Decentralized Power Generation: Opportunities in Rural India

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India's Electricity Scenario

- Installed Capacity ~ 100,000 MW
  - Fifth largest in the world
  - 1,500 MW in 1947
- 95% of villages electrified
  - 40% of households have access
- Per Capita Consumption : 350 kWh
  - World Average: 2000 kWh
- Need to add 10,000 – 15,000 MW annually
  - Actually added 4000 – 5000 MW p.a.

Regulatory Framework & Structure

Generation: Central | State | IPP

Transmission: State Utilities

Distribution: State/Private Utilities

CEA

SERC

MoP

MNES

CERC

Mismatch in Tariff & Consumption

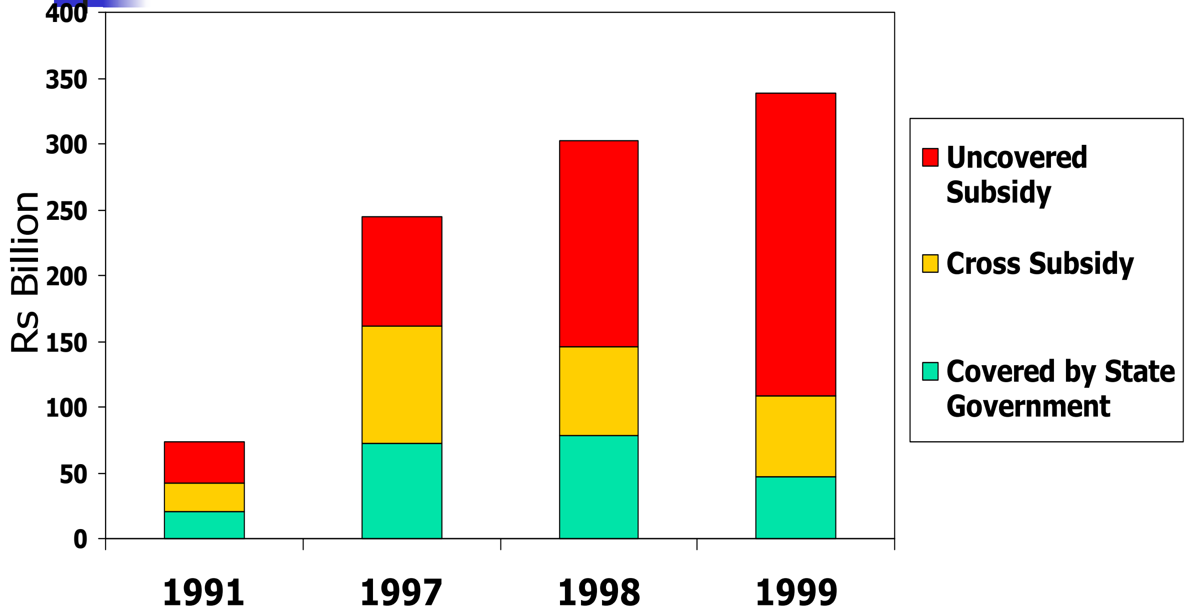
- Agriculture supply subsidized
  - Free in some states
  - Not metered
- Average cost of supply: Rs 3.04/kWh
- Average Revenue: Rs 2.12/kWh

Category	Consumption	Tariff Rs/kWh
Domestic	17%	Rs 1.20/kWh
Agriculture	31%	Rs 0.22/kWh
Industrial	35%	Rs 4.50/kWh
Commercial	5%	Rs 4.70/kWh

1 US $ = Rs 48

Source: Karnataka Electricity Regulatory Commission

Uncovered Subsidies are Growing



Rural Electricity Supply

- Intermittent
- Voltage and frequency fluctuations
  - Equipment damage
- Vicious circle: (*World Bank, 2001*)
  - Subsidized Tariffs
  - Low Investments
  - Poor quality
- T&D Losses > 30% (I^2R + Theft)

Advantages of DG

- Generate close to rural load centers (NRECA, US Department of Energy, FERC, California Energy Commission)
  - Reliability of supply
  - Lower distribution losses
  - Improve voltage profiles
  - Peak shaving
  - Local supply of reactive power

