Demonstration of Three-Phase Armature Winding in Classroom Using a Proposed Portable Hardware Tool

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***Abstract*— Three-phase armature winding is a very important topic in teaching of rotating electrical machines. Typically, the teaching of the three-phase armature winding in the classroom is used a pure theorem through 2-D or 3-D developed diagram. This paper presents the portable hardware tool for integrating the three-phase armature winding in the classroom. The main components of the proposed portable hardware tool consist of an induction motor, 12 winding coils, an armature winding board, and a mini inverter. It is found that it is cheaper to modify an existing single-phase motor than to build a suitable three-phase induction motor. This paper proposes the method of modifying a single-phase induction motor used in an air conditioner to be a three-phase induction motor. Because of compact size, low weight, low voltage, low current, and reasonable time frame, then it is suitable for a lecturer to carry it and demonstrate the three-phase armature winding in the classroom. This proposed tool makes the teaching and learning of rotating electrical machine a more active by using interactive learning to its real world. The effects of reversing two of three voltage phases and changing their frequencies on rotating electrical machine are also demonstrated. The proposed methods have been successfully integrated into the electric machinery course at Kasetsart University Sriracha Campus.**

Keywords—three-phase armature winding, induction machine, synchronous machine, developed diagram, hardware tool

I. Introduction

Three-phase rotating machines such as induction machine, synchronous machine, etc. are widely used in both industries and universities. It is usually taught in electrical engineering curriculum at universities [1]-[7]. The electrical engineering student should have a reasonable background in both theory and practice before go working as an engineer. The development of both theory and laboratory of the electric machinery course for undergraduate curriculum at Massachusetts Institute of Technology was reported in [8].

For many years, many methods have been proposed to improve teaching and learning of three-phase rotating machine in various proposes. Some researches proposed the software tools. For example, the software tool using MATLAB/Simulink was proposed to estimate the parameters of an induction motor and it has been successfully integrated into the IM course at Drexel University, USA, Nigde University, Turkey, and Oregon State University [9]-[10]. The student's positive attitude of using the software tools for learning synchronous machine was reported in [11]. Some researches proposed the hardware tools. For example, the low voltage and low cost synchronous machines were proposed in [12] and the low voltage and low cost induction machine for teaching its control method were also reported in [13].

The armature winding plays very important roles in determining the behavior of all rotating electrical machines. The laboratory for the measurement air gap magnetic field of the three-phase rotating machine has been proposed in [14]. Three-phase armature winding is the coil winding in which an electromotive force (emf) is induced by virtue of the rotating electrical machine. Their energy conversion taking place through the medium of the magnetic field, and emf in coil winding that is excited by flux linkage. Typically, three-phase armature winding is taught by using 2-D or 3-D developed diagram which shows the detail of the arrangement or connection of coil winding in the slot at stator [15]. It is very important for studying, designing and repairing the three-phase rotating machine. Most practices use 2-D developed diagram because it is simple. However, it may be too difficult for the student who has no experience or dealing with real physical rotating machines. In addition, it is unable to reach the real world of rotating electrical machine.

This paper proposes the portable and suitable hardware tool for demonstrating the three-phase armature winding of rotating electrical machine in the classroom. It can be applied to demonstrate the various effects of changing the three voltage phases on rotating electrical machine. The proposed methods have been successfully used in electric machinery course. This paper is organized as follows: Section II describes the proposed portable hardware tool. Section III step-by-step of demonstrations of the armature winding including a procedure of its utilization in the classroom is presented in detail. The results of using a proposed method are discussed in Section IV. In this section, student satisfaction and some selected comments are also reported. Finally, in Section V, the conclusion and future work are drawn.

II. Proposed Hardware Tool

The teaching sequence of the three-phase winding for students who take electric machinery course at Kasetsart University Sriracha Campus starts in theory, developed diagram, and demonstration of a proposed hardware tool. The

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proposed hardware tool has been proposed with the goals of marking it as easy as possible for the student to understand and for the lecturer to integrate it into the classroom. Its characteristics are given by the following:

- compact size and low weight;
- commercially available hardware;
- reasonable time frame;
- low voltage and low current;
- low cost;
- potential to demonstrate the real world of a rotating electrical machine.

