GOVERNMENT OF TUVALU

TUVALU ELECTRICITY AUTHORITY

VOLUME 1

ELECTRIFICATION STUDY

OCTOBER 1988

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Consulting Electrical Engineers
Apia
Western Samoa
CURRENCY EQUIVALENTS USED

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The currency used in Tuvalu is the Australian Dollar.

ABBREVIATIONS

ECU    European Unit of Currency
AUD    Australian Dollar
UKL    United Kingdom Pounds Sterling
NZD    New Zealand Dollar
FJD    Fiji Dollar
k      Kilo, thousands, 000
M      Mega, million, 000,000
kWh    Kilowatt hour
MWh    Megawatt hour
V      Volts
kV     Kilovolt
kW     Kilowatt
PF     Power factor
m      Meter
l      Litre
ML     Megalitres
AAGR   Average Annual Growth Rate
TEA    Tuvalu Electricity Authority
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FOR DEVELOPMENT PLAN AND DESIGN OF NEW POWER STATION
(separately indexed)
1. **EXECUTIVE SUMMARY**

This report notes that in Funafuti the use of electricity has grown at a very rapid rate over the past ten years and that this rapid growth is still continuing. This year for the first time the peak load will exceed the firm capacity of the power station. Unless action is taken to install additional generators the reliability of electricity supply in Funafuti will rapidly decline even if the present good maintenance is continued.

While an additional 150 kW machine similar to those already in the power station is recommended and can be installed quickly, action is also required to plan and budget for a new and larger power station for commissioning by the end of 1991.

Alternatively, but at the cost of unreliable electricity supply in 1990, immediate and rapid action could be taken to install the larger power station by the end of 1990, avoiding the installation of the additional 150 kW generating set.

Engineering consultants should be appointed to prepare a development report on the need, timing, cost, final design, and specification of the required generating sets.

While safety practices are generally good in the Tuvalu Electricity Authority the fire risk to the power station is severe and requires urgent attention.

The equipment listed in the terms of reference is reviewed.
2. RECOMMENDATIONS

2.1 As additional generators are needed to keep up with the rapid growth in the use of electricity one of the following alternatives is recommended:

EITHER

2.1.1 Install immediately a 150 kW diesel generator in the existing power station for operation by the end of 1989 at an estimated cost of AUD 97,000 and simultaneously commence planning and design for a new power station with larger diesel generators. The new power station would need to be in operation by the end of 1991 and would cost about AUD 1.5 million.

OR

2.1.2 Avoid the expense of installing a 150 kW diesel generator and immediately install a new power station with larger generators for operation by the end of 1990. Although this option will be the cheapest it may result in unreliable electricity supply from early 1990 until the completion of the new power station. For that reason it should only be considered if finance can be committed to the project without delay.

2.2 Appoint engineering consultants to prepare a least cost development plan setting the timing and size and cost of required additional diesel generating plant, and to design and specify a fuel efficient diesel power station.

2.3 Request British Petroleum (South West Pacific) to:

2.3.1 Carry out a Health, Safety & Environmental Audit of the Tuvalu power station fuel and lubricating oil installations.

2.3.2 Supply, or if they are not willing to supply the installation, then to design, a bunded, catch pit drained, bulk fuel and lubricating oil storage for the power station.

2.3.3 Supply and install an additional storage tank at the power station.
2.3.4 Clean and calibrate all oil flow meters in the power station, and calibrate or check calibrate a dip stick for the main tanks.

2.4 Install a 1.5 hour fire rated ceiling in the power station engine room (preferably executed by the Public Works Department).

2.5 Obtain for TEA use, listed in rough order of descending priority:

2.5.1 Fire Protection Equipment
2.5.2 Energy Meter Test Equipment
2.5.3 Protection Relay Test Equipment
2.5.4 Power Station Lifting Gantry
2.5.5 Diesel Fuel Purifier
2.5.6 Engine Cooling Modification
2.5.7 Safety Equipment
2.5.8 Two Transporters
2.5.9 Radio Communications
2.5.10 Computer
2.5.11 Load Dissipation Unit
2.5.12 Pick-up Vehicle
2.5.13 Silica Gel Dryer

2.6 Arrange training visits by the acting Supply Engineer to other pacific island electricity authorities.
3. INTRODUCTION

The Funafuti power station was constructed in 1980 and at that time had ample spare capacity. Since that time electricity consumption has increased by fourfold without any additional plant being installed. This year the electrical demand will exceed the firm capacity of the power station.

This report reviews the electrical load in Tuvalu and the efficiency and safety of the plant used to generate and distribute electricity. Based on the sparse historic sales and generation data readily available the report projects medium term load growth and proposes a general development strategy for the Tuvalu Electricity Authority.

Within the context of the development strategy proposed the items of plant listed in the Terms of Reference for consideration are reviewed.
4. ELECTRICITY ON FUNAFUTI

4.1 The Electrical Load on Funafuti

4.1.1 The Nature of the Load

In 1987 the Tuvalu Electricity Authority generated 1,186,000 kilowatt hours with an annual peak load of 245 kilowatts. The load factor was 55.4% and the 423 customers used an average of 1858 kWh in the year. See Table 1, page 10.

The load has a high daily peak in the early evening indicating that electricity is used mainly for domestic lighting. Monthly generation data, see Figure 1, page 11, shows an even use of electricity throughout the year. There is very little industrial electrical load and significant commercial load is limited to fish freezers, the hospital, and the Public Works Department.

4.1.2 Past Growth

The use of electricity has been increasing rapidly with a 17.4% average annual growth rate of generated units over ten years and an AAGR of 21.3% in metered sales over the past three years. See Table 1, page 10 and Figure 2, page 12.

Following the general pattern of development experienced in similar islands, electricity use has the potential for very rapid growth from it's currently small base despite the limitations of resources on Funafuti. Initially a significant growth in demand could follow a from a small increased use of domestic refrigeration, or a minor increase in commercial air-conditioning for hotel or electronic equipment preservation, or a small increment in light industrial use. With this change in type of use, electricity demand will be spread over more hours of the day than the current dominant lighting load. This will increase load factor and equipment utilization.
### TABLE 1. STATISTICS & PROJECTIONS

