Solid state electric field sensor

Maciej A. Noras
Dept. of Engineering Technology
University of North Carolina at Charlotte
phone: (1) 704-687-3735
e-mail: mnoras@uncc.edu

***Abstract*—Power measurement systems, such as Phasor Measurement Unit (PMU) structures, require installation of special voltage and current instrument transformers connected to the energized conductor to collect data from the power line. While non-contacting methods of current monitoring are already well known and implemented, the contactless voltage monitoring is still lacking. This paper describes a tunable capacitance solid state electronic structure that is very promising in its electric potential measurements. The sensor is capable of the voltage monitoring on energized wires and unshielded cables in a non-contacting fashion. The theoretical background of the sensor operation along with experimental results are presented.**

I. Introduction

Modernization of the existing power electric grid became a goal of many nations, corporations and businesses. The much anticipated power network of the future has been dubbed "smart grid", and represents a vision for a digital, interactive power infrastructure. It promises numerous enhancements, such as increased reliability and efficiency, affordability, digitalization, energy security, integration of renewable and alternative energy sources, etc. [1, 2, 3]. Most of the potential improvements that have been and will be implemented rely on quick, automated communication, monitoring and protection of the power grid. Fast and reliable flow of information enables the smart grid system to respond to the changing conditions in a proactive and timely way. The next paragraphs will briefly describe existing voltage measurement techniques utilized in power line monitoring, followed by description of a novel, solid state sensor and its feasibility to power line voltage measurements.

II. Present state of The voltage sensing techniques

There is an abundance of various current sensing techniques available for power line monitoring. These sensors rely on either direct connection to the conductor (shunts) or on the magnetic field created by the flowing current (current transformer, Rogowski coil, Faraday and Hall effect sensors, magnetoimpedance sensors). Voltage sensors do not come in such broad variety. Methods used for voltage measurements can be divided into the direct measurement and the electric field coupling techniques.

A. Voltage sensors

Resistive divider - the power line voltage can be very easily measured by a resistive voltage divider, directly hooked to the live conductor. The resistors need to be of high precision and very high resistance (especially for high voltage lines) to minimize the current flow through the divider [4]. Resistive dividers are subject to change of the divider ratio due to resistor material instability over long period of time [5]. Due to this issue they are seldom used in power line measurement and monitoring. They are also relatively large and heavy.

Voltage transformers - the wire-wound voltage transformers are precise at the nominal frequency, but introduce large errors for frequencies beyond the transformer bandwidth. The capacitor-coupled transformer (CCVT) became a very popular instrument for voltage measurements due to its relatively low cost. During the transient conditions the reading error of the CCVT is very large because the transformers characteristic deteriorate at frequencies other than the fundamental. Its readings are easily influenced by stray capacitances, therefore it requires shielding. Parameters of the CCVTs are not stable and shift with time, introducing additional errors [6]. Several hybrid voltage sensors were proposed to improve the CCVTs performance (for example, resistive/capacitive divider that improves accuracy for high frequency transient signals, [4]).

Electrooptical sensors - the Kerr and Pockel's effects are the electrooptical phenomena used for the DC and AC voltage measurement. The Kerr phenomenon is observed in polar liquids and requires very high electric fields. The electrooptical response is nonlinear (quadratic). It has not been used for power line voltage monitoring, only very limited experimental work on its use in fault detection was published [7]. In Pockel's effect the response is directly proportional to the electric field, and it has been attracting much more attention (for example, [8, 9]). Units that integrate Pockel's and Faraday effects are available from companies such as ABB [10] or ALSTOM [11]. Unfortunately, Pockel's effect devices are expensive and need an external laser beam source.

