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Use of virtual industry and laboratory machines to teach electric circuit theory

Ailson P de Moura[1] and Adriano AF de Moura[2]

Abstract

At the beginning of Fall 2012, the new modules of the Electrical Engineering Department at the Federal University of Ceara, Technology Center, Brazil, significantly modified the instructional philosophy of the TH0 176 Electric Circuit II module. The theory course was enhanced by the introduction of more engineering designs into the curriculum, adopting the virtual industry, and laboratory machine as a methodology to teach alternating electric circuit. This paper discusses the use of this new methodology in detailed form. An example is discussed, along with mathematical models, which describes electric circuit behavior, and it helps each team of students to have a specific homework. The approach presented in this paper can be adapted to any other course in engineering/science that involves mathematical calculations. So far, the course evaluations suggest that the students are more motivated and excited about electrical engineering as a career.

Keywords

Circuit analysis, engineering education, educational technology

Introduction

Two landmark studies have both informed the engineering education community and influenced research retention in engineering: in Marra et al.[1] a qualitative work, identified two categories of students who leave science/engineering programs: those who feel they must leave because of a loss of academic self-confidence

[1]Federal University of Ceara – Campus do Pici – PO Box 6001– Fortaleza – Ceara – Brazil
[2]Federal Rural University of Semi-Arid – Department of Environmental Science and Technology – Av Francisco Mota, 572 Bairro Costa e Silva – Mossoró-RN, Zip Code: 59625-900, Brazil

Corresponding author:
Ailson P de Moura, Department of Environmental Science and Technology, Federal University of Ceara, Fortaleza 60455-768, Brazil.
Email: ailson@ufc.br

in the competitive environment and those who become bored or disappointed with the curriculum.

In electrical engineering curriculum, the undergraduate modules offered at the beginning of the undergraduate course have too much theoretical content, along with some laboratory practice. This theoretical content unrelated to any real practice held by an electrical engineer helps even more to discourage students with the chosen career. One of the modules that is part of this scenario is the Alternating Current Circuit. Some publications are cited related to this topic: in Palma et al.[2] is discussed the use of the Quiz tool within WebCT for the construction of question base and its publication at a WebCT server. Course evaluations suggest that the students are more motivated and excited about electrical and computer engineering as a career. Butun et al.[3] showed that the problem-based learning (PBL) approach is an effective method to cope with these changes and demands. This was confirmed, when compared to previous courses, by observations as follows: even though there was no attendance requirement, class participation improved; group members' compliance with the timetable increased; outputs of group projects were more cost effective; out of class hours were increased. A cooperative learning (group work) method was applied in lectures of an advanced engineering course in microelectronics packaging technology and reliability, and a continuous student feedback system was used in a student control reception and learning is presented in Myllymaki.[4] According to the author, the result of using student feedback after every lecture was perhaps the most positive outcome of the study. Yang[5] discusses the effect on circuit performance of non-ideal parameters. A concept 'loop gain' is introduced, and the dynamic behavior is analyzed based on a first-order dynamic model. Finally, Iqbal[6] describes Electrical Engineering Design course details: organization, design methodology, types of projects and course outcome. Project final reports that students submit at the end of the term clearly indicate great student learning and interest in the course.

This paper discusses the use of a new methodology to teach electric circuit in a detailed form. An example is discussed, with mathematical calculations, which describes electric circuit behavior and it helps each team of students to have a specific homework.

This paper is organized as follows: Firstly, the course structure is presented. Secondly, a project example made by students is shown. Concluding remarks are contained in this paper as well.

Module structure

The Electric Circuit Theory module emphasizes in-depth circuit analysis, including some aspects of circuit design. The course includes a laboratory to expose students to measurement equipment, simulation of circuits and verification of their designs on breadboards. Historically, this module has been taught primarily from the perspective of engineering science, in which mathematical and analytical tools required to solve electrical circuit responses have been presented and exercised through extensive problem solving classes. This approach is somewhat sterile and has not been effective in demonstrating the excitement and creative opportunities afforded by careers in electrical engineering. Therefore, at the beginning of Fall 2012, the new courses of the Electrical Engineering Department at the Federal University of Ceara, Technology Center, Brazil, significantly changed the module format of its TH0 176 Electric Circuit Theory module by introducing more engineering design in the curriculum and adopting a virtual industry and laboratory machine as a new methodology. Furthermore, several other changes were made to introduce more challenging and industry-related experiments in the laboratory portion of this course.

