Teaching Numerical Analysis Course for Electrical Engineering Students Using MATLAB

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Abstract

Numerical Analysis course is a very important and useful course for the students of undergraduate program of electrical and electronic engineering. This course has real life applications in these fields of engineering. Therefore, this course has to be taught effectively so that students can apply the knowledge earned from this course in solving their practical problems. On the other hand, MATLAB is very powerful computing software for the scientists and engineers. If the students become skilled enough in developing MATLAB codesfor different numerical techniques then they will be able to solve many real life problems numerically. In this way, teaching and learning will also be effective. Therefore, in this paper, the teaching method of numerical analysis course for undergraduate electrical and electronic engineering students using MATLAB has been described.

Keywords: *Numerical Analysis, Teaching, Assessment, MATLAB Programming*

I. Introduction

Numerical Analysis course is a very important and useful course in the curriculum of the undergraduate program of electrical and electronic engineering (EEE). This course occupies a special position in EEE curriculum since this course is designed to teach students how to apply mathematics and computer to solve various practical problems of electrical and electronic engineers. This course is considered as a 'bridge' between the mathematical theories and objectives in the real field. So, this course should be designed and taught in such a way so that the students are prepared to master various methods for solving their real-time engineering design problems (B. Yu *et al.*, 2009, L. Belousova *et al.*, 1999, M. H. Bhuyan *et al.*, 2014, A. K. Kaw *et al.*, 2003).

Any engineering program should be mandated by an accreditation agency (such as, in USA it is 'Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, EAC/ABET) and the accreditation of an engineering program will be judged with respect to define program outcomes. Each program must have an assessment process for continuous improvement with documented results. Any well thought course required for an engineering

degree should be able to contribute towards fulfilling the program educational objectives, which are mandated by the ABET criteria 2000 (EAC/ABET, 2004).

Currently, the education system is undergoing rapidchanges. Various new methods are introduced and used. Further, it makes teaching more effective and learning is highly significant. Today the use of MATLAB in teaching the engineering curriculum is widespread. MATLAB has grown into a comprehensive programming environment suitable for solving the wide range of engineering problems. Many engineering textbooks are being written based on MATLAB.The MathWorks' web site *(www.mathworks.com)* lists hundreds of engineering texts that feature MATLAB examples and exercises. There is also an extensive literature on the use of these tools to augment engineering courses (A. Azemi *et al.*, 1996, A. R. Miller, 1999, M. H. Bhuyan *et al.*, 2012, E. Yaz *et al.*, 1995). These references provide a representative sampling of the various approaches of exploiting these tools in the curriculum. Now the challenge is to prepare the undergraduate students for different courses so that they can solve the real life problems using MATLAB effectively, e. g., designing an engineering system in the industry.

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In numerical analysis course, one has to employ different mathematics courses, such as, Calculus, Linear Algebra, Differential Equations, Coordinate Geometry and Statistics etc. Besides, huge and repetitive computations are required to get a solution. It is also time consuming. If a student makes mistake at one stage of computation then the error propagates till the end of the calculation. Hence a student finds this course very difficult. Hence it is the main obstruction of teaching and learning numerical analysis course. Therefore, a user-friendly computation environment, like MATLAB, is essentially required for teaching numerical analysis. Therefore, in this paper, teaching method of numerical analysis course for the undergraduate students of electrical and electronic engineering program using MATLAB has been described.

II. Constraints of Teaching Numerical Analysis

Enabling students to develop a scientific mindset is also complicated by student's views on the Nature of Science (NoS). Elby (A. Elby, 2001) has said "students' epistemological beliefs- their view about the nature of knowledge and learning affect their mindset; metacognitive practice, and study habits… ." According to Paul Hewitt, their actual epistemology is quite different from that of their teachers (P. Hewitt, 1995).

Learning is an activity that leads to change and control of what is taught, while teaching is a practical activity or action, be intentional and conscious to assist learning. Teachers should act an essential role as a facilitator in the process of teaching and learning.

We, as human beings, are born with limited memory. If we learn and know certain things, those things decay almost exponentially from our memory unless those are repeated. Thus, it does not matter what we teach, students will either forget or the materials will become obsolete, even before they become graduate. Therefore, we should teach the students in such a way so that the students can develop certain abilities during their study.

