Remote Experimentation of "No-load Tests on a Transformer" in Electrical Engineering

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Abstract— **Currently, rapid developments are taking place to increase the efficiency and outreach of engineering education. Remote-laboratories for remote experimentation is a highly significant and effective development in this area. However, Electrical Engineering experiments are generally difficult to automate due to the risks of high voltages/currents associated with them. In addition digitally controllable electrical machines are expensive and not widely found in many smaller universities. In this paper, remote experimentation of the important experiment "No load tests on a transformer" using PSoC and Labview is presented. More experiments in allied fields can be automated by drawing on this work. In addition it would also serve as an impetus to stronger efforts in this field enabling increased access to high-end laboratories even among the universities with lesser financial capabilities.**

Keywords— ***remote labs, remote experiments, Virtual instrumentation, Electrical Engineering education, distance learning***

I. INTRODUCTION

Experimentation plays an important role in any scientific or technical endeavour and at times requires state-of-the-art equipment and laboratories. However, in several cases, such experimental facilities require large investments in terms of initial cost, training and maintenance. Many institutions with limited resources at their disposal might shy away from installing such facilities. On the other hand, while at places where such a setup is indeed available, the utilization might remain mostly sub-optimal. In such a case, sharing the resource among different campuses or different institutions could be a very effective , 'sought-for' strategy to optimize the resources while providing excellent facilities to wide population of students.

Such a sharing is made possible by the use of various internet-enabled technologies like virtual instrumentation and associated electronics and instrumentation. The remote laboratories architecture allows users to run experiments in a laboratory located in a different geographic location right from their browsers. It is a potent vehicle that would help share the infrastructure while cutting costs and increasing the reach of the infrastructure.

It is unlike simulation, where the reality perspective is missing most of the time and a computational engine models the actual behavior, subject to many assumptions. In the remote-controllable experimental setups, experiments are conducted physically on actual devices and with the help of a simple browser, the results are logged and /or relayed to the user either in real-time or in an event-triggered manner. This concept is indeed a bridge between simulation and real time laboratory experiment run, incorporating the benefits of each. Such a setup would effectively help sharing and scheduling resources, thereby reducing the costs.

In view of this, rapid developments to increase the efficiency and outreach of engineering education are taking place on remote-laboratories for remote experimentation. However, electrical engineering experiments are generally difficult to automate due to the risks of high voltages/currents associated with them. In addition digitally controllable electrical machine used by M.P. Kazmierkowski, M. Liserre, are expensive and not widely found in many smaller universities[1]. In this paper remote experimentation of the experiment, "No load tests on a transformer" in Electrical Engineering is presented. More experiments in allied fields can be automated by drawing on the concepts laid down in this work. In addition, it would also serve as an impetus to stronger efforts in this field enabling increased access to high-end laboratories even among the universities with lesser financial capabilities.

II. DESCRIPTION OF THE EXPERIMENT

This experiment is a part of the Electro-mechanical Energy Conversion Laboratory at BITS Pilani, India undertaken by all Electrical & Electronics Engineering/Instrumentation undergraduate students and for all students doing . The objective is to find out the electrical parameters of a conventional single-phase transformer (230V/115V 1KVA). This is achieved by performing the standard no load tests on the device.

The steps followed in the run are listed below.

1. First, the transformer is excited at different voltages on one of its ports (V_{in}) and the corresponding voltages on the other side (V_{out}) are noted. These values are noted to obtain the turns ratio of the transformer using equation (1).

$$Turns\ Ratio, N = \frac{V_{out}}{V_{in}}\ ,\ V_{out} > V_{in} \quad (1)$$

2. The next step is to determine the shunt and series parameters respectively using the no load tests (open circuit and short circuit tests respectively). In the open circuit test, the low voltage (LV) side of the transformer is excited at the rated voltage, and the high voltage (HV) side is left open (Fig1). The equivalent circuit is shown in Fig.2.

