KEMA

Quantification of the Power System Energy Losses in South Pacific Utilities

Niue Power Corporation, Niue

Submitted to

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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 Niue Power Corporation (NPC) in Niue.

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 NPC 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, 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 NPC's Energy System Losses

KEMA's analysis of the NPC power system determined total losses of 11.86% consisting of:

- 5.19% in power station auxiliaries (station losses), which is relatively high.
- 4.7% in technical losses, which is a in the normal range.
- 0.03% in non-technical losses, which is an excellent level.
- 1.94% in unbilled usage for street lights and a portion of the consumption by the water system.

The loss through unbilled street light usage cannot be considered to be a system loss, but is a financial loss for NPC because it is unbilled usage. For power delivered to the water company, NPC has an arrangement with the government for delivering power at an annual fee. KEMA estimates that the current yearly fee only covers some 25% of the actual costs, based on estimated usage. We recommend that NPC meter the actual usage for water pumps so that the true cost of providing this service can be determined.

When deducting the 1.94% for financial losses, the following figures are resulting out of the calculations for quantification of the NPC power system losses:

- **5.19% in station losses.**
- **4.73% in system losses.**

1.2.1 Generation

In addition to analyzing power station and distribution system losses KEMA also looked at the NPC generators' fuel efficiency. As an average over a year the fuel efficiency was 4.2 kWh/liter, which is a rather high efficiency level for small sized generating units of 500 kW each. This efficiency value meets the manufacturer's specification when loaded at 80 to 100% of their nameplate capacity. The generating units are only 3 to 4 years old and are well maintained.

Regarding the power station's own auxiliary usage there was no readily available information for estimating these station losses, because the energy entering into the distribution system has not been recorded in the power station logs in the past. Therefore, in order to determine the station losses KEMA needed to calculate the difference between total energy produced by the generating units and total energy entering into the distribution system over a 24 hour period. Both the generators and the outgoing feeders were read during the site visit after an interval of 24 hours, in order to determine the station losses for this period. This information was then extrapolated to an annual value.

After also identifying the presence of some more users which are connected to the power station LV busbar, such as other NPC buildings at the power plant site, some streetlights and some nearby houses, the information was further integrated into KEMA's analysis of station losses.

The 24 hours measurement in March 2011 revealed that the average power station load in this period was 24.8 kW, but this measured amount does not include power delivery by a 2 kW solar panel system at the power station site. For estimating the station losses (power station own usage) we furthermore deducted estimated consumption for the houses and the streetlights and ended up at 5.19%. This percentage is somewhat high and ideally should be reduced to 4% or lower.

Also, in order to improve loss monitoring, KEMA highly recommends that NPC includes hourly readings of the feeder meters in the power station log sheets on a routine basis in the future.

1.2.2 Distribution

The technical losses in the distribution system amount to 4.7% which is reasonable. Transformer "no-load" (core) losses accounted for 48.31% of the technical losses. NPC has two power transformers rated at 750kVA. Given the current loads, these transformers are oversized and as such the relatively high core losses of these transformers are contributing to the technical losses, which is also the case for the core losses of numerous oversized distribution transformers. NPC has 74 distribution transformers and in average they are loaded to 17.98% of full capacity during peak load condition. KEMA recommends close monitoring of distribution transformer loads and developing a plan for installing reduced transformer nameplate capacity when banks need to be replaced in specific locations.

Another aspect of the NPC system that has effect on feeder losses is the leading power factor at the generator terminal (i.e. under excited generators). The leading power factor is due to cable charging and light loading. Since most of the distribution feeders in the NPC system are underground cables, when there is not enough VAr demand from load, it requires leading capacitive VAr output from generators to compensate the excess cable charging. As a result of this leading power factor at the generator terminals, there is a flow of VAr through the distribution system toward the power station which causes additional losses on the feeders. There are two shunt reactors identified in the one-line diagram that can be used to correct power factor. These reactors are currently not in service since they have burned out. KEMA's study revealed that the technical losses can be reduced by 50% under peak load conditions if two new 150 kVAr shunt reactors are installed.

1.2.3 Non-technical

KEMA's calculations show that non-technical losses are approximately 0.03%, which is a very low level.

This result demonstrates that electricity theft, meter tampering, and meter by-passing are rare occurrences in Niue. In fact, KEMA was informed by NPC that there may only be one case in some 5 years when such irregularities are found at a client's location.

However, KEMA's analysis indicates that there may be meter reading inaccuracies based on the variable pattern of losses from month to month in NPC's historical meter statistics.

The monthly statistics show energy generated in a full month, but meter values for energy sold typically covers the period from the middle of the previous month until the middle of the current month. KEMA's data analysis indicates that there is quite some difference per month between "energy generated" and "energy sold". In 2010 the difference varied per month between 1.1% and 20.4%, while the average was 11.86%.

Also the energy entering into the feeders is not recorded in NPC's generation log sheets, which means that power station own usage cannot be determined as separate losses, distinct from the distribution system losses.

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 NPC.

Regarding power delivered to water pumps, for which the government pays a yearly compensation of NZ$ 10,000, it is recommended that NPC determine the actual usage for water pumps, since the current annual payment amount only covers an hourly usage of 3 kWh (based on an average production cost of NZ$ 0.37/kWh in January and February 2011). KEMA's analysis indicates that actual water pump usage is probably much higher than the 3 kWh level.

1.2.3.1 Metering

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 will more or less cover the same monthly period as the monthly generation statistics. Therefore, the calculation of monthly sales will have a higher accuracy.

Furthermore, it should be noted that irregular levels in monthly customer power readings may also result from inaccurate meter reading. However, NPC does not really have a Customer Information System that gives red flags when such irregularities occur. Detection of irregular consumption can help to identify bad meter readings and other metering anomalies, but is dependent on the vigilance of administrative personnel.

1.3 Recommendations

1.3.1 Generation

KEMA recommends the following based on its findings:

- Energy generated by the solar panel systems should be added to the monthly generation statistics.

