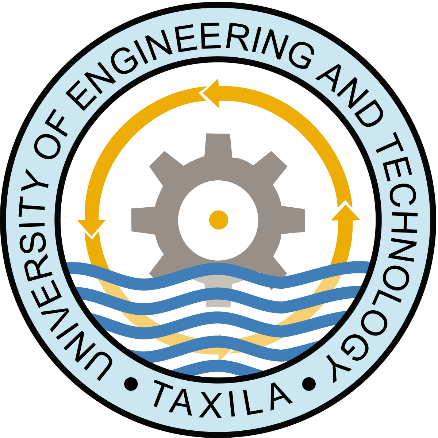
**OPTIMIZATION-TECHNIQUES**

**ASSIGNMENT NO# 01**



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## **ASSIGNMENT NO# 01**

## **Assignment Title**

## Implementation of Harmonics Estimation Problem in MATLAB using Non-linear Programming

## **Title Overview:**

## The increasing prevalence of non-linear loads, driven by the widespread use of electronic devices, has introduced harmonics into power systems, creating a significant challenge. If not managed effectively, these harmonics can lead to various negative outcomes, including disruptions in power quality, potential equipment damage, higher energy consumption, and safety concerns. Additionally, strict regulatory guidelines define acceptable limits for harmonics in power systems, necessitating swift and accurate real-time monitoring and control procedures. The innovative solution proposed, the Non-linear framework, offers a promising way to address this complex issue. The framework aims to enhance the accuracy and efficiency of real-time harmonics estimation.

## **Research Objectives:**

## Development of an efficient method for a Real-time monitoring and estimation framework.

## Enhancement of Power Quality Management.

## Optimization of the Energy Consumption.

1. Establishment of a technique that outperforms others in terms of accuracy and computational time.

**Mathematical Interpretation of Problem:**

Harmonics are the key constituents that are mainly responsible for power quality deterioration. Power system harmonics must be correctly estimated and filtered to increase power quality. Estimating the harmonics within the power signal model involves the assessment of two key elements: the linear estimation of amplitudes and the nonlinear estimation of phases. Analyzing the harmonics in power signals is a challenging task due to the ever-changing characteristics of these signals. Essentially, any signal can be expressed as a combination of multiple frequencies represented by the sum of sine and cosine functions.

It can be expressed as:

=

where n is the harmonic order, is the amplitude of harmonics present in the signal, being the angular frequency of harmonics of higher order, is the phase angle of harmonics. The term shows the additive DC decaying offset present in power signals. Moreover, is given by:

The realistic signal can be modeled by the addition of the noise , given as:

=+

The sampling of the continuous signal is performed to convert it into a discrete signal for the computer simulation. Hence, the sampled signal is given as:

=+

Where being the sampling time for the discrete signal, using the trigonometric identity and with the application of the Taylor series on the DC Component. The above equation can be written as:

=+

The estimated signal is written in matrix form as given below:

where, X is the vector of unknown parameters which need to be updated to estimate the signal correctly. X vector and H(m) vector can be expressed as:

X= []

H(m)= [

When the vector of unknown parameters X is identified corresponding to minimum fitness using WLS–MVO framework, the angles, and amplitudes of corresponding frequencies can be calculated using following relations:

The parameters of DC decaying offset can be computed using following relations:

The overall fitness function for the estimation of harmonics problem can be formulated as:

where denotes the actual signal, denotes the estimated signal. Whereas ω is the weight that is tuned according to the optimization requirements of the harmonic estimation problem.

**Implementation on MATLAB:**

The implementation that is performed on the MATLAB is being discussed in the form of pseudocode as follows:

1. To begin with, we need to provide a description of the signal parameters. Secondly, we should proceed with the next step of declaring the test case dataset.
2. Initialize Actual Signal and then add the harmonic component to Actual Signal.
3. Additive White Gaussian Noise with specified SNR is then added to Actual Signal that makes the Noisy Signal we called it as a realistic signal.
4. For the Estimated signal, we have to initialize the H matrix with the zeros and randomly generated the X estimated matrix.
5. Define the function for Unconstrained Optimization.
6. Calculate the estimated signal using the X and H.
7. Compute the fitness as the sum of squared differences between Noisy Signal and the Estimated Signal.
8. Calculation of amplitude and phase for each harmonic component.
9. Plotting the Graphs of the different Signals.
10. Reporting results followed by discussion.

