International Journal of Engineering Education Vol. 28, No. 1, pp. 219–226, 2012
Printed in Great Britain

0949-149X/91 $3.00+0.00

WWEM: A New Educational Software Package Based on MATLAB for Optimal Designing of Wire Winding of Electrical Machines to Undergraduate Students*

GHOLAMREZA SHAFIPOUR[1]** and ABDOLVAHHAB FETANAT[2]
[1] Department of Computer Engineering, Behbahan Branch, Islamic Azad University, Behbahan, Iran.
E-mail: pp_shafipour@yahoo.com
[2] Department of Electrical Engineering, Behbahan Branch, Islamic Azad University, Behbahan, Iran.
E-mail: av-fetanat@behbahaniau.ac.ir

Although several researchers have studied the use of educational software in electrical machine courses, the lack of educational software to design wire winding of electrical machines is felt. It has been continually the concern to create an educational software package to help both the students and lecturers to design wire winding diagrams easily because the process of design by hand is difficult.This paper introduces an interactive software package created by the authors, named WWEM (Wire Winding of Electrical Machines), to assist students to grasp various wire winding models and their design principles. In addition, it tries to facilitate the process of designing diagrams in order to improve students' learning and at the same time lecturers' teaching. WWEM consists of various wire winding models of electrical machines, Particle Swarm Optimization (PSO)—a swarm intelligence technique—and MATLAB programming. WWEM gives optimal design of wire winding using PSO. The present study was performed on undergraduate students attending the course 'wire winding of electrical machines'. A statistical hypothesis test on student marks in the final exam showed that the majority of the students who had employed WWEM got the highest marks; they had became more competent in the area of wire winding. Based on this, the authors suggest that the use of WWEM will help lecturers to identify the students' level of understanding so that they can explain better the concepts of wire winding. WWEM is capable of being included in MATLAB Power System Toolbox (SimPowerSystems) as one the characteristics of electrical machines and used on the Web, as well.

Keywords: educational software package; electrical machines; MATLAB; PSO; wire winding; WWEM

1. Introduction

Wire winding courses at the undergraduate level typically consist of classroom and laboratory sections. The classroom section generally covers the basic concepts of designing wire winding. In the laboratory section students must manually design a diagram of a wire winding model on paper, and then implement that model to meet specifications agreed upon with the lecturer.

Department of Electrical Engineering, Behbahan Branch, Islamic Azad University offers wire winding of electrical machines course at sophomore level that concentrates on the designing wire winding of electrical machines. The objective of the course is to provide students with an understanding of wire winding models and their design principles.

The course had been offered 14 semesters previously and had followed quite a traditional format for a university engineering course: one hour of lecturing and three hours of laboratory per week, plus a final exam at the end of a 17-week semester.This four hour course, required for those who are in the power track, must be taken in the same semester.

The students' motivation to put effort into their learning had appeared low and the lecturer felt that the learning results had been poor. The students did not learn well from the lecture format, and their problem-solving skills did not develop sufficiently to allow them to solve the related exercises and problems.

The lecturer felt that the current teaching methods were inadequate and that it was time to reshape the teaching methods.At this stage, a cooperation with the lecturer was initiated. The problem was that students generally had difficulty when they came to the laboratory to carry out wire winding experiments even though the corresponding theory was extensively covered in the classroom with a detailed description of the procedure of the experiments.

The students were not familiar with experiments that contain relatively complex designing methods and diagrams as compared with other diagrams they had prepared. Also, the process to design diagrams was hard to perform by hand. However, the time constraints during the laboratory exercise were also a problem. Because of these limitations,

** Corresponding author.

* Accepted 20 September 2011.

```
Function PSO Algorithm
Begin
  For each Particle
    1. Initialize
    2. Compute Fitness Value
    3. P_best = Fitness Value
  End For
  Do
      4. Choose the Particle with the Best Fitness Value
         in the Population
         Call it g_best
         For each Particle
            If the Fitness Value is better than P_best Then
               5. P_best = Fitness Value
            End If
            6. Perform the Flight
            7. Add Turbulence
            8. Update Fitness Value
         End For
  While Stopping Condition not Satisfied
End.
```

Fig. 1. Pseudo-code for Particle Swarm Optimization (PSO).

students often rushed through an experiment in order to finish on time, which prevented them from getting a true feeling for wire winding models and from appreciating diagrams that they had designed during the laboratory practice.

