ENERGY AUDIT REPORT OF OVERHEAD LINE AND ITS MOST ECONOMICAL CONDUCTOR

WORKS/ PROJECT: Test Project

Report Date: 26/11/04

CASE STUDY:
A 2.5 km long, 11 kV overhead line with ACSR 'LYNX' conductor having 183 mm² equivalent aluminium area, delivers power to a certain works having an electrical load of 2000 kW at 0.9 power factor. The equivalent spacing between overhead line conductors is 700 mm and its temperature is 55°C. The annual load factor of the works is 0.5.

Generate report of this existing line suggesting Most Economical Conductor for the above system. Also generate information of the suggested line alongwith benefits over the existing one. Take cost of unit energy as Rupees 3.05, rate of maximum demand charge as Rupees 200 per kVA per month and conductor Area Index as 2030.

ANALYSIS REPORT:
The overhead line under examination is making an annual transmission loss of 63109 kWh of energy. This loss of energy is equivalent to Rupees 1.925 lakh(s) per annum at the rate of Rupees 3.05 per kWh energy charge.

Voltage Regulation in the existing overhead line is 1.27 percent. This Regulation is OK as per Indian Electricity Rules.

Loading capacity of the existing overhead line is 35.99 MWkm under the given peripheral conditions.

Current through the overhead line is 118.1 ampere(s) for the given load of 2000 kW.

Most Economical Conductor for the overhead line under the given boundary conditions is 2 circuit(s) of DOG conductor having cross sectional area of 105 mm² (Equivalent aluminium area) i.e. 65 mm² equivalent nominal copper area.

The Most Economical Conductor will reduce the annual line losses from 63109 kWh to 54332 kWh leading to an annual saving of 8777 kWh. In monitory terms this saving is equivalent to Rupees 0.268 lakh(s) per annum.

Equivalent loss part of kVA demand (rms) will reduce from 7.2 kVA (rms) to 6.2 kVA (rms). This reduction in kVA demand leads to a gain of 1 kVA. The loading capacity of the line increases accordingly within the same contract demand. Further this reduction in kVA is equivalent to a saving of Rupees 0.024 lakh(s) per annum at the rate of Rupees 200 per kVA of Maximum Demand per month.

Gross monitory saving will be Rupees 0.292 lakh(s) per annum.

One time investment on re-organization of 2.5 km overhead line will be Rupees 6.598 lakh(s) only towards the cost of conductors and its associated accessories. This amount does not include the cost of existing conductors, which will be about Rupees 5.583 lakh(s) only, had it been new conductors. However, it is to be noted that this Re-organization scheme has considered the continuation of the services of the existing overhead line and its conductor.

In the re-organized arrangement of Most Economical Conductor, the number of circuits/ parallel conductors/ bundled conductors per phase will be 2 and additional number of parallel overhead line structures (on rail poles) will be 0. Thus the additional cost of structures will be Rupees 0 lakh(s).

Estimated cost of exclusively new overhead line(s) as suggested above, with the Most Economical Conductors will be approximately Rupees 5.799 lakh(s) per km. This estimation is based on the Conductor Index of 2030 and rail pole structure for the overhead line.

Assuming the production losses due to the downtime of the overhead to be 25% of the additional investment in re-organization, the downtime losses come to Rupees0.254 lakh(s) only.

The total cost of re-organization, comprising of investment on additional conductors & related accessories, investment on additional overhead line structures and downtime losses, comes to Rupees1.269 lakh(s).

Loading capacity of the line with the most economical conductor will be 46.958 MWkm.

Voltage Regulation in the new overhead line will be 0.98 percent. This Regulation is BETTER than that in the existing line and is OK as per Indian Electricity Rules.

For more details, the following annexed result sheets, obtained from the computerized program, may be consulted:

1. RESULTS OF REGULATION & DROP WHEN SENDING VOLTAGE IS KNOWN
2. RESULTS OF MOST ECONOMICAL CONDUCTOR SELECTION

Pay Back period of this re-organization scheme will be 4.35 years.

RECOMMENDATION: IMPLEMENT THE FINDINGS

Report generated by Elect 7.05

REGULATION AND VOLTAGE DROP IN SINGLE CONDUCTOR OHL (Vs GIVEN)

INPUT DATA :

1. Sending end voltage in kV	11.000
2. Receiving end Load in kW	2000
3. Power factor of the load	0.900
4. Load factor of the system	0.500
5. Name of overhead line Conductor	LYNX
6. Length of the overhead line in km	2.5
7. Equiv.spacing between conductors in mm	700
8. OHL Conductor temperature in °C	55.0

R e s u l t s :

1	Receiving end load shared by conductor path	kW	2000.0
2	Receiving end voltage of the OHL	kV	10.86
3	Sending end power factor	Factor	0.8968
4	Percentage voltage regulation	%	1.27
5	Voltage drop in the overhead line/ phase	Volts	93.00
6	Annual energy losses in the overhead line	kWh	63109
7	Total line losses (Maxm.)	kW	18.44
8	Total line losses (rms value)	kW	7.20
9	Resistance/ conductor of the OHL at 55°C	Ohms	0.4405
10	Inductive React./ conductor of the OHL.	Ohms	0.6525
11	Capacitive React./ conductor of the OHL.	Ohms	-
12	Capacitance/ conductor of the OHL.	MFD	0.0325
13	Form factor of the system.	Factor	1.25
14	Line efficiency of the OHL system.	%	99.09
15	Surge impedance of the OHL.	Ohms	252.747
16	Current through conductor of the OHL	Amps.	118.1
17	Disruptive critical voltage/ phase	kV	72.2
18	Equivalent impedance/ phase of OHL	Ohms	0.7873
19	Equivalent Cu cs area of conductor	sq.mm.	110
20	Equivalent Al cs area of conductor	sq.mm.	183
21	Current carrying capacity of conductor	Amps.	360

RESULTS OF MOST ECONOMICAL CONDUCTOR SELECTION

INPUT DATA :

1. Limiting conductor size for the overhead line	LION (140 mm²)
2. OHL system voltage in kV (Sending end)	11.000
3. Loading capacity of OHL in kW	2000.0
4. Power factor of the load on overhead line	0.900
5. Annual Load factor of the system	0.500
6. Length of the overhead line in km	2.5
7. Average span of the overhead line in m	120
8. Overhead line Conductor temperature in °C	55.0
9. Permissible voltage regulation in percent (%)	9.000
10. Inflated value of cond. area constant	2030.00
11. Annual interest+depr. of conductor cost in %	15.00
12. Cost of unit electricity in Rupees	3.050

Results:

1 Most economical number of OHL feeder(s)	2 Circuit(s)
2 Most economical Conductor selected for the OHL	DOG 65 mm²
3 Receiving end voltage of the OHL	10.893 kV
4 Sending end power factor of the OHL	0.8985
5 Percentage voltage regulation of OHL	0.98 %
6 Voltage drop in the overhead line/phase	64.56 Volts
7 Total overhead line losses (rms)	6.20 kW
8 Line efficiency of the OHL system	99.7 %
9 Current through the overhead line	116.6 Amps
10 Disruptive critical voltage/phase	62.2 kV
11 Total corona loss in the OH Line	0.000 kW
12 Annual energy loss in the OH Line	54332 kWh
13 Total resistance/ phase of the OH Line	0.778 Ohms
14 Total inductive reactance/ phase of OHL	0.788 Ohms
15 Total capacitance of the line/ phase of OHL	0.027 MFD
16 Maximum sag of the overhead line	693 mm
17 Recommended spacing between conductors	1141 mm
18 Standard capacity of the selected OHL/feeder	23479 kWkm/ 9% rg
19 Cost of selected OHL & conductor /km in Rupees	579900 per km
20 Most economical conductor's equiv. Cu cs area	65 mm², 2 x DOG
21 Least no. of circuits for the given regulation	1 x DOG
22 Cond. selected on the basis of max. load current	48 mm², 1xRACOON

CALCULATION RESULTS FOR SAG AND TENSION OF OVERHEAD LINE
(Data executed on 26/11/04 at 9:23:18 PM)

I N P U T D A T A :

Name of OHL Conductor = WOLF
Overall conductor dia. in mm. = 18.13
Cross sectional area in mm² A = 194.04
Weight of cond. in kg/m Wc = 0.726
Ultimate Tensile strength in kg UTS = 6720
Coefficient of linear exp./°C (alpha) å = 17.78 × 10^-6
Modulus of Elast.'Initial' kg/m² E = 6260
Mod. of Elasticity 'Final' kg/m² E = 8158
Normal Span of overhead line in m span = 225
Ruling Span of overhead line in m span = 200
Minimum temp. of conductor in °C = 5
Everyday temp of conductor in °C = 32
Maximum temp.of conductor in °C = 75
Wind pressure in kg/sq.m. = 151.3
Percentage Worst Limiting Tension = 70
% Initial Limiting Tension at no load = 35
% Final Limiting Tension at no load = 25
Thickness of ice layer in mm = 0
Specific gravity of ice = 0.9168

C A L C U L A T I O N S :

TENSION EQUATION IN TERMS OF STRESS IS GIVEN BY:

f² = [f-(K - å × (t2-t1) × E)] = Z0 × (Loading Factor)²

Where Z0 = (span × Delta)² × E / 24
t2 = Cond. temperature correspondig to stress f
t1 = Cond. temperature correspondig to stress f1
å = Coefficient of linear expansion of cond. material
E = Modulus of Elasticity (Final)
K = f1 - (span × Delta × Loading factor)² × E / (24 × f1²)
f1 = Stress corresponding to temperature t1

GIVEN STARTING CONDITION:

No Wind and 32°C Factor of Safety = 4.00

Tension T = UTS / FoS = 6720 / 4.00 = 1680 kg.
Corresponding stress f1 = T/A = 1680 / (194.04 × 10^-6) = 8.658 × 10^6 kg/m²

Conductor density- Delta = Wc/A = 0.726 / [194.04 × 10^(-6)] = 3741 kg/cu.m.
Wind load = Wind pressure × conductor dia. = 151.3 × 0.01813 = 2.7431 kg/m.

