Quantification of the Power System Energy Losses in South Pacific Utilities

Te Aponga Uira O Tumu -Te-Varovaro, Cook Islands

Submitted to

European Union

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May 16, 2012

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These appendices will be provided separately

1. Executive Summary

KEMA at the request of the Pacific Power Association (PPA) conducted an energy efficiency study titled: "Quantification of Energy Efficiency in the Utilities in South Pacific Utilities" for 10 Southern Pacific Island Utilities. This report summarizes study results for Te Aponga Uira O Tumu-Te-Varovaro (TAU) in Rarotonga, Cook Islands.

Project objectives and deliverables:

- Quantification of energy losses in the power system.
- Preparation of an Electrical Data Handbook containing electrical characteristics of the power system high voltage equipment.
- Preparation of a digital circuit model of the power system using EASY POWER, an established commercial package.
- Identification of sources of non-technical losses.
- Recommendations for strategies on reducing technical and non-technical losses.
- Preparation of a prioritized replacement list of power system equipment to reduce technical losses.

1.1 Quantification of Losses

Losses through the system of TAU consist of power station losses and distribution system losses. Both loss categories are quantified.

- Station Losses: Efficiency of generating units and power plant auxiliary loads
- Distribution System Losses: these losses can be divided into technical and non-technical losses.
  - Technical losses: Summation of transformer core losses, transformer copper losses, distribution feeder losses, secondary wire losses and losses of any other equipment

in the system, like reactors, capacitor banks. Technical losses will become higher as power factors drop below unity.

– Non-technical losses: inaccurate meters, meter tampering or by-passing, theft, meter reading errors, irregularities with prepaid meters, administrative failures, wrong multiplying factors, others.

– Unbilled Usages: Energy consumption that is not billed should be considered a financial loss for the company rather than a non-technical loss.

1.2 Energy System Losses

KEMA's analysis of the TAU power system determined total losses of 10.33% consisting of:

- 1.96% in power station auxiliaries (station losses), which is relatively low.
- 4.41% in technical losses, which is a typical value.
- 2.96% in non-technical losses, which is a rather low level.
- 1.00% in unbilled usage such as for street lights.

Unbilled usage cannot be considered to be a true system loss as it is a financial loss for TAU because the power is delivered for services (street lighting) that are not paid for. It is highly recommended that TAU considers calculating the actual usage for street lights and including it as financial loss in future financial statements.

Ignoring the 1.00% for financial losses, the results of KEMA's calculations for quantification of the TAU power system losses are as follows:

1.96% in station losses.

7.37% in system losses.

1.2.1 Generation

In addition to analyzing power station and distribution system losses KEMA also looked at recent figures from early 2011 on the generators' ***fuel efficiency*** in the Avatiu Valley Power

Station. This data showed that Generator 7 has the highest fuel efficiency of 4 kWh/liter, other generators that have been running in the first part of 2011 (generators 1, 2 and 4) have a fuel efficiency of 3.7 to 3.8 kWh/liter. The fuel efficiency of the standby units in this same period was lower and varied between 2.77 and 3.0 kWh/liter, but the data appeared to show much higher values in previous months. TAU informed KEMA that the fuel meters at the power station are unreliable and inaccurate which makes it difficult to accurately determine the generators' fuel efficiencies.

Another aspect that may be contributing to the reduced efficiency is that most of the generators are de-rated. The overall fuel efficiency furthermore depends on the way how generators are dispatched and will be highest if generating units are loaded to some 80% to 90% of their capacity. It must be noted that TAU has a spinning reserves policy to ensure that power delivery will remain interrupted in case the largest generator trips.

With these conditions in mind, a fuel efficiency of 3.8 kWh/liter (the average of 2009-2010) is reasonable. Fuel meters need to be repaired or replaced by accurate, temperature compensated fuel meters. TAU has a generation expansion plan, but unit sizes and types (e.g., medium or high speed diesels) are still to be determined. For the expansion, a new power house has to be built adjacent to the existing power station.

The ***power station's own usage*** is 1.96% of the total power generated, which places TAU as best in class compared with other Pacific utilities.

1.2.2 Distribution

The technical losses in the distribution system amount to 4.41% which is a typical value. A breakdown of the technical losses as calculated shows the following loss percentages:

Distribution feeder losses	1.03%
Transformer core losses	0.32%
Transformer core losses	0.73%
Secondary wire losses	2.33%
Total technical losses:	4.41%

The figures for the distribution feeder losses and the transformer losses are very good, while the percentage of 2.33% for secondary wire losses is reasonable compared with other, similar island systems.

1.2.3 Non-technical

KEMA's calculations show that non-technical losses are only 2.96% of total energy generated, which ranks among the best of the Pacific island utilities studied.

TAU advises that incidents of electricity theft, meter tampering, and meter by-passing only occur sporadically. Therefore, when summarizing probable causes for TAU's non-technical losses we can conclude that there may be meter inaccuracies, which is discussed further in the next section.

As already indicated these losses do not include power usage for streetlights, which have been separated from the system losses and are considered to be a financial loss for TAU.

1.2.3.1 Metering

KEMA observed that TAU uses different meter reading dates for energy production versus energy sales. In order to have a more accurate correlation between energy sold and energy entering into the distribution system, it would be better to perform the monthly customer meter reading around the last day of each month. This way the energy sales data would cover essentially the same monthly period as the monthly generation statistics and the calculated losses will have a higher accuracy.

The meter readers are equipped with a device that generates the electricity bill for immediate delivery to the customer after the readings have been entered into the device. Clients will be disconnected within 7 days after payment due date. The reconnection fee is NZ$ 146. As an average there are 4 to 6 disconnections per month.

The Customer Information System gives red flags when irregular usage occurs. In cases of low usage the meter is inspected and tested on site. The majority of the meter population is old and from testing results it is known that the accuracy of the old meters has decreased. This year a number of old meters will be taken out of the grid for accuracy testing. Bad meters are replaced. TAU is considering installation of an Automated Metering Infrastructure.

1.3 Recommendations

1.3.1 Generation

The Power Station's own usage (1.96%) is relatively low. Even so a comprehensive energy efficiency audit of the power station could reveal options for improvement. Fuel meters also need to be repaired or replaced by accurate, temperature compensated fuel meters.

