Best Practices of Rural Electrification in Developing Countries

Panos Kotsampopoulos

National Technical University of Athens

Aalborg 2015 Symposium on Microgrids, 27-28 August
Overview

- Technologies and case studies
  - Diesel Based PV/Wind Hybrid
  - PV/Wind with Battery Storage
  - Solar Lanterns and Irrigation System
  - Micro-hydro
  - Biomass

- Case Study of Hybrid System in rural Ethiopia
Technologies and Case Studies

- Diesel Based PV/Wind Hybrid
  - Diesel Generators: Most common
    - High operation costs: fuel, transportation, maintenance
  - Hybrid: reduction in fuel cost and generator use.
Technologies and Case Studies

- Diesel Based PV Hybrid
  - Applied to existing diesel systems and also to new-built systems
  - PVs cover the morning to mid-day load, whereas the diesel genset can meet the load demand for many hours overnight.
  - Avoiding a low load factor, reverse power flows and insufficient spinning reserve due to the intermittent renewable source is considered into the design and operation of the system.
  - 100 Pilot Projects: Kenya, Rwanda, Mali, Senegal, Tanzania. PV capacity from 5 to 30kWp
Technologies and Case Studies

- Diesel Based Wind Hybrid
  - Feasible solution in areas with a good wind resource.
  - Saint Helena Island, in South Atlantic Ocean (4,200 population)
  - Wind turbines from 50kW to 300kW provide 20% of the islands energy needs thus saving the equivalent energy cost in diesel fuel and transportation costs.
Technologies and Case Studies

- PV/Wind with Battery Storage

- Main energy provider is the renewable resource.
- Diesel generator has a back-up role or is not present.
- A Wind Turbine can be combined with PVs due to their complementarity
- The Wind Turbines can be manufactured in a community level using local materials and approaches.
Technologies and Case Studies

Individual home system and community systems

- Story of Bangladesh

- Solar Home Systems (SHS)

- 1.6 million SHS of 50Wp that supply DC loads have already been installed.
- Target of 4 million by 2015.
- Different paying methods:
  - full amount in small parts becoming the owner of the system at the end of the payment.
  - Smaller amount for a longer period and rent the equipment from the seller.
Technologies and Case Studies

- Lao PDR
  - Over 9000 SHS and community centers
  - Target of 90% electricity coverage by 2020.

- Peru
  - 3000 SHS since 2012
  - The government funds 80% of the total cost of the system, leaving the rest 20% to be covered by the users.
  - Educating and training people to the daily operation of SHS.

- India: 670,000 SHS

- Indonesia 200,000 SHS

- Kenya, Ghana and Ethiopia are making efforts
Technologies and Case Studies

- Solar Lantern
  - PV, battery and LED lamp
  - Aiming to replace the use of Kerosene Lamp.
  - According to World Health Organization nearly 1.2 million people die from indoor air pollution every year, a large proportion of which is due to the use of Kerosene lamps.
  - 800,000 in use in India, 200,000 in Bangladesh, and many in other countries in sub-Saharan Africa and Asia.
Technologies and Case Studies

- **Solar Photovoltaic Irrigation System**
  - Stand-alone, often battery-less solar photovoltaic system that can pump water.
  - Minimum maintenance.
  - Ideal for remote locations.

- **Benin**
  - 60% of households lack food-security in rural areas
  - Solar-powered irrigation systems are used to irrigate fields for consumption and sale during the dry season.
  - Over 48,000 people are already benefiting from these systems.
  - Electrification of households and community centers is the next step
Technologies and Case Studies

- Micro-Hydro

- Adaptable to local conditions.
- Energy production 24 hours/day at full capacity.
- Can promote local technology and skills, with the transfer of necessary knowledge and the manufacture of several components locally.
- Cost effective
Technologies and Case Studies

• Nepal

- Successful cooperation of NGO with government promoted local manufacturing
- Run-of-the-river plants, that use the natural flow of the river to generate power.
- 2,500 micro-hydro plants have already been installