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D6.3.112 Mapping and testing of potential sensor solutions

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High frequency current transformer sensors

- The basic principal of current transformer is to produce an alternating current in its secondary winding which is proportional to the alternating current flowing through its primary winding.
- There are number of coupling techniques available for monitoring PD activity. Coaxial cable sensors, directional couplers, inductive HFCT transformers and the Rogowski coil.

HFCT vs. the Rogowski Coil

- HFCT sensors may suffer from saturation if they are installed around the phase conductor and the phase current is high.

- The Rogowski has an air core so it does not saturate but their transfer impedance is poor when compared to HFCT sensor. The Rogowski coil also needs an analog or digital integrator to obtain the primary current waveform.

- HFCT has good frequency range and transfer impedance but poor saturation property.

- An effective PD sensor should be compact and easy to install, sensitive to tens of pC of PD level and have a high saturation current.

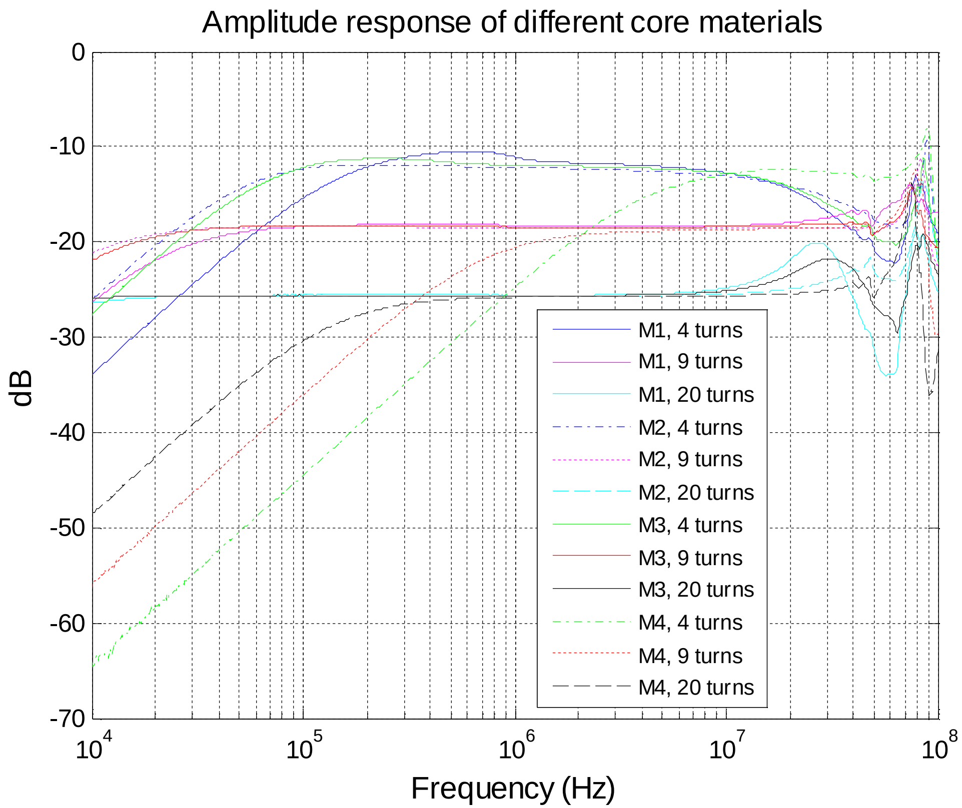
Sensors studied

- Novel HFCTs developed at TUT were studied and compared with a commercially available HFCT and a Rogowski coil.
- Sensors are characterized by suitable frequency response for measuring fast and sharp PD pulses, transfer impedance which is the ratio between the secondary voltage and the primary current and the saturation current of the sensor in order to measure the PD pulse properly.
- A series of laboratory measurements were performed on different ferrite cores to develop the best possible sensor.