Generation expansion as planned by TAU will also bring the benefit of improving overall fuel efficiency, particularly if the newer more efficient engines are run for based load and if the old units 4 and 5 which appear to be near the end of their useful operating lifetime are retired from service.

A cost/benefit analysis has shown that the cost of installing a new generating unit with a capacity of 2.7 MW would be paid back in 7 years based on a projected overall increase of fuel efficiency from 3.8 kWh/liter to 4.0 kWh/liter.

1.3.2 Distribution

KEMA developed a power flow model in Easy Power for the power system in Rarotonga Island with all existing equipment that was in operation prior to June 2011.

Since the distribution feeders are all laid out with underground cables the power factors as shown in the generator log sheets are quite good (0.96 to 0.98 lagging). This also contributes to the relatively low technical losses in the power system. When looking at the total capacity of all distribution transformers, these transformers are loaded at less than 35% of full connected capacity under peak demand. This increases the level of no-load losses. It should be possible to achieve a reduction in annual energy losses by more closely matching the ratings of transformers to peak load at individual locations over a number of years as new transformers are purchased. Based on the number of customers/load connected per transformer it can be determined which distribution transformers are the best candidates to be rotated.

When buying new transformers TAU should request sufficient data from bidders that can be used for evaluating copper and iron losses. A NZ$ value per kW should be applied as part of the evaluation by which the total transformer life cycle costs (capital and losses) can be calculated. This approach often shows that a transformer with lower losses, even if somewhat more expensive, can be more cost effective over its lifetime.

1.3.3 Non-technical

KEMA recommends the following based on findings in the current study:

- Replacement of the old meter population with new meters is recommended, since accuracy of meters deteriorate with aging.
- Perform the monthly meter readings on or around the last day of the month in order to get a more accurate comparison between "energy entering into the feeders" and "energy sold" and achieve more accurate figures on total losses and non-technical losses.

1.4 Prioritized list of equipment for replacement

As previously noted, replacement of the old meter population is recommended. In addition, as discussed below, there would be benefits from replacing older generation assets.

Generation extension has already been planned by TAU. This extension is needed for covering load growth (expected to be 4% per year) along with the decommissioning of the aged engines, Units 4 and 5. With this approach the reserve margin will remain at an acceptable level consistent with the n-2 principle, and last but not least, fuel efficiency will increase with newer and more efficient base load engines.

KEMA estimates a 7 year economic payback period for installing a new 2.7 MW generator, assuming overall fuel efficiency will increase from 3.8 kWh/liter to 4.0 kWh/liter. The NPV calculation supporting this estimate is further described in Chapter 7.

When looking at the total capacity of all distribution transformers, these transformers are loaded at less than 35% of full connected capacity. Loss reduction savings can be achieved by optimizing the ratings over a number of years as new transformers are purchased. During the site visit the age of the different transformers could not be identified, otherwise an estimate could have been made on transformer replacements in the coming 10 years. On the other hand, these low loading levels will tend to extend the transformers' lifetimes. Even so, issues like corrosion, bad connections, oil leakages, should be monitored in order to identify those transformers that need maintenance and/or replacement.

2. Project Approach

In January 2011, KEMA launched 10 studies on behalf of the Pacific Power Association (PPA) to quantify power system energy losses by utilities across the South Pacific region. The purpose of these studies is to review the power system and quantify the energy losses in each utility's existing generation facilities, transmission and distribution networks, and billing procedures and to identify where losses occur in the system and to quantify those losses. Finally, these studies will supply recommendations to minimize energy losses and prioritize which assets will reduce losses most through upgrades or replacement for each utility.

Within weeks of contract award, KEMA submitted data requests to the appropriate utilities and proposed project execution methodologies to PPA for approval to gain an understanding of each utility's systems prior to conducting site visits.

2.1 Data Collection

Prior to visiting TAU in Rarotonga for data collection and technical assessments of the power system, KEMA sent data request documents to TAU on February 9, 2011. The major Data Request document contained a list of all data needed for the study, while an additional Excel document was sent for entering all required data of equipment and system components. These data needed to be collected to create a power system model in the grid calculation program EasyPower®. Most of the specification consists of extractions from EasyPower's model specification, so that the data definitions are consistent with the simulation software to ensure the accuracy of the study results.

Subsequently KEMA visited TAU in Rarotonga in the week of February 28, 2011, for data collection, interviews and an assessment of the power system.

During the visit much relevant data has been gathered, although not all data was readily available. Personnel at TAU were very helpful with supplying additional data after the visit as requested.

For the quantification of losses study we had to make assumptions, based on our experience, in certain areas:
- electrical parameters of the generating units
- secondary wires/service lines.

2.2 Utility Operations

TAU in Rarotonga, Cook Islands, currently has a maximum load of around 4.9 MW and had a peak of 5.1 MW in previous years. For the coming years a demand growth is expected of 4% per year.

The power system consists of:

- a power station with in total 9 generating units as specified in chapter 3, all burning diesel # 2 as the fuel. Two generating units (nrs. 4 and 5) have reached the end of their useful life. Power station control is done manually in the power station control room. The power station has 3 fuel tanks of 54,000 liter each and 2 day tanks (12,000 and 15,000 liters). Most of the installed generators' capacity has been de-rated. With the total available capacity TAU can keep up with the n-2 criterion. TAU has a spinning reserve policy that provides in uninterrupted power supply in case the largest generator trips. The power station's substation has two types of 11 kV switchgear with a bus connection (Merlin Gerin and Reyrolle Pacific). Each generator's output is metered. Generator meters are from Schlumberger, class 1. Fuel meters are not temperature compensated and show inconsistencies as already identified in a previous study. These meters should be repaired or replaced and should be tested on a regular basis for monitoring the meters' accuracy.
- an 11 kV distribution system consisting of six 11 kV distribution feeders, all underground, with ring main units (Merlin Gerin and ABB) installed for distribution transformers 11 kV / 415 V. These pad mounted ring main units are called substations. Feeder meters in the power station are from Schlumberger, class 1.
- around 5,000 customers. Customer meters have class 2.5 but many customer meters are old and not tested. Of all meters 95% are of the electromechanical type and 5% are electronic meters. The oldest meters (Ferranti) are some 20 to 30 years old, the newest meters are from 2006 (Delta Star, New Zealand). Currently three-phase meters of Iskra are being trialed. This year some 20 old meters will be taken out of the system at random for accuracy tests. TAU has plans to buy a new test bank. The Omega test bank that is currently being used is 20 years of age and has never been calibrated.