Loading factor corresponding to No Wind
= Effective load on cond./ Conductor weight
= Sqrt[(ZeroWind)² + (Weight_Cond)²] / (Weight_Cond)
= Sqrt(0.² + 0.726²) / 0.726 = 1.0

Constant K = stress - (span × Delta × Loading factor)² × Mod. of Elas./ (24 × stress²)
Or K = 8.658 × 10^6 - (200 × 3741 × 1.0)² × 8158 × 10^6 / (24 × 8.658² × 10^12)
= 6.1189 × 10^6

Now Sag = EffectiveConductorLoad × span² / (8 × Tension)
= Delta × LoadingFactor × span² / (8 × stress)
= 3741 × 1.0 × 225 / (8 × 8.658 × 10^6)
= 10.688 m (Deflected)

Vertical Sag = Delta × NoWind_LoadingFactor × span² / (8 × stress)
= 3741 × 1.0 × 225² / (8 × 8.658 × 10^6)
= 2.735 m

Swing from Vertical at Full Wind Load & 36% Wind Load:
Angle of swing = Arctan (Wind load/ Dead wt. of conductor)
Full load swing Angle = 75.2°
36% Wind load swing Angle = 53.7°

Note: Values of Vertical & Horizontal components of Sags can be found using these angles suitably for different loading conditions.

Values of K - å × (t2-t1) × E at 5°C, 32°C, 75°C respectively are:

K - å × t × E = 6.1189 × 10^6 - 17.780 × 10^-6 × (5 - 32) × 8158 × 10^6
= 10.0352 × 10^6
K - å × t × E = 6.1189 × 10^6 - 17.780 × 10^-6 × (32 - 32) × 8158 × 10^6
= 6.1189 × 10^6
K - å × t × E = 6.1189 × 10^6 - 17.780 × 10^-6 × (75 - 32) × 8158 × 10^6
= -.1183 × 10^6

Value of Z0 is given by:

Z0 = (200 × 3741)² × 8158 × 10^6 / 24
= 190.3370 × 10^18

VALUES OF Z, STRESS AND TENSION AT FULL WIND AND DIFFERENT TEMPS.

Stress is found from the Tension equation by putting values of Z and K-å.(t2-t1).E

VALUES AT FULL WIND & 5°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 3.908^2$
$= 2907.5481 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 5°C:
$f^2 = [f- (10.0352 \times 10^6)] = 2907.5481 \times 10^{18}$
Stress (f) at Full Wind & 5°C = 18.5158×10^6 kg/m² (by iterative method)
Tension at 5°C = Stress × Area = $18.5158 \times 10^6 \times 194.04 \times 10^{-6}$
= 3593 kg
Sag at 5°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 3.908 \times 225^2 / (8 \times 18.516 \times 10^6)$
= 4.998 m

VALUES AT FULL WIND & 32°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 3.908^2$
$= 2907.5481 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 32°C:
$f^2 = [f- (6.1189 \times 10^6)] = 2907.5481 \times 10^{18}$
Stress (f) at Full Wind & 32°C = 16.6308×10^6 kg/m² (by iterative method)
Tension at 32°C = Stress × Area = $16.6308 \times 10^6 \times 194.04 \times 10^{-6}$
= 3227 kg
Sag at 32°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 3.908 \times 225^2 / (8 \times 16.631 \times 10^6)$
= 5.564 m

VALUES AT FULL WIND & 75°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 3.908^2$
$= 2907.5481 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 75°C:
$f^2 = [f- (-.1183 \times 10^6)] = 2907.5481 \times 10^{18}$
Stress (f) at Full Wind & 75°C = 14.2334×10^6 kg/m² (by iterative method)
Tension at 75°C = Stress × Area = $14.2334 \times 10^6 \times 194.04 \times 10^{-6}$
= 2762 kg
Sag at 75°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 3.908 \times 225^2 / (8 \times 14.233 \times 10^6)$
= 6.502 m

VALUES OF Z, STRESS AND TENSION AT 36% WIND LOAD AND DIFFERENT TEMPS.

VALUES AT 36% WIND LOAD & 5°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.688^2$
$= 542.4875 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 5°C:
$f^2 = [f- 10.0352 \times 10^6] = 542.4875 \times 10^{18}$
Stress (f) at 36% Wind Load & 5°C = 13.1651×10^6 kg/m² (by iterative method)
Tension at 5°C = Stress × Area = $13.1651 \times 10^6 \times 194.04 \times 10^{-6}$
= 2555 kg
Sag at 5°C = Delta × Loading factor × span² / (8 × stress)
= $3741 \times 1.688 \times 225^2 / (8 \times 13.165 \times 10^6)$
=3.036 m

VALUES AT 36% WIND LOAD & 32°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.688^2$
$= 542.4875 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 32°C:
$f^2 = [f- 6.1189 \times 10^6] = 542.4875 \times 10^{18}$
Stress (f) at 36% Wind Load & 32°C = 10.7837×10^6 kg/m² (by iterative method)
Tension at 32°C = Stress × Area = $10.7837 \times 10^6 \times 194.04 \times 10^{-6}$
= 2092 kg
Sag at 32°C = Delta × Loading factor × span² / (8 × stress)
= $3741 \times 1.688 \times 225^2 / (8 \times 10.784 \times 10^6)$
=3.707 m

VALUES AT 36% WIND LOAD & 75°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.688^2$
$= 542.4875 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 75°C:
$f^2 = [f- -.1183 \times 10^6] = 542.4875 \times 10^{18}$
Stress (f) at 36% Wind Load & 75°C = 8.1164×10^6 kg/m² (by iterative method)
Tension at 75°C = Stress × Area = $8.1164 \times 10^6 \times 194.04 \times 10^{-6}$
= 1575 kg
Sag at 75°C = Delta × Loading factor × span² / (8 × stress)
= $3741 \times 1.688 \times 225^2 / (8 \times 8.116 \times 10^6)$
=4.925 m

VALUES OF Z, STRESS AND TENSION AT NO WIND LOAD AND DIFFERENT TEMPS.

VALUES AT NO WIND LOAD & 5°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.0^2$
$= 190.3370 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 5°C:
$f^2 = [f- 10.0352 \times 10^6] = 190.3370 \times 10^{18}$
Stress (f) at NO Wind Load & 5°C = 11.4794×10^6 kg/m² (by iterative method)
Tension at 5°C = Stress × Area = $11.4794 \times 10^6 \times 194.04 \times 10^{-6}$
= 2227 kg

Sag at 5°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 1.0 \times 225^2 / (8 \times 11.479 \times 10^6)$
$= 2.063$ m

VALUES AT NO WIND LOAD & 32°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.0^2$
$= 190.3370 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 32°C:
$f^2 = [f- 6.1189 \times 10^6] = 190.3370 \times 10^{18}$
Stress (f) at NO Wind Load & 32°C = 8.6580×10^6 kg/m² (by iterative method)
Tension at 32°C = Stress × Area = $8.6580 \times 10^6 \times 194.04 \times 10^{-6}$
= 1680 kg
Sag at 32°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 1.0 \times 225^2 / (8 \times 8.658 \times 10^6)$
$= 2.735$ m

VALUES AT NO WIND LOAD & 75°C:

$Z = Z0 \times (\text{Load factor})^2 = 190.3370 \times 10^{18} \times 1.0^2$
$= 190.3370 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 75°C:
$f^2 = [f- -.1183 \times 10^6] = 190.3370 \times 10^{18}$
Stress (f) at NO Wind Load & 75°C = 5.7131×10^6 kg/m² (by iterative method)
Tension at 75°C = Stress × Area = $5.7131 \times 10^6 \times 194.04 \times 10^{-6}$
= 1109 kg
Sag at 75°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 1.0 \times 225^2 / (8 \times 5.713 \times 10^6)$
$= 4.144$ m

