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A Virtual Environment for Remote Testing of Complex Systems

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Abstract* – Nowadays complex systems, realized by integration of several components or sub-systems, require suitable and complex simulator devices. Obviously the best option is to simulate the entire system together, with each component modeled in the most convenient way for its particular field; this approach is possible only if the model of the components is available. In industrial applications, where a system can be a mix of different devices produced by different manufacturers, the knowledge of the model could be difficult. Starting from this point the idea of creating a Virtual Environment (VE) able to test the real single component remotely employing simulators with remote signal processing capability has been considered. In this paper an application of a VE is presented and, in particular, a remote test is developed, involving signals generated by a system located at the Politecnico di Milano, acquired by a Virtual Instrument located at the University of South Carolina, USA, and processed by Virtual Test Bed environment.

I. INTRODUCTION

Complex systems, realized by integration of several components or sub-systems, where each of them can again be represented as a complex system, are more and more employed in industrial applications, health-care systems, environmental sensing and monitoring, military systems.

An exhaustive testing of such systems cannot be done by testing each component or sub-system independently on each other, since even when all of them meet their own specifications, unpredictable interference and/or malfunctions may appear when the whole system is assembled. If these malfunctions can be detected with preliminary tests, the economical benefits of this result are extremely high.

Moreover, several applications exist where the whole system is realized with components produced by different manufacturers, often in competition with each other. Most of the technical information that each manufacturer makes available to the final customer is strictly confidential, and is not supposed to be forwarded to the other manufacturer in order to perform tests as exhaustive as possible. When military systems are involved, this is reinforced by security reasons.

The availability of a Virtual Environment (VE) that allows testing the single components as if they were already part of the whole system, before the system is actually assembled, appears to be the best solution to the problems sketched above.

If the VE features the capability of processing remote signals, tests can be performed at the customer's site, leaving the device under test (DUT) at the manufacturer's site. This results in a dramatic reduction of time and cost of moving the DUT from the manufacturer's to the customer's site for testing, and back to the manufacturer's site for the modifications, if needed. Moreover, no confidential information about the whole system needs to be passed to the manufacturer.

This paper presents an application based on the partnership between a Virtual Instrument (VI) with remote signal processing capabilities and a Virtual Test Bed (VTB) that realizes the VE. Two different systems will be adopted to perform analysis by means of the proposed VE.

II. THE VIRTUAL TEST BED

The simulation of complex systems where many components of different nature interact presents peculiar challenges. Different users might analyze an individual system focusing on different aspects of the system performance and having a different metric for what is important. The complexity of the system may bridge several areas of technical expertise, and users in each of those technical areas traditionally work with their own set of design and simulation tools.

Suppliers of a particular subsystem may have already invested significant efforts in the creation of a simulation model for that subsystem, which encapsulates their in-depth knowledge of the system. Exporting the model to the simulator of choice for the overall system is difficult, time-consuming and results in a duplication of efforts.

Some parts of the system may be already available while other parts are still being designed. To the possible extent, one may wish to substitute real components for their models every time a new component becomes available. Such an approach keeps the design/simulation "alive", promotes iteration, allows an opportunity to validate models and detect, at the earliest possible time, potentially complicating nuances that were not originally accounted for in the component models. The cost of this approach is that it requires a sophisticated capability for working with diverse modeling languages and with Hardware In the Loop (HIL) [1].

All of these considerations suggest the desirability of a new high-level interface that allows many types of users to be comfortable with the virtual prototyping tool. An attempt to develop such a tool has been underway at the University of South Carolina for several years now under the program name Virtual Test Bed [2, 3].

The VTB approach solves the traditional dichotomy in modeling that universally plagues designers, allowing them now to use a proper instrument for each part of the system design problem. In contrast, classical simulators, where a single specification language is available to the users, really limit the analysis of such systems.

