KEMA

Quantification of the Power System Energy Losses in South Pacific Utilities

Electric Power Corporation, Samoa

Submitted to

European Union

Pacific Islands Forum Secretariat

Prepared by KEMA International B.V.

Final Report - May 22nd, 2012

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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.

Project objectives and deliverables:

- Quantification of energy losses in the power system.
- Preparation of an Electrical Data Handbook containing electrical characteristics of the power system high voltage equipment.
- Preparation of a digital circuit model of the power system using EasyPower, an established commercial package.
- Identification of sources of non-technical losses.
- Recommendations for strategies on reducing technical and non-technical losses.
- Preparation of a prioritized replacement list of power system equipment to reduce technical losses.

This report summarizes study results for Electric Power Corporation (EPC) in the Independent State of Samoa. EPC is producing and distributing power in the islands Upolu and Savaii. Power consumption in Savaii is around 10% of power consumption in Upolu. For this report the study is focused on the power system of Upolu only.

The scope of the study for EPC has been changed however - as agreed upon with the PPA, the funding agencies and the management of EPC – after it became clear during KEMA's site visit to EPC that a study on grid losses has already been performed for EPC in 2007, while EPC also possessed a digital circuit model of its power system already, and while a comprehensive handbook with data on the power system high voltage equipment was also available at EPC, in the stage of finalization.

The revised scope for EPC has been determined and agreed upon as follows:

1. Review of the study as performed in 2007 and update of the 2007 results using recent data of 2010;

2. Review and comment on the EPC data handbook;
3. Add the new power plant to the power system model and deliver a working model for stability studies based on data to be provided by EPC. This way the model will become ready for performing stability and protection studies which is of importance for EPC;
4. Review the loss reduction plan, identify results already booked because of measures that have been implemented and give comments when appropriate.

1.1 Quantification of losses

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

- Station Losses: Efficiency of generating units and power plant auxiliary loads
- Distribution System Losses: these losses can be divided into technical and non-technical parts.
  - Technical losses: Summation of transformer core losses, transformer copper losses, distribution feeder losses, secondary wire losses and losses of any other equipment in the system, like reactors, capacitor banks. Technical losses will become higher as power factors drop below unity.
  - Non-technical losses: inaccurate meters, meter tampering or by-passing, theft, meter reading errors, irregularities with prepaid meters, administrative failures, wrong multiplying factors, others.
  - Unbilled Usages: Energy consumption that is not billed should be considered a financial loss for the company rather than a non-technical loss.

When studying the Report called “System Loss Reduction Project by JICA Senior Volunteer H. Sato” as prepared for EPC in 2007 (further called the “2007 Report” in this Report) we identified that:

- Losses in secondary wires have not been quantified;
- Non-technical losses have not been identified;

- Station Losses were not identified.

Furthermore no attention is paid in the 2007 Report to generation efficiency. With data as provided KEMA estimated losses using the methodology as used for all studies for the South Pacific Islands. Furthermore KEMA has looked into Station Losses and generation efficiency. For the different calculations assumptions have been made where information was not sufficient.

In addition to that, KEMA estimated losses in the secondary wires using our own methodology, since this loss category is not estimated in the report for 2007. With this secondary losses estimated, KEMA is able to derive non-technical losses while in the 2007 report, non technical losses were not identified. Where information was not sufficient, assumptions were made to facilitate the estimation.

1.2 Energy System Losses

KEMA's analysis of the EPC power system determined total losses of 16.41% consisting of:

- 1.28% in power station auxiliaries (station losses), which is relatively low.
- 6.67% in technical losses, which is a typical value.
- 7.56% in non-technical losses, which is a rather high level.
- 0.90% in unbilled usage for street lights and Magiagi.

Although unbilled usage cannot be considered to be a true system loss, it is still a financial loss for EPC because the power is delivered for services (street lighting) that are not paid for. It is highly recommended that EPC considers calculating the actual usage for street lights and includes it as a financial loss in future financial statements.

When not taking the 0.90% for financial losses into account, the results of KEMA's calculations for quantification of the EPC power system losses are as follows:

1.28% in station losses.

14.23% in system losses.

1.2.1 Generation

In addition to analyzing power station and distribution system losses KEMA also looked at figures from the year 2010 on the generators' ***fuel efficiency*** in the island of Upolu.

Some 42% of the electrical energy has been produced in Upolu with hydro power units. In total EPC has 8 hydro units in Upolu of which one unit was out of service through the year 2010.

The other 52% of electrical energy has been produced in Upolu with Diesel # 2 with a contribution of coconut oil of some 0.05%. Furthermore around 6 MWh has been produced in 2010 by PV panels.

Total production in 2010 was 100,442 GWh, with a peak load in May 2010 of 17.99 MW. (Production in the island of Savaii was 11,418 GWh in 2010, with a peak load of 2.83 MW in March 2010).

