Determination of parameters of an equivalent circuit of a single-phase transformer using a remote laboratory

Joanna Baraniak†, Krzysztof Pachowicz†, Andrew Nafalski‡, Hugh Considine‡ & Zorica Nedic‡

Lublin University of Technology, Lublin, Poland†
University of South Australia, Adelaide, Australia‡

ABSTRACT: Remote laboratories, in which experimentation on real equipment is controlled over the Internet, with downloadable experimental results for further analysis and reporting, have been available since the 1990s. Sharing them on a computer network provides opportunities for creating large pools of diverse laboratory experiments, available either on a commercial or free-access basis [1][2]. The NetLab remote laboratory was developed in 2002 and is in operation at the University of South Australia (UniSA) since then. In this article, the authors report on novel remote experimentation using the NetLab, developed by PhD students/staff from Poland and UniSA staff/PhD students for determining equivalent circuit parameters of a transformer. Technical and pedagogical aspects of the experiment are discussed.

INTRODUCTION

The NetLab remote laboratory, was developed at the University of South Australia (UniSA) and has been operational since 2002 in a variety of structured courses at undergraduate, Masters and PhD levels in Australia, Sweden, Singapore, Sri Lanka and Poland. It has demonstrated the merits of its open access, robustness, user friendliness and coursework relevance [3].

Over the years, tens of thousands of students from over 50 countries accessed the NetLab to conduct experiments on real equipment located in the SCT Building at the Mawson Lakes Campus of UniSA.

The SCT Building was named after the Post Master General of South Australia Sir Charles Todd (SCT), one of the great South Australians who commanded the construction of the overland telegraph line between Adelaide and Darwin (some 3,000 km of virtually uninhabited terrain, without roads and infrastructure), and from there linking Australia by an under-ocean cable communication to the rest of the world.

Increasingly, remote laboratories, are used to apply learning analytics, by examining student on-line behaviour to draw conclusions on student progression and to guide follow-up actions to improve student learning outcomes. This applies also to the NetLab [4].

The aim of this research is to explore by a binational collaboration, an opportunity to use the NetLab remotely to design and conduct a novel remote experiment for the determination of the equivalent circuit parameters.

The classical two-port equivalent circuit of a transformer [5] was applied, consisting of the resistive-leakage inductance impedance of the primary and the secondary windings, the magnetic core loss resistance and the magnetisation reactance.

Students first conduct their measurements on the real equipment using the NetLab to perform open-circuit and short-circuit tests on a transformer. They also use analytical formulae to calculate the parameters of the transformer equivalent circuit and, finally, they simulate the circuit using LTSpice software. The three approaches to measuring, calculating and simulating of an electric circuit lead to the student development of deep knowledge of the subject matter and iterative approach to engineering procedures.

The remote laboratories enhance worldwide opportunities to conduct engineering experiments on equipment some thousands of kilometres away from the students' physical location, adding to the globalisation of engineering and technology education.

THE NETLAB

The NetLab is a remote freely accessible laboratory (only registration is needed for the access) for experimentation with real electronic instruments and electrical circuits. Students can control remotely an oscilloscope, a multimeter and a signal generator, and get their readings in real time. When they click a button on an instrument in the NetLab, the corresponding real instrument in the laboratory responds in real time in the same way as if the button on the front panel had been physically pressed.