Sensor configurations

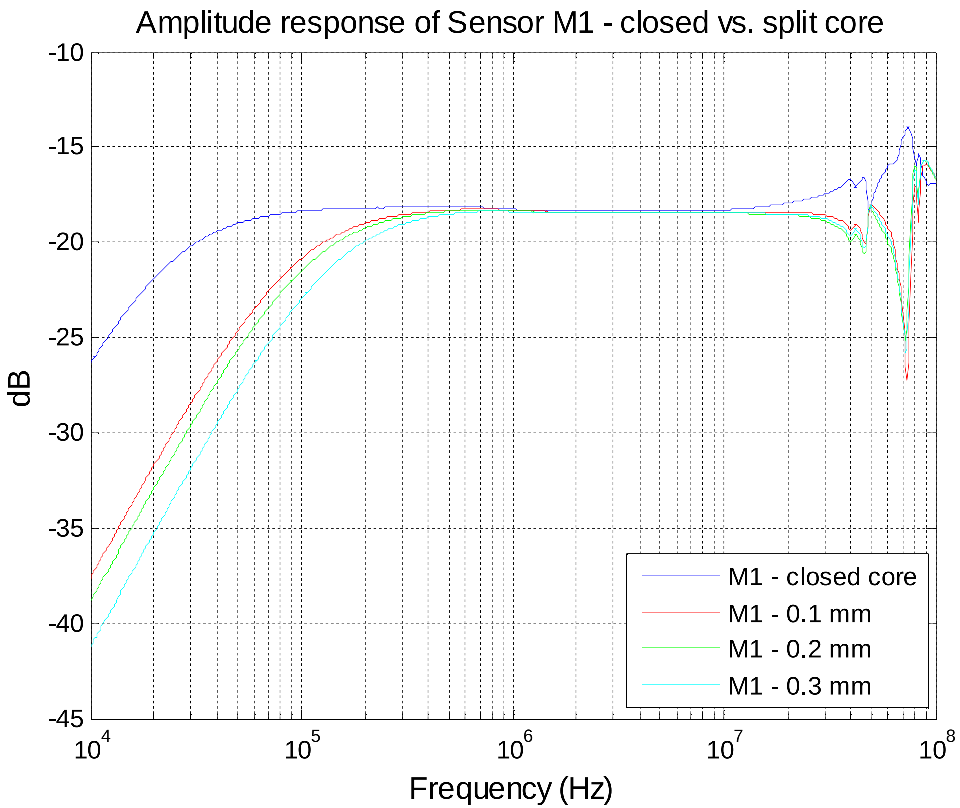
- HFCT cores used are combination of manganese and zinc (MnZn) and nickel and zinc (NiZn). These compounds show good magnetic properties.
- All HFCTs were wound using an enamel wire of diameter 0.19mm.
- The windings were spread evenly around the core.
- All the sensors were terminated into 50 ohm during the measurements.

Amplitude response – Closed HFCT cores



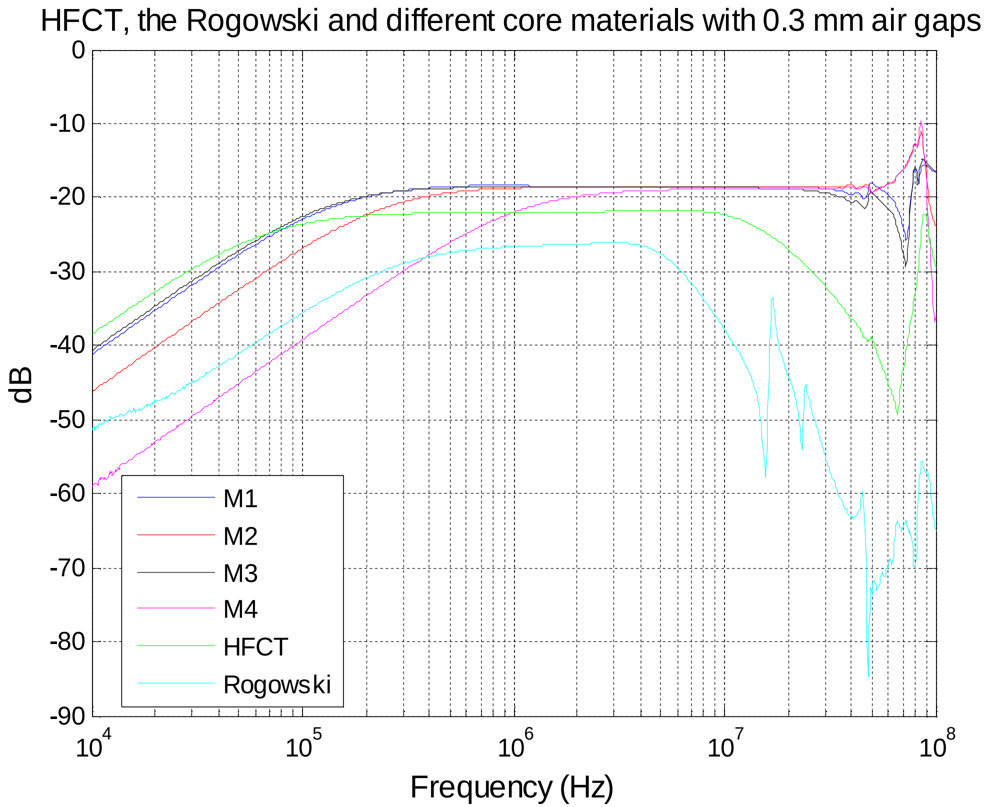
- Amplitude response of HFCTs wound on different Ferrite materials with different winding configurations.
- Sensor M1 with 9 turns winding configuration seems to be the best choice among materials as well as number of turns.
- It exhibits high enough sensitivity, flat amplitude response between 30 kHz to 45 MHz as well as low resonance peak which is an excellent choice for PD monitoring.

