Development of Microprocessor Based Industrial Starter and Slip Regulator of an Induction Motor

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Received: 15 May 2000; accepted: 7 September 2000

In this investigation, an attempt has been made to develop a smart and intelligent digital controller to regulate the slip of an induction motor at a desired speed. The overall control and regulation have been provided by controlling the average value of the applied voltage. Besides microprocessor, the hardware consists of three pairs of anti-parallel thyristors connected to three-phase supply lines. An 8085A CPU based microprocessor has been used for sequential, symmetrical and accurate firing and for trigger pulse generation at proper instant. To overcome the loss of synchronism, to eliminate hardware portion appreciably and for generation of a set of six trigger pulses, intelligence of microprocessor has been utilised to calculate the effective trigger angle and deliver trigger pulse in such a way that after delivering a set of six trigger pulses, it finds the particular reference phase which has been used for synchronisation of control circuit with power circuit. For smooth starting, the software has been so developed that the same controller provides reduced voltage starting. The software-based starter, referred to as industrial starter, eliminates the conventional starter. A set of oscillograms giving the speed response of motor has been presented, based on which the developed controller can be recommended over conventional starter.

Introduction

Though it is regarded that, the induction motor is a constant speed drive, its slip varies from no-load to full-load. For example a 3-phase, 415 V, 5 A (line), 4 polar machine suffers from the speed fluctuation from 1475 rpm to 1380 rpm when operated from no-load to full-load. Hence, in a wire manufacturing industry and some other industries, where constant speed drive is required, such a speed variation of induction motor leads to problems.

The speed of the induction motor may be controlled within a narrow range by controlling the supply voltage or supply frequency. To control the speed of an induction motor, inverter may be used. Literature survey shows that, for controlling speed by applied voltage control, a number of modern speed controllers have already been recommended, where electronic or solid-state controllers are the main streams to fabricate modern controllers. However, the reliability of these controllers is poor and suffers from complex circuit. The present trend is to use digital controllers for the purpose of speed control of industrial drives.

For smooth starting, by limiting starting current within recommended range, and to adjust acceleration time (that is starting time), a number of electromagnetic starters are commonly used in industrial practice. Electronic starter came into being in the later part of the present century. Use of electromagnetic or electronic starter requires additional space for the hardware and additional cost of installation, and further needs periodical maintenance and repair.

To reduce the conventional hardware and electronic circuitry, and to enhance reliability and flexibility in control, use of microprocessor along with interfacing circuitry in electrical engineering is the present state-of-art in industrial setups. In the present investigation, an attempt has been made to develop a digital controller along with a software package for starting and slip control of an induction motor utilising an 8085A CPU based microprocessor. Due attention has been given to develop intelligent and powerful software to minimise (or replace part of) conventional hardware, and to elicit quicker response in operation and to further enhance control accuracy and reliability.
Modeling and Control Strategy

Figure 1 represents the schematic block diagram of the theoretical model of the microprocessor-based developed scheme for starting and regulating the slip of an induction motor. In the present model, a microprocessor has been employed as the workhouse for starting and control of slip of the induction motor through utilisation of software. A separately excited dc generator has been coupled to the motor to simulate the load variation.

The signal receiving circuitry (SR) receives voltage signal from power line and converts it into microprocessor-compatible voltage signal. The microprocessor, upon receipt of the signal, synchronises itself with power line, and delivers trigger pulses at correct instants through triggering circuitry (TC) to trigger the controlling elements.

The feedback element (FE) provides voltage signal corresponding to the instantaneous speed of a motor. The microprocessor receives instantaneous dynamic signal through the data acquisition system (DAS).

The control strategy has been so developed that, on receipt of the signal from the signal receiver, microprocessor synchronises itself with power line and generates a set of six trigger pulses for three sets of anti-parallel thyristors. In this way, the thyristors conduct at a particular trigger angle and the controlled voltage is impressed on the stator of the induction motor. For smooth starting, the microprocessor initially generates trigger pulses at a maximum possible trigger angle and then continues the process for a number of cycles to stabilise the motor. Then, the microprocessor successively decreases the trigger angle, and following the same cyclic operation gradually increases the impressed voltage and hence the speed. At every instant, the microprocessor receives feedback on the instantaneous speed signal through DAS and compares it with the previously stored set value. When the instantaneous speed matches the set speed, the microprocessor fixes the trigger angle and continues with the same speed cyclic operation.

