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Virtual Laboratory for Basic Electronics

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Abstract: *In modern education system, e-learning plays a vital role, where different technologies are being assimilated to enhance its web-based presence. Computer simulations have always been treated as an aid to teaching science. In some cases, demonstration of experiments has been a challenge in classrooms. One of these courses is basic electronics devices, circuits and their fabrication. This paper describes a set of experiments for this course that could help both teachers and students in their respective capacities. This Virtual lab is designed to support a hands-on learning environment for teaching this course. These learning materials can be illustrated while taking theoretical classes while students can use those independently to exercise their theoretical knowledge. Each experiment has some course material, virtual simulation environment, optional video lecture and experiments to challenge the knowledge of the student. The experiments are developed using free open source software, HTML5 and JavaScript.*

Keywords: Virtual Laboratory, Distance Learning, Visualization, e-learning, Basic Electronics Laboratory.

I - INTRODUCTION

The course on electronic devices, circuits and fabrication represents the culmination of modern microelectronic manufacturing process [1]. In todays education structure, apart from theoretical studies, hands-on experimentation plays a vital role to understand electronic science [2]. A virtual laboratory for this course offers students a way to learn the working of instruments and circuits much the same way as in an actual laboratory, there are some important differences also. A virtual laboratory supports an ideal environment where circuits behave as expected. The flip side is that certain realities learnt through experimentation are missed out.

While studying electrical circuits, students ought to understand the application of the laws of electricity to those circuit towards understanding their behaviour as exhibited through physical experimentation. In many cases, students fail to explain the observed behaviour of circuits. Simulation mechanisms can help the student in such situation through easy visualisation of the interrelationships between the various circuit currents and voltages. Such visualisation is often harder to achieve in a real laboratory. The best option perhaps would be to develop the concepts through practice in a virtual laboratory and reaffirm those through true experimentation in a real laboratory. Due to limitations in the available physical infrastructure, adequate experimentation in a real laboratory may not always be possible.

The rest of the paper is organized as follows: Section II provides a brief review of existing basic electronics virtual laboratory and methodologies to perform simulation of the experiment. In section III the format of experiments is described. In section IV some experiment of the virtual laboratory on basic electronics are presented. Section V describes the feedback received from workshops conducted to familiarise teachers and students with this virtual laboratory; finally, the paper is concluded in section VI.

II - BACKGROUND AND RELATED WORK

According to CE-CAE Circuits and Electronics, Association for Computing Machinery (ACM) IEEE Computer Society [11] has some core learning outcomes which includes use of Ohm's Law, the relationship between current and voltage, zener diode, designing a diode circuit to include rectifiers. In this paper, we describe experiments for various circuits and analyze the circuits in specific ways using the virtual laboratory tool. The aim is to give a general idea of the working of specific circuits or devices and then to challenge the student to evaluate his understanding. For this purpose, we avoid using a general purpose circuit simulator, rather each experiment is handled in a specific manner that is thought to be appropriate for that particular experiment.

The relationship between laboratory and theory knowledge of the engineering laboratories has been done[4]. Evaluation on students' collaboration in real laboratories working in group or independently has also been made. There are advantages of working independently, the students gain a deeper understanding of concepts. The concept of a virtual laboratory to allow students to work independently is supported by this study. In [10] a virtual model for an electronics laboratory is built up using Virtual Intelligent SoftLab (VIS) experimentation. The developer has constructed the programs in Visual Basic, but VBScript is supported only in Internet

Explorer, limiting its usage and also being a proprietary solution. An experiment was proposed Ohm's law [3] using Matlab/Simulink. Users need some application software enabled in their web browser or system for using Matlab software. However, present day client side programming framework based on HTML5/javascript is powerful enough to handle a significant amount of computational and graphic intensive work within the browser itself. We have taken advantage of these developments to evolve our virtual laboratory to work without such dependencies while at the same time being free and open source software (FOSS) compliant. A set of experiments has been introduced that developed in FOSS [5].