CHECKING PARAMETERS WITH INITIAL MODULUS OF ELASTICITY AT NO WIND LOAD AND EVERYDAY TEMPERATURE

VALUES AT NO WIND LOAD & 32°C:

$Z = Z0 \times (\text{Load factor})^2$
$= 190.3370 \times 10^{18} \times 1.0^2 \times 6260 \times 10^6 / (8158 \times 10^6)$
$= 146.0541 \times 10^{18}$

Solving the obtained equation for Stress/ Tension at 32°C:
$f^2 = [f- .0000 \times 10^6] = 146.0541 \times 10^{18}$
Stress (f) at NO Wind Load & 32°C = 5.2663×10^6 kg/m² (by iterative method)
Tension at 32°C = Stress × Area = $5.2663 \times 10^6 \times 194.04 \times 10^{-6}$
= 1022 kg
Sag at 32°C = Delta × Loading factor × span² / (8 × stress)
$= 3741 \times 1.0 \times 225^2 / (8 \times 5.266 \times 10^6)$
$= 4.496$ m

CHECKING PARAMETERS WITH INITIAL MODULUS OF ELASTICITY AT FULL WIND LOAD AND EVERYDAY TEMPERATURE

VALUES AT FULL WIND LOAD & 32°C:

Z = Z0 × (Load Factor)²
= 190.3370 × 10^18 × 3.908² × 6260 × 10^6 / (8158 × 10^6)
= 2231.0923 × 10^18

Solving the obtained equation for Stress/ Tension at 32°C:
f² = [f- .0000 × 10^6] = 2231.0923 × 10^18
Stress (f) at FULL Wind Load & 32°C = 13.0669 × 10^6 kg/m² (by iterative method)
Tension at 32°C = Stress × Area = 13.0669 × 10^6 × 194.04 × 10^-6
= 2535 kg
Sag at 32°C = Delta × Loading factor × span² / (8 × stress)
= 3741 × 3.908 × 225² / (8 × 13.067 × 10^6)
= 7.082 m

Calculations generated by Elect 7.05 from SofexIndia

CALCULATION RESULTS FOR ELECTRICITY BILL
(Data executed on 26/11/04 at 9:27:47 PM)

I N P U T D A T A :

Power Supply Company = ComF
Bill No. = 51040200050
Bill Cycle = January '2004
Payment made = Before due Date
Due Date = 27/03/2004
Meter ID No. = BH-NJ-TVMSEMWBU02088
Voltage = 11000.
Multiplic. Factor (kWh) = 6.00
Mult. Factor (MaxDem) = 6.00
Contract Demand kVA = 400
Maximum Demand kW = 214.00
Maximum Demand kVA = 350.00
Opening Reading = 10390.00
Closing Reading = 14805.00
Total Hours = 792.00
Interruption Hrs. = 2.98
Rebate Hours = 0.00
Domestic Units = 0
Industrial Units = 26490
Commercial units = 0
Exempted Units = 0

Ind. Duty Rate (%) = 7.50
Dom. Duty Rate (%) = 10.00
Enr.Tariff (Rs./Unit) = 3.0743
Intrm. Ch. (Re./Unit) = 0.06
Meter Rent = 1200.00
Avail compens. (%) = 1.00
Rebate/ kWh on Energy Charge for Timely Payment (paise) = 10
Penalty/ kWh on Energy Charge for Late Payment (paise) = 10
Rate of Surcharge for Late Payment/month or part (%) = 1.25
Penalty on shortfall of cons. below 20% LF (Paise/kWh) = 20
Rebate on excess cons./kWh above 80% LF in paise = 20
Rate of Penalty for Exceeding CD on Net Energy Bill (%) = 1

C A L C U L A T I O N S :
(Note: Units & Amounts have been converted to long integer)

kVA Contract Demand taken for calculations = 400 kVA
Units consumed = Diff. in Open-Close readings × MF
= (14805 - 10390) × 6
= 4415 × 6
= 26490
Power Factor = Maximum kW Demand/ Maximum kVA Demand
= 214 / 350
= 0.61
Load Factor = Units consumed × 100 / (CD × Available Hours × PF)
= 26490 × 100 / [400 × (792.0 - 2.98) × 0.610]
= 13.76
Energy Charges = Units consumed × Unit Energy Charge
= 26490 × 3.0743
= 81438.00
Load Factor Penalty Charge for LF of 13.76
Panalty = Rate of penalty × CD × (20 - LF) × Available Hours × PF/100
= 0.20 × 400 × (20 - 13.76) × (792.0 - 2.98) × 0.610/100
= 2403.00

REBATE / PENALTY FOR TIME OF PAYMENT
Since payment made is Before due Date
Rate of rebate is = 0.1
Rabate for timely payment = Rebate Rate × Units Consumed
= 0.1 × 26490
= 2649.00

TOTAL NET CHARGE:
Net Energy Charge = Energy Ch. + LF Penalty - Pay Time Rebate
= 81438.00 + 2403.00 - 2649.00
= 81192.00

INTERIM CHARGE INDUSTRIAL+COMMERCIAL+DOMESTIC:
Interim Indusrial Energy Charge = Industrial Units × Rate
= 26490 × 0.06

= 1589.00
Interim Domestic Energy Charge = Domestic Units × Rate
= 0 × 0.06
= 0.00
Interim Commercial Energy Charge = Commercial Units × Rate
= 0 × 0.06
= 0.00
TOTAL Interim Charges = 1589.00 + 0.00 + 0.00
= 1589.00

COMPENSATION FOR LOW AVAILABILTY OF POWER:
Power Availability Factor = (Total Hours - Interruption) × 100/ Total Hours
= (792 - 2.98) × 100 / 792
= 99.62
Since, Availability is more than 90%
Compensation = 0.00

GOVERNMENT DUTY:
Duty on Ind. Consumption = Ind. Duty Rate × Ind. Units Consumed
× (Unit Energy cost - Rebate for Timely payment)
= 7.5 × 26490 × (3.0743 - 0.1) / 100
= 5909.00
Similarly:
Duty on Dom. Cons. = 10 × 0 × (3.0743 - 0.1) / 100
= 0.00
And,
Duty on Com. Cons. = 10 × 0 × (3.0743 - 0.1) / 100
= 0.00
Total duty = 5909.00

INTERIM DUTY:
Interim Duty on Ind. Cons. = Interim Ind. Duty Rate × Interim Ind. Charge
= 7.5 × 1589.00 / 100
= 119.00
Similarly:
Duty on Dom. Cons. = 10 × 0.00 / 100
= 0.00
And,
Duty on Com. Cons. = 10 × 0.00 / 100
= 0.00
Total Inerim Duty = 119.00 + 0.00 + 0.00
= 119.00

PENALTY ON MAXIMUM DEMAND
Penalty on Demand = Penalty Rate × Net Energy Charge
Since MD < CD
Penalty on Demand = 0 × 81192.00
= 0.00

TOTAL PAYABLE BEFORE DATE

Total = Net Charge + Total Interim + Total Duty + Interim Duty
+ Meter Rent + Demand Penalty - Availability Compensation
= 81192.00 + 1589.00 + 5909.00
+ 119.00 + 1200 + 0.00 - 0.00
= 90009.00

SURCHARGE FOR DELAYED PAYMENT
Delay Surcharge = 0.00

Calculations generated by Elect 7.05 from SofexIndia

PERCENTAGE IMPEDANCE CALCULATION OF TRANSFORMERS
CALCULATION RESULTS FOR LOSSES AND IMPEDANCE VOLTAGE OF TRANSFORMER
(Data executed on 26/11/04 at 9:35:26 PM)

I N P U T   D A T A :

Transformer Capacity in kVA = 100
Rated value of High Voltage in kV = 11
Rated value of Low Voltage in kV = 0.433
Reference Temp. for Transf. resistance in °C = 24
Measured value of High Volt. Resist. in Ohms = 20.2
Measured value of LV Resist. in milli-Ohms = 20.3
Temp. for which values are required in °C = 75
Impedance Voltage at ambient temp.in Volts = 488
Average measured value of HV current in A = 5.26
Measured Load Losses in Watts = 1484
Winding material of Transformer = Aluminium

C A L C U L A T I O N S :

HV rated current Ip = Rated kVA / (1.732 × Voltage)
= 100 / (1.732 × 11)
= 5.2 Amps.

LV rated current Is = Rated kVA/(1.732 × Voltage)
= 100 / (1.732 × 0.433)
= 133.3 Amps.

