

# Tools for Three-Phase System Laboratory Sessions

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**Abstract** - Training on measurements to determine the characteristics of three-phase electrical systems is very useful for a deep knowledge of the theoretical aspects, particularly for electrical engineering undergraduates. The technological development requires the realization of tools which gradually familiarize the students with advanced technologies for measurement during the training activity. Three different tools have been implemented during the last three years in order to improve on purpose the didactic value of the laboratory sessions.

In the first tool a complex hardware and software system is implemented: the system includes electromechanical instruments for a better understanding of the three-phase system operation and can be used in distance learning sessions, on account of the realized virtual instrument.

The second tool provides different features from the previous one: indeed, it is based on advanced technologies and has been redesigned in order to realize an electronic power meter, active and reactive, in a wide range of current values.

The last tool is a didactically valuable three-phase energy meter, an industrial technical instrument, ready to be characterized.

**Key-Words:** Training on three-phase system measurements, Electromechanical instruments, Digital instruments, Virtual instruments, Micro-controllers.

## I. Introduction

Experimental training on three-phase electrical systems is very useful for undergraduates in the electrical engineering area: indeed, they can verify the acquired knowledge of various theoretical aspects on the operation of the power system in different load conditions. For this reason, adequate laboratory sessions are needed, but there are some technical difficulties to overcome.

The settlement of a three-phase measurement station, designed for training, requires a careful choice of adequate components (for instance, the elements of the three-phase load with proper values of the electric quantities, the instruments with appropriate ranges); additionally, security requirements must be taken into account. A proper design can overcome the drawbacks, and will provide the students with a preliminary deep experience on the power system behaviour.

For such measurements electromechanical instruments have been used in the past and subsequently electronic instruments.

The teaching perspectives have been considerably modified on account of the powerful improvement of the technology. Moreover the cultural background of the students is continuously changing, therefore the didactic planning of the measurement environment needs to be modified [1].

In the last years the authors have developed some tools for experimental training of the undergraduates. In previous developments they proposed several educational systems, aimed to enhance the availability and the effectiveness of the experimental activity. In the progress of the work, advanced technologies have been used (virtual instruments, implemented in the LabVIEW™ environment, micro-controller, digital acquisition board installed in the PC, super visioning tool and web cam). The tool presented in [2] implements an experimental session for carrying out measurements on first-order and second-order systems using advanced methodologies.

The feasibility of remotely controlling connected instruments has been investigated: this technique will be more and more suitable.

On account of the good results, great attention has been recently dedicated by the authors to the three-phase system measurements and some tools have been implemented [3, 4, 5, 6, 7].

Each tool has been designed in order to exhibit peculiar features and to present didactic value.

There are many properties highly required for an effective and updated didactic activity on three-phase system measurements, among them:

1. suitable hardware arrangement (electromechanical instruments for a deep comprehension of the related theory, digital instruments to be acquainted with advanced technology, signal conditioning circuits and data acquisition systems connected to the personal computer);
2. adequate software (for programming microcomputers, for implementing virtual instruments and for distance learning).

Some solutions to perform laboratory training in the considered field have been implemented [6]:

1. The first tool implements a remotely managed laboratory session. The image of the instruments in the lab is captured by a web-cam and is presented in the front panel of the virtual instrument: in their distance training the students can have the feeling of performing real experiments.

2. The second system improves the previous solution: a laboratory session has been implemented by using a micro-controller based architecture. A key point of the adopted strategy consists of using smart and stand alone architectures, efficient paradigms for signal processing.

The reduced cost of the solution proposed, compared to traditional set-up to perform the experiment, allows for an efficient duplication of the laboratory session.

The management of user-friendly environment for signal processing and elaboration is used (hardware, firmware and software tools): the student interacts with the system, produces its own modification and can validate the results.