TAU works with IEC standards.

TAU keeps extensive and detailed records of outages, outage durations and customers interrupted with figures per substation and feeder, resulting in overall figures for SAIDI, SAIFI, CAIDI and CAIFI. In the detailed spreadsheets the outage causes per outage can be identified.

For SAIDI TAU has set a target of 4 hours (in previous years 4.5) and for SAIFI a maximum target has been set at 2 interruptions (in previous years 4 interruptions). When looking at benchmarking figures of isolated small island systems, these targets (which are relatively well achieved by TAU) are for islands which are 'best in class'.

Meters are read monthly with intervals of 28 to 32 days and the meter readers are equipped with devices that generate the bill on site after the reading has been entered. After the bill has been delivered by the meter reader, payment is due within 30 days. TAU's billing system raises red flags in cases of irregular consumption, which occurs as an average some 5 times per month.

2.3 Identifying and Quantifying Losses

Electric power is generated in power stations and delivered through transmission and/or distribution systems to customers. Energy losses occur in each part of the power system until reaching the customer's meter point. Power system energy losses are divided into the categories based on where the losses happen and the cause of losses:

Power station losses – energy consumed by the equipments in support of power generation, also called power station auxiliary load or power station own usage.

System losses – losses occurred along power transferring through the transmission and distribution systems, such as transformers, overhead line conductors, areal cables or underground cables and service wires. At the metering point also losses may occur because of the accuracy margin of the meters.

Losses in category 2 consist of both Technical Losses and Non-technical Losses. Technical losses are the losses that can be estimated as a result of electric current passing through the power system equipments. In contrast to technical losses, there are non-technical losses, which are not directly caused by power system equipments. Causes of non-technical losses can be: theft, inadequate or inaccurate meters, meter tampering or by-passing, meter-reading errors, irregularities with prepaid meters, administrative failures, wrong multiplying factors, etc.

There is another category of loss due to energy usage that is not accounted for and subsequently not billed for. The unbilled usage results in financial loss to the utility and should not be included as part of non-technical loss. Examples of unbilled usages that KEMA found in some cases are: street lighting, utility's own building usage, electric power used for supplying other utilities such as water and sewage.

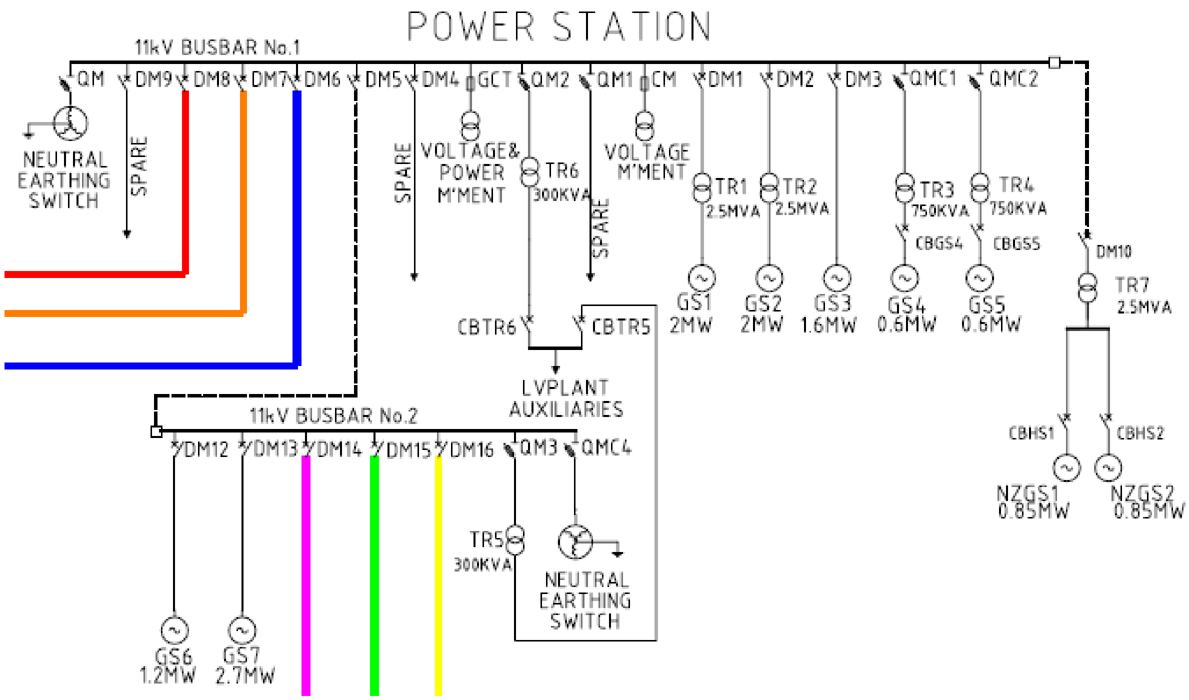
Furthermore, financial losses may be present due to a non-optimized efficiency of the generation system and individual generating units. Improvement of the generation efficiency will lead to fuel savings.

In this study, KEMA estimated power station losses and distribution system losses. Where information was not sufficient, assumptions were made to facilitate the estimation. KEMA created a power flow model in Easy Power to represent the power system in Rarotonga island. The power flow study was performed to calculate system kW losses at peak demand, including primary feeder losses. Furthermore an Excel spreadsheet was created to estimate kW losses that are not calculated in the power flow study, such as losses of distribution transformers and service wires. These kW losses were converted to kWh energy losses on annual basis by utilizing the estimated Loss Factor. Unbilled usage was estimated for all the causes identified.

The total system energy loss was calculated as the difference between total annual generation after station's own usage and annual energy sold. Non-technical loss was then derived by comparing the total system loss and the sum of the estimations for technical losses and unbilled usage.