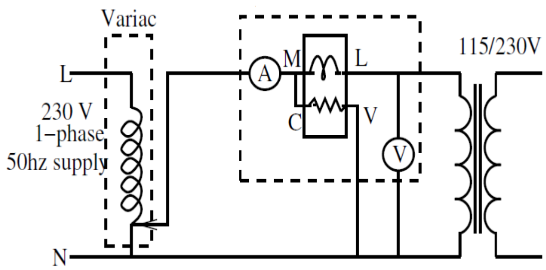

Fig. 1 Schematic of the Open-circuit Test

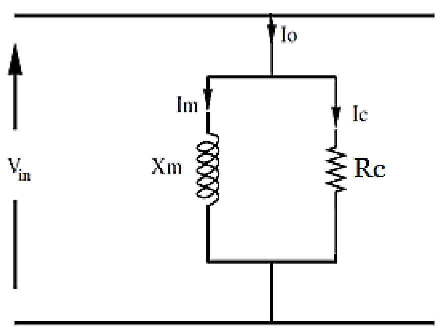

Fig. 2 Equivalent diagram of the transformer under the open-circuit test

3. Now using the following expressions, the shunt parameters can be computed.

Active power read by Wattmeter, $W = V_{in} \times I_c$ (2.1)

$$\therefore I_c = W/V_{in} \quad (2.2)$$

Ammeter reads Io

$$\therefore I_m = \sqrt{I_o^2 - I_c^2} \quad (2.3)$$

$$\therefore R_c = \frac{V_{in}}{I_c} \quad (2.4)$$

$$\therefore X_m = \frac{V_{in}}{I_m} \quad (2.5)$$

4. In the short circuit test, the HV is excited at the rated current while the LV side is shorted. The transformer in this state is shown in Fig 3. Its equivalent circuit is shown in Fig 4.

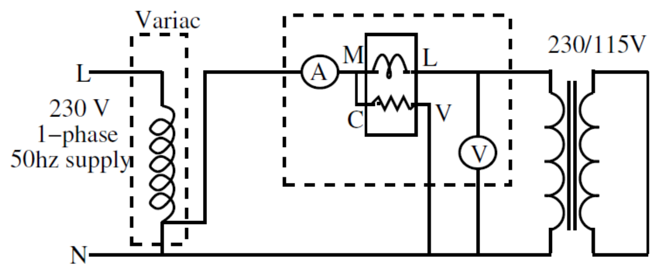

Fig. 3 Schematic of the Short-circuit Test

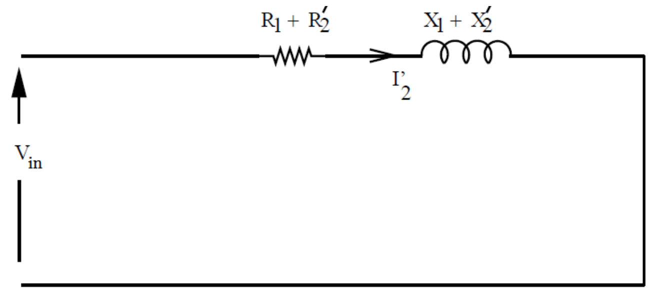

Fig. 4 Equivalent diagram of the transformer under the short-circuit test

5. Using the equations in (3), the series parameters can be computed.

$$R_1 + R'_2 = R \quad (3.1)$$

$$X_1 + X'_2 = X \quad (3.2)$$

$$\text{Wattmeter reading}, W = I'^2_2 R \quad (3.3)$$

$$\therefore R = W/I'^2_2 \quad (3.4)$$

$$\therefore Z = V_{in}/I'_2 \quad (3.5)$$

$$X = \sqrt{Z^2 - R^2} \quad (3.6)$$

In accordance with the above procedures, the experimental infrastructure in the setup enables execution of the following steps :

a. The user is presented an interface to vary the input parameters of the above system.

b. The hardware present in the laboratory uses these inputs, sets the system to the specified state.

c. The software (LabVIEW®) acts as the middle manager in transmitting the inputs to the hardware and results to the user's browser.

