How Recent Graduates Perceive Some of the Preliminary Concepts in Electrical Engineering

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***Abstract*— This research paper is about some of the electrical engineering topics that are widely misunderstood among recent graduates despite the fact they are simple and well established scientifically. The misunderstanding is discovered through the responses collected via a survey distributed among engineers who identify themselves as either senior student or recent graduate with background in electrical, electronic, or computer engineering, including engineering technology disciplines. The electrical topics that were discussed in this paper are:1) grounding, 2) RMS quantities, 3) circuit analysis, and 4) the difference between science and engineering. These topics are clearly well-defined and articulated among scientific communities whereas many recent graduates and engineering students failed to explain them correctly and/or in detail. It seems that either engineering education is not delivering the aforementioned topics as they should be delivered or educators overlook them. In this paper, the concept of the aforementioned topics are presented and how textbooks, curricula, and instructor notes are presenting them. Despite the fact that some of the responses to technical questions were correct, amazingly, none of the participants provided a satisfactory distinction between engineering and science - which is a fundamental question. Such observations deserve attention from engineering colleges and educational institutions.**

Keywords*— *RMS, demarcation, power, engineering education.

I. Introduction

Electrical engineering (EE) education has changed over the last century in a response to changes in industry. This is evident after world war II (WWII). Before WWI [3], [4], the EE curriculum was heavily concentrated on DC and AC circuits and power system equipment because it aimed to prepare students to enter the newly and rapidly growing electrical manufacturing industry. The devoted time to science and mathematics courses had increased gradually in EE curriculum whereas shopwork and drawing courses had declined until 1950's [1], [2]. However, more courses in microwave, wireless, vacuum tube, radar, etc. had been included in EE curriculum profoundly post-WWII. Then, after WWII [2], the pace had been accelerated and more disciplines within EE had emerged such as electronics and communications in a response to workforce demand. Similarly, in a response to industry, Electrical Engineering Technology (EET) born of EE womb, figuratively, to satisfy certain workforce requirements [5].

The industrial requirements for engineering skills are still evolving and EE education is improving along with them. Such evolutionary path in EE education could produce engineers who know a lot about something and less about another due to the fact that engineering education is dictated by industry. In this paper, few technical topics in EE have been surveyed, that are not necessarily among the widely pervasive topics in industry. These topics have been selected carefully by the author, despite their simplicity, as they receive less attention in EE curriculum. Therefore, a survey has been created and distributed in social media, especially Linkedin, that is targeting either recent graduates or senior students.

Four topics have been surveyed. Each topic is presented in an independent section in this paper along with its results and discussion. In section II, the survey result with regard to grounding in electrical system is presented. Section III is dedicated for root-mean-square (RMS) quantities whereas section IV and V contain the survey result of circuit analysis questions and students' perception of the differences between engineering and science, respectively. The questionnaire are not meant to be comprehensive to cover all knowledge areas falling under certain topic; and they are not designed to gauge participants' knowledge in electrical engineering. In other words, this survey cannot be used to (dis)qualify the participant's credential by any means. Actually, the survey is surveying the topics themselves [not participants' knowledge] to enhance engineering education in certain blind spots.

The survey is more focused on technical topics and is less concerned about the participants' background. Therefore, the participants' educational institution have been eliminated from the questionnaire because the goal of this survey is **neither about quality of education of specific institution nor about comparing countries' education**. The survey is concerned solely with certain topics in EE education but they have been measured via the responses of recent graduates or senior students, regardless of where they are graduated from. The survey was open to everyone who wants to participate as long as they self-identify as an engineer who graduated recently. Also, the survey was in an electronic form by which the participant clicks on a link that would take him/her to another online questionnaire.