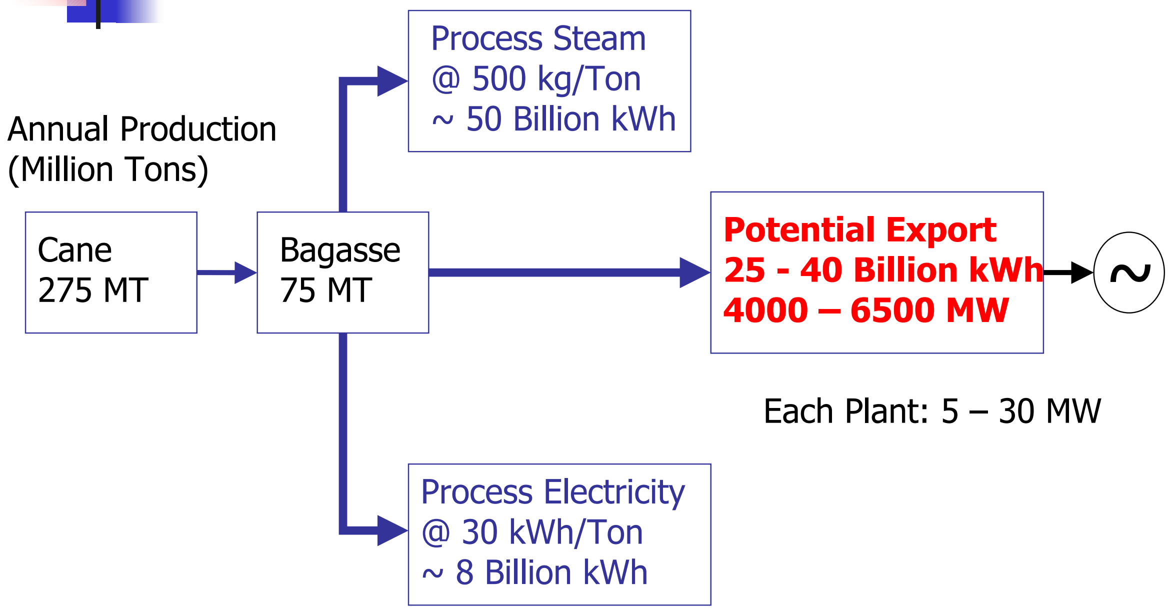
- Create incentives for increasing agricultural tariff
  - Willingness to pay for good quality power (*World Bank, 2001*)

Biomass for Decentralized Generation

- Biomass power potential 17,000 MW
  - Gasifier-reciprocating engine
  - + 5,000 MW from sugarcane bagasse and rice husk cogeneration

- Sugar Mills (> 2500 Tons per Day)
  - Export 5 – 30 MW

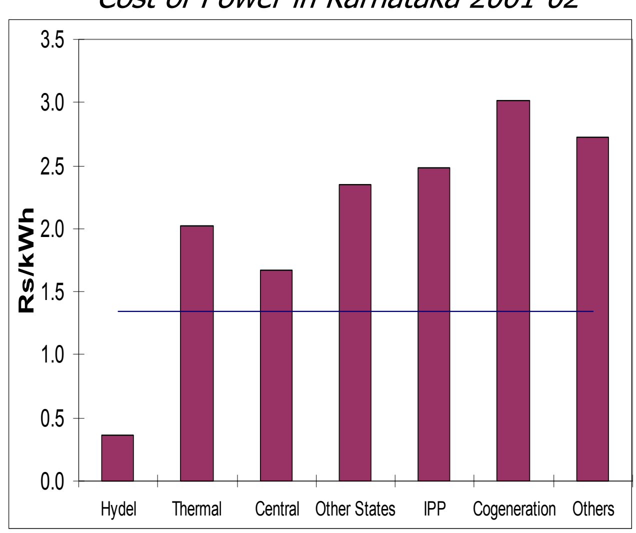
Enormous Potential of Power From Sugar Mills



SEB Policy for Renewable (DG):

- Buy-Back: Rs. 3.01/kWh
  - Expensive
  - Interconnect at 66/33 kV
  - Delay of months in payments
  - No reduction in SEB's losses
- Wheeling: up to 20% charges
  - SEBs view DG as a threat
- Reactive power not valued
- Present policies overlook potential benefits of DG

