Quantification of the Power System Energy Losses in South Pacific Utilities

Nauru Utilities Corporation

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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 Nauru Utilities Corporation (NUC) on the island of Nauru.

Project objectives and deliverables:

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

1.1 Quantification of Losses

Losses through the Nauru system 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 parts.
  - 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 and 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 non-technical loss.

1.2 NUC's System Energy Losses

KEMA's analysis of the NUC power system determined that total losses are 22.41% of annual generation, which is relatively high. These losses consist of:

- 2.27% in power station auxiliaries (station losses), which is a very low value.
- 4.37% in technical losses and unbilled usage, which is a relatively high value.
- 15.77% in non-technical losses, which a very high value.

The NUC power system provides power for the water system as well as street lighting on the island. To KEMA's understanding, this usage is not metered, and therefore, unaccounted for. The loss through unbilled usage cannot be considered a system loss, but is a financial loss for NUC because the unbilled usage is power delivered for services (street lighting) that are not paid for. Because there was no information available to KEMA on which to base the calculation, unbilled usage was combined with the non-technical losses.

Ignoring financial losses, calculations that quantify the NUC power system losses result in the following figures:

- **2.27% in station losses.**
- **20.14% in system losses (technical plus non-technical).**

1.2.1 Generation Losses

In addition to analyzing power station and distribution system losses, KEMA requested generator fuel usage data to evaluate the NUC generator fuel efficiency. Based on "Report No. 2" which is shown in Appendix B, as provided by NUC, the system average fuel efficiency for 2009-2010 was found to be 3.3 kWh/liter. This is a fairly low fuel efficiency figure and NUC should consider possible ways for improving fuel efficiency, assuming this is still the current situation.

NUC both owns and leases generating units. The generating units owned by NUC are in poor condition and in need of repair and maintenance. The leased units are about 8 years old and are well maintained by Cummins under the lease agreement. The majority of power produced for the NUC system currently comes from these leased units.

Regarding the power station internal losses it should be noted that there was no historical energy metering data available that could be used to determine station losses, because the energy entering into the distribution system is not normally recorded in the power station logs. For determining the station losses, one must calculate the difference between total energy produced by the generating units and total energy entering into the distribution system. KEMA estimated the power station internal losses of 2.27% from the monthly readings provided in Report No. 2 in Appendix A.

In the future, it is highly recommended that NUC include hourly readings of meters on the feeders in the power station log sheets, along with the generator log sheets.

1.2.2 Distribution Losses

The Nauru system does not have any transmission facilities. Each of the three feeders in the Nauru 11 kV distribution system is supplied from the power station in a radial configuration. The Nauru primary system losses were estimated from the power flow study and metering data, combined with calculations in Excel spreadsheets for transformer losses and LV system losses.

1.2.3 Non-technical Losses

NUC's non-technical losses are 15.77%, which is a very high value. KEMA's experience indicates that a reasonable value should be below 4 percent for a system such as NUC. Based on the pattern observed in NUC's monthly loss statistics, it is possible that there is a higher than normal level of meter reading inaccuracies. In addition, activities such as electricity theft, meter tampering, and meter by-passing may be contributing to the level of non-technical losses on the island of Nauru. Furthermore, the non-technical loss figure calculated includes unbilled energy used to serve the water system and street lights. Metering of these services would provide NUC with an indication of the amount of these financial losses and allow the development of a cost recovery strategy.

Therefore, this type of analysis should be a major focus for loss improvement on the island of Nauru. KEMA offers suggestions in this regard described in the following sections.

1.2.3.1 Metering

The timing of monthly generation and load statistics at NUC do not coincide, which makes it difficult to accurately compare energy sold to energy produced on a monthly basis. In order to have a better match between energy sold and energy entering the distribution system, it would be beneficial to perform the monthly meter reading every month around the last day of this month. This way the energy sold would cover nearly the same monthly period as the monthly generation statistics and the calculated losses would have a higher degree of accuracy.

NUC does not currently have a Customer Information System that gives red flags when customer metering irregularities occur. Irregular or inconsistent usage figures for certain customers could be used by NUC personnel to trigger an inspection of the meters serving these customers. More consistent, higher accuracy meter reading will also make it easier to identify irregularities in customer usage.

Adding metering for power delivered to the water system and for street lighting (although not billed) would provide NUC with useful information for future decision-making and the ability to consider cost recovery methods, if they choose to do so.

Additional metering for the power station auxiliary loads, and any particular loads that are directly served from the generator terminal bus at 3.3kV, would provide more data to more accurately estimate power station usage.

A program of meter inspection, testing, and maintenance – particularly for aged meters - should be implemented as soon as financially possible. Since NUC does not have a meter test facility, this work could be contracted to an experienced provider of this type of service.

1.3 Recommendations

1.3.1 Generation Losses

The loss component due to power station usage (2.27%) is a relatively low figure and there may not be many options for improvement. However, an energy efficiency audit could reveal possibilities for energy savings.

KEMA also recommends that generator log sheets and distribution feeder log sheets be maintained and kept at the power station and used to evaluate calculation of power station own usage in the future. A sample generator log sheet is shown in Appendix C.

1.3.2 Distribution Losses

The distribution system on Nauru is comprised mostly of overhead aluminum (AL) conductors for the North and South feeders and underground cables with AL conductors for the East feeder. These conductors are adequately sized for load-serving purposes and do not require replacement to serve the existing load.   As long as future load growth does not create a risk of the distribution feeder conductors being loaded beyond their thermal limits, KEMA does not recommend changing feeder conductors only for the purpose of reducing losses. Should system load or patterns require an increase in conductor size, then consideration should be given to losses in the choice of conductor size.

Thermal losses can also occur at specific locations on the distribution system due to corrosion, bad connectors, and other undesirable maintenance conditions. These should be eliminated wherever possible through implementing a program of equipment inspection at regular intervals and replacement of corroded or ineffective connectors as soon as discovered. Field inspections with and infrared camera can be an effective approach to identifying such problems.

1.3.3 Non-technical Losses

1.3.3.1 Metering

KEMA recommends additional metering points and better identification of non-technical losses. A program focused on detecting theft, meter tampering, throw-ups, and other causes of non-technical losses should be implemented. See Section 6, Findings and Recommendations for more details.

Methodologies must be developed to measure distribution transformer load profiles, either through software which takes into account the customer meters downstream from each of the transformers, or through the installation of demand meters on each transformer secondary to measure and record the load readings at regular intervals.