**TOTAL ELECTRICITY AUTHORITY**

Assuming 150 kW generating set installed by end 1967

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>GENERATION</td>
<td>MWh</td>
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<td>FOMER STATION USE</td>
<td>MWh</td>
<td>89.9</td>
<td>90.0</td>
<td>92.5</td>
<td>2.0</td>
<td>94</td>
<td>115</td>
<td>118</td>
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<td>STREET LIGHT USE</td>
<td>MWh</td>
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<td>126</td>
<td>126</td>
<td>0.0</td>
<td>151</td>
<td>154</td>
<td>151</td>
<td>151</td>
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<tr>
<td>SALES</td>
<td>MWh</td>
<td>534</td>
<td>633</td>
<td>766</td>
<td>21.3</td>
<td>954</td>
<td>1157</td>
<td>1409</td>
<td>1763</td>
<td>2066</td>
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<td>TOTAL SALES &amp; ST. LIGHTS</td>
<td>MWh</td>
<td>660</td>
<td>759</td>
<td>912</td>
<td>17.6</td>
<td>1105</td>
<td>1368</td>
<td>1555</td>
<td>1854</td>
<td>2217</td>
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<td>LOSSES</td>
<td>MWh</td>
<td>171</td>
<td>204</td>
<td>162</td>
<td>3.0</td>
<td>192</td>
<td>201</td>
<td>210</td>
<td>220</td>
<td>232</td>
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<td>LOSSES % OF GENERATION</td>
<td>%</td>
<td>18.6</td>
<td>19.4</td>
<td>15.3</td>
<td>14</td>
<td>12</td>
<td>11</td>
<td>9</td>
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<td>P.S. USAGE % OF GEN.</td>
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<td>9.7</td>
<td>8.6</td>
<td>7.8</td>
<td>6.8</td>
<td>7.1</td>
<td>6.3</td>
<td>5.5</td>
<td>4.8</td>
<td>4.1</td>
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<td>ANNUAL PEAK</td>
<td>kW</td>
<td>185</td>
<td>225</td>
<td>245</td>
<td>15.1</td>
<td>289</td>
<td>334</td>
<td>384</td>
<td>443</td>
<td>515</td>
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<td>LOAD FACTOR</td>
<td>%</td>
<td>55.9</td>
<td>53.6</td>
<td>55.4</td>
<td>55.0</td>
<td>55.5</td>
<td>56</td>
<td>56.5</td>
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<td>NUMBER OF CUSTOMERS</td>
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<td>332</td>
<td>381</td>
<td>423</td>
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<td>GROWTH SALES &amp; ST. LIGHTS</td>
<td>%</td>
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<td>20.2</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GROWTH GENERATION</td>
<td>%</td>
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<td>6.3</td>
<td>74.9</td>
<td>17.6</td>
<td>9.6</td>
<td>9.4</td>
<td>5.1</td>
<td>14.5</td>
<td>12.6</td>
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<td>GROWTH CUSTOMERS</td>
<td>%</td>
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<td>14.8</td>
<td>11.0</td>
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<td>FUEL OIL USE</td>
<td>ML</td>
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<td>0.101</td>
<td>0.274</td>
<td>0.316</td>
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<td>SPECIFIC FUEL CONSUMPTION</td>
<td>l/kWh</td>
<td>0.297</td>
<td>0.110</td>
<td>0.260</td>
<td>0.266</td>
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<td>TARIFF ABOVE 100kW MONTH</td>
<td>cent</td>
<td>36.0</td>
<td>38.0</td>
<td>38.0</td>
<td>38.0</td>
<td>38.0</td>
<td>38.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REFLATOR</td>
<td>%</td>
<td>11.1</td>
<td>9.1</td>
<td>8.7</td>
<td>3.9</td>
<td>3.8</td>
<td>8.5</td>
<td>6.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRICE (1961 BASE)</td>
<td>cent</td>
<td>38</td>
<td>34.5</td>
<td>31.5</td>
<td>30.3</td>
<td>29.2</td>
<td>26.7</td>
<td>25.0</td>
<td>-6.7</td>
<td></td>
</tr>
<tr>
<td>DM PER CUSTOMER</td>
<td></td>
<td>1688</td>
<td>1661</td>
<td>1815</td>
<td>1856</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>POPULATION</td>
<td></td>
<td>7677</td>
<td>8112</td>
<td>8209</td>
<td>8215</td>
<td>8227</td>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
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<tr>
<td>GSP, ADJUSTED_REAL</td>
<td></td>
<td>452</td>
<td>279</td>
<td>356</td>
<td>406</td>
<td>375</td>
<td></td>
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<tr>
<td>INSTALLED CAPACITY</td>
<td>kW</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>750</td>
<td>750</td>
<td>750</td>
<td>750</td>
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<tr>
<td>AVAILABLE CAPACITY</td>
<td>kW</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>383</td>
<td>383</td>
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<tr>
<td>PEAK MARGIN</td>
<td>kW</td>
<td>70</td>
<td>30</td>
<td>10</td>
<td></td>
<td>-34</td>
<td>-48</td>
<td>-61</td>
<td>-133</td>
<td>-224</td>
</tr>
</tbody>
</table>

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FIGURE 1. MONTHLY GENERATION
TUVALU ELECTRICITY AUTHORITY

STANDARDISED MONTH
JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEPT  OCT  NOV  DEC

MHW/HWM
FIG. 4. SINGLE LINE DIAGRAM
Tuvalu Electricity Authority

4,150 KW, 260 AMP
3 N, 415V, 50 HZ
DIESEL GENERATORS
It is predicted with a high level of confidence that a substantial growth in the demand for electricity will continue over the next few years. This growth will be much higher in percentage terms than is experienced in larger countries because:

* the base upon which the percentage increase is measured is small.
* the electrical load is changing in nature from a mainly lighting load towards an appliance base.

4.2 Equipment and Technical Efficiency

4.2.1 General Description

The Tuvalu Electricity Authority has four 150 kW, 3 phase, 415 volt, 50 Hz, diesel generators in one power station with room for one more engine only. The engines are 1500 rpm, six cylinder, turbo charged 4 cycle diesels manufactured by Cummins Engine Co., Model NT-855-C. The generators are 415 volt, 3 phase continuously rated at 260 amps, neutral earthed, brushless with class F insulation. The power station has a 415 volt switchboard to which are connected the four generators and on the outgoing side two 350 kVA transformers. These two transformers step up the output of the generators from 415 volts to 11,000 volts for high voltage distribution. Distribution is via a ring main of underground 25mm aluminium three core paper insulated lead covered steel wire armoured cable (Refer figure 4, page 14). Distribution transformers step down the 11,000 volts carried by this cable to 415 volts and 240 volts used in the customers premises. Five of the seven distribution transformers are supplied directly from the high voltage underground cable ring main whilst two are supplied from a spur cable off the ring main. The seven distribution transformers, totaling 643 kVA, are each supplied through a manual ring main feeder switch with a tee off fuse switch. At each distribution transformer site is a low voltage feeder pillar and from these pillars via underground low voltage cables are connected some 116 service pillars for the underground services.

The equipment is well maintained.
The present loading on the power station exceeds the station's firm capacity, and load development at the Wharf Substation, which is fed from a spur cable has reduced the reliability of the ring main distribution layout.

Almost all the generation and distribution equipment in Funafuti was installed around 1980. This fairly new equipment gives the Tuvalu Electricity Authority an operational advantage, but the design, selection and layout of the electrical equipment in Funafuti is not of a consistently high standard.

The purpose built power station has a ceramic tiled floor, and an air-conditioned control room, but lacks a maintenance crane. Even more surprisingly it has a low wooden truss ceiling to which the exhaust pipes are attached resulting in a severe fire hazard. The fuel oil and lubricating oil storage areas are not in any way bunded or drained and appear to lack thoughtful layout, although the distribution of fuel to the engine daily fuel tanks is well done.

Fire fighting facilities are limited to a few small and elderly extinguishers, even though a serious fire could easily occur. Any substantial fire would quickly affect all engines and would leave Funafuti without electricity for many weeks or months. On the other hand housekeeping in the power station is good. Inflammable materials are not stored unnecessarily in the station, and oil spills are promptly cleaned.

The power station sea water cooling system has an ad-hoc look about it as if was designed while it was being built, and the station suffers from sea water cooling problems.

The power station has only sufficient room for expansion by 25% over it's initial capacity.

The selection of high speed 1500 rpm diesel engines for base load duty in what must is a remote power stations could be said at best to have been brave. That for seven years the engines have performed with reasonable reliability is partly due to an initial over capacity and therefore light load (in 1981 the peak load was less
than the capacity of even one of the four engines) and to sensible maintenance. In the original engine specification it seems unlikely that the need for low maintenance and high fuel efficiency was given adequate weight.

The distribution equipment has even greater contradictions of design. The use of underground cabling and the sensible use of service and feeder pillars is eminently suited to the location. The 11,000 volts used for distribution is a higher voltage than needed for the distance and loads. This high voltage for the power handled may make loss reduction by generation at distribution voltage somewhat difficult to achieve in the future. Surprisingly there are no circuit breakers on the high voltage side of the step up transformers. Thus the power station operators cannot control the load when the engines are in difficulty, and there is no means of automatic load shedding.

The paper insulated aluminium high cable is difficult to repair without specialist jointers yet cables which require a low level of jointing skill are readily available.

For many aspects of both generation and distribution design it would seem that the designer was unfamiliar with the task of designing for the conditions (and the cost of fuel and maintenance) on a small Pacific island. Given that around 1980 a complete electrical system was designed and installed the opportunity to construct the electrical system for low maintenance and high efficiency was missed.

Some unsuitable decisions, such as the type of underground cable selected, must be accepted. Other matters, such as the reliability and inherent efficiency of the generators, distribution technical losses and the control of the high voltage circuits, can be improved as the system is augmented with demand increases. Some other matters such as the fire hazard in the power station, need to be addressed immediately.
4.2.2 Safety

The electrical equipment in the power station and outside, has been well designed for safety and presents no danger to a trained operator or electrician following normal trade practice. As far as was observed, operator and electrician work practices were safe. The acting Supply Engineer enforces safety practices. Some minor additional safety equipment is required as are some training aids.

