Improving the Teaching of Vector Group of Three-Phase Transformer by Integrating Software and Hardware Tools into Classroom

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***Abstract*—This paper proposes methods of improving the teaching of vector group of three-phase transformer by integrating software and hardware tools into the classroom. Vector group of the three-phase transformer is an essential topic in electrical engineering curricula at universities. Typically, vector group of the three-phase transformer is taught in the classroom using pure theorem. In this paper, the advantages of hardware and software tools are used to reinforce the teaching of vector group of a three-phase transformer. Firstly, an object-oriented vector group of three-phase transformer simulation environment is constructed using Simulink. Secondly, to verify the validity of the simulation results, portable hardware tools of vector group of a three-phase transformer are integrated into the classroom. The main components consist of three single-phase transformers, a smart oscilloscope, and a mini inverter. Because of the components' compact size, low weight, low voltage, low current, and reasonable cost, they are very suitable for a lecturer to integrate them into the electric machinery course. The effect of some forms of vector groups on the reduction of harmonics is also presented. The proposed methods have been successfully used at Kasetsart University Sriracha Campus, Thailand. They can help students to understand vector group of a three-phase transformer and assists lecturers to enhance the effectiveness of the teaching. The proposed methods have produced a favorable response from the students.**

Keywords— transformer, vector group, software tool, hardware tool, electric machinery

I. Introduction

Three-phase transformers are essential topics in electric machinery courses of electrical engineering curricula at universities. A vector group of the three-phase transformer is the international electromechanical commission (IEC) method of categorizing primary and secondary winding configurations of a three-phase transformer. There are various forms of vector group of a three-phase transformer. The vector group indicates the phase difference between the primary and secondary sides, introduced as a result of the particular connection configuration of the three-phase transformer windings [1]-[2]. Few researches presented the methods to enhance the understanding vector group of a three-phase transformer.

Reference [3] proposed the software tools, MATLAB, for drawing the vector diagram which determines the phase difference between the primary and secondary sides. Reference [4] proposed the software tools, Simulink, for analyzing the vector group of a large power transformer. The advantages of using the software tools are that the students feel safe and it is easy to set up an activity given by the lecturer. The advantage of the hardware tools is that they fully reflect the real world. However, the teaching of vector group is typically taught in the classroom by a pure theorem whereas the hardware tools of teaching vector group are separately used in the laboratory.

In this paper, both the software and hardware tools are proposed for improving the teaching of vector group in the classroom. The software tools, Simulink, for simulating the vector group of the low power transformer is first used after the teaching theory was conducted. Then the proposed hardware tools are used to reinforce the student's understanding. The proposed hardware tools are compact size, low weight, low voltage, low current, and low power. It is very convenient for a lecturer to carry and integrate them into the classroom. Goals of the proposed methods are to:

- enhance student interest in the vector group of a three-phase transformer.
- reinforce the student understanding of the vector group of a three-phase transformer.
- simplify the vector group of a three-phase transformer.
- improve an electrical engineering curricula.
- support the teaching of the vector group of a three-phase transformer.

II. Background

The vector groups of the three-phase transformer in common curriculums of electrical engineering are divided into four groups [5]. Table I, Table II, Table III, and Table IV show the Group 1, Group 2, Group 3, and Group 4, respectively. The small and capital letters in symbol represent the low voltage

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and high voltage winding connections. Figures 0, 1, 6, 1, and 11 indicate phase displacement by hands of the clock. The symbol of d, y, and z represent the delta, wye, and zigzag, respectively.

For example, dY11 means that the primary winding is low voltage and connected in delta whereas the secondary is high voltage and connected in wye. The voltage at secondary side (V_{AB}) leads voltage at primary side (V_{ab}) by 30º.

