Effect of Variation in Sampling Time in Speed Regulation of a Synchronous Motor Drive that is Self-Controlled

C. O. Azubuike\textsuperscript{1*}, K. C. Aladum\textsuperscript{1}, C. E. Kizito\textsuperscript{1}

\textsuperscript{1}Department of Mechanical Engineering, Federal University of Technology, Owerri, Nigeria

\textsuperscript{*}Corresponding Author’s Email: azubuikechuik@gmail.com

ARTICLE HISTORY:

Received: 4\textsuperscript{th} May, 2023
Revised: 22\textsuperscript{nd} May, 2023
Accepted: 28\textsuperscript{th} May, 2023
Published: 5\textsuperscript{th} Jun, 2023

KEYWORDS:

Drive, Motor, Regulation, Sampling, Speed, Synchronous

ABSTRACT: This paper presents an analysis in the variation of sampling time of a synchronous motor drive that is self-controlled. The benefits of the synchronous motors are replacing classical induction and direct current (DC) motor drives. It is anticipated that they may be more significant in the imminent future. Because permanent magnet synchronous motors drives are preferred to perform vital tasks in most applications such as in the automotive industry and aerospace, the system reliability is usually an important consideration. Owing to these reasons, the sampling time of the drives have to be taken into consideration regarding how strong the impact of variation in sampling time can affect the drive performance. The drive is fed with three phase power and is utilized in speed regulation. Proportional integral (PI) regulatory approach is studied and is implemented in a PI-based speed regulatory system is presented. Simulation results of the motor current speed, and torque signals from the synchronous machine dynamics of the field flux are given. It was shown that an increase in sampling time results in the elimination of high frequency signal components.

1. INTRODUCTION

Currently, many processes and applications depend on variable speed AC drives centered around the permanent magnet synchronous motors. The benefits of the synchronous motors are replacing classical induction and direct current (DC) motor drives. It is anticipated that they may be more significant in the imminent future. Because permanent magnet synchronous motors drives are preferred to perform vital tasks in most applications such as in the automotive industry and aerospace, the system reliability is usually an important consideration. Owing to these reasons, the sampling time of the drives have to be taken into consideration regarding how strong the impact of variation in sampling time can affect the drive performance (Ukoima, 2019).

Magnetically salient rotor synchronous motors like the permanent-magnet assisted synchronous reluctance motors, interior permanent-magnet synchronous motors and the synchronous reluctance motors are frequently used for industrial applications, electric cars and heavy-duty working machines. It was noted that in such scenarios, the highest operating frequencies and highest speeds have extremely high values (e.g., 10 000 r/min equivalent to the frequency of 1000 Hz for a machine that is ten-pole). Because of losses, there is a limitation in the converter rate of switching the motor. As a result, the proportion between the maximum fundamental frequency and that of the frequency of switching may be very low. This in turn affects the sampling rate. Normally it is either equivalent to the switching rate or twice the rate of switching.

In synchronous motor drives, a current regulator is usually aimed in the continuous time domain. It is then digitalized for implementation in the digital domain. Although this is a well-known method used in many applications, the
proportion between the maximum operating rate and that of the frequency of sampling ought to be more than 13 in surface permanent-magnet synchronous motors (Kim et al., 2010). The interior permanent-magnet synchronous motors and the synchronous reluctance motors are acknowledged to be further demanding from this viewpoint (Peters et al., 2011; Altomare et al., 2015; Ukoima et al., 2020). Similarly, the sampling frequency limits the closed-loop control bandwidth. Upper top speeds, top vibrant performance, and superior toughness at a certain sampling rate can be attained by discrete time domain controller design.

Advances in semiconductor variable frequency sources (converters and inverters) have allowed the use of synchronous motor drives in variable speed applications. These applications include: induced and forced draft fans, servo drives, high power and high-speed compressors, blowers, main line traction, etc. This study analyses the effect of variation in sampling time on these sources.