I^2R loss in HV windings at 24°C:
$= 3 \times Ip^2 \times Rp \times 0.5$
$= 3 \times 5.2^2 \times 20.2 \times 0.5$
= 834.7 Watts

I^2R loss in LV windings at 24°C:
$= 3 \times Is^2 \times Rs \times 0.5 / 1000$
$= 3 \times 133.3^2 \times 20.3 \times 0.5 / 1000$

$= 541.4$ Watts

Total I^2R loss of transformer at 24°C:
$= 834.7 + 541.4$ Watts
$= 1376.1$ Watts

Total I^2R loss of transformer at 75°C:
$= (225 + T2) \times I^2R$ loss at T1 °C / $(225 + T1)$
$= (225 + 75) \times 1376.1 / (225 + 24)$
$= 1657.9$ Watts

Full load loss at 24°C:
= (Ip / Measured HV Current Ipm)^2
× Measured load loss
$= (5.25 / 5.26)^2 \times 1484$
$= 1477.6$ Watts

Stray losses at 24°C:
= Full load loss - Total I^2R loss at ref. temp.
$= 1477.6 - 1376.1$
$= 101.5$ Watts

Stray losses at 75°C:
$= (225 + T2) \times$ Stray losses at 24°C / $(225 + T2)$
$= (225 + 75) \times 101.5 / (225 + 75)$
$= 84.3$ Watts

Full load loss at 75°C:
= Total I^2R loss at 75°C + Stray losses at 75°C
$= 1657.9 + 84.3$
$= 1742.2$ Watts

Impedance voltage at 24°C:
= Rated HV Current × Imp. Voltage at 24°C
/ Measured HV Current at 24°C
= Ip × Imp. Voltage at 24°C / Im
$= 5.2 \times 488 / 5.3$
$= 486.9$ Volts

Percentage Imp. Voltage at 24°C:
= Imp. Voltage at 24°C × 100 / HV in Volts
$= 486.9 \times 100 / 11000$
$= 4.43$ %

Percentage Resistance at 24°C:
= Full load loss at 24°C × 100 / Rated kVA
$= 1477.6 \times 100 / (100 \times 1000)$
$= 1.48$ %

Percentage Reactance:

= Root(Impedance²-Resistance²)
= Root(4.43² - 1.48²)
= 4.17 %

Percentage Resistance at 75°C:
= Full load loss at 75°C × 100 / Rated kVA
= 1742.2 × 100 / (100 × 1000)
= 1.74 %

Percentage Impedance at 75°C:
= Root(Reactance²+Resistance²)
= Root(4.17² - 1.74²)
= 4.52 %

Calculations generated by TransElect™ from SofexIndia™

TRANSFORMERS - PERCENTAGE IMPEDANCE

Sl. NO.	DESCRIPTION OF OUTPUT RESULTS	Result Value	Unit
1	Rated Current of High Voltage side	5.2	Amps.
2	Rated Current of Low Voltage side	133.3	Amps.
3	I^2R loss in HV windings at 24°C	834.7	Watts
4	I^2R loss in LV windings at 24°C	541.4	Watts.
5	Total I^2R loss of transformer at 24°C	1376.1	Watts
6	Total I^2R loss of transformer at 75°C	1657.9	Watts
7	Full load loss at 24°C	1477.6	Watts.
8	Stray losses at 24°C	101.5	Watts
9	Stray losses at 75°C	84.3	Watts
10	Full load loss at 75°C	1742.2	Watts.
11	Impedance voltage at 24°C	486.9	Volts
12	Percentage Imp. Voltage at 24°C	4.43	%
13	Percentage Resistance at 24°C	1.48	%
14	Percentage Reactance	4.17	%
15	Percentage Resistance at 75°C	1.74	%
16	Percentage Impedance at 75°C	4.52	%

TRANSFORMER - I N P U T   V A L U E S

1	Transformer winding material	Aluminium
2	Transformer Capacity in kVA	100
3	Rated value of High Voltage in kV	11
4	Rated value of Low Voltage in kV	0.433
5	Reference Temp. for Transf. resistance in °C	24
6	Measured value of High Volt. Resist. in Ohms	20.2
7	Measured value of LV Resist. in milli-Ohms	20.3
8	Temp. for which values are required in °C	75
9	Impedance Voltage at ambient temp.in Volts	488
10	Average measured value of HV current in A	5.26
11	Measured Load Losses in Watts	1484

Generated by TransElect on 26/11/04

CABLE SELECTION - RECOMMENDED CABLE

S.N.	D e s c r i p t i o n	Value	Remarks
1	Required number of the cable lengths in parallel	1	
2	Cross Sectional Area of the selected cable sq.mm.	150	
3	Percentage voltage regulation (%)	0.914	
4	Voltage drop in the cable/phase in Volts	17.6	
5	Annual energy loss in the selected cable in kWh	39320	
6	Percentage line efficiency of the cable (%)	99.1	
7	Resistance of the cable/phase/conductor in ohms	0.0796	
8	Ind. reactance of the cable/phase/conductor in ohms	0.0386	
9	Capacitance of each cable/phase in MFD	0.3332	
10	Total losses in the cable (Average)- kW component	4.489	
11	Total losses in the cable (Maximum)- kW component	9.538	
12	Total dielectric losses in the cable- Watt component	8	
13	Total sheath loss in the cable- Watt component	88	
14	Sending end power factor	0.88	
15	Sending end voltage (L-L) in kV	3.33	
16	Calculated RMS current based on LF & FF in Amperes	135.6	
17	Maximum load current in Amperes	198.8	
18	Derating factor due to ambient temperature	0.953	
19	Derating factor due to ground temperature	1	
20	Derating factor due to depth of cable laying	0.994	
21	Derating factor due to soil resistivity	1.03	

CABLE SELECTION - BASED ON FAULT CURRENT

S.N.	D e s c r i p t i o n	Value	Remarks
1	Required number of the cable lengths in parallel	1	
2	Cross Sectional Area of the selected cable sq.mm.	120	
3	Percentage voltage regulation (%)	1.048	
4	Voltage drop in the cable/phase in Volts	20.3	
5	Annual energy loss in the selected cable in kWh	46483	
6	Percentage line efficiency of the cable (%)	98.9	
7	Resistance of the cable/phase/conductor in ohms	0.0942	
8	Ind. reactance of the cable/phase/conductor in ohms	0.0392	
9	Capacitance of each cable/phase in MFD	0.3164	
10	Total losses in the cable (Average)- kW component	5.306	
11	Total losses in the cable (Maximum)- kW component	11.277	
12	Total dielectric losses in the cable- Watt component	7.6	
13	Total sheath loss in the cable- Watt component	104	
14	Sending end power factor	0.881	
15	Sending end voltage (L-L) in kV	3.335	
16	Calculated RMS current based on LF & FF in Amperes	135.6	
17	Maximum load current in Amperes	198.8	
18	Derating factor due to ambient temperature	0.953	
19	Derating factor due to ground temperature	1	
20	Derating factor due to depth of cable laying	0.994	
21	Derating factor due to soil resistivity	1.03	

CABLE SELECTION - BASED ON RMS CURRENT

S.N.	D e s c r i p t i o n	Value	Remarks
1	Required number of the cable lengths in parallel	1	
2	Cross Sectional Area of the selected cable sq.mm.	150	
3	Percentage voltage regulation (%)	0.914	
4	Voltage drop in the cable/phase in Volts	17.6	
5	Annual energy loss in the selected cable in kWh	39320	
6	Percentage line efficiency of the cable (%)	99.1	
7	Resistance of the cable/phase/conductor in ohms	0.0796	
8	Ind. reactance of the cable/phase/conductor in ohms	0.0386	
9	Capacitance of each cable/phase in MFD	0.3332	
10	Total losses in the cable (Average)- kW component	4.489	
11	Total losses in the cable (Maximum)- kW component	9.538	
12	Total dielectric losses in the cable- Watt component	8	
13	Total sheath loss in the cable- Watt component	88	
14	Sending end power factor	0.88	
15	Sending end voltage (L-L) in kV	3.33	
16	Calculated RMS current based on LF & FF in Amperes	135.6	
17	Maximum load current in Amperes	198.8	
18	Derating factor due to ambient temperature	0.953	
19	Derating factor due to ground temperature	1	
20	Derating factor due to depth of cable laying	0.994	
21	Derating factor due to soil resistivity	1.03	

CABLE SELECTION - BASED ON VOLTAGE REGULATION

S.N.	D e s c r i p t i o n	Value	Remarks
1	Required number of the cable lengths in parallel	1	
2	Cross Sectional Area of the selected cable sq.mm.	25	
3	Percentage voltage regulation (%)	3.934	
4	Voltage drop in the cable/phase in Volts	84	
5	Annual energy loss in the selected cable in kWh	207054	
6	Percentage line efficiency of the cable (%)	95.2	
7	Resistance of the cable/phase/conductor in ohms	0.42	
8	Ind. reactance of the cable/phase/conductor in ohms	0.0482	
9	Capacitance of each cable/phase in MFD	0.2156	
10	Total losses in the cable (Average)- kW component	23.636	
11	Total losses in the cable (Maximum)- kW component	50.267	
12	Total dielectric losses in the cable- Watt component	5.2	
13	Total sheath loss in the cable- Watt component	463.5	
14	Sending end power factor	0.887	
15	Sending end voltage (L-L) in kV	3.436	
16	Calculated RMS current based on LF & FF in Amperes	135.6	
17	Maximum load current in Amperes	198.8	
18	Derating factor due to ambient temperature	0.953	
19	Derating factor due to ground temperature	1	
20	Derating factor due to depth of cable laying	0.994	
21	Derating factor due to soil resistivity	1.03	