These meters can be installed while using current transformers (CT’s) mounted on the pole or on the pad mounted transformers. It is not necessary to install these meters on all distribution transformers. Areas which are experiencing more tampering, or where transformers seem to be over loaded or under loaded, may benefit from these installations. If customers are equipped with new digital meters and can be linked in a database or in the CIS to the distribution transformers, it may not be necessary to install these meters at the distribution transformers.

1.4 Prioritized list of equipment for replacement

Based on KEMA's review of the NUC electric system, the following list of equipment is recommended for replacement.

1. Generators. Six of the eight medium-speed diesel units owned by NUC were not operable at the time of KEMA's site visit. Several of the units had been removed entirely or were in a partially assembled condition. In addition, two of the four high-speed package units, although they are being maintained, were also out of service and under repair. NUC currently relies on the leased high-speed package units for most of the electrical needs and is the only practical option in the short-term. However, NUC should consider investing in replacement of the retired units and the implementation of a rigorous maintenance program to keep the new units operable and efficient. Investment in new generators, properly specified for reliability and fuel efficiency, would dramatically improve the NUC generator and fuel efficiency performance.

2. Metering. Old meters should be tested at regular intervals and replaced when found to be inaccurate. Additional metering should be added to enhance loss and theft detection and categorization of losses. Meters should also be added at key locations to provide a better determination of losses.

KEMA

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 quantify the power system energy losses in each electric power system by generation, transmission and distribution facilities, evaluate the metering and billing system, 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 system prior to conducting site visits.

2.1 Data Collection

Prior to visiting the island of Nauru for data collection and technical assessments of the NUC power system, KEMA sent data request documents on February 9, 2011. These data inputs are needed to create a power system model using EasyPower®, so that the data definitions used in the data request were consistent with the simulation software to ensure the accuracy of the study results.

Subsequently KEMA visited Nauru during the week of February 21-25, 2011 to collect data, interview key NUC personnel, and assess the power system.

During the visit much relevant data was gathered and NUC personnel were very helpful, although some of the relevant data was not readily available. Two NUC system one-line diagrams were provided, as well as copies of pages from previous reports. Data obtained from these reports was a useful source of information in this report and as system data for the NUC system model.

The reports, in order provided, are described as follows:

- Report No. 1 – Done by the Asian Development Bank, titled "Reform of NPC", done in 2006, selected pages from 29-170 were provided that describes the current status of the NUC infrastructure and electricity demand forecast.

- Report No. 2 – This document has no title, but provides some average fuel usage numbers for 2009-2010.

- Report No. 3 – Done by TransEnergie, titled “support to the Energy Sector in Five ACP Pacific Islands (REP-5)”, done in 2008, provides a study of rate tariff structures for NUC.

- Report No. 4 – Done by the Australian Agency for International Development, titled “Report for Nauru Power Sector”, done in 2008, provides a review of Nauru’s Power Station Assets.

- Report No. 5 – Done by Factor 4 Energy Projects GmbH titled “Nauru Wind Power Feasibility Study”, done in 2010, provides an evaluation of wind data on the island of Nauru.

- Report No. 6 – provides solar production data for the “South Roof” and “North Roof” for October 2008 through January 2011, with no identification of location or how this is interconnected with the NUC electric system.

After the on-site visit some clarifications were requested by e-mail but no further information has been received. Therefore assumed data was used in place of missing data based on KEMA’s experience and making use of typical industry values and parameters, including data such as:

- Electrical parameters of the generating units.
- Transformer impedances and distribution transformer losses.
- Secondary wires/service lines.

2.2 Utility Operations

The NUC power system is relatively small compared to the other utilities covered by the PPA loss quantification study. The maximum peak demand for the NUC system is currently 3,300 kW.

The power system consists of:

- A central power station with 4 Ruston units (3 out of service), 2 Caterpillar diesel units (1 out of service), 2 Paxman diesel units (both out of service), and 4 lease-package Cummins diesel units (2 under service repair). Counting only the units that were available for service at the time of KEMA's visit, the NUC power station had a station capability as follows:

Table 1 - Generator Units

Unit Designation	Power Rating (kW)
Unit 1	1,900
Unit 4	1,600
HS-1	1,200
HS-2	1,200
PV (Community College)	40
Total	**5,940**

- An 11 kV distribution system consisting of three 11 kV distribution feeders (two overhead and one underground).
- 1,836 customers.

The system load peaked at 4,000 kW in 2004, but the NUC system load has declined since then and current peak demand is about 3,300 kW.

With a peak load of 3,300 kW and 5,940 kW of reliable generation available for service, the NUC system has a resource reserve margin of 80%. However, with an n-1 reliability criteria (loss of the largest unit), the operating reserve margin would then be only 22%. Using an n-2 reliability criteria, the operating reserve margin would be negative (not enough units in reserve to meet the criteria).

A Wind Power Feasibility Study was performed on the island of Nauru from July 2009 to June 2010 for the South Pacific Regional Environment Programme (SPREP). The results, presented in September of 2010, recommended continued monitoring, but it is not known if further wind measurements were taken or recorded.

2.3 Identifying and Quantifying Losses

Electric power is generated in power plants and delivered through transmission and 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:

1. Power Station Losses – energy consumed by the equipment in support of power generation, also called power plant auxiliary load or power plant own usage.

2. Distribution System Losses – losses due to power flow through the distribution system, including transformers, overhead line conductors, areal cables and underground cables.

3. Service Wire Losses – losses due to power flow from the distribution transformer secondary winding to the customer's meter.

Losses in category 2 and 3 together are considered Technical Losses. Technical losses are the losses that can be estimated as a result of electric current passing through the power system equipment.

In contrast to technical losses, there are non-technical losses. Non-technical losses are caused by theft, inadequate or inaccurate meters, meter tampering or by-passing, meter-reading errors, irregularities with prepaid meters, administrative failures, incorrect multiplying factors, and other causes.

There is another category of losses due to energy usage that is not accounted for and subsequently not billed. The unbilled usage results in financial loss to the utility and should not be included as part of the non-technical losses. Examples of unbilled usages that KEMA found in some cases are: street lighting, the utility's own building usage, and 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 technical losses through power equipment in the distribution system and the service wires. Where information was not sufficient, assumptions were made to facilitate the estimation. KEMA created power flow model in Easy Power to represent the NUC electric power system. A power flow study was performed to calculate system kW losses, including primary feeder losses and power transformer copper losses. An Excel spreadsheet was created to estimate kW losses that were not calculated in the power flow study, such as transformer core loss and service wires losses. These kW losses were converted to kWh energy losses on an annual basis by utilizing the estimated Loss Factor. Unbilled usage was estimated for all the causes identified.