Initially, a virtual laboratory for electronics was built using proprietary software such as PSPICE, ORCAD, MATLAB/Simulink etc. In order to perform these experiments a user needed to have these software installed in their systems, which in many cases would not be feasible or put limitations for frequent access. The other option was to have these installed locally on a server and access those via a portal using suitable application software. This model was not scalable, as it was limited by the licensing terms. Also, there was a significant time lag for the simulation results to appear to the user's console. It was observed that the proprietary software was often being used for solving problem that could easily solved using open source software. These concerns and observations led to the development of the later version of virtual laboratory for this course using open source software, mainly HTML5 and javascript. This scheme makes the virtual laboratory highly scalable, as the server is minimally loaded with most of the computations happening on the client side. More complex programming on the client side may require downloaded applications, as in case of the virtual laboratory for computer organisation [6].

In newer version, the users can't draw circuit, but can change circuit parameters according to their need. On changing the parameters, the corresponding results will be generated and user can analyze the results from the graph obtained.

The experiments in virtual laboratory for basic electronics laboratory has been divided into six parts: theory, procedure, simulation, assignment, quiz, references. The proposed laboratory can be accessed through the following link:http://vlabs.iitkgp.ernet.in/be/. The GUI of the new version of this laboratory is shown in Figure 1.

III - FORMAT OF EXPERIMENTS

Theory: This section deals with the theoretical concept of the experiment. In this portion mathematical part of the concept is introduced. This helps the student to understand the concepts and grasping the idea behind the mathematical formulation and thus increases learning capability of the student. In case of verification of Ohms Law experiment, the current through a metal conductor is directly proportional to the voltage is already shown in the virtual experiment.

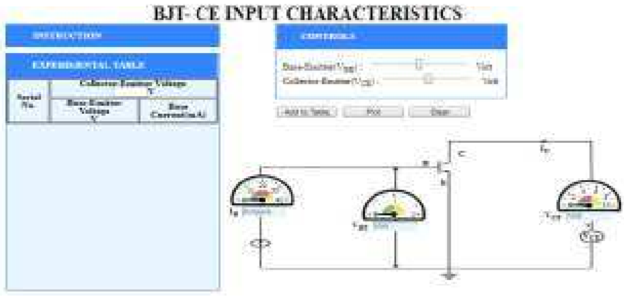

Figure 1: Main GUI of basic electronics laboratory

Procedure: In this section, the steps involved to perform the particular experiment are explained. The procedure section helps in understanding the way to perform the experiment

Simulation: The virtual experiments, which are designed using HTML5, emulate physical instruments in a real laboratory. Student can analyze the results by controlling the parameters and can verify the formulae. In each stage, there are sliders to vary the input parameters, graphs to show the relation between the input and output charcteristics. The experiment helps the student to understand the concept of electric circuits and visualize the concept more clearly. To execute the simulation, the following features are available in the virtual environment of the experiments:

- Ranges of circuit elements { resistance is exactly as present in circuit element boxes in a real laboratory.
- Ranges of measurement devices like the AC ammeter, DC ammeter, Voltmeter are implemented exactly as in the real laboratory.
- Plot and test results can be generated.

Quiz: In this section, it contains a questionnaire in which self assessment is done to achieve the self-learning system after learning the concept of the experiment. The fundamental aim of this assessment is to regulate the learning process of the students. In this questionnaire, it comprises a set of objective questions.

Assignments: This section deals with few subjective questions, the student takes this assessment to achieve the self-learning system after learning the concept of the experiment.

References: This section provides external books name, web pages, NPTEL video links for more information related to the concept of the experiment.

The experiments done by the students can be uploaded online to a system for WBCM [9] for recording the evaluation carried out and also reproduction of the activity for further use.

A circuit is an abstract thing which is difficult to visualize the mechanism of the circuit. In order to overcome the difficulties virtual laboratory is a proposed tool. In remote areas, due to lack of good facilities of laboratory, the users face problems in understanding the circuit phenomenon. In solving the problem, the virtual platform is made where the student can change the parameters of the circuit and study the mechanism of the particular circuit. In engineering, theoretical knowledge is not sufficient to gain knowledge, the virtual platform is available to the user to test their theoretical knowledge.