The mechanical equipment is not well designed for safety. Within the power station the hot engines with large daily fuel tanks in close proximity and the exhaust pipes suspended from the wooden trusses supporting the roof create a severe fire hazard. The unbundled undrained bulk fuel tanks external to the station are also a fire hazard, and one which would also threaten the power station. Despite the evident fire hazards there is very little in the way of fire fighting equipment.

The lack of suitable lifting equipment creates safety problems at times of major overhaul. The poor sea water cooling system while not threatening life directly does increase the possibility of a catastrophic failure of the engines with the likelihood of salt contamination of the jacket water cooling water.

4.2.3 Reliability of Electricity Supply

The plant was not been selected or laid out in order to ensure a high degree of reliability although reliability of electricity supply must rank as one of the main objectives of the TEA. Considering the unsuitable equipment and poor layout of the equipment the TEA has in recent times maintained supply with a good reliability record.

High speed diesel alternators as installed would not usually be considered suitable for base load electricity generation by power utilities. Whilst their high speed substantially reduces their capital cost they are not as reliable, require more maintenance and have a shorter life than do the more usual power station low or
medium speed diesel generator.

The electrical distribution system whilst being constructed of robust adequately rated equipment has not been arranged to permit rapid identification and isolation of faults and does not permit either automatic or manual load control. The rationale of the design of a single ring main for electricity distribution in Tuvalu is difficult to understand, and is almost never used by electricity authorities elsewhere. In Tuvalu faults often cause the whole system to blackout, instead of the trouble being isolated to one particular area. System disturbances in one portion of the system, caused by transient faults or otherwise, are reflected to all parts of the system, causing wide spread malfunction of customer's electronic equipment.

4.2.4 Electrical Losses

In 1985, 1986 and 1987 electrical losses were between between 19% and 15% of generated energy. For the small, compact, recently installed electrical system in Funafuti that is high. These losses can be expected to rise with increasing electrical load unless strong action is taken to reduce losses.

Some electrical losses, called technical losses, are inevitably incurred in the distribution of electricity. The amount of technical losses which occur depends on the level of capital investment in plant, on the standard of engineering design, and the effectiveness of operation of the electrical system.

The remaining losses, called non technical losses, may occur with metering errors, non metered loads, accounting errors, or with theft of electricity. Most commonly the predominant cause is theft.

4.2.4.1 Technical Losses

The level of technical losses expected in the Funafuti system with the existing method of operation and existing equipment is calculated as 9.65% of generation. The main areas of anticipated technical losses and are summarised in Table 2 below.
### Table 2: Estimated Technical Losses

<table>
<thead>
<tr>
<th>Description of Equipment</th>
<th>Losses</th>
<th>Losses %</th>
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</thead>
<tbody>
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<td>11kV Cable</td>
<td>4.1</td>
<td>0.34</td>
</tr>
<tr>
<td>Distribution Transformers</td>
<td>36.3</td>
<td>3.06</td>
</tr>
<tr>
<td>Step up Transformers</td>
<td>38.4</td>
<td>3.24</td>
</tr>
<tr>
<td>Low voltage network (est. 3%)</td>
<td>35.6</td>
<td>3.00</td>
</tr>
<tr>
<td>TOTAL ESTIMATED SYSTEM LOSSES</td>
<td>114.4</td>
<td>9.65</td>
</tr>
</tbody>
</table>

The high level of technical losses is mainly due to losses in the transformers used to step up the 415 volts generated in the power station to 11,000 Volts for distribution and in the transformers used to step down the 11,000 volts to 415 Volts and 240 Volts for use in the customers' premises. Losses in the 11kV cable are very low.

Attention has already been drawn to the unsuitability for Funafuti of the plant selection and layout used for generation and distribution. It is evident that given the high price of diesel fuel in Funafuti insufficient attention was paid by the designers to minimizing present or future technical losses.

In particular it seems that inadequate attention was paid to the need for high transformer efficiencies in the design and selection of the transformers. This point needs close attention as transformers are replaced. The distribution voltage of 11000 volts is higher than will be required for many years in Funafuti, but it will make the future generation at distribution voltage and the elimination of losses from the step up transformers difficult to achieve.

From an operational aspect options to reduce technical losses are
limited. A reduction of losses resulting in a saving of about AUD 2816 a year could be achieved by de-energising one of the power station transformers. The resulting increase in 11kV cable losses would be insignificant and there would be few operational disadvantages and some protection advantages involved in operating with an open point in the high voltage ring main.

4.2.4.2 Non Technical Losses

It is of interest that non technical losses appear to run at between 9.75% and 5.65%. For fuel cost alone this amounts to between AUD 14,454 and AUD 8,376 per annum. Action needs to be taken to reduce these losses. All supply points, except perhaps street lighting, should be checked to ensure they are universally and correctly metered. There should be a comprehensive check of all metering by a program of routine meter testing, commencing with a careful check of the supply metering at the power station. It may well be that the domestic meters in use are inaccurate at the low level of lighting load experienced in many installations in Tuvalu. In that event a gradual change over time to a meter type more accurate at very low loads may be justified.

The level of non technical losses is an indicator of operational efficiency of an electricity authority. If the staff of an authority are aware of this, and are given training in the methods of minimising losses, dramatic improvements in loss prevention are possible.

4.2.5 Generation Efficiency.

While the engines are well maintained and operated it is not evident that they are monitored and operated for maximum fuel efficiency. The figures which were supplied for fuel oil consumption for the power station are unbelievably low. As the error is consistent it may be caused by slow fuel flow meters on the fuel delivery line. The station's specific fuel consumption in litres per kWh based on figures supplied by the TEA was 0.297 in 1984, 0.260 in 1986, and 0.266 in 1987. The fuel consumed figure obtained for 1985 was obviously under stated and has been discarded. The manufacturer's
stated specific fuel consumption for these engines is 0.300 litres per kWh at most efficient load. For the average over four engines, given the age of the engines, and the variable load required of them, a specific fuel consumption of 0.333 litres per kWh would be considered good, and 0.4 litres per kWh poor.

Action which could be taken to improve fuel efficiency include:

(a) Clean the fuel oil by centrifuging before use.

(b) Check the accuracy of fuel meters or dip sticks used to measure the fuel oil consumed by each machine.

(c) Check the accuracy and wiring of electricity energy meters used to measure the energy generated by each machine.

(d) Check the specific fuel consumption of each machine weekly, and compare with previous figures, and with the other machines.

(e) Check cylinder compression each month.

(f) Monitor cooling water temperature each hour to ensure coolant temperature at entry to heat exchanger is near the maximum of 93.3 degrees Celsius. (The normal error is to run the engine too cool for engine efficiency.)

(g) Check injectors, valves, timing, turbo-charger operation and air intakes in accordance with the manufacturer's instructions.

(h) Monitor exhaust temperature of each operating engine hourly and compare with a standard exhaust temperature for each engine for each load. (Any inefficiency in the operation of the engine will be reflected in the exhaust temperature. In general many of the cooling difficulties common to the Pacific Islands which are said to cause high exhaust temperature, resolve into inefficient operation of the engine.)

4.2.6 Voltage Drop on High Voltage Cable

Fears were expressed by TEA that there may be excessive voltage drop
under some conditions on the 11kV underground cable. Approximate calculations, indicate that at the peak loading anticipated in 1990, and with the worst possible loading situation, the voltage drop on the cable is 1.38%. The cable has ample capacity, see Table 3 below.

