Quantification of the Power System Energy Losses in South Pacific Utilities

Public Utilities Board, Kiribati – Tarawa Atoll System

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Prepared by KEMA International B.V.

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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 Public Utilities Board (PUB) on the island of Tarawa Atoll in the Republic of Kiribati.

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 in the Tarawa Atoll system consist of power station losses and distribution system losses. Both loss categories are quantified.

- Station Losses: power plant auxiliary loads.
- 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, 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 a non-technical loss.

1.2 PUB's System Energy Losses

KEMA's analysis of the PUB power system determined that total losses are 20.63% of annual generation, which is relatively high. These losses consist of:

- 4.81% in power station auxiliaries (station losses).
- 5.90% in technical losses.
- 5.23% in non-technical losses.
- 1.93% in PUB own building usage.
- 2.76% in unbilled water and sewer pump usage.

Unbilled usage of the Tarawa Atoll power system includes the PUB's own building as well as pumps for the public water and sewer systems. To KEMA's understanding, these usage data were estimated and not metered. Although such unbilled usage might not be viewed as a system "loss" in the classical sense, it still represents a financial loss for PUB because the unbilled usage represents power delivered for services that are not paid for. In particular, the cost of power usage for water and sewer pumps could be allocated and billed to the water and sewerage company.

1.2.1 Generation Losses

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 data provided. As previously mentioned, this values was estimated as 4.81%.

1.2.2 Distribution Losses

The Tarawa Atoll system is not a radial system in a traditional sense. There are two power stations: Betio Power Station on the west side of the atoll and Bikenibeu Power Station south of the airport. Due to the routine generator maintenance schedule, when Unit DEG1 at Betio Power Station is off line for maintenance, power is supplied from the Bikenibeu power station only. Therefore, KEMA prepared 2 power flow cases. The first one represents dispatch of a single power station and the second case represents dispatch of both power stations. The estimated primary feeder losses were then subsequently based on the kW losses from these two power flow scenarios.

The Tarawa Atoll power system is comprised entirely of underground conductors connecting Ring Main Units (RMU) that serve the distribution transformer loads. The primary system losses were estimated from the power flow study and metering data that was combined with calculations in Excel spreadsheets for transformer losses and LV system losses.

1.2.3 Non-technical Losses

The non-technical losses at PUB are 5.23%, which is slightly high. KEMA's experience indicates that a reasonable value should be below 4 percent for a system such as PUB. Activities such as electricity theft, meter tampering, and meter by-passing may be contributing to the level of non-technical losses on Tarawa Atoll.

Therefore, an analysis of non-technical losses is an opportunity for loss improvement on Tarawa Atoll. KEMA offers suggestions in this regard described in the following sections.

1.2.3.1 Metering Issue Losses

KEMA found no significant metering issues or irregularities, but does not have good data on the condition of the meter population.

1.2.3.2 Other Losses

PUB is not aware of any billing losses. Billing collection losses are not considered system losses. As non-technical losses are slightly high, theft could be a greater issue than currently recognized by PUB.

1.3 Recommendations

1.3.1 Generation Losses

The loss component due to power station usage (4.81%) is in the normal range but there may still be options for improvement. An energy efficiency audit could reveal possibilities for energy savings.

1.3.2 Distribution Losses

The Tarawa Atoll distribution system is comprised entirely of 11 kV underground copper conductors. The older underground cables are 16 mm^2 paper-insulated lead sheathed cables with copper conductors. Recent upgrades to the 11kV distribution system have included:

- 95 mm^2 XLPE 3-conductor Cu cable between Bikenibeu Power Station and RMU-17
- 50 mm^2 XLPE 3-conductor Cu cable between Bikenibeu Power Station and RMU-31
- 25 mm^2 XLPE 3-conductor Cu cable between RMU-43 and RMU-44

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.

1.3.3 Non-technical

PUB's non-technical losses of 5.23% are slightly high.

1.3.3.1 Metering

KEMA recommends additional metering points and better identification of non-technical losses. A program focused on discovering theft, meter tampering, and other causes of non-technical losses should be implemented. Since PUB does not have a meter test facility, this work could be contracted to an experienced provider of this type of service. See section 6, Findings and Recommendations for more details.

1.3.3.2 Other Losses

As non-technical losses are slightly high, theft could be a greater issue than currently recognized by PUB.

Adding metering to the water and sewer system pumps (although not billed) would provide PUB with useful information on the energy costs for these pumps, which would also enable PUB to determine if it should seek to recover these costs by billing them to the water and sewerage company.

1.4 Prioritized list of equipment for replacement

As part of the study scope KEMA also observed certain equipment replacement needs and analyzed generation efficiency and supply side reliability. Based on KEMA's review of the PUB electric system, the following list of equipment is recommended for replacement:

1. Generators. Four of the eight diesel units owned by PUB were not operable at the time of KEMA's site visit. The current PUB electric system does not meet n-1 reliability criteria. PUB should consider retiring the inoperable units, implementation of a rigorous maintenance program for the rest of its fleet of generators, and installing 1-2 new diesel generators. If properly specified, this would dramatically improve PUB's reliability and overall fuel efficiency and result in net economic savings.