2. SYNCHRONOUS MOTOR DRIVE MODEL COMPONENTS

The synchronous self-controlled motor drive model consists of 6 key blocks in Figure 1. The WFSM motor, the 3-Φ inverter, the 3-Φ rectifier, vector control block, and the speed and rectifier regulator (Bose, 2002; Kruase, 1986).

2.1 Speed Controller

Shown below in Figure 2 is the speed regulator and is based on a PI controller. The set points for the flux applied to the vector regulator block and the torque forms the outputs of this regulator.

2.2 Rectifier Controller

The controller for the rectifier is centered on a proportional integral controller of the direct current bus voltage. The direct constituent of the alternating line current forms the yield of this controller. The reactive part of the alternating line current is fixed at 0 in order to function at a power factor that is 1 shown in Figure 3.

2.3 Vector Controller

Figure 4 shows the component of the vector controller.

Estimation of the motor stator flux is performed by the estimator block. The flux PI controller performs the flux regulation. The dq current constituents is translated into abc phase variables by the dq2abc block. The normal operation mode and magnetization switching is done by the magnetization control unit.

2.4 Average - Value Inverter and Rectifier

Figure 5 shows the internal structure of the inverter and rectifier.
3. METHODOLOGY

This simulation model is based on a synchronous motor drive that is self-controlled with active front-end rectifier. The synchronous motor built-in-drive is served with a pulse width modulation inverter (voltage-source). The speed control loop which is also built in the drive uses a proportional integral controller to generate the current and flux orientations for the control block (vector). The vector regulator in the drive performs computation of the three motor line reference currents which corresponds to the rotation reference. These currents are then supplied to the motor utilizing a 3-Φ current regulator. Also, computation of the flux estimate and comparison with the desired value is performed by the vector controller. The information produced is used to generate the field excitation voltage (Figure 6).

Figure 6: Self-Controlled Synchronous Motor Drive Model.

3.1 Model Parameters of the Drive

i. SP: This represents the speed or torque set point. At \( t = 2 \) seconds the speed SP is set to 250 rpm and remains at this value till \( t = 5 \) seconds when it is set to 0. Time \( = [2 5] \). Amplitude \( = [250 0] \) (Tables 1-3).

ii. \( T_m \) or \( W_m \): \( T_m \) represents the input load torque (mechanical) \( W_m \) represents the motor speed. At \( t = 4 \) seconds the input is \(-792\)Nm and remains at this value till \( t = 6 \) seconds when it is set to 792Nm. Time \( = [4 6] \). Amplitude \( = [-792 792] \).

iii. A, B, C: This is the 3-Φ terminals of the motor drive.

iv. Motor: This represents the vector for motor measurements.

v. Conv: This is the 3-Φ vector for converters measurement.

vi. Ctrl: This is the vector for controller measurements.

Table 1: Motor Parameter

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nominal Power</td>
<td>159 KVA</td>
</tr>
<tr>
<td>2</td>
<td>Rated Phase Voltage</td>
<td>560 V</td>
</tr>
<tr>
<td>3</td>
<td>Nominal Frequency</td>
<td>60Hz</td>
</tr>
<tr>
<td>4</td>
<td>Stator Parameters</td>
<td>Rs (2.01mW) Ls (0.5289mH)</td>
</tr>
<tr>
<td>5</td>
<td>Field Parameters</td>
<td>Rf(0.5084mW), Lf(0.529mH)</td>
</tr>
</tbody>
</table>

Table 2: Three Phase Source Parameters.

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Phase Voltage</td>
<td>560V</td>
</tr>
<tr>
<td>2</td>
<td>Connection</td>
<td>Star</td>
</tr>
<tr>
<td>3</td>
<td>Frequency</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>Base Voltage</td>
<td>25000</td>
</tr>
<tr>
<td>5</td>
<td>Source Resistance</td>
<td>0.02Ω</td>
</tr>
<tr>
<td>6</td>
<td>Source Inductance</td>
<td>0.05mH</td>
</tr>
</tbody>
</table>

Table 3: Mechanical Input Parameters.