The average fuel efficiency of the diesel fired generating units in Upolu has been 3.736 kWh/liter. With inclusion of the newly installed Cummins engines that came online by the end of 2010, 14 diesel fired production units are installed of which 5 are hire sets. None of the engines showed fuel efficiency higher than 4 kWh/liter, one engine (nr. 12) even showed a fuel efficiency of lower than 3 kWh/liter.
For engines with a capacity of 3000 to 4000 kW the fuel efficiency should be minimal in the range of 4.2 kWh/liter, particularly when generators are dispatched economically.

The ***power station's own usage*** is 1.28% of the total power generated, which places EPC as best in class compared with other Pacific utilities.

1.2.2 Distribution

The technical losses in the distribution system amount to 6.67% which is a typical value.
A breakdown of the technical losses as calculated shows the following loss percentages:

33 kV and 22 kV line losses	1.24%
Feeder losses	1.78%
Transformer losses	2.22%
Secondary wire losses	1.43%
Total technical losses:	6.67%

These figures all look reasonably well, while the loss figure for the secondary wires can even be categorized as a ‘best in class’ figure.

1.2.3 Non-technical

KEMA’s calculations show that non-technical losses are only 7.56% of total energy generated, which should be considered too high.

EPC informed us that incidents of electricity theft, meter tampering, and meter by-passing occur and that a Meter Tamper and Electricity Theft Policy will be developed, with furthermore the implementation of increased meter spot checks.
Although not related to non-technical losses also priority is given to debt recovery policies such as Disconnection and Reconnection Policy, Prepayment Meter Policy and Bad Debt and Write-Off Policy. The objective of these policies is to improve the collection of debts.
As observed in other places the increase of non-technical losses is quite often going hand in hand with the increase of bad debt.

KEMA would like to emphasize that other non-technical loss causes should also be examined systematically, such as accuracy of the meter population, problems as mentioned in this report occurring with prepaid meter tokens, wrong information because of meter readings and dispersed meter reading cycles, administrative failures and others. An approach for combating non-technical losses is described under section 6.3 of this report.

As already indicated these non-technical losses do not include power usage for streetlights, which have been separated from the system losses and are considered to be a financial loss for EPC.

1.2.4 Metering

KEMA observed that EPC uses different meter reading dates for energy production versus energy sales. In order to have a more accurate correlation between energy sold and energy entering into the distribution system, it would be better to perform the monthly customer meter reading around the last day of each month. This way the energy sales data would cover more closely the same monthly period as the monthly generation statistics, and the calculated losses will therefore have a higher accuracy.

Furthermore EPC has encountered problems with the prepayment meters in the years 2010 and 2011 which may have caused additional non-technical losses.
EPC has planned to replace at least 75% of existing conventional meters with prepayment meters by the end of 2012. It is advised to randomly check the aged population of electromechanical meters for accuracy and replace meters when appropriate.
Furthermore generator meters and feeder meters should be checked for their class and accuracy. In fact these meters should be revenue class meters. As KEMA understood a meter recalibration program should be started by the end of 2010 to maintain both the necessary accuracy of production as well as of customer meters.

1.3 System Data Handbook

KEMA has received data as present in the DigSilent model as well as power generation data from EPC, but not to the extent that a Data Handbook could be prepared with all data and characteristics of the EPC high voltage equipment. During the site visit in June 2011 it appeared to KEMA however that EPC has an extended database with data of all its power system assets, in fact a Data Handbook. This database was set up in Excel and the printed booklet was at a large size, most probably having the A3 format.

As part of the revised scope of work for EPC, KEMA should review and comment on the Data Handbook. We have repeatedly asked EPC to send the database (hand book) to KEMA for a review and for giving comments where appropriate.

1.4 System Model

After the visit to EPC in June 2011 KEMA received the Power System Model in DigSilent software, representing the actual situation of the Upolu Power System. There were some limitations however because the EPC license for DigSilent only allows for a maximum of 200 buses. Some months later KEMA received a new version of the Power System Model, which should represent the future situation. The future situation showed hardly any overlaps with the present situation and part of the existing data was left out, most probably because EPC's license only allows usage of a maximum of 200 buses.

In February 2012 KEMA received data of the new Fiaga power station and new Transmission Line Routes i.e. two from Fiaga to Fuluasou underground & overhead & one underground from

Fuluasou to Tanugamaono, as well as two overhead line Feeder Routes coming out of Fiaga called Lefaga and West 1.

KEMA has added the information in the EPC DigSilent model, having the advantage of no limitation in buses. However, it is recommended that EPC changes its licenses so the complete model can be used for EPC's calculation purposes.

The updated EPC DigSilent model is provided in Appendix B.

1.5 Loss reduction plan

The major efforts on loss reduction should be spent on reduction of non-technical losses, since power station losses are at a very acceptable level and technical losses are also at a reasonable level, although some recommendations are given in this report for further improvement such as developing a long term policy for reducing transformer losses, investment in infrared equipment for detecting hot spots and possibly installing capacitor banks if measurement s have shown low power factor in certain grid parts.

EPC already initiated actions for combating non-technical losses. These initiatives are mainly focused on theft and meter tampering. It is KEMA's experience that non-technical losses have much more causes which have to be identified and addressed. In chapter 6 we have outlined an approach for systematically combating non-technical losses, by a number of actions and by conducting audits of the whole process from meter reading to billing and last but not least by appointing a Revenue Assurance Officer who will be responsible for initiating and executing a Loss Reduction Strategy.