B. Need for small, inexpensive and integrated sensors

With the advent of the smart grid, there is a growing need for accurate, reliable, inexpensive, easy to mount on the line or cable and small sensors that can provide real-time information about the state of the power lines. Traditional transformer methods are not feasible due to the size, cost and loss of accuracy when used beyond the specified bandwidth. The electrooptical current and voltage sensors provide high accuracy in magnitude measurements, but he phase angle measurements exhibit significant time delay that translates to phase angle error in the single degrees range [6]. The biggest inconvenience of the all optical methods is that they require laser source that powers the optical system, and the entire device becomes large and bulky. Typically, the power source and data processing unit are located on ground with the signal and data optical fiber link connected to the sensor attached to the power line. The current sensing technology offers abundance of methods. Some of the techniques are already being used in power lines measurements and monitoring, some need to reach their maturity before the can be utilized. Voltage sensing does not seem to have that many options available. Smart grid network would benefit greatly from voltage sensing devices that are accurate, inexpensive (i.e. can be massively deployed). Long distribution lines are a good example demonstrating a need for voltage sensors. The feeder distribution point must deliver the voltage that is excessively high to ensure that the voltage at the end of the line is never below the specified minimum value. The voltage sensor at the end of the line, which can report real-time voltage data back to the feeder, will allow for the voltage adjustments, as demanded. In result, the network can be used more efficiently. Since early 1990s there is an ongoing effort on development and deployment of commercial phasor measurement systems. A typical phasor measurement unit (PMU) collects simultaneously the magnitude and the phase shift of the voltage and current and provides that information to the data center along with the time at which the measurement was taken. A typical PMU system like the one shown in Figure 1 requires bulky instrumentation. This work proposes a voltage sensor that can be a step toward much smaller PMU devices.

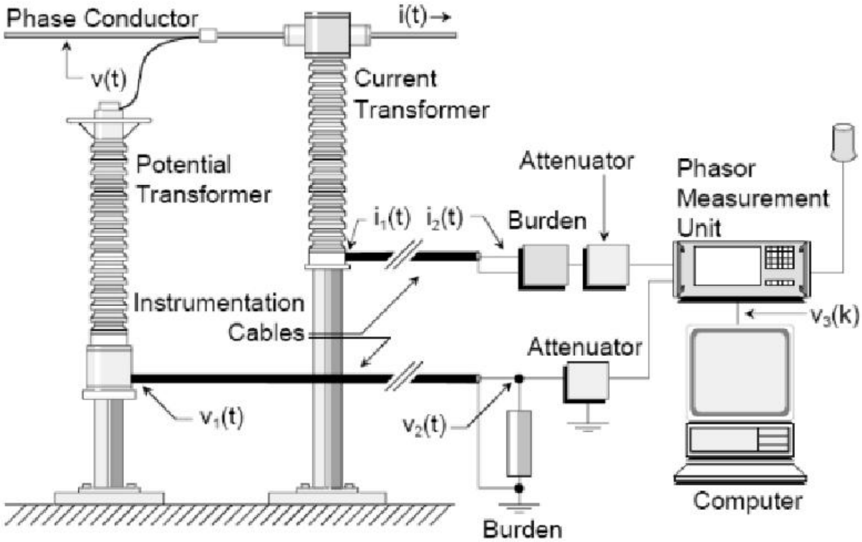

Figure 1. Typical PMU system [6].

III. VARACTOR DIODE AS A VOLTAGE SENSOR

The technique proposed for the voltage sensing was described in detail elsewhere [12]. Figure 2 presents the basic circuit diagram of the sensor. The varactor couple used in the design has to be carefully matched, so they have identical capacitance-voltage characteristics. They are driven with a high frequency 1 MHz sinusoidal signal. from an external function generator through a 1 to 1 transformer. The DC voltage in proximity of the sensor causes changes in the capacitance of the varactor and affects the magnitude of the high frequency waveform. That change can be detected as change in the value of the current flowing through the center tap wire of the transformer, and recorded as a voltage drop across the 1 kΩ resistor. The sensor has been successfully used in low DC voltage tests. In order for it to be useful in the power line/cable monitoring, it has to be capable of detecting AC voltages of 50/60 Hz and of high frequency transients.

