

TRANSIENT HARMONIC ANALYSIS OF TRANSFORMER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology
In
Electrical Engineering**

By

Nikhil Mallikarjun(10502040)

Devdutta Sahoo(10502044)



**Department of Electrical Engineering
National Institute of Technology
Rourkela**

2009

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Under the Guidance of

Prof. Sharmili Das



**Department of Electrical Engineering
National Institute of Technology
Rourkela**

2009



**National Institute of Technology
Rourkela**

Certificate

This is to certify that the thesis entitled “***TRANSIENT HARMONIC ANALYSIS OF TRANSFORMER***” submitted by Shri Nikhil Mallikarjun and Shri Devdutta Sahoo in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date :

Place:

Prof. Sharmili Das
Dept. of Electrical Engg.
National Institute of technology
Rourkela-769008

ACKNOWLEDGEMENT

We would like to articulate our deep gratitude to our project guide Prof. Sharmili Das who has always been our motivation for carrying out the project. We wish to extend our sincere thanks to Prof. B.D. Subudhi, Head of our Department, for his invaluable guidance.

It is our pleasure to refer “Microsoft Word” exclusive of which the compilation of this report would have been impossible. Also it would not have been possible to complete the project without the simulation software”MATLAB”.

A project of this nature could never have been attempted with our reference to and inspiration from the works of others whose details are mentioned in references section. We acknowledge our indebtedness to all of them. Last but not the least, our sincere thanks to all our friends who have patiently extended all sorts of help for accomplishing this undertaking.

Nikhil Mallikarjun

Devadutta Sahoo

ABSTRACT

The project focuses on the harmonic analysis of transformer during the switching transient period. Analysis is made using Discrete Time Fourier Transforms (DTFT). Measuring fundamental and second harmonics of differential current, an algorithm based on the Discrete Fourier Transform and an amplitude estimator are used to simulate and list various harmonic components of current and flux. Generalized functions for describing the relationships between resultant flux and harmonic components are derived. This is important to find these relations for further use in detecting non-linearity and elimination of harmonic components.

PROJECT DEFINITION:

This project will focus on carrying a transient analysis of a transformer. The components of current and magnetizing flux are derived and the hysteresis loop is to be plotted. The current and flux relations with respect to time are simulated for different conditions of phase angle and Residual Flux. Generalized functions for describing the relationships between resultant flux and harmonic components were derived.

AIMS:

- Determine the relationship between Magnetizing Field (H) and harmonic components of flux.
- Determine the magnitude and relative percentages of the different harmonic components of current in a single-phase transformer in variation with respect to the phase angle (switching constant) and Residual Flux.
- Simulate the harmonic distribution and hysteresis relations derived from above.

INTRODUCTION

A literature survey to document the transient behavior of CT's behavior was conducted. Harmonic analysis of current transformer is made using Discrete Time Fourier Transforms (DTFT). Measuring fundamental and second harmonics of differential current, an algorithm based on the Discrete Fourier Transform and an amplitude estimator which uses 20 samples in order to find the magnitudes of harmonics are used. Magnitudes of harmonic frequencies are obtained by discrete Fourier transform, using a sliding window of one cycle.

Harmonic analysis shows high even harmonics in current. Even harmonics are the characteristic harmonics of transformer saturation and they are used to restrain the operation of differential protection of the transformer during energizing. Even harmonics are not common in power systems and basically depict the asymmetry between the positive and negative half-cycle of waveform.

Transients and Switching transients

Transients: It means any sudden change in the circuit, i.e. either closing the circuit or opening the circuits. The transients are two types in power transformer, switching transients and over-voltage transients. Due to transients the behavior of a system has got two components, steady state and transient. Sometimes the initial transient of a system has a very high value, it is known as inrush.

Transients in a 1-φ R-L circuit in switching operation

The equation of the given circuit is

$$Ri + L (di/dt) = V_{\max} (\sin(\omega t + \alpha)) \quad (1)$$

$$I(t) = I_{\max} (\sin(\omega t + \alpha - \phi)) + A e^{-(R/L)t} \quad (2)$$

$$\& A = -I_{\max} (\sin(\alpha - \phi)) \quad (3)$$

$$\phi = \text{atan}(\omega L/R)$$

$$I_{\max} = V_m / (R^2 + (\omega L)^2)^{1/2}$$

And If $\alpha = \phi$;

There will be no transient; the current has got only steady part.

Case 1:

Initial inrush will be minimum,

When switching angle = power factor angle

And inrush will be maximum, when $\alpha - \phi = 90$

II Switching of a 1-φ Transformer:

Neglecting the leakage reactance of the primary and secondary & assuming the no-load, the transformer primary side emf equation can be written as: -

$$V_s = r_p i_p + I_p (di_p/dt) + e_s'; \quad (4)$$

e_p -> Primary induced voltage

e_s -> Secondary induced voltage

e_s' -> equivalent Secondary induced voltage

$$e_p = -(d\lambda/dt)$$

$$\lambda = n_p \phi_m; \quad (5)$$

$$\phi_m = f(i_p);$$

Solving eqn (4) & (5), the behavior of current transient of transformer can be predicted, but for that ϕ_m has to be determined correctly. ϕ_m is dependent of the nature of the core, since it is non-linear in nature, it introduces certain complexity. So overall eqn (4) & (5) and the non-linear nature of transformer core determines the initial transient or inrush nature.

Introduction

Transformer exhibit inrush phenomenon during initial energization.

Due to flux symmetry or temporary over fluxing, which gives rise to high current at the initial energization of a transformer core. The saturation of one or more cores results in high magnitude of current.

⇒ Being high magnitude of current, the transformer energizing current is full of harmonics.

⇒ Both even and odd harmonics occur during energization.

They can excite system resonance resulting in dynamic over voltage.

Factors:

⇒ Point on voltage wave switching

⇒ Magnitude and polarity of remnant flux

⇒ Total resistance of primary winding circuit

⇒ Inductance of the air core

⇒ Geometry of the transformer core

⇒ Maximum flux carrying capability of the core material

Impacts

➔ Large inrush current causes the voltage dips in the supply system. Which leads to mal operation of sensitive electronics equipment and interrupt manufacturing process.

➔ It will be highly unbalanced among 3- ϕ , unbalance caused by inrush current could easily result in motor tripping.

➔ The waveform of an inrush current is far from sinusoidal containing a lot of high frequency component; such harmonics excite resonances in the system causing significant magnification of voltage or currents at various locations in the system which can damage sensitive electronics equipment, surge suppressor over heating, capacitor fuse blowing and failure.

➔ The dc component of the inrush current can lead to oscillatory torque in motors resulting in increase in motor vibration and aging.

Mitigation

- Over sizing fuse
- Series resistance insertion
- Ground resistor insertion
- Controlled closing or controlled energization or point on voltage wave switching.
- Soft starting

Inrush analysis can be carried out in four steps these are

Identification

Determination and discrimination

Calculation

Mitigation

This current has been a problem in the design and performance of differential protective relays used in power transmission and distribution system. Power transformers play an important role in power system, so in order to ensure the safe operation of these transformers.

Calculation

Inrush magnetizing current and its waveform is calculated ->

Numerical analysis using

- MATLAB

Transformer equivalent model can be represented as

$$R_i + [L(i) + LL](di/dt) = (2)^{1/2} E_{\max} (\sin wt);$$

The magnitude and peak of inrush current waveform is dependent

- ⇒ On instant of switching
- ⇒ Remnant flux density

For a single phase transformer, equation can be written as

$$R_i + L di + d\lambda_m/dt = E_{\max} \sin(wt);$$

Neglecting L

$$R_i + d\lambda_m/dt = E_{\max} \sin(wt);$$

$$\lambda_m = N\phi_m$$

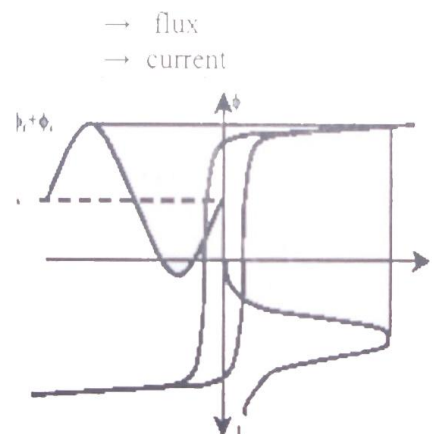


fig- flux current relation ship

$$\phi_m = f(i_m)$$

$$d\phi_m = [(E_{\max} \sin(\omega t) - Ri)dt]/N;$$

$$dB_m = d(\phi_m)A;$$

$$B_m = B_m + dB_m; \text{ as } H_m = F(B_m)$$

$$I_m = (H_m l)/N;$$

So, the value of current can be determined by solving above equation.

Generally an inrush current transient is 10 to 20 times the rated value and it lasts for 20 to 3600 cycles.

⇒ **Without considering Residual Flux**

⇒ **Considering Residual Flux**

Transformer Rating -> 150 MVA, 500 KV

ASSUMPTION

i> Residual flux is generally in the range between 20 to 70%

ii> Flux Pattern is like one near zero and other two +/- values.

This method is applicable to both 1 ϕ and 3 ϕ transformer circuit.

The basic assumptions behind induced flux linkage (prospective flux) are the integral of the applied voltage and it lags it by 90.

As given by the equation:

$$Ri + L (di/dt) + d\lambda_m/dt = E_{\max} \sin(\omega t)dt;$$

Neglecting the drops

$$\text{Or, } \int \phi_m dt = 1/N \int E_{\max} \sin(\omega t)dt;$$

$$\text{Or, } \phi_t = \phi_r + 1/N \int E_{\max} \sin(\omega t)dt;$$

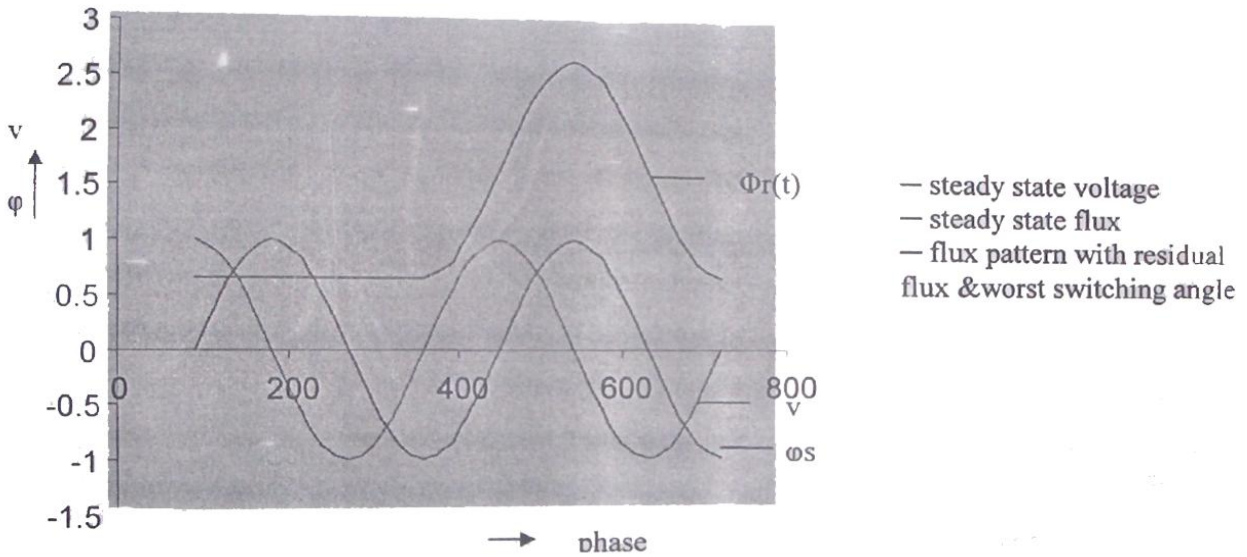


fig-voltage flux relationship at worst switching case

If residual flux left in the core, then flux builds up from that level and sinusoidal flux wave symmetry will be dc offset by the residual flux amount. In order to limit such asymmetry, at the instant of energization the residual flux should be equal to the prospective flux (i.e. prospective flux). So that flux wave follows the normal pattern without any offset.

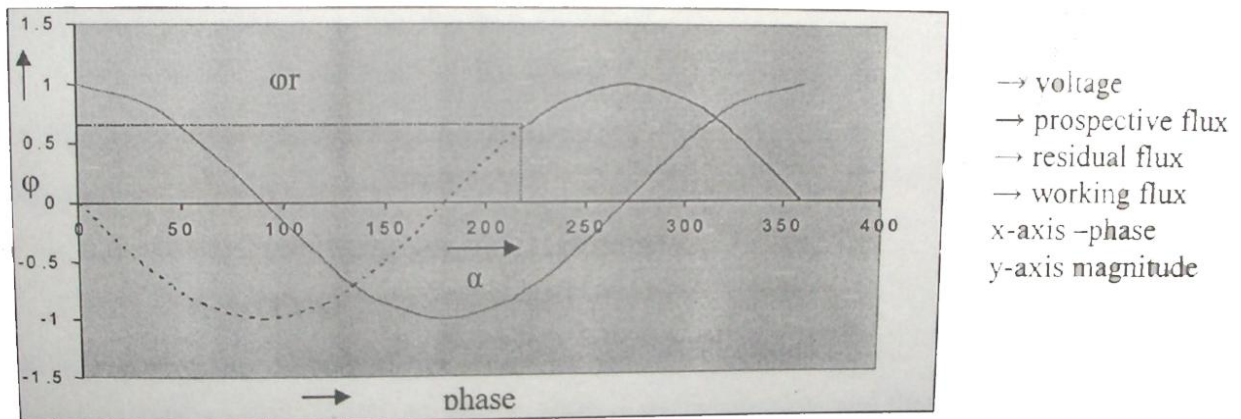


fig-optimal energization instant

Case 1: Single phase transformer

As given in the equation & the figure given above, without residual flux, flux will maintain steady state if it starts from zero.

i.e. if $\phi_t = 0.0$, at $(t=0 \ \& \ \phi_r=0) \rightarrow$ steady state symmetry (no inrush)

Here $\alpha = 90$.

In case of loaded circuit optimal instant of switching is

$\alpha = \theta$ -> **w.r.t. flux wave**

$\alpha = 90 + \theta$ -> **w.r.t. voltage wave**

Case 2: Single phase transformer with residual flux

As given previously the reason behind magnetic asymmetry which resulted either due to residual flux or point on switching voltage wave. Point on voltage switching means the different instant on voltage wave at which the transformer is re-energized, depending on that instant flux builds up from a particular dc offset level.

i.e. minimum, when $V_{s(t)} = E_{\max}$ -> $\alpha = 90$;

& maximum, when $V_{s(t)} = 0.0$ -> $\alpha = 0$ or $\alpha = 180$ and $\phi_t = 2\phi_{\max}$ or $-2\phi_{\max}$;

For the remnant flux case, when transformer is re-energized, the flux builds up from the previous remnant value and the maximum value of remnant to which the flux builds up depends upon the instant of switching.

At, Worst switching -> $\phi_t = \phi_r + 2\phi_{\max}$;

This asymmetry can be nullified if transformer is switched on when;

The applied flux value is same as residual flux

i.e. $\alpha = \sin^{-1}(\phi_r/\phi_{\max})$ -> **w.r.t. flux wave**

$\alpha = 90 + \sin^{-1}(\phi_r/\phi_{\max})$ -> **w.r.t. voltage wave**

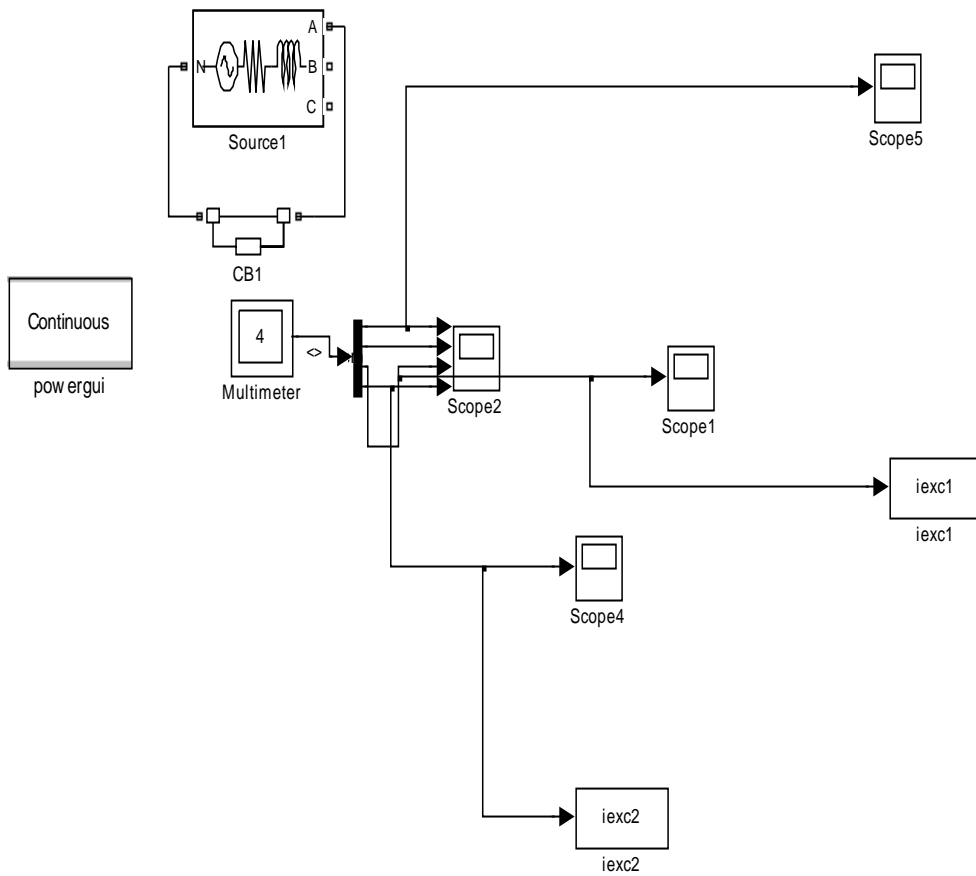
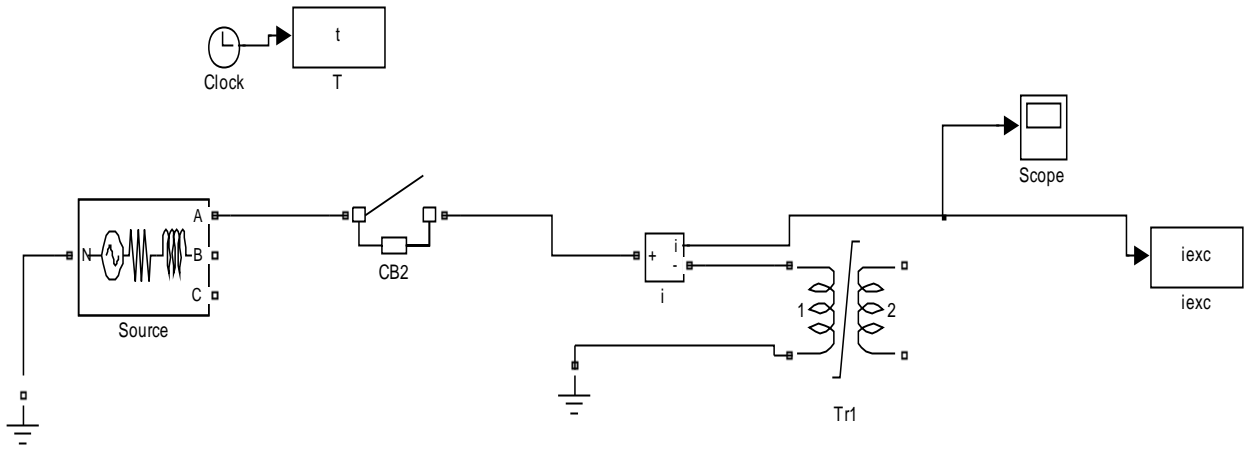
Where

α -> Switching instant optimal

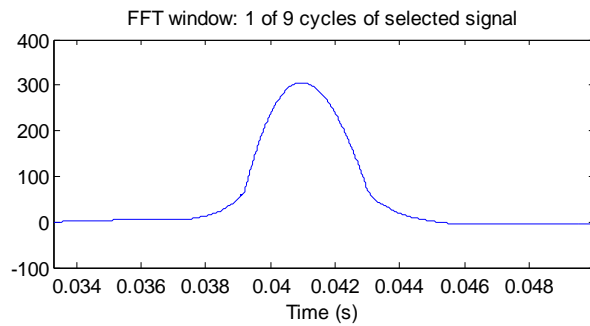
θ -> power factor angle.

