Development of Kalman Filter based Digital Signal Processing (DSP) Tools for Voltage Sag with Graphical User Interface

Fadhilah Najmi Binti Razali
Faculty of Electrical Engineering
Universiti Teknologi MARA
40000 Shah Alam
e-mail: najmipaddy@gmail.com

Abstract **- Voltage sag are characterized by a pair of data, the magnitude and the duration. This paper described the application of Digital Signal Processing (DSP) tools by applying Graphical User Interface (GUI) on Kalman Filtering method for analysis of voltage events in power system. The GUI integrates the Kalman filtering technique and analysis the established of frequency as well as the magnitude. The application also allowed the analysis of simulated voltage events of different magnitude and different frequency on the analysis of real voltage events from records taken by power quality monitoring equipment.**

Keywords – Digital Signal Processing (DSP) tool, Graphical User Interface (GUI), Voltage Events, voltage sag, Kalman Filtering.

I. INTRODUCTION

Power Quality disturbances in voltage supply are a major concern for many industrial and commercial systems. An important group of these disturbances are those that produce a sudden and temporary increase or decrease in the magnitude of the voltage supply. Voltage dips, short interruptions and transient or temporary over voltages may produces the tripping or malfunctioning of equipment connected to the power systems [1]. These voltage events are considered the most important power quality problem facing many industrial customers due to the economic effects that they could have on industrial process. For this reason, there is a great need for automated tools for the rapid detection and quantification of these voltage events in order to prevent their negative effects [1], [3].

There are different methods for the estimation of the magnitude of supply voltage and its time evolution during a voltage event. The computation of r.m.s voltage is the simplest processing tool and is the method proposed in power quality measurements standards but it has the limited performance especially in the case of short duration of voltage events. Therefore, Kalman Filtering method is one of the alternative methods for analysis of voltage events.

One of the purpose for this paper is to develop Digital Signal Processing (DSP) tools by applying the Kalman Filter method using MATLAB GUI for the detection and analysis of voltage events in power systems [3],[4].

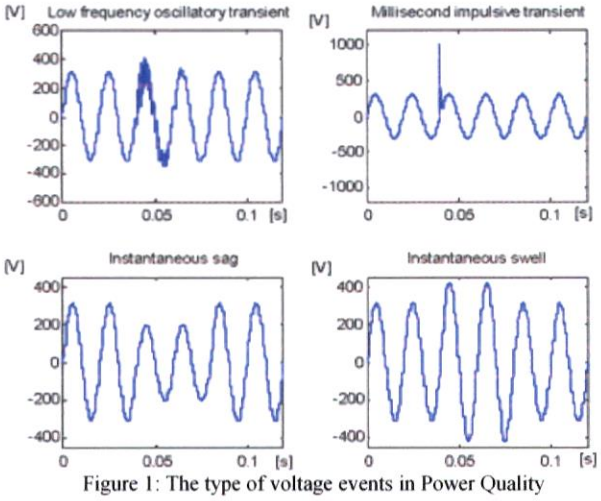


Figure 1: The type of voltage events in Power Quality

Figure 1 above shows the type of voltage events which are transient, sag and swell. Voltage sag is the most common power disturbances in power quality. Voltage sag is defined as a decrease in RMS voltage at the power frequency for durations from 0.5 cycles to 1 minute which reported ad the remaining voltage. The measurement of voltage sag is started as a percentage of nominal voltage from 10% to 90% which means 0.1 up to 0.9 in per unit [2], [5].

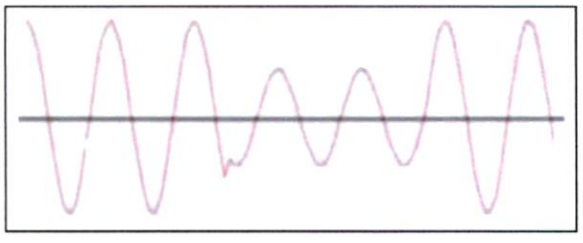


Figure 2: The waveform of voltage sag

II. THE GRAPHICAL USER INTERFACE (GUI)

In order to facilitate the analysis of Power Quality source detection, a program with Graphical User Interface (GUI) feature is suitable and proposed. The GUI features provided the user with visual interactive capability with less tedious and repetitive work on parameter adjustment and calculation. The design environment is based on the MATLAB Graphical User Interface Development Environment (GUIDE).