For example, we can rate the student's knowledge of the subject materials as zero at the start of the class. On the day of final, students should have the highest knowledge of the subject materials and we can rate the student's knowledge as logic 1 at the start of the exam. But, after one or two years, that knowledge would decay almost to logic 0, the same logic value as the start. The logic knowledge pattern can be described as {0 1 0} (M. H. Rashid, 2008).

On the other hand, a student who never attended a class and earned no knowledge, his logic states of the knowledge can be described as {0 0 0}. But there is difference between a student who started with 0 knowledge, gained the highest knowledge (logic 1) and then forgot the knowledge (logic 0) and another student who started with 0 knowledge, did not gain any knowledge (logic 0) and no knowledge to forget (logic 0) (M. H. Rashid, 2008). Because, students gain some experience through this learning process. Hence teaching of numerical course should be conducted in such a way so that the students gain some experience in solving the problems of their own fields of interest. Today the researchers concentrate on the latest innovations in mathematics teaching. The main constraints in teaching numerical course by using MATLAB are lack of computer knowledge, lack of programming knowledge, lack of interest to learn MATLAB coding and to apply in solving the real life problems using numerical techniques etc. Therefore, numerical analysis course design should be in such a way so that the students can overcome these constraints.

III. Designing Numerical Analysis Course

One of the desired attributes of an engineer (M. H. Rashid, 2004, J. A. White, 2001, D. O. Swain, 2001) in the global marketplace in the new knowledge economy is that an engineer should have good understanding of engineering fundamentals and design/manufacturing processes. Therefore, any undergraduate course should be designed in such a way so that the students are able to design the systems both analytically and numerically and also to solve their real life problems using MATLAB software. Keeping this in mind, 'Numerical Analysis' course is designed as discussed in the following sub-sections.

A. Course Contents

This gives the complete description of the course. The course contents should be designed in such a way so that the students get a deep knowledge and develop their skills to apply the knowledge in their fields and course objectives are achieved. Incorporation of too many topics in the course may impede the students' learning objectives. So, the optimal contents for 'Numerical Analysis' course are set as follows:

Introduction, solution of algebraic and transcendental equations: methods of iteration, Bisection, False position, Newton-Raphson and

Secant methods; Solution of simultaneous linear equations: Cramer's rule, Iteration method, Gauss-Jordan, Gauss-Elimination, Gauss-Seidel and Jacobi methods, Choleski's process; Interpolation: diagonal and horizontal differences, differences of a polynomial, Newton's formula for forward and backward interpolation, Spline interpolation; Integration: Trapezoidal, Simpson's and Weddle's rules; Solution of ordinary differential equations: Euler's, Heun's, Picard's, Milne's method, Taylor's series and Runge-Kutta methods; Least squares approximation of functions: Linear and polynomial regression, Fitting exponential and trigonometric functions.

B. Course Objectives

Learning objectives or instructional objectives are statements of what students should be able to do if they have acquired the knowledge and skills the course is supposed to teach them. The objectives of numerical analysis course have been set as follows:

1. To learn efficient methods for obtaining approximate solutions to complex engineering problems using simple arithmetic but systematic operation

2. To solve linear, non-linear and transcendental equations using various numerical methods

3. To learn how to interpolate experimental data and fit them in the curves

4. To learn how to integrate and differentiate various equations numerically

5. To learn how to solve ordinary differential equation numerically.

C. Course Outcomes

Course outcomes or learning outcomes reflect the degree to which the program has met its objectives; outcome indicators, the assessment instruments and procedures that will be used to determine whether the graduates have achieved the outcomes. After successful completion of the numerical analysis course with a minimum grade of 'C+', the students will be able to-

1. Design various complex engineering circuits/systems using numerical methods

2. Find the solutions of linear and non-linear system of equations while solving electrical engineering problems

3. Apply their experimental data to fit in the curve

4. Find the various parameters of electrical circuits/systems from any given equation using various integration and differentiation techniques

