Multimedia system for e-learning about modulatioin techniques in three phase voltage inverters

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***Abstract*—The multimedia system for e-learning about modulation techniques in three phase voltage controlled inverter is introduced. Block commutation, Sine Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM) were performed on three phase voltage controlled inverter. The multimedia system features for all three modulation techniques are illustrated. Advantages of proposed laboratory exercise are indicated. Also, some improvement in using introduced multimedia system is given.**

Keywords*—*e-learning, multimedia system, modulation techniques, three phase voltage controlled inverter.

I. INTRODUCTION

Power electronic converters are now used in many grid-connected applications especially for integration renewable energy sources into the grid (e.g., photovoltaic, wind etc.) [1-3]. These converters are commonly type of a voltage source inverter (VSI) connected to the supply network and operated in such manner to achieve objectives such as power flow regulation or power factor optimization. For this purpose, different pulse width modulation (PWM) techniques are implemented [4-6]. Also, PWM techniques are widely used in different applications such as variable speed drives (VSD) and uninterruptible power supplies (UPS). Therefore, it is necessary to find approach how to make closer knowledge of these techniques for students which are studying Electrical Engineering. Laboratory exercises together with lectures give students good starting position to understand the basic principle of VSI converters control [7-9]. That is why one, chosen multimedia system for e-learning about modulation techniques is presented and described in the paper.

The main advantage of purpose multimedia e-learning system is depicted and illustrated. This system is laboratory set-up for students on graduate study program of Power Engineering, elective block Sustainable Power Engineering as well as elective block Industrial Power Engineering. The Block commutation, SPWM, Trapezoidal PWM, Sine SVPWM and Line SVPWM as typical PWM techniques are introduced for students on second semester at course Application of Power Electronics in Power Engineering and Electromobility.

II. MULTIMEDIA SYSTEM FOR E- LEARNING

Multimedia system for e-learning [10] used in this paper is PC based experimentation and training system for vocational and further training and education. This system can be used for learning modulation techniques in three phase inverters. The system consists of hardware and software sections. The hardware section contains several subsystems: Interface, two experimenters and two experimentation cards. The software section includes application with installed course about power electronics i.e. three phase power inverters. Personal computer with installed Windows OS is necessary for given software.

A. Hardware

The Interface in this system is used for two-way communication between three phase inverter and computer. Furthermore, with appropriate external power supply, the interface is providing required power feed for experimenters and associated cards. The power output is limited to the voltage of 40 volts and the current of one ampere. That implies that this is safe system to work with hands on it, even when the device is in operation. The interface has two analog inputs for gathering measurement data such as voltage or current, which are then sent to the PC for further processing. Each of two attached experimenters contains one corresponding card. First in a series is the three-phase inverter card and the second one is the three-phase resistive-inductive load card. The whole setup is shown in Fig. 1.

Fig. 1. Hardware setup of the multimedia system

The three-phase inverter (Fig. 2-left) consists of six MOSFETs in bridge configuration, as the main switching components. Each MOSFET has attached LED diode on it so the students can visually see whether transistor is in ON or OFF state. Also, the top side of the card is protected with transparent plate on which is drawn schematic of the inverter with corresponding markings. This can be useful in learning modulation techniques due to the fact that one can see real switching components with schematic support and representation of MOSFETs switching states. The integrated two channel multiplexer output on inverter's card provides simultaneous voltage and current measurements as well as the possibility of FFT waveform analysis. One of the downsides concerning the card is the lack of possibility for observing MOSFETs gate signals, at least not without going into the circuit. Otherwise, this option would be helpful in analysis of different modulations algorithms.

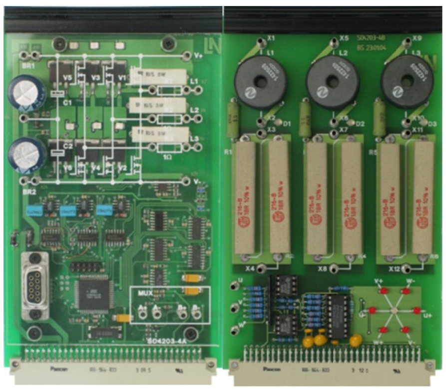

Fig. 2. Inverter card (left) and load card (right)