2. Metering. Old meters should be tested at regular intervals and replaced when found to be inaccurate. Meters should also be added at key locations to provide a better determination of losses. Additional metering should be added to enhance loss and theft detection and 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 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 Tarawa Atoll for data collection and technical assessments of the PUB power system, KEMA sent data request documents on February 23, 2011 regarding information 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 and to ensure the accuracy of the study results.

Subsequently KEMA visited Tarawa Atoll during the week beginning February 27th, 2011 to collect data, interview key PUB personnel, and assess the power system.

During the visit much relevant data was gathered and PUB personnel were very helpful and provided information regarding billing, generation, and loss statistics. Plant generator schedules, equipment nameplate information and other relevant data were all readily accessible.

After the on-site visit some clarifications were requested by e-mail and additional generation, load, and loss information was promptly received.

2.2 Utility Operations

The PUB system reached an all-time maximum peak demand of 5,250 kW during July, 2006. The power system consists of:

- Betio power station and Bikenibeu power station together house eight (8) diesel generators. Data for these units is in the Data Handbook. The generator capabilities are summarized as follows:

Unit Designation	Power Rating (kW)	Location
No. 1 *	600 kW	Bikenibeu Power Station
No. 2 *	600 kW	Bikenibeu Power Station
No. 3	1,400 kW	Bikenibeu Power Station
No. 4	1,400 kW	Bikenibeu Power Station
No. 5	1,400 kW	Bikenibeu Power Station
No. 6 *	750 kW	Betio Power Station
No. 7 *	750 kW	Betio Power Station
No. 8	1,000 kW	Betio Power Station
Total	**5,200 kW**	**available for service**

NOTE: * These units were not operable at the time of KEMA's visit.

- An 11kV distribution system comprised of two feeders that exit Bikenibeu Power Station and two feeders that exit Betio Power Station. Feeder-2 from Bikenibeu Power Station connects with the two feeders from Betio at RMU-13B. Feeder-1 from Bikenibeu Power Station serves the airport and vicinity.

- 8,337 customers.

Although the PUB system load peaked at 5,250 kW in 2006, the load has since declined to a peak demand of about 4,490 kW in 2010.

With a peak load of 4,490 kW and 5,200 kW of available generation, the PUB system has an installed resource reserve margin of 15.8%. At the time of KEMA's visit, with 4 older generating units inoperable, the system could not meet an n-1 reliability criterion (e.g., serve peak load with the loss of the largest available unit). However, if at least one of the units that were unavailable for service during KEMA's visit were returned to service (or replaced), then the criterion would be met.

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

2. System losses – losses occurring along power transferring through the transmission and distribution systems, such as transformers, over-head line conductors, areal cables or underground cables, as well as service wires, which are all technical losses and non-technical losses.

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

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

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 generation efficiency, power station losses and distribution system losses. Where information was not sufficient, assumptions were made to facilitate the estimation. KEMA created Power flow models in EasyPower® to represent the PUB power system in Tarawa Atoll. Power flow studies were performed for peak load condition. Losses including primary feeder losses and power transformer copper losses were estimated based on the results from power flow studies. Excel spreadsheets were created to estimate kW losses that are not calculated in the power flow study, such as voltage regulator core loss, losses of distribution transformers, and service wires. These kW losses were converted to kWh energy losses on annual basis by utilizing the estimated Loss Factor. Unbilled usage was estimated for all the causes identified.

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

3. Generation

At the time of KEMA's visit to Tarawa Atoll, Betio and Bikenibeu Power Stations together housed a total of eight (8) diesel generators. Four of these units were unavailable for service at the time of KEMA's visit, leaving PUB with only four units available and a total generation capacity of 5,200 kW.

Betio Power Station has one Nishishiba generator coupled with a Daihatsu diesel engine available for service. The other two machines at Betio Power Station were out of service.

Bikenibeu Power Station has three Nishishiba generators coupled with Daihatsu diesel engines available for service. The other two units at Bikenibeu Power Station were out of service.

3.1 Equipment

Generation equipment specifications are listed in the PUB Data Handbook. The following pictures illustrate the condition of units during the time of KEMA's visit.

<u>Major characteristics of the generating units</u>

Unit 1: 750 kVA, 600 kW
0.415 kV, 50 Hz, 750 RPM LOCATION: Bikenibeu
This unit and unit 2 were out of service during the time of KEMA's visit.

Unit 5: Daihatsu diesel generator
1,750 kVA, 1,400 kW
11 kV, 50 Hz, 750 RPM LOCATION: Bikenibeu

Unit 7: Unknown specifications LOCATION: Betio
This unit and unit 6 were out of service at the time of KEMA's visit.

