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Instructional Software for Teaching PWM AC Voltage Controller Using MATLAB'S Graphical User Interface

Ibrahim A. Altawil
Department of Electrical Power Engineering, Faculty of Hijjawi,
Yarmouk University, Irbid, Jordan

Abstract: This study presents an adequate approach for teaching the sinusoidal pulse width modulation (SPWM) in AC voltage control regulators. In this paper the Graphical User Interface (GUI) functions, which constitute one of the important pillars of MATLAB software, are developed to an easy-to-use educational software tool. Single-Phase Ac voltage controller is mathematically modeled and then simulated using basic MALAB commands. GUI is implemented to construct an active link with these models. Therefore, GUI interactive simulations instructors can demonstrate the change in system response due to parameter variation, in order to know how to place hands in the design problem. An example, using the GUI, is provided to demonstrate the usefulness of the developed software.

Key words: Computer simulations, PWM, AC voltage controller, teaching aids, graphical user interface

INTRODUCTION

Educational experimental modules are not only costly but also, rarely provide the necessary facilities to realize PWM control or to switch from one scheme to another. Therefore, computer aided design packages such MALAB, or Pspice can be very helpful tools to enhance the student's ability to understand the idea under discussion. The majority of current software packages are highly reliable and versatile[1]. Therefore, the new trends in engineering education are strongly relying on these packages in teaching and assisting engineers in solving their problems. Furthermore the new authors and revisers of recently published textbooks have incorporated new exercises and problems based on computer-aided design packages. This stimulated the teaching decision-makers and curriculum designers at universities and other academic institions to include these packages within their teaching plans course descriptions.

Matlab's GUI techniques have been employed in teaching power electronics material. This teaching technique gives the instructors the opportunities to focus on both fundamental and advance concept. The software packages are intended to do computation tasks, where students can learn by observing the parameters variations during the simulation process, which can be repeated several times. This inevitably strengthens student's ability to grasp the key concept of system behavior and digest the power electronics principle such as PWM techniques.

The present study demonstrates an attractive approach for teaching Sinusoidal Pulse Width Modulated (SPWM) in using a MATLAB environment. It explains the principle single-phase PWM AC voltage controller and how the student can simulate the single-phase PWM AC voltage controller more easily using only basic MATLAB instructions. Then, a brief description of GUI windows is given followed by an animated demonstration of the behavior and performance of the SPWM AC voltage controller results. At this stage, students can show the advantage of MATLAB GUI and how he/she can learn the capabilities to develop an attractive and user-friendly software packages for teaching PWM AC voltage controller. This eventually enhances the theoretical understanding of the studies topic and facilitates the analysis and design experience in this field. Finally, the paper concludes the results done in the study.

AC voltage controller: Ac voltage controllers are employed in many industrial applications such as heating, lighting and they supply variable voltage for induction motors. Triacs or anti-parallel connected thyristors are commonly used to obtain variable AC voltage from a fixed AC voltage source. Medium-to-high frequency chopping with PWM control is employed to vary the rms amplitude of the output voltage. Improved performance of AC voltage controllers could be achieved by using less reliable, more complex and expensive forced commutated regulators[2,3]. In spite of the fact that AC voltage controllers have large harmonic distortion and poor power factor they are widely used in small AC drive applications. Sinusoidal PWM and uniform PWM technique have been used commonly to improve performance and efficiency of AC voltage controllers. In SPWM technique used, the

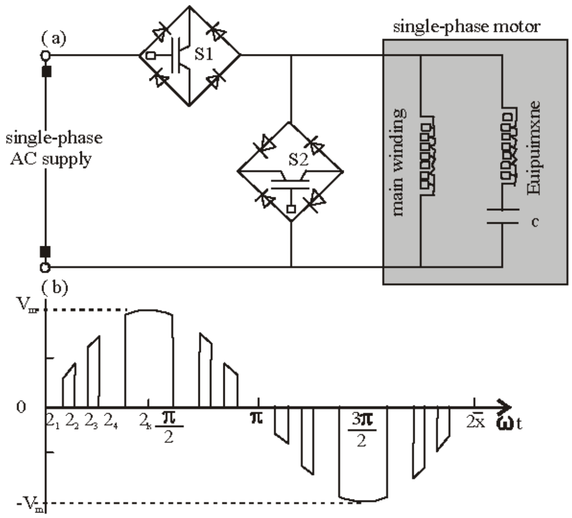

Fig. (1) a: Ac voltage controller power circuit, b. typical output voltage of SPWM AC voltage controller

