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765 kV Substation Acoustic Noise Impact Study by Predictive Software and Computational Approach

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ABSTRACT

Acoustic noise termed audible noise generated by substations comes from various equipment sources such as transformers and their cooling systems, reactors, breakers, etc. As a basis of evaluating different approaches, one needs to predict the noise levels around a substation as accurately as possible. This can be for new substations or before committing additional equipment to an existing substation. Hence great care has to be taken at the design stage not to produce unacceptable audible noise.

Pre-determination of audible noise thus becomes important at the transmission design stage itself. Since accurate assessment of the noise levels must consider all propagation paths the sound waves take to travel from the source to the receivers (reflections on barriers and ground, diffraction around barriers, transmission through barriers, etc.) a computer program best performs all the calculation chores. Audible noise caused by the high voltage rated equipment in substations or from transmission lines is the factor that has a huge impact on people living close by to the substation.

The usage of predictive software in environmental impact study is very frequent. In this paper, an acoustic noise analysis of operating 765 kV substations is performed in the environment, with the aid of SoundPlan software. A measurement campaign was designed and performed, according to quality procedures, in order to describe the internal acoustic climate, to characterize the noise sources and to have reference values to be used in the acoustic noise model.

With the source characterization, the internal simulations are performed and compared with measured levels. In this way, a procedure to perform complete predictions, both inside and outside the 765 kV substations, is given, showing, in the validation test, a good agreement with the measured values.

KEYWORDS

Substation Audible Noise, Transformers, Reactors, Predictions

1. INTRODUCTION

Eskom Substation Engineering department has raised an issue around the high levels of audible noise (AN) being experienced around the newly built 765 kV substations. A program was initiated, to investigate the high levels of AN. This investigation forms part of the project "Corona and Field Effects from 765 kV substations" which is controlled by Eskom Research, Testing and Development.

This paper discusses the noise criteria defined to be adhered to in South Africa, presents a series of measurements and predictions of audible noise around two of Eskom's 765 kV substations and draws conclusions.

2. BACKGROUND

Most utilities use electronic and barrier methods to reduce substation equipment (transformer, reactors, etc.) noise levels. It is important to have reliable predictions of future noise levels for the increasing number of power substations being installed.

Planning new substations or expanding existing ones in built-up areas must take into account the impact on local environmental noise, and comply with community noise regulations.

Audible noise in substations emanates principally from the vibrations from transformer cores and from the cooling system (fans, pumps, radiators, etc.). The problem becomes acute because transformer noise is continuous while noise limits are significantly reduced during night-time.

In order to minimize the impact of power substations on environmental noise, different approaches may be taken:

- Select a proper site for a new substation.
- Reduce noise at the source by improving the performance of magnetic material or by using noise absorbing screens.
- Locate noise sources (transformers) near the control buildings to screen and restrict the propagation of sound waves.
- Erect noise absorbing barriers at selected locations along the borderline of the substation.

As a basis for evaluating different approaches, one needs to predict the noise levels around a substation as accurately as possible before committing additional equipment.

Since an accurate assessment of the noise levels must consider all propagation paths the sound waves take to travel from source to receivers (reflections on barriers and ground, diffraction around barriers, transmission through barriers, etc.), a PC computer program best performs all the calculation chores.

This article describes such a computer program, developed at Hydro-Quebec. It is available on PC to help the substation designer estimate the contours of noise levels resulting from a selected substation layout.

3. NOISE LEVEL CRITERIA

A large degree of international consensus has emerged over the years as what constitutes unacceptable levels of noise exposure and what should be the maximum levels of exposure for certain specific situations. At the international level, the World Health Organisation

(WHO) together with the Organisation for Economic Co-operation and Development (OECD) are two of the main bodies that have collected data and developed their own assessments on the effects of the exposure to environmental noise. On the basis of these assessments, guideline values for different time periods and situations have been suggested.

The World Health Organisation has recommended that a standard guideline value for average outdoor noise levels of 55 dBA be applied during normal day-time in order to prevent significant interference with the normal activities of local communities. The ambient sound level is defined as the equivalent continuous A-weighted sound pressure level L_{Aeq} at a specific place and over a specific time inclusive of intruding noises. Intruding noise in this context is defined as noise in spaces that is generated by sources other than those resulting from the intended activities in those spaces.

