

Rotor DC Current Measurement by Using Standard Current Transformers

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1 ABSTARCT

Generator protection has traditionally only measured stator AC currents and voltages. Measurement of rotor DC current was typically more difficult and required special measurement equipment (e.g. resistive shunt) in the rotor DC circuit.

With advance of numerical technology it is now actually feasible for modern Intelligent Electronic Devices (i.e. IEDs) to measure the rotor winding DC current by utilizing standard CTs installed on the excitation transformer which feeds the static exciter (see Figure 1). By utilizing the measured AC currents from this CT the rotor DC current can be accurately measured by the IED. This can improve generator protection in several ways. Also useful information about excitation system behavior can be obtained from such measurements. Theoretical background and actual site measurements in a trail installation on a 315MVA, 11kV synchronous machine in a pump-storage hydro power plant will be presented in this paper.

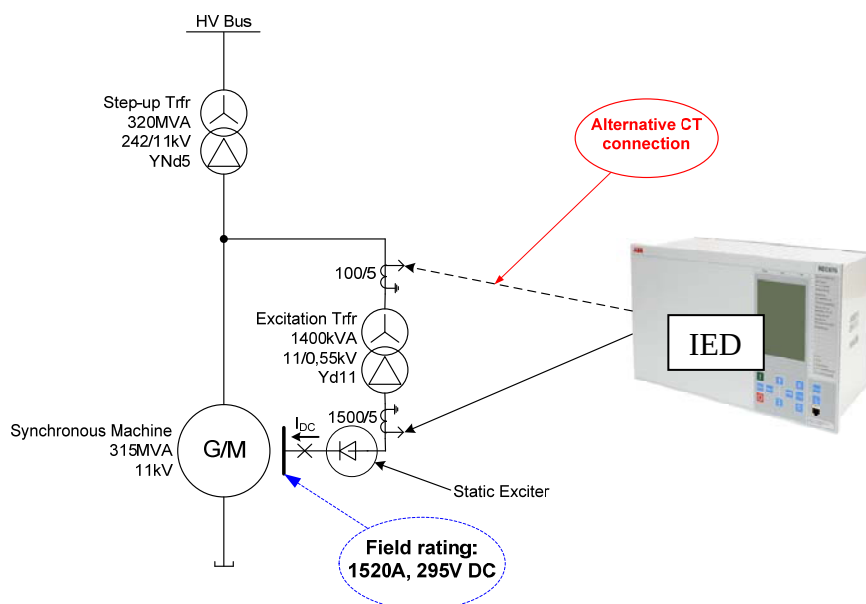


Figure 1: Typical SLD for a synchronous generator with a static excitation system

2 INTRODUCTION

Static excitation systems are the most dominant type of the excitation equipment used today in the power plants around the world. Typical structure of a static excitation system for a synchronous machine is shown in Figure 2.