width of each pulse is varied proportionally to the amplitude of a sine wave. This type of technique is commonly used in industrial application to reduce the Total Harmonic Distortion (THD) and low-order harmonics. The power circuit of a PWM AC chopper driving a single-phase induction motor is shown in the Fig. (1a).

There are two switches labeled as S_1 and S_2; S_1 is used for connecting the load to the source and S_2 is employed to free wheel the load current, when S_1 is switched off. S_1 is turned on at various switching angles, α_1, α_3, ..., α_{k-1} and turned off at α_2, α_4, ..., α_k per quarter cycle. The output voltage of the AC chopper with k pulses per half cycle is shown in Fig. (1b). The switching angles are symmetrical with respect to $\pi/2$. The output voltage can be expressed using Fourier series as follows:

$$V_o = a_0 + \sum_{1}^{n} A_n \cos(n\omega t) + B_n \sin(n\omega t) \quad (1)$$

$$\text{where} \quad n = 1, 2, 3, 4, 5$$

Referring to the output voltage shown in Figure (b), it is observed that even harmonics are absent due to the symmetry of the wave. Furthermore, the coefficients A_n and a_0 are zero, thus, the above equation is reduced to:

$$V_o = \sum_{1}^{n} B_n \sin(n\omega t) \quad \text{where} \quad n = 1, 3, 5 \quad (2)$$

The value of B_n is computed as:

$$B_n = \frac{2V_m}{\pi}\left[\frac{\sin(n-1)\omega t}{(n-1)} - \frac{\sin(n-1)\omega t}{(n+1)}\right]_{\alpha_1,\alpha_3,\cdots\alpha_k}^{\alpha_2,\alpha_4,\cdots\pi/2} \quad (3)$$

$$n \neq 1$$

Where V_m is the maximum value of the input sine wave. The fundamental component is given by:

$$V_1 = \frac{2V_m}{\pi}\left[\omega t - \frac{\sin(n-1)\omega t}{(n+1)}\right]_{\alpha_1,\alpha_3,\cdots\alpha_k}^{\alpha_1,\alpha_4,\cdots\pi/2} \quad (4)$$

The total Harmonic Distortion THD, which is a measure of closeness in shape between a waveform and its fundamental component, is defined as

$$THD = \frac{1}{V_1}\left[\sum_{2}^{\infty} V_n^2\right]^{\frac{1}{2}} \quad (5)$$

The input power factor of the AC voltage controller is defined as

$$PF = \frac{I_{s1}}{I_s}\cos\phi \quad (6)$$

Where I_{s1} is the fundamental of the component of the input current I_s and ϕ is the angle between the fundamental component of the input current and supply voltage

Building MALAB GUI: GUI is simply an interface that can call upon different Matlab operations and operate them without the necessity of using the MATLAB commands. GUI incorporates graphics objects such as windows, icons, buttons, menu and text. Activating these objects by mouse or other pointing device causes an action or change to occur. Several windows are designed and presented in this paper to show the crucial role of GUI applied for this approach. The proposed GUI for simulating a mathematical model of SPWM AC voltage controller supplying (R-L) load has been developed to suite the current work. Particularly, the GUI functions in callbacks string used to execute the user selection as shown in Fig. (2a). When a GUI command is typed, it calls up a window created by the GUI programmer where a possible window element such as menus, buttons, lists,