1.6 Prioritized list of equipment for replacement

Out of the findings and recommendations in this Report it can be derived that the following replacements are to be recommended:

- Replacement of aged electromechanical meters in case random testing of a number of old meters shows that the accuracy of these meters has exceeded the accuracy class. One could also consider cleaning and gauging all meters, which however would be time consuming while the cost of new meters are relatively low.

- Replacement of malfunctioning prepayment meter pads and installing of a renewed system of tokens should is supposed to be completed since 2010/2011 or is maybe still ongoing. This is important for achieving less non-technical losses.

- Generator and feeder meters maybe need to be replaced after these meters have been checked. They may be out of the range of revenue class, even after recalibration.

- Based on the relatively low fuel efficiency of the diesel fired generating units KEMA would have proposed replacement of certain generating units justified by cost/benefit analyses. However, EPC will install four new 5 MW generating units in Fiaga and by the end of 2011 also some 6 MW of generating capacity has been added. On top of that all engines will have had a major overhaul by the end of 2011, as stated in the Corporate Plan 2011-2014, which means that the overhauled generation units will also have improved efficiency while none of the current units will be decommissioned. It is assumed that the hire sets will be removed. When also counting the hydro production capacity of EPC the reserves margin of EPC's generation capacity will grow far over 100% after the new engines in Fiaga have been put into service.

- For T&D no replacements are recommended after the re-conductoring program has been completed. Power factor problems may ask in the future for adding capacitor banks.

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 utilities' 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 EPC in Samoa for data collection and technical assessments of the power system, KEMA has sent data request documents to EPC in February, 2011. The major Data Request document contained a list of all data needed for the study, while an additional Excel document was sent for entering all required data of equipment and system components.

Subsequently KEMA visited EPC in Samoa in June 2011, for data collection, interviews and an assessment of the power system.

During the visit a number of relevant data has been gathered, although not all data was readily available. Personnel at EPC was providing information on the grid model in PowerFactory and it appeared that the number of buses available from the software license was too limited for having the grid completely modeled. Also a Handbook with data of EPC assets was shown. The Handbook appeared to be close to completion.

Furthermore a report has been shown on quantification of technical losses in the year 2007. This report called "System Loss Reduction Project by JICA Senior Volunteer H. Sato" did not cover losses in secondary wires and non-technical losses.

After the visit additional data has been requested, which in the end resulted in the situation that for the quantification of losses study we had to make assumptions, based on our experience, particularly in the areas of:

- electrical parameters of the generating units,

- information on transmission lines and feeders,
- load distribution and number of customers in the feeders,
- transformer data.

Without this information loss calculations can in fact not be made. For that reason we took the information of the earlier Report of 2007 and recalculated losses in this report while making use of load statistics and customer information of the year 2010. We also assumed that measures for reducing technical losses have not really been effectuated in 2010. During the site visit in June 2011 we noticed that re-conductoring of certain feeders has been started. Also a program for addressing power factor issues in certain grid parts was not started yet.

2.2 Utility Operations

EPC in Samoa had a maximum load in the island of Upolu in 2010 of 17.99 MW. For the coming years a demand growth is expected of not more than 2% per year.

The power system consists of:

- 8 hydro units with a total (de)rated capacity of 11,450 kW in 5 different locations. In 2010 these hydro units contributed to 42% of the total production of electrical energy.
- In the Tanugamanono power station EPC's production with diesel fired generating units is concentrated with in total 12 generating units of which units 6B and 9A not running as we could observe in the statistics as provided. The power station has 4 main tanks with a total capacity of around 200,000 liter, a number of smaller service tanks and furthermore there are two coconut tanks (30,000 liter). Coconut oil contributes only around 1% of the total production compared to the production with diesel. The total running hours of the generating units in Tanugamanono power station is relatively low. In December 2010 engine no. 12 had the highest amount of running hours at almost 80,000 hours.
- It was planned during the time of our visit that by December 2010 5 new Cummins generators from China should be installed and in operation, adding 6 MW additional capacity to the system.
- A new power plant is being built at Fiaga. It is envisaged that in total 20 MW will be installed in this new power station in the year 2012, consisting of 4 units of 5 MW each. It

is expected that this will lead to a better fuel efficiency. With this unit size of 5 MW and a maximum load of 18 MW and a minimum load of around 13 MW the grid may become unstable if a 5 MW unit, when operating at full load, trips. Under-frequency load shedding may not work adequate if 28 to 38% of the production capacity trips, which means that attention should probably be paid to additional spinning reserve or an automated contingency arming system.

- 33 kV and 22 kV transmission lines
- 4 major substations
- 7 major feeder lines which are:
  - West Coast Feeder 22 kV
  - East Coast Feeder 22 kV
  - Vaitele Feeder 22 kV
  - South Coast Feeder 22 kV
  - Hospital Feeder 6.6 kV
  - Alaoa Feeder 6.6 kV
  - Beach Road Feeder 6.6 kV
- 30,458 customers.

