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Energy Loss Analysis of Yemen National Grid For the Period 2000 – 2004

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Abstract

Energy losses occur in the process of supplying electricity to consumers due to technical and commercial (non-technical) losses. The technical losses are due to energy dissipated in the conductors and equipments used for transmission, transformation, sub-transmission and distribution of power. These technical losses are inherent in a system and can be reduced to an optimum level .These losses can be further sub- grouped depending upon the stage of power transformation and transmission system as Transmission Losses (400kV/220kV/132kV/66kV), as

Sub transmission losses (33kV/11kV) and distribution losses (11kV/0.4kV).

The commercial losses are caused by pilferage, defective meters, and errors in meter reading and in estimating unmetered supply of energy. This paper presented power flow using Newton Rahpson method, and analyzed the technical and non-technical losses in the existing system (Yemen national grid), and in Aden Network for the period 2000-2004. The cost of the total energy loss in each year is calculated and compared; and the value of amount 1% reduction of energy loss per year is determined as saving money in RialYemeni (R.Y). The paper is ended by conclusions and recommendations.

Keywords: Power system, Power flow, Technical loss, Commercial loss, Energy loss.

الملخص

تتضمن هذه الدراسة معرفة اسباب فقدان الطاقة الكهربائية والفنية وغير الفنية (التجارية) في الشبكة الوطنية اليمنية، ومن اجل معرفة كمية فقدان القدرة الكهربائية ثم دراسة انسياب الأحمال للقدرة الكهربائية باستخدام طريقة نيوتن رافسن في البرنامج العلمي (ETAP) ومن خلال النتائج العلمية تم تحديد نسبة الفاقد للطاقة الكهربائية للأعوام 2000-2006م.

وتهدف هذه الدراسة الى تحليل ومقارنة النتائج بالواقع العملي من خلال احتساب قيمة الطاقة المفقودة سنويا بالريال اليمني.

وخلصت الدراسة الى مجموعة من التوصيات والمقترحات على ضوء النتائج التي توصلت اليها الدراسة لمعرفة الوفر المالي السنوي عند تخفض نسبة الفاقد بواقع 1%.

1. INTRODUCTION

Electric distribution losses may be divided into two types: i) Power losses, and ii) Energy losses. The power losses at the time of system peak increase the requirement of generating capacity, while the energy losses make it necessary to supply additional energy over that required by the system load. Allocation of these losses may be made according to the general components of an electric system as follows: 1) Transmission

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system losses: a) high-voltage transformer losses b) transmission line losses c) substation transformer losses. 2) Distribution system losses: a) primary-feeder and line-equipment losses b) distribution transformer losses c) meter losses. Losses in transmission components are relatively simple to determine on account of the recording meter readings generally available on both input and output terminals of these components. However, no comparable source of information is available on distribution system components, and the losses in them must be calculated from known circuit parameters and loads. Moreover, although much has been published on the loss-coefficients method of calculating transmission line losses in conjunction with load flow studies of power systems, few references found on the subject of distribution losses [Nelson, 1968; Yahya and Elangonvan, 1984 and Bin Saroor and A. Saleh, 1997].

Experience in many parts of the world demonstrates that it is possible to reduce the losses in a reasonably short period of time and that such investments have a high internal rate of return. A clear understanding on the magnitude of technical and commercial losses is the first step in the direction of reducing transmission and distribution losses. This can be achieved by putting in place a system for accurate energy accounting. This system is essentially a tool for energy management and helps in breaking down the total energy consumption into all its components. It aims at accounting for energy generated and its consumption by various categories of consumers, as well as, for energy required for meeting technical requirement of system elements. It also helps the utility in bringing accountability and efficiency in its working [Bhalla, 1992; Rao, 1999; P. Khare, 2002 and Suriyamongkol, 2002].

The following are the major reasons for technical losses:

- Haphazard growths of sub-transmission and distribution system with the short-term objective of extension of power supply to new areas.
- Large scale rural electrification through long 11kV and Low Tension (LT) lines
- Too much stage of transformations.
- Improper load management.
- Inadequate reactive compensation.

The main **r**easons for non-technical (commercial) losses are:

- Making unauthorized extensions of load, especially those having high power tariff.
- Tampering the meter readings by mechanical jerks, placement of powerful magnets or disturbing the disc rotation with foreign matters.
- Stopping the meters by remote control.
- Willful burning of meters.
- Changing the sequence of terminal wiring.
- Bypassing the meter.
- Changing C.T. ratio and reducing the recording.
- Errors in meter readings and recording.
- Improper testing and calibration of meters.

