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Contents

[Simulation 1 (PWM Inverter) 3](#_Toc119204174)

[Question 1 3](#_Toc119204175)

[Question 2 5](#_Toc119204176)

[Question 3 7](#_Toc119204177)

[Question 4 9](#_Toc119204178)

[Simulation 2 (v/f control) 12](#_Toc119204179)

[Question 1 12](#_Toc119204180)

[Question 2 14](#_Toc119204181)

[Question 3 16](#_Toc119204182)

[Experiment 1 17](#_Toc119204183)

[Question 1 18](#_Toc119204184)

[Experiment 2-A 20](#_Toc119204185)

[Question 2 20](#_Toc119204186)

[Experiment 2-B 21](#_Toc119204187)

[Question 3 21](#_Toc119204188)

# Simulation 1 (PWM Inverter)

## Question 1

**Run the program with a carrier frequency of 500 Hz (it is rather low due to the educational set-up that we have in the lab., otherwise it should be of the order of 20 kHzs or so) and reference waveform amplitude 0.8 and 50Hz frequency. Set the resistance to be 600 ohms. Observe how to generate the control signals for each switch and the relationship between the switching signal and line voltage *Vao*, *Vab* from the scope. You can magnify the waveforms and try to understand the operating principles of the three-phase sine PWM inverter.**

**Use the Matlab file ‘PWMplot.m’ to understand the working principles of PWM scheme. Use the Matlab file ‘inverterplot.m’ to observe the line voltages *Vao* and *Vab*. Use the ‘powergui’ block in the Matlab simulation model to check FFT of the current for phase-a.**

Chart

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From the PWM Modulation plot, it can be observe that the triangular waveform has a period of 0.002s, while the sinusoidal waveform has a period of 0.2s. The period of the triangular waveform is due to the 500Hz frequency of the carrier waveform set in the simulation and the period of the sinusoidal waveform is due to the 50Hz frequency of the reference waveform set in the simulation.

Whenever the reference waveform is higher than the carrier waveform, the 2 switching signal plots for TP1 and TP4 shows that TP1 is turned on while TP4 is turned off . At the same time, will be positive. The opposite happens when the reference waveform is lower than the carrier waveform and TP1 turns off while TP4 turns on. At the same time, will be negative.

As is of a similar shape to but will be phase shifted as it is a 3 phase power and this explains the waveform for as . Thus, is positive when both and is positive, it is 0 when either or is positive and the other is negative, and it is negative when both and is negative.

The figure belows shows the FFT results.Chart

Description automatically generated with medium confidence

According to the FFT results, THD=92.07%. From the FFT Plot, harmonics can be observed at every odd multiple of the carrier frequency (500Hz, 1500Hz, 2500Hz, 3500Hz). The waveform also contains side bands centered around multiples of the carrier frequency and the frequencies are given by the following equation:

Where  **is the carrier frequency, f is the reference frequency and (K+k) is an odd integer.**

## Question 2

**Only change the frequency in the block of carrier waveform to 2 kHz and observe the difference in the switching signals, and the line voltage *Vao,* and *Vab* in the scope and comment accordingly in the report.**

**Use the Matlab file ‘PWMplot.m’ to understand the working principles of PWM modulation. Use the Matlab file ‘inverterplot.m’ to observe the phase and line voltages *Vao* and *Vab*. Use the ‘powergui’ block in the Matlab simulation model to check FFT of the current for phase-*a*.**

A picture containing chart

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Similar phenomenon in the previous simulation can be observed here. As the triangular waveform frequency is increased to 2kHz from 500 Hz in the previous simulation, in the switching frequency of the switches increases and thus, (and ) switches between negative and positive more frequently as well and the duty cycle increases. Hence, the frequency within each positive and negative pulses of also increases and its duty cycle increases as well.

Box and whisker chart

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The FFT shows the THD to be 91.57% which is lower than that of the previous simulation, which indicates a higher efficiency due to the higher frequency. From the plot, it can be observed that the frequencies of the harmonics are increased as the carrier frequency is increased.

## Question 3

**Now place inductors (e.g. 1.6 H) in series with the resistive load for each phase. Then observe and discuss the voltage and current waveforms across the resistance.**

**Use the ‘powergui’ block in the Matlab simulation model to check FFT of the current signal in phase-a. Use the Matlab file ‘inverterplot.m’ to observe the voltage and current across the resistance.**

A picture containing chart

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Description automatically generatedChart

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There are no noticeable changes to the PWM and voltages plots compared to the previous simulation as nothing was change except for the introduction ofinductors**.Graphical user interface, chart, histogram

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According to the FFT, the THD is 6.09% which is much lower than that of the previous simulation, indicating a higher efficiency. From the FFT plot, it can be observed that the harmonics is greatly reduced as the higher frequencies are being filtered out by the inductors.