TABLE I: SUCCESS RATE OF PARTICIPANTS IN GROUNDING QUESTIONNAIRE

Question	1.a	1.b	1.c	1.d	1.e	1.f	1.g	1.h	1.i
Success Rate, %	64	69	54	59	46	72	87	79	49
Question	1.j	1.k	2.a	2.b	2.c	2.d			
Success Rate, %	46	36	69	72	90	85			

II. GROUNDING

Grounding is a fundamental component of any electrical or electronic project. However, the author had a belief that the topic of grounding has not received sufficient attention from educators; Thus, he included the topic of grounding in the questionnaire to discover how much do recently graduated engineers know about it.

The questions related to grounding are presented in Fig. 1; It consists of two questions in which the participant choose the correct statement. The correct statements in the first question are ‘d’, ‘e’, and ‘g’ whereas ‘c’ and ‘d’ are the correct answers of the second question. Thirty nine participants were involved and their answers are summarized in Table 1.

As it can be noticed from Fig. 1, the questionnaire is testing the level of students’ understanding about the concepts of “ground”, “reference”, “neutral” and “return path” without detailed calculations. From the result in Table I, it can be inferred that the majority of participants understand the role of neutral wire and grounding wires during unbalanced and fault circuit conditions respectively. They, also, clearly know the role of “return path” in electric circuits. However, they demonstrated a relatively less distinction between “reference” and “ground” and their association to “return path.” Also, 46% thought that “ground” does not constitute physical connection to the soil.

Such result indicates that participants are not equipped with clear distinction between “reference” and “ground” in electric system. Therefore, the author investigated the widely used textbooks in engineering colleges to find whether they offer enough distinction between “ground” and “reference.” Two textbooks were chosen for investigation that appeared in Electric Circuit courses in most of engineering colleges; The first textbook is titled as *Electric Circuits*, 10th edition, by J.W. Nilsson [6]; The second textbook is titled as *Principles of Electric Circuits*, 10th edition, by T.L. Floyd [7]. The former provides extensive explanation of “reference” but nothing about “ground” although it has been used multiple times to explain amplifiers. The latter differentiates between “reference” and “ground” and it names them as “ earth ground” and “ reference ground” respectively.

The author, also, investigated the courses offered by some universities that involve the word “grounding” in course title and he found that only a handful of them are available by few universities, some of them are electives. The list of universities under investigation has been omitted from this document because it might harm their reputation or could constitute free advertisement and will not serve the research purpose either way - the same argument is applicable to the rest of this paper.

Thus, it can be deduced from above discussion that less attention from engineering colleges to simple, but important, topics such as “grounding” resulted in remarkable confusion among recent graduating engineers.

1. In the context of electrical circuit, what is the difference between ‘reference point,’ ‘return path’, and ‘ground’? choose all applicable answers:
   a. Reference and ground are the same thing, interchangeably used.
   b. Reference could be a ground but not the opposite.
   c. A ground could be a reference but not the opposite.
   d. Reference could be ground and vice versa.
   e. Return path should pass through ground node, if exist.
   f. The return path is always the grounding path.
   g. A circuit can be constructed without ground. However, return path is an essential part of the circuit.
   h. A circuit can be constructed without return path. However, ground is an essential part of the circuit.
   i. A circuit cannot be constructed without ground.
   j. Ground is a referential concept and it does not constitute physical connection to the soil.
   k. Electric potential of ground is zero and this is why we use it as a reference.
2. Neutral wire is connected to neutral node whereas grounding wire is connected to grounding node. Which statement is true in your think.
   a. If neutral node is connected to grounding node, then, both of grounding wire and neutral wire will carry the same current.
   b. In unbalanced 4-wire system, grounding wire is supposed to carry current.
   c. In unbalanced system, neutral wire is supposed to carry current.
   d. During some faults, grounding wire is supposed to carry current.