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>s</td>
<td>4s</td>
</tr>
<tr>
<td>2</td>
<td>Initial Value</td>
<td>-792W</td>
</tr>
<tr>
<td>3</td>
<td>Final Value</td>
<td>792W</td>
</tr>
<tr>
<td>4</td>
<td>Stop Time</td>
<td>6s</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSIONS

Case 1: Step time 2µs, controller time 150µs, vector controller 20µs.

Figure 7: Plot of Current Against Time.

Figure 8: Plot of Speed Against Time.
In case 1, there is discretization of the power system with a time step of 2µs. The speed regulator makes use of a sample with 150µs. The control of the vector makes use of a sample time of 20µs. When the simulation is started, it can be observed that at time $t = 2s$, the speed set point is 250rpm. It can also be observed that the acceleration ramp is been followed by the speed precisely as seen in Figure 8 and that the frequency and amplitude of the stator current gradually rises as shown in Figure 7. At $t = 4.0s$, a nominal valued resistive torque is used as input to the shaft of the motor. This torque be likely to slow down the motor (Matlab, 2019). This provides an explanation to the slight undershoot in the speed of the motor. This can be seen in Figure 8 when the motor reaches 250rpm. At $t = 5.0s$, the set point of the speed is altered to 0rpm. As a result of this, a lower electric torque is produced in the motor. Following the deceleration ramp, the speed decreases down to 0rpm. At $t = 6.0s$, the set point of the speed extends to 0 rpm. At $t = 6s$, the load torque sign that is applied to the shaft of the motor is inverted and changes from $-792$ N.m to 792 N.m as shown in Figure 9. Correspondingly, a minor overshoot in the speed of the motor and the electric torque stabilization at its nominal value can be observed. As shown in Figure 10, the bus voltage (direct current), however, is controlled for the whole period of simulation.

**Figure 9: Plot of Torque Against Time.**

**Figure 10: Plot of Voltage Against Time.**

**Figure 11: Plot of Current Against Time.**

**Figure 12: Plot of Speed Against Time.**

**Figure 13: Plot of Torque Against Time.**

**Figure 14: Plot of Voltage Against Time.**
In case 2, a time step of 50µs is used. This was achieved from keying in the workspace, 'Ts = 50e-6' and also by altering the speed regulator time of sampling to 150e-6, the DC bus controller sampling time to 50e-6 and the vector controller sampling time to 50e-6. When the simulation is started, it can be observed that the acceleration ramp and that the stator current amplitude is been precisely followed by the speed. There is a steady increase in frequency too. These are shown in Figures 11-14. At t = 4.0s, a resistive torque of the nominal value is applied to the motor shaft. Again, at t = 5.0s, the set point of the speed is altered to 0 rpm. As a result of this, a lower electric torque is produced in the motor. Following the deceleration ramp, the speed decreases down to 0rpm. At t = 6.0s, the speed set point culminates to 0 rpm. At t = 6s, there is a reversal in the sign of the load torque that is applied to the shaft of the motor. Similar to case 1, the overshoot is minor in the speed of the motor. Stability of the nominal valued electric torque can be observed also. The direct current bus voltage is controlled for the whole period of simulation as in case 1.

It can be observed that the results of case 1 and 2 are similar. The difference is that the higher frequency signal components in case 1 are eliminated in case 2.

5. CONCLUSION

In conclusion, we have studied the effects of variation in sampling time in the performance of a synchronous motor drive that is self-controlled. We began with a traditional description of the model components of a synchronous motor drive that is self-controlled. We have shown the similarities that exist in the sampling time variation. In case 1, there is discretization of the power system with a time step of 2µs. The speed regulator makes use of a sample with 150us. The control of the vector makes use of a sample time of 20µs. When the simulation is started, it can be observed that at time t = 2s, the speed set point is 250rpm. It can also be observed that the acceleration ramp is been followed by the frequency and amplitude of the stator current gradually rises. In case 2, a time step of 50us is used. It can be observed that the acceleration ramp and that the stator current amplitude is been precisely followed by the speed. There is a steady increase in frequency too. The difference is the elimination of high frequency signal components. The results of this study can be used to further improve on the design of the regulatory system and control of the synchronous machine drives that is self-controlled.

REFERENCES