A graphical user interface (GUI) is a graphic interface to a program and it can make programs easier to use by providing them with a consistent appearance and with intuitive controls like pushbuttons, list boxes, sliders, axes, menus, and so on. The GUI should behave in understandable and predictable manner, so that a user knows what to expect when performs and action. For example, when a mouse click on pushbuttons, the GUI should initiate the action described on the label of the button [8], [10].

Generally, MATLAB GUIs offer a simple solution using a common script language. Although M-file scripts and function are excellent for solving many problems, there are often situations where user interactivity with the application is integral for solving a particular problem [9].

One of the key elements for understanding how to develop GUIs is to recognize features available in MATLAB that may be used for graphical user interface design. Creating specifications for and application and determining what is possible are much easier when have detailed knowledge about the function and tools available [9]. A graphical user interface provides the user with a similar environment to work. This environment contains the pushbuttons, list, popup menus, text boxes and so forth, all of these functions which are already familiar to the user, so that he or she can concentrate on using the application rather than on the mechanics involved in doing things [9],[10].

Automatic code generation is another compelling reason to develop at a high-level. Each objects creation in GUIDE allows M-file code generation automatically with control of the naming of function and objects. Code generation saves you from typing or copying code section for every GUI object definition and associated callback functions [10].

Key features of GUIDE provide additional advantages that assist you in speedy development. The Property Inspector and Object Browser provide a visual, interface for each component object in the design. This allows user to access and initialize all the properties of the GUI components [8]. Furthermore, each GUI components have different properties for controlling their appearance and behavior. The Property Inspector eases the task of determining for what is available in each GUI component [10].

There are three principle elements required when to create a MATLAB Graphical User Interface which is:

1. Components. Each item on a MATLAB GUI (pushbuttons, labels, edit boxes, pop menus, etc) is a graphical component. The types of component include graphical controls (pushbuttons, edit boxes, lists, sliders, etc), static element which are frames and text strings, menus and axes. Graphical controls and static elements are created by function uicontrol, and menus are created by the function uimenu, and uicontextmenu. Axes which are used to display graphical data are created by the function axes.

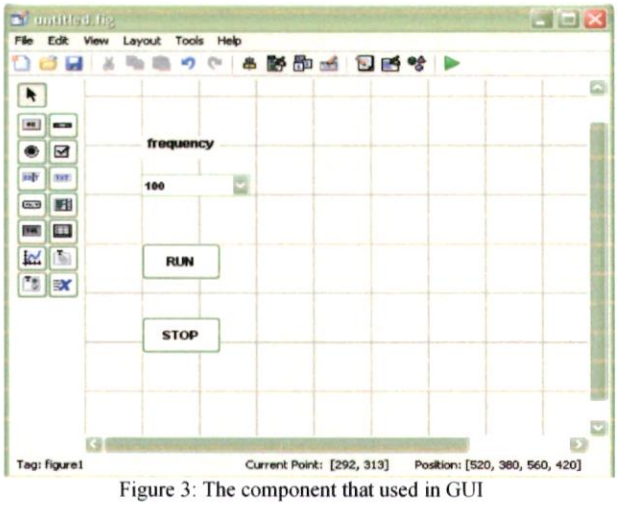


Figure 3: The component that used in GUI

2. Figures. The components of a GUI must be arranged within a figure and before this; figures have been created automatically whenever we plotted data. However, empty figures can be created with the function figure and be used to hold any combination of components.

