

A Shunt Based Low Frequency Current Sensing Approach at an Earthing Switch for Power Grid Applications

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Summary: Low frequency currents (LFCs) in the power grid, typically caused by geomagnetic disturbances or man-made sources, can lead to transformer saturation and grid instabilities. This work presents a shunt based measurement approach using an existing earthing switch as a sensing element. Due to the low and temperature-dependent resistance of the switch, an inline calibration method is introduced to determine the shunt sensitivity during operation. A custom test bench simulates realistic current signals and validates the concept. The resulting system achieves an estimated measurement uncertainty of 20 mA, primarily limited by thermoelectric effects. This approach offers a robust and low-complexity alternative for monitoring LFCs in high-voltage environments.

Keywords: low frequency currents, quasi-DC, shunt based measurement, inline calibration, earthing switch

LFC Currents and Measurement Approaches

The power grid, a backbone of modern infrastructure, carries not only the expected 50 Hz current but also low-frequency quasi-DC currents. These low frequency currents (LFCs), typically in the range of 0.1 mHz to 0.1 Hz [1], are gaining importance due to increasing grid utilization. They are usually caused by geomagnetic disturbances such as solar flares and coronal mass ejections, but also by man-made sources like public transportation systems [2]. LFCs can lead to half-cycle saturation of transformers, resulting in harmonic generation, elevated reactive power demand, and voltage instabilities [1, 2]. Reported measurement systems mostly use closed-loop zero flux current transducers to measure LFCs [3]. However, this method comes with disadvantages such as: nonlinearities of the magnetic approach, requirement of offset compensation in regular, frequent intervals and it is also unclear whether they can withstand a short circuit event. In this work we introduce the shunt based LFC measurement approach, which is depicted in figure 1, as well as concepts that deal with the challenges involved.

Shunt Based Measurement Approach

Figure 1 illustrates the proposed shunt based measurement concept, where the existing earthing switch connecting the transformer neutral point to ground is used as a shunt. The main current components flowing through the switch are:

- i_{ac} : residual 50 Hz current, typically a few hundred mA,
- I_{lfc} : usually below 1 A, up to 330 A globally [4],
- i_{ref} : a low frequency sinusoidal reference signal with no DC or LFC components, amplitude

up to a few amperes. This current is required for the inline calibration method, which is introduced later in this work.

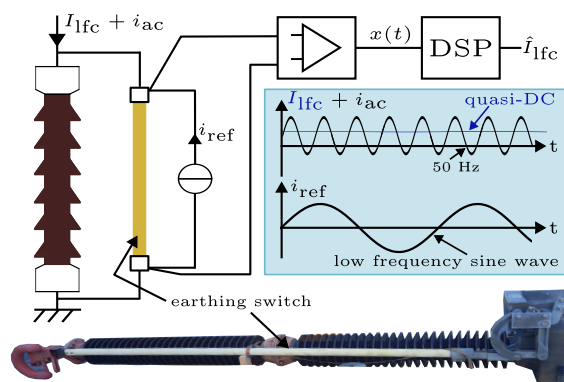


Fig. 1: Shunt based LFC measurement with schematic illustration of the three current components

The voltage signal across the switch is measured using 4-wire-technique and amplified to obtain the signal $x(t)$. While this approach is conceptually simple, it introduces several practical challenges:

- low, temperature-dependent shunt resistance,
- thermoelectric voltages at junctions,
- offset voltages from electronic components,
- electrical noise, particularly at low frequencies.

