KEMA

Quantification of the Power System Energy Losses in South Pacific Utilities

Tuvalu Electric Corporation, Tuvalu

Submitted to

European Union

Prepared by KEMA International B.V.
Final Report , May 25th, 2012

Experience you can trust.

1. Executive Summary 5
1.1 Quantification of System Losses 5
1.2 TEC System Energy Losses 6
1.2.1 Generation Losses 7
1.2.2 Distribution System Technical Losses 7
1.2.3 Non-technical Losses 7
1.2.3.1 Metering 7
1.3 Summary of Recommendations 8
2. Project Approach 9
2.1 Data Collection 9
2.2 Utility Operations 10
2.3 Identifying and Quantifying System Losses....11
3. Generation 13
3.1 Equipment 13
3.2 Analysis of Losses 15
3.3 Findings 16
4. Distribution 17
4.1 Equipment 19
4.1.1 Distribution System 19
4.1.2 LV Wires 20
4.2 Analysis of Losses 20
4.3 Findings 23
5. Non-Technical Losses 25
5.1 Sources of Non-technical Losses 25
5.1.1 Metering Issues 25
5.1.1.1 Aged Meters 25
5.1.1.2 Electricity Theft, Meter Tampering and Bypassing 25
5.1.1.3 Inaccurate Meter Reading 26
5.1.2 Billing Losses 26
5.1.3 Billing Collection Losses 26
5.1.4 Administrative Failures 26
5.1.5 Line Throw-ups 26
5.2 Related Observations 26
6. Overall Findings and Recommendations 27
6.1 Generation 27
6.2 Distribution 27

6.3 Non-Technical Losses 28
7. Suggested Equipment Replacement 29
A. Data Handbook 30
B. Loss Worksheet 31
C. Easy Power Model 32

List of Figures:

Figure 1 - Power Station Building (as Viewed from Gate)

Figure 2 - Generator Room

Figure 3 – Typical RMU with switches

Figure 4 – System One Line from Easy Power

Figure 5 – Typical Daily Production Curve

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 Tuvalu Electric Corporation (TEC). TEC serves several islands, but this report, data handbook, and power system model focus on the main island of Funafuti Atoll. All references to TEC in the remainder of this report refer the Funafuti Atoll system.

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.

1.1 Quantification of System Losses

Losses through the TEC system consist of power station losses and distribution system losses. Both loss categories are quantified.

- Station Losses: Efficiency of generating units and power plant auxiliary loads
- Distribution System Losses: these losses can be divided into technical and non-technical parts.
    - Technical losses: Summation of transformer core losses, transformer copper losses, distribution feeder losses, secondary wire losses and losses of any other

equipment in the system, like reactors and capacitor banks. Technical losses will become higher as power factors drop below unity.

- Non-technical losses: inaccurate meters, meter tampering or by-passing, theft, meter reading errors, irregularities with prepaid meters, administrative failures, wrong multiplying factors, others.

Unbilled Usages: Energy consumption that is not billed should be considered a financial loss for the company rather than a non-technical loss.

1.2 TEC System Energy Losses

KEMA's analysis of the TEC power system determined that total losses are 8.15% of annual generation, which is fairly low. The total system losses equal to the total energy supplied into the distribution system from TEC's power station minus total energy sold to customers. These losses consist of:

- 3.62% in technical losses, which is a relatively low value.
- 3.53% in non-technical losses, which is a fairly low value.
- 1.00% in unbilled usage, which is a fairly low value.

In addition to these system losses, the power station auxiliary losses (station's own use) was provided as 8.63% of total production (including PV station production), which is somewhat high.

The unbilled energy usage came from the street lights, which is approximately 1% of annual generation. TEC's own building usage, which was given as 2.51% of total production, is metered and accounted for, and therefore not regarded as unbilled usage. The fact that TEC meters the building usage is commendable. This data is often not provided and goes unaccounted for. A summary of estimated losses is provided in section 4 (see Exhibit 4-1).

1.2.1 Generation Losses

TEC provided system and load statistics in an Excel spreadsheet format. This data was extremely valuable in estimating system losses on the TEC system. In addition to analyzing distribution system losses, KEMA obtained generator fuel usage data in order to evaluate the TEC generator fuel efficiency. TEC provided monthly and annual generation data.

Based on this data, for the time period under review, the power station's own usage was estimated to be 8.63% of production, which is somewhat high. Therefore, conducting a more detailed energy efficiency audit of power station usage may be of value to TEC.

