Inverarnan 275/132kV Substation (Sloy)

TRANSMISSION INFRASTRUCTURE FOR RENEWABLE GENERATION - INVERARNAN SUBSTATION TECHNICAL REPORT

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Contents

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1. Executive Summary

Inverarnan substation was constructed to connect the Scottish Hydro Electric Transmission Limited (SHETL) 132kV system to the Scottish Power Energy Networks (SPEN) 275kV system in the South West area of Scotland. The aim was to enable spare capacity on an existing SPEN 275kV line to be utilised to increase the capacity of the SHETL South West boundary so that new renewable generation could be connected to the system.

The substation comprises of two 275/132kV, 240MVA Supergrid Transformers (SGT), which interconnect the SPEN 275kV and SHETL 132kV systems, and separate 275kV and 132kV switchgear compounds. The 275kV compound is owned by SPEN with the 132kV compound owned by SHETL. The 132kV switchgear is a duplicate busbar type arrangement comprising Main 1, Main 2 and Reserve busbars enabling adequate flexibility for re-configuration of circuits during maintenance and repair periods.

The forecast capability for the South West boundary reinforcement was estimated at 220MVA prior to construction of the scheme and 380MVA after construction. The South West boundary capacity at Sloy is 220MVA therefore the remaining 160MVA of forecast capability will flow through the 275kV SPEN system via Inverarnan substation. Under N-1 conditions the substation would be able to deliver 240MVA; therefore the scheme is fully capable of delivering the forecast capability.

However, the 240MVA SGT's are at present non-operational due to damage sustained during transport to site. The scheme, constructed in accordance with the design established in 2004, will fully meet the forecast capability of 380MVA, subject to the successful repair and commissioning of the SGT's. After setting into service of the transformers, Sinclair Knight Merz (SKM) will re-visit SHETL to confirm full operation of the scheme upon which a completion certificate will be issued.

1.1. Addendum to Executive Summary

Since this report was first issued in June 2010, the 240MVA transformers have been successfully repaired, commissioned, and put into service; the first in late 2010 and the second in July 2011. Consequently, SKM carried out a site visit to Inverarnan in August 2011 to confirm operation of the transformers and hence of the Sloy scheme. Details of the site visit are given in section 6.

Based on observations at site with limited load flow and review of relevant design type test reports and repeat test reports after repair SKM confirmed that the forecast capability of 380MVA had been achieved. A construction completion certificate is included in Appendix A.

2. Introduction

SHETL appointed SKM as Independent Technical Reviewers to carry out a post construction technical review to meet the Transmission Investments for Renewable Generation (TIRG) licence conditions as set out by Ofgem. The Ofgem approved TIRG project of concern is the Sloy scheme which incorporates the newly constructed 275/132kV substation at Inverarnan.

To discharge SHETL's licence obligations under Special Licence Condition J3 –Restriction of Transmission Charges (Part B 10 (d) (ii)), SKM were to provide:

- A post construction technical report setting out the extent to which the project complies with the TIRG output measures
- A construction completion certificate

This document fulfils the requirement for the post construction technical report. A construction completion certificate is issued separately.

To facilitate the review a visit to SHETL's offices in Perth took place on the 15 April 2010. SHETL personnel presented a description of the project and the status in terms of the construction. Documentation related to the substation construction was presented to SKM for review. SHETL's staff was very cooperative and SKM had access to all information requested and required for the purposes of this report. SHETL also provided additional documentation and evidence via e-mail when requested where additional clarifications were required following the consideration of the information obtained during the visit.

SKM is satisfied that it had access to the relevant documentary evidence that allowed review of the technical construction details of the substation and to assess compliance with the appropriate output measures.