The first major challenge is the low resistance of the earthing switch, typically around $500 \mu\Omega$, which varies depending on the switch design, mechanical connections and environmental factors such as temperature. To compensate for this, we introduce an inline calibration method

that determines the shunt sensitivity ($S(\theta)$) during operation. The LFC current is then calculated using the DC component of the spectral analysis of $x(t)$ and the calibrated sensitivity $S(\theta)$. Thermoelectric voltages pose the most significant source of uncertainty. For example, assuming a maximum temperature gradient of 30 °C and a measurement accuracy of 10 %, the resulting discrepancy is 3 °C. Considering a Cu–Al junction with a Seebeck coefficient of approximately 3 $\mu\text{V}/\text{K}$, this yields a thermoelectric voltage of 9 μV , equivalent to about 18 mA of LFC current. Offset voltages, from electronic components are less critical, as they can largely be eliminated by performing a baseline measurement with the circuit disconnected from the shunt. The remaining contribution is about 0.5 μV . Overall, the total uncertainty in the LFC measurement is around 20 mA. To reduce noise, a zero-drift amplifier without 1/f noise was used. Remaining white noise is minimized through signal averaging.

Test Bench PCB and Measurement Setup

To validate the shunt based measurement, a dedicated test bench PCB was developed. The circuit simulates the relevant current components flowing through the earthing switch. A summing amplifier combines three input voltages u_{i1} , u_{i2} , and u_{i3} , corresponding to i_{ac} , I_{lfc} , and i_{ref} . This signal is fed into a power amplifier. By placing the shunt resistor R_f in the feedback path, the amplifier operates as a current source and generates the combined current $I_{out} = i_{ac} + I_{lfc} + i_{ref}$. The resulting voltage drop across the earthing switch is amplified to form the signal $x(t)$, which is captured using a Picoscope, while the current signals are measured with a current clamp.

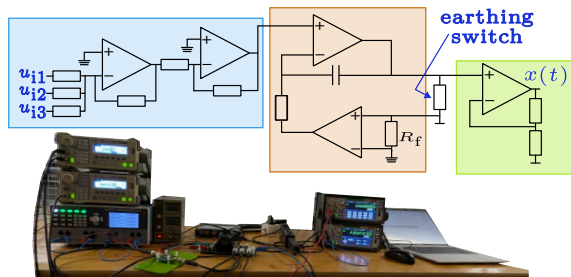


Fig. 2: Schematic of the test bench PCB and photograph of the measurement setup.

Results and Inline Calibration

To obtain the LFC value (\hat{I}_{lfc}) the shunt sensitivity $S(\theta)$ must be known, which can be achieved by applying the inline calibration method: Therefore, i_{ref} is introduced into the system, whose value is obtained from the current clamp signal by extracting its spectral component at 3 Hz. To determine $S(\theta)$, the amplitude of the 3 Hz reference component in $X(f)$ is used combined with the known i_{ref} . Since i_{ref} contains no DC components, both offset voltages and thermoelectric

contributions do not affect the calibration and can be neglected. For accurate calibration, i_{ref} must remain stable and its amplitude precisely known. Once $S(\theta)$ is determined, the LFC current \hat{I}_{lfc} is calculated by dividing the DC component of $X(f)$ by the calibrated sensitivity. A small peak at 50 Hz, caused by i_{ac} , is also visible but does not influence the LFC estimation.

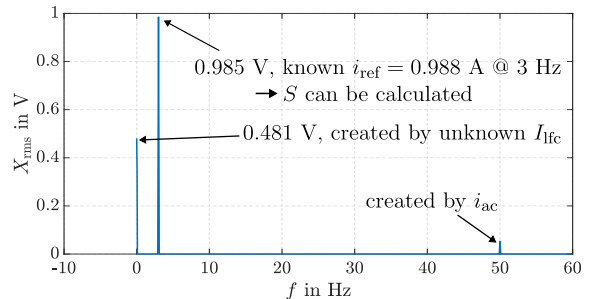


Fig. 3: Spectral analysis of $x(t)$ showing reference signal, DC component, and residual 50 Hz peak.

Conclusion

This work demonstrated the feasibility of a shunt based approach for measuring LFC in power grid applications and addressed key challenges such as temperature-dependent sensitivity and thermoelectric effects. By applying an inline calibration method, the LFC current can be determined with an estimated uncertainty of 20 mA, primarily due to thermoelectric voltages. The full paper will provide a detailed uncertainty analysis.

Acknowledgement

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