Unit 8: Daihatsu diesel generator
1,250 kVA, 1,000 kW
11 kV, 50 Hz, 750 RPM LOCATION: Betio

The data for the power transformers that feed the PUB distribution system are given in the PUB Data Handbook. There are three power transformers on the PUB system. T-1 (300 kVA) provides station service to Bikenibeu Power Station from bus PS-2. T-2 (200 kVA) provides station service to Betio Power Station from RMU-2. T-51 connects the Bikenibeu power house to bus PS-2 through RMU-51. The PUB power transformers are listed below.

Description	kVA Rating	Location	Voltage Rating
T-1 (Station Service)	11 kV – 415 V	Bikenibeu	300 kVA
T-2	11 kV – 415 V	Betio	200 kVA
T-51	11 kV – 415 V	Bikenibeu	1,250 kVA

3.2 Analysis of Losses

Generation losses are defined as the generation efficiency losses and station losses (own usage).

Fuel Efficiency

Fuel usage statistics for December, 2010 were provided to KEMA and used to determine efficiency of the generators that were in operation during that time, as summarized below:

Diesel Engine Generator	Diesel Fuel (Liters)	kWh	kWh/Liter
Unit 3	90,800	319,470	3.52
Unit 4	139,120	528,930	3.80
Unit 5	110,560	385,700	3.49
Unit 8	135,110	505,090	3.74
Total	**475,590**	**1,739,190**	**3.65**

Well-maintained and properly dispatched diesel engine fuel efficiency should average 4 kWh per Liter. These fuel efficiency figures indicate that there are possibilities for improvement in PUB generator dispatch and engine maintenance programs.

Station Losses

As already mentioned, the station losses were estimated as 4.81%. Station losses are the difference between total energy produced by the generating units and total energy entering into the distribution system. This value for station losses is in the normal range, but options for reducing these losses should be investigated.

3.3 Findings

A comprehensive program to record generator and feeder log sheets, fuel usage, generator outputs, and maintenance practices is useful for evaluating generator fuel efficiency and identifying needed improvements to generator performance and reliability. KEMA recommends further investigation into fuel usage of the engines in operation to improve generation efficiency.

4. Distribution

During KEMA's site visit to Tarawa Atoll in the Republic of Kiribati, PUB provided a one-line diagram of the PUB distribution system. This one-line diagram included parameters which were used in the EasyPower model such as conductor types, line section lengths, distribution transformer locations, and connected kVA. KEMA used this data to prepare the EasyPower model which was then used to evaluate system losses.

PUB also provided total generation and sales figures for the PUB system for 2010 which were also used in the evaluation of system losses.

The distribution system consists of all underground conductors placed in PVC conduits serving Ring Main Units (RMU). The getaway cables for the two feeders exiting Bikenibeu power station are 50 mm^2 Cu XLPE and 95 mm^2 Cu XLPE. The getaway cables for the two feeders exiting Betio power station are 25 mm^2 Cu PILC, one of which was labeled on the one-line diagram as faulty. Therefore, this line section (to RMU-6) was modeled as open in EasyPower.

There is a 3,000 kVA voltage regulator on the feeder between Betio and Bikenibeu power stations. This feeder and the two feeders leaving Betio power station have a common interconnection point at RMU-13B. KEMA assumed that all switches were closed.

The one line diagram of the EASY POWER model is provided in the following figures. Larger versions of these diagrams, along with an Excel spreadsheet file of the loss calculations, are included with the data handbook in Appendix A.