<table>
<thead>
<tr>
<th>Cable</th>
<th>Length</th>
<th>Current</th>
<th>Section</th>
<th>Cummulat.</th>
<th>Route</th>
<th>meter</th>
<th>Amps</th>
<th>Volt Drop</th>
<th>Volt Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.S. to 1:</td>
<td>600</td>
<td>32.8</td>
<td>45.3</td>
<td>45.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. to 2.</td>
<td>450</td>
<td>30.3</td>
<td>31.3</td>
<td>76.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. to 3.</td>
<td>520</td>
<td>27.0</td>
<td>32.3</td>
<td>100.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.to 4.</td>
<td>450</td>
<td>20.4</td>
<td>21.2</td>
<td>130.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. to 4A.</td>
<td>550</td>
<td>7.4</td>
<td>9.3</td>
<td>139.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a.to 4B</td>
<td>830</td>
<td>6.5</td>
<td>12.5</td>
<td>151.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. to 5.</td>
<td>1450</td>
<td>6.5</td>
<td>21.8</td>
<td>151.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Maximum volt drop on 11kV cable = 1.38 %

Assumptions:
1. HV fuse switch at transformer No 2 is open.
2. 11 kV cable has a VD of 2.3 mv/m/amp.
3. Transformer utilisation 78% (1990 peak 500kW)
4. Transformer loading proportional to rating

Augmentation of the high voltage cable may be required despite it's ample load capacity to ensure reliability of electric supply. Work may be required to complete the ring main to the Wharf/Fisheries/Oil Depot area, and/or to allow a degree of operating flexibility by rearranging the high voltage ring into three circuits switchable from the power station control room.

4.3 Organisation

TEA is part of the public service in Tuvalu and in the past has been headed by an expatriate Supply Engineer. Currently a Tuvaluan
electrical technician is acting Supply Engineer. It is submitted that for such a small utility a full time electrical engineer may not be warranted and that the Chief Executive of the Authority is indeed more suitably qualified as an electrical technician. Nevertheless there are functions of planning and design associated mainly with the growth of electricity demand which always will require regular electrical engineering attention preferably over a period by the same engineer. Furthermore the Chief Executive of the Authority may need to seek engineering advice on operational matters. Consideration could be given to requesting foreign aid donors for help in retaining an electrical engineering consultant for the TEA.

It was also noted that the acting Supply Engineer has had the opportunity to learn current trade practices in the metropolitan countries of Australia and New Zealand, but has not had the benefit of observing practices in electricity authorities in the region which are more relevant to the size and style of the TEA. Visits by the acting Supply Engineer to electricity authorities in Vanuatu, Tonga, Niue, Rarotonga and Western Samoa, lasting about a week for each country, should be invaluable to the acting Supply Engineer.
5. **FUTURE GENERATION PLANT REQUIREMENTS**

5.1 **Projected Load Growth**

A confident estimation of future electricity demand is needed because

(a) the size of each generator in relation to the load is important for reasons of reliability and efficiency,
(b) generators take time to manufacture,
(c) the size of the generator is usually much larger than the size required at the time of installation (i.e. the investment is lumpy), and
(d) to allow an economic comparison between alternative proposals.

Projections are almost always based on past trends of sales of electricity. Where adequate and accurate statistics are available a multiple regression analysis is preferred. In a multiple regression analysis mathematical models are established relating past electricity consumption to variables which are thought to affect electricity consumption such as national income, price of electricity, number of electricity customers, or population, or number of tourists and etc. Where accurate statistics are not available or a simpler method is preferred past sales are simply extrapolated forward.

Extrapolation of growth in the demand for electricity requires an act of faith, for there is no guarantee that the conditions which created or limited the sales of electricity in the past will continue into the future, and these conditions are not given consideration. We can be fairly sure the conditions affecting electricity demand, whatever they may be, will not continue forward unchanged. For example in Funafuti it is possible that the demand for electricity could unexpectedly increase because of an sudden increased demand for fish freezing or because of some national development project which may increase electricity consumption only as a secondary an unexpected effect.

For Tuvalu past records of electricity sales earlier than 1985 could
not be readily obtained. Annual energy generated figures are available back to 1978, but the accuracy of the records is suspect. Generation peak figures were available back to 1985. On the other hand macro economic statistics for Tuvalu were available only up to 1985 and official projections were not available.

Because of the limited statistics collected it was decided to extrapolate forward only seven years, on the basis of the three years annual sales figures from 1985 to 1987. See Table 1, page 10.

Sales grew from 1985 to 1987 at an annual rate of 21.3%. Extrapolating this forward without modification may provide a rate of growth on the high side, but given the uncertainty of the statistics a high estimate of sales growth will allow some margin of safety in the analysis of additional future plant required.

Street light sales are estimated to increase by 20% in 1988, and to be constant thereafter.

Power station usage of electricity has been growing at 2% pa and this is extrapolated forward at that rate, except for a 20% step in 1989 to allow for the electricity which may be consumed by the auxiliaries of an additional engine.

Over the past three years distribution losses have been growing at a rate of 3% pa. For projection purposes it has been assumed that losses will be reduced by the implementation of a loss reduction program by 10% pa.

Generation annual energy requirements are calculated by adding together sales, losses, street light usage and power station usage. For the assumptions stated, generated energy will grow at a rate of 16.6% pa. This is slightly below the long term AAGR from 1978 to 1987 of 17.4% pa.

Load factor over recent years has been between 56.9% and 53.6%. As the electrical system matures and the usage of electricity spreads over more hours of the day, rather than being mainly confined to the evening hours for lighting, the system load factor may be expected
to rise and an increase of about 10% pa has been assumed.

Expected peak load for each year is calculated from the projected load factor and the projected annual energy to be generated.

The future annual peak growth is calculated as 15.6%. This figure is consistent with the peak growth over the past three years and is also consistent with the other data collected including the long term generated energy growth, and with what is known of the development of electricity usage in Tuvalu.

It would seem to be the best interim basis we have for medium term equipment scheduling.

5.2 General Development Strategy

5.2.1 Generation,

5.2.1.1 The Need for Augmentation

To calculate the firm capacity of an isolated power station such as Tuvalu it is normal to allow for the largest generator to be under maintenance, perhaps awaiting spare parts, and for the second largest generator to give trouble. Under these not uncommon conditions the remaining machines must meet peak load at 85% loading. At 85% loading the machines should be able to clear a fault on the distribution circuits without causing a system blackout.

The firm capacity of the existing power station with its four 150 kW generators is therefore 255 kW. The 1987 peak load was only slightly less at 245 kW. It is anticipated that this year's peak load will exceed the firm capacity of the power station by 34 kW and in 1989 there will be a deficit of 79 kW.

There is little doubt that additional generation capacity is required, and required quickly.

For a graphical representation see Figure 3, page 13.

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5.2.1.2 Upgrading Existing Engines

It has been suggested that the existing Cummins engines could be upgraded to a higher power output. That is practical in the sense that new engines of the type in use in Tuvalu are now being sold by the manufacturer with an optional higher power output. Nevertheless the high speed Cummins diesel presently in the power station would normally be considered as already too highly stressed for the base load duty of a power authority. The engine would be considered as very suitable for standby purposes or where continuous engine output approaching full load is not required. Upgrading these engines for additional power output would increase the stress placed on them and probably decrease their reliability to a level unacceptable in an isolated base load power station.

Even if the expected decrease in reliability and increase in maintenance were thought acceptable upgrading the engines would require replacement of the alternator and cooling systems, and probable replacement of electrical cables, instruments and the like. It is not considered that this option should receive detailed investigation.

5.2.1.3 Additional Generator in the Existing Power Station

Although the engine type in Tuvalu is not considered suitable for power station base load duty there appears to be good reasons for installing one more of the same engine of type. The station has been constructed for the addition of one more engine of the same type. A concrete foundation is in place and the power and control cables are already installed. It would not be reasonable to install an engine of slower speed and therefore larger size in the space provided, nor would it be reasonable to install an engine of similar speed but larger size.

It is an option to install a Cummins engine of the same type as the existing engine but with a higher rated output. An output of 232 kW could be obtained from the upgraded version, or with after cooling 280 kW. On a cost per kilowatt installed this upgraded engine would be a cheap option, but such a highly stressed engine would not be suited to the location or duty.
Installation of an 150 kW diesel generating set of the existing type within the existing power station could be quickly completed, and would increase the generating plant margin to an adequate level until the firm capacity of the power station is passed by rising demand in 1990. The installation of a fifth engine will buy two years in which to plan and install a new base load power station which would be required for commissioning in 1991.

Upon the construction of a probable future diesel base load power station the Cummins engines could be used in a very necessary role as peak load and standby engines, a service to which they would be admirably suited.