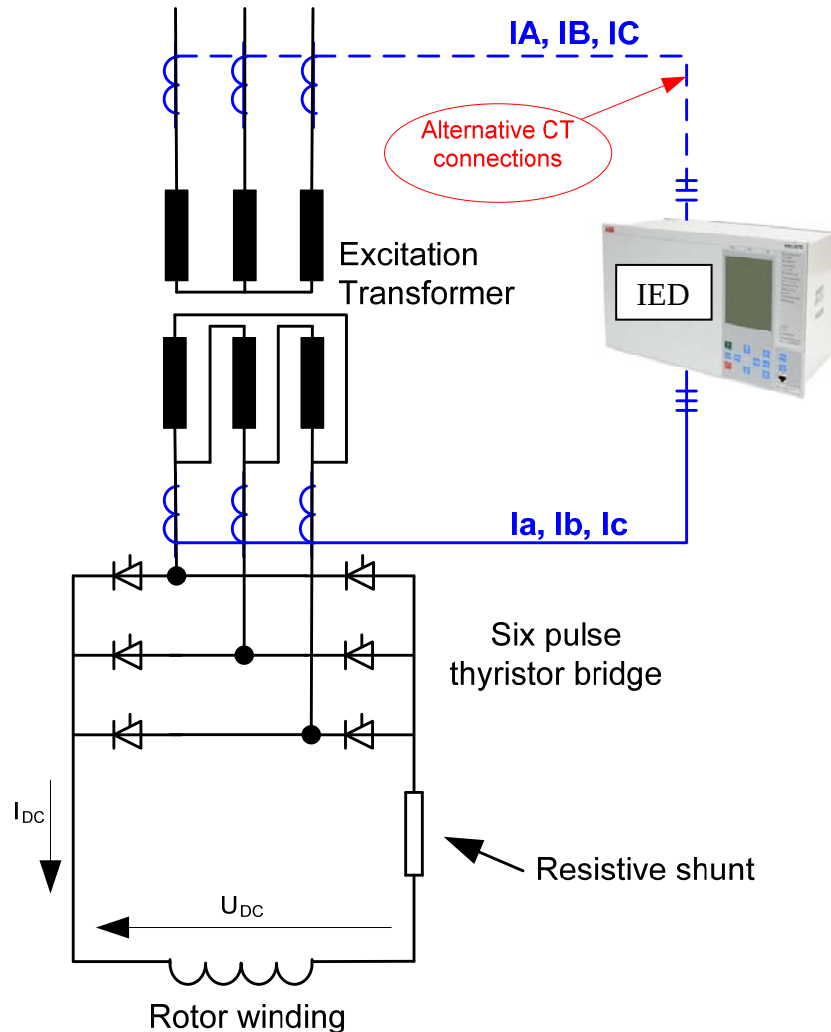


Figure 2: Typical structure of static excitation system

For the generator protection, control and monitoring equipment it would be very beneficial to be able to measure the DC current (i.e. I_{DC} in Figure 1 and Figure 2) in an easy way. However it typically requires special measurement sensors and special inputs into the protection / control / monitoring IEDs. The new method to achieve the DC current measurement is proposed here by using only conventional current transformers and standard IEDs with 1A/5A CT inputs which are readily available.

3 OPERATING PRINCIPLES OF DC CURRENT MEASUREMENT

Full wave rectifier principle has been successfully used in older ABB solid-state relays such as busbar protection type RADSS [1]. Latter the similar principle were implemented in a digital world in ABB numerical busbar protection [2]. Thus such rectifiers are not new for “relay protection world” within ABB. Experience gained from these products was then re-applied in order to calculate the six-pulse rectifier current on the DC side by using procedure from [2]. In order to do that, the waveforms

of all three-phase currents on the LV side of the excitation transformer (i.e. I_a , I_b and I_c) must be measured by the IED, as shown in Figure 2.

Sometimes the LV CTs are not available. Therefore alternative measurement point from the three-phase CTs on the HV side of the excitation transformer (i.e. currents I_A , I_B and I_C as shown in Figure 2) can be used. In such installation experience from ABB transformer numerical differential protection [3] is used. In such case matrix equations given in reference [3] must be used to first recalculate the excitation transformer LV side three-phase currents from the measured HV-side currents. To perform that calculation the excitation transformer rating data and its vector group must be given to the IED as parameter settings.

When waveforms of the I_a , I_b and I_c currents are known, either directly measured or calculated from HV side currents, the DC side instantaneous current I_{DC} of the six-pulse rectifier can be calculated in the simplest way by using the following equation:

$$I_{DC} = \frac{|I_a| + |I_b| + |I_c|}{2} \quad (1)$$

Note that this calculation shall be performed on a per sample level (e.g. 20 times per fundamental power system cycle). Thus, the DC current waveform is actually obtained. Then it is possible to calculate the RMS value of the DC current over one power system cycle by using the following equation:

$$IDC_RMS = \frac{1}{T} \cdot \int_0^T I_{DC} \partial t \quad (2)$$

Now this RMS DC current value can be used to perform the following functions within the IED for protection of the synchronous machine:

- Rotor winding thermal overload protection in accordance with ASA-C50.13 (American Standard)
- Rotor winding over-current protection (e.g. over-excitation condition of the machine)
- Rotor winding under-current protection (e.g. loss of field condition of the machine)

At the same time IDC_RMS value can be displayed as a service value on the:

- IED built-in HMI (see Figure 3)
- Power plant control system via communication protocol (e.g. IEC 61850, DNP3, etc.)

Finally the IDC_RMS value can be as well stored within the disturbance record file captured by the generator protection IED [4], as shown in Figures 5, 6, 7 and 8.

Therefore, the availability of the rotor winding DC current value will definitely improve generator protection and monitoring.