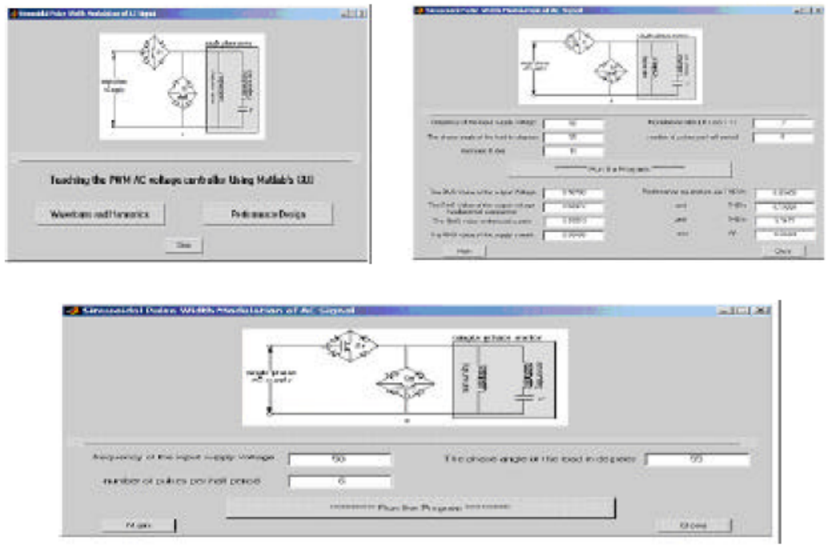

Fig. 2a: The main GUI window, b. The waveform analysis window c: Performence design GUI windo.

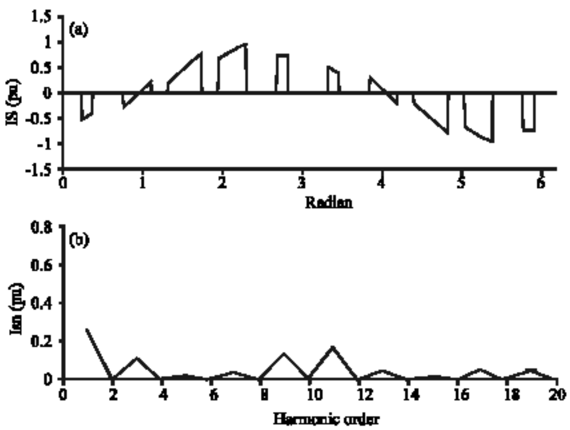

Fig. 3: The input currant waveform in (pu), b: The harmonic spectrums of the input current

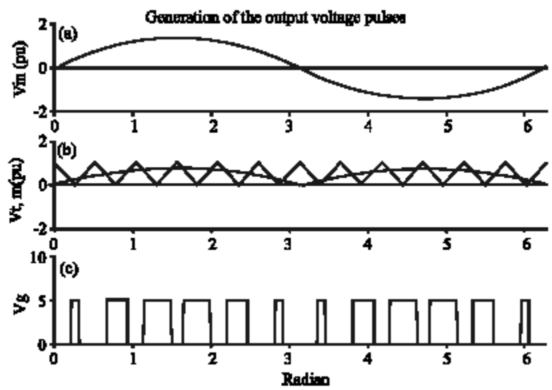

Fig. 4: The sinusoidal reference waveform, b: The triangle waveform (carrier signal) and the sinusoidal waveform (the reference signal), c: The generated gating signal

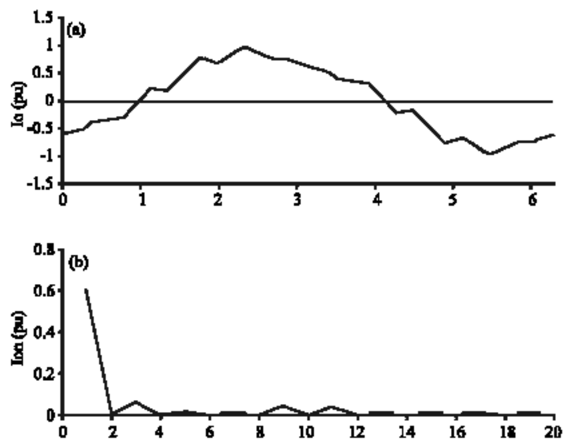

Fig. 5: The output currant waveform in (p.u.)b:The harmonic spectrum soft heout put current waveform

fields and clickable buttons as the GUI window shown in Fig. (2b). In order to simulate the mathematical model of the AC voltage controller, it is initially required to input the values of parameters of the AC voltage controller in the fields of the main GUI window before executing the run command and calling the MATLAB program.