5.2.1.4 Future Generation Options

Additional generation will be required by the end of 1991 even after the 150 kW generating set recommended above has been installed, and by the end 1990 if the 150 kW generator is not installed. There is little possibility that any of the alternative energy possibilities will be economic within the next decade for the size of electrical load required in Funafuti. The most economic form of electricity generation will remain the diesel engine.

A feasibility study is required to collect and check available historic records and project electricity demand growth in Funafuti over the next twenty years. The study should consider the possibility of conservation of energy by the more efficient use, generation and distribution of electricity. The study should recommend the timing and size of generating plant required.

For a new power station careful engineering consideration should be given to specifying engines with a low specific fuel consumption and to designing controls and monitors in such a way as to encourage continued operation of the engines in an efficient manner. Auxiliaries should be designed to minimise parasitic power consumption. Although there may be engineering difficulties consideration should be given to generation at the distribution voltage of 11 kV thus avoiding step up transformer losses.
Subject to further studies on possible future load growth the new power station would probably initially contain two 300 to 500 kW engines. Design should commence as soon as possible as tendering and construction will take two years and the engines will be required by the mid 1991. A preliminary budget figure for design and construction is AUD 1,500,000.

A possible alternative strategy is to proceed immediately and with urgency with the construction of a new power station. Allowing for a study, approvals, tendering, procurement and installation this station could be completed in two years from the commencement of initial studies, that is by the end of 1990 at the earliest. Under this proposal in 1990 TEA would be 150 kW short of capacity and would need to postpone any major overhauls of the four existing engines. If any engine developed serious mechanical or electrical trouble load shedding and blackouts may be needed over the peak period throughout 1990.

Providing the Government is willing to accept a low reliability of electricity supply in 1990 it may be economically preferable to avoid the installation of a fifth small high speed engine and to proceed immediately to the new power station. If this latter strategy is adopted and engines of 300 kW or 500 kW are installed then a minimum of two engines will be required for electricity security. If only one large engine is installed when it is under maintenance or repair the four remaining 150 kW engines would not be sufficient to securely maintain supply beyond 1990.

The terms of reference of this present study do not permit us to further pursue this possibility.

5.2.2 Distribution

The existing size and type of 11 kV underground cable will be adequate for many years. The low voltage network is also adequate. If new additions are kept to the standard of the initial installation there should be no difficulties with the low voltage installation, except where a heavy load develops in an unexpected location.
Action is required to provide control over the high voltage system, and to install an alternative 11 kV cable feed to the Wharf area.

It is suggested that installation of 11 kV circuit breakers in the control room, and the re-arrangement of the 11 kV cables into a radial feeder form, and the installation of an additional 11 kV cable to the Wharf area should await the installation of the new power station, for a new control room, and cable alterations will be required in any event at that time.
6. RECOMMENDATIONS AND COSTS

6.1 Fuel system upgrading

The diesel engines in the Power station used 316,000 litres of light diesel fuel in 1987. This consumption can be expected to double in four years with increased electricity use. Even allowing for the isolation of Tuvalu, British Petroleum appear to carry adequate buffer stock of light diesel fuel in their bulk depot which is located reasonably close to the power station.

Fuel is delivered to the power station by British Petroleum (South West Pacific) in 3500 litre tank trailers. On average a delivery is needed every four days.

The power station has two identical bulk tanks each of 3500 litre capacity. When a full load delivery is due, that is when the bulk tanks are drawn down by 3500 litres, the station has reserves in the bulk tanks of four days supply. However the load on the power station and therefore the fuel consumption is rising rapidly. Given the proximity of the fuel company’s bulk depot we would suggest the installation of one additional tank. With the installation of an oil purifier this would allow untreated oil to be stored in two tanks and purified oil in one tank.

The power station bulk tanks are surrounded by spilt oil which presents an unacceptable fire and environmental hazard. The tanks are not bunded, there are no catch pits, and there is no fire fighting equipment.

The four 1000 litre daily fuel tanks within the power station are not adequately bunded and the cable ducts are not sealed to prevent the spread of burning oil.

The provision of concrete bunds with catch pits around the bulk tanks, adequate bunding around the daily storage tanks, and the sealing of cable pits in the power station are well within the resources of the Government. The fuel company supplying the fuel oil
will accept a degree of responsibility, certainly for the provision of surveys, advice, and designs.

At the request of the Government the oil company may provide a satisfactory power station bulk tank depot, for that is not unusual in other islands in the Pacific.

In order to save time and reduce exposure to fire risk, we have requested British Petroleum (South West Pacific), subject to the Government's approval, to carry out a Health, Safety & Environmental Audit. They readily agreed to the request and will carry out the survey as a matter of urgency.

Oil flow meters require regular cleaning and calibration to maintain their accuracy. Accurate oil flow meters are required for monitoring of engine efficiency. British Petroleum should be requested to clean and calibrate TEA's meters on a regular basis on a fee of cost customer service basis. Oil flow meters must not be used to measure deliveries from British Petroleum. They are too inherently inaccurate for that purpose. All deliveries should be measured by dipping the power station bulk tanks.

Given the distance travelled by the oil, its holding time, and the humid climate in Tuvalu, it would be surprising if the oil did not contain sludge and water condensate. Water and sludge foul the injector tips and cause inefficient operation of the diesel engines. To avoid such contamination the fuel oil should be centrifuged. The only centrifuge suitable for this purpose as far as we are aware is that manufactured by Alfa Laval. More specifically the equipment required is an Alfa Laval distillate fuel oil purifier module. This purifier is similar to a lubricating oil clarifier but has a slightly different arrangement of bowl and has plumbing for the removal of water.

RECOMMENDATIONS

1. As a matter of urgency arrange for British Petroleum (South West Pacific) to carry out a Health, Safety & Environmental Audit of the Tuvalu Power Station.
ESTIMATED COST: NIL

2. Request British Petroleum to supply, or if they are not willing to supply the installation to design, a bunded, catch pit drained bulk fuel and lubricating supply area for the power station.

ESTIMATED COST: NIL

3. Request British Petroleum to supply and install an additional storage tank.

4. Request British Petroleum to clean and calibrate all oil flow meters in the power station, and to calibrate or check calibrate a dip stick for the main tanks.

ESTIMATED COST: NIL

5. Install a distillate fuel oil purifier module based on an Alfa Laval purifier type MAB 103-24.

ESTIMATED COST: Including freight, commissioning and training, AUD 15,000

6.2 Power Station Crane

The existing power station does not have a traveling crane and the building is not designed to accommodate such a crane. To modify the building to accommodate a crane would be expensive, as the roof would require replacing and lifting and load bearing columns erected. Estimated cost for this work is AUD 200,000 plus the cost of the crane. Although this work would also remove the fire hazard of the existing wooden truss roof it would seem to be a high price to pay for a light crane which would be used infrequently.

Most maintenance on the Cummins NT engine can be carried out in situ, however if the engine or the alternator requires removal an overhead gantry on wheels with a three ton chain block and trolley would seem to be an adequate interim measure, providing the gantry
is designed to suit the low ceiling height in the power station.

RECOMMENDATION

That a gantry on wheels with a three tonne chain block and trolley with a maximum overall height of 2700 be purchased.

ESTIMATED COST: AUD 6,000

6.3 Dummy Load Unit

A dummy load unit, or an energy dissipation unit, would allow the diesel generators to be tested on load after maintenance and before connecting the machine to the electrical system. For Tuvalu one unit could be mounted on castors and shared between machines.

Such energy dissipation units are really only practical for very small power stations for they would become prohibitively expensive and impractical for large machines. Larger power stations test their engines by connecting them to the electrical system with spare capacity on line to meet any load rejection by the recently repaired or maintained engine.

RECOMMENDATION

1. That prices be obtained for the supply of an energy dissipation unit and that the decision to purchase be based on availability of funds.

ESTIMATED COST: AUD 12,000

6.4 Energy Meter Test Equipment

Although Tuvalu has less than 500 kWh meters in service there is a need for an inexpensive means of applying load to and testing these energy meters. Without any means of testing kWh meters there can be no certainty about the efficiency of the machines, or the extent of distribution losses.
The Tuvalu Electricity Authority would like a meter test desk of the "Zenith" type. These test desks are used by power authorities to facilitate the testing of a large number of meters simultaneously. For a small desk of the size requested for Tuvalu, Zenith provided a budget estimate of AUD 76,000. For the testing of 500 meters that is uneconomic.