Simulation

MATLAB MODEL



Phase Angle = 0, Residual Flux = 0.0



```

Sampling time = 1.75131e-005 s
Samples per cycle = 951.667
DC component = 56.69
Total Harmonic Distortion (THD) = 246.07%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	56.69
60 Hz Fund	104.14
120 Hz (h2)	75.23
180 Hz (h3)	47.26
240 Hz (h4)	23.82
300 Hz (h5)	9.30
360 Hz (h6)	1.75
420 Hz (h7)	4.36
480 Hz (h8)	5.05
540 Hz (h9)	3.28
600 Hz (h10)	1.29
660 Hz (h11)	1.08
720 Hz (h12)	1.83
780 Hz (h13)	1.79
840 Hz (h14)	0.92
900 Hz (h15)	0.20
960 Hz (h16)	0.83

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

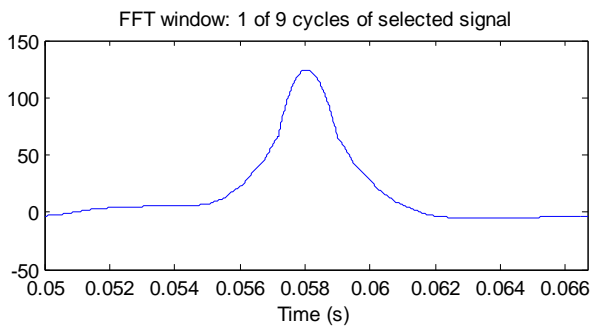
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75131e-005 s
Samples per cycle = 951.667
DC component = 18.64
Total Harmonic Distortion (THD) = 261.56%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	18.64
60 Hz Fund	35.96
120 Hz (h2)	24.79
180 Hz (h3)	16.92
240 Hz (h4)	9.75
300 Hz (h5)	6.61
360 Hz (h6)	4.56
420 Hz (h7)	3.38
480 Hz (h8)	2.51
540 Hz (h9)	1.72
600 Hz (h10)	1.16
660 Hz (h11)	0.54
720 Hz (h12)	0.11
780 Hz (h13)	0.23
840 Hz (h14)	0.38
900 Hz (h15)	0.44
960 Hz (h16)	0.44

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

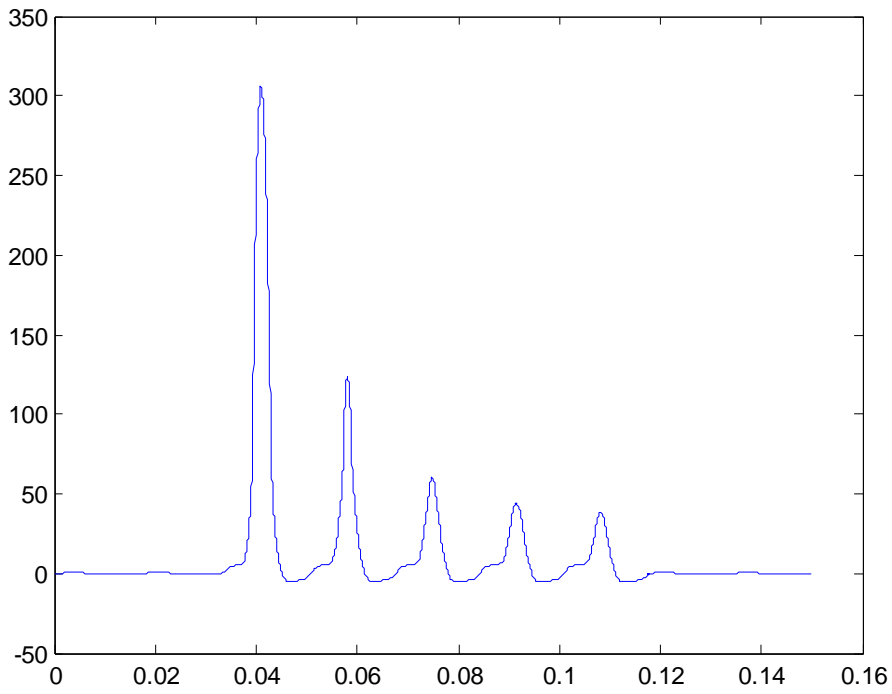
Frequency axis: Hertz

Display style : List (relative to specified ba...)

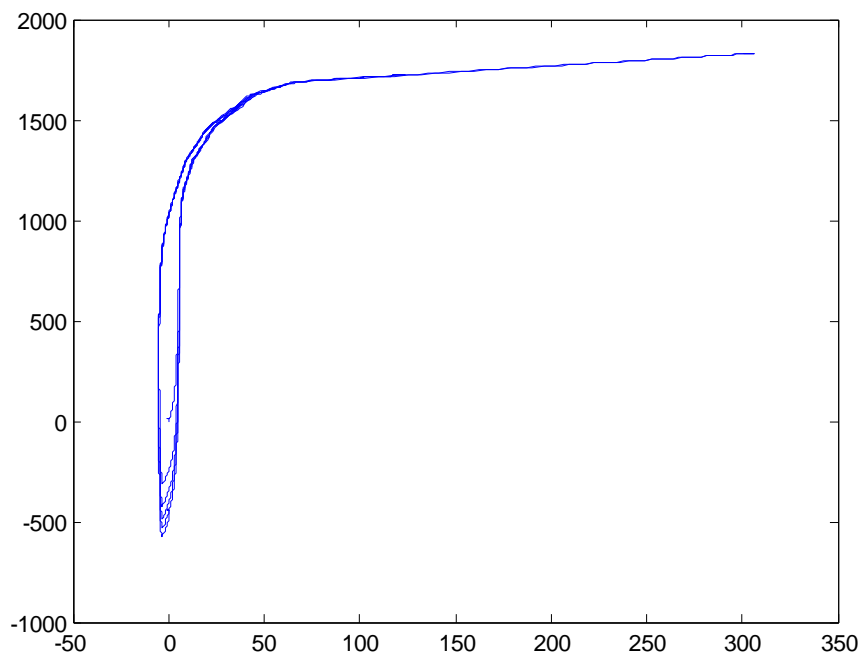
Base value: 1.0

Display Close

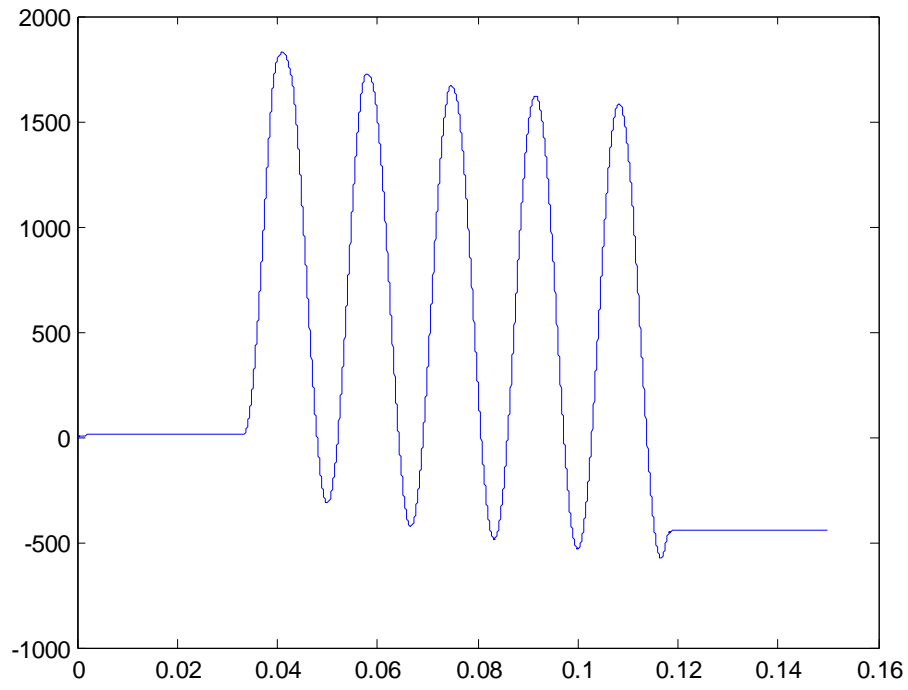
Current vs. Time



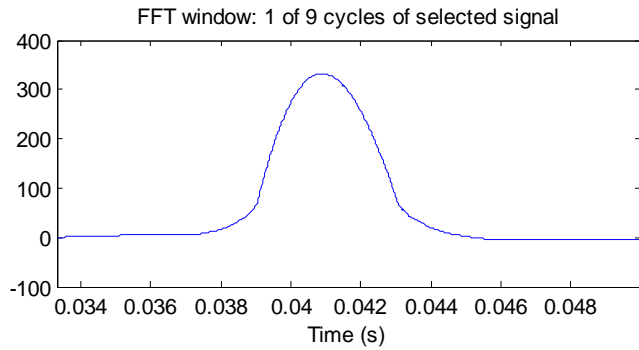
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.05



```

Sampling time = 1.74927e-005 s
Samples per cycle = 952.778
DC component = 63.68
Total Harmonic Distortion (THD) = 241.67%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	63.68
60 Hz Fund	116.36
120 Hz (h2)	83.00
180 Hz (h3)	50.45
240 Hz (h4)	23.61
300 Hz (h5)	7.45
360 Hz (h6)	3.29
420 Hz (h7)	5.82
480 Hz (h8)	5.28
540 Hz (h9)	2.55
600 Hz (h10)	0.65
660 Hz (h11)	2.02
720 Hz (h12)	2.21
780 Hz (h13)	1.39
840 Hz (h14)	0.33
900 Hz (h15)	0.93
960 Hz (h16)	1.15

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

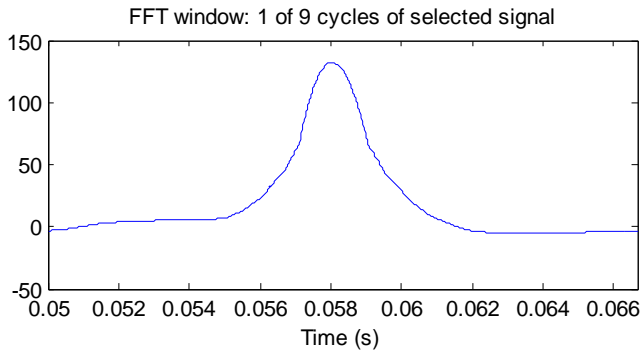
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.74927e-005 s
Samples per cycle = 952.778
DC component = 19.88
Total Harmonic Distortion (THD) = 262.87%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	19.88
60 Hz Fund	38.26
120 Hz (h2)	26.66
180 Hz (h3)	18.33
240 Hz (h4)	10.78
300 Hz (h5)	7.32
360 Hz (h6)	5.01
420 Hz (h7)	3.60
480 Hz (h8)	2.57
540 Hz (h9)	1.64
600 Hz (h10)	0.97
660 Hz (h11)	0.29
720 Hz (h12)	0.20
780 Hz (h13)	0.48
840 Hz (h14)	0.57
900 Hz (h15)	0.57
960 Hz (h16)	0.52

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

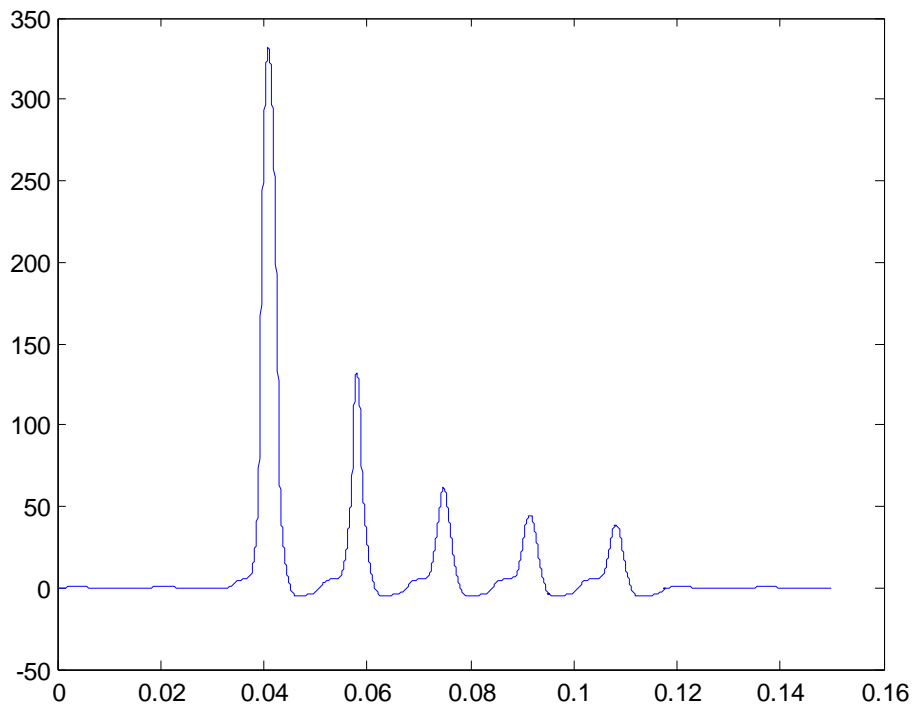
Frequency axis: Hertz

Display style : List (relative to specified ba...)

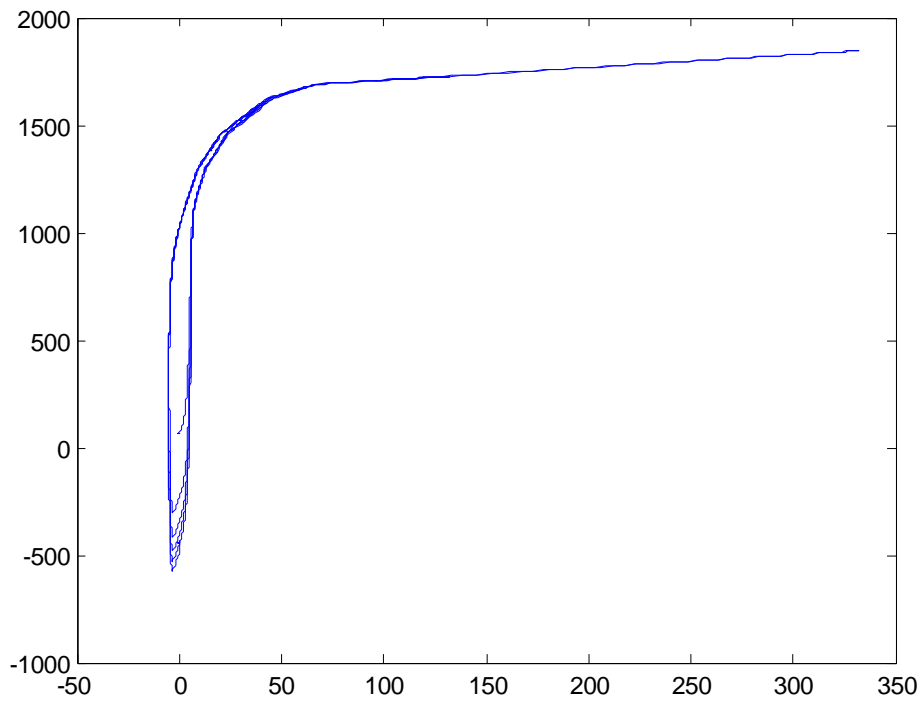
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Display Close

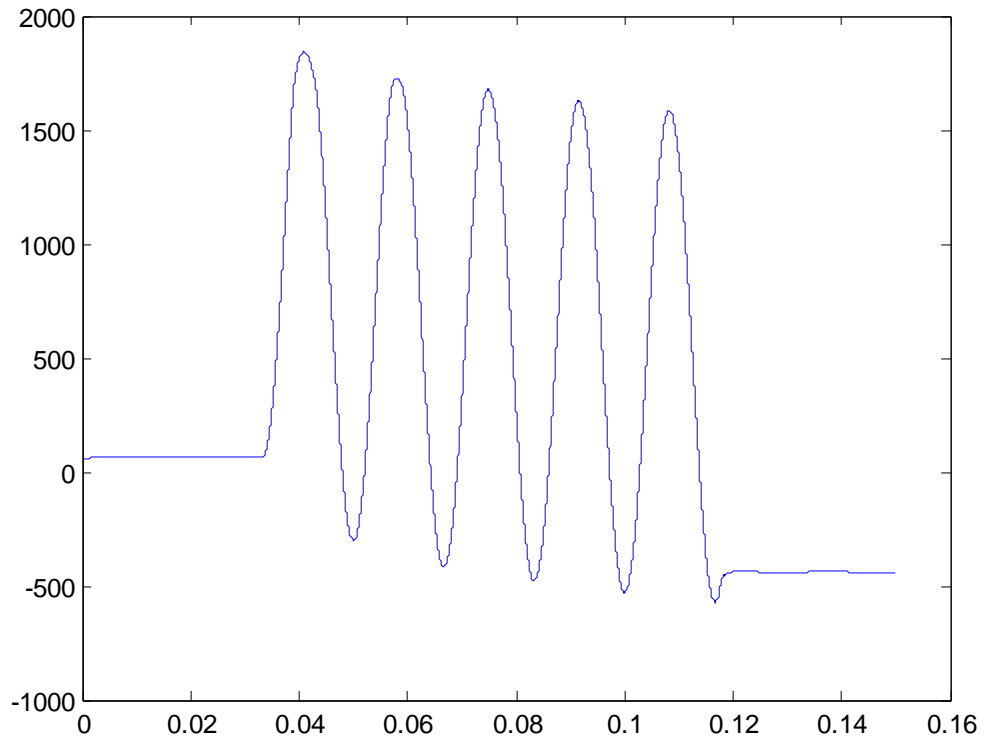
Current vs. Time



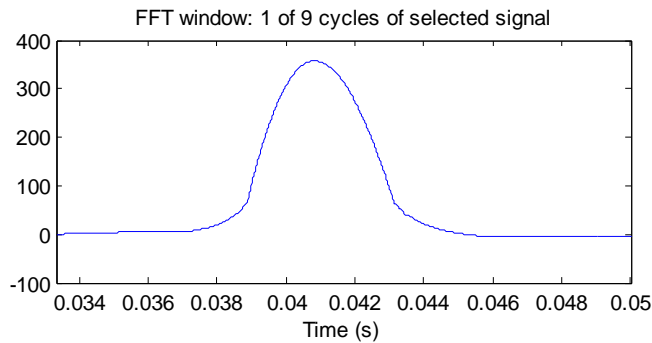
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.1



```

Sampling time = 1.74784e-005 s
Samples per cycle = 953.556
DC component = 70.78
Total Harmonic Distortion (THD) = 237.40%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	70.78
60 Hz Fund	128.67
120 Hz (h2)	90.49
180 Hz (h3)	53.09
240 Hz (h4)	22.86
300 Hz (h5)	5.47
360 Hz (h6)	5.30
420 Hz (h7)	6.87
480 Hz (h8)	4.98
540 Hz (h9)	1.58
600 Hz (h10)	1.54
660 Hz (h11)	2.65
720 Hz (h12)	2.10
780 Hz (h13)	0.63
840 Hz (h14)	0.84
900 Hz (h15)	1.42
960 Hz (h16)	1.01

Structure :

ScopeData

Input :

input 1

Signal number:

1

Start time (s):

2/60

Number of cycles:

1

Display FFT window

Fundamental frequency (Hz):

60

Max Frequency (Hz):

1000

Frequency axis:

Hertz

Display style :

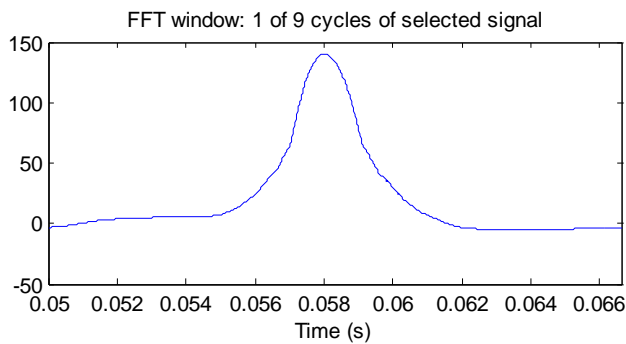
List (relative to specified ba...

Base value:

1.0

Display

Close



```

Sampling time = 1.74784e-005 s
Samples per cycle = 953.556
DC component = 21.06
Total Harmonic Distortion (THD) = 263.80%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	21.06
60 Hz Fund	40.45
120 Hz (h2)	28.44
180 Hz (h3)	19.65
240 Hz (h4)	11.72
300 Hz (h5)	7.95
360 Hz (h6)	5.38
420 Hz (h7)	3.75
480 Hz (h8)	2.55
540 Hz (h9)	1.49
600 Hz (h10)	0.75
660 Hz (h11)	0.15
720 Hz (h12)	0.46
780 Hz (h13)	0.69
840 Hz (h14)	0.72
900 Hz (h15)	0.65
960 Hz (h16)	0.54

Structure :

ScopeData

Input :

input 1

Signal number:

1

Start time (s):

3/60

Number of cycles:

1

Display FFT window

Fundamental frequency (Hz):

60

Max Frequency (Hz):

1000

Frequency axis:

Hertz

Display style :

List (relative to specified ba...

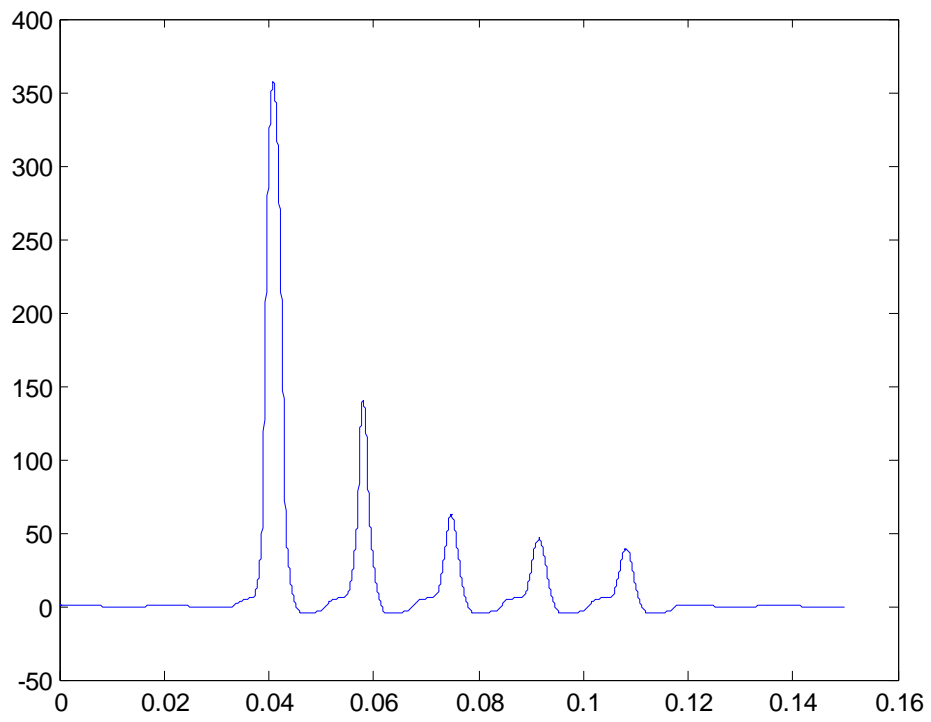
Base value:

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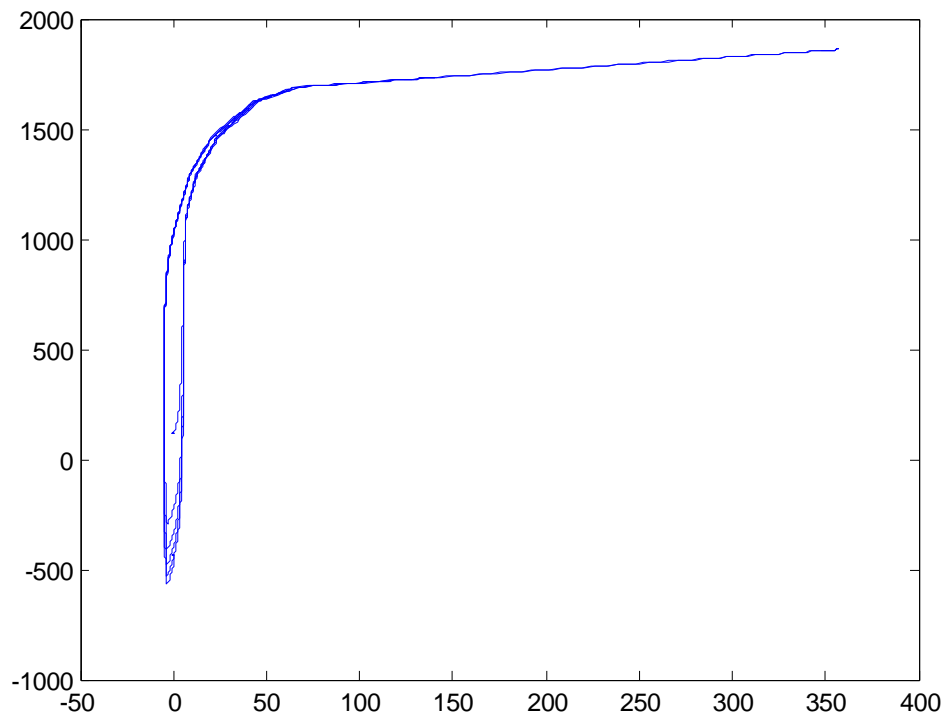
Display

Close

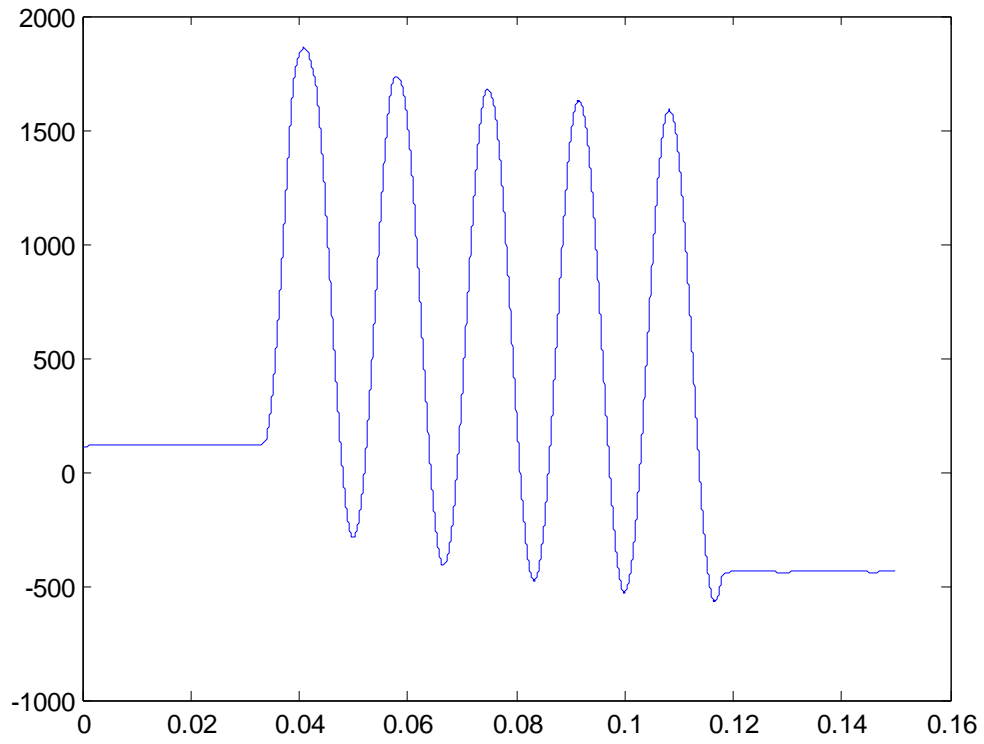
Current vs. Time



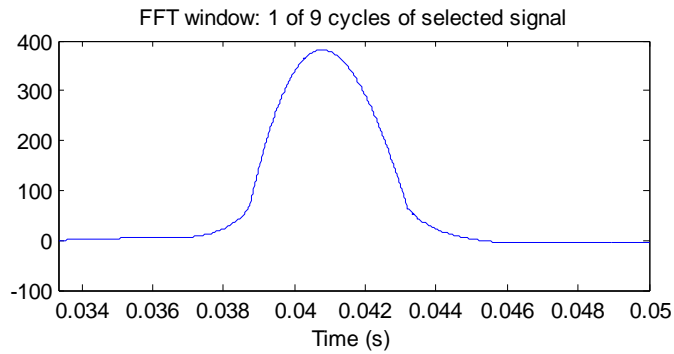
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.15



```

Sampling time = 1.75254e-005 s
Samples per cycle = 951
DC component = 78.07
Total Harmonic Distortion (THD) = 233.12%
    
```

