Quantification of the Power System Energy Losses in South Pacific Utilities

Papua New Guinea Power Limited (PPL)

Submitted to

PPA

nzaid
New Zealand's International Aid & Development Agency

European Union

Pacific Islands Forum Secretariat

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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 the Papua New Guinea Power and Light (“PPL”) Port Moresby system.

Project objectives and deliverables for PPL include:

1) Quantification of energy losses in the Port Moresby power system.

2) Preparation of a prioritized replacement list of power system equipment to reduce technical losses.

3) Recommendations for strategies on reducing technical and non-technical losses.

Insufficient data for the Port Moresby system was available to KEMA to develop a data handbook or model the distribution voltage level facilities.

1.1 Quantification of System Losses

Losses throughout the PPL system consist of power station losses, transmission system losses and distribution system losses, as defined below:

- Station Losses: power plant auxiliary loads and/or station services.
- Transmission System and Distribution System Losses: these losses can be divided into technical and non-technical parts as well as unbilled usage.
  - Technical losses: summation of transformer core losses, transformer copper losses, transmission line losses, distribution feeder losses, secondary wire losses and losses of any other equipment in the system, such as 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, and 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 PPL's System Energy Losses

KEMA's analysis of the PPL Port Moresby power system determined that total losses are 24.45% of annual generation, which is a very high percentage. These losses consist of:

- 2.09% in transmission system losses (which is a very reasonable level)
- 22.36% power station auxiliaries (station losses) and distribution system losses (which is a very high value).

Due to the lack of data, KEMA could not identify what portion of these losses are technical vs. non-technical in nature. No unbilled energy usage information was provided for the PPL system.

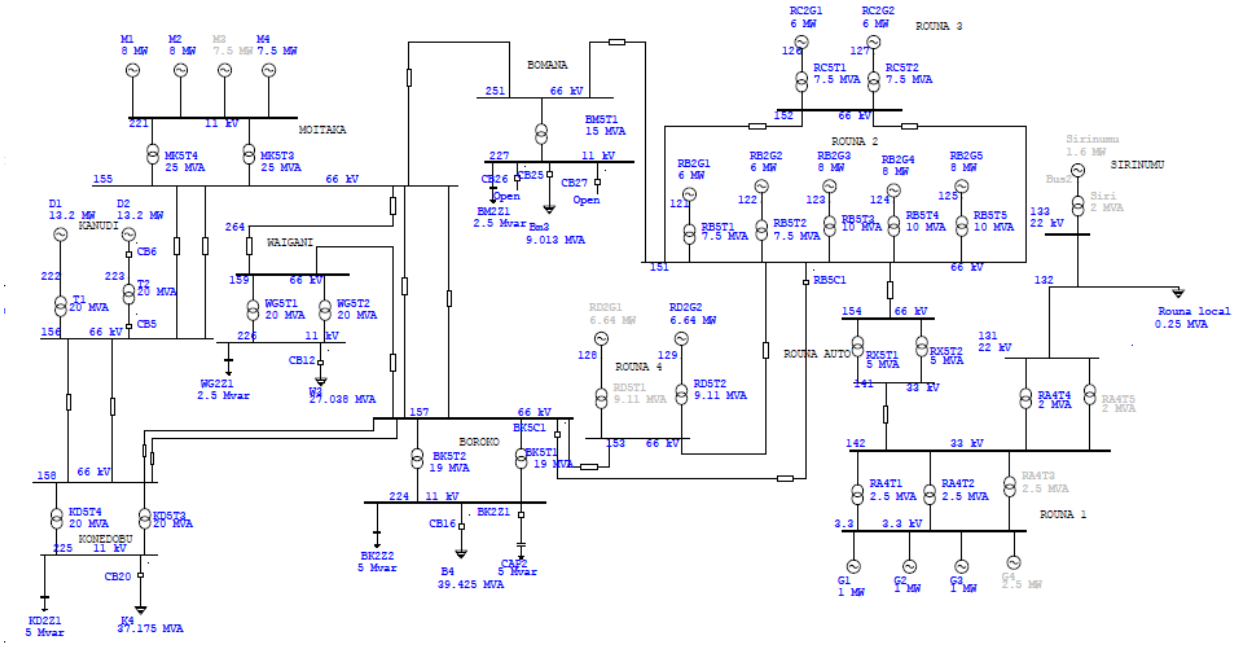
1.2.1 Generation Losses

PPL operates one hydroelectric generation station (Rouna) and two diesel generating stations (Moitaka and Kanudi). Station losses are typically calculated as the difference between total energy produced by the generating units and total energy entering into the transmission and distribution delivery system. KEMA was unable to estimate the station losses from the data provided.