The resistive-inductive load (Fig. 2.-right) consists of three resistors and three inductors, one of each for every phase. Every phase contains one multicolor LED diode for visual representation of current flow direction. In the lower right corner of the load card a set of LED diodes is located. The diodes are arranged in the form of an equilateral hexagon. This can be effective when studying space vector modulation due to the visual display of the fundamental and/or intermediate vector position, particularly if used with earlier mentioned utilization of MOSFETs LED diodes. The main drawback of the load card is that there is no option for changing time constant τ given by the expression:

$$\tau = \frac{L_d}{R_d} \; [s] \tag{1}$$

where are: L_d [H] – inductance of inductor; 3.3 millihenries and R_d [Ω]– resistance of resistor; 18 ohms. In other words, the one can't change the load components which are fixed. Otherwise, this would be a usable option for further analysis of behavior of the voltage inverter.

B. Software

One of the benefits using the PC as main controller and measuring device for the three-phase inverter is the ability of connecting it to the projector. The Fig. 3. shows the e-learning system in teaching course.

Fig. 3. E-learning system in teaching course

This has certain advantages when maintaining the course in front of a larger number of people. Another feature is capturing and storing data measurements. Thus, the using of this system equipped with the software package should be more beneficial in terms of teaching about modulation techniques than the conventional way. Software used in this paper has several more features other than being just a controlling and measuring device. One of the features is that it includes theoretical background which imply the basic explanation of each modulation and certain formulas which are necessary for students to understand different types of modulation (Fig. 4.). Another feature is knowledge test for each modulation technique after finishing the certain course. This is usable feature for monitoring student's progress, but it has limitation due to the impossibility of creating instructor's own questions.

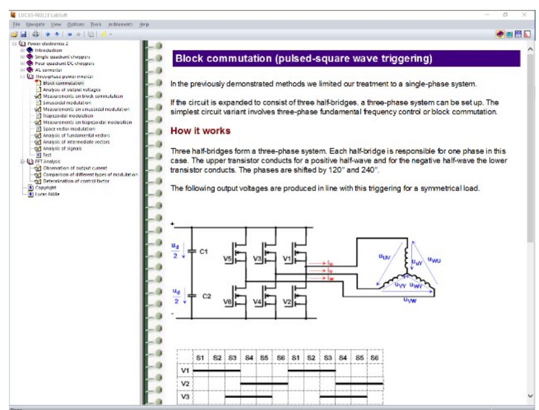

Fig. 4. Software main window with course page

The software includes several virtual instruments which are essential for understanding different types of modulation, determining their advantages and disadvantages, fields of applications etc. Included instruments are: Oscilloscope, Time Diagram, Spectrum Analyzer and Virtual Voltmeters. The Oscilloscope has two channels, with maximum peak-to-peak voltage of 80 volts and time base down to 100 nanoseconds per division. The resolution of Oscilloscope is sufficient in terms of capturing data for the given inverter. Time Diagram is virtual instrument similar as the Oscilloscope and it is used via

Multiplexer. Main advantage in using it over the Virtual Oscilloscope is ability to view both filtered and unfiltered phase and line voltages as well as filtered and unfiltered phase current. This feature is crucial in learning about different types of modulation, especially when observing THD. The Spectrum Analyzer is another virtual instrument of importance when it comes to determine quality of modulation. This virtual instrument can display harmonic content up to the wanted frequency. Furthermore, it is possible to readout the THD which is calculated by the software. This is another feature for direct quality comparison of various types of modulations.

III. MODULATION TECHNIQUES OF THE USED MULTIMEDIA SYSTEM

The multimedia system used in this paper can obtain five different modulation algorithms in the three-phase inverter: Block commutation, SPWM, Trapezoidal PWM, Line SVPWM and Sine SVPWM. Fig. 5. shows the power section principled schematic of the used inverter with added resistive-inductive load.

