MOVING AVERAGE FILTER FOR RIPPLE CURRENT ELMINATION

SITI INTANSYAFINAZ BINTI ABDUL KADIR

UNIVERSITI MALAYSIA PAHANG

## UNIVERSITI MALAYSIA PAHANG

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# MOVING AVERAGE FILTER FOR RIPPLE CURRENT ELMINATION

SITI INTANSYAFINAZ BINTI ABDUL KADIR

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Electrical and Electronic Engineering (Power System)

Faculty of Electrical and Electronic Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

## STATEMENT OF AWARD FOR DEGREE

**Bachelor Final Year Project Report**

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Electrical and Electronic Engineering (Power System).

# SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical and Electronic Engineering (Power System).

Signature :

Name of Supervisor : DR.HAMDAN BIN DANIYAL

Date : JUNE 2012

# STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : SITI INTANSYAFINAZ BINTI ABDUL KADIR

ID Number : EC08088

Date : JUNE 2012

**Dedicated to my parents:**
**Abdul Kadir Bin Othman and Jamilah Binti Mohd Derim;**
**and siblings:**
**Siti Nur Ain Binti Abdul Kadir and Siti Nur Syazwani Binti Abdul Kadir.**

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# ABSTRACT

In power electronics field concerning power converter applications; current control is becoming one of the key research areas. Typically, in current control applications, the inductor current is shaped to closely follow its reference. This is achieved by regulating the current via current control strategies. The rapid switching of the power semiconductor devices will forms the ripples on the regulated current. In analysis stage, for proper comparison between the regulated current and reference current, it is crucial that the current ripples are eliminated. Common fixed cut-off frequency filter, however, is not suitable in this application due to variable switching frequency nature of some current control techniques. Therefore, in this project, a variable cut-off frequency filtering technique based on numerical algorithm is developed to eliminate the current ripple without destroying the non-ripple data. To verify its performance, the algorithm is tested on several real data of regulated current. Result shows that the algorithm is able to filter the ripple current satisfactorily.

# ABSTRAK

Dalam bidang kuasa elektronik mengenai penggunaan penukar kuasa; kawalan arus menjadi salah satu bidang penyelidikan utama. Biasanya, dalam aplikasi kawalan arus, arus pearuh rapat mengikut bentuk arus rujukan. Ini dicapai dengan mengawal selia arus melalui strategi kawalan arus. Pensuisan pesat peranti semikonduktor kuasa akan membentuk riak pada arus yang dikawal. Pada peringkat analisis, perbandingan yang betul antara arus terkawal dan arus rujukan , ia adalah penting untuk riak pada arus dihapuskan. Frekuensi potong yang telah ditetapkan untuk penapis biasa digunakan, walaubagaimanapun, tidak sesuai dalam penggunaan ini kerana frekuensi pensuisan berubah sifat dalam beberapa teknik kawalan arus. Oleh itu, dalam projek ini, kekerapan boleh ubah frekuensi potong untuk teknik penapisan berdasarkan algoritma berangka dibangunkan untuk menghapuskan riak arus tanpa memusnahkan data bukan-riak. Untuk mengesahkan prestasi, algoritma diuji dengan beberapa data arus sebenar yang dikawal selia. Keputusan menunjukkan bahawa algoritma, ini mampu untuk menapis semasa riak memuaskan.

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# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Current control regulates the inductor current in power electronics devices to closely follow the reference current. This regulation is carried out by rapid switching of the power semiconductor which forms saw-tooth ripples on the regulated current. Often, the ripples need to be suppressed in data analysis to clearly compare the regulated current and its reference.

Ripple current is an unwanted small change in periodic output variation of the direct current output from an alternating current of a power supply. This ripple is due to incomplete suppression of alternating waveform of source. Ripple is an undesirable in power electronic applications for several reasons and has been considered as an unwanted effect.

Moving average filter is one of the methods that has been used to filter generate input signals in digital form for a better analysis. Moving average digital filter specially designed for this application needed. The moving average operation used in fields is a particular kind of low-pass filter. A low-pass filter is an electronic filter that passes low-frequency signals but reduces the amplitude of signals with frequencies higher than the cut off frequency. So, this is a technique of implementing the introduction of optimum signal current ripple are analysed.

The moving average filter is commonly used for smoothing an array of sampled data or signal. It takes samples of input at a time and takes the average of those samples and produces the desired output. It is a very simple Low Pass Finite Impulse Response (FIR) Filter for filtering the unwanted current ripple from the intended data. The input is current ripple and the aim is to analysis the current ripple.

## 1.2 PROJECT BACKGROUND

Signal data is something numerical issues that usually very difficult to analyse in real world. Any algorithm method that related to analysis the data would be troubled to obtain and sometimes it is not very easy to use. To this end, the idea of the moving average filter is been developed and by using this process, a set of signal data are been looked for the midpoint and fitted between each of the middle points to find the continuous and smooth curve. So that, the ripple current can be eliminated successfully.

## 1.3 PROBLEM STATEMENT

Current ripple frequencies are varies, so fixed cut off frequency filter is not effective. The signal is too complicated and difficult to analyze but when the data is been simplified with certain frequency, the desired data is disappear. A filter has been designed, so that it can eliminate the ripple and the analysis on current control can be performed.

## 1.4 OBJECTIVES OF THE RESEARCH

In this research project, the main objective is to develop a technique based on numerical algorithm for elimination of the current ripple to better analysis performance of current control. To verify the performance of this technique, the system will be simulated with various data collection using Matlab program and the simulation results will validated by using the proposed technique. This method should able to remove the ripple with various cut off frequency and also able to maintain the overshoot and undershoot on oscillating after been filtered.

## 1.5 SCOPE OF PROJECT

The scope of the project is about the investigation of any possible technique or filter that can eliminate the current ripple for maximum achievement for better performance of current control in power electronic field.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

The main intention of this section is to provide a review of past research efforts related to filter used and extrapolation and interpolation technique. An opinion of other relevant study studies is also provided including the currently research effort. The review is show a little bit of scope and direction of this project.

## 2.2 FILTER APPLICATION

### 2.2.1 The Advantages of Adaptive Filter

"The adaptive algorithm for FIR filters are is widely used in different applications such as biomedical, communication and control due to its easily implementation, stability and best performance. Its simplicity makes it attractive for many applications where it is needed to minimize computational requirements" [1].

Algorithms that can be adapted for FIR are widely used in various field because it is easy implementation, stable, computation requirement is minimum and best perform. FIR is a type of a signal processing filter which responded to any length input in finite duration.

### 2.2.2 The Functions of Adaptive Filter

"The notion of making filters adaptive, i.e., to alter parameters (coefficients) of a filter according to some algorithm, tackles the problems that we might not in advance know, e.g., the characteristics of the signal, or of the unwanted signal, or of a system influence on the signal that we like to compensate. Adaptive filters can adjust to unknown environment and even track signal or system characteristics varying over time" [2].

Changing the parameter of a filter according to some algorithms is to address the problem of the signal characteristics by identifying the unwanted signal that give bad influence to the performance of a system. Adaptive filter can be used in different circumstances from time to time. For simple comprehension, adaptive filter is about the changing of coefficient over time which is to adapt the change in signal features.

### 2.2.3 Moving Average Filter

"A moving average filter is a very simple FIR filter. It is sometimes called a boxcar filter…" [3]

A moving average filter smooth the data by replacing each data point with the average of the neighbouring data points which is defines as range by using simple equation. A boxcar is a railroad car which it is carrying container and also known as goods van or covered wagon and generally used to carry freight. The boxcar is not the simplest freight car design since it can carry more loads. In other words, the container is kind of a boxcar with the wheels and under frame. Moving average filter is one of the methods that can analyse too many data. This is not easy technique to compliance the computation of all data with so many complexities. So that, the filter is much similar as boxcar.

