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3rd International Conference on Innovative Academic Studies
September 26-28, 2023 : Konya, Turkey

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An Automated System for the Electrical Measurements of a Rectifier Circuit Using SCPI

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Abstract – This paper presents an automated method to perform the electrical measurements of a single-phase full-wave rectifier system having a constant load voltage. Using a combination of SCPI commands and MATLAB for the purpose of adjusting the desired measurement settings of an oscilloscope, transferring data from the oscilloscope to MATLAB, and processing data in this high-level language, then finally offering the measurement results in a proper presentation. The process utilizes the brief nature of the SCPI commands and the programming environment that MATLAB provides, and their employment together offers convenient and accurate readings of the implemented system. Besides that, the approach provides an example of an alternative technique to the traditional method used when controlling various instruments including function generators, spectrum analyzers, DC power supplies, and other instruments that support SCPI common commands. All the hardware components that are necessary for the proper execution of the system working conditions and accurate measurement acquiring are also presented in this research paper.

Keywords – Rectifier, Scpi, Matlab, Automated Measurement, Programming.

I. Introduction

The classic method to control measurement instruments such as oscilloscopes is usually done by direct input using physical controls like buttons and using the local software on the device, and even with the increased adoption of touch screens and improving the user interfaces and ease of use on these devices, that is still different from the remote control that can be used with them, for such purpose, SCPI can be used to achieve control over the instrument from personal computers using proper software or programming language, and following the common commands from the device manufacturer. SCPI stands for (Standard Commands for Programmable Instrumentation), it is a common interface language that is standardized, and the building of this instrument programming language is based on the IEEE 488.2 standard[1]. The command sets of SCPI vary from one manufacturer to another and can also vary from a certain instrument model to another provided by the same manufacturer, commands follow a modular tree layout and encompass numerous subsystems. The command subsystem is comprised of a primary keyword and multiple secondary keywords. Despite that every device might have its own set of standard control commands, it could be generally said that one of its common features is that the device would either receive a set or query operation, an example of the first could be setting the channel source to (channel 1) and ask the instrument about its current sampling rate for the second query operation. Sending an SCPI command to the instrument can be carried by software provided by the device manufacturer, and usually, the interface of such software is organized in a simple way that makes using the program fast and just by placing the desired command and sending it. The other option of the process consists of using additional programming languages on a personal computer, such as C or C++, the graphic-based LabVIEW, and other high-level programming languages like MATLAB[2].

The process of reading the electrical measurements of any implemented electrical system is an essential part of testing and evaluating its performance properties, besides being a main factor in the examination of the characteristics of that system. Here comes the opportunity to use the oscilloscope to perform that task, where this device offers a convenient method to perform electrical measurements, besides that the oscilloscopes can have very high bandwidth as well as fast sampling rate, they are storage devices, and some of their models can have generously deep memory and high resolution, all these features can introduce the oscilloscope as a reliable means of measurement. Various standard interfaces that are supported by the VISA technologies can be used to establish communication between the personal computer and the device that supports SCPI, such as GPIB, USB, RS-232, and the instrument control over LAN can also be possible if provided by the manufacturer, some devices offer more port options than others, which might increase the convenience and flexibility of use compared to others. MATLAB programming environment was the chosen option to create the communication and to control the used oscilloscope, that is Rigol DS1054Z, over the USB serial communication.

Reviewing literature associated with using SCPI shows the possibilities to accomplish several models of automated measurement methods, control instruments or even working in a complementary manner with personal computer programming languages to achieve a wide range of diverse applications, they can be considered as examples of the flexibility of SCPI as a capable tool, where Roland Szabó, Aurel Gontean, Ioan Lie, and Mircea Babaita introduced two methods to control two different oscilloscopes, where they used RS232 standard interface to send SCPI commands to the first oscilloscope and make its drivers in MATLAB, which considered as a traditional way to make a connection with the instrument and to achieve more appropriate control over it, without drivers needed, while in the second case, faster controllability was possible, in this case drivers were used with LabVIEW[3]. Another example is where Rhile Liu Guili and Kong Quancun proposed a virtual oscilloscope design, The study shows the possibility of convenient transplantation of SCPI in a higher-level language to present a successful design that possesses the capabilities of displaying waveforms, measuring parameters, and storing data. The GPIB interface and LabVIEW were utilized for this purpose[4]. Also, Fu Zaiming, Zhang Zhixiang, Zhao Yijiu, and Ma Min presented a design that combines the device's local program with the remote control program, the research aimed to considerably decrease the workload of the software, and provide efficient operation of code, which was achieved by the abstraction of the user operation in order to generate SCPI commands, then to do the analysis and response to these orders[5].