The interactive image of the oscilloscope is such that on a standard 17" monitor it has approximately the same size as the real oscilloscope front panel (Figure 1). Please note the identity of signals on the simulated oscilloscopes on the left, and the real oscilloscopes on the right. The grey box in the figure on the right is the Agilent 256x256 relay switching matrix, controlled via the Internet physically connecting components and instruments. The PCBs on the right, in front of the switching matrix are the variable R, L and C components controlled remotely through the Internet. An effective circuit configuring system called Circuit Builder and a session booking system in the users' time zone are integral parts of the NetLab [6].
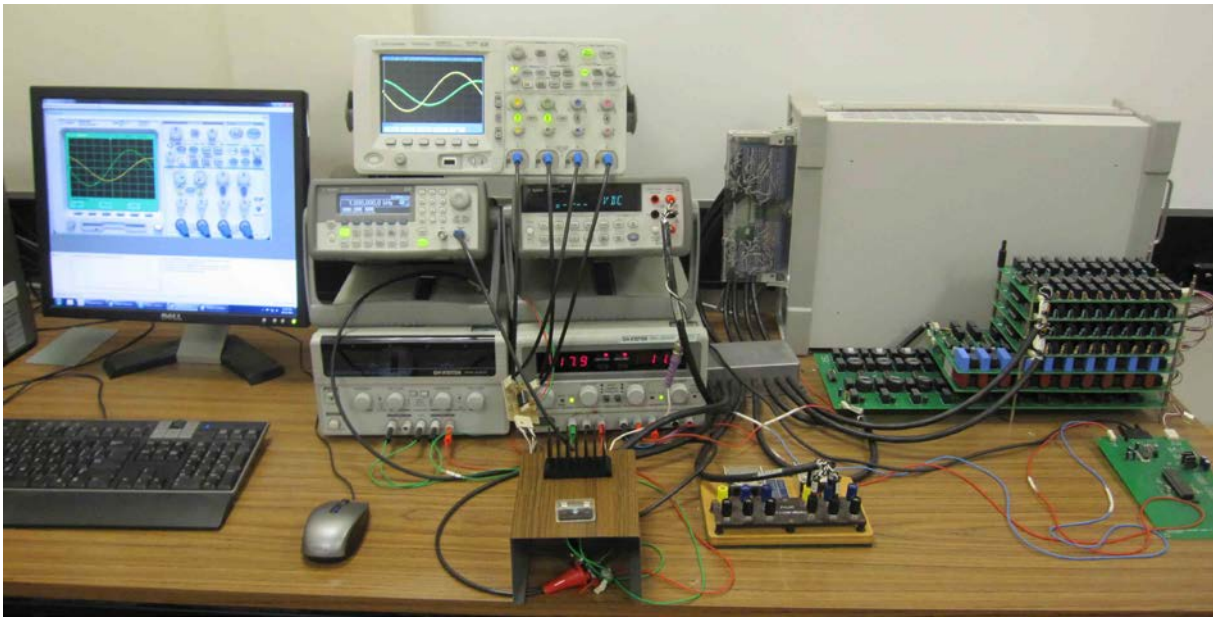

Figure 1: Physical appearance of the remote laboratory NetLab 2.

To access the NetLab, users should use the following links: http://netlab.unisa.edu.au or http://netlab2.unisa.edu.au as there are now two nearly identical systems of the NetLab available to anyone in the world who registers to use the self-defined configuration of a circuit to conduct remote measurements.

THE EQUIVALENT CIRCUIT OF A TRANSFORMER

The classical equivalent circuit of a single-phase transformer (or a single-phase representation of a three-phase transformer) is used in the experiment (Figure 2) [5].
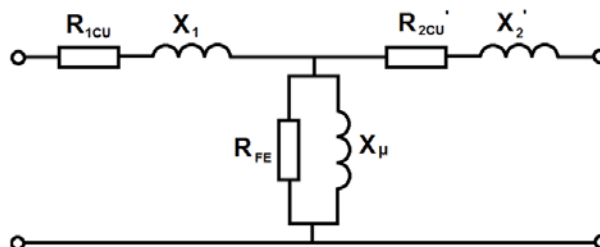

Figure 2: The equivalent circuit of a single-phase transformer.

The individual components shown in the diagram have the following meaning:

R_{1CU} - the primary winding resistance representing losses in primary copper winding;
R_{2CU}' - the resistance of the secondary winding reflected to the primary side;
X_1 - the primary leakage reactance of the winding;
X_2' - the secondary leakage reactance of the winding, reflected to the primary side;

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R_{FE} - the resistance representing the core losses in a transformer;
$X\mu$ - the magnetisation reactance of the transformer core.

The simplified circuits of the open-circuit and the short-circuit test to be performed in the NetLab are shown in Figure 3 and Figure 4, respectively. In the open circuit test, the impedance of the secondary winding is neglected, along with the impedance of the primary winding due to a small primary current and no current in the secondary.
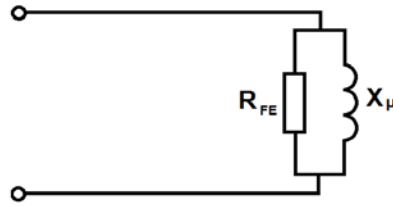

Figure 3: The open-circuit test equivalent circuit of a transformer.

In the case of a short-circuit test, the equivalent circuit consists of the sum of the transformer primary winding impedance, and the secondary winding impedance reflected to the primary side, R_{CU} and X_R.
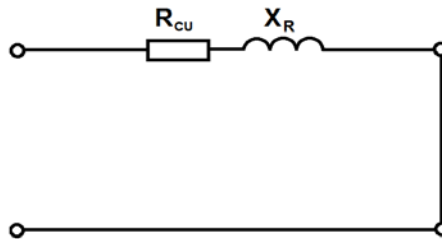

Figure 4: The short-circuit test equivalent circuit of a transformer.

