KEMA

Quantification of the Power System Energy Losses in South Pacific Utilities

Tonga Power Limited, Tonga

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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 Tonga Power Limited (TPL). TPL serves several islands, but this report, data handbook, and power system model focus on the main island of the Tongatapu.

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 EasyPower®, 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.

1.1 TPL System Energy Losses

KEMA's analysis of the TPL power system determined that total losses are estimated at 14.54% of annual generation, which is fairly high. These losses consist of:

- 3.82% in technical losses, which is a relatively low value.
- 9.72% in non-technical losses, which is a fairly high value.
- 1.00% in unbilled usage, which is a fairly low value.

In addition to these losses, the power station auxiliary losses (station's own use) were estimated to be 2.96% of total production, which is relatively low.

The total system losses are equal to the total energy entering into the distribution system out of the power station(s) minus the total energy sold and the energy unaccounted for. TPL made

KEMA aware that their total system loss “target” (see Figure 12) is 13%. This is a commendable target and TPL should continue to strive to reduce its losses accordingly. The TPL power system provides power for street lighting on the island for which TPL is compensated by the government. The energy used for street lighting is therefore not part of TPL’s losses.

An overall summary of estimated losses is provided in Tables 3 and 6.

1.1.1 Generation

In addition to analyzing power station and distribution system losses, KEMA asked for generator fuel usage data to evaluate the TPL generator fuel efficiency. TPL provided monthly and annual generation, as well as system and load statistics in an Excel spreadsheet format. TPL also provided fuel efficiency values for all months, as well as the annual total, for 2007 through 2010 and part of 2011. This data was valuable in estimating system losses on the TPL system.

The power station own usage was estimated to be 2.96% of production, which is a reasonable value. The typical value fuel efficiency appears to be 4.08 kWh/liter, which is a good efficiency rate. This indicates that TPL apparently dispatches its units in an efficient manner, and that the units, including coolers and auxiliaries, are well-maintained.

1.1.2 Distribution

Each of the three distribution feeders on the island of Tongatapu are supplied from the Popua Power Station at 11 kV. The TPL primary system losses were estimated from the power flow study and metering data, combined with calculations in the Excel spreadsheets for transformer losses and LV system losses. Losses on the distribution primary feeders, distribution transformers, and LV wires are considered technical losses, which are 3.82% of the energy generated.

1.1.3 Non-technical

TPL’s non-technical losses are 9.72%, which is a fairly high value. While no direct evidence of activities such as electricity theft, meter tampering, or meter by-passing (all examples of non-technical losses) were witnessed during KEMA’s visit to the island of Tongatapu, these may be issues that need investigation.

1.1.3.1 Metering

TPL is currently undergoing a meter replacement program. Half of the meters are new and therefore expected to be in optimal condition. The other half of the meter population is aged and may be a source of non-technical losses.

TPL has a customer information system that aggregates the customer meter readings and is able to calculate the loading for each distribution transformer. This is a very valuable tool for planning and for identifying when customer metering irregularities occur.

1.2 Recommendations

The loss component due to power station usage (2.96%) is a reasonable figure, but there could be options for improvement. KEMA recommends that an energy efficiency audit be performed to reveal possibilities for future energy savings in station use.

Thermal losses can occur at specific locations on the distribution system due to corrosion, bad connectors, and other undesirable maintenance conditions. These should be eliminated where-ever possible through a program of equipment inspection at regular intervals and replacement of corroded or ineffective connectors as soon as discovered. Field inspections with infrared cameras can be a very effective approach to identifying such problems. While KEMA does not believe this to be a big problem on the island of Tongatapu, preventative inspections such as this at regular periodic intervals can identify potential problems before they become large.

TPL provided distribution transformer load profiles in spreadsheet form with graphs, produced by TPL personnel using their monitoring equipment, which allowed a much closer calibration of the modeling assumptions for estimation of losses. KEMA recommends continued monitoring of transformer loading in this way to assess transformer performance and prepare future replacement recommendations.

1.3 Prioritized List of Equipment for Replacement

TPL is currently undergoing a program of meter replacement. KEMA recommends that this program be continued along with inspection of the current equipment looking for signs of tampering as these upgrades are being carried out. This will help identify sites where theft may be an issue.

No other equipment replacements are recommended based on the system loss analysis.

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, distribution network, 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 replacements 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 the island of Tongatapu for data collection and technical assessments of the TPL power system, KEMA sent data request documents on February 10, 2011. Some of the data inputs that were requested were needed to create a power system model using EasyPower®, so that the data definitions used in the data request were consistent with the simulation software to ensure the accuracy of the study results.

Subsequently KEMA visited Tongatapu on March 18-21 to collect data, interview key TPL personnel, and assess the power system. The overall condition of the TPL facilities made a good impression, including the Popua Power Station, which was clean, and well-maintained.

During the visit much relevant data was gathered and TPL personnel provided very helpful information on billing, generation and loss statistics for Tongatapu. In addition, TPL provided copies of certain previous reports including:

Report No. 1 – Done by Sinclair Knight Merz for Tonga Power Limited (TPL), titled "Tonga Protection Review", Version 3 Report done January 2011, describes the Popua power station, and its existing protection schemes.

Report No. 2 – Done by World Bank for TPL, titled "Load Forecast Report", Report done March 2010, describes the power system of the 3 islands powered by TPL, and explores the feasibility of incorporating renewable energy sources.

Copies of these reports can be found in Appendix B – Data Collected. Data obtained from these reports was used as partial input data for KEMA's study. Geographical Information System (GIS) data was also later provided that allowed KEMA to develop the system one-line diagrams and distribution model in the EasyPower® software.

After the on-site visit there were some e-mail requests for circuit data which were later provided by TPL personnel.

2.2 Utility Operations

The maximum peak demand for the TPL system on Tongatapu is currently 7,697 kW.