Another example is where Tomas Shejbal, Matej Petkov, Tomas Zalabsky, Jan Pidanic, and Ludek Zaplatilek introduced a working environment with automated measurements of radiation patterns of antennas, that system included connecting a signal generator and spectrum analyzer to a PC through an Ethernet interface and LAN and controlled in one application operating in MATLAB. The procedure is executed automatically, far from manual assistance from the user. Which enabled seamless, rapid, and accurate measurements[6]. And B Aravind Balaji, S Sasikumar, and K Ramesh showed an autonomous test environment to examine the performance quality of instruments, for the purpose of time-saving and improving the production process, using a set of measuring instruments utilizing only one programming environment, LabVIEW, and SCPI commands to control the instruments remotely by using USB and Ethernet protocols[7]. Also, Deborah Homan presented a method to set a series of commands related to the instrument that executes essential preparation and measurement, while also ensuring the accurate syntax and options for the next part of the process in an automated system. The proposed procedure also examines the possibility of either modifying the commands in case of changing the measurement instrument or not working with it. After the development of the command series, it can be used with several development environments, such as MATLAB, LabVIEW, Visual Studio, and Excel[8].

The system under test consists of a Variac, an isolation transformer of 12-volt RMS output voltage, a full wave bridge rectifier, and a lead acid battery as a constant load. Voltage and current probes were used to carry the electrical measurements. The test method has proven to be successful in making the electrical readings and presenting them in the desired form.

This research paper is organized in an order where it starts by defining the meanings and use cases of the technologies used to bring the concept behind the study to real and practical usage. Then the paper demonstrates the methodology and approach, besides the several electrical and electronic devices, and components used to make the working measurement system possible. After that, the results section shows the gained results from the system and discusses them. Finally, the conclusion is presented to summarize the overall used approach and highlight the success of the study.

II. Materials and Method

The study aims to achieve a successful approach to reading the implemented circuit's electrical measurements and transferring them to MATLAB properly, therefore, a proper selection of components and method of execution is needed. The general structure that shows the individual parts of the measurement system and their order, then the measurement system connection with the personal computer utilizing MATLAB is shown in Figure 1.

First, the Variac was used to adjust the mains voltage benefiting from its wide range of adjustments, then, the Variac's output was provided to an isolation transformer that can output up to 17 volts of peak voltage. Then, that AC voltage was supplied to the rectifier circuit under test, and then a current probe and voltage probe were used to transfer the electrical measurements to the oscilloscope. The connection of the oscilloscope and MATLAB was possible through the personal computer's serial USB port, and this method of connection made use of Visa drivers which enable the computer operating system and the other software, whether they're the manufacturer's original software or third-party programming environments to recognize the oscilloscope.