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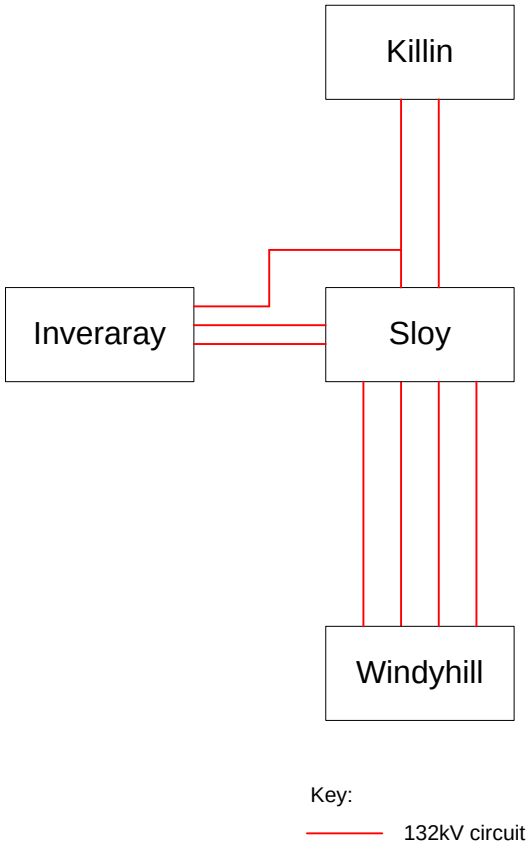
3. Background

3.1. Requirement for Reinforcement

Four critical transmission system boundaries exist on the SHETL transmission system. The South West boundary of the system encompasses power flows to the North and South at Sloy substation located to the North end of Loch Lomond. This boundary includes a significant amount of existing hydro-electric generation and new renewable generation in the Argyll, Kintyre and Cowal areas which feeds into the system to Sloy via Inveraray. Demand in the area is centred around Oban, Mull, Islay, Campbeltown, Arran and Dunoon. The power into this boundary generally flows from Killin in the North and out of the boundary to the South towards Windyhill (near Glasgow). The boundary comprises the 132kV transmission circuits between Killin and Sloy and between Sloy and Windyhill. A simplified illustration is shown in Figure 3.1 below.

Figure 3.1 – SHETL 132kV South West Boundary



In 2004 a system study was undertaken by SHETL which represented the winter peak demand and 95MW of contracted renewable generation connected behind the South-West boundary at that time.

The power transfer across the South-West transmission boundary was estimated at 105MW, which was well within the boundary capability of 220MW.

Under planning criteria requirements of double (N-D) and single (N-1) circuit contingencies at the winter peak demand condition, the study results indicated that the South West transmission capability was adequate for the connected generation (see Table 3.1).

Table 3.1 – Circuit Loading Under Outage conditions (with 95MW generation connected)

Boundary Reference	Circuit Outage	Outage type	Critical Circuit	Circuit Loading (MVA)	% of Circuit Rating
South West	132kV Sloy to Windyhill	N-1	132kV Sloy to Gareloch border (to Windyhill)	74.4	56.5
	132kV Sloy to Windyhill	N-D	132kV Sloy to Gareloch border (to Windyhill)	104	78.3

However, an additional 170MW of new renewable generation schemes in the Argyll, Kintyre and Cowal areas had received signed connection offers in 2004. The power transfer across the South-West boundary under winter peak conditions with the additional generation was estimated at 234MW, which was in excess of the boundary capability of 220MW. It was therefore identified that network reinforcement would be required before the last of these schemes could be connected to the system.

Table 3.2 gives the study results for the network including connection of the additional generation. This showed that the network would not be compliant with the planning standards for N-D outage conditions since the system would be thermally overloaded.

Table 3.2 – Circuit Loading Under Outage Conditions (with additional 170MW of generation connected)

Boundary Reference	Circuit Outage	Outage Type	Critical Circuit	Circuit Loading (MVA)	% of Circuit Rating
South West	132kV Sloy to Windyhill	N-1	132kV Sloy to Gareloch border (to Windyhill)	86.2	66.7
	132kV Sloy to Windyhill	**N-D**	**132kV Sloy to Gareloch border (to Windyhill)**	**142**	**108**

The new renewable generation projects were intended to connect into 132kV radial circuits in the Argyll, Kintyre and Cowal areas which feed into the Main Interconnected Transmission System (MITS) at Sloy. These connections would have overloaded the MITS beyond Sloy, thus requiring reinforcement works to ensure that SHETL complied with its licence obligations and with UK Security and Quality of Supply Standards. Sloy is connected to Killin substation in the North with two 132kV circuits and to SPEN's Windyhill substation in the South with four 132kV circuits.