The power system consists of:

- Popua Power Station. This single, central power station contains 6 diesel generating units connected to the Old Popua Power Station 11 kV bus (BUS-1), and 2 diesel generating units connected to the New Popua Power Station 11 kV bus (BUS-2). The two buses are connected through two 35 mm^2 Cu cables in PVC conduit. All units were clean, well-maintained, and available for service during the time of KEMA's visit. None of the 8 diesel generating units were de-rated. The TPL - Popua Power Station generator capability is shown below:

Table 1 - Popua Power Station Generator Capacities

Unit	Engine make	Capacity (kW)
1	Caterpillar 3516BDITA	1,400
2	Caterpillar 3516BDITA	1,400
3	Caterpillar 3516BDITA	1,400
4	Caterpillar 3516BDITA	1,400
5	Caterpillar 3516BDITA	1,400
6	Caterpillar 3516BDITA	1,400
7	Caterpillar CM32	2,800
Trailer	Caterpillar 3516BDITA	1,400
TOTAL		**12,600**

- An 11 kV distribution system consisting of three 11 kV distribution feeders (all overhead except for the underground getaway cables) operated as 3 separate radial feeders connected through inline switches that are normally open at the following locations:
    - Feeders 1 and 2 are connected through a normally open switch at pole numbers H00070, H02823, and H03164.
    - Feeders 1 and 3 are connected through a normally open switch at pole number H00334.
- The TPL system has 16,850 customers.

Refer to Figure 3 for a simplified one-line diagram of the Popua Power Station.

With a peak load of 7,697 kW and 12,600 kW of generation, the TPL system has an installed generator reserve margin of over 63%. Using an n-1 reliability criteria (loss of the largest unit), the operating reserve margin would then be just over 27%. Using an n-2 reliability criteria (loss of the largest 2 units), the operating reserve margin would be above 14%.

TPL uses and adheres to IEC standards.

2.3 Identifying and Quantifying Losses

Electric power is generated in power plants and delivered through the distribution system 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 the 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 due to power transfer through the distribution system, such as transformers, over-head line conductors, aerial or underground cables.

3. Service wire losses – losses due to power transfer from the low voltage side of distribution transformers to the customer's metering point.

Losses in category 2 and 3 together are considered as 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. 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 are: street lighting, utility's own building usage, electric power used for supplying other utilities such as water and sewage.

Furthermore, financial losses may occur due to less than optimum efficiency of the generation system dispatch and issues with individual generating units. Improvement of the generation efficiency will lead to fuel savings.

In this study, KEMA estimated technical losses through power equipment in the distribution system and the service wires. Where information was not sufficient, assumptions were made to facilitate the estimation. KEMA created a Power flow model in EasyPower® to represent the TPL power system on the island of Tongatapu. Power flow study was performed to calculate system kW losses including primary feeder losses and power transformer copper losses. An Excel spreadsheet was created to estimate kW losses that were not calculated in the power flow study, such as transformer core losses and service wires losses. These kW losses were converted to annual kWh energy losses by utilizing the estimated Loss Factor. Unbilled usage data for street lights was provided by TPL as 1.00% of total production.

The system total loss was calculated as the difference between total annual generation after station's own usage and annual energy sold.

3. Generation

At the time of KEMA's visit to the island of Tongatapu, the TPL Popua Power Station consisted of eight (8) diesel generators, all of which were well-maintained and available for service. The power station facility was very clean and orderly. All of the generator units were manufactured by Caterpillar. Units 1 through 6 are Caterpillar model No. 3516BDITA and rated 1.4 MW each. The trailer unit is a mobile CAT unit, also rated at 1.4 MW. Unit 7 is a model CM32 and rated at 2.8 MW.

3.1 Equipment

The TPL Popua power station generating equipment is listed in the Tonga Data Handbook. The following pictures show the good condition of the power station during the time of KEMA's visit. Units 1-6 are located in the CAT building, which is shown in figure 1.

Figure 1 - 3516BDITA Generator

Unit 7 is located in the TEPB building and is shown in figure 2.

Figure 2 - CM32 Generator

There are 2 interconnecting bus ties through underground cables forming a ring bus between the Old Popua Power Station bus (located in the CAT building) and the New Popua Power Station bus (located in the TEPB building).

The Popua Power Station auxiliary loads are served through two (2) 11 kV – 500 volt, 500 kVA transformers connected to Popua Power Station bus no.2. The layout of Popua Power Station is shown in the one-line diagram in Figure 3.