In order to help students to design diagrams easily, to eliminate errors in manual designing, to save time and to give them insight into the experimental procedure, the authors created WWEM, which they anticipated could be used for the next course. The authors made observations during the research and gave feedback to the lecturer on a regular basis and surveyed the students' opinions.

In this paper, the authors describe their software, as well as its impact on students' learning of wire winding at the Department of Electrical Engineering, Behbahan Branch, Islamic Azad University, Behbahan, Iran.

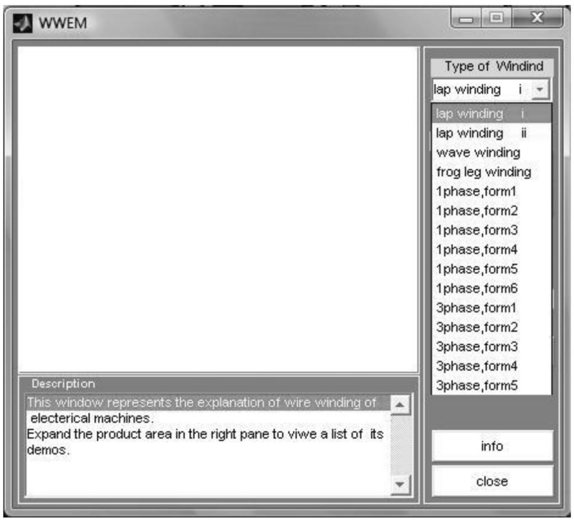

Fig. 2. Main window of WWEM showing selection of wire winding model.

2. Particle swarm optimization (PSO)

PSO is a minimizing global algorithm which has been inspired by the swarm behaviour of birds while searching for food. In this algorithm, each solution, which is called a particle, is the equivalent of one bird in the swarm movement of birds.

Each particle has a fitness value, which is calculated by a function called fitness function. The more the particle in the search is closer to the target (food in the movement model of birds), the better fitness it has. Also, each particle has a velocity which undertakes the navigation of the particle movement.

PSO is based on the principle that in each moment of search, the location of each particle in the search area, with due attention to the best location which has so far been located in it (*p*ersonal *b*est (p_{best})) and the best location which exists in its whole neighbourhood and in fact the best p_{best} in swarm (*g*lobal *b*est (g_{best})) is regulated. The location of each particle is updated with the use of Eq. (1) and Eq. (2) and by considering the values of p_{best} and g_{best} [1, 2]:

$$v[\,] = w * v[\,] + c1 * rand(\,) * (p_{best}[\,] - present[\,]) \quad (1)$$
$$. + c2 * rang(\,) * (g_{best}[\,] - present[\,]).$$

$$present\,[\,] = present\,[\,] + v[\,]. \quad (2)$$

v[ ] is the velocity of the particle and *present*[ ] is the present location (position/location is a particle's *n*-dimensional coordinates which represents a solution to the problem.) of the particle, both of which are in the arrays as long as the number of the problem dimensions.*rand( )* is a generated uniformly distributed random number in the range [0, 1] generated according to a uniform probability distribution. Variables *c1* and *c2* are two positive constants, called cognitive learning rate and social learning rate, respectively. *W* is the inertia weight factor, a control parameter which controls the effect of velocity of present particles on their next velocity. The location of other swarm's particles affects the search method of a particle. By updating the location of particles and with due attention to their fitness, PSO guides the swarm toward an optimal response. Fig. 1 shows a pseudo-code for particle swarm optimization.

3. WWEM

WWEM tries to lead users to increase their wire winding skills. For this, many functions have been described which increase the productivity of the users. This is why by using these functions they

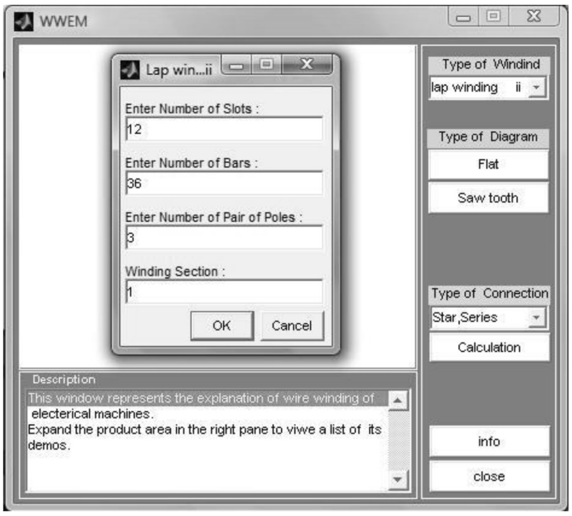

Fig. 3. Data input on the data entry form.

have are able to design some of the diagrams which were impossible previously for them to design by hand.