There are a number of alternatives. Probably the most economic is to purchase a rotating standard kWh meter, which is a normal kWh meter which has been made into a portable form, suitable for easy connection of wires, and with special attention being given to accuracy. The meter would be suitable for connection of a number of ranges of current loads. A similar meter can be purchased in an electronic, solid state form. These meters can be wired adjacent to the meter required to be tested and after a suitable period the reading of the standard meter and the meter under test can be compared. Cost is about AUD 5,000.

Often a watt meter together with a stop watch is used to check the accuracy of a kWh meter. Although simple the accuracy of this method is suspect for it depends on the load (and thus the voltage) being held constant throughout the test.

On a more expensive level a portable "phantom" load can be purchased. This load supplies the meter current coil with a low voltage current and for test purposes "tricks" the meter into believing it is measuring a real load. Electronic phantom loads can be used together with a standard meter (see above) to produce a variety of test conditions. An electronic phantom load would cost about AUD 7000.

Probably the best alternative is a portable electronic microprocessor controlled energy meter tester designed for fast and easy testing. The tester has a built in solid state standard kWh meter and a phantom load. It is accurate, rugged, and gives instantaneous results. The disadvantage of the instrument is that being electronic it requires occasional attention from an electronic technician. The present Acting Supply Engineer would be capable of maintaining the instrument, or alternatively it could be returned to Australia for
maintenance. An instrument of this type would cost about AUD 10000.

RECOMMENDATION

That an electronic KWh meter tester capable of testing both single phase and three phase domestic meters, complete with phantom load be purchased.

ESTIMATED COST: AUD 10,000

6.5 Protection Relay Test Equipment

TEA have a need for a relay test set. They have "GEC Measurements" protection relays installed in their power station and require a "GEC Measurements" portable, overcurrent relay test set. They also require a set of specialist relay maintenance tools.

Without such a test set the accuracy of the relays which disconnect electricity from the lines the power in the event of a faulty condition cannot be guaranteed.

RECOMMENDATION

That protective relay test equipment and a relay tool kit be purchased.

ESTIMATED COST: AUD 7,600

6.6 Insulating Oil Servicing Equipment

The proposed equipment filters the insulating oil used in transformers. The cost of the smallest filter available is about AUD 22,000. Electricity authorities use such filters to clean the oil in their large and expensive major substation and generating station transformers, but rarely filter the oil in distribution transformers except in large transformer workshops. Experience has proven that given the most adverse conditions of loading and climate, distribution transformers are unlikely to fail from contaminated oil.
In Tuvalu the total amount of insulating oil used in the transformers is about 1500 litres. This oil in normal service will not need filtering or replacing. If due to maintenance or fault some oil does become contaminated it would be far cheaper to replace it with new oil rather than investing in a filter.

In future purchases of transformers sealed and pressurised transformers should be considered.

**RECOMMENDATION**

That purchase of an insulating oil filter be deferred at this time.

6.7 **Safety and Fire Protection Equipment**

6.7.1 **Safety Equipment**

There is a need for the following safety and training equipment in Tuvalu:

6.7.1.1 One AMBU training manikin with simulator, for training.
6.7.1.2 Two pairs of rubber gloves with soft leather over gloves suitable high voltage switch gear operation
6.7.1.3 Five pairs of gloves suitable for LV working
6.7.1.4 Twenty pairs of safety boots
6.7.1.5 One cable spiking gun

6.7.2 **Fire Fighting Equipment**

As has been noted earlier in this report there is a severe fire hazard at the power station. A small fire could quickly spread and create enough damage to put the power station out of service, and leave Funafuti without electricity for a considerable period. There is an inadequate supply of fresh water to install high pressure hydrants, and sea water is to be avoided in a power station. It is recommended else where in this report that a
fire rated ceiling should be installed in the power station and that fuel supplies should be bunded.

While these measures may reduce the risk of catastrophic fire damage the primary defense against fire must be a consciousness of all personnel of the means and need to reduce the likelihood of a fire starting and spreading. A most important element in this is training (of which more later) but portable fire extinguishers are required both for fire fighting and for training purposes.

For fires which may occur in the control room, BCF extinguishers are recommended so as to minimize damage to delicate electrical control equipment during fire fighting. It is recommended that the largest readily available portable extinguisher be used which in the case of BCF is 11 kg. Three extinguishers are required for the control room, and a further three are suggested for training and to permit routine checking and refilling of the extinguishers overseas.

Fires on the machine floor are likely to be oil fed. Dry chemical powder extinguishers are recommended. The largest readily available portable extinguisher is 9kg. Five of this size and eight of the more easily handled 4.5 kg size are recommended for fire fighting, training and maintenance.

RECOMMENDATION

That the following equipment be purchased:

One AMBU training manikin for CPR training. AUD 2500
Two pairs of HV rubber gloves. AUD 230
Five pairs of LV gloves. AUD 170
Twenty pairs of safety boots. AUD 1100
One cable spiking gun. AUD 4000
Six 11 kg BCF fire extinguishers. AUD 1700
Five 9 kg dry chemical fire extinguishers. AUD 1400
Eight 4.5 kg dry chemical fire extinguishers. AUD 1100

ESTIMATED COST AUD 12200
6.8 Office Equipment

6.8.1 Personal Computer

A small XT Class IBM compatible personal computer with hard disk, monochrome monitor and dot matrix printer is recommended for Tuvalu. Software for purchase with the computer should include a word processing package such as Word Star, a spreadsheet such as Lotus, and a database management system such as DBase III. Installation of the computer and training in the use of the software and maintenance of the machine is required.

A small computer of this class has an enormous utility for an organisation such as the Tuvalu Electricity Authority. Meter reading, billing, customer classification, electrical inspections, staff records, statistical data, and accounting could be handled simply and with ease. The difficulty is familiarising the operators with the machine and software and their capabilities, and then efficiently adapting the available software for use in the Authority.

At this time little more is proposed than training to allow the senior employees to become familiar with the techniques and to devise some of their own preliminary systems.

6.8.2 Video Training Set

In view of the isolation of Tuvalu video training is a good option in the fields of first aid training and in fire fighting. Electrician and cable jointing training videos are not common, and those that are available may not suit the practices or conditions in Tuvalu. For first aid and fire fighting video tapes are available on loan from authorities in both Australia and New Zealand. As the number of training tapes suitable for the TEA is small and the hours that a video machine would be used in training is little and as the tapes likely to be used operate in the machines already in Tuvalu it is not considered economic to purchase a machine at this time unless further use additional to training can be proposed.
RECOMMENDATION

1. That an IBM compatible XT Class personal computer with 10 Mb hard disk, and 640k of memory, monochrome graphics card, monochrome monitor, dot matrix printer and relevant software together with installation and training be purchased.

ESTIMATED COST

AUD 8200

2. That the purchase of a video machine and tapes be deferred at this time.

6.9 Fifth Diesel Generator Unit

As discussed in Section 4.2.1.3 above, the installation of a fifth generator similar to the existing machines is recommended as a matter of urgency. The major difference to the existing machines is that radiator cooling is recommended.

RECOMMENDATION

That the following equipment be purchased:

One, 150 kW, three phase, 0.8 power factor, 50Hz, 1500 rpm, continuous rated, skid mounted diesel generating set with remote radiator forced draft cooling, Woodward PSG governor, electric motor start, turbocharged, brushless direct driven generator, solid state regulator, control panels and circuit breaker to match existing equipment, 1000 litre daily fuel tank and all associated cabling and fuel and cooling piping, and erection and commissioning of all equipment.

ESTIMATED COST

AUD 97000

6.10 Upgrading of Existing Generators

As discussed in Section 4.2.1.2 upgrading of the existing generators
is neither practical nor desirable.