The VTB environment, vice versa, addresses these challenges by choosing to support:

- Multi-formalism: different languages can be used to build models of the different components that compose a system. This allows an individual to build models using the preferred language within his or her discipline (in this case mechanical, electrical, chemical).
- Co-Simulation: users can change the language and also use other solvers together with the main VTB solver. This means that any part can be solved with the more appropriate integration step and method without affecting the solution of the rest of the system.
- High-level visualization: visualization models of the system can be easily created and linked to live simulation data. Visualization helps the user to rapidly comprehend the system performance. Visual outputs include data-driven animation of the motion of solid objects, imposition on top of the solid objects of novel representations of abstract simulation data, or simply oscilloscope-like graphs. Furthermore, a high level visualization better supports the interchange of information among the designers cooperating on the project.
- Hardware in the simulation loop: This is a rather new feature for the VTB environment.

The capability of VTB to integrate in its own simulation environment components modeled in different languages and environments has been extended to widely popular design tools, as extensively described in [4-6]. The newest extension is LabView. This new co-simulation capability opens a whole new set of possibilities related to the pre-testing of VI's and the use of the integrated environment for the training of the instrument itself, if needed, and of the operator.

Moreover, real signals coming from the DUT can easily be acquired and processed by the VIs under the LabView environment [7]. The real measured data can hence be compared with those simulated in the VTB environment, thus allowing to assess whether the DUT meets the design specifications or not. Conversely, the real measured data can be supplied to the other blocks of the VTB simulator and analyze how the other components in the system react to the presence of a real component.

The capability of LabView to interconnect remote VIs in an extremely easy way through an Internet connection [8], makes quite immediate encapsulating remote tests within the VTB VE.

III. VIRTUAL INSTRUMENT AND VIRTUAL TEST BED PARTNERSHIP

The process of interaction between VTB and LabView is based on Dynamic Link Library (DLL).

The LabView environment is able to export any VI project in the format of a DLL. The DLL is also the basis for the library management in the VTB software.

Thanks to the definition of a new model class the VTB software is now able to recognize, load and execute LabView DLLs.

Let us focus on a very simple example. Suppose LabView is a signal generator for VTB.

The system is summarized in fig. 1. The capture on the upper left corner represents the LabView schematics. This has been compiled and then imported in VTB as shown in the main central picture. Activating the VTB simulation, LabView generates a sinusoidal signal as reported in the upper right corner.

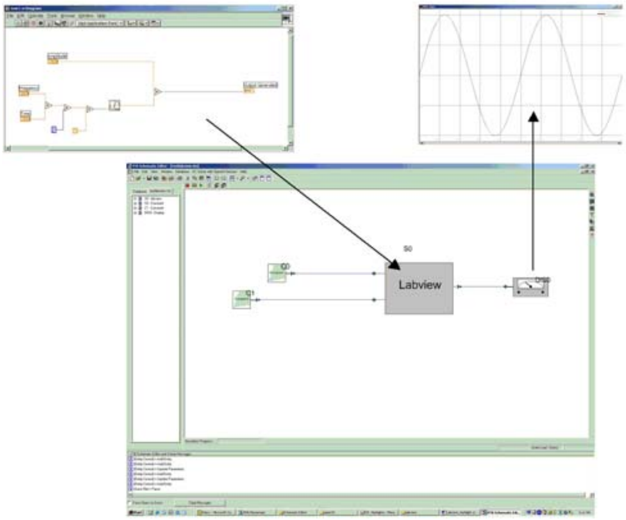


Fig. 1: VTB and LabView cosimulating

This example shows a trivial VI but the procedure can be applied to any level of complexity allowing the virtual testing of any VI we want to develop within LabView.

A set of different options can be considered to perform the connection between the two environments. The two most significant cases are described in the following:

1. The whole process is performed by using virtual data. The Labview environment can have input and output data exchange with VTB

2. LabView generates test cases for the VE acquiring data from a real plant. This process can be performed sending one sample per simulation cycle or it can be based on a buffer of acquired data. The second case easily allows the remote execution without any concern for the delay introduced by the network connection, as far as hard real-time operations are not necessary.

The availability of such an environment allows the execution of critical activities that are here summarized.