TABLE I. GROUP 1

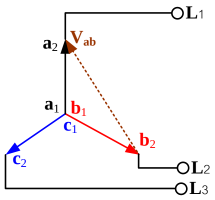
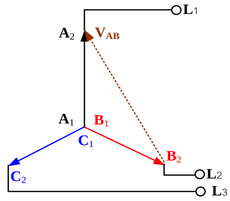
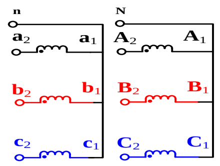
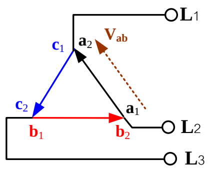
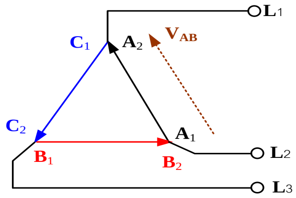
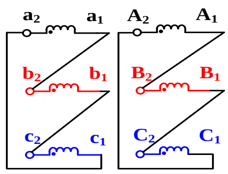
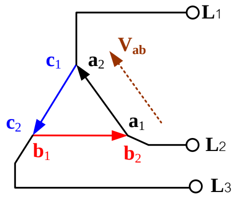
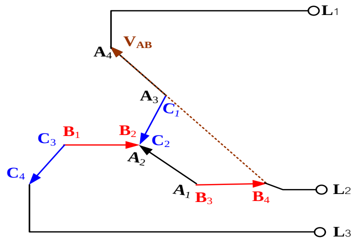
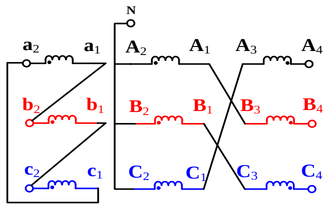
Symbol	Vector Diagram of Induced Voltage		Winding Connection
	Primary Side	**Secondary Side**	
yY0			
dD0			
dZ0			

TABLE II. GROUP 2

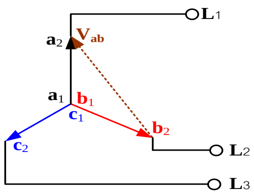
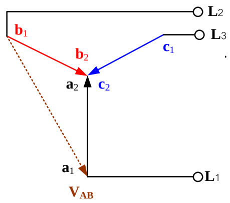
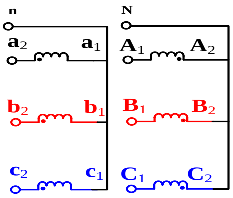
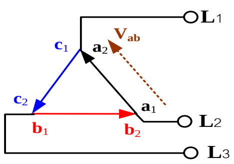
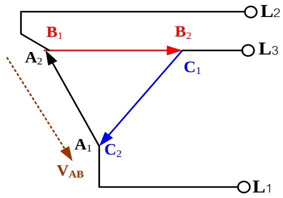
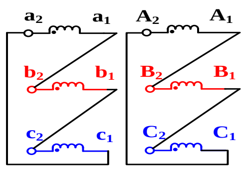
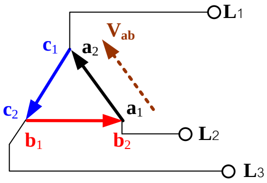
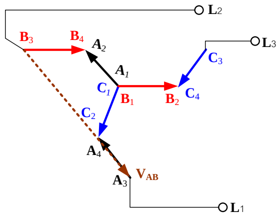
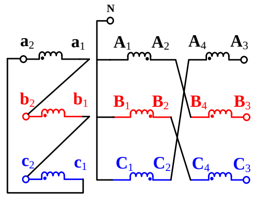
Symbol	Vector Diagram of Induced Voltage		Winding Connection
	Primary Side	**Secondary Side**	
yY6			
dD6			
dZ6			