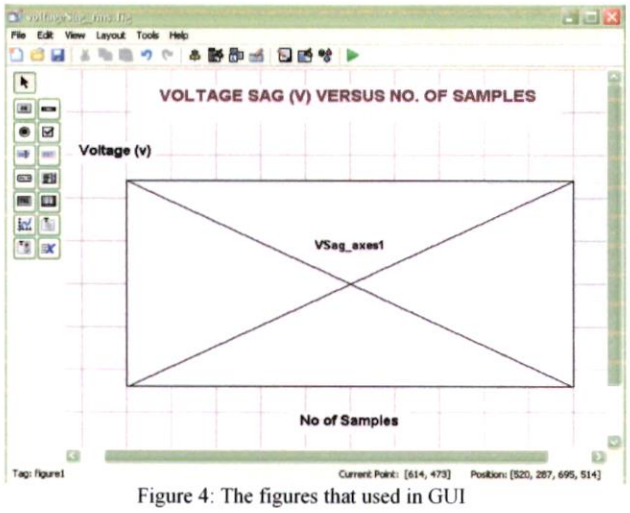


Figure 4: The figures that used in GUI

3. Callbacks. Finally, there must be same way to perform an action if user clicks a mouse on a button or types information on a key board in command window. A mouse click or press is an event, and the MATLAB program must respond to each event if the program is to perform its function. For example, if user clicks on a button run, that event will cause the MATLAB code to implements the function of the button run to be executed. The code executed in response to an event is known as a callback. There must be a callback to implement the function of each graphical component on the GUI [9],[10].

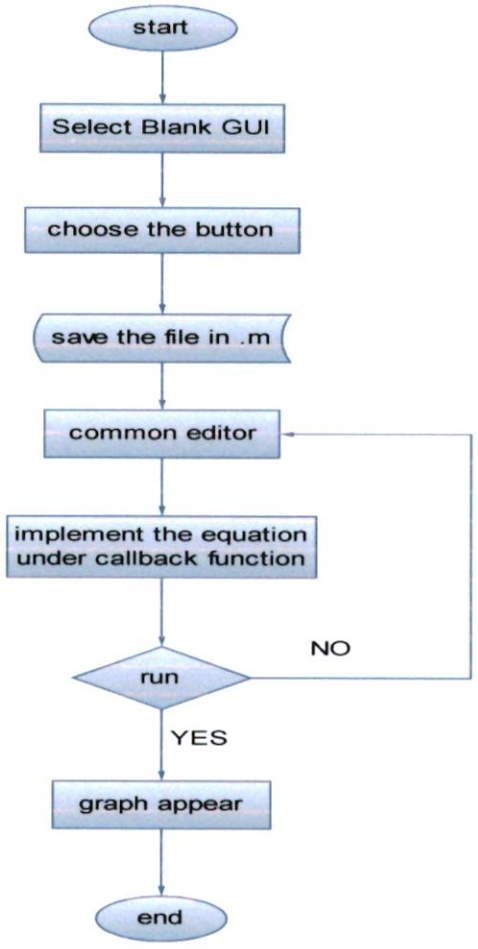


Figure 5: The flowchart of the process in designing GUI in MATLAB

Figure 5 shows that the process of flowchart in designing Guide User Interface (GUI) in MATLAB software. At first, select the GUIDE button. Then choose the blank GUI and click OK. It will appear the untitled.fig and chooses the button that needed such as axes button, push button, edit text and statics text. After that, double click at each of the button and the property inspector will appear and change the name that needed in Tag and String. After that, the file must be save in .m and the Editor will appear with the programming automatically. In the programming of the Editor, write the equation of the Kalman filter method under a callback function and run the Editor. If the equation is correct, the graph will appear but if the programming equation is wrong, the error will come out at command window. At command window, it will state which line the mistaken of the programming and it can be corrected at Editor. The process will keep continued if the programming is wrong and it will stop until the correct graph come out after run the Editor.

III. KALMAN FILTERING

Kalman Filtering is one of the most method that been used for Digital Signal Processing (DSP) tools. Besides that, Kalman Filters have been used for the optimal estimation of electrical magnitudes power systems from their sampled values. They provide the best estimation of these magnitudes with the smallest numbers of samples and in the shortest time. Voltage and current phasors, harmonic distortion, frequency deviations, voltage flicker and other parameters can be computed using Kalman Filtering [3].

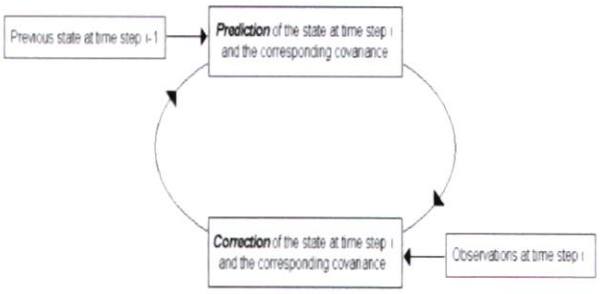


Figure 6: Circuit of the Kalman filter

The basic components of the Kalman filter are the state vector, the dynamic model, the observation model and figure 6 showed the flow of Circuit on the Kalman filter.

