Non-Isolated Linear/ Switching Regulated DC/DC Converter for Remote Experimentation

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***Abstract*—This paper reports on the development of two advanced remote electronic circuits experiments: 1) non-isolated linear regulated DC/DC Converter; and 2) non-isolated switching regulated DC/DC converter. These experiments are oriented to labor markets and industrial needs; they allow students to study the behavior of electronics components and commercial Integrated Circuits (ICs) using manufacturers' datasheets and comparing them with measured values. They also allow calculating heat dissipation in electronic components either in transient or in steady state, as well as, studying the effect of either room temperature or applied heat sinks in heat dissipation. The experiments are built on top of the state-of-the-art platform for wiring and measuring electronic circuits online, Virtual Instrument Systems in Reality (VISIR). In this paper, the development of the two experiments is explained along with the necessary configuration to the core-platform VISIR. This is preceded by a brief overview on VISIR including its hardware and software components. Finally, remote retrieved results are presented.**

Keywords-component; DC/DC converter; industrial electronics; remote laboratory; VISIR

I. Introduction

The recent era of remote laboratories [1-3] development for analog electronics saw more efforts directed to undergraduate curricula and dealt with issues such as parameter measurements, I/O characteristics, and basic circuit theory acquaintance. To a significant extent, many of this kind of solutions have been successfully achieved. For instance, in [4], a remote laboratory was developed for studying the DC characteristics of different types of diodes (light-emitting, silicon, and germanium). In [5], a remote lab was developed for studying I/O characteristics of T-notch filter, PNP and NPN transistors, A and B class amplifiers, RC filters, and operational amplifiers (an adder and a subtractor circuits). In [6] a remote laboratory was developed for studying I/O characteristics of a BJT common emitter amplifier circuit. In [7] a remote laboratory was developed for studying the I/O characteristics of non-inverting operational amplifier, integrators and differentiators, and half and full wave rectifiers. None of the existing solutions, however, goes beyond the undergraduate curricula or contemplates industrial related-issues. Yet, little attention has been paid to advanced electronics circuits and components, and remote laboratories tailored for understanding their behavior haven't been reported. The reason is twofold: (1) the infrequent interaction between academia and industry, as well as the lack of industrial experience in the profile of the predominant academic teachers; and (2) the complexity of implementing this kind of experiments in a remote environment, as they require a high level of manipulation and precision.

In response to these needs, in this paper, a first-of-its-kind remote electronics experiments were developed. The experiments are: 1) non-isolated linear regulated DC/DC Converter; and 2) non-isolated switching regulated DC/DC converter. The experiments are oriented to labor markets and industrial needs and they enable: studying the behavior of electronics components and commercial Integrated Circuits (ICs); using manufacturers' datasheets and comparing them with measured values; and calculating heat dissipation in electronic components either in transient or in steady state, as well as studying the effect of room temperature and of applied heat sinks in heat dissipation. The experiments were realized, also, taking into consideration issues such as safety and protection of components, configuration for high precision measurement with minimum possible distortion, and full switching and automation mechanism.

The remote laboratory project—Virtual Instrument Systems in Reality (VISIR) [8, 9]—was selected as a core platform for the new designed circuits. VISIR is a combination of open source software packages and commercial equipment from National Instruments (NI) for creating, wiring, and measuring electronics circuits online. The project was initially started at the Blekinge Institute of Technology (BTH) and supported by several partners within the project consortium [10]. So far, three universities have built basic remote electronics circuits experiments using VISIR and deployed them in undergraduate engineering practices with satisfactory results [11, 12]. It was possible to build basic electronics experiments including basic resistive circuits, voltage divisors, operational amplifiers, half-wave rectifiers, zener regulated circuits, and BJT amplifiers. In this contribution, we extend the application range of VISIR by adding advanced electronic circuits experiments for DC/DC converters. For this purpose, actual VISIR hardware and software were configured to adopt new types of components such as inductors, thermistors, and bridge rectifiers (i.e., as an IC). External circuits were attached to its relay switching matrix in order to expand the application range.

The rest of the paper is structured as follows: Section II provides a brief overview on the core platform, VISIR, defining each of its hardware and software components. Section III describes the design and development of the DC/DC converter experiments. Section IV summarizes the necessary configurations and modifications realized on VISIR to introduce the new experiments. Section V provides online results obtained from the mounted experiment circuits remotely. Finally a conclusion is drawn in Section VI.