2.3 Identifying and Quantifying Losses

Electric power is generated in power stations and delivered through transmission and/or 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:

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

System losses – losses occurred along power transferring through the transmission and distribution systems, such as transformers, overhead line conductors, areal cables or underground cables and service wires. At the metering point also losses may occur because of the accuracy margin of the meters.

System losses 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, etc.

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: 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 updated transmission and distribution system losses for the Upolu power system in 2010 based on the annual energy production, peak demand and energy sold figures for this year in comparison to the distribution system losses figures for 2007 as established in the report: Report for Upolu Grid System Losses 2007 from the System Loss reduction Project by JICA Senior Volunteer H. Sato. In addition to that, KEMA estimated losses in the secondary wires using our own methodology, since this loss category is not estimated in the report for 2007. With the secondary losses estimated, KEMA is able to derive non-technical losses while in the 2007 report, non technical losses were not identified. Where information was not sufficient, assumptions were made to facilitate the estimation.

Another task KEMA completed for EPC is updating the "Current System" power flow model in DigSilent Power Factory. Specific efforts including: 1) add 3 additional transmission lines, 2) add the new FIAGA power station, 3) add the dynamic model for all generators in support of future stability studies. Since the new equipments added in 1) and 2) will not be in service until 2013, they are set in out-of-service state in the model.

3. Generation

In total EPC has ***8 hydro power units*** with a total (de)rated capacity of 11,450 kW in 5 different locations as follows:

- 1 unit in Alaoa: 1000 kW
- 1 unit in Fale ole Fee: 1650 kW
- 2 units in Samasoni: no. 1 - 660 kW
  no. 2 - 640 kW
- 2 units in Lalomauga: no.1 - 1750 kW
  no. 2 - 1750 kW
- 2 units in Taelefaga: no. 1 - 2000 kW
  no. 2 - 2000 kW

In the Tanugamanono power station EPC has 12 diesel fired generating units of which units 6B and 9A were not running in 2010 and of which unit PM 4A has been removed of the list of Mirrlees units as we could observe in the statistics as provided. Five of these generating units are hire sets. Total generation capacity of the diesel fired units is 18,820 kW.

The plant has the following 4 Mirrlees gensets:

PM 5A: 3500 kW

PM 7A: 4000 kW

PM 9A: 3000 kW

PM 12: 3000 kW

furthermore the following 2 Cummins units:

No. 13: 640 kW

No. 14: 640 kW

And 5 hire sets named NZGH1, NZGH2, NZGH3, NZGH4 and NZGH5 each with a generation capacity of 800 kW, with exception of NZGH4 which has a generation capacity of 640 kW.

If diesel fired engines and hydro power engines can all be considered to be available for base load the total capacity will be 30,270 kW, which means that EPC's reserve capacity is 68% based on a peak load of 18,000 kW, which is a quite high reserves margin.

Furthermore, if all engines are operable, the power supply can even be maintained in an n-3 situation.

The fuel efficiency of the diesel fired units is low (3.736 kWh/liter) which may be caused by:

- non economic dispatch
- maintenance issues, including issues with cooling, filters, etc
- bad fuel quality

It was planned during the time of our visit that by December 2010 5 new Cummins generators from China should be installed and in operation, adding 6 MW additional capacity to the system and - as can be expected - with a higher fuel efficiency.

Furthermore a new power plant is being built at Fiaga. It is envisaged that in total 20 MW will be installed in this new power station in the year 2012, consisting of 4 units of 5 MW each. It is expected that this will again lead to a better fuel efficiency.

In theory such an expansion would not be needed yet, looking at the available generation capacity and also looking at the relatively low amounts of running hours of the existing diesel fired engines.

Issues on the condition of the existing engines and their low efficiencies may have led to the decision of building the new Fiaga power plant, supported by a positive cost/benefit analysis in case of replacing oldest and most inefficient units by the new 5 MW units in Fiaga.

3.1 Analysis of Losses

When it comes to analysis of losses in Generation we can identify the generation efficiency and the station losses (own usage).

Fuel Efficiency

On the topic of fuel efficiency of the diesel fired engines it has already been shown that the level of fuel efficiency is too low with an average value of 3.736 kWh/liter and with some engines even around or under 3 kWh/liter. As mentioned before new Cummins engines have been added and in Fiaga 4 units of 5 MW will be installed. It was first assumed that these new generators will replace older units with low fuel efficiency but instead the Corporate Plan 2011-

2014 that has been issued indicates that ALL diesel engines in Upolu will have had a complete overhaul by December 2011. Fuel efficiency will therefore increase while still the efficiency of older unilts that will remain available for power supply should be brought at highest efficiency by optimizing the engines' performance.

Station Losses

As already mentioned station losses are very low at 1.28%, which does not give much room for further improvement. It should be monitored and controlled that the current low amount of station losses will remain at this level.

3.2 Findings

The analysis has shown that the power station is operating at low fuel efficiency, but that a substantial amount of new generation will be added, by which fuel efficiency will improve and will stay at a better level in case of economic dispatch of the engines and continuous maintenance at an appropriate level.