0 Hz (DC)	78.07
60 Hz Fund	141.11
120 Hz (h2)	97.69
180 Hz (h3)	55.13
240 Hz (h4)	21.55
300 Hz (h5)	3.75
360 Hz (h6)	7.24
420 Hz (h7)	7.46
480 Hz (h8)	4.21
540 Hz (h9)	1.03
600 Hz (h10)	2.57
660 Hz (h11)	2.86
720 Hz (h12)	1.56
780 Hz (h13)	0.49
840 Hz (h14)	1.46
900 Hz (h15)	1.46
960 Hz (h16)	0.50

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

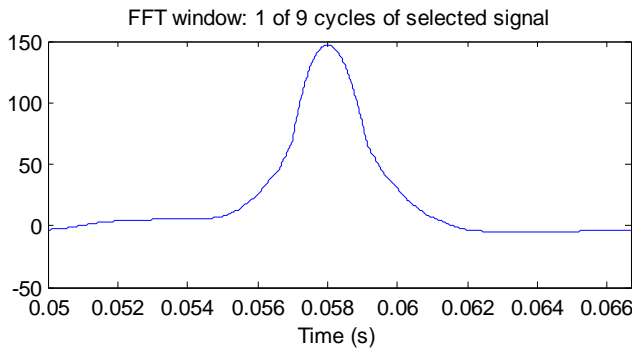
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75254e-005 s
Samples per cycle = 951
DC component = 22.21
Total Harmonic Distortion (THD) = 264.28%
    
```

0 Hz (DC)	22.21
60 Hz Fund	42.58
120 Hz (h2)	30.13
180 Hz (h3)	20.88
240 Hz (h4)	12.57
300 Hz (h5)	8.49
360 Hz (h6)	5.67
420 Hz (h7)	3.81
480 Hz (h8)	2.46
540 Hz (h9)	1.30
600 Hz (h10)	0.52
660 Hz (h11)	0.34
720 Hz (h12)	0.71
780 Hz (h13)	0.87
840 Hz (h14)	0.82
900 Hz (h15)	0.68
960 Hz (h16)	0.50

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

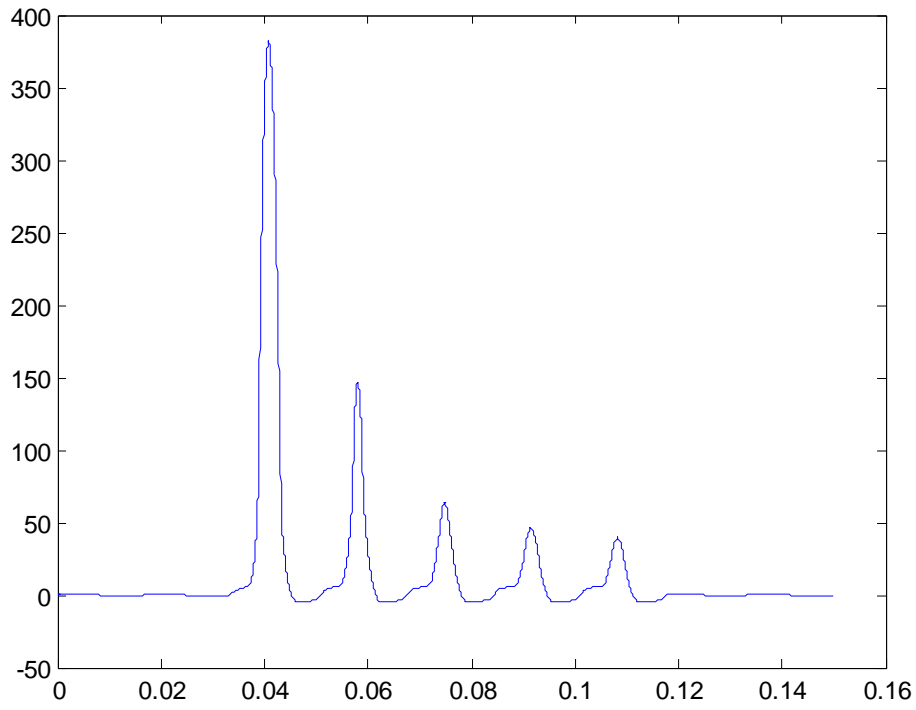
Frequency axis: Hertz

Display style: List (relative to specified ba...)

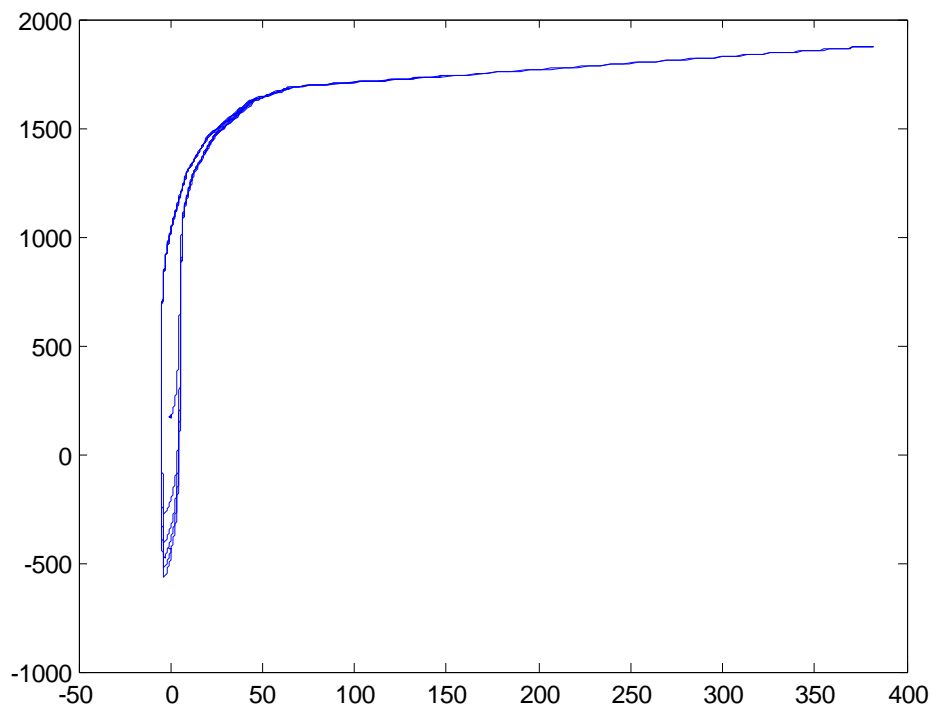
Base value: 1.0

Display Close

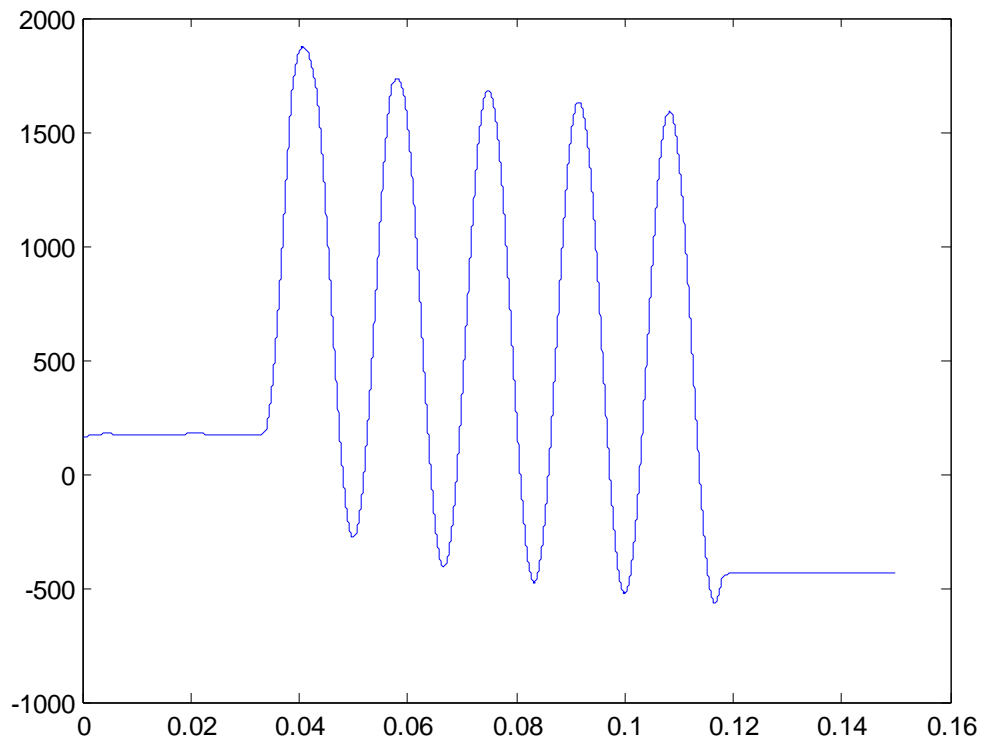
Current vs. Time



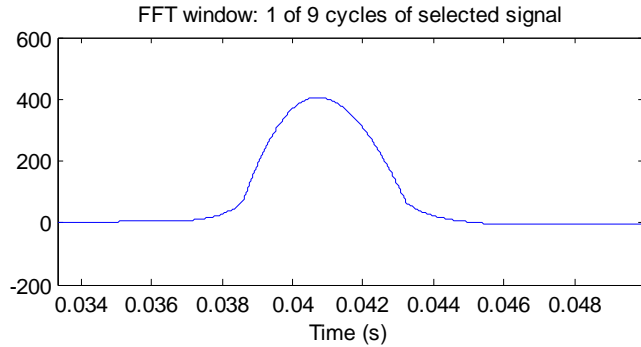
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.2



```

Sampling time = 1.75357e-005 s
Samples per cycle = 950.444
DC component = 85.49
Total Harmonic Distortion (THD) = 228.95%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	85.49
60 Hz Fund	153.61
120 Hz (h2)	104.55
180 Hz (h3)	56.59
240 Hz (h4)	19.80
300 Hz (h5)	3.42
360 Hz (h6)	8.93
420 Hz (h7)	7.56
480 Hz (h8)	3.11
540 Hz (h9)	1.82
600 Hz (h10)	3.31
660 Hz (h11)	2.62
720 Hz (h12)	0.81
780 Hz (h13)	1.33
840 Hz (h14)	1.72
900 Hz (h15)	1.08
960 Hz (h16)	0.34

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

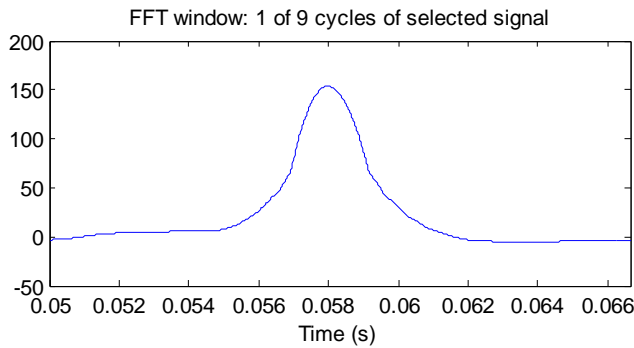
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75357e-005 s
Samples per cycle = 950.444
DC component = 23.31
Total Harmonic Distortion (THD) = 264.52%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	23.31
60 Hz Fund	44.61
120 Hz (h2)	31.74
180 Hz (h3)	22.04
240 Hz (h4)	13.35
300 Hz (h5)	8.96
360 Hz (h6)	5.89
420 Hz (h7)	3.82
480 Hz (h8)	2.33
540 Hz (h9)	1.09
600 Hz (h10)	0.34
660 Hz (h11)	0.60
720 Hz (h12)	0.92
780 Hz (h13)	1.00
840 Hz (h14)	0.86
900 Hz (h15)	0.65
960 Hz (h16)	0.42

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

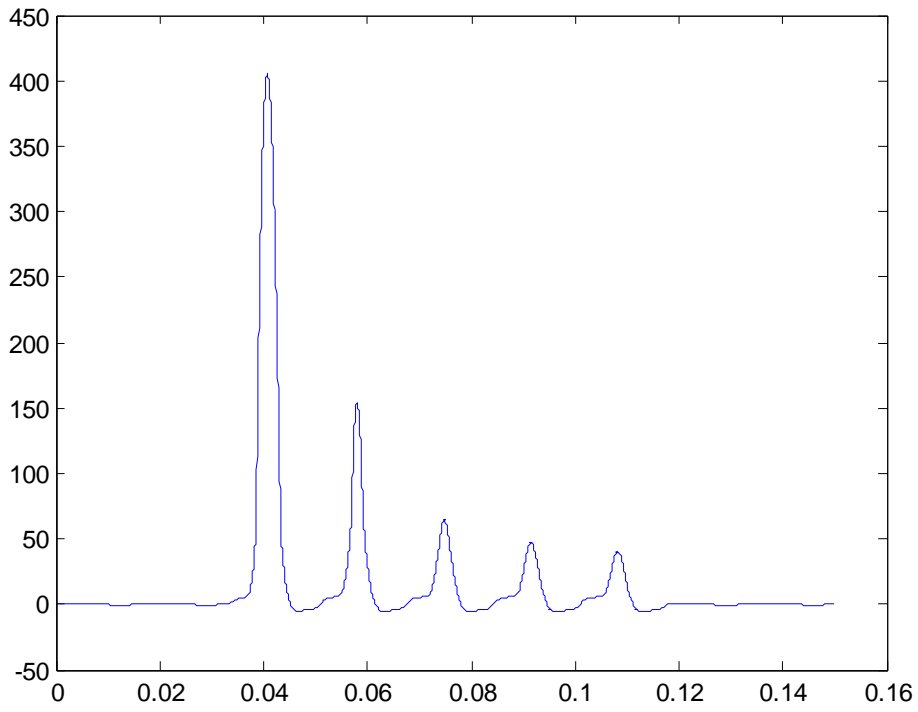
Frequency axis: Hertz

Display style: List (relative to specified ba...)

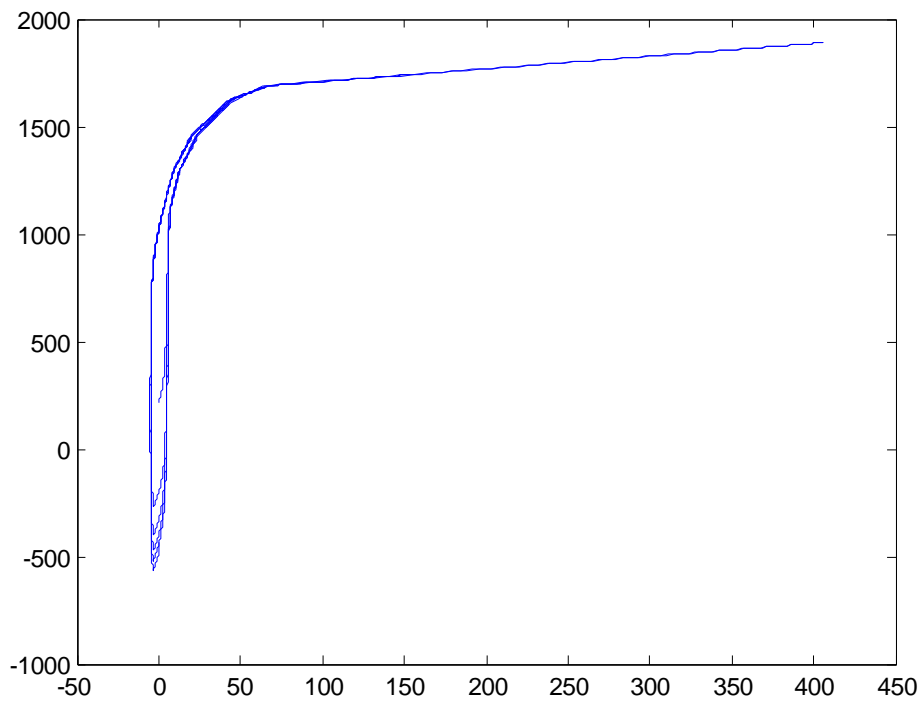
Base value: 1.0

Display Close

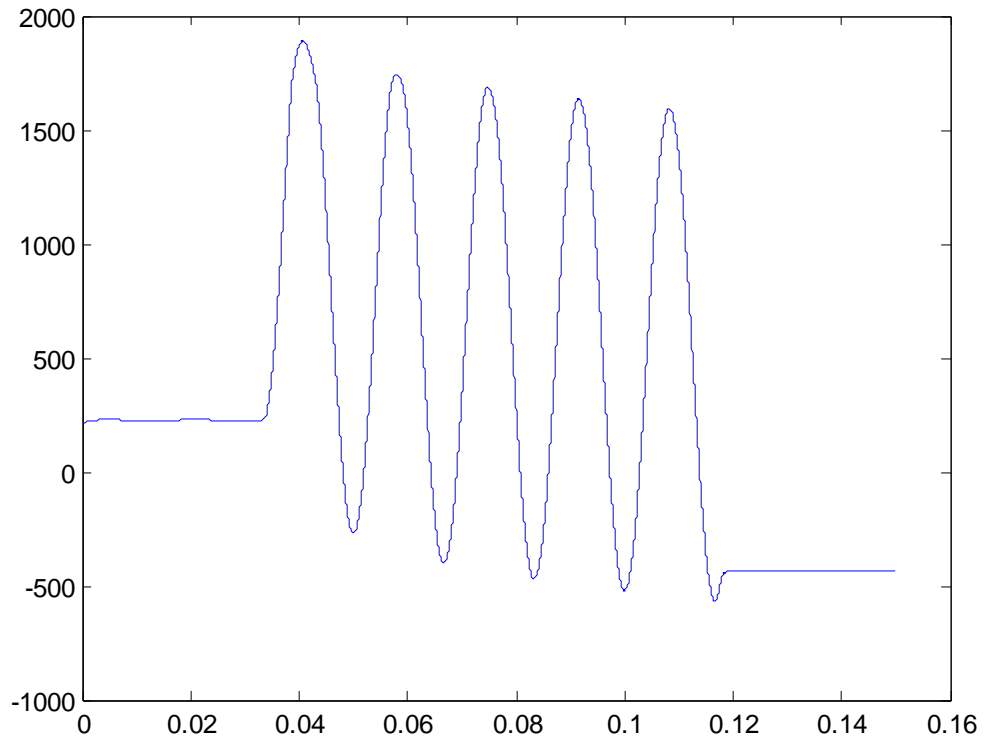
Current vs. Time



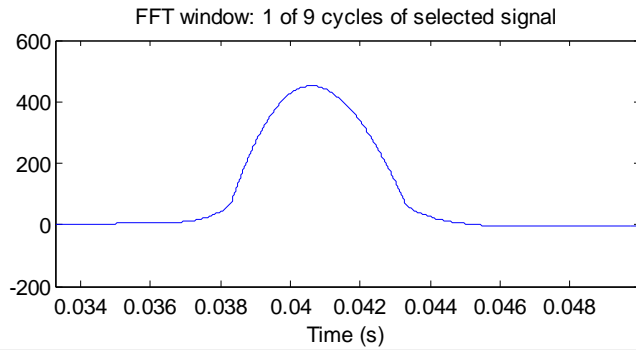
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.3



```

Sampling time = 1.75953e-005 s
Samples per cycle = 947.222
DC component = 100.5
Total Harmonic Distortion (THD) = 221.27%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	100.52
60 Hz Fund	178.52
120 Hz (h2)	117.20
180 Hz (h3)	58.00
240 Hz (h4)	15.44
300 Hz (h5)	6.97
360 Hz (h6)	11.22
420 Hz (h7)	6.52
480 Hz (h8)	1.10
540 Hz (h9)	3.87
600 Hz (h10)	3.63
660 Hz (h11)	1.16
720 Hz (h12)	1.45
780 Hz (h13)	2.24
840 Hz (h14)	1.09
900 Hz (h15)	0.46
960 Hz (h16)	1.37

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

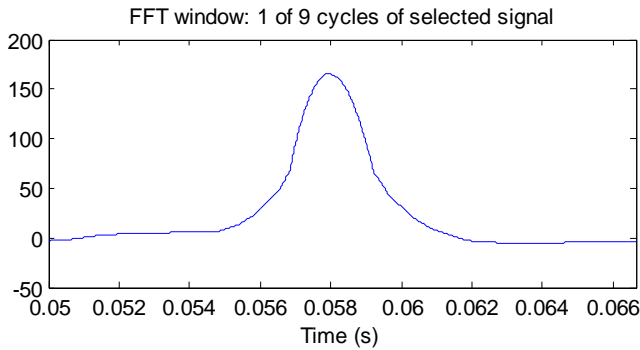
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75953e-005 s
Samples per cycle = 947.222
DC component = 25.35
Total Harmonic Distortion (THD) = 264.77%
    
```

Frequency (Hz)	Magnitude
0 Hz (DC)	25.35
60 Hz Fund	48.38
120 Hz (h2)	34.72
180 Hz (h3)	24.17
240 Hz (h4)	14.74
300 Hz (h5)	9.73
360 Hz (h6)	6.19
420 Hz (h7)	3.73
480 Hz (h8)	2.01
540 Hz (h9)	0.68
600 Hz (h10)	0.50
660 Hz (h11)	1.05
720 Hz (h12)	1.24
780 Hz (h13)	1.14
840 Hz (h14)	0.85
900 Hz (h15)	0.51
960 Hz (h16)	0.22

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

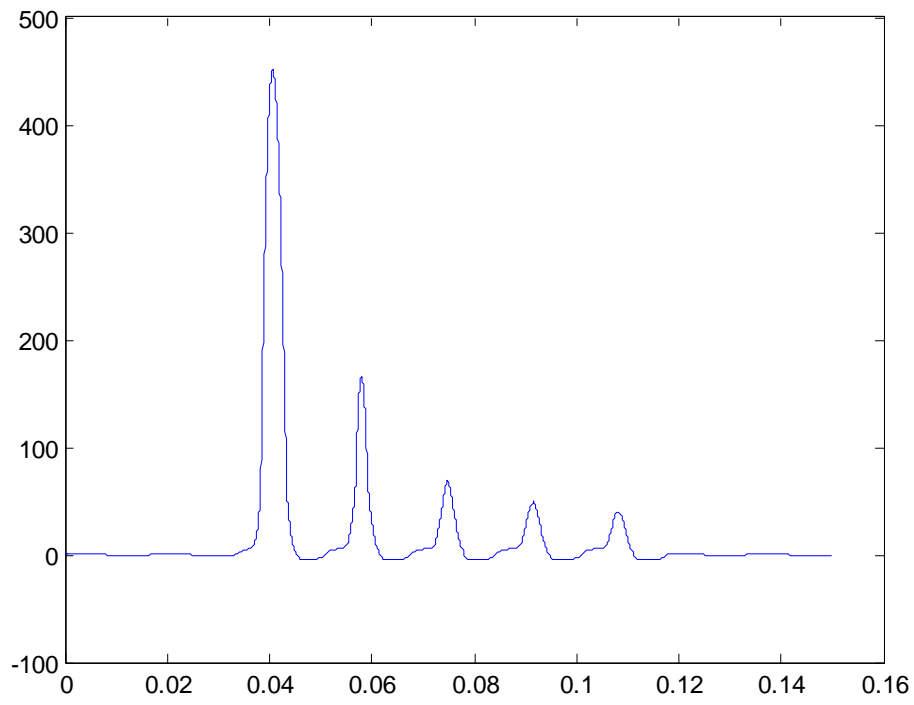
Frequency axis: Hertz

Display style : List (relative to specified ba...)