- Validation of an available model: by acquiring transients on the real plant it is possible to validate the simulation model available on the VTB environment
- Monitoring of a modelled system: once the model has been validated it is possible to use the developed procedure to periodically compare real data and simulated data. Any deviation from the standard behaviour can be easily identified by continuously comparing the validated model with the acquired data
- Troubleshooting of a plant: once a validated model is available and the deviation from the standard behaviour has been determined, it is possible to use the simulated system to determine the cause for the deviation itself.
- Insertion of new equipment in a big plant: if new equipment has to be inserted in a complex plant, it is possible to use real data from the plant to test the sensitivity of the new equipment to any kind of disturbance present in the system.

In the following, two simple examples of application of the proposed methodology are described. In the first case the equipment under test was located in the same building as the one of the simulation platform, while in the second case the equipment was located in Italy and the simulation platform was located in USA.

IV. EXAMPLE OF APPLICATION: ANALOG FILTER MODEL VALIDATION

In this first example, a simple third order active filter is considered, as reported in **Fig. 2**.

The values adopted for the circuit element are reported in Table 1.

Tab. 1: Values adopted for the elements of the circuit in Fig. 2.

Description	Value
R1	160 KΩ
R2	240 KΩ
R3	750 KΩ
C1	0.1 μF
C2	0.01 μF
C3	0.047 μF

The filter has been connected to an external signal generator and the input and output voltages have been connected to a data acquisition board equipped with 8 input channels, ±10V range, with simultaneous sampling up to 500 kHz sampling rate on a single channel. This board is handled through the LabView VI reported in **Fig. 3**.

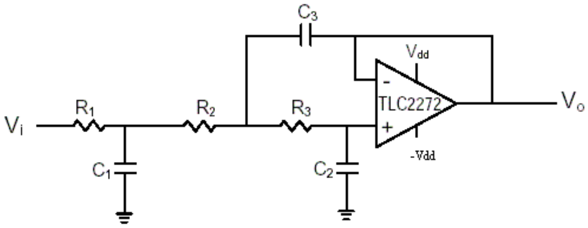
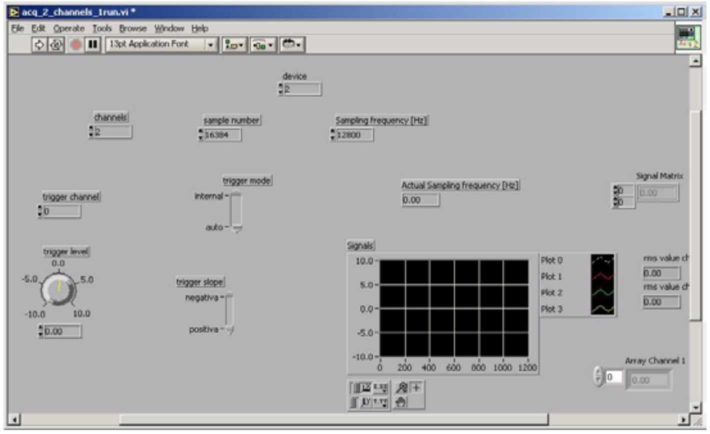


Fig. 2: The filter under test



device: 2
channels: 2
sample number: 16384
Sampling frequency [Hz]: 12800
trigger channel: 0
Actual Sampling frequency [Hz]: 0.00
Signal Matrix: 0 0 0.00
trigger level: 0.00
rms value ch: 0.00
rms value ch: 0.00
Array Channel 1: 0 0.00

Fig. 3: The VI adopted to handle the data sampling

This VI is able to capture a buffer of data for the two channels acquiring the signals with a predefined sampling frequency. All those parameters can be defined through the VI panel.

By exporting the VI to a DLL is possible to create a suitable function that makes the buffer available for every instance of a function call.

The VTB block designed to interface this kind of LabView functions is able to collect the buffer and to release the samples to the virtual environment emulating the correct time evolution.

In this specific case this feature has been adopted to compare the experimental results with the calculation performed in VTB by using the theoretical transfer function applied for the filter design.