## 2.3 EXTRAPOLATION APPLICATION

### 2.3.1 The midpoint method

Area Approximations

"… Before learning how to use anti-derivatives to calculate the exact value of these integrals, students can approximate the value of the area using approximations such as the endpoint methods, the midpoint method and the trapezoid method."[6]

Methods of Approximation

"The four most common methods of approximating the area between two curves are the left and right endpoint methods, the midpoint method and the trapezoid method…"[6]

Error and Concavity

"… If the error is positive, then the approximation is larger than the actual area; if it is negative, then the approximation is smaller than the actual area. Larger error values indicate greater differences between the actual area and the approximation. Different methods yield different errors depending on the types of curves that bound the area."[6]

The midpoint rule is one of the fundamental method that learner can be able to calculate the appropriate value of the area. This is the most frequently techniques of approximating the area between two curves. The error values represent the differences between the approximation area and the actual area of curves. The approximation area is larger than the actual area if the error is positive while the approximation area is smaller than the actual area if the error is negative. So, these kinds of practices have advantages over the area approximations, methods of approximation and error determination. Different methods will generate different assumptions.

## 2.4 INTERPOLATION APPLICATION

### 2.4.1 The Used of Cubic Spline Method

"Cubic splines are widely used to fit a smooth continuous function through discrete data. They play an important role in such fields as computer graphics and image processing, where smooth interpolation is essential in modeling, animation, and image scaling. In computer graphics, for instance, interpolating cubic splines are often used to define the smooth motion of objects and cameras passing through user-specified positions in a key frame animation system. In image processing, splines prove useful in implementing high-quality image magnification. Cubic splines interpolate (pass through) the data with piecewise cubic polynomials. The use of low-order polynomials is especially attractive for curve fitting because they reduce the computational requirements and numerical instabilities that arise with higher degree curves. These instabilities cause undesirable oscillations when several points are joined in a common curve. Cubic polynomials are most commonly used because no lower-degree polynomial allows a curve to pass through two specified endpoints with specified derivatives at each endpoint. The most compelling reason for their use, though, is their C2 continuity, which guarantees continuous first and second derivatives across all polynomial segments…"[7]

Cubic splines are used extensively in fitting a smooth continuous function thru discrete data and leading to the important role in various fields with difference usefulness such as the definitions of object's motion, implementing high quality image magnification and any other applications. Cubic splines interpolate the data with piecewise cubic polynomials. The use of low degree order of polynomials is to reduce the computational requirements and numerical instabilities instead higher degree curves, which may cause the undesirable oscillations when the points are joined in a cubic spline curve. Cubic polynomials are widely used because no lower-degree polynomial allows a curve to pass through two specified endpoints with specified derivatives at each endpoint and  the continuity of the first and second derivatives across all polynomial points is been ensured.

### 2.4.2 The Function of Cubic Spline Method

"… A cubic spline curve is a piecewise cubic curve with continuous second derivative. The resulting curve is piecewise cubic on each interval, with matching first and second derivatives at the supplied data-points. The second derivative is chosen to be zero at the first and last points…"[8]

Piecewise is a function that's a real data changes depending on the value of the independent variable in intervals. That's mean piecewise function is holds for each piece of the data which are known as knots or marks in curve fitting before the interpolation process.

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

The methodology for this project is shown in **Figure 3.1**. First and foremost, the maximum point is found. Then, the minimum point is found. After that, the maximum and minimum point is connected by using the interpolation. The midpoint is found after the interpolation. By using the spline interpolation, the entire midpoints are connected. All the steps that has been discussed are involved in designing the filter.

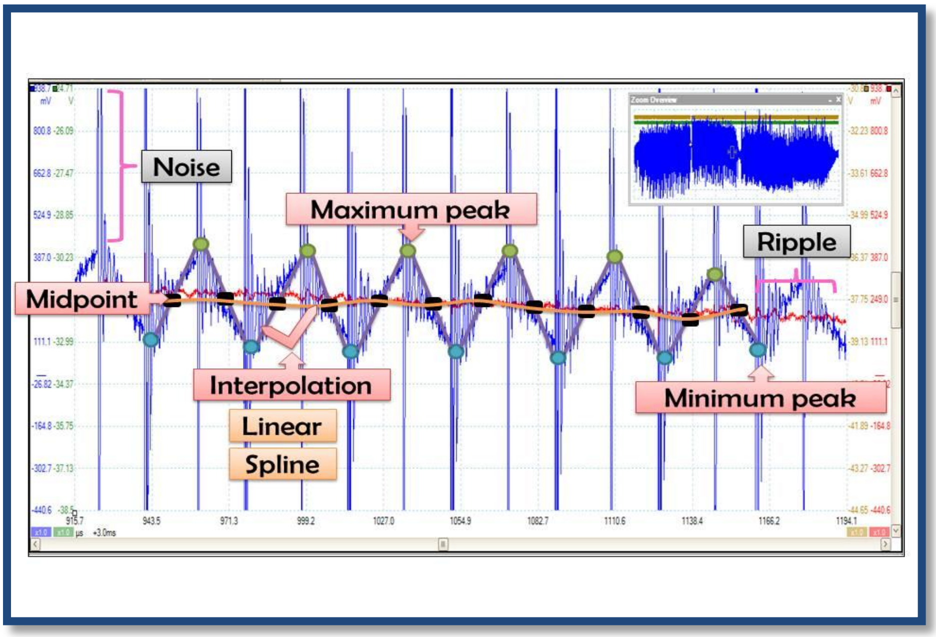


**Figure 3.1** Methodology for ripple current filter design

The block diagram for this project is shown in **Figure 3.2** as follow:

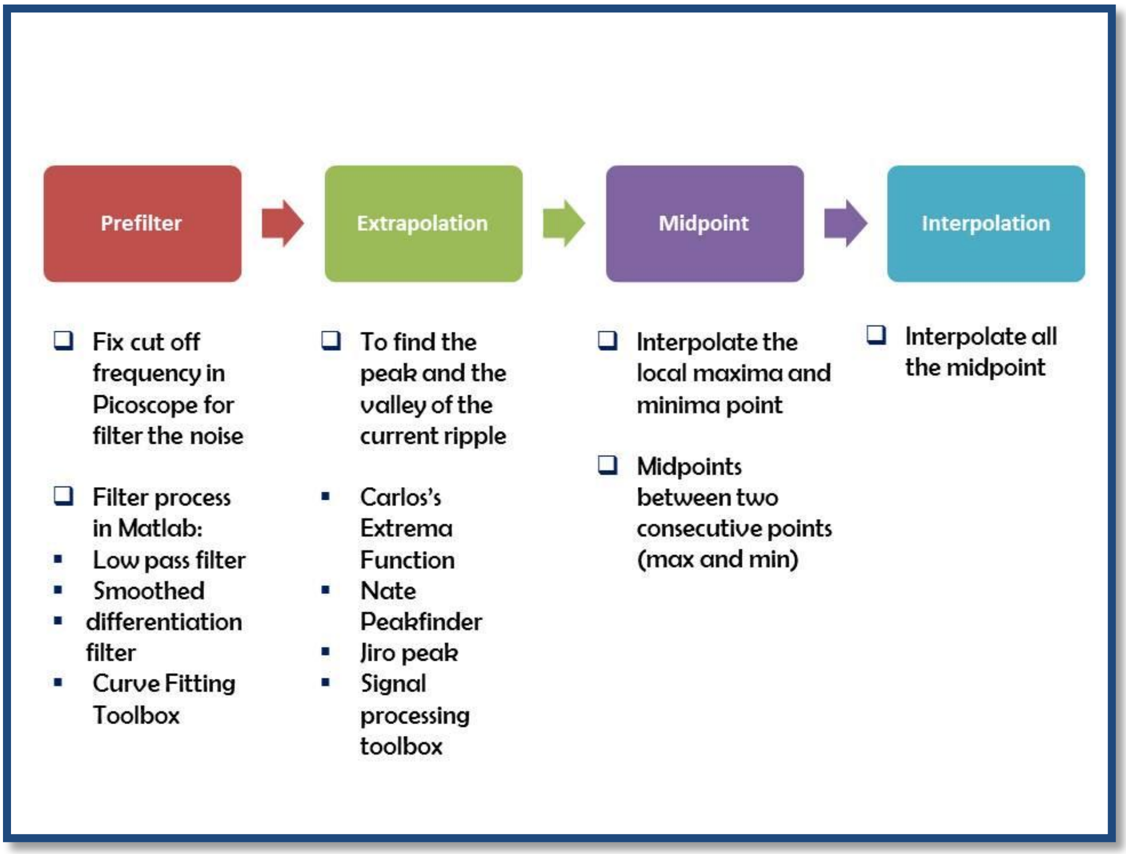


**Figure 3.2** Block diagram for ripple current filter design

The input signals data which is current ripple is in digital form. The signal is too complex where the current ripple frequencies are varies with different values of overshoot and undershoot. It takes samples of current input at a time.