Amplitude response – Closed vs. Split cores



- Amplitude response of M1, closed vs. split cores with 3 different air gaps size.
- Lower -3dB cut-off frequency which was around 30 kHz in case of closed core increases to around 100 – 200 kHz but still the amplitude response is quite flat over the frequency range of interest with air gaps of 0.1mm to 0.3mm.
- The working frequency range of M1 (as set by the lower and upper -3dB cut-off frequency) is between 100 kHz to 45 MHz which is quite promising to detect PD signals.

Amplitude response – comparison



- M1 has good sensitivity as well as flat amplitude response which extend up to 45 MHz when compared to other core materials, commercial HFCT and the Rogowski coil.
- Commercial HFCT has flat amplitude response up to 15 MHz. However, the sensitivity is considerably lower when compared to M1 and M2 in the frequency range 90 kHz to 15 MHz.
- In comparison, the Rogowski sensor has the lowest overall sensitivity and unstable amplitude response at higher frequencies.

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Passband transfer impedance

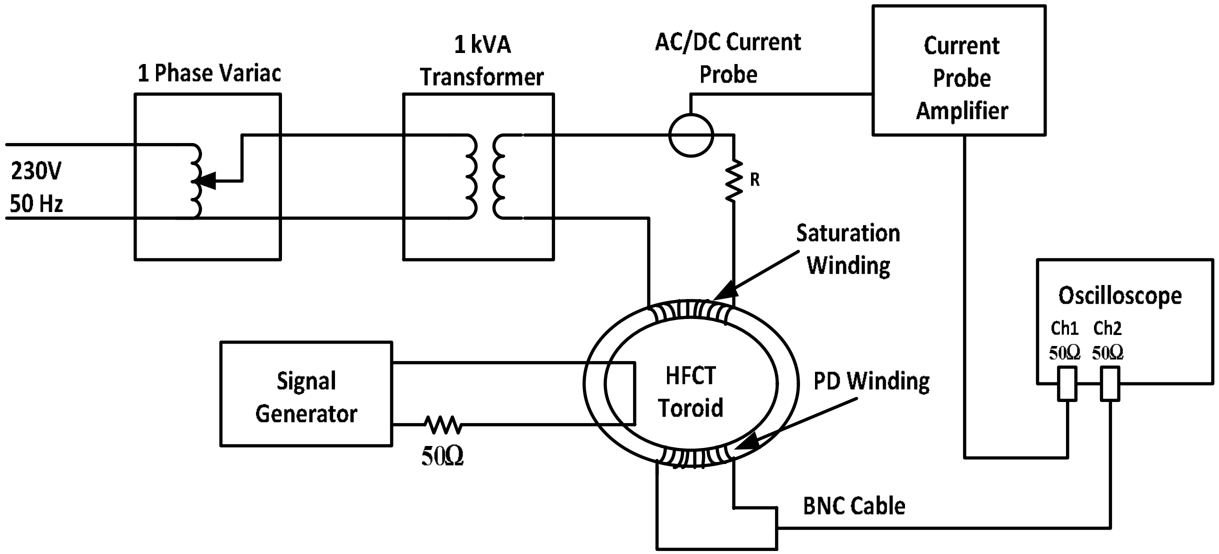
Table 1. Transfer Impedance of commercial HFCT, the Rogowski coil and developed sensors with different air gaps size