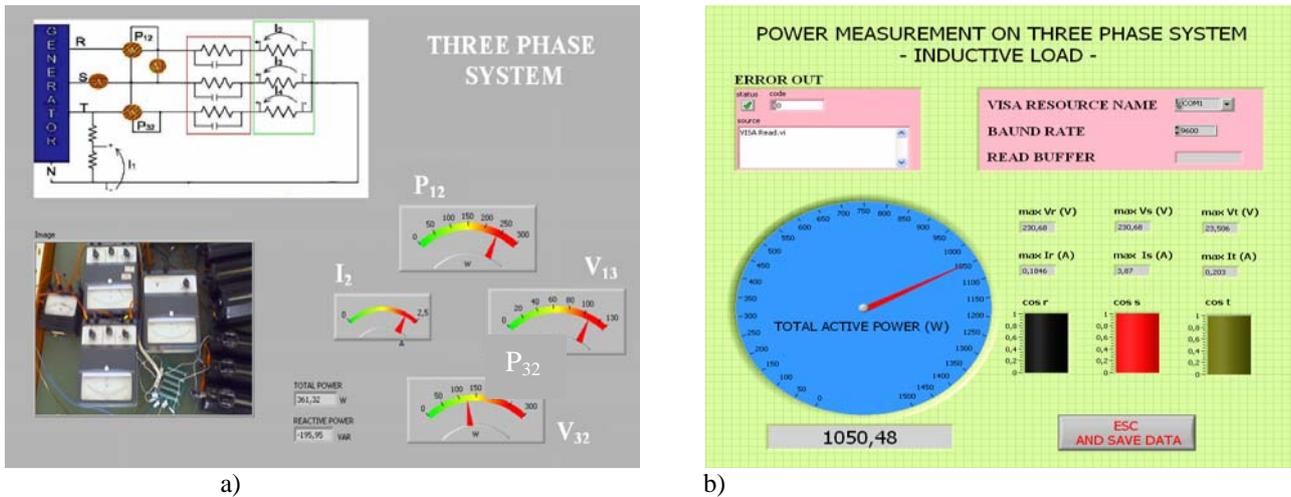
In this paper two already presented tools [5, 6, 7] are briefly outlined for their didactic value. The second tool has been completely redesigned and has been developed by a group of students in electrical engineering area during guided sessions, in collaboration with a local spin-off company, operating in the field of embedded systems. Moreover, the third tool is presented: it represents the last development and has been realized in the form of a portable electronic power meter.

## II. The first and the second didactic Tools

Fig.1a emphasizes the didactic usefulness of the first presented tool, which represents the front panel of the virtual instrument as it appears to the remote user.

As shown in the figure, the tool exhibits some didactically useful features, among them:

1. electromechanical instruments are used in the set up arranged in the laboratory;
2. LabVIEW™ environment enables the virtual instrument to be implemented, which emphasizes the use of advanced technology;
3. in order to adapt the voltage level of signals supplied by the real three-phase system to the ones to be applied at the input terminals of the data acquisition board additional electronics is implemented.



a) first tool: Front panel of the virtual instrument on the remote monitor;  
 b) second tool: Front panel of the instrument.

The circuit diagram on top of the figure shows the traditional arrangement of the three-phase symmetrical system in case of balanced load. The first box includes the model of the load, which consists of three equal impedances in the star connection. Two watt-meters in Aron configuration and the voltmeter represent the set of instruments needed in order to perform the measurements by using traditional electromechanical instruments, actually used in the lab: indeed, the figure under the circuit diagram is the image captured by the web-cam.

In the understanding process the students have carried out some practice in the lab for a short time and can continue the training as far users, on the base of the realized virtual instrument, implemented in LabVIEW™.

The implemented software computes the voltages of the three-phase system on the basis of the voltage at the voltage divider, shown in the circuit diagram; moreover, the virtual instrument computes the line currents, on the basis of the voltages at the terminals of the three resistors included in the last box of the circuit diagram.

The software performs the various procedures, according to the design, computes the various electrical quantities, realizes the front panel of the virtual instrument and displays the results on the same figure. It should be emphasized that the digital virtual instruments, shown on the right, display the same results as the ones given by the electromechanical instruments. The opportunity of comparing the features of the traditional instruments and those of the virtual instruments

implemented in the LabVIEW™ environment is enabled by the web-cam, located in the lab. As last results, the software computes the values of the total active power and the reactive power, that are displayed in the proper boxes. A theoretical report on the subject is supplied to the undergraduate as on-line help. Therefore the tool, designed as a friendly tool for remote users, can improve the availability of the lab.

Fig.1b shows the front panel of the virtual instrument of the second tool. This tool is based on the micro-controller ST52F513 belonging to the ST-FIVE family of 8-bit Intelligent Controller Units (ICU), by ST-Microelectronics; it requires the Visual Five by ST-Microelectronics environment for programming. The processed data are transferred to the PC and then managed by a dedicated software developed in the LabVIEW™ environment. Indeed, it allows for the development of software instruments for smart and efficient signal processing and data manipulation and employs many facilities to manage general purpose advanced hardware, through communication supported by standard protocols. In this case an RS-232 connection between the microcontroller board and the PC has been established.