The system total 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

At the time of KEMA's visit to Nauru, the NUC Power Station consisted of four medium-speed Ruston units (2 of which were under repair), two Paxman diesel engines (both out of service), two high-speed Caterpillar diesel units (both decommissioned), and four lease-package high-speed Cummins diesel units (2 under repair). This means that 6 of the 8 units owned by NUC and 2 of the leased units were not available for service at the time of KEMA's visit to the island. This results in a remaining operable power station capacity of 5,940 kW.

3.1 Equipment

The Nauru power station fuel system is supplied from sea going vessels through a pipeline to a fuel tank referred to as the Tank Farm located about a kilometer from the power station. The fuel flows through a purifier and filters into a service tank using gravity feed. The service tank has a capacity of 9,600 liters.

Generation equipment is listed and specified in the NUC Data Handbook. The following pictures show the condition of each unit during the time of KEMA's visit.

Major characteristics of the generating units

Unit 1: Ruston model 12RK270 diesel generator
2500 kVA, 1900 kW
3.3 kV, 50 Hz, 750 RPM STATUS: Operational

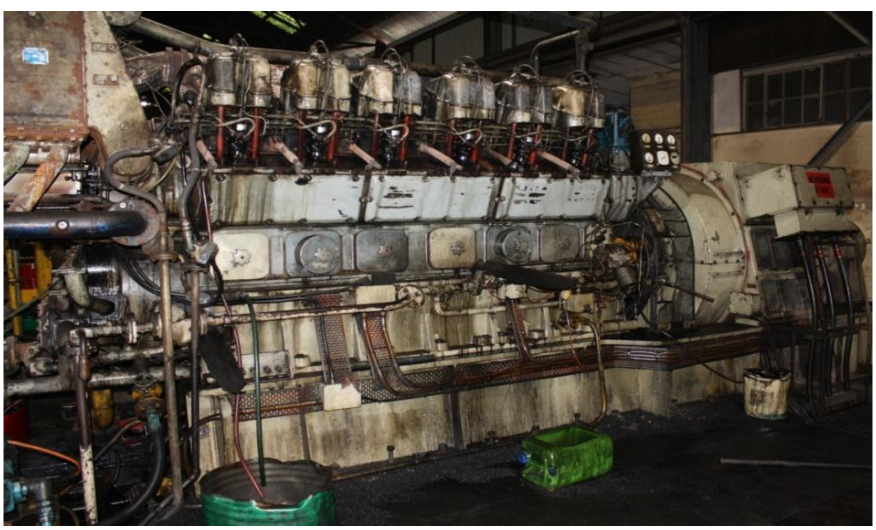

Figure 1 - Unit 1

Unit 2: Paxman model 12VP185 diesel generator
2000 kVA, 1600 kW
3.3 kV, 50 Hz, 1500 RPM STATUS: Decommissioned

Figure 2 - Unit 2

Unit 3: Caterpillar model 3516B diesel generator
1600 kVA, 1250 kW
3.3 kV, 50 Hz, 1500 RPM STATUS: Decommissioned

Figure 3 - Unit 3

Unit 4: Ruston model 16RK3C diesel generator
2000 kVA, 1600 kW
3.3 kV, 50 Hz, 750 RPM STATUS: Operational

Figure 4 - Unit 4

Unit 5: Ruston model 16RK3C diesel generator
2000 kVA 1600 kW
3.3 kV, 50 Hz, 750 RPM STATUS: Under Repair

Figure 5 - Unit 5

Unit 6: Ruston model 16RK3C diesel generator
2000 kVA 1600 kW
3.3 kV, 50 Hz, 750 RPM STATUS: Under Repair

Figure 6 - Unit 6

Unit 7: Paxman model 12VP185 diesel generator
2000 kVA 1600 kW
3.3 kV, 50 Hz, 1500 RPM STATUS: Under Repair

Figure 7 - Unit 7

Unit 8: Caterpillar model 3516B diesel generator
1600 kVA, 1250 kW
3.3 kV, 50 Hz, 1500 RPM STATUS: Decommissioned

Figure 8 - Unit 8

Caterpillar has also delivered 4 lease-package high-speed diesel units.
Model 1120-DFLC-7158B
1500 kVA, 1200 kW
3.3 kV, 50 Hz, 1500 RPM STATUS: 2 of 4 Operational

Figure 9 - Caterpillar Diesel Units

These lease-package units currently provide most of the electrical power requirements for NUC.

The data for the power transformers that feed the NUC distribution system are given in the NUC Data Handbook. There are three main power transformers, each rated 2,500 kVA, at the Nauru power station that step up the voltage from 3.3 kV to 11 kV for the three distribution feeders.

In addition, there are three power transformers that serve auxiliary plant loads and other industrial loads, as follows:

Table 2 - Power Transformers Ratings

Description	Voltage Rating	kVA Rating
LV Service No.1	3.3 kV – 550 V	1,000
LV Service No.2	3.3 kV – 550 V	1,000
LV Service No.3	6.6 kV – 3.3 kV	1,500

3.2 Analysis of Losses

Generation losses can be identified by determining the generation efficiency losses and station losses (own usage).

Fuel Efficiency

On the topic of fuel efficiency, the only information that was made available to KEMA was a report labeled “Report No. 2” (see Appendix B), which provided a comparison of total fuel statistics for 2008 and 2010. From this report, KEMA found that the average fuel consumed was 524,955 liters/month to generate an average of 1,740,300 kWh/month, which results in an average generator fuel usage of 3.3 kWh/liter (note that this was mislabeled in the original NUC report as liters/kWh).[1]

Other than what is listed and shown in Appendix B, KEMA has not received generator log sheets or monthly fuel analysis log sheets on which to base estimates of fuel efficiency. Without this type of information, no further assessment of generator fuel efficiency can be made.

[1] An alternate calculation method would be to use actual fuel usage measurements for a monthly or daily period, but such data was not available to KEMA.

Generator engine efficiency measurement and improvement requires good maintenance and record keeping of the engines, the cooling systems, and other associated equipment in accordance with manufacturer guidelines. With regards to the fuel efficiency. KEMA recommends that NUC keep records of all engine maintenance and generator log sheets in the future as well as maintain and dispatch the units in accordance with this policy.