3. Generation

All generation is concentrated in TAU's Avatiu Valley Power Station. The figure below is the power station's one line diagram. The specification of the installed generating units is given in chapter 3.1.



For determining generation efficiency and power station losses KEMA gathered information and interviewed TAU personnel. KEMA also paid attention to the condition of equipment, maintenance practices, power station metering points and metering accuracy.

KEMA's major findings:

- Generator numbers 1 to 6 have been de-rated because of cooling problems and mechanical problems in some cases.
- As mentioned in chapter 2 fuel meters are not temperature compensated and show inconsistencies as identified in a previous study. These meters should be repaired or replaced and should be tested on a regular basis for monitoring the meters' accuracy. For determining the generation efficiency it is important to have reliable metering data.

- Recent figures for early 2011 on the generators' fuel efficiency in the Avatiu Valley Power Station showed that generator 7 has the highest fuel efficiency of 4 kWh/liter, other generators that have been running in the first part of 2011 (generators 1, 2 and 4) have a fuel efficiency of 3.7 to 3.8 kWh/liter. The fuel efficiency of the standby units was low in this period and varied between 2.77 and 3.0 kWh/liter. However, in previous years these units had high fuel efficiency. The unreliable fuel meters are the likely cause of lowered (and apparently wrong) efficiency figures.

  The overall fuel efficiency depends on the condition of the generating units and on the way the generators are dispatched and will be highest if generating units are in good condition and are loaded to some 80% to 90% of their capacity. It must also be noted that TAU has a spinning reserves policy which requires that power delivery remains uninterrupted in case the largest generator trips. Another aspect is that most of the generators are de-rated because of cooling problems or mechanical problems.

  With these conditions in mind an average fuel efficiency of 3.8 kWh/liter (the average of 2009-2010) is reasonable.

- The power station own usage is 1.96% which is a relatively low value and puts TAU at the # 1 position in the ranking of small Pacific utilities regarding power station losses.

3.1 Equipment

Generation equipment is listed below and also specified in the NPC Data Handbook.

Gen. 1: Duvant Crepelle / 12V26N	rated 2000 kW	de-rated 1500 kW
Gen. 2: Duvant Crepelle / 12V26N	rated 2000 kW	de-rated 1500 kW
Gen. 3: Mirrlees Blackstone / MB 275-8	rated 1600 kW	de-rated 1200 kW
Gen. 4: Lister Blackstone / ETSL	rated 600 kW	de-rated 400 kW
Gen. 5: Lister Blackstone / ETSL	rated 600 kW	de-rated 400 kW
Gen. 6: Mirrlees Blackstone / ESL 16	rated 1200 kW	de-rated 900 kW
Gen. 7: MAN B&W / L9-27/38	rated 2700 kW	2700 kW
Standby units:		
Gen. 8: Cummins / KTA50-G3	rated 800 kW	800 kW

Gen. 9: Cummins / KTA50-G3	rated 800 kW	800 kW
TOTAL rated	**12,300 kW**	
TOTAL de-rated		**10,200 kW**

In an n-2 situation the production capacity (based on the de-rated values) will be 6000 kW, while currently the peak load is 4,900 kW.

Based on information provided to KEMA, engines 4 and 5 have reached the end of their useful life and it may get harder to get spare parts for these engines. Even without engines 4 and 5 the n-2 criterion will still be met (production capacity of 5200 kW). However, TAU is anticipating a yearly demand growth of 4% which means within 2 years the peak load will grow to 5300 kW. Hence, additional generation capacity would be needed then to meet the n-2 criterion.

The power station has 3 fuel tanks of 54,000 liter each and 2 day tanks (12,000 and 15,000 liters).

The power station's substation has two types of 11 kV switchgear with a bus connection (Merlin Gerin and Reyrolle Pacific). Short circuit withstand current and breaking capacity of the Reyrolle Pacific breakers is 25 kA, for the Merlin Gerin switchgear in the power station and in all substation the breaking capacity is 12.5 kA.

Furthermore the power station has a control room where generating units and auxiliaries are controlled manually 24 hours per day.

3.2 Analysis of Losses

When it comes to analysis of losses in Generation we can identify the generation efficiency and the station losses (own usage).

Fuel Efficiency

On the topic of fuel efficiency, it has already been shown in Chapter 3 that the recent level of average fuel efficiency has been running around 3.8 kWh/liter. Given the age of the engines and the cooling problems this is a reasonable efficiency level. Fuel meters should be repaired or replaced and tested regularly in order to ensure that right efficiency figures will be obtained.

Given the current situation, there is not really much room for substantial improvement in fuel efficiency with the existing equipment. However, overall fuel efficiency can be improved when new generators are installed and commissioned and generators 4 and 5 have been decommissioned.

The impact of replacement of old generators by new generators is addressed in Chapter 6. The cost/benefit analysis performed by KEMA takes into account load growth as well as the n-2 principle as a pre-condition.

Station Losses

As already mentioned, station losses are very low at 1.96% of the total energy generated, which is particularly low given that the losses of the step-up transformers are included in the total amount of station losses. Even so, a detailed energy efficiency audit of the station could still reveal possible options for incremental energy savings.