1.2.2 Transmission and Distribution Losses

The PPL transmission and distribution (T&D) system consists of a 66kV transmission backbone that serves eight 11kV, 6.6kV and 3.3kV distribution substations over a rather large geography. Most of the distribution substations are 66/11kV, but a small 33kV sub-transmission system supplies some 3.3kV distribution from Rouna and there is also a small 22/6/6kV sub-transmission/distribution system at Sirinumu. A one-line diagram of the 66kV system is shown in Figure 1.

Figure 1 - One Line Diagram of POM System from ETAP



PPL provided a power system model of Port Moresby system in the ETAP database along with one-line diagrams. This model included power plants, station transformers and power transformers, as well as the transmission system from 66kV to the 11kV distribution substation. However, PPL did not provide a power flow model of the 11 kV distribution system. Therefore, KEMA relied on PPL's existing ETAP power flow model.

There was no information provided for distribution system except for rudimentary diagrams, which do not provide sufficient information such as circuit loading, conductor types and lengths as needed to estimate distribution losses. Therefore, distribution system losses were not explicitly analyzed except as part of the overall system loss estimate.

1.2.2.1 Non-technical Losses

No data on non-technical losses was available for the Port Moresby system. Based on KEMA's experience a good value would be below 4 percent for a system such as PPL. Activities such as electricity theft, meter tampering, and meter by-passing may lead to higher levels of non-technical losses.

1.2.2.2 Customer Metering

KEMA did not receive any data on the condition of the customer meter population. Old meters should be tested at regular intervals and replaced when found to be inaccurate. Meters should also be added at key locations, such as water and sewage pumps to allow for a more accurate categorization of losses.

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 utility across the South Pacific region. The purpose of these studies is to review the power system 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 the 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 Identifying and Quantifying Losses

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

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

2) System losses – losses incurred by moving power through the transmission and distribution systems, including transformers, over-head line conductors, areal cables or underground cables, and LV secondary service wires.

Losses in category 2 consist of both Technical Losses and Non-technical Losses. Technical losses are the losses that can be estimated as a result of electric current passing through the power system equipment. In contrast to technical losses, there are non-technical losses, which

are not directly caused by power system equipment. Causes of non-technical losses can include inadequate or inaccurate meters, theft, meter tampering or by-passing, meter-reading errors, irregularities with prepaid meters, administrative failures, and wrong multiplying factors.

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 a financial loss to the utility and should not be included as part of non-technical loss. Examples of unbilled usages that KEMA found in some cases include street lighting, own building usage, and electric power used for supplying other utilities, such as water and sewage.

Furthermore, financial losses may 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 was able to estimate the aggregate of power station losses, transmission losses and distribution system losses.

2.2 Data Collection

KEMA visited PPL the week of March 12, 2011 for the purpose of on-site data collection. KEMA met with key utility personnel and was able to view selected T&D facilities, but was unable to visit generating stations due to distances and security concerns. PPL provided the following types of data to KEMA for use in this study:

- Technical data for generators, transmission lines and substation transformers
- ETAP power flow model for the electric transmission system
- Rudimentary one-line diagrams of the distribution system

KEMA made a formal request for Port Moresby customer metering information to PPL management on March 15, 2011 including the following types of data:

- How many meters (number), type (mechanical, electronic, prepaid), and by whom were they manufactured?
- What is the customer type (residential, commercial, or industrial)?
- When were they installed?
- What are the maintenance and calibration practices?
- What is the process for reading the meters?
- What is the procedure for identifying billing discrepancies?
- What is the process for detecting tampering?
- What is the percentage of meters in a year that show signs of tampering?
- What percentage of total annual billings does this represent?
- Are there meters in the substation? If yes, what are the types and manufacturers? When were they installed; i.e., how old are they?