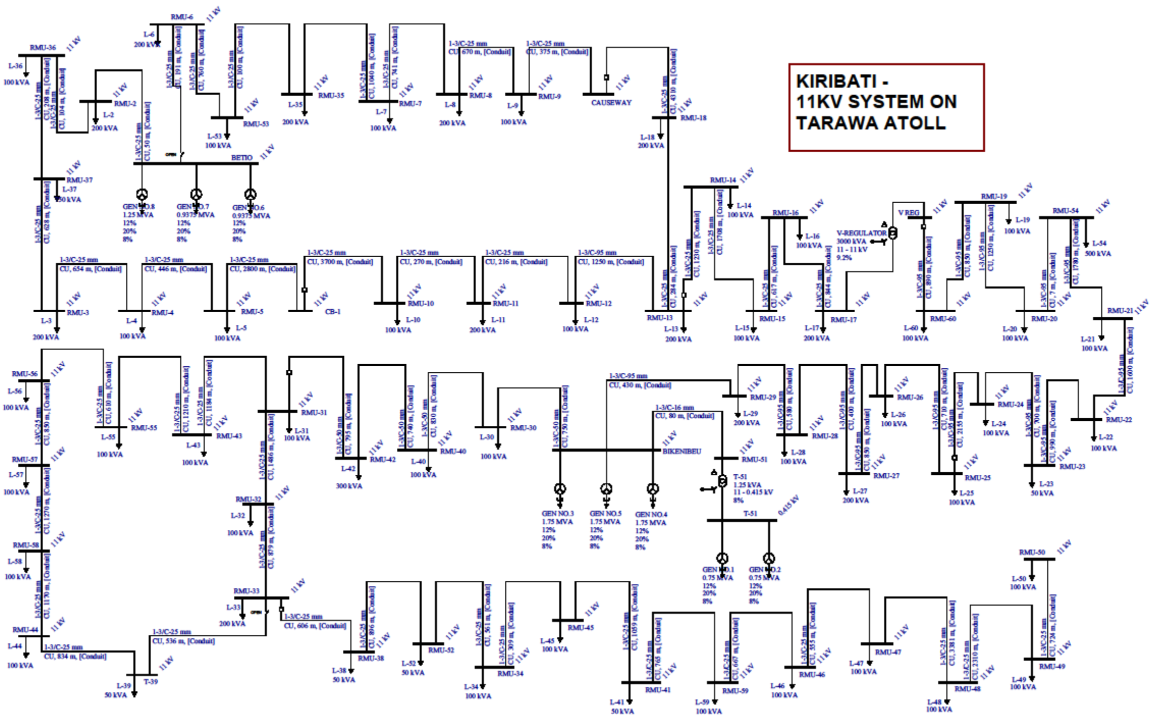


Figure 4.1 – PUB 11kV System One-Line Diagram From EasyPower

The following PUB power system statistics are relevant to the loss study:

- There are 58 distribution transformers with total installed capacity of 8,000 kVA.
- The PUB system peak load on Tarawa Atoll is 4,490 kW.
- There are 8,337 customers on Tarawa Atoll.
- The PUB distribution system contains no switched reactors or shunt capacitors.

PUB provided KEMA with monthly data for gross energy generated and the energy billed on Tarawa Atoll for 2009 and 2010. These are shown graphically in Figure 4.1 below.

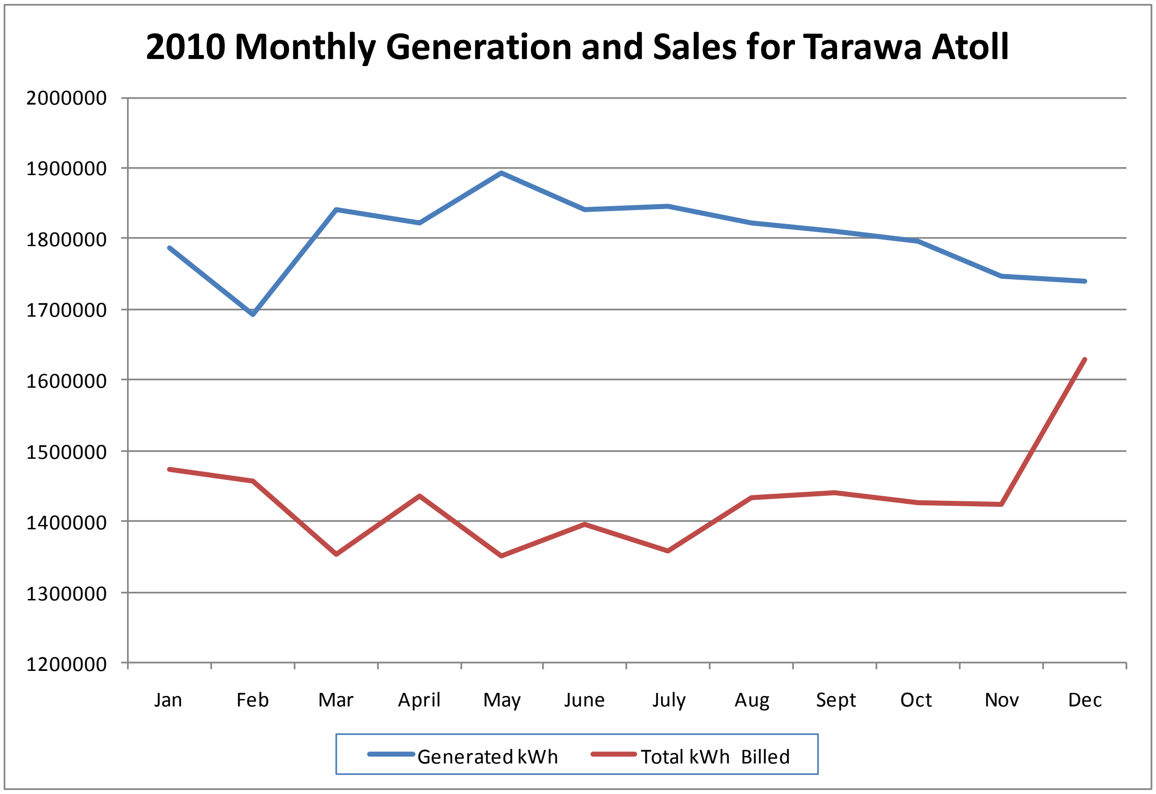


Figure 4.1 – Monthly Energy Generated and Billed (kWh)

The difference between energy billed and energy generated represents the total of all station losses and distribution system losses on Tarawa Atoll.

4.1 Equipment

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

4.1.1 Distribution System

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

- Feeder-1 exits the Bikenibeu power station through a three-core 50 mm^2 Cu XLPE underground outgoing feeder cable with full concentric neutral.