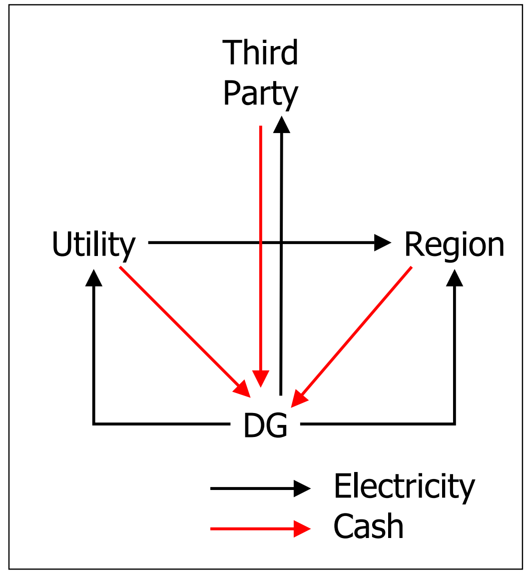
Cost of Power in Karnataka 2001-02

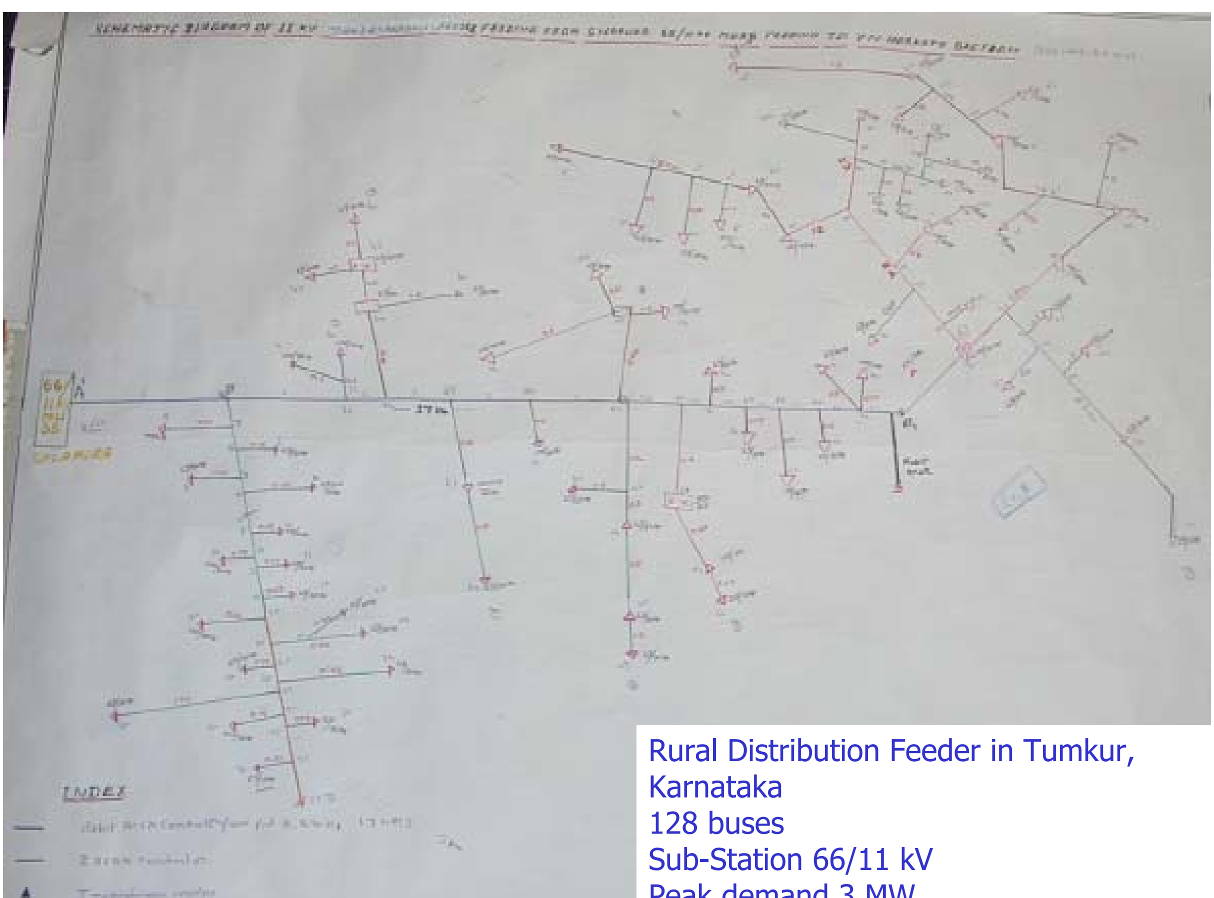


(Karnataka Electricity Regulatory Commission, Bangalore)

Research Objectives

- Techno-Economic Analysis of Rural Micro-Grids
  - Break the vicious circle
- Options for Pricing Reactive Power
- Rational basis for assessing wheeling charges





Rural Distribution Feeder in Tumkur, Karnataka
128 buses
Sub-Station 66/11 kV
Peak demand 3 MW

Present Tariffs & Consumption

Consumer	Tariff Rs/kWh	Units Consumed
Domestic	1.20	183,940
Commercial	4.50	900
Irrigation Pumps	0.20	?
Industrial	4.75	13,320
Losses (Technical)		?
Losses (Commercial)		?
TOTAL		7,831,400

Load Flow Studies (3 Phase AC)