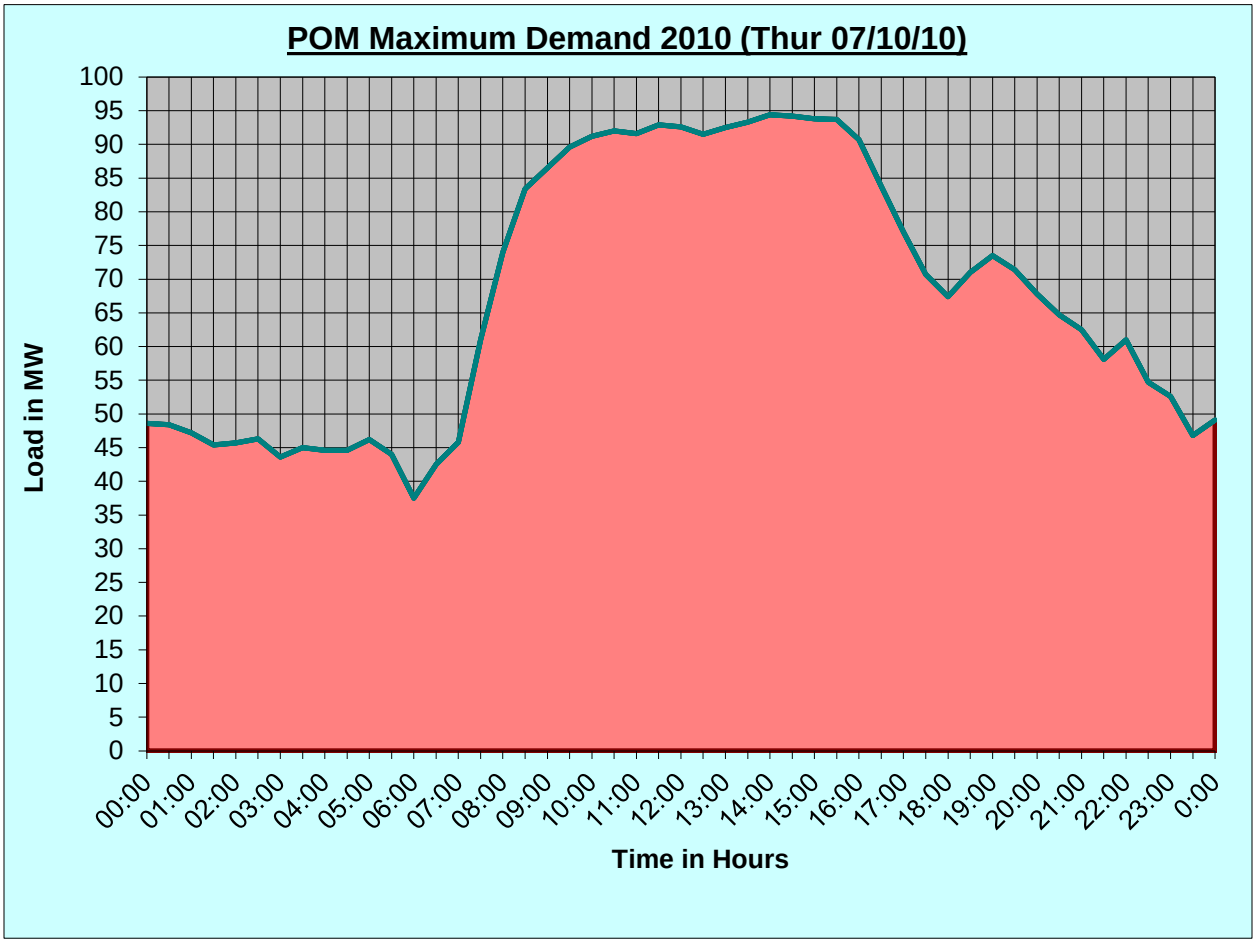
PPL agreed to provide the additional data needed for KEMA to complete the full scope of its analysis subsequent to the on site visit. Although KEMA made a concerted effort to obtain this missing data, including a lengthy follow-up conference call with PPL management in September 2011, much of the requested data has not been received.[1] Likewise, the PPA Secretariat followed up on the request but was similarly unsuccessful. PPL also informed KEMA that the utility was working on a loss reduction strategy and inferred that it had a draft report on this activity, but in spite of repeated requests this information was not provided to KEMA.

2.3 Utility Operations

PPL's Port Moresby system is located on the western end of the island of Papua New Guinea. It is a rapidly developing load area with a 2010 peak demand of approximately 95 MW, a growth rate of about 10 percent per year and annual energy sales of 376,234 MWH in 2010. The Port Moresby (POM) 2010 peak day hourly demand curve is shown in Figure 2.