## 3.2 EXTRAPOLATION AND INTERPOLATION

Extrapolation is a method to find the midpoint of graph. There are some choices of which extrapolation method to apply for solving the problem such as linear extrapolation, polynomial extrapolation, conic extrapolation, French curve extrapolation and so on [4]. It depends on the suitability solution based on problem, the smooth of resulting graph and the self-basic knowledge if want to find the best option. Same goes to interpolation method. Interpolation is kind of way to connect all the midpoint of graph to be a smooth curve. Some of interpolation methods are piecewise constant interpolation, linear interpolation, polynomial interpolation, spline interpolation, Gaussian interpolation and others [5]. The accuracy and the appropriate algorithms used for each method are different. A better way is to find the easy method but give the best performance in curve fitting problems.

The main function of extrapolation methods is to evaluate the large numbers of data point with highly precision by applying various numerical methods to find the middle point of the signal after been filtered with various cut off frequency. The main application of interpolation techniques is for curve fitting which is simple, can fit to any kind of data set, no matter how random the data may be seem and effectively and efficiently connect all the midpoints with smooth pattern signal. The development of this practices combination with simplest algorithms and straight forward will contribute the solution towards the ripple current elimination in real situations. Applying a simple rules will makes these methods extremely powerful, expeditious and accurate in the process.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 RESULTS