Tonga Power Limited (TPL) Popua Power Station
One-line Diagram

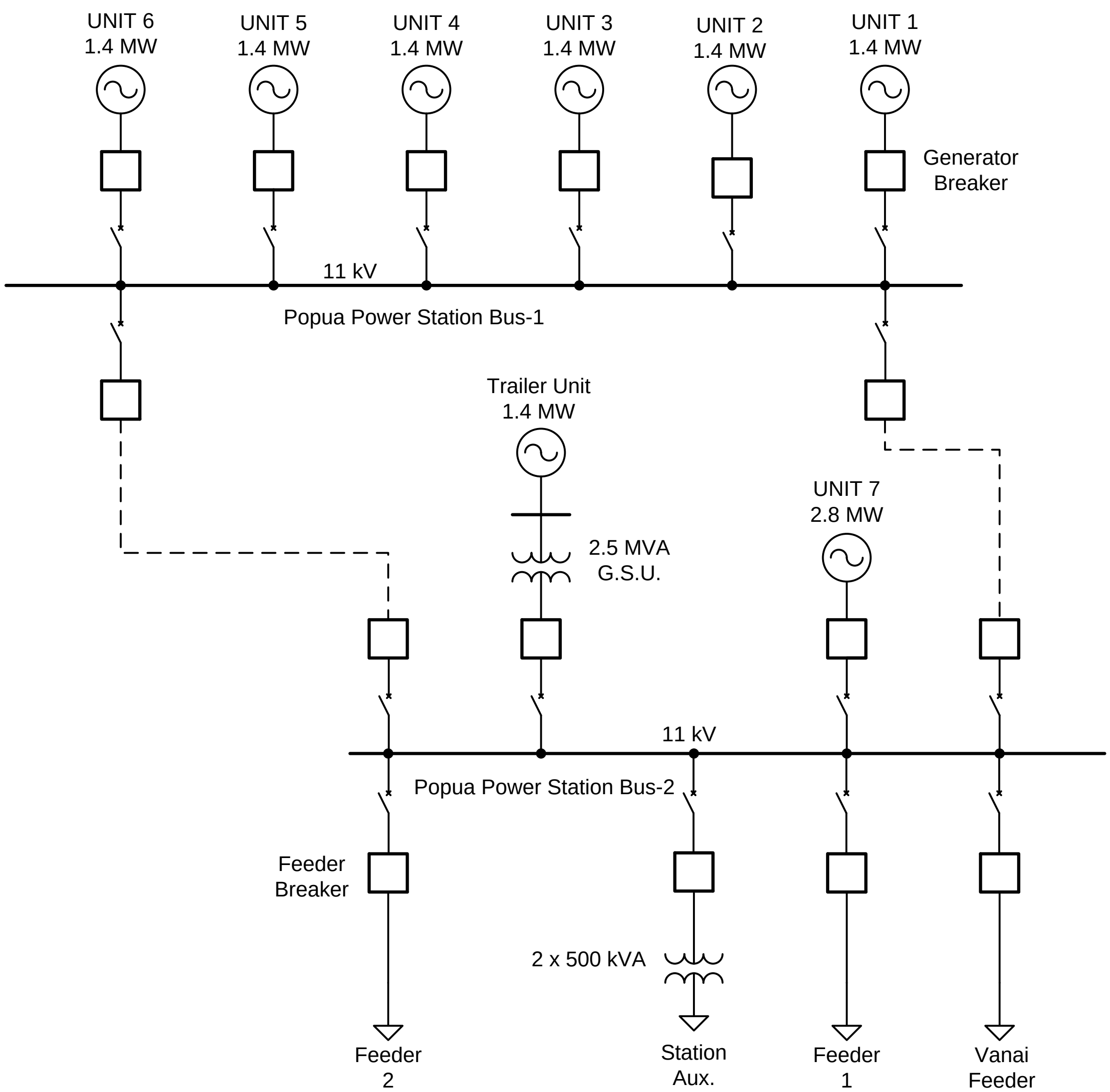

Figure 3 - Popua Power Station One-Line Diagram

3.2 Analysis of Losses

Generation loss performance can be assessed by reviewing the generation fuel efficiency and station losses (own usage).

Fuel Efficiency

At the time of KEMA's visit, TPL provided monthly and annual statistics for Popua Power Station in an Excel spreadsheet covering the years 2007 through 2010, and part of 2011. A summary of the annual statistics is provided in table 2.

Table 2 - Annual Total Fuel Use

YEAR	Liters	% CHANGE	kWh	% CHANGE	kWh/Liter
2007	11,771,682	-	48,035,978	-	4.08
2008	11,978,402	0.0176	48,954,776	0.0191	4.09
2009	11,132,090	-0.0707	45,213,574	-0.0764	4.06
2010	11,084,001	-0.0043	45,187,421	-0.0006	4.08

This summary shows that the fuel efficiency for the Popua Power Station has been about 4.08 kWh/liter. This is a good fuel efficiency figure and shows that the TPL diesel engines are kept in good condition and dispatched in a manner conducive to economic loading. Generators run more efficiently near their full rated output than when running at low percentage of rated output. Running the fewest number of units needed to maintain system reliability allows each unit to run nearer to its rated output, and helps to improve generator fuel efficiency.

Station Losses

Station losses are the difference between total energy produced by the generating units and total energy entering the distribution system. This represents the power station's own usage. For TPL this was estimated to be 2.96% of production, which is a reasonable value.

3.3 Findings

KEMA's review of the Popua Power Station revealed that all of the units are all well maintained and in good condition. Table 3 below shows the varying annual system energy production, sales, and total system losses plus power station losses for 2007 through 2010. Total sales dropped 7.93% between 2008 and 2009 with a corresponding reduction in total system losses and power station losses of 6.33% in absolute kWh's. However, the loss percentage actually increased by 0.3% because gross generation was considerably lower. On the other hand, between 2009 and 2010, total sales increased by 0.84% which resulted in a 0.7% reduction of the loss percentage.

Table 3 - Total Annual Generation, Sales, and Losses

	Total Gross Generation		Total Energy Sold		Total System & Power Station Losses		Losses
YEAR	kWh	% CHANGE	kWh	% CHANGE	kWh	% CHANGE	% of TOTAL
2007	**48,035,978**	-	**39,461,503**	-	**8,574,475**	-	17.8
2008	**48,954,776**	1.91%	**40,152,248**	1.75%	**8,802,528**	2.66%	17.9
2009	**45,213,574**	-7.64%	**36,968,204**	-7.93%	**8,245,370**	-6.33%	18.2
2010	**45,187,421**	-0.06%	**37,278,899**	0.84%	**7,908,522**	-4.09%	17.5

4. Distribution

The distribution system on the island of Tongatapu consists of 3 main feeders. Feeder-1 (Nuk1) serves the western end of the island and exits Popua Power Station via three single-conductor 300 mm^2 Cu cables. Feeder-2 (Nuk-2) serves the central commercial district and exits Popua Power Station via a three-conductor 300 mm^2 Cu cable. Feeder-3 (Vaini) serves the airport and the eastern end of the island and exits Popua Power Station via a three-conductor 70 mm^2 Cu submarine cable. Most of the TPL distribution system on the island of Tongatapu consists of overhead aluminum conductors. Common conductors used on the TPL distribution primary system are shown in Table 4 below.