[1] See Appendix A for the remaining list of data requested at the time of the September 2011 conference call.

Figure 2 - POM Maximum Demand for 2010



This demand data excludes sizeable liquefied natural gas (LNG) facilities located in the Port Moresby area which self-provide 100% of their generation requirements and do not depend on PPL for either supply or backup capacity. Other than the existing hydroelectric facilities, the installed capacity of other categories of renewable resources in the Port Moresby system is negligible at this time.

2.4 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 equipments in support of power generation, also called power plant auxiliary load or power plant own usage.

2) System losses – losses occurred along power transferring through the transmission and 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 occur as a result of electric current passing through the power system equipments. In contrast to technical losses, there are non-technical losses. The cause 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, and wrong multiplying factors.

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 can be:

- Utility's own building usage,
- Electric power used for supplying other utilities such as water and sewage, and
- Other non-reimbursed social usage such as street lighting.

Furthermore, financial losses may be present due to a non-optimized efficiency of individual thermal generating units. Generation efficiency data was not provided to KEMA for the evaluation of the Port Moresby system.

In this study, KEMA estimated technical losses through power equipment in transmission system. Losses in distribution system and the service wires are not estimated due to a lack of information. PPL has a working power flow model in ETAP for Port Moresby system 66kV to 11kV and provided a peak load base case to KEMA. KEMA estimated transmission system losses based on the power flow study results for peak demand. KEMA created an Excel spreadsheet to estimate other losses such as power transformer no-load losses for all transformers provided in the ETAP model. These estimated losses in MW were then converted to MWh energy losses on an annual basis. PPL has not provided any information on usage of its own buildings, street lighting and any other energy consumption for social purposes.

The annual total loss was calculated as the difference between total annual generation and annual energy sold, including the power stations' own usage. Total losses determined in this manner represent the sum of transmission system technical losses, power station losses, technical losses in the distribution system, unbilled energy usage and non-technical losses. KEMA determined total system losses and transmission system technical losses, but was unable to determine the distribution system and generation station loss components due to lack of information.

3. Generation

More than half of PPL's generation capacity in the Port Moresby system is hydroelectric. There are a total of 13 hydro units with a combined capacity of 60.78 MW located at the Rouna Station. In addition, PPL has six diesel units with a total capacity of 55.96 MW at the Moitaka and Kanudi stations. The total generation capacity in the Port Moresby system is approximately 117 MW.

3.1 Equipment

Based on PPL's concerns regarding their system's security, they would not provide KEMA with any photographs of any POM generation facilities.

3.1.1 Generators

An inventory of the Port Moresby generating units and locations is provided in Table 1.

Table 1 - Inventory of POM Generating Units and Locations

Unit(s) Designation	Type	Voltage Rating (kV)	Number of Units	Plant Output (kW)	Unit Power Rating (kW)
Rouna Unit 1-3	Hydro	3.3	3	3,000	1,000
Rouna Unit 4	Hydro	3.3	1	2,500	2,500
Rouna 2	Hydro	11	5	30,000	6,000
Rouna 3	Hydro	11	2	12,000	6,000
Rouna 4	Hydro	11	2	13,280	6,640
Moitaka D1&2	Diesel	11	2	15,700	7,860
Moitaka D2&3	Diesel	11	2	16,260	8,128
Kanudi	Diesel	11	2	24,000	12,000

4. Transmission and Distribution

KEMA observed an assortment of T&D facilities during the on-site visit and found these facilities to be of modern construction and generally good repair.

4.1 Equipment

Examples of the typical Port Moresby (POM) area T&D equipment are shown below.

4.1.1 Transmission Lines

A sample 66kV transmission corridor in the Port Moresby area is shown in Figure 3. As shown, the facilities appear to be in good condition. An under built distribution line also appears to the right of the photo.

Figure 3 - Sample POM 66kV Transmission Spans

4.1.2 Distribution Lines

A sample wood pole structure on the POM 11kV distribution system is shown in Figure 4 and Figure 5. As shown, the structure appears to be in good condition.

Figure 4 - Sample POM 11kV Distribution Line

Figure 5 - Sample POM 11kV Distribution Pole

4.1.3 Transformers

As shown in Figure 6, Figure 7, and Figure 8 the typical condition of the POM substations was modern and appeared to be in generally good condition. However, corrosion was evident on some equipment.