The new methodology drives the students of the course TH0 176 to make a project of a virtual industry relating theory seen in classroom and other content studied in previous modules with industrial reality. The industry can be of any type, that is for instance, shoes industry, textile industry, production of granite slabs, cashew nuts processing industry and others. Students research in the internet about the manufacturing process of various types of industry, and visit the regional industries. Then, each team of four or five students defines the type of industry that will be virtually created, as follows: They prepare a floor plan and a 3D perspective of the chosen industry. Respective figures are drawn using AutoCAD, Google SketchUp or other software. Then, raising the powers of hypothetical lighting loads, plugs and electrical motors is calculated, and the hours of operation of each daily load are established. Thus, it is possible to make the demand curve of the virtual industry. Now, they are related concepts of alternating current industrial reality. The concepts in question are: Phasors, single-phase circuits alternating current, active, reactive and apparent power, power factor correction, power factor, voltage and phase currents and line circuits connected in star and triangle, capacitor bank and three line diagram. To relate the concepts of power factor and power factor correction a software is developed in MATLAB, VBA or other programming language that performs the correction of power factor of the virtual industry. In addition, practices with induction motors and synchronous machines, using the laboratory of electrical machines, are held to bring the concepts of alternating current with industry reality. A laboratory practice where a synchronous machine can operate with inductive, capacitive or unity power factor is shown in Figure 1.

Auditing standards and the Regional Energy Company, regarding facilities of light and strength, are required in the development of virtual design industry. It uses standards (NBR) of the Brazilian Association of Technical Standards (ABNT): NBR 5410/2004 – Low Voltage Electrical Installations; Technical standards (NT)/State Energy Company of Ceara (COELCE) – 002/2010 – Power Supply Primary Voltage electrical Distribution; NBR 5413/1992 – Interior Illuminance and NBR 14039/2005 – Medium Voltage electrical Installations of 1.0 kV to 36.2 kV.

According to these standards, the demand of each individual motor is given by

$$D_m = \frac{P_m \times 0.736 \times F_u \times F_s}{PF \times \eta} \tag{1}$$

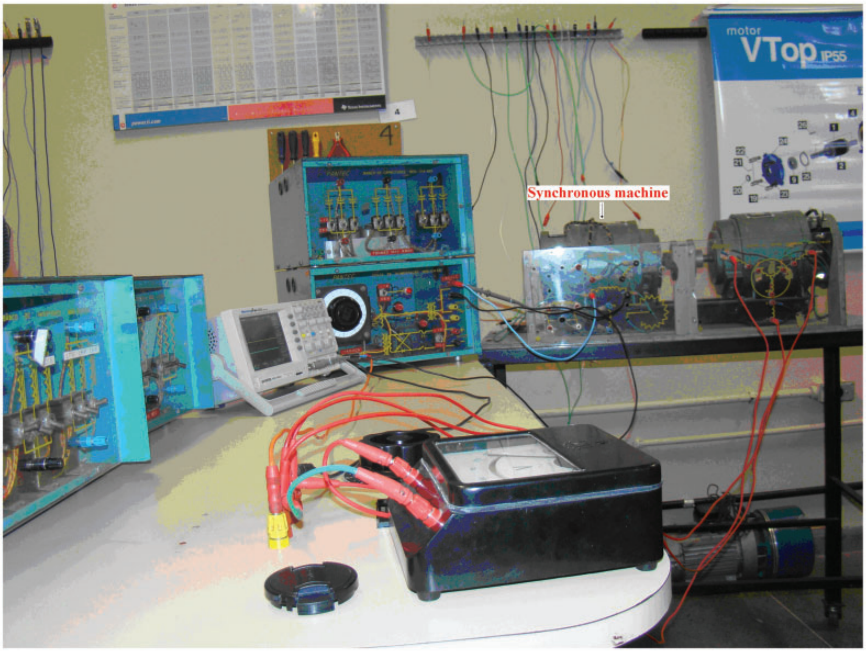

Figure 1. Laboratory machines – practice using synchronous machine.

where

D_m – motors demand in kVA.
P_m – nominal power of the motor in HP.
F_u – motor utilization factor.
F_s – motor simultaneity factor.
PF – motor power factor.
η – motor efficiency.