IV - CASES STUDIES OF EXPERIMENTS

4.1 Ohm's Law Verification

In electronics, electric circuits are analyzed in terms of three basic circuit laws: Ohms Law, Kirchhoffs Current law (KCL) and Kirchhoffs Voltage Law (KVL). Basically, electric circuits are composed of active and passive components. Active components are those with the ability to control electron flow electrically. For a circuit to be properly called electronic, it must contain at least one active device. Diode, transistors are examples of active components whereas resistors, capacitors are examples of passive components. The resistor is simplest and basic passive circuit element among all the other passive elements. This section describes of a simple circuit containing a voltage source, a resistor, an ammeter and a voltmeter. Considering the first circuit as Ohms Law circuit which is verified using virtual environment. Ohms law is one of the fundamental law of electric circuits. The law states that the electric current through a metal conductor between two points is directly proportional to the voltage across the two points, for any given temperature. Such a conductor is characterized by its Resistance (R) measured in Ohms. Simulation template for this experiment is shown in Figure 2.

$$V = I \times R$$

V is the Voltage in Volts across the conductor.

- I is the electric current in Amperes through the conductor.
- Voltage (V) is directly proportional to current i.e.

  $V = I \times R.$
- Resistance (R) in inversely proportional to current (I)

  i.e. $I = \frac{V}{R}$

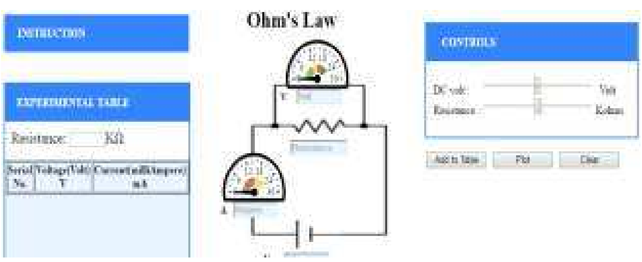

Figure 2: Simulation template of Ohms Law

The experimental table below shows the values from the simulation for constant Resistance value1 kΩ

Table 1: Experimental Table for Ohm's Law

Serial No.	Voltage (V)	Current (mA)
1	0	0.00
2	2	2.00
3	4	4.00
4	6	6.00
5	8	8.00
6	10	10.0

The mathematical relationship *(V = I×R)* that exists between potential difference and current, voltage is directly proportional to current for a constant resistance. The student thus can analyze the result obtained from the data. This virtual expriment gives a general idea of the working of specific circuits. The corresponding graph for Ohm's Law Verification is shown in Figure 3.

4.2 I-V Characteristics of Diode

Using Web-based simulation tool, simulating the current vs voltage characteristics both under forward bias and reverse bias. Current cannot flow through the diode, if the diode is in reverse bias. To overcome this barrier potential at the junction DC voltage is applied. The aim of this experimentation is to show that current flows through the diode, if the diode is in forward bias. This section describes the current vs voltage characteristics of PN junction diode in forward bias and also in reverse bias virtually. Simulation template is shown in Figure 4.

The mathematical equation of diode

$$I_d = I_s \left(\exp^{\frac{k \times V_d}{T}} 1\right) \qquad (1)$$

where,
I_s is reverse saturation current or leakage current,

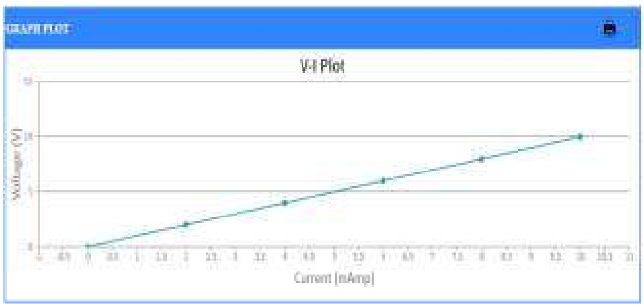

Figure 3: Corresponding graph

I_d is total current through the diode,
V_d is cut-in voltage of the diode

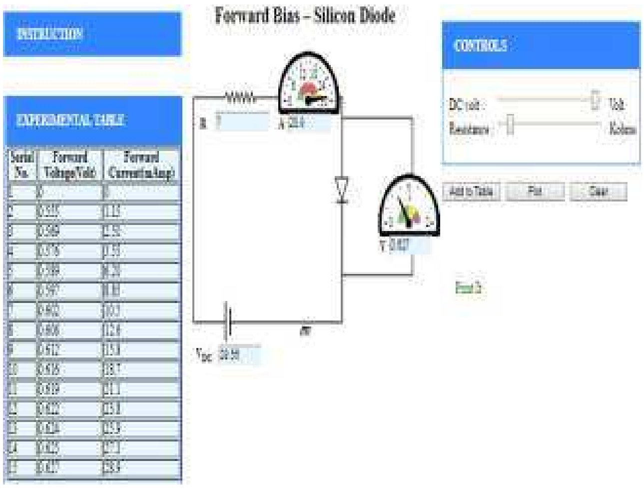

Figure 4: Simulation template of Diode characteristics

From the graph the student can analyze cut-in voltage of Si diode. The corresponding graph for forward bias Si Diode characteristics is shown in Figure 5.