Fig. 4 illustrates the VTB set up. The LabView block is parameterised to load the DLL created by the VI in **Fig. 3**. By running the simulation, the VTB block acquires the data and creates two streams of signals interacting with the rest of the simulated environment. Channel 1, representing the real input of the filter, is used as the input for the model while channel 2 can be compared with the results of the virtual filter.

Applying the signal reported in **Fig. 5** the results of **Fig. 6** have been obtained. In order to create a measure of the quality of the simulation the following index have been defined:

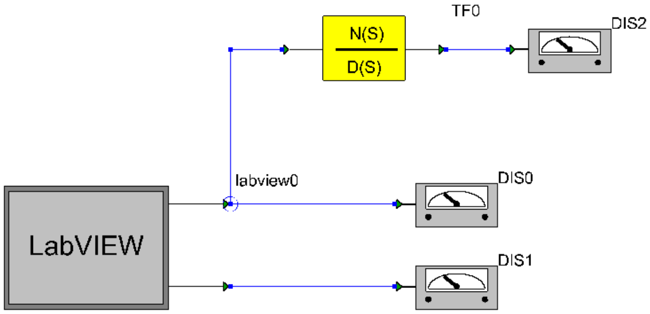


Fig. 4: the VTB schematic for the filter example

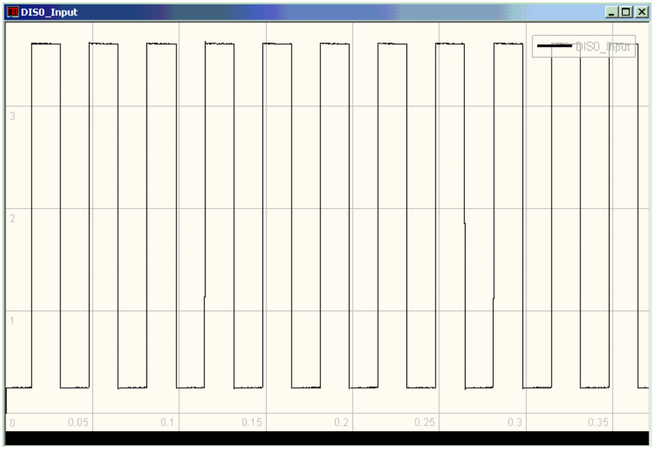


Fig. 5: the acquired input signal (x-axis in seconds and y axis in volts)

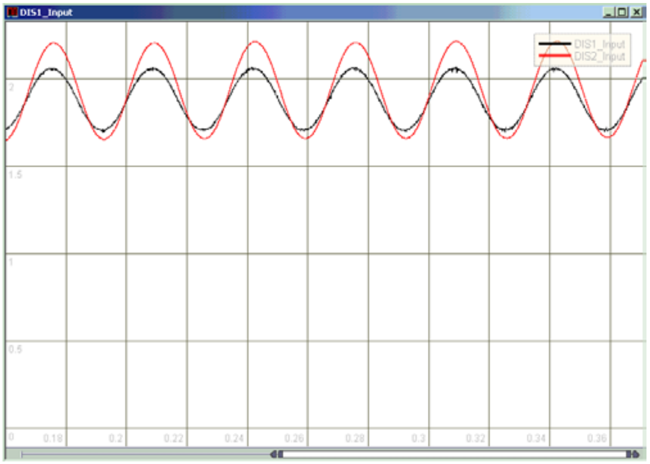


Fig. 6: Comparison between theoretical and real output signals for the filter case.

$$e=\frac{\sqrt{\sum_{k}\left(vm_k-vs_k\right)^2}}{\sqrt{\sum_{k} vm_k^2}}100$$

where:

- vm_k is the generic sample of the measured quantity
- vs_k is the generic sample of the simulated quantity

The sum has been extended over one period of the input signal. In this specific example a value of 4.88 % has been calculated.

Such result can be considered as a starting point to evaluate the quality of the model and, if desired, as reference to improve the quality of the model itself.