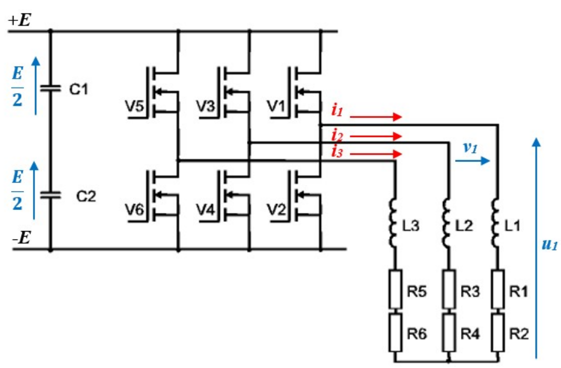

Fig. 5. Power section principled schematic of the used inverter with added load

A. Block Commutation

The Block Commutation in this system is used to show students basic working principle of power inverters and PWM. The parameters of Block Commutation user can change are: switching frequency (977 hertz or 7810 hertz), output amplitude (0 - 100% of output voltage) and output frequency (0 - 100 hertz). The main PWM controller is shown in Fig. 6.

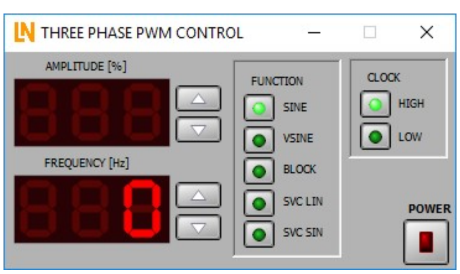

Fig. 6. Main PWM controller

When all parameters are left in its initial condition, inverter output waveforms correspond to unmodulated inverter. This is start point in studying about power inverters. When lowering output voltage, PWM begins to emerge in output voltage waveforms. If user lowers output frequency to 20 hertz or lower, MOSFETs switching becomes visible via integrated LEDs. For the measure of modulation quality apart from recording output voltage and current waveforms, it is necessary to carry out the FFT analysis. This is performed with Spectrum Analyzer as mentioned before. Fig. 7. shows FFT analysis of the output phase voltage of Block Commutation with initial parameters set on.

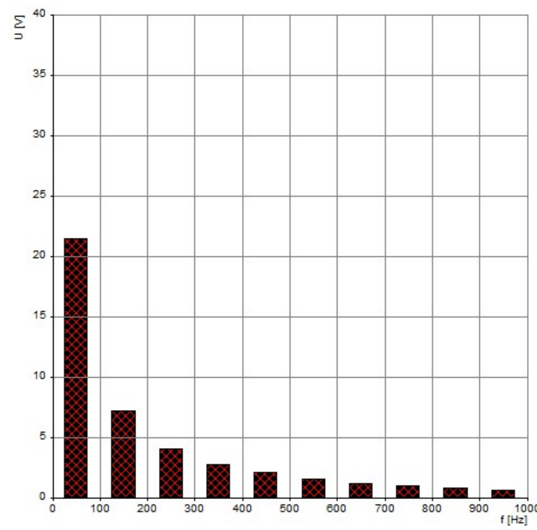

Fig. 7. FFT analysis of the output phase voltage of Block Commutation

From the obtained results, students can read out harmonic content and the THD_F (total harmonic distortion referred to the fundamental) which is calculated according to the formula:

$$THD_F = \frac{\sqrt{U_2^2+U_3^2+\ldots+U_n^2}}{U_1} \tag{2}$$

where is: U_1 – phase voltage RMS value of the fundamental component; U_2 - U_n – RMS amplitude of a set of higher harmonic frequencies. From the graph (Fig. 7.) user can determine frequency and amplitude of each higher harmonic.

B. Sine Pulse Width Modulation

Block Commutation is obtained by using simple circuitry. But a major drawback is the high harmonic content due to the square waveform of the voltage. When used in electrical machines, the Block Commutation method is characterized by its rough operating character which increases power loses and operating noise. This can be remedied by using sinusoidal modulation of the output voltage using SPWM. Fig. 8. shows filtered waveforms of phase voltage and current using SPWM.

By observing output voltage waveform of one phase and changing its value with controller, students can see the principle of SPWM. Another parameter which is significant in PWM is the clock frequency. By measurements it can be concluded that higher clock frequency results in a higher quality waveforms, hence lowering THD.