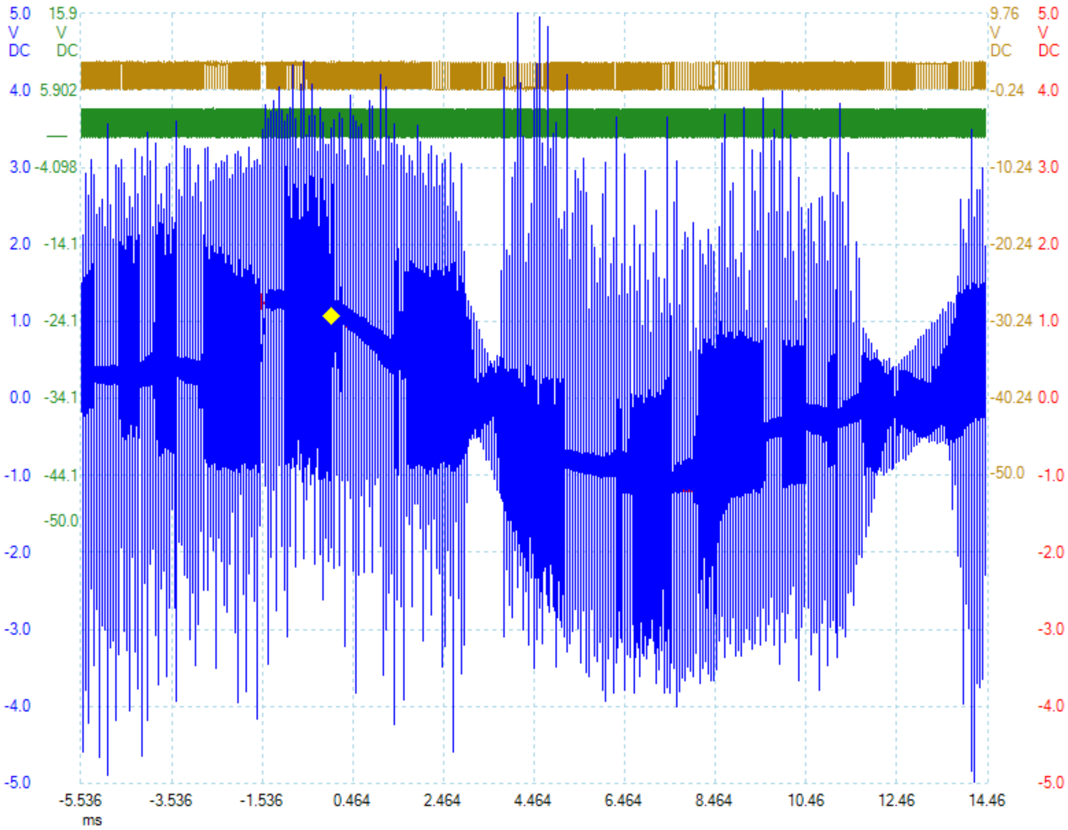


**Figure 4.1** The raw signals of PI from Picoscope

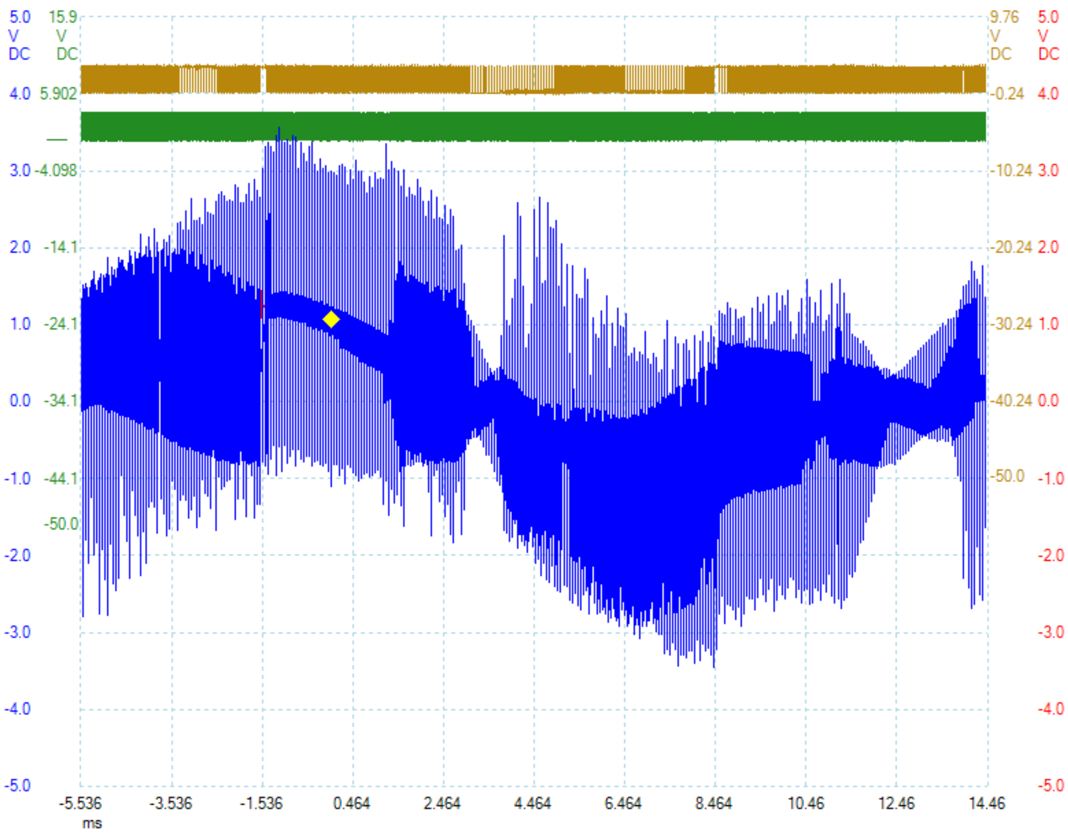


**Figure 4.2** The pre-filtered signal of PI from Picoscope

### 4.1.1 The span of the moving average is 100

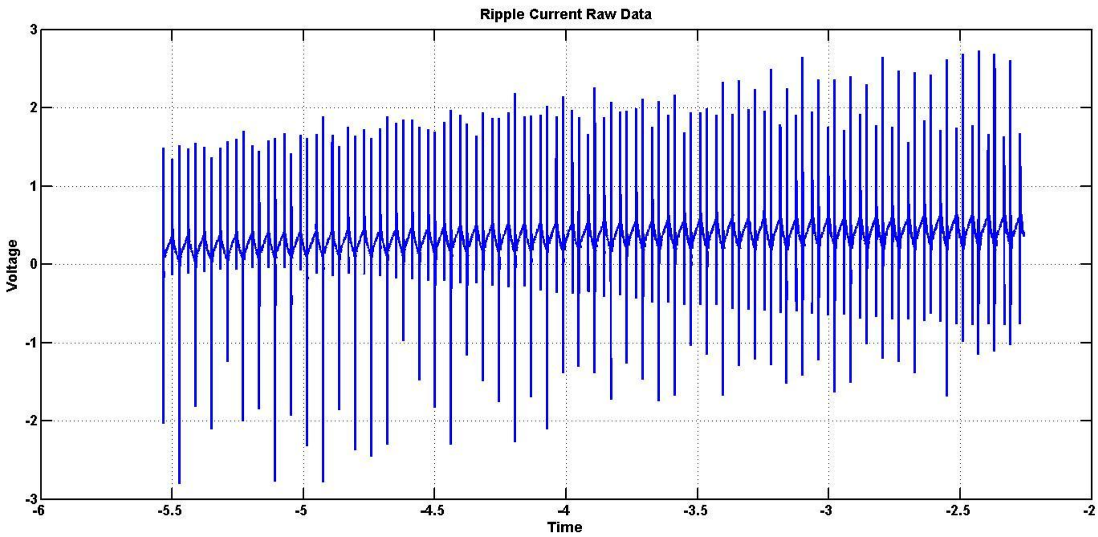


**Figure 4.3** The ripple current raw signals in Matlab

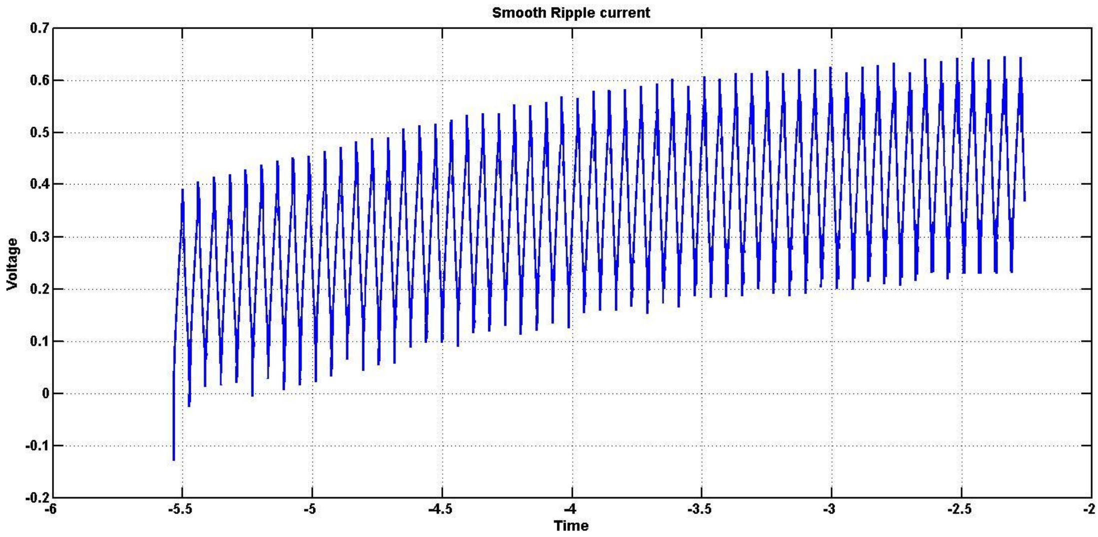


**Figure 4.4** The smooth ripple current in Matlab

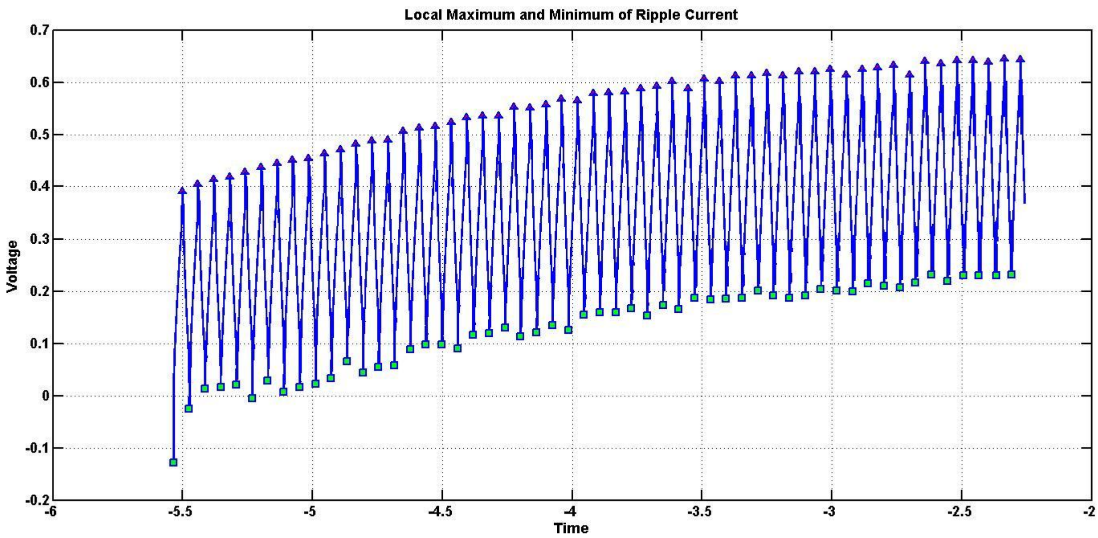


**Figure 4.5** The local maximum and minimum of ripple current in Matlab

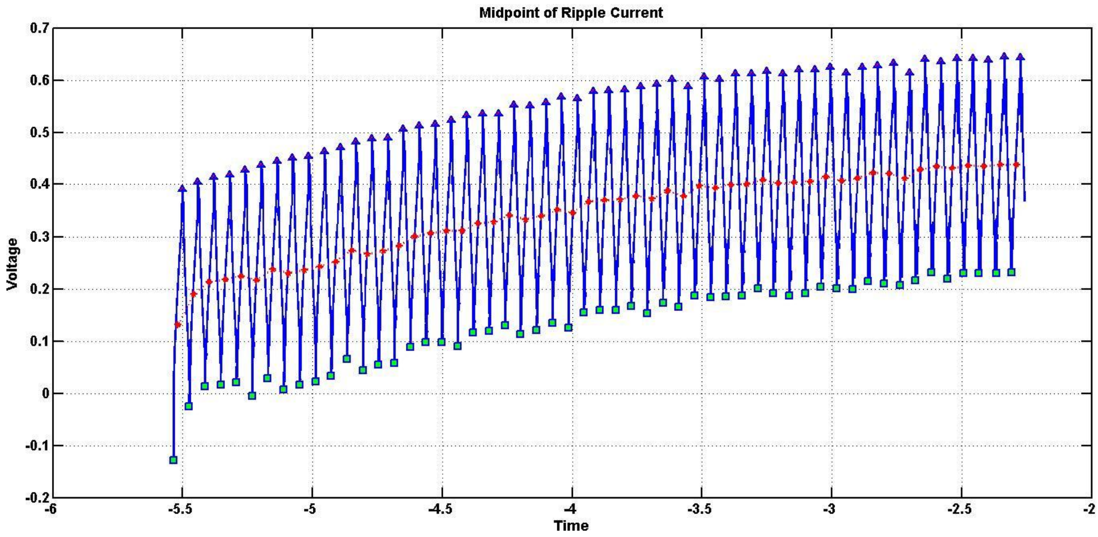


**Figure 4.6** The midpoint of ripple current in Matlab

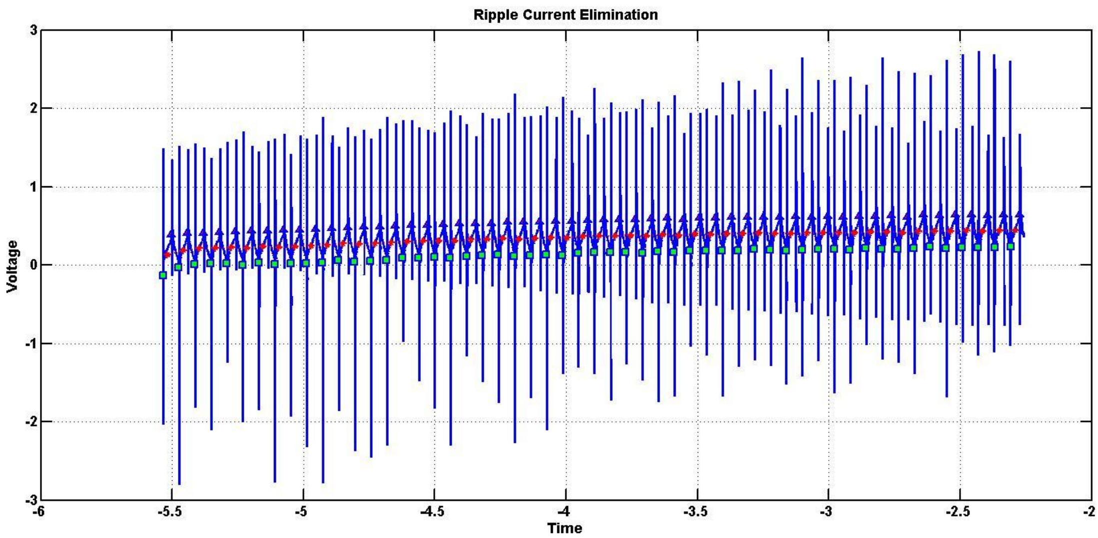


**Figure 4.7** The ripple current elimination in Matlab

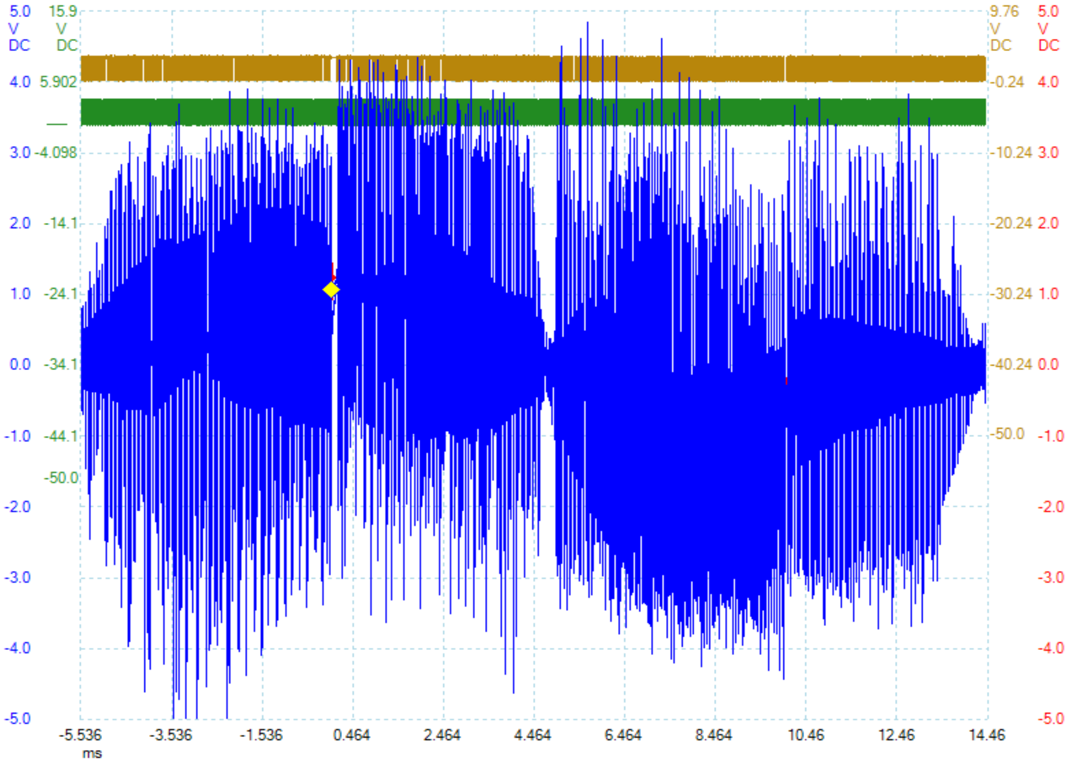


**Figure 4.8** The raw signals of Hysteresis from Picoscope

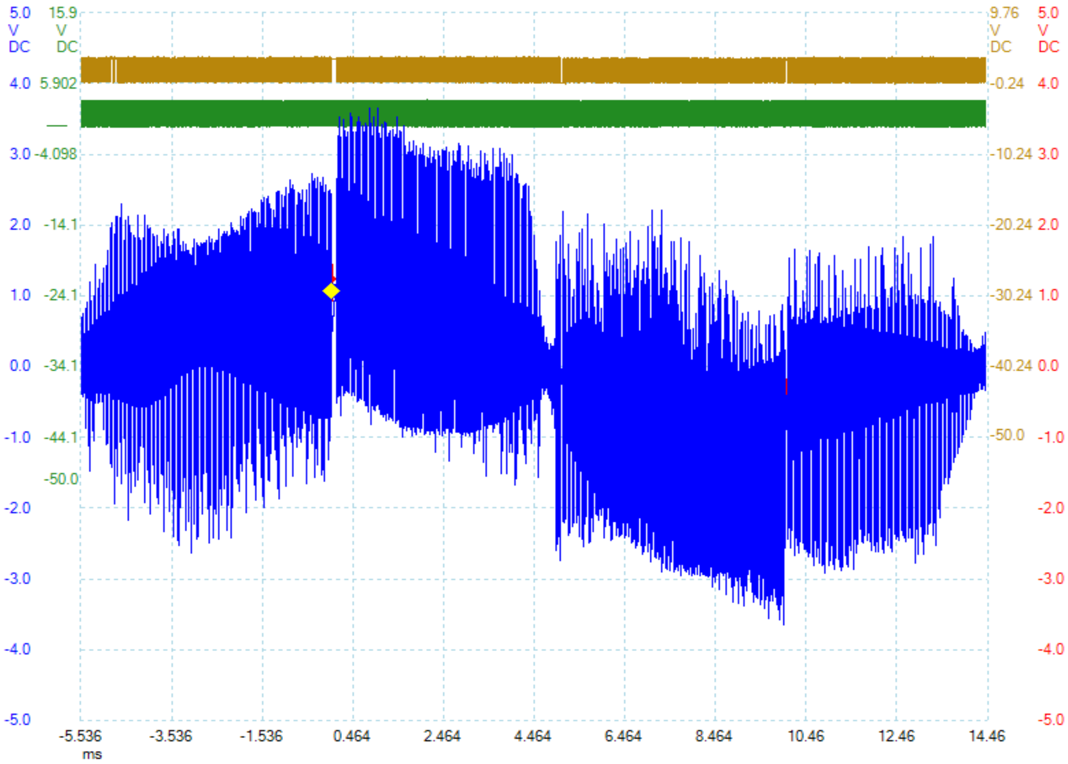


**Figure 4.9** The pre-filtered signal of Hysteresis from Picoscope

### 4.1.2 The span of the moving average is 200

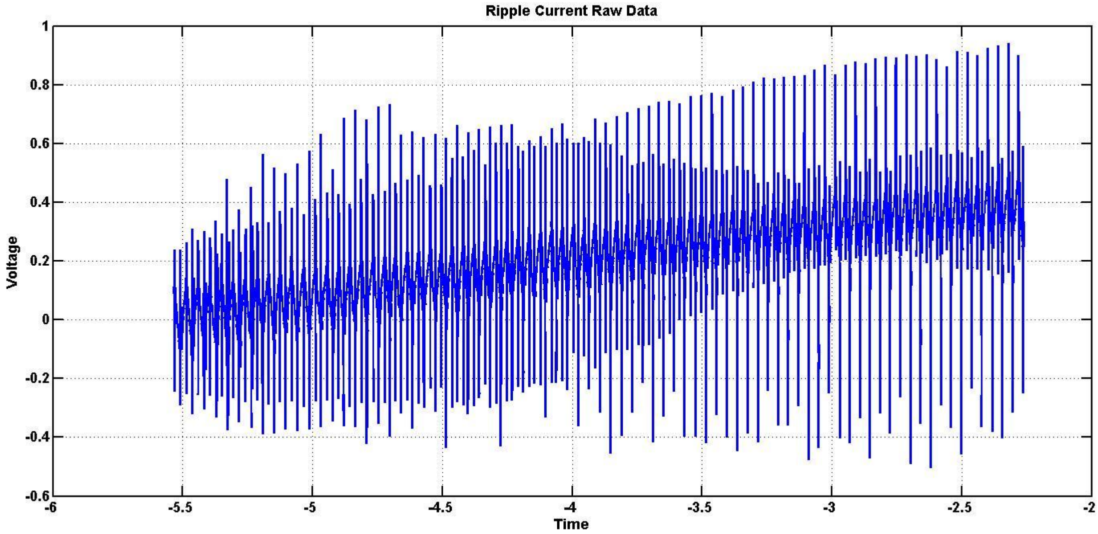


**Figure 4.10** The ripple current raw signals in Matlab

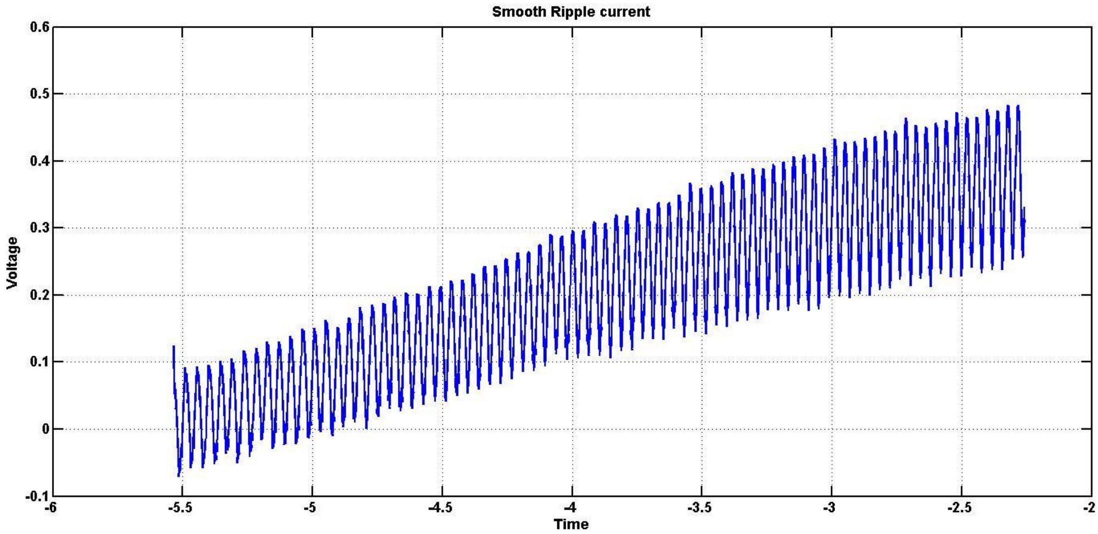


**Figure 4.11** The smooth ripple current in Matlab

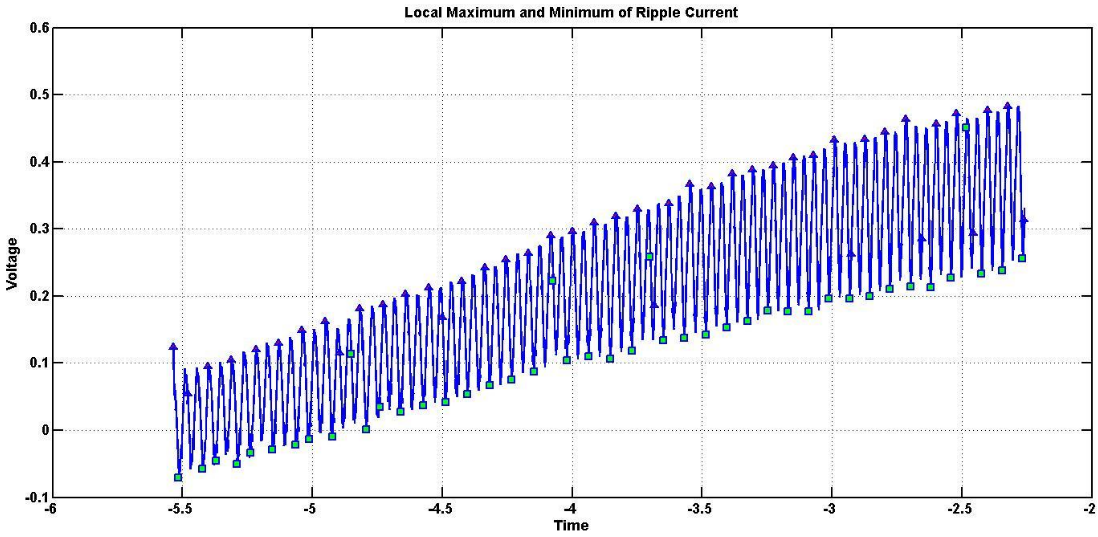


**Figure 4.12** The local maximum and minimum of ripple current in Matlab

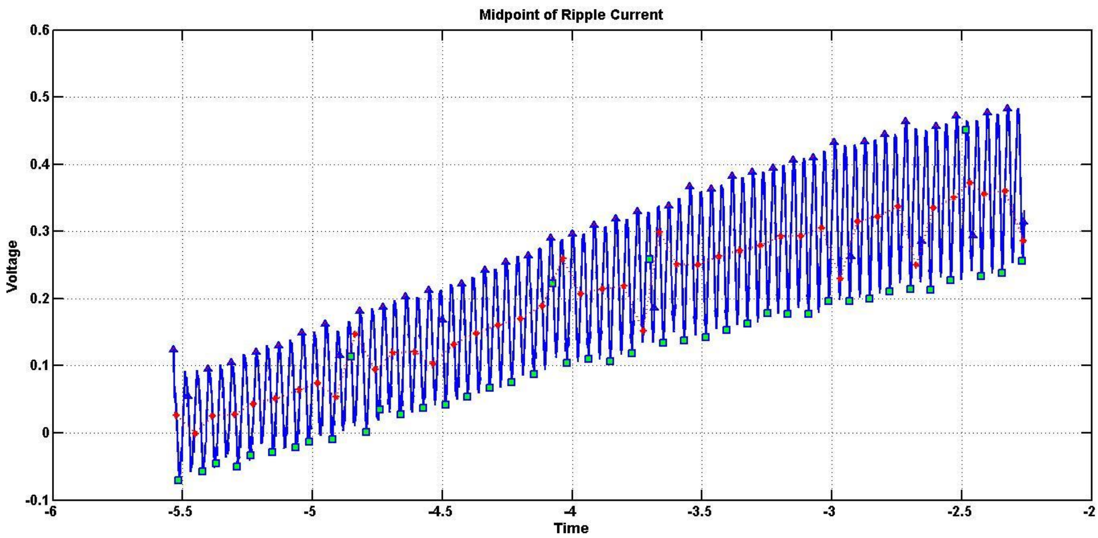


**Figure 4.13** The midpoint of ripple current in Matlab

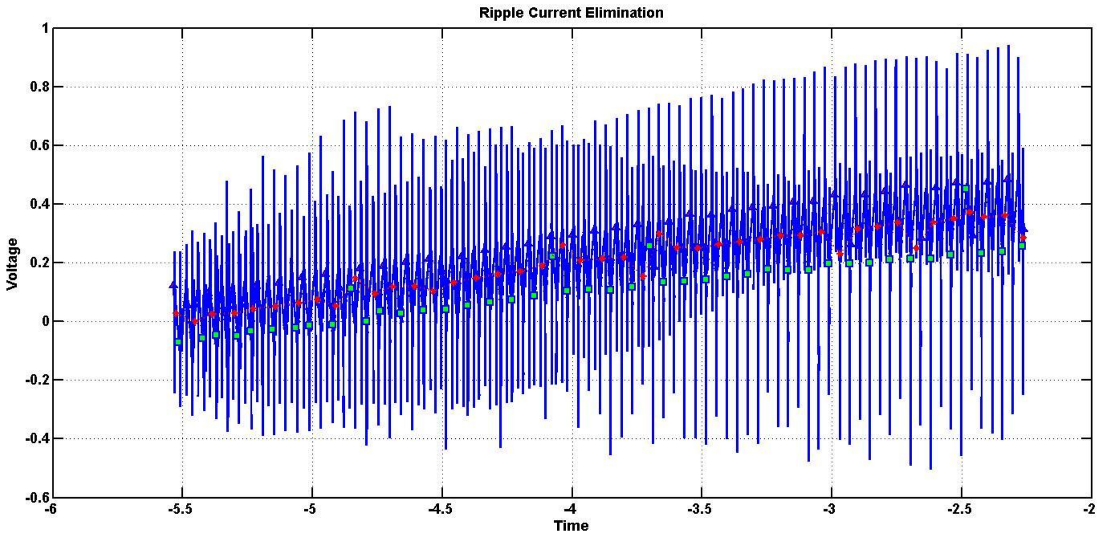


**Figure 4.14** The ripple current elimination in Matlab

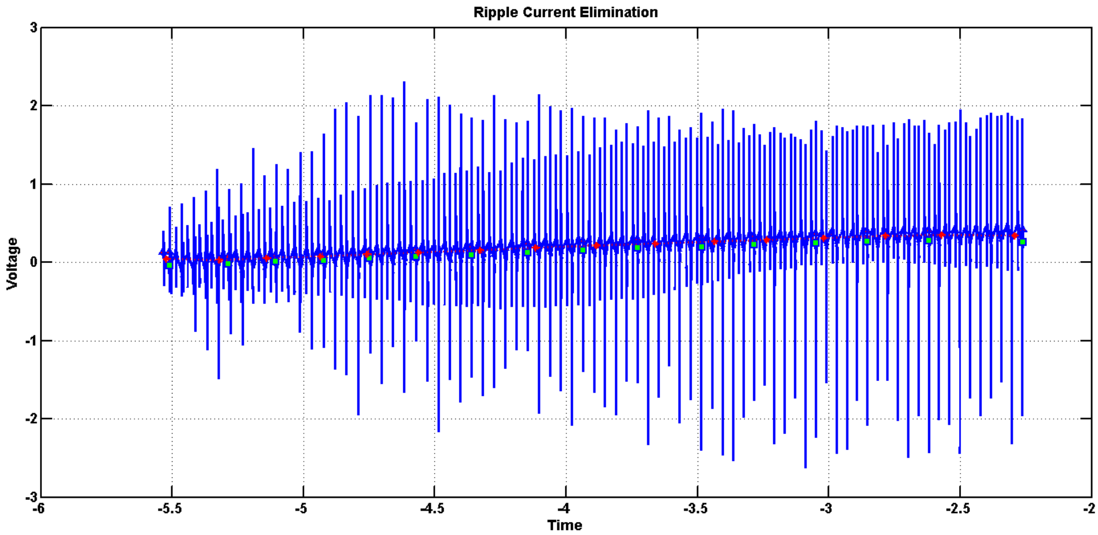


**Figure 4.15** The ripple current elimination in Matlab

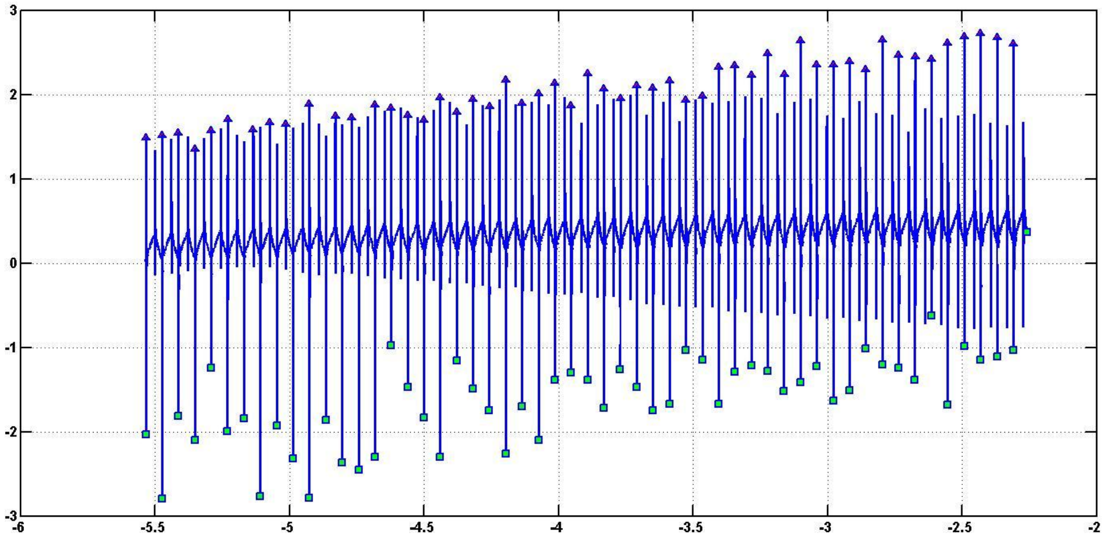


