DESIGN, REALIZATION AND CHARACTERIZATION OF A HIGH CURRENT MEASUREMENT SYSTEM WITH ROGOWSKI COIL SENSOR

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Abstract

This paper describes the design, realization and basic characterization of the high-voltage high-current measurement system based on Rogowski sensor using electro-optical transfer of the measured signal. We present the principal schemes of the system and partial evaluation results. The system is aimed for precision on-site measurements on the HV distribution grids.

Introduction

The work was done as a part of „Power and Energy“ project in the framework of the European Metrology Research Programme [1]. The aim of the work was to design, realize and characterize a precision AC current measurement system for electrical current up to 10 kA in HV environment based on the Rogowski coil for application in on-site measurements.

Measurement System Design

The HV current sensor is based on patented multi-winding technique [2] of Rogowski coil.

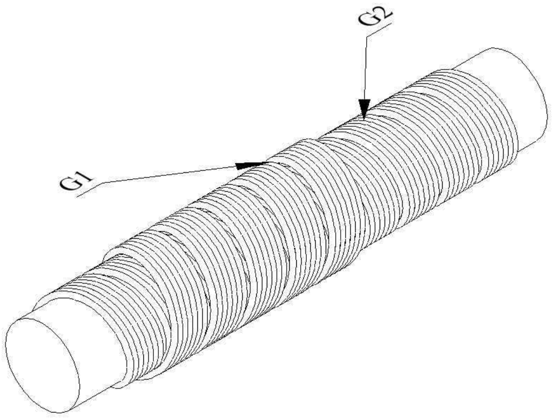

Fig 1. Winding structure of Rogowski coil

The sensing coil consists of two wire groups wound in opposite direction on the same supporting core. This arrangement ensures nearly ideal superimposition of the axes of forward and return sensing coil and therefore excellent suppression of external transversal magnetic fields. The electrical shielding of the sensor coil consists of two wire groups similar to sensor coil wound in opposite direction. The shielding wires are individually isolated and interconnected in one single point. This shielding construction eliminates the circular current affecting the sensing coil functionality but maintains the low impedance needed for shielding functionality. The low impedance is principally ensured by compensation of magnetic field. The ground current from external electric field coupled to the shielding flows symmetrically in two identical wire groups but in opposite direction and therefore the internal magnetic field from this source is mutually cancelled. In comparison to classic metal foil shielding the patented shielding coil arrangement ensures excellent mechanical flexibility of the sensor cable and excellent inductance i.e. impedance elimination.

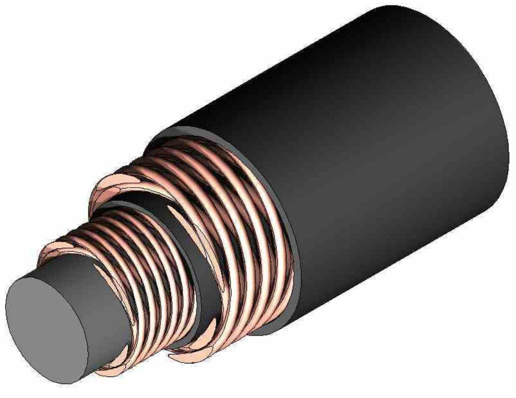

Fig. 2. Structure of complete sensor cable with sensor coil and electrical shielding coil

The HV current sensor is expected to work in a high voltage environment and therefore the sensing part has to be galvanically separated from the reading part of the measurement system with respect to working high-voltage environment. The measurement system is designed as two standalone units mutually interconnected only via pair of optical fibers. The real-time data are sampled with the sensor unit and transferred through the first optical fiber to the processing output unit. The second optical fiber is used to power the sensor unit. This fiber is fed by a laser emitter located in the output unit. The laser beam energy is converted into electrical energy in the sensor unit by means of high efficiency photovoltaic cell. This concept of power supply enables continuous long-term measurement without interruption due to limited life-time of a battery.

The principal diagram of the sensor unit is shown in the figure 3.