6.11 Engine Cooling

The existing engines are cooled by a rather poorly designed sea water system operating from a shallow well at the rear of the power station. In diesel generation the "Achilles Heel" of the reliability of generation is cooling. All power station operators rate a high degree of reliability of equipment second only to safety. This follows the impatience of electricity customers towards electricity interruptions. Theoretical studies and customer surveys have indicated that customers value a reliable power supply highly. The most reliable method of diesel cooling is by radiator with one radiator to each engine. This method of cooling is therefore preferred by almost all diesel generator operators.

It is not as well recognised by operators that for peak fuel efficiency the engine should be run at it's maximum recommended operating temperature. Operators generally run engines too cool and fuel consumption suffers. A preferred cooling system automatically regulates engine temperature without wasting it's own parasitic energy consumption.

In theory the sea water cooling used in Tuvalu could be energy efficient and safe. However where sea water is introduced to close proximity to the engines there is a risk of contamination of the engine jacket cooling water and subsequent severe corrosion damage to the engine. This has indeed been the experience at Tuvalu.

For the existing engines there is a choice between replacing the existing unsatisfactory sea water cooling system with a well designed sea water system, or in replacing the existing cooling system with a separate and remote radiator for each engine. Whatever decision is taken it would be very much cheaper to do the work in conjunction with the installation of the fifth generator, using the erectors associated with the new engine.

Previously in Tuvalu there has been concern at the energy which would be consumed by the fans associated with radiator cooling sys-
tem. That is a valid concern given the data available in the quotation received by TEA from Cummins NZ where an engine mounted radiator continuously consuming 9 kW was proposed. Low energy consuming remote radiators with two speed electric fan motors are readily available, and should be considered for Tuvalu where the cost of energy is high.

A remote radiator to suit one of the existing engines would have a dual speed motor rated at 3.4 kW at full speed and 1.1 kW at part speed. The radiator would be located externally to the station.

Upon engine start up the radiator fan would not operate. As the load is applied to the engine and the temperature of the cooling water rises the fan spins at the lower speed and consumes 1.1 kWh per hour. Beyond say, 90% loading the fan will spin at the higher speed and consumes 3.4 kWh per hour. A transfer pump is not required between the engine and the radiator providing adequately sized piping is used and that the radiator is within 15 meters of the engine.

As the engines operate below 90% loading except in an emergency the energy consumption of the fan would be about the same (or perhaps less) as the 1.5 kW pump used on sea water cooling.

This controlled method of cooling allows the operating temperature of the engine to be set regardless of load. As the efficiency of the engine is partly dependent on adequate temperature being reached by the engine the specific fuel consumption of the engine may be expected to be reduced with the installation of controlled radiator cooling.

RECOMMENDATION

That the existing sea water cooling at the power station be replaced with four remote individual engine radiator cooling with dual speed fans at the same time as the fifth generator is installed.

ESTIMATED COST: AUD 70,000
6.12 **Communications**

TEA has requested the inclusion of radio communications, similar to the units used by Telecom Tuvalu. They require one mobile unit for the Supply Engineer's vehicle and five base units to be located in the power station and in the residences of key technical personnel. The objective of the proposed system is to locate key personnel quickly in the absence of a comprehensive telephone system.

**RECOMMENDATION** That the requested funds be budgeted, but that TEA investigate with Telecom Tuvalu the possibility of providing a simpler, cheaper paging system capable of transmitting an alarm and a short written message.

**ESTIMATED COST** AUD 32,000

6.13 **High Voltage Control**

A means of controlling the high voltage circuits and a layout of the cables in a radial form from the control point is required. It would be preferable to defer the re-arrangement of the high voltage circuits until TEA constructs an additional power station and control room. Completion of this work is estimated in 1991.

**RECOMMENDATION** That high voltage control works be deferred until the new control room is installed.

6.14 **Transporters**

TEA requests the provision of two agricultural all terrain transporters with two trailers. These machines have a small engine and are rather like a four wheeled motor cycle. They are rugged and are provided with few extras. Fitted with a trailer they would appear to provide an excellent means of transport for TEA repair men.

**RECOMMENDATION**

That two 250cc all terrain transporter with trailers be purchased.
6.15 Pick-up Vehicle

The vehicle currently in use by the TEA is due for replacement. It is proposed to replace this vehicle with a one tonne pick-up complete with rear canopy.

RECOMMENDATION

That a one tonne pick-up vehicle complete with rear canopy be purchased.

ESTIMATED COST AUD 12,800

6.16 Silica Gel Dryer

TEA require a dryer to reprocess the small quantities of silica gel used to dry the air breathed by their distribution transformers. A dryer similar to a small domestic oven is required.

RECOMMENDATION

That a small dryer for silica gel be purchased.

ESTIMATED COST AUD 15,000

6.17 Fire Rated Power Station Ceiling

The existing power station has no ceiling and a low timber truss supported roof. The hot exhaust pipes are suspended from the timber trusses. Within a diesel power station there are many factors which may lead to the start of a fire. Oil dropping or squirting onto the exhaust system is one. In this power station such a fire would rapidly spread vertically to the very dry timber trusses holding roof and would be uncontrollable within seconds. As the power sta-
tion has one open side the fire would not be denied oxygen.

It is strongly that the existing ceiling be fire rated by lining it with a 14.5mm plaster board with a 1 1/2 hour fire rating. This board could be installed without interrupting electricity supply. Considerable timber framing will be required as will and the plaster board will require fixing and stopping. It is important that the ceiling height not be lowered excessively by the timber framing required.

It is considered that this work is within the abilities of Public Works in Tuvalu

RECOMMENDATION

That the power station ceiling should be fire rated by lining it with 14.5 mm plaster board with a fire rating of one and a half hours, and that procurement and construction be carried out by the Government of Tuvalu.

ESTIMATED COST AUD 10,000

6.18 Training

TEA technical staff require continuous in service training in CPR resuscitation, fire fighting, including fire fighting drill, first aid, safety practices in a wide range of technical subjects where their skills need frequent updating. In this small authority the majority of such training must be carried out by the acting Supply Engineer.

The logic of this situation is that the first step is to provide a broad range of training experiences in relevant situations for the acting Supply Engineer.

It is suggested that he should receive brief fire fighting and first aid treatment and CPR Resuscitation training preferably arranged with the Fiji Electricity Authority. That he should be seconded for periods of about one week each to the electricity authorities in
Samoa, Rarotonga, Niue, Vanuatu, and Tonga in order to establish a depth of perspective in the techniques of operating a small island power authority, including the training aspect.

For budget calculations this would result in around six weeks of training, broken into three trips each of two weeks duration. Allowing average air fares per trip of AUD 1,500 plus per diem of AUD 630 per week plus general expenses of AUD 200 per week a budget total of AUD 9,480, may allow AUD 10,000

**RECOMMENDATION**

That the Government of Tuvalu arrange for short training visits by the Acting Supply Engineer to neighboring island states to receive specific training in fire fighting, CPR resuscitation, and first aid, and to familiarise him with the techniques of operating a small island electricity authority.

**ESTIMATED COST** (fares, accommodation) AUD 10,000

6.19 **Contract Supervision**

Engineering supervision will be required for tender comparison, negotiation with the successful contractor and site supervision associated with the fifth generator. In view of the remoteness of Tuvalu it is recommended that two site visits during construction and one site visit at completion for commissioning and certification of commercial completion would be adequate.

**RECOMMENDATION**

That the Government engage consulting engineers for tender comparison, contract supervision, and plant commissioning

**ESTIMATED COST** AUD 30,000

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6.20 Development Plan

A study is required to collect and check available historic sales and generation records and to project electricity demand growth in Funafuti over the next twenty years. The plan should consider the possibility of conservation of energy by more efficient use, generation and distribution of electricity and should recommend the timing, size, preliminary design and cost of required generating plant. The plan should recommend and methods and cost of high voltage control and the re-arrangements and augmentation required for the 11 kV cable.

It is anticipated that such a plan would take three man months to complete.

RECOMMENDATION

That the Government engage engineering consultants to prepare a generation and distribution development plan TEA.

ESTIMATED COST

AUD 80,000

6.21 Design for new power station

Design of a new power station up to and including specification stage but not including the calling of tenders would take about three months. The overall time for the development plan and design to specification could be reduced from the estimated six months to five months or less if the two studies were combined.