The software makes use of fourteen models (Fig. 2) for optimal designing.They are as follows:

(1) Three models for DC machines (e.g. lap winding);
(2) Six models for single-phase machines (e.g. one-layer model);
(3) Five models for three-phase machines (e.g. two-speed model).

Also, there are two ways to show the wire winding diagrams:

(1) Flat diagram;
(2) Saw-tooth diagram.

The values of wire winding properties in diagrams have been connected to the variants in the work environment by the dialogue box (data entry forms). Therefore, the users are able to update the values of properties which exist in each diagram. They must fill completely the dialogue boxes with values so that WWEM creates an optimal design of wire winding by means of these data and PSO (Fig. 3). For example, in AC section, these data generally include the following:

(1) The number of stator slots;
(2) The number of phases;
(3) Frequency of network;
(4) Rotation of rotor. This is important because by using that one is able to specify the number of a wire winding's poles [3, 4].

WWEM was programmed using MATLAB 7.0.

3.1 WWEM architecture

Software architecture is the structure of the components of a program, their relationships to each other and to the environment and the principles guiding its design and evolution [5, 6].

The architecture pattern of WWEM is heterogeneous and its management system has been designed as MATLAB-based.

The quality model of the software architecture includes:

(1) High Performance: the new software is the interactive tool whose basic data element is an array that does not require dimensioning. This allows users (lecturers or students) to solve many technical problems in a small fraction of the time.
(2) Security: this issue depends upon MATLAB and the way the software is locked. The way the software is supposed to be locked is on the basis of the application.
(3) Availability: WWEM is easy to use by students at any educational level.
(4) Reliability: high reliability in proportion to the tasks.
(5) Portability: the volume of the created software is low. Also, it is executed in all computers in the same way, following MATLAB.
(6) Extensibility: this software is the extensible tool. Also, it has the capability to be implemented by means of other evolutionary algorithms (e.g. Ant Colony Optimization (ACO)).
(7) Ease of Learning: users do not need to know MATLAB environment, they only fill the data entry forms with parameters and after sending it for processing, they receive back the expected response.

3.2 PSO for optimal designing of wire winding

Depending on the type of wire winding, each particle ($\overrightarrow{P} = z_i, k_i, q_i, r_i, f_i, n_i, x_i$) can follow features which generally include:

(1) z_i : The number of slots;
(2) k_i : The number of bars (commutator segments);
(3) q_i : The number of poles;
(4) r_i : The number of phases;
(5) f_i : Frequency of network;
(6) n_i : Rotation of rotor;
(7) x_i : Plex of wire windings (e.g., simplex, duplex).

In this work, these features are allowed to change in the WWEM parameters fields. Shafipour [7] supposing that these features are constant. The obtained diagrams were not necessarily optimal diagrams.

The particles are released in WWEM. The movements of particles in the software are influenced by their and their neighbour's features which are received under the preliminary conditions by the users.

The fitness functions of the WWEM consider as better solutions the smaller trajectory achieved through the presented environment, taking into account that the trajectory must not collide with any obstacles. According to the type of wire winding that the users choose, different fitness functions are created; as an example, one of these functions is as (3):

$$(z_i \ Mod \ 12) \ OR \ (k_i \ Mod \ 12) = 0. \qquad (3)$$

Equation (3) shows that each of the components should become zero. Since the residual of z_i and k_i divided by 12, becomes from 0 to 11, we should reach the minimum rest; i.e. zero. Therefore, we need to minimize the fitness function which consists of two components; as a result, the optimization problem is a multiobjective kind. In this study, the constraints are as follows:

The number of slots
The number of commutator segments
The number of poles
The number of phases (4)
Frequency of network
Rotation of rotor
Plex of wire windings

It should be noted that depending on the type of wire winding, lower bounds and upper bounds are different for each constraint.

