Teaching Fundamental Power Engineering Concepts using the VisPhasor App

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Abstract— **This Innovative Practice Category Work-in-Progress Paper presents the design and deployment of a mobile app for teaching fundamental power-engineering concepts to undergraduate electrical engineering and computer engineering students. In power engineering, it is difficult to visualise AC circuit behaviour as compared to DC circuits due to the use of sinusoidal waveforms and phasors defined by multiple parameters such as amplitude, frequency and phase difference as compared to a constant value for DC parameters. The app helps the student visualise phasors, phasor arithmetic, phase differences and voltage and current of different AC circuit parameters. The mobile app uses a split screen interface that helps the student visualise the time domain representation of the waveforms as well as the phasors at the same time. The app first introduces the fundamental concept of phasor and then takes it further by analyzing different AC circuits such as RLC circuits and Generator Equivalent Circuits. The student can modify different parameters on the top screen using the touch screen and they see a corresponding change in the phasors on the bottom screen. Instant evaluation along with visual feedback in a simple yet effective mode of deployment are the key takeaways from this work.**

KEYWORDS: Mobile learning, power systems education, visualisation

I. Introduction

Power Systems engineering is a fundamental discipline of electrical engineering. In power engineering, it is difficult to visualise AC circuit behavior as compared to DC circuits due to the use of sinusoidal waveforms and phasors defined by multiple parameters such as amplitude, frequency and phase difference as compared to a constant value for DC parameters. [1]. The introduction of the concept of impedance in AC circuits further makes it difficult for the students to analyze these circuits. Phasors help simplify this complexity by using directional arrows to represent the amplitude and phase difference [2]. The introductory power systems course at the National University of Singapore for undergraduate students covers a wide array of topics ranging from phasors, AC circuit analysis, power generation, transmission, and distribution. Visualisation of these concepts would help the student in understanding and assimilating the basic knowledge of power engineering.

Authors at [3] used PowerGraf, a windows based software to supplement classroom, laboratory and self-learning for power flow problems. Multiple power system simulation software are available that support this functionality but need a powerful desktop system to use them. It is much more convenient to have a lightweight mobile app that can be used at any place or time.

Mobile devices have become a convenient new medium for educators to reach out to their students. Ktoridou and Etekleous defined mobile learning in the framework of e-learning but implemented on mobile or handheld devices [4]. Ozdamali developed a pedagogical framework for mobile learning and identified its four key aspects as integration of tools, pedagogical approaches, assessment techniques and teacher training [5]. Bae and Kim worked on understanding the educational use of smart phone applications using smart clicker apps for effective communication between the instructor and the student [6].

Broademeadow et.al. studied the effectiveness of using digital tablets as a tool for enabling blended learning in a power engineering course. They outlined the different use case scenarios for the tablet and concluded that the majority of students preferred using delivery using digital tablets [7]. Goergen et.al successfully used SimVascular as an Instructional Tool in the classroom for students to understand blood flow modeling project [8]. Banavar et.al developed the Reflections Echolocation app to teach signal processing and machine learning concepts [9].

The visualisation of different AC concepts on a mobile platform has not been done before. The designed mobile app aims to create a simple yet effective e-learning platform that helps the students visualise and learn these concepts.

II. Mobile Learning Framework

The framework proposed by Ozdamali in [5] which takes [4] as reference forms the basis for developing this mobile app. The four key aspects identified are as follows:

A. Integration of Tools

The visPhasor mobile app is developed as a supportive tool for power engineering modules. Students can visualise and check different parameters for common power circuits with the swipe of a finger. It is being designed as a companion app for these modules.

B. Pedagogical Approaches

Blended learning combines digital content with traditional classroom teaching wherein online videos are used to deliver

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lecture content [10]. Griffiths proposed a blended approach to support modern learners post lecture using technology and investigated different online tools for the same [11]. The supportive nature of this app makes it an ideal candidate to adopt the blended learning pedagogy. The instructor can push different changes to the mobile app remotely and the students can use it for supplementing online instructions, theory and numerical problems.

C. Assessment Techniques

The mobile app is a companion app for different power engineering modules hence formative assessment is proposed for evaluating the students. The students can use the mobile app to scaffold their learning and visualise different power engineering concepts.

D. Teacher Training

Teacher training would involve training the instructor on how to use the mobile as well as to customize it for their own modules.

III. Design of *visPhasor*

A waveform in this context is defined as a sinusoidal function with a magnitude, angular frequency and a phase angle. We assume that the angular frequency remains constant. A phasor is a two-dimensional vector representation of a waveform with the magnitude divided by square root two being the length of the vector and the phase angle corresponds to the vector's angle.