PARAMETERS OF THE EQUIVALENT CIRCUIT OF A TRANSFORMER

The step-up transformer used for measurements and simulations had the following parameters:

The rated power:	SN = 50 VA
The supply frequency	f = 50Hz
The primary voltage:	U1N = 5V
The secondary side voltage:	U2N = 230V
The percentage of no-load current:	$\Delta I0\% = 1.46\%$
Percentage of no-load power:	$\Delta P0\% = 0.07\%$
Percentage of short-circuit voltage:	$\Delta UZ\% = 0.66\%$
Percentage of short-circuit power:	$\Delta PZ\% = 0.2\%$

The calculations were conducted using formulae [5] resulting from the equivalent circuits presented in Figure 3 and Figure 4. Numerical values of the calculated equivalent circuit parameters are given in Figure 5 (open-circuit) and Figure 8 (short-circuit).

SIMULATIONS AND MEASUREMENTS

The next steps of the research were simulation models using LTSpice and measurements using the NetLab. The simulation model and Circuit Builder for the open-circuit configuration are shown in Figure 5 and Figure 6, respectively.
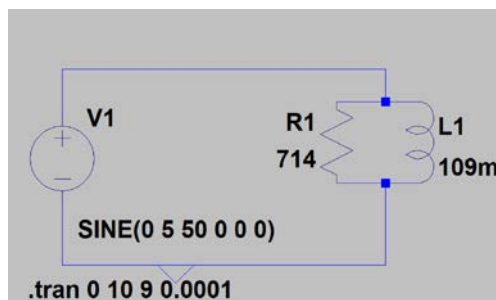

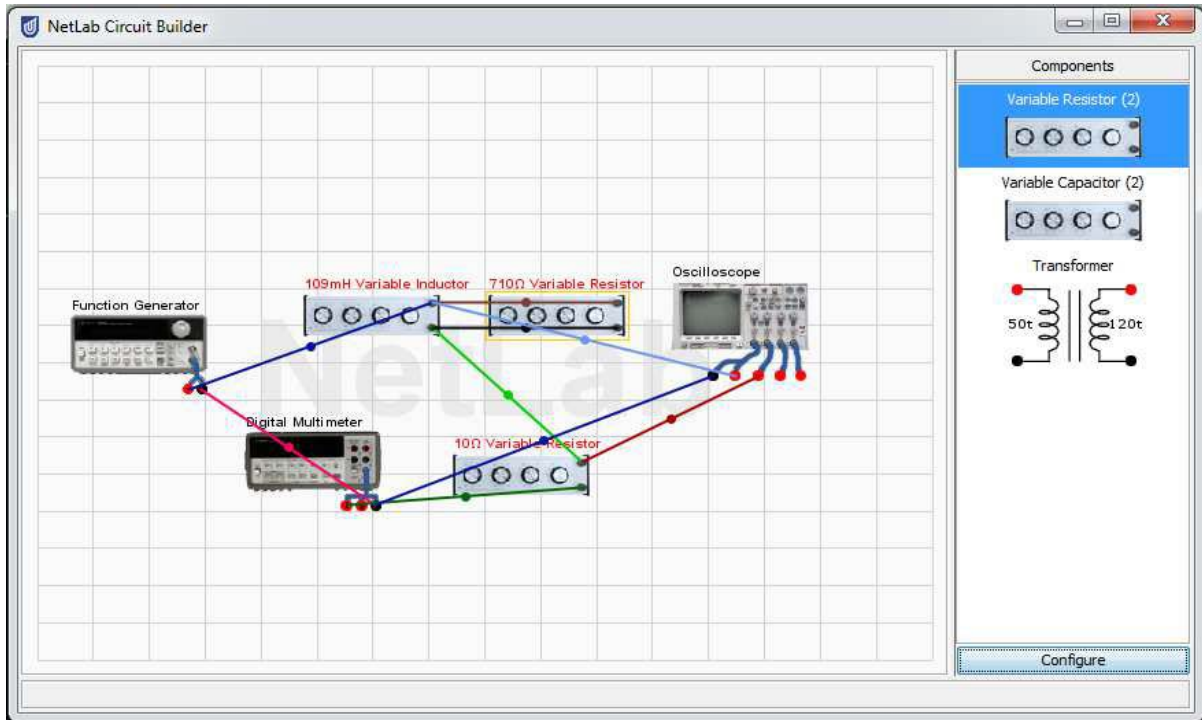Figure 5: Open-circuit simulation schematics in LTSpice.