Station Losses

As already mentioned, the station losses were estimated as 2.27%. Station losses are the difference between total energy produced by the generating units and total energy entering into the distribution system. KEMA was able to estimate the station losses from the monthly data provided in Report No. 2 (see Appendix B). This is a low value for station losses. Still, KEMA recommends an energy efficiency audit to reveal possible ways to reduce these losses.

3.3 Findings

A comprehensive program to record generator and feeder log sheets, fuel usage, generator outputs, and maintenance practices should be implemented in order to evaluate generator fuel efficiency and identify needed improvements to generator performance and reliability.

4. Distribution

During KEMA's site visit to the island of Nauru, NUC provided a one-line diagram and an operating diagram of its 11 kV distribution system. These were very useful in developing a power flow model in EasyPower since the one line diagram also gave the sizes of all distribution transformers. The distance for overhead feeder sections was given as 50 meters from pole to pole and this was used to estimate feeder section lengths.

The distribution system consists of three 11 kV feeders, the North Feeder, the South Feeder, and the East Feeder. The North and South Feeders consist of mostly overhead conductors while the East Feeder consists mostly of underground cables.

As indicated on the one-line diagram, the three feeders have a major interconnection point near the Minen Hotel with 2 feeder tie switches assumed normally open and the hotel served from the East Feeder (underground). There is also an open feeder tie switch between the South and East Feeders near the Airport and Government offices and workshops.

When considering the average and the maximum load of the NUC power system it appears that certain components of the distribution system are oversized:

- Each feeder is connected to a separate 11 kV feeder bus in the Nauru power station and connects to the 3.3 kV generator bus via a 3.3 – 11 kV, 2500 kVA transformer. The maximum NUC system load is 3300 kW.

- The maximum feeder current is calculated to be 172 amps, while the assumed outgoing feeder cable size is a 95 mm² CU XLPE cable.

- The total rated power of all distribution transformers connected to 11kV feeders is 6550 kVA, while the total NUC system load is 3,300 kVA (including a portion of load directly connected to 3.3kV power station terminal bus).

The one line diagram of the EasyPower model is provided in the following figure. Larger versions of this diagram, along with an Excel spreadsheet file of the loss calculations, are included with this report in Appendix C.

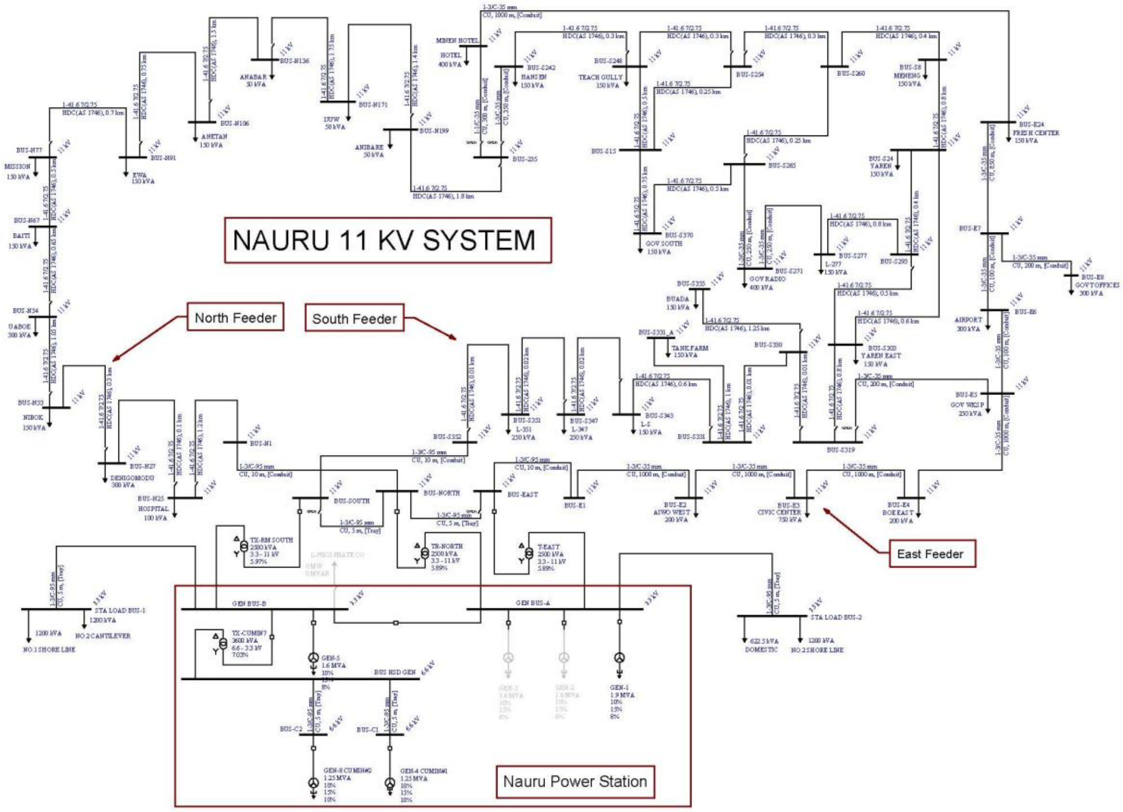

Figure 10 - NUC 11kV System One-Line Diagram

The power flow results did not show any overloaded facilities or unacceptable voltage drops under the peak load condition studied.

4.1 Equipment

The NUC 11 kV distribution system equipment is discussed in the following sections.

4.1.1 Distribution System

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

- From power station 3.3 kV switchgear, the North, South, and East Feeders are connected via power transformers rated at 3.3 - 11 kV and 2,500 kVA each. The North

Feeder transformer impedance is 5.96%, the South Feeder transformer impedance is 5.97%, while the East Feeder transformer has an impedance of 5.89%. Since these transformers never or rarely operate in parallel with the HV feeder bus tie switch closed, exact matching impedances are not required.

- The 11 kV side of the power transformers are connected to the 11 kV bus through SF6 switchgear.
- The 11 kV feeder bays are in SF6 switchgear.
- The 11kV outgoing feeder cable are assumed to consist of 3-single phase 95 mm² Cu underground XLPE cables laid in a trefoil configuration. Most of the overhead conductors for the North and South Feeders are hard-drawn copper conductors on a flat cross-arm configuration.
- NUC has 32 distribution transformers installed along the 11kV distribution feeders, all of them 3-phase, with a total installed capacity of 6,550 kVA. There are a number of distribution transformers serving loads from 3.3kV power station terminal buses. Based on one-line diagrams provided by NUC, KEMA estimated the total connected kVA at 3.3kV is assumed as 4,222.5kVA.
- Feeders have three tie points with normally open switches.
- There are no capacitor banks on the NUC system.
- There are also no shunt reactors on the NUC system.