Kalman Filtering uses a mathematical model of the signal in state variable form. The state described the average of Filter which is

$$x'_{k+1} = \emptyset_k x_k + w_k$$

where x_k is the state vector at the instant k of size $2n$, $\emptyset_k$ is the state transition matrix and w_k is random variable vector that represents the variation of state variables due to an input white noise sequence [2].

The change in magnitude of the fundamental component of the voltage supply is used to detect and to analyse the voltage events. An important advantage of Kalman filtering over the others method such as

wavelet and r.m.s method is that the phase-angle of the fundamental component of voltage supply and the point-on-wave the event begins and ends can also be determined [3]. The efficiency in the detection and analysis of voltage events using Kalman filtering depends on the model of the system used. The performance of different Kalman filters for real-time tracking of the fundamental and the harmonic components of voltage and current waveforms are seen in [8] and [9].

The Kalman filter offers the possibility of dynamic tracking of the harmonic content, increasing the accuracy of the analysis and providing a possible input to feedback control scheme such an active filter [5].

IV. METHODOLOGY

As to analyze the simulated voltage event, the developed software; MATLAB Graphical User Interface is generate the Kalman filter method and will enables the selection of the sampling frequently (samples/cycle), magnitude (in percentage of nominal voltage), duration (in samples) and point on the wave beginning of the event (in sample from zero-crossing). Once the parameters of the voltage event are selected, the system will generates an event record made up of at least two cycle of voltage waveform pre-event of magnitude, the voltage event itself and three cycles of voltage supply post-event.

This section presents the flow of Kalman Filter method for analysis of voltage events. Figure 7 shows the flowchart on how to produce output waveform of voltage events by implement the Kalman filtering method.

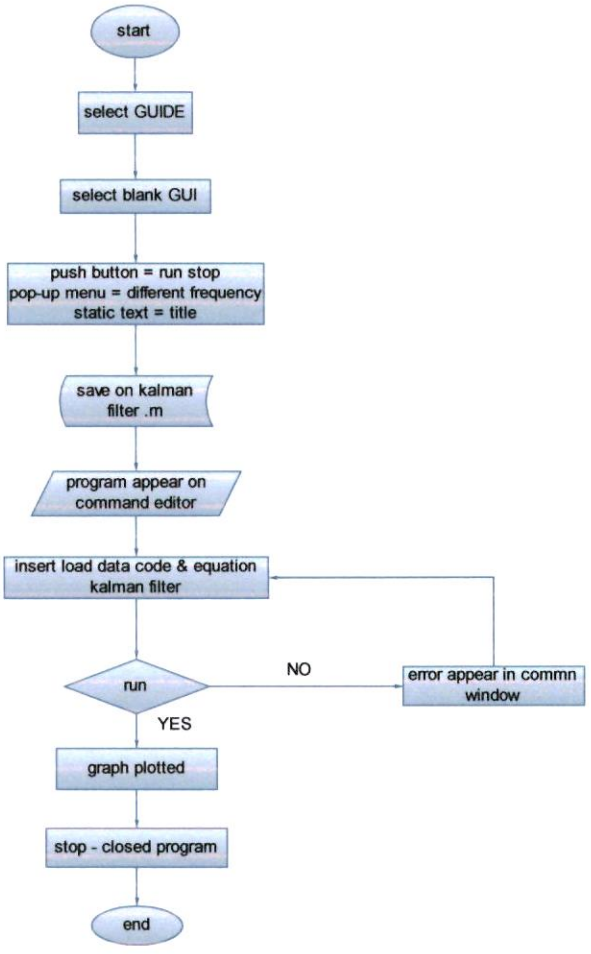


Figure 7: Flowchart for determine the output waveform of voltage sag.

First of all, the user has to select data from a list of power quality disturbances recordings which is Devlan Power Supply and transfer the data to Microsoft excel and save the data in .xls. Then the user has to select kalman filter.m in Current folder. After that, insert the equation of Kalman filter under the run_callback function. From workspace, click the imported data button to load the data that the user have save in excel.

The user has to rename the data first before save the data in .mat file. In under run_callback function, write the command to load the data that user save in workspace. After finish all the instruction, the user can run the button and the graph will plot instantaneously. The output waveform of voltage sags will come out and if the output waveform does not appear, the user has to start the process again. In simulation mode, the Kalman filtering can performed on the selected register. As a result the voltage waveform and the r.m.s magnitude, the magnitude of fundamental component of voltage

supply or the coefficients with the other digital signal tools method.