A particle that meets the conditions of Equation (3) will be the most suitable particle. The result of modelling swarm behaviour in this software is a search process in which the particles learn from each other and, on the basis of the gained knowledge, go towards optimal design of wire winding. One of the

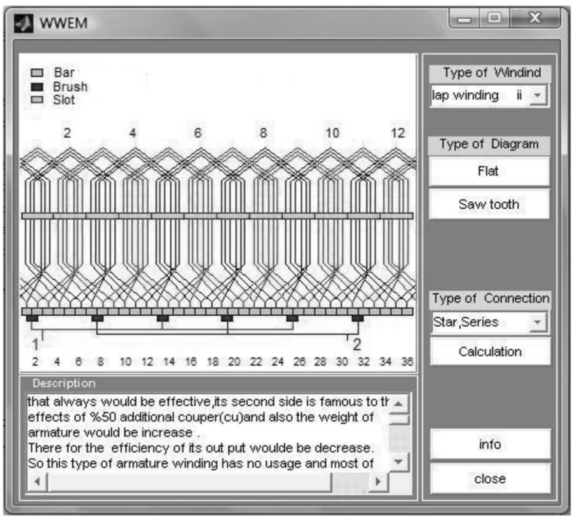

Fig. 4. Flat diagram, optimal design, simplex lap winding, wound progressively (12 Slots, 36 Bars, 6 Poles).

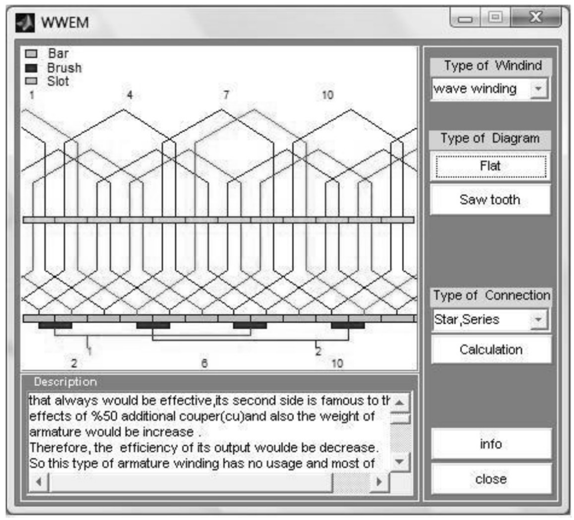

Fig. 5. Flat diagram, optimal design, simplex wave winding, wound progressively (12 Slots, 12 Bars, 4 Poles).

salient advantages of optimal designing is to economize on the raw materials (e.g. copper wire).

4. Educational objectives

The main purpose of WWEM in DC machines is to study the condition of connection armature coils together and to bars; see, for example, Fig. 4 to Fig. 6; And in AC machines (single phase and three phases) studies are focused on the condition of connection coils and the position of coils in stator slots; see, for example, Fig. 7 to Fig. 10; And finally investigation on the effect that these methods have on the force of the generator, the torque of motors and so on.

Once the windings are installed in the rotor slots,

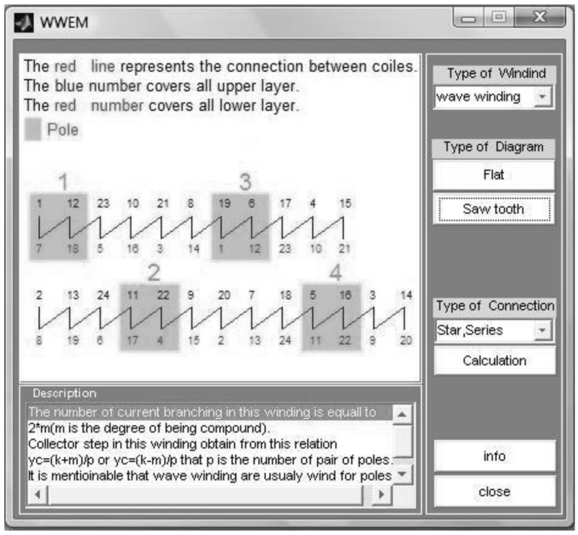

Fig. 6. Saw-Tooth diagram, optimal design, duplex wave winding, wound progressively (24 slots, 24 bars, 4 poles).