**Figure 4.16** The example of peak finding for noise in Matlab

## 4.2 DISCUSSIONS

For **Figure 4.1**, it has shown a raw signal where it is not being filtered yet. As the eye can see, it looked like the complex signal with much ripple and noise. The undershoot and the overshoot are too high. The simulation has been done to the data of PI and Hysteresis current control by using the PicoScope software. To overcome this problem, the raw or original signal is being filtered with a fix cut off frequency of 2 MHz as shown in **Figure 4.2**. By comparing the **Figure 4.1** and **Figure 4.2**, it can be seen that **Figure 4.2** has reduced in noise as well as the ripple. Based on **Figure 4.3**, signal of the ripple current elimination in Matlab is extracted as the Excel data. MATLAB import file of microsoft excel spreadsheet file and read between the range of row 4 and 65536 for the A and B column (A is the time in seconds and B is one of the current channel). The range for the y-axis of voltage is decided from -3 V to 3 V while the range for the x-axis of time is decided to be from -6 s to -2 s. By using MATLAB, **Figure 4.3** has proved the existence of the complex noise and ripple. For the **Figure 4.4**, the range for the y-axis of voltage is between -0.2 V and 0.7 V while for the x-axis range of time is remained the same as in **Figure 4.3**. The curve fitting toolbox has been applied as moving average filter for eliminating the ripple and also acted like the fixed cut off frequency in filtering the noise. By using the syntax of yy = smooth(y,span), it can smoothed the response data where the span is equal to 100. Every 100 data is being averaged for the smoothing purpose is defined for 100 spans. The duration for 65533 data is estimated to 3.3 s where for single data, it is equal to 50 us. In addition, the window range for the current control of PI value is 5000 us with the frequency of 200 Hz. Moreover, **Figure 4.4** has shown the smooth ripple without noise. **Figure 4.5** is shown that when maximums and minimums point are plotted, the points are all next to