Background

The DC converter station located at Sellindge consists of 4 Poles – each rated at 500MW giving an overall capacity of 2000MW. The Poles operate at 270kV DC and can be operated in Bipolar or Monopolar modes. They are declared as separate BMUs in the trading / settlement system.

Tariff Metering is installed on the DC side of the converter station enabling mid channel (commercial boundary) metering to be performed without the complexity of station losses. The metering was upgraded by Datum Solutions (now Siemens) in 1998 – these meters remain in service to date. They are calibrated on a 5 yearly cycle. The meters have never required adjustment during calibration to achieve the required accuracy (Class 0.2s).

Elexon Code of Practice 1 covers metering systems for 100MVA and above. However, as the code is based on standards that are intended for AC metering systems, the station operates under a dispensation. The dispensation is operated on the basis of needing to meet the same error limits (both overall and for each metering component – meter, CTs and VTs) as applicable for AC metering.

The overall metering system accuracy requirements of Code of Practice 1 are:

(i) Active Energy

CONDITION	LIMIT OF ERRORS AT STATED SYSTEM POWER FACTOR	
Current expressed as a percentage of Rated Measuring Current	Power Factor	Limits of Error
120% to 10% inclusive	1	± 0.5%
Below 10% to 5%	1	± 0.7%
Below 5% to 1%	1	± 1.5%
120% to 10% inclusive	0.5 lag and 0.8 lead	± 1.0%

The station underwent a replacement of its Thyristor Valves, Controls and Protection systems in 2011 and 2012. The original Hall effect DC CTs were removed and replaced with Fibre Optic Current Transducers (FOCTs). These weren't originally specified to provide the accuracy require for tariff metering purposes (IEC 60044-1).

Annual calibration checks of the accuracy and stability were conducted but, initial attempts to make the system compliant with the accuracy requirements were unsuccessful.

A redesign of the FOCT connectivity was executed between 2014 and 2015 to provide an independent output, dedicated to tariff metering. This resulted in a far more stable, accurate system but, overall secular stability remained marginal.

A number of system installation errors were found on the cabling associated with all 4 poles all of which were corrected in 2016 and the systems were adjusted to remove scale-factor and offset errors. The DC current measurement system remains unadjusted since the calibration checks in late 2016.

For metering (and control purposes), the voltage of each pole is measured using a potential divider. A large resistor (located in the high voltage DC area) is combined with a low value resistor located in a measurements cubicle to provide a suitable (5V at 270.0kV). The 5V is distributed to the various systems using a buffer card made by Alstom (now GE). The loading effect of this card is compensated for within the measurements cubicle.

The accuracy of the voltage measurement system was checked in 2016 by injecting high voltage DC to the bus bar and measuring at the potential divider and output of the buffer card that feeds the Meter. It wasn't possible to find a test system that could perform these tests at the full pole operating voltage – they were performed at 150kV but provide a very good indication of the ratio errors. Any error due to DC offset in the buffer cards would be less dominant at the full pole operating voltage.

Metering System Components

In line with Code of Practice 1, Main and Check Voltage and Current measuring devices are fitted to each Bipole (4 main, 4 check - 8 in total) and Main and Check meters are used.

The metering system consists of the following components:

- Fibre Optic Current Transducers (FOCTs) – Main and Check on 4 poles – 8 total
- Potential Dividers + Buffer Amplifiers – Main and Check – 8 total
- Datum Solutions (Siemens) Energy Meters – Main and Check – 2 total

To assess the overall accuracy of the metering system, the known errors in each of these systems must be included. However, adding the static errors only provides an assessment of the overall error at the time the calibrations were performed – Secular stability (the repeatability of results over an extended time period) is also a key factor.

Fibre Optic Current Transducer (FOCT) Calibration

The FOCTs are scaled to produce 5V at the nominal station load (1852A). These are calibrated by connecting a high current DC source to the Neutral Bus Bar using a number of earthing cables and suitable clamps. The number of cables is reduced at lower current to enable better regulation by the source.