Industry demand is calculated using the virtual NT-002/COELCE and it is given by

$$D = \left(\frac{0.77}{Pf} a + 0.7b + 0.95c + 0.59d + 1.2e + f + g \right) \quad \text{(kVA)} \tag{2}$$

where

D – Total demand of the installation, in kVA.
a – Demand of power in kW for lighting and outlets for general use (fans, calculators, television, sound, etc.) calculated according to Table 5 of NT-002/2011 (COELCE).

Pf – Power factor of the installation of lighting and outlets. Its value is determined according to the type of lighting and ballasts used.

b – Demand of all heating appliances in kVA (shower, heaters, ovens, stoves, etc.), calculated according to Table 6 NT-002/2011 (COELCE).

c – Demand of all air conditioners, in kW, calculated according to Table 7 of NT-002/2011 (COELCE).

d – Nominal power, in kW, the water pump system installation service (not considering standby pump).

e – Demand for all lifts in kW calculated as shown in Table 8 NT-002/2011 (COELCE).

f – Demand of power in kVA, for driving loads. The value should be determined by the expression

$$f = \sum (0.87 \times P_{mn} \times F_u \times F_s) \quad (3)$$

P_{mn}: Motor rated power in HP used in industrial process.
F_u: Motor utilization factor given in Table 9 of NT-002/2011 (COELCE).
F_s: Motor simultaneity factor given in Table 10 of NT-002/2011 (COELCE).
g: Other charges not related in kVA. In this case, the designer must stipulate their demand factor characteristic.

Notes

1. In the premises, the engines operate with a high degree of concurrency, such as in the industries of spinning and weaving. It is worth noting that the designer can adopt other values.
2. For sizing measures of the power transformer, it is admitted to a value of installed power of up to 30% higher than the demand calculated according to the formula presented in this standard. This increase is fully justified by the designer. Exceptionally, if there is no commercially available transformer with rated power that meets the criteria above, values of power transformer more than 30% of demand calculated will be accepted.
3. The sizing of the conductors and protecting the secondary of the transformer must be calculated depending on the output thereof.
4. A maximum of 10% of the installed load and sockets is allowed for lighting circuits reservation.

Project example

In any project chosen, necessarily, students must present a complete history of the type of industry. This procedure allows students to know in depth the origins of the chosen industry.

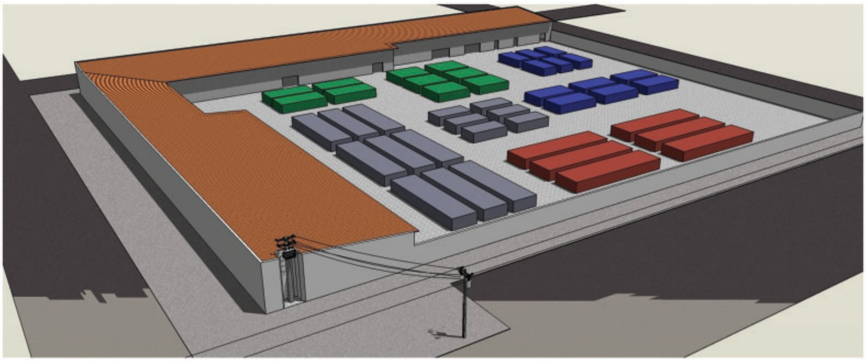

Figure 2. 3D view – Virtual industry.

Objectives

This project aims to describe the processes and complete lifting of loads from a textile industry and the preparation of the load curve industry operating and project realization correction of excess reactive (capacitor banks).

Characterization project

The main features of this project are: Santa Ana Textile Industry S/A, which has its headquarters in the city of Fortaleza, Brazil. The factory is open from 07.00 until 17.00 daily.

The textile industry consists of three sectors: administrative, production control and productive sectors. The perspective of the virtual 3D textile industry is presented in Figure 2.

The administrative sector comprises: reception, room of the CFO, an auditorium, a canteen for the board, a cafeteria, and male and female toilets. The sector production control consists of central air conditioning, laboratory, packaging and storage of finished products, raw material depot, warehouse and substation. The productive sector, which is composed of the industrial shed: laundry, two looms, auto-coner, centrifuge, stamping and spinning machines.