CABLES VOLTAGE REGULATION & DROP

S.N.	Description	Unit	OUTPUT
1	Receiving end load shared by cable path	kW	150
2	Sending end voltage of the cable (L-L)	kV	3.302
3	Sending end current/ phase of the system	Amps.	30.36
4	Sending end power factor of the system	Factor	0.8644
5	Percentage voltage regulation of the system	%	0.05
6	Annual energy losses in the cable(s)	kWh	335
7	Total losses (max. in eq. kW) in the system	kW	0.08
8	Total line losses (rms eq. kW) in the system	kW	0.04
9	Resist./phase/cond. of the cable at 75°C	Ohms	0.0295
10	Inductive react./phase/cond. of the cable	Ohms	0.0074
11	Line efficiency of the cable feeding system.	%	99.95
12	Receiving end current/ phase in cable(s)	Amps.	30.52
13	Form factor of the system.	Factor	1.22
14	Total Capacitance/ phase of the cable(s)	MFD	0.5
15	Receiving end capacitor current	Amps.	0.05
16	Cable line mid point capacitor current	Amps.	0.2
17	Sending end capacitor current	Amps.	0.05
18	Capacitive react./phase/cond. of the cable	k.Ohms	6.4
19	Equivalent impedance/ phase of cable(s)	Ohms	0.0305
20	Type of conductor material of the cable	Type	cu
21	Cross sectional area of cable(s)	sq.mm.	70
22	Current carrying capacity of cable(s)	Amps.	165
23	Voltage DROP per phase in the cable(s)	Volts	0.9

DISPLAY OF 3 SELECTED FIELDS DATA OF 8 METERS (21 FOUND)

SN	MeterNo	BillCycle	Bill Number	Contract Demand	Units_ cons	Tot_Bill
1	NKC-TVMSEMWBB02626	1/02/04	51040200156	2000	772560	2521892
2	LKC-TVMSEMWBB02627	1/02/04	51040200158	1600	479232	1570458
3	CLJ-TVMSEMWBU02081	1/02/04	51040200056	750	224436	734558
4	BH-RJ-TVMSEMWBD01710	1/02/04	51040200053	1000	370584	1211400
5	BH-PJ-TVMSEMWBB00671	1/02/04	51040200057	850	268696	879033
6	BH-NJ-TVMSEMWBU02088	1/02/04	51040200159	1100	349500	1146270
7	HRP-TVMSEMWBB02637	1/02/04	51040200048	1300	413860	1364850
8	BH-PJ-TVMSEMWBB00671	1/03/04	51040300038	850	272336	890894
9	LKC-TVMSEMWBB02627	1/03/04	51040300148	1600	597960	1957733
10	BH-RJ-TVMSEMWBD01710	1/03/04	51040300034	1000	445008	1454149
11	NKC-TVMSEMWBB02626	1/03/04	51040300146	2000	899160	2934832
12	HRP-TVMSEMWBB02637	1/03/04	51040300009	1300	461920	1521615
13	CLJ-TVMSEMWBU02081	1/03/04	51040300037	750	271020	886509
14	BH-RJ-TVMSEMWBD01710	1/01/04	51040100081	1000	403092	1317438
15	BH-PJ-TVMSEMWBB00671	1/01/04	51040100089	850	271144	887019
16	BH-NJ-TVMSEMWBU02088	1/03/04	51040300149	1100	389870	1277915
17	HRP-TVMSEMWBB02637	1/01/04	51040100166	1300	475100	1564607
18	NKC-TVMSEMWBB02626	1/01/04	51040100037	2000	867360	2831085
19	CLJ-TVMSEMWBU02081	1/01/04	51040100087	750	222136	727056
20	BH-NJ-TVMSEMWBU02088	1/01/04	51040100163	1100	401870	1317095
21	LKC-TVMSEMWBB02627	1/01/04	51040100189	1600	399816	1323303
	GRAND	TOTAL		1229	9256660	30319711
				AVERAGE	TOTAL	

OHL COST BREAK-UP

S.N.	ITEM DESCRIPTION	UNIT	QNTY.	UNIT RATE	AMOUNT IN Rs.
1	ACSR 'DOG ' Conductor having eq. Al csa=105 mm²	km	3.3	42849	141404
2	Rail Pole (52kg/m) '9 metres' height	no.	12	16050	192600
3	11kV Disc Type Insulators	no.	36	963	34668
4	Line Hardwares-brackets/clamps etc.	set	12	368	4424
5	7x2.59 mm Galvanized Earth Wire	km	1.1	17922	19715
6	PCC Work at Pole/ Tower Sites	no.	12	553	6636
7	Earthings at Pole/ Tower Sites	no.	2	986	1972
	SUB-TOTAL				401419
8	Transportation, erection, bracket and insulator fitting, wire stranding, supervision etc.	LS	25%	401419	100354
	GRAND-TOTAL				**501774**

Rupees Fifty Lakh One Thosand Seven Hundred SeventyFour Only.

POWER BALANCE FOR UNDERGROUND PROJECT

SUPERPOSITION METHOD

Sl. No.	Description	Connected Load in kW	Working Load in kW	Demand Factor	Power Factor (cos ø)	tan ø	Apparent load in kW	Reactive load in kVAr	Maximum Demand in kVA	Running Hours/ day	Annual Working days	Annual Consump. In MkWh
1	Vertical Transport	400	200	0.80	0.85	0.62	160	99	188	10	300	0.480
2	Pumping	1200	1000	0.80	0.85	0.62	800	496	941	16	365	4.672
3	Surface Lighting	300	100	0.90	0.90	0.48	90	44	100	12	365	0.394
4	Underground lighting	200	200	0.90	0.90	0.48	180	87	200	24	365	1.577
5	Colony	750	500	0.80	0.85	0.62	400	248	471	10	365	1.460
6	Direct Haulage	800	600	0.80	0.80	0.75	480	360	600	15	300	2.160
7	Endless Haulage	70	35	0.80	0.80	0.75	28	21	35	15	300	0.126
8	Belt Conveyor	100	70	0.80	0.75	0.88	56	49	75	15	300	0.252
9	CHP	200	150	0.80	0.80	0.75	120	90	150	12	300	0.432
10	Compressor	200	100	0.60	0.70	1.02	60	61	86	10	300	0.180
	Sub-Total	**4220**	**2955**	**0.80**	**0.84**	**0.66**	**2374**	**1555**	**2838**			**11.733**
	Superposition factors											
	0.925	For kW										
	0.964	For kVAr	2955	0.74	0.83	0.68	2196	1499	2659			
	Improving PF upto											
	0.95		2955	0.74	0.95	0.33	2196	722	2311			

Capacitor Bank required for power factor improvement in kVAr	260 x 3 kVAr
Required Transformer Capacity in kVA	1387 x 2 kVA
Selected Transformer Capacity in kVA	1600 x 2 kVA
Percentage Voltage Impedance of the Selected Transformer	6.25 %

POWER BALANCE FOR UNDERGROUND PROJECT

DIVERSITY FACTOR METHOD

Sl. No.	Description	Connected Load in kW	Working Load in kW	Demand Factor	Power Factor (cos ø)	tan ø	Apparent load in kW	Reactive load in kVAr	Maximum Demand in kVA	Running Hours/ day	Annual Working days	Annual Consump. In MkWh
1	Vertical Transport	400	200	0.8	0.85	0.620	160	99	188	10	300	0.480
2	Pumping	1200	1000	0.8	0.85	0.620	800	496	941	16	365	4.672
3	Surface Lighting	300	100	0.9	0.9	0.484	90	44	100	12	365	0.394
4	Underground lighting	200	200	0.9	0.9	0.484	180	87	200	24	365	1.577
5	Colony	750	500	0.8	0.85	0.620	400	248	471	10	365	1.460
6	Direct Haulage	800	600	0.8	0.8	0.750	480	360	600	15	300	2.160
7	Endless Haulage	70	35	0.8	0.8	0.750	28	21	35	15	300	0.126
8	Belt Conveyor	100	70	0.8	0.75	0.882	56	49	75	15	300	0.252
9	CHP	200	150	0.8	0.8	0.750	120	90	150	12	300	0.432
10	Compressor	200	100	0.6	0.7	1.020	60	61	86	10	300	0.180
	Sub-Total	**4220**	**2955**	**0.80**	**0.84**	**0.655**	**2374**	**1555**	**2838**			**11.733**
	Taking Diversity factor for kW and kVAr as 1.23		2955	0.65	0.84	0.655	1930	1264	2307			
	Improving PF upto 0.95		2955	0.65	0.95	0.329	1930	634	2032			

