Innovating current sensor for NILM application

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Abstract— The reduction of energy consumption, in particular the electric consumption in buildings, is a major challenge which the modern societies have to solve. The optimization and the reduction of the electric consumption require the implementation of accurate current wireless sensors to monitor this power consumption. The cost of deploying a sensors network in a small existing building has limited its development. Minimizing the number of sensors, implementing non-intrusive technology and reducing the price of a sensor node are so many challenges as we have to recover to decrease the global cost of such a setup and make profitable the monitoring of energy consumption of all appliance. In order to respond to this challenge, the main objective of this work is to finalize compact, autonomous (wireless power) current sensors, the measured signals allow, after an appropriate software treatment, an effective reading. Two fundamental topics should be taken into account. A first aspect is the use of the sensors on the field and their implementation. The second one is the effective use of the signals acquired by these sensors in the current chain of treatment. The innovative aspect of this research subject is the combining of research on various theoretical fields: sensors technology, electronics and communication, signal processing and microelectronics conception.

Keywords- Current sensor, NILM, magnetic field, thin layer, WSN, impulse response, steady state

I. INTRODUCTION

A “smart” grid is emerging as modern-day information technology is applied to the infrastructure that delivers our electricity. While innovative ideas and technology can improve reliability and reduce costs at all points in a given system, the real value of a smart grid heavily depends on how smart buildings can be [1]. Optimization and reduction of electric consumption cannot occur unless accurate monitoring is performed by wired or wireless sensors connected in a network (WSN : Wireless Sensor Network) [2]. Non-Intrusive Appliance Load Monitoring (NIALM) aims to the development of a non-intrusive system that monitors the power consumption of individual appliance by only looking at the energy from the central node of an electric network [3]. In comparison with intrusive monitoring method, NIALM has high speed transferring with huge data from the acquisition node while intrusive method is limited in bandwidth by the communication between its nodes [4]. NIALM requires added-value algorithms to analyze, classify, breakdown and assign power consumption to the appropriate appliances while intrusive methods require direct sensing at device level, as illustrated in fig.1.

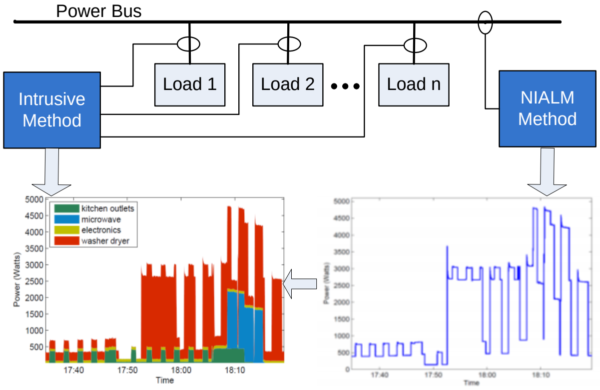


Figure 1. Intrusive and NIALM method in power monitoring application

II. CONTEXT AND CHALLENGES

There is a growing need for non-intrusive, easy to install, but still accurate plug & play sensors. Unfortunately current and voltage sensors are now an impediment to the large deployment of electric consumption monitoring in residential and industrial areas because of their costs. The main objective of this work is to develop low-power (or battery less) small wireless current sensors. The developed sensor will therefore have to meet several criteria, including size; it must be non-intrusive, autonomous and communicating. The innovating current sensor will then allow responding to operational problems existing on this type of setup of current sensors. The first problem arises during the display of current sensors within an electrical cabinet. It is necessary in order to realize an installation in perfect conditions to respect some conditions. The developed sensor will be miniaturized to achieve a competitive edge. Thus differing from the regular sensors which are fairly cumbersome and difficult to install. The use of wireless connection will increase this ease of installation. Another innovation will concern the communicating aspect of the sensor by using wireless technologies such as ZigBee. By becoming communicating the developed sensor will ease up data recovery. Indeed currently the use and the setup of the sensors is a real problem on the field. As illustrated in fig.2, the electrical cabinets being small and, at times, congested, do not allow a big amplitude of operation for the technician.

Figure 2. Internal sight of an electrical cabinet with sensors of current

As seen in figure 2, several cables overlap and the installation of such sensors is a real challenge. Moreover, the locking of the sensors in a both restricted and congested place makes the deployment even more complicated. By developing this new sensor which is both miniaturized and also simpler to install, reducing the expenses of cost. Firstly, the production cost but also the deployment cost on the field by answering the problem related to the complexity and size of the electric panel.