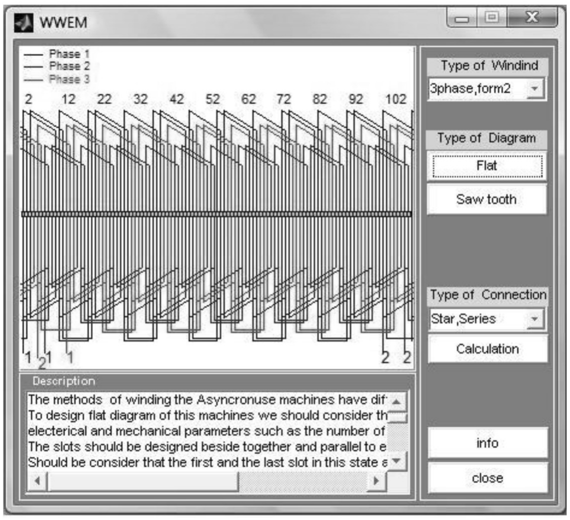

Fig. 7. Flat diagram, optimal design, three-phase machine (108 slots, rpm: 500, frequency: 50).

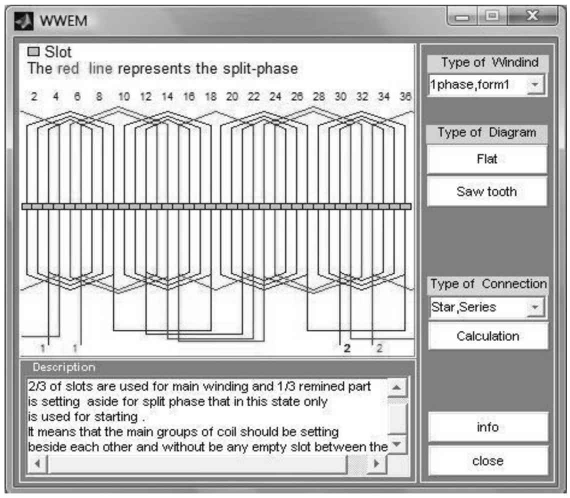

Fig. 9. Flat diagram, optimal design, single-phase machine, one-layer model (36 slots, 4 poles).

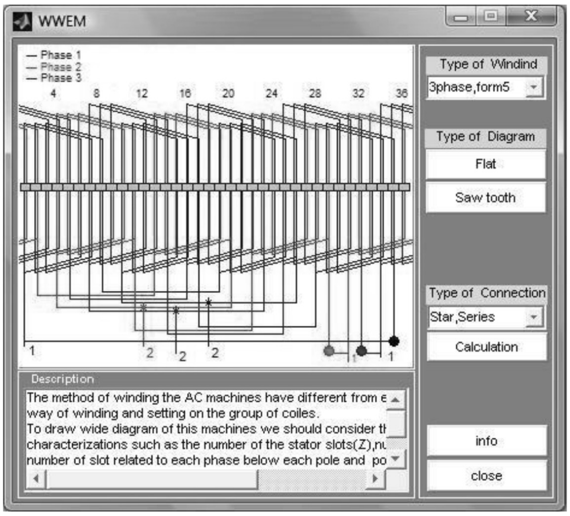

Fig. 8. Flat diagram, optimal design, three-phase machine, two-speed model (36 slots, 4 or 8 poles).

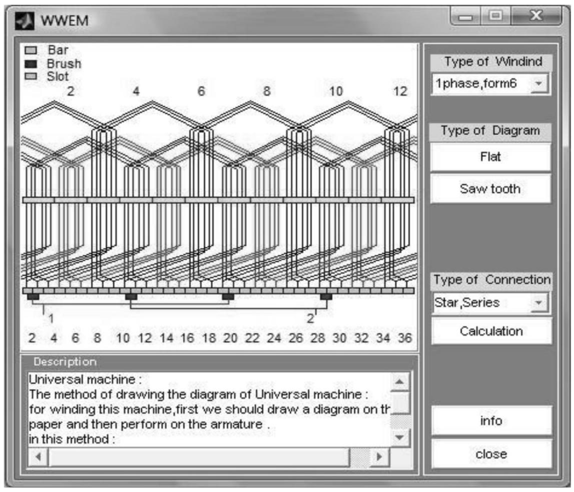

Fig. 10. Flat diagram, optimal design, universal machine (12 slots, 36 bars, 4 poles).

they must be connected to the commutator segments. There are a number of ways in which these connections can be made; the different winding arrangements have different advantages and disadvantages when compared to each other. If the end of a coil or a set number of coils (e.g. for wave construction) is connected to a commutator segment ahead of the one its beginning is connected to, the winding is called a progressive winding. If the end of coil is connected to a commutator segment behind the one its beginning is connected to, the winding is called retrogressive winding [3, 4].