On the issue of power station own usage it is clear that the own usage is already very low and it should be taken care of to keep the station losses low, also once new generation has been installed.

4. Transmission and Distribution

The EPC transmission system consists of 33 kV and 22 kV substations and lines.

There are 4 major substations with Tanugamanono at 22 kV. From there a 33 kV line goes (via a 22/33 kV auto-transformer) to 22 kV substations Lalomauga & Taelefaga where the line comes in again via a 33/22 kV auto-transformer. Also via a 22/33 kV auto-transformer an underground cable connection goes to the 33 kV busbar of substation Fuluasou. In this substation the 33 kV busbar is connected to a distribution busbar via two auto-transformers, and from this distribution busbar four local feeders are going out for distribution. From the 33 kV busbar at Fuluasoa two 33 kV lines have been planned for connecting the transmission system to 33 kV substation Fiaga where the new 5 MW generators will be connected.

Next to the 33 kV and 22 kV transmission lines (of which one 33 kV line is an underground cable connection) the distribution is at 22 kV and 6.6 kV level, of which the 7 major feeder lines are:

7 major feeder lines which are:

- West Coast Feeder 22 kV
- East Coast Feeder 22 kV
- Vaitele Feeder 22 kV
- South Coast Feeder 22 kV
- Hospital Feeder 6.6 kV
- Alaoa Feeder 6.6 kV
- Beach Road Feeder 6.6 kV

4.1 LV Wires

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

The secondary wire commonly used on the island is overhead 6, 10 and 16 mm, twin core. This is used mostly for the service lines. It average length can vary from 25 to 100 m. Fly is used for LV lines on the secondary side of transformers. Fly is Aluminum core, 60mm with a max resistance at 30 deg of 0.451 ohm/km. It is assumed that the typical secondary system is in tree structure, with the 3-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.

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 (01/2010-12/2011) was used for the study.

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

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

EPC has provided the one-line diagram of its power system in Upolu grid. A power flow model of the Upolu grid is provided in DigSilent PowerFactory and KEMA updated the model with transmission lines and power station that are under construction and expected to come online toward the end of 2013.

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.

A brief discussion is provided here to explain the approach KEMA took on updating the losses of the transmission line, primary feeder and transformers. We really do not have enough information to estimate those losses for 2010. To reflect the losses for 2010, 2007 losses estimation from existing report are scaled proportionally to reflect the changes in annual production, peak demand and loss factor. By doing that, it is assumed that system equipments and electrical connectivity changes does not have significant effect on loss estimation. By doing this, the figures for each category calculated in existing report and adjust it by the following factors:

- For transformer no-load losses, no change. Since total number of transformer is not provided, it is assumed that there is no significant change between year 2007 and 2010.

Since transformer no-load losses are constant existence for transformer in service, loss figure for this category is the same for 2010.

- For all other system losses, including transformer load losses, transmission and distribution conductor losses, they are i2R losses. Annual loss in kWh= loss in kW * 8760*loss factor. What's changed between 2007 and 2010 are loss in kW, as well as the loss factor. It is assumed that loss in kW is proportional to square of peak kW demand, together with the loss factor calculated for both 2007 and 2010, losses in kWh are calculated based on loss in kWh figure provided in 2007 report.

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. Secondary wire information was provided by email from EPC in Nov. 15, 2011, the secondary wire commonly used on the island is overhead 6, 10 to 16 mm, twin core. This is used mostly for the service line. It average length can vary from 25 to 100 m. Fly is used for LV lines on the secondary side of TX. Fly is Aluminum core, 60mm max resistance at 30 deg ohm/km = 0.451. Based on this, KEMA developed typical secondary wire configuration to estimate secondary losses. Assuming the typical secondary system was in tree structure, with the 3-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. Number of customer for 2007 and 2010 are identified from annual report[1]. The typical secondary system is described below:

- Service Line (SL), also referred as LV feeder or secondary feeder (in contrast to 11kV feeder as primary feeder). Service Line connects from LV side of the distribution transformer with service drops tapping along it. Assuming in average, there is 1 SL per distribution transformer with average length of 500 meter per SL. Typical SL cable is assumed as FLY 60mm^2 Aluminum 3-phase cable, with resistance of 0.451 ohm/km.

- Service Drops (SD) are tapped from SL and extended to customer meter. Typical SD was assumed as single phase 10mm^2 Aluminum cable with average length of 20 meter for loss estimation.

[1] Annual report published in EPC website: http://www.epc.ws/imgsrcPortals56abouticonjpgaltAbout/PoliciesPublications/tabid/1536/language/en-US/Default.aspx

- Average number of customer per Service Line was calculated for loss estimation
- Average customer consumption kW is calculated for all customers for loss estimation.

4.3 Findings

The total system losses equal to the total energy entered into the distribution system out of power plants subtracted by total energy sold and the energy unaccounted for. For EPC unbilled energy usage came from street light and energy used in Magiagi. Both unbilled usages for 2010 are estimated as the same as in 2007. A summary of estimated losses is provided in Exhibit below.