The main components of the portable hardware tool for demonstration of three-phase armature winding are:

1) Induction Motor

Most of the three-phase induction motors are not suitable for a lecturer to carry and integrate them into the classroom because they are high current, high voltage, and high weight. Some single-phase induction motors in some electrical appliances are low current, low voltage, and low weight and it can be modified to be a three-phase induction motor. It is necessary to consider the economics as to whether it is cheaper to modify an existing single-phase motor or to build a suitable three-phase induction motor. It was found that it is cheaper to modify an existing single-phase motor than to build a suitable three-phase induction motor. This paper proposed the method of modifying a single-phase induction motor used in an air conditioner to be a three-phase induction motor. In addition, it is easily available at the general repair air conditioning shop. It consists of a rotor, 24 stator slots, and end bells as shown in Figure 1. A single-phase induction motor as shown in Figure 1 can be operated as a three-phase induction motor by rewinding the coils as given in Table I and Figure 2 [16]. The slot number tag and placing insulation at slot should be prepared in advance. This method will save time when the lecturer gives the demonstration of the armature winding.

Fig. 1. An induction motor.

TABLE I. THREE-PHASE ARMATURE WINDING OF 24 SLOTS, 4 POLES, AND SINGLE LAYER

Phase *a* (Black)		**Phase *b* (Red)**		**Phase *c* (Blue)**	
Coil Side 1 (Slot No.)	***Coil Side 2 (Slot No.)***	***Coil Side 1 (Slot No.)***	***Coil Side 2 (Slot No.)***	***Coil Side 1 (Slot No.)***	***Coil Side 2 (Slot No.)***
1	7	5	11	9	15
2	8	6	12	10	16
13	19	17	23	21	3
14	20	18	24	22	4

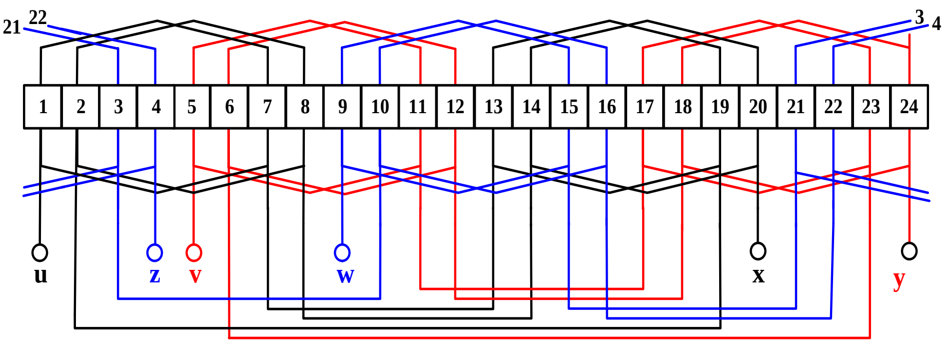


Fig. 2. 2-D developed diagram of the three-phase armature winding of 24 slots, 4 poles, and single layer.

2) 12 winding coils

The rewinding of the armature coil consists of 4 coils in each phase and each coil side is joined by soldering with jack cable as shown in Figure 3. The black, red, and blue cables are represented by armature winding of phase *a*, phase *b* and phase *c*, respectively.

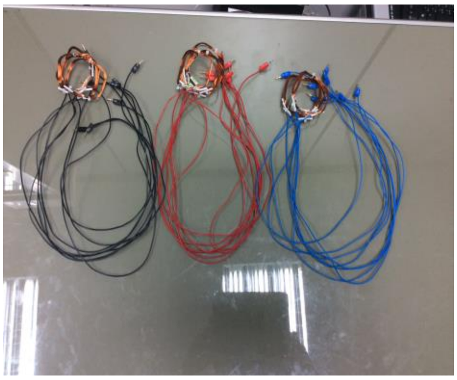


Fig. 3. 12 winding coils.

3) Armature winding broad

The armature winding broad as shown Figure 4 is used to demonstrate the relationship between the 2-D developed diagram as shown in Figure 2 and the real physical machine as shown in Figure 1. The broad dimension is designed to fit the projector because it allows us to achieve the mass course teaching.

Fig. 4. An armature winding broad.

4) *Mini inverter*

A mini inverter as shown in Figure 5 is able to convert the single-phase voltage (input) to controllable three-phase voltage (output). Thus, it allows us to plug in a socket usually available in the classroom. The three-phase voltage can be controlled both its magnitude and frequency through mini-inverter. Its weight is around 0.3 kg.

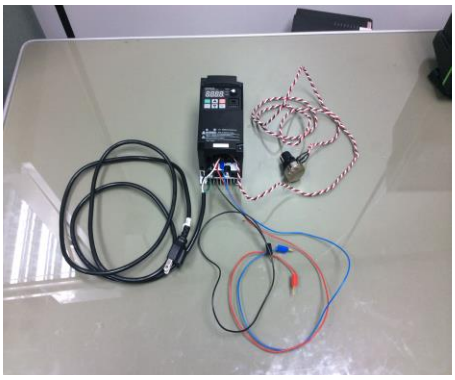


Fig. 5. A mini inverter.