The transmission infrastructure in the South West area also included the SPEN radial 275kV double circuit line bewteen Dalmally and Windyhill which carries power from the Cruachan pumped storage scheme connected at Dalmally. This line had spare capacity but was not interconnected to the SHETL 132kV system. However, it crossed over the 132kV circuits, which connect Sloy and Killin, at Inverarnan (nearby Sloy) and therefore provided potential for connecting additional generation capacity in the South West area.

3.2. Proposed Solution

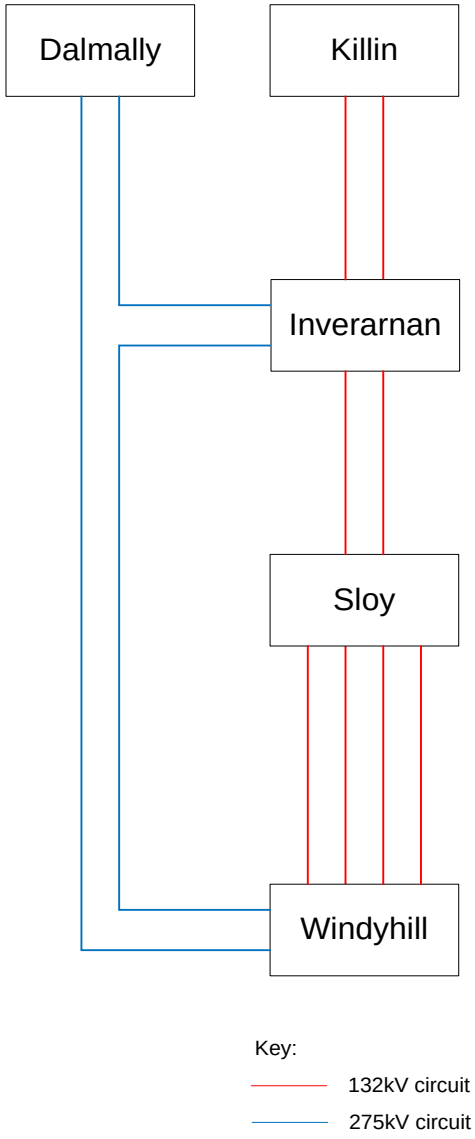
A proposal was made by SHETL to interconnect the existing 275kV Dalmally/Windyhill No.2 circuit (owned by SPEN) and the 132kV Sloy/Killin double circuits (owned by SHETL). This interconnection would provide export capacity via the 275kV circuits.

The proposal would be facilitated by the construction of a new substation in the Glen Falloch area close to where the two lines cross to the South of Inverarnan, which is within the Loch Lomond and The Trossachs National Park. The two overhead lines diverge rapidly both to the South and North of this point, therefore, without extensive new transmission lines, the area for the location of the substation was limited to a 2km site centred on Glenfalloch Lodge, Inverarnan.

The design of the proposed substation at Inverarnan would be such that the two Sloy-Killin circuits would be split to form two Sloy-Inverarnan circuits and two Inverarnan-Killin circuits. These circuits would interconnect with the 275kV Dalmally/Windyhill No.2 circuit via two new 275/132kV SGT's at the substation.

A simplified illustration of the new transmission arrangement is shown in Figure 3.2 below.

Figure 3.2 – Reinforced South West Boundary



4. Review of New 275/132kV Substation at Inverarnan

In 2005, SHETL commenced development work on the proposed 275/132kV substation at Inverarnan, near Ardlui, Loch Lomond. The substation was intended to interconnect the SHETL 132kV double circuit line between Sloy and Killin with the SPEN 275kV double circuit line between Dalmally and Windyhill.

The Sloy scheme was developed to utilise existing spare capacity on the SPEN 275kV double circuit line between Dalmally and Windyhill to allow export of renewable generation capacity connected to the SHETL system in the Argyll area.

The substation boundary encompassing the 275kV switchgear at the site was to be owned and operated by SPEN, whilst the boundary encompassing the 275/132kV SGT's and 132kV switchgear was to be owned and operated by SHETL.