The slip may fluctuate with fluctuation of load, supply voltage and/or the supply frequency. Since the speed is proportional to the supply voltage, it is possible to recover the speed by adjusting the supply voltage corresponding to the speed fluctuation. On the basis of information through FE based on data accessed through DAS, the microprocessor computes required trigger angle in steps and delivers the trigger pulses through triggering circuitry.

Hardware Organisation and System Functioning

Based on the proposed scheme, a prototype model has been developed using a microprocessor and the interfacing circuitry. The simplified block diagram has been presented in Figure 2. For easy and quick installation and maintenance, the developed hardware portion has been sectionalised into four parts, viz., i) Power circuit module, ii) Signal receiving circuitry, iii) Control module, and iv) Feedback module.
In power circuit module (Figure 3), the three-phase supply is connected to the induction motor through three sets of anti-parallel thyristors, with trigger pulses for thyristors being generated and controlled by the microprocessor.

In signal receiving circuitry (Figure 4), a potential transformer (PT) is connected between R-phase (reference phase) and neutral for receiving voltage signal. The PT scales down the load bus voltage. The sinusoidal voltage signal is fed to an isolated ZCD (zero crossing detector), which produces a train of rectangular pulses during each positive half-cycle from rising to falling edge of ac waveform and supplies the same to the microprocessor.

In control circuit module, the microprocessor, used as speed compensator and trigger angle controller, senses through an I/O port the zero crossing instant at the rising edge (i.e., starting instant of positive half-cycle) of the
From supply bus

<table>
<thead>
<tr>
<th>B</th>
<th>Y</th>
<th>R</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To motor
+ 5 V

To microprocessor

**Figure 4 — Signal receiving circuitry**

```plaintext
From Microprocessor

100

1

2

3

MCT-2E

6

5

4

SL 100

10 K

47

1N 4007

To Gate

To Cathode

+ 5 V

10 K

470
```

**Figure 5 — Triggering circuitry.**

reference voltage waveform obtained from ZCD, and emits a set of six trigger pulses through the I/O port sequentially to trigger the six thyristors at a particular trigger angle. In a closed-loop system, the microprocessor, on receiving the feedback signal through the I/O port, decides the further course of action.

As the microprocessor output is utilised to control applied voltage of induction motor connected to the power line, it is necessary to isolate power circuit from the logic circuit. Therefore, an opto-isolator circuit based on MCT-2E with an amplifier circuitry was used, which electrically isolates microprocessor and switches from the transistor. The details of the circuit diagram for triggering circuitry are shown in Figure 5. When the output is high, it causes current to flow through LED of MCT-2E, energising the light sensing diode and the voltage connected externally with pin-5 of MCT-2E is impressed on the 10K resistor through the transistor SL-100 and the same voltage is impressed on the gate of the thyristor and the thyristor conducts.

In feedback circuitry module, the conventional tachogenerator (TG) connected to the motor shaft is used.
as a feedback element which generates the instantaneous analog voltage signal, proportional to the speed of the motor. The A/D converter based on IC-8009 was used as DAS, which converts the analog voltage signal into digital form for supply to the microprocessor.

System Software
The software has been developed in such a way that, the microprocessor initialising the stack pointer and assigning port PA as input port and ports PB and PC as output ports, preserves starting delay number $\delta(s)$ [Annexure - I], upper limit $\delta(ul)$, lower limit $\delta(ll)$ of delay number, delay number corresponding to 120 degree $\delta(120)$, delay number corresponding to 60 degree $\delta(60)$ and the set value corresponding to the set speed in memory locations $M$ to $(M+6)$, and calls subroutine ‘Sync’ for synchronisation of ac signal with software and to detect the starting instant of R-phase voltage. Then,
Table 1 - Triggering sequence and conduction period (in degree) of the thyristors