II. Overview on VISIR

This section provides a brief overview on VISIR, which is important for the subsequent discussions.

1. *Hardware Description*

The instrumentation platform of VISIR is based on PCI eXtensions for Instrumentation (PXI) from NI. The NI PXI platform consists of a controller card (i.e., an embedded PC), instrument module cards (DC power supply, digital multi-meter, oscilloscope, and function generator), and a chassis into which all the cards are plugged. The terminals of the NI PXI-modules are connected to a relay switching matrix. The matrix communicates with the controller through a USB cable.

The relay switching matrix is a stack of “PCI/104” sized boards. It creates circuits by manipulating—by opening and closing relays with regard to the received circuit design from the controller—the connection of the NI PXI-modules’ terminals and the components’ leads on a common 10 nodes (A-I, 0) propagating through all the boards of the matrix. The matrix contains three instrument boards and up to 16 component boards. Each component board comprises 10 sockets and each socket is connected to a Double-Pole Single-Throw (DPST) relay—four of these sockets can be connected instead to 2 Single-Pole Single-Throw (SPST) relays each. Thus, a matrix can contain up to 16×10 DPST relays. Two leads components occupy one socket, while more leads components occupy more sockets. According to the data sheet, the maximum carry current of the relays is 2 A and the minimum life expectancy is 3×10^{8} operations (approximately two operations per second continuously for five years). The matrix contains a main Peripheral Interface Controller (PIC18F4550), in addition to a separate controller (PIC16F767) for each board, which sends commands to the relays of that board to open or close accordingly.

2. *Software Description and Operation cycle*

VISIR software is an open-source that is released under a GNU General Public License (GPL). The source could be downloaded from [13]. The software package encompasses:

- *Learning Management System (LMS):* It is the portal of VISIR which handles all the administration, access, authentication, and reservation processes. It is written in the scripting language PHP and hosted in an Apache HTTP Web server with a MySQL database. It provides users with access to the “Experiment Client” once they are authenticated.
- *Experiment Client:* It is the Graphical User Interface (GUI) and the simulated workbench of VISIR as shown in Figure 1. It is an applet written in Action Script for Adobe Flash and hosted in the Web server as well. User drags the selected components to the virtual breadboard, wires his/her circuit, and configures the instruments with his/her PC-mouse, and afterwards presses the “perform experiment” button to retrieve the results from the physical equipment. The designed circuit created by the user is transferred first to the “Measurement Server” in form of an XML-based protocol, called “Experiment Protocol”, which uses either XML Socket or TCP over the TCP/IP model to transport the requested data.

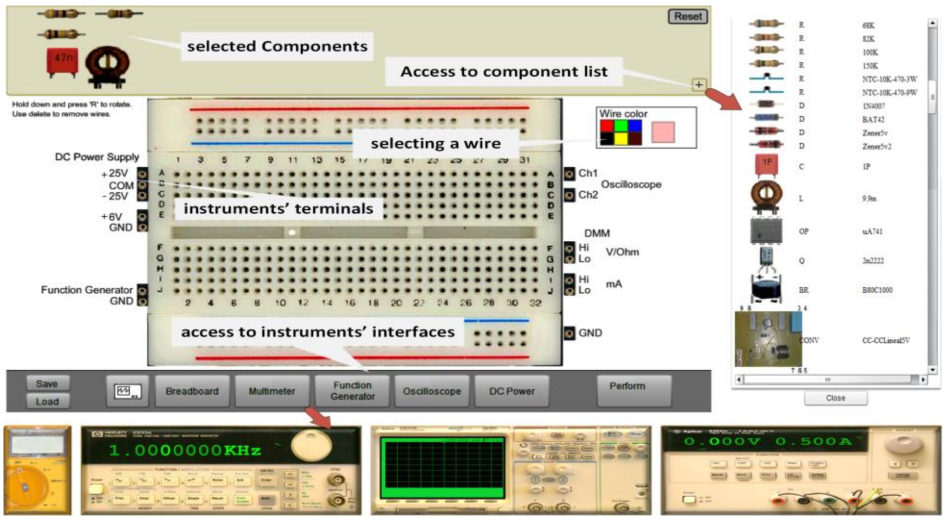

Figure. 1. Simulated work bench of VISIR.