The development and overall project management for the substation was undertaken by SHETL, including installation of the substation platforms to sub-formation level, whilst SPEN appointed their own contractors to complete the civil and equipment construction works within their ownership boundary of the substation.

SHETL have now completed the works within their boundary limits of the substation which encompasses the 275/132kV SGT's and 132kV switchgear. The four 132kV circuits connected to the substation were commissioned in October 2009, however commissioning of the SGT's could not be completed due to damage of the winding insulation. SPEN have also completed commissioning of their 275kV equipment aside from the SGT's.

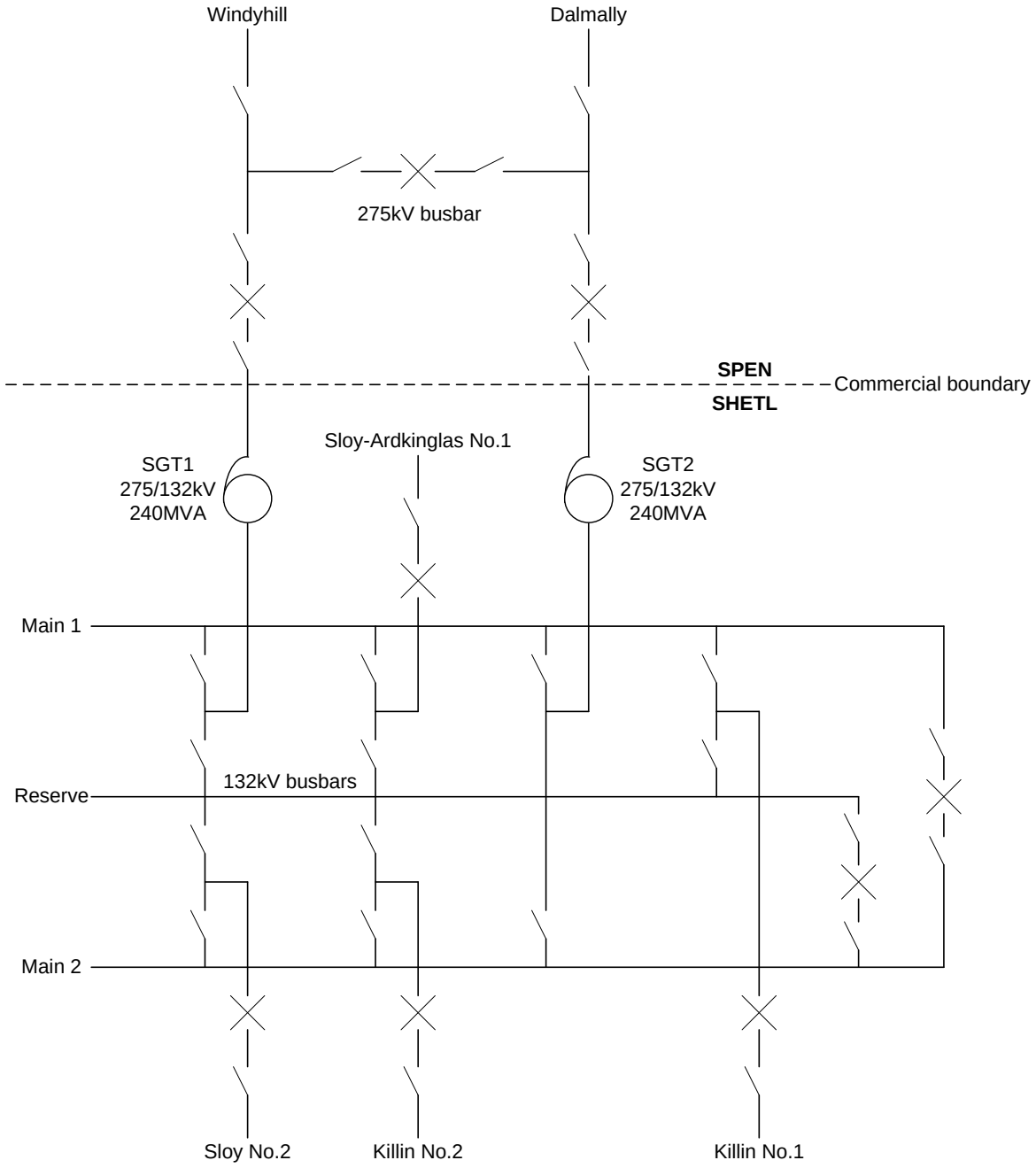
4.1. Configuration

The configuration of the 132kV substation owned by SHETL is of the duplicate busbar type and comprises Main 1, Main 2 and Reserve busbars. Each circuit is capable of being selected for connection to either one of the Main busbars (Main 1 or Main 2) or to the Reserve busbar via busbar disconnectors. In the event of a fault to a main busbar each circuit can be transferred to the reserve busbar with minimal disruption to supply.

A busbar section circuit breaker between Main 1 and Main 2 busbars allows both main busbars to be operated separately or as one busbar. A busbar coupler circuit breaker between Main 2 and the Reserve busbar allows on-load transfer between the main and reserve busbars which prevents loss of supply when maintenance is required on a particular busbar.

Prior to the construction of the substation there were two 132kV overhead line circuits passing through the area which connected between Sloy and Killin substations. These two circuits have now been split and diverted into Inverarnan substation. The result is that there is now a double circuit feeder between Inverarnan and Killin and a double circuit feeder between Inverarnan and Sloy. The feeder circuits connecting into Inverarnan are named Sloy-Ardkinglas No.1, Sloy No.2, Killin No.1 and Killin No.2. There are also two SGT circuits, namely SGT1 and SGT2 which facilitate connection onto the SPEN 275kV network. The basic single line diagram of the substation is shown in Figure 4.1.

Figure 4.1 – Inverarnan Substation Single Line Diagram



4.2. Location, Layout and Construction

The substation site is located within a National Scenic Area in the Loch Lomond & the Trossachs National Park. It lies on a hillside plateau on Garabal Hill approximately 0.5km South of Inverarnan and between the West Highland railway and A82 trunk road. Figure 4.2 shows the access track during construction; the substation site construction had not commenced at this time.