Table 4 - Common TPL Conductors on Tongatapu

Commonly Used Primary Conductors				
OVERHEAD CONDUCTORS				
Name	Insulation Material	Conductor Size (mm^2)	Conductor Type	Comments
Cockroach	OH	250	AAC	Standard
Lynx	OH	175	ACSR	Standard
Hornet	OH	150	AAC	Standard
Dog	OH	100	ACSR	Standard
Horse	OH	70	ACSR	Standard
Fly	OH	60	AAC	Standard
Gopher	OH	25	ACSR	Standard
Aphis	OH	25	AAC	Standard
Squirrel	OH	20	ACSR	Standard
UNDERGROUND CONDUCTORS				
Single Conductor	XLPE	70	Cu	Submarine Cable
Single Conductor	XLPE	300	Cu	Standard
3-Conductor	XLPE	300	Cu	Standard
3-Conductor	XLPE	35	Cu	Standard
3-Conductor	XLPE	25	Cu	Standard
3-Conductor	XLPE	16	Cu	Standard

These conductors are adequately sized 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.

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

- There are 292 distribution transformers with total connected capacity of 28,295 kVA.
- The TPL system peak load on Tongatapu is 7,697 kW.
- There are 16,850 customers on Tongatapu.
- There are 5 capacitor banks on the distribution system, each rated 150 kVAR.

The GIS map display of Tongatapu Island showing the location of the distribution feeders relative to the roads that was provided by TPL is shown below.