The visPhasor app is being developed using the programming language 'Python' and an open source Python library called 'Kivy'. Kivy is a cross-platform, multi-touch friendly, GPU Accelerated library that can run on Linux, Windows, OSX, Android, iOS and Raspberry Pi. The cross platform nature of the app ensures that maximum students can access it. Currently it is being developed as a Windows App. The multi-touch nature of the library is a natural fit on mobile devices.

The visPhasor App is fundamentally divided into four sections. The main screen of the app has navigation buttons that direct the student to the corresponding sections as shown in Fig. 1. Each section uses a split screen interface that helps the student visualise the different parameters of the circuit change in terms of waveforms or values as well as the corresponding change in phasors at the same time.

A. Single Phase Visualiser

The single phase visualiser is a simple visualisation of waveforms in the time domain and the phasor domain as shown in Fig. 1. The split screen interface displays the time domain waveform(s) in the top half while the corresponding phasor is shown in the bottom half. The waveforms can be manipulated individually by clicking and holding on the corresponding label and either moving up or down to change the magnitude of the waveform or moving left or right to change the phase angle of the signal. A '*Home*' button navigates the student back to the home screen.

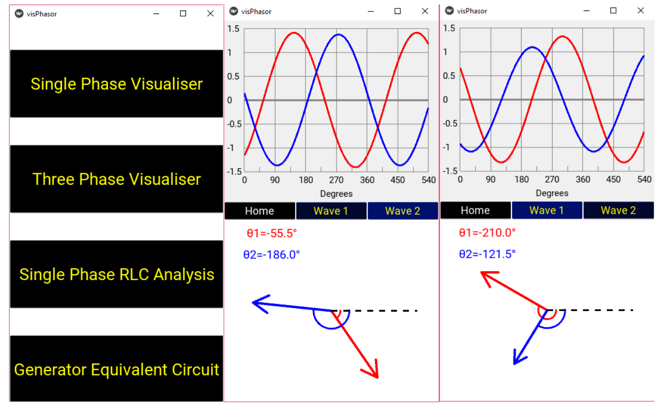

Fig. 1. Main Screen of the visPhasor App (Left) and visualising single phase waveforms at different phase angles with respect to each other (Middle and Right)

B. Three Phase Visualiser

Three phase waveforms are the primary voltage waveforms of generators and power is transmitted in three phase over transmission lines. Visualising waveforms when they move independent of each other is relatively easy as compared to visualising waveforms when they change at the same time as is the case with three phase systems. The phases are denoted by letters 'a', 'b' and 'c'. The three waveforms are 120° apart with respect to each other and can have two configurations *"abc"* or *"acb"* depending on if waveform *'b'* or *'c'* occurs after waveform '*a*'.

The three phase visualiser has the same split screen interface as the 'single phase visualiser'. It displays options to view the three waveforms in the default "*abc*" configuration or switch to the "*acb*" configuration using the toggle button labeled "*acb*". There is also an option to view the line waveforms and the corresponding phasors. The line waveforms are the summation of one phase waveform and the negative of another phase waveform for all three waves. The line phasors can be viewed for both the "*abc*" and "*acb*" configuration using the "*acb*" toggle button. These different configurations are shown in Fig. 2. The toggle button "*acb*" can be used to control the magnitude and phase of the three waveforms similar th the 'single phase visualiser'. A '*Home*' button navigates the student back to the home screen.

C. Single Phase RLC Analysis

Determining different parameters for a simple AC circuit is the fundamental requirement of power engineering. This section focuses on showing the students, the change in different AC parameters such as voltage across or current through different components as the student manipulates different impedance parameters.

The Single Phase RLC Analysis screen is designed differently from the previous two sections. Here, it is important to visualise how different AC parameters are changing. Hence, the top part of the split screen now displays a simple AC circuit with a voltage source connected to a resistive(R) and inductive (XL) load with a capacitor (XC) connected

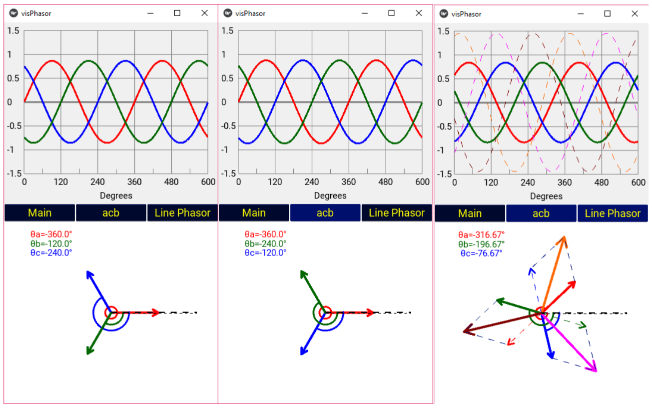

Fig. 2. Visualising three phase waveforms in *abc* phase sequence (Left), *acb* phase sequence (Middle) and *acb* sequence with line values (Right)

in parallel to the resistive inductive load. Each component has the corresponding voltage and current values next to it. These values are updated in real time. Each AC parameter is designated a different colour and the same colour is used to draw the phasors in real time in the bottom half of the screen.