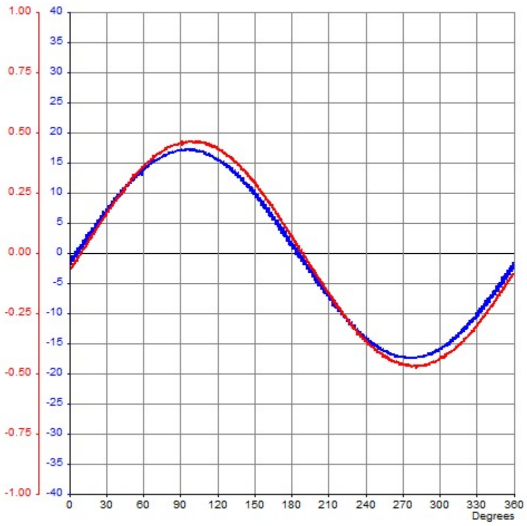

Fig. 8. Smoothed phase voltage (blue) and current (red). Clock frequency is 7810 hertz

C. *Space Vector Pulse Width Modulatioin*

The SVPWM represents a different approach to three-phase voltage generation, where the three-phase voltages are represented with one space vector. The space vector represents the spatial situation while its length reflects the intensity of the physical variable. SVPWM permits field-oriented control of electrical machines. Space vector model is shown in Fig. 9.-left, while on Fig. 9.-right, the physical representation of space vector as a part of the load card is shown.

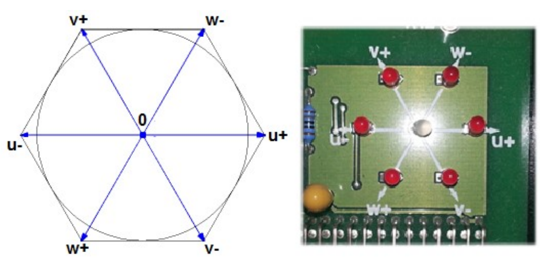

Fig. 9. Space vector model (left) and physical representation of space vector (right)

In learning of SVPWM it is necessary to begin with base vectors. For this purpose, the software is equipped with the base vector control which basically is switching state matrix (Fig. 10.-left). With proper matrix programming students can create correct algorithm to obtain a full 360 degrees rotating vector. If applied to the three-phase rotating electrical machine, rotating magnetic field is yielded. As in Block Commutation for PWM, this is start point for SVPWM. By combining the two adjacent basic vectors it is possible to acquire intermediate vectors. The position of intermediate vector is determined by the duration of each of the two switching states. Adding a null switching state (all upper or lower MOSFETs are ON) will result in lowering space vector length, thus lowering its intense. Space vector controller with all parameters is shown if Fig. 10.-right. When using space vector control, students can see instantaneous space vector position with physical representation of space vector (Fig. 9.-right). Null vector is represented with the LED in the middle of the hexagon. Also, engagement of each switching state is indicated with the amount of LED light.

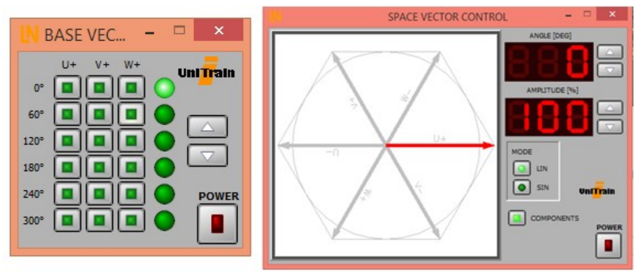

Fig. 10. Base vector control (left) and space vector control (right)

Students also can conduct the FFT analysis for the SVPWM with Spectrum Analyzer and make conclusions about modulation quality. A desirable feature in further learning of SVPWM would be the insight into the switching states algorithms, meaning the possibility of recording MOSFETs gate signals.

IV. LABORATORY EXERCISES WITH MULTIMEDIA SYSTEM IN POWER ELECTRONICS COURSE

Multimedia system described in this paper is used for three laboratory exercises in course „Application of Power Electronics in Power Engineering and Electromobility “. The title of the first laboratory exercise is „Block Commutation of the three phase inverters “. In this exercise students are learning about uncontrollable voltage inverters. This is essential in further learning about control algorithms of the three phase inverters. Second exercise is titled „Sine Pulse Width Modulation of the three phase inverters “. In this exercise students learn about application of PWM in the three phase inverters as one way of controlling output voltage and frequency of the inverter. All measurements are done with fixed output frequency (f_1=50 hertz) and fixed switching frequency (f_s=7810 hertz). Thus, the frequency modulation index m_f remains fixed. Frequency modulation index m_f is defined by the expression:

$$m_f = \frac{f_s}{f_1} \quad ; \quad f_s \gg f_1 \tag{3}$$

where are: f_s – switching frequency; f_1 – output frequency.
The waveforms of the output voltage and current for the SPWM with maximum output voltage as well as reduced

output voltage to 75% of maximum output are shown on Fig. 11.

