the stator flux and current. This is the main disadvantage of the conventional DTC method.
- Another algorithm that can be used in conjunction with the basic DTC system is the Space Vector Modulation, which eliminates the common disadvantages of the conventional DTC method.

III. DIRECT TORQUE CONTROL SPACE VECTOR MODULATION (DTC-SVM)

The alteration of the voltage waveforms to maintain the motor at constant speed is done by employing SVM algorithm in a Voltage Source Inverter (VSI) but the extent of the alteration is determined by the DTC algorithm. In the voltage source inverter, conversion of DC power to AC power is performed in the switched mode. The actual power flow in each motor phase is controlled by the duty cycle of the respective switches. To obtain a suitable duty cycle for each switch, the technique of Pulse Width Modulation (PWM) is used.

Table I. Switching Table in SVM

Space Vectors		Switching State	ON-State Swit
Zero Vectors	V0	[0 0]	S4 S2
	V3	[1 1]	S1 S3
Active Vectors	V1	[0 1]	S4 S3
	V2	[1 0]	S1 S2

The voltage source inverter here is an H-bridge inverter that consists of several power electronic switches. The switching power devices can be constructed using power BJTs, GTOs, IGBTs, etc.The choice of switching devices is based on the desired operating power level, required switching frequency, and acceptable inverter power losses. The ON and OFF states of the lower switches are complementary to the upper ones. Two switches on the same leg cannot be closed or opened at the same time. The switch combinations can be represented as binary codes that correspond to the equivalent switches and the eight inverter states can transformed into eight corresponding space vectors.

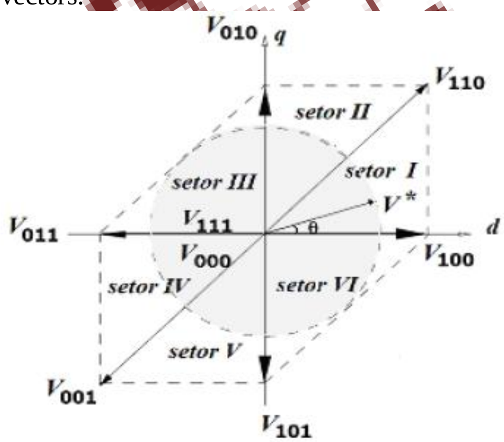

Fig.3. Reference Voltage Vector Synthesis

Thus, SVM defines a space vector table that represents the states (ON or OFF) of the individual switches. In a three phase system, eight voltage vectors maybe defined, out of which two are null vectors and six are active vectors. In a single phase system there would be only four voltage vectorsas shown in table 1. The space vector table or the switching table is shown in table 1. The reference voltage vector is realized by the sequential switching of active and zero vectors.

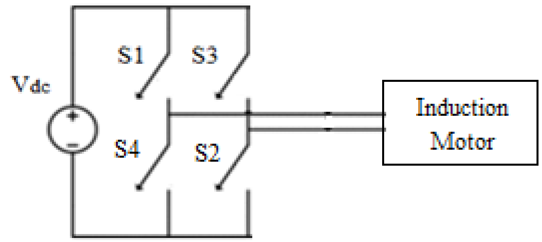

Fig.2. Schematic Diagram of Voltage Source Inverter

The stator voltage vectors are selected from the switching table to minimize the error signal that comes from the DTC section. Once the voltage vectors are selected, the switches of the inverter are switched ON and OFF with the required duty cycle such that the average outputvoltage of the inverter is obtained by using a weighted average of the three closest switching states. This way, a sine wave of the right magnitude and frequency to bring the motor to its normal speed is made by a series of DC pulses. The first pulse has a very short ON time, followed by longer ON period until the widest pulse appears at the centre of the sine wave.

Comparison between SPWM and SVPWM

- SVPWM has lesser Total Harmonic Distortion (THD) compared to SPWM.
- SVPWM offers better DC bus utilization compared to SPWM (by about 15.4%).
- SVPWM gives enhanced fundamental output with better quality.

IV. PLC MONITORING SYSTEM

Programmable Logic Controllers (PLCs) have become an integral part of the industrial environment. AProgrammable Logic Controller(PLC) is a compact computer based electronic system that uses digital or analog input/output modules to control machines, processes, and other control modules. A PLC is able to receive (input) and transmit (output) various types of electrical and electronic signals and use them to control and monitor practically any kind of mechanical and electrical systems.

A.Overview of the System

Fig.4 shows the block diagram of a PLC based monitoring system.

(a)Data Acquisition System (DAS)

The data acquisition system takes information signals from sensor outputs. All the motor parameters like temperature, speed, voltage and current are physical quantities which are in the form of analog signals. To be read by the processor, these analog signals are changed to its digital value which maybe further processed.