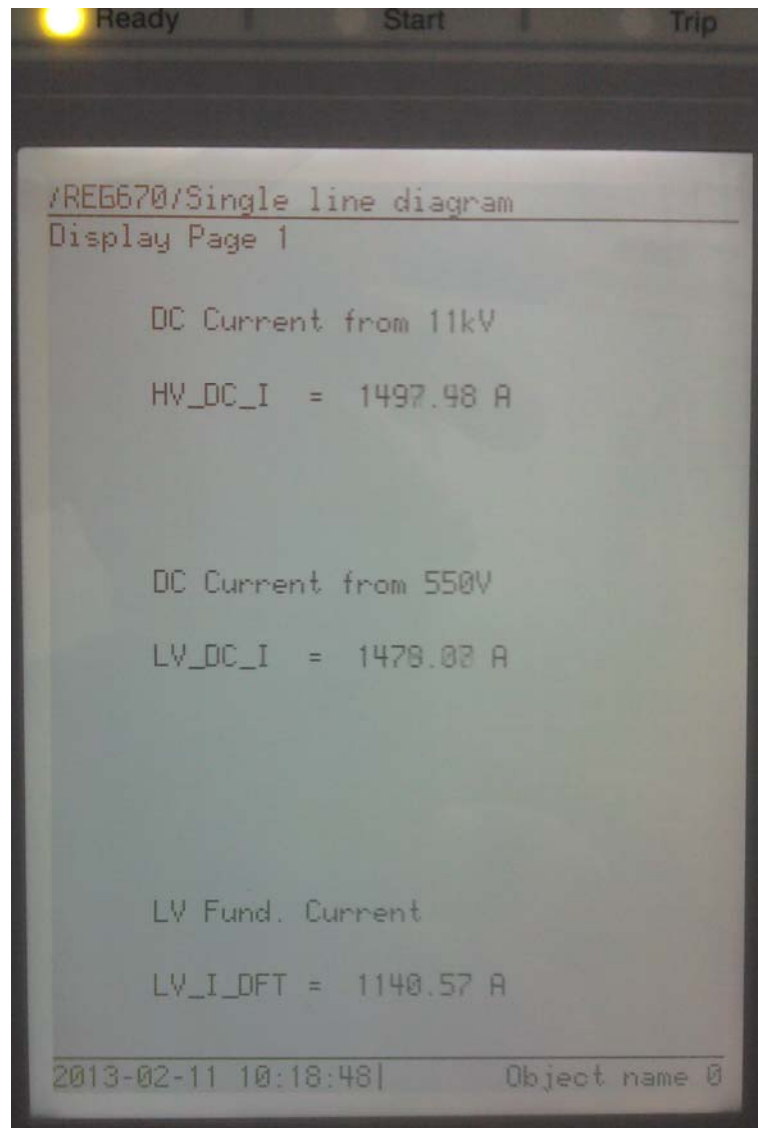


Figure 3: Relay HMI in the pilot installation

4 PILOT INSTALLATION

This pilot site has two identical 315MVA, 11kV, 428.6 rpm hydro machines in a pump storage facility. These two generator-motor units are connected to the 220kV transmission system. The new DC current measurement scheme was installed on the excitation transformer of the first motor-generator unit.

4.1 Detailed information about the pilot installation

This synchronous machine rotor winding has rating 292.4V, 1520A DC. The existing excitation equipment three-line diagram is given in Figure 4.