- The Power Station's own usage (5.19%) is somewhat high and should be reduced to a percentage below 4%.NPC should perform an energy efficiency survey of the power plant premises (lighting and equipment in the buildings, and energy usage by auxiliaries in the power station when only one or two engines are running). NPC should then prepare a plan for improving the power station's energy efficiency.

- Furthermore, NPC should determine what power usage is involved in supplying the street lights and two houses that are connected to the power station LV system in order to determine the actual power station own usage.

- 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 three solar panel systems into the log sheets

1.3.2 Transmission and Distribution

KEMA recommends the following based on its findings:

- As already mentioned the introduction of two shunt reactors would reduce the technical losses substantially (more than 50% lower). This would save 75,000 kWh per year of technical losses, representing a value of NZ$ 27,750. NPC has already tendered for new shunt reactors but was not successful in getting bids from manufacturers. KEMA will contact NPC for recommending manufacturers who will be able to quote on shunt reactors as needed by NPC.

- When looking at the total capacity of all distribution transformers, on average these transformers are loaded at less than 20% of full capacity. Loss reduction savings can be achieved by optimizing the ratings over a number of years as existing transformers fail and need to be replaced. Based on the level of customer load connected per transformer it's also possible that some of the existing distribution transformers can simply be rotated (exchanged) to achieve lower system transformer losses.

- When buying new transformers NPC should require loss data from bidders so that the cost of copper and iron losses can be evaluated as part of the selection process. A NZ$ value should be applied to both core and copper losses so that the total life cycle costs of each transformer design can be calculated. This approach often shows that a somewhat more expensive transformer can be more cost effective over its lifetime because of lower losses.

1.3.3 Non-technical

KEMA recommends the following based on its findings:

- Replacement of the older meter population by new meters, as planned by NPC, is recommended, since accuracy of meters deteriorates with aging.

In order to achieve better and more accurate figures on total losses and non-technical losses our recommendations are:

- 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”.

1.4 Prioritized list of equipment for replacement

Replacement of NPC’s old meter population is recommended and KEMA has been advised that this replacement has already been planned for the end of 2011.

No generator replacements are recommended in NPC’s power station, since the equipment is rather new and in good condition, which is confirmed by the station’s fuel efficiency. In order to reduce the relatively high power station’s own usage it is recommended to perform an energy efficiency survey, which may lead to selected replacement(s) of equipment like lighting and other auxiliary or office equipment.

The 11 kV distribution feeders consist, for the major part, of rather new underground cables. Overhead line sections which are still in service (only some 4.5 km of the total grid) should not necessarily be replaced, but the condition of clamps, connectors, conductors should be monitored.

When looking at the total capacity of all distribution transformers, they are loaded on average at less than 20% of full capacity. Loss reduction savings can be achieved by optimizing the ratings of transformers installed over a number of years as new transformers are purchased. During the site visit by KEMA the age of the different transformers could not be identified, so no estimate could be made of transformer replacements in the coming 10 years. Issues like corrosion, bad connections, oil leakages, should be monitored in order to identify those transformers that need maintenance and/or replacement.

KEMA's calculations have shown it would be very beneficial to replace the faulty (burnt out) shunt reactors on the distribution grid. The system's leading power factor can be brought back to almost unity, with which technical losses can be reduced by more than 50%. This means that investing in two 150 kVAr shunt reactors at total costs of NZ$ 80,000 would save 75,000 kWh per year on technical losses, representing a value of NZ$ 27,750 per year (based on cost per unit of NZ$ 0.37 as calculated in the monthly production cost statistics of January and February 2011). Payback time will be 3.5 years.

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 NPC in Niue for data collection and technical assessments of the NPC power system, KEMA has sent data request documents to NPC 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 NPC in Niue in the week of March 7, 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. NPC personnel was very helpful and for example during the visit period a one line diagram has been put together.

For the quantification of losses study we had to make assumptions, based on our experience, in certain areas:

- electrical parameters of the generating units
- transformer impedances and transformer losses
- secondary wires/service lines.

After the visit some clarifications had to be asked by e-mail.

2.2 Utility Operations

NPC in Niue is the smallest of the utilities that we visited for the study on Quantification of Losses. The maximum load has peaked up to 500 kW during 2010, but currently peak demand is between 350 and 400 kW.

The power system consists of:

- a power station with 4 Caterpillar diesel generating units, each 508 kW at 415 V;
- an 11 kV distribution system consisting of two 11 kV distribution feeders, almost all underground
- three grid-connected PV systems, having capacities of 36 kW, 24 kW and 2 kW.
- 869 customers, among them a few large customers (the largest is a quarry, having an intermittent load).

The power station has newly been built and commissioned in the year 2008.

With a maximum load of 350 to 400 kW and an availability of 4 generators 508 kW each, the power station is in fact operating in an n-3 situation. All generators are in good shape and for reasons of efficiency there is usually only one generator running. In case the quarry starts its operations, a second generator is started, to avoid stability problems as experienced with one generator under the intermittent quarry load. The usage of generators is rotated in order to have them all running regularly.

During the visit the running hours of generators 3 and 4 (around 12,500) were behind on the running hours of generators 1 and 2 (between 17,000 and 18,000). In order to avoid the situation that all engines will need a major overhaul within a limited period of time NPC can achieve a better balance of the running hours in order to spread out the overhauls during the years.

The 4 generators are connected to the power station's LV busbar and from there power is taken for the power station's own usage, NPC's buildings at the power station site, a few nearby houses and a few nearby street lights.

From the LV busbar the two Feeder bays North and South are connected to transformers 415 V/ 11 kV, 750 kVA each. There are two feeder connection points on the island, but these points are normally open. Looking at the load of some 200 kW per feeder it can be concluded that the feeder transformers are quite oversized.