4.3 Half-wave Rectification

This section describes of a rectification of a diode. The half-wave rectifier is a circuit that allows only part of an input signal to pass. The circuit is the combination of a single diode in series with a resistor, where the resistor is acting as a load. On the positive cycle the diode is forward bias and on the negative cycle the diode is reverse bias. By using a diode, conversion of an AC source into pulsating DC source is possible using this virtually laboratory. This helps students in learning the concept of rectification more deeply. Simulation template is shown in Figure 6.

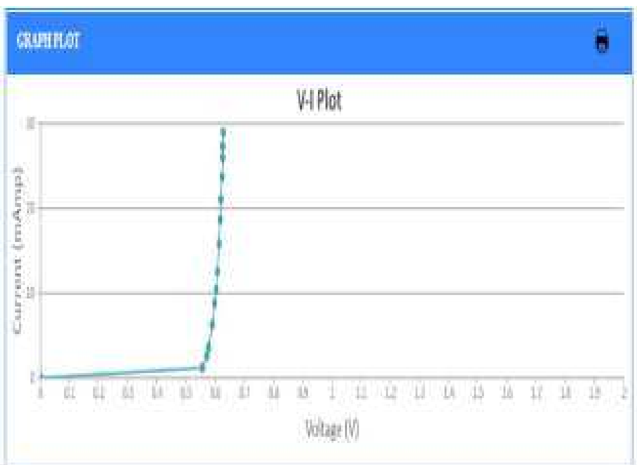

Figure 5: Corresponding graph Forward bias Si Diode characteristics

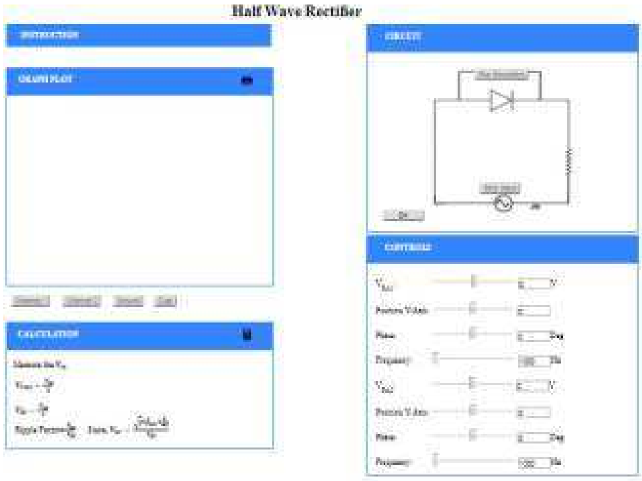

Figure 6: Simulation template of Half Wave Rectifier

In this virtual experiment the student can control the V_{pch1} the peak voltage of input sine wave varies. The number of oscillations that occur each second of time can also be varied by controlling the frequency controller. On the basis of input given by a student the sinusoidal waveform will be generated. The rectified output is generated when the student clicks on \Run Simulation" tab. Likewise, the parameters of output wave can also be varied using the controller. Corresponding rectified output is shown in Figure 7.

The student can also switch between the waveform display by clicking on Channel 1 to observe input waveform, Channel 2 to observe the rectified output, Ground, Dual to study the both input and rectified waveform.