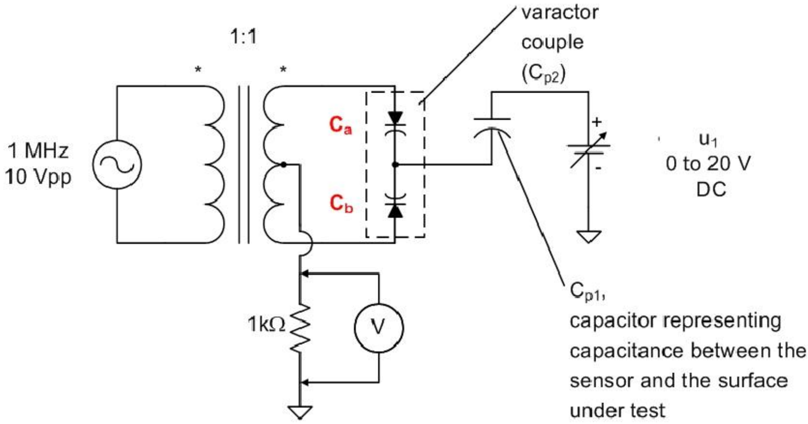

Figure 2. Varactor-based variable capacitance [12]

A. *Experimental setup*

The varactor sensor was installed on an open-ended (no load, therefore no current flowing through the conductor) insulated wire (AWG 12, diameter of the wire 2.05 mm, PVC (polyvinyl chloride) insulation thickness of 2 mm), as shown in Figure 3.

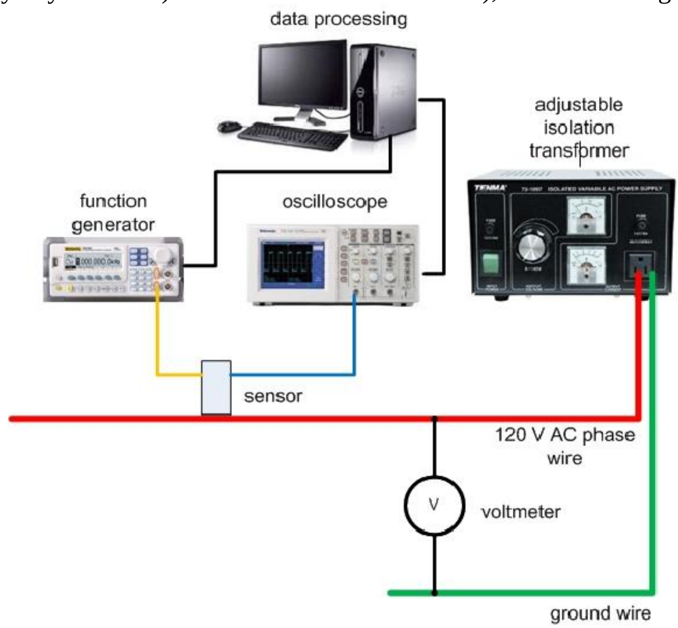

Figure 3. Test setup

There was no galvanic connection between the sensor and the conductor. The AC voltage of 60 Hz applied to the wire was adjusted between 0 and 173 V (rms). The sensor’s response is in the form of AC signal which is exactly in phase with the AC signal in the wire. Figure 4 presents the peak-to-peak value of the voltage coming out of the sensor vs. the rms value of the voltage present on the conductor in the cable. Thanks to the modulated varactor technique there was no charge accumulation on the sensor, therefore the signal did not drift and was very stable. The varactors are driven with 1 MHz 10 V peak-to-peak sine signal from the external function generator and the sensitivity of the sensor can be adjusted by changing the driving signal magnitude.