However, if the load does grow from 500 kW to 1 MW, even 1.5 MW, the power system already has the capabilities for production and distribution of such loads. There are no signs, however, that the Niue load will grow substantially in the coming years and there are at the same time initiatives underway to install more solar power, to be less dependent on diesel. The two major solar panel systems are connected to the low voltage sides of the South Feeder transformers near the High School (24 kW) and the Hospital (36 kW), while the small 2 kW solar panel system is connected to the NPC office at the power station site..

It must be noticed that the power system is operating under a low and leading power factor, even down to 0.8 and lower. This is caused by the combination of a low load being distributed by an underground network with a relatively high capacitance. Once the load grows, this situation will improve and the power factor already shows improvement when for example the quarry load is on the system. In this report we will further elaborate on remedial measures by introducing shunt reactors.

Low voltage systems are underground with individual customer connection, the cable joint and the meter located in a pillar box (picture to left).

NPC works with IEC standards and equipment such as generating units, power station auxiliary equipment, switchgear, transformers, cables is mainly from New Zealand suppliers.

NPC does not keep records of outages, outage durations and customers interrupted in such a way that reliability figures according to SAIDI and SAIFI definitions can be produced.

Meters are read every month within a period of two days, around the 16^{th} or 17^{th}. Readings are processed in Excel files and sent to the Government's Finance Department who takes care of the billing.

2.3 Identifying and Quantifying Losses

Electric power is generated in power stations 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 categories based on where the losses take place and the cause of losses:

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

2. Distribution system losses – losses due to power transfer through the distribution systems, such as transformers, over-head line conductors, areal cables or underground cables and service wires.

Losses in category 2 consist of both Technical Losses and Non-technical Losses. Technical losses are the losses that can be calculated 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 losses 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 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 calculated technical losses through power equipment in the distribution system and the service wires. Where information was not sufficient, assumptions were made to facilitate the calculations. KEMA created a Power flow model in Easy Power to represent the NPC power system. A power flow study has been performed to calculate system kW losses including primary feeder losses and power transformer copper losses. An Excel spreadsheet has been created to calculate kW losses that are not calculated in the power flow study, such as transformer core losses and service wires losses.

These kW losses are then converted to kWh energy losses by utilizing the estimated Loss Factor. Unbilled usage is estimated for all the causes identified.

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

During the visit to NPC in March 2011 KEMA noticed that NPC keeps record of power produced by the generating units per hour (generation log), that also fuel usage is metered per generator, and that monthly the energy sold is derived out of the meter reading results.

However, the meters in the North and South Feeder bays are not read. This means that there was no insight in the power station own usage (which is: total energy generated – energy entering into the distribution system through the feeder bays). It is recommended to keep logs of the feeder meters as well. In order to get a figure for the power station own usage the feeder meters and generator meters have been read twice with a time interval of 24 hours. This way the power station own usage was measured over a 24 hours period. It has also been identified that the measured power station own usage includes the usage of NPC buildings on the power station site as well as the usage of two nearby houses and two nearby streetlights. For estimating the power station's own usage only (including NPC buildings on the power station site) KEMA deducted estimated usage of these houses and streetlights. in so doing, the power station own's usage ended up at 5.19% as mentioned in the Executive Summary. This percentage may be somewhat lower because the NPC office at the power station site is also getting power during daytime from a 2 kW solar panel, which is not metered.

Another aspect of importance was that in the NPC statistics of energy generated the energy from the grid-connected PV systems was not included. On site the 24 kW and 36 kW solar system meters have been read, showing the total production during the period from commissioning of the systems. The average production per month of the solar systems has subsequently been calculated and has been added to the total of the energy entering into the NPC system per month. It is recommended to read the solar panel meters at least monthly in order to determine the amount of energy that has been delivered to the grid by the solar panel systems.

3. Generation

For power generation NPC has its Niue Power Station with four Caterpillar generation units with a capacity of 508 kW each and furthermore three solar panel systems are installed near the High School (24 kW), the Hospital (36 kW) and the NPC Office (2kW), where these systems only deliver during day times since no storage batteries have been installed.

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

KEMA's major findings:

- The Caterpillar generators are only 3 to 4 years old, are in good condition and NPC will keep to the necessary maintenance program;

- Given the maximum load of the NPC power system, the power station is oversized and even if the maximum load grows from some 400 kW to 1000 kW there will still be an n-2 situation;

- Given the situation that mostly one generator is dispatched at some 80% of its capacity, this implies that an optimal situation occurs regarding fuel efficiency. The fuel efficiency as found in NPC's generation logs shows values up to 4.2 kWh/liter, which is a good figure for generators with a nameplate capacity of around 500 kW.

- The power station own usage is 5.19% and should be less than 4% when comparing with similar utilities. Reasons for this high percentage can be identified as follows:
  - the power station is oversized
  - other buildings at the power station site are also connected to the power station LV bus
  - some nearby streetlights and two nearby houses are also connected to the power station LV bus

- The solar panel systems have been in service since September/October 2009 and so far the two largest of the three systems together delivered around 66,000 kWh per year, which for 2010 represents 2.15% of total energy produced.

Note that the maximum capacity of 62 kW is at some 15 to 16% of the average load of the NPC system.

Metering of the energy produced is located in the generator bays of the LV switchgear, and also the energy entering into the two distribution feeders is metered in their bays in the LV switchgear, all Class 1. Every generator also has a fuel meter, but the accuracy is unknown.

3.1 Equipment

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

Major characteristics of the generating units:
4 Caterpillar generating units model 700F, with auxiliaries
508 kW, 538 kVA
410/237 V, 50 Hz
fuel: diesel # 2
The power station has two diesel storage tanks, 20,000 liter each.

Caterpillar has also delivered the LV switchgear (see picture below) with a single busbar system, to which the generators are connected and from which the connections to the two feeders depart. Furthermore there is an LV bay for power station auxiliaries/own usage.

Furthermore the power station has a control room as delivered by Caterpillar where real-time generating units' parameters and alarms can be monitored by shift operators. For each generating unit a Woodward 3000 load control computer has been installed.