4.4 Zener Diode - Voltage Regulator

A zener diode is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to

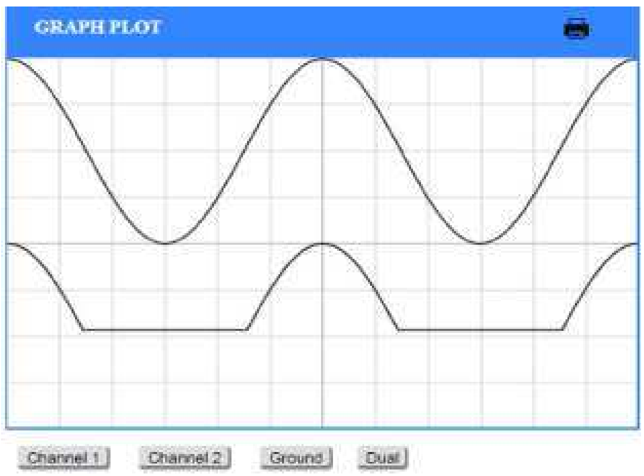

Figure 7: Corresponding Rectified Output

flow in the reverse direction when the voltage is above the breakdown voltage. Zener diodes are designed so that their breakdown voltage is much lower { for example just 2.4V. A voltage regulator is an electronic circuit that provides a stable DC voltage independent of the load current, temperature and AC line voltage variations. A zener diode of break down voltage V_Z is reverse connected to an input voltage source V_I across a load resistance R_L and a series resistor R_S. The voltage across the zener diode will remain steady at its break down voltage V_Z for all the values of zener diode current I_Z as long as the current remains in the break down region. Hence a regulated DC output voltage $V_0 = V_Z$ is obtained across R_L, whenever the input voltage remains within a minimum and maximum voltage. Basically there are two type of regulations such as:

Line Regulation: In this type of regulation, series resistance and load resistance are fixed, only input voltage is changing. Output voltage remains the same as long as the input voltage is maintained above a minimum value.

Load Regulation: In this type of regulation, input voltage is fixed and the load resistance is varying. Output voltage remains same, as long as the load resistance is maintained above a minimum value In Line Regulation, load resistance is constant and input voltage varies. V_I must be sufficiently large to turn the zener diode ON. Simulation template of Line Regulator is shown in Figure 8.

Mathematical Equation for Line Regulator:

$$V_L = V_Z = \frac{V_{Imin} \; R_L}{R_S + R_L} \quad (2)$$

So, the minimum turn-on voltage V_{Imin} is :

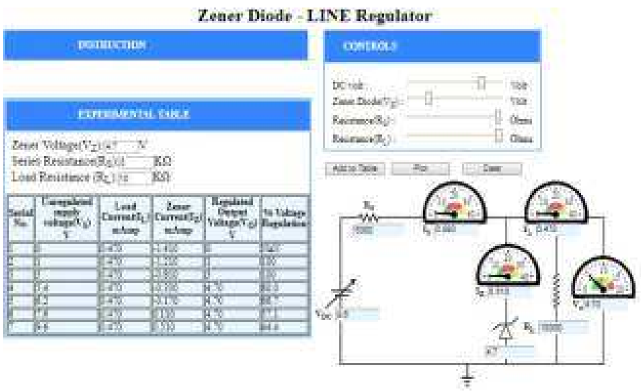

Figure 8: Simulation template of Zener Diode Line Regulator

$$V_{Imin} = \frac{V_Z \; (R_S + R_L)}{R_L} \quad (3)$$

The maximum value of V_I is limited by the maximum zener current I_{Zmax}

$$I_{Rmax} = I_{Zmax} + I_L \quad (4)$$

I_L is fixed at :

$$\frac{V_Z}{R_L} \qquad \text{Since, } V_L = V_Z \quad (5)$$

So maximum V_I is

$$V_{Imax} = V_{Rmax} + V_Z \quad (6)$$

For $V_I < V_Z$,

$$V_O = V_I \quad (7)$$

For $V_I > V_Z$,

$$V_O = V_I - I_S x R_S \quad (8)$$

To check the line regulator circuit, Zener Voltage (V_Z)=4.7V, Series Resistance (R_S)=5KΩ and Load Resistance (R_L)=10KΩ has been specified to the virtual regulator circuit. On varying the unregulated supply voltage (V_S), corresponding graph of Zener Diode Line Regulator is shown in Figure 9. The student can change the zener voltage for another set of experiment and analyze the result further.