In this case, for example, it has been estimated that part of the error was related to the non-linearity of the operational amplifier working too close to the saturation limit (the power supply was working at +/- 5 V).

The experiment of comparison has been repeated with a sinusoidal signal with a lower amplitude. The results are reported in **Fig. 7**.

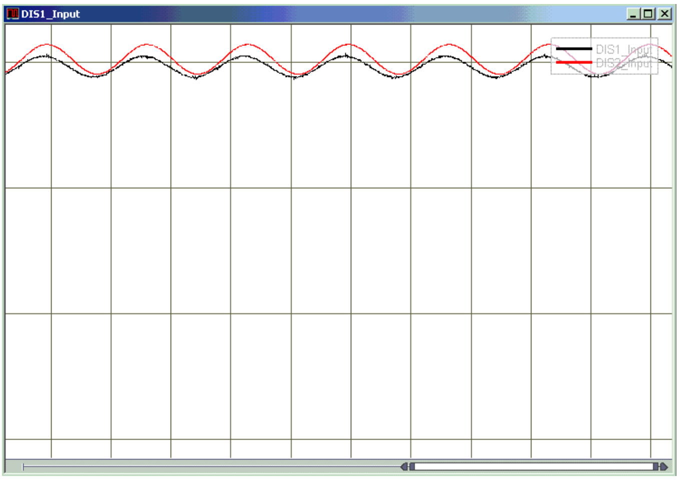


Fig. 7: A second experiment with the same filter model as the one in Fig. 6.

Evaluating the same index for this second experiment a value of 2.23 % has been obtained showing an increment in the simulation accuracy of about 50 %. A further improvement could be easily obtained and verified inserting, for example, the correct values for the resistance and capacitance instead of the nominal values given by the manufacturers.

V. EXAMPLE OF APPLICATION: A TRANSFORMER MODEL

A second experiment has been conducted adopting a transformer as the testing model. In this case the equipment was located in Italy while the acquisition process for the simulation was performed in USA. This gave also the opportunity of verifying the possibility to perform the operations between two remote locations.

The VI is executed in the VTB environment at the University of South Carolina and accesses, through an Internet connection, an analog-to-digital conversion board (ADC).

The connection is developed using the LabView Remote Device Access (RDA server); this protocol allows the control of an ADC device plugged into a computer located on an

Internet node as a shared resource.

The board adopted for the data acquisition features the same performance as the one used for the tests reported in the previous section, so that the same VI as that shown in Fig. 3 could be used.

The transformer under test is a single-phase transformer, with 100 VA rated power and 210 V/18 V rated transformer ratio. In order to avoid the use of voltage transducers, the transformer has been fed with a 6.72 V rms sinusoidal signal. The ADC board channel dedicated to the acquisition of the transformer secondary voltage was set to a gain value of 10.

The VTB model has been obtained by combining an ideal transformer model and two suitable inductors to represent leakage and magnetization effects.

The schematic of the VTB experience is reported in **Fig. 8**. The two gain blocks connected to the LabView channels are applied to keep into account the channel gains and adapt the signals to the proper voltage levels.

One channel is connected to the circuit simulation model where a signal controlled voltage source feeds the transformer model with the same input signal as the one applied to the real transformer.

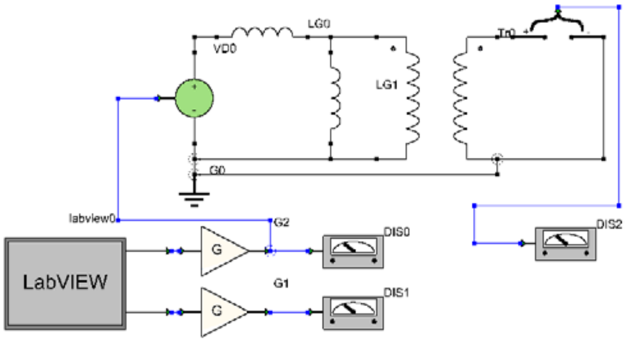


Fig. 8: The VTB schematic for the transformer example

In this case the input signal is a pure sinusoidal voltage that is applied to the system working at no-load conditions. The time evolution is documented in Fig. 9.