Load table

In the load table, we can have a more general overview of the project that we are dealing with. It shows information needed to dimension consumption and evaluate factors such as power factor, demand and others. The table contains the circuits that make up the system in question, where each circuit has its terminations and equipment connected thereto. We prefer to divide the load table in table lighting, outlets and frame motors because their potency is different and requires greater specificity. Tables 1 to 3 are the tables of loads.

Table 1. Lighting power.

Ambient	Active power (kW)	Apparent power (kVA)
Reception	0.715	0.715
CFO	1.17	1.17
Auditorium	1.82	1.82
Canteen collective	1.848	1.848
Canteen board	0.84	0.84
Male toilet	0.588	0.588
Female toilet	0.588	0.588
Laboratory	3.612	3.612
Warehouse	1.008	1.008
Deposit of Raw material	3.360	3.360
Substation	1.176	1.176
Packaging and storage products	1.952	1.952
Climate central	2858	2858
Industrial shed	51.12	51.12
Total	72.65	72.65

Table 2. Total of single-phase wall socket.

Ambient	Apparent power (VA)
Reception	1100
CFO	1200
Auditorium	1100
Canteen collective	3100
Canteen board	2700
Male toilet	1800
Female toilet	1800
Laboratory	1500
Warehouse	1200
Deposit of raw material	2000
Substation	1300
Packaging and storage products	1400
Climate central	2000
Industrial shed	5000
Total	27,800

Table 3. Frame motors.

Motors										
Sector	Ambient	QTD –	Active power (hp)	Power factor –	Efficiency (%)	Utilization factor –	Simultaneity factor –	Total (by ambient) (kW)	(kVAr)	[kVA]
Productive control	Packaging and storage products	2	15	0.75	86	0.80	0.85	17.46	15.40	23.28
	Climate central	6	175	0.88	90	0.90	0.70	540.96	291.98	614.73
Productive (Hangar Industrial)	Laundry	4	50	0.86	92	0.90	0.80	115.20	68.36	133.95
	Ring spinning machine	9	50	0.86	92	0.90	0.70	226.80	134.58	263.72
	Stamping	6	30	0.83	90	0.90	0.80	105.98	71.22	127.69
	Automatic winder	6	25	0.84	90	0.90	0.80	88.32	57.05	105.14
	Centrifuge	6	10	0.85	86	0.80	0.75	30.81	19.09	36.25
	Looms	12	25	0.84	90	0.90	0.80	176.64	114.10	210.29
Total load								1302.17	771.77	1515.05

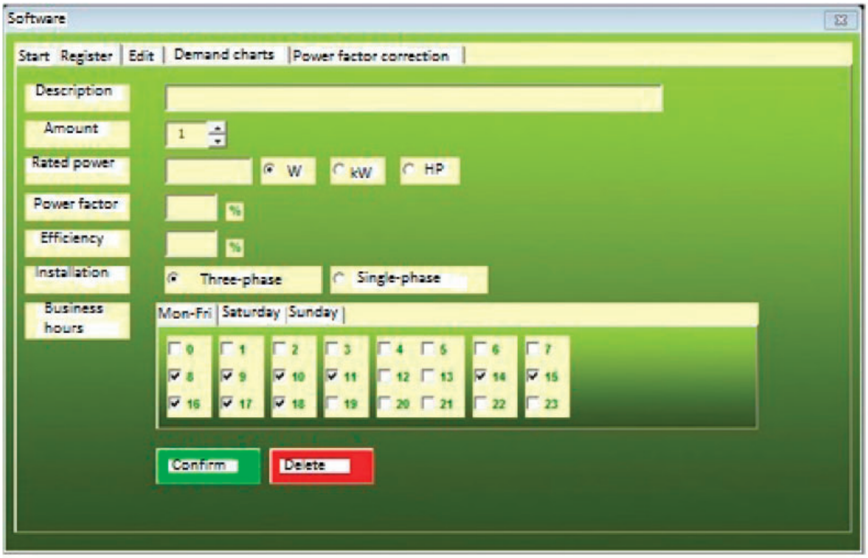

Figure 3. Software screen for power factor correction in VBA language.

Demand curves

A program in VBA language, whose screen is shown in Figure 3, was developed to survey the demand curve.