Capacitor Bank required for power factor improvement in kVAr	210 x 3 kVAr
Required Transformer Capacity in kVA	1219 x 2 kVA
Selected Transformer Capacity in kVA	1250 x 2 kVA
Percentage Voltage Impedance of the Selected Transformer	5 %

RESULTS OF SAG TENSION CALCULATIONS

Temp. in °C	Description of OHL / condition	Cond.+Ice kg/m.	Wind load kg/m.	Eqv. load kg/m.	Stress kg/sq.cm.	Tension in kg	Tension % UTS	SagDefl in mm	SagVert in mm	SagHrz in mm	Remarks
5	WITH FULL WIND LOAD	0.726	2.743	2.838	1852	3593	53.5	10688	2735	10332	Ok, Tension within the limit of 70%.
5	WITH 36% WIND LOAD	0.726	0.988	1.226	1317	2555	38	3036	1798	2446	Swing from vertical = 75.2° at full wind
5	WITHOUT WIND LOAD	0.726	0	0.726	1148	2227	33.1	2063	2063	0	Swing from vertical = 53.7° at 36% wind
											** Assumed Factor of Safety = 4.00 at 25% UTS
32	WITH FULL WIND LOAD	0.726	2.743	2.838	1663	3227	48	5564	1424	5379	
32	WITH 36% WIND LOAD	0.726	0.988	1.226	1078	2092	31.1	3707	2196	2986	
32	WITHOUT WIND LOAD	0.726	0	0.726	866	1680	25.0**	2735	2735	0	Ok, Tension within the limit of 25%.
75	WITH FULL WIND LOAD	0.726	2.743	2.838	1423	2762	41.1	6502	1663	6285	
75	WITH 36% WIND LOAD	0.726	0.988	1.226	812	1575	23.4	4925	2917	3968	
75	WITHOUT WIND LOAD	0.726	0	0.726	571	1109	16.5	4144	4144	0	
32	No wind load (Initial)	0.726	0	0.726	527	1022	15.2	4496	4496	0	Ok, Tension within the limit of 35%.
32	Initial with wind load	0.726	2.743	2.838	1307	2535	37.7	7082	1812	6846	

INPUT DATA	VALUE
Conductor name	WOLF
Conductor dia. in mm.	18.13
Cond. CS Area in mm²	194.04
Conductor Wt. in kg/m	0.726
Conductor UTS in kg	6720
OHL normal span in m	225
OHL ruling span in m	200
Minimum temp. in °C	5
Everyday temp. in °C	32
Maximum temp. in °C	75

VALUE	INPUT DATA
6260	Initial Modulus of Elasticity in kg/m²
8158	Final Modulus of Elasticity in kg/m²
151.3	Wind pressure in kg/m²
70	% Limiting tension (Worst at given °C)
35	% Initial limiting tension
25	% Limiting tension (No wind at given °C)
0	Thickness of ice in mm
0.9168	Specific gravity of ice
17.78	x 10^(-6) Coeff. of linear exp./°C

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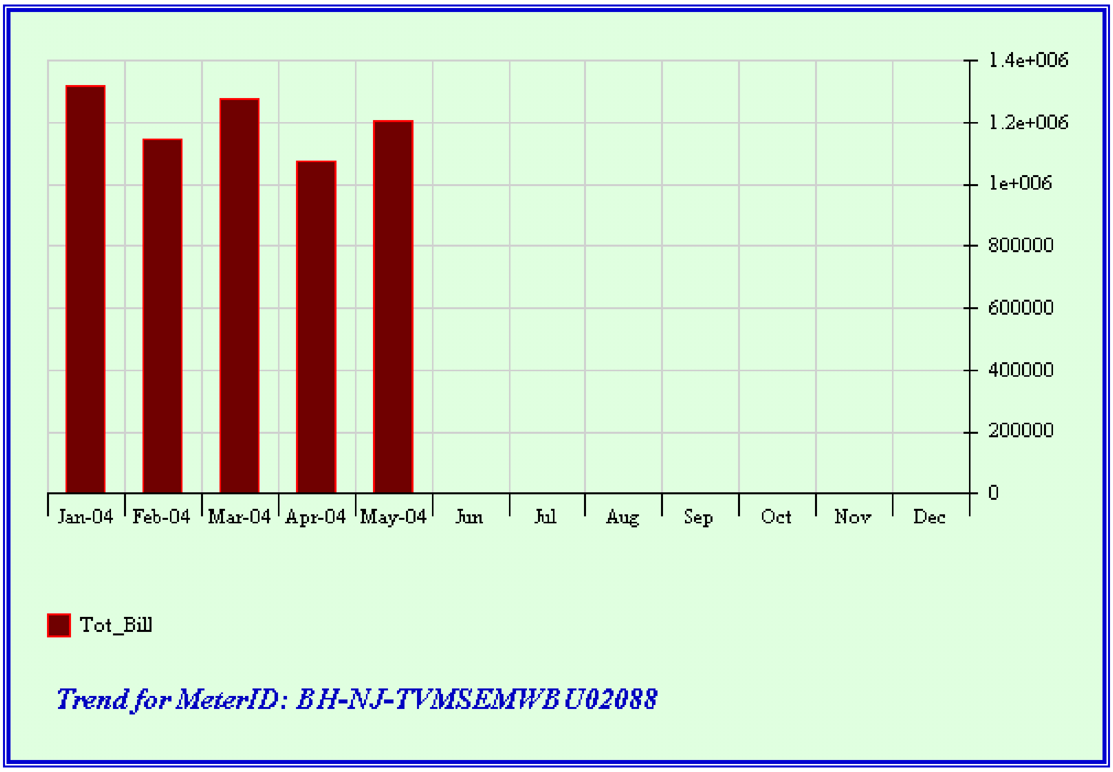
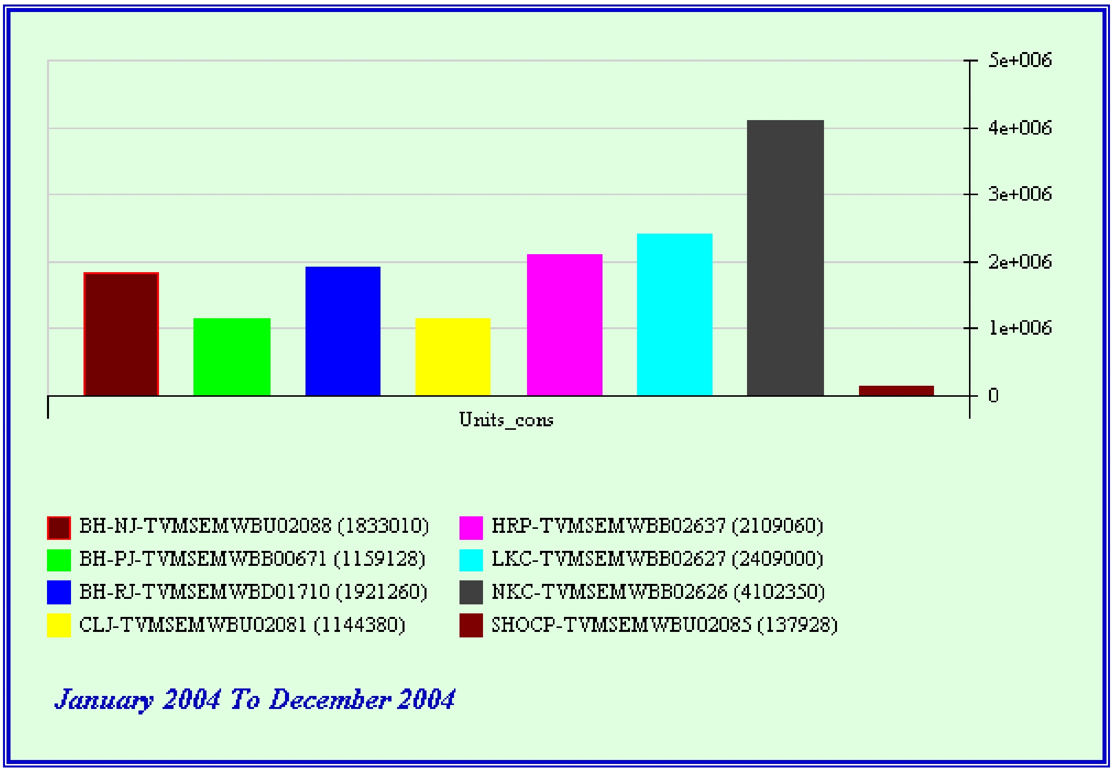
ENERGY BILL ANALYSIS