TEC also provided fuel efficiency values for all months as well as annual totals for 2008, 2009 and 2010. The typical value seems to fall between 3.79 and 3.90 kWh/liter, which is somewhat low (i.e. inefficient). Therefore, TEC may want to consider changes to its dispatch approach in order to improve this efficiency level.

1.2.2 Distribution System Technical Losses

Each of the three distribution feeders on Funafuti Atoll are supplied from the New Fogafale power station at 11 kV. The TEC primary system losses were estimated from the power flow study and metering data, combined with calculations in the Excel spreadsheets for distribution transformer losses and LV system losses. Losses on TEC's distribution feeders, distribution transformers and LV wires are included in the technical losses, which total 3.62% of production.

TEC provided distribution transformer load profiles in spreadsheet form with graphs, produced by TEC 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 and prepare future replacement options.

1.2.3 Non-technical Losses

TEC's non-technical losses are 3.53%, which is a relatively low value. This suggests that undesirable activities such as electricity theft, meter tampering, and meter by-passing (all examples of non-technical losses) are not much of a problem on the Tuvalu system.

1.2.3.1 Metering

TEC has well-maintained, modern meters and a Customer Information System that aggregates the customer meter readings and is able to calculate the loading for each distribution transformer. This is an extremely valuable tool for planning and identifying when customer metering irregularities occur. Irregular or inconsistent usage figures for certain customers could be used by TEC personnel to trigger the need for an inspection of the meters serving these customers. Overall, the metering system and data were sufficient to estimate the TEC system losses.

1.3 Summary of Recommendations

The loss component due to power station usage (8.63%) is a rather high figure and there may be options available to improve this usage level. KEMA recommends that a detailed power station energy efficiency audit be performed to reveal possibilities for future energy savings in station use.

There may also be future opportunities to reduce no-load losses on TEC's 15 distribution transformers. On average these transformers are loaded to 37.33% of nameplate capacity during the peak load condition. This is relatively light loading and means that the no-load losses on many of the transformers is higher than desired. Therefore, KEMA recommends implementing a goal for replacing existing transformers with smaller kVA rated units when existing transformers need to be replaced due to end or life issues. Evaluation and selection of replacement transformers should be done through a Net Present Value analysis that includes the purchase price as well as the core and copper losses.

Distribution system conductors on Funafuti Atoll consist mostly of underground cables with a mix of copper and aluminum conductors. 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 solely for the purpose of reducing losses. However, if system load changes require an increase in conductor size, then consideration should be given to losses in the choice of the replacement conductor size.

Thermal losses can also occur at specific locations on the distribution system due to corrosion, bad connectors, and other undesirable maintenance conditions. These should be eliminated 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 Funafuti Atoll, preventative inspections such as this at regular periodic intervals can identify potential problems.

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 the island of Funafuti Atoll for data collection and technical assessments of the TEC power system, KEMA sent data request documents on February 9, 2011. Some of the data inputs that were requested were needed to create a power system model using Easy Power®, 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 Funafuti Atoll during the week of March 25-28 to collect data, interview key TEC personnel, and assess the power system. KEMA personnel were generally impressed with the overall condition of the TEC facilities, including the Fongafale Power Station, which was clean and well-maintained.

During the visit much relevant data was gathered and TEC personnel were very helpful by providing billing information and system one-line diagrams for Funafuti Atoll, as well as copies of previous Energy Efficiency reports. Data obtained from these reports was used in this report and the one-line diagrams that were provided by TEC were extremely valuable as system input data for the TEC system model in Easy Power. The reports, in order provided, are described as follows:

Report No. 1 – Done by Empower Consultants Ltd for the Ministry of Economic Development, titled "Tuvalu Electricity Corporation: Loss Reduction Programmme", Stage 1 Report done November 2008, describes the TEC electric infrastructure and loss reduction incentives.

Report No. 2 – Done by Empower Consultants Ltd for the Ministry of Economic Development, titled "Tuvalu Electricity Corporation: Loss Reduction Programmme", Stage 2 Report done April 2009, builds on the Stage 1 Report.

Copies of these reports can be found in Appendix B – Data Collected.

After the on-site visit a few clarifications were requested by e-mail which were quickly provided by TEC personnel. TEC personnel were very responsive to KEMA requests for data.

2.2 Utility Operations

The TEC power system on Funafuti Atoll is relatively small compared to the other utilities covered by the PPA loss quantification study.