The following section describes the hardware setup and the interface presented to the user.

III. EXPERIMENTAL SETUP, INTERFACE AND THE SOFTWARE

In this section, first, the hardware and interface aspects are discussed jointly, because for each controllable hardware element, there is an interface control present. Therefore, it would provide better insight into the functioning of the experiment by looking at them jointly. Next, the software that transfers user inputs to the hardware and the executed results in the other direction is discussed.

A. Hardware Setup and Interface

Fig. 5 depicts a schematic of the hardware equipment of the experiment and the interface presented to the user.

A 1kVA, 115/230V transformer is connected to voltmeters on either side. It is also connected to a measurement setup, consisting of a wattmeter and an ammeter. The measurement setup can be connected to either the LV side or the HV side. This flexibility is needed because, each of the No load tests demands measurement across either side. This connection is realized using switched relays.

The relays act as connected wires when the control pin is set high and act as disconnected otherwise. In this regard, regulating these relays is equivalent to manually connecting or removing wires in a manual execution of the experiment. Therefore, for measurement across a particular side, the switched relays for that particular side are set high and those on the other side are set low. In the interface, (LV_1, LV_2) and (HV_1, HV_2) represent the relays that are mentioned above.

A variac (autotransformer) draws power from the main 230V single-phase power supply and is used to change the voltage input to the transformer. It consists of a disk-head that can be rotated to vary the output voltage. A small 12V DC motor is attached to this disk head for rotating it. There are controls present in the interface to enable the motor to rotate either Left or Right. The connection between the variac and the measurement devices is regulated by a switched relay (labeled Var_Meter). Another relay (LV_Short) is used to short the LV side during the short circuit test.

In addition, there is a start/stop button to activate/deactivate the session. There is a “Run” button to transfer the settings selected on screen to the hardware.

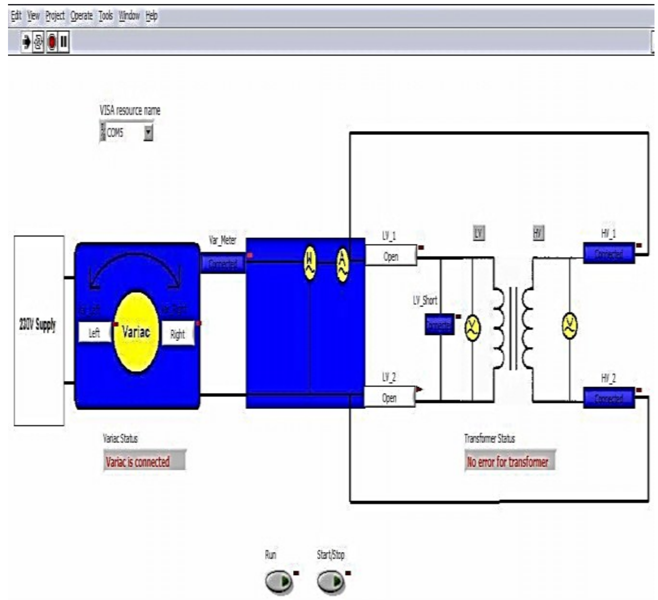

Fig 5. The schematic of the No load tests on a transformer experiment

The control signals of all the relays and the 12V DC motor are issued from a Programmable System on Chip (PSoC) based embedded system. As the 12V DC motor operates at a higher voltage than the rest of the system, a motor driver IC, L293D is used. Fig 6 shows the pin diagram and connection of this IC. It is a dual H-Bridge circuit to enable the motor rotate clockwise (A = 1, B = 0) /anti-clockwise (A = 0, B = 1) or brake it (A = B = 0). The PSoC issues the direction and power control signals to this driver IC and the IC drives the motor at the rated 12V supply based on these inputs.