Figure 6: The Circuit Builder in the NetLab for the open-circuit test.

The results of the measurement are shown in Figure 7; they are used to evaluate the amplitudes of the signals (voltage and current) and their phase shift. The comparison of NetLab, LTSpice and calculated values are shown in Table 1.

Table 1: Comparison of simulation, measurement and calculated values for the open-circuit test of the transformer.

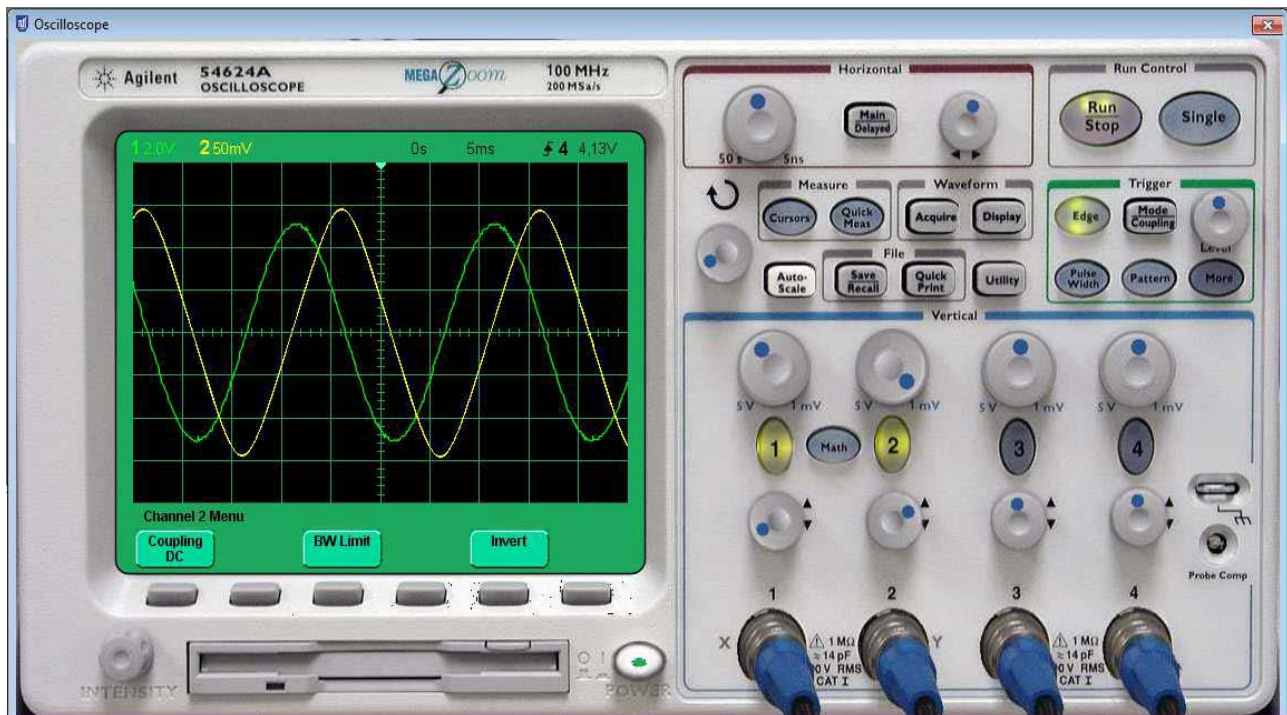|	NetLab	LTSpice	Calculated value
Voltage V [V]	5.0	5.0	5.0
Current I [mA]	140.5	145.4	146.0
Phase shift φ [°]	85.0	86.4	87.2

Figure 7: The voltage and current signals measured using the NetLab.

The simulation model (LTSpice) and Circuit Builder for the open-circuit transformer's configuration are shown in Figure 8 and Figure 9, respectively.
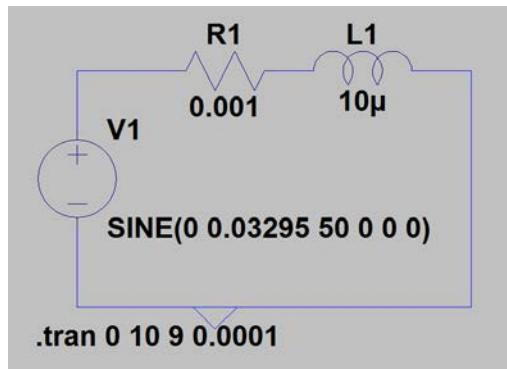
Figure 8: Short-circuit simulation schematics in LTSpice.