each other that gave a smooth point plotted. To achieved the finding of peak and valley, [pks,locs] = findpeaks(data, minpeakdistance) of syntax from signal processing toolbox has been used for the 1000 data. The minimum and maximum are plotted for every 1000 data. The window range is 0.05 s with the frequency of 20 Hz. For **Figure 4.6**, the midpoint rule is determined as the formula below,

$$midpoint1 = \frac{x1 + x2}{2} \; and \; midpoint2 = \frac{y1 + y2}{2}$$

After that, the interpolation method has been applied to all midpoint. **Figure 4.7** has shown the result of the ripple filter in real data for better current control analysis.

For Hysteresis current control, the explanation for **Figure 4.8** and **Figure 4.9** is same like the **Figure 4.1** and **Figure 4.2**. The difference between the simulation of hysteresis and PI is the span value. For the hysteresis case, span value that has been chosen is 200. The range for the y-axis of voltage is decided from -0.6 V to 1 V while the range for the x-axis of time is decided to be from -6 s to -2 s. The window range is 0.01 s with the frequency of 100 Hz is used to smooth the ripple and there is no problem with the ripple smoothing. The problem arise when to plot the local maxima, minima and midpoint. The minimum and maximum are plotted for every 1000 data. By comparing the **Figure 4.12** to **Figure 4.5**, there are several points that are not next to each other that resulting not so smooth of midpoint interpolation. The improvement has been done so that the smooth interpolated midpoint is achieved. By changing the span value to 500, the window range is increased to 0.025 s with the frequency of 40 Hz. The right minpeakdistance is 3500 data with the window range is 0.175 s and the frequency of 5.7143 Hz. Based on the improvement that has been done, the result shown in **Figure 4.15** is better than **Figure 4.14**. For reference,