V. RESULTS AND DISCUSSIONS

Figure 8 shows the data from notepad. From the notepad, it will save to excel and then it will imported data to workspace and store the data as 'najmi.xls'. A 'najmi.xls' button is a component that the user can click on to trigger a specific action which is load data. The pushbutton generates a callback when the user clicks the mouse on it.

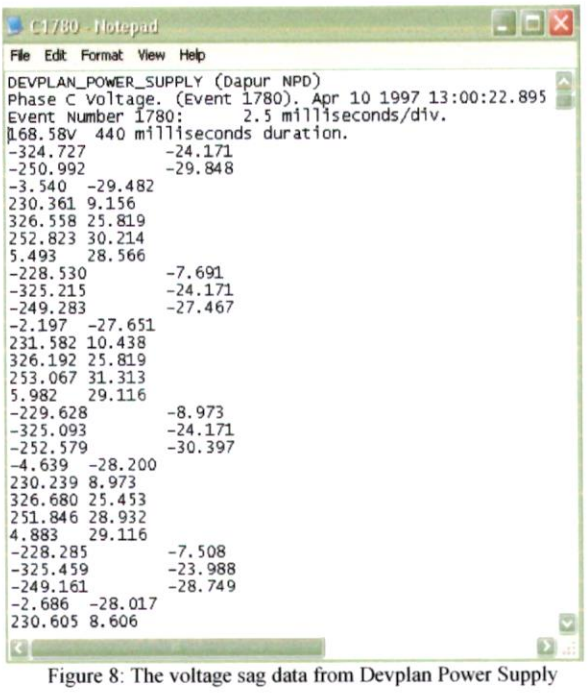


Figure 8: The voltage sag data from Devplan Power Supply

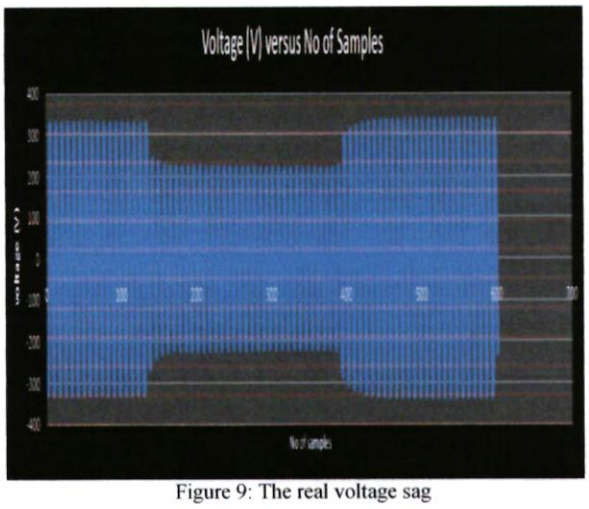
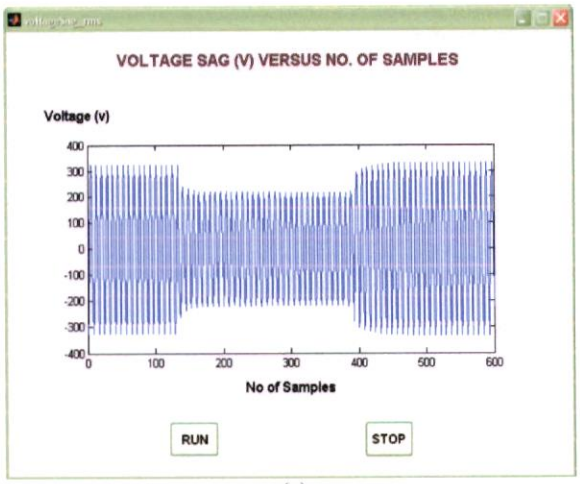
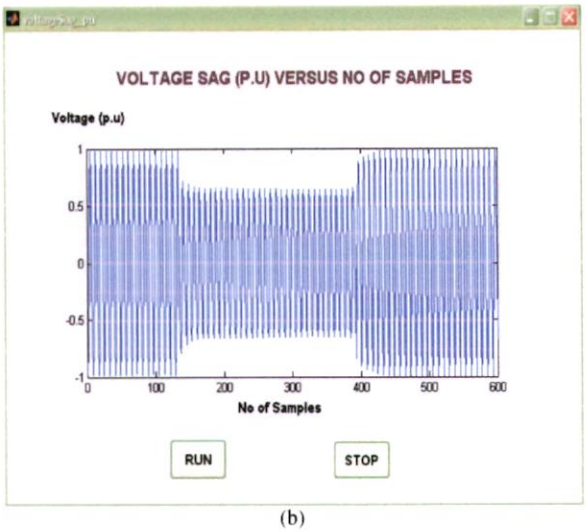