In Load Regulation, input voltage is constant and Load resistance varies. Too small a load resistance R_L, will result in $V_{Th} < V_Z$ and zener diode will be OFF. Simulation

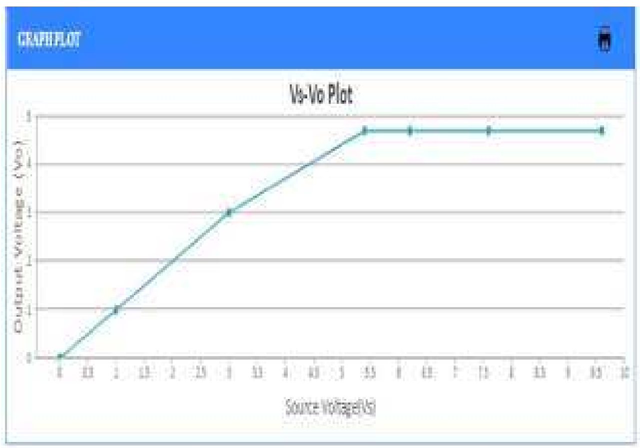

Figure 9: Corresponding graph of Zener Diode Line Regulator

template of Line Regulator is shown in Figure 10. Mathematical Equation for Load Regulator:

$$V_L = V_Z = \frac{V_{Imin} * \; R_L}{R_S + R_L} \quad (9)$$

So the minimum load resistance R_L

$$R_{Lmin} = V_Z * \frac{R_S}{V_I - V_Z} \tag{10}$$

Any load resistance greater than R_{Lmin} will make zener diode ON

$$I_S = I_L + I_Z \tag{11}$$

R_{Lmin} will establish maximum I_L as

$$I_{Lmax} = \frac{V_L}{R_{Lmin}} = \frac{V_Z}{R_{Lmin}} \tag{12}$$

V_R is the voltage drop across R_S

$$V_R = V_{Imin} + V_Z \tag{13}$$

$$I_S = \frac{V_{Imin} \quad V_Z}{R_S} \tag{14}$$

For $R_L < R_{Lmin}$ -

$$V_O = V_I \tag{15}$$

For $R_L > R_{Lmin}$ -

$$V_O = V_I - I_S * R_S \tag{16}$$

To check the load regulator circuit, Zener Voltage (*Vz*)=10V, series resistance (*Rs*)=1KΩ and DC voltage (*Vs*)=50V has been specified to the regulator circuit. On varying the Load Resistance (*RL*), corresponding graph of Zener Diode Load Regulator is shown in Figure 11. The student can change the zener voltage for another set of experiment and analyze the result further. This virtual experiment motivates the student to work independently to analyze the line and load regulation. Using this Virtual lab software, a variety of the experiments related to basic electronics can be conducted, such as those listed below; these are also common curricular experiments.

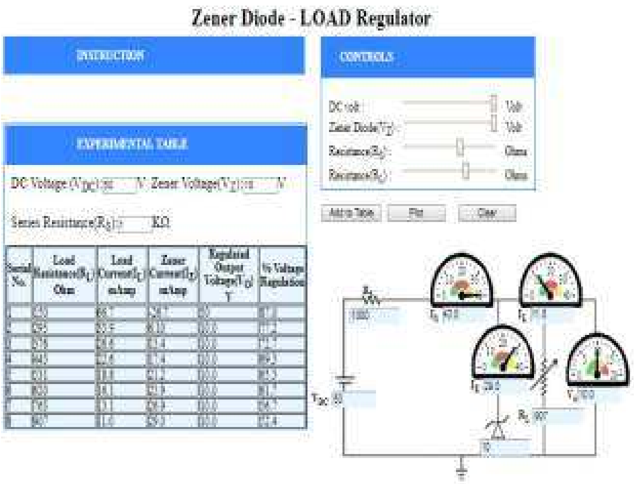

Figure 10: Simulation template of Zener Diode Load Regulator

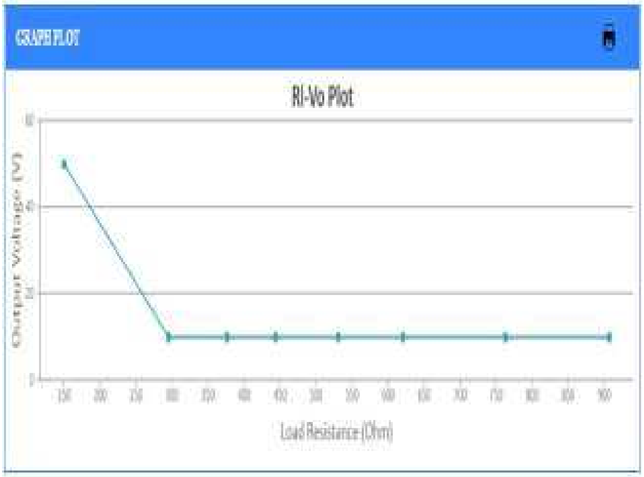

Figure 11: Corresponding graph of Zener Diode Load Regulator

• Familiarisation with Resistors-Here the student would gain an idea about resistors, the student can calculate the value of the resistors using the color code mnemonic method.