	Air Gap (on one side of the core)			
Sensor	Closed	0 mm	0.2 mm	0.3 mm
HFCT-M1	6.20 Ω	6.05 Ω	5.95 Ω	5.90 Ω
HFCT-M2	6.02 Ω	5.93 Ω	5.80 Ω	5.72 Ω
HFCT-M3	6.05 Ω	5.95 Ω	5.93 Ω	5.88 Ω
HFCT-M4	4.74 Ω	4.70 Ω	3.85 Ω	3.80 Ω
HFCT	-	-	-	3.45 Ω
Rogowski	-	-	-	1.45 Ω

- The results suggest that the sensitivity of the developed sensors reduces as the size of air gaps increases.
- In comparison, developed sensors and commercial HFCT sensor has much higher transfer impedance than the Rogowski coil.
- However, the sensitivity of the developed sensors is still much better when compared to the commercial HFCT sensor.

Saturation current test setup

A high current test was set up using a VARIAC to increase the 50 Hz current. 10 primary turns around the developed sensors and commercial HFCT was used to yield high current.



Saturation current

Table 2. Saturation current of commercial HFCT, the Rogowski coil and developed sensors with different air gaps size

	Air Gap (on one side of the core)			
Sensor	Closed	0 mm	0.2 mm	0.3 mm
HFCT-M1	10.0A	12.5A	68.0A	100.0A
HFCT-M2	3.0A	13.5A	55.4A	67.3A
HFCT-M3	6.6A	21.0A	60.0A	65.2A
HFCT-M4	18.8A	28.0A	31.0A	35.3A
HFCT	-	-	-	64A
Rogowski	-	-	-	-

- It is clearly visible from the table that air gaps increase the saturation current of the core.
- The saturation current of all the developed sensors except M4 with 0.3 mm air gap is higher than the commercial HFCT sensor.
- All sensors have high saturation performance as well as wider working frequency range when compared to the commercial HFCT.

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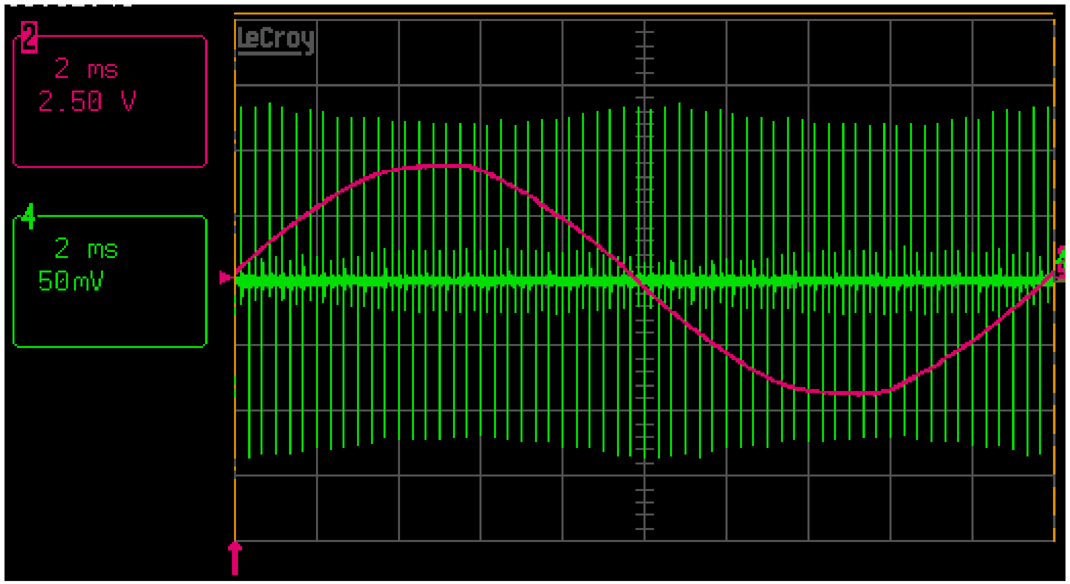
Saturating waveform