- *Measurement Server:* It is a software application written in Microsoft Visual C++ and runs on a separate PC (i.e., as a server). It is responsible for the periodical authentication versus database during sessions for more security, queuing simultaneous requests, and verifying designed circuits created by users versus maximum allowed parameter values listed in the "max lists" (i.e., these lists are configured by the teacher depending on the specification of the available components) in order to avoid hazardous circuits. After validating and queuing the requests, it starts to send them sequentially to the "Equipment Server".
- *Equipment Server:* It is a software application for instrumentation control developed by LabVIEW and hosted in the NI PXI controller (i.e., an embedded server module inserted in the PXI chassis). It receives users' verified circuit designs from the "Measurement Server" in "Experiment Protocol" format and executes them through the physical equipment. Eventually, the results return back to the users on their PC-screen (i.e., in the instrument interfaces) with the same sequence. All the instrument drivers are Interchangeable Virtual Instruments (IVI) compliant in order to support other platforms such as LAN eXtensions for Instrumentation (LXI) or General Purpose Interface Bus (GPIB or IEEE-488.2). The "component list" is inserted to the "Equipment Server" so that it can identify all the mounted components and connected instruments.

The main components of VISIR and the overall operation cycle are demonstrated in Figure 2.

III. Design and Development of the New DC/DC Converter Experiments

From each experiment circuit numerous exercises are derived such as: comparing between simulations or theoretical calculations and measurement; and comparing between datasheets and component's behavior. The new designed circuits are:

1. *Non-Isolated Linear Regulated DC/DC Converter*

The circuit is shown in Figure 3(a). The purpose of the circuit is to study the effect of load variation on the input and output signals, the effect of input signals' variation on the output signals, and the thermal effect of the regulator IC due to power dissipation. The circuit controls the amount of current flowing through the load—so as to maintain a constant output voltage—by comparing the supply's DC output with a fixed internal reference voltage. A LM7805 linear regulator IC is used. A LC filter circuit is inserted to reduce voltage spikes and eliminate the emission of Radio Frequency Interference (RFI) by the power supply. The effect of the filter on the internal current is monitored across R_{sh2} by connecting the oscilloscope to terminal 3. The input and the output of the IC are protected against reverse polarity and excessive voltage by a 1.5KE unidirectional Transient Voltage-Suppression (TVS) diode. Capacitors are attached to the input and the output, as well, to eliminate spikes and maintain a constant output voltage with load variations. High resistance resistors are added for discharging capacitors without affecting circuit's operation. The current maximum value is adjusted by the power supply and extra-protection is provided by adding fuses to the input and output terminals of the entire circuit.

The major disadvantage of linear regulators is that the extra energy is dissipated as heat which increases temperature and reduces efficiency (P_{out}/P_{in}) to lower than 50% typically. Two regulator ICs are used, one with a heat sink (LM7805-A) and the other without (LM7805-B). In order to measure the temperature of the regulator IC in each case and see the effect of the heat sink in heat dissipation, a B57861S0103F045 Negative Temperature Coefficient (NTC) thermistor is used for each and a third one (NTC 3) is used to measure room temperature. Two 30.22 electrical relays of nominal voltage 5V are used to switch connection between the two regulator ICs and their coils are excited by the same DC power source of VISIR (at open circuit they connects LM7805-A). The relays are protected by a 1.5KE unidirectional TVS of 6.8V. The datasheet of the thermistors is used to calculate the temperature and a reasonable time should be considered