Fig. 1. Grounding Part of the Questionnaire

III. RMS QUANTITIES

From mathematical point of view, RMS is similar to standard deviation (SD). The latter is measured around the mean whereas the former is measured around any origin -which is zero in electrical applications- other than the mean [8]. In other words, RMS measures how far the AC signals are deviated from

Voltage and current measured at a residential meter is shown below. Note that the exact numeric values are not given, only waveforms. Could you sketch the waveform of the apparent power [not the instantaneous power] delivered to the residential house? Feel free to sketch any other waveform that would help you to reach to the correct answer as long as you label each waveform. You don't have to provide exact numbers; Just estimate the correct value and sketch it.

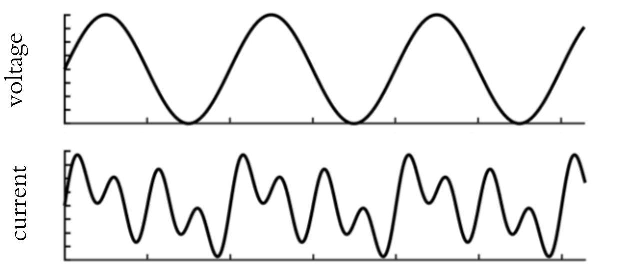

Fig. 2. RMS Questionnaire

zero as shown in (1) [n represents total number of discretized points of a continuous AC signal while x_i represents the i^{th} discrete value]. If AC signal is purely sinusoidal, it will be a special case of (1) and can be simplified as shown in (2).

$$RMS = \sqrt{(1/n)\sum_i x_i^2} \tag{1}$$

$$RMS = \sqrt{2}X_{peak} \tag{2}$$

RMS as a metric is extremely helpful for steady state studies because they are concerned with the overall trend of signals over definite intervals rather than instantaneous fluctuations. Thus, only the RMS of AC signals will be utilized in steady state studies. Thus, RMS is very handful to measure power consumption because utilities want to bill customers based on their overall consumption of power over a definite interval, regardless of the instantaneous fluctuations of consumption. Therefore, power has been defined historically [1] as the multiplication of the RMS value of both voltage and current as shown in (3). Note that (3) is different from instantaneous power because it is a function of RMS quantities.

$$Power = V_{rms}I_{rms} \tag{3}$$

Hence, the following observations can be concluded from the definition in (3), as follow:

- Due the fact that the power is defined using RMS quantities, it is suitable for steady state models of power system and totally irrelevant to transient models, where instantaneous data points are of main concern[2] rather than overall pattern.

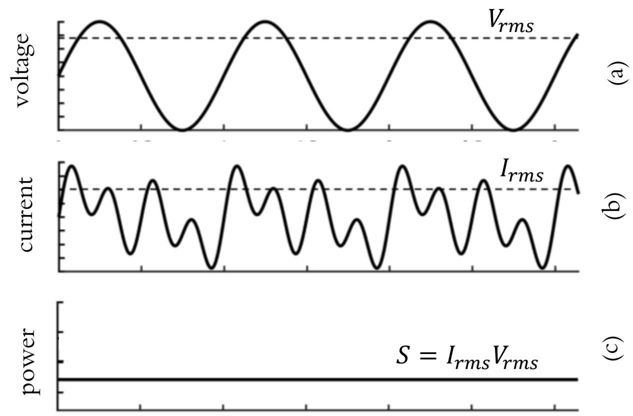

Fig. 3. Expected answer to the questionnaire in Fig. 2.

- Power in (3) is applicable to AC signals and can be simplified to (4) in the case of sinusoidal waveforms.

$$Power = 2V_{peak}I_{peak} \tag{4}$$

The author surveyed the participants' knowledge of above discussion using the questionnaire in Fig. 2. Note that the question in Fig.2 is asking the participants to find power, which is suitable for steady state models, whereas the provided signals are in time domain, which are suitable for transient models. The correct answer is shown in Fig. 3. Note that the answer in Fig. 3(c) is showing power as a constant RMS value, regardless of its numeric value. Thus, this question investigates the student understanding of how RMS quantities are applied to electric signals.