TABLE III. GROUP 3

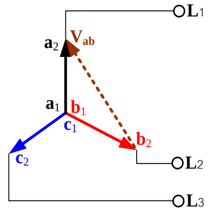
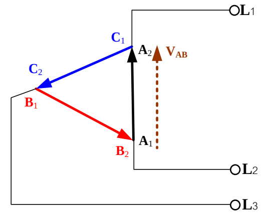
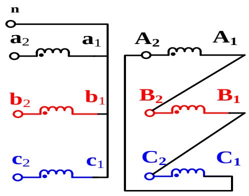
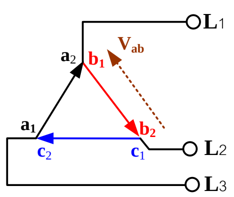
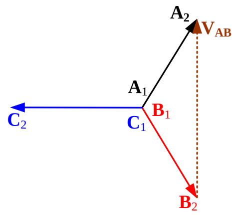
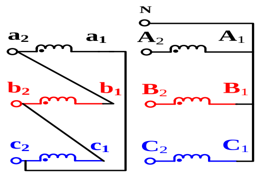
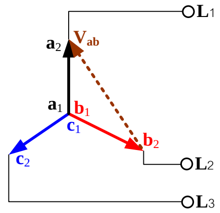
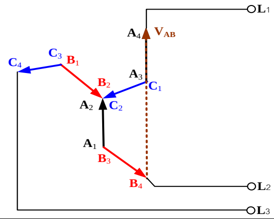
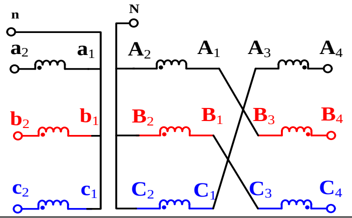
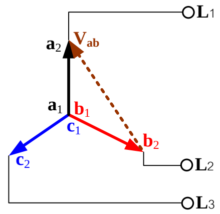
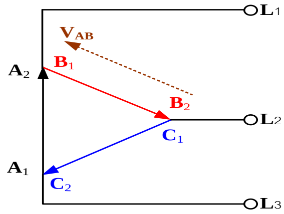
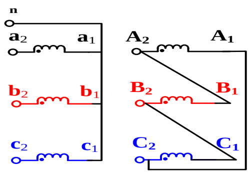
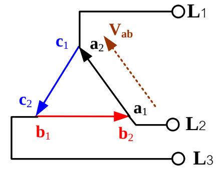
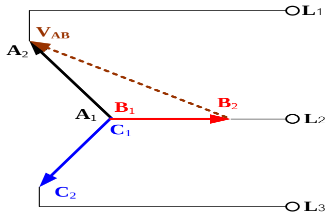
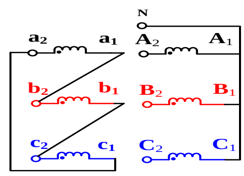
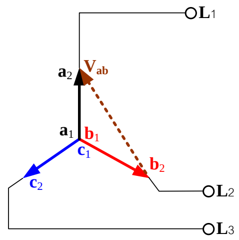
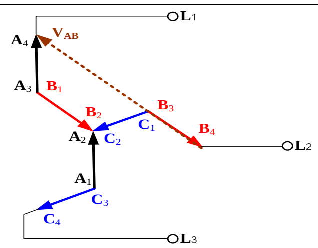
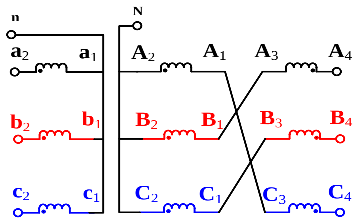
Symbol	Vector Diagram of Induced Voltage		Winding Connection
	Primary Side	*Secondary Side*	
yD1			
dY1			
yZ1			

TABLE IV. GROUP 4

Symbol	Vector Diagram of Induced Voltage		Winding Connection
	Primary Side	*Secondary Side*	
yD11			
dY11			
yZ11			

III. THE PROPOSED METHODS

This section describes the details of the proposed software and hardware tools, their integration into the classroom, and reactions to the proposed methods. It can be seen from the Table I-Table IV that there are twelve forms of vector group of a three-phase transformer. The dY11 was first selected to describe the vector group through the proposed methods because it is commonly used in various industries. In this paper, three-phase transformers consist of three single-phase transformers and connect them in three-bank.