<table>
<thead>
<tr>
<th>Triggering angle ((\alpha), degrees)</th>
<th>Phase</th>
<th>Firing sequence</th>
<th>Firing instant, degrees</th>
<th>Conduction period with respect to R-phase, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>TH1</td>
<td>(\alpha)</td>
<td>(\alpha) + 120</td>
<td>to 180</td>
</tr>
<tr>
<td>B</td>
<td>TH6</td>
<td>(\alpha) + 60</td>
<td>(\alpha) + 180</td>
<td>to 360</td>
</tr>
<tr>
<td>Y</td>
<td>TH3</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 240</td>
<td>to 60</td>
</tr>
<tr>
<td>R</td>
<td>TH2</td>
<td>(\alpha) + 60</td>
<td>(\alpha) + 300</td>
<td>to 120</td>
</tr>
<tr>
<td>B</td>
<td>TH5</td>
<td>(\alpha) + 60</td>
<td>(\alpha) + 300</td>
<td>to 120</td>
</tr>
<tr>
<td>Y</td>
<td>TH4</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 120 + 120</td>
<td>to 180</td>
</tr>
<tr>
<td>R</td>
<td>TH1</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 120 + 120</td>
<td>to 360</td>
</tr>
<tr>
<td>B</td>
<td>TH6</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 120 + 180</td>
<td>to 300</td>
</tr>
<tr>
<td>Y</td>
<td>TH4</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 120 + 300</td>
<td>to 360</td>
</tr>
<tr>
<td>R</td>
<td>TH2</td>
<td>(\alpha) + 120</td>
<td>(\alpha) + 120 + 300</td>
<td>to 360</td>
</tr>
</tbody>
</table>

it starts the operation of digital starter using the subroutine 'Cycle'. The digital starter, being completely based on software, replaces the conventional starters generally used in individual drives. The flow charts (Figures 6 and 7) for soft starter have been so developed that, the microprocessor compares the starting delay number \(\delta(s)\) with \(\delta(120)\). As \(\delta(s) > \delta(120)\), the microprocessor computes operational delay number \(\delta(op) = \delta(s) - \delta(120)\), calls subroutine 'Redge' to detect the zero crossing instant of rising edge of the R-phase voltage, makes a delay corresponding to the delay number \(\delta(op)\) and releases a set of six trigger pulses at a time interval of 60 degree to trigger the thyristors in the sequence TH5, TH4, TH1, TH6, TH3 and TH2, respectively, during both positive and negative half cycles, and continues the cyclic operation for N-cycles to stabilise the speed of the machine.

When \(\delta(s) < \delta(120)\), the microprocessor compares \(\delta(s)\) with \(\delta(60)\). As \(\delta(s) > \delta(60)\), the microprocessor computes \(\delta(op) = \delta(s) - \delta(60)\) to release the trigger pulses after a time delay corresponding to \(\delta(op)\) from the instant of detecting the rising edge at the zero crossing instant of R-phase voltage. In this case, the trigger pulses are released to trigger the thyristors in the sequence TH4, TH1, TH6, TH3, TH2 and TH5, respectively, each at a time interval of 60 degree. The procedure is followed for N-cyclic operation.

If \(\delta(s) < \delta(60)\), then the microprocessor detects the rising edge of the zero crossing of the R-phase, calls the delay subroutine corresponding to \(\delta(s)\), and generates and outputs the trigger pulses at an interval of 60 degree to trigger the thyristors in the sequence TH1, TH6, TH3, TH2, TH5 and TH4 for N-cycles to stabilise speed of the motor. The firing sequence for different range of trigger angle has been given in Table 1.

Then, it receives instantaneous signal from TG, properly digitised through A/D converter, and compares it with the set value of the speed stored previously in some memory location. If the instantaneous speed is less than the set value, microprocessor reduces the delay number \(\delta(s)\) by one and calls the subroutine again to enhance the instantaneous speed. In this way, the machine attains the set speed through digital starter.