The student can manipulate the values of the voltage source (V), resistance (R), inductance (XL) or capacitance (XC) similar to the button functionality of the 'single phase visualiser'. As these values change, the corresponding phasors in the bottom half and the circuit labels in the top half of the screen change concurrently as shown in Fig. 3. A '*Home*' button navigates the student back to the home screen.

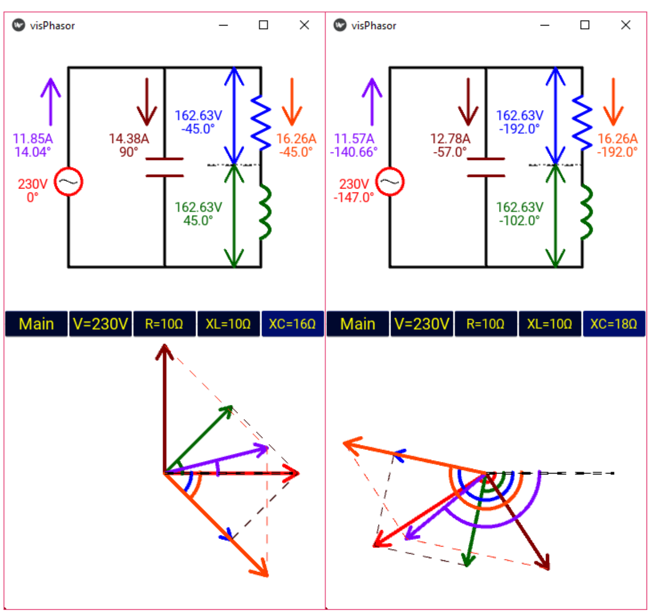

Fig. 3. RLC circuits with different values of R, XL and XC at different voltage phasors

- *Power Factor Correction*: An example application for Single Phase RLC Analysis would be power factor correction of a lagging (resistive and inductive) load. The student can initially fix the values of R and XL to satisfy the load power factor requirements. Then he/she can increase the value of the capacitance (XC) to see the improvement in power factor and further increasing capacitance would make the power factor leading in nature as shown in Fig. 4. This is an important concept for understanding load side operation and reducing electrical consumption. The visualisation of the change in the excitation voltage would help students understand this much better.

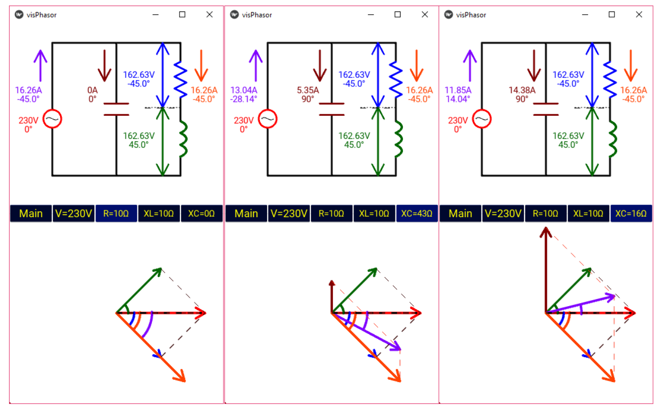

Fig. 4. Visualising Power Factor Correction by applying an increasing capacitor to the RL load

D. Generator Equivalent Circuit

A generator is one of the basic electrical machines. Understanding and knowing the equivalent circuit of a generator and the different parameters associated with it is critical for a power engineer.

The Generator Equivalent Circuit Analysis screen is designed similar to the previous section. The top part of the split screen now displays the generator equivalent circuit with a generator excitation voltage, armature resistance (Ra), synchronous reactance (Xs) and the terminal voltage V. The phase angle of the generator excitation voltage is known as the '*power angle*'. Each component has the corresponding voltage and current values next to it. These values are updated in real time. Each AC parameter is designated a different colour and the same colour is used to draw the phasors in real time in the bottom half of the screen. The terminal voltage magnitude and phase angle doesn't change as it is a function of the grid voltage magnitude and its phase angle.

The student can vary the generator parameters to see its effect on the generation excitation voltage and the power angle as shown in Fig. 5. A '*Home*' button navigates the student back to the home screen.