The operation of this instructional software has been divided into two modes of operations. The first GUI window is the parameters and waveform analysis window. It contains five input fields, which are for the possible variable parameters of the AC voltage controller, as shown in Fig. (2b). These fields are frequency of the input power supply, the phase angle of the load, the modulation index, the number of pulses per half cycle and harmonic order. As soon as, the fields attains the required values within the specific range the computation is commenced after ordering the run command of GUI's function. The

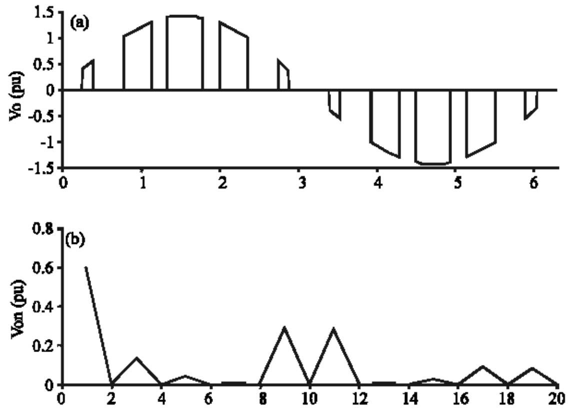

Fig. 6: The output voltage waveform in (p.u.), b: The harmonic spectrums of the output voltage

results are displayed to represent different types of performance parameters with their computed values. Furthermore, various plots of waveforms of input and output currents and voltages of the Ac voltage controller appear in time and frequency domain as shown in Fig. 3-6. Also, results of GUI's output demonstrate how the gates signals of the AC voltage controller have been generated as shown in Fig. (4).

The second GUI window is the performance design GUI window that is used to simulate and showed the performance behavior of system with variable modulation index M and variable phase angle load (PF). This window gives the opportunity to insert different input frequency and different number of pulses per half cycle before executing the running command as shown in Fig. (2c).