The main controlling criteria in South Africa to date have been from:

- SANS 10103:2003 (SABS 0103) [1]
- National Noise Control Regulations [4]

SANS 10103:2003 [1], the Code of Practice for *The Measurement and Rating of Environmental Noise with Respect to Land Use, Health, Annoyance and Speech Communication* recommends maximum noise levels for residential and non-residential areas. Table 1 taken from this Code of Practice lists the recommended maximum ambient sound levels which should not be exceeded.

These sound pressure levels include corrections for tonal character and impulsiveness of the noise. This is also known as the *rating level* for the ambient noise (L_r).

TABLE 1: Typical Rating Levels for Noise in Districts from SANS 10103 (Table 2)

1	2	3	4	5	6	7
Type of district	**Equivalent continuous rating level ($L_{Req.T}$) for noise** dBA					
	Outdoors			**Indoors, with open windows**		
	Day/night $L_{R,dn}$ [a]	**Daytime** $L_{Req,d}$ [b]	**Night-time** $L_{Req,n}$ [b]	**Day/night** $L_{R,dn}$ [a]	**Daytime** $L_{Req,d}$ [b]	**Night-time** $L_{Req,n}$ [b]
a) Rural districts	45	45	35	35	35	25
b) Suburban districts with little road traffic	50	50	40	40	40	30
c) Urban districts	55	55	45	45	45	35
d) Urban districts with one or more of the following: workshops; business premises; and main roads	60	60	50	50	50	40
e) Central business districts	65	65	55	55	55	45
f) Industrial districts	70	70	60	60	60	50

In the Western Cape in terms of Cabinet Meeting Minute No. 424/1995 dated 7 June 1995, has under section 25 of the Environmental Conservation Act. 1995 (Act 73 of 1989) [4], made the regulations in the schedule to control environmental noise in the Province of the Western Cape. For industrial noise directly adjacent to an industry should not exceed 61 dBA.

4. AMBIENT NOISE LEVELS

The degree of annoyance with continuous audible noise is dependent in a large part upon the relative level of the ambient noise. The human ear will normally notice the more dominant of several noises only.

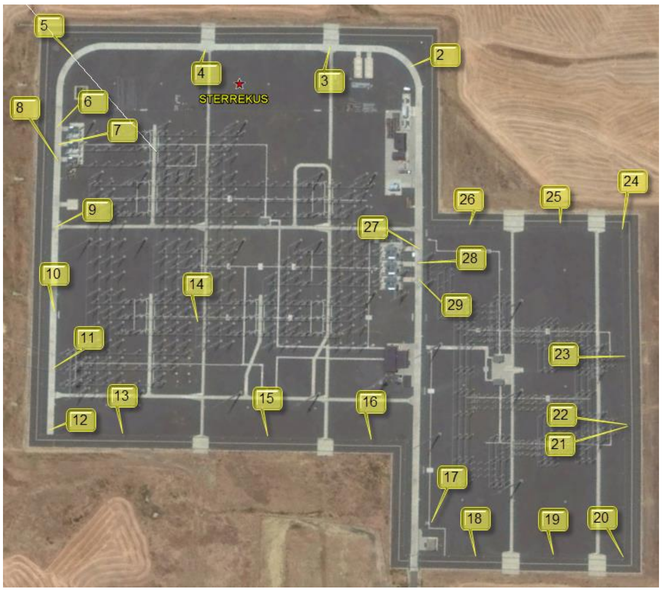
Sources of ambient noise in the community include vehicular or railway traffic, factories, aircraft, animals, and appliances such as attic fans, air conditioners, and lawn mowers. If ambient noise is very low, even a small amount of wind can override the other noise sources and become the dominant ambient noise.

The human ear distinguishes a particular sound source and establishes whether it is objectionable or not by comparing it to the general background or ambient noise to which it has become accustomed. Ambient noise is generally a broadband noise that covers a large range of frequencies, with no pronounced or outstanding tones. The addition of another broadband noise source, such as a fan, would not likely be distinguishable by the human ear. Car horns, gun shots, and transformer noise, being more or less of a pure tone, can readily be distinguished by the human ear if loud enough. Some jurisdictions may have additional requirements related to pure tones.