There were about 31 participants in the questionnaire but valid attempts were only 16. Thus, 15 attempts has been discarded from the survey. Out of the 16 valid attempts, only two participants sketched the power as a constant value (because RMS quantity is supposed to be constant value). This amounts to 12.5% success, which is remarkable!

In order to interpret above result, the textbooks in [6], [9], and [7] are visited and it turned out that they offer detailed explanation of instantaneous power; They, also, offer explanations of power in (3) but only for purely sinusoidal waveforms. However, the textbook by Hart [10] offers detailed explanation of power calculations using RMS quantities including none sinusoidal waveforms. Since the book in [10] is well known as a textbook for Power Electronic courses, it can be inferred that student who has taken such course would be able to answer the questionnaire in Fig. 2. Since most of electrical engineering curricula nowadays includes Power Electronic courses, we cannot infer a conclusive result from the survey result and more research is required in order to identify the causes of the low success rate (12.5%) of the provided survey.

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[1] It is a conventional definition of electrical energy that has been developed historically and accepted universally[14], [15], [16].

[2] RMS quantities and transient models are incompatible. However, in some instances where RMS values are of the main concern, they can be embedded with transient models provided that all necessary adjustments are being taken care of.

A generator generating square waveform voltage, denoted as $v(t)$ and its angular frequency is denoted as ω. The generator is connected in parallel to a load. The load consists of an inductor and a resistor connected in series. The current flowing in the load is denoted as $i(t)$. Select true statement below.

$[A]$ the current flowing in the load is equal to $\frac{V_{rms}}{R+j\omega L}$.

$[B]$ according to Kirchhoff's Voltage Law, $v(t) = i(t)R + Li'(t)$

$[C]$ the current flowing in the load is equal to $\frac{V_{peak}}{R+j\omega L}$

$[D]$ according to Kirchhoff's Voltage Law, $v(t) = I_{rms}R + I_{rms}(j\omega L)$

$[E]$the RMS of the voltage is $V_{rms} = \sqrt{2}V_{peak}$

$[F]$the power consumed by the load is $(R + j\omega L)I_{rms}^2$

$[G]$ the power consumed by the load over one cycle is $\left(RI_{rms}^2 + L(I_{rms})(I'_{rms})\right)$.

Legends

I_{rms}= RMS of $i(t)$., I'_{rms}= RMS of $i'(t)$

V_{rms}= RMS of $v(t)$., V_{peak}= peak of $v(t)$

Fig. 4. None sinusoidal waveforms Questionnaire

IV. Circuit Analysis

Sinusoidal – either single or three phase – waveforms dominate utility power industry. Thus, they receive the highest attention in engineering education. However, would this disproportionate attention lead to misunderstanding among recent engineers if they are confronted with none sinusoidal AC problem? To answer such question, a questionnaire has been distributed surveying participants knowledge about none sinusoidal AC systems as shown in Fig. 4. The correct statements in questionnaire in Fig. 4 are B and G only.

There were thirty nine participants in the survey. The success rate of the participants' responses are 54%, 64%, 54%, 49%, 54%, 46%, and 59% for statements A, B, C, D, E, F, and G respectively. It seems from the result that participants are more inclined to differentiate between laws applicable to sinusoidal and to none sinusoidal waveforms because the highest success rate is associated with statement B and G (64% and 59% respectively). However, there is still a significant percentage (at least 46%) of participants who did not choose the correct answer.

In an effort to find the cause of such confusion, some of instructors' notes from various institutions has been surveyed (only those that are published for public). It has been found that none sinusoidal AC signals constitute less than 2% (estimated) of the instructors' notes whereas the rest is totally dedicated to the analysis of purely sinusoidal signals. Also, it has been observed that none of the surveyed notes revisit both sinusoidal and none sinusoidal laws to establish a comparison between them. Therefore, it can be deduced that the lack of emphasis of instructors on the differences between laws applicable to sinusoidal and none sinusoidal waveforms created confusion among recent graduate engineers.