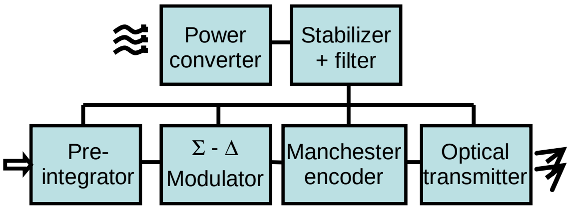

Fig 3 The sensor unit communicating and powered via optical fiber

The sensor is principally a di/dt sensing element and therefore the signal amplitude increases with high frequency content. In order to avoid saturation of the measurement system with current signal containing transient or high harmonic content, the signal is pre-integrated by passive low-pass filter in the sensor unit prior to active processing. The pre-integrator transfer function is then eliminated in the output unit by complementary design of the post-integrator filter.

The linearity of the sensor unit is guaranteed using Σ - Δ A/D conversion technique with 24-bit no missing code resolution. At data rate 40 kHz the effective resolution is 19-bit. In order to reduce the number of the optical fibers needed for the transfer of data into the processing output unit the data are Manchester encoded (Phase encoding). With the Manchester encoding the clock signal can be recovered directly from the data signal via phase-lock loop and therefore no extra clock link is needed.

The figure 4 shows the principal diagram of the output unit.

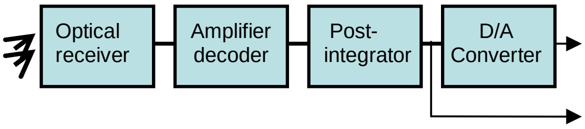

Fig 4. The output unit of the measurement system

The received digital encoded signal is decoded and post-integrated with Field Programmable Gate Array (FPGA). The pre- and post-integrator are designed as partial complementary filters which in cascade realize the integrator function converting the di/dt signal from the sensing coil into current-proportional signal. The output signal from the processing unit is available in two modes: digital word sequence for digital end-devices and analog signal for analog end-devices. The analog output circuitry uses composite 24-bit D/A converter in order to recover the dynamics of the input 24-bit A/D conversion technique. The partial D/A converters of the composite arrangement are individually in-situ calibrated and individually controlled by the FPGA via Σ - Δ 24-bit A/D feedback conversion. The feedback A/D converter has the same design as the input sampling A/D converter. This approach ensures accuracy and dynamics of the whole current measurement chain determined principally by the parameters of the A/D converter.

High Current Source Design

The high current needed for calibration and test purposes is generated in the toroidal arrangement. The air core toroidal coil generates homogeneous circular magnetic field simulating the field of ideal infinite wire. At normal operation the sensor coils are placed into the toroid. The sensitivity of the sensor coil to transversal magnetic field can be precisely evaluated by closing the sensor over the toroid winding. The integrated power source contains signal generator with capability of basic harmonic signal with programmable higher harmonics content and special signal shapes generation for transient simulations. The source is equipped with 1kVA power amplifier with current control servo loop ensuring output current distortion at full power lower than 0.1%. The calibration toroid is an inherent part of the source.

The principal diagram of the High Current Power Source is shown on the figure 5.

The High Current Source is shown on fig. 6 and 7.

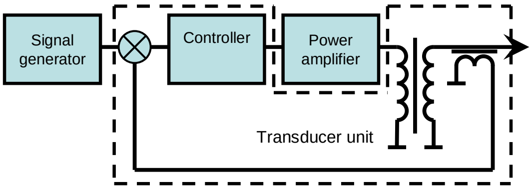

Fig.5. Current source – principal diagram

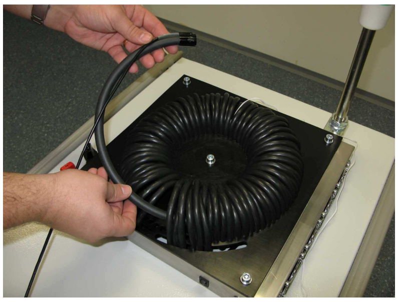

Fig. 6. Current source – calibration toroid

Fig.7. Current source – generator and power unit

Characterization

The measurement of linearity was done in the range of current 2 – 6000 A in two subranges at industrial frequency 50 Hz. The subranges were used to obtain optimum resolution from the reference standard of power and energy RS 2310E. The RS2310E specifies maximum current measurement error of 0,01% (product of APPLIED PRECISION Ltd.).