For load flow calculations for the existing system (Yemen national grid) and Aden power network the software packages [Etap, 2003; Synr GEE, 2002] are used. The total amount energy losses for the period 2000-2004 are analyzed and evaluated in next paragraphs.

2. CALCULATION OF ENERGY LOSSES IN POWER SYSTEM NETWORKS:
Electrical power systems designed with generating units that are widely scattered and interconnected by transmission lines may suffer significant losses. The losses depend upon the line resistance and currents and are referred to thermal losses. While the line resistances are fixed, the current are a complex function of the system technology and the location of generation and load. Consider the well-known power flow equations [Murty, 1984; Rao, 1999 and Suriyamongkol, 2002], with the complex power, Si = Pi+ jQi, injected at bus i as

$$P_i = V_i \sum_{j=1}^{n} Y_{ij} V_j Cos(\delta_i - \delta_j - \gamma_{ij}) \tag{1}$$

$$Q_i = V_i \sum_{j=1}^{n} Y_{ij} V_j Sin(\delta_i - \delta_j - \gamma_{ij}) \tag{2}$$

Where Y_{ij} is the magnitude of the $i-j^{th}$ element of the bus admittance matrix, V_i is the voltage magnitude at the i^{th} bus, γ_{ij} is the angle of the $i-j^{th}$ element of the bus admittance matrix, and δ_i is the phase angle of the voltage V_i .
In this work, only the real power injections as they relate to transmission losses are of concern. The system losses *can be expressed* as [Suriyamongkol, 2002]:

$$Ploss = \mathrm{Re}[\sum_{i=1}^{n} Vi(\sum_{j=1}^{n} VjYij)*] = \sum_{i=1}^{n}\sum_{j=1}^{n} ViVjYij\cos(\delta i - \delta j - \gamma ij) \tag{3}$$

$$P_{loss} = \sum_{i=1}^{n} P_{Gi} - \sum_{i=1}^{n} P_{Di} \tag{4}$$

Where P_{loss} *is the real power loss,* P_{Gi} is the real power generated at the i^{th} bus, P_{Di} is the load demand at the i^{th} bus.
However, in order to calculate the total energy loss at voltages of 132 kV or 33kV. The load factor (LF) and loss load factor (LLF) are computed for identified substations from hourly reading and empirical formulae [Dechpande, 1984] as given by eq. (5). The annual technical energy loss of the system is then calculated by multiplying the technical power by loss load factor and number of operating hours in the year.

$$LLF = 0.8(LF)^2 + 0.2(LF) \tag{5}$$

Where LF = average demand / peak demand.

Annual energy loss = *Ploss* * LLF * 8760 (kWh) (6)

2.1 Energy Losses in Distribution Systems:
The distribution network can be categories into high tension (H.T) system (11 kV) and low tension (L.T) system (400V) including the service line to the consumer. The total energy losses in the distribution system would thus be the sum of the H.T and L.T system losses. Power system studies were carried out using sophisticated software [Synr

GEE, 2002] corresponding to the daily peak load condition on the feeders, to calculate the technical power loss in the 11 kV feeder including the 11/0.4 kV distribution transformer losses located on simulated feeder. The L.T system technical power loss (kW) is then converted to L.T system technical energy loss (kWh) by multiplying technical power loss with the (LLF) and the number of operating hours.

The losses in the distribution systems can be shown as due to (i) 11KV line losses, (ii) losses in distribution transformer, (iii) LT line losses. These should be calculated for 11KV feeders at the existing power factor and by considering the utilization factor *UF*.

Peak-power loss in the feeder line (PPL) [Dechpande, 1984] as:

$$PPL = 3I^2R(UF)^2 \quad \text{(KW)} \tag{7}$$

$$\text{Annual energy loss} = PPL * LLF * 8760 \quad (kWh) \tag{8}$$

$$\text{The percentage losses in the system} = \frac{\text{Total units received} - \text{total units sold}}{\text{Total units received}} \tag{9}$$