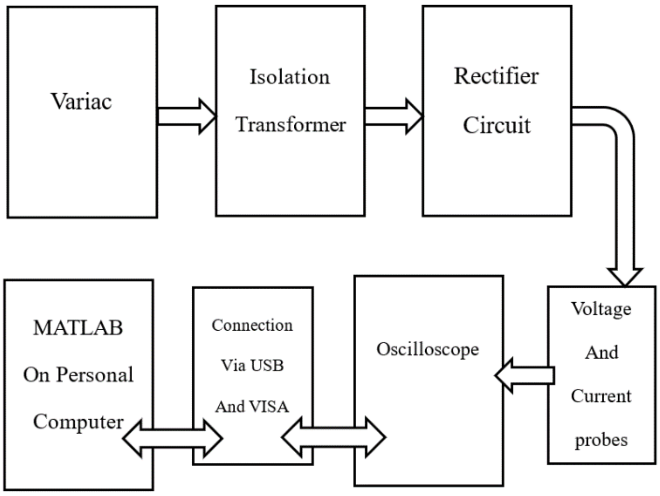

Fig. 1 The general structure of the measurement system

Providing the input part of the implemented circuit with the proper voltage source is one of the essential processes. To supply the desired input voltage level to the rectifier system, a Variac was used, which offered the possibility to adjust the amplitude of the voltage at a wide range (from 0 to 220 volts). The Variac that was used in this research supports an output power of up to (1 KVA) shown in Figure 2.

Fig. 2 The used Variac with manual control

The Variac's output was used to supply the voltage to an isolation transformer, which transforms the 220 volts to 12-volt RMS, which translates to a peak voltage of about 17 volts. Using the isolation transformer provided the advantage of having a finer tuning of the voltage level depending on the voltage amplitude received from the Variac, and an isolation from the earth terminal. The manual operation of the Variac was used to supply the transformer with the corresponding voltage values that would make the isolation transformer output the desired voltage amplitudes to the implemented system. Two different voltage amplitudes were supplied to the rectifier circuit, the first was 16.5 volts peak voltage, and the second was 14.5 volts peak voltage.

An additional beneficial solution that can control the output voltage amplitude of the Variac by an automatic method can also be mentioned, where a feedback portion of the control process could be sent to the voltage level adjusting part of the operation and decides either to deliver the voltage to the next circuit under test or to adjust it further, that algorithm is shown in Figure 3.

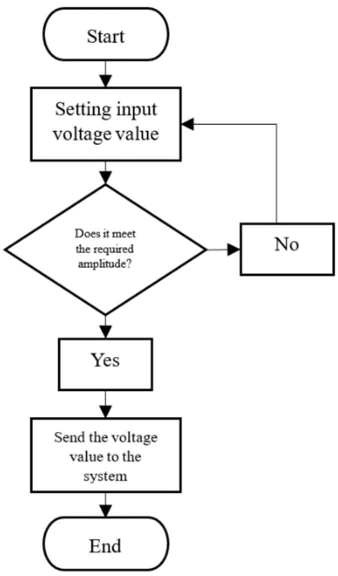

Fig. 3 A proposed algorithm for autonomous Variac operation

The full-wave bridge rectifier was constructed of four diodes[9], and MBR560 Schottky was used for that purpose. This diode model tolerates high current well, with up to 5 amperes, and works properly with high frequency, another big advantage, is that it has a low forward voltage rating[10]. The diodes were soldered on a prototype PCB to construct the rectifier. There is a smoothing inductor of 470 micro-Henry value at the input side of the rectifier. The circuit construction benefits from a lead acid battery of 12 volts and 12 ampere-hour rating, that was used as a constant load. The schematic of the implemented rectifier system can be seen in Figure 4.

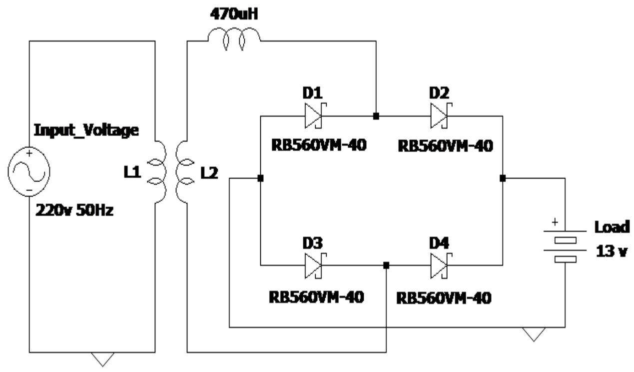

Fig. 4 Schematic of the implemented rectifier system

The oscilloscope can only read voltage, hence there was the need to use a proper method to transform current to voltage, for that purpose, a current probe that benefits from a Hall effect sensor was used, and the resulting readings were considered as current values by the corresponding measured voltages. Using a Hall effect sensor on the current probe offers a convenient method for electrical current reading, this isolated current sensing method can present accurate measurements, besides the reasonable dimensions of the probe device and straightforward method of using after setting the attenuation switch to the proper choice in accordance to the current value to be measured[11].