Figure 6 - Sample POM 66 / 11 kV Substation

Figure 7 - Sample 66 kV and 11 kV Dead-end Structures at POM Area Substation

Figure 8 - Sample POM Area Substation Switchgear

4.1.4 Distribution Secondary Wires

Figure 9 - Sample POM Area Service Wire Assembly

4.2 Analysis of Losses

To quantify losses through the PPL transmission system and distribution system the following conditions and assumptions were taken:

1) KEMA quantified losses for PPL's Port Moresby system.

2) The power output over the past year (2010) was used for the annual energy production and consumption.

3) The peak demand of PPL system is identified as total generation in the ETAP power flow case, based on the fact that power plants' own usages are not included in the model.

4) The typical value of no load loss for power transformers as derived from the loss curve[2] is used to calculate core losses of power transformers.

PPL provided a power system model of Port Moresby system in ETAP database along with one-line diagrams. This model includes power plants, station transformers and power transformers as well as the transmission system from 66kV to the 11kV distribution substation. However, it does model the rest of the 11kV distribution. PPL did not provide a power flow model of the 11 kV distribution system. Therefore, KEMA relied on PPL's existing ETAP power flow model.

There is no information provided for the distribution system. Therefore, distribution system losses are not estimated.

In 2010, PPL annual energy production was 484,711 MWh. Annual total energy sold was 376,234 MWh and the generator's peak output was 94.5MW. Total system demand as modeled in the peak power flow case in ETAP was 92.88MW. PPL transmission system's load factor is estimated as 59.6% and loss factor estimated as 40.3%. The peak load power flow analysis provided losses on the transmission system under peak demand conditions. No-load losses for power transformers were estimated separately. Together, these 2 losses become technical losses in MW in transmission system at peak which was subsequently converted into an estimate of the associated MWh energy losses. The quantification approaches for system energy losses are discussed in the following sections.

[2] Areva Power Transformers Handbook (2008)

4.2.1 Transmission System Losses

For the transmission system, technical loss consists of power transformers no load losses and load losses, plus transmission line and cable losses. A power flow study of peak load case provided by PPL calculated losses in MW through the Port Moresby transmission system.

Due to lack of transformer loss data, typical no load loss data is derived from loss curve[3] and used to estimate no load losses for the population of power transformers in the ETAP model. Since power transformers can be purchased with custom loss specification built by cost, estimation based on typical loss data could result in a large margin of difference between the estimated losses and the actual losses. KEMA recommends that PPL to collect No Load Loss and Load Loss data for the power transformers to improve the accuracy of transformer loss estimation. Note that transformer No Load Loss is also referred to as core loss and Load Loss is also known as copper loss. Both names may be used in this KEMA report and in other supporting materials.

With transmission system line losses estimated for peak load in MW, annual energy loss in MWh is calculated by the following formula:

$$Transmission\ line\ and\ cable\ loss\ in\ MWh = LineandCableLossMW * SystemLossFactor * 8760$$

Power transformer energy loss in MWh is estimated by the following fomula:

$$Transformer\ annual\ energy\ loss\ MWh = (NoLoadLossMW + LoadLossMW * LossFactor) * 8760$$

4.2.2 Distribution System Losses

For the distribution system, technical loss consists of primary feeder losses, distribution transformer no load losses and load losses, and secondary wire losses. However, there is no information provided for PPL distribution system. Therefore, distribution system losses are not estimated.

[3] Areva Power Transformers Handbook (2008)

4.3 Findings

The total system losses are the total energy entering into the system out of power plants subtracted by total energy sold and the energy unaccounted for. No information is provided for the power station's own usage. No information is provided for unbilled usage. A summary of estimated losses is provided below in Table 1 and **Table 3**:

Table 2 - Total Loss

2010 data	MWh
Annual Generation Production	484,711
Annual Energy Sold	376,234
Total Energy Losses (including power stations' own usage)	118,533
Total Loss in (%) of Annual Production	24.45%

Table 3 - Transmission System Technical Loss Estimation

	MW	MWh	% of transmission loss	% of total loss	% of total production
Transmission line and cable losses	1.59	5,603	55.6	4.73	1.16
power transformer load losses	0.88	3,120	30.96	2.63	0.64
power transformer no load losses	0.15	1,354	13.43	1.14	0.28
total transformer loss	1.04	4,474	44.40	3.77	0.92
Total transmission system losses	2.63	10,078	100	8.50	2.08

PPL Port Moresby system in 2010 had total losses of 24.5% of annual energy production. The estimated technical loss in the transmission system is 2.08% of total energy generated, which is a low percentage. Transmission system loss accounted for 8.5% of total losses. The rest of the total loss equal to 21.7% of annual energy production consists of the power station's own usage, distribution system losses, non technical losses and unbilled usage. Due to lack of information, losses under each of these categories cannot be estimated.