As reported in **Fig. 10** the correspondence between simulated and real data is quite perfect.

In this case, the model could be applied to monitor the system under different operating conditions, in order to identify a possible malfunctioning.

VI. FUTURE TRENDS

The authors are currently working on the implementation of more complex experiments. In particular a new platform has been selected to perform a more challenging comparison between simulated and real data. A test bench has been set up at the University of south Carolina, where a 4-pole, wound-rotor, 3.5 kW induction motor with rated 220V/380V, 50 Hz voltage and frequency respectively has been simulated. A six-step inverter has been simulated as well as the motor supply. Both the motor and the inverter are located at the Politecnico di Milano, in Italy. A VI has been developed in order to acquire the three-phase voltages and currents at the motor terminals.

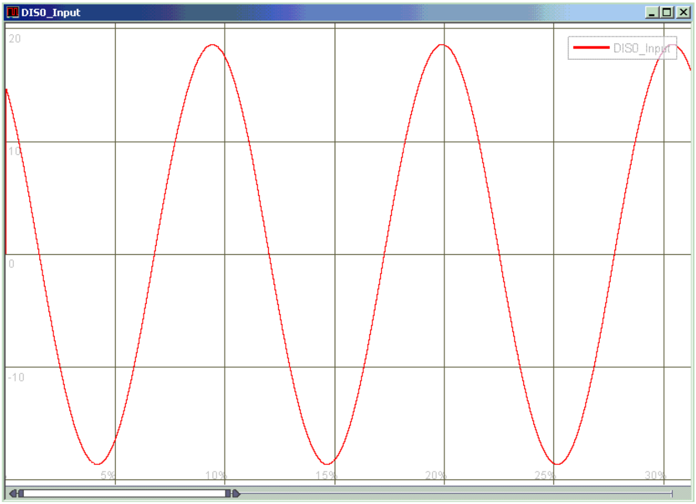


Fig. 9: The transformer input voltage (x axis in percentage of saved data, y axis in volts)

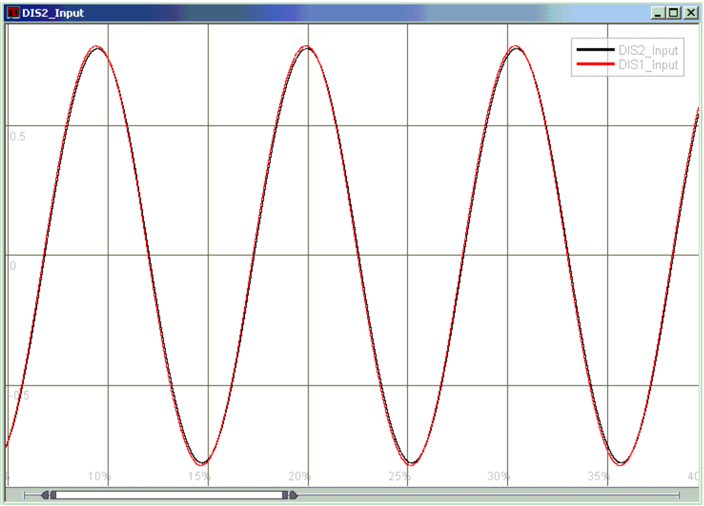


Fig. 10: Comparison between simulated and real secondary voltages for the transformer (x axis in percentage of saved data, y axis in volts)

Fig. 11 shows the voltage and current signals acquired in Milano and displayed in real time at the University of South Carolina, as a preliminary result of the realized remote test bench. Next step will be the integration of this VI in the VTB environment to compare the results with the simulation activity. By means of the multiformalism capability of VTB the authors are also planning to introduced sophisticated signal processing on the data by means of the Matlab environment such as fuzzy-logic based diagnostic algorithms.