Armature windings are further classified according to the plex of their windings. A simplex rotor winding is a single, complete, closed winding wound on a rotor. A duplex rotor winding is a rotor with two complete and independent sets of rotor winding. If a rotor has a duplex winding, then each of the windings will be associated with every other commutator segment (e.g. one winding will be connected to segments 1, 3, 5 and the other winding will be connected to segments 2, 4, 6).

Finally, armature windings are classified according to the sequence of their connections to the commutator segments. There are two basic sequences of armature winding connections; lap windings and wave windings. In addition, there is a third type of winding, called a frog-leg, which combines lap and wave windings on a rotor [3, 4].

These ways of wire winding are made according to the needs of their users, and in fact are the basis for examining their features and differences with regard to their structural design (e.g. the number and place of brushes on commutator segments) and electrical design (e.g. the number of parallel current

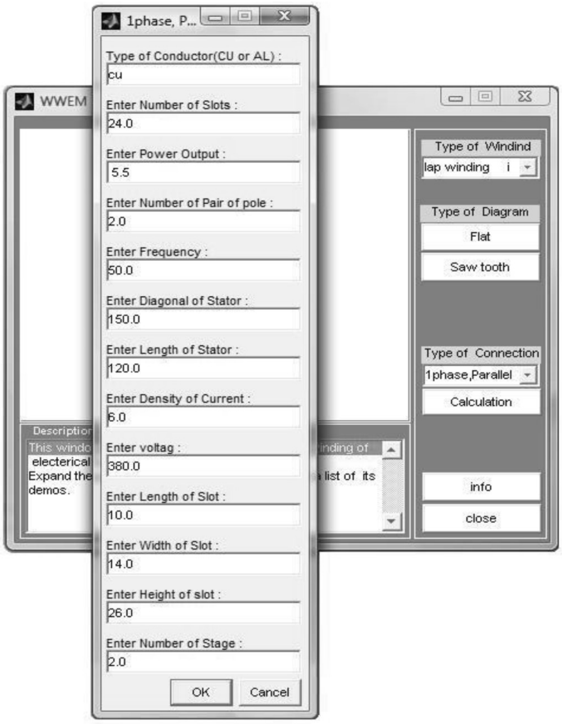

Fig. 11. Calculation.

paths in the rotor, the voltage of output current from the rotor).

Two important features of the optimal designs of DC models are:

(1) When getting the current from collector, no harmful spark is made;
(2) It generates the maximum torque, current and voltage with the least oscillation.

Also, WWEM designs the wire winding of AC machines from the view point of all poles and as a result from all phases in a symmetrical way. The behaviour aims in AC section are:

(1) To give a clear insight to the users for identification of the necessary specifications for optimal designing of different types of wire winding;
(2) To help understand various types of wire winding and the effect of the type of connection on the properties of these wire windings.

Now, the questions are: what specifications does this group of coils have? What material is the conductor made of (e.g. copper or aluminum)? What is the cross-section of the conductors of the coil group? And finally, how many turns of conductor a group of coils is made of? See, for example, Fig. 11.

The answering mechanism of WWEM to these questions is so that it meets the requirements of both lecturers and students.

5. Assessment

A total of 60 students were selected based on their marks in the final exam of a pre-requisite course for wire winding class, i.e. electrical machines; they needed to have a mark between 14 to 18 (out of 20). In other words, the selected subjects were at an upper-intermediate level. Then the subjects were randomly divided into two groups (each of 30 students); a control group and an experimental group.

A typical wire winding course is divided into two parts; one deals with the theory of designing wire winding and the other one deals with the implementation of the designed diagrams.

The lecturer taught the control group students based on the traditional method; i.e. manual designing of wire winding; while students of the experimental group were trained to design a wire winding diagram with the help of WWEM. In the experimental group the students were initially asked to design a wire winding diagram manually and then to design that diagram using WWEM; after which they needed to check and correspond the manually-designed diagram with that of WWEM to find the errors and eliminate them.

