Decentralized Power Generation: Opportunities in Rural India

India’s Electricity Scenario

- Installed Capacity \( \sim 100,000 \text{ MW} \)
  - 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

<table>
<thead>
<tr>
<th>Generation</th>
<th>Central</th>
<th>State</th>
<th>IPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>State Utilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>State/Private Utilities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## 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

<table>
<thead>
<tr>
<th>Category</th>
<th>Consumption</th>
<th>Tariff Rs/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>17%</td>
<td>Rs 1.20/kWh</td>
</tr>
<tr>
<td>Agriculture</td>
<td>31%</td>
<td>Rs 0.22/kWh</td>
</tr>
<tr>
<td>Industrial</td>
<td>35%</td>
<td>Rs 4.50/kWh</td>
</tr>
<tr>
<td>Commercial</td>
<td>5%</td>
<td>Rs 4.70/kWh</td>
</tr>
</tbody>
</table>

1 US $ = Rs 48  
*Source: Karnataka Electricity Regulatory Commission*
Uncovered Subsidies are Growing

- Uncovered Subsidy
- Cross Subsidy
- Covered by State Government

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

Annual Production (Million Tons)
- Cane: 275 MT
- Bagasse: 75 MT

Process Electricity @ 30 kWh/Ton
~ 8 Billion kWh

Process Steam @ 500 kg/Ton
~ 50 Billion kWh

Potential Export
25 - 40 Billion kWh
4000 – 6500 MW

Each Plant: 5 – 30 MW

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

<table>
<thead>
<tr>
<th>Consumer</th>
<th>Tariff Rs/kWh</th>
<th>Units Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>1.20</td>
<td>183,940</td>
</tr>
<tr>
<td>Commercial</td>
<td>4.50</td>
<td>900</td>
</tr>
<tr>
<td>Irrigation Pumps</td>
<td>0.20</td>
<td>?</td>
</tr>
<tr>
<td>Industrial</td>
<td>4.75</td>
<td>13,320</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Losses (Technical)</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses (Commercial)</td>
<td>?</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>7,831,400</td>
</tr>
</tbody>
</table>

## 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: \( V_k V_{kk} = \frac{(P_k - jQ_k)}{V_k} - \sum_{i=1}^{N} Y_{ki} V_i \)
- Iterate till convergence

Results: Voltage Profiles:

![Voltage Profiles Graph]

Voltage Profiles for Load 75%, Theft 15%:
- Power Factor: 0.90
- Power Factor: 0.80
- Power Factor: 0.70
Technical Distribution Losses

Load 60%, Theft 15%

Impact of Sub-Station Voltage

Sub-Station Voltage = 11 kV
Sub-Station Voltage = 10 kV
Impact of DG on Voltages

Load 60%, Theft 15%, Power Factor 0.8

Voltage (pu)

Bus #

Impact of DG on Losses

Load 60%, Theft 15%, Power Factor 0.6

Technical Losses (%)

Generator Power Factor = 0.95

Generator Power Factor = 0.80
### Capacitors in Grid

**CAPACITOR(MVAR) IN THE GRID**

**SOURCE:** KPTCL ADMIN REPORTS

<table>
<thead>
<tr>
<th>YEAR</th>
<th>110KV</th>
<th>66KV</th>
<th>33KV</th>
<th>11KV</th>
<th>TOTAL MVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>96-97</td>
<td>640</td>
<td>871</td>
<td>170</td>
<td>559.12</td>
<td>2240.12</td>
</tr>
<tr>
<td>97-98</td>
<td>800</td>
<td>1051</td>
<td>170</td>
<td>559.12</td>
<td>2580.12</td>
</tr>
<tr>
<td>98-99</td>
<td>840</td>
<td>1091</td>
<td>170</td>
<td>559.12</td>
<td>2660.12</td>
</tr>
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### Power Transactions with Grid

**MW, MVAR**

**Reactive Power**

**Real Power**

-0.4 0.0 0.4 0.8 1.2 1.6

-0.4 0.9 0.95 1

Generator Power Factor
Economic Analysis:
SEB’s Present Losses

Tariff Levied : Rs 1.2 Million

Consumers

Tariff Collected : Rs 0.6 Million

Units Sold : 7.8 Million kWh

Cost of Supply: Rs 22 Million

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

- SEB
- Consumers
- Third Party
- DG 2.5 MVA

- Revenues Expected: Rs 41.6 Million @ Rs. 3.01/kWh
- Rs 10.1 Million
- Rs 2.2 Million
- Rs 29.3 Million
- 2.8 MU
- 11.0 MU
**Scenario I – No Tariff Changes**

**SEB’s Perspective**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of HT Consumer to IPP</td>
<td>2.82 MU</td>
</tr>
<tr>
<td>Disbursement to IPP</td>
<td>- Rs 29.3 Million</td>
</tr>
<tr>
<td>Savings of Power from the Micro-grid &amp; Potential Sale to HT Consumer</td>
<td>7.8 MU</td>
</tr>
<tr>
<td>Net</td>
<td>- Rs 8.8 Million</td>
</tr>
</tbody>
</table>

**Scenario II: Increase in Irrigation Tariff**

- **Policy Options**
  - 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)

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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