5. Find the numerical solution of ordinary differential equations developed for the linear systems

6. Compare the efficiency of different numerical methods.

IV. Laboratory Experiment Design in MATLAB

In this work, MATLAB programming language is used to teach the numerical analysis course to the undergraduate electrical engineering students. Because, MATLAB is a numeric computation software for engineering and scientific calculations. It is primarily a tool for matrix computations. It is being widely used for solving real life mathematical problems or designing practical systems. It has several simple programming features that can be used to teach numerical techniques efficiently. The main reasons of using MATLAB are as follows:

1. MATLAB is a high level language whose basic data type is a matrix that does not require dimensioning

2. There is no compilation and linking of programs as it is normally done in other high level languages, such as, C or FORTRAN

3. Here, all computations are done in complex valued double precision arithmetic to guarantee high accuracy

4. It has a rich set of plotting capabilities. The graphics are integrated into it

5. Since MATLAB is also a programming environment, a user can extend the functional capabilities of MATLAB by writing new modules

6. It has a large collection of toolboxes for variety of applications. A toolbox consists of functions that can be used to perform some computations in that domain

7. Reinforcement of student understanding of theoretical principles by means of enhanced graphical aids and interactive simulations

8. Analysis of more complex systems that can be treated by pencil and paper

9. The instructors' ability to assign fairly complex design problems that otherwise would have been unrealistic without the help of such software.

To teach numerical analysis course using MATLAB,it should have two parts, such as, theory and laboratory courses. In theory part, whole course should be covered in such a way so that the course objectives are full-filled and the learning outcomes are achieved. In the laboratory part, there should be some experiments that are to be done using MATLAB. But to overcome the constraints discussed in section II, in the first few laboratory classes students should be taught the basic MATLAB commands and coding. Then using simple MATLAB programs student should solve various problems using different numerical techniques learned in the theory classes. Then they should compare various techniques in terms of execution time, number of iterations required, accuracy of the results etc. Ten experiments have been proposed for the numerical analysis course using MATLAB based on the knowledge the students have gathered in theoretical part. These are listed as follows:

1. Determining the initial guesses for the open and close root location methods

2. Finding roots of an equation using Bisection and Regula-Falsi methods

3. Finding roots of an equation using Newton-Raphson and Secant methods

4. Solving simultaneous equations using Gauss-Seidel and Jacobi methods with and without relaxation

5. Finding the maximum power delivered to a load using Golden-Section Search and Newton's methods

6. Fitting the experimental data obtained from the response of a linear circuit to a linearly regressed equation and hence finding the circuit parameters

7. Finding the rms and average current of a circuit using Trapezoidal rule

8. Finding the amount of charge stored in a device using Simpson's rules

9. Solving the first order equation of a simple R-L circuit to find the transient current using RK method

10. Finding data from linear and quadratic interpolation.

V. Program Development Using MATLAB

To develop program using MATLAB, at first basic programming techniques were taught. Then they were taught how to develop algorithms, draw the flow charts of the program and write the final program using MATLAB. The final program may have two or more parts- one is the main program and the others are the function programs, if required. As an illustration, the procedures of the first experiment are shown and that for the other experiments are not shown here for brevity (S. C. Chapra *et al.*, 2002).

The switch in RLC circuit shown in Fig. 1 is thrown at position 'A' for sufficiently long time to establish the full DC voltage across the capacitor, C and then the switch is thrown back to position 'B' to discharge it through resistance and inductance, *R* and *L* respectively. This circuit design problem requires finding the resistance for which the capacitor is discharged to 1.0 % of its original value at a time 0.05 sec using the Bisection method. The function of *R* (the only unknown variable) is given in (1). The values of *L* and C are 5.0 H and 100 μF respectively. The lower and upper limits of *R* are 200 Ω and 400 Ωrespectively. The specified error limit, ε_s is 1 % (S. C. Chapra *et al.*, 2002).

$$f(R) = e^{-\frac{Rt}{2L}} \cos\left[\sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} t\right] - \frac{q}{q_0} \tag{1}$$
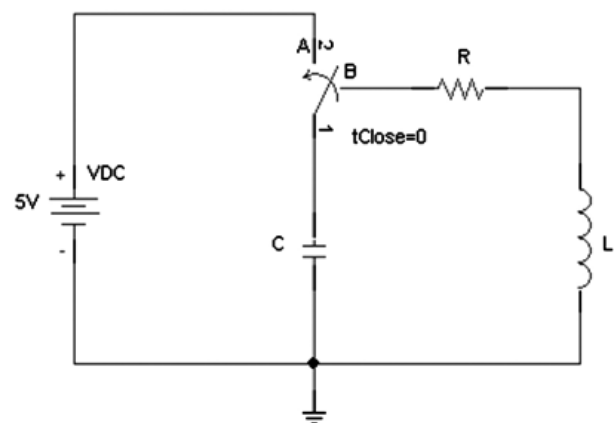

Figure 1: An RLC circuit for discharging the capacitor(M. H. Bhuyan *et al.*, 2014).