3.3 Findings

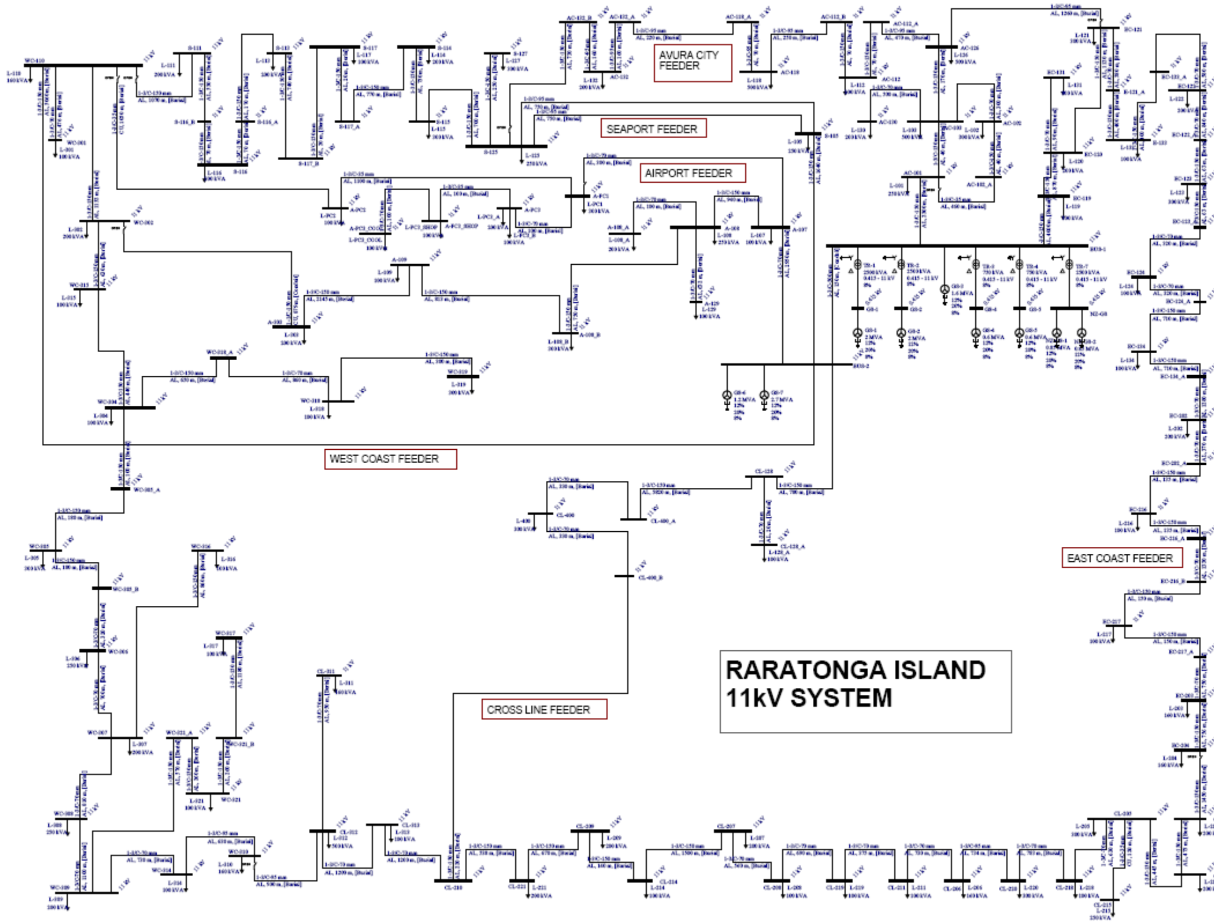
The analysis has shown that the power station is operating at a reasonable fuel efficiency, given the current condition of the engines and the operational procedures. When the time comes for the older engines 4 and 5 to be decommissioned there is clearly an opportunity to improve fuel efficiency. KEMA's analysis of this in chapters 6 and 7 shows that such generator replacement has a potential payback period of 7 years.

On the issue of power station own usage, it is clear that the station usage is already very low. Appropriate measures should be taken to keep the station losses low when new generation is installed in a new building adjacent to the existing power station.

4. Distribution

The TAU distribution system consists of six 11 kV feeders, all consisting of underground cables and pad mounted ring main units with distribution transformers, which are named substations.

The TUA one line diagram – as reproduced below - has been added to the electronic version of this report as a PDF attachment and is included in the report's hard copies in A3 format.



Feeders have connecting points to other feeders (where open breakers are shown in the one line diagram) but these connecting points are normally open. In the power flow study for determining losses we have applied the normal situation with connecting points open.

When looking at the power flow results at maximum load it shows that most cables are loaded to less than 10% of their capacity and only a few up to 20% and with one exception with a loading up to 32.5%. Even the feeder cables going out of the power station's buses are not higher loaded than some 20%. It can be said that the distribution system is oversized. Also, the distribution transformers are generally speaking oversized as well. The total of kVA's of all distribution transformers is 15,320 kVA, while the peak load is 4,900 kVA.

This explains why technical losses in feeders and transformers are very low, while the majority of the technical losses are in the low voltage wires.

4.1 Equipment

4.1.1 11 kV distribution

The TAU 11 kV distribution system consists of the following equipment:

- 11 kV XLPE underground three-phase cables are used for all feeders, but with different conductor sizes, which are 70 mm^2, 95 mm^2 and 150 mm^2, all conductors Aluminum. Three cables in the TAU system are paper lead cables with 35 mm^2 copper conductors.
- The distribution substations are ring main units (Merlin Gerin and ABB) with distribution transformers 11 kV / 415/240 V. These pad mounted ring main units are called substations. Distribution transformer sizes vary from 100 kVA to 500 kVA.
- Feeder meters in the power station are from Schlumberger, class 1
- Feeders have connecting points with switches normally open.
- No capacitor banks.

4.1.2 LV Wires

The low voltage system operates at a voltage level of 415/240 V.

TAU has provided KEMA with an overview of all low voltage cables per distribution substation. Conductor sizes vary from 16 to 95 mm^2. All LV cables are three-phase four wire cables of

which 80% are installed overhead and 20% underground. New installations are all underground, using the same cable type for both overhead and underground.
The main cables have in some cases a length of up to 5 km but is shorter in most cases.

4.2 Analysis of Losses

To quantify losses through the distribution system and service wires, the following assumptions were made:

- The total energy generated and energy sold over the past one year (07/2010-06/2011) was used for the study.
- Loads were distributed based on the distribution transformer locations.
- Loads were allocated proportionally to the kVA capacity of each distribution transformer.
- Actual voltage drops through primary feeders were calculated in a power flow study with the grid model in Easy Power. However, voltage drops through feeders were not considered in loss estimations for distribution transformers and secondary services wires.
- Secondary wire losses were estimated based on average customer consumption for Domestic and Commercial customers combined. TAU has 14 Demand customers and it is assumed that those customers' meters are at the low voltage terminal of the distribution transformer, therefore no secondary losses.
- Typical secondary service wire types and sizes were assumed, based on information provided. Assumptions were made for average wire lengths and general configuration of service wire. For TAU, Cook Islands, the typical secondary line and service drop configuration is developed based on the CAD drawings provided.