(b)Input and Output Modules

The input and output modules are used to interface the input devices (sensors) with the microprocessor and the microprocessor with the output devices. The input and output information is transferred from the sensors to the processor and from the processor to the output devices of the PLC system. These also provide isolation to the PLC from any fluctuations in the signal voltages or current.

(c)*Processor*

The processor is the heart of the PLC system. It can be a 1 bit processor for logical operations or a word processor to involve texts, numerical etc. It accepts input data from the Data Acquisition System. Then, executes the user program on the data and sends the appropriate output commands to the control devices as required.

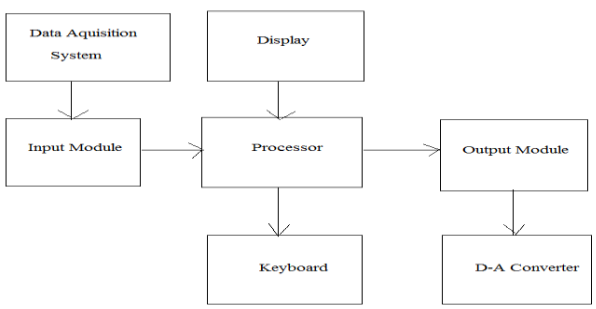

Fig.4. Block Diagram of PLC Monitoring System

(d)Keyboard and Display

Keyboard and display allows the user to set values, to read current values of processed variables and issue commands.

(e)Digital to Analog Converter

In applications where a PLC system is to drive an analog circuit, it becomes necessary to convert the processed digital values into continuous signals. This function is carried outhere PLC takes input instructions in the form of ladder diagram or computer software instructions. Ladder logic is a programming language that represents a program by a graphical diagram and is widely used to program PLCs, where sequential control of a process or manufacturing operation is required. The name is based on the observation that programs in this language resemble ladders, with two vertical rails and a series of horizontal rungs between them. A "rung" in the ladder represents a rule. When implemented in PLC, the rules execute sequentially by software in a continuous loop.

The following are the major advantages of using PLCs over conventional monitoring systems:

- Flexibility
- Ease of troubleshooting
- Space efficiency
- Low cost
- Testing
- Visual operation

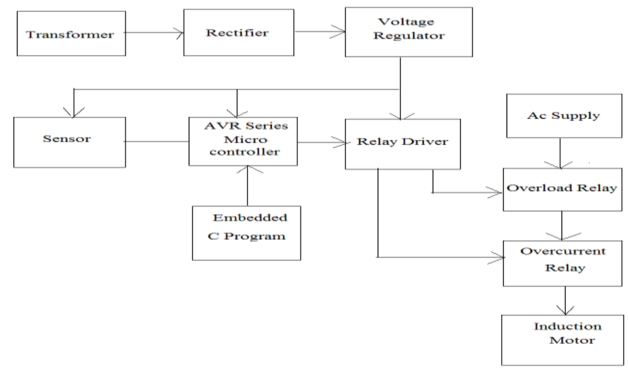

Fig.5. Block Diagram of Motor Protection System

V. MOTOR PROTECTION

Motor protection safeguards the motor, the supply system and personnel from various operating conditions of the driven load, the supply system or the motor itself. Motor protection categories in this paper include:

- Overcurrent Protection
- Overload Protection

Overcurrent protection interrupts the electrical circuit to the motor upon excessive current demand on the supply system from either short circuits or ground faults. It is required to protect the motor branch circuit conductors and control equipment from these large currents.

Overload protection is installed in the motor circuit to protect the motor from damage from mechanical overload conditions when it is operating. The effect of an overload is an excessive rise in temperature in the motor windings due to current higher than full load current. The larger the overload, the more quickly the temperature rises to a point that damages the insulation and lubrication of the motor.

The block diagram of the motor protection system is as shown in fig.5. After the single phase AC supply is steeped down using a transformer, it is converted into DC using a rectifier and prevented from any variations using a voltage regulator. A current sensor keeps track of the motor current, which when goes beyond the limit, makes the microcontroller to trigger off the relay driver. At the time of overload or overcurrent, the respective relay disconnects the motor from supply and thus protection is ensured. After the situation is taken care of, the motor regains its state of operation.

CONCLUSION

In this paper, a most convenient industrial control scheme for voltage source inverter-fed induction motor drives was presented with reference to the conventional DTC method. The DTC-SVM has a simple structure and it can be analyzed and implemented in a simple way. This is a very important feature of DTC-SVM. This method would provide operation in a wide power range.

Industrial system designers of PLCs continue to push for higher performance and functionality relying on its promising features. PLC monitoring would ensure a highly accurate monitoring system. A simplified operational block diagram of the PLC based monitoring system was discussed, pointing out the advantages as well.

Also, the need for motor protection and the method to overcome the conditions of downtimes was examined. Thus this paper proposes a reliable, all in one motor conditioning system using microcontrollers that is capable of replacing complicated circuits by a single, efficient unit.

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