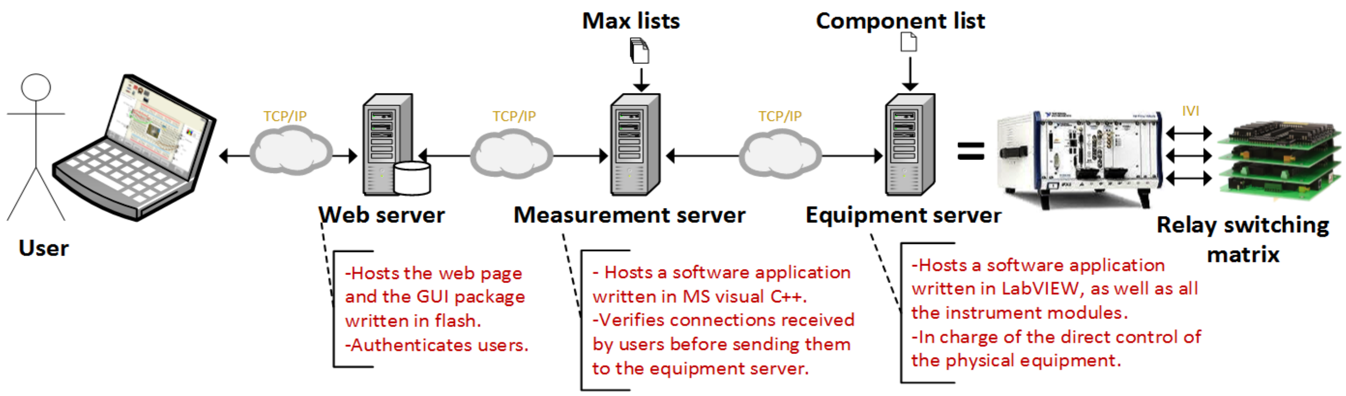

Figure. 2. VISIR components and overall operation cycle.

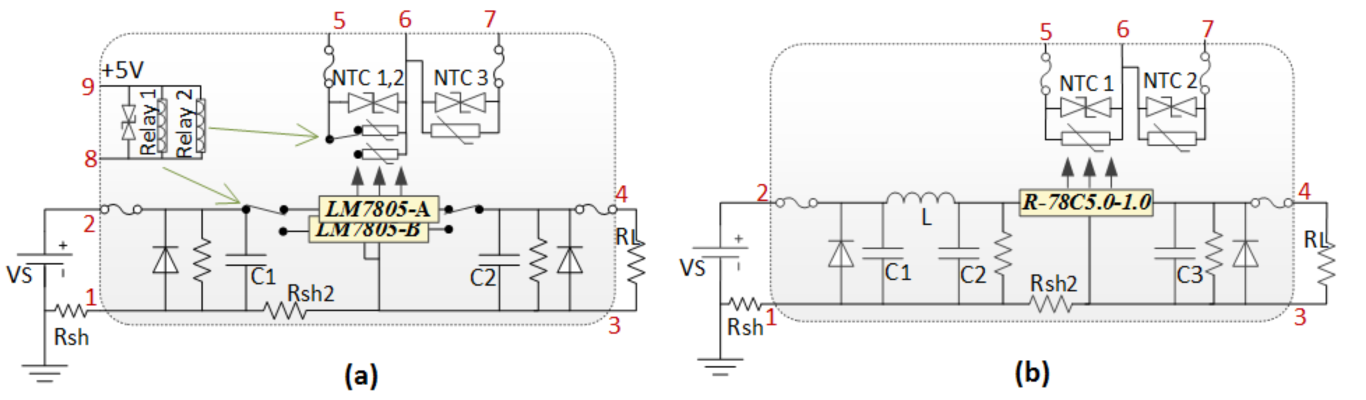

Figure. 3. New designed DC/DC converter circuits for remote experimentation.

(about 5 to 10 minutes) between each measurement. Users by error could apply voltage across thermistors connecting it to the power supply, which may destroy the thermistors. Therefore, each thermistor is protected by a 1.5KE bidirectional TVS of 15V and with a negligible surge current (1mA approximately) so that it doesn't affect the measurements. Thus, the maximum allowed power dissipation across each thermistor is 60mW considering a worst case where temperature reaches 45° (regarding to the datasheet the resistance of the thermistor at this temperature is 4.369KΩ) owing to a previous utilization of the component. Additionally, a fuse was added to protect the TVS by controlling current passing to it.

2. *Non-Isolated Switching Regulated DC/DC Converter*

The circuit is shown in Figure 3(b). It has the same purpose of the previous circuit but with an R-78C5.0-1.0 switching regulator instead. The regulator is step-down configured (buck converter) and thus its output voltage is smaller than its input voltage. Switching regulators are much more efficient than their linear counterpart; their power efficiency can exceed 85%.

IV. Installation and Configuration

In order to introduce new circuits into VISIR the following configurations were realized:

3. *Hardware Configuration*

For simplicity and space consideration, the shaded area of the converters' circuits shown in Figure 3(a) and Figure 3(b) were mounted in an external circuit then connected to the matrix as a black box with input and output terminals as shown in Figure 4(a) and Figure 4(b), respectively. Each terminal of the external circuits is connected to a SPST relay. Thus, users will only be concerned with the specific characteristics of the circuit rather than getting bogged down with its connections. Finally, necessary protection scheme for each circuit or component was realized as described in the previous section. The overall connection of the designed circuits in the matrix is shown in Figure 5.