- Feeder-2 exits the Bikenibeu power station via three-phase 95 mm^2 Cu XLPE underground cable with full concentric neutral that connects to the 3,000 kVA voltage regulator at RMU-17.

- PS-1 connects with PS-2 through RMU-51 within Bikenibeu Power Station via 16 mm^2 PILC cable.

- Feeder-BE (Betio East) exits the Betio Power Station through a three-core 16 mm^2 Paper-Insulated Lead Copper (PILC) underground cable to RMU-6. This conductor was listed as faulty on the one line diagram provided by PUB and was assumed open.

- Feeder-BW (Betio West) exits the Betio Power Station through a three-core 16 mm^2 XLPE underground outgoing feeder cable with full concentric neutral and has a common point of interconnection with Feeder-2 and Feeder-BE at RMU-13B.

- PUB has 58 three-phase distribution transformers installed along the 11 kV distribution feeders with a total capacity of 8,000 kVA.

4.1.2 LV Wires

The secondary system consists of wires connecting from the low voltage (LV) side of distribution transformers to the customer meter. Since no information in regards to the secondary system was provided, KEMA made assumptions about typical secondary wire configurations in order to estimate the secondary wire losses.

4.2 Analysis of Losses

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

1. The total energy generated and energy sold over the past one year (01/2010-12/2010) was used for the study.

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

3. Loads were allocated proportionally to the kVA capacity of each distribution transformer.

4. Actual voltage drops through primary feeders were calculated in a power flow study with a model in Easy Power. However, voltage drops through feeders were not considered in loss estimations for distribution transformers and secondary services wires.

5. A typical value of power transformer no-load losses from literature[1] was used to estimate voltage regulator core losses.

6. Secondary wire losses were estimated based on average customer consumption for all customers combined.

7. Typical secondary service wire type, size and configuration were assumed, no information was provided.

PUB has provided a one-line diagram of its power system in Tarawa Atoll. Feeder segment distance, conductor type and size, and kVA capacity of distribution transformers are identified on the one-line diagram. Some of the equipment data as well as energy production, consumption and customer sales statistics are also provided in an excel spreadsheet. KEMA developed a power flow model in Easy Power for the power system at Tarawa Atoll based on the one-line diagram and estimated losses based on all information received. In this distribution system model, two power plants and the 11kV distribution system are modeled. Distribution transformers are represented as spot loads with a constant kVA load equal to transformer capacity and load power factor of 0.9. Easy Power provides a feature to scale load into a specific value when power flow is performed.

Specific discussions about the PUB power flow model:

1. Normally Open switches are not identified on the one-line diagram. In the EasyPower model, two open switches were assumed to be located between Betio power plant and RMU-6, as well as between RMU-33 and T39 Bonriki pump station. As a result, all 11 kV distribution feeders are operated as radial feeders except the interconnection between Betio Power Station and Bikenibeu Power Station through the voltage regulator.

[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. Power flow through feeders, especially power flow through the path between the two power stations is affected by the operation and maintenance schedule of generators. According to PUB's maintenance schedule, at any given time, one of the four generators is standby or under weekly service. Since DEG1 is the only working generator at Betio power station, operating with or without power output from it makes big difference in power flow distribution. Power flow study results for both cases are shown in the summary below:

Table 4-1: Power Flow Summary

Case	With DEG1	Without DEG1
Assumed % of total operating hours in each mode per year	75%	25%
power flow through V Regulator kVA	1647	2370
Voltage Regulator load %	55%	79%
feeder and Voltage Regulator load loss kW*	207.6	362.3
Voltage Regulator load loss kW	6.7	13.9

*Power flow only calculates load loss for transformers.

To estimate annual system losses, peak kW losses were calculated for both cases and then adjusted according to percentage of time operated.

3. According to the one-line diagram, underground line sections from RMU-17 to RMU-13B are comprised of 16 mm^2 Cu three-phase cable. However, this cable rating is not sufficient to carry the power flow to the load area close to Betio Power Station when there is no output from DEG1. It was therefore assumed that this portion of feeder has been upgraded to 95mm^2 Cu three-phase cable.[2] This is the same size cable as Feeder-2 from the Power Station to RMU-17. With this modification, the power flow can be solved with no current or voltage violation.

Losses in kW through the primary feeders and voltage regulating transformers were calculated in a power flow study at the system peak demand. System load is allocated proportionally to the distribution transformer capacities connected to each feeder. KEMA studied power flow with the 4,490 kW peak load condition for 2010 by applying a system Utilization Factor of 62.36% to all loads with a total connected capacity of 8,000 kVA.

[2] This status of this cable replacement should be reviewed by PUB.

For PUB's power system on Tarawa Atoll, electric power is supplied from two generation plants. In 2010, annual generation production was 21,641,320 kWh and the 5% of annual generation production that was used by the power station's own need measured 1,040,917 kWh. Energy sent out to the distribution system after power plant's own usage was measured as 20,600,403 kWh. In 2010, system peak demand was 4,490 kW. Tarawa system load factor was estimated as 55% and loss factor was estimated as 35%. The technical losses in kW were converted into kWh energy losses and the results are presented in the next section.