**Code for Test Case 01:**

clc

clear

close all

%%%% M. BILAL RAZA %%%%

%%%% 22-MS-EE-07 %%%%

% Define signal parameters

K=64; % Sampling Frequency

C=1; % No. of Cycles

F=50; % Fundamental Frequency

Ts=1/(K\*F); % Sampling Time

k=0:C\*(K-1); % Samples for Graph Plotting

% Signal To Noise Ratio in db

%SNR=0;

SNR=20;

ActualSig=zeros(1,length(K)); % Initialized the Actual Signal with zeros

% Generation of random integer between -5 and 5

X0= randi([-5 5],1,10);

omega=1;

% The signal from the Data Set

% | | | | |

% |HO|FR| AMP | Phase|

Data = [1 50 0.95 -2.02

5 250 0.09 82.1

7 350 0.043 7.9

11 550 0.03 -147.1

13 650 0.003 162.6];

%%% Declaring the Actual Signal

for i=1:size(Data,1)

ActualSig = ActualSig + ( Data(i,3)\*(sin(2\*pi\*k\*Ts\*Data(i,2)+Data(i,4)\*pi/180)) );

end

%%% Declaring the Noisy Signal

NoisySig=awgn(ActualSig,SNR,'measured')

%%% Declaring the Estimated Signal

for i=1:size(Data,1)

H(2\*i-1,:) = sin(Data(i,2)\*2\*pi\*k\*Ts);

H(2\*i ,:) = cos(Data(i,2)\*2\*pi\*k\*Ts);

end

%%% Function to Perform Uncounstrainted Optimization

[X,fval]=fminunc(@(X) fitnessFunction(X,H,NoisySig),X0)

%%% Estimation of Signal

EstimateSig = X\*H

%%% Plotting of the Signal

plot(k,NoisySig,'r-');

hold on

plot(k,EstimateSig,'b.');

hold on

title('Signal Harmonic Graph(C1) By 22MS-EE-07')

plot(k,ActualSig,'g\*');

%%% Labelling the Graph

xlabel('Time(s)')

ylabel('Amplitudes')

legend('ActualSig','EstimateSig','NoisySig')

grid on;

%%% Amplitude and Phase Calculation

Amplitude= zeros(1, 5);

Angle = zeros(1, 5);

for n=1:5

Amplitude(n) = sqrt(X(2\*n - 1)^2 + X(2\*n)^2);

Angle(n) = (180/pi)\*atan2(X(2\*n),X(2\*n - 1));

end

Amplitude

Angle

%%% Weight Least Square

WLS = omega\*sum((NoisySig - EstimateSig).^2)

%%% Mean Square Error

squared\_diff = (ActualSig - EstimateSig).^2;

mse = 1/K \* sum(squared\_diff)

%%% Perforamnce Index

PER = sum((ActualSig - EstimateSig).^2) / sum(ActualSig.^2)

%%% Function for Overall Estimation of Harmonic Problem

function f = fitnessFunction(X,H,NoisySig)

EstimateSig = X\*H;

f = sum((NoisySig - EstimateSig).^2);

end

**Code for Test Case 02:**

clc

clear

close all

%%%% M.BILAL RAZA %%%%

%%%% 22-MS-EE-07 %%%%

% Define signal parameters

K=64; % Sampling Frequency

C=1; % No. of Cycles

F=50; % Fundamental Frequency

Ts=1/(K\*F); % Sampling Time

k=0:C\*(K-1); % Samples for Graph Plotting

% Signal To Noise Ratio in db

%SNR=0;

SNR=20;

ActualSig=zeros(1,length(K)); % Initialized the Actual Signal with zeros

% Generation of random integer between -5 and 5

X0= randi([-5 5],1,10);

omega=1;

% The signal from the Data Set

% | | | | |

% |HO|FR| AMP | Phase|

Data = [1 50 1.5 80

3 150 0.5 60

5 250 0.2 45

7 350 0.15 36

11 550 0.1 30];

%%% Declaring the Actual Signal

for i=1:size(Data,1)