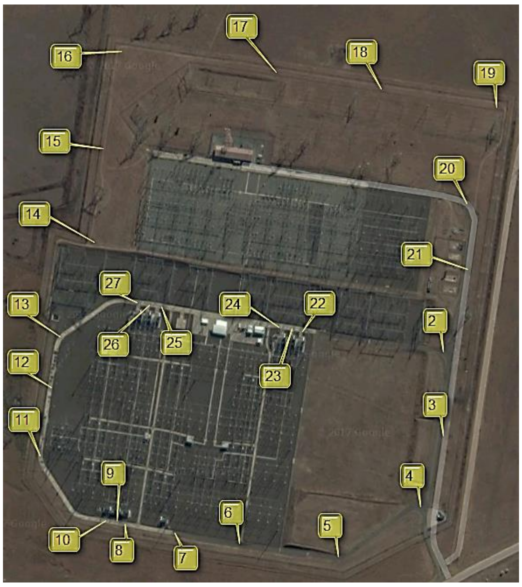
Highway traffic can provide a base ambient noise that can help shield substation noise. While it is easy to measure traffic noises near the highway, it becomes increasingly difficult to measure them at distances of 1.5 km to 3 km. A substation could benefit from the shielding effect of highway noise if it is located less than 3 km from a highway.

5. SUBSTATION LAYOUTS

The two substation layouts of Eskom’s 765 kV substations are shown in Figure 1, on which the audible noise studies have been conducted. Figure 1 indicated the audible noise positions where audible noise readings were conducted around the perimeter of the substation. Both day-time (06:00 – 22:00) and night-time (22:00 – 06:00) audible noise measurements were conducted.



Substation A



Substation B

FIGURE 1: Substation Layouts of Eskom’s 765 kV substations

6. AUDIBLE NOISE MEASUREMENT PROCEDURE

The audible noise measurement procedure is based on the SANS 10103 [1] and SANS 10083 [2] standards. Predefined measurements positions were selected around the perimeter of the 765 kV substations, where day-time and night-time audible noise measurements were conducted. See Figure 1 for the measurement positions.

A RION NA-28 sound level meter and third octave band real-time analyser was used to measure the audible noise. All items of the acoustic measuring equipment used in this project are traceable to either national or international acoustic measurement standards.

Prior to commencing with the measurements, the sensitivity of the sound level meter together with its associated microphone and preamplifier were checked with the RION NA-74 acoustic calibrator in accordance with the manufacturer's instructions.

On completion of the day's measurements, the calibration check was repeated. The pre- and post-calibration levels coincided.

The weather parameters were also recorded throughout the time of measurement at spot times. Table 2 and Table 3 records the weather parameter during the measurement period at Substation A and Substation B respectively.

TABLE 2: Weather Parameters Conducted During the Measurement Program on the 16 and 17 February 2017 for Substation A

DATE:	16 February 2017		17 February 2017	
TIME:	21:57	22:34	08:29	11:52
TEMPERATURE (°C):	19.6	18.5	21.5	28.5
HUMIDITY (%RH)	70.6	78.0	60.0	36.2
PRESSURE (hPA)	1005.2	1003.6	1002.4	1001.9
WIND SPEED (m/s)	< 3.8	< 3	< 2	< 2
COMMENTS	Clear moonlight sky, with slight breeze		Weather was fine, sunny and no clouds present	

TABLE 3: Weather Parameters Conducted During the Measurement Program on the 15 March 2017 for Substation B

TIME	**TEMPERATURE (°C)**	**HUMIDITY (%RH)**	**PRESSURE (hPA)**	**WIND SPEED (m/s)**
15:04	29.8	30.5	836.9	< 3
15:32	28.2	31.2	836.4	< 3.2
22:00	18.6	63.5	838.5	No wind
22:44	17.0	69.1	839.2	No wind
00:00	21.5	56.2	839.4	< 0.1

7. AUDIBLE NOISE MEASUREMENTS PREDICTIONS

The audible noise measurements and predictions around the perimeter of the two Eskom 765 kV substations are given in Appendix B for information and comparison.