• Familiarisation with Capacitors-Here the student would be able to explain how a capacitor can be constructed to give a particular value of capacitance and also can identify the polarity of terminals (when applicable).

• Familiarisation with Inductors-This experiment helps the student to understand the behaviour of the inductor, including its mathematical characterisation.

• Full Wave Rectification-Here the student can understand the flow of unidirectional current through the load during the entire sinusoidal cycle. A full-wave rectifier converts the input waveform to one of fixed polarity at its output while utilising both the positive and negative cycles of the supply voltage.

• Capacitative Regulation-This experiment allows the student to regulate the pulsating output of the rectifier to a steady DC supply. This can be done by filtering the pulsating output signal of the rectifier.

• BJT Common-Emitter Characteristics-This particular experiment explains the Operation of Bipolar Junction Transistor for Common-Emitter characteristics and allows the student to experimentally examine the input characteristics and output characteristics.

• BJT Common-Base Characteristics-This particular experiment explains the operation of Bipolar Junction Transistor for common-base characteristics and allows the student to experimentally examine the input characteristics and output characteristics.

• RC Differentiator and Integrator - This experiments explains charging of RC circuit with a DC source, explains discharging of RC circuit with a DC source, explains use of RC circuit as an integrator, explains RC circuit as a differentiator.

V - ANALYSIS OF USER FEEDBACK

The virtual laboratory on basic electronics has been deployed in many prospective places through several workshops to gather its usability from the feedback of the participants who performed several experiments. This section describes the deployment of basic electronics, user feedback from workshops and evaluation of the students. Total of four workshops are organized targeted for prospective students and faculty members. Workshops were organized in engineering colleges of two different universities of West Bengal. Students with background in electronics and communication engineering participated in the workshops organised in 2017. Workshop were also organized in two engineering colleges outside West Bengal. Students with similar background participated in these workshops also organized in 2017. From the gathered feedback, 129 feedback sets were analyzed, The virtual laboratory on basic electronics gained very positive and encouraging response from both the students and teachers mentioning some benefits such as the web interface for the client side applications being easy to understand, very time and effort saving with respect to bread board based experimentation and being available 24 hours over Internet without any setup overhead. In the feedback questions, upon asking usefulness of this virtual laboratory. Figure 12 shows the details of feedback received.

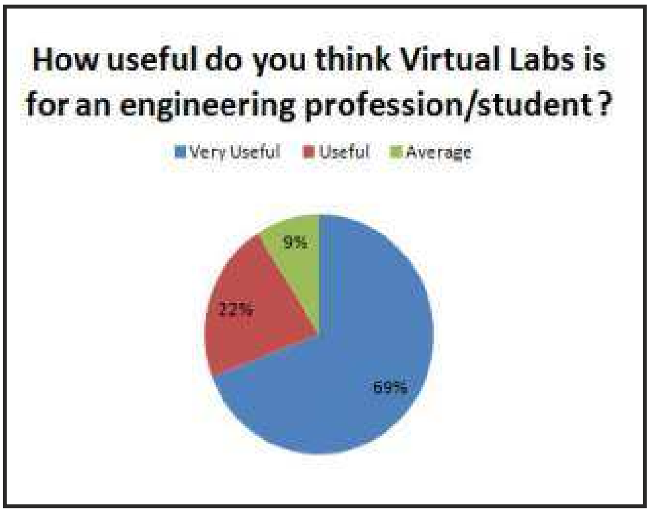

Figure 12: User Feedback

On asking the quality of GUI of the BE virtual laboratory, the students have rated the GUI in the scale of excellent, very good, good, better. 16% said excellent, 19% said very good, 59% said good and 6% said better. Figure 13 shows the feedback of the question.