Figure 9: The real voltage sag

Figure 9 show the real voltage sag from the data that had been taken. As the user can see, the voltage sag happened when the number of sample is around 140 samples and the voltage dropped autimatically from 320.0880V to 230.369V.



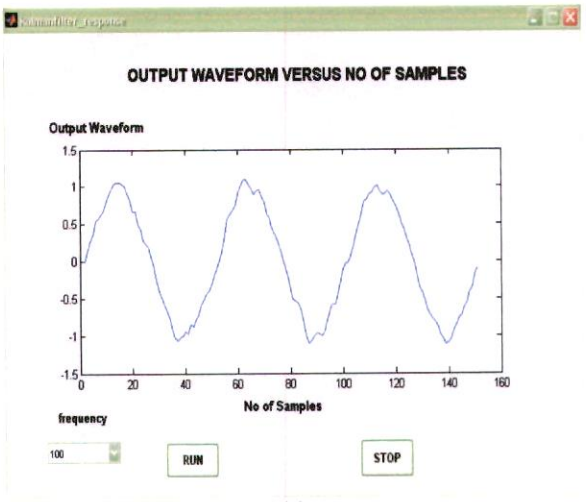
(a)



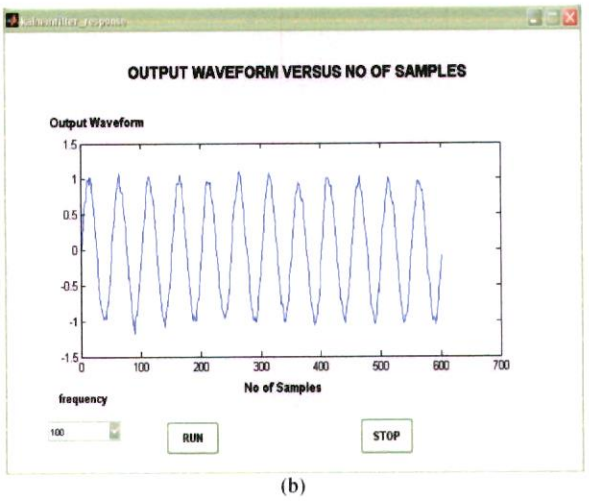
(b)

Figure 10: (a) Voltage waveform of a voltage sag in Voltage value, (b) Voltage sag in per unit system.

The figure 10 (a) and (b) shows result of voltage sag in Volt and in per unit system after running the GUI. The Devplan Power Supply (Dapur NPD) contained 1024 of samples data but in this project, the numbers of sample are limited to 600 samples in a low-voltage distribution network. From the result, the maximum voltage is in range 320.0880V. The user can see that the voltage sag happened between 140 to 380 number of given sample data. At 140 number of sample, the voltage drop stop and the voltage will increased back to 1.0 p.u. the voltage always happened in between 0.1 to 0.9 of their nominal value.



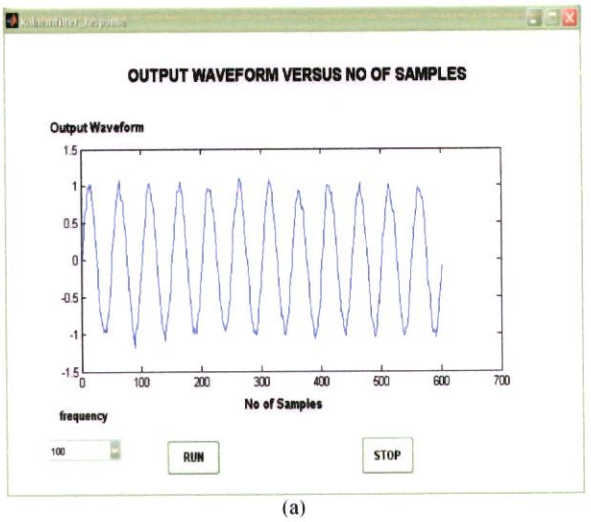
(a)