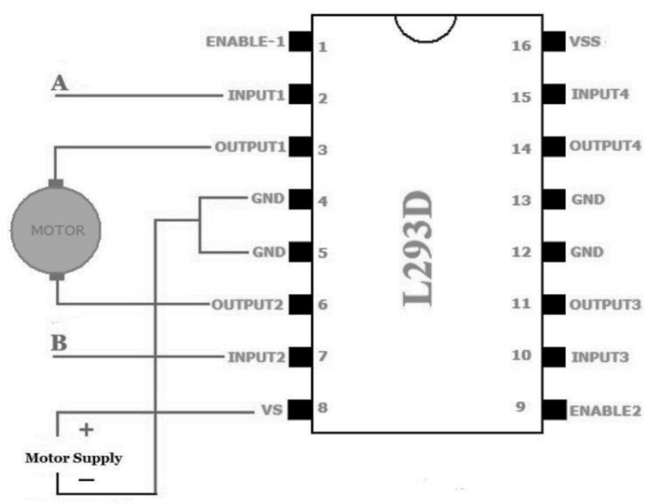

Fig. 6 The L293D dual motor driver IC

B. Software

All the interaction experienced by the user on his/her browser screen is reflected, via Ethernet, in a lab server that hosts the central software. This communication via Ethernet is achieved by NI Datasocket connection[3]. Whenever a user makes a change (click a button, say) in the browser, the same action happens in the lab server. This server is attached to the PSoC based system using RS-232 protocol.

When the user specifies the intended connections and presses the Run button, the software takes these settings and processes them. It checks for any fatal connections that might occur if the specified settings were replicated on the hardware [a typical case could be the LV side being connected to the variac and is shorted (by connecting the LV_Short wire)]. This is required as the voltages (115-230V) and currents (5-10A) here are quite high and could be fatal.

At this stage, the hardware is not yet activated by the software. Thus, any fatal case is caught by the software. The fatal causes constitute a Boolean diagram as shown in the LabVIEW® code segment in Fig. 7. Only when none of the hazard conditions or improper conditions is found, the software starts to activate the hardware. An error message is displayed if the circuit fails this check. Fig. 8 and Fig. 9 show two cases where there are circuit errors. Fig. 10 shows a correct configuration. This is equivalent to a laboratory supervisor inspecting the connections made on a physical device before the power is turned on, in a normal run.

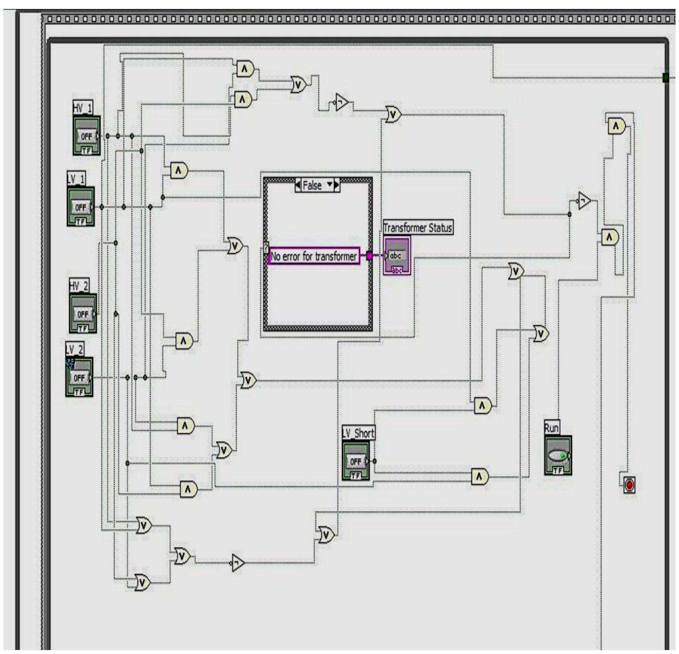

Fig 7. The internal circuit verifier segment that checks for unwanted power hazards in the circuit.