For a final assessment, both groups had to sit an exam which consisted of two parts (each with 10 points), a theoretical-based exam and a practical one. In the first part, they were given the specifications of one model for wire winding to be designed manually. In the second part, they were asked to implement what they had designed manually. It should be emphasized that in the final exam WWEM was not used.

Student marks from the exam were transferred to SPSS software version 17.0 for statistical analysis. Then, a t-test was used for comparison. After an analysis of the marks, the results obtained were

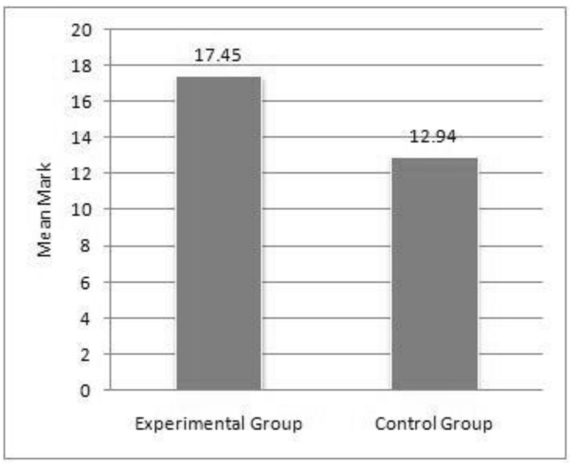

Fig. 12. Comparison of mean marks of experimental group and control group.

highly satisfactory, but the experimental group was better (mean marks of the experimental group were 17.45 out of 20 and the mean marks for control group were 12.94 out of 20.). This is shown in Fig. 12.

Regarding the significant difference between critical value and observed value (P-value < 0.05), the first hypothesis was accepted strongly (with 95% confidence).

6. Discussion

Although several studies have examined the use of educational software in electrical machine courses [8–13], the lack of educational software to design wire winding of electrical machines is strongly felt. The purpose of this paper was to test the hypothesis that WWEM can be effective in increasing student success. WWEM was used on undergraduate students. Those in the experimental group had positive attitude towards WWEM. The effects of WWEM and the traditional learning method on student success in teaching the subject of wire winding have been compared. Results obtained showed significant difference in favour of WWEM. Finally, the findings emerging from this study revealed that the students' experience with WWEM played a significant scaffolding role in students' learning about wire winding. Further long-term research is needed in order to determine if the software is really helping the student master the design of wire winding and its theory.

7. Applications and benefits

The applications and benefits of using WWEM are as follows:

(1) Having the capability for optimal designing of wire winding, the educational software can be a supplementary version for the calculating software of other electrical machines (especially MATLAB). Since most calculating software has weaknesses regarding wire winding graphics. It is recommended that in SimPowerSystems there should be an additional option, i.e.WWEM. It is shown in Fig. 13.

(2) This software can be a supplementary source for the instruction of wire winding courses. Hence, the following results can be concluded:
   - Controlling the errors that students commit while designing wire winding manually;
   - Providing a more dynamic and active teaching/learning environment for better and more interactions between lecturers and students;
   - Enhancing the teaching of wire winding and making this more attractive to the students;

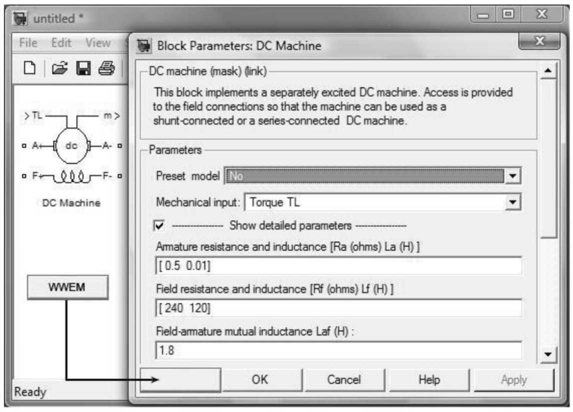

Fig. 13. The use of WWEM in MATLAB (e.g. MATLAB | Library browser | SimPowersystem | Electrical machines | Type of machine | WWEM button | WWEM Environment).

   - Enhancing the student's competence and knowledge, significantly.

WWEM can be a supplementary collection for factories' staff that aim at an initial introduction of wire winding. It is capable of being used on the web.