A. Software and Hardware Tools

After the theory teaching is done, the software tools are first used to reinforce student learning using following steps:

Step 1: Review the use of some necessary toolboxes in Simulink such as *power gui*, *ac voltage source*, *voltage probe* etc.

Step 2: Demonstrate the Simulink construction of the dY11 as shown in Figure 1.

Step 3: Simulate the dY11 in Simulink and show the line voltage on the primary and secondary sides as shown in Figure 2. It can be seen from the Figure 2 that the line voltage on the secondary side leads the line voltage on the primary side by 30º.

Step 4: Measure all voltage magnitudes and voltage angles on both primary and secondary sides.

Step 5: Draw the vector diagram of induced voltage as shown in Table IV using data from step 4.

Step 6: Allow students to follow step 2 to step 5 in other forms of vector groups.

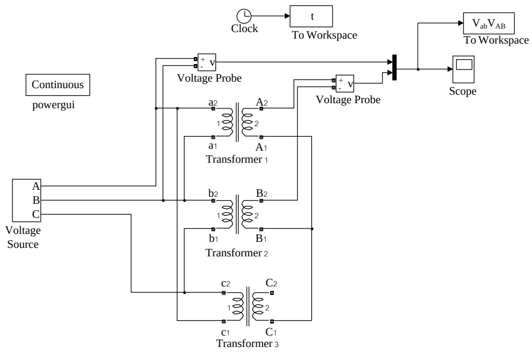


Fig. 1. Simulink block diagram of dY 11.

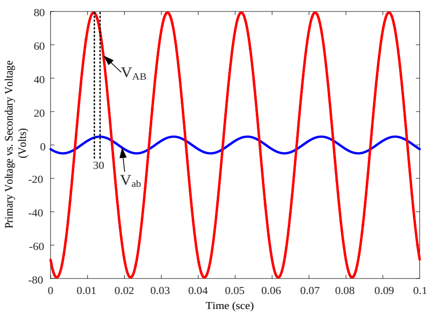


Fig. 2. Line voltage on primary and secondary sides of Figure 1.

The next step is to integrate the hardware tools into the classroom. The characteristics of hardware tools are given by:

- compact size and low weight.
- low voltage, low current, and low power.
- reasonable cost.
- ability to export the oscilloscope display to a projector.