The didactic value of this tool consists of an extensive use of advanced technologies. This instrument can be used as a portable electronic active and reactive power meter, in a wide current range (220 V, 0-20 A).

Some boards have been designed for reducing the input voltage and current values, adapting and conditioning the signals, decoupling the impedance in order to realize the correct connection to the microcontroller, programming the micro-controller, and managing the communication with the computer. In the new version the micro-controller PIC18F2620 has been adopted. The programming software is MPLAB IDE v7.40. A common communication program, the “Hyper Terminal”, has been chosen for displaying the results.

### III. The three-phase Energy Meter

The last tool has been implemented as a development of a research carried out in conclusion of a step by step activity for enhancing the didactic quality of the experimental training in the area of three-phase systems for electrical engineering students. The contribution of the students has been effective.

The developed three-phase energy meter is composed by two stacked boards packaged in a standard 9 module DIN enclosure: the main board, for the Analog Front End (Protection Circuitry and Power Supply) and the Data Processing Board, as shown in Fig. 2.

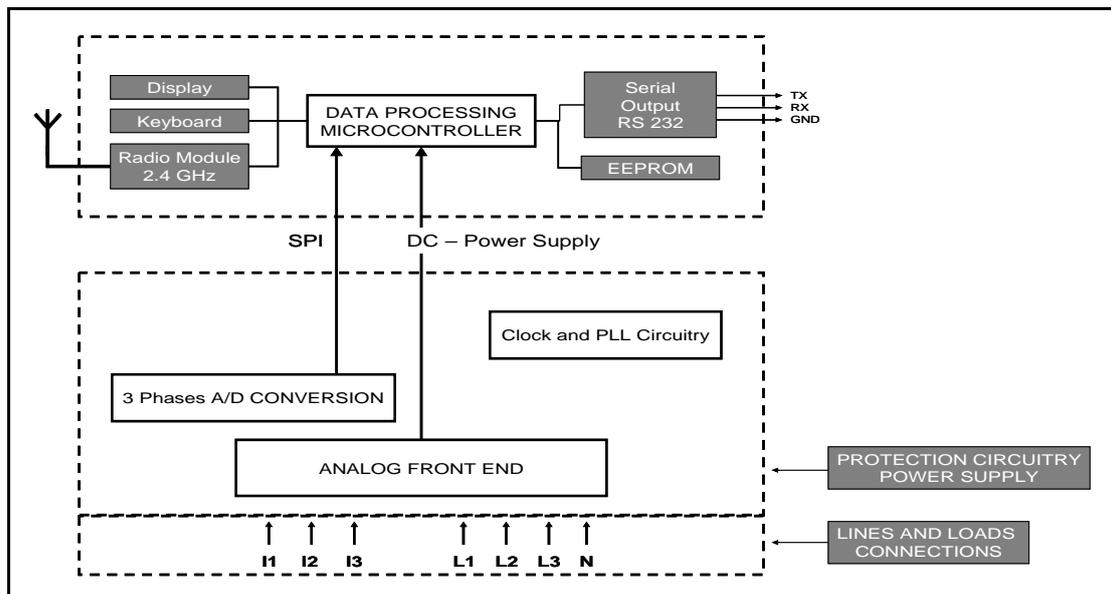


Fig.2: Functional block diagram

The power supply circuit uses three voltage transformers to step down the 220V line voltages to the 5 volt regulator. The 2W maximum current consumption specification of the IEC62053 and legacy IEC61036 specifications limit the power supply voltage to an input voltage low enough to keep the power below this level.

The voltage channel uses resistors to achieve a suitable divider ratio. The current channel of each phase uses current transformer with settable turns ratios such that twice the rated maximum current of the meter is still within the input range of the A/D converters.

In the Data Processing board two microcontrollers process the signals from the SPI port of the 16 bit A/D converters with a suitable time sampling, and manage the communication with I/O, respectively.

To achieve simultaneous sampling across the three phases, all the A/D converters devices use the same clock source. In particular, six delta-sigma ADCs are clocked simultaneously. The source used in this reference design is the output of the phase lock loop (PLL) circuit locked to the line frequency. The target number of samples per line cycle is 128. For

class 0.2 or class 0.1 meter designs that require harmonic analysis the use of a PLL was in fact recommended. Using this approach, the MCU can gather the waveform data immediately after the data ready pulse, at up to 10 MHz. The remainder of the time can be used to calculate the power measurements to achieve true line cycle sampling with zero blind cycles. Moreover, the SPI data can be access at up to 20 MHz. This speed enables quick data retrieval in between conversion times. For 3-phase metering applications with multiple ADCs, this fast communication is essential to allow for power calculation windows between conversions.