Exhibit 4-1: Loss Estimation for 2010 in Comparison to 2007

	2007		2010	
	Amount	**% total production**	**Amount**	**% total production**
Peak Energy Produced kW	18000		17943	
Total Production MWh	106317		100442	
Power Station Usage	803.2	0.76%	1283	1.28%
Power Station Usage average kW demand	92		146	
Power for Sale (System Consumption) MWh	105513.8	99.24%	99159	98.72%
Estimated System Peak Demand kW	17908		17797	
Energy Sold MWh	90165	84.81%	83965	83.60%
Unbilled usage street light MWh	631.45	0.59%	631	0.63%
Unbilled usage Magiagi MWh	270.3	0.25%	271	0.27%
System loss MWh	14447.05	13.59%	14292	14.23%
System loss figure in 2008 report[2]	14507	13.65%		

[2] As indicated in this line, there is a small mismatch from the System Loss figure as indicated in 2007 report, compare to the value as calculated from the system production and sales figure.

Based on data provided by EPC, for 2010, among the total energy production, EPC Upolu system has 1.28% station loss, 0.9% unbilled usage and 14.23% system loss.

Categories of losses within technical losses were estimated and non-technical losses is derived. A summary of loss in each category is provided in table below.

Exhibit 4-2: System Loss Estimation in Categories for 2010 in Comparison to 2007

Loss categories	2007			2010		
	MWh	% total production	% of system loss	MWh	% total production	% of system loss
Total system loss	14507	13.65%	100.00%	14292	14.23%	100.00 %
HV line loss	3378.2	3.18%	23.29%	3030	3.02%	21.20%
total feeder line loss	1989.5	1.87%	13.71%	1784	1.78%	12.49%
22kV transmission line loss	330.7	0.31%	2.28%	297	0.30%	2.08%
33kV transmission line loss	1058	1.00%	7.29%	949	0.94%	6.64%
Transformer loss	2333.4	2.19%	16.08%	2236	2.23%	15.64%
Main transformer	544	0.51%	3.75%	510	0.51%	3.56%
no-load loss	209.3	0.20%	1.44%	209.3	0.21%	1.46%
load loss	334.7	0.31%	2.31%	300	0.30%	2.10%
Distribution transformer	1789.4	1.68%	12.33%	1726	1.72%	12.08%
no-load loss	1174.2	1.10%	8.09%	1174.2	1.17%	8.22%
load loss	615.2	0.58%	4.24%	552	0.55%	3.86%
LV line losses	8795.4	8.27%	60.63%	9026	8.99%	63.1%
Secondary loss	1763	1.66%	12.15%	1438	1.43%	10.06%
Non-technical loss	7033	6.61%	48.48%	7589	7.56%	53.09%
Technical Loss	7474	7.03%	51.52%	6703	6.67%	46.91%

For 2010, EPC Upolu system technical losses were estimated as 5.84% of annual energy production, non-technical losses as estimated 8.39% of annual generation.

5. Non-Technical Losses

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

During the site visit we noticed that:

- Prepayment meters show irregularities and for that reason entry pads have to be replaced problems with tokens that clients can re-enter must be resolved by introducing a new system with 20 digit tokens instead of 16 digit tokens.

- Meters are read monthly with different intervals which causes large differences in monthly calculations of losses.

- Electricity theft, meter tampering, meter by-passing are phenomena that occur and need to be addressed.

EPC is enforcing the EPC Act 1980 which makes meter tampering a crime, while at the same time a public awareness program will be developed to advice customers on the consequences of meter tampering. Also an aggressive meter check program will be put in place. It is advised that also prepayment meters, which are not visited monthly for meter reading, are checked on a regular basis.

When summarizing probable non-technical loss causes we can identify that next to theft and meter tampering there may possibly be meter inaccuracies at old electromechanical meters, maybe meter reading inaccuracies and it also the administrative processes from processing meter reading up to billing should be audited, also looking at irregular usage patterns of customers, tariff data and data on multiplying factors.
As KEMA found in its loss calculations as summarized under Section 4.3 the non-technical losses appear to be high, namely 7.56%.

In Chapter 6.3 further suggestions are described for combating non-technical losses.

5.1 Sources of Non-technical Losses

5.1.1 Metering Issue Losses

In order to have a better match between energy sold and energy entering into the distribution system, it would be better to perform the monthly meter reading every month around the last day of this month. This way the energy sold is (almost) covering the same monthly period as the monthly generation statistics. This way – particularly when looking at a period of one year – the measured losses will have a higher accuracy.

5.1.1.1 Aged Meters

The condition of the rather old electromechanical meter population is not really known. EPC has planned to provide at least 75% of its customers with prepayment meters. Replacement of remaining old electromechanical meters should be considered once the results of suggested random checks are known.

5.1.1.2 Meter Tampering and Meter Bypassing

Meter readers are regularly confronted with tampered or by-passed meters. As already mentioned EPC wants to enforce that meter tampering is considered a crime by law, while aggressive meter checks have been planned.

5.1.1.3 Inaccurate Meter Reading

Inaccurate meter reading will lead to an irregular figure for power usage. The Customer Information System is supposed to give red flags when irregularities occur. In these cases meters should be inspected on site and clients should be asked for any reasons of the irregular usage. Clients will complain if they are charged higher because of inaccurate readings. This is happening very seldom.