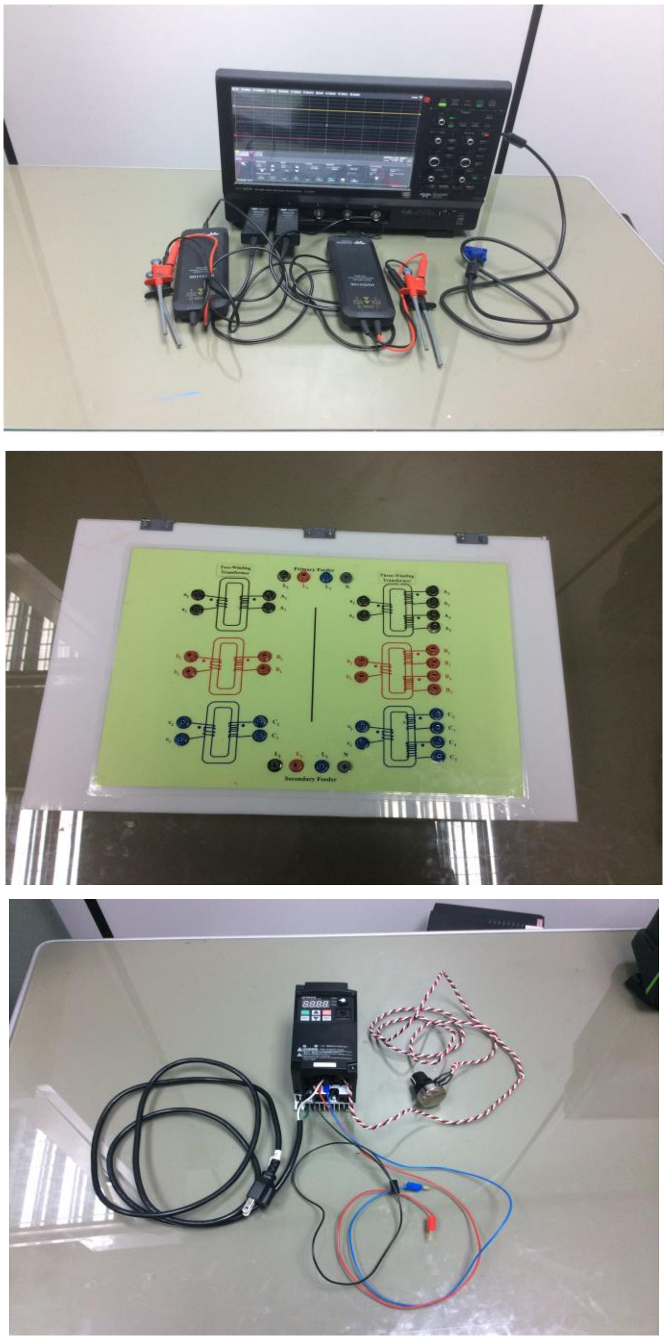


Fig. 3. Proposed Hardware Tools.

Step 7: Describe the components of hardware tools. It consists of a portable digital oscilloscope, three single-phase transformers, and a mini single to a three-phase inverter as shown in Figure 3.

Step 8: Connect the cable jacks for the dY11 connection as shown in Figure 4.

Step 9: Demonstrate the line voltage on the primary and secondary sides as shown in Figure 5. It was shown that the line voltage on the secondary side leads the line voltage on the primary side by 30º.

Step 10: Record all voltage magnitudes and angles both the primary and secondary sides.

Step 11: Draw the vector diagram using data from step 10.

Step 12: Ask for some volunteer students to do a demonstration of vector group of three-phase transformers in other forms as shown in Figure 6.

Step 13: Demonstrate the effect of some forms of vector groups on the reduction of harmonics. It can be observed from Figure 7 and Figure 8 that the yD11 generates harmonics greater than yZ11.

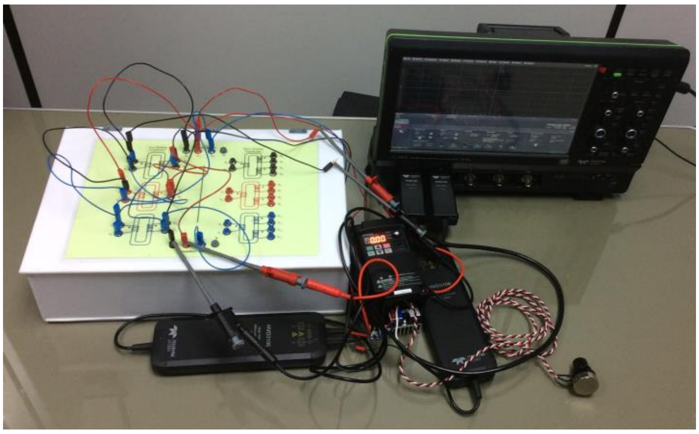


Fig. 4. A completed connection of the dY11.