3. BRIEF DISCUSSIONS FOR THE ENERGY LOSSES AND RESULTS OF THE SIMULATIONS:

The source of informations required like input data for the existing system (Yemen national grid) are taken from (PEC) [A. Aziz, 2004], the statistical data for non-technical loss during year 2000-2002 are detailed in [A. Alnaser, 2002] and the non-technical losses for Aden grid system are given in [Y. Wazir, 2004]. Total installed capacity of the existing system is 908 MW. The maximum demand for Yemen network reached 656 MW in year 2004, whereas maximum demand in Aden network reached 180 MW in year 2004. The maximum loads for the main areas of Yemen are shown in Fig.1. The maximum power losses in (MW) of some Yemen areas are evaluated and described in Fig.2. The maximum % losses are in Marib 59.6 %, and in Amran 45.2 % ; while the minimum % losses in Dhamar 19.2 %, Taiz 19.8 %, and Aden 19.9 % respectively. The total magnitude of sent, sold and % loss energies, during the period 2001-2003 are summarized in Table (1). It is observed that the total energy loss, in distribution of the existing system reached 1030.6 GWh, about 31.46% of the total sent energy to the regions, or about 46 % of the total sold energy in year 2001, as a result the cost of annual energy loss would be 12.75 milliar (R.Y), by taking the average cost of energy / kWh 12.38 (R.Y). It is noted that, the rate of change up to the end of year 2001 was higher than in year 2001 about 0.1%; also it is shown that, at the end of year 2002, the total energy loss was reduced to 934.53 (GWh), about 27.42% of the total amount of energy sent to the regions, and 38% of the total sold energy. The total cost of energy loss 12.0 milliar (R.Y), by taking the average cost of energy / kWh 12.85 (R.Y). Comparing between the results above, it is observed that the difference was 96.07 (GWh), or the net change energy loss (ΔE) 4.04 % from the total sent energy with total cost 1.27 milliar (R Y). Similarly Fig.3 described in details the data for the year 2003. The total energy sent from generation is 3,646 (GWh), total energy sent to regions are 3,342 (GWh), and the total energy sold is 2,543 (GWh), by subtraction the total sold energy from the total sent energy, therefore, the total energy loss is reduced to 799 (GWh), about 21.19% of total energy generated,

23.9 % of total sent energy, or about 31.4% of total sold energy, the difference was 135.53 (GWh). Therefore, the net change energy loss (ΔE) was 3.52 % from the total sent energy, with total cost 1.77 milliar (R Y), which means the (PEC) saved money about 1.77 milliar due to this reduction in losses. By assume the main bus bar of Hiswa power station (33) kV as swing (ref.) bus, the summary of final results of the load flow of Yemen (National grid) for year 2004 are shown in appendix (A). It is seen that, from load flow results, the total power generation of Hiswa power station is 115 MW, total power losses are 7.984 MW, the total power demand is 452.794 MW. Fig. 4 shows the power loss values in (%) of the main equipments such as overhead lines, cables, transformers.