- *Effect of Load Power Factor on Excitation Voltage and Power Factor*: The student can change the power factor angle by toggling the θ button and increasing or decreasing the power factor. It can be visually seen that as the power factor goes from lagging to leading the magnitude of the excitation voltage is reducing and may become smaller than the terminal voltage if it is a highly leading power factor as shown in Fig. 6. This is an important concept for understanding generator operation and the visualisation of the change in the excitation voltage would help students understand this much better.

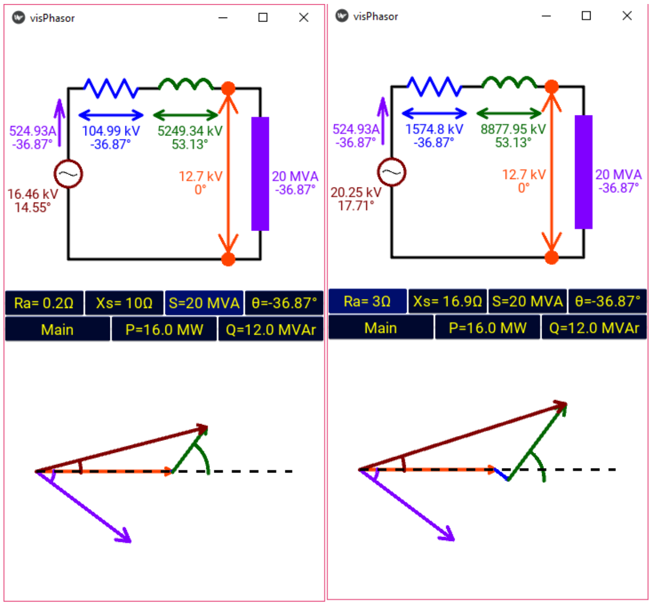

Fig. 5. Changing Generator Parameters (Ra and Xs) and seeing its effect on different AC parameters

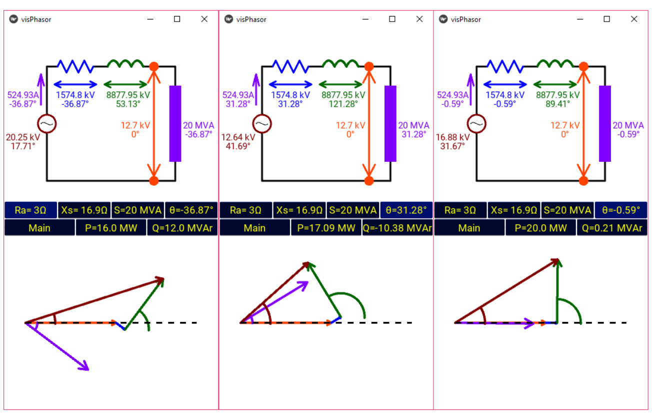

Fig. 6. Visualising the effect of different load power factors on the generator excitation voltage and power angle

IV. Survey Results

A survey was conducted for the outgoing cohort who took the power engineering module the traditional way without the *visPhasor* app to understand their perception on the requirement of such an app. The survey was optional, voluntary, anonymous and 28 students answered the following questions. The results are shown in Fig. 7

- MQ1: I want guidelines on how to draw phasors
- MQ2: I want to see how phasors change as different parameters change in circuits
- MQ3: I want to visualize the 3-phase quantities as phasors
- MQ4: I want a feedback system that can verify answers related to phasors

The survey results show that more than 60 % of the class *agreed* or *strongly agreed* to the survey questions. Thus, the development of the app will help the students in their learning journey.

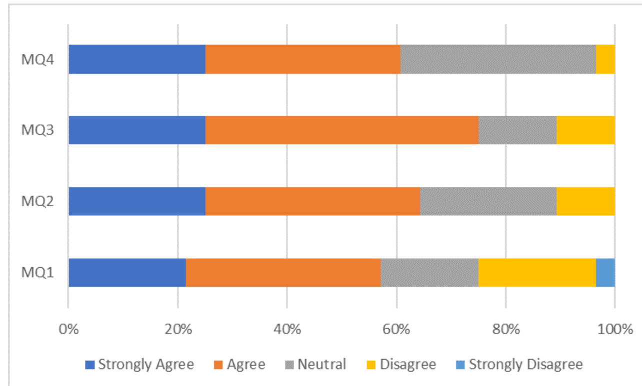

Fig. 7. Survey outlining the requirements of a visualisation app

V. Conclusion and Future Works

This work-in-progress paper outlines the design and framework of a visualisation companion mobile app called ***visPhasor*** for power engineering modules. The features and applications of the app was discussed and different scenarios were presented on how the student can use the app for learning concepts as well as verify answers for numericals.

The app needs to be developed for different platforms and launched, data on how students use the app needs to gathered and studied to gain insights in to the trends in learning.

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