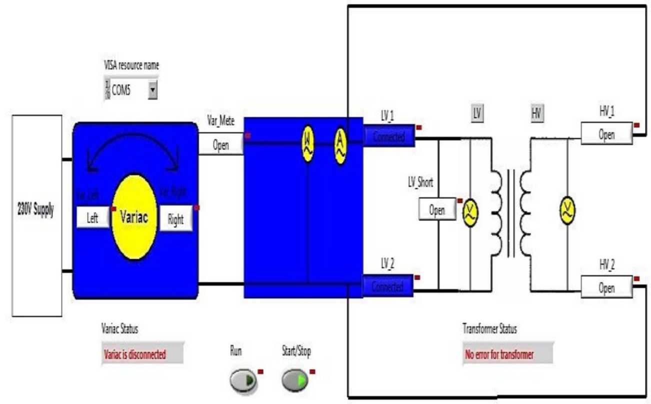

Fig. 8 Error case where the “Variac is disconnected” and the experiment does not run.

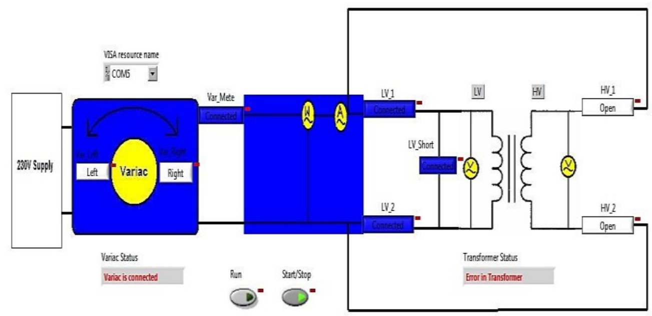

Fig. 9 Error case where the Transformer LV side is shorted and the experiment does not run.

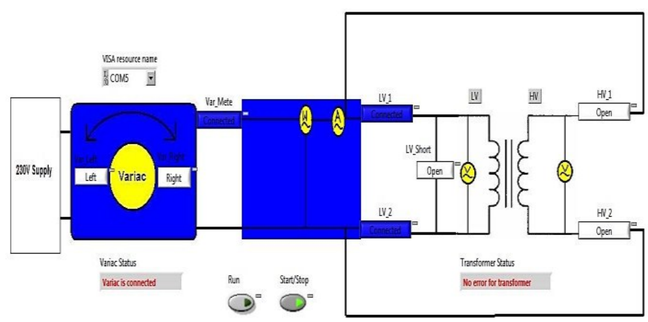

Fig. 10 No error in the circuit.

In the activation phase, the software encodes the status of each relay into 1 bit each. So, we get an 8 bit number for the 8 relays in the circuit (Left, Right, Var_Meter, LV_1, LV_2, HV_1, HV_2, LV_Short). Initially the bits for Left and Right relays are set to 0. This 8-bit number is sent to the PSoC based system using RS-232 protocol. On receiving this, the PSoC system acknowledges this information and sets these physical relays. Now, the setup is powered on. It should be noted that from now on, except for the left and right relays, the status of other relays is not allowed to change since changing relay settings after the power is on would mean swapping wires on the transformer which is not permissible and is dangerous. If the user intends to change the connections, the current run must be stopped and the new settings must be selected again.

After this initialization is complete, the software is ready to accept the user's inputs for the varying the input voltage to the transformer. As the user rotates the motor, the voltage is correspondingly changed, and is displayed to the user. There is a set limit on the voltage that the user is allowed to change. This is required, because in the short circuit test, the voltage is not expected to go beyond the rated LV side voltage. There are safety fuses installed throughout the circuit to limit the maximum current allowed through the setup.

While the user is running the experiment, the entire process is displayed onto a window on the browser screen. This enables the user to take readings of the different measurement devices in the setup. The experiment can be ended by clicking the Stop button which reset the system taking it to the default state and again wait tills the next session is started.