Distribution transformer losses were estimated with typical loss data. Secondary wire losses were estimated with typical configuration and average customer consumption for all customers. The secondary system consists of wires connecting from the low voltage (LV) side of distribution transformers to the customer meter. Since no information in regards to the secondary system was provided, KEMA took assumption of typical secondary wire configuration to estimate secondary losses. Assuming the typical secondary system was in tree structure, with the three-phase LV cable as the Secondary Line (SL) and single-phase wires as Service Drops (SD) tapping along the Secondary Line in equal distance and extending to each customer meter. All customers were considered and assumed to be mixed along the SL.

- Service Line (SL) is also referred to as a LV feeder or secondary feeder (in contrast to the 11kV feeder as a primary feeder). Service Line connects from LV side of the distribution transformer with service drops tapping along it. Assuming in average, there are 2 SL per distribution transformer with average length of 800 meter per SL. Typical SL cable is assumed as 16mm^2 Cu three-phase cable. PUB should collect data for the actual SL type and size to develop typical based on that.

- Service Drops (SD) tapped from the service line (SL) extend to the customer meter. A typical SD was assumed as single-phase 16mm^2 Aluminum cable with an average length of 100 meters for loss estimation. PUB should collect data for the actual SL type and size to develop a typical SD based on that.

- Average number of customer per Service Line and average customer kW consumption were calculated for loss estimation.

4.3 Findings

The total system losses are equal to the total energy entered into the distribution system out of power stations minus total energy sold and energy unaccounted for. For PUB the unbilled energy usage came from PUB's own usage and energy used for water and sewage pumps.

The PUB office usages were metered and recorded. Water and sewage usage were estimated. A summary of estimated losses is provided in Exhibit below.

Table 4-2: Loss Estimation

	kWh	% of generation	% of system consumption
annual generation	21,641,320	-	-
annual station auxiliary	1,040,917	4.81%	-
annual system consumption	20,600,403	95.19%	-
annual energy sold	17,176,916	79.37%	83.38%
system loss including unbilled usage	3,423,487	15.82%	16.62%
PUB own building usage	417,868	1.93%	2.03%
water and sewer pump usage	597,432	2.76%	2.90%
technical loss	1,275,925	5.90%	6.19%
non-technical loss	1,132,261	5.23%	5.50%

PUB system technical losses were estimated as 5.9% of annual energy production, non-technical losses as estimated 5.23% of annual generation.

To improve the loss estimation, KEMA recommends continuing meter monitoring and meter calibration, as well as maintaining historical data. KEMA also recommends keeping record of all power equipment from manufacture including equipment specifications, name plate information and test data.

5. Non-Technical Losses

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

As summarized under Section 4.3, the non-technical losses appear to be slightly high (5.23%). This value of non-technical losses does not include the metered power usage by PUB's own building or estimated usage for water and sewer pumps. Unbilled usage is separated from the system losses and considered to be a financial loss for PUB.

Adding metering for water and sewage pump usage would provide PUB with financial information for future decision-making and cost recovery methods.

Since non-technical losses were found to be above average, electricity theft, meter tampering, and meter by-passing are potential issues that may need to be investigated on Tarawa Atoll.

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

Methodologies should 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 (CTs) mounted 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.

5.1 Sources of Non-technical Losses

5.1.1 Metering Issue Losses

KEMA noticed no irregularities as far as metering issues. The generation data provided by PUB clearly covered the same time period as the monthly meter reading data so that show energy generated in a full month matches with the energy sold. This significantly improves the accuracy of the loss calculation.

5.1.1.1 Aged Meters

KEMA does not have good data on the condition of the meter population. A program of periodic meter testing and replacement of inaccurate meters is recommended for the PUB system. Since PUB 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

PUB did not report instances of tampered or by-passed meters, yet non-technical losses are slightly high. Therefore, energy theft may be more of a problem than PUB 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 reading will lead to irregular monthly figures for power usage. PUB 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

PUB 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 PUB hardly identifies any loss through theft, yet non-technical losses are slightly high. PUB 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 PUB system.

5.1.6 Line Throw-ups

No line throw-ups were identified during KEMA's visit. PUB's feeders are entirely underground and therefore line throw-ups are not really feasible.

5.2 Analysis of Losses

When analyzing non-technical losses it can be noticed that the loss calculations show a slightly high percentage of non-technical losses (5.23%).

Non-technical losses can 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 Findings and Related Observations

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

- Non-technical losses are slightly high (5.23%)
- The meter population may be old and a program of replacement of old or inaccurate meters should be considered.

- The presence of theft, meter tampering, and meter by-passing cannot be documented with the data that PUB was able to provide. However, since non-technical losses are somewhat high for the PUB 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 a significant cause of inaccuracies in the account billing process.

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

6. Findings and Recommendations

This chapter provides a compilation of findings and recommendations for the PUB system.