A. Main File

The flow chart of the main program for the root calculation using Bisection or Regula-Falsi method is shown in Fig. 2.

In the main file, at first initial guesses and other parameter values are declared. Then approximate root and function value for lower limit are calculated. After that the main file enters into a loop where algorithm of a particular method of root location is written as shown in Fig. 2 that calls the function file of Fig. 3 several times.

Root is calculated according to the algorithm of a particular method. Then the percentage of approximate error (ε_a) is calculated. The absolute value of ε_a is compared to the absolute value of the specified error limit (ε_s). If the absolute value of ε_a is greater than the absolute value of ε_s then the method does not converge yet and iteration is continued after changing the initial guess for the next iteration. If the absolute value of ε_a becomes less than the absolute value of ε_s then the method converges, iteration is stopped and finally, the results are displayed at the command prompt of MATLAB. Execution time of the each program is also displayed at the command prompt of MATLAB. Besides, the number of iterations required to calculate the optimum values and percentage of approximate errors are saved in a text file for the analysis of the results and comparison of the different methods.
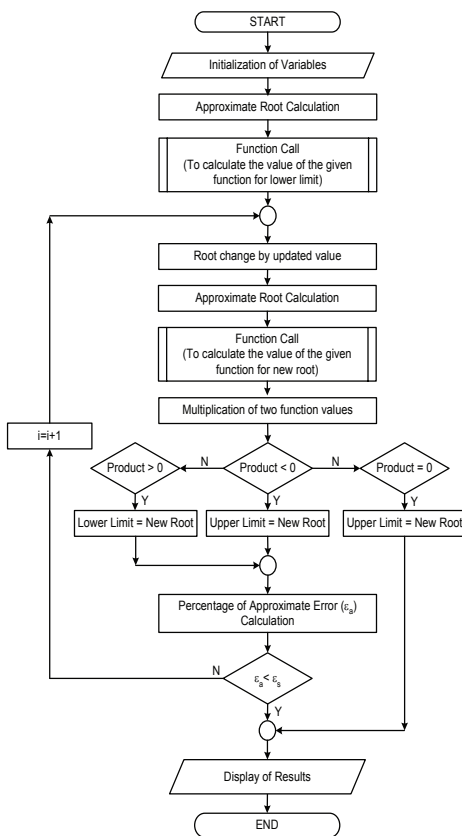
Figure 2: Flow chart of the main program developed in MATLAB for the root calculation using the Bisection or Regula- Falsi method

B. Function File

The function file is written in a separate text file using the MATLAB command, 'function' followed by the variable where calculated value of the function is saved and returned to the main file. Then function name is inserted by which the main file calls the function file and the argument of the function is given in parenthesis through which the main file sends the value of the function's unknown variable. This first line is known as function declaration as in Fig. 3. After that, this file initializes all the parameters required for calculation of the function value for the obtained value of the argument variable from the main file. The main file calls this function file each time for calculation of the function values which are returned to the main file.
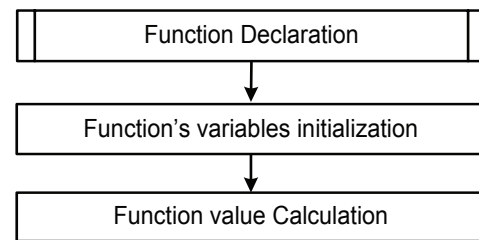
Figure 3: Flow chart of the 'function' file developed in MATLAB for the optimum value calculation using the proposed method of optimization and also for the Newton's method of optimization

In MATLAB, function file should be named by the function name. In the third step of the program, function value is calculated for the given function in (1). For the Bisection and Regula-Falsi methods, no derivative of the function is required. In function file, function declaration, variables initialization and function value calculation are needed.