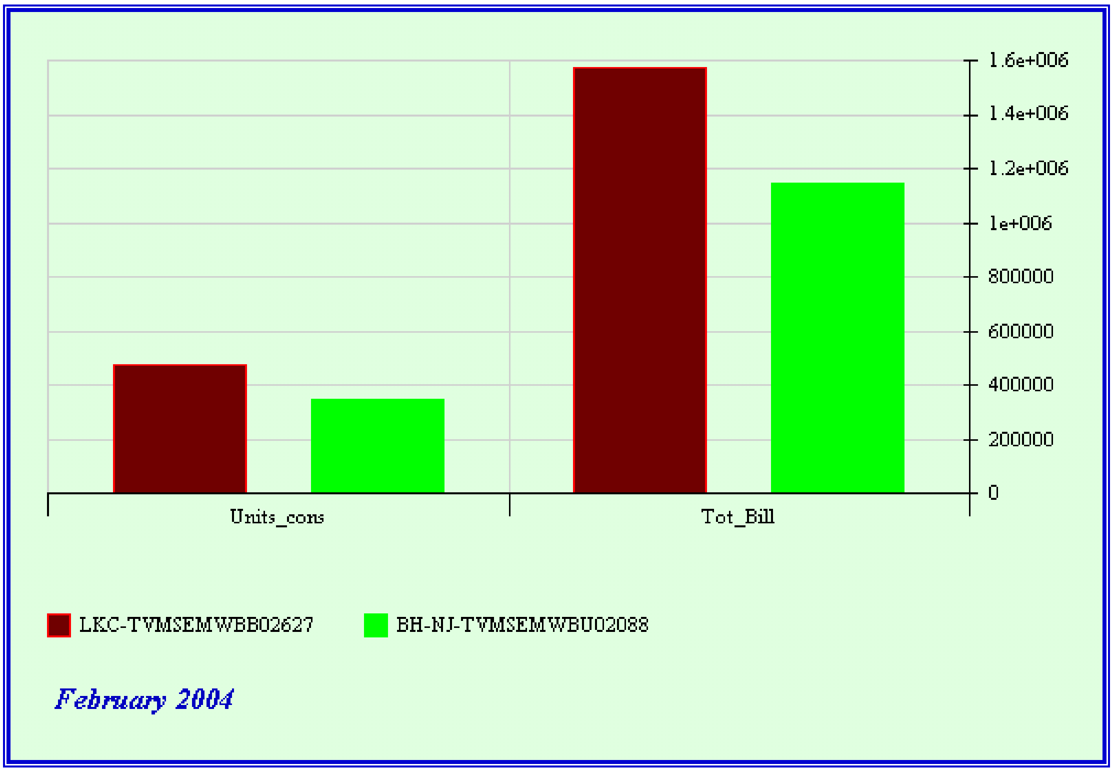
TREND OF BILL AMOUNT OF SINGLE METER - GRAPHICAL VIEW



COMPARATIVE VIEW OF UNITS CONSUMED DURING A PERIOD BY NUMBER OF METERS - GRAPHICAL VIEW

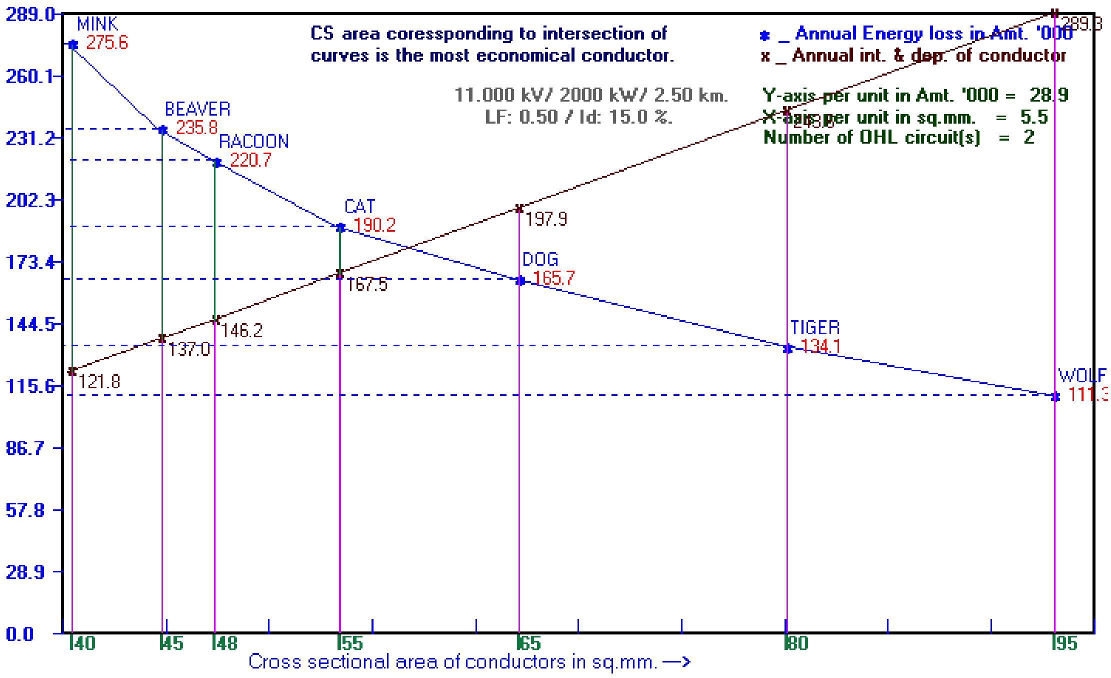


COMPARATIVE VIEW OF SELECTED FIELDS AND METERS IN A GIVEN MONTH – GRAPHICAL DISPLAY



MOST ECONOMICAL CONDUCTOR SELECTION

VARIATION OF CONDUCTOR COST VS ENERGY LOSS FOR A GIVEN POWER TRANSMISSION THROUGH OHL



PROPERTIES OF OVERHEAD LINE CONDUCTORS

Conductors are formed with a number of stranded aluminium wires. To strengthen the conductor, steel wires are used in the core of the strands. It is always better to use steel wires in the inner section because of the lower current density in the inner part, compared to outer part of the conductor section. The higher resistivity of steel thus has a very little effect on voltage drop and regulation.

Two types of conductors are in common use:

1. ACSR (Aluminium Conductor Galvanised Steel Reinforced)
2. AAAC (All Alloy Aluminium Conductor)

One more type AAC (All Aluminium Conductor) is also in use, but is being replaced by AAAC due to superior quality of AAAC over AAC.

In ACSR Conductors, normally the core is made up of steel wires to strengthen the tensile properties. Numbers of layers are then placed over this core to form the desired size of conductors. There are standards for the size of wire sections both of steel and aluminium. In normal practice, both steel and aluminium wires of conductors are kept of the same size or else the outer diameter of steel core is approximately equal to diameter of individual aluminium wires. This is done to reduce the spacing factor of the conductor i.e. to make the conductor more compact.

The maximum number of wires that can be placed over a layer is given by 6n, where n is layer number. The constant 6 is the integer value of 2π. Thus; wire arrangement in the section of a 4-layer conductor will be as under:

CORE	-	1
LAYER 1	-	6
LAYER 2	-	6x2
LAYER 3	-	6x3
LAYER 4	-	6x4
TOTAL	**-**	**61**

In AAAC type overhead line conductors, the construction is same as above, except the core, which is also of aluminium instead of steel. The breaking load/ tensile strength (UTS) of AAAC is comparable to ACSR, rather it is better than ACSR.

The resistance and current density qualities of AAAC are also superior to those of same size of ACSR. The only poor part of AAAC is that it can be cut more easily than ACSR.

Consider the following variables for further discussion:

n_a = Number of Aluminium wires

n_s = Number of Steel wires

d_a = Outer diameter of Aluminium wires in mm
d_s = Outer diameter of Steel wires in mm

1. OVERALL RADIUS OF CONDUCTOR

For a conductor made up of a given number of Aluminium/ Steel wires of given outer diameters, the overall radius r_d of the conductor so formed is given by:

$r_d = (d_s + 2d_a)/2$ For 1 steel and 6 aluminium stranded conductor (7 Strands)
$r_d = (3d_s + 2d_a)/2$ For 7 steel and 6 aluminium stranded conductor (13 Strands)
$r_d = (3d_s + 4d_a)/2$ For 7 steel and 30 aluminium stranded conductor (37 Strands)
$r_d = (3d_s + 6d_a)/2$ For 7 steel and 54 aluminium stranded conductor (61 Strands)

These empirical relations are required to assess the inductance and capacitance of the overhead line comprised of these conductors.