TAU, Cook Islands, has provided the one-line diagram of its power system on the island of Rarotonga. Feeder segment distances, conductor types and sizes, and kVA capacity of distribution transformers are identified on the one-line diagram. Some of the equipment data as well as energy production, consumption and customer sales statistics are also provided in excel spreadsheet, initially up to June 2010, subsequently, up to June 2011. KEMA developed the power flow model in Easy Power for the power system in Rarotonga island with all new equipments in operation up to June 2011. In this distribution system model, the power plant and 11kV feeders are modeled. Normally Open switches are identified. As a result, all 11 kV distribution feeders are operated as radial feeders. Distribution transformers are represented as spot loads with constant kVA load same as transformer capacity and load power factor of 0.9. Easy Power provides a software feature to scale load into specific values when the power flow is performed.

Losses in kW through the primary feeders and step-up power transformers are calculated in a power flow study at the system peak demand. The system load is allocated proportionally to distribution transformer capacities connected to each feeder. KEMA studied the power flow for a 4,830 kW peak load condition for the July 2010 – June 2011 fiscal years by applying a system Utilization Factor of 35.03% to all loads with a total connected capacity of 15,320 kVA.

For the TAU power system in Rarotonga Island, electric power is supplied from one power station. In fiscal year July 2010 – June 2011, the annual generation production was 28,869,891 kWh and 1.96% of annual generation production was used by the power station's own need measured at 565,921 kWh. Energy sent out to the distribution system after power plant's own usage is measured as 28,303,970 kWh. In the year 2011, so far the system peak demand is 4,830 kW. The Rarotonga system load factor is estimated as 67% and the loss factor is estimated as 49%. The technical losses in kW are converted into kWh energy losses and the results are presented in the next section.

Distribution transformer losses were estimated with actual loss data as indicated in the transformer data sheet per kVA capacity size. Secondary wire losses were estimated with typical configuration and average customer consumption for Domestic and Commercial customer combined. The number of active customers per category is used, based on the actual customer number in June 2011 adjusted by inactive customers, as listed in table below:

Customer Category	Customer Number 07/2011	Active Customer Number *
Commercial	1018	911
Domestic	4307	4093
Demand	14	14
Total	5339	5019

* KEMA is informed to assume that 6% of the total number of customers per month as being non active, with 4% non active domestic, and 2% non active commercial.

The secondary system consists of underground cables connecting from the low voltage (LV) side of distribution transformers to the customer meters. A typical secondary wire configuration has been used to estimate secondary losses. Assuming the typical secondary system is in a tree structure, with the LV cable as the Secondary Line (SL) and Service Drops (SD) tapping along the Secondary Line in equal distance and extending to each customer meter. Both Commercial and Domestic customers are considered and assumed to be mixed along the SL.

Service Line (SL): also referred as LV feeder or secondary feeder (in contrast to 11kV feeder as primary feeder). The Service Line connects from the LV side of the distribution transformer with service drops tapping along it. Based on the number of LV Feeders as provided in *Substation Detail Listing – Aug 2010.xls*, on average, there are 3 Service Lines per one distribution transformer. Based on the data provided for LV cable in excel spreadsheet *HV Cable Register KEMA.xls*, the average LV cable resistance was calculated and used for loss estimation.

Service Drops (SD) are tapped from SL and extended to customer meters. KEMA reviewed the LV drawings and identified that the most popular SD cable size is $16mm^2$, second popular size is $10mm^2$. There are some 3-phase SD, but most SD's are single phase. Service wire material type is not specified on CAD drawings, assumption is taken here as Aluminum conductor and the cable resistance is taken from the cable datasheet provided to KEMA. Typical SD was assumed as single phase $16mm^2$ Aluminum cable with average length of 50 meter for loss estimation.

The average number of customers per Service Line has been calculated for Domestic and Commercial customers combined and used for loss estimation

The average customer consumption in kW is calculated for Domestic and Commercial customers combined and used for loss estimation.

4.3 Findings

The total system losses equal to the total energy entered into the distribution system out of power stations subtracted by total energy sold and the energy unaccounted for. For Te Aponga Uira O Tumu -Te-Varovaro, Cook Islands, unbilled energy usage came from the street lights, estimated by the utility as approximately 1% of annual generation. A summary of estimated losses is provided in Exhibit 4-1.

Exhibit 4-1: Loss Estimation

Column1	kWh	% of generation	% of system consumption
annual generation	28,869,891		
annual station auxiliary	565,921	1.96%	
annual system consumption	28,303,970	98.04%	
annual energy sold	25,886,928	89.67%	91.46%
system loss including unbilled usage	2,417,042	8.37%	8.54%
unbilled usage	288,699	1.00%	1.02%
technical loss	1,273,836	4.41%	4.50%
non tech loss	854,507	2.96%	3.02%

The estimated technical loss for the Te Aponga Uira O Tumu -Te-Varovaro system is 4.41% of annual energy generation, non-technical loss is estimated at 2.96% of annual generation.

To improve the loss estimation, KEMA recommends continuing meter monitoring and meter calibration to maintain accurate historical data. KEMA also recommends keeping record of all power equipment from manufacturers including equipment specifications, name plate information and test data.

5. Non-Technical Losses

In the category of non-technical losses one can identify different loss causes, such as meter inaccuracy, administrative and/or billing failures, electricity theft, meter tampering, meter by-passing, and others. Sometimes non-reimbursed power deliveries (for example for street lighting or water company activities) are also considered to be non-technical losses. Those power deliveries however – if they are not accounted for or not paid for – are a financial loss for the company and not a non-technical system loss.

During the site visit we noticed that:

- All meters are read monthly with intervals of 28 to 32 days;
- All meter readings are recorded in a meter reader's handheld device which generates the bill, which is delivered to the client after the meter reading has been recorded;
- Meter readings on the handheld devices are uploaded to the CIS at the end of the day and the generated bills are booked in the financial system.
- The CIS/billing system raises a red flag when irregular usage is found. As an average this happens some 5 times per month. The meters of the customers with irregular usage are inspected.
- Payment must be done within 30 days, disconnection follows after 7 days.