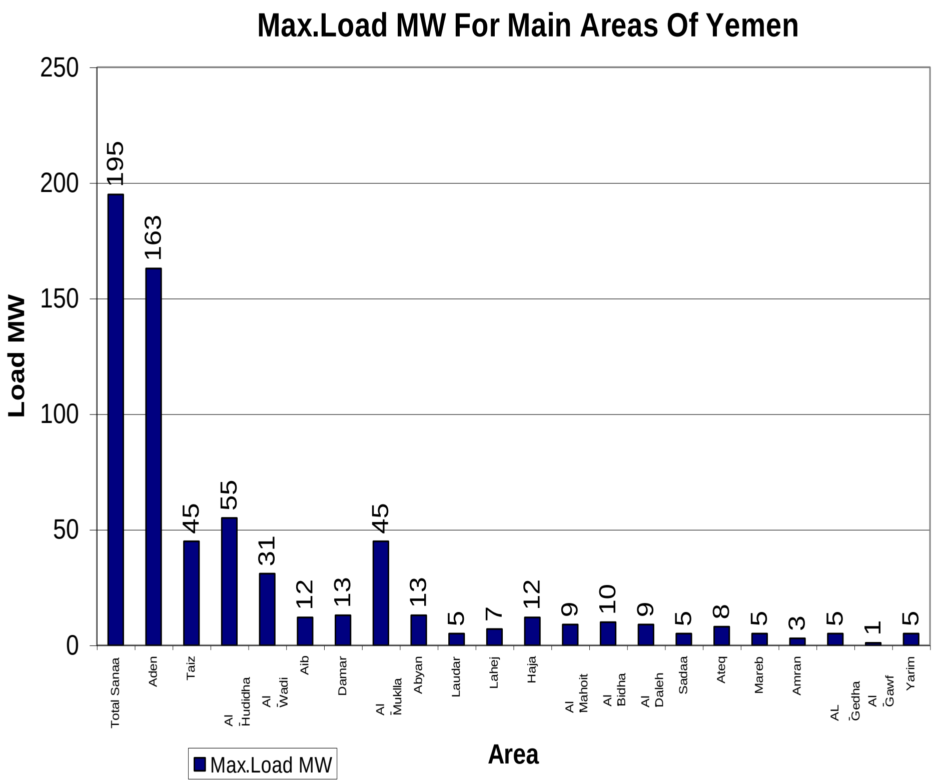

Fig. 1

Table 1.: Sent Energy, Sold Energy and Loss For (Yemen National Grid**).**

Indicators	Year 2001	Year 2002	Year 2003
Total amount of sent energy (Gwh) by Distribution Network	3275.9	3408.21	3342
Total amount of sold energy (Gwh)	2240.43	2473.67	2543
% loss (energy loss / sold energy)	46	38	31.4
% loss (energy loss / energy sent from distribution network)	31.46	27.42	23.9
% loss (net change energy loss ΔE)		4.04	3.52

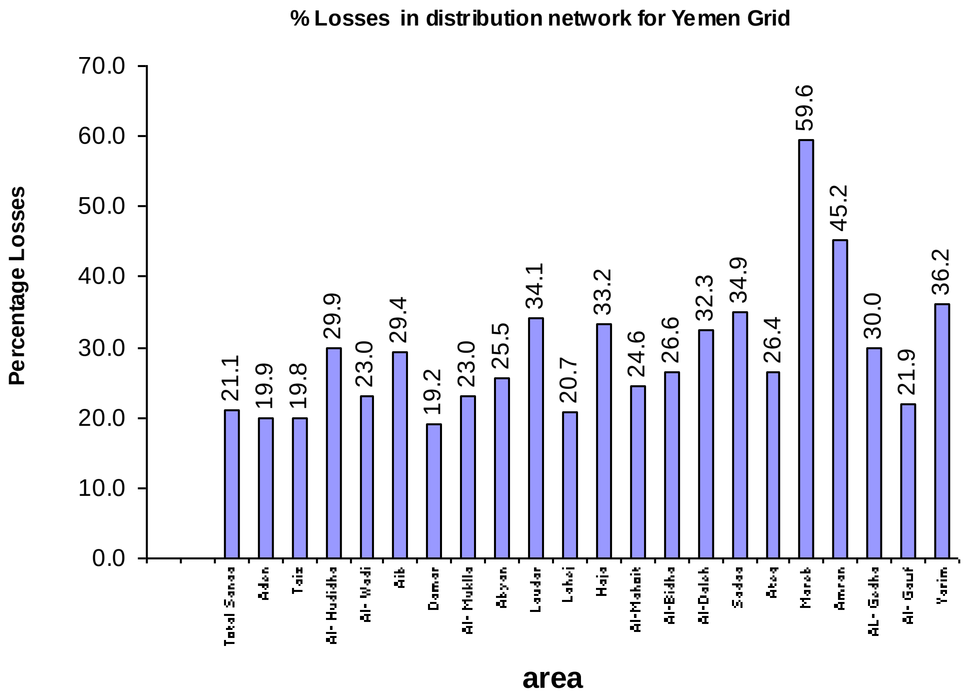
% Losses in distribution network for Yemen Grid
Percentage Losses
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
21.1
19.9
19.8
29.9
23.0
29.4
19.2
23.0
25.5
34.1
20.7
33.2
24.6
26.6
32.3
34.9
26.4
59.6
45.2
30.0
21.9
36.2
Total Sanaa
Aden
Taiz
Al- Hudidha
Al- Wadi
Aib
Damar
Al- Muklla
Abyan
Laudar
Lahej
Haja
Al-Mahait
Al-Bidha
Al-Dalah
Sadaa
Ataq
Mareb
Amran
AL- Gadha
Al- Gauf
Yarim
area