5.1.2 Billing Losses

Billing losses can occur because of administrative failures or by applying wrong tariff categories to certain customers. Regular audits of the billing process and the billing data should be carried out.

5.1.3 Billing Collection Losses

Billing collection losses and bad debt are not to be counted to system losses. Any billing losses or bad debt amounts that have to be written off are financial losses and not system losses.

5.1.4 Loss through theft

As already mentioned EPC has identified losses through theft, often because of meter tampering.

5.1.5 Administrative Failures

The occurrence of administrative failures (in the process from meter reading to billing) should be investigated by conducting regular audits.

5.1.6 Line Throw-ups

No line throw-ups have been identified.

5.2 Analysis of Non-Technical Losses

When analyzing non-technical losses it can be noticed that the loss calculations show a high percentage of non-technical losses (7.56%). This percentage has been determined for the year 2010 by deducting the technical losses as calculated, from the total losses as found in the statistics. The non-technical losses were at 6.61% in 2007 as re-calculated, which means that non-technical losses have increased in 3 years time.

As described in section 4.3 the calculation of technical losses could only be done with a number of assumptions, and by making use of our experience and information of literature.

Non-technical loss causes that can occur are mentioned in chapter 5.1. From the information we have EPC's major issues for combating non-technical losses are measures to reduce meter tampering and resolving the issues as mentioned with prepayment meters.
Once an audit has been performed as advised in chapter 6.3 on all loss causes that may contribute to EPC's non-technical losses, there may be better information available for

performing an analysis of non-technical loss causes and on how to address identified issues that are causing non-technical losses.

5.3 Findings

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

- Non-technical losses are at a high level (7.56%)

- The electromechanical meter population is old. A random check of the accuracy of old meters could reveal information on the accuracy of the old meters. EPC has planned to replace at least 75% of all meters by prepayment meters, which means that the random check is still of importance for the remaining 25% of the meter population

- Theft, meter tampering and by-passing, are issues that will be addressed by EPC (tampering should be considered a crime by law, awareness programs, aggressive meter checks)

- Accuracy of generator and feeder meters will be addressed by recalibration of current meters or by installing new meters

- Problems with prepayment meters as already described in this Report are being resolved

- Since meter readings occur halfway in each month while the amount of “energy entering into the feeders” is compiled at the end of each month there is no accurate comparison between “energy entering into the feeders” and “energy sold”

- It has not been investigated yet what other non-technical loss causes could be contributing to the total of 7.56% non-technical losses. Chapter 6.3 gives recommendations on an approach to identify the whole spectrum of non-technical loss causes.

6. Findings and Recommendations

This chapter gives a compilation of findings and recommendation.

6.1 Generation

Fuel efficiency

Fuel efficiency of the diesel fired engines is too low with an average value of 3.736 kWh/liter and with some engines even around or under 3 kWh/liter. As mentioned before new Cummins engines have been added and in Fiaga four units of 5 MW will be installed. It is assumed that these new generators will replace older units with low fuel efficiency, although we have not seen decommissioning of old engines in the EPC Corporate Plan 2011-2014. Instead the Corporate Plan indicates that ALL diesel engines will have had a complete overhaul by December 2011. Fuel efficiency will therefore increase while still the efficiency of older units that will remain available for power supply should have been brought at highest efficiency by optimizing the engines' performance during the engines' overhaul in 2011.

Station Losses

As already mentioned station losses are very low at 1.28%, which does not give much room for further improvement. It should be monitored and controlled that the current low amount of station losses will remain at this level.

The analysis has shown that the power station is operating at low fuel efficiency, but that a substantial amount of new generation will be added, by which fuel efficiency will improve and will stay at a better level in case of economic dispatch of the engines and continuous maintenance at an appropriate level.

On the issue of power station own usage it is clear that the own usage is already very low and it should be taken care of to keep the station losses low, also once new generation has been installed.

6.2 Transmission and Distribution

Calculation of technical losses of the EPC transmission and distribution system showed to be 6.67% of all energy produced in 2010. In 2007 technical losses were at 7.03%. The reduction of technical losses may have been achieved by loss reduction measures as taken by EPC as taken after the 2007 losses study, such as re-conductoring certain feeders and addressing power factor issues in certain grid parts.

When looking at the total capacity of all distribution transformers, which we have estimated, these transformers are loaded at less than 35% of full connected capacity under peak demand. This increases the level of no-load losses. It should be possible to achieve a reduction in annual energy losses by more closely matching the ratings of transformers to peak load at individual locations over a number of years as new transformers are purchased. Based on the number of customers/load connected per transformer it can be determined which distribution transformers are the best candidates to be rotated.

When buying new transformers EPC should require sufficient data from bidders that can be used for evaluating copper and iron losses. A $ value per kW should be applied as part of the evaluation by which the total transformer life cycle costs (capital and losses) can be calculated. This approach often shows that a transformer with lower losses, even if somewhat more expensive, can be more cost effective over its lifetime.