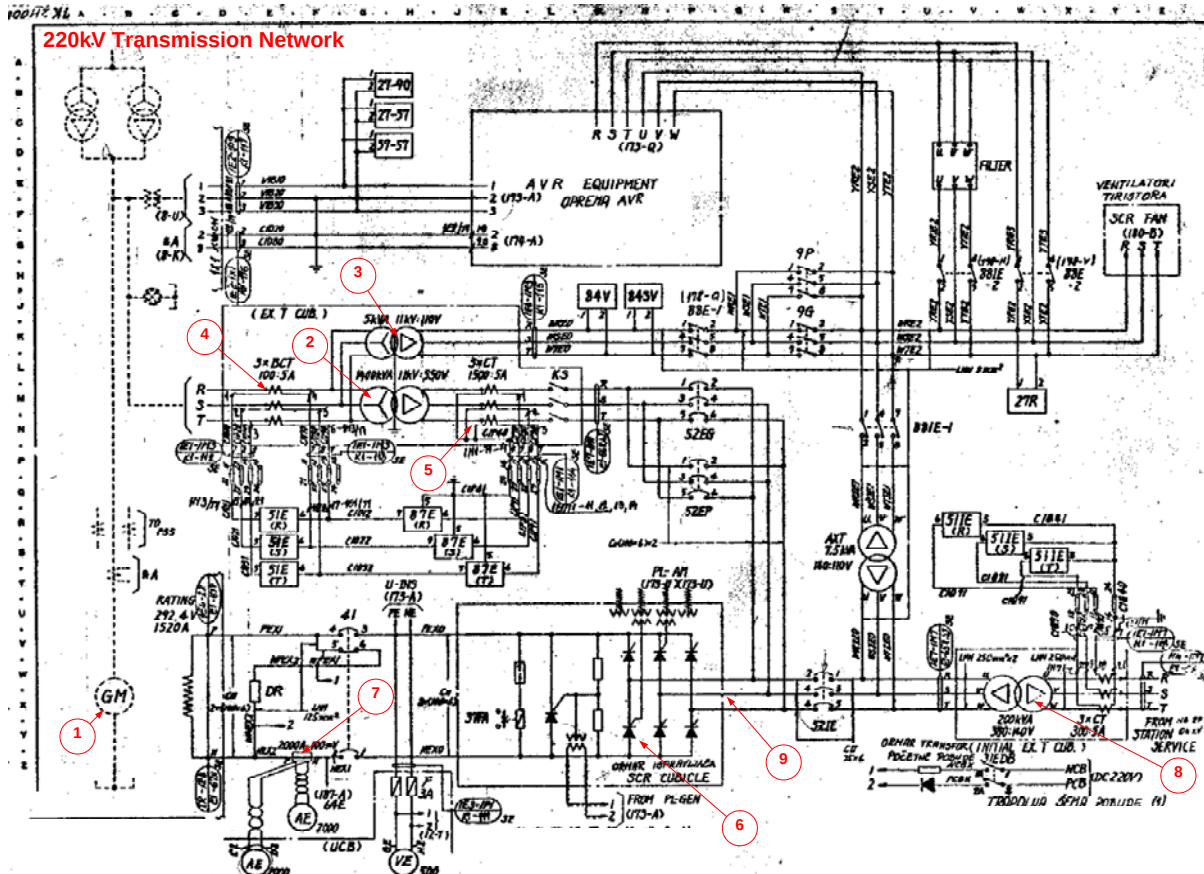


Figure 4: Drawing of the existing static excitation equipment

The red numbers 1 to 9 in the above figure point out the following parts of this installation:

- 1) 315MVA synchronous generator/motor unit
- 2) 1400kVA; 11kV/0.55kV; Yd11 excitation transformer
- 3) 5kVA auxiliary power supply transformer installed in the differential zone of the excitation transformer
- 4) 100/5 CTs installed on HV side of the excitation transformer
- 5) 1500/5 CTs installed on LV side of the excitation transformer
- 6) Six pulse thyristor bridge
- 7) 2000A/100mV resistive shunt presently used for the rotor DC current measurement
- 8) 200kVA initial excitation transformer used during machine start-up and electrical braking
- 9) Ideal location for CTs intended for rotor winding DC current measurement

In any pilot installation, it is most important to obtain as much real-life information as possible and insure good performance of the equipment under test. Therefore, both LV and HV CTs from the excitation transformer (see Figure 4) were connected to the same IED. Practically this IED was then measuring the rotor DC current twice (once from every of the two used CT sets as shown in Figure 3). This enabled us to directly compare the two measured RMS values of the DC current.

Third way to check the DC current value was the resistive shunt which is installed within the existing excitation equipment (see point 7 in Figure 4). This check was performed manually and it was concluded that the IED DC current measurement are identical with the resistive shunt measurements.

4.2 Performance of the DC current measurement

The IED installed in the pilot installation had built-in disturbance recorder. The captured disturbance recordings by the IED will be used to present the performance of the new equipment.