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 the information was readily available. KEMA received generation log sheets for the week of February 21 through 27, 2011, as well as Monthly Fuel Analysis Log sheets for the months of January 2011 and February 2011.

There are log sheets per 8 hours shifts and the sheets show recordings per half hour of relevant parameters of engines that were on line, such as currents, voltages, frequencies, power factor, kWh meter readings, peak load per generator and other relevant parameters, such as oil pressure, oil temperature, water temperature, etc. The fuel meters are only read at the beginning and the end of each 8 hours shift. This means that fuel usages per generator are recorded for 8 hours periods and dependent on the number of engines that were online during this period, the total fuel efficiency is calculated on the log sheet.

This means that if only one generator was online during an 8 hours period the calculated fuel efficiency is the fuel efficiency of this single generator only. An example of this is February 25, 2011, when from midnight until 8.00 AM only generator 4 was online, with a maximum load varying from 299 kW (4.00 AM) to 368 kW (7.00 AM). The fuel efficiency for this generator 4 during this period was 4.28 kWh/liter.

Other sheets show 8 hours periods where during a number of hours not one but two generators were online and where the load was divided per the two generators (for example at a certain time 199 kW and 199 kW) and although each of the generators was then running at less than 50% of its capacity the fuel efficiency still was 4.13 kWh/liter.

The lowest efficiency was 3.95 kWh/liter in a period when generators 2 and 4 were on and off because of maintenance on the one hand and forced starts for the quarry.

Highest efficiency was in the morning of February 21, 2011, with two generators (Gen 4 and Gen 1) online and a total fuel efficiency of 4.78 kWh/liter which is remarkably high.

For the months of January 2011 and February 2011 the average fuel efficiencies were 4.2742 kWh/liter and 4.1983 kWh/liter.

If NPC keeps continuing good maintenance of the engines, the cooling systems, etc, these efficiency figures can be continued and are compliant with manufacturer ratings for this type of generating units.

Station Losses

As already mentioned there was no information available for identification of the station losses, because the energy entering into the distribution system was not recorded in the power station logs. For determining the station losses it is needed to calculate the difference between total energy produced by the generating units and total energy entering into the distribution system.

For that reason meters on the generators and the outgoing feeders have been read during the site visit with an interval of 24 hours, in order to determine the station losses for this period of 24 hours.

It is highly recommended to include hourly readings of the feeder meters in the power station log sheets.

Once introduced it would be good to determine whether the station losses as measured during this 24 hours snapshot in March 2011 are representative for the station losses as measured over periods of months.

After also identifying the presence of some more users which are connected to the power station LV busbar, such as the other NPC buildings, some streetlights and some nearby houses, the information was complete for further analysis of the station losses.

The 24 hours measurement in March 2011 revealed that the average load in this period was 24.8 kW.

The power used by the two nearby residential customers should be measured. If the meters at these nearby houses are read at the end of each month, the usage of these houses can be deducted from the station losses as well the estimated power usage of the nearby street lights, which are also connected to the power station's LV system. This way the power station's own usage will remain as a figure that should also be incorporated in the monthly summaries. For estimating the station losses (power station own usage) we already deducted estimated amounts for the houses and the streetlights and ended up at 5.19% as already mentioned in the Executive Summary.

3.3 Findings

The analysis has shown that the rather new power station is operating at acceptable fuel efficiency, but the power station's own usage is on the high side (5.19%) and should be brought back to 4% or lower.

An energy efficiency survey of the power station premises should be undertaken (lighting and equipment) and of effective usage of auxiliaries in the power station when only one or two engines are running. These issues should be investigated in order to make a plan of power station energy efficiency.

4. Distribution

During KEMA's site visit in Niue NPC had prepared a one line diagram of its 11 kV distribution system. This was a very useful exercise since the one line diagram also gave the sizes of all distribution transformers.

The distribution system consists of two 11 kV feeders, the North Feeder and the South Feeder. The North Feeder consists of only underground cables and the South Feeder has some 4.5 km overhead while the major part of this feeder consists of underground cables.

The two feeders have two connecting points which are normally open.

When considering the average and the maximum load of the NPC power system it is clear that the distribution system is oversized:

- Each feeder is connected to the power station's LV bus bar via a transformer 11 kV / 415 V with a rated power of 750 kVA, while the maximum load is around 500 kW. The distribution of load over the two feeders is around 60% (North Feeder) against 40% (South Feeder), which means that under normal operating conditions the transformers are never loaded higher than 300 kVA (North Feeder) and 200 kVA (South Feeder). It must be noted that on the 11 kV side of each power transformer an 11 kV switching bay is installed for the feeder connection. For the two power transformers the switching bays are separated and are not connected to an 11 kV bus bar.