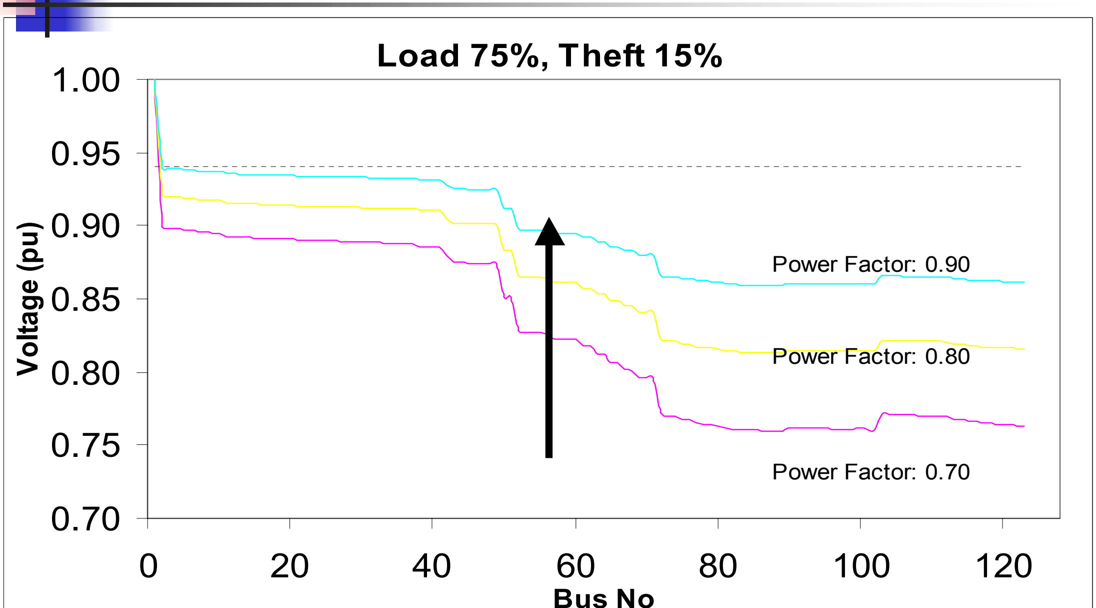
- We know:
  - Total kWh at the sub-stations
  - Sanctioned load at each bus (kW)
  - Length and impedances of conductors between buses
- We don't know:
  - kWh at each bus
  - Power factor (hence kVAR at each bus)
  - Unauthorized connections (theft)
  - Sub-Station Voltage

Load Flow Studies (3 Phase AC)

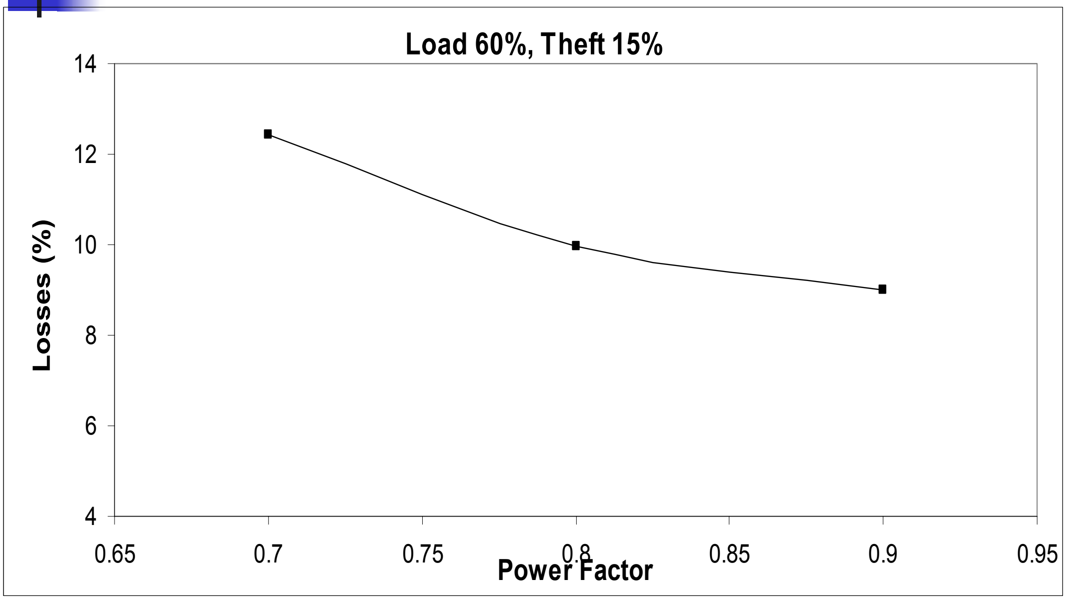
- Assumptions (Unknown Variables):
  - On-Line Load (40% - 75%)
  - Power Factor (0.7 – 0.9)
  - Theft (15%)
- POWERWORLD Simulation
- Gauss - Seidel Method
  - Admittance Matrix (128 X 128)
  - $Y_{ij} = \frac{1}{R + j\omega L}$
  - Voltage at each node: $V_k Y_{kk} = [\frac{(P_k - jQ_k)}{V_k} - \sum_{i=1}^{N} Y_{ki} V_i]$
  - Iterate till convergence

P	Real Power
Q	Reactive Power
V	Voltage
Y	Admittance Matrix
R	Resistance
L	Inductive Resistance
ω	Angular Frequency