In Figure 5 and Figure 6 recordings captured during normal operation of the synchronous machine is shown. In the three sub-figures the following quantities measured by the protection relay are shown:

- a) Three phase current waveforms on HV side of the excitation transformer (in primary Amperes)
- b) Three phase current waveforms on LV side of the excitation transformer (in primary kA)
- c) Rotor winding DC current RMS value calculated from HV & LV side CTs (in kA)

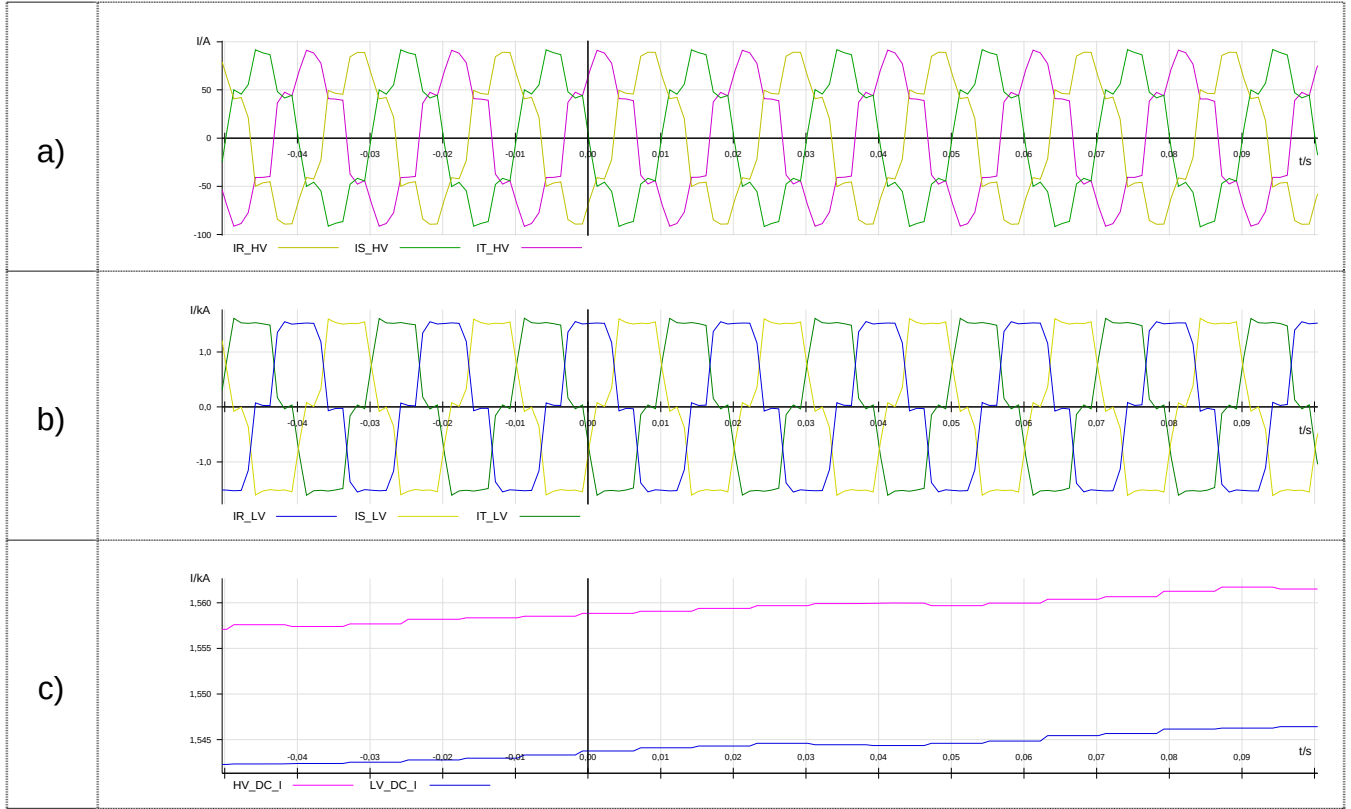
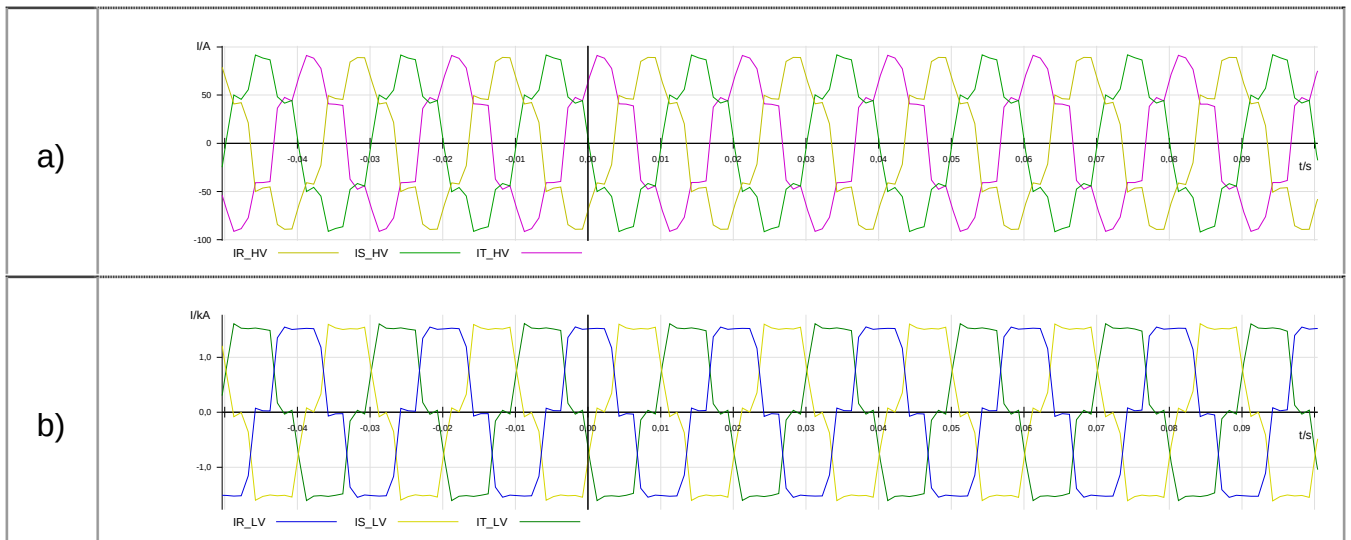