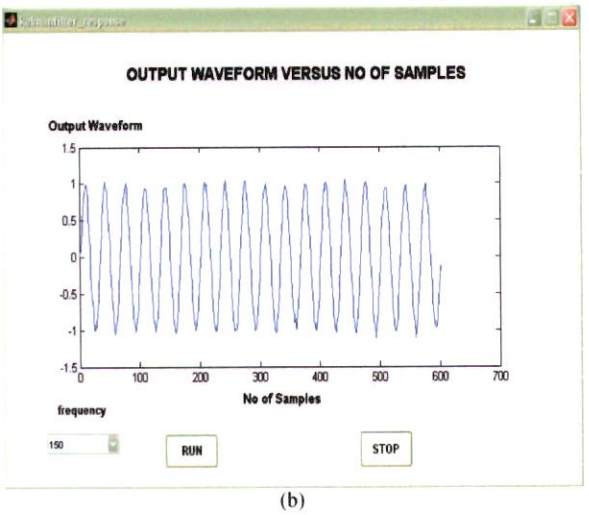
(b)

Figure 11: (a) The graph shows the true response of Kalman filter, (b) After the Kalman filter method inserted filter equation.

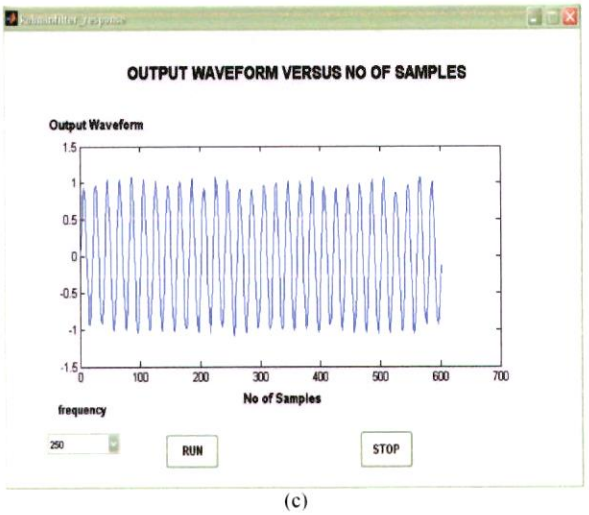
Figure 11 (a) shows the graph of the true response of Kalman filtering method by using the digital signal processing tools. After the Kalman filtering method is inserted in voltage sag data, the graph of volatge sag in (b) changed due to the Kalman filtering equation. The user can see the changes of voltage sag waveform and identified the characteristic of Kalman filter in voltage sag data. Figure 11 (b), the frequency that been use is still maintain at 100Hz and the frequency will varies to see the effect at Kalman filter method.



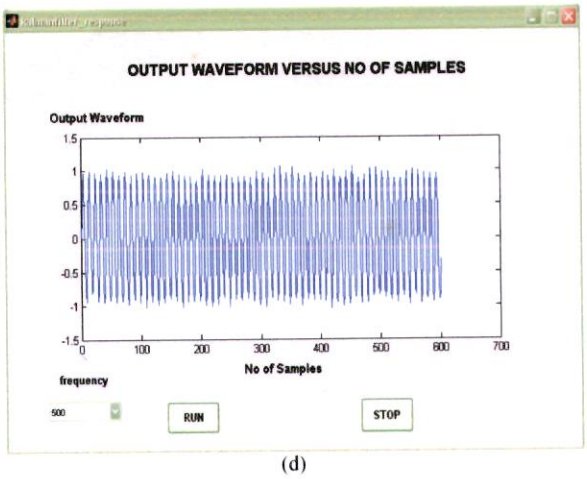
(a)