Fig. 2

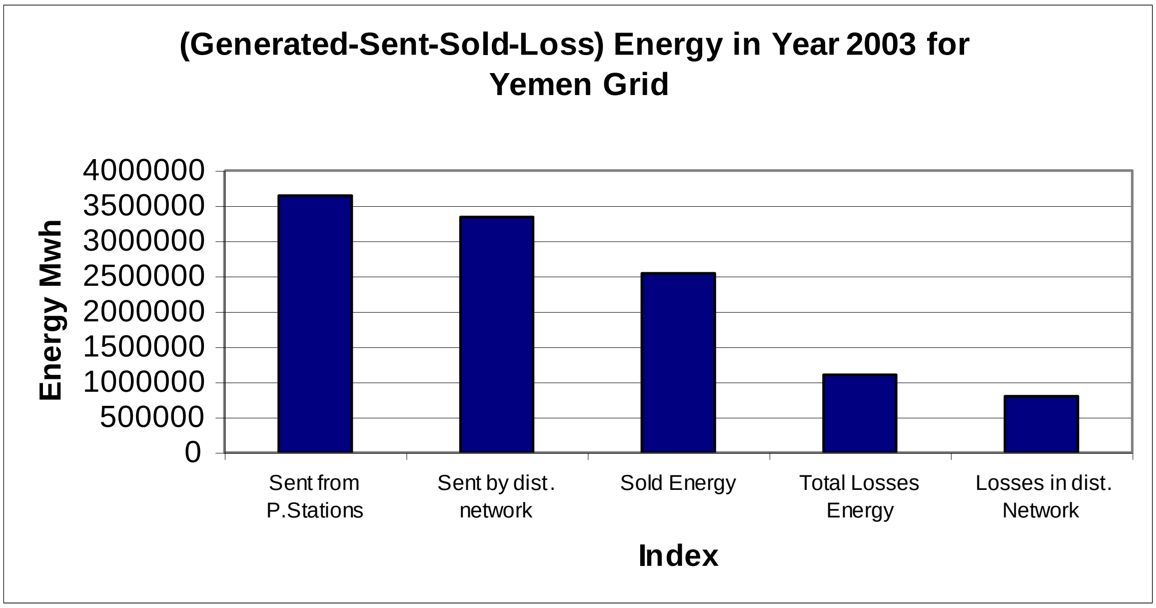
(Generated-Sent-Sold-Loss) Energy in Year 2003 for Yemen Grid
Energy Mwh
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Sent from P.Stations
Sent by dist. network
Sold Energy
Total Losses Energy
Losses in dist. Network
Index