Connection of the high current is made via a calibrated shunt (nominally 50µ Ohm). Main and Check FOCTs are mounted on the same bus bar and calibrated simultaneously. The voltage across the shut is measured along with the outputs from Main and Check FOCTs by 3 calibrated long scale DVMs. The DVMs are connected to bespoke software which uses the calibrated shunt error to calculate the actual injected current to calculate the expected FOCT output to enable errors to be calculated at each load point. A number of readings are used at each load point to calculate ratio errors.

FOCT Calibration summary:

		FOCT As Left - 2018							
		Pole 1		Pole 2		Pole 3		Pole 4	
Percent	**Nominal**	**Main**	**Check**	**Main**	**Check**	**Main**	**Check**	**Main**	**Check**
108	2000.16	0.066	0.124	0.035	0.024	-0.034	0.018	0.010	-0.066
100	1852	0.081	0.131	0.034	0.029	-0.030	0.015	0.007	-0.081
50	926	0.047	0.121	-0.020	0.001	-0.052	0.019	0.063	-0.108
20	370.4	-0.108	0.113	-0.218	-0.104	-0.122	-0.052	0.112	-0.208
10	185.2	-0.270	0.075	-0.470	-0.199	-0.200	-0.158	0.260	-0.322
5	92.6	-0.607	0.009	-1.045	-0.390	-0.311	-0.213	0.460	-0.518

Out of specification (IEC60044-1) results are shown in Red. Marginal results are shown in Amber

FOCT Secular Stability

		Pole 1					
		As Left 10.10.16		As Left - 2018		Change	
Percent	Nominal	Main	Check	Main	Check	Main	Check
108	2000.16	-0.019	0.039	0.066	0.124	0.132	0.113
100	1852	-0.024	0.013	0.081	0.131	0.119	0.135
50	926	-0.002	0.011	0.047	0.121	0.056	0.106
20	370.4	-0.066	0.111	-0.108	0.113	-0.036	-0.041
10	185.2	-0.050	-0.059	-0.270	0.075	-0.223	0.016
5	92.6	0.007	-0.028	-0.607	0.009	-0.632	-0.192

		Pole 2					
		As Left 10.10.16		As Left - 2018		Change	
Percent	Nominal	Main	Check	Main	Check	Main	Check
108	2000.16	-0.009	0.005	0.035	0.024	0.071	0.015
100	1852	-0.015	0.017	0.034	0.029	0.085	0.023
50	926	0.018	0.024	-0.020	0.001	0.011	-0.007
20	370.4	-0.022	-0.054	-0.218	-0.104	-0.143	-0.031
10	185.2	-0.023	-0.086	-0.470	-0.199	-0.409	-0.116
5	92.6	-0.025	-0.121	-1.045	-0.390	-0.910	-0.251

		Pole 3					
		As Left - 2016		As Left - 2018		Change	
Percent	Nominal	Main	Check	Main	Check	Main	Check
108	2000.16	0.002	-0.009	-0.034	0.018	-0.036	0.026
100	1852	-0.003	-0.008	-0.030	0.015	-0.027	0.023
50	926	0.000	0.015	-0.052	0.019	-0.052	0.003
20	370.4	-0.053	-0.047	-0.122	-0.052	-0.069	-0.005
10	185.2	-0.099	-0.071	-0.200	-0.158	-0.102	-0.087
5	92.6	-0.156	-0.098	-0.311	-0.213	-0.155	-0.115

		Pole 4					
		As Left - 2016		As Left - 2018		Change	
Percent	Nominal	Main	Check	Main	Check	Main	Check
108	2000.16	-0.023	-0.001	0.010	-0.066	0.033	-0.065
100	1852	-0.012	-0.001	0.007	-0.081	0.019	-0.080
50	926	0.009	-0.049	0.063	-0.108	0.054	-0.059
20	370.4	-0.004	0.054	0.112	-0.208	0.116	-0.262
10	185.2	-0.008	0.099	0.260	-0.322	0.268	-0.421
5	92.6	0.015	0.142	0.460	-0.518	0.444	-0.659

Out of specification (IEC60044-1) results are shown in Red. Marginal results are shown in Amber

Potential Divider Calibrations

System voltage needs to be measured to enable the metering system to calculate power and energy values. For compliance with Code of Practice 1, these should be within the accuracy requirements of IEC60044-2 (0.2%).