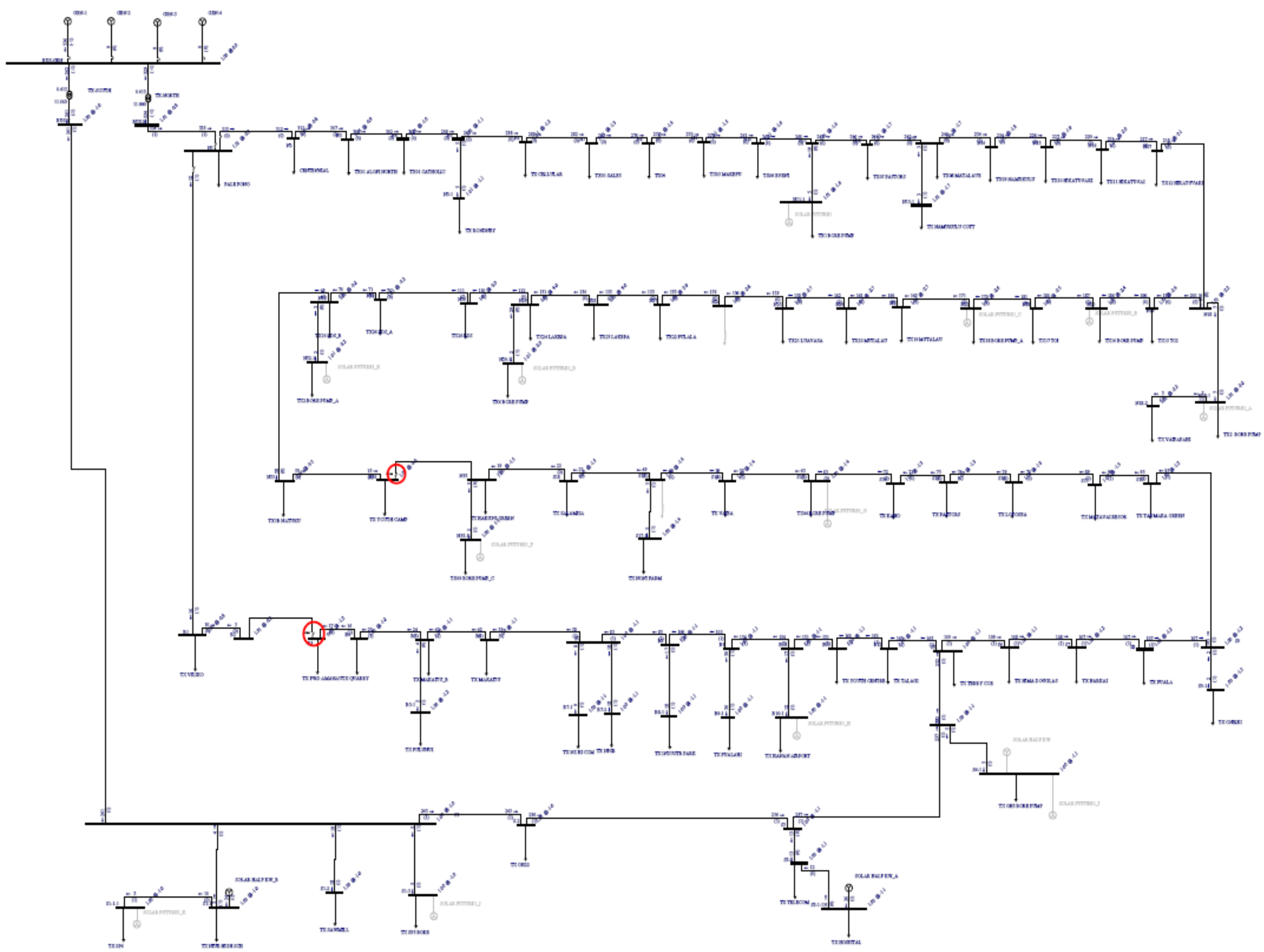
- Feeder currents will not be higher than some 15 A, while conductor sizes are 35 mm² Cu *(*or in some cases Al), allowing for far over 100 A, dependent on the laying conditions.

- The total rated power of all connected distribution transformers is 3,090 kVA, while the total load does not exceed 500 kW.

As already mentioned before, the capacitance of the underground cables has a dominant influence on the system's power factor, particularly in the NPC situation where the system's load is quite low. In the generation logs we have seen the power factor mostly between 0.8 and 0.85 (leading), sometimes even down to 0.75 and only in cases when two generators are running while the quarry is operating, the power factor sometimes comes to a value just over 0.9.

The one line diagram and the load flow analysis results are shown in the attachments "one line diagram" and "NPC loss worksheet".

Below the one line diagram is also shown, but it is better readable on the A3 sheet that is attached to this report's hard copy.



NPC one line diagram

4.1 Equipment

4.1.1 11 kV distribution

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

- From the LV switchgear in the power station, the North and South Feeder switching bays are connected to power transformers (415 V / 11 kV), each with a rated power of 750 kVA. It must be noted that the transformers have different impedances: North Feeder transformer 4.99%, South Feeder transformer 4.36%. Both 11 kV neutrals are grounded.

- The 11 kV sides of the power transformers are connected to 11 kV switchgear with a North Feeder Bay and a South Feeder Bay, made by Reyrolle Pacific and with Argus relays.

- The North and South Feeders consist of underground XLPE cables (newly installed) with conductor sizes varying from 3x35 mm² Cu, CWA, trefoil single composite cable, 3x35 mm² Al, AWA, single cores flat laid, to 3x50 mm² Cu, CWA, trefoil single composite cable, while the overhead parts of the South Feeder consist of 3x35 mm ², Cu bare on 2.6M X-arms.

- NPC has 74 distribution transformers with a total capacity of 3,090 kVA. Most single phase transformers are 25 kVA, made by ENEL, some commercial customers have three-phase transformers 100 kVA.

- Feeders have two connecting points with switches normally open.

- No capacitor banks.

- NPC used to have two shunt reactors but these are not operational anymore (burnt out).

4.1.2 LV Wires

The low voltage system operates at a voltage level of 410/235 V.

To each distribution transformer a main cable 70 mm² Al is connected, or in some cases a 95 mm² Cu cable. Customer connections are branched off from the main cable with 16 mm² Al cable. Some transformers may have 15 to 20 customer connections whilst some have only 4 or 5.

The main cable has in some cases a length of 800 to 900 m, but in most cases is shorter. Customers mostly have a 1 kVA connection.

4.2 Analysis of Losses

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

1. The average power output over the past year (2010) was used for the annual energy consumption.
2. A typical value for power transformer no-load losses from literatures[1] [2] was used for the South feeder and North feeder power transformers 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. The system's non-technical loss is assumed to be close to zero. The estimated technical loss kWh is calibrated to keep total generation in balance with total load and losses.

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[1] 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.

[2] Electric Utility Engineering Reference Book distribution systems by Electric Utility Engineers of the Westinghouse Electric Corporation 1959, 1965, data for single phase transformers.