Over all cost of the design study including fees and expenses would be about 9% of the cost of the power station, that is about AUD 135,000.
### 7. ESTIMATE SUMMARY

<table>
<thead>
<tr>
<th>Description</th>
<th>Australian Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Fuel System</td>
<td>15,000</td>
</tr>
<tr>
<td>7.2 Power Station Crane</td>
<td>6,000</td>
</tr>
<tr>
<td>7.3 Dummy Load Unit</td>
<td>12,000</td>
</tr>
<tr>
<td>7.4 Energy Meter Test Equipment</td>
<td>10,000</td>
</tr>
<tr>
<td>7.5 Protection Relay Test Equipment</td>
<td>7,600</td>
</tr>
<tr>
<td>7.6 Insulating Oil Servicing Equipment</td>
<td>NIL</td>
</tr>
<tr>
<td>7.7 Safety &amp; Fire Protection Equipment</td>
<td>12,200</td>
</tr>
<tr>
<td>7.8 Computer Including Training</td>
<td>8,200</td>
</tr>
<tr>
<td>7.9 Fifth Diesel Generator Unit</td>
<td>97,000</td>
</tr>
<tr>
<td>7.10 Upgrading of Existing Generators</td>
<td>NIL</td>
</tr>
<tr>
<td>7.11 Existing Engine Cooling</td>
<td>70,000</td>
</tr>
<tr>
<td>7.12 Communications</td>
<td>32,000</td>
</tr>
<tr>
<td>7.13 High Voltage Control</td>
<td>NIL</td>
</tr>
<tr>
<td>7.14 Transporters (two)</td>
<td>12,800</td>
</tr>
<tr>
<td>7.15 Pick-up Vehicle</td>
<td>15,000</td>
</tr>
<tr>
<td>7.16 Silica Gel Dryer</td>
<td>1,000</td>
</tr>
<tr>
<td>7.17 Fire Rated ceiling</td>
<td>10,000</td>
</tr>
<tr>
<td>7.18 Training</td>
<td>10,000</td>
</tr>
<tr>
<td>7.19 Contract Supervision</td>
<td>30,000</td>
</tr>
<tr>
<td>7.20 Feasibility Study for Development</td>
<td>80,000</td>
</tr>
<tr>
<td>7.21 Design of New Power Station</td>
<td>135,000</td>
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<tr>
<td><strong>SUB TOTAL</strong></td>
<td>563,800</td>
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<tr>
<td><strong>Physical contingency 10%</strong></td>
<td>56,380</td>
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<tr>
<td><strong>Price Contingency 5%</strong></td>
<td>25,190</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>645,370</strong></td>
</tr>
</tbody>
</table>

These estimates, except 7.8, 7.12, and 7.15 to 7.21 were obtained as budget prices from standard industry sources during June to October 1988. FOB estimates were increased by 15% to convert to estimated CIF price. Estimate 7.12 was obtained from the Tuvalu Electricity Authority. The remaining prices were estimated from recent data.

If funding to this extent recommended cannot be obtained it is sug-
gested that expenditure would be best reduced by deferring the following items, in order:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (AUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica Gel Dryer</td>
<td>1,000</td>
</tr>
<tr>
<td>Pick up Vehicle</td>
<td>15,000</td>
</tr>
<tr>
<td>Load Dissipation Unit</td>
<td>12,000</td>
</tr>
<tr>
<td>Computer</td>
<td>8,200</td>
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<tr>
<td>Radio Communications</td>
<td>32,000</td>
</tr>
<tr>
<td>Transporters</td>
<td>12,800</td>
</tr>
<tr>
<td>Cable Spiking Gun</td>
<td>4,000</td>
</tr>
<tr>
<td>Existing Engine Cooling</td>
<td>70,000</td>
</tr>
</tbody>
</table>
8. ECONOMIC ANALYSIS

The approximate stream of costs for the 5th generator listed in Table 4 below. This preliminary economic analysis indicates a Net Present Value of the investment in the generator as AUD 148,451 at an annual discount rate of 10%.

Economically the purchase of the generator is viable.

TABLE 4. STREAM OF ANNUAL COSTS FOR NO. 5 GENERATOR
TUVALU ELECTRICITY AUTHORITY

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>TOTAL GENERATION: MWh</td>
<td>1883</td>
<td>2195</td>
<td>2572</td>
<td>3029</td>
<td>3582</td>
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</tr>
<tr>
<td>5th GENERATOR:</td>
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<td></td>
</tr>
<tr>
<td>ENERGY GENERATED: MWh</td>
<td>377</td>
<td>439</td>
<td>514</td>
<td>151</td>
<td>151</td>
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<tr>
<td>FUEL CONSUMED: ML</td>
<td>0.12</td>
<td>0.14</td>
<td>0.17</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>LUBE OIL USED: l</td>
<td>1427</td>
<td>1664</td>
<td>1950</td>
<td>574</td>
<td>574</td>
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<tr>
<td>MAINTENANCE: AUD</td>
<td>2259</td>
<td>2634</td>
<td>3087</td>
<td>909</td>
<td>909</td>
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</tr>
<tr>
<td>ANNUAL REVENUE:</td>
<td>128020</td>
<td>149233</td>
<td>174909</td>
<td>51493</td>
<td>51493</td>
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<tr>
<td>ANNUAL COSTS: AUD</td>
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<tr>
<td>PURCHASE &amp; ERECT: AUD</td>
<td>97000</td>
<td></td>
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<tr>
<td>FUEL: AUD</td>
<td>57778</td>
<td>67353</td>
<td>78941</td>
<td>23240</td>
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<tr>
<td>LUBE OIL: AUD</td>
<td>2611</td>
<td>3044</td>
<td>3568</td>
<td>1050</td>
<td>1050</td>
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<tr>
<td>MAINTENANCE: AUD</td>
<td>2259</td>
<td>2634</td>
<td>3087</td>
<td>909</td>
<td>909</td>
<td></td>
</tr>
<tr>
<td>TOTAL ANNUAL COST: AUD</td>
<td>97000</td>
<td>62649</td>
<td>73030</td>
<td>85595</td>
<td>25199</td>
<td>25199</td>
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<tr>
<td>NET REVENUE: AUD</td>
<td>-97000</td>
<td>65371</td>
<td>76203</td>
<td>89314</td>
<td>26294</td>
<td>26294</td>
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<tr>
<td>NET PRESENT VALUE</td>
<td>148451</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ASSUMPTIONS

5th generator commissioned end 1989.
6th Generator commissioned end 1992
Life of generator 15 years, value after 5 years 2/3 of new.
Specific fuel consumption 0.33 l/kWh
Specific lubricating oil consumption 0.00379 litres/kWh
Maintenance costs 0.6 cents/kWh
No additional operator costs
Constant prices including oil price.
Duty free fuel oil price AUD 0.465/litre
Lube oil duty free price AUD 1.83/litre
Average revenue per kWh sold AUD 0.34
Discount rate 10% pa
9. SUMMARY OF TERMS OF REFERENCE

1. Make recommendations, including cost, and prepare necessary drawings and technical specifications for the supply and installation of the following:
   a) Fuel system upgrading
   b) Power station crane
   c) Dummy load unit
   d) Energy meter test equipment
   e) Protection relay test equipment
   f) Insulating oil servicing equipment
   g) Safety equipment and fire protection equipment
   h) Office equipment including video television set complete with training programmes. Also small office computer and colour camera.
   i) Fifth diesel generator unit and all necessary associated control equipment, control panel extensions, cooling system, fuel system and exhaust system.
   j) Upgrading and modification of existing generators.

2. Make recommendations on type of fire protection suitable for the power house and electrical equipment and also study and make recommendations on the safety aspects (in general) of the Tuvalu Electricity Authority.
   a) Include estimated cost of fire protection equipment recommended for power house and electrical equipment.
   b) Report on safety equipment existing in TEA and make comments on its present safety situation.
   c) Make recommendations on the necessary safety requirements and include cost of equipment and instruction manuals required for safety.
   d) Prepare the necessary technical specifications for the supply of fire protection equipment and safety equipment, including a rescue breathing training mannequin.
   e) Carry out an economic analysis of the Tuvalu Electricity Authority Programme.