NUC has provided current measurements in amperes for 19 distribution transformers along RING MAIN NORTH, RING MAIN SOUTH, and RING MAIN EAST, which adds up to 1,098.5 kVA. Besides these loads, NUC also has distribution transformers serving load directly from the 3.3kV bus at power station terminal bus. For these loads, there are 3 current measurements provided to KEMA. All measured loads that were provided represent 37% of the peak load of 3.3 MW.

4.1.2 LV Wires

The Nauru power station low voltage system feeds station auxiliary loads and other loads at a voltage level of 550 V.

No information was provided on LV secondary service wires. Assumptions of typical secondary wire type, length and configurations were used to estimate the secondary losses.

4.2 Analysis of Losses

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

1. The average power generation and power consumption over the past year (2010) was used for the study. This data was provided in Report #1 from the Asian Development Bank entitled “Reform of NPC” under section 3, Electricity Demand Forecast.

2. Distribution transformer losses were estimated by using typical values for distribution transformer no-load losses and load losses from literature[2]. A typical loss percentage derived from these typical no load loss is used to estimate power transformer core losses.

3. Loads were distributed based on the distribution transformer locations.

4. Loads were allocated proportionally to the kVA capacity for each distribution transformer.

5. Actual voltage drops were calculated in the system power flow model in Easy Power. However, voltage drops through feeders were not considered in loss estimations for distribution transformers and secondary services wires.

6. Secondary wire losses were estimated based on average customer consumption. Typical secondary service wire types and sizes were assumed, based on information provided. Assumptions were made for average wire lengths and general structures.

7. Connected kVA of 3.3kV/415v distribution transformers are assumed and several lump sum loads are put into EasyPower power model.

[2] EN 50464-1, 2007 Three-phase oil-immersed distribution transformers 50 Hz, from 50 kVA to 2500 kVA with highest voltage for equipment not exceeding 36 kV - Part 1: General requirements, data for three-phase transformers.

In addition, NUC has provided current readings for three transformers connected to the main 3.3 kV buses ‘A’ and ‘B’. However, after reviewing the 2 one-line diagrams that NUC provided, it is identified that there are a total of 22 circuit breakers connected to these 3.3 kV buses (8 generators and 14 feeders). The circuit breakers locations, loads they are servicing and transformers connected to them as identified from the one-line diagrams are listed in the table below.

Table 3 - 3.3 kV breaker and transformers identified from one-line diagrams

Position No.	Bus No.	Service To	Transformer kVA[1]
1	A	WVC Desalination Plant	Not indicated
2	A	LV Service No. 2	Not indicated
3	A	South Feeder	2400
4	A	Location Station	Not indicated
5	A	No. 1 Shore Line	1200
6	A	Fields Unit	3355
7	A	No. 2 Cantilever	1200
8	A	Diesel Unit No. 8	0
9	A	Diesel Unit No. 7	3600
10	A	Diesel Unit No. 6	0
11	A	Diesel Unit No. 5	0
12	B	Diesel Unit No. 4	2000
13	B	Diesel Unit No. 3	0
14	B	Diesel Unit No. 2	0
15	B	Diesel Unit No. 1	2500
16	B	East Feeder	2550
17	B	No. 2 Shore Line	600
18	B	N.I.G.C. Freezer	Not indicatd
19	B	Domestic Service	450
20	B	North Feeder	1600
21	B	LV Service No. 1	Not indicatd
22	B	LV Service No. 3	Not indicatd

[1] Transformers kVA is from the one-line diagrams as provided by NUC, however information on which transformers were actually in service was unavailable.

Since some of the essential load information was not provided to identify all loads served from the 3.3 kV buses, KEMA made some assumptions to facilitate the loss analysis and build EasyPower model. It is assumed that total connected kVA of transformers at 3.3kV bus is 4222.5kVA, with 2400kVA connected at Bus A and 1822.5kVA connected to Bus B. The estimated utilization factor of 9.25% is applied to these transformers and result in 351.7 kW load served from 3.3kV bus in power flow study.

NUC provided two different one-line diagrams of its power system, one in color and the other in black & white (see Appendix B). The average distance between two neighboring poles is given on the black & white diagram as 50 meters. Feeder segment distances were based on the pole numbers and this average distance between poles. Conductor sizes and types were provided separately.

The black & white one-line diagram of the NUC power system also provided the kVA capacity of distribution transformers along the feeder. Nameplate information for the generators and power transformers were identified from the pictures taken by KEMA during the site visit. However, because of discoloration and corrosion, the nameplate information was not always readable.

Based on this information, KEMA developed a power flow model in Easy Power for NUC. In this distribution system model, the power station and the three primary feeders were modeled. Distribution transformers are represented as spot loads with constant kVA loads that match the transformer capacities and an estimated load power factor of 0.9. EasyPower provides a feature that allows the user to scale loads to match specific values when a power flow is performed. This feature was used in the NUC power flow study to match the total system peak load of 3.3 MW.

System losses in kW through the primary feeders and copper losses of power transformers were calculated in the power flow study for the system peak demand. Load allocation was based on distribution transformer capacities connected to each feeder. A unique aspect of the NUC system is that there is a small portion of load is connected to the 3.3 kV bus at the Nauru Power Station. KEMA modeled that portion of the NUC load based on actual load measurements provided by NUC and proportionally increased it to match the 3.3MV peak demand. The KEMA power flow study used a system peak load of 3.3 MW at an estimated power factor of 0.9 lagging. A utilization factor of 50.01% is estimated for 11kV distribution transformers, and utilization factor of 9.25% is estimated for loads served directly from 3.3kV bus. With 3.3MW peak demand and 16,716,072kWh annual energy consumption, NUC system has estimated load factor of 58% and loss factor of 38%. The estimated technical losses in kW were converted to kWh energy losses and are presented in the next section.

4.3 Findings

The total system losses were calculated as the total energy entering the system out of the power plant less the total energy sold and the energy unaccounted for. Insufficient data was provided to estimate unbilled energy usage. A summary of NUC power station and system losses is provided in the table below.