The one-line diagram of the power system as provided by NPC shows feeder segment distances, conductor types and sizes, and kVA capacity of distribution transformers. Based on this information, KEMA developed a power flow model in EasyPower for NPC. In this distribution system model, the power station and two primary feeders are modeled. Distribution transformers are represented as spot loads with constant kVA loads same as transformer capacities and an estimated load power factor of 0.9. Easy Power provides a feature to scale loads into specific values when a power flow is performed.

Losses in kW through the primary feeders and step-up power transformers are calculated in the power flow study for the system peak demand. Load allocation was based on distribution transformer capacities connected to each feeder. KEMA studied a power flow for 500kW peak load condition by applying system Utilization Factor of 17.98% to all loads with a total connected capacity of 3090 kVA. 500kW peak load is assumed as the total system load that is supported by both the power station and the grid-connected PV.

With annual energy consumption of 2,793,356 kWh and peak demand at 500kW, NPC system has a load factor estimated at 67% and a loss factor estimated at 50%. The technical losses in kW are converted into kWh energy losses and the results are presented in the next section.

4.3 Findings

The total system losses are the total energy entering into the system out of power stations subtracted by total energy sold and the energy unaccounted for. For NPC, the unbilled energy usage came from the street lights. A summary of estimated losses is provided in Exhibit 4-1.

Exhibit 4-1: Loss Estimation - 2010

	kWh	% of generation	% of system consumption
annual generation	3,168,797		
annual station auxiliary	164,358	5.19%	
annual system consumption	3,004,439	94.81%	
annual energy sold	2,793,356	88.15%	92.97%
system loss including unbilled usage	211,083	6.66%	7.03%
unbilled usage	61,320	1.94%	2.04%
technical loss	148,934	4.70%	4.96%
non tech loss	829	0.03%	0.03%

The initial estimation for technical losses is based on the typical loss for transformers and typical configuration for the service wires. The result from the estimation shows non-technical loss as negative percentage. Subsequently, the technical losses estimated value is calibrated so that it is close to zero for the non-technical loss and total energy generated is balanced with total load and losses. A few factors can bring contribution to the estimation error:

- Inaccuracy in meter reading for total generation, consumption and energy sold. In particular, the amount of solar energy entered in NPC system may not be accurate.
- Error introduced in loss estimation by taking assumptions where no sufficient data is available. Example here is that transformer no-load loss and full-load loss data is not available for transformers.
- The loss quantification methodology is developed from the system point of view considering the diversity of the distribution system so that estimation errors introduced by assumptions would not result in significant deviations in the quantity of each of the loss categories. NPC has a very small power demand compare to other Pacific Island utilities.

To improve the loss estimation result, KEMA recommends continuing meter monitoring and meter calibration to improve the accuracy of historical data. KEMA also recommend that NPC should keep record of all power equipment from manufacturers including equipment specifications, name plate information and test data.

The estimated technical loss is 4.73% of the annual generation. Among all the causes, transformer core loss is accounted for 48.31% of the technical loss. A big contributor of energy loss is the core loss of the distribution transformers. NPC has 74 distribution transformers and on average they are loaded to 17.98% of full capacity during peak load condition. KEMA recommends close monitoring of distribution transformer loads and plan for reduced capacity in replacement.

Another aspect of the NPC system that has effect on feeder losses is the leading power factor at the generator terminal. The leading power factor is due to cable charging and light loading. Since most of the distribution feeders in the NPC system are underground cables, when there is not enough VAR demand from load, it requires the generator to absorb VAR(s) in order to compensate the cable charging. Due to the high amount of reactive power, the feeder currents are much higher causing excessive feeder losses. There are two reactors identified in the one-line diagram that can be used to correct power factor. These reactors are currently not in service since the reactors have burned out. KEMA conducted a power flow study with selected reactor capacities in a study case representing an NPC peak load of 500kW and average load factor of 0.9. Base case is the peak power flow case, with generator output voltage at 1pu (11kV) and no reactor online. The scenarios studied are to bring one or more reactors online adjusting reactor kVAr capacity only. The results are listed in the table below.

Peak Load	500kW	BaseCase	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Reactor North Feeder	Ohms	off-line	1000	1000	807	605
	kVAr	0	121	121	150	200
Reactor South Feeder	Ohms	off-line	off-line	1000	807	605
	kVAr	0	1	121	150	200
Generator Output	kW	512	506	506	506	506
	kVAr	-289	-165	-44	14	113
	Power Factor	-0.871	-0.951	0.996	1	0.976
Losses	kW	12	6	6	5	6
	kVAr	-494	-491	-488	-485	-481

As the results show, with both reactors of 150kVA, the power factor is brought to 1 and kW loss is reduced over 50% in peak load condition. Since the average load condition is lighter then the peak load, larger reactor capacity of 200kVA is studied. With them, power factor becomes lagging, with no further improvement on the kW loss.

It is worthwhile to point out that KEMA studied the reactor capacity for the peak load condition, with the goal of correcting the power factor and reducing feeder losses. With load growth, the power factor will correct itself. For the NPC system, the power factor will reach 1 if the load is 35% of the total kVA capacity or equivalent to 973kW.

KEMA recommends that NPC considers reactors with taps so that the VAr output can be adjusted in a range, e.g. from 50% to 100%. With taps, the output of the reactor can be accommodated to various loading levels. KEMA also recommends that NPC should request a sizing study from vendors that covers other considerations beyond loss reduction. For example, installing reactors can also correct elevated voltages at the end of feeder, which is also caused by cable charging. However, that requires further detail modeling to study, and is not covered as part of this project.

A few other recommendations are provided below.

1. Meter data collection: regularly collect meter data at generator, auxiliary usage and sending-out points so that accurate statistics of energy production and consumption is accumulated.

2. Regularly update the EasyPower model to keep synchronism with the actual situation.

3. Monitor and update the utilization factor on per-feeder and system-wide basis.

4. Record peak demand and update load and loss factors for each feeder.

Recommendations listed above are for improving the accuracy of the Easy Power model and will help improve the accuracy of the loss estimation within a few years.