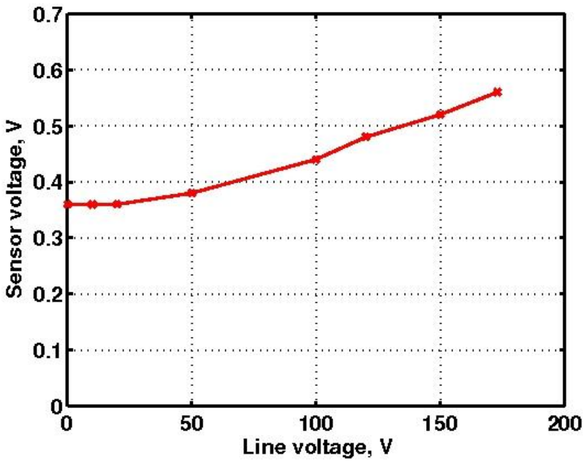

Figure 4. Example result of the AC voltage sensing

IV. Conclusion

The voltage sensor presented here is a promising tool for the line voltage monitoring. The next step in this research involves combining the sensor with a current measurement technique and development of the self-powered (utilizing electromagnetic field of the power line), integrated phasor measurement unit.

References

[1] U. S. Department of Energy, “Smart grid: An introduction,” http://www.oe.energy.gov/ Documentsand-Media/DOE_SG_Book_Single_Pages(1).pdf, 2008.

[2] EPRI, “Smart grid leadership report: Global smart grid implementation assessment,” http://my.epri.com /portal/server.pt?Product_id=000000000001021417, 2010.

[3] S. Massoud Amin and B. Wollenberg, “Toward a smart grid: power delivery for the 21st century,” IEEE Power and Energy Magazine, vol. 3, no. 5, pp. 34 – 41, 2005.

[4] R. Minkner and E. O. Schweitzer, “Low power voltage and current transducers for protecting and measuring medium and high voltage systems,” in Proceedings of Western Protective Relay Conference, Spokane, WA, Oct. 1999, (WPRC ’99), 1999.

[5] V. Proca and N. Paduraru, “Methods for non-conventional measuring sensor integration in the medium voltage electrical equipment,” in Proceedings of 2005 IEEE Power Tech, 27-30 June 2005, St. Petersburg, Russia, pp. 1 – 6, 2005.

[6] Z. Huang, B. Kasztenny, V. Madani, K. Martin, S. Meliopoulos, D. Novosel, and J. Stenbakken, “Performance evaluation of phasor measurement systems,” in Proc. of Power and Energy Society General Meet-

ing - Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh, PA, July 20-24, 2008. IEEE, pp. 1–7, 2008.

[7] T. Englert, B. Chowdhury, and E. Grigsby, "A laboratory investigation of electro-optic Kerr effect for detection of electric transmission line faults," IEEE Trans. Power Deliv., vol. 6, no. 3, pp. 979 – 985, 1991.

[8] T. Giallorenzi, J. Bucaro, J. Dandridge, A., G. Sigel, J. Cole, S. Rashleigh, and R. Priest, "Optical fiber sensor technology," IEEE Trans. Microw. Th. Techn., vol. 30, no. 4, 1982.

[9] J. Zhang, C. Xie, and Z. Yuan, "Application of the Pockels effect to high voltage measurement," in 8th International Conference on Electronic Measurement and Instruments, 2007. ICEMI '07, pp. 4–495 – 4–499, 2007.

[10] ABB, "ABB: OMU Optical Metering Unit 72.5-550 kV Systems, 50/60 Hz," http://www05.abb.com/global/scot/scot245.nsf/veritydisplay/f299f407c604c3048525755f006c7cfd/$file/omu_2gnm110052_new.pdf, 2010.

[11] ALSTOM, "COSI-NXCM specifications," http://www.nxtphase.com/products-nxcm-specs.php, 2011.

[12] M. A. Noras, "Electric field sensor based on a varactor diode/MIS/MOS structure," in Proceedings of 2010 IEEE Industry Applications Society Annual Meeting (IAS), 2010, pp. 1 – 3.