Figure 5: Normal operation of the 315MVA machine in the generating mode



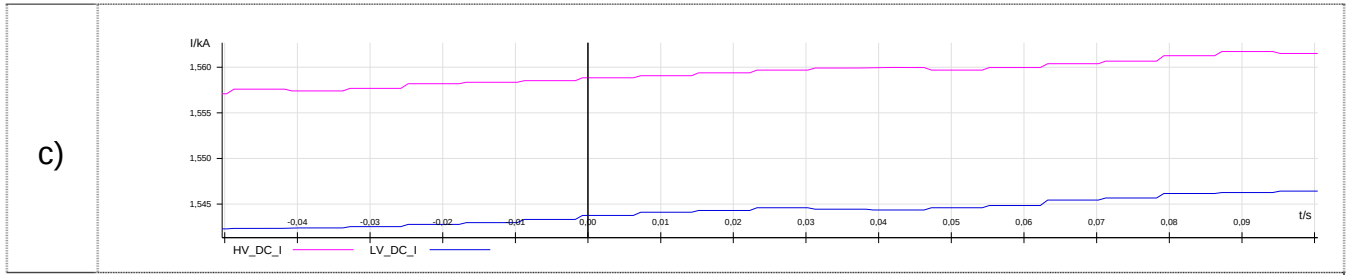


Figure 6: Normal operation of the 315MVA machine in the motor mode

From these two records it can be concluded that both HV and LV side based DC current measurements gives practically the same result. The fixed difference of about 20A between these two measurements is caused by the magnetizing currents of the excitation transformer and the presence of the small 5kVA auxiliary power supply transformer connected in between the HV CTs and the excitation transformer (see number 3 in Figure 4). Note that the error of 20A is practically negligible in comparison with the rated DC current of the rotor winding which is 1520A.

In Figure 7 and Figure 8 recordings captured during external faults in the 220kV network are shown. Due to length of these records only the two measured rotor DC current RMS values calculated from HV & LV side CTs (in kA) are shown.