An example of a comparison of calculated, measured and simulated results of examining a short circuit of a transformer is shown in Table 2. Current results are scaled down (1,000 times) by increasing values of the resistance and the inductive reactance due to limited current yield of the NetLab. The results show a fair amount of agreement between different approaches to same circuit analysis and measurements.

Table 2: Comparison of simulation, measurement and calculated values for the short-circuit test of a transformer.

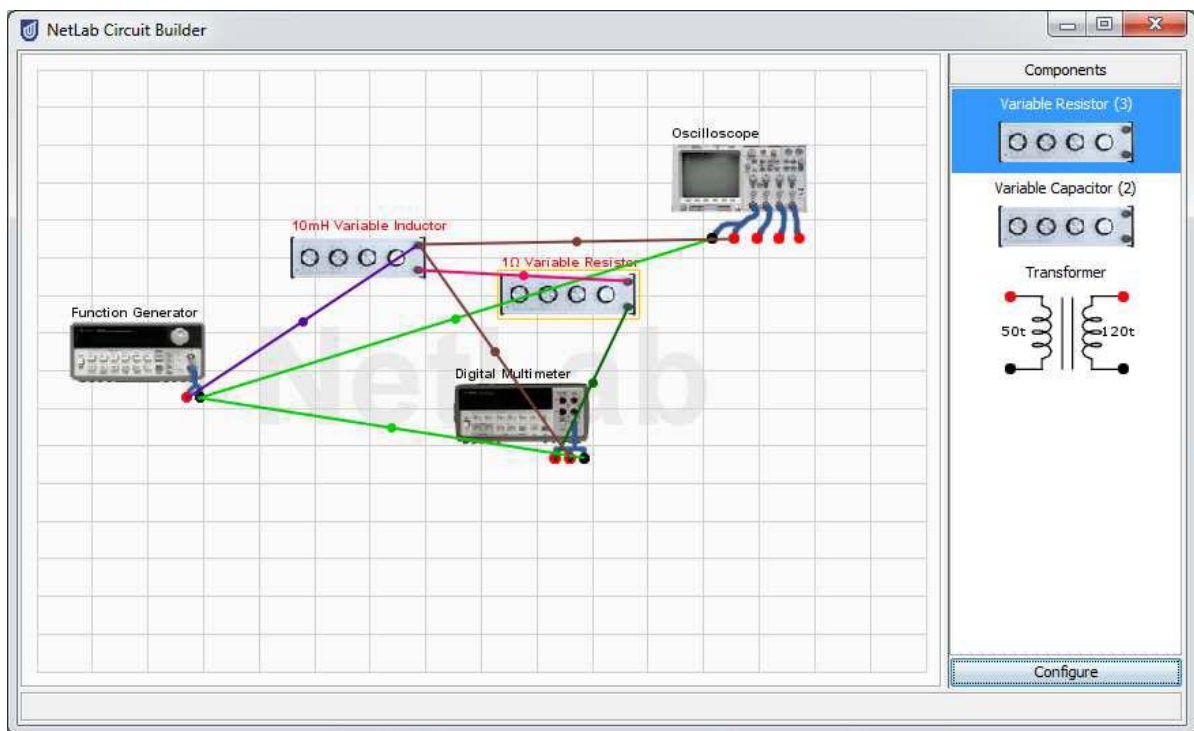|	NetLab	LTSpice	Calculated value
Voltage U [mV]	32.95	32.95	32.95
Current I [mA]	9.77	9.99	10
Phase shift φ [°]	72	72	72.33

Figure 9: The Circuit Builder in the NetLab for the short-circuit test.

CONCLUSIONS

Results of conducted measurements, simulations and calculations of a single-phase transformer are consistently similar. However, in the case of the NetLab, circuit components were real, not idealised as in the case of calculations and simulations. Real components contain parasitic elements; for example, a resistor also has a capacitance and an inductance. The same applies to connecting leads, which have certain resistances, inductances and capacitances. Therefore, using real components and instruments via a remote access brings a certain degree of realism to measurements, required by engineering and technology students, to understand the real-world environment.

Remote laboratories are increasingly used in engineering, technology and science education. Many of them are versatile, allowing for variations in system parameters and changes of configurations to be tested. These laboratories can be accessed from any place in the world via the Internet. They overcome the limitations of real laboratories related

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to scheduling classes, as they are available all the time and allow for experiments to be repeated as many times as required, also in collaboration with students from around the world. They develop the students' analytical and practical skills, something that is important for their future careers in modern industry.

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