III. Procedure

After the theory teaching and step-by-step teaching of 2-D diagram are done, the proposed tool is used to strengthen student understanding. The steps of integration the proposed methods into the electric machinery course at Kasetsart University Sriracha Campus are given in the following.

Step 1: Provide the explanation of all components of a proposed portable hardware tool. The constructional features of rotating electrical machine as shown in Figure 1 are also explained in this step.

Step 2: Put the coil side 1 and coil side 2 of the coil winding 1 (phase *a*) into slot 1 and slot 7, respectively as shown in Figure 6 (a).

Step 3: Explain the relationship between the 2-D developed diagram as given in Figure 4 and the real hardware as shown in Figure 6 by connecting cable jack into the armature winding board as shown in Figure 6 (b).

Step 4: Put the left coils until coil winding 12 (phase *c*) is completed.

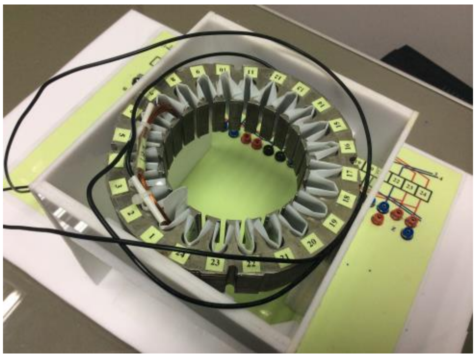
Step 5: Hold the bunch of cables and coil windings together by using cable ties as shown in Figure 6 (c).

Step 6: Assemble the induction motor as shown in Figure 7.

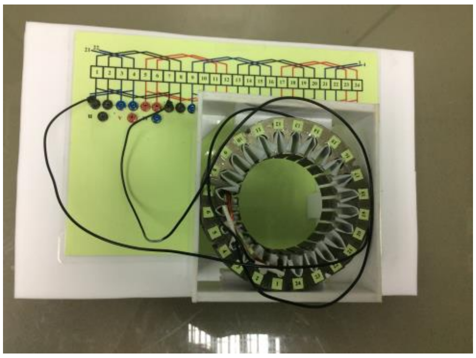
Step 7: Supply the input voltage to induction motor as shown in Figure 7 by gradually increasing voltage magnitude at the fundamental frequency (50 Hz) until the rotor is rotated.

Step 8: Demonstrate the effect of reversing two of three input voltage phases on the rotating magnetic field which determines the direction of rotating electrical machine. It is shown that the direction of rotating electrical machine changes when two of three input voltage phases is reversed.

Step 9: Demonstrate frequency affecting machine speed by gradually adjusting the frequency of three-phase voltage. It is shown that the machine speed is proportional to the frequency of input voltage.



(a)



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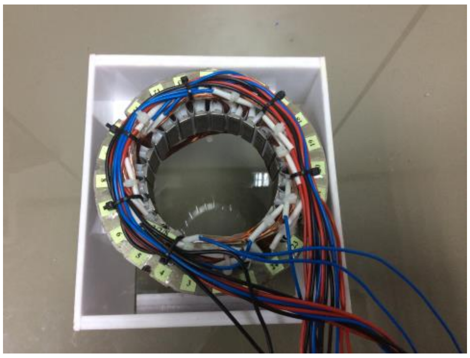


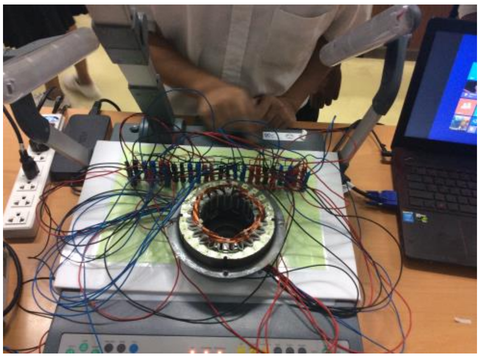
(c)

Fig. 6. Step 2 to step 5 of demonstration of the three-phase armature winding.

Fig. 7. Supply three-phase input voltage to the induction motor.

IV. RESULTS

The demonstration of three-phase armature winding in the classroom using a proposed portable hardware tool has been successfully integrated into the electric machinery course at Kasetsart University Sriracha Campus. It has a compact size, low weight (around 5 kg), low voltage (10 volts), low current (0.5 Amperes), and reasonable time frame (45 minutes). In addition, the broad dimension is designed to fit the projector as shown in Figure 8(a). It allows us to demonstrate the three-phase armature winding in mass classes as shown in Figure 8(b). In addition, the students can get a closer look after the classroom is finished as shown in Figure 8(c).