The current linearity in the range 2 – 120 A

The linearity error and calibration curve of the measurement system with the Rogowski coil is shown in the figure 8. The linearity error for current amplitude measurement is within 0,01% in the whole range and it remains within 0,005% for currents above 10 A .

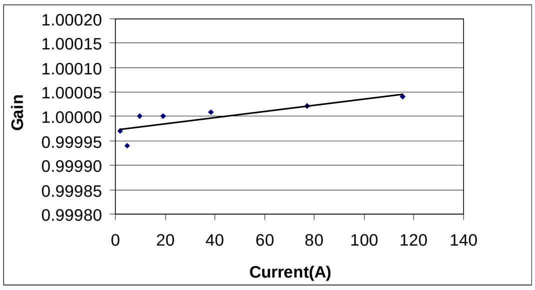

Fig.8.The current amplitude measurement error and the calibration curve from 2A to 120 A

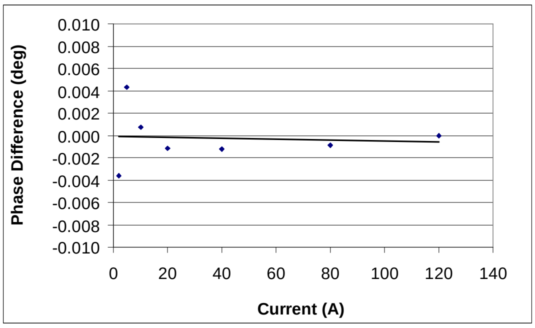

Fig.9.The current phase error and the calibration curve from 2A to 120 A

The phase error remains in the range within 0,005 deg.

The current linearity in the range 120 – 6000 A

The figures 10 and 11 show linearity error as calibration curves of the Rogowski coil sensor in the measurement range from 120A to 6000 A. The linearity error for current amplitude measurement is within 0,01%.

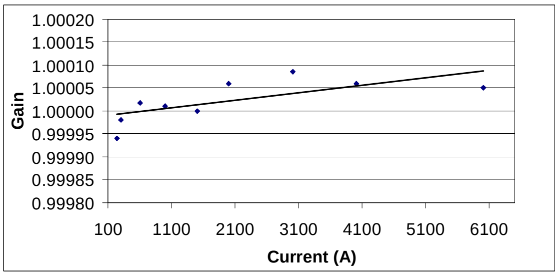

Fig 10. The current amplitude measurement error and the calibration curve in the range from 120 A to 6000 A

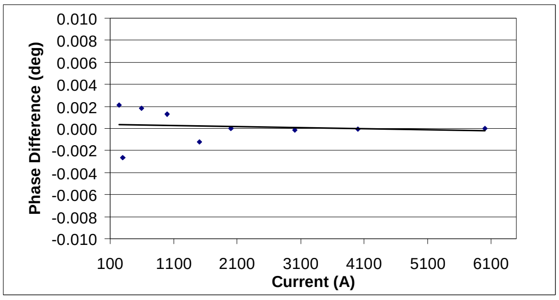

Fig 11. The current phase error and the calibration curve from 120 A to 6000 A

The phase error in the measurement range from 120A to 6000A remains within 0,005 deg.

Conclusion

The measurement system of high currents for on-site application was designed and realized. The galvanic separation of the Rogowski current sensor and the output unit was achieved by using the optical fibers for data and power transfer. The system was characterized in the current range 2 A - 6000 A by linearity error for current amplitude measurement and phase error in two subranges. The linearity error of amplitude measurement was lower than ± 0.01% and the phase error did not exceed ± 0,005 deg in the whole evaluated measurement range from 2 A to 6000 A .

Further measurements up to 10 kA on innovated Rogowski coil sensors are planned to be done in the near future

Acknowledgement. Partial research leading to these results has received funding within EURAMET joint research project from the European Community's Seventh Framework Programme, ERA-NET Plus, under Grant Agreement No. 217257. Partial research leading to these results has received funding from the Slovak Research and Development Agency under project APVV-0546-07.

References

[1] P. Vrabček, "The SMU Activity in the JRP T4.J01 Power and Energy " , *WP 5 Meeting, MIKES 2009 Digest*, Espoo, Finland, pp. 1-3, June, 2009.

[2] L. Grno, "Precision flexible current sensor" European patent EP1960796