VII. CONCLUSIONS

A first realization of a Virtual Test Bench able to acquire real signals from a remote DUT has been proposed.

The preliminary results show the feasibility of this solution and are extremely encouraging towards further developments of the VTB-LabView partnership. In particular, the paper detailed some possibility in terms of model validation for two simple example systems.

VIII. REFERENCES

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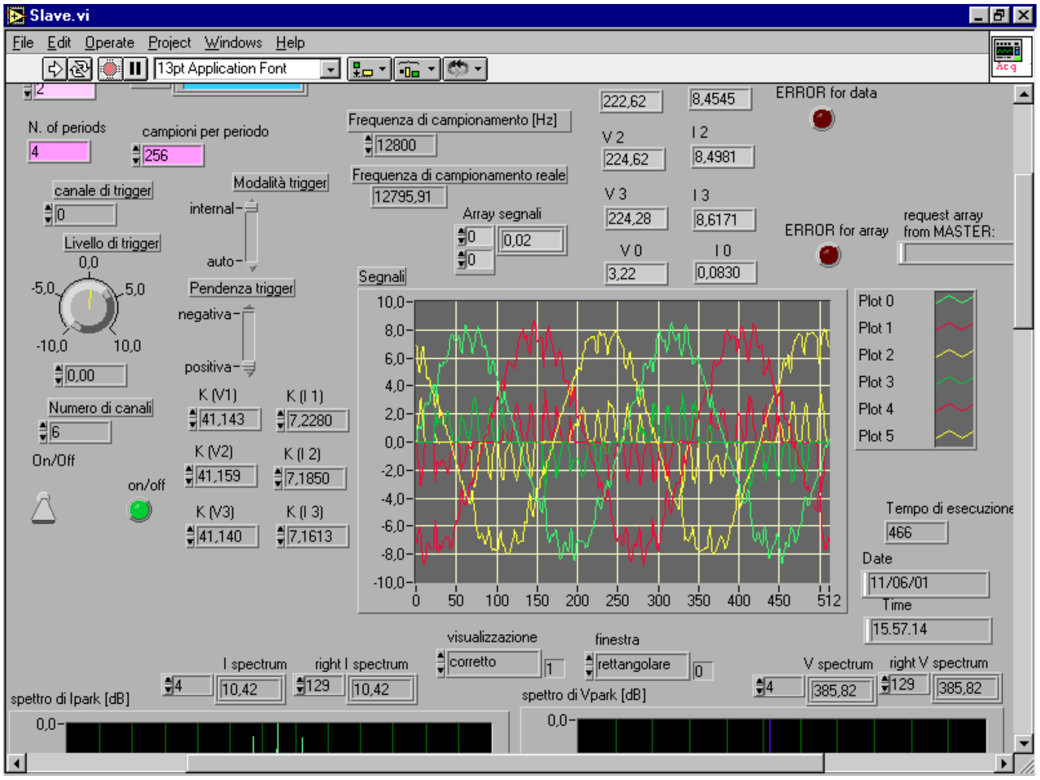

2

N. of periods: 4

campioni per periodo: 256

Frequenza di campionamento [Hz]: 12800

Frequenza di campionamento reale: 12795,91

canale di trigger: 0

Modalità trigger

Livello di trigger: 0,00

Pendenza trigger

Numero di canali: 6

Array segnali: 0, 0; 0,02

K (V1): 41,143

K (I 1): 7,2280

K (V2): 41,159

K (I 2): 7,1850

K (V3): 41,140

K (I 3): 7,1613

222,62

8,4545

V 2: 224,62

I 2: 8,4981

V 3: 224,28

I 3: 8,6171

V 0: 3,22

I 0: 0,0830

request array from MASTER:

Tempo di esecuzione: 466

Date: 11/06/01

Time: 15.57.14

visualizzazione: corretto; 1

finestra: rettangolare; 0

I spectrum: 4; 10,42

right I spectrum: 129; 10,42

V spectrum: 4; 385,82

right V spectrum: 129; 385,82

Fig. 11: The new VI that will be adopted for the future experiment