ActualSig = ActualSig + ( Data(i,3)\*(sin(2\*pi\*k\*Ts\*Data(i,2)+Data(i,4)\*pi/180)) );

end

%%% Declaring the Noisy Signal

NoisySig=awgn(ActualSig,SNR,'measured')

%%% Declaring the Estimated Signal

for i=1:size(Data,1)

H(2\*i-1,:) = sin(Data(i,2)\*2\*pi\*k\*Ts);

H(2\*i ,:) = cos(Data(i,2)\*2\*pi\*k\*Ts);

end

%%% Function to Perform Uncounstrainted Optimization

[X,fval]=fminunc(@(X) fitnessFunction(X,H,NoisySig),X0)

%%% Estimation of Signal

EstimateSig = X\*H;

%%% Plotting of the Signal

plot(k,NoisySig,'r-');

hold on

plot(k,EstimateSig,'b.');

hold on

title('Signal Harmonic Graph (C-2) By 22MS-EE-07')

plot(k,ActualSig,'g\*');

%%% Labelling the Graph

xlabel('Time(s)')

ylabel('Amplitudes')

legend('ActualSig','EstimateSig','NoisySig')

%%% Amplitude and Phase Calculation

Amplitude= zeros(1, 5);

Angle = zeros(1, 5);

for n=1:5

Amplitude(n) = sqrt(X(2\*n - 1)^2 + X(2\*n)^2);

Angle(n) = (180/pi)\*atan2(X(2\*n),X(2\*n - 1));

end

Amplitude

Angle

%%% Mean Square Error

squared\_diff = (ActualSig - EstimateSig).^2;

mse = 1/K \* sum(squared\_diff)

%%% Perforamnce Index

PER = sum((ActualSig - EstimateSig).^2) / sum(ActualSig.^2)

%%% Weight Least Square

WLS = omega\*sum((NoisySig - EstimateSig).^2)

%%% Function for Overall Estimation of Harmonic Problem

function f = fitnessFunction(X,H,NoisySig)

EstimateSig = X\*H;

f = sum((NoisySig - EstimateSig).^2);

end

**RESULTS**

**For the Test Case 01**

* **For the 0 bd noise we the following obtained values:**

The Estimated value of the X Matrix are as follows:

X= [0.8523 0.0252 -0.3127 -0.0130 0.0883 0.2667 -0.0362 0.0845 0.0495 0.0987]

The local minima found for the objective function at 23.6015.

**Performance Indices**

The **Mean Square Error** has a value of 0.1108.

The **Weighted Least Square function** has a value of 23.6015.

The **Performance Index Ratio** has a value of 0.2426.

**Tabular Representation of Results**

The table below describes the estimation of the harmonics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Order of Harmonics** | **Test Signal Amplitude** | **Estimated Signal Amplitude** | **Difference** | **Test Signal Phase** | **Estimated Signal Phase** | **Difference** |
| **1** | **0.95** | **0.8527** | **0.0973** | **-2.02** | **1.6961** | **-0.3239** |
| **5** | **0.09** | **0.3129** | **-0.2229** | **82.1** | **-177.61** | **-95.51** |
| **7** | **0.043** | **0.2809** | **-0.2379** | **7.9** | **71.682** | **63.782** |
| **11** | **0.03** | **0.0919** | **-0.0619** | **-147.1** | **113.171** | **-33.929** |
| **13** | **0.003** | **0.1104** | **-0.1074** | **162.6** | **63.365** | **99.235** |

**Signal Plots**

The Signal harmonics graph at 0db noise.



* **For the 20 bd noise we the following obtained values:**

The Estimated value of the X Matrix are as follows:

X= [0.9704 -0.0801 0.0164 0.1066 0.0474 0.0171 -0.0283 -0.0046 -0.0017 0.0080]

The local minima found for the objective function at 0.1488.

* **Performance Indices**

The **Mean Square Error** has a value of 0.0016.

The **Weighted Least Square function** has a value of 0.1488.

The **Performance Index Ratio** has a value of 0.0036.