The power system consists of:

- Fogafale Power Station. This single, central power station contains 5 units connected to the Old Fogafale Power Station 415 volt bus, and 3 units connected to the New Fogafale Power Station 11 kV bus. The two buses are connected through two 415V-11kV, 750 kVA generator step-up transformers and a single 25 mm^2 Cu cable. All units were clean, well-maintained, and available for service during the time of KEMA's visit. The TEC - Fogafale Power Station generator capability is shown in Table 1.

<table>
<tr><th>Unit Designation</th><th>Power Rating (kW)</th><th>Location</th></tr>
<tr><td>UNIT 1</td><td>1,000</td><td rowspan="5">Old Fogafale</td></tr>
<tr><td>UNIT 2</td><td>100</td></tr>
<tr><td>UNIT 3</td><td>245</td></tr>
<tr><td>UNIT 4</td><td>400</td></tr>
<tr><td>UNIT 5</td><td>400</td></tr>
<tr><td>UNIT 6</td><td>600</td><td rowspan="3">New Fogafale</td></tr>
<tr><td>UNIT 7</td><td>600</td></tr>
<tr><td>UNIT 8</td><td>600</td></tr>
<tr><td>TOTAL</td><td>3,945</td><td>2,345 kW firm based on n-2 criteria</td></tr>
</table>

Table 1 – Fogafale Generator Units

- An 11 kV distribution system consisting of three 11 kV distribution feeders (all underground) operated as a network with a common connection point at RMU-ES.

- 1,081 customers.

With a peak load of 1,018 kW and 3,945 kW of generation, the TEC system has an installed generator reserve margin of over 287%. Using an n-1 reliability criteria (loss of the largest unit), the reserve margin is about 189%. Using an n-2 reliability criteria (loss of the largest 2 units), the reserve margin is still over 130%.

There is a 40 kW grid connected PV system located on the roof of the local soccer field whose output is included in the production numbers and system loss calculation.

2.3 Identifying and Quantifying System 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 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 transmission and distribution systems, such as transformers, over-head line conductors, areal cables 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 categories 2 and 3 together are considered as Technical Losses. Technical losses are the losses that can be attributed to electric current passing through the power system equipments. In contrast to technical losses, there are non-technical losses. 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, and wrong multiplying factors.

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

Furthermore, financial losses may be present due to a non-optimized efficiency of the generation system and individual generating units. Improvement of the generation efficiency will lead to fuel savings.

In this study, KEMA estimated technical losses through power equipment in the distribution system and the service wires. Where information was not sufficient, assumptions were made to facilitate the estimation. KEMA created Power flow model in Easy Power to represent TEC power system on Funafuti Atoll. 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 distribution transformer 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 TEC.

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

3. Generation

At the time of KEMA's visit to Funafuti Atoll, the TEC Fogafale Power Station housed eight (8) diesel generators, all of which were well-maintained and available for service. Units 6, 7 and 8 were manufactured by Daihatsu in 2006 and are the units used the most for power generation.

3.1 Equipment

The TEC Fogafale power station generation equipment is specified in the Generation Data Handbook. The following pictures show the excellent condition of the power station during the time of KEMA's visit.

Figure 1 - Power Station Building (as Viewed from Gate)

Figure 2 - Generator Room

The data for the power transformers that feed the TEC distribution system on Funafuti Atoll are given in the TEC Data Handbook. There are 2 main power transformers, each rated 750 kVA, which step up the voltage from 415 V to 11 kV and connects the Old and New Fogafale Power Stations.

Additionally, there is one 11 kV – 415 V distribution transformer, rated 300 kVA, that serves the station auxiliary load.

3.2 Analysis of Losses

TEC's Fogafale Power Station was analyzed for fuel efficiency and station losses (own usage).

At the time of KEMA's visit, TEC provided monthly and annual statistics for Fogafale Power Station - as well as distribution sales and loss data - in an Excel spreadsheet covering the years 2008 thru 2010. A copy of the annual statistics as received from TEC is shown in Table 1.