With the change of supply voltage or load, the speed of the machine may vary. If the instantaneous speed exceeds the set value, the microprocessor calls the subroutine 'Cycle' to calculate the effective trigger angle \(\delta(op)\) and outputs a set of six trigger pulses at an interval of 60 degree and repeats the cyclic operation for N-cycle.

Again, after receiving the instantaneous tacho signal through ADC, microprocessor compares it with the set speed and performs the similar cyclic operation of trig-
triggering if the instantaneous speed becomes equal to the set speed. But, if the instantaneous speed is different from the set speed, the microprocessor increases or decreases $\delta(s)$ according to whether $E(\text{in})$ is greater than or less than $E(\text{set})$, respectively, compares the new $\delta(s)$ with the upper and lower limiting value $\delta(ul)$ and $\delta(ll)$, as the case may be, collects either $\delta(ul)$ or $\delta(ll)$ according to the situation, and preserves it for the continuation of the triggering phenomena and hence the rotation of the motor.

Through the procedure described above the microprocessor, maintaining the motor speed at set value under the supply or load fluctuation. It also controls the triggering angle at the upper and lower limiting value under the rigorous fluctuation of supply voltage or load.
Starting time = 5 S

Direct starting

Starting time = 23 S

Digital starting

X - axis: 1 V / Div.

Figure 8 — Speed response oscillogram during starting.

Trigger angle = 138°
Delay number = 8 A H

Trigger angle = 96°
Delay number = 60 H

Trigger angle = 90°
Delay number = 5 A H

Trigger angle = 74°
Delay number = 4 A H

Figure 9 — Stator current waveform at different trigger angle.
It may be mentioned that the upper limit of trigger angle is necessary to overcome the inertia, and the lower limit is necessary to avoid misfiring occurring because of local short circuit due to transients during two consecutive triggering in highly inductive circuit.

**Limitation**

The developed scheme is unique and advantageous in many respects with a limitation of the zone of triggering operation due to high inductance of stator coils.

As the applied voltage is not free from harmonics, the controller could not be applied for heavy duty operation of a high powered motor.

**Experiment**

On the basis of the proposed scheme, a prototype model was developed and implemented in the laboratory for starting and to regulate the slip of a three phase squirrel cage induction motor [Annexure 2].
The speed response curves for direct starting and digital starting using software-based starter, referred to as industrial starter, are presented in Figure 8. The starting time as well as steps of gradual speed increment can be altered by altering only the number of cyclic operations (N) with every operating delay number \( \delta(s) \) in digital starting.

The oscillogram of the stator current for different delay number (trigger angle) is presented in Figure 9, from which the upper limit of trigger angle has been determined. In these oscillograms, points 'A' and 'B' represent the triggering instants at positive and negative half cycles, respectively.

In closed-loop control, the initial operating Delay number is stored in a particular memory location for the motor running at a speed with 33 per cent slip of the motor, which is considered as the set speed. The oscillograms showing the speed response characteristics corresponding to sudden change of load was recorded and presented in Figure 10. In these speed response curves, the points 'S' and 'R' refer to speed fluctuation and speed recovery instants, respectively.

**Conclusion**

The present investigation highlights the replacement of conventional electromagnetic starter or electronic circuitry by microprocessor-based digital controller with a software package for starting and slip regulation, thereby eliminating complicated hardware by simple ones, providing sequential and accurate control, and enhancing reliability of the system.

Development of intelligent software for calculating effective trigger angle and delivering a set of six trigger pulses sequentially without loss of synchronism may be claimed as one of the important development in the area of three phase voltage control.

Development of software-based starter utilizing the same controller referred to as industrial starter, eliminates hardware-based electromagnetic or electronic starter, reducing additional cost of installation. The starting time may be adjusted as per requirement to suit the machine accelerating time.

**References**


**Annexure 1**

It is possible to compute delay time corresponding to the triggering angle in terms of a group of instruction, a pre-set number of times. The number of repetition of a basic time delay has been referred to in this paper as “delay number” and is denoted by \( \delta \).

**Annexure 2**

The induction motor under test had the following specifications on its name plate:

- 3-phase, Star connected, Squirrel Cage,
- 415V, 5A (line)
- 1425 rev / min for 50 Hz supply