Although other methods of measuring current are also possible using several approaches, the current probe provided a simple and easy style of operation, and accurate measurements when compared to the multimeter. The screen of the oscilloscope shows the current readings as voltage readings, but they are considered as current readings, and they are accurate.

All voltage measurements were carried by the oscilloscope's probes that support 100 MHz bandwidth, and the lead acid battery that was used as the constant load. The implemented system and the practical measurement method can be seen in Figure 5. The operational algorithm is in Figure 6.

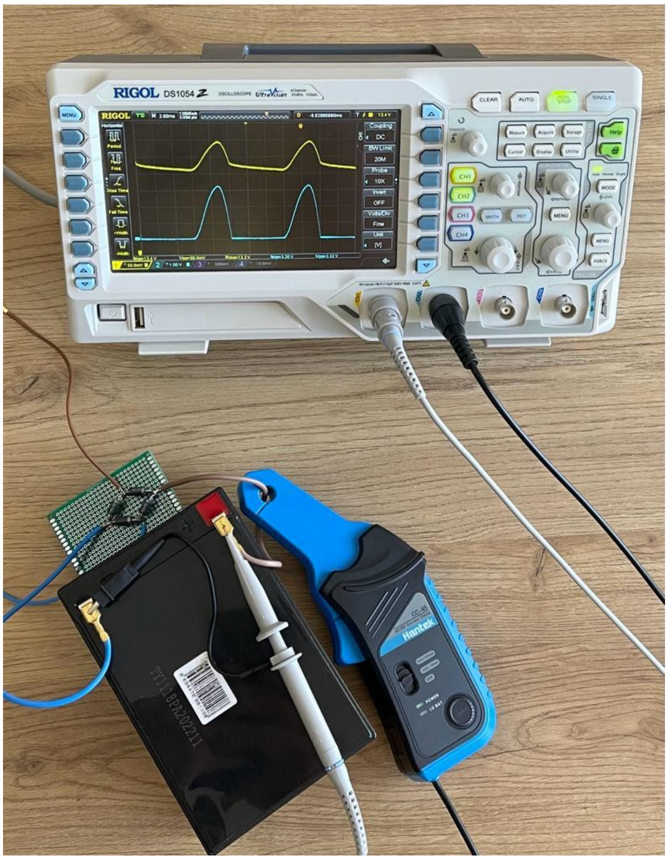

Fig. 5 The measurement system and rectifier circuit

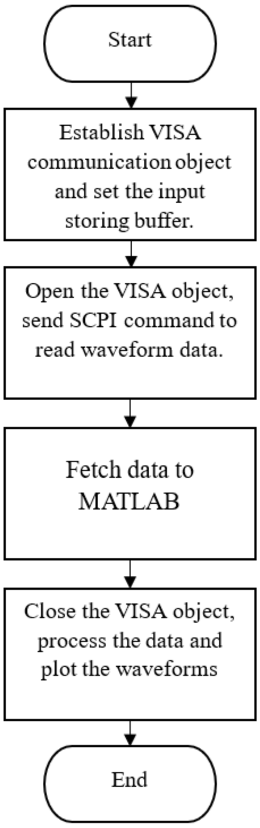

Fig. 6 Flowchart of the used approach for communication between MATLAB and Oscilloscope and to read the data[2]

III. RESULTS

The electrical measurement results are presented in this part of the study in the following order: input voltage, input current, output voltage, and output current. The measurements were done twice, utilizing Variac's variable output voltage feature, to introduce the rectifier system to two different peak amplitudes of input voltage.