	Fogafale Power Station Statistics			
	Year	**2008**	**2009**	**2010**
	Installed Capacity	2,800	2,800	2,800
	Old Pow er Station (kW)	2,430	2,430	2,430
	New Pow er Station (kW)	1,800	1,800	1,800
	No. of Hours/Month (hrs)	8,784	8,784	8,784
	Available Generating Capacity (kW)	**2,510**	**2,510**	**2,510**
	Old Pow er Station (kW)	800	800	800
	New Pow er Station (kW) @ 95%	1,710	1,710	1,710
	Total Production (kWh)	**4,761,082**	**4,580,669**	**5,394,652**
Load	Peak Load (kW)	867	825	1,018
Load	Average Peak Load (kW)	761	669	840
Load	Average Load (kW)	564	500	613
Gen	Generation Losses (kWh)	417,902	366,603	471,152
Gen	Generation Losses (%)	8.8%	8.0%	8.7%
Distribution	Distribution - Solar (kWh)	58,586	57,181	65,179
Distribution	Distribution - Total (kWh)	4,289,856	4,129,561	4,860,379
Distribution	**Total Sales (kWh)**	**4,001,172**	**3,670,519**	**4,406,445**
Distribution	Total Distribution losses (kWh)	288,684	459,042	453,934
Distribution	Total Distribution losses (%)	7%	13%	10%
Fuel	Fuel Consumed (Litres)	1,235,475	1,196,424	1,423,277
Fuel	Fuel cost per litre (Average)	2.0328	1.3713	1.3881
Fuel	Fuel Saved from Solar (litres)	15,203	14,935	17,196
Fuel	Average Fuel Consumed per day (litres)	3,688	3,571	4,249
	Fuel Efficiency (kWh per fuel litre)	**3.85**	**3.83**	**3.79**
Factors	Load Factor (%)	65.1%	60.6%	60.2%
Factors	Capacity factor	33.0%	29.2%	35.8%
Factors	Utilisation factor	48.4%	48.2%	59.5%

Table 2 - Data Table Provided by TEC

Fuel Efficiency

Based on Table 1 data, fuel efficiency for the Fogafale Power Station is in the neighborhood of 3.80 kWh/liter (e.g., kWh produced per year / Fuel Consumed in Litres per year). However, efficiency has been gradually declining over the past few years, even though the capacity factor has increased. These fuel efficiency results suggest that there may be opportunities for improving the way that TEC dispatches its generation on Funafuti Atoll.

Station Losses

The average power station losses (own usage) for 2008-2010 were 8.5%, which is a relatively high value. In addition, TEC's office energy usage is also served directly from Fogafale Power Station. Based on data provided by TEC its office usage was 137,122kWh in 2010 which equates to an additional 2.51% of annual production.

3.3 Findings

KEMA's review of the Fogafale Power Station revealed that all of the units are all well maintained and in excellent condition. However, based on recorded generation fuel efficiency levels, TEC should consider looking into improvements to the economic dispatch methodology of the Fogafale units to improve generator fuel efficiency.

4. Distribution

The distribution system on Funafuti Atoll is comprised of underground cables with a mix of copper and aluminum conductors for all three feeders. The main 11 kV distribution loop is comprised of 50 mm^2 Cu direct-buried cables. There are also some 25 mm^2 Cu and Al cables used in other branches.

Feeder-1 goes directly to RMU-1, Feeder-2 goes to RMU-9 and Feeder-ES goes directly to RMU-ES. As indicated on the one-line diagram, all three feeders have an interconnection point at RMU-ES. Since no open points were identified on the one-line diagram provided, all 3 feeder tie switches were assumed to be normally closed.

A typical Ring Main Unit (RMU) transformer with switches is shown in Figure 3 below.

Figure 3 – Typical RMU with switches

The TEC distribution system is comprised of the following main equipment:

- Each feeder is connected to the New Fogafale 11 kV bus through a 12 kV vacuum circuit breaker (VCB).
- Feeder-1 and Feeder-2 each exit the station with 3 single-conductor, direct-buried 50 mm^2 copper (Cu) cables.
- Feeder-ES exits the power station with 3 single-conductor, direct-buried 25 mm^2 aluminum (Al) cables.
- New Fogafale and Old Fogafale Power Stations are connected through two parallel step-up transformers, rated 415V–11kV, 750 kVA each.
- There are 15 distribution transformers with total connected capacity of 3,030 kVA.
- The total TEC system load on Funafuti Atoll is 1,018 kW.

A one-line diagram of the Easy Power model is provided in Figure 4. A larger version of this diagram and an Excel spreadsheet with KEMA's loss calculations are included in Appendix C.