IV. OPERATION OF THE EXPERIMENT

In the implementation of this experiment, the GUI (developed using NI LabVIEW®) shown in Fig. 5 is presented to the user. To interact with this setup on a browser, user only needs to download the plugins available free on the internet [4] [5]. The user can then connect the different components of the circuit using the controls presented. After all the connections are made on this window, the internal connection verifier checks for possible fatal terminal shorts in the circuit.

Once the user is connected to the lab server specific to an experiment, the GUI is activated on the user's web browser with all the controls for the experiment. At this point of time, the GUI that the user sees in his/her web browser is actually a LabVIEW® program hosted on the Lab server. The GUI on the user's window and the lab server communicate using the NI Datasocket connection. The user can then interact with the experiment as user would do in real time and these interactions are implemented in reality on to the experiment apparatus. The experiment is streamed online to the user's browser window.

V. DISCUSSION

The experiment described in the earlier section was implemented at the Electromechanical Energy Conversion Laboratory at BITS Pilani and was demonstrated to faculty and students. The following are the salient features of the implementation.

The chief advantage of this implementation is three fold – safety, scalability, economic efficiency.

The two-stage deployment of the run enables to check for the validity of the connections without implementing them. In this way, power hazards, illegal settings do not happen in the laboratory. This could be compared to an instructor approving the student's connections before powering on the Transformer. As a double check, there are fuses that are set to break the circuit and report the status to the user.

The methodology can be used in the implementation of remote experiments of electrical engineering, such as tests on Synchronous, DC and Induction machines. Just as different blocks are connected here by the use of relays, the same model can be used on these machines. Only the user interface and the type of hazard conditions would change. However, the methodology can be reused without investing in the framework development. No additional resources beyond extra relays are required. This is chiefly due to developing the implementation on the software front while minimizing the use of hardware. This allows flexibility and programmability in providing quick and efficient solutions to a range of experiments.

In addition, the setup is also scalable across the conventional electrical machines and the new digitally controllable machines. In the case of digitally controllable machines, the PSoC is used to communicate the specific settings to the machine via a USB/RS 232 protocol as supported by the machine vendor. This was another motive in choosing a Programmable System on Chip than a custom microcontroller based embedded system. In the former case, both types can be switched to without much burden on the programmers, irrespective of the type of machine.

The setup presented here has the advantage on the economics front too. The user need not install any expensive software in his machine. The PSoC system and the relays are less expensive alternatives over purchasing a digitally controllable machine. A single PSoC system can be time shared across multiple users for different experiments. Multiple experiments can also be done by latching the values, but this approach has not been tested yet.

The experiment is so designed to resemble a conventional, manually supervised run of the experiment closely. This makes it intuitive for early adopters and facilitates switching to this framework from the conventional setups, without much time and financial investment in training the students.

VI. RESULTS AND SCOPE OF FUTURE WORK

After the deployment of the setup, feedback was taken from faculty and students. An important feedback obtained was to modify the GUI presented to the user, making it more realistic to the actual transformer. This would also enhance the experience of the user in the remote environment and thereby give him/her a better learning insight. While the current interface closely reveals details of the underlying hardware, more focus can be put on making the interface more realistic and enhance the overall experience of the user.

As our studies have revealed that this model can be easily scaled to include other electrical experiments, better techniques to implement them and bring electrical engineering experiments on a single platform are be developed. Efforts would also go into improving the process of an economically viable and truly scalable solution instead of buying costly digitally controllable electric machines or upgrading the available machines.

VII. CONCLUSIONS

A scalable, cost-effective approach to remote experimentation of the experiment, “No load tests on a transformer” in Electrical Engineering is discussed in detail revealing the hardware, software and interface details of the setup. Using the models presented in this paper, more electrical experiments can be automated.

VIII. ACKNOWLEDGMENTS

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