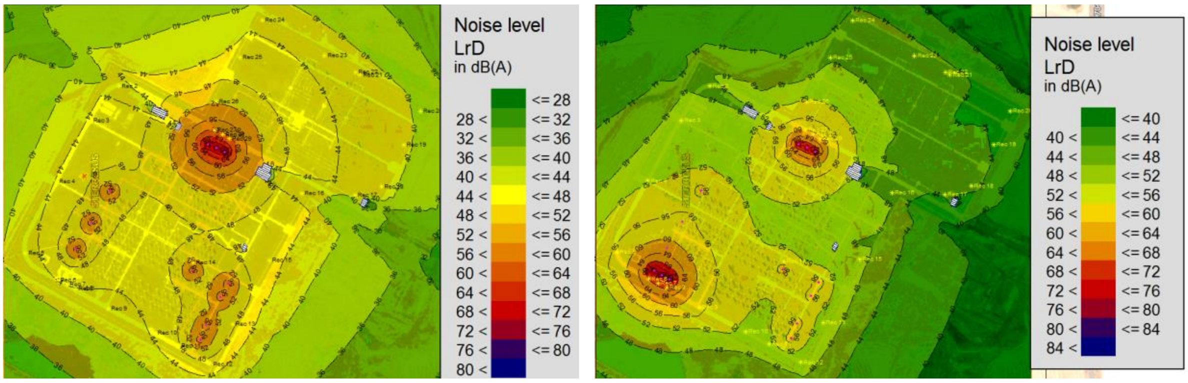


FIGURE 2: Substation A Audible Noise Predictions (Left: Without the Reactor Noise, Right: With the Rector Noise)

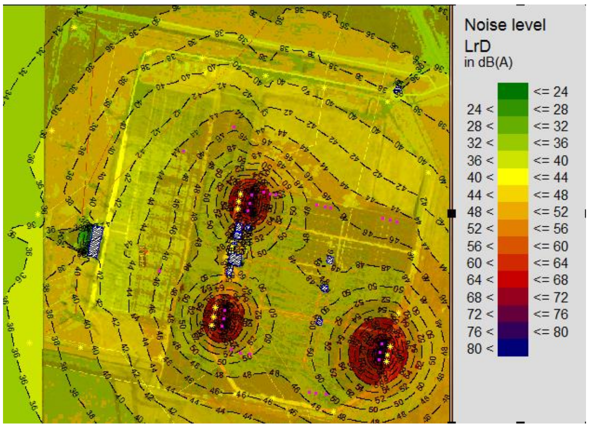


FIGURE 3: Substation B Audible Noise Predictions

8. DISCUSSION OF THE RESULTS

Both Substations A and B from Figure 1 were imported into the SoundPlan software [3] package and audible noise predictions conducted.

The noise spectrum used in the predictions for the transformers, reactors and corona noise is shown in Appendix A. These sources were used to calculate the noise at the predefined measurement locations around the perimeter on the Sterrekus 765 kV substation (see Figure 1).

The audible noise receivers were set at the same positions where actual audible noise measurements were conducted. These points are inside the perimeter fence of the substations. Further audible noise measurements were conducted inside the substation around the noise components (transformers, rectors and corona sources).

All predictions have included corona noise being generated by the hardware inside the 765 kV substations.

From the measurements conducted, it is noted, that the night-time audible noise levels are similar to the day-time measurements at the predefined positions around both the 765 kV substations.

The frequency spectrum is also different during the day-time and night-time period. This is probably linked to the lighter loads on the transformers and as seen from the system data (TEMSE), the reactors were not energised during the day-time measurement period for Substation A. The measured transformer noise during both periods is similar, but can be influenced by the cooling system during high load conditions. The difference from the measurements is approximately 2 - 3 dBA.

It can be seen that at each location the noise levels are consistent and also that there is little variation between the day-time and night-time periods, except near the reactors. This was due to the reactors being out of service during the day-time measurements for Substation A. This observation indicates that the noise climate in the area is dominated by plant and industrial noise.

9. CONCLUSIONS

In this paper, the noise pressure level, spectrum and attenuation characteristics of two of Eskom's 765 kV substations were measured, predicted and analysed.

From the investigation, the following was conducted:

- Measurements of the existing audible noise levels from both the 765 kV substations at the boundary fence for both the day-time and night-time were conducted,
- Predictions based on the noise sources of the existing station with and without the reactors energised were conducted,
- Measured and predictions of the audible noise from the two 765 kV substations were analysed,

The following conclusions can be drawn for the investigation:

- The main noise sources come from the transformers; reactors and corona in both the 765 kV substations. They are mainly in middle and low-frequency band. However, the noise level of the reactors is relatively higher than that of main transformers. The cooling fans can influence the noise of main transformers.
- Interference phenomenon exists in the noise propagation process of the transformers and reactors, and the interference of 100 and 200Hz is most obvious. Layout optimization of the HV reactors could reduce the noise emission level at the substation boundary.
- It can be seen that at each location the noise levels are consistent and that there is little variation between the day-time and night-time periods, except near the reactors. This was due to the reactors being out of service during the day-time measurements. This observation indicates that the noise climate in the area is dominated by plant and industrial noise.