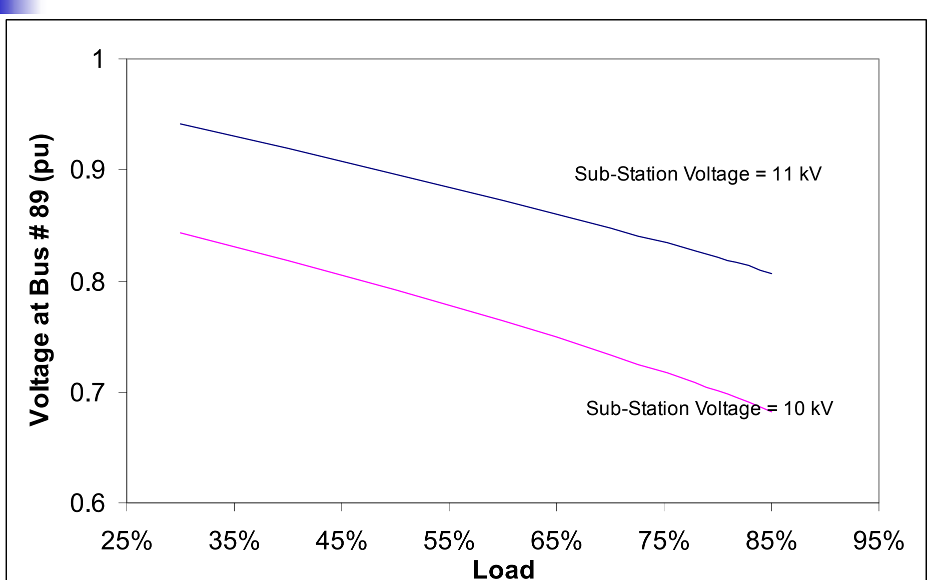
Results: Voltage Profiles:



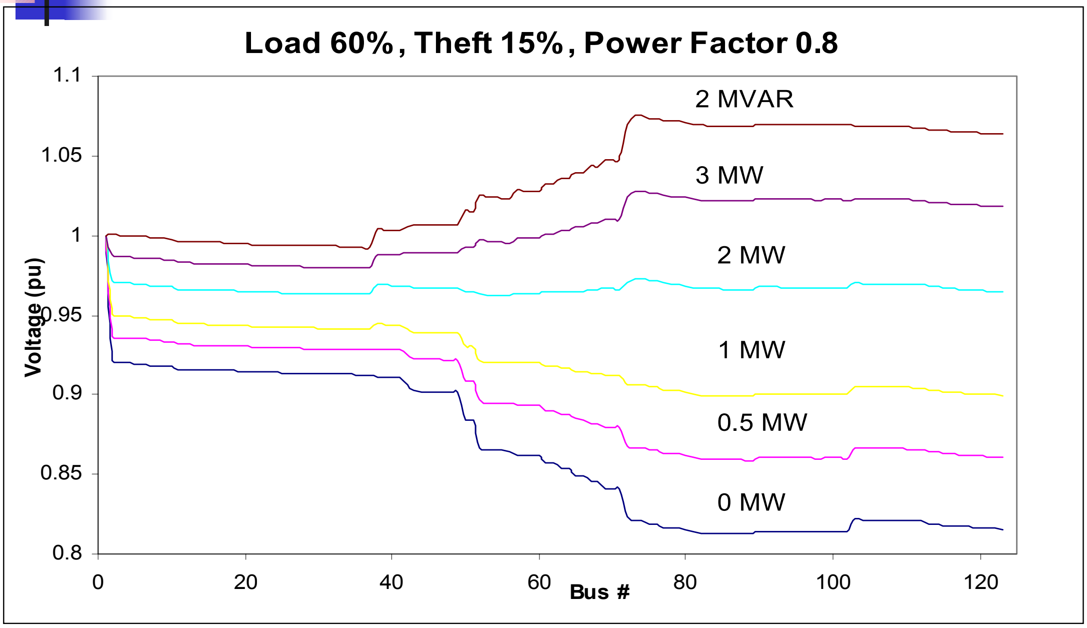
Technical Distribution Losses



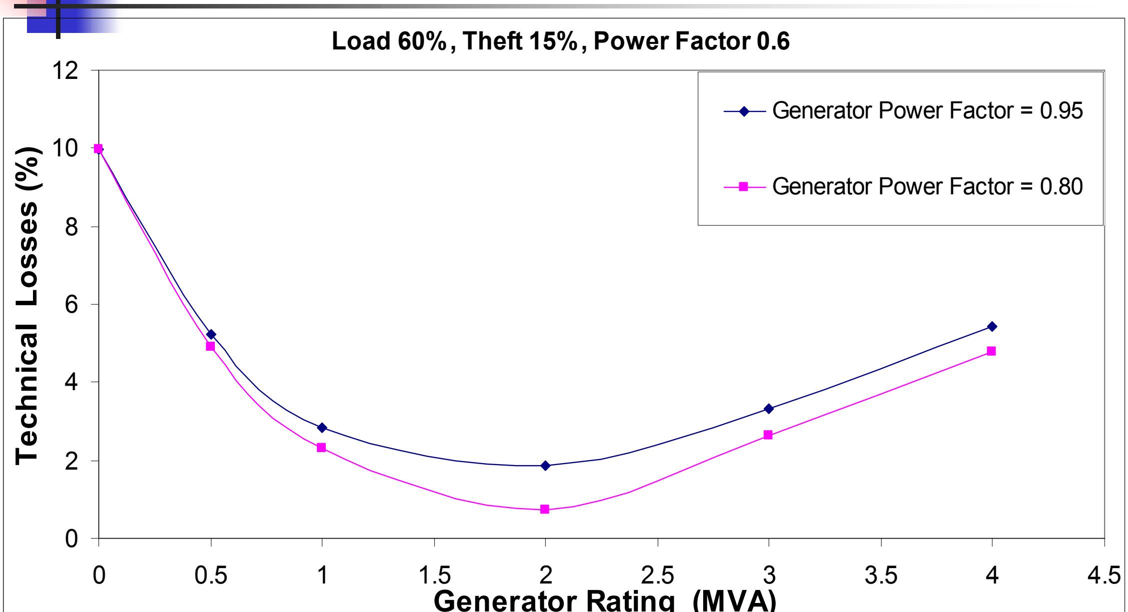
Impact of Sub-Station Voltage



Impact of DG on Voltages



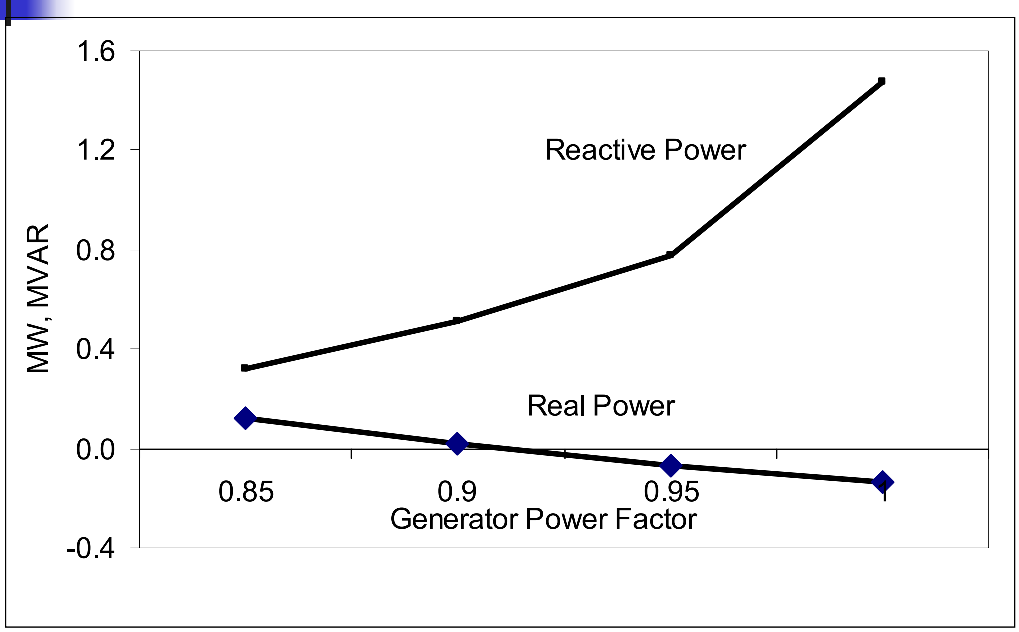
Impact of DG on Losses



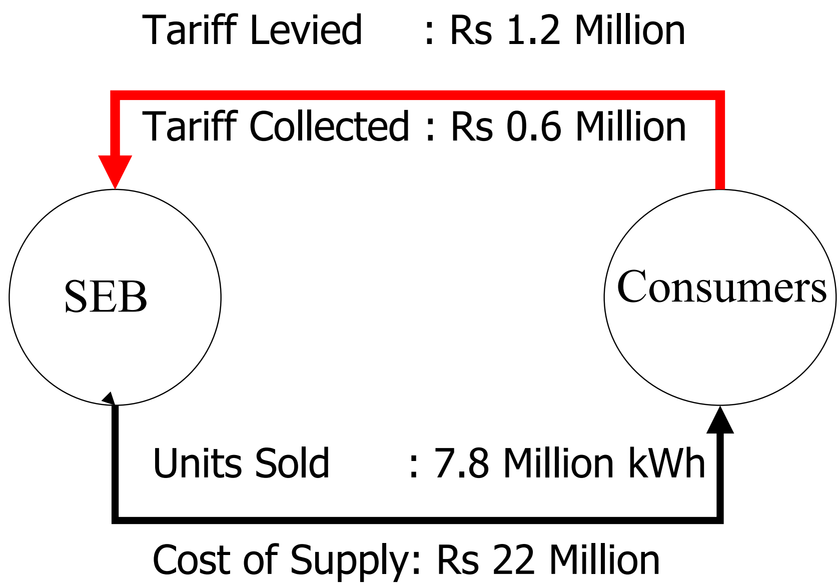
Capacitors in Grid

CAPACITOR[MVAR] IN THE GRID					
SOURCE: KPTCL ADMIN REPORTS					
YEAR	**110KV**	**66KV**	**33KV**	**11KV**	**TOTAL MVAR**
96-97	640	871	170	559.12	2240.12
97-98	800	1051	170	559.12	2580.12
98-99	840	1091	170	559.12	2660.12
99-00	840	1091	170	559.12	2660.12