A final recommendation is to regularly check electrical connections of clamps, bushings, connectors in the HV and LV systems. This could be done with an infrared camera. It is KEMA's experience that these types of connections can become hot spots after being in service for years. As such hot spots will bring higher losses.

6.3 Non-Technical Losses

KEMA recommends the following based on findings.

- Make sure that problems with prepayment meters have been resolved satisfactory.
- Randomly check the aged population of electromechanical meters for accuracy and replace meters when appropriate.
- Check generator meters and feeder meters for their class and accuracy. In fact these meters should be revenue class meters. As KEMA understood a meter recalibration program should be started by the end of 2010 to maintain both the necessary accuracy of production as well as of customer meters.
- perform the monthly meter readings on or around the last day of the month in order to get a more accurate comparison between "energy entering into the feeders" and "energy

Furthermore KEMA recommends the following:

In larger utilities with too high amounts of non-technical losses, one of the main areas in aligning a utilities' operation to Revenue Assurance is to implement a Revenue Assurance Process making use of an advanced Revenue Intelligence System. For conducting most efficient fraud prevention/detection and revenue operation audits with limited resources, an advanced Revenue Intelligence system is very helpful. Such a system can detect potential fraud based on information from multiple sources using advanced detection rules. It will vastly increase the hit rate and support a range of revenue assurance activities. These changes/processes should include:

- Implementation of a formal Revenue Assurance Process including an overall Audit Process.
- Implementation of Revenue Intelligence software to support Revenue Assurance oriented operations

However, for a **small utility**, implementation of a Revenue Assurance Department and implementation of Revenue Intelligence software requires a large investment and may have a large organizational impact.

A more pragmatic approach can be developed to locate non-technical losses and increase the effectiveness of revenue-protection operations.

EPC should consider the following:

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

- Develop a program for checking old meters.

- Train meter readers to identify tampering, by-passing, broken seals, 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. When selecting accounts with highest revenues the recovery potential and hit rates will be the most efficient, particularly when only limited resources will be available.

- Make operations less predictable. EPC's own experience may possibly 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. Once a fraud is found, measures should be implemented to ensure 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 EPC's top management.

- Employ right tactics for each group of customers. It is a fact 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. In general, customers should be grouped based on their usage patterns and payment capabilities. Establishing typical usage patterns and payment capabilities for each group is a very important task of Revenue Assurance. Results should then be used as the basis for employing right tactics for each group of customers.

7. Suggested Equipment Replacement

Out of the findings and recommendations in this Report it can be derived that the following replacements are to be recommended:

- Replacement of aged electromechanical meters in case random testing of a number of old meters shows that the accuracy of these meters has exceeded the accuracy class. One could also consider cleaning and gauging all meters, which however would be time consuming while the cost of new meters are relatively low.

- Replacement of malfunctioning prepayment meter pads and installing of a renewed system of tokens should is supposed to be completed since 2010/2011 or is maybe still ongoing. This is important for achieving less non-technical losses.

- Generator and feeder meters maybe need to be replaced after these meters have been checked. They may be out of the range of revenue class, even after recalibration.

- Based on the relatively low fuel efficiency of the diesel fired generating units KEMA would have proposed replacement of certain generating units justified by cost/benefit analyses. However, EPC will install four new 5 MW generating units in Fiaga and by the end of 2011 also some 6 MW of generating capacity has been added. On top of that all engines will have had a major overhaul by the end of 2011, as stated in the Corporate Plan 2011-2014, which means that the overhauled generation units will also have improved efficiency while none of the current units will be decommissioned. It is assumed that the hire sets will be removed. When also counting the hydro production capacity of EPC the reserves margin of EPC's generation capacity will grow far over 100% after the new engines in Fiaga have been put into service.

- For T&D no replacements are recommended after the re-conductoring program has been completed. Power factor problems may ask in the future for adding capacitor banks.

A. Loss Calculation Worksheet

Loss worksheet is provided in EPC loss worksheet.xlsx

B. Updated Power Factory Grid Model

The updated model is provided in EPC System 2010 NP (KEMA Add Future).pfd

KEMA has performed the follow work to update the Power Factory model for EPC future system:

(1) Updated DIgSILENT Powerfactory system model by adding new lines and power plant as provided by EPC. This expands the configuration of the “existing model” with the configuration of “future model”: 33kV cable connecting Tanugamanono and Fuluasou; 33kV lines/cables connecting Fuluasou and Fiaga; 22kV lines/cables from Fiaga serving west coast loads.

(2) All lines/cables parameters are set according to the data provided by EPC. Multi-section O/H and U/G pieces are modeled as lump sum O/H line and U/G cable.

(3) The transformers and generators are modeled according to the specification sheet from EPC. Missing data is substituted by the model of existing unit.

(4) Since the generation dispatch or load information is not available, the west coast load and additional generators’ outputs are assigned arbitrarily. Power flow can be solved without voltage or thermal violations.

(5) All generators are added with exciter model and governor model for dynamic simulation. Simplified exciter system model (SEXS) and Woodward diesel governor model (DEGOV1) are used with typical settings.