In the first case, 16.5 volts peak voltage was supplied to the rectifier circuit, and in the second case it was 14.5 volts peak voltage. The one period of any introduced and plotted waveform was 20 milliseconds; since the utility main electricity was used for test purposes, with 50 Hz frequency. The input measurements were separated from the output; for the purpose of having better representations of the plotted waveforms. In each case of testing the input voltage waveform was introduced first, since the characteristics of this main waveform affect the rest of the electrical measurements.

Bringing the readings of the input or output parts was done by adjusting the information source, which is done using the SCPI command with MATLAB to the oscilloscope, by that, two channels of the device were used each time, and setting for each channel source was done by opening a Visa object then close it for each SCPI command. The general introduced method showed a successful approach to performing the electrical measurements of the implemented rectifier system, results are accurate, with good resolution and presentation.

The use of Variac made adjusting voltage values easy, and the current probe was convenient to use and provided accurate readings. The oscilloscope sampled the waveforms in preparation to be transferred to the personal computer. Repeating the experiment twice with two different input voltage values showed that the electrical current would decrease by a considerable value when the input and output voltages of the system come close together in their amplitudes. Results plotting starts with the first case in Figure 7 in the previously mentioned order.

In the first case of testing the rectifier's input voltage is 16.5 peak voltage. The features of the plotted waves are discussed to highlight the noticeable differences between the two test cases.

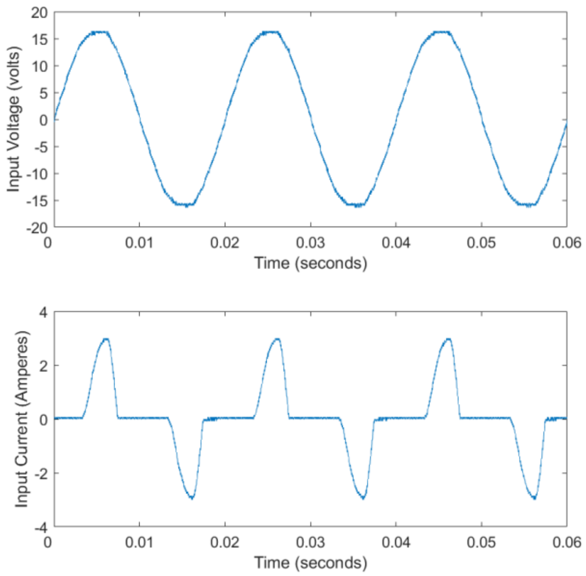

Fig. 7 Input voltage and input current of the first case

From the input plots in Figure 7, it can be noticed that the rectifier worked in discontinuous mode, where the input current kept fluctuating between connecting and disconnecting during the operation. The peak value of the input current was also of a higher amplitude, with 3.04 Amperes peak current.

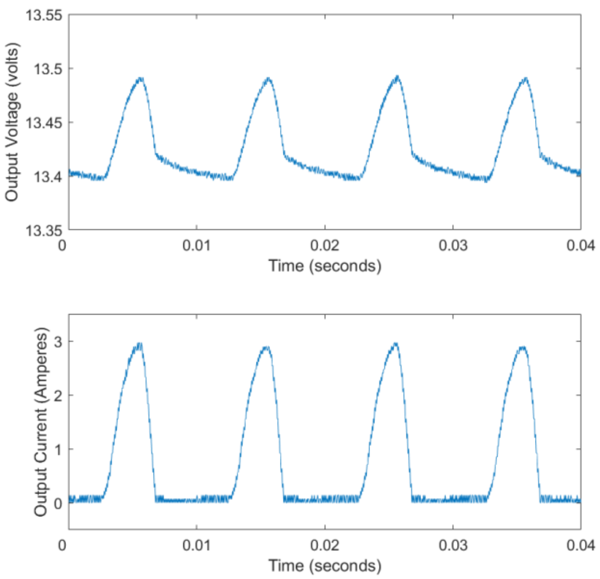

Fig. 8 Output voltage and output current of the first case

Figure 8 shows that the constant load voltage had a very small ripple rate of about 100 millivolts without the need for an additional capacitor to filter the output wave of the full wave rectifier, and the output current also follows the input current in its discontinuous performance. These output results are of two periods of waveforms for both current and voltage, as was previously mentioned, the period of each waveform is 20 milliseconds, and four peaks of each wave were introduced to have a better look at the quality and consistency of the plotted output results.