In similar way, programs for the other experiments have been developed and are used to study and verify the theory learned in the numerical analysis course. All the experiments are designed for solving the problems related to electrical engineering design or verification. Based on the results obtained from the different experiments several types of analysis and comparison were also made.

Students were given several similar design or verification problems to be solved by MATLAB programming as laboratory report to test their ability. The student response was found very significant.

VI. Measurement of Students' Learning Outcome

Students' learning outcome is measured through the continuous assessment of all the students in the 'Numerical Analysis" course. This is a three (3) hour theory and three (3) hour laboratory course. For theory, two (2) classes of 1.5 hours duration are conducted per week in a semester of 13 weeks excluding the mid-term and final examination weeks. For laboratory, one (1) class of 3 hours duration is conducted per week, lab quiz was taken in the middle of the semester and lab viva was taken at the end of the semester. For the continuous assessment of the students in theory and laboratory classes, the following marks distributions are followed:

For theory:

Attendance:	07 %
Assignment:	05 %
Presentation:	08 %
Quizzes:	10 %
Mid-term:	30 %
Final Exam:	40 %
Total:	**100 %**

Marks are given in attendance if a student is present at least 75% of the classes conducted in the course and if a student is present 100% of the conducted classes then he/she got 7 marks and for each 5% less attendance then 0.5 marks are deducted from 7. Two assignments- one on numerical computation and another on MATLAB programming are given each having 2.5 marks. Each student has to give a presentation either on a numerical method or its MATLAB programming. Four quizzes- two on numerical computation and two on MATLAB programming are taken each having 10 marks. Average of the best three (3) quizzes is taken. One and a half hour mid-term examination was taken in the middle of the semester. Student has to answer any three out of four questions given. Comprehensive final examination was taken with duration of two hours at end of the semester and a student has to answer four out of five questions given. Questions on numerical computation and MATLAB programming on different techniques are given both in mid-term and final examinations.

For laboratory:

Attendance:	10 %
Lab performance:	10 %
Lab reports:	20 %
Lab quiz:	10 %
Lab viva-voce:	10 %
Lab Final Exam:	40 %
Total:	**100 %**

Marks are given in attendance if a student is present at least 70% of the laboratory classes conducted in the course and if a student is present 100% of the conducted classes then he/she got 10 marks and for each 5% less attendance then 0.5 marks are deducted from 10. Lab performance is taken after each laboratory work is completed. Students have to submit the laboratory reports individually every week on the experimental findings/analysis and MATLAB programming, each having 2.0 marks. One mid-term laboratory quiz on MATLAB programming is taken having 10 marks. After the end of all the experiments, a comprehensive viva is taken for each student individually. Finally, the comprehensive final examination was taken with duration of two hours at end of the semester and a student has to answer four out of five questions given. Questions of the final examination are set on numerical computations and MATLAB programming on ten experiments conducted in the class.

Based on the accumulated score final grades of the theory and laboratory course are awarded separately as per grading policy given Table 1. It is to be mentioned that this uniform grading policy is approved by the University Grants Commission (UGC) of Bangladesh.

Table 1: Grading Policy

Marks out of 100	Grade	Grade Point
80 - 100	A+	4.00
75 - 79	A	3.75
70 - 74	A-	3.50
65 - 69	B+	3.25
60 - 64	B	3.00
55 - 59	B-	2.75
50 - 54	C+	2.50
45 - 49	C	2.25
40 - 44	D	2.00
< 40	F	0.00

As a case study, one section (A) of students of the 'Numerical Analysis' course, having class population of 40, is considered in one particular semester of Electrical and Electronic Engineering Department of Green University of Bangladesh. In laboratory class, students are divided into two sub-sections (A_1 and A_2) each having 20 students. Then five groups are formed in each sub-section each group having 4 students. Each group has to perform one experiment in a week in MATLAB

environment, but each student has to submit laboratory report separately on the following week. At the end of the final examinations, statistical analyses of the grade points are calculated as shown in Tables 2-7.