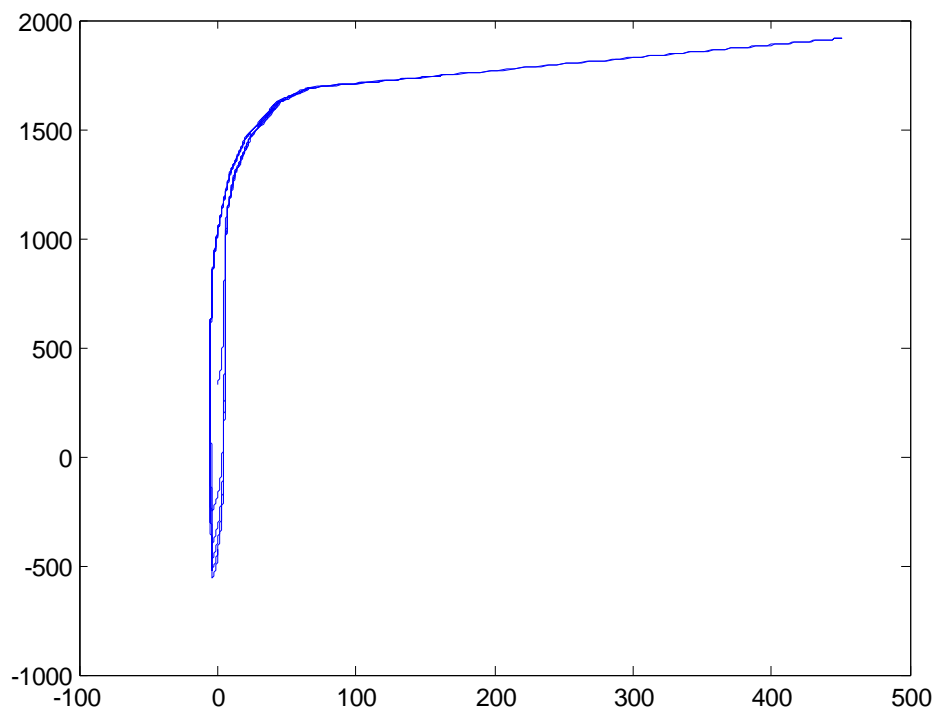
Base value: 1.0

Display Close

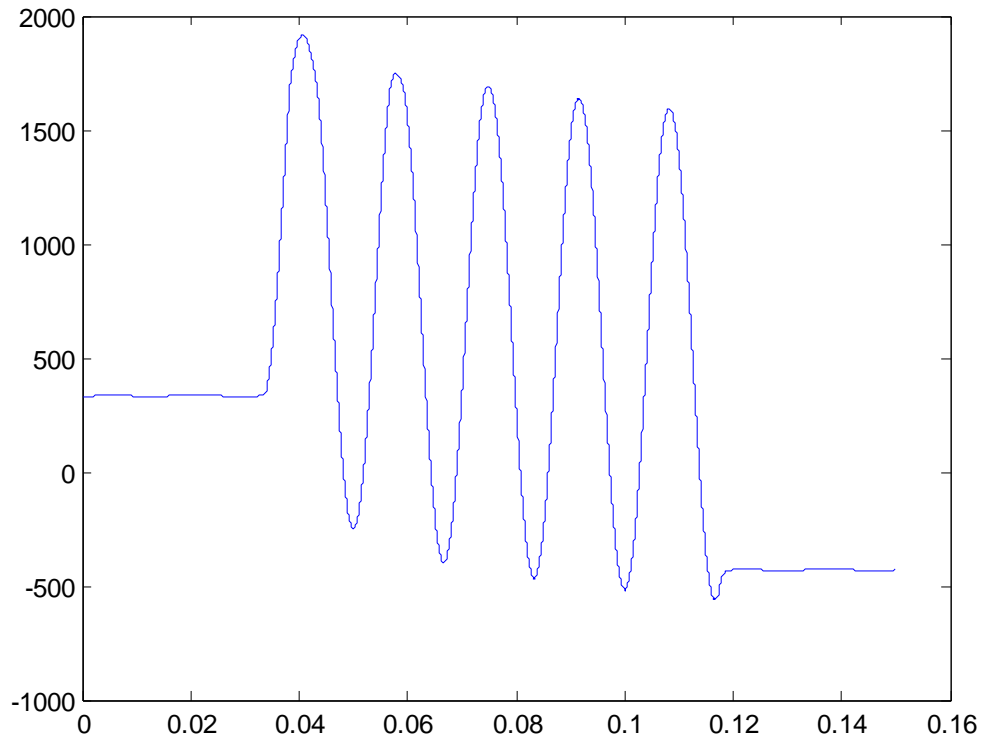
Current vs. Time



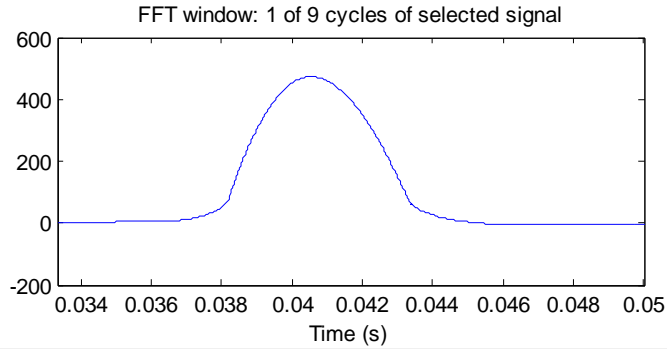
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.35



```

Sampling time = 1.75706e-005 s
Samples per cycle = 948.556
DC component = 108.1
Total Harmonic Distortion (THD) = 217.72%
    
```

0 Hz (DC)	108.10
60 Hz Fund	190.87
120 Hz (h2)	122.97
180 Hz (h3)	58.01
240 Hz (h4)	13.02
300 Hz (h5)	9.18
360 Hz (h6)	11.78
420 Hz (h7)	5.51
480 Hz (h8)	1.90
540 Hz (h9)	4.52
600 Hz (h10)	3.23
660 Hz (h11)	0.64
720 Hz (h12)	2.11
780 Hz (h13)	2.14
840 Hz (h14)	0.46
900 Hz (h15)	1.08
960 Hz (h16)	1.43

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

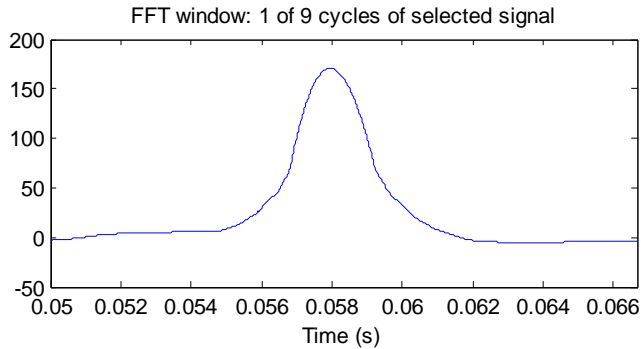
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75706e-005 s
Samples per cycle = 948.556
DC component = 26.28
Total Harmonic Distortion (THD) = 264.85%
    
```

0 Hz (DC)	26.28
60 Hz Fund	50.12
120 Hz (h2)	36.10
180 Hz (h3)	25.14
240 Hz (h4)	15.36
300 Hz (h5)	10.05
360 Hz (h6)	6.28
420 Hz (h7)	3.64
480 Hz (h8)	1.83
540 Hz (h9)	0.54
600 Hz (h10)	0.70
660 Hz (h11)	1.24
720 Hz (h12)	1.35
780 Hz (h13)	1.17
840 Hz (h14)	0.80
900 Hz (h15)	0.42
960 Hz (h16)	0.15

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

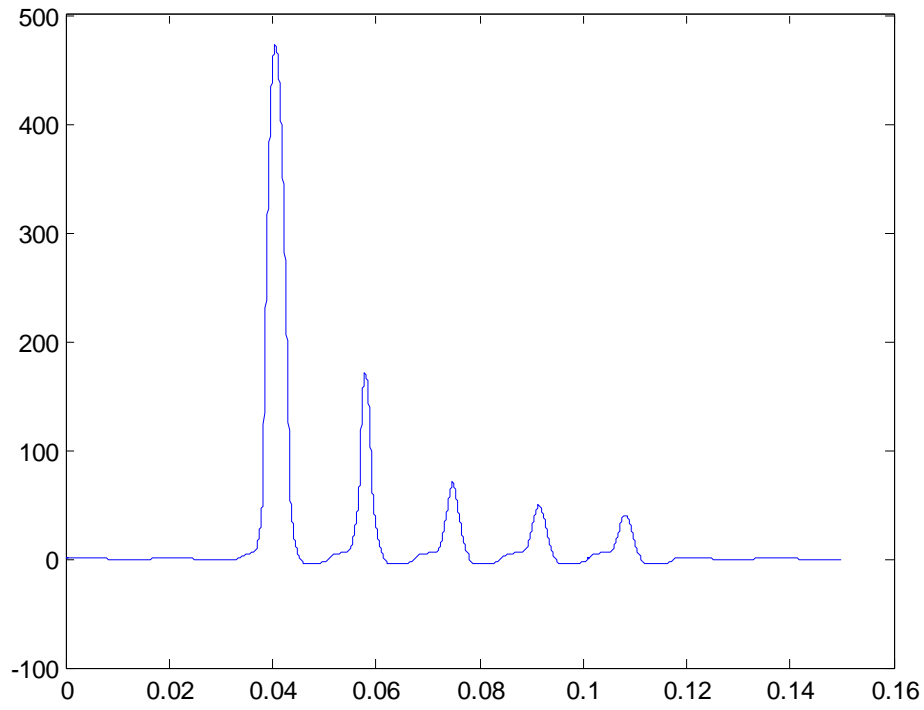
Frequency axis: Hertz

Display style: List (relative to specified ba...)

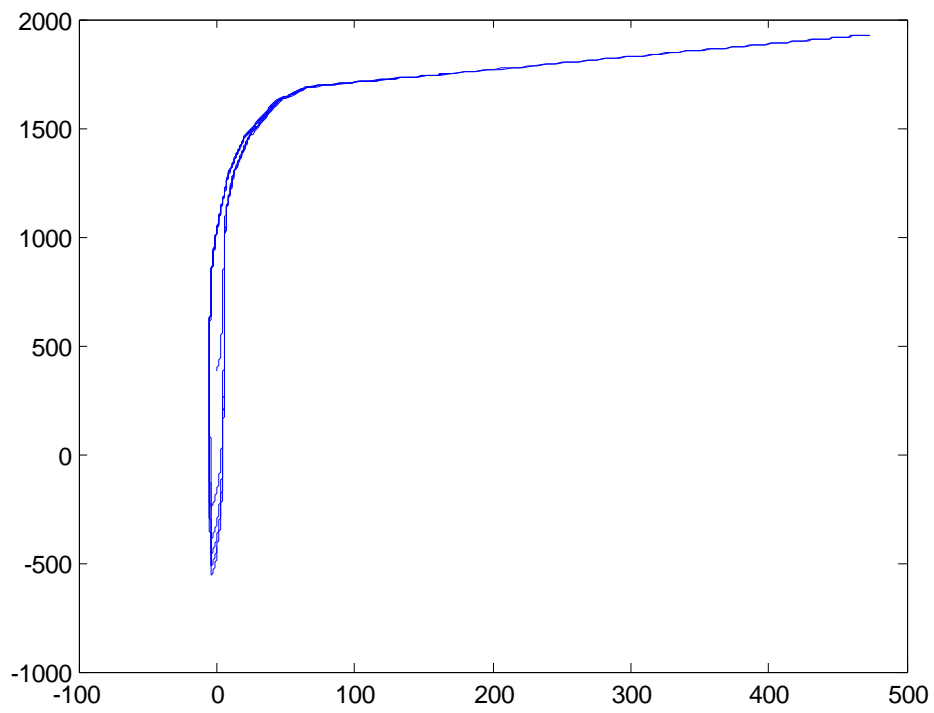
Base value: 1.0

Display Close

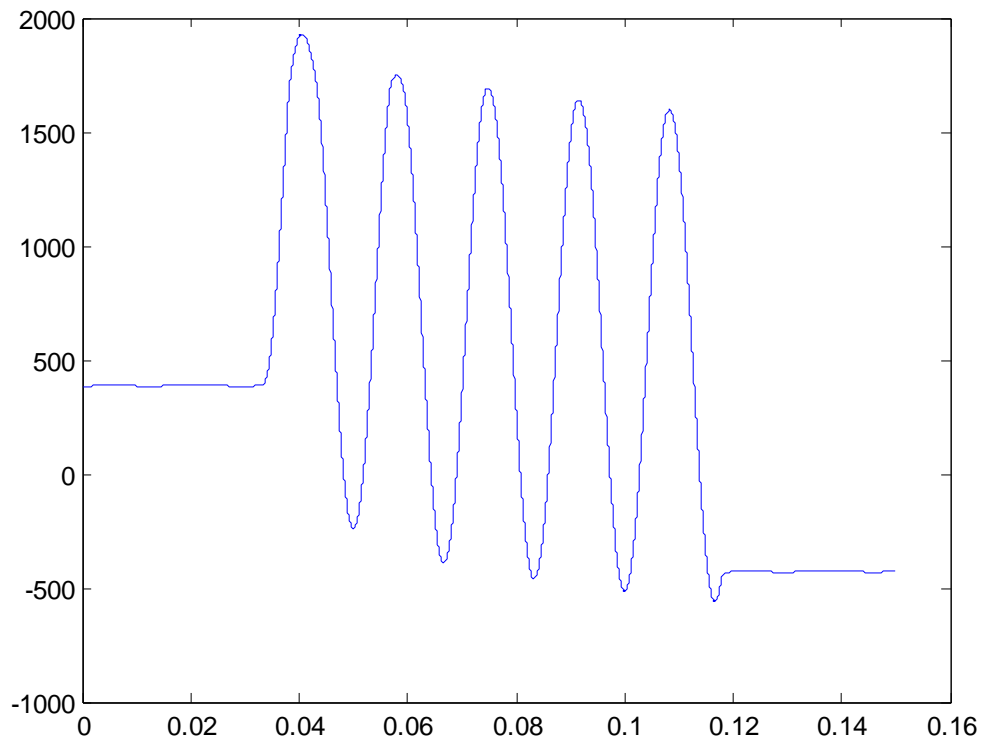
Current vs. Time



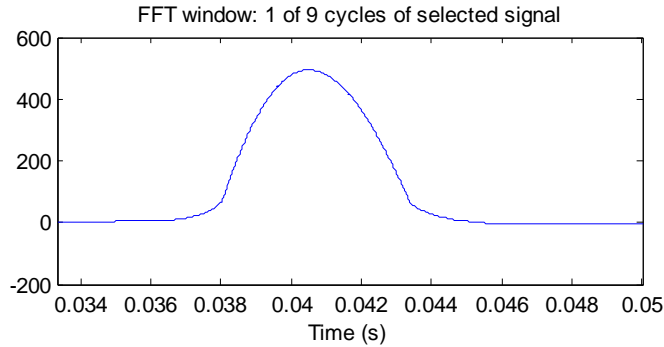
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.4



```

Sampling time = 1.76824e-005 s
Samples per cycle = 942.556
DC component = 115.8
Total Harmonic Distortion (THD) = 214.17%
    
```

0 Hz (DC)	115.84
60 Hz Fund	203.27
120 Hz (h2)	128.35
180 Hz (h3)	57.48
240 Hz (h4)	10.50
300 Hz (h5)	11.32
360 Hz (h6)	11.93
420 Hz (h7)	4.24
480 Hz (h8)	3.22
540 Hz (h9)	4.84
600 Hz (h10)	2.52
660 Hz (h11)	1.30
720 Hz (h12)	2.51
780 Hz (h13)	1.68
840 Hz (h14)	0.59
900 Hz (h15)	1.51
960 Hz (h16)	1.15

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

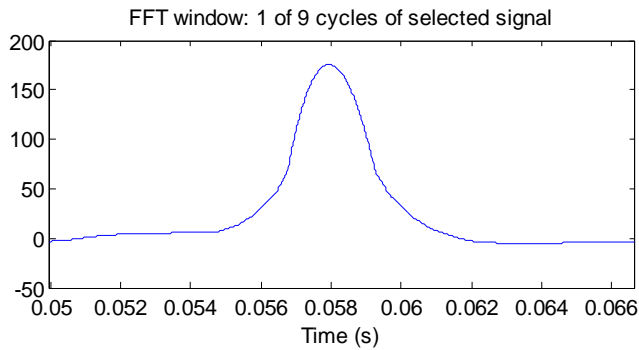
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.76824e-005 s
Samples per cycle = 942.556
DC component = 27.2
Total Harmonic Distortion (THD) = 264.70%
    
```

0 Hz (DC)	27.20
60 Hz Fund	51.81
120 Hz (h2)	37.41
180 Hz (h3)	26.04
240 Hz (h4)	15.91
300 Hz (h5)	10.32
360 Hz (h6)	6.33
420 Hz (h7)	3.53
480 Hz (h8)	1.64
540 Hz (h9)	0.47
600 Hz (h10)	0.90
660 Hz (h11)	1.40
720 Hz (h12)	1.43
780 Hz (h13)	1.16
840 Hz (h14)	0.72
900 Hz (h15)	0.31
960 Hz (h16)	0.16

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

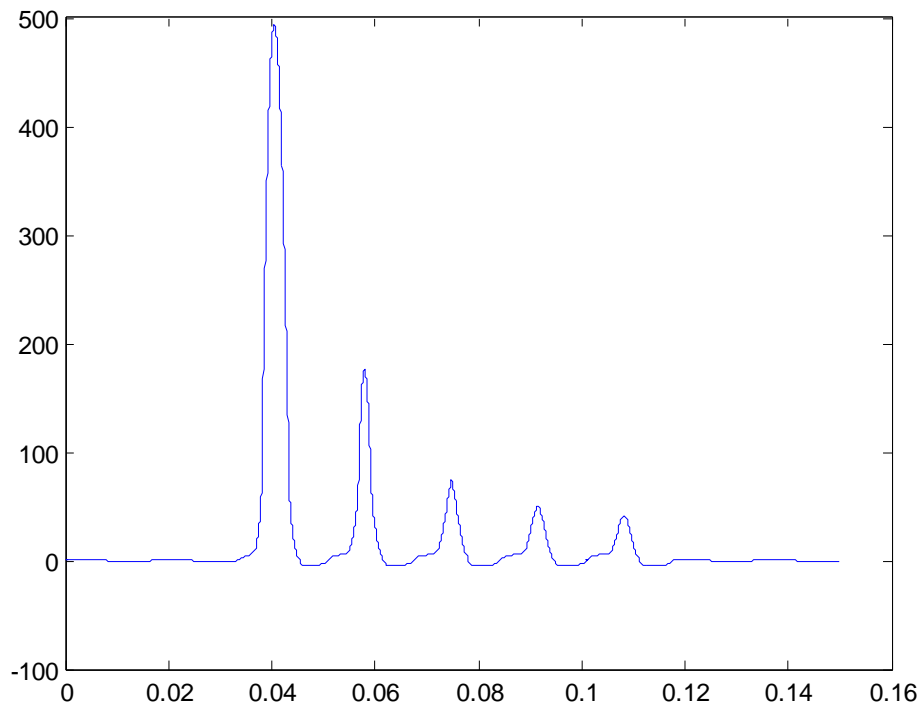
Frequency axis: Hertz

Display style : List (relative to specified ba...)