Table 4 - NUC System Loss Summary

	kWh	% of generation	% of system consumption
annual generation[1]	17,103,672		
annual station auxiliary	387,600	2.27%	
annual system consumption	16,716,072	97.73%	
annual energy sold	13,271,197	77.59%	79.39%
system loss including unbilled usage[2]	3,444,875	20.14%	20.61%
unbilled usage	n/a	n/a	n/a
technical loss	747,123	4.37%	4.47%
non tech loss	2,697,752	15.77%	16.14%

[1] Annual energy generated does not include the estimated 48,000 kWh / year from PV installations

[2] With production from PV installations taken into account, figure would be 20.08% of generation

Total NUC system losses are estimated to be 20.14% of annual generation, which is relatively high. Technical losses are estimated at 4.37% and non-technical losses are estimated at 15.77%, which is also high and includes unbilled energy usage. However, no specific data on unbilled usage was available to KEMA for the study. Therefore, KEMA recommends that for future reference NUC identify the components of unbilled usage (e.g., street light loads, number of water pumps, hours of operation during each day, etc). With this information, unbilled usage can be estimated and quantified as a financial loss. Furthermore, with such information, NUC can more clearly identify the leading causes of non-technical losses so that actions can be taken to reduce this component of system energy losses.

Other recommendations that can be used to help improve the accuracy of the technical loss estimation in future years include:

1. Record meter readings. Recording the meter readings regularly for metering in both the power plant and feeders would have a direct impact on the determination of system losses and help identify possibilities for improvements.

2. Regularly update the EasyPower model to keep synchronism with the system upgrades and improvements in model data as they become available.

3. Monitor and update the utilization factor of the system. The utilization factor represents the average level of usage of the total installed transformer capacity of all distribution transformers at the peak load condition.

4. Record peak demand and update load and loss factor of the system. Load factor represents how much peak load various from the base load of the system.

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 loss.

During the site visit KEMA noticed that:

- The meter population is getting old and NUC does not have meter testing facilities. It could be possible that meter accuracy has deteriorated for some of the older meters which may no longer be performing within their accuracy class.

- Since non-technical losses were found to be very high, electricity theft, meter tampering, and meter by-passing are potential issues that need to be investigated by NUC.

- Meter inaccuracies and meter reading inaccuracies are also possible contributors to non-technical losses.

As summarized under Section 4.3, the non-technical losses appear to be very high (15.77%). This value of non-technical losses could include power usage for streetlights and water pumps, which is not estimated due to lack of information. Once identified, unbilled usage should be separated from the system losses and considered to be a financial loss for NUC.

Regarding power delivered to the water pumps, it is recommended that NUC measure the actual usage for all water pumps to get a more accurate estimate of this energy usage component.

Adding metering for water and making power usage calculations for street lights (although not billed) would provide NUC with financial information for future decision-making and cost recovery methods. In lieu of adding meters, a fairly accurate estimate of water supply energy use could be made with data such as the number of pumps, consumption/size of each pump, and the average hours of operation per day.

Street lights are also part of the unbilled usage. That usage could be estimated from data such as the number of lights, average watts per light fixture and the average number of hours of operation per day, or the street light energy usage could be metered for more accuracy.

Additional metering for the LV services and plant auxiliary loads would provide more data to more accurately estimate power station usage and losses.

Methodologies must be developed to measure distribution transformer load profiles either through software which takes into account the customer meters on each of the transformers or through physically measuring the load by installing demand type meters on the secondary side of each of the transformers.

These meters can be installed while using current transformers (CT's) mounted on the pole or on the pad mounted transformers. It is not necessary to install these meters on all distribution transformers. Areas which are experiencing more tampering, or where transformers seem to be over loaded or under loaded, may benefit from these installations. If customers are equipped with new digital meters and can be linked in a database or in the CIS to the distribution transformers, it may not be necessary to install these meters at the distribution transformers.

A program of meter inspection, testing, and maintenance should be implemented as soon as financially possible. Since NUC does not have a meter test facility, this could to be contracted to an experienced provider of this type of service.

5.1 Sources of Non-technical Losses

5.1.1 Metering Issues

As already mentioned the monthly statistics show energy generated in a full month, the energy sold is covering the period from the middle of the previous month until the middle of the current month. Since in some months the usage can be different, also because the number of days per month is different, there is quite some difference per month between "energy generated" and "energy sold". It is recommended to:

- Include meter readings of the feeder bays in the power station log sheets in order to be able to separate the station losses from the distribution system losses (by deducting "energy entering into the feeders" from "energy generated").

- include meter readings of the energy delivered by all grid-connected PV systems into the log sheets;
- Note that the total of "energy entering into the feeders" is the sum of the energy as metered in the feeder bays plus the energy delivered by the solar panel systems.
- 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".

5.1.1.1 Aged Meters

KEMA does not have good data on the condition of the meter population, but it seems to be rather old. A program of periodic meter testing and replacement of inaccurate meters is recommended for the NUC system. Since NUC does not have a meter test facility, KEMA recommends that meters be tested by a third party and replaced when found to be inaccurate.

5.1.1.2 Meter Tampering and Bypassing

NUC advises that its meter readers very seldom report tampered or by-passed meters, yet non-technical losses are high. Therefore, energy theft may be a bigger problem than NUC realizes. Meter readers should be trained to look for unusual meters that have had their seals removed or provide other clues that they have been tampered with and report those to management immediately. Cases of meter tampering should be investigated immediately (with assistance of local police, if necessary, to ensure employee safety) and corrective actions should be taken to reduce incidents of energy theft to a minimum.

5.1.1.3 Inaccurate Meter Reading

Inaccurate meter readings will lead to irregular monthly figures for power usage. NUC does not have a Customer Information System that gives red flags when irregularities occur. Irregular figures may be noticed by the administrative personnel. Most of the time inaccurate readings can be corrected by the next meter reading.

5.1.2 Billing Losses

NUC is not aware of any billing losses.

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 are written off are actually financial losses and not system losses.

5.1.4 Loss through Theft

As already mentioned NUC hardly identifies any loss through theft, yet non-technical losses are very high. NUC needs to look into this further.

5.1.5 Administrative Failures

The occurrence of administrative failures (in the process from meter reading to billing) was not identified as a problem for the NUC system.

5.1.6 Line Throw-ups

No line throw-ups were identified during KEMA's visit. Two of NUC's feeders consist of overhead lines and should be patrolled and inspected periodically to ensure that there are no throw-ups.