Fig. 3

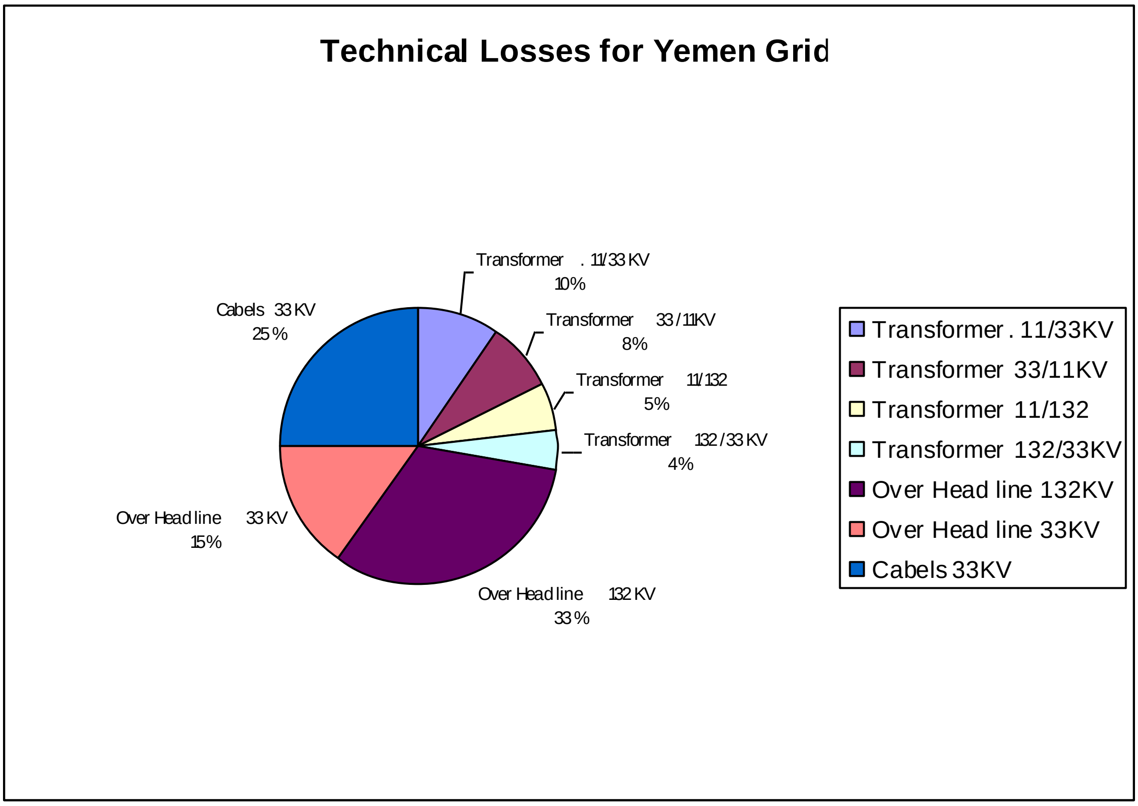

Fig. 4

It is shown that the power loss in the over head transmission lines is 132 kV, 33% out of the total power losses of the system, which are due to the long lines, and high voltage drops may be due to the conductor's resistance. From the results of the power flow of the Yemen national grid, the total annual energy loss is calculated as 55.9 GWh in the main 132-33KV system, the total generated energy is calculated as 3966 GWh, the total sent energy is 3910 GWh / year, total sold energy is 3067 GWh /year, and the total energy loss is 22%. Therefore if the energy loss is reduced per year 1% due to improvement of the system, the corresponding saving money will be 420 million (R.Y) / year approximately.

The final results of total power loss for Aden power system 11 kV networks and (L.T) 400V distribution systems are given in Appendix B; whereas the sent energy and the sold energy for the period 2000-2004 were summarized in Table 2.0. It is shown from Figs. (5) and (6) that the total energy loss is reduced because of the system improvement. It is clear from Fig.6 that losses for Aden network have been reduced from 33.7% to 20.51%. This reduction in energy losses are due to improvement in the network lines, and installing new energy meters to reduce the non-technical losses. The total technical losses and the non technical losses are shown in Fig.7.

Table 2: Sent Energy, Sold Energy and Loss For Aden Region

Indicators	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004
Sent Energy (MWH)	597986	634077	636435	678257	688558
Sold Energy (MWH)	396248	414842	488463	524664	547357
Loss (MWH)	201738	219235	147972	153593	141201
% Loss	33.74	34.58	23.25	22.65	20.51