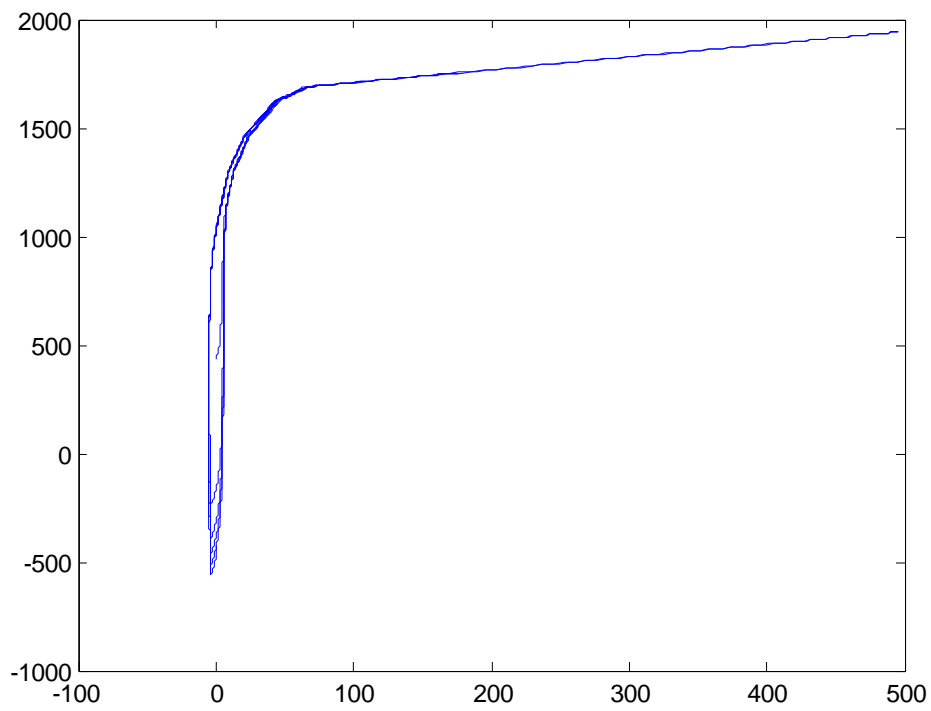
Base value: 1.0

Display Close

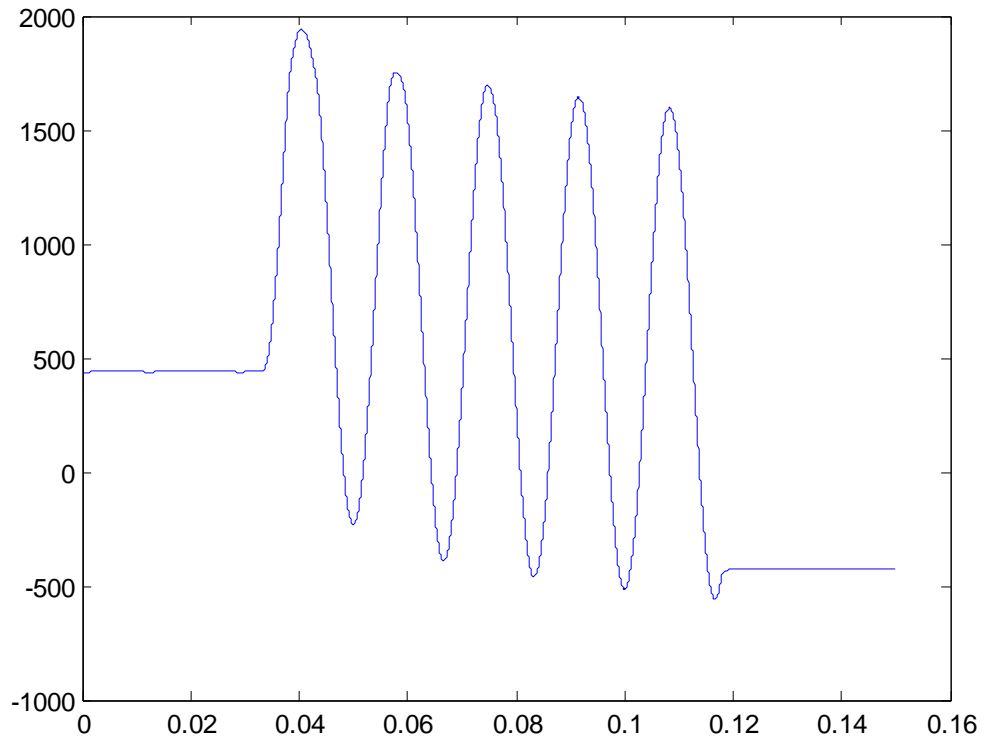
Current vs. Time



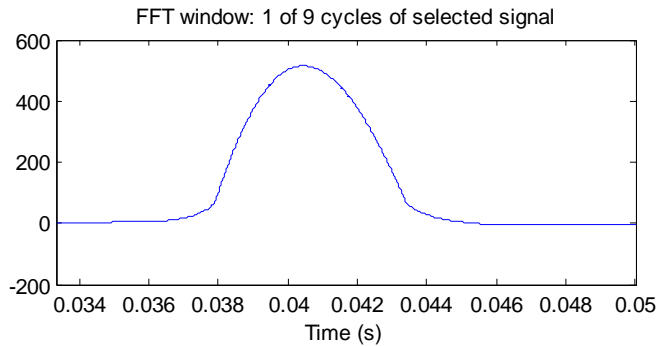
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.45



```

Sampling time = 1.75891e-005 s
Samples per cycle = 947.556
DC component = 123.7
Total Harmonic Distortion (THD) = 210.73%
    
```

0 Hz (DC)	123.65
60 Hz Fund	215.60
120 Hz (h2)	133.32
180 Hz (h3)	56.47
240 Hz (h4)	8.16
300 Hz (h5)	13.27
360 Hz (h6)	11.68
420 Hz (h7)	2.89
480 Hz (h8)	4.46
540 Hz (h9)	4.79
600 Hz (h10)	1.63
660 Hz (h11)	2.18
720 Hz (h12)	2.57
780 Hz (h13)	0.99
840 Hz (h14)	1.27
900 Hz (h15)	1.63
960 Hz (h16)	0.60

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

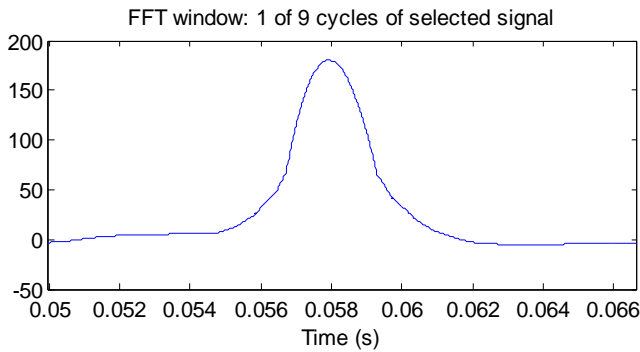
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.75891e-005 s
Samples per cycle = 947.556
DC component = 28.08
Total Harmonic Distortion (THD) = 264.49%
    
```

0 Hz (DC)	28.08
60 Hz Fund	53.42
120 Hz (h2)	38.66
180 Hz (h3)	26.89
240 Hz (h4)	16.42
300 Hz (h5)	10.55
360 Hz (h6)	6.35
420 Hz (h7)	3.40
480 Hz (h8)	1.45
540 Hz (h9)	0.53
600 Hz (h10)	1.10
660 Hz (h11)	1.54
720 Hz (h12)	1.49
780 Hz (h13)	1.13
840 Hz (h14)	0.64
900 Hz (h15)	0.22
960 Hz (h16)	0.24

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

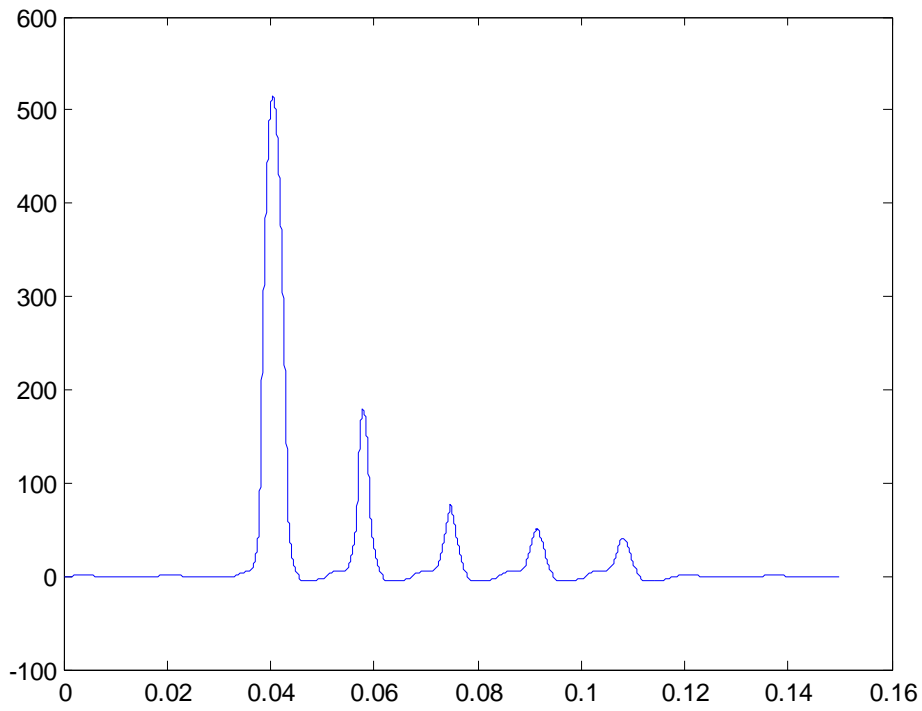
Frequency axis: Hertz

Display style: List (relative to specified ba...)

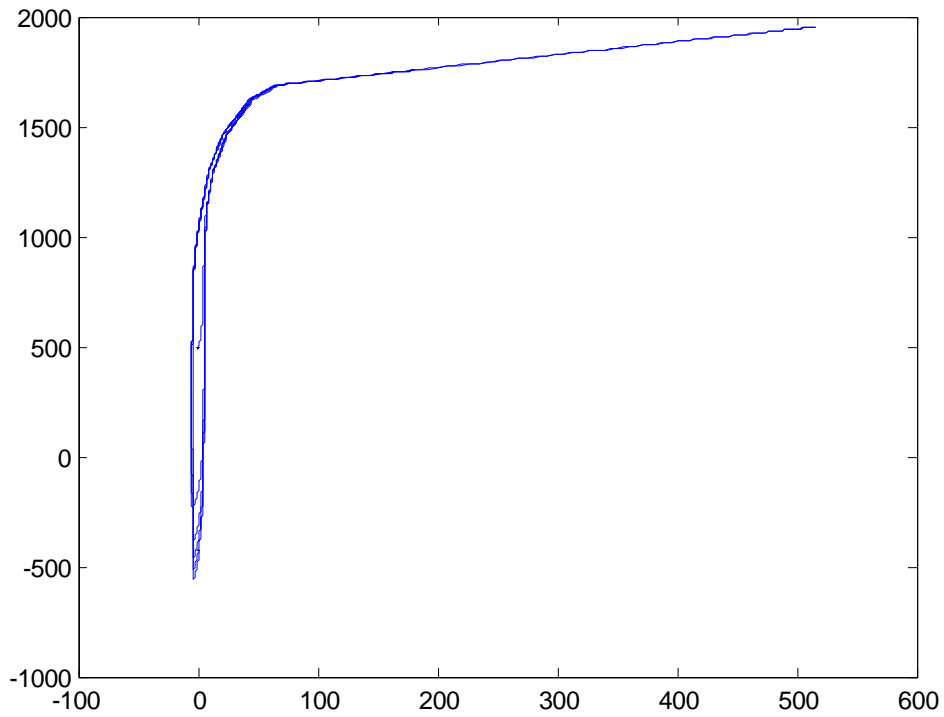
Base value: 1.0

Display Close

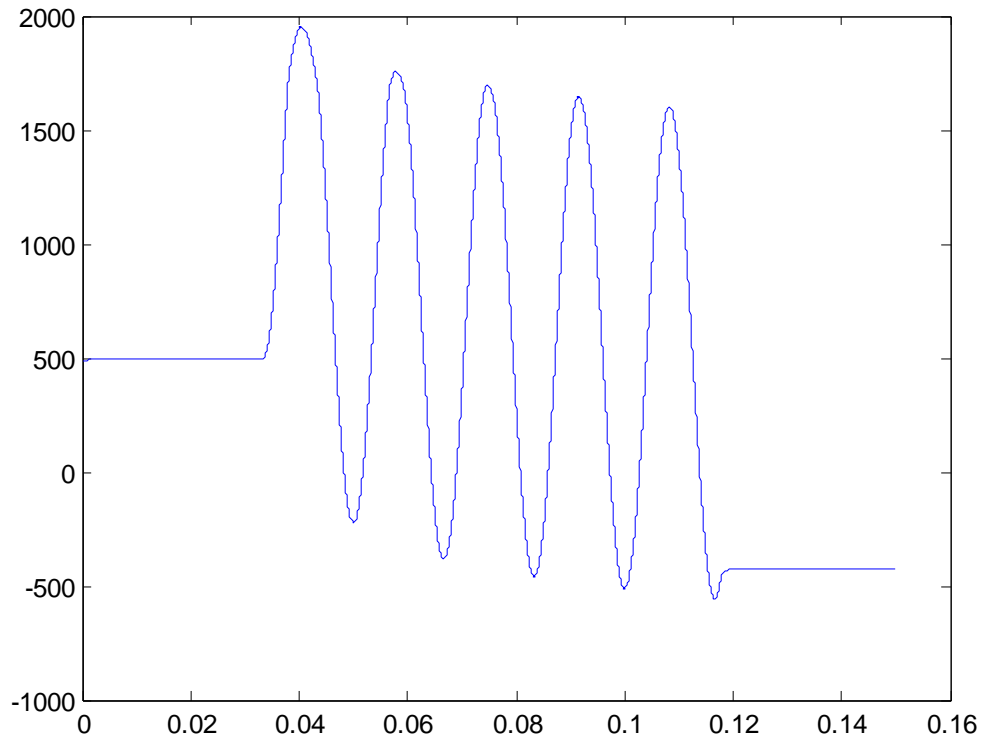
Current vs. Time



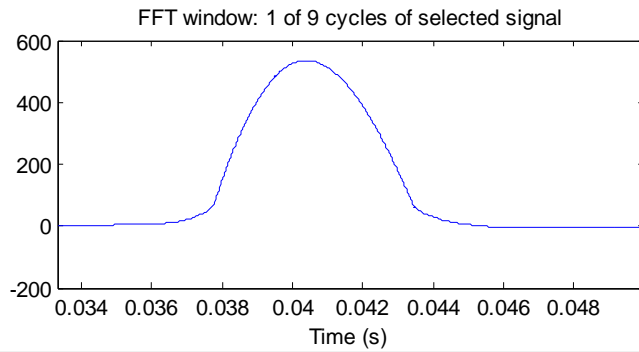
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.5



```

Sampling time = 1.76222e-005 s
Samples per cycle = 945.778
DC component = 131.6
Total Harmonic Distortion (THD) = 207.36%
    
```

0 Hz (DC)	131.56
60 Hz Fund	227.90
120 Hz (h2)	137.86
180 Hz (h3)	55.00
240 Hz (h4)	6.45
300 Hz (h5)	14.96
360 Hz (h6)	11.05
420 Hz (h7)	1.83
480 Hz (h8)	5.49
540 Hz (h9)	4.39
600 Hz (h10)	0.93
660 Hz (h11)	2.87
720 Hz (h12)	2.29
780 Hz (h13)	0.37
840 Hz (h14)	1.77
900 Hz (h15)	1.40
960 Hz (h16)	0.23

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

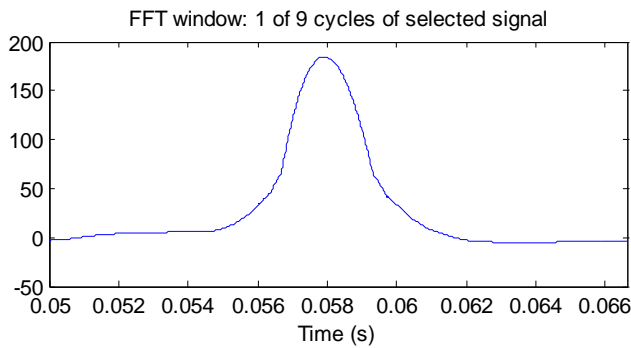
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.76222e-005 s
Samples per cycle = 945.778
DC component = 28.92
Total Harmonic Distortion (THD) = 264.20%
    
```

0 Hz (DC)	28.92
60 Hz Fund	54.98
120 Hz (h2)	39.85
180 Hz (h3)	27.70
240 Hz (h4)	16.89
300 Hz (h5)	10.75
360 Hz (h6)	6.35
420 Hz (h7)	3.26
480 Hz (h8)	1.26
540 Hz (h9)	0.66
600 Hz (h10)	1.29
660 Hz (h11)	1.67
720 Hz (h12)	1.52
780 Hz (h13)	1.09
840 Hz (h14)	0.54
900 Hz (h15)	0.15
960 Hz (h16)	0.34

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

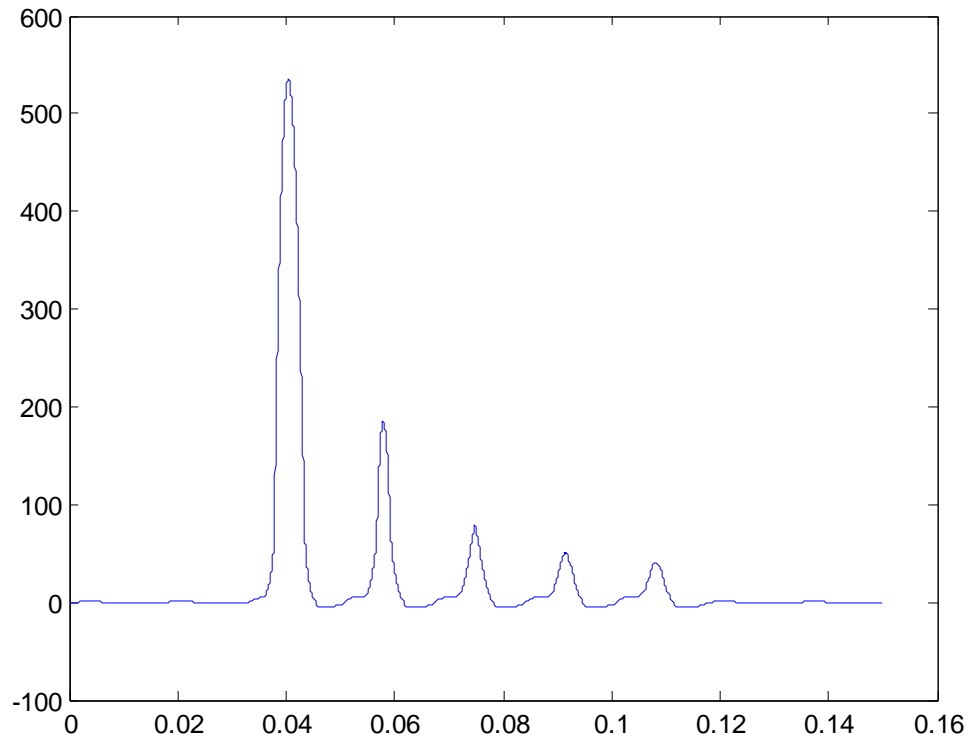
Frequency axis: Hertz

Display style: List (relative to specified ba...)

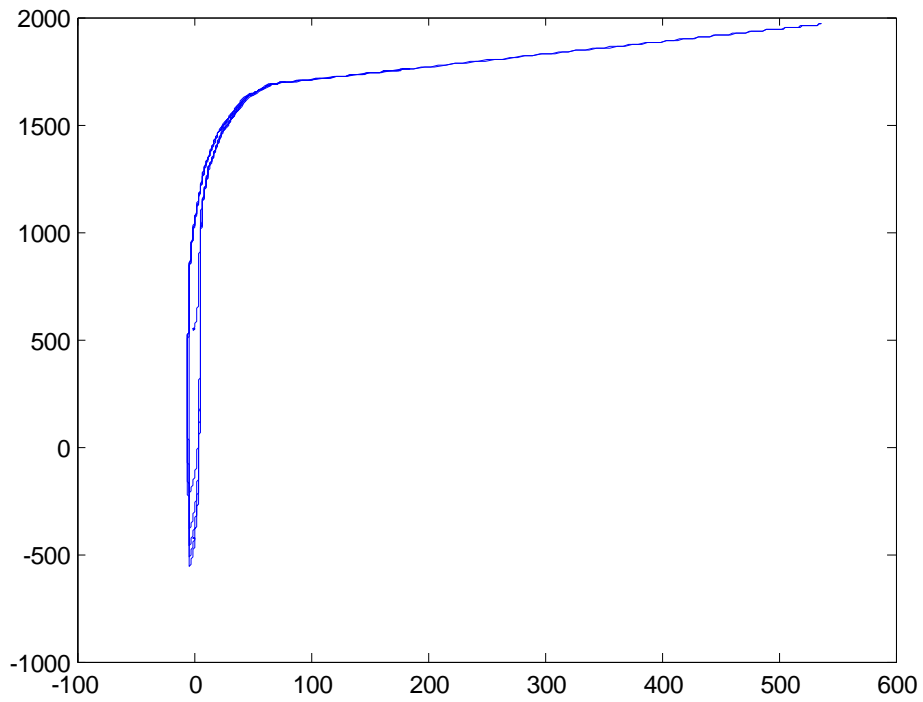
Base value: 1.0

Display Close

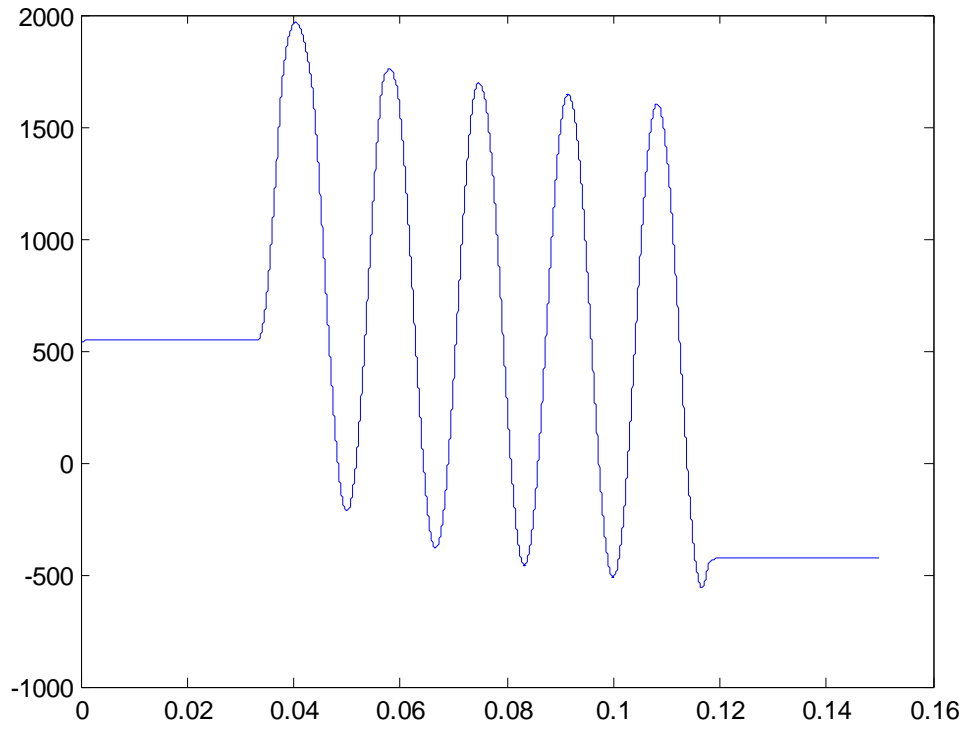
Current vs. Time



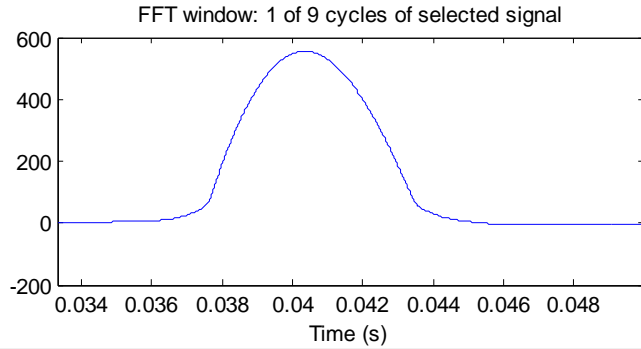
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.55



```

Sampling time = 1.76887e-005 s
Samples per cycle = 942.222
DC component = 139.6
Total Harmonic Distortion (THD) = 204.06%
    
```

0 Hz (DC)	139.58
60 Hz Fund	240.14
120 Hz (h2)	141.96
180 Hz (h3)	53.07
240 Hz (h4)	6.11
300 Hz (h5)	16.35
360 Hz (h6)	10.06
420 Hz (h7)	2.05
480 Hz (h8)	6.23
540 Hz (h9)	3.66
600 Hz (h10)	1.30
660 Hz (h11)	3.27
720 Hz (h12)	1.72
780 Hz (h13)	0.91
840 Hz (h14)	1.99
900 Hz (h15)	0.91
960 Hz (h16)	0.84

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

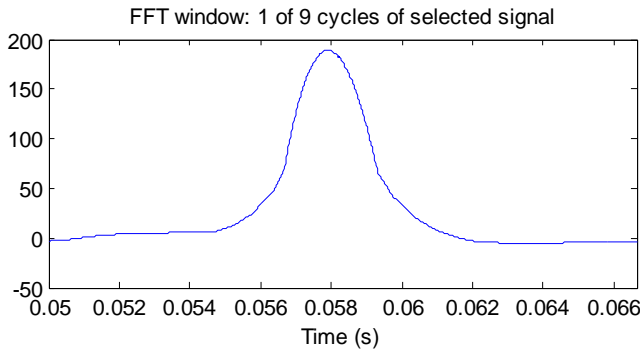
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style: List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.76887e-005 s
Samples per cycle = 942.222
DC component = 29.74
Total Harmonic Distortion (THD) = 263.82%
    