The above relations may be generalized for n layers conductor over the central core, the diameters of component wires being equal:

$$r_d = (2n+1) \times d_a / 2$$

2. EQUIVALENT ALUMINIUM AREA (eqa)

Equivalent aluminium area of the composite conductor formed of Aluminium and steel may be given by:

$$eqa = Total\_Al\_Area + Total\_Steel\_Area \times \left(\frac{Al\_\mathrm{Re}sistivity}{Steel\_\mathrm{Re}sistivity} \right)$$

or $$eqa = ala + Steel\_Area \times \left(\frac{\rho_{al}}{\rho_s} \right)$$

3. NOMINAL EQUIVALENT COPPER AREA (eqc)

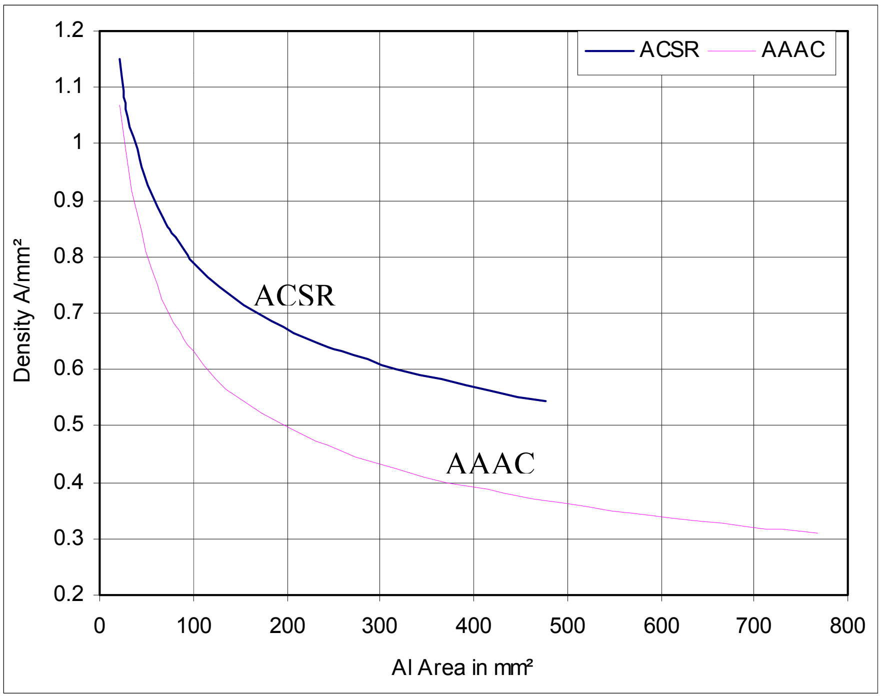
To find the nominal equivalent copper area, the first step is to convert the equivalent aluminium area to equivalent copper and then set this value to the nearest standard value as specified in standards:

$$eqc = \frac{eq\_Al\_area \times \mathrm{Re}sistivity\_Copper}{\mathrm{Re}sistivity\_Alu\min ium}$$

or $$eqc = eqa \times \left(\frac{\rho_{cu}}{\rho_{al}} \right)$$

4. CURRENT CARRYING CAPACITY (CCC) & CURRENT DENSITY

The current density in a section of conductor is not uniform. The practical values of current density show it to vary exponentially. The author has arrived at the following empirical relationships for current density in different types and cross sectional area of conductors:



CURRENT DENSITY CURVES FOR ACSR & AAAC CONDUCTORS

Empirical relation of the ACSR curve (shown black) is given by:

$$\log(\delta) = 0.8642 - 0.2385 \times \log(eqa)$$

or $$\delta = e^{0.8642 - 0.2385 \times \log(eqa)}$$

Empirical relation of the AAAC curve (shown pink) is given by:

$$\log(\delta) = 1.137 - 0.3468 \times \log(eqa)$$

or $$\delta = e^{1.137 - 0.3468 \times \log(eqa)}$$

Based on the above empirical relations of the current density, the current carrying capacity of different size of conductors may be calculated out as under:

$$ccc = Cond\_Al\_equiv\_area \times Current\_density$$

or $$ccc = eqa \times e^{0.8642 - 0.2385 \times \log(eqa)}$$ For ACSR

And $$ccc = eqa \times e^{1.137 - 0..3468 \times \log(eqa)}$$ For AAAC

5. RESISTANCE (R at 20°C)

ACSR CONDUCTORS

Let Steel wires= ns numbers each of diameter ds mm.
Aluminium wires= na numbers each of diameter da mm
Resistvity of steel = ρ_{st}
Resistvity of aluminium = ρ_{al}

Equivalent aluminium area $eqa = al\_area + steel\_area \times \frac{\rho_{al}}{\rho_{st}}$

or $$eqa = na \times \frac{\pi}{4} \times da^2 + ns \times \frac{\pi}{4} \times ds^2 \times \frac{\rho_{al}}{\rho_{st}}$$

Resistance/km in Ohms $R = \frac{\rho_{al}}{eqa}$ Where ρ_{al} is in $\Omega mm^2 / km$

NOTE: IS 398 (Part-III)-1976 neglects the conductivity of steel core and calculates resistance taking a factor for accounting stranding and lay ratio.

AAAC/AAC CONDUCTORS

Equivalent aluminium area $ala = na \times \frac{\pi}{4} \times da^2$

Resistance/km in Ohms $R = \frac{\rho_{al}}{eqa}$ Where ρ_{al} is in $\Omega mm^2 / km$

NOTE: IS 398 (Part-III)-1976 calculates resistance taking a factor for accounting stranding and lay ratio.

Resistance at any other temperature than 20°C is given by:

$$R_t = R_{20}\left(\frac{241.5 + t}{241.5 + 20}\right)$$

6. REACTANCE (x_l and x_c)

Inductance L in Henry/m of the overhead line comprised of conductors of radius r mm and spacing between conductors d mm is given by the following formula:

$$L = 0.5 + 2 \times \ln\left(\frac{d}{r}\right) \times 10^{-7} \qquad \text{Henry/m}$$

Corresponding inductive reactance per km of the overhead line is thus given by:

$$x_l = \frac{\pi}{100}\left[0.5 + 2 \times \ln\left(\frac{d}{r}\right)\right] \qquad \text{Ohms/km}$$

And Capacitance C in microfarad/km of the overhead line comprised of conductors of radius r mm and spacing between conductors d mm is given by the following formula:

$$C = \frac{1}{18 \times \ln\left(\frac{d}{r}\right)} \quad \text{mfd/km}$$

Corresponding Capacitive reactance per km of the overhead line is thus given by:

$$x_c = \frac{1}{2\pi f C} = \frac{18 \times 10^6 \times \ln\left(\frac{d}{r}\right)}{2\pi f} \quad \text{Ohms/km}$$

Note: From the above equations of x_l and x_c it may be noted that both the inductive and capacitive reactance depend on the spacing between conductors of the overhead line. Further, the spacing between overhead line conductors depends on the system voltage, span, sag, weather conditions etc. The values calculated are for a default conductor spacing of 700 mm.

7. WEIGHT OF CONDUCTOR

ACSR CONDUCTORS

Weight/Mass of ACSR conductor/km

= (Vol. of steel/km) x Steel_density + (Vol. of Al/km) x Al_density

$$W = \frac{\pi}{4} \times ds^2 \times \delta_s + \frac{\pi}{4} \times da^2 \times \delta_{al}$$

Where ds and da in mm

δ_s and δ_{al} in gm/cc (or kg/litre)

AAAC/AAC CONDUCTORS

Weight of AAAC conductor/km

= (Vol. of Al/km) x Al_density

$$W = \frac{\pi}{4} \times da^2 \times \delta_{al}$$

Where da in mm

δ_{al} in gm/cc (or kg/litre)

NOTE: IS-398 (Part-II) & (Part-III) – 1976 takes mass of the conductor as the sum of masses of individual wires multiplied by a factor which accounts for stranding of wires (because the length of stranded wires are greater than that of central wire).

8. TENSILE STRENGTH

Tensile strength/ breaking load of conductor is taken as 98 percent of the sum of the breaking loads of the aluminium wires plus 85 percent of the sum of breaking loads of the component wires *before* stranding.

VOLTAGE REGULATION LIMITS IN OH LINES

RULE 54 & 55 OF INDIAN ELECTRICTY RULE- 1956
(AMMENDED UPTO 1st JULY 1990)

54. *Declared voltage of supply to consumer* – Except with the written consent or with the previous sanction of the State Government a supplier shall not permit the voltage at the point of commencement of supply as defined under Rule 58 to vary from the declared voltage:

   (i) in the case of low or medium voltage, by more than 6 per cent, or;
   (ii) in the case of high voltage, by more than 6 per cent on the higher side or by more than 9 per cent on the lower side, or;
   (iii) in the case of extra high voltage, by more than 10 per cent on the higher side or by more than 12.5 per cent on the lower side.

55. *Declared frequency of supply to consumer* – Except with the written consent or with the previous sanction of the State Government a supplier shall not permit the frequency of an alternating current supply to vary the declared frequency by more than 3 per cent.