6.1 Generation

From the data provided, the fuel efficiency for Betio and Bikenibeu Power Stations averaged 3.65 kWh/liter in December 2010. This is a bit low and it may be possible to improve it by changing the way the units are dispatched and by keeping the units in optimal operating condition. KEMA recommends that PUB consider looking at opportunities for improving its economics of generation dispatch.

The power station own usage for PUB was provided 4.81% of production, which is a reasonable figure. A good figure for auxiliary consumption is typically below 5%, and this figure is below that threshold. Therefore, KEMA has no recommendations in regards to power station usage, other than to say that coolers and other auxiliary loads that comprise power station usage should be well-maintained according to manufacturer recommendations. Furthermore it is recommended to conduct an energy audit in order to identify possible efficiency improvements.

At the time of KEMA's visit to Tarawa Atoll, there were several generating units that were out of service and obviously not being maintained. Given this situation, the PUB has just enough generating capacity with its currently available units to meet its peak demand, which means that it can't meet an n-1 resource contingency criteria (generally considered the minimum acceptable standard for reliability). Therefore, KEMA recommends that PUB install at least one new 1200 kW diesel generator as soon as possible in order to improve peak load dispatch capability and system reliability, as well as improve generator efficiency.

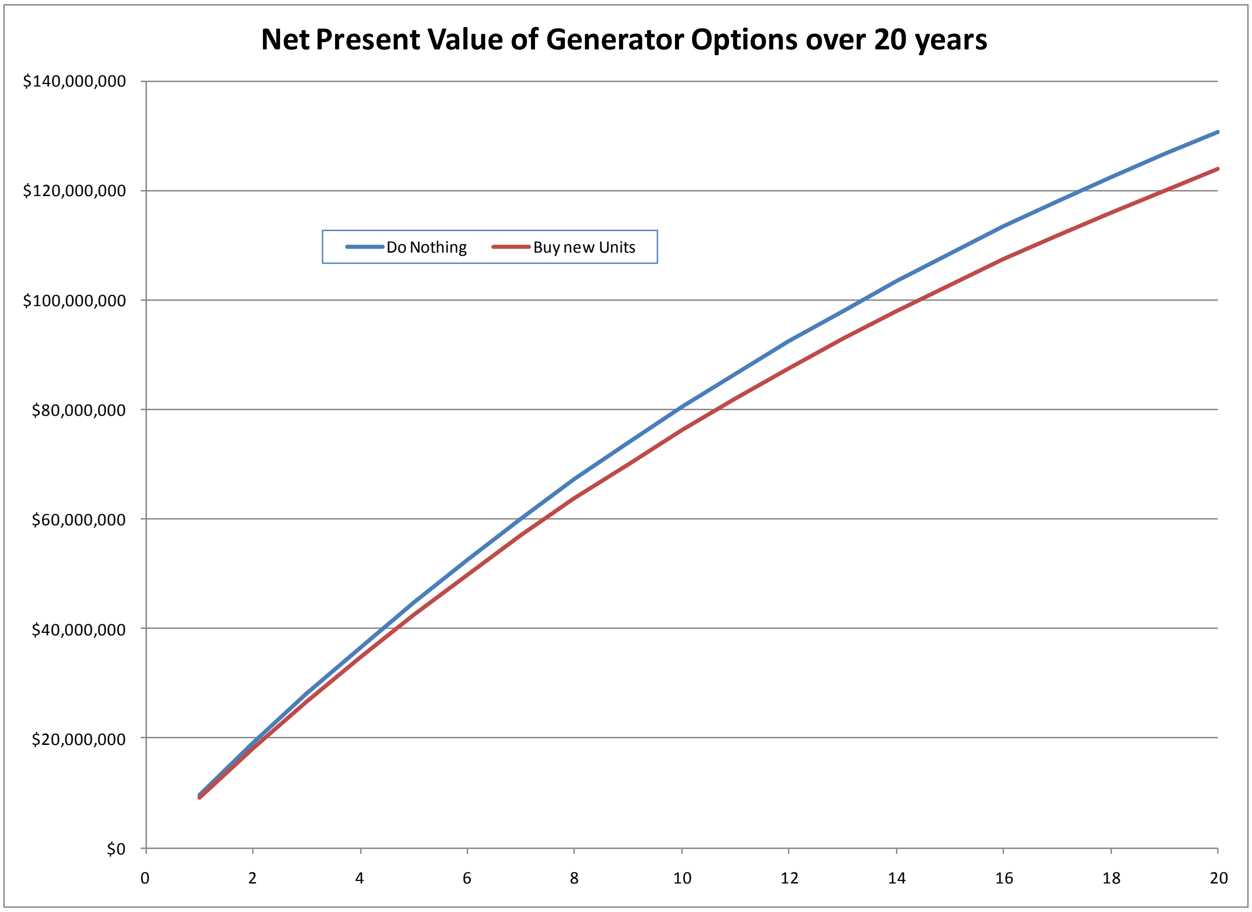
Furthermore, as shown below, it appears that installing two new generating units would be justified based on the economic benefits as a result of improved fuel efficiency. The Net Present Value (NPV) to install two new, 1200 kW, high-efficiency diesel generating units was compared to the NPV with the existing generator fleet and efficiency levels. The calculation indicates that purchasing two new 1200 kW diesels would yield a net savings to PUB of nearly $7 million over 20 years because of improvements in generator efficiency. The results of this calculation are shown in the table below and graphically in Figure 6.1.