```

0 Hz (DC)	29.74
60 Hz Fund	56.47
120 Hz (h2)	40.99
180 Hz (h3)	28.45
240 Hz (h4)	17.31
300 Hz (h5)	10.92
360 Hz (h6)	6.32
420 Hz (h7)	3.10
480 Hz (h8)	1.09
540 Hz (h9)	0.83
600 Hz (h10)	1.46
660 Hz (h11)	1.76
720 Hz (h12)	1.53
780 Hz (h13)	1.03
840 Hz (h14)	0.44
900 Hz (h15)	0.16
960 Hz (h16)	0.43

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

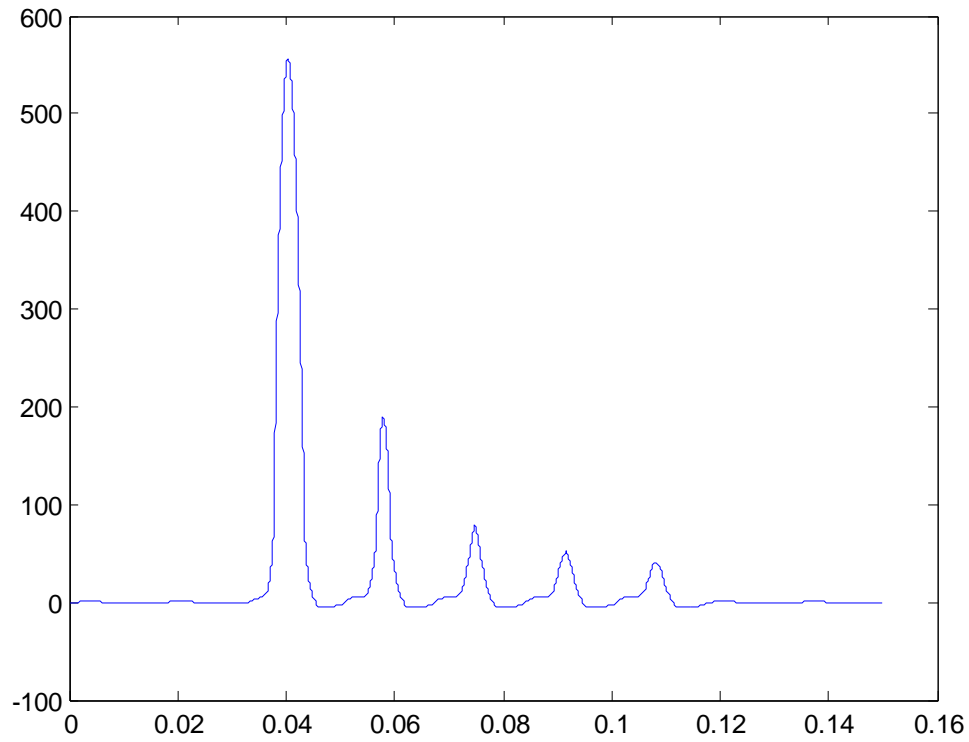
Frequency axis: Hertz

Display style: List (relative to specified ba...)

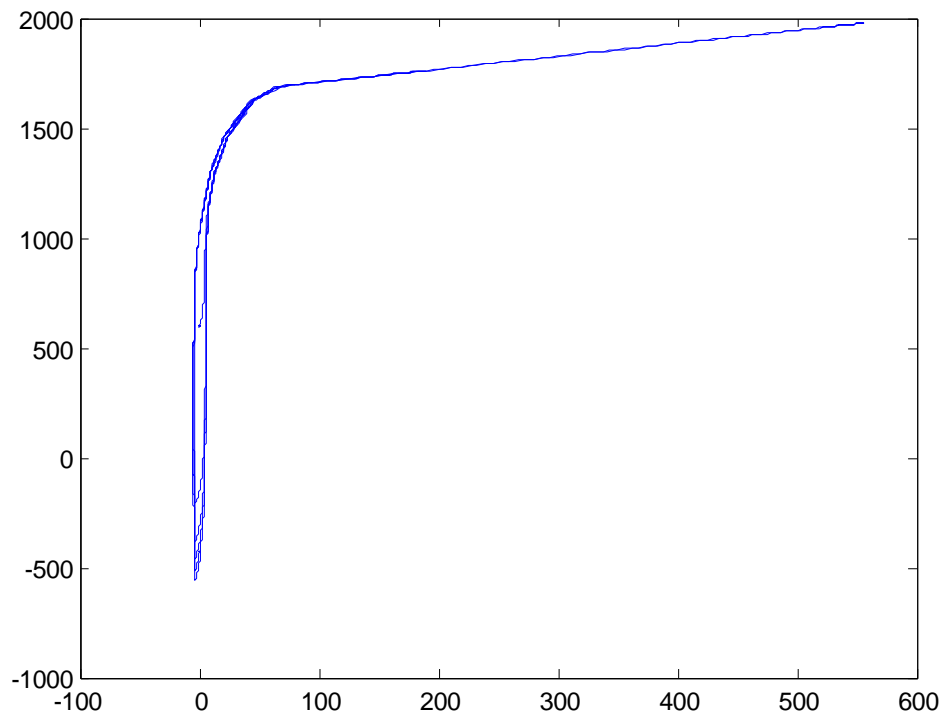
Base value: 1.0

Display Close

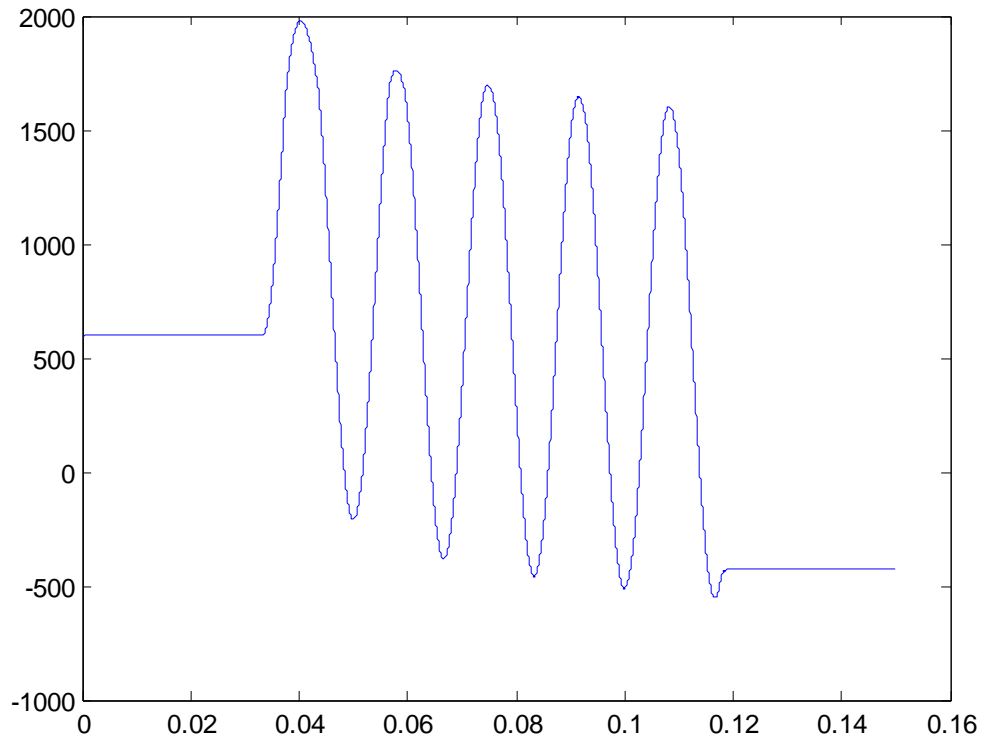
Current vs. Time



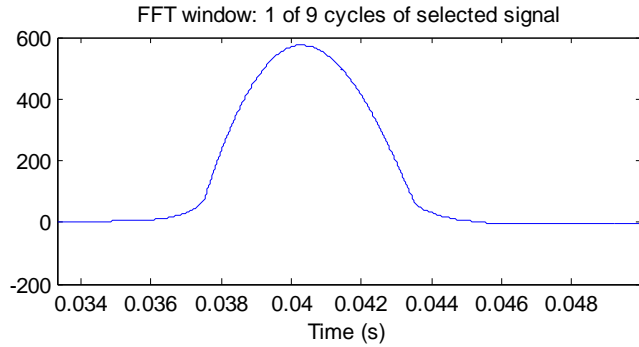
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.6



```

Sampling time = 1.77347e-005 s
Samples per cycle = 939.778
DC component = 147.5
Total Harmonic Distortion (THD) = 200.99%
    
```

0 Hz (DC)	147.51
60 Hz Fund	252.13
120 Hz (h2)	145.68
180 Hz (h3)	50.91
240 Hz (h4)	7.32
300 Hz (h5)	17.38
360 Hz (h6)	8.82
420 Hz (h7)	3.24
480 Hz (h8)	6.62
540 Hz (h9)	2.73
600 Hz (h10)	2.18
660 Hz (h11)	3.33
720 Hz (h12)	1.01
780 Hz (h13)	1.60
840 Hz (h14)	1.87
900 Hz (h15)	0.37
960 Hz (h16)	1.33

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

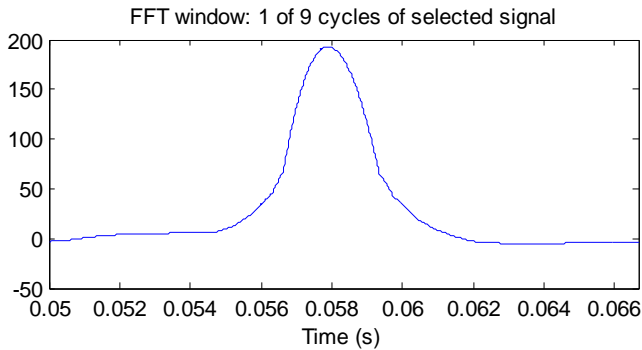
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.77347e-005 s
Samples per cycle = 939.778
DC component = 30.5
Total Harmonic Distortion (THD) = 263.63%
    
```

0 Hz (DC)	30.50
60 Hz Fund	57.86
120 Hz (h2)	42.06
180 Hz (h3)	29.16
240 Hz (h4)	17.72
300 Hz (h5)	11.07
360 Hz (h6)	6.30
420 Hz (h7)	2.96
480 Hz (h8)	0.94
540 Hz (h9)	1.00
600 Hz (h10)	1.61
660 Hz (h11)	1.85
720 Hz (h12)	1.54
780 Hz (h13)	0.96
840 Hz (h14)	0.35
900 Hz (h15)	0.23
960 Hz (h16)	0.51

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

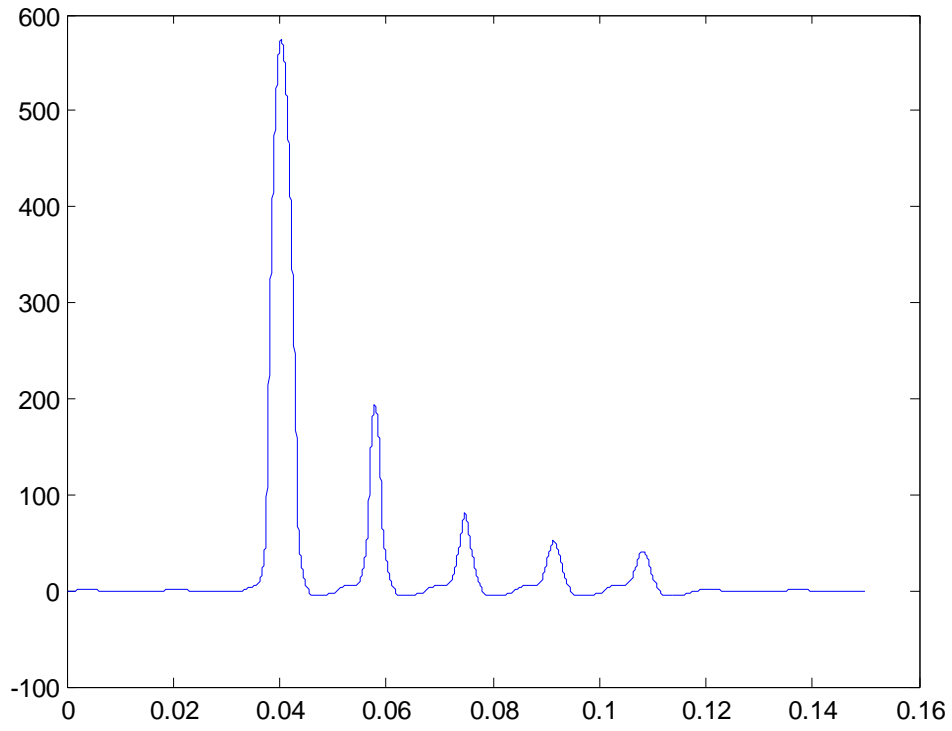
Frequency axis: Hertz

Display style : List (relative to specified ba...)

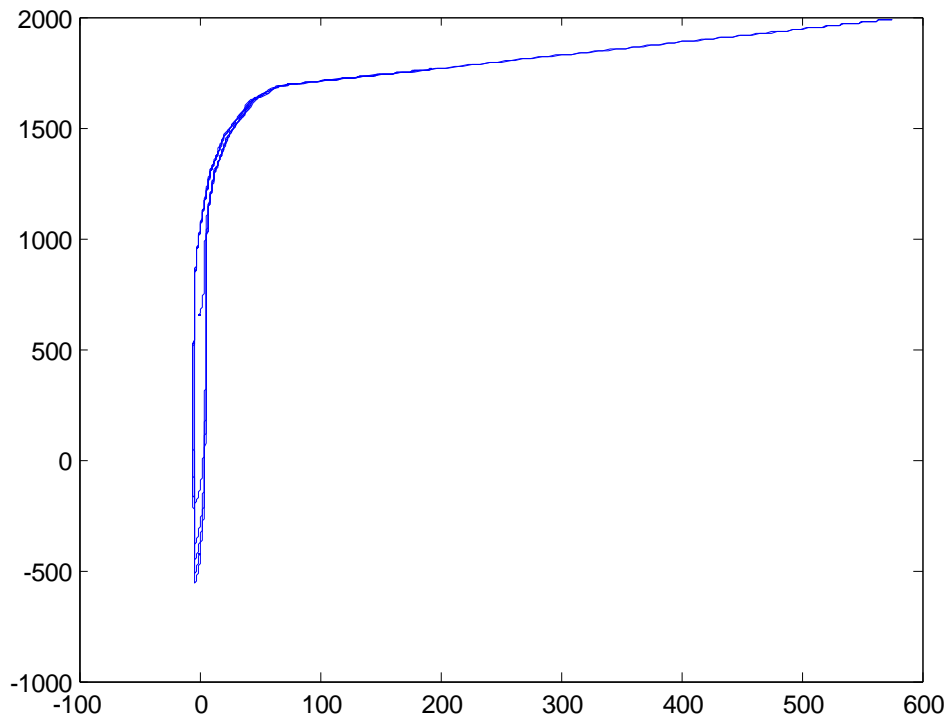
Base value: 1.0

Display Close

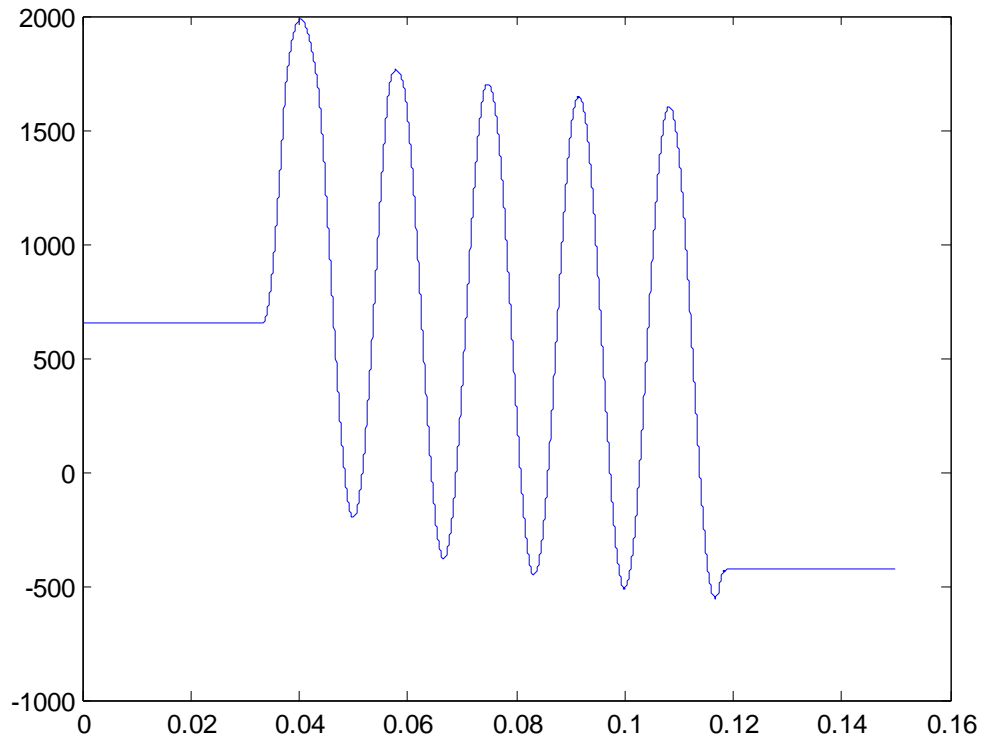
Current vs. Time



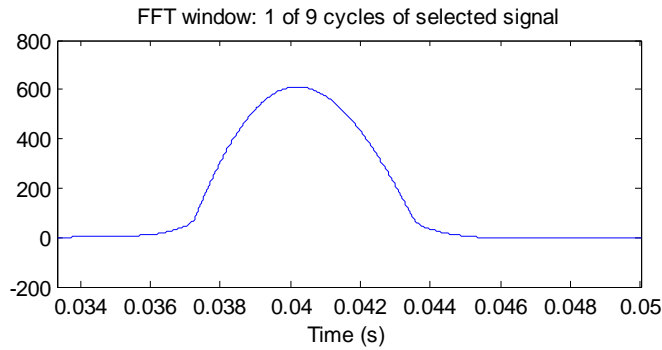
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.7



```

Sampling time = 1.76263e-005 s
Samples per cycle = 945.556
DC component = 163.6
Total Harmonic Distortion (THD) = 194.97%
    
```

0 Hz (DC)	163.63
60 Hz Fund	275.82
120 Hz (h2)	151.72
180 Hz (h3)	45.43
240 Hz (h4)	11.91
300 Hz (h5)	18.43
360 Hz (h6)	5.63
420 Hz (h7)	5.92
480 Hz (h8)	6.39
540 Hz (h9)	0.94
600 Hz (h10)	3.60
660 Hz (h11)	2.49
720 Hz (h12)	1.06
780 Hz (h13)	2.31
840 Hz (h14)	0.84
900 Hz (h15)	1.17
960 Hz (h16)	1.48

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

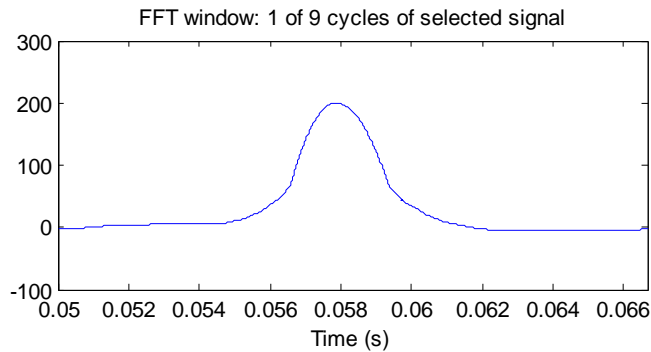
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.76263e-005 s
Samples per cycle = 945.556
DC component = 31.93
Total Harmonic Distortion (THD) = 263.04%
    
```

0 Hz (DC)	31.93
60 Hz Fund	60.48
120 Hz (h2)	44.05
180 Hz (h3)	30.46
240 Hz (h4)	18.43
300 Hz (h5)	11.30
360 Hz (h6)	6.20
420 Hz (h7)	2.65
480 Hz (h8)	0.74
540 Hz (h9)	1.33
600 Hz (h10)	1.87
660 Hz (h11)	1.96
720 Hz (h12)	1.50
780 Hz (h13)	0.81
840 Hz (h14)	0.18
900 Hz (h15)	0.41
960 Hz (h16)	0.65

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

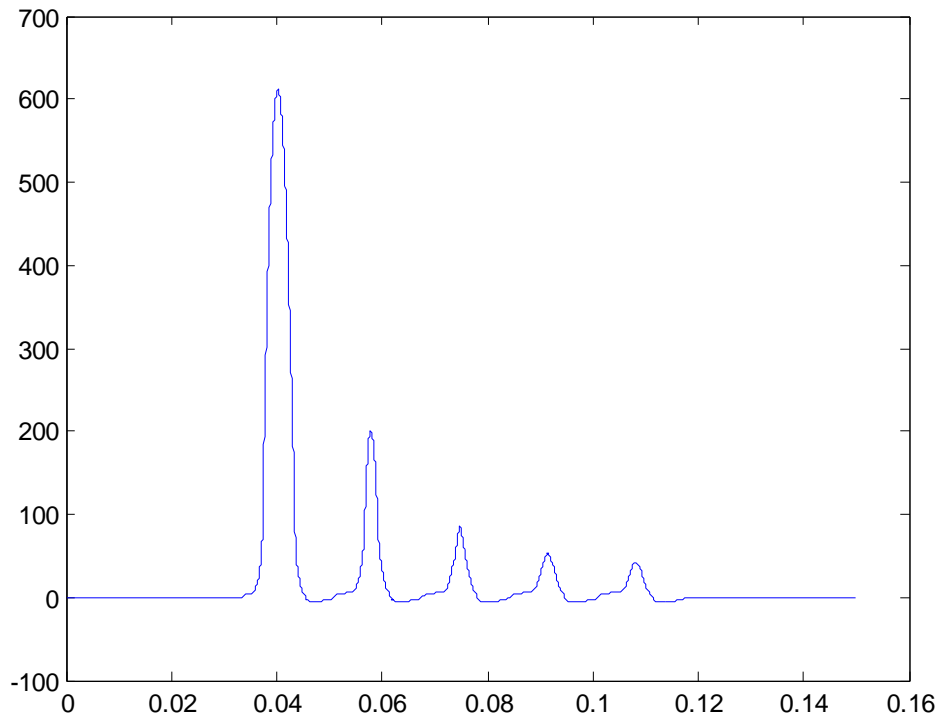
Frequency axis: Hertz

Display style : List (relative to specified ba...)

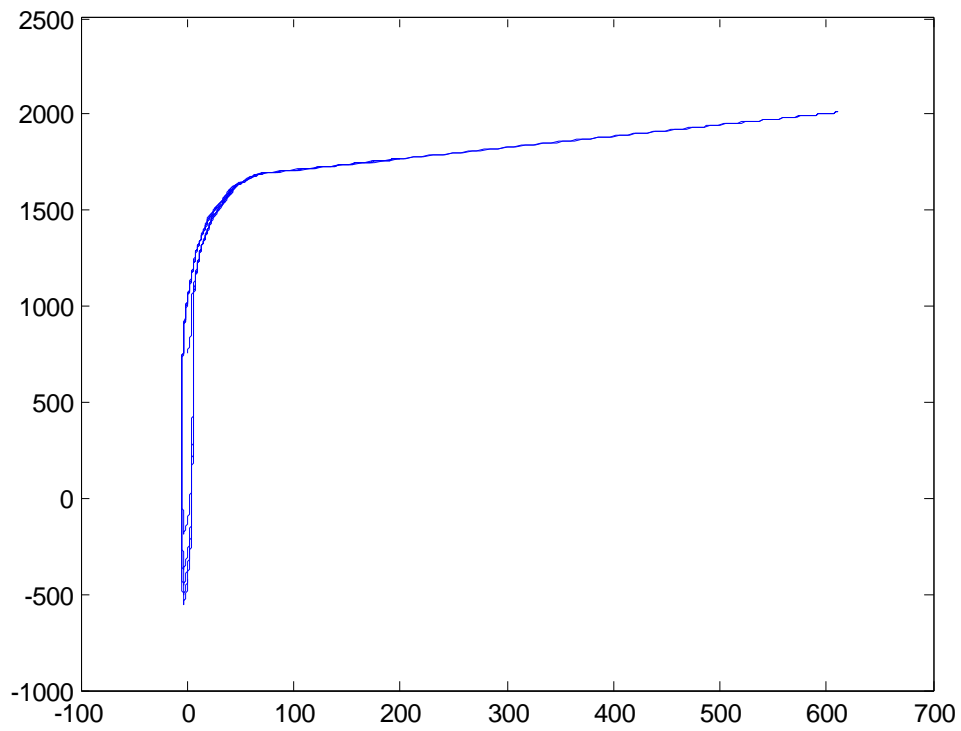
Base value: 1.0

Display Close

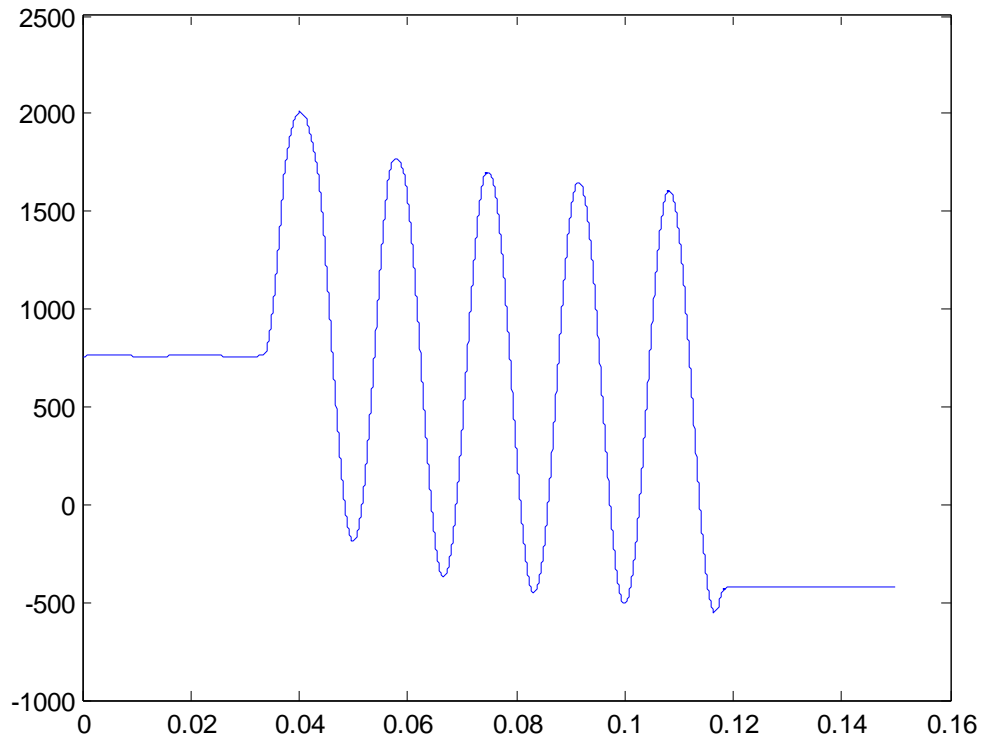
Current vs. Time



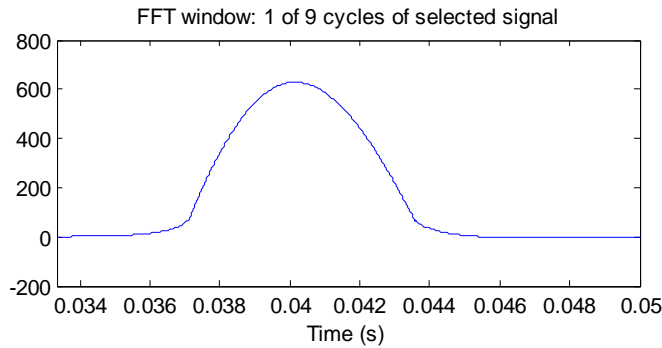
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.75