## Question 4

**Change the amplitude of the reference signals for phase *a*, *b*, *c* to 0.5, and the frequency of the reference signals to 100 Hz. Observe and explain the voltage and current waveforms across the load.**

**Use the ‘powergui’ block in the Matlab simulation model to check FFT of the current signal in phase-a. Use the Matlab file ‘inverterplot.m’ to observe the voltage and current across the resistance.**

4. Chart, line chart

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A picture containing chart

Description automatically generatedChart, bar chart, histogram

Description automatically generatedChart

Description automatically generatedChart, line chart

Description automatically generated

The frequency of the sinusoidal reference waveform increases to 100Hz and hence, the frequency of the switches increases. Amplitudes of and remains unchanged. However frequency and duty cycle of increases due to the increase in reference waveform frequency. Likewise, has an increase in frequency of its pulses.

Graphical user interface, application

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From the FFT, there is a larger THD value of 8.81% compared to the previous simulation. Due to the increase in reference frequency (f), the carrier ratio is reduced and thus, the frequency of the harmonics is reduced as observed from the FFT plot, therefore, they are less easily filtered out by the inductance, leading to a higher THD.

# Simulation 2 (v/f control)

## Question 1

**Set the speed reference to the values of 300, 900, 1500 rpm respectively. For each setting, record the data of the frequency and amplitude of the motor input voltage, the value of the field flux and the speed at steady state. Plot the graph of the ‘*v* – *f*’ plot and explain how *v/f* control scheme works.**

The figures below show the results for 300rpm:

Graphical user interface, chart

Description automatically generated

Graphical user interface, chart, line chart

Description automatically generated

The results for the various rpm are recorded in the table below

|  |  |  |
| --- | --- | --- |
| Speed (RPM) | Voltage (Vrms) | Frequency (Hz) |
| 300 | 58.6653 | 10.8711 |
| 900 | 154.1192 | 31.9623 |
| 1200 | 202.8073 | 42.6344 |
| 1500 | 230.0347 | 53.7466 |
| 1800 | 230.0347 | 63.3333 |
| 2000 | 230.0347 | 66.505 |

Next the v-f graph is plotted in the figure below.

The equation for the voltage is as follows:

Where is the supply frequency, is the flux, N is the number of turns and is the winding factor. If the supply frequency is reduced while voltage remains constant, the flux will increase. This will cause saturation in the core, leading to line current distortions and higher magnetising current. This results in higher stator copper as well as core losses. Alternatively, if the supply frequency is increased while keeping voltage constant, then flux will decrease, reducing torque producing capability of the motor.

Therefore, it is necessary to vary the terminal voltage with the supply frequency so that the ratio (v/f) is constant which would maintain a constant flux in the machine. This is shown in the graph plotted above where the gradient is constant below the rated frequency.

Above rated frequency, the terminal voltage is held constant due to supply side limitation and hence flux decreases with increase in frequency. This is shown in the graph plotted above by the horizontal line where the gradient is 0 above the rated frequency.

## Question 2

**Investigate the performance of the drive system when the reference speed is step-changed from 1500 rpm to 1200 rpm at *t* = 2 sec and from 1200 rpm to 900 rpm at *t* = 3 sec. Please note that no external mechanical load is applied.**

**Use the Matlab file ‘wTplot.m’ in the Matlab window to observe the motor drive system response to the speed step-change and identify the forward motoring and forward braking operation.**

Chart, line chart

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The motor operates in the forward motoring region from t=0s to approximately t=1s. During this period, both the motor torque and speed is positive. As the motor speed increases until steady state, the motor torque increases and peaks before falling back to 0.

The period from t=2s to t=2.5s as well as the period from t=3s to t=3.5s, the motor is operating in the forward braking region as the motor torque is negative while the motor speed is positive. As the speed decreases until steady state, the motor torque decreases and reaches a minimum point before rising back to 0.

## Question 3

**Investigate the performance of the drive system when the load torque is step-changed from 0 to 5 N.m at *t* = 2 sec. Please note that the reference speed is kept constant at 1000 rpm.**

**Use the Matlab file ‘wTplot.m’ in the Matlab window to observe the motor drive system response to the speed step-change and identify the forward motoring and forward braking operations.**

Chart, line chart

Description automatically generated

Chart, line chart

Description automatically generated

The motor is operating in the forward motoring region from t=0s and t=1s as both the motor torque and speed is positive. As the motor speed increases to steady state, the motor torque increases and peaks before falling back to 0Nm.