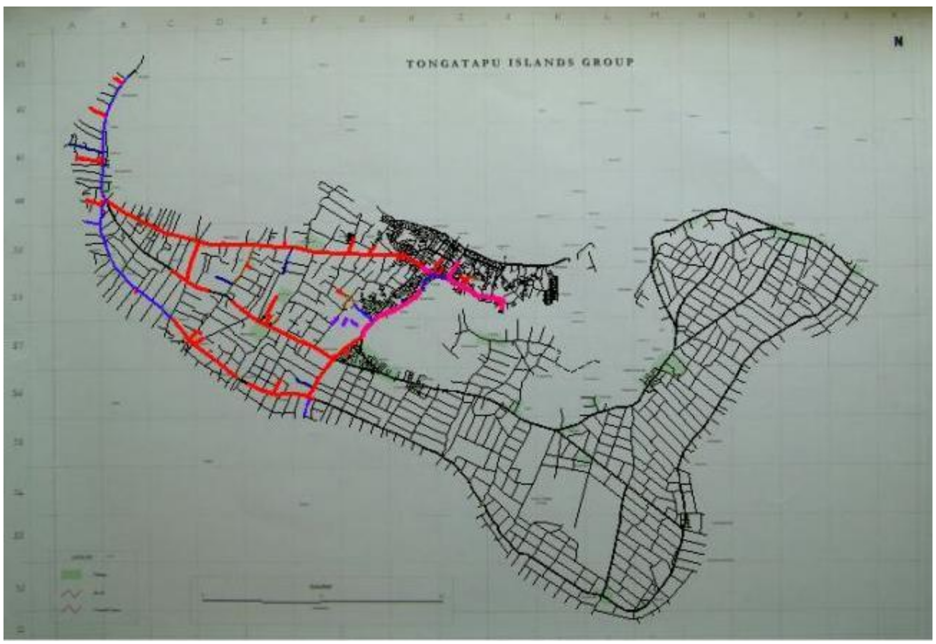

Figure 4 - Geographical Layout of Feeder 1

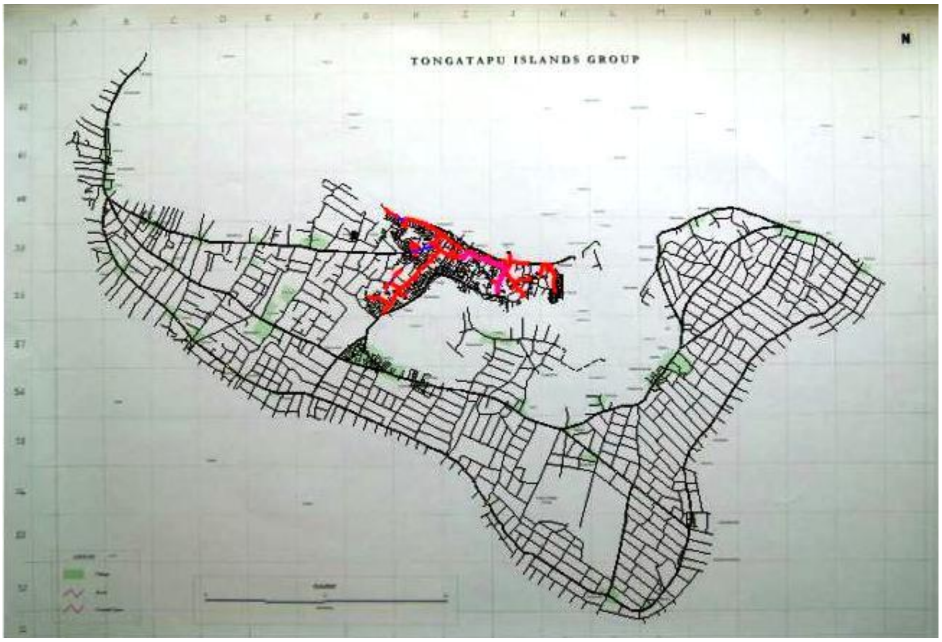

Figure 5 - Geographical Layout of Feeder 2

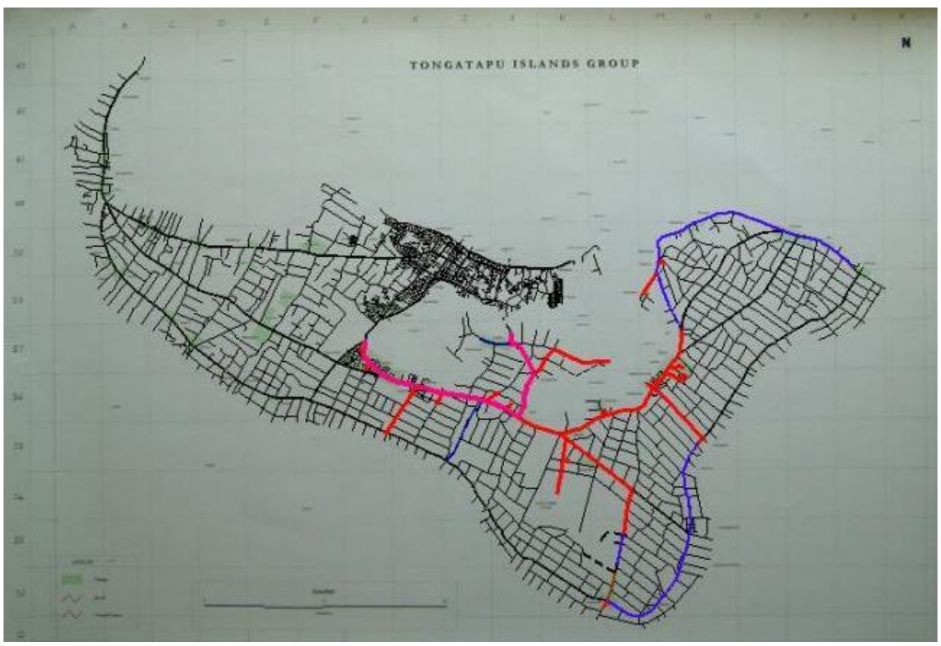

Figure 6 - Geographical Layout of the Vanai Feeder

TPL provided KEMA with monthly data for gross energy generated at the Popua Power Station, the energy delivered to the customers, and the energy billed on the island of Tongatapu from July 2007 to January 2011. These are shown graphically in Figure 7 below.

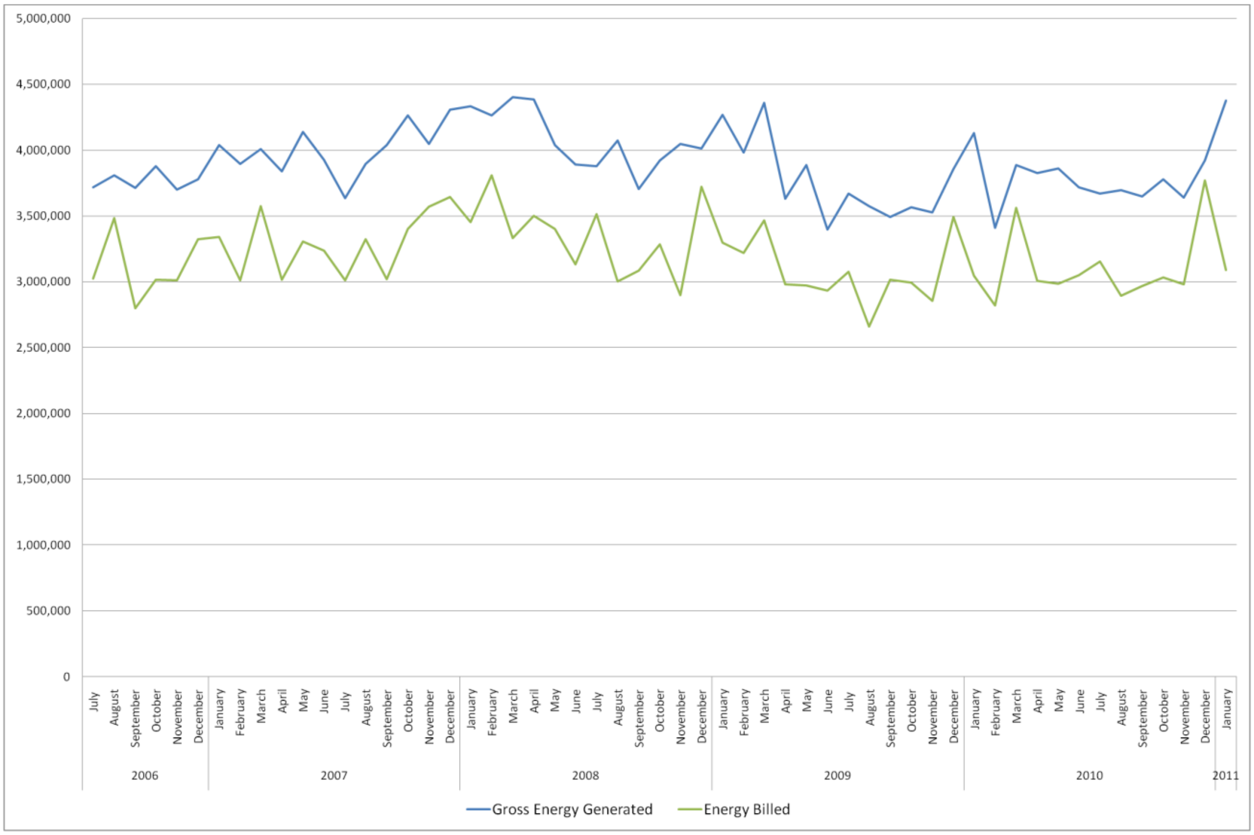

Figure 7 - Monthly Energy Generated and Billed (kWh)

The difference between these graphs represents the total system losses on the island of Tongatapu, including station losses.