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 noticed that:

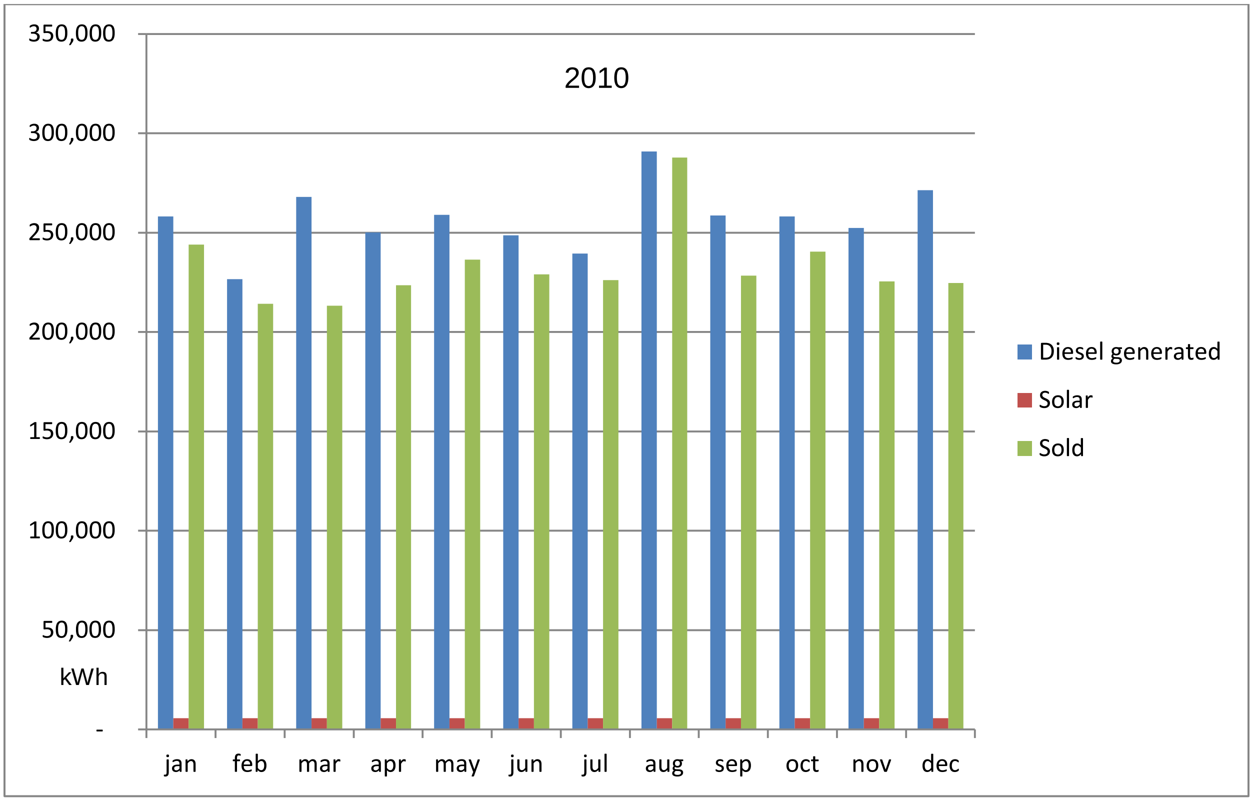
- All meters are read monthly on two subsequent days in the middle of the month, mostly on the 16th and the 17th;
- All meter readings are recorded by NPC's administration in Excel files.
- The Excel files, containing the power usage per customer based on the meter readings are sent to the Treasury department of the Niue government.
- The Treasury department takes care of billing and collections.
- Payment must be done within 30 days, disconnection follows after 3 months or earlier in cases of high amounts.

Meters in the NPC system are well protected in the metal boxes as shown in the picture on Page 11. The meter population is old and NPC does not have meter testing facilities. It could be possible that some of the old meters no longer meet their accuracy class. But NPC informed KEMA that meters will be replaced by the end of the year 2011.

Since the monthly statistics show energy generated in a full month, the energy sold is covering the period from the mid of the previous month until the mid 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". In 2010 the difference varied per month between 1.1% and 20.4%, while the average was 11.86%.

Note that in the 11.86%, the power station's own usage (station losses) is still included. Those losses are estimated at 5.19% as a result of a 24 hour measurement on site.

The average value of 11.86% should be close to reality but will still have an inaccuracy because energy generated was measured from January 1, 2010 to January 1, 2011, while energy sold was measured from December 16/17, 2009 to December 16/17, 2010. The following graph shows the differences per month as identified.



Electricity theft, meter tampering, meter by-passing are phenomena that hardly exist in Niue. As KEMA was informed there may be one case in some 5 years when such irregularities are found at a client's location.

When summarizing probable non-technical loss causes we can identify that there may possibly be meter inaccuracies, maybe meter reading inaccuracies when looking at the volatile pattern of losses per month in the graph above, and in fact there are no or negligible 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 very low, namely 0.03%. First calculations even showed negative non-technical losses, which result had to be corrected by further fine-tuning of transformer losses estimates, which reduced the outcome for technical losses and only left 0.03% for non-technical losses. 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 NPC.

Regarding power delivered to water pumps, for which the government pays a yearly compensation of NZ$ 10,000, it is recommended that NPC measures the actual usage for water pumps, since this amount represents an hourly usage of 3 kWh (when using the average production costs of NZ$ 0.37/kWh in January and February 2011), which may probably be lower than the actual usage.

5.1 Sources of Non-technical Losses

5.1.1 Metering Issue Losses

As already mentioned the monthly statistics show energy generated in a full month, the energy sold is covering the period from the mid of the previous month until the mid of the current month. It is recommended to perform the monthly meter readings on or close to the last day of the month in order to get a more accurate comparison between the monthly figures for “energy entering into the feeders” and “energy sold”.

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 three solar panel 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

The condition of the rather old meter population is not really known, but replacement of meters has been planned for the end of the year 2011.