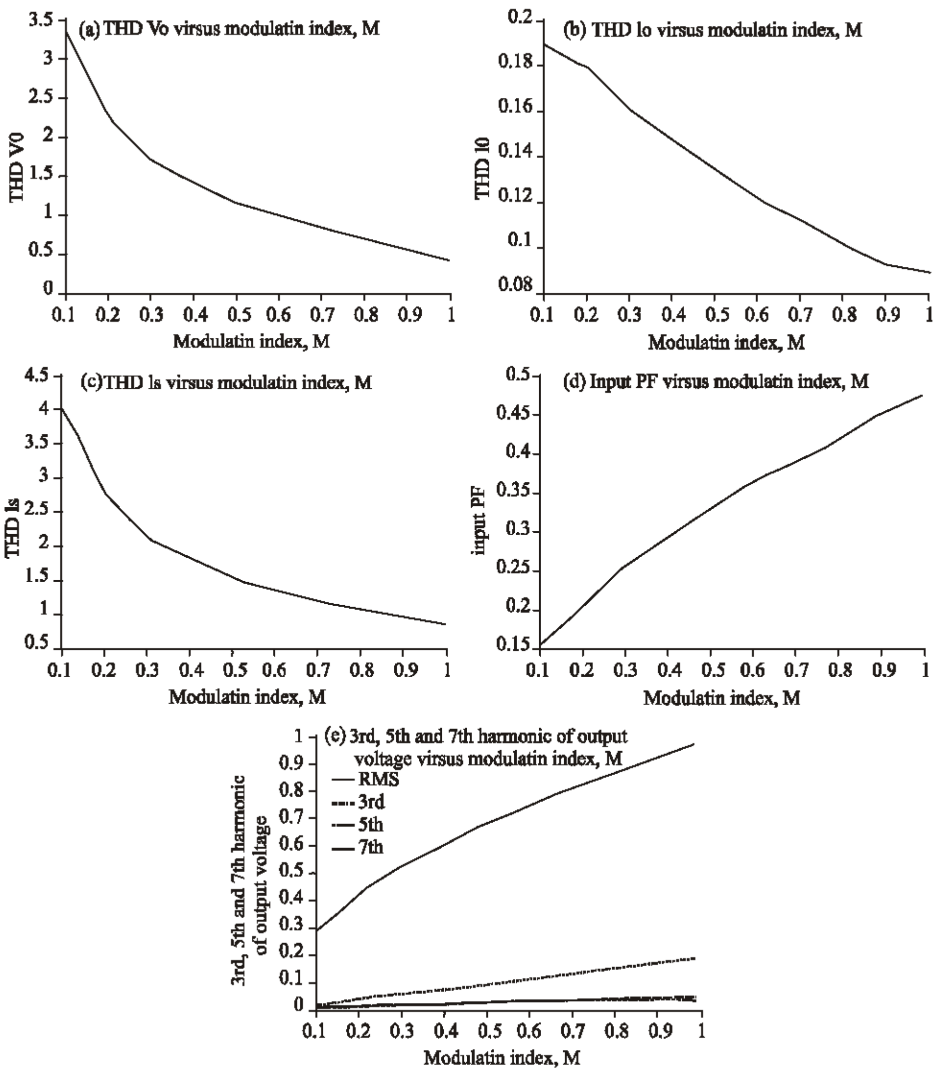

Fig. 7: AC voltage controllers for k = 6 and load PF= 0.57 a) THD Vo versus M, b) THD Io versus M, c) THD Is versus M, d) The input Pf versus M, e) RMS, 3rd, 5th, 7th harmonics of the output voltage versus M

Then using the capabilities of the software preforms computation and the results are displayed in the form similar to that shown in Fig. (7). An example, for k = 6 and load PF= 0.57 has been commence to examine the best design order. The developed instructional software results display the performance parameters of the AC voltage controller, which are the input PF, THD's versus different modulation index. Also, RMS, 3rd, 5th, 7th harmonics of the output voltage versus different modulation index. These plots facilitate examine the behavior of the system and select the best design condition.

Responses to matlab GUI's: The simplicity of handling tool presented, help students accurately understand the analysis and the design requirements of the SPWM AC voltage controller. One of the significant features of this simple tool, can effectively illustrate the changing in the system behavior and focus on both fundamental and advanced concept of the system. On the other hand, students can efficiently run this program many times with different input values to see how the behavior of the system changes and select the best performance for design. This instructional tool made the teaching of SPWM a very attractive task and encourages students to learn while playing. Electrical engineering students mastering the GUI such as can learn several power electronics principles:

- The SPWM technique in switching signal generating
- Explore THD as the function of modulation index Observing the different number of pulses per half cycle and how can affect the THD
- Monitoring the current and voltage waveforms at different power factor loads
- Students place their hands in the design problems
- Enhance student's interest in design and understand the power electronics course easily and deeply

CONCLUSION

An adequate and useful approach for teaching a SPWM AC voltage controller has been presented in this paper. A mathematically model was built and simulated for this type of controller using basic MATLAB instructions. The developed MATLAB GUI tool has been simplified by providing an active link with the simulated models. This instructional tool is characterized by its versatility and repeated applications by group of users. It is fully integrated and allows understanding waveform analysis and flexible design approach through the variation of circuit parameter values. An illustrative example is presented to show the significance and usefulness of the developed tool.

List of symbols:

V_o	The rms output voltage
v_o	The instantaneous output voltage
V_1	The rms value of the fundamental component of the input voltage
I_s	The rms value of the input current
I_{s1}	The rms value of the fundamental component of the input current
THD	Total harmonic distortion
PF	Power factor

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