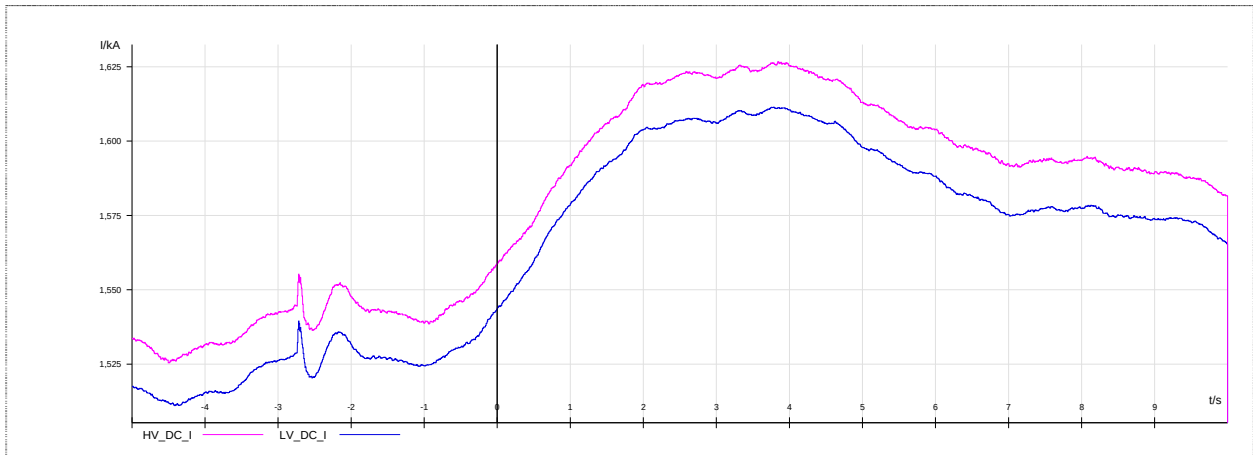


Figure 7: RMS value of the rotor DC current of 315MVA generator during remote fault in the 220kV transmission network

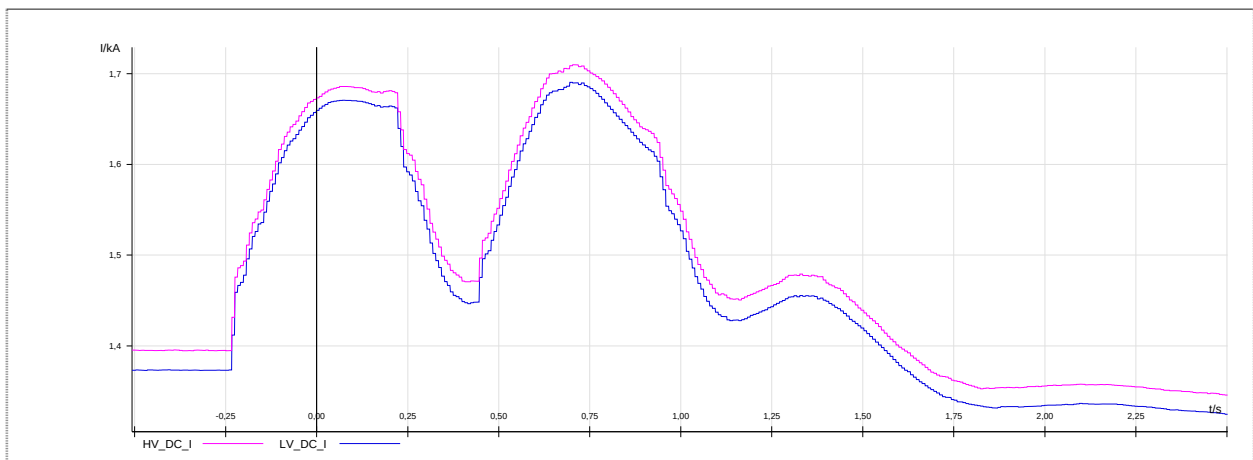


Figure 8: RMS value of the rotor DC current of 315MVA motor during external fault and consequent auto-reclosing attempt in the 220kV transmission network

From these two records it can be concluded that from such DC current recording even the dynamic performance of the AVR system can be determined. For example in Figure 8 even the operation of the excitation current limiter can be clearly seen.

5 CONCLUSION

The availability of the patented DC current measurement in the numerical IED [4] will definitely improve the synchronous generator protection and monitoring. First of all the current based protection for the rotor winding can be done in an easy way (i.e. thermal overload). Secondly the possibility to record and monitor the rotor winding DC current will help power plant engineers to optimize the operational performance of the power plant.

When more than one power source is used for the excitation equipment supply, the CT located just in front of the six-pulse rectifier bridge shall be ideally used in order to have DC current measurement available during all operating conditions of the machine (see point 9 in Figure 4).

REFERENCES

- [1] ABB Document: 1MDB05003-EN; RADSS Buyer's Guide
- [2] ABB Document: 1MRK 505 208-UEN; REB670 Technical Reference Manual
- [3] ABB Document: 1MRK 504 113-UEN; RET670 Technical Reference Manual
- [4] ABB Document: 1MRK 502 027-UEN; REG670 Technical Reference Manual