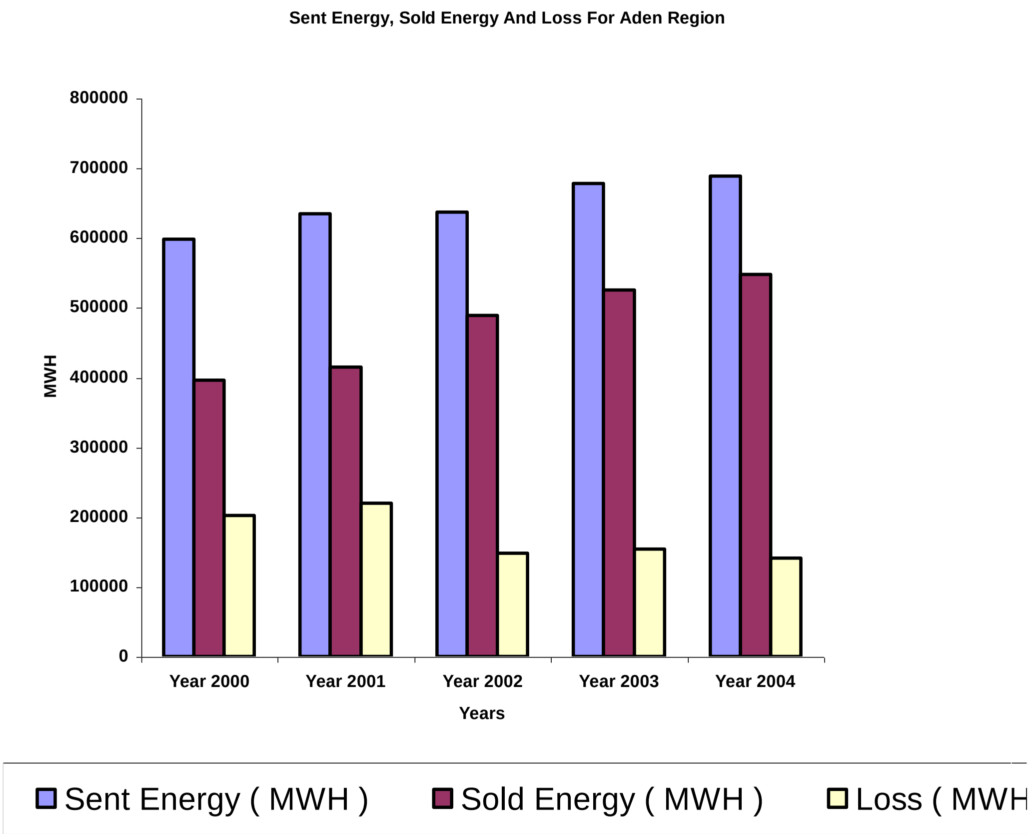

Fig. 5

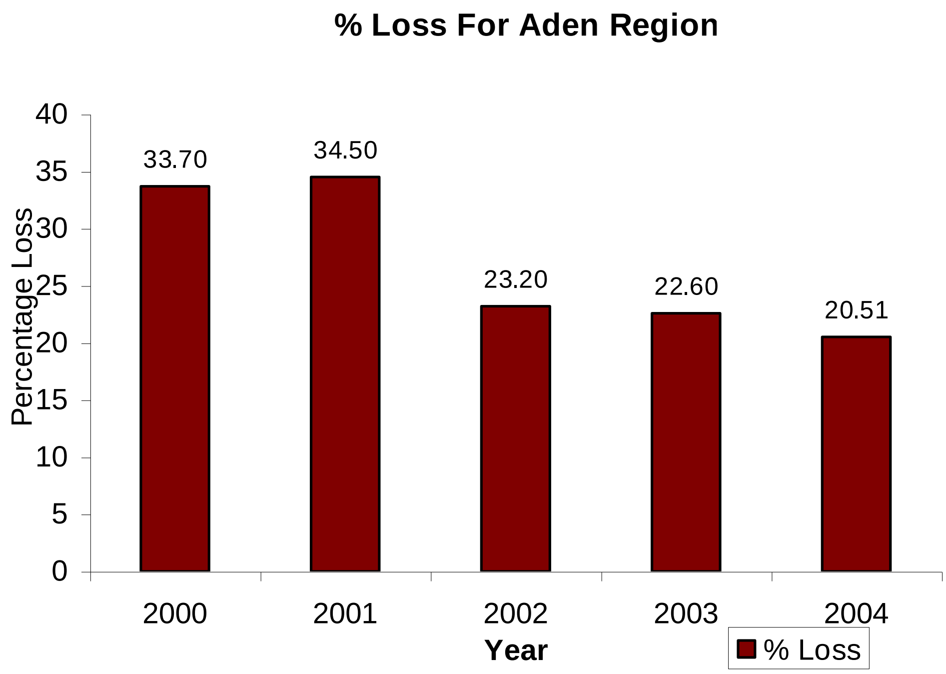
% Loss For Aden Region
40
35
30
25
20
15
10
5
0
Percentage Loss
33.70
34.50
23.20
22.60
20.51
2000
2001
2002
2003
2004
Year
% Loss

Fig. 6

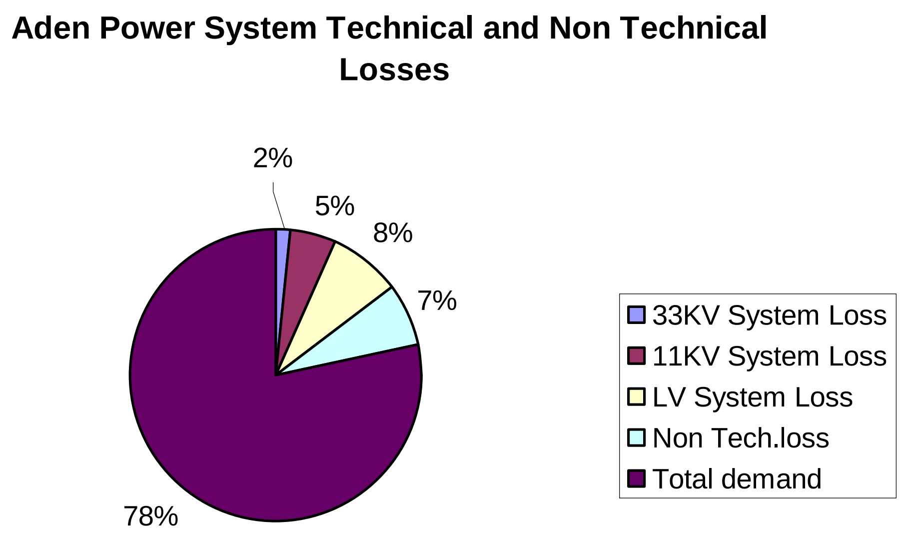
Aden Power System Technical and Non Technical Losses
2%
5%
8%
7%
78%
33KV System Loss
11KV System Loss
LV System Loss
Non Tech.loss
Total demand