4.1 Equipment

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

4.1.1 Distribution System

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

- There are two 300mm^2 Cu XLPE underground cables that serve as bus ties connecting the two 11 kV buses in Popua Power Station creating a virtual ring bus.
- The 11 kV feeders are connected to the Popua Power Station 11 kV bus through Hawker-Siddley 12 kV switchgear (rated 630A continuous, 20kA interrupting).
- Feeder-1 (Nuk-1) exits the Popua Power Station through 3 single-phase 300 mm^2 Cu XLPE cables.
- Feeder-2 (Nuk-2) exits the Popua Power Station through a three-phase 300 mm^2 Cu XLPE cable.
- Feeder-3 (Vaini) exits the Popua Power Station through a three-phase 70 mm^2 Cu submarine cable.
- TPL has 292 distribution transformers installed on the 11kV distribution feeders, many of them 3-phase, with a total installed capacity of 28,295 kVA.
- There are interties between the feeders that are normally open.
- There are 5 shunt capacitor banks on the TPL system, rated 150 kVAR each.
- There are also no shunt reactors on the TPL system.

Figures 8 and 9 show fairly typical 11 kV distribution equipment on the TPL system.

Figure 8 - Typical TPL 11 kV Distribution Line

Figure 9 - Typical Distribution Pole with Transformer

4.1.2 LV Wires

Secondary service wire types and sizes were provided during KEMA's visit, and are listed in the Data Handbook. Typical secondary service wire configurations were used in the calculation of LV wire losses. A distribution pole showing the low voltage service wires is shown below.

Figure 10 - Low Voltage Service Wires

Figure 11 - Distribution Pole Showing Low Voltage Wires

4.2 Analysis of Losses

Loss quantification analysis is focused on the Tongatapu island grid. TPL also operates three other systems in Vava'u, Ha'apai and 'Eua, however they are not part of this study. To quantify losses through the distribution system and service wires, the following assumptions were made:

1. The total energy produced and energy sold in the Tongatapu system 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 power flow study with model in EasyPower®. However, voltage drops through feeders were not considered in loss estimations for distribution transformers and secondary services wires.

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

6. Typical secondary service wire type, size and configuration were assumed based on the data provided in GIS database.

TPL has provided a one-line diagram and a GIS database of its power system on the island of Tongatapu. Feeder segment distance, conductor type and size, and kVA capacity of distribution transformers are identified based on both files. 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 EasyPower® for the TPL model of the island of Tongatapu based on the GIS database and map. In this distribution system model, Popua Power Station and an 11kV distribution system are modeled. Normally, open switches locations are assumed in the model so that all 3 distribution feeders are radial feeders. Distribution transformers are represented as spot loads with constant kVA load same as transformer capacity and load power factor of 0.9. EasyPower® provides a feature to scale the load into a specific value when power flow is performed.

Losses in kW through the primary feeders were calculated in power flow study at the system peak demand. System load is allocated proportionally to distribution transformer capacities connected to each feeder. KEMA studied power flow with 7,697 kW peak load condition for 2010. System Utilization Factor is calculated as 30.23% with peak load of 7,697 kW and a total connected capacity of 28,295 kVA. However, due to anomalies in the GIS database in some locations, the connected kVA capacity in EasyPower® model is 25,705 kVA. A scaling factor of 33.27% is applied to all loads in the power flow study to represent a system load of 7,697 kW.

For the TPL power system on the island of Tongatapu, electric power is supplied from Popua power station. In 2010, annual generation production was 45,187,421 kWh and energy sent out to the distribution system was 43,848,517 kWh. Power station's own usage was 1,338,904 kWh. In 2010, the system peak demand was 7,697kW. The Tongatapu system load factor was estimated as 65% and the loss factor was estimated as 47%. 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 actual loss data provided by TPL. Secondary wire losses were estimated with typical configuration and average customer consumption for all customers. Secondary system consists of wires connecting from the low voltage (LV) side of distribution transformer to the customer meter. To estimate secondary losses, assumptions for typical secondary wire type, size and configuration are developed based on the data provided in GIS database for Tongatapu LV lines.

From the GIS database, typical secondary configurations are identified for three-phase distribution transformers as well as for single-phase distribution transformers.

- From three-phase transformers, three-phase LV lines extend as the Secondary Line (SL) main trunk and single phase SL tapped along the 3-phase Secondary Line; single-phase wires as Service Drops (SD) tapped along the single-phase Secondary Line and extended to each customer meter.

- From single-phase transformers, two single-phase LV lines extend as the Secondary Line (SL) and single-phase wires as Service Drops (SD) tapped along the single-phase Secondary Line and extended to each customer meter.

Based on this finding, it is assumed that the typical secondary system is in a tree (radial) structure. All customers were considered and assumed to be mixed along the Secondary Line. The assumptions used in secondary losses estimation are listed in table 5.

Table 5 - Secondary Loss Estimation Assumptions

	1-Phase	3-Phase
number of customers	641	16209
number of distribution transformers	45	247
number of SL (- 1-phase) per 1-ph dist transformer	2	0
number of SL (- 3-phase) per 3-ph dist transformer	0	2
number of SL (- 1-phase) per 3-ph SL	0	3
number of SD (- 1-phase) per 1-ph SL	7	12

TPL has mixed secondary lines with both underground cable and overhead wire. Typical three-phase SL line/cable is assumed as AAC/1350 fly 3-Ph wires. Typical single-phase SL line/cable is assumed as 10mm^2 Copper cable/wire.

Typical SD was assumed as single phase 6mm^2 Copper cable/wire of 25 meter long. Lack of information about SD, 6mm^2 Copper cable/wire as the smallest size of all LV wires in TPL GIS database is taken here as typical service drop size for loss estimation. TPL should collect data for the actual SD type, size and length to develop typical one based on that.

4.3 Findings

The total system losses are equal to the total energy that entered the distribution system minus the total energy sold and the energy unaccounted for. A summary of estimated losses is provided in table 6.

Table 6 - Estimated Energy Losses by Category

	kWh	% of generation	% of system consumption
annual generation	45,187,421	1	-
annual station auxiliary	1,338,904	0.0296	-
annual system consumption	43,848,517	0.9704	-
annual energy sold	37,278,899	0.825	0.8502
system loss including unbilled usage	6,569,618	0.1454	0.1498
social usage: street light	451,874	0.0100	0.0103
technical loss	1,727,656	0.0382	0.0394
non tech loss	4,390,088	0.0972	0.1001

TPL system technical losses were estimated as 3.82% of annual energy production while non-technical losses were estimated as 9.72% 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 records of all power equipment technical data received from manufacturers including equipment specifications, name plate information and test data.