Figure 4 – System One Line from Easy Power

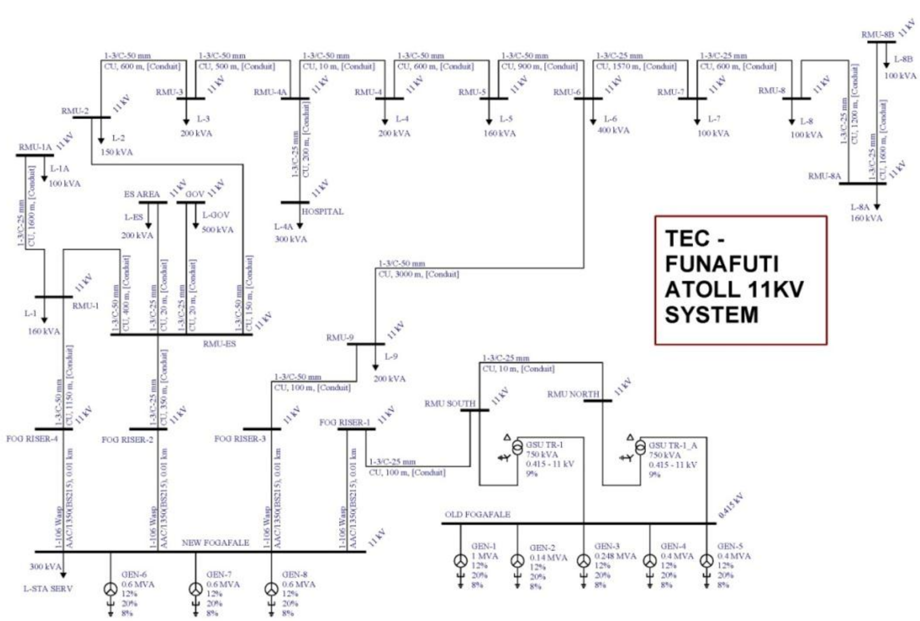

Figure 5 shows a typical daily production curve for Funafuti Atoll.

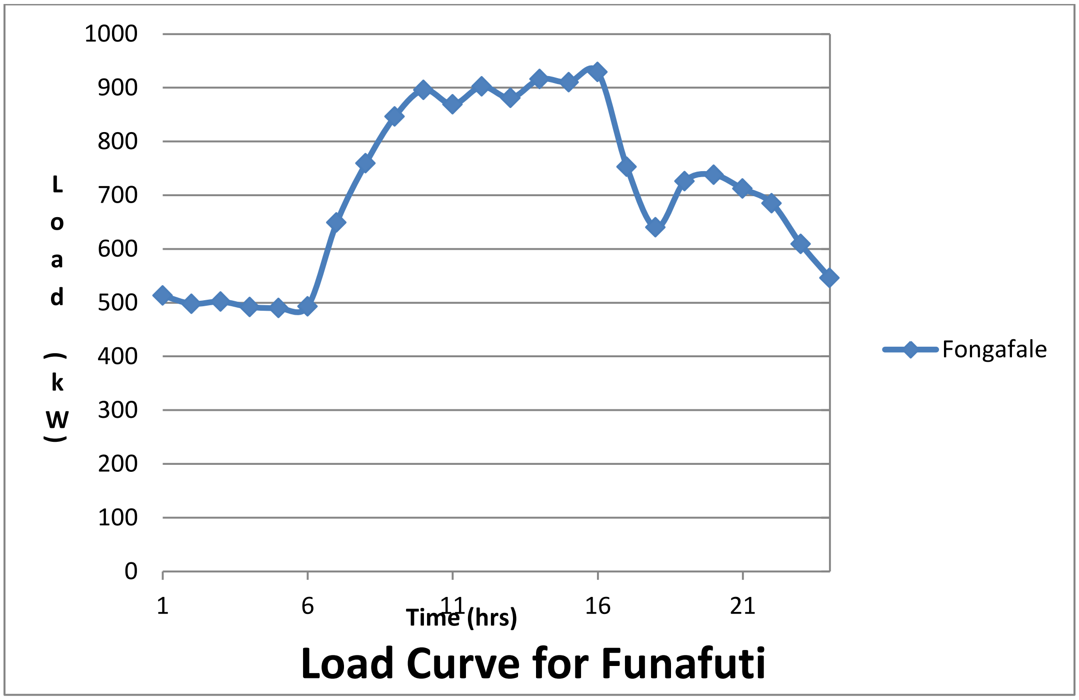

Figure 5 – Typical Daily Production Curve

4.1 Equipment

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

4.1.1 Distribution System

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

- From the New Fogafale Power Station feeder breakers, the 11 kV feeders exit the power station through a short overhead section (assumed to be 100 meters) before reaching the riser pole and underground getaway conductor.
- There are two 415V-11kV power step-up transformers in parallel that connect the Old Fogafale 415 V bus with the New Fogafale 11 kV bus.