5.2 Analysis of Losses

When analyzing non-technical losses it can be noticed that the loss calculations show a very high percentage of non-technical losses (15.77%). In reality these non-technical losses include unbilled energy used by the water system and street lighting, which could not be estimated from the data provided.

Non-technical losses can also be caused by inaccurate meters and monthly calculations of the non-technical losses are also affected by the fact that there is currently a discrepancy between the recording periods of "energy sold" and "energy generated".

5.3 Related Observations

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

- Non-technical losses are very high (15.77%)

- The meter population is probably old and a program of replacement of old or inaccurate meters should be implemented.

- The presence of theft, meter tampering, and meter by-passing cannot be documented with the data that NUC was able to provide. However, since non-technical losses are so high for the NUC system, line patrols and meter inspections should be performed on a regular periodic basis to determine the extent of such problems.

- Administrative failures in the process from meter reading to billing do not appear to be significant cause of inaccuracies in the account billing process.

- Additional metering should be added to enhance detection and categorization of losses.

6. Overall Findings and Recommendations

This chapter provides a compilation of findings and recommendations.

6.1 Generation

Recent figures on fuel efficiency could not be calculated with the information provided. There were no records of generator log sheets, fuel usage, or maintenance logs. This information is absolutely necessary to calculate fuel efficiency. As this information was never provided, no evaluation of generator fuel efficiency was made. In "Report No. 2", a figure of 3.3 kWh / liter was provided as the system average fuel usage for 2009-2010, but was mislabeled in that report as "liters / kWh". This is a fairly low fuel efficiency figure and can be improved if this is still the current situation.

Nauru Power station's own usage (2.27%) is very low and may not have many options for improvement. An energy efficiency audit may reveal areas for improvement. The power station log sheets should include logging the energy entering into the feeders in order to be able to calculate the power station own usage (which is energy generated minus energy entering into the feeders).

In addition, energy generated by the grid-connected PV systems should be added to the monthly generation statistics and correlated by time.

6.2 Distribution

The technical losses on the NUC distribution system are 4.37%, which is in normal range. A good figure is typically less than 5%.

6.3 Non-Technical Losses

KEMA recommends the following based on findings.

- Replacement of the old meter population by new meters is recommended, since aging meters tend to get more inaccurate, and may run out of their accuracy class.

In order to achieve better and more accurate figures on total losses and non-technical losses, our recommendations from section 5.1.1. are repeated here:

- include meter readings of the feeder bays in the power station log sheets in order to be able to separate the station losses from the distribution system losses (by deducting "energy entering into the feeders" from "energy generated").

- include meter readings of the energy delivered by the solar panel systems into the log sheets and correlate the recorded times.

- note that the total of "energy entering into the feeders" is the sum of the energy as metered in the feeder bays plus the energy delivered by the solar panel systems.

- 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".

- Adding metering for water and power usage calculations for street lighting (although not billed) would provide NUC with financial information for future decision-making and cost recovery methods.

- Additional metering for the LV services and plant auxiliary loads would provide more data to more accurately estimate power station usage.

- A program of meter inspection, testing, and maintenance should be implemented as soon as financially possible. Since NUC does not have a meter test facility, this could be contracted to an experienced provider of this type of service.

KEMA recommends the following:

In larger utilities with too high levels of non-technical losses, one of the main areas in aligning a utilities' operation to Revenue Assurance is to implement a Revenue Assurance Process making use of an advanced Revenue Intelligence System. For conducting most efficient fraud prevention/detection and revenue operation audits with limited resources, an advanced Revenue Intelligence system is very helpful. Such a system can detect potential fraud based on information from multiple sources using advanced detection rules. It will vastly increase the hit rate and support a range of revenue assurance activities. These changes/processes should include:

- Implementation of a formal Revenue Assurance Process including an overall Audit Process.

- Implementation of Revenue Intelligence software to support Revenue Assurance oriented operations

However, for a small utility, implementation of a Revenue Assurance Department and implementation of Revenue Intelligence software requires a large investment and may have a large organizational impact.

A more pragmatic approach can be developed to locate non-technical losses and increase the effectiveness of revenue-protection operations.

NUC should consider the following:

1. Assign a senior staff member to be Revenue Assurance Officer, responsible for Loss Reduction Strategies, and who plans and initiates loss reduction programs, keeps records of progress, and reports to the General Manager.

2. Develop a program for checking old meters.

3. Train meter readers to identify tampering, by-passing, broken seals, hook ups.

4. Train a customer service staff member to audit 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.

5. Select targets for inspection, also focusing on commercial customers. When selecting targets for inspection, the potential of the estimated amount of revenue recovery should be a major selection factor. When selecting accounts with highest revenues the recovery potential and hit rates will be the most efficient, particularly when only limited resources will be available.

6. Make operations less predictable. PUC's own experience may possibly show that there are sophisticated fraud activities that take advantage of known patterns of Revenue Assurance operations. This should be countered with less predictable operations (e.g. occasional night inspections, computer-generated random daily target lists, and so on). This will help to identify these fraudsters and increase the deterrent effect.

7. Prevent repeat fraud activities. Once a fraud is found, measures should be implemented to ensure it will not occur again.

8. Prevent and curb internal collusion activities. One important aspect of effective revenue protection operation is to prevent and curb potential internal collusion. Internal collusion seriously undermines the effectiveness of any revenue assurance process. One possible solution is to bring in non-local inspection teams to conduct critical revenue-protection operations, such as large account audits under the direct control of PUC's top management.

Employ right tactics for each group of customers. It is a fact that different types of customers have different needs for electricity, different usage patterns and different payment capabilities. A successful revenue assurance strategy should take this into account to develop corresponding tactics for each group of customers. In general, customers should be grouped based on their usage patterns and payment capabilities. Establishing typical usage patterns and payment capabilities for each group is a very important task of Revenue Assurance. Results should then be used as the basis for employing right tactics for each group of customers.

7. Suggested Equipment Replacements

During KEMA's site visit to the island of Nauru we observed NUC's generation, distribution, and metering equipment. Once the on-site visit was completed, based on our evaluation of the current equipment, we considered equipment replacement opportunities that would yield energy savings if NUC makes the required capital investment.

The conclusion of this process is that NUC generator replacement appears to be the greatest need. Six of the eight units owned by NUC were not operable during the time of KEMA's visit. To meet an n-2 reliability criteria (e.g., loss of any single unit with one unit out for maintenance), KEMA recommends that NUC consider installing four new, high-efficiency diesel units, rated at 2 MW (2.5 MVA) each. This would provide enough generating reserve to meet a 4 MW peak load under any n-2 generator condition. This should be done as soon as financing can be secured for the capital investment.