Another important aspect of the innovation concerns the whole issue of efficiency in order to help the analysis teams to classify in an algorithmic way. By relying on a restricted number of current sensors which can offer a good precision, we can install sensors which allow easy detection of the standby mode or the activity of specific equipment or another condition.

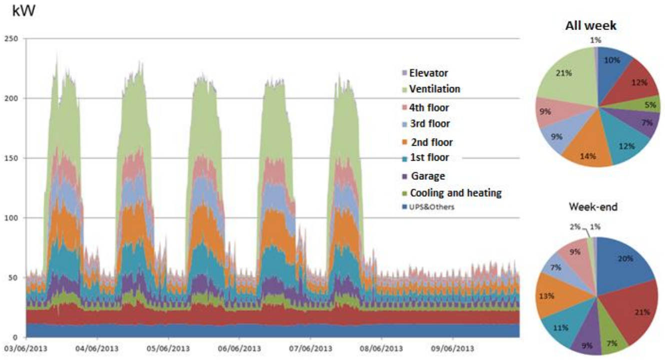


Figure 3. Example of load curve of an installation

So, the complexity of the processed information is reduced (volume, proportions, treatment, etc.) to retain only relevant information (ON/OFF, standby, etc.). The acquisition system will then evolve towards the use of precise sensors on the main circuit of the installation and will rely on secondary sensors who allow interpreting effectively a curve of precise load. This will allow deploying precise sensors only in the general panel, thus further reducing the setup cost. The load curve, on figure 3, can be analyzed by the joint use of pattern recognition algorithms and the easier lecture of the signals by attributing the consumed energy by usage.

The challenge is to design and develop miniaturized sensors able to measure the magnetic field variation induced by a current flowing through an electrical cable.

III. DESIGN OF THE FIRST PROTOTYPE

The developed sensor will therefore have to meet several criteria, including size; it must be non-intrusive, autonomous and communicating. Regardless of the selected sensor, the main selection criteria are: the accuracy of the sensor, its sensitivity, its dynamic range, footprint, ease of installation, and the nature of the signals to measure (DC or AC). Indeed there are two types of signal to measure: depending on if the signal changes rapidly or remains constant.

Magnetic current sensors are often used for direct sensing, but can be made non-intrusive and used in lower quantities when applying NIALM technologies [4]. The first approach is theoretical and is about simulating the environment in order to understand how the sensor is going to react on the field. Various properties have been tested such as the materials that include copper and aluminum, currents ranging from the ampere to the kilo ampere, frequencies of 50 Hz up to hundreds of kilo Hertz or if the measured cable is equivalent to mono strand or multi strand.

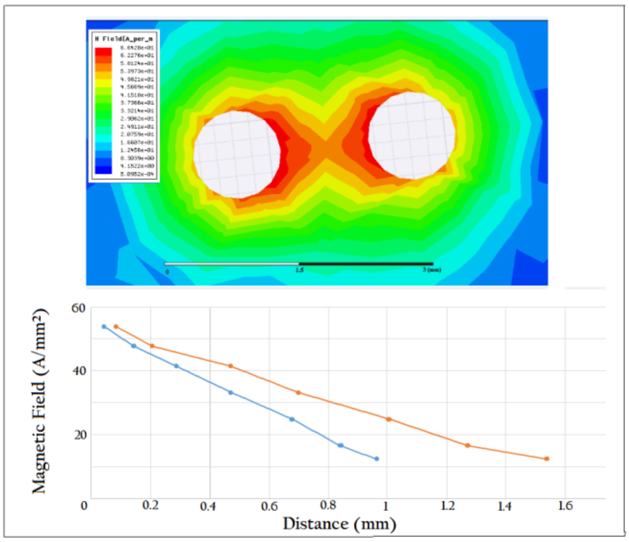


Figure 4. Study of the magnetic field

This work will then allow choosing the sensor which suited the best to our case. In figure 4, the magnetic field is presented in figure 4 (simulated using HFSS) is generated by a current of 10 A in two wires. The orange curve represents the field according to the X dimension and the blue one according to Y. The results obtained allow identifying the skin depth effect, an important fact to take into consideration when planning the design of the sensor.

$$\delta = \frac{1}{\sqrt{\mu\omega\sigma}} \qquad (1)$$

Where δ represents the skin depth, ω is the pulsation, μ is the magnetic permeability, and σ is the electrical conductivity.