4. *Software Configuration*

As mentioned previously, VISIR software [13] is an open source, which allows developers to download it and modify it

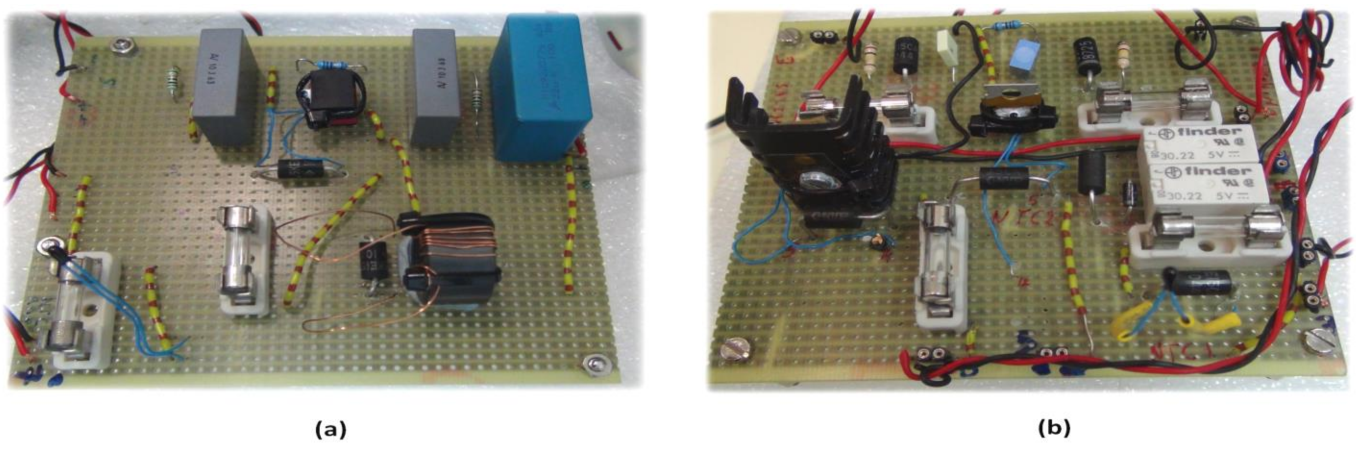

Figure. 4. External DC/DC converter boards.

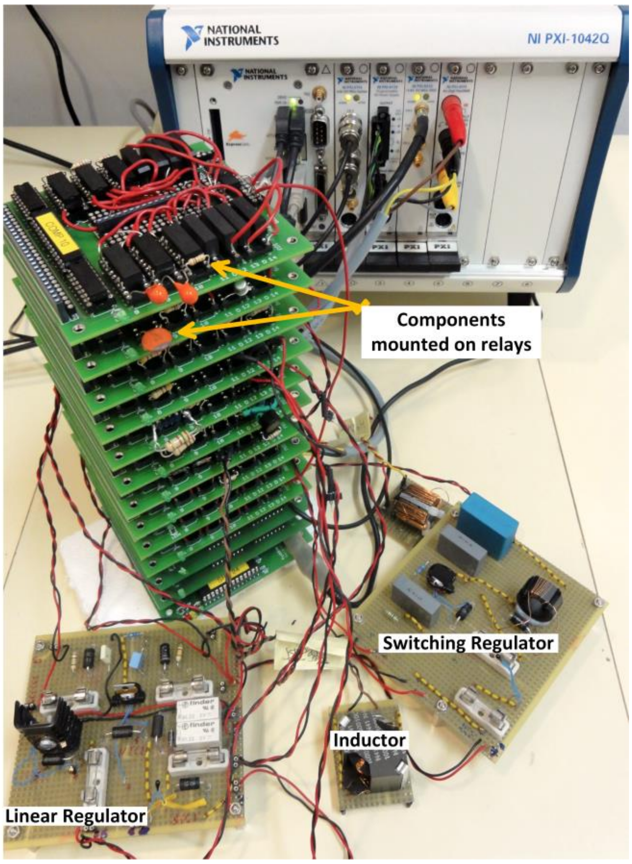

Figure. 5. External DC/DC converter boards connected to the matrix.

to adapt it to their applications. The software configurations were realized as explained in the following steps:

- The "Measurement Server" software code was modified to add new types of component classes along with their properties: 9-leads black box (LinearConverter9), and 7-leads black box (SwitchingConverter7).
- All the components used in the mounted circuits of the experiments are listed, with their corresponding connection and value, in the "component list" file in order to be recognized by the "Equipment Server". The "component list" and the "max list" files follows the PSpice netlist format. For instance, the switching converter is listed as:

  SwitchingConverter7_**8**_4:**8**_5:**8**_6:**8**_7:**8**_11:**8**_12:**8**_13   B H F E C G A   DC-DC Switching Converter 5V

  This code means a component of class "SwitchingConverter7" is connected in the component board number 8 over the relays 4, 5, 6, 7, 11, 12, and 13 to the nodes B, H, F, E, C, G, and A, respectively. The term "DC-DC Switching Converter 5V" is what appears to users in the GUI.
- For each exercise created by the teacher, a "max list" file is prepared in which the allowed connections or maximum values of instruments for such exercise are listed. For instance, a DC power supply can be listed as:

  VDC+25V_4   B   max: 20 imax: 0.5

  That is to say that the maximum allowed values of the DC power supply—located in the "source board" and connected to the node B through the relay 4—are 20V and 0.5A, respectively.
- The last step is to modify the GUI package and add the new classes of components in an XML format, which gives information about the component's class, value, pins, position with respect to the PC-mouse cursor, possible rotations, and own photo. For instance, the SwitchingConverter7 was added as follows:

```
<component type="SwitchingConverter7" value="DC-DC Switching Converter 5V" pins="9">
  <rotations>
    <rotation ox="-65" oy ="-51.5" image="SwitchingConverter7.png" rot="0">
      <pins>
        <pin x="-65" y="-51.5"/>
        <pin x="-52" y="-51.5"/>
        <pin x="-39" y="-51.5"/>
        <pin x="-26" y="-51.5"/>
        <pin x="52"  y="-51.5"/>
        <pin x="65"  y="-51.5"/>
        <pin x="65"  y="51.5"/>
        <pin x="52"  y="51.5"/>
        <pin x="39"  y="51.5"/>
      </pins>
    </rotation>
  </rotations>
</component>
```

V. Remote Retrieved Results

As a final phase, the developed circuits were tested. The circuits were mounted and wired remotely (outside campus) from scratch by the available components and instruments in the virtual workbench as shown in Figure 6. Afterwards, online measurement results are retrieved from each circuit as a case study. For demonstration purpose, measurements are retrieved from each circuit with certain parameters, however, parameters are changeable in each circuit with regarding to the purpose of the exercises based on that circuit. The selected measurements are the following:

1) The circuit shown in Figure 3(a) is mounted with the following values: RL= 75 Ω, Vs= 25 V, and Vrelays= 5V DC (in case we want to connect LM7805-B otherwise it is not connected). While the following values are fixed values in the design of the black box: C1= 0.33 µF, C2= 0.1 µF, Rsh2= 10 Ω, and NTC1= NTC2= NTC3= 10 kΩ (25°C, 1%). The datasheet of the NTCs and the linear regulator are consulted in the following measurements. First, the temperature of the ambient is measured by the NTC3 as shown in Figure 6(a), which corresponds to approximately 25°C. Afterwards, the input signal is applied to the regulator LM7805-A for 5 minutes and then its temperature is measured by the NTC1 as shown in Figure 6(b), which corresponds to approximately 75°C. By subtracting the room temperature, the increment in regulator's temperature will be 50°C. Theoretically, the power loss or the power dissipated