KEMA also made an economic comparison of buying four new high-efficiency diesel units versus continuing to depend on the existing lease package agreement with Cummins. The net present value (NPV) was calculated for each plan and presented below.

20 Yr. NPV Economic Comparison of NUC Generator Replacement vs. Lease Option (including associated assumptions)

Economic Inputs

Inflation	**3.00%**
Cost of Capital	**8.00%**

Generator Option 1 - Install 4 new 2 MW, high-efficiency diesel generators

Generator Replacement Cost		
Unit Cost	$1,400	per kW
	$2,800,000	per machine
No. of units	4	
Total Cost	$11,200,000	
Generator Maintenance		
AnNUCl Cost	$12,000	per machine
No. of units	4	
Total Cost	$48,000	per year
Fuel Cost		
Fuel Efficiency	4.25	kWh/liter
Production	13,275,000	kWh/year
Fuel Usage	3,123,529	liters/year
Cost of Fuel	$1.75	per liter
Total Cost	$5,466,176	per year

Installed Capital Cost (NPV)	**$11,200,000**
NPV of generator maintenance	**$604,309**
NPV of Fuel expenditures	**$68,817,877**
Total NPV of Generator Replacements	**$80,622,185**

Generator Option 2 - Continue lease of 4 Cummins high-speed diesel generators

Generator Lease Cost		
AnNUCl Cost	$350,000	per machine
No. of units	4	
Total Cost	$1,400,000	per year
Fuel Cost		
Fuel Efficiency	3.30	kWh/liter
Production	13,275,000	kWh/year
Fuel Usage	4,022,727	liters/year
Cost of Fuel	$1.75	per liter
Total Cost	$7,039,773	per year

NPV of lease cost	**$17,625,671**
NPV of Fuel expenditures	**$88,629,084**
Total NPV of Leased Units	**$106,254,75**

Since generator maintenance has also been a continuing issue at NUC, those costs have been included in the above NPV calculation. The results of the NPV calculation are shown in figure 11 below, and indicate that purchase of new units has a net pay-back period of 5 years.

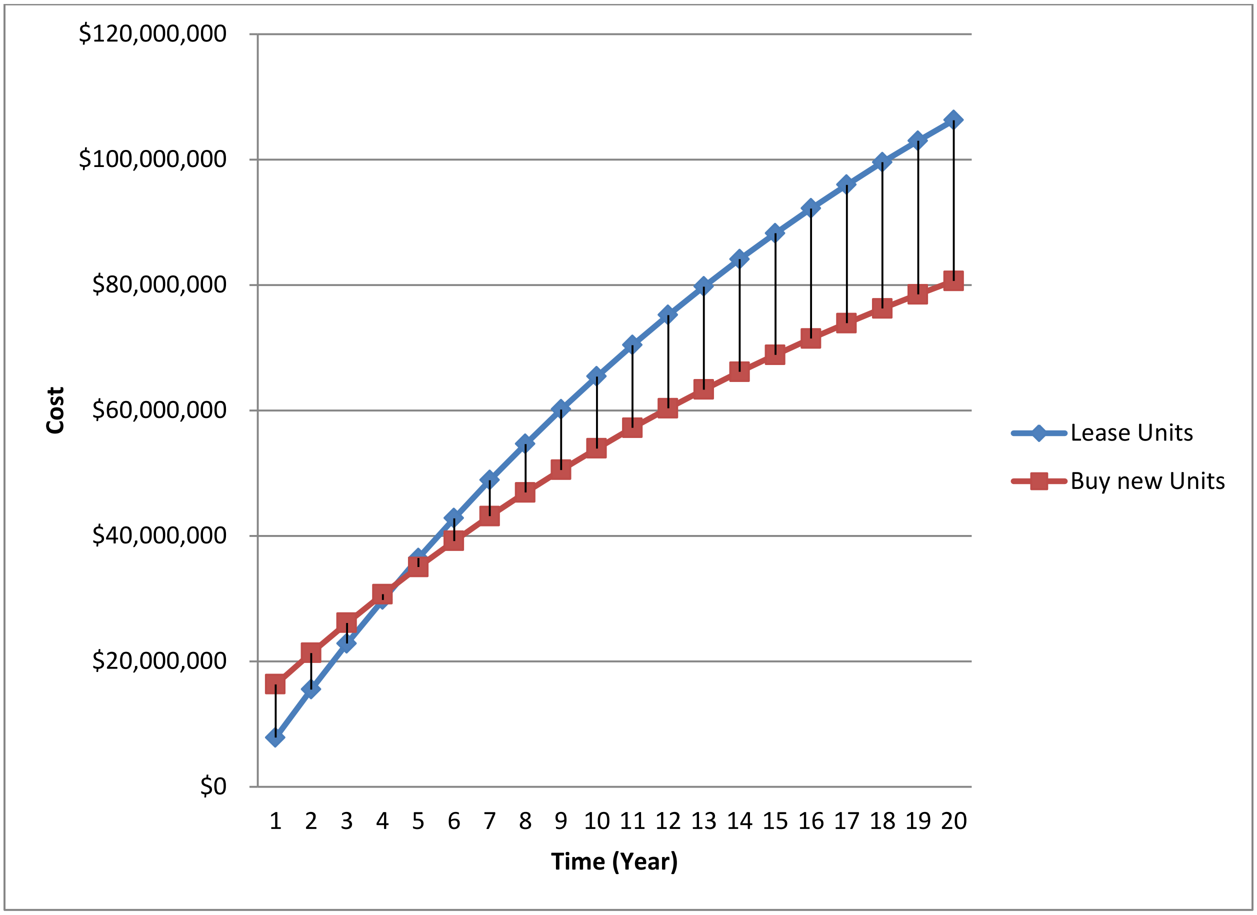

Figure 11 - NPV Results

A. Data Handbook

See attached NUC data handbook.docx

B. EasyPower Model

See attached NUC System.dez

C. One-line Diagram from EasyPower

See attached NUC One-Line.pdf

D. Loss Worksheet

See attached NUC loss worksheet.xlsx

E. Report # 1

See attached Report #1.pdf

F. Report # 2

See attached Report #2.pdf

G. Report # 3

See attached Report #3.pdf

H. Report # 4

See attached Report #4.pdf

I. Report # 5

See attached Report #5.pdf

J. Report # 6

See attached Report #6.pdf