Figure 4.2 – Inverarnan Substation Site (pre-construction)

Due to the topography of the location, the substation was constructed on two levels. The 275kV substation, both SGT's and space for quad boosters were located at 25m Above Ordinance Datum (AOD). The 132kV substation was located at 28m AOD. Each substation has its own single storey control building.

The total area of the substation is approximately 155m x 210m and both the 275kV and 132kV substation are surrounded by a palisade security fence 2.7m high.

The existing double circuit 132kV overhead line circuit (Killin-Sloy) which crossed the site along a North-South axis prior to construction has now been diverted into the substation. To achieve this two new terminal towers were installed. The new towers replaced the two existing towers with one tower located within the substation boundary, while the other was located to the South outside of the boundary fence. The latter tower was connected to the substation by underground cables. The sealing end structures for these cables were located on a platform on the tower.

The double circuit 275kV overhead line circuit (Dalmally-Windyhill) which crossed the South of the site on a West-East axis has also been diverted into the substation. To achieve this one new tower was erected within the substation, in line with the existing circuits.

The substation comprises the following 132kV circuits:

- Feeder circuit, Killin No.1
- Feeder circuit, Killin No.2
- Feeder circuit, Sloy-Ardkinglas No.1
- Feeder circuit, Sloy No.2
- Supergrid transformer circuit, SGT No.1
- Supergrid transformer circuit, SGT No.2

The design of the 132kV substation is based upon a conventional air insulated switchgear construction. The layout comprises a two level construction with the main busbars at high level and the circuit connections at low level. The main busbars run in parallel on a West-East plane with the Reserve busbar in the centre and Main 1 / Main 2 busbars to the outer edges. The circuit connections run in a North-South plane.

The circuits generally utilise switchgear equipment which includes:

- 132kV Dead tank circuit breakers with integral CT's
- 132kV Open Terminal Pantograph and Rotating Centre Post disconnectors with integral earth switches
- 132kV Capacitor Voltage Transformers

- 132kV Cable sealing ends

The Killin No.1 / No.2 circuits terminate onto the switchgear directly via an overhead line connection; the double circuit tower being located at the North end of the site within the substation boundary. The Sloy-Ardkinglas No.1 / Sloy No.2 circuits terminate onto the switchgear via short lengths of cable which connect to the double circuit tower at the South end of the substation, external to the substation boundary.