- The 11 kV feeders and the power step-up transformers are connected to the New Fogafale 11 kV bus through vacuum circuit breakers.

- The 11kV feeder getaways consist of 3 single-phase direct-buried 50 mm^2 Cu underground XLPE cables laid in a trefoil configuration. The exception is Feeder-ES, which exits the power station through 3 single-phase direct-buried 25 mm^2 Al cables.

- TEC has 15 distribution transformers installed on the 11kV distribution feeders, all of them 3-phase, with a total installed capacity of 3,030 kVA.

- Feeders 1 and 2 have a common tie point at RMU-ES, with normally open switches.

- There are no capacitor banks on the TEC system.

- There are also no shunt reactors on the TEC system.

4.1.2 LV Wires

The Fogafale power station auxiliary transformer (rated 300 kVA) feeds the station auxiliary loads at a voltage level of 415 V.

Typical secondary service wire types and sizes were assumed, based on the information provided during KEMA's visit.

4.2 Analysis of Losses

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

1. Calculations were based on 2010 annual energy production and consumption.

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

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

4. Actual voltage drops through primary feeders were calculated in system power flow model in the Easy Power. However, voltage drops were not considered in estimating losses for distribution transformers and secondary services wires.

5. Secondary wire losses were estimated based on average customer consumption. Typical secondary service wire types and sizes were assumed, based on information provided.

6. Assumptions were made for average wire lengths and general configuration. For TEC, the typical secondary line and service drop configuration is developed based on the Service Pillar drawings in Visio file provided for each distribution transformer.

TEC provided one-line diagram of its power system on the island of Funafuti Atoll. Feeder segment distance, conductor type and size, and kVA capacity of distribution transformers are identified on the one-line diagram. Based on this information, KEMA developed power flow model in Easy Power for TEC. In this distribution system model, the power plant and 11kV feeders are modeled. Distribution transformers are represented as spot loads with load power factor of 0.9 lagging.

There are 3 RMUs – RMU1, RMU ES and RMU9 - where electric power enters the distribution system. No normally-open point was identified along 11kV primary feeder loop in the information provided by TEC. Therefore the distribution system was modeled as a normally-closed loop[1].

Losses in kW through the primary feeders and generating station step-up power transformers are calculated in the power flow study for the system peak demand. Load allocation was based on distribution transformer capacities connected to each feeder. KEMA modeled peak customer demand in the power flow of 1018kW. Since there is a total connected distribution transformer capacity of 3030 kVA, the average transformer utilization factor is 37.33%.

On Funafuti Atoll, electric power is supplied from both the thermal generating station and the solar power facilities. In 2010, annual generation production consisted of 5,394,652 kWh from the thermal generating station and 65,179 kWh from the solar facilities. A total of 8.63% of this combined annual generation production was used to supply the thermal power plant's own usage of 471,152 kWh. TEC also advised that its own building usage of 137,122 kWh was

[1] KEMA notes that generation statistics in the 2010.xls file from TEC indicated that no energy was delivered through the RMU-ES feeder. This could be a metering error, a data recording error, or it could indicate that the loop is actually open at RMU-ES. This needs to be verified by TEC and, if the actual topology is not normally-closed, it could have a slight impact on the technical losses shown in this report.

supplied from the power plant terminal bus in 2010. Energy delivered to the distribution system from the power plant in 2010 was measured as 4,795,200 kWh.[2]

Distribution transformer losses were estimated with actual loss data indicated in the excel file *TEC - Loss Model - comments.xls* provided by TEC. Secondary wire losses were estimated with typical configuration and average customer consumption. Secondary system consists of wires connected from the low voltage (LV) side of distribution transformer to the customer meter. A typical secondary configuration used to estimate technical loss is described as following:

- From LV side of the distribution transformer to Feeder Pillar (HRC Fuse): 100mm^2 cable, 4 conductor + earth, copper with armor shielding; Dominion Cables (Fiji) and Olex (Australia). Typical length is 10 meter.

- From Feeder Pillar (HRC Fuse) to Service Pillars: 25mm^2 cable, 4 core + earth, copper with armor shielding. Distance from service pillar to service pillar range from 100 meter to 200 meter apart; typical distance of 150 meter is used for loss estimation.