Fig. 7

4. CONCLUSIONS AND RECOMMENDATIONS:

1) For national grid system of Yemen the reduction of 1% of energy loss will save approximately 420 million (R.Y) /year.
2) For Aden network the reduction of 1 % of energy loss will save approximately 65 million (R.Y) / year, by considering the average load / year for Aden = 102 MW, the utilization Factor = 0.8 , load factor =0.7 , and the average cost /kWh of energy is 12.85 (R.Y).

4.1 Recommendations for reducing technical losses:

a) Short term measures:

- Identification of the weakest areas in the distribution system and strengthening / improving them so as to draw the maximum benefits of the limited resources.
- Reducing the length of LT lines by relocation of distribution sub stations/ installations of additional distribution transformers (DTs).
- Installation of lower capacity distribution transformers at each consumer premises instead of cluster formation and substitution of DTs with those having lowered no load losses such as amorphous core transformers.
- Installation of shunt capacitors for improvement of power factor.

b) Long term measures:

- Mapping of complete primary and secondary distribution system clearly depicting the various parameters such as conductor size line lengths etc.
- Compilation of data regarding existing loads, operating conditions, forecast of expected loads etc.
- Carrying out detailed distribution system studies considering the expected load development during the next 8-10 years.
- Preparation of long-term plans for phased strengthening and improvement of the distribution systems along with associated transmission system.
- Estimation of the financial requirements for implementation of the different phases of system improvement works.
- Formulation of comprehensive system improvement schemes with detailed investment program so as to meet system requirement for first 5 years period.

4.2 Recommendations for Reducing the Non -Technical Loss:

- Any power system would have some loads that are not metered at all which would affect as non technical loss; the obvious solution to this is to install meters at every billed load.
- In some cases where people already stealing electricity the new meters would simply be more valuable target, meters that can perform the required duties which include sending data to the computing facilities, these types would be more expensive than the regular type of meters.
- Some important factors that affect the overall impact and magnitude of losses are the political and economic situation in the local areas.
- Use of statistical analysis methods for detecting electricity theft by analyzing utility billing information.

- Cost analysis for utilities theft detection and prevention efforts compared to the recouped revenues, as well as cost analysis for efforts to measure the non technical loss more accurately.
- The possible use of newer metering technologies on an experimental basis for example the developed meters that could be read remotely by the utilities staff. Such meter could be fitted with diagnostics equipment to detect meter tampering.
- Re location of the meter position to install out side the houses.
- Using the meter boxes with sealing the boxes and meters.

Finally, it is recommended from (PEC) to keep the losses percentage within the acceptable range by taking in consideration the above recommendations to increase its income.

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Appendix A:

SUMMARY OF LOAD FLOW CALCULATION RESULTS (TOTAL GENERATION, LOADING & DEMAND) OF YEMEN GRID

	MW	**Mvar**	**MVA**	**% PF**
Swing Bus:	115.014	79.109	139.594	82.39
Lagging				
Generators:	337.780	196.704	390.881	86.42
Lagging				
Total Demand:	452.794	275.814	530.185	85.40
Lagging				
Total Motor Load:	26.095	16.172	30.700	85.00
Lagging				
Total Static Load:	418.715	283.156		
Apparent Losses:	7.984	-23.514		
System Mismatch:	0.000	0.000		

Number of Iterations: 2

Appendix B:

SUMMARY OF ADEN NETWORK LOSSES:

	Aden 11KV Network	11KV Lines Losses		Dist. Transf.losses	
S.No	Area	Loss-Kw	%	Loss-Kw	%
1	Tawahi +Malla	586	3.4	606.8	2.68
2	Crater	129	0.5	389	2.05
3	Khormaksar	185	2.7	675	2.59
4	Mansura	195	1.1	340	1.5
5	ShekhOthman+Darsaad	674	4.1	567	2.1
6	M.Asshb+Burika	890	7.5	311	3.2
	Total	2659	2	2888.8	2.3
	Aden LT (400V)Network	L.V cables Losses		O/H lines Losses	
		Loss-kW	%	Loss-kW	%
		3575	2.82 *	8072	6.36*

* % Loss with respect to line load