To survey the demand curve, the operating regime of the industry was estimated. Plots were estimated with the demand of each sector to define the framework for operation of the industry. This procedure emulates more accurately the operating profile of the factory and, thus, raised the demand curves for active, and reactive, apparent demand and power factor of the installation time. The time intervals are 1 h. The percentages of demands adopted for motors, lighting the shed, general lighting and outlets are presented in Table 4. We considered the operation of driving loads to start at 18.00, with engines starting in a 2-h interval that goes from 18.00 to 20.00. This procedure aims to reduce a load step, because the departure of all engines in a short space of time can cause an elevated peak demand and hence high demand contracted or exceeded demand contracted. At the end of the day, we also considered a shutdown 'smooth' driving loads. The sinking demand happens in the range of 11.30 to 13.00, at lunchtime, and it was regarded as a reduction in driving loads, lighting sockets and break due to industry during this common time interval. We also considered two peak periods of demand related to possible use of many loads as laundry, looms and central air conditioning, common in textile industries.

The demand curve for active power, the demand curve of reactive power, the curve of the power factor before correction and the curve of the power factor time after correction are shown in Figures 4–7, respectively.

Table 4. Average percentage of loads utilization.

Intervals (h)	Motors (%)	Lighting (%) Hangar	Lighting (%) General	Wall socket (%)
00.00 to 06.00	0	20	10	10
06.00 to 07.00	30	50	10	10
07.00 to 08.00	60	90	50	40
08.00 to 11.30	90	95	95	75
11.30 to 12.00	80	80	85	70
12.00 to 13.00	70	60	65	60
13.00 to 13.30	80	80	85	70
13.30 to 16.30	90	95	95	75
16.30 to 17.30	65	60	50	40
17.30 to 18.30	30	35	10	15
18.30 to 00.00	0	20	10	10

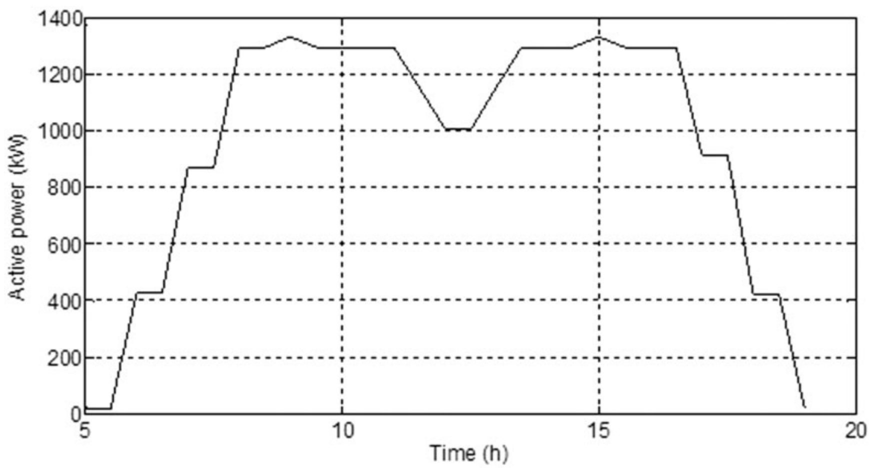

Figure 4. Curve of daily operational load (active power).

At the end of each semester, students were questioned regarding the methodology used in the module of TH0 176 Electric Circuit II, compared with the traditional method only with lectures. The results are shown in Table 5.

According to Table 5, more than 94% of the students preferred the new teaching method.