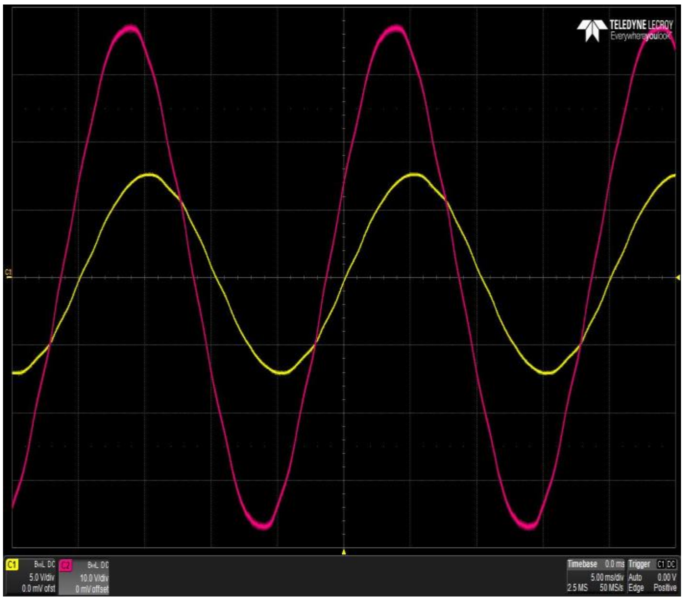


Fig. 5. Line voltage on the primary and secondary sides of Figure 4.

Fig. 6. Actual picture of demonstration of vector groups in the classroom using the hardware tools.

Fig. 7. Harmonics of yD 11.

Fig. 8. Harmonics of yZ 11.

B. *Reactions to the Proposed Methods*

The proposed software and hardware tools have been used for students attending a course on electromechanical energy conversion II at Kasetsart University Sriracha Campus. An anonymous survey was given to all participants. The participants, 91 students, were asked to fill out a questionnaire as shown in Table V. The questionnaire uses a five-point scale: 1—very poor; 2—poor; 3—satisfactory; 4—good; and 5—very good. Some selected comments are shown in Table VI.

TABLE V. STUDENTS' RESPONSES

Question	**Student**	**Point Scale**				
		1	**2**	**3**	**4**	**5**
1) Do the proposed methods enhance your interest in vector group?	Number	0	2	14	35	40
	%	0	2	15.38	38.46	43.96
2) Do the proposed methods reinforce your understanding?	Number	0	4	14	27	46
	%	0	4	15	29.67	50.55
3) Are the proposed methods easy to understand?	Number	0	0	8	29	54
	%	0	0	9	31.87	59.34
4) Do the proposed methods contribute to your overall academic growth?	Number	0	0	13	23	55
	%	0	0	14.29	25.27	60.44

TABLE VI. STUDENTS' COMMENTS

Some Selected Comments
" I have an impression of the sequential teaching method starting with theory, simulation, and experiments"
"The classroom should be divided students into study groups of three or four partners and let each student group conducts the hardware experiments"
"The integrations of the software tools and hardware tools into the classroom should be applied in other subjects"

IV. CONCLUSION AND FUTURE WORK

In this paper, the software and hardware tools for improving teaching vector group of three-phase phase transformer in the classrooms have been proposed. The environment of the software tools using Simulink is well suited for educational purposes, as the user interface is interactive and intuitive with a graphical, object-oriented model representation. Students can take part in activities provided by the lecturer. Hardware tools were used to reinforce the students' understanding and verify the validity of the simulation results. The hardware tools' integration into the classroom is very convenient because of their compact size, low weight, low voltage, low current, and low power.

The results from the students' responses indicated that the proposed methods can achieve the goals. Reactions from the majority of students are very positive. The proposed methods have received a 4.37/5.0 rating. To the best experience of the author, the proposed methods can improve effectiveness and efficiency of teaching in a large classroom.

According to some students' comments, it is possible to set up the hardware experiments in the classroom. The classroom will be divided into groups of three or four students. Similar to what is performed in the simulation, each student group can take measurements required to draw the vector diagram and examine the phase displacement.

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