The MCU accomplishes the following energy meter calculation outputs per phase, per line cycle: RMS Current, RMS Voltage, Active Power, Apparent Power, Active Energy, Apparent Energy, Power Factor.

Finally, it must be highlighted that there are two outputs consisting of a radio module (ISM 2.4 GHz) and a LCD output display. This solution allows for a local or remote connection to several energy meters (depending on the Data Collector features), as shown in Figure 3.

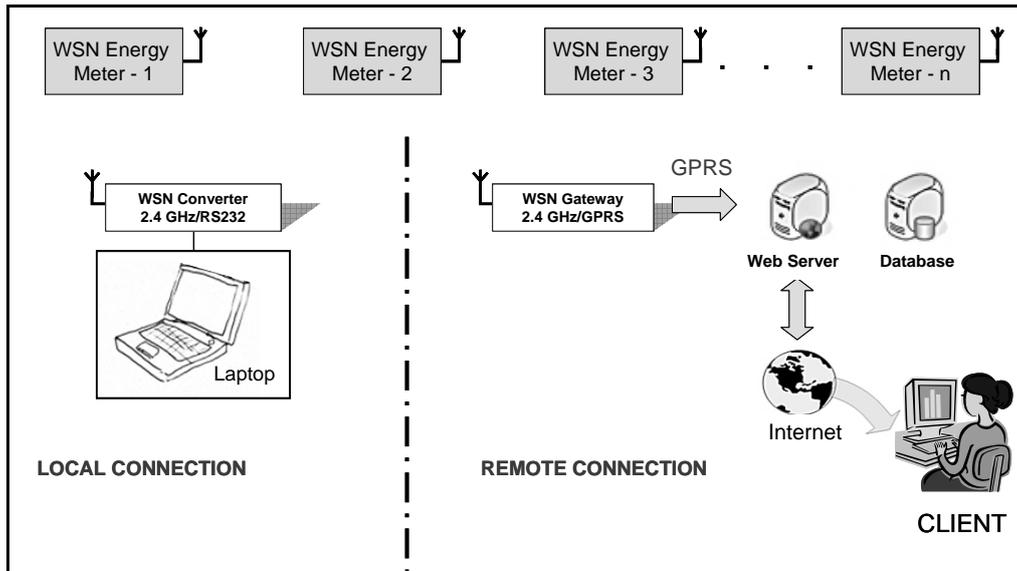


Figure 3: System architecture for local and remote connection to the energy meters.

In the first case, the local users can read the LCD display or download the data from multiple meters to a local PC, through a 2.4 GHz/USB converter (a limit of 15 meters is dictated by usual PC hardware features). In the second case, a remote download of the data can be performed through an Internet connection to a host in which a MYSQL Database has been installed. A converter from the 2.4 GHz to GPRS has been actually developed to work as Data Collector also in areas where a LAN connection is not present. In both cases, local or remote users can gather and analyze energy data through a JAVA-based tool.

On the basis of the tests already carried out, the instrument works properly and the precision level is very high. The precision level of the measurement system also depends on the selected connections for lines and loads. In particular, the indirect measurement of current is considered in this case through the use of external current transformers. Accuracy in measurements of voltages is then better since a direct connection to the sampling architecture is realized with a suitable voltage divider.

The characterization procedure will be performed very soon with collaboration of students attending the Electric Measurement Courses.

#### IV. Conclusions

Three developed didactic tools have been presented: they represent a progressive approach to the use of advanced technologies:

- The first one includes electromechanical instruments for a very clear understanding of the system operation, it is based on a virtual instrument and can be used in distance learning sessions.
- The second tool implements an electronic active and reactive power meter, based on a micro-controller and a virtual instrument. It represents a further step for undergraduates approaching advanced technologies.
- The last tool consists of an electronic three-phase energy meter, a valuable didactic device, useful for training in advanced measurement courses.

It should be emphasized that these tools have been designed to perform different features, taking into account didactic improvements as a consequence of the impressive development of the technology. A gradual approach has been used and tests have been performed only in the local area. The interesting results induce including the tools in the courses at different levels.

In future developments the characterization of the last implemented instrument will be carried out.

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