Power Transactions with Grid



Economic Analysis: SEB's Present Losses



Methodology

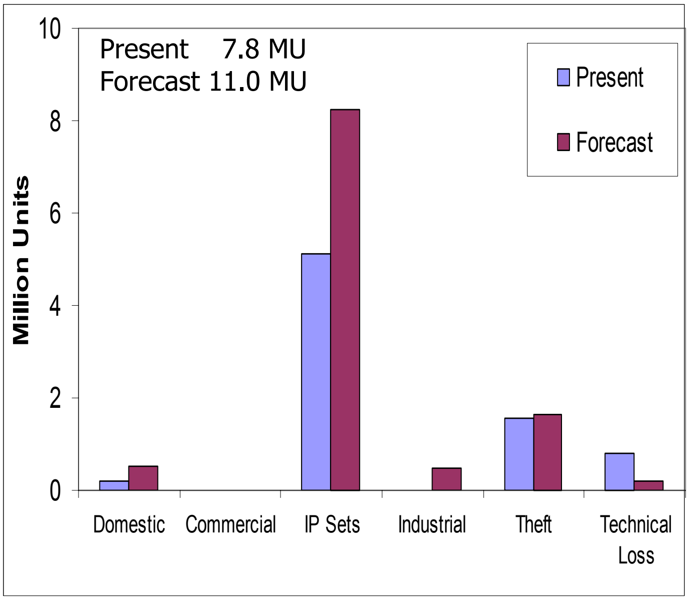
1. Estimate Generation Potential of IPP (2.5 MVA)
   - PLF: 70%
   - Auxiliary Power: 5%
   - Power Factor of Generator: 0.95

2. Estimate consumption under unconstrained supply
   - Forecast for domestic, commercial, industrial consumers
   - Forecast for IP Set consumption
   - Technical Losses

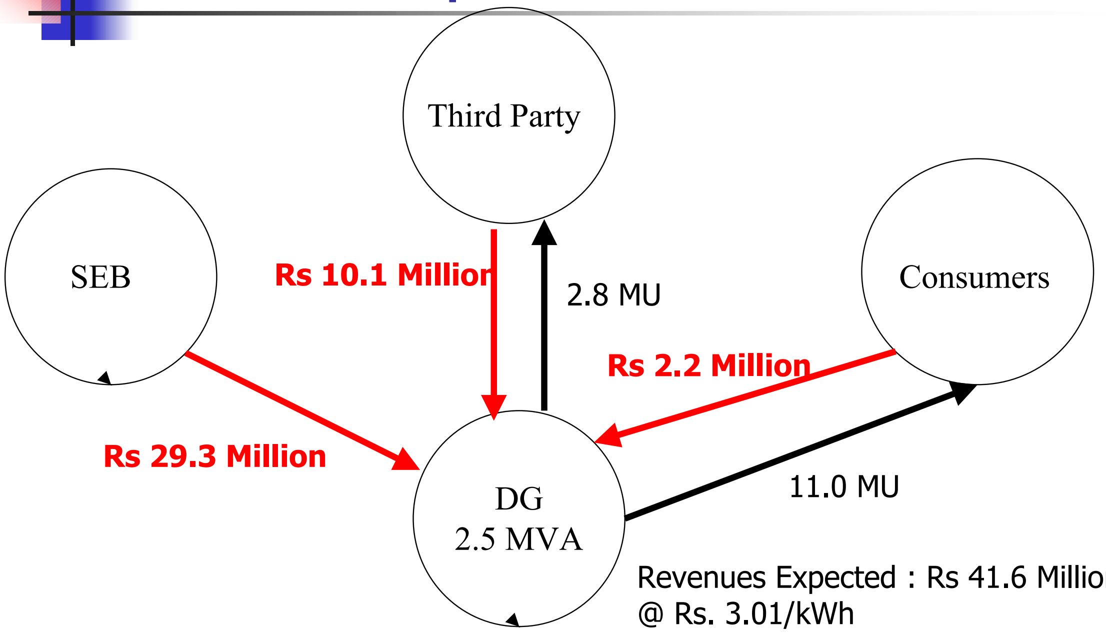
3. Surplus available for Export to Grid/Third Party

Consumption Forecast Under Increased Supply

- Elasticity of Demand not applicable
- Obtain Upper Limit of consumption
  - Increase hours of supply to ~ 12 – 14
  - Can't flood the fields !!
- Technical Losses: 2%
- Commercial Losses: 15%