```

Sampling time = 1.77494e-005 s
Samples per cycle = 939
DC component = 171.9
Total Harmonic Distortion (THD) = 191.97%
    
```

0 Hz (DC)	171.85
60 Hz Fund	287.52
120 Hz (h2)	153.99
180 Hz (h3)	42.10
240 Hz (h4)	14.51
300 Hz (h5)	18.39
360 Hz (h6)	3.80
420 Hz (h7)	7.05
480 Hz (h8)	5.74
540 Hz (h9)	1.51
600 Hz (h10)	3.92
660 Hz (h11)	1.68
720 Hz (h12)	1.77
780 Hz (h13)	2.21
840 Hz (h14)	0.24
900 Hz (h15)	1.58
960 Hz (h16)	1.07

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

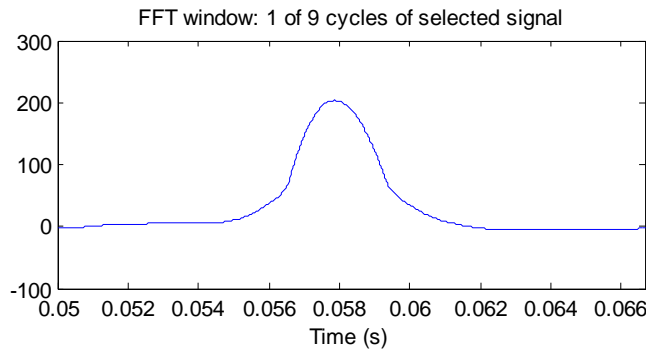
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.77494e-005 s
Samples per cycle = 939
DC component = 32.61
Total Harmonic Distortion (THD) = 262.64%
    
```

0 Hz (DC)	32.61
60 Hz Fund	61.72
120 Hz (h2)	44.98
180 Hz (h3)	31.05
240 Hz (h4)	18.73
300 Hz (h5)	11.38
360 Hz (h6)	6.13
420 Hz (h7)	2.49
480 Hz (h8)	0.69
540 Hz (h9)	1.50
600 Hz (h10)	1.98
660 Hz (h11)	2.00
720 Hz (h12)	1.46
780 Hz (h13)	0.72
840 Hz (h14)	0.15
900 Hz (h15)	0.50
960 Hz (h16)	0.71

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

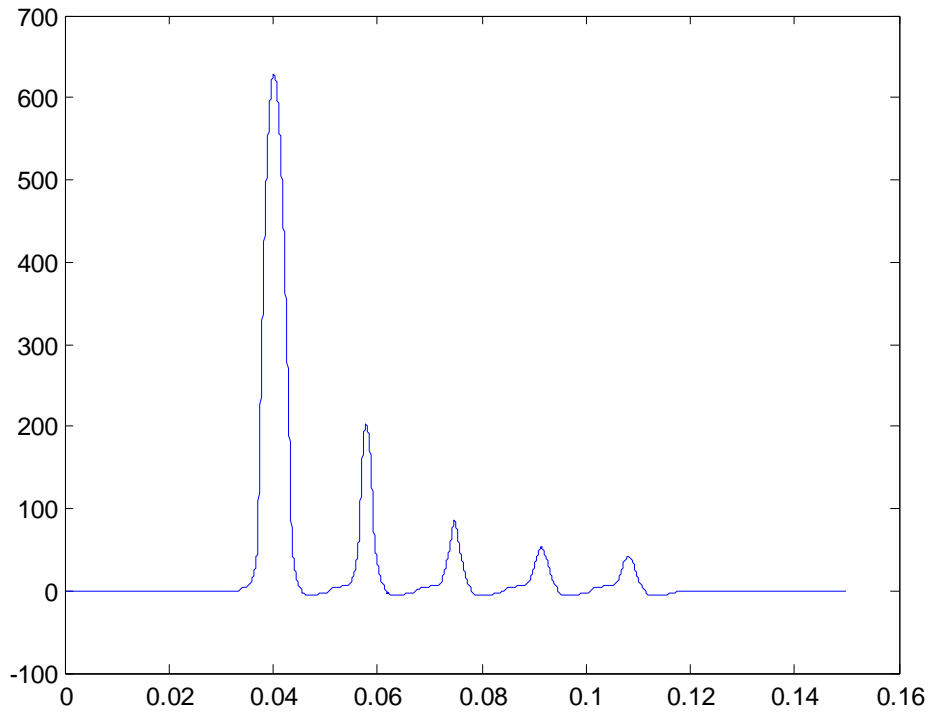
Frequency axis: Hertz

Display style : List (relative to specified ba...)

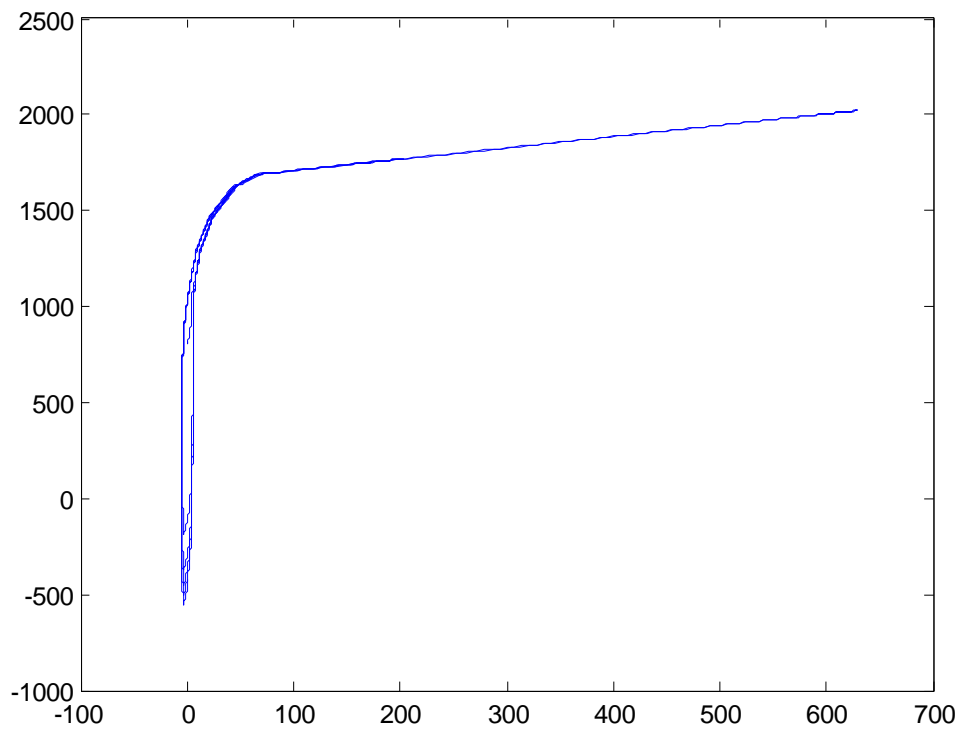
Base value: 1.0

Display Close

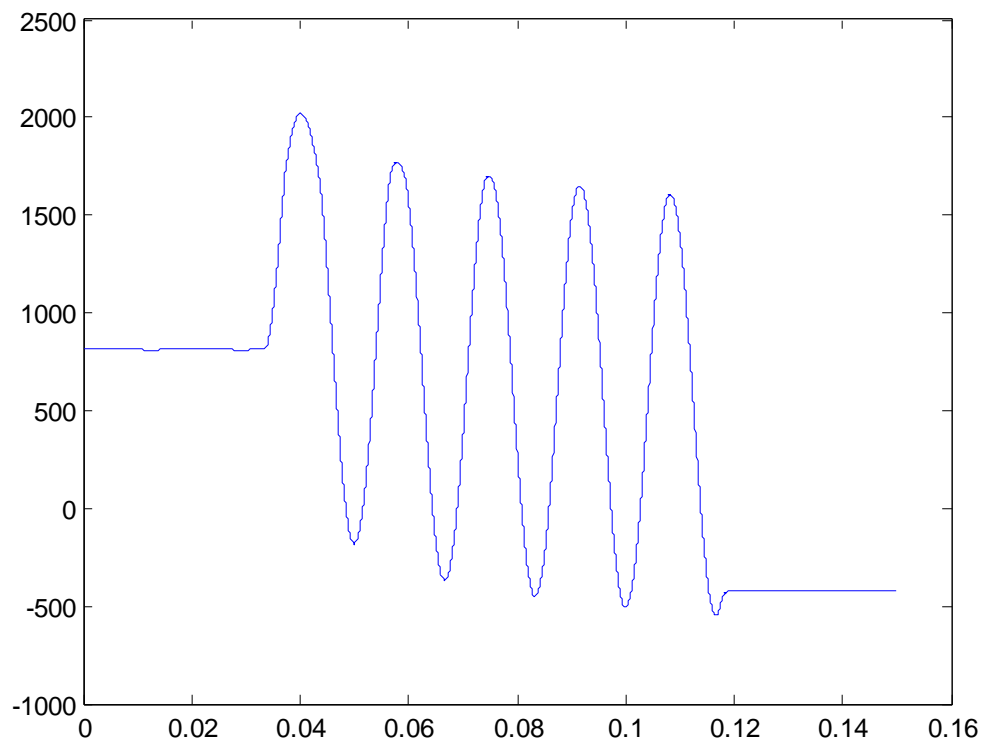
Current vs. Time



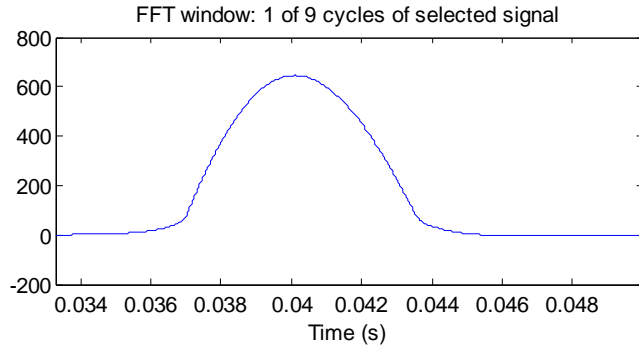
Flux vs. Current



Flux vs. Time



Phase Angle = 0, Residual Flux = 0.8



```

Sampling time = 1.77284e-005 s
Samples per cycle = 940.111
DC component = 180
Total Harmonic Distortion (THD) = 189.08%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	180.04
60 Hz Fund	298.96
120 Hz (h2)	155.81
180 Hz (h3)	38.59
240 Hz (h4)	16.98
300 Hz (h5)	18.02
360 Hz (h6)	2.14
420 Hz (h7)	7.90
480 Hz (h8)	4.81
540 Hz (h9)	2.56
600 Hz (h10)	3.91
660 Hz (h11)	0.79
720 Hz (h12)	2.31
780 Hz (h13)	1.83
840 Hz (h14)	0.80
900 Hz (h15)	1.71
960 Hz (h16)	0.47

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

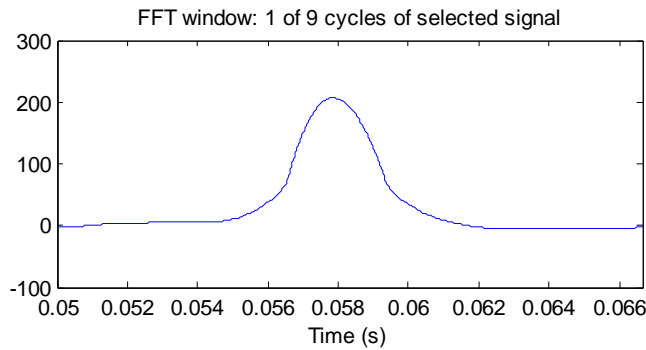
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 1.77284e-005 s
Samples per cycle = 940.111
DC component = 33.25
Total Harmonic Distortion (THD) = 262.29%
    
```

Frequency (Hz)	Amplitude
0 Hz (DC)	33.25
60 Hz Fund	62.89
120 Hz (h2)	45.86
180 Hz (h3)	31.61
240 Hz (h4)	19.01
300 Hz (h5)	11.46
360 Hz (h6)	6.06
420 Hz (h7)	2.33
480 Hz (h8)	0.70
540 Hz (h9)	1.65
600 Hz (h10)	2.08
660 Hz (h11)	2.02
720 Hz (h12)	1.42
780 Hz (h13)	0.63
840 Hz (h14)	0.18
900 Hz (h15)	0.58
960 Hz (h16)	0.76

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

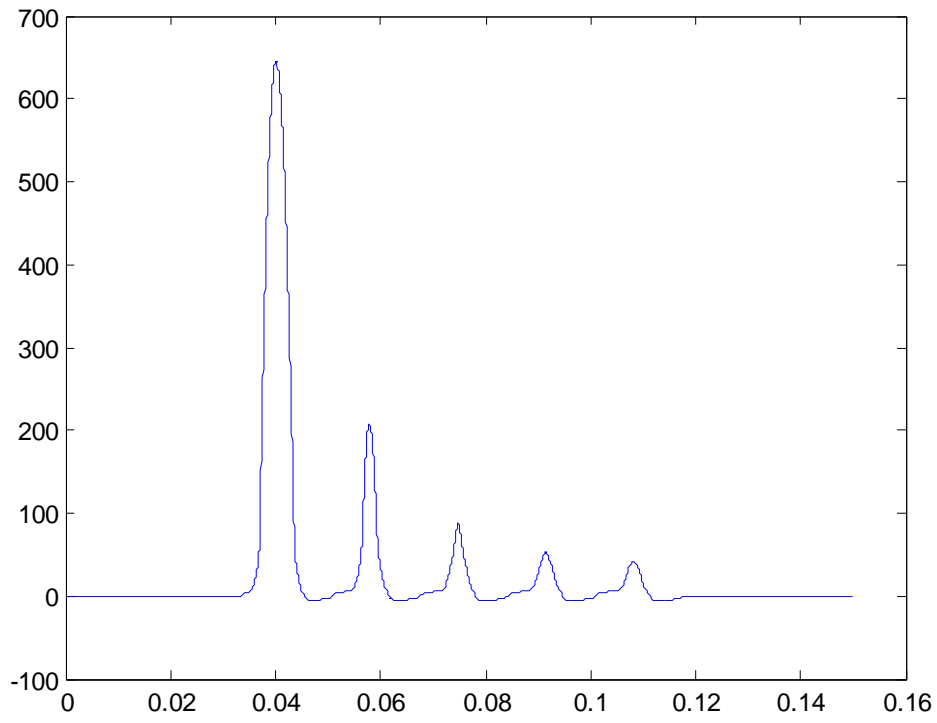
Frequency axis: Hertz

Display style : List (relative to specified ba...)

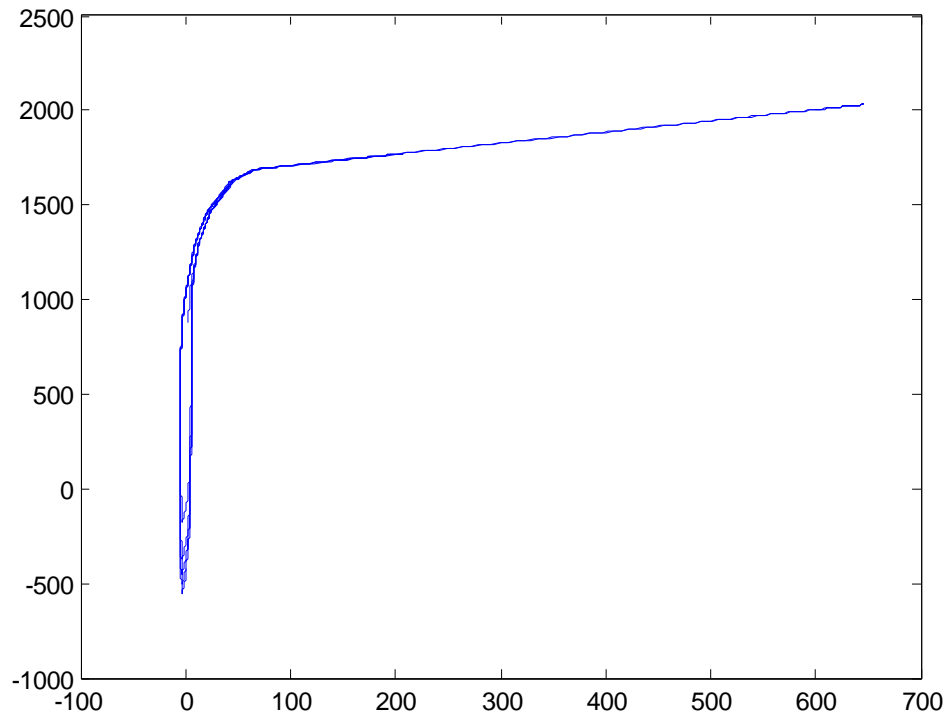
Base value: 1.0

Display Close

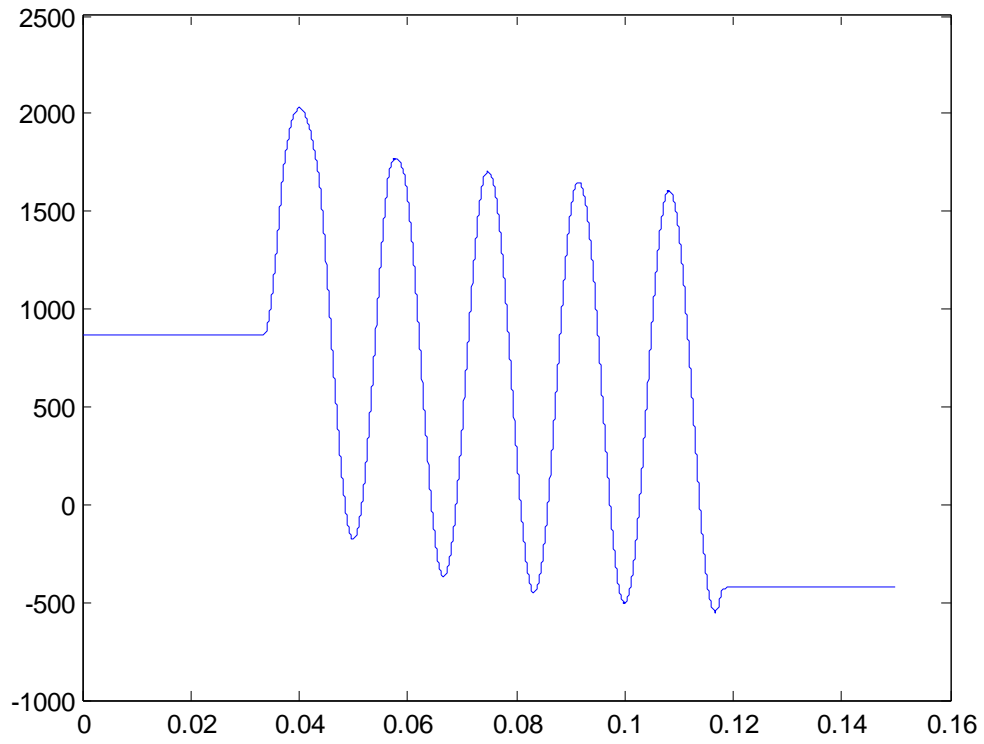
Current vs. Time



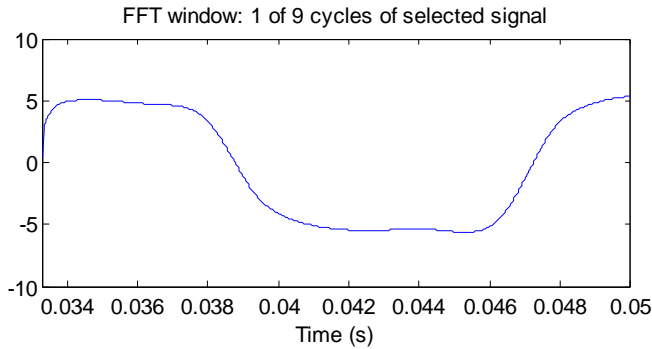
Flux vs. Current



Flux vs. Time



Phase Angle = 90°; Residual Flux = 0.0



```

Sampling time = 9.84123e-006 s
Samples per cycle = 1693.56
Fundamental = 6.241 peak (4.413 rms)
Total Harmonic Distortion (THD) = 24.35%
    
```

0 Hz (DC)	0.28
60 Hz Fund	6.24
120 Hz (h2)	0.17
180 Hz (h3)	1.41
240 Hz (h4)	0.16
300 Hz (h5)	0.46
360 Hz (h6)	0.07
420 Hz (h7)	0.11
480 Hz (h8)	0.05
540 Hz (h9)	0.10
600 Hz (h10)	0.06
660 Hz (h11)	0.05
720 Hz (h12)	0.05
780 Hz (h13)	0.05
840 Hz (h14)	0.05
900 Hz (h15)	0.04
960 Hz (h16)	0.04

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 2/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

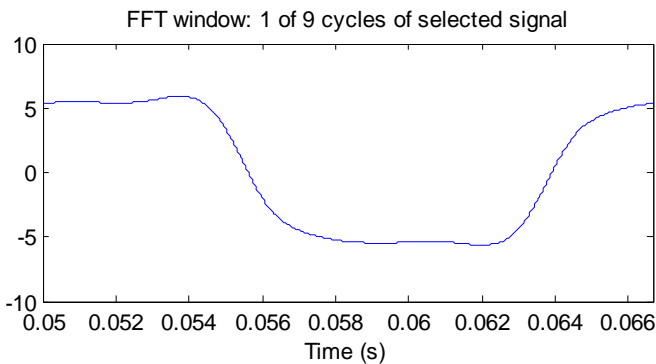
Max Frequency (Hz): 1000

Frequency axis: Hertz

Display style : List (relative to specified ba...)