The generated magnetic field depends on the position of the sensor. In order to overcome this problem, the possibilities offered by a flexible sensor on foil were explored. These sensors must be made with thin layers of magnetic material, with an original design for the detection of the magnetic field induced by the variation of the detected current. A first prototype was designed with the following characteristics (cf. figure 5): 2 coils (12.5mm*30mm), 30 spires by coil with a pitch of 200µm between 2 spires. The sensor used two coils connected in opposition.

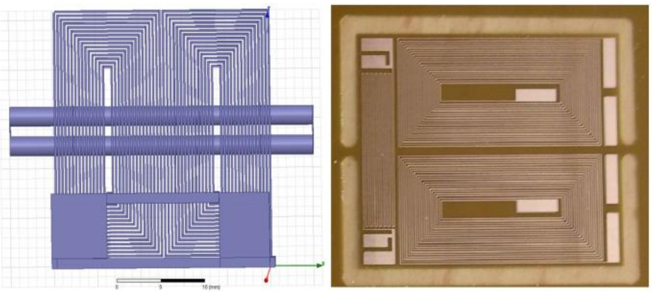


Figure 5. First prototype, layout on the left and real sensor on the right

After tests on sensors made up of iron and a second version made of silver, the first functional prototype will consist of copper on a substrate in Kapton ®. In this publication the presented sensor will be a current sensor possessing 200µm wide and 200µm spacing, however four different sensors have been designed with spacing geometry varying between 50µm and 200µm. This sensor presents a thickness around 32µm.

IV. MEASURE OF CURRENT AND IMPULSIVE RESPONSES

As explained above there are two types of signal to measure: transient and constant. The first sensor in copper will allow measuring impulsive responses. In the future and with the use of an integrator-type electronic device the steady state will be detected and measured.

In order to test the capacity of the sensor to measure a current passer-by in a cable, we use an oscilloscope to observe the change of current during a variation of power. The system will be placed in an armored setup to limit the impact of the environment on the sensor as illustrated on figure 6. The sensor will be positioned on a support and will be in direct contact with the cable sheath to measure.

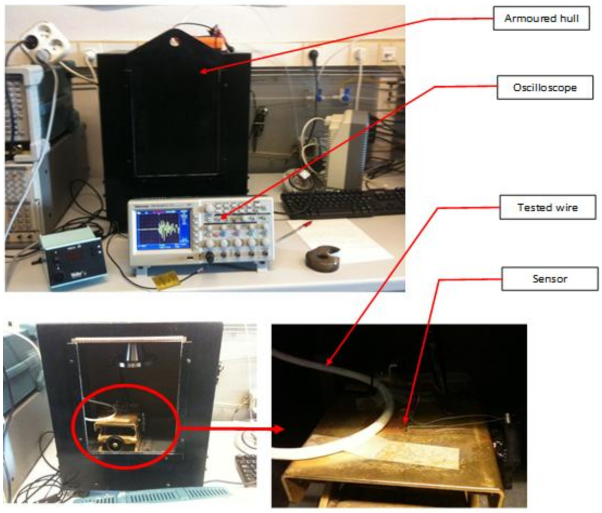
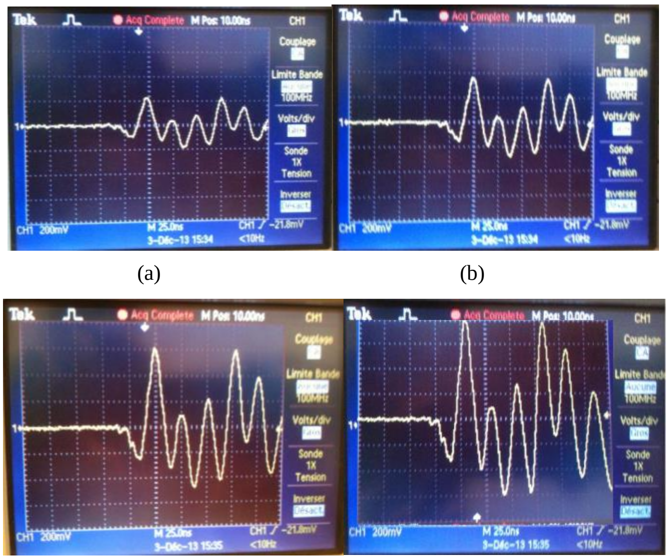