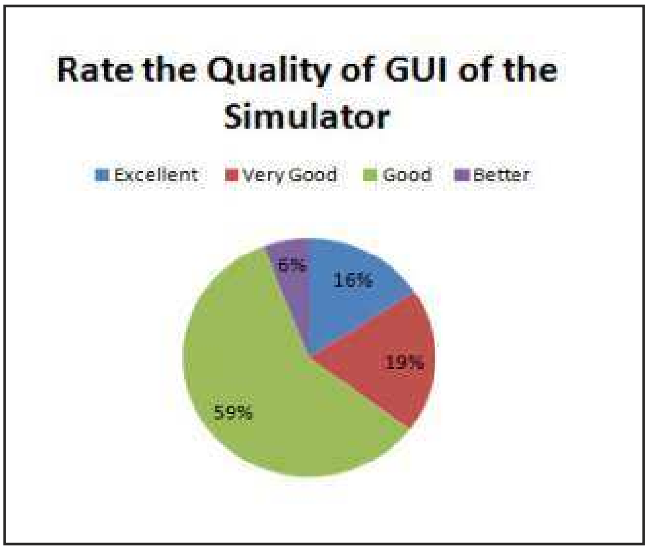

Figure 13: User Feedback-Quality of GUI

On asking about the clear understanding of the experiment after performing the experiment, 85% said yes. The detail pie chart for the feedback question is shown in Figure 14.

77 % user found the procedure and manual associated with each experiment to be helpful. Figure 15 shows the corresponding plot for feedback question.

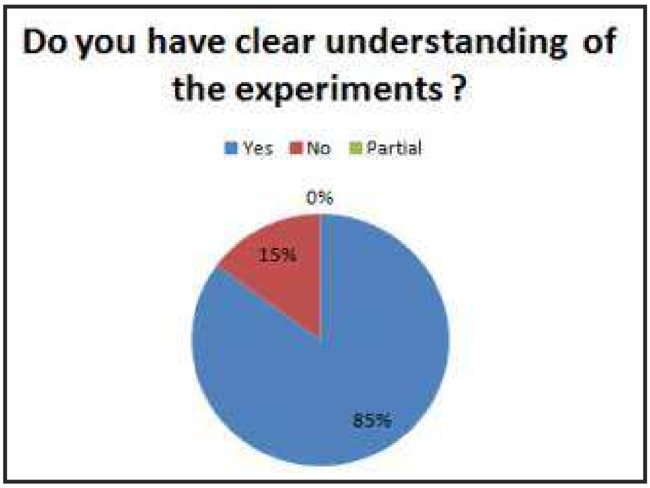

Figure 14: User Feedback- On Clear Understanding

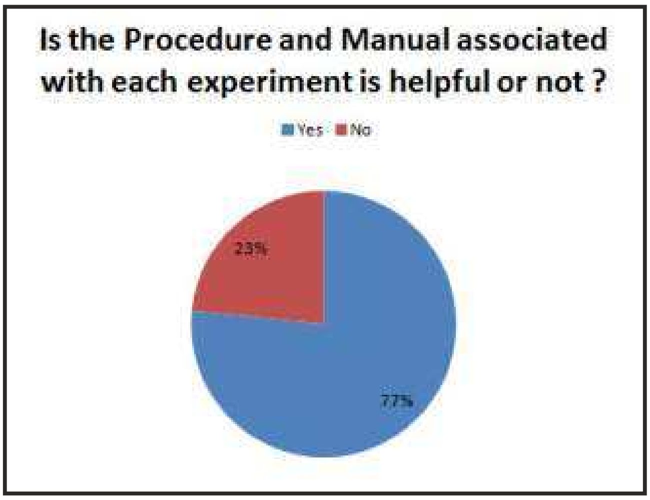

Figure 15: User Feedback-Procedure and Manual to be helpful

VI - CONCLUSION

For distance learners, the virtual lab has been presented as an innovative solution to developing and enhancing laboratory practice and access. A student can establish some idea about the experiments before performing the real experiments in hardware. The web-based laboratory will augment student knowledge about the theory and this methodology can be used for engineer training. It is also useful for the students who can't afford practical laboratory setups. It's a great educational tool that enables teachers to explain circuit ideas and experiments to the students by illustrating the operation of the circuits through the virtual laboratory. The main motive for this study was to show the possibilities of building an active learning environment by the use of FOSS and to evaluate its effectiveness upon students' understanding of electric circuits. Feedback received from the students through workshops appear to support the hypothesis.

Acknowledgment

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