- Number of customer connect to a service pillar depends on the number of customer living close to that particular service pillar, usually there are 9 – 12 fuses provided in each service pillar. Average number of customer per service pillar is calculated and used for loss estimation

- Most service main cable range from 4mm^2 – 10mm^2, 2 core + earth with armor shielding. Assumed with copper conductors. The length of the service drop depends mainly on the distance of the customer from the Service Pillar. Typical length of 100 meter from Service Pillar to customer meter is assumed and used for loss estimation. Typical service wire resistance is calculated as average resistance of 4mm^2, 6mm^2 and 10mm^2, and used for loss estimation.

- Assuming the typical secondary system is a tree structure, with the 100mm^2 cable as the trunk and the 25mm^2 cables as branches. Average number of branches per trunk is calculated based on the Service Pillar drawing in Visio file. Service Pillars are tapped along the 25mm^2 cable with equal distance of 150 meter. Multiple services drops are

[2] Equals summation of meter readings at RMU-1, RMU-ES and RMU-9 (Note: RMU-ES readings are zero).

connected from Service Pillar to customer meters as leaves. Average number of service drops per Service Pillar is calculated.

4.3 Findings

The total system losses equal the total energy entered into the distribution system out of power plants less the total energy sold and the energy unaccounted for. For TEC, the unbilled energy usage came from the street lights, which was given as 1% of annual generation; and TEC's own building usage, which was given as 2.51%. A summary of estimated losses is provided in Exhibit 4-1.

	kWh	% of generation	% of system consumption
annual generation power plant	5,394,652		
annual generation solar power	65,179		
total annual energy produced	5,459,831		
annual station auxiliary	471,152	8.63%	
office usage	137,122	2.51%	
annual system consumption	4,851,557	88.86%	
annual energy sold	4,406,445	80.71%	90.83%
system loss including unbilled usage	445,112	8.15%	9.17%
unbilled usage	54,598	1.00%	1.13%
technical loss	197,647	3.62%	4.07%
non tech loss	192,866	3.53%	3.98%

Table 2 - Loss Estimation (Based on 2010 Data)

The estimated technical losses for the TEC system are 3.62% of annual generation, while the non-technical losses are estimated to be 3.53% of annual generation. These values are both within acceptable range.

KEMA also made the following observations in regard to technical losses:

1. TEC has only 15 distribution transformers, but these represent a total installed capacity of 3030 kVA (an average of over 200kVA per transformer). The results show that distribution transformer losses accounted for 38.08% of the annual technical losses, with 30.05% as no-load (core) loss and 8.03% as copper loss.

2. Using 15 distribution transformers to serve 1018 customers yields an average of 72 customers per distribution transformer. This is a large number of customers per transformer and results in relatively high secondary wire losses, which include losses through the main cable (the secondary cable connecting the distribution transformer to the feeder pillar), the secondary line (the secondary cable connecting the feeder pillar to the service pillar), and the LV secondary wire and service drop. However, since the main cable and LV secondary line are three phase, losses are relatively low when compared to single phase connections serving the same amount of load. KEMA estimates that secondary losses represent 57.46% of the TEC annual technical losses.

A few other recommendations that would improve loss estimation in the future are as follows:

1. Regularly update the Easy Power model to stay accurate with system upgrades and improvements.

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

3. Continue to record peak demand data and update the load and loss factors for the system. Load factor represents how much peak load varies from system base load.

4. Continue meter monitoring and meter calibration to improve the accuracy of historical data.

5. Keep a record of all power equipment data received from manufacturer's including equipment specifications, name plate information and test data.

These measures will help to improve the accuracy of the Easy Power model and the assessment of system losses.

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. Non-reimbursed power deliveries (for example for street lighting or water company activities) are a financial loss for the company and not a non-technical system loss.

As shown in Table 2, the non-technical losses appear to be fairly low (3.53%).

5.1 Sources of Non-technical Losses

5.1.1 Metering Issues

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

5.1.1.1 Aged Meters

KEMA does not have good data on the condition of the meter population, but it seems to be well maintained, but not tested. A program of periodic meter testing and replacement of inaccurate meters is recommended if not already being done for the TEC system. Since TEC does not have a meter test facility, KEMA recommends that meters be tested by a third party.