In the second testing case, the input voltage of the rectifier circuit was reduced to 14.5 volts peak voltage, benefiting from the Variac, and the isolation transformer enabled choosing the specific wanted amplitude in a finer approach of control.

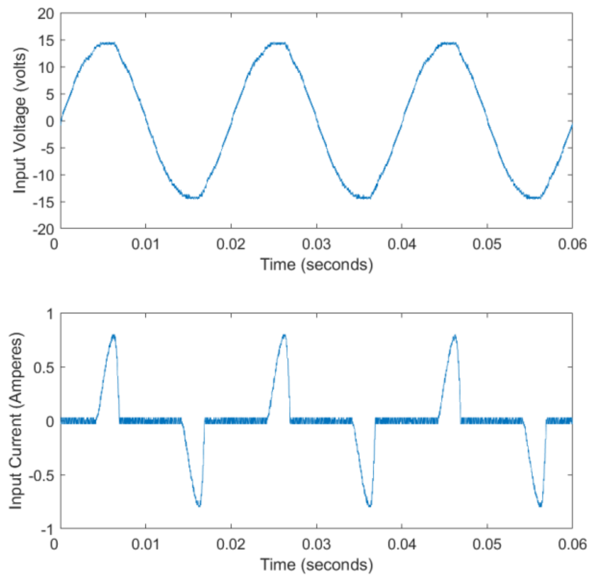

Fig. 9 Input voltage and input current of the second case

In Figure 9, it can be seen that reducing input voltage decreased the input current by a reasonable value, where it's only about 800 milli-Amperes, compared to the 3.04 Amperes in the first testing case. Another thing is that the conducting period of the input current was also reduced more, compared to the previous case.

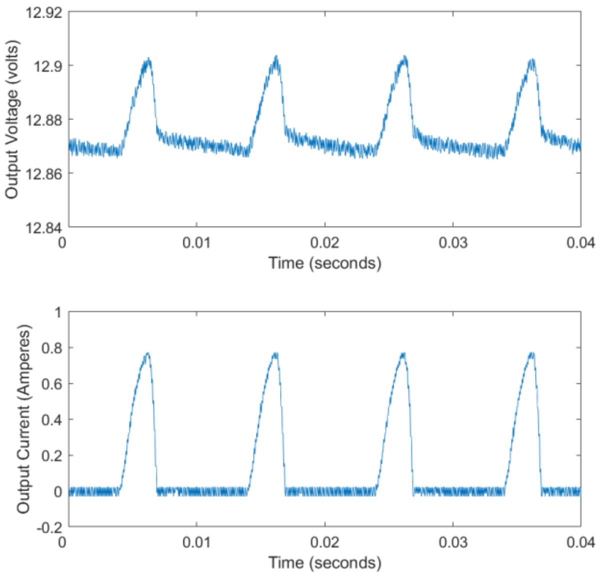

Fig. 10 Output voltage and output current of the second case

Figure 10 shows the output characteristics of the second testing case. The output voltage ripple decreased to about 40 milli-volts compared to the 100 milli-volts of the first case, and the output current follows the input current in its reduced amplitude and conducting period.

IV. CONCLUSION

A proposed automated method for electrical measurements of a rectifier system was introduced and performed, where the desired outcome was attained by merging MATLAB's rich programming environment and the SCPI's common command language. The aim of this study was to prove the success of the combination of these two programming languages to produce the readings in a proper approach and quality representation, and that was achieved in a successful process. The utilization of the oscilloscope's support for an appropriate sampling rate and a wide variety of SCPI commands made the aim possible, and MATLAB provided the needed high-level ground for processing and plotting the measurements in a suitable form. The competent parts and device choices were also important in completing the integration between the programming, data processing, circuit implementation, and reading accurate results, to present the study in a successful consideration.

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