(a)

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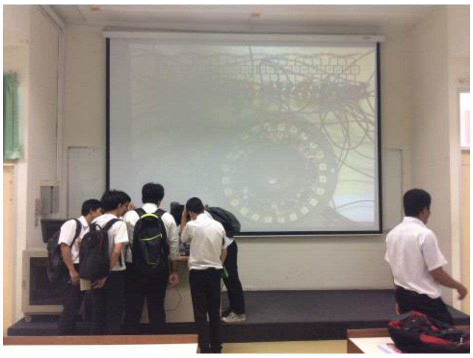

(c)

Fig. 8. Real picture of integration the proposed methods into the electric machinery course.

TABLE II. STUDENT SATISFACTION

Questions	Student	Response					
		1	2	3	4	5	Mean
1) The proposed methods are helpful to understand the constructional features of three-phase rotating machines.	Number	0	0	0	53	41	4.44
	%	0	0	0	56.38	43.62	
2) The proposed methods are useful to comprehend the operating principles of three-phase rotating machines.	Number	0	0	17	48	29	4.13
	%	0	0	18	51.06	30.85	
3) The proposed methods help you to better understand the 2-D developed diagram of the three-phase armature winding.	Number	0	0	13	60	21	4.09
	%	0	0	14	63.83	22.34	
4) The proposed methods help you to build the self-confidence of marking three-phase armature winding other forms.	Number	0	8	13	60	13	3.83
	%	0	9	14	63.83	13.83	
5) The proposed methods contribute my overall academic growth.	Number	0	0	8	60	26	4.19
	%	0	0	9	63.83	27.66	
6) I have an impression of the proposed methods.	Number	0	0	11	50	33	4.23
	%	0	0	12	53.19	35.11	

TABLE III. STUDENT COMMENTS

Questions	Some Selected Comments
1) What is the most useful benefit you gain from this proposed method?.	"Understand the 2-D developed diagram which I have been seen before"
	"Deeper understanding the armature winding of three-phase rotating machine"
	"Want to further study the armature winding of three-phase rotating machine in the level that I can repair and design it"
	"Deeper understanding of the operating principles of rotating electrical machine"
	"Get closer to the real world of rotating electrical machine"
2) What other suggestions can you offer to improve this proposed method?.	"More demonstration of three-phase armature winding"
	"Provide the hardware tool for student groups"

Student satisfaction is increasingly becoming an important indicator in the evaluation of university management performance and it was also used to validate the success of these proposed methods. An anonymous survey was given to all participants. The participants were 94 students who attended the electric machinery course. They were asked to respond to 6 questions. The questionnaire uses a five-point scale: 1—very poor; 2—poor; 3—satisfactory; 4—good; and 5—very good. The evidence for students 'level of satisfaction is summarized in Table II. Question 1-Question 3 were used to assess the effects of the proposed methods on the enhancing student learning of the three-phase rotating machine. Question 4 was used to evaluate the effect of the proposed methods on the student confidence of marking three-phase armature winding other forms. Question 5-Question 6 were used to assess the student's perception of the proposed methods. The mean of the 6 questions is 4.15. The majority of the student provided the positive response. For the third question, 9% of students provides the negative response.

V. CONCLUSION AND FUTURE WORK

This paper proposed the hardware tool for demonstrating the three-phase armature winding of the rotating electrical machine**.** The method of modifying a single-phase induction motor used in an air conditioner to be a three-phase induction motor help us to save time and reduce cost. Because of low weight, compact size, low voltage, low current, and reasonable time frame, the proposed tool allows us to integrate it into the electric machinery course. Step-by-step demonstrations show how to do three-phase armature winding of rotating electrical machine from start to finish. It can help lecturer to demonstrate the real world of starting induction motor, reversing the direction of the machine, and affecting frequency on machine speed. The proposed method has contributed to student learning and to lecturer teaching in an electric machinery course at Kasetsart University Sriracha Campus. It has been used for reinforcing student learning after the teaching theory was dawn. The proposed methods have produced a favorable response from the students.

According to some student comments as given in Table III, it is possible to increase the student satisfaction. It can be observed in a student comment as shown in Table III that some students want to practice armature winding. In the future work, the lecturer will provide the hardware tool to each student group. The different forms of the armature winding will be assigned to each student group. In addition, the various factors such as time frame, budget, student response improvement, etc. are required to further consider and study in future work.

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