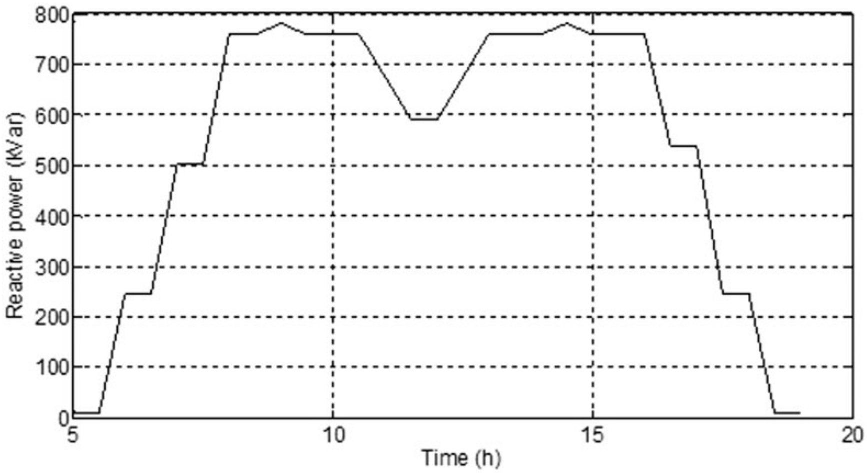

Figure 5. Curve of daily operational load (reactive power).

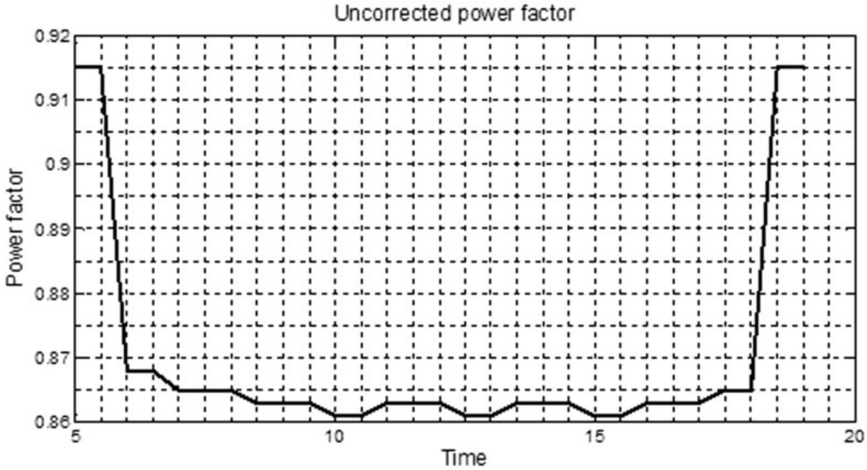

Figure 6. Power factor without correction.

In addition, we observe during each semester the increased interest and motivation of each student to the new methodology applied at the time of preparation and presentation of the work done by the students, and in informal conversations outside the classroom. Thus, we can conclude that the use of virtual industry and laboratory machines to teach electric circuit theory is an essential pedagogic complement to modern teaching.

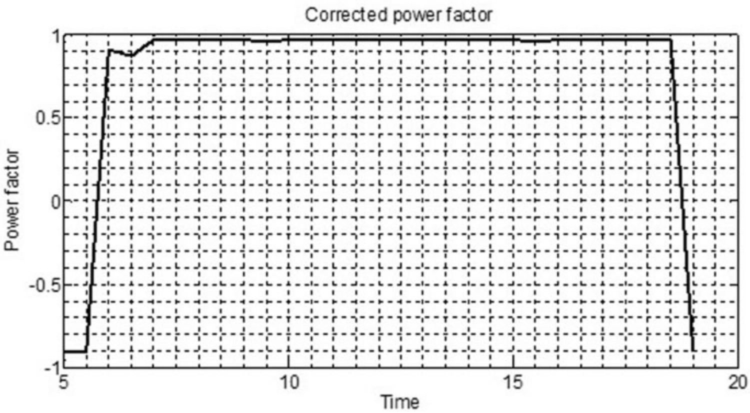

Figure 7. Power factor corrected.

Table 5. Research with students.

Year – first semester	Number of students participating in the project	Students conducive to teaching methodology with only lectures (%)	Favorable students to teaching methodology with lectures and design virtual industry and laboratory machines (%)
2012	58	3.45	96.55
2013	52	5.77	94.23
2014	63	1.59	98.41

Concluding remarks

In this educational paper, the use of virtual industry and laboratory machines to teach electric circuit theory is an essential pedagogic complement to modern teaching. The study developed in this paper is an important contribution in the educational domain for the students and lecturers of the Electrical Engineering Department of Federal University of Ceara – Brazil. The authors' experience in teaching alternating electrical circuit theory shows that students have some difficulties in carrying out their understanding and motivation properly. To overcome this, the authors propose a pedagogic approach based on the use of the virtual industry and laboratory machines to increase understanding and motivation of electrical engineering students.

Declaration of Conflicting Interests

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