Within the South African context, SANS 10103:2003 gives an indication of the criteria for an assessment of annoyance. This scientific approach is complex and it is not appropriate to provide all the details in this report. The reader is however referred to Section 8 of SANS 10103. In overview this Standard indicates that there are likely to be specific responses by communities/groups to given changes in noise level from the residual noise level of an area.

SANS 10103 specifies audible noise levels that must be adhered to in South Africa for different environments (noise districts). These are shown in Table 1.

From the predictions and measurements conducted, for the transformers and reactors both for the day-time and night-time and comparing it to the acceptable noise levels in Table 1 (Table 2 from SANS 10103), it is concluded, that the noise levels exceed the rural and suburban districts with little road traffic.

10. REFERENCES

[1] SANS 10103, The Measurement and Rating of Environmental Noise With Respect to Annoyance and to Speech Communication.

[2] SANS 10083, The Measurement and Assessment of Occupational Noise for Hearing Conservation Purposes.

[3] Braunstein + Berndt GmbH / SoundPLAN International LLC, SoundPlan User's Manual and Software Version 7.4, February 2014.

[4] Environmental Conservation Act. 1989 (Act 73 of 1989).

11. APPENDIX A – NOISE SOURCE SPECTRUM USED IN THE MODELS

The following noise sources were used in the predictiuions of the audible noise predictions:

A1 Transformer Noise Sperctrum
A2 Rector Noise Spectrum
A3 Coronsa Noise Spectrum

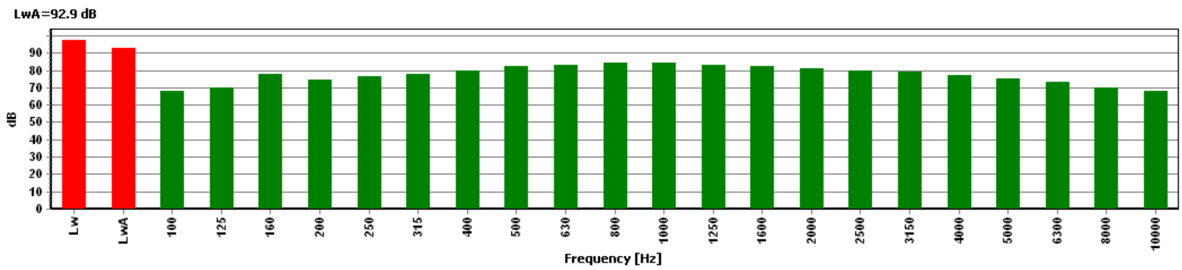


FIGURE A1: Transformer Noise Spectrum of Noise

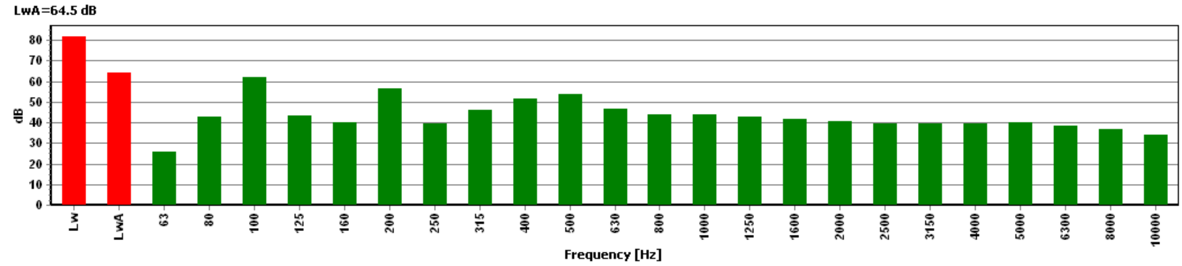


FIGURE A2: Reactor Noise Spectrum of Noise

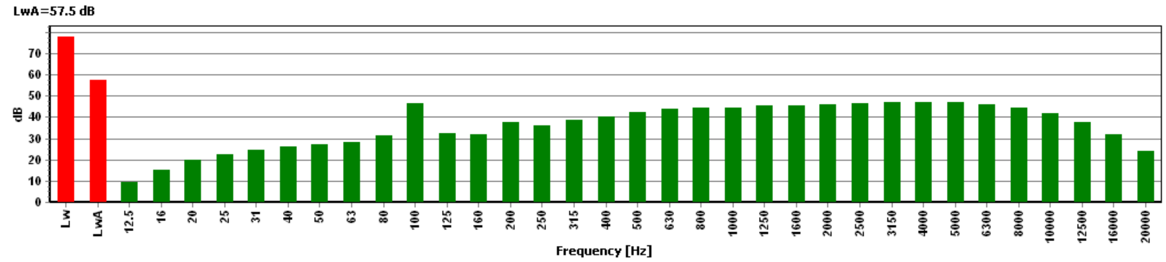


FIGURE A3: Corona Noise Spectrum of Noise

12. APPENDIX B – AUDIBLE NOISE MEASUREMENTS FOR THE VTWO 765 kV SUBSTATIONS

TABLE B1: Day-time and Night-time Spot Nosie Measurements at Substation A 765 kV Substation – 16 February 2017

