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A Current-Comparator-Based High-Voltage Reference Inductor

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Abstract — **The development of a current-comparator-based high-voltage reference inductor at the National Research Council of Canada (NRC) for calibrating loss measurement systems of large high voltage shunt reactors is presented. The high voltage reference inductor features an adjustable loss angle equivalent to a power factor from zero to 0.01. It has an uncertainty of less than 10×10^{-6} in both magnitude and phase.**

Index Terms — **Current-comparator-based, high-voltage, loss angle, reference inductor, shunt reactor, uncertainty.**

I. INTRODUCTION

For economic reasons, large high-voltage (HV) shunt reactors are designed to operate at very low power factors, typically 0.001 to 0.004. Accurate loss measurement at such low power factors is difficult because of the presence of the large quadrature component of current. The acceptable accuracy limits when measuring loss in HV shunt reactors are important to manufacturers and utilities since there is a penalty (at least $5 000/kilowatt) for every kilowatt of loss exceeding the guaranteed value. The excess penalty because of measurement error with 5 percent and 1 percent uncertainties, could amount to at least $50 000 and $10 000 respectively for a 0.001 power factor, 200 MVA shunt reactor. For a power measurement that is accurate to 1 percent of 0.001 power factor, a technique with an overall accuracy of (0.001 x 1) or 0.001 percent is required. It is therefore very important that the loss measurement system be properly calibrated to ensure that it meets its proper accuracy specifications and traceability requirements.

A current-comparator-based high voltage reference inductor (CCB HV Reference Inductor) with adjustable loss angle has been developed that could serve as a reference single phase shunt reactor to calibrate and provide traceability of a shunt reactor loss measurement system.

II. A CCB HV REFERENCE INDUCTOR

The basic circuit diagram of the CCB HV Reference Inductor is shown in Figure 1. It consists of a CCB HV Capacitive Divider DIV followed by a unity-gain CCB Integrator INT [1]. The output of the integrator is a voltage E_0 with a frequency characteristic of an inductive current. This voltage signal then drives a voltage-to-current converter V-I with several rated output currents ranging from 20 A to 100 A., with the capability of being extended to 1000A.

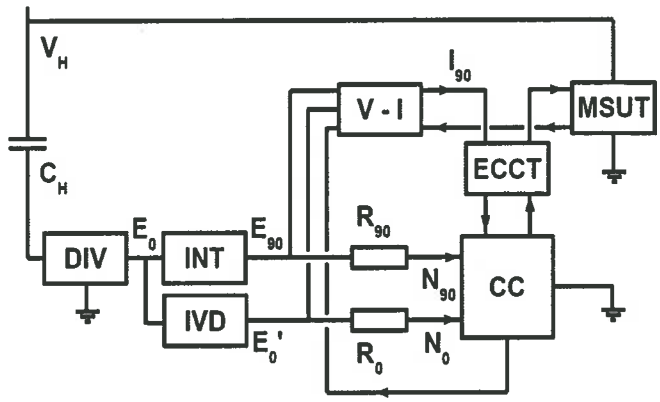

Fig. 1. CCB HV Reference Inductor

The voltage-to-current converter V-I produces an approximate inductive current derived from the output voltage E_{90} of the Integrator INT. Adjustable loss angle is achieved by using an inductive voltage divider IVD, to vary the output voltage E_0 of the HV Capacitive Divider DIV to produce an adjustable in-phase voltage E_0'.

A current comparator technique is used to compare the inductive output current of the voltage-to-current converter V-I through an electronically-compensated current transformer ECCT [2] against reference currents, derived from E_0' and E_{90}, via reference resistors R_0 and R_{90}, respectively, and to introduce a feedback correction to the inductive output current of the voltage-to-current converter V-I to ensure an ampere-turn balanced condition of the current comparator CC, thereby having the proper correct inductive output current I_{90}. The current ratio of ECCT can be configured to correspond with the rated output inductive current of V-I ranging from 20 A to 1000 A.

The maximum voltage rating of the CCB HV Reference Inductor is determined by the maximum voltage rating V_H of the high-voltage low-loss gas-dielectric reference capacitor C_H of the CCB HV Capacitive Divider DIV, which has seven gain settings G of 1, 2, 5, 10, 20, 50, and 100. Thus, the CCB HV Reference Inductor could be operated at a current range output of 20 A to 1000 A with an input voltage range of V_H/G. For a reference capacitor C_H of 500 kV, the CCB HV Reference Inductor could be operated at 500 kV, 250 kV, 100 kV, 50 kV, 25 kV, 10 kV, 5 kV with the same output current range I_{90} of the voltage-to-current converter V-I. This load current I_{90} with adjustable loss angle can then be used as reference to calibrate a shunt reactor loss measurement system MSUT.

III. PERFORMANCE

The current comparator CC with its feedback circuit ensures the V-I output load current I_{90} to be stable and repeatable. The gain of the feedback circuit is approximately 100, sufficient to minimize any changes in the load current due to drift in the V-I amplifier to within 10 x 10^{-6} for both magnitude and phase. The overall uncertainty of the load current I_{90} is primarily determined by the performance characteristics of the main components of the HV Reference Inductor. They are the CCB HV Capacitive Divider DIV, Unity Gain Integrator INT, reference resistors R_{90} and R_0, and the current comparator CC. The known measured errors of these components can be accounted for, leaving only the measurement uncertainties of the calibration of these components.

A complete uncertainty analysis, including performance evaluation, of the CCB HV Reference Inductor will be described.

IV. CONCLUSION

The development of a current-comparator-based high voltage reference inductor at the National Research Council of Canada for calibrating loss measurements systems of large high voltage shunt reactors is described. It basically simulates a reference high-voltage single-phase shunt reactor with adjustable loss angle equivalent to power factors from zero to 0.01.

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