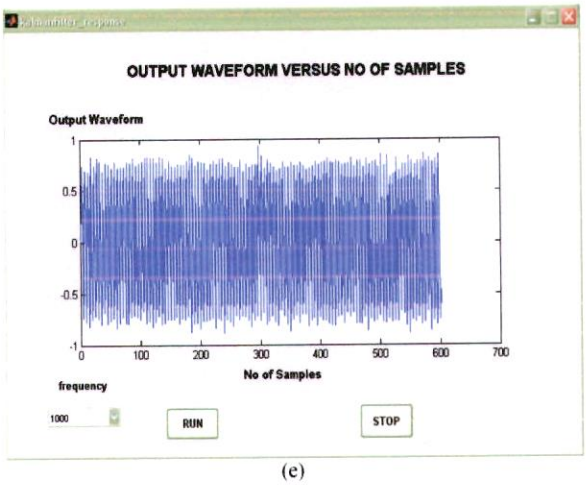
(b)



(c)



(d)



(e)

Figure 12: (a) The output waveform of Kalman Filter when the frequency is maintain at 100Hz, (b) at frequency 150Hz, (c) at frequency 200Hz, (d) at frequency 500Hz, (e) at frequency 1000Hz

In figure 12 (a) showed the output signal waveform of Kalman filter method when the frequency is still maintained at 100Hz. When the user change the frequency at 150Hz in figure 12 (b), at frequency 200Hz in figure 12 (c), at frequency 500Hz in figure 12 (d) and at frequency 1000Hz in figure 12 (e), the user can see the change of cycle output and the pattern of output waveform become more district than usual. Each one cycle in figure 12 (a) contains 50 samples/cycle and the frequency is 100Hz. As the frequency increase, the sample of cycle also become narrow and at the frequency 1kHz or 1000Hz, the user can see that the high frequency totally effect the signal on the response of Kalman filter method. As a result, the high frequency also will effect the response of the Kalman filter method and this method not suitable in high range frequency.

VI. CONCLUSION

The paper presents the procedure and analysis of voltage events and the frequency by using Kalman filtering method. For the expected result, the software can develop and enables the selection of magnitude and the different frequency that we need and also the effect of different frequency for the voltage sag. Furthermore, the digital signal processing tools can implement in two different modes such as simulation of voltage sag and analysis of real voltage sag by using Kalman Filtering method.

ACKNOWLEDGMENT

I would like to grab the opportunity to show my gratitude to my family and to all the people that helped me in the whole process of this report. Appreciation is expressed to my researcher advisor, Associate Prof. Dr Zuhaina Zakaria for her supervision and thoughtful advices that make my project are success.

REFERENCES

[1] Julio Barros and Enrique Pérez, 'Automatic Detection and Analysis of Voltage Events in Power Systems', in *Proc. IEEE Transactions on Instrumentation and Measurement October, 2006* (IEEE, New York, 2006), Vol. 55, No. 5.

[2] Math H. J. Bollen, "Understanding Power Quality Problems: Voltage Sags and Interruptions", New York: IEEE Press, 2000

[3] A. A. Girgis, W. B. Chang, and E. B. Makram, "A digital recursive measurement scheme for on-line tracking of power system harmonics,". *IEEE Trans. Power Del.*, vol. 6, no. 3, pp. 1153-1160, Jul. 1991.

[4] V. M. Moreno and J. Barros, "Application of Kalman filtering for real-time tracking of power system harmonics," in *Proc. Inst. Electr. Eng.—Generation, Transmission and Distribution*, Jan. 1997, vol. 144, pp. 13–20.

[5] M.H.J. Bollen and I.Y.H.Gu, *Signal Processing of Power Quality Disturbances* (John Wiley, New York, 2006).

[6] S. A. Soliman, M, H. Abdel-Rahman, and M. E. El-Hawary, "Linear kalman filtering algorithm applied to measurements of power system voltage magnitude and frequency: a constant-frequency model," *Canadian Journal of Electrical and Computer Engineering*, vol. 22, no. 4, pp. 145-153, Oct 1997.

[7] K. Kennedy, G. Lightbody, and R. Yacamini, "Power system harmonic analysis using the Kalman filter," in *Proc. IEEE Power Eng. Soc. Annu. Meeting*, 2003, vol. 2, pp. 752–757.

[8] Patrick Marchand, O. Thomas Holland: *Graphics and Guis with MATLAB*: Chapman & Hall/CRC publisher, 2003.

[9] S. T. Smith, *MATLAB: advanced GUI development*: Dog Ear Publisher, 2006.

[10] S. J. Chapman, *MATLAB Programming for Engineers*, 2, illustrated ed.: Brooks/Cole Pub Co, 2001.