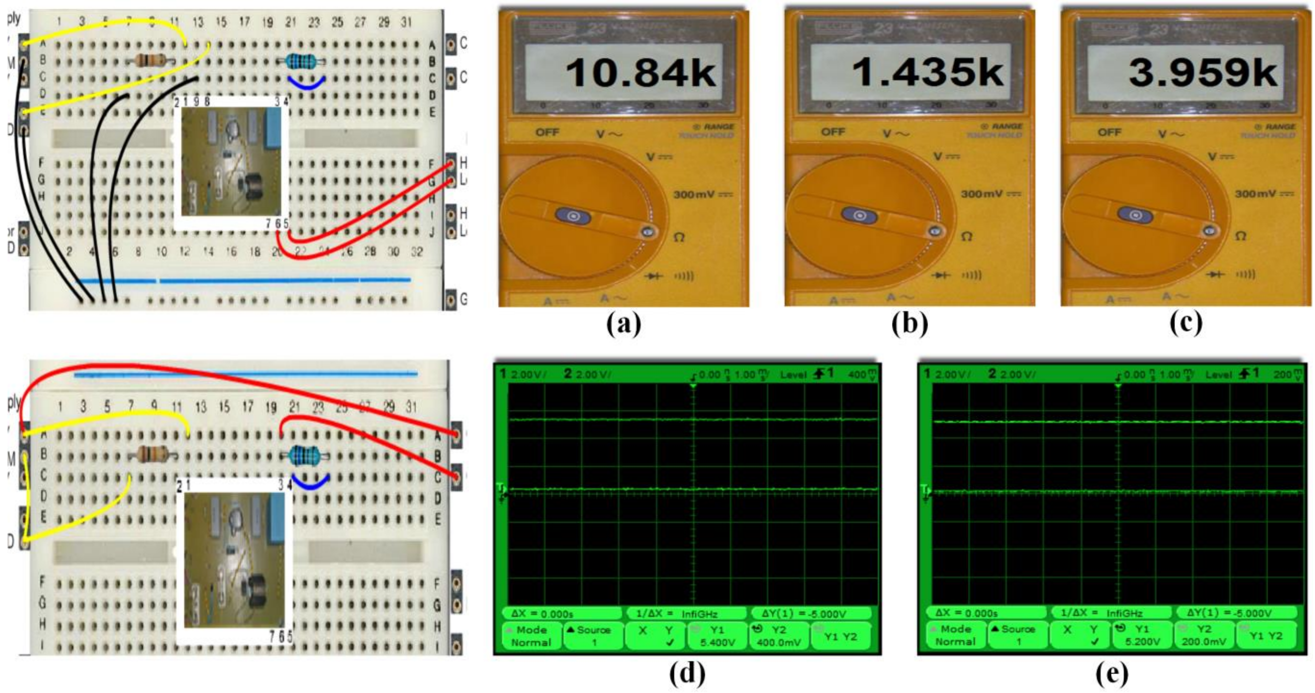

Figure. 6. GUI connections and remote retrieved results.

across the regulator could be approximated using (1) and neglecting the protection components.

$$P_{loss} = V_{reg} \times I_L = \left(V_S - V_L\right) \times \left(\frac{V_L}{R_L}\right) = \left(20 - 5\right) \times \left(\frac{5}{75}\right) = 1W \quad (1)$$

If the thermal resistance of the regulator equals 60 °C/W (junction air thermal resistance – junction cases thermal resistance), thus in ideal case its temperature at steady state should be 60°C for a unit power dissipation, which is nearly close to the practical measurement—considering measurement drops between the physical component and sensor and the tolerance of the materials. Afterwards, the regulator LM7805-B is connected by applying a 5V DC input signal to the relays. The temperature of the regulator LM7805-B is measured by the NTC2 as shown in Figure 6(c), which corresponds to an increase of approximately 50°C. By subtracting the room temperature, the increment in regulator's temperature will be 50°. The total thermal resistance is 21°C/W, which is the sum of the thermal resistances of the heat sink (14 °C/W) and the junction cases of the regulator, in addition to 2 °C/W due to the imperfection of the contact between the regulator and the heat sink. Thus theoretically, the in ideal case its temperature at steady state should be 21°C for a unit power dissipation, which approximates with the practical measurement.

2) The circuit shown in Figure 3(b) is mounted with the following values: RL= 75 Ω and Vs= 25 V. While the following values are fixed values in the design of the black box: C1= 22 µF, C2= 10 µF, C3= 10 µF, L= 56 µH, Rsh2= 10 Ω, and NTC1= NTC2= 10 kΩ (25º, 1%). Figure 6(d) and Figure 6(e) show the output voltage (difference of voltages measured at points 3 and 4) at applied voltage of 20 V and 10 V respectively, which is fixed to 5 V regardless of the applied voltage.

VI. Conclusion

In this contribution a novel electronics experiments, oriented to labor market needs and industrial real-world, were successfully designed and implemented online. The experiments encompass 1) non-isolated linear regulated DC/DC Converter; and 2) non-isolated switching regulated DC/DC converter. They leverage, and was built on, the remote experimentation platform VISIR, converting it into a unique training platform of its kind. The experiments enabled: studying the behavior of electronics components and commercial ICs; using manufacturers' datasheets and comparing them with measured values; and calculating heat dissipation in electronic components either in transient or in steady state, as well as studying the effect of room temperature and of applied heat sinks in heat dissipation. Afterwards, the system was tested and measurement results were retrieved remotely from the mounted circuits are provided as a case study.

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