POSITION	DAY-TIME		NIGHT-TIME		COMMENTS
	LA_{eq}	LA_{eq} (Predicted)	LA_{eq}	LA_{eq} (Predicted)	
CAL	93.9		93.9		Calibration of instrument
REC 2	49.6	40.3	47.2	47.2	
REC 3	48.2	44.6	48.8	49.6	
REC 4	50.2	44.3	52.0	52.2	
REC 5	48.4	42.4	59.0	56.8	
REC 6	49.4	44.1	64.4	68.2	Reactor 1
REC 7	49.6	44.2	69.8	69.8	Reactor 2
REC 8	50.7	43.9	69.4	69.2	Reactor 3
REC 9	51.4	43.1	57.7	56.9	
REC 10	49.7	44.6	52.5	51.9	
REC 11	50.2	47.5	54.0	51.6	Line trap/ surge arrestors
REC 12	50.1	46.3	53.6	50	
REC 13	51.8	48.5	53.6	51	
REC 14	55.5	53.3	57.5	54.8	Beneath the PI with no corona rings
REC 15	51.3	46.0	53.7	49.1	
REC 16	49.0	41.2	52.9	46.1	
REC 17	45.0	40.9	47.0	44.9	
REC 18	43.2	41.7	46.1	44.8	
REC 19	41.3	40.8	44.8	44.1	
REC 20	39.7	39.9	44.0	43.1	
REC 21	45.5	42.1	52.5	44.8	
REC 22	45.5	42.2	50.2	44.9	
REC 23	44.1	43.1	49.9	45.5	
REC 24	44.5	43.5	45.6	45.6	
REC 25	49.9	46.4	47.8	48.1	
REC 26	51.5	51.6	50.4	52.5	
REC 27	60.0	59.9	54.7	60.1	Transformer 1
REC 28	59.6	60.9	55.0	61.1	Transformer 2
REC 29	57.1	60.9	55.6	61	Transformer 3
REC 30	93.9		93.9		

TABLE B2: Day-time and Night-time Nosie Measurements at the 765 kV Substation B (15 and 16 March 2017)

POSITION	DAY-TIME		NIGHT-TIME		COMMENTS
	LA_{eq}	**LA_{eq} (Predicted)**	**LA_{eq}**	**LA_{eq} (Predicted)**	
CAL	93.9	-	93.9	-	Calibration of instrument
REC 2	47.1	39.6	49.0	39.6	
REC 3	47.3	39.8	50.2	39.8	
REC 4	46.6	39.3	49.6	39.3	
REC 5	49.9	40.7	53.5	40.7	
REC 6	54.0	45	59.0	45	
REC 7	57.7	53.4	59.8	53.4	
REC 8	69.9	65.5	70.3	65.5	Reactor 1
REC 9	66.9	67.5	71.5	67.5	Reactor 2
REC 10	70.3	66	72.1	66	Reactor 3
REC 11	55.2	48.3	58.2	48.3	
REC 12	52.6	46.2	55.7	46.2	
REC 13	54.0	45.3	56.6	45.3	
REC 14	49.4	44.4	50.0	44.4	
REC 15	45.1	38.1	44.8	38.1	
REC 16	40.5	35.5	41.0	35.5	
REC 17	39.4	34.5	45.0	34.5	
REC 18	38.5	35	42.7	35	
REC 19	38.9	33	42.5	33	
REC 20	42.0	36	45.4	36	
REC 21	41.9	37.7	46.4	37.7	
REC 22	63.1	60.2	58.9	60.2	Transformer 1
REC 23	61.6	60.9	58.2	60.9	Transformer 1
REC 24	60.5	60.4	58.0	60.4	Transformer 1
REC 25	61.5	60.6	57.9	60.6	Transformer 2
REC 26	64.0	61.6	59.2	61.6	Transformer 2
REC 27	59.7	60.5	60.9	60.5	Transformer 2
REC 28	93.9	-	93.9	-	Calibration of instrument