V. Science Versus Engineering

Engineering students start their learning journey by taking general education (GenEd) courses, such as physics, chemistry, English writing etc. Then, few semesters later, they take courses in their major. However, from student perspective, both engineering courses and GenEd courses look structurally similar because they both discuss natural phenomenon from scientific perspective. So, it is left to engineering students to pick up or to figure out the difference between engineering and science through their learning journey in school, and may be after graduation. In this paper, the student perspective on the difference between science and engineering is surveyed to find whether they really picked up the true differences or not?

Before answering above question, we would need to know the true differences between science and engineering. From an idealistic perspective, scientists conceive knowledge while engineers use this proven knowledge to the betterment of human life [11]. However, in reality, an overlap could happen between science and engineering. For instance, an engineer might need to wear the scientist's hat at some instances, or even the technician's hat. Therefore, a definition of engineering is needed. One such attempt to define engineering is made by Luegenbiehl, [12] "the transformation of the natural world, using scientific principles and mathematics, in order to achieve some desired practical end." Another definition by Lee Shulman [13] states that "An engineer is someone who uses math and the sciences to mess with the world – by designing and making things that people will buy and use; … and once you mess with the world, you are responsible for the mess you've made." In this context, four main distinctions are presented in [11] to differentiate between science and engineering:

- Engineer picks up where the scientist left off.
- Scientist uses technology to conceive knowledge while engineer uses science to achieve practical end.
- The core of science is "discovery" whereas the core of engineering is "making."
- Science results in an academic achievement whereas engineering results in material wealth.

Considering above discussion, a survey is prepared to find out how the students or recent engineers perceive engineering as oppose to science. An essay question is given to participants asking them this "*Do you agree that scientist is not an engineer? If yes, write below how they differ. Instead of writing an essay, simply list the differences in bullets. In every bullet, state something about engineering and state its counterpart in science, and so on.*" About 39 participants involved in the survey. However, only 11 attempts were considered because the remaining participants gave no answer. The answers have been analyzed and classified into three groups. The first group gave no meaningful difference although they agree that there is a difference between engineering and science. The answers of first group explained engineering and science but without pinpointing clear differences. For instance, a participant from first group could mention that scientist works on technology but later mentions that the word “technology” as an exchange word for engineering. The second group provided some differences between science and technology but the offered differences are not correct. For instance, a participant from second group would believe that scientist could apply for Nobel prize while engineers cannot. Third and last group had some distinction in their mind between engineering and science but they could not state them in a manner that would establish an accurate distinction. For instance, a participant belongs to third group could mention that engineer wear safety helmet and work in construction whereas scientist works in the Lab.

Above result shows that young engineers failed to distinctively identify their identity. A possible cause for such result could be the engineering curricula because none of them offers a course or a lesson answering this question: what is engineering?

The field of study that is concerned with the differences between science and engineering is philosophy: namely, philosophy of technology. So, an elective course or a lesson within a course introducing philosophy of technology would be helpful.

VI. Conclusion

Some technical topics in electrical engineering have been surveyed and presented. The selected topics simple and well-established scientifically but the author thought they receive less attention in curricula. The target group in this survey are recent graduate engineers or senior students in electrical engineering or related fields. The topics that have been surveyed are related to grounding in power system, RMS quantities, circuit analysis of AC system, and the perception of the difference between science and engineering.

The result of the survey shows that a significant portion of the participants demonstrated lack of knowledge, though they are less than 50% of the participants. It has been noted, also, that the participants have no clear distinction between science and engineering. Some of the textbooks, instructors’ notes, and curricula have been visited too to explain the result of the survey and it has been determined that whenever curricula or educators pay less attention to a topic, even simple one, results in a wide misunderstanding among young engineers.

Future research could study the concept of “electrical energy” from philosophical point of view. A question like “why it has been decided to multiply current by voltage to generate third quantity?” and “why this quantity is named energy?” Since electrical energy (as any other form of energy) is a defined quantity and such concept should not be taken for granted but should be investigated philosophically.

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