System calibration was performed by injection of a high voltage at the bars in the DC area. This voltage was connected to a calibrated divider (1000:1). This voltage along with the potential divider and buffer amplifier outputs were measured and recorded to enable the calculations shown below.

Calibrations were performed at 75kV, 107kV and 150kV. Results are shown only for 150kV as this is closest to the nominal pole voltage.

The Standard Divider Output column is the voltage measured across the calibrated resistor that forms part of the test set.

This is multiplied by the ratio 54000:1 (the nominal PD ratio at Sellindge) to calculate the injected voltage.

The PD output column shows the voltage measured across the low end of the potential divider – this is then multiplied by 54000:1 to give the actual pole voltage.
The Output to Meter column is the voltage from the buffer amplifier – this is then multiplied by 54000:1 to give the voltage that the meter should use when calculating power and energy.

The end to end errors are shown in Blue.

		Std Divider Output	Calculated Injected	PD Output	PD Voltage	Output to Meter	Meter Voltage	Divider Error %	Meter Error %
Pole 1	Main	-151.482	-151481.7	-2.8041	-151418.8	-2.8028	-151352.9	-0.042	-0.085
Pole 1	Check	-151.199	-151198.8	-2.7986	-151126.5	-2.7973	-151052.1	-0.048	-0.097
Pole 2	Main	-152.691	-152690.7	-2.8267	-152641.2	-2.8260	-152605.6	-0.032	-0.056
Pole 2	Check	-152.613	-152613.2	-2.8257	-152586.4	-2.8253	-152568.5	-0.018	-0.029

		Std Divider Output	Calculated Injected	PD Output	PD Voltage	Output to Meter	Meter Voltage	Divider Error %	Meter Error %
Pole 3	Main	-149.795	-149794.6	-2.7725	-149715.0	-2.7726	-149719.4	-0.053	-0.050
Pole 3	Check	-148.842	-148842.2	-2.7557	-148806.5	-2.7556	-148803.3	-0.024	-0.026
Pole 4	Main	-150.085	-150085.4	-2.7798	-150107.5	-2.7783	-150029.2	0.015	-0.037
Pole 4	Check	-150.864	-150864.3	-2.7966	-151014.0	-2.7952	-150940.0	0.099	0.050

The above tables show that the voltage measurement systems used on all poles are within the accuracy requirements of IEC60044-2.

DC Meters

The meters used for measuring energy at Sellindge are of a bespoke design to enable site operating conditions and site specific parameters such as cable resistances to be taken into account to calculate mid channel power values. The meters were specified to meet the same accuracy requirements as AC meters used in this application (IEC62053-22 Class 0.2S).

The meters have a facility to compensate for known static errors to minimise the overall system error. However, these compensations are presently all set to zero as, the errors in the Current Measurement system are dominant and until recently, have not been sufficiently stable to enable any reliable compensations to be made.

The DC meters are calibrated in a temperature controlled laboratory by injecting a constant voltage on the voltage input and, at various points on the load curve on the current inputs. The meter has a calibration output that can configured to provide good resolution across the load curve. A National Traceable certificate is provided for each meter. This provides an unbroken chain of calibration for the equipment used, back to the National Standards held by NPL.

To minimise risk, 3 DC meters are used during the calibration process - two being in service and one in transit. When the meters fall due for calibration, the transit meter is taken from storage and calibrated. This meter is then used to replace one of the two in service units. The removed meter is returned for laboratory calibration. Once calibrated, the unit is returned to site and fitted in place of the other meter that is due for calibration – the removed meter is returned to the laboratory for calibration to check the data it has been producing remains within the required accuracy limits. In this way, the station is only metered by one meter for the shortest period of time. It also means there is a calibrated spare meter in storage that could be fitted in the event that one of the in service meters fails.