To improve the loss estimation result, KEMA recommends:

- Continuing meter monitoring and meter calibration to improve the accuracy of historical data for energy demand, consumption and production.
- Create and maintain historical statistics for distribution feeders.
- Create and maintain a power flow model for the distribution system.
- Keep records of all power equipment from manufacturers, including equipment specifications, name plate information and test data.
- Compare the power flow study results with the test data of the power transformers and adjust parameters to improve the accuracy of MW loss calculated. PPL has already put some effort into this area.

5. Non-Technical Losses

Most of the meters on the Port Moresby system are prepayment type meters.

5.1 Sources of Non-technical Losses

Very limited data was available for the typical components of non-technical losses on the distribution system, as outlined in the subsections below.

5.1.1 Metering Issues

Limited information on metering issues was provided to KEMA, except as noted in section 6.1.1.2.

5.1.1.1 Aged Meters

No information was provided.

5.1.1.2 Meter Tampering

PPL management reported that about 4,000 out of 88,000 meters (4.5%) have been flagged for possible tampering. They anticipate that they could find problems with as many as 50% of these 4,000 meters.

At the time of KEMA's on-site visit, PPL advised that all 4,000 of the flagged meters will be inspected for evidence of tampering. No further information was provided to KEMA on this issue. However, based on the above statistics, even if 50% of these suspect meters were found to be tampered with that would amount to only 2.5% of the customer meters in the Port Moresby area. This is a relatively small portion of total customer meters. Therefore, negligible impact on non-technical losses would be expected from tampering activities.

5.1.1.3 Meter Bypassing

No information was provided.

5.1.1.4 Inaccurate Meter Reading

No information was provided.

5.1.2 Billing Losses

No information was provided.

5.1.3 Billing Collection Losses

No information was provided.

5.1.4 Loss through Theft

Except for the metering tampering situation discussed in section 6.1.1.2, no other information was provided.

5.1.5 Administrative Failures

No information was provided.

5.1.6 Line Throw-ups

No information was provided.

6. Findings and Recommendations

To improve loss estimation results for the Port Moresby system, KEMA recommends:

- Continuing meter monitoring and meter calibration to improve the accuracy of historical data for energy demand, consumption and production.
- Create and maintain historical statistics for distribution feeders.
- Create and maintain a power flow model for the distribution system.
- Keep records of all power equipment from manufacturers, including equipment specifications, nameplate information and test data, along with any loss reports.
- Compare the power flow study results with the test data of the power transformers and adjust parameters to improve the accuracy of calculated transformer losses. KEMA understands that PPL has already put some effort into this area.

7. Suggested Equipment Replacement

During KEMA's site visits to the Port Moresby system we observed various transmission and distribution equipment. This equipment appeared to be in generally good condition with minimal rust or other signs of aging.

The results of loss analysis for the transmission system showed this component of losses is quite low. As a result, there is no apparent need for any transmission equipment based on loss reduction needs.

Due to the limited amount of technical data provided for generation, distribution and metering equipment, KEMA is unable to determine the condition of this equipment or assess whether there would be sufficient loss reduction to recommend replacement of any of the associated equipment.

Appendix A – Original Data Request

The original data request prepared by KEMA was transmitted to PPA on January 25, 2011.

See attached *KEMA data request.pdf*

Appendix B – Distribution System Data Sample

To mitigate possible confusion in aggregating the data KEMA deemed necessary to conduct the requested study of the distribution system, a data table template was provided. KEMA did not receive this data for the POM system.

See attached *Distribution system data sample.xlsx*

Appendix C – Memo of September 14, 2011 Conference Call

A conference call occurred on September 14, 2011 between participants from both KEMA and PNG Power. The purpose of this call was to discuss the data needed to support the project – Quantification of Power System Energy Losses in Southern Pacific Utilities. The appended memo summarizes this conversation and was transmitted to all participants on September 14, 2011.

See attached *Meeting memo 9-14-2011.pdf*

Appendix C – Loss Worksheet

See attached *PPL loss worksheet.xlsx*