5.1.1.2 Electricity Theft, Meter Tampering and Bypassing

TEC advises that its meter readers very seldom report tampered or by-passed meters. Since non-technical losses are fairly low, energy theft may not 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. Based on KEMA's observations, electricity theft, meter tampering, and meter by-passing currently do not appear to be significant issues on Funafuti Atoll at this time.

5.1.1.3 Inaccurate Meter Reading

Inaccurate meter reading will result in irregular monthly figures for power usage. The responsibility for noticing irregular usage figures is on the administrative personnel. Most inaccurate readings can be corrected by the next meter reading. However, at this time meter inaccuracies and meter reading errors do not appear to be major contributors to TEC's non-technical losses.

5.1.2 Billing Losses

TEC 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 Administrative Failures

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

5.1.5 Line Throw-ups

Line throw-ups do not exist since the TEC distribution system is entirely underground.

5.2 Related Observations

The condition of the TEC system on Funafuti Atoll at the time of KEMA's visit was extremely good. Overall the electric system seems to be well maintained and in good working order. Also, TEC staff provided extremely useful metering information that KEMA used to estimate the system losses.

Since non-technical losses were so low, the TEC metering, billing, and maintenance practices seem to be correct. Theft and other losses are apparently not a problem, either.

6. Overall Findings and Recommendations

This chapter provides a compilation of findings and recommendations. Overall, KEMA found that TEC's existing system practices (design, operating, metering) should be continued, although there may be some opportunities for improvement as discussed below.

6.1 Generation

The fuel efficiency for Fogafale Power Station has been averaging 3.82 kWh/liter over the past few years. However, this figure has declined from 3.85 kWh/liter in 2008 to 3.79 kWh/liter in 2010. While this is a fairly good figure, it might be improved by changing the way the units are dispatched. TEC should consider options for its generation dispatch that could improve the overall fuel efficiency.

Fogafale Power Station's own usage was provided as 8.7% of thermal production (8.63% if including production from the PV station). This figure excludes office loads served from the power station, which consume another 2.51% of the annual energy production. These station losses are fairly high and suggest that a more detailed energy efficiency audit of the station, and particularly the office use, would be beneficial.

6.2 Distribution

The technical losses on the TEC distribution system are 3.62%, which is in the normal range. A typical figure is 5%, and TEC's technical losses are well below that.

KEMA recommends that TEC take advantage of the distribution transformer load data available to develop transformer loading, loss, and asset condition assessments. This can be accomplished 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. This will provide more information on individual distribution transformer loading and asset condition.

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.

6.3 Non-Technical Losses

The non-technical losses on the TEC distribution system are 3.53%, which is also in the low to normal range and does not appear to pose any concerns at this time.

TEC should determine if irregular metering figures can be detected and flagged by the Customer Information System.

7. Suggested Equipment Replacement

During KEMA's site visit to the island of Funafuti Atoll in Tuvalu we observed TEC's generation, distribution, and metering equipment. Based on our evaluation of the current equipment, we considered equipment replacement opportunities that would yield energy savings if TEC makes the required capital investment.

The conclusion of this process is that there does not appear to be any urgent replacement needs related to loss reduction. However, there may be future opportunities to reduce no-load losses on TEC's 15 distribution transformers. On average these transformers are loaded to 37.33% of nameplate capacity during the peak load condition. Since this is relatively light loading it means that the no-load (core) losses on many of the transformers is higher than desired. Therefore, KEMA recommends implementing a goal for replacing existing transformers with smaller kVA rated units when existing transformers need to be replaced due to end or life issues. Evaluation and selection of replacement transformers should be done through a Net Present Value analysis that includes the purchase price as well as the core and copper losses.

The distribution system on Funafuti Atoll is comprised mostly of underground cables with a mix of copper and aluminum conductors for all three feeders. The main 11 kV distribution loop is comprised of 50 mm^2 Cu direct-buried cables. There are also some 25 mm^2 Cu and Al cables used elsewhere. These conductors seem to be 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 solely for the purpose of reducing losses. However, if system load changes require an increase in conductor size, then consideration should be given to losses in the choice of the replacement conductor size.

Thermal losses can also occur at specific locations on the distribution system due to corrosion, bad connectors, and other undesirable maintenance conditions. These should be eliminated 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 Funafuti Atoll, preventative inspections such as this at regular periodic intervals can identify potential problems.

A. Data Handbook

See attached TEC data handbook.docx

B. Loss Worksheet

See attached TEC loss worksheet.xls

C. Easy Power Model

See attached TEC.dez