The substation has been designed on the basis that maintenance, extension and repairs can be carried out with a maximum of only one circuit and one busbar section out of service simultaneously. Clearances for maintenance access have been designed to allow for mobile access platforms, scaffolding, cranes etc.

The 132kV substation layout incorporates space to allow for the future installation of one phase-shifting transformer (Quad Booster) on each of the SGT circuits designed to allow construction with minimum disruption to service continuity. This space is within the 132kV substation boundary located 25m AOD.

The substation also incorporates space for one spare bay on each busbar. The spare bays have not been populated with switchgear or foundations but marshalling kiosks have been provided.

Figure 4.3 below shows the substation close to completion.

Figure 4.3 – Inverarnan Substation (near completion)

5. Output Measures

The output measures specified in Schedule C of the TIRG licence for the Sloy scheme both prior to and post construction are given in table 5.1 below.

Table 5.1 – Sloy Scheme Output Measures

Project scope	Capability as estimated at 31 March 2005 (MVA)	Forecast capability prior to construction start date as estimated at 31 March 2005 (MVA)	Forecast capability post construction as estimated (MVA)
South West reinforcement	220	220	380

The Sloy scheme has been constructed in accordance with the design established in 2004. Hence with the 132kV circuits at the South West boundary loaded at their capacity of 220MVA the post construction forecast capability of the South West boundary would be realised with the remaining 160MVA flowing through the 275kV circuit to Windyhill, via Inverarnan substation. The two 240MVA SGT's installed at the substation would be able to deliver a firm capacity of 240MVA under N-1 outage conditions. Thus the Sloy scheme is fully capable of delivering the forecast output measures.

However, the 240MVA SGT's are not yet in service due to damage sustained during transit to site, so at the present time Inverarnan substation is acting simply as an interconnection point in the 132kV transmission system. Subject to the successful repair and commissioning of the SGT's it is expected that the forecast capability of 380MVA will be achieved.

Upon commissioning and setting into service of the SGT's, SKM will re-visit SHETL to obtain evidence to demonstrate satisfactory operation of the scheme. A completion certificate will then be issued by SKM.

6. Site visit

The damaged 240MVA SGT's underwent factory repairs during 2010 and 2011 prior to being re-commissioned and put into service in late 2010 for the first transformer and July 2011 for the second. It was noted that SGT1 was not initially intended to be installed at Inverarnan but due to the nature of the damage to the original, a transformer of the same design and rating, which was intended for a different site, was instead installed at Inverarnan. The replacement for SGT1 had also undergone similar repairs as the original SGT1 and SGT2. The test reports of repeat dielectric tests performed on the transformers after repair were reviewed to confirm satisfactory performance.

SKM undertook a site visit on 17 August 2011 to confirm that the transformers were installed and the scheme was fully operational. Figure 6.1 and 6.2 shows SGT1 and SGT2 as installed.

Figure 6.1 – SGT1 transformer as installed

Figure 6.2 – SGT2 transformer as installed

To confirm that the transformers were operational the power flows through each were recorded. The recordings were taken from metering installed on the protection panels in the control room. Export power flows from the 132kV system to the 275kV system were recorded as 32.0MW through SGT1 and 32.3MW through SGT2. These are shown in figures 6.3 and 6.4.

Figure 6.3 – Power recorded through SGT1

Figure 6.4 – Power recorded through SGT2

The nameplate rating for each transformer was also recorded to confirm the 240MVA capacity of each transformer. These are shown in figures 6.5 and 6.6. Furthermore the type test report for this transformer design was reviewed to confirm the performance at this rating.