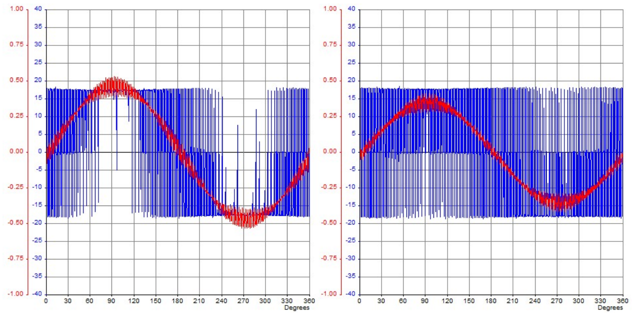

Fig. 11. Output voltage (blue) and current (red) of max output (left) and reduced output to 75% (right)

On Fig. 12. output voltage is reduced to 50% of maximum (left) and to 25% of maximum (right).

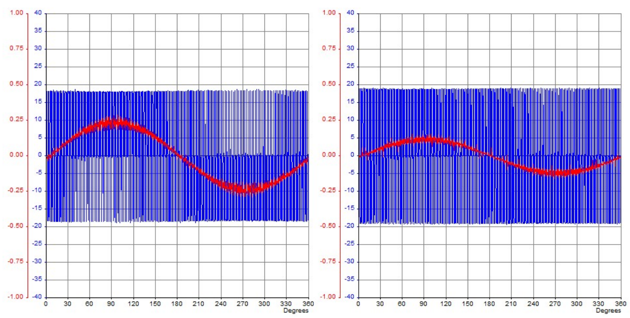

Fig. 12. Reduced output voltage and current to 50% (left) and 25% (right)

For all four examples the spectral analysis is conducted, from which amplitude of the fundamental phase voltage is read. From performed measurements students can determine the amplitude modulation index; m_a which is one of the key parameters of modulation in voltage inverters. For a given topology (Fig. 5.) the amplitude modulation index is determined by the expression:

$$m_a = \frac{\hat{U}(1)}{\frac{2}{\pi} \cdot E} \quad ; \quad 0 < m_a < 1 \tag{4}$$

where are: $\hat{U}(1)$ – amplitude of the fundamental phase voltage; E – input voltage of the DC link. Therefore, higher modulation index implies higher RMS output of the fundamental voltage for the same DC link input voltage. Table 1. shows calculated amplitude modulation index from conducted measurements according to Fig. 11. and Fig. 12.

TABLE I. CALCULATED AMPLITUDE MODULATION INDEX FOR DIFFERENT OUTPUT VOLTAGE AMPLITUDE OF SPWM.

	Output amplitude [% of max]			
	100%	75%	50%	25%
E [V]	35,9	36,3	36,7	37,9
$\hat{U}(1)$ [V]	17,4	13,07	8,75	4,45
m_a	0,761	0,565	0,374	0,184

Third laboratory exercise: „Space Vector Pulse Width Modulation in three phase voltage inverters “, is described in chapter III. subsection „ Space Vector Pulse Width Modulation “. By applying knowledge from SVPWM students perceive advantages of SVPWM regarding SPWM in total harmonic distortion.

V. CONCLUSION

With the development of technology, e-learning multimedia based systems are becoming substantially in training new students. Modern approach with „All in one multimedia system “in teaching has several advantages:

- Portable laboratories require less space than conventional laboratory equipment.
- The use of virtual instruments is less expensive than using external measuring devices.
- The possibility of connecting system to the projector significantly improves the quality of teaching in front of a large number of people.
- Low voltage of the system enables safe operation.
- User friendly software enables easy operation and integration of theory and practice.

In teaching modulation techniques in three phase voltage inverters, one of the crucial things is to overlook control algorithms simultaneously with the output waveforms. The lack of this option in presented system is main disadvantage of the system and the proposal is to introduce additional instruments for measurements like laboratory digital oscilloscope or/and power analyser.

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