5.1.1.2 Meter Tampering and Meter Bypassing

Meter readers are very seldom confronted with tampered or by-passed meters (maybe one case per 5 years).

5.1.1.3 Inaccurate Meter Reading

Inaccurate meter reading will lead to an irregular figure for power usage. NPC does not really have a Customer Information System that gives red flags when irregularities occur. Irregular figures may be noticed by the administrative personnel. Most of the times the inaccurate reading will be corrected again by the next meter reading. 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 Governmental Treasure department. NPC 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 have to be written off, are financial losses and not system losses.

5.1.4 Loss through Theft

As already mentioned NPC 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. Only a small part of NPC's feeders consist of overhead lines.

5.2 Analysis of Non-Technical Losses

When analyzing non-technical losses it can be noticed that the loss calculations show a very low percentage of non-technical losses (0.03%). 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. In reality non-technical losses may possibly be higher than 0.03% if technical losses calculations should result in a lower percentage.

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".

5.3 Findings

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

- Non-technical losses are very low (0.03%)
- The meter population is old, but replacement of meters will take place by the end of 2011;
- Theft, meter tampering and by-passing, are phenomena that hardly occur in Niue;
- 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 generated” is compiled at the end of each there is no accurate comparison between “energy generated” / “energy entering into the feeders” and “energy sold”.

6. Findings and Recommendations

This chapter gives a compilation of findings and recommendations.

6.1 Generation

Energy generated by the solar panel systems should be added to the monthly generation statistics.

Fuel efficiency of the relatively new generating units is quite optimal, considering the generators' capacity of 500 kW each. The most efficient situation (4.28 kWh/liter) is reached in the periods when only one generator is running at some 350 to 400 kW and even when two generators are dispatched the efficiency is still 4.13 kWh/liter or higher.

Power station's own usage (5.19%) is high and should be reduced to a percentage below 4%. NPC should perform an energy efficiency survey of the power station premises (lighting and equipment in the buildings, effective usage of auxiliaries in the power station when only one or two engines are running). NPC should then prepare a plan on improving the power station energy efficiency.

Before that the power station log sheets should be extended with 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). Furthermore it must be determined what power usage is involved by some street lights and two houses that are connected to the power station LV system in order to determine the actual power station own usage.

6.2 Distribution

Since the distribution system is oversized technical losses remain relatively low. Still there is potential for substantial reduction of technical losses:

- The 750 kVA power transformers are oversized and have high core losses. However, at the current loading condition, replacing them with transformers of reduced capacity would not realize much of saving on losses. With size reduced, core losses are reduced but copper losses will increase since load current through each transformer is of a higher percentage of capacity. The existing transformers are only 3 to 4 years of age, still have a depreciation period to go, which will make the replacement unattractive unless the 750 kVA transformers can be sold at a price level that compensates the remainder of the capital costs, which is unlikely. Another issue is that if unexpected demand growth will occur by new economic developments the n-1 situation will be affected and an undersized situation would then be the case.

For these reasons replacement of the power transformers is not recommended.

- As indicated in section 4.3 the introduction of two shunt reactors would reduce the technical losses substantially (more than 50% lower). This would save 75,000 kWh on technical losses, representing a value of NZ$ 27,750.

  Costs for shunt reactors 150 kVAr with taps are estimated, including transportation costs and installation costs) at NZ$ 40,000 per reactor.

  With capital costs at 8% per year the pay-back time will be 3.5 years, based on an NPV calculation.

- When looking at the total capacity of all distribution transformers, these transformers are loaded at less than 20% of full capacity. Loss reduction savings can be achieved by optimizing the ratings over a number of years as new transformers are purchased. Based on customers connected per transformer it could be found out whether distribution transformers can be rotated. Furthermore more appropriate ratings should be considered when buying new distribution transformers.

  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. When it comes to the transformers' lifetimes, there is not really a concern when the loads are so low. However, issues like corrosion, bad connections, oil leakages, should be monitored in order to identify those transformers that need maintenance and/or replacement.

- When buying new transformers the transformer total life cycle costs should be considered when evaluating bids. Hence bidders must also specify copper and iron losses to evaluate cost of operating the transformer using NZ$ value per kW. It often shows that somewhat more expensive transformer can be more cost effective over its lifetime because of lower losses.

6.3 Non-Technical Losses

KEMA recommends the following based on findings.

- Replacement of the old meter population by new meters, as planned by NPC, 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 of 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 three 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”.

7. Suggested Equipment Replacement

Replacement of NPC's old meter population has already been planned for the end of 2011.

No replacements are recommended in NPC's power station, since the equipment is rather new and in good condition, which is shown by the station's fuel efficiency. In order to reduce the relatively high power station's own usage it is recommended to perform an energy efficiency survey, which may lead to replacements of equipment like lighting devices and possibly other auxiliary or office equipment.

The 11 kV distribution feeders consist for the major part of new underground cables. Overhead lines which are still in service (only some 4.5 km of the total grid) should not necessarily be replaced but the condition of clamps, connectors, conductors should be monitored.

When looking at the total capacity of all distribution transformers, these transformers are loaded at less than 20% of full 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. When it comes to the transformers' lifetimes, there is not really a concern when the loads are so low. Issues like corrosion, bad connections, oil leakages, should be monitored in order to identify those transformers that need maintenance and/or replacement.

As our calculations have shown it would be very beneficial to replace the faulty (burnt out) shunt reactors in the distribution grid. The system's low power factor can be brought back to almost 1, with which technical losses can be reduced with more than 50%. This means that investing in two 150 kVAr shunt reactors at total costs of NZ$ 80,000 would save 75,000 kWh per year on technical losses, representing a value of NZ$ 27,750 per year (based on costs per unit of NZ$ 0.37 as calculated in the monthly statistics of January and February 2011). Payback time will be 3.5 years.

ATTACHMENTS

- The NPC Data Handbook
- The NPC one line diagram (A3 sheet attached to the hard copy)
- The NPC loss calculations worksheet

These appendices will be provided separately.