Scenario I – No Tariff Changes DG's Perspective

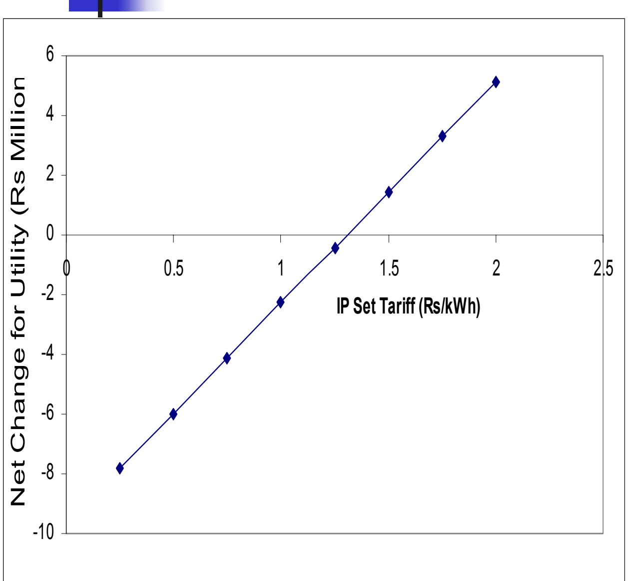


Revenues Expected : Rs 41.6 Million
@ Rs. 3.01/kWh

Scenario I – No Tariff Changes SEB's Perspective

Loss of HT Consumer to IPP	2.82 MU	**- Rs 13.5 Million**
Disbursement to IPP		**- Rs 29.3 Million**
Savings of Power from the Micro-grid & Potential Sale to HT Consumer	7.8 MU	Rs 34.0 Million
Net		**- Rs 8.8 Million**

Scenario II: Increase in Irrigation Tariff



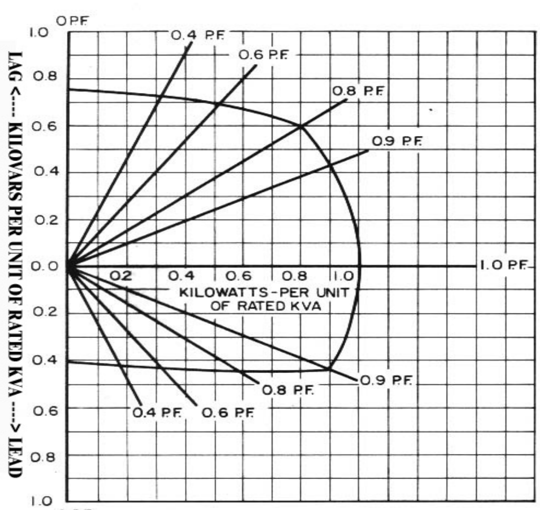
<u>Policy Options</u>

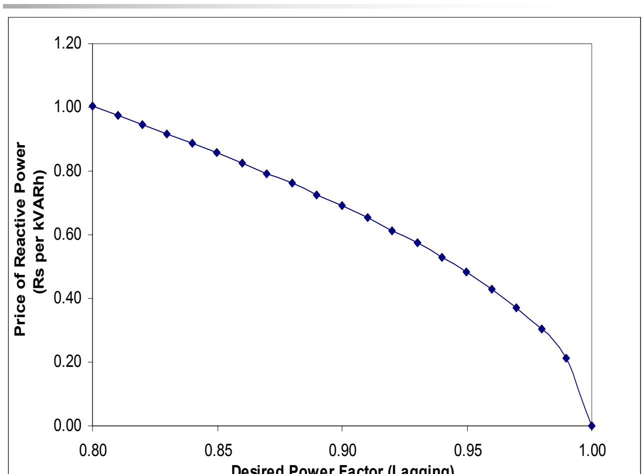
- Pricing of biomass
  - Income to Farmers: Rs 11.5 Million @ Rs 0.5/kg
  - New IP Tariff : Rs 11.1 Million @ Rs 1.50/kWh
- Restrictions on water usage
  - Depending on farm size, land, crop, pump etc.

Reactive Power Pricing Options

- Ancillary service in deregulated world (FERC Order # 888)
  - Most rural buses have low power factor
  - DG Can supply reactive power
  - BUT, at the cost of real power
- Classical economic definition (Baughman 1997, Chattopadhyaya 1995, Dai 2001)
  - Optimal Power Flow: Marginal cost of reactive power at a bus
  - Problem: Intermittent supply & lack of data in rural India.
- Avoided cost of synchronous condensers (Silva 2001)
- Cost of not producing real power (Generator Capability Curve)

Reactive Power Pricing: Generator Capability Curve





Make the generator indifferent to producing reactive power.

Wheeling of Power

- Current policy:
  - Wheeling rates ~ 20%
  - Not allowed in some states.
- Rationale:
  - Threat to SEB's cash cow.
  - Impose the T&D Losses (20%) as wheeling charges.
- But, wheeling benefits the utility also.
- More scientific basis needed for estimating wheeling charges.

Estimating Wheeling Charges

- Strict Economic Definition: (Schweppe 1988, Caramanis 1986)
  - Solve Optimal Power Flow and obtain the marginal costs from Lagrangian Dual.
  - Wheeling Rate between bus i & j = Difference of marginal cost of power at the two buses.
  - Wheeling rates can be negative if it results in lower T&D Losses.
- Load Flow Studies
  - Lower Distribution Losses ~ 2%
  - Voltage Support to SEB.
  - Wheeling rates should be low, if not negative.

Conclusions

- Rural micro-grids can benefit SEB & consumers
  - Lower losses
  - Improved quality of supply
- Reactive power pricing useful
- Rational basis for assessing wheeling charges