**Tabular Representation of Results**

The table below describes the estimation of the harmonics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Order of Harmonics** | **Test Signal Amplitude** | **Estimated Signal Amplitude** | **Difference** | **Test Signal Phase** | **Estimated Signal Phase** | **Difference** |
| **1** | **0.95** | **0.9396** | **0.0104** | **-2.02** | **-3.2620** | **1.242** |
| **5** | **0.09** | **0.0914** | **0.0014** | **82.1** | **99.6142** | **-17.5142** |
| **7** | **0.043** | **0.0518** | **-0.0088** | **7.9** | **17.4070** | **-9.507** |
| **11** | **0.03** | **0.0562** | **-0.0218** | **-147.1** | **-148.2056** | **1.1056** |
| **13** | **0.003** | **0.0172** | **-0.0142** | **162.6** | **-68.0790** | **94.521** |

**The Signal harmonics graph at 20db noise.**

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**For the Test Case 2**

For the 0db noise signal we the following obtained values

* The Estimated value of the X Matrix are as follows:

X= [0.3457 1.3574 0.4442 0.2449 0.3103 0.2726 0.3887 0.3110 0.0368 -0.2518]

* The local minima found for the objective function at 58.2139.

The **Mean Square Error** has a value of 0.1776.

The **Weighted Least Square function** has a value of 58.2139.

The **Performance Index Ratio** has a value of 0.1380.

**Tabular Representation of Results**

The table below describes the estimation of the harmonics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Order of Harmonics** | **Test Signal Amplitude** | **Estimated Signal Amplitude** | **Difference** | **Test Signal Phase** | **Estimated Signal Phase** | **Difference** |
| **1** | **1.5** | **1.4008** | **0.0992** | **80** | **75.7113** | **4.2887** |
| **3** | **0.5** | **0.5072** | **-0.0072** | **60** | **28.8690** | **31.131** |
| **5** | **0.2** | **0.4130** | **-0.213** | **45** | **41.3076** | **3.6924** |
| **7** | **0.15** | **0.4978** | **-0.3478** | **36** | **38.6646** | **-2.6646** |
| **11** | **0.1** | **0.2544** | **-0.1544** | **30** | **-81.6741** | **-51.6741** |

**Signal Plot**

* The Estimation of the Harmonics at 0db noise.



**For the 20 db noisy signal we have the following values:**

* The Estimated value of the X Matrix are as follows:

X= [0.2903 1.4622 0.2923 0.4399 0.1591 0.1043 0.0789 0.0708 0.0604 0.0523]

* The local minima found for the objective function at 0.7648.

The **Mean Square Error** has a value of 0.037.

The **Weighted Least Square function** has a value of 0.7648.

The **Performance Index Ratio** has a value of 0.0029.

**Tabular Representation of Results**

The table below describes the estimation of the harmonics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Order of Harmonics** | **Test Signal Amplitude** | **Estimated Signal Amplitude** | **Difference** | **Test Signal Phase** | **Estimated Signal Phase** | **Difference** |
| **1** | **1.5** | **1.4907** | **0.0093** | **80** | **78.7692** | **1.2308** |
| **3** | **0.5** | **0.5282** | **-0.0282** | **60** | **56.3957** | **3.6043** |
| **5** | **0.2** | **0.1903** | **0.0097** | **45** | **33.2349** | **11.7651** |
| **7** | **0.15** | **0.1060** | **0.044** | **36** | **41.8828** | **-5.8828** |
| **11** | **0.1** | **0.0798** | **0.0202** | **30** | **40.8902** | **-10.8902** |

* The Graph for estimation of the Harmonics at 20db noise.



**DISCUSSION:**

For the estimation of the harmonics, the nonlinear programming is being considered and the two SNR ratio i.e. [0db,20db] and a test cases one and two are to be taken from Ref paper [1] and [2] respectively, the value of the X matrix is being calculated and based upon that the fitness value is being computed and then the mean square error is being checked followed by the performance index calculation. The results depict the effectiveness of non-linear programming for the harmonic estimation problem at higher values of SNR.

**Reference:**

[1] Ashraf, M.M.; Ullah, M.O.; Malik, T.; Waqas, A.; Iqbal, M.; Siddiq, F. Robust extraction of harmonics using heuristic advanced gravitational search algorithm-based least square estimator. Nucleus 2018, 54, 219–231.

[2] Ashraf, M.M.; Ullah, M.O.; Malik, T.; Waqas, A.; Iqbal, M.; Siddiq, F. A Hybrid Water Cycle Algorithm-Least Square based Framework for Robust Estimation of. Nucleus 2018, 55, 47–60.