**Figure 4.13** is the midpoint plotted all alone as the **Figure 4.14** is the combination of all point plotted. If the smooth curve fitting is not applied to the raw signal, it will affect the plotting of peak and valley. As the result, the maximum and minimum point will be plotted at the noise, as shown in **Figure 4.16**, but not at the ripple. This can cause the maximum and minimum plotted at different span value, thus the midpoint could not be plotted (error happened after coding has been run).

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 CONCLUSION

The main objective which is to develop a technique based on numerical algorithm to eliminate the current ripple for better understanding of current control is been achieved.

## 5.2 RECOMMENDATIONS FOR THE FUTURE RESEARCH

The technique develop on moving average filter is one of adaptive filter method. So, there is various ways to implement this project. For the recommendation, develop additional algorithm which can fix with different of current control data including ripple factor analysis with GUI performance.

# REFERENCES

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# APPENDICES

# A Moving Average Filter for Ripple Current Elimination

```
%Moving Average Filter for Ripple Current Elimination
%import data from excel sheet
%read microsoft excel spreadsheet file
x=xlsread('PI.xls','A4:A65536');
y=xlsread('PI.xls','B4:B65536');

%signal plot
figure(1)
plot(x,y);
title('Ripple Current Raw Data');
xlabel('Time');
ylabel('Voltage');
grid on;

%curve fitting toolbox
%smooth
%signal plot
figure(2)
yy=smooth(y,100);
plot(x,yy);
title('Smooth Ripple current');
xlabel('Time');
ylabel('Voltage');
grid on;

%signal processing toolbox
%findpeaks
%signal plot
figure(3)
[pks,locs]=findpeaks(yy,'minpeakdistance',1000);
[pkstop,locstop]=findpeaks(yy,'minpeakdistance',1000);