8. Limitations of the study

Limitations of WWEM, are as follows:

(1) The results might not be generalized to all universities, since the survey included only one course and the sample contained a limited population of 60 students.
(2) In this study, only some types of wire winding models that are widely used at undergraduate level were targeted. There are some other types that can be used and studied.
(3) Due to the screen size limit, the authors have limited some parameters such as the number of slots so as to give a clear picture of the diagrams.

9. Conclusions

The authors' software, called WWEM, has been presented here, with the main objective of making the design of wire winding easier to teach and to achieve better learning results. The authors have given a view of work done at their university to improve the teaching/learning quality and the monitoring of students' work in the course 'wire winding of electrical machines'. Results suggest that WWEM can be used both by the teacher in his or her lectures in order to make the subject topics more interesting and attractive to students, and by students in their attempts to grasp the subject matter fully. WWEM tries to bridge the gap between theory and practice, to satisfy both university lecturers and students. As a final point, it is worth noting that

WWEM was more effective than the traditional learning method in increasing the success rate in the teaching of wire winding. Furthermore, the students in the experimental group had a positive attitude towards WWEM. For future research, it is recommended that this study can be replicated by increasing the sample size, i.e. in more universities, adding other types of wire winding models and performing WWEM on the web.

References

1. J. Kennedy and R. C. Eberhart, Particle swarm optimization, in *Proc. IEEE Int. Conf. Neural Networks*, Perth, Australia, 1995, pp. 1942–1945.
2. Y. Shi and R. C. Eberhart, A modified particle swarm optimizer, in *Proc. IEEE Conf. Evol. Comput.,* Anchorage, AK, 1998, pp. 69–73.
3. P. S. Bimbhra, *Electric machinery*. Khanna Publishers, 2004, pp. 831–880.
4. S. J. Chapman, *Electric machinery fundamentals*. McGraw-Hill, 1985, pp. 161–226.
5. L. Bass, P. Clements and R. Kazman, *Software architecture in practice*. 2nd Ed. Addison-Wesley, 2003.
6. L. Dobrica and E. Niemela, A Survey on software architecture analysis methods, *IEEE Transactions on Software Engineering*, **28**(7), 2002, 638–653.
7. G. Shafipour, The creation of a new educational software for designing wire winding of electrical machines using MATLAB, in *Proc. 4th IET Conf. Power Electronics, Machines and Drives (PEMD)*, York, UK, 2008, pp. 214–217.
8. B. Vahidi and M. R. BankTavakoli, Simulation of synchronous generator on matlab-simulink for teaching performance characteristics to undergraduate students, *International Journal of Engineering Education*, **25**(2), 2009, 289–295.
9. N.Ertugrul, New Era in Engineering Experiments: an Integrated and Interactive Teaching/Learning Approach, and Real-Time Visualizations, *International Journal of Engineering Education*, 1998, **14**(5), 344–355.
10. S. Ayasun and G. Karbeyaz, DC motor speed control methods using MATLAB/Simulink and their integration into undergraduate electric machinery courses, *Computer Applications in Engineering Education*, **15**(4), 2007, 347–354.
11. T. Kikuchi, T. Kenjo, and S. Fukuda, Developing an educational simulation program for the PM stepping motor, *IEEE Transactions on Education*, **45**(1), 2002, pp. 70–78.
12. L. A. Pereira, Software for teaching electrical machines and electromagnetics for graduate and undergraduate courses, in *Proc. IEEE Int. Conf. Electric Machines and Drives,* (IEMDC 2001), Cambridge, MA, 2001, pp. 798–802.
13. S. Linke, J. Torgeson, and J. Au, An interactive computer-graphics program to aid instruction in electric machinery, *IEEE Transactions on Computer Applications in Power*, **2**(3), 1989, 19–25.

Gholamreza Shafipour received the B.S. degree in Computer Engineering (Specialization in Software Engineering) from Behbahan Branch, Islamic Azad University, Behbahan, Iran. His field of interest includes computers in industry.

Abdolvahhab Fetanat is currently a Professor in the Electrical and Computer Engineering Department, Behbahan Branch, Islamic Azad University, Behbahan, Iran. He received the B.S. degree from Amirkabir University of Technology (Tehran Polytechnic), and the M.S. degree from the University of Tehran, all in electrical engineering. His research interests include power system optimization and computer applications in power systems.