Base value: 1.0

Display Close



```

Sampling time = 9.84123e-006 s
Samples per cycle = 1693.56
Fundamental = 6.621 peak (4.682 rms)
Total Harmonic Distortion (THD) = 24.73%
    
```

0 Hz (DC)	0.06
60 Hz Fund	6.62
120 Hz (h2)	0.08
180 Hz (h3)	1.55
240 Hz (h4)	0.03
300 Hz (h5)	0.51
360 Hz (h6)	0.00
420 Hz (h7)	0.14
480 Hz (h8)	0.01
540 Hz (h9)	0.04
600 Hz (h10)	0.00
660 Hz (h11)	0.01
720 Hz (h12)	0.00
780 Hz (h13)	0.01
840 Hz (h14)	0.00
900 Hz (h15)	0.01
960 Hz (h16)	0.00

Structure : ScopeData

Input : input 1

Signal number: 1

Start time (s): 3/60

Number of cycles: 1

Display FFT window

Fundamental frequency (Hz): 60

Max Frequency (Hz): 1000

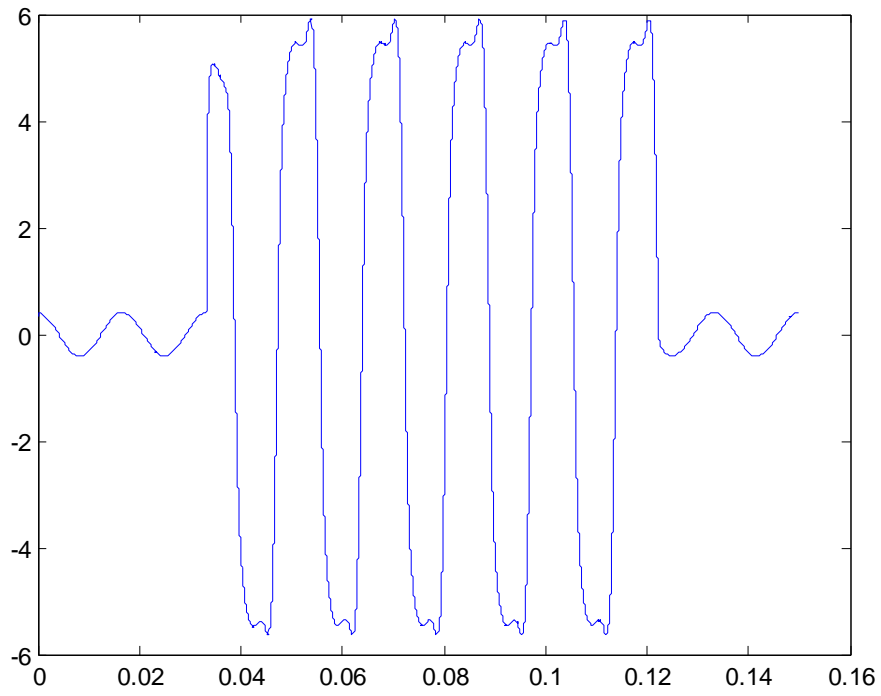
Frequency axis: Hertz

Display style : List (relative to specified ba...)

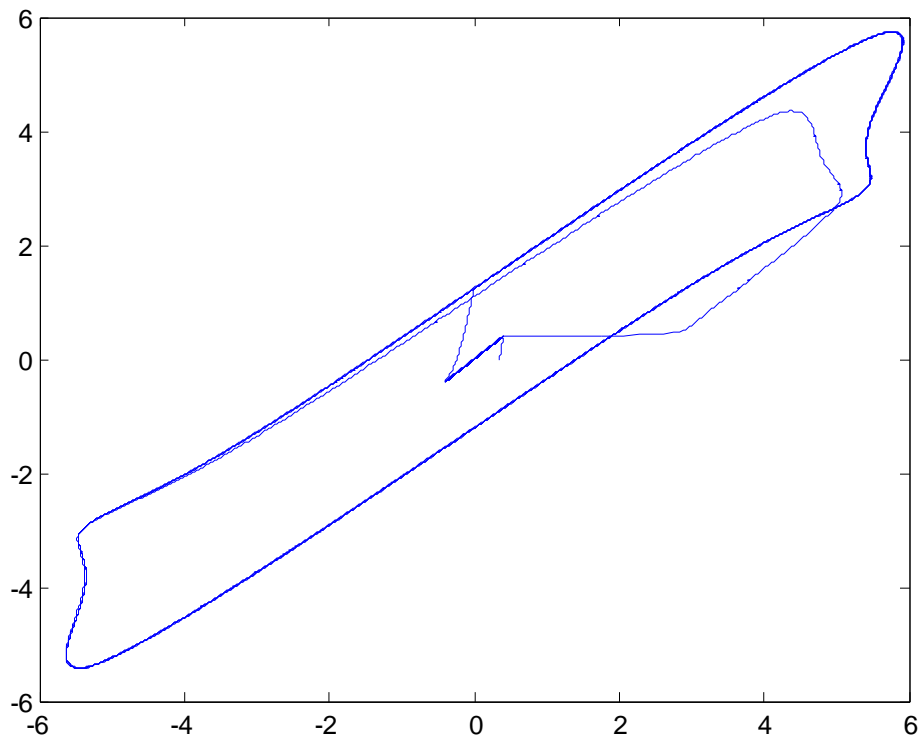
Base value: 1.0

Display Close

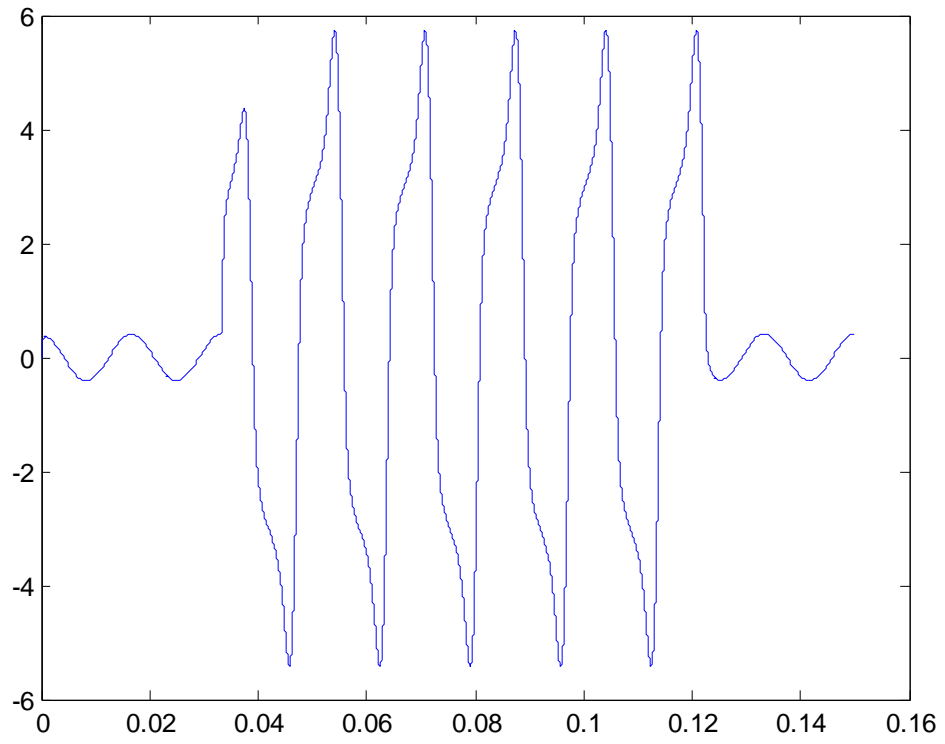
Current vs. Time



Flux vs. Current



Flux vs. Time

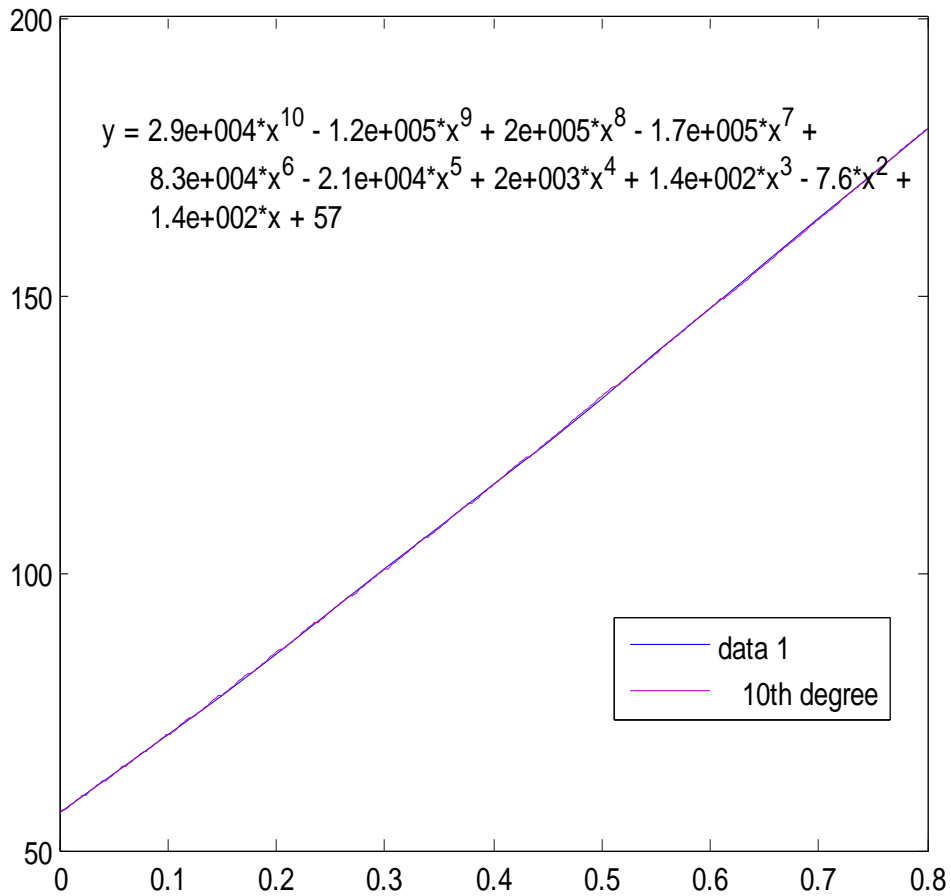


Tabulation

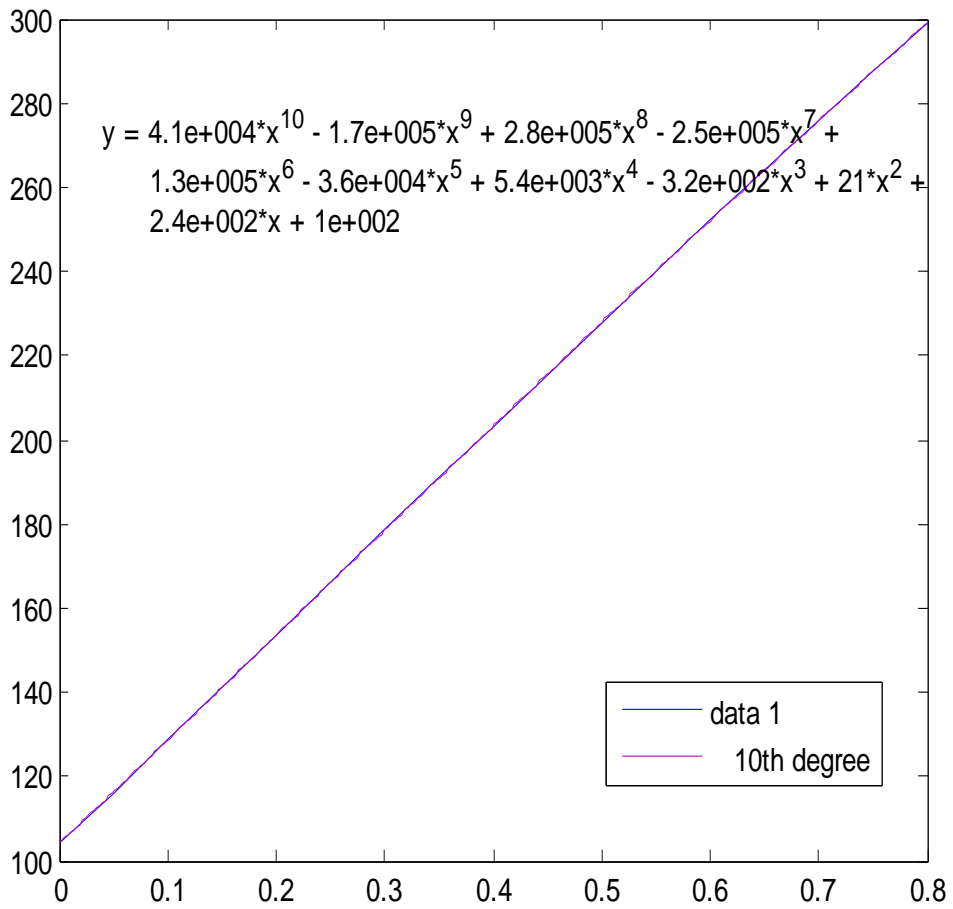
ϕ_r	DC offset (0 Hz)	Fund h1 (60 Hz)	h2 (120 Hz)	h3 (180 Hz)
0.0	56.69	104.14	75.23	47.26
0.05	63.68	116.36	83.00	50.45
0.10	70.78	128.67	90.49	53.09
0.15	78.07	141.11	97.69	55.13
0.20	85.49	153.61	104.55	56.59
0.30	100.52	178.52	117.20	58.00
0.35	108.10	190.87	122.97	58.01
0.40	115.84	203.27	128.35	57.48
0.45	123.65	215.60	133.32	56.47
0.50	131.56	227.90	137.86	55.00
0.55	139.58	240.14	141.96	53.07
0.60	147.51	252.13	145.68	50.91
0.70	163.63	275.82	151.72	45.43
0.75	171.85	287.52	153.99	42.10
0.80	180.04	298.96	155.81	38.59

Calculation

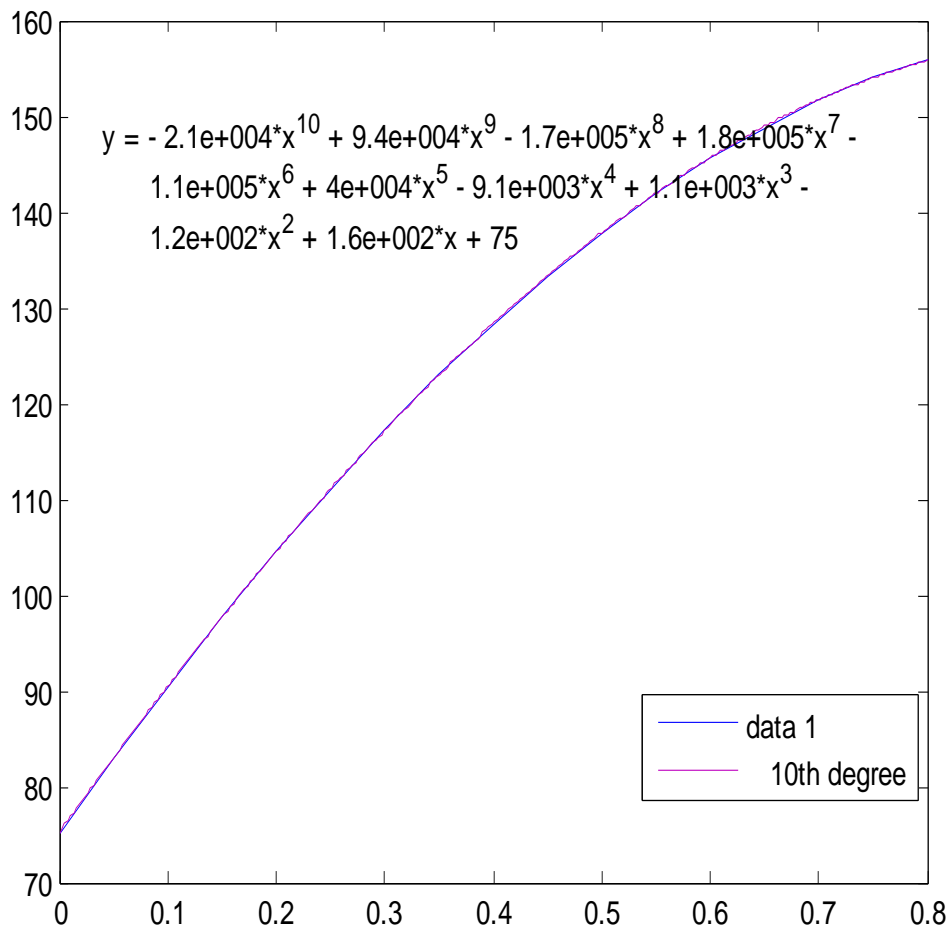
Resultant Flux vs. DC offset (0 Hz)



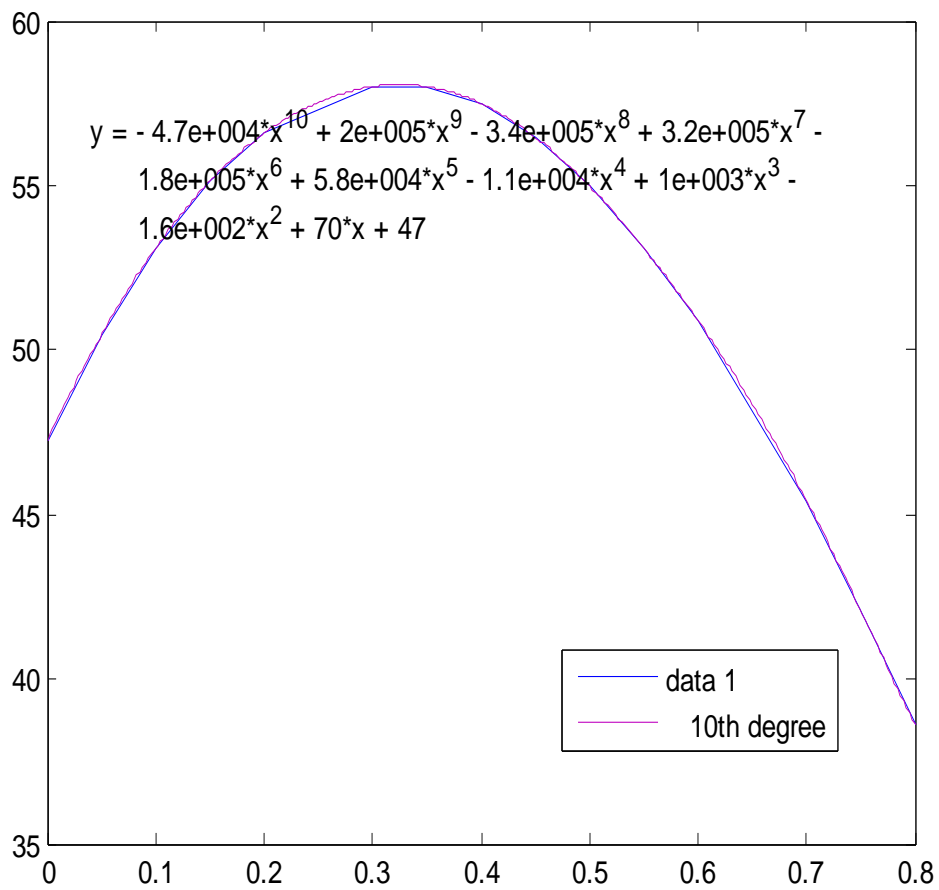
Resultant Flux vs. Fundamental Harmonic (h1 – 60 Hz)



Resultant Flux vs. 2nd Harmonic (h2 – 120 Hz)



Resultant Flux vs. 3rd Harmonic (h3 – 180 Hz)



Results:

The **Generalized Functions** were calculated to be:

Resultant Flux vs. DC offset (0 Hz) -> $2.9e + 004*x^{10} - 1.2e + 005*x^9 + 2e + 005*x^8 - 1.7e + 005*x^7 + 8.3e + 004*x^6 - 2.1e + 004*x^5 + 2e + 003*x^4 - 1.4e + 002*x^3 - 7.6*x^2 + 1.4e + 002*x + 57$

Resultant Flux vs. Fundamental Harmonic (h1 – 60 Hz) -> $4.1e + 004*x^{10} - 1.7e + 005*x^9 + 2.8e + 005*x^8 - 2.5e + 0.005*x^7 + 1.3e + 005*x^6 - 3.6e + 0.004*x^5 + 5.4e + 003*x^4 - 3.2e + 002*x^3 + 21*x^2 + 2.4e + 002*x + 1e + 002$

Resultant Flux vs. 2nd Harmonic (h2 – 120 Hz) -> $-2.1e + 004*x^{10} + 9.4e + 004*x^9 - 1.7e + 005*x^8 + 1.8e + 005*x^7 + 1.1e + 005*x^6 + 4e + 004*x^5 - 9.1e + 003*x^4 + 1.1e + 003*x^3 - 1.2e + 002*x^2 + 1.6e + 002*x + 75$

Resultant Flux vs. 3rd Harmonic (h3 – 180 Hz) -> $-4.7e + 004*x^{10} + 2e + 005*x^9 - 3.4e + 005*x^8 + 3.2e + 005*x^7 - 1.8e + 005*x^6 + 5.8e + 004*x^5 - 1.1e + 004*x^4 + 1e + 003*x^3 - 1.6e + 002*x^2 + 70*x + 47$

Exponential Form:

Resultant Flux vs. DC offset (0 Hz) -> $1.1e^{5x} - 11e^{4x} + 46e^{3x} - 1.3e^{002}e^{2x} + 3e^{002}e^x - 1.5e^{002}$

Resultant Flux vs. Fundamental Harmonic (h1 – 60 Hz) -> $1.4e^{5x} - 17e^{4x} + 92e^{3x} - 2.9e^{002}e^{2x} + 6.1e^{002}e^x - 2.9e^{002}$

Resultant Flux vs. 2nd Harmonic (h2 – 120 Hz) -> $3.3e^{5x} - 39e^{4x} + 1.9e^{002}e^{3x} - 5e^{002}e^{2x} + 7.2e^{002}e^x - 3e^{002}$

Resultant Flux vs. 3rd Harmonic (h3 – 180 Hz) -> $9.3e^{5x} - 95e^{4x} + 4e^{002}e^{3x} - 8.5e^{002}e^{2x} + 9.2e^{002}e^x - 3.3e^{002}$

Conclusion

The study of inrush currents and its effects on harmonics was carried out in detail. The harmonic distortion was simulated using MATLAB for various residual fluxes; the relationships for characteristics of current and flux were plotted over time. Generalized functions for describing the relationships between resultant flux and harmonic components were derived.

Future Plans:

Harmonic components are identified to get the non-linearity of the core, this can be used in the elimination of the harmonics.

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- [7] C-L Huang C. E. Lin, C.L Cheng and J.C. Yeh. Investigation of magnetization inrush current in transformer. (ii) Harmonic Analysis. IEEE Transactions on Power Delivery, 8(1):256-263, Jan 1993