Electricity theft, meter tampering, meter by-passing are phenomena that incidentally occur in Rarotonga.

When summarizing probable non-technical loss causes we can identify that there may possibly be meter inaccuracies, maybe meter reading inaccuracies and it looks like there are not many losses to be taken into account because of theft, tampering or by-passing.

As KEMA found in its loss calculations as summarized under Section 4.3 the non-technical losses appear to be low, namely 2.96%. As indicated in the table in section 4.3 the non-technical losses do not include power usage for streetlights, which have been separated from the system losses and are considered to be a financial loss for TAU.

5.1 Sources of Non-technical Losses

5.1.1 Metering Issue Losses

In order to have a better match between energy sold and energy entering into the distribution system, it would be better to perform the monthly meter reading every month around the last day of this month. This way the energy sold is (almost) covering the same monthly period as the monthly generation statistics. This way – particularly when looking at a period of one year – the measured losses will have a higher accuracy.

5.1.1.1 Aged Meters

The condition of the rather old meter population is not really known. During 2011 at random a number of old meters will be taken out of the system in order to verify accuracy of this old meter population. Replacement of meters should be considered once the results of the accuracy verification are known. TAU is considering an Automated Metering Infrastructure (AMI) which will enable TAU to accurately measure system losses and which also opens opportunities for two-way communication with clients and related benefits for both clients and TAU.

5.1.1.2 Meter Tampering and Meter Bypassing

Meter readers are very seldom confronted with tampered or by-passed meters.

5.1.1.3 Inaccurate Meter Reading

Inaccurate meter reading will lead to an irregular figure for power usage. TAU has a Customer Information System that gives red flags when irregularities occur. This happens some 5 times per month and in these cases meters are inspected on site and clients are asked for any reasons of the irregular usage. Clients will complain if they are charged higher because of inaccurate readings. This is happening very seldom.

5.1.2 Billing Losses

Billing is done by the meter reader after the readings have been entered in a device that generates the bill on site. In principle clients are disconnected 7 days after payment due date. The reconnection fee is NZ$ 146.

5.1.3 Billing Collection Losses

Billing collection losses and bad debt are not to be counted to system losses. Any billing losses or bad debt amounts that have to be written off are financial losses and not system losses.

5.1.4 Loss through Theft

As already mentioned TAU hardly identifies any loss through theft.

5.1.5 Administrative Failures

The occurrence of administrative failures (in the process from meter reading to billing) has not been identified.

5.1.6 Line Throw-ups

No line throw-ups have ever been identified. Overhead low voltage wires are insulated.

5.2 Analysis of Non-Technical Losses

When analyzing non-technical losses it can be noticed that the loss calculations show a reasonably low percentage of non-technical losses (2.96%). As described in section 4.3 the calculation of technical losses could only be done with a number of assumptions, making use of our experience and information of literature.

Non-technical loss causes that can occur are inaccurate meters and furthermore the overall non-technical loss figure is also being influenced by the fact that there is a discrepancy between the recording periods of “energy sold” and “energy entering into the feeders”. Incidental administrative failures may contribute to non-technical losses, although not really identified at TAU. However, verification of the quality of billing system data, such as multiplying factors for larger customers, should be carried out periodically

5.3 Findings

The findings on non-technical losses can be summarized as follows:

- Non-technical losses are at a reasonably low level (2.96%)

- The meter population is old. A random check of the accuracy of old meters will take place during the year 2011;

- Theft, meter tampering and by-passing, are phenomena that hardly occur in Rarotonga;

- Administrative failures in the process from meter reading to billing are not likely;

- Since meter readings occur halfway in each month while the amount of “energy entering into the feeders” is compiled at the end of each month there is no accurate comparison between “energy entering into the feeders” and “energy sold”.

6. Findings and Recommendations

This chapter gives a compilation of findings and recommendations.

6.1 Generation

As already mentioned in Chapter 3, TAU has in total nine generating units, of which six are de-rated for different reasons and generators 4 and 5 appear to have reached the end of their useful lifes.

Fuel meters conditions are somewhat of a problem at TAU which makes it impossible to have accurate fuel usage recordings. Therefore, highly accurate fuel efficiency calculations cannot be made for the individual generating units. Still it is known that the largest generator, unit 7 (2700 kW), and the two standby generators - units 8 and 9 (800 kW each) have highest fuel efficiency. Average fuel efficiency of the entire power station ran around 3.8 kWh/liter in 2009 and 2010, which is a reasonable level of efficiency, especially given the situation with de-rated engines and taking into account that TAU operates to a stringent spinning reserves policy.

The power station own usage is 1.96% which is a relatively low value and puts TAU at the # 1 position in the ranking of small Pacific utilities regarding power station losses.

During KEMA's site visit TAU was in the process of determining in which way and with what types of gensets generation expansion should be realized. Currently the peak load is 4.9 MW, while the n-2 capacity of the power plant is at 6 MW. If generators 4 and 5 are decommissioned in the coming years the n-2 capacity goes down to 5.2 MW. TAU anticipates a load growth of 4% per year in the coming years, which means that the peak load will be 5.3 MW in 2013 and new generation capacity needs to be installed. One could consider deferring a new generator by not decommissioning generators 4 and 5 and taking the risk of not being able to maintain these units due to future unavailability of spare parts. However, as calculated in chapter 7, decommissioning units 4 and 5 and buying a new generator of 2.7 MW (same size of generator 7) will actually have a favorable payback time because of higher fuel efficiency.

In the meantime the Cook Islands Government (CIG) and Te Aponga Uira (TAU) have been developing the Cook Islands Renewable Energy Chart (CIREC) and a strategy for introducing renewable energy with the objective of having 50% renewable electricity by 2015 and 100% by 2020. After an implementation strategy study has been carried out TAU has adopted a number of important implementation strategies which will be worked out further in the near future.

Developing a generation expansion plan, whether with fossil fuel fired generation units or with renewable energy sources, is not part of the current study on Supply Side Energy Efficiency. However, KEMA's analysis indicates that fuel savings can lead to a reasonable payback time, assuming that no significant renewable energy capacity is introduced in the next several years.