The effect of 50 Hz saturation is demonstrated in the Figure below by inputting a 1Vpp, 3 kHz pulse (channel 2 - green) into 50Ω with simultaneous primary 50 Hz current (channel 1 - pink) through the HFCT.

Saturation can be seen to occur when the amplitude of the 3 kHz pulses starts to decrease at the peaks of the primary sinewave current.



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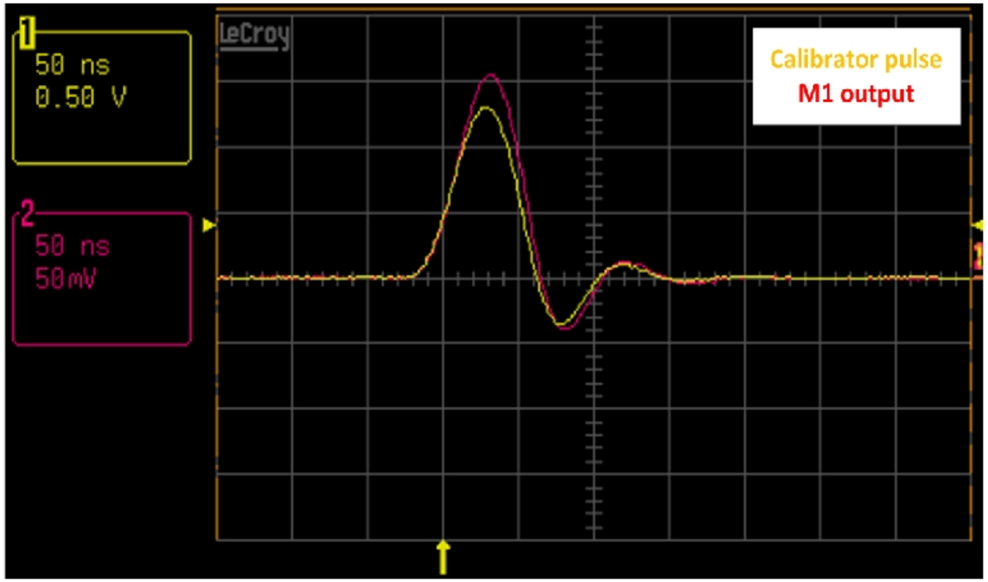
Impulse response



- A sensor should be able to reproduce the shape of the PD pulse as close as possible.
- With reference to the Figure, M1 output (red) reproduces the calibrator waveform quite accurately.
- The signal-to-noise ratio is high enough and the sensitivity is sufficient to prevent the signal from vanishing under the background noise.

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Conclusion

- The working frequency range of all sensors except M4 is between 130 kHz to 45 MHz whereas commercial HFCT sensor has frequency range of 70 kHz to 15 MHz.
- The saturation current of sensor M2 and M3 closely matches the saturation current of the commercial HFCT sensor which is 64A but their transfer impedance is still better than the commercial HFCT sensor.
- In comparison, sensor M1 seems to be the best candidate because of its higher transfer impedance and saturation performance as shown in Table 1 and Table 2, respectively when compared to other developed sensors as well as commercial HFCT sensor and the Rogowski coil.
- Sensor M1 has a saturation current of 100A, highest of all the sensors and lower resonance peak. Moreover, it has a transfer impedance of 5.9Ω (at 1 MHz) which is around 1.7 and 4 times more sensitive than the commercial HFCT sensor (3.45Ω at 1 MHz) and the Rogowski coil (1.45Ω at 1 MHz), respectively.

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References

- Bashir Ahmed Siddiqui, P. Pakonen, Pekka Verho, Novel Sensor Solutions for On-line PD Monitoring”, The 23rd International Conference & Exhibition on Electricity Network, CIRED, Lyon, France, June 2015 (Accepted).