Table 2: Grade Distribution of Theory Section A

Grades	No of Students
A+	5
A	5
A-	6
B+	7
B	6
B-	5
C+	3
C	2
D	1
F	0
Total	40

Table 3: Statistics of Grade Points of Theory Section A

Statistical Parameter	Value
Mode	3.25
Median	3.25
Mean	3.21
Lowest Marks	2.00
Highest Marks	4.00
Standard Deviation	0.54
Quartile1	2.75
Quartile3	3.56
Average Deviation	0.44
Class CGPA	3.05

Table 4: Grade Distribution of Laboratory Section A_1

Grades	No of Students
A+	3
A	4
A-	4
B+	3
B	2
B-	2
C+	1
C	1
D	0
F	0
Total	20

Table 5: Statistics of Grade Points of Laboratory Section A_1

Statistical Parameter	Value
Mode	3.50
Median	3.50
Mean	3.35
Lowest Marks	2.25
Highest Marks	4.00
Standard Deviation	0.51
Quartile1	3.00
Quartile3	3.75
Average Deviation	0.42
Class CGPA	3.35

Table 6: Grade Distribution of Laboratory Section A_2

Grades	No of Students
A+	3
A	3
A-	5
B+	3
B	3
B-	2
C+	1
C	0
D	0
F	0
Total	20

Table 7: Statistics of Grade Points of Laboratory Section A_2

Statistical Parameter	Value
Mode	3.50
Median	3.50
Mean	3.38
Lowest Marks	2.50
Highest Marks	4.00
Standard Deviation	0.44
Quartile1	3.00
Quartile3	3.75
Average Deviation	0.36
Class CGPA	3.38

From the tables, it is observed that the results are very satisfactory as there is almost no F grade or D grade. Class CGPA is also above 3.00. Standard deviation is

around 0.5, average deviation is near 0.4. Mean grade is near B+. Grade distributions among the students are normal. That is, too much students did not get A+, only 5 students in theory and 6 students in laboratory. Results of laboratory sections are better than those of theory section. It may be due to more orientation of MATLAB programming in the laboratory sections.

Conduction of numerical analysis course using MATLAB programming including laboratory, the following things are observed in the class:

1. Students feel enthusiastic about learning MATLAB and apply it to do numerical computations;

2. Effects of changing different parameters on the outputs are easily possible to find;

3. Time can be saved in case of changing the designs several times;

4. Students become acquainted with the use of computer technology for solving numerical problems;

5. Teaching and learning environment has been modernized and enhanced through the use of computer;

6. Students can learn more things in the class;

7. Students are well-prepared to solve real-time engineering problems in future.

To improve teaching quality in numerical analysis course, if this method is to be adopted then there are few suggestions that are to be implemented. These are as follows:

1. A computer laboratory with at least 20 PCs having latest configuration must be set-up;

2. MATLAB program of latest version must be installed in each PC;

3. Multimedia facility must also be installed in the laboratory so that teacher can explain the programming techniques and other things directly from the PC;

4. Course Teacher must be trained adequately before starting the course;

5. Laboratory sheets must be well prepared and supplied to the students;

6. Practice facilities must be provided in the laboratory class room so that the students can prepare their assignments and laboratory reports;

7. Standard text and reference books must be suggested to conduct the course;

8. Each teacher must be equipped with a computer in the faculty room so that he/she can practice before going to the class and can help students during counselling;

9. Suggested assessment processes must be followed.

VII. Conclusions

Present world economy is knowledge-based. Engineering plays a leading role for shaping the future technology. The engineering graduates must be well prepared in the changing global competitive knowledge-based market. Like all of us in the real world, the engineering graduates must have the ability for knowledge management through the use of computer and information technology. Therefore, universities are facing challenges as well as opportunities for creating and transferring knowledge to the students in efficient and smart way for their survival.

This paper describes the teaching method of numerical analysis course for undergraduate electrical engineering students using MATLAB. Both the theoretical course and laboratory experiments are designed based on MATLAB. This is discussed with example. The laboratory experiments have been developed in such a way that add values to the teaching and learning activity in the theory as well as laboratory class and provide the students with a deeper understanding of the course. Since numerical analysis is an important core course in the curriculum of undergraduate electrical and electronic engineering program, therefore, this course must be taught in such a way so that the students are able to develop their problem solving skills on numerical computation to solve their real life design and verification problems using MATLAB.

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