PUB Diesel Generator Costs
Install two new 1200 kW diesel generators

Economic Inputs		
Inflation	**3.00%**	(percent)
Cost of Capital	**8.00%**	(percent)
Financial Life	**20**	(years)

Installed Cost for 2 new diesel generators			**Cost of Doing Nothing**		
Unit Cost	$1,400	per kW	Unit Cost	$0	per kW
	$1,680,000	per machine		$0	per machine
No. of units	2		No. of units	0	
Total Cost	$3,360,000		Total Cost	$0	
NPV of Capital Cost		**$4,308,512**	**NPV of Capital Cost**		**$0**
Additional Generator Maintenance			**Additional Generator Maintenance**		
Annual Cost	$12,000	per machine	Annual Cost	$12,000	per machine
No. of units	2		No. of units	0	
Total Cost	$24,000	per year	Total Cost	$0	per year
NPV of generator maintenance		**$302,154**	**NPV of generator maintenance**		**$0**
Fuel Cost			**Fuel Cost**		
Fuel Efficiency	4.00	kWh/liter	Fuel Efficiency	3.65	kWh/liter
Production	21,641,320	kWh/year	Production	21,641,320	kWh/year
Fuel Usage	5,410,330	liters/year	Fuel Usage	5,929,129	liters/year
Cost of Fuel	$1.75	per liter	Cost of Fuel	$1.75	per liter
Total Cost	$9,468,078	per year	Total Cost	$10,375,975	per year
NPV of Fuel expenditures		**$119,200,870**	**NPV of Fuel expenditures**		**$130,631,090**
Total NPV of 2 new Generators		**$123,811,537**	**Total NPV of doing nothing**		**$130,631,090**

The cumulative NPV for each plan is shown graphically by year below. This graph shows that the savings to PUB would begin immediately assuming financing can be obtained.



6.2 Distribution

The technical losses on the PUB distribution system are 5.9%, which is slightly high. A good figure is typically less than 5%.

Technical losses include primary line losses, distribution transformer losses, LV secondary wire losses, and other non-conventional sources such as bad connectors and hot spots. Therefore KEMA recommends that PUB perform infrared inspection of key connections and facilities throughout its system to determine if such hot spots do indeed exist. These inspections will help determine locations of bad connectors that need replacement.

With a system utilization factor of 62.36%, which was calculated for the power flow study, the PUB distribution transformers may be slightly oversized for the loads served. This means higher distribution transformer losses in the form of no-load losses. A system utilization factor of 75% or higher is desirable from a system utilization standpoint to maximize efficiency and minimize losses. KEMA recommends that PUB purchase transformers that more closely match the projected loads to be served.

The power flow study assumed a power factor of 90%. Since no power factor data was provided, this seems to be a reasonable figure to use. However, if the loads on the PUB system have a power factor lower than 0.9, distribution system losses will be much higher than if power factors were maintained near unity. Since there are no capacitor banks on the Tarawa Atoll system, power factor and voltage drop must not be a problem.

KEMA recommends that a distribution transformer and load power factor study be done for the system on Tarawa Atoll. This will help to determine individual transformer loading and power factor correction requirements, which will help to improve technical losses on the PUB distribution system.

6.3 Non-Technical Losses

The non-technical losses on the PUB distribution system are 5.23%, which is slightly above average. A good value for non-technical losses would be below 5%. Additional measures as discussed in Section 5.3 should be considered.

7. Suggested Equipment Replacement

During KEMA's site visits to Tarawa Atoll, the PUB system generation and distribution equipment was reviewed. KEMA gathered data to complete the loss analysis and develop a list of PUB equipment, including condition. Upon completion of the loss analysis, we compiled a prioritized list of equipment needed to achieve greater energy savings for the PUB system.

The result of this effort indicates that the most urgently needed equipment for PUB is procurement of at least one, and possibly two, new 1200 kW diesel generator(s). Four of the eight units owned by PUB were out of service during the time of KEMA's visit and current generation capacity does not meet an n-1 availability criterion (i.e., the requirement that peak system load must still be served if the largest generating unit is forced out of service). Furthermore, installing two new, high-efficiency diesel units rated 1200 kW (1500 kVA) each would yield a net present value (NPV) savings as presented in section 6.1 and would provide enough generating capacity to serve a 4.8 MW peak load even under an n-2 outage condition, thus improving system reliability.

A. Data Handbook

See attached PUB data handbook.docx

B. Loss Worksheet

See attached PUB loss worksheet.xls

C. Easy Power Model

See attached PUB system.dez