The meters currently in use at Sellindge are Serial Numbers 02 and 04. These were last calibrated in 2015 on certificate numbers NT15057 and NT15099 respectively.

It should be noted that the voltage polarity changes to control Import vs Export. When the dividers were calibrated, the source could only generate a negative high voltage. Any errors recorded at the metering output from the buffer amplifiers will consist of both scale factor and an offset component.

As the poles operate in opposite polarities when the system is running in bipolar mode, the worst case error for each power flow polarity (import / export) will be used from the meter calibration certificate to assess the worst case meter error.

With the above compromise, the meter errors for the 2015 calibrations are shown below:

			Main Meter – Serial No: 4				Check Meter – Serial No: 2			
Percent	**Nominal**	**Meter Test Point**	**Pole 1**	**Pole 2**	**Pole 3**	**Pole 4**	**Pole 1**	**Pole 2**	**Pole 3**	**Pole 4**
108	2000.16	2000	-0.04	-0.07	-0.07	-0.07	0.03	0.03	0.03	0.03
100	1852	1850	-0.04	0.06	-0.04	0.06	0.03	-0.01	0.01	0.06
50	926	1000	-0.04	0.07	0.07	-0.07	0	0.03	0.07	-0.03
20	370.4	400	-0.03	-0.07	0.06	-0.04	0.04	0.04	0.04	0.07
10	185.2	200	0.03	-0.07	-0.07	0.03	0.1	0.07	0.1	0.1
5	92.6	100	-0.07	-0.03	0.06	0.06	0.16	0.19	0.19	0.22

It can be seen that the all of the results are within the error limits of the IEC requirements.

Overall Metering System Error

For the purposes of assessing the overall Metering System Error, the following assumptions are made:

- It will be assumed the error at the meter test point will remain unchanged when realigned to the CT test points as determined in IEC 60044-1.
- The ‘As Left 2018’ FOCT errors will be used as these are the most up to date figures.
- No account for Secular Stability in the FOCTs shall be considered.

	Main Meter				
Percent	**Nominal**	**Pole 1**	**Pole 2**	**Pole 3**	**Pole 4**
108	2000.16	-0.059	-0.091	-0.154	-0.097
100	1852	-0.044	0.039	-0.120	0.029
50	926	-0.078	-0.006	-0.033	-0.045
20	370.4	-0.223	-0.343	-0.112	0.034
10	185.2	-0.325	-0.596	-0.321	0.252
5	92.6	-0.762	-1.131	-0.301	0.482

	Check Meter				
Percent	**Nominal**	**Pole 1**	**Pole 2**	**Pole 3**	**Pole 4**
108	2000.16	0.057	0.025	0.022	0.044
100	1852	0.064	-0.011	-0.002	0.029
50	926	0.023	0.002	0.062	-0.088
20	370.4	0.056	-0.093	-0.038	-0.088
10	185.2	0.078	-0.159	-0.084	-0.171
5	92.6	0.072	-0.230	-0.049	-0.247

The overall accuracy of the energy measurements at or referred to the Defined Metering Point shall at all times be within the limits of error as shown:-

(i) Active Energy

CONDITION	LIMIT OF ERRORS AT STATED SYSTEM POWER FACTOR	
Current expressed as a percentage of Rated Measuring Current	Power Factor	Limits of Error
120% to 10% inclusive	1	± 0.5%
Below 10% to 5%	1	± 0.7%
Below 5% to 1%	1	± 1.5%
120% to 10% inclusive	0.5 lag and 0.8 lead	± 1.0%

Conclusion

Based on the assumptions given, it can be seen from the tables above that with the exception of the highlighted cells, the overall metering system errors on both Main and Check Meter systems fall well within the overall allowable errors within Code of Practice 1. Out of specification results are principally as a result of DC offsets within the FOCTs.