TAU's largest generating unit size of 2.7 MW is quite high compared with a peak load of 5.3 MW. If the 2.7 MW generator is generating a substantial part of the base load it could run the risk of the entire power system going down if this generator trips, due to frequency/voltage decay or instability of the remaining generators. After the addition of a second 2.7 MW generator it is assumed that under normal conditions both units would supply similar shares of base load. In that case, when either one of the 2.7 MW generators trip, there should be less risk of an underfrequency, undervoltage or stability issue. However, a dynamic simulation should be carried out as part of the generation expansion plan to determine the precise impact of a sudden trip of either of these large generators under different operating scenarios.

Once a new 2.7 MW generator has been added in 2013 and the generators 4 and 5 are decommissioned in this same year, the n-2 capacity will be 6.7 MW with which a large margin has been created to cover an annual load growth of 4% up to the year 2017. Assuming the existing 2.7 MW generator and a new 2.7 MW generator serve the majority of the base load requirements, the average fuel efficiency should go up from 3.8 kWh/liter to at least 4.0 kWh/liter.

As previously stated, developing a generation expansion plan is not part of the scope of work of this study. TAU may choose other options, like introducing significant renewable energy capacity in the short term or installing a smaller diesel generator sets. However, Chapter 7 considers the example of adding a 2.7 MW generator to illustrate the benefits of better fuel efficiency and the payback time that can be realized. Similar calculations can be made with other generation expansion scenarios.

Regarding power station own usage it can be seen that with only 1.96% of total power generated, there will not be much room for further decreasing this percentage. Still an energy efficiency audit could be undertaken for identifying any further options for energy savings.

6.2 Distribution

The TAU distribution system is in good condition with pad-mounted substations (ring main units) and where all distribution feeders are laid out with underground cables. This contributes to the fact that power factors as shown in the generator log sheets are quite good (0.96 to 0.98 lagging), which also contributes to the relatively low technical losses in the power system.

Another factor is that the load flow study showed that all feeders and buses are in fact oversized as can be seen in the Power Flow Summary Report (which is part of the Excel file: Cook Islands Loss Worksheet). The distribution system is for this reason also ready to accommodate higher future loads. Even when the demand has doubled the system can still carry the loads. Only ratings of some individual distribution transformers may be too low in certain future growth scenarios.

When looking at the total capacity of all distribution transformers, these transformers are loaded at less than 35% of full connected capacity under peak demand. This increases the level of no-load losses. It should be possible to achieve a reduction in annual energy losses by more closely matching the ratings of transformers to peak load at individual locations over a number of years as new transformers are purchased. Based on the number of customers/load connected per transformer it can be determined which distribution transformers are the best candidates to be rotated.

When buying new transformers TAU should request sufficient data from bidders that can be used for evaluating copper and iron losses. A NZ$ value per kW should be applied as part of the evaluation by which the total transformer life cycle costs (capital and losses) can be calculated. This approach often shows that a transformer with lower losses, even if somewhat more expensive, can be more cost effective over its lifetime.

Overall, with technical losses of 4.46% there will not be much room for further improvement, except for the few issues as mentioned above. A final recommendation is to regularly check electrical connections of 11 kV cable terminations with substation switchgear and transformers and connections in the LV system. This could be done with an infrared camera. It is KEMA's experience that these types of connections to switchgear and transformer bushings can become hot spots after being in service for years. As such hot spots will bring higher losses.

6.3 Non-Technical Losses

With non-technical losses at 2.96% of total energy generated TAU is among 'the best in class'.

KEMA recommends replacement of the old meter population by new meters in case the envisaged tests of a series of aged meters show that the meters have run out of their accuracy class. TAU could consider AMI as an alternative for a large replacement program. A cost/benefit analysis should be undertaken in order to determine whether introduction of AMI can be justified.

In order to achieve better and more accurate figures on total losses and non-technical losses it is our recommendation that TAU performs the monthly meter readings on or around the last day of the month in order to get a more accurate comparison between “energy entering into the feeders” and “energy sold”.

Furthermore it is advised to keep meter readers alert and train them to identify tampering, by-passing, broken seals.

Another recommendation is to train a customer service staff member for auditing metering and billing processes (including quality checks of billing system data such as multiplying factors, tariff categories applied to customers, functioning of red flags in the case of irregularities) and non-technical loss causes found by meter readers, such as meter tampering or by-passing.

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7. Suggested Equipment Replacement

Out of the findings and recommendations in this Report it can be derived that the following replacements are to be recommended:

- Replacement of the aged meter population in case the random testing of a number of old meters shows that the accuracy of these meters has exceeded the accuracy class. One could also consider cleaning and gauging all meters, which however would be time consuming while the cost of new meters are relatively low. Apart from that TAU is looking at introducing an Automated Metering Infrastructure and costs and benefits of using AMI versus new meters are still to be determined. A decision on meter replacement or introducing AMI will follow later after evaluations of options have taken place.

- Dependent on further investigations by TAU on the failing fuel meters, it may be decided to replace fuel meters.

- As already mentioned a planned generation expansion could be aligned with a replacement policy and with the goal of increasing fuel efficiency. The example of a generation expansion option combined with the replacement of two aged engines that have reached the end of their lifetimes has been described in Chapter 6.1. In this example, decommissioning engines 4 and 5 and purchasing a new 2.7 MW generating unit at an installed cost of US$ 3.8 M would yield a pay-back period of 7 years, based on Net Present Value (NPV) and assuming an increase of the fuel efficiency from 3.8 kWh/liter to 4.0 kWh/liter. This NPV result is based on the following data (assumptions):

  - Generating unit capital costs, including installation, of US$ 1,400 per kWh
  - Fuel cost US$ 1.75 per liter
  - Fuel cost increase per year 3% (which is a conservative estimate)
  - Interest rate 8%
  - Annual gross generation 28,000 GWh per year (which is a conservative amount given the demand growth expectation of 4% per year).

A. Data Handbook

Rarotonga Data Handbook.docx

B. Loss Calculation Worksheet

CookIslands loss worksheet.xlsx

C. Easy Power Grid Model

Rarotonga Island.dez