The TPL system losses on the island of Tongatapu are shown in figure 12.

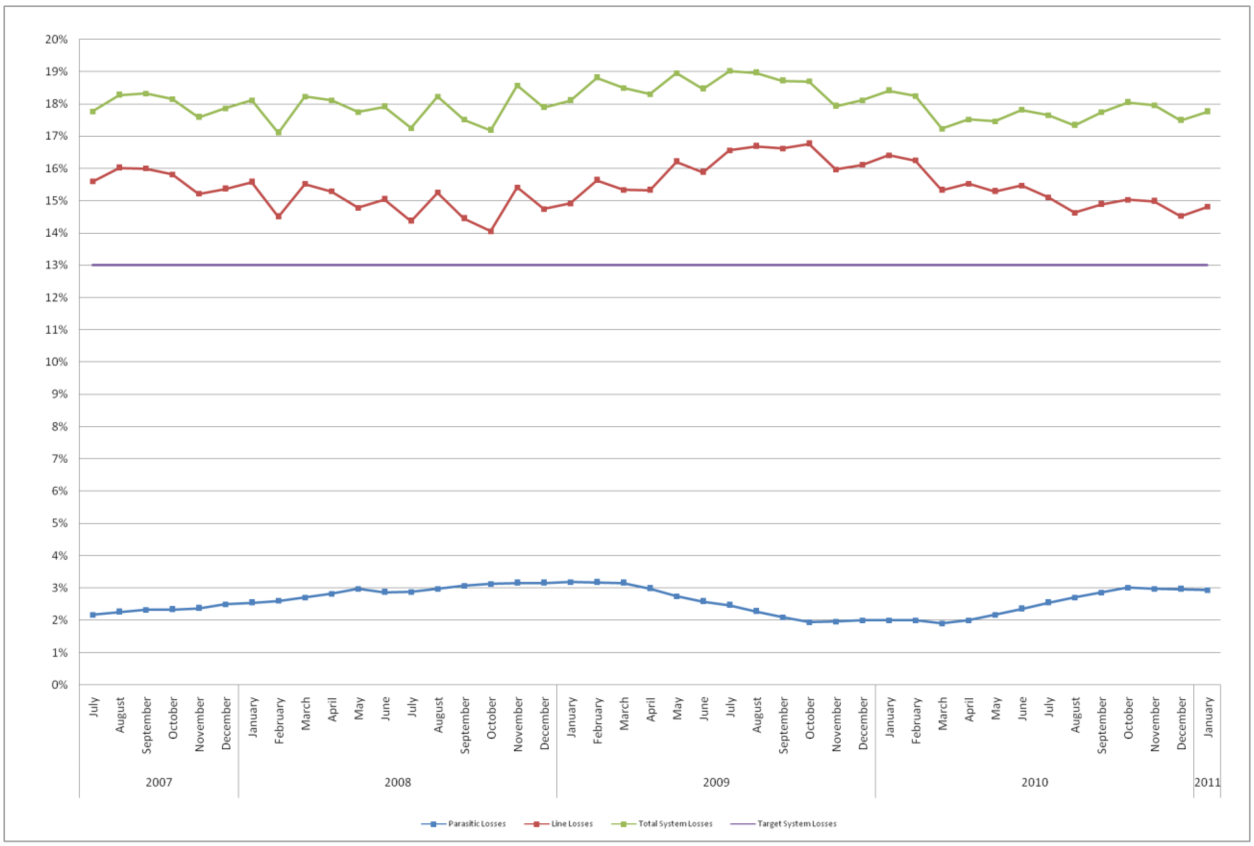

Figure 12 - Monthly Total System Losses, including Station Losses

For TPL, street lights usage is estimated as 1% of annual generation. Some compensation for street light usage is paid by the government, but it's unclear if this covers TPL's full cost for the service. No other reason for unbilled usage is identified in the data from TPL.

The legend in Figure 12 refers to several loss categories that require definition. These are explained below.

“Parasitic Losses” = Total Losses – Line Losses = Station Losses (own usage)
“Line Losses” = Technical Losses (includes losses in the HV lines, LV lines, and the distribution transformers).
“Target System Losses” = Total system loss goal

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 are relatively high (9.72%). This implies that there may be causes of non-technical losses, such as theft or possibly unmetered usage. Therefore, KEMA recommends that TPL investigate possible causes of non-technical losses more vigorously.

KEMA recommends that TPL take steps to obtain, monitor and record distribution transformer load data to develop an asset assessment data base for these transformers, either through software which takes into account the customer meters on each of the transformers or through physically measuring the load by installing demand type meters on the secondary side of each of the transformers.

These meters can be installed while using current transformers (CT's) mounted on the pole or on the pad mounted transformers. If customers are equipped with new digital meters and can be linked in a database or in the CIS to the distribution transformers, it may not be necessary to install these meters at the distribution transformers.

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 TPL 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

TPL has indicated that they are currently systematically replacing aged meters, and that about half of the customer meters are fairly new. A program of periodic meter testing is recommended to ensure the accuracy and reliability of the monitoring system. Since TPL does not have a meter test facility, KEMA recommends that meters be tested by a third party.

5.1.1.2 Meter Tampering and Bypassing

TPL did not indicate that meter tampering or by-passing was an issue. However, since non-technical losses are high, energy theft may be a problem. 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 result in irregular monthly figures for power usage, and therefore inaccurate system studies. Most inaccurate readings can be corrected by the next meter reading. A common source of metering inaccuracy is the unreliability of manual reads. TPL indicated that they are to upgrade their current techniques by incorporating a hand-held unit (HHU) reading system. This will greatly simplify meter reading and reduce the chance of technician errors in collecting data.