Figure 6.5 – Nameplate rating of SGT1

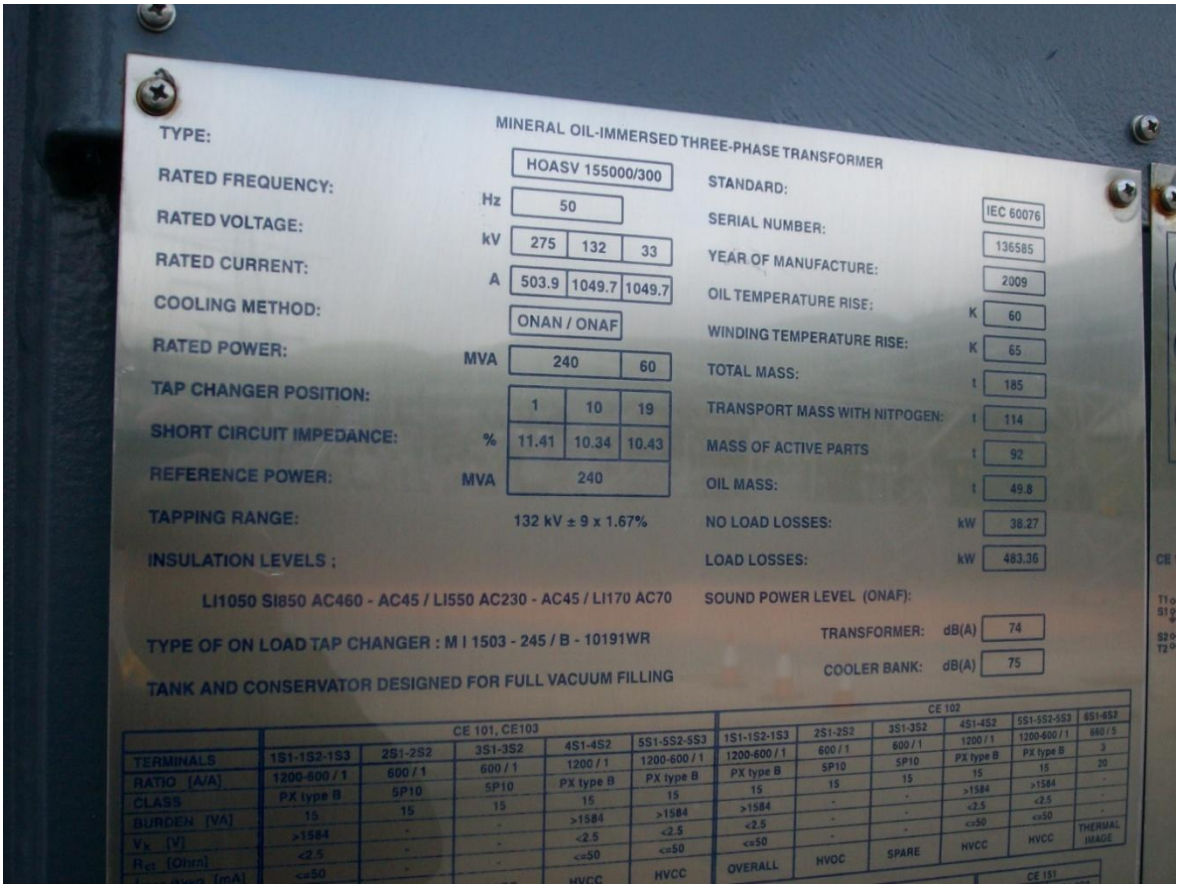


Figure 6.5 – Nameplate rating of SGT2

SKM were satisfied that the information presented was sufficient to confirm that the Sloy scheme is in full operation and able to meet the forecast capability of 380MVA as specified in the output measures in Schedule C of the TIRG licence.

A construction completion certificate to confirm this is included in Appendix A.

Appendix A Construction completion certificate

TRANSMISSION INVESTMENTS FOR RENEWABLE GENERATION

CONSTRUCTION COMPLETION CERTIFICATE

Licensee: Scottish Hydro Electric Transmission Limited (SHETL)……

Scheme: Sloy .....

It is hereby certified that the Licensee named above is considered to have completed all construction activities necessary to fulfil its obligations in terms of the output measures specified in Schedule C of the TIRG licence for the above named scheme.

Signature:  .....

Name: N Keeler .....

Date: 30/08/2011 .....

Designation: Senior Electrical Engineer .....