Figure 6. Measurement setup

These tests are made by using only one of the two coils of the sensor. By using the sensor connected in series, similar results can be obtained with however a more important current and a noisier signal. These tests were also able to assess the impact of the position of the sensor, whether it is parallel or perpendicular to the direction of the cable. The results, presented on the figure 7, show the pulse during a starting up of a device of 95W. By adding an autotransformer, the power of this device can be modulated. So the signature of a given device can be checked according to several amplitudes.



(a) (b)

(c) (d)

Figure 7. Transient measurements according to the power

The signature of the measured device has been well verified. Its amplitude modulates according to the transmitted power. The figure 7.(a) corresponds to 20 % of the maximal power of the device, in (b) 30% of the maximal power, (c) is 50% while 70% of the 95W is transmitted on the figure (d). The sensor has a linear response regarding the input power. By decreasing the spacing between turns an increase of the noise is perceptible. In conclusion this first prototype allows to capture the impulsive response of a device and to check its signature as well as its amplitude after calibration. The major drawback of this first sensor comes from the non-detection of the steady state.

V. FUTURE TASKS

In order to resolve this, an electronic system must added. As a first step, a test bench will be used to design a Rogowski coil model. A Rogowski coil is composed of n uniformly wound of turns on a nonmagnetic core, and corresponds to an improved version of our new sensor. The study of this model would provide a better understanding of our prototype. Former of constant cross-sectional area A_c in toroidal fashion forms a closed loops, the voltage $V_{rc}(t)$ induced within the coil can be expressed as :

$$V_{rc}(t) = -\mu_0 A_C n \frac{di_p(t)}{dt} \qquad (2)$$

where μ_o is the permeability of vacuum and $\mu_o A_c n = M_c$ is the mutual inductance of the coil and also termed as sensitivity of RC.[5]. Coupled with this theoretical study the implementation of a calibrated bench of measure, as shown in figure 8, would lead a better accuracy of the model.

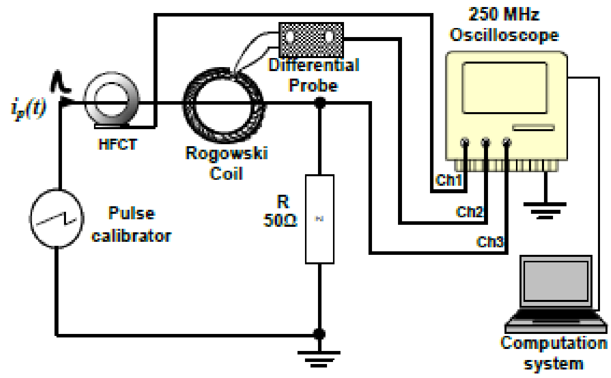


Figure 8. Laboratory experimental setup for Rogowski coil measurements [6]

This test phase will allow choosing different parameters such as diameter of the core and number of turns of the current sensor. The diameter will be selected so that the coil should be able to fit into tight spaces, moreover, suitable diameter is important for stable design of an RC system. The increase of the number of turns will make the system more sensitive and will lower the resonant frequency. The performance of this experimental setup joint with the used of an integrator will validated the impulse response as discussed above.

VI. CONCLUSION

Wireless sensors networks will play a major place in our life through smart building application or BAN (Body Array Network) where the reduction of energy is a major challenge. The sensors, as well as the associated electronics, have to solve a double paradox, be more efficient (non-intrusive, high input dynamic, good accuracy, wireless transmission) and to be as cheap as possible, in particular for the small buildings. To minimize the number of sensors, to implement non-intrusive technology and to reduce the prize on a sensor node are so many challenges as we have to recover to decrease the global cost of such an setup and make profitable the monitoring of energy consumption of all appliance. Furthermore, the selected sensor will have to fulfill various problems: electrical requirements (desired performance, maximum overload to tolerate...), mechanical requirements (size, weight and material) as well as environmental constraints (temperature, external interference, external power...).

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