5.1.2 Billing Losses

KEMA was not made aware of any billing losses.

5.1.3 Billing Collection Losses

Billing collection losses and bad debts are not to be counted as 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 TPL non-technical losses are fairly high. Therefore, KEMA recommends that TPL implement a program of training meter readers to look for instances of theft; particularly in rural areas, where meter-tampering is typically more common.

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 TPL system. However, since non-technical losses were so high, an audit of the administrative department may reveal some discrepancies.

5.1.6 Line Throw-ups

Line throw-ups were not identified as a problem during the KEMA visit to the site.

5.2 Analysis of Losses

The loss calculations show a fairly high percentage of non-technical losses (9.72%), which includes meter errors, theft and a number of other types of losses. The loss calculations indicate high non-technical losses while no indication was given during the site visit as to the possible causes. The meter population appeared to be in fairly good condition and line throw-ups were not seen during KEMA's visit, so based on data made available to KEMA it's unclear why non-technical losses are almost 10%.

Non-technical losses exclude energy for street lighting, which TPL indicated was 1.00%.

5.3 Findings and Related Observations

Since non-technical losses were very high, KEMA recommends implementing a strategic effort at TPL to combat non-technical losses as discussed below (also see Chapters 6 and 7). A pragmatic approach can be developed to locate non-technical losses and increase the effectiveness of revenue-protection operations including the following measures:

- Maintain a thorough program for checking old meters.
- Train meter readers to identify tampering, by-passing, broken seals, and unauthorized hook ups.
- Train a customer service staff member to audit metering and billing processes (including quality checks of billing system data such as multiplying factors, tariff categories applied to customers, functioning of red flags in the case of irregularities) and non-technical loss causes found by meter readers, such as meter tampering or by-passing.
- Select targets for inspection, also focusing on commercial customers. When selecting targets for inspection, the potential of the estimated amount of revenue recovery should be a major selection factor. With limited resources, selecting accounts with highest revenue recovery potential of and hit rates will be the most efficient use of the limited resources.
- Make operations less predictable. TPL's own experience may show that there are sophisticated fraud activities that take advantage of known patterns of Revenue Assurance operations. This should be countered with less predictable operations (e.g. occasional night inspections, computer-generated random daily target lists, and so on). This will help to identify these fraudsters and increase the deterrent effect.
- Prevent repeat fraud activities. Proper measures should be taken to ensure that it will not occur again.
- Prevent and curb internal collusion activities. One important aspect of effective revenue protection operation is to prevent and curb potential internal collusion. Internal collusion seriously undermines the effectiveness of any revenue assurance process. One possible solution is to bring in NON-LOCAL inspection teams to conduct critical revenue-protection operations, such as large account audits, under the direct control of TPL's top management.

- Employ tactics tailored to each group of customers, knowing that different types of customers have different needs for electricity, different usage patterns, and different payment capabilities. A successful revenue assurance strategy should take this into account to develop corresponding tactics for each group of customers. Establishing typical usage patterns and payment capabilities for each group of is an important task of a Revenue Assurance process.

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

A more sophisticated approach would be to implement a Revenue Assurance Process that employs an advanced Revenue Intelligence system. Such a system can detect potential fraud based on information from multiple sources using advanced detection rules and would provide TPL with the most efficient fraud prevention/detection and revenue operations audit capability. However, for a small utility, implementation of a Revenue Assurance Department and Revenue Intelligence Software requires a large investment and may have a large organizational impact.

6. Findings and Recommendations

This chapter provides a compilation of overall findings and recommendations.

6.1 Generation

The fuel efficiency for Popua Power Station has been averaging 4.08 kWh/liter over the past year. This figure has remained reasonably constant through 2010 remaining between 3.87 and 4.18 kWh/liter. While this is a good figure, it may be possible to further improve it by changing the way the units are dispatched and by keeping the units in optimal operating condition. KEMA recommends that TPL consider looking at opportunities for improving its economic dispatch of generation resources.

Popua Power Station's own usage was provided as 2.96% of production, which is a reasonable figure. A good figure for auxiliary consumption is typically below 5%, and this power station is well below that threshold. Therefore, KEMA has no recommendations in regards to power station usage.

6.2 Distribution

The technical losses on the TPL distribution system are 3.82%, which is lower than the normal range. A good figure is typically less than 5%, and TPL's technical losses are well below that. Therefore, KEMA has no recommendations to improve distribution system technical losses based on the figures provided. However, infrared inspection of critical system connections is recommended to ensure there are no degraded, corroded, or otherwise bad connectors.

6.3 Non-Technical Losses

The non-technical losses on the TPL distribution system are 9.72%, which is in the very-high range. A good value for non-technical losses would be below 5%. TPL personnel indicated during KEMA's visit that the monitoring system of meters is currently being overhauled. This will greatly enhance the reliability and accuracy of the metering improvement efforts, and will help identify sources of non-technical losses by ruling out inaccurate metering. Additional measures as discussed in Section 5.3 should also be considered.

7. Suggested Equipment Replacement

The condition of the TPL system on the island of Tongatapu at the time of KEMA's visit was very good. Overall the electric system seems to be well maintained and in good working order. During KEMA's site visit to the island of Tongatapu, we saw no visual evidence of TPL's generation and distribution equipment indicating a need for replacement. Furthermore, no major equipment replacements are recommended based on the system loss analysis.

TPL is currently undergoing a program of meter replacement. KEMA strongly recommends continuation of this program along with inspection of the current equipment for signs of tampering as these upgrades are being carried out. This will help identify issues with the load monitoring system, and will expose sites where theft may be an issue.

A. Data Handbook

See attached *TPL data handbook.docx*

B. EasyPower Model

See attached *TPL system.dez*

C. One-line Diagram from EasyPower

See attached *TPL one-line.pdf*

D. Loss Worksheet

See attached *TPL loss worksheet.xls*