z1=findpeaks(yy,'minpeakdistance',1000);
plot(x,yy);
hold on;
plot(x(locs),z1,'b^','markerfacecolor','r');
[pks,locs]=findpeaks(-yy,'minpeakdistance',1000);
[pks,locsbot]=findpeaks(-yy,'minpeakdistance',1000);
pksbot=(-1)*findpeaks(-yy,'minpeakdistance',1000);
z2=(-1)*findpeaks(-yy,'minpeakdistance',1000);
plot(x,yy);
hold on;
plot(x(locs),z2,'bs','markerfacecolor','g');
title('Local Maximum and Minimum of Ripple Current');
xlabel('Time');
ylabel('Voltage');
grid on;

k=65533;
compile=zeros(k,1);
for m=1:k
for n=1:n>=10
if(locsbot(n)==m)
compile(m)=pksbot(n);
end
if(locstop(n)==m)
compile(m)=pkstop(n);
end
```

```
end
end

%signal plot
%figure(4)
%plot(x(locs),z1,'k+',x(locs),z2,'k+');
hold on;
xi=-6:.01:-2;
y1=interp1(x(locs),z1,xi,'linear');
y2=interp1(x(locs),z2,xi,'linear');
%plot(x(locs),z1,xi,y1);
hold on;
%plot(x(locs),z2,xi,y2);
title('Interpolation of Local Maximum and Minimum of Ripple
Current');
xlabel('Time');
ylabel('Voltage');
%grid on;

%signal plot
%figure(5)
%plot(x(locs),z1,'k+',x(locs),z2,'k+');
hold on;
%plot(x(locs),z1,xi,y1);
hold on;
%plot(x(locs),z2,xi,y2);
hold on;
mid1=(x(locstop)+x(locsbot))/2;
mid2=(pkstop+pksbot)/2;
%plot(mid1,mid2,':r*');
title('Midpoint of Ripple Current');
xlabel('Time');
ylabel('Voltage');
%grid on;

%signal plot
figure(6)
[pks,locs]=findpeaks(yy,'minpeakdistance',1000);
[pkstop,locstop]=findpeaks(yy,'minpeakdistance',1000);
z1=findpeaks(yy,'minpeakdistance',1000);
plot(x,yy);
hold on;
plot(x(locs),z1,'b^','markerfacecolor','r');
[pks,locs]=findpeaks(-yy,'minpeakdistance',1000);
[pks,locsbot]=findpeaks(-yy,'minpeakdistance',1000);
pksbot=(-1)*findpeaks(-yy,'minpeakdistance',1000);
z2=(-1)*findpeaks(-yy,'minpeakdistance',1000);
plot(x,yy);
hold on;
plot(x(locs),z2,'bs','markerfacecolor','g');
plot(mid1,mid2,':r*');
title('Local Maximum and Minimum of Ripple Current');
xlabel('Time');
ylabel('Voltage');
grid on;
```