The motor is operating in the forward motoring region from t=2s and t=2.5s as both the motor torque and speed is positive. As the motor speed dips to a minimum before rising back to its original value of 1000rpm, the motor torque increases from 0Nm until a steady state of 5Nm.

At t=2s, the incerase in the load, from 0Nm to 5Nm causes the motor speed to drop as . However, the close loop system will adjust to bring the motor speed back to the setpoint of 1000rpm by increasing the motor torque.

# Experiment 1

After setting up the circuit as required, the power supply is turned on by setting its main power switch to the marked I (on) position and set voltage control knob to reach the motor rated speed.

The load torque is then increases by increments of approximately 0.3N.m starting from 0 to MAX. For each torque setting, motor speed is then recorded in the table below.

|  |  |
| --- | --- |
| Load Torque | Motor speed/rpm |
| 0 | 1467 |
| 0.32 | 1439 |
| 0.6 | 1410 |
| 0.89 | 1379 |
| 1.19 | 1342 |
| 1.52 | 1294 |
| 1.8 | 1249 |
| 2.09 | 1180 |
| 2.46 | 1068 |

The graph of the speed versus torque characteristics on the oscilloscope is also captured in the figure below.

A screenshot of a computer

Description automatically generated with medium confidence

## Question 1

**In your report, plot the graph of motor torque versus motor speed by using the measured data. Compare the curve of the torque (*T*) as a function of the speed (*n*) plotted to the theoretical result.**

The two results are similar and it can be oserved that as speed increases, the torque decreases. Since , at constant output power , as speed increases, torque decreases.

From 0Nm to approximately 1.5Nm, the torque speed characteristics is linear, after which, it is gradient is non constant. Hence, the pull out torque is at approximately 1.5Nm.

# Experiment 2-A

After the circuit is setup as required, the drive wizard is then connected to the motor and the OPEN PARAM file is ran.

## Question 2

**Vary the input frequency of the motor by varying the frequency reference of the Vector-control Drive Converter. Using the computer, set the frequency reference to the values such as 5, 10, 20, 30, 40, 50, 60 Hz. (Don’t speed up the motor suddenly.) For each frequency, record the data of the motor input voltage V2 and steady state speed. In your report, plot the graph of the input voltage of motor-the reference frequency and explain how v/f control scheme work?**

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency (Hz) | Input Voltage (V) | v-f ratio | Speed (rpm) |
| 5 | 40 | 8 | 120 |
| 10 | 70 | 7 | 260 |
| 20 | 110 | 5.5 | 536 |
| 30 | 150 | 5 | 818 |
| 40 | 195 | 4.875 | 1105 |
| 50 | 235 | 4.7 | 1394 |
| 60 | 240 | 4 | 1626 |

The equation for the voltage is as follows:

Where is the supply frequency, is the flux, N is the number of turns and is the winding factor. If the supply frequency is reduced while voltage remains constant, the flux will increase. This will cause saturation in the core, leading to line current distortions and higher magnetising current. This results in higher stator copper as well as core losses. Alternatively, if the supply frequency is increased while keeping voltage constant, then flux will decrease, reducing torque producing capability of the motor.

Therefore, it is necessary to vary the terminal voltage with the supply frequency so that the ratio (v/f) is constant which would maintain a constant flux in the machine. This is shown in the graph plotted above where the gradient is constant below the rated frequency (50Hz).

Above rated frequency, the terminal voltage is held constant due to supply side limitation and hence flux decreases with increase in frequency. This is shown in the graph plotted above by the horizontal line where the voltage is approximately constant above the rated frequency(50Hz).

# Experiment 2-B

After the circuit is adjusted accordingly, the drive wizard is connected to the motor and the CLOSE PARAM file is ran.

## Question 3

**Vary the input frequency of the motor by varying the frequency reference of the Vector-control Drive Converter. Using the computer, set the frequency reference to the values such as 5, 10, 20, 30, 40, 50, 60 Hz. (Don’t speed up the motor suddenly.) For each frequency, record the data of the motor input voltage V2 and steady state speed. In your report, plot the graph of the input voltage of motor-the reference frequency and note the difference with the same of the previous run.**

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency (Hz) | Input Voltage (V) | v-f ratio | Speed (rpm) |
| 5 | 80 | 16 | 143 |
| 10 | 100 | 10 | 284 |
| 20 | 190 | 9.5 | 581 |
| 30 | 280 | 9.333333 | 878 |
| 40 | 370 | 9.25 | 1176 |
| 50 | 400 | 8 | 1469 |
| 60 | 405 | 6.75 | 1754 |

The input voltage versus frequency graphs have similar shape for both experiments where the v-f ratio is relatively constant below the rated frequency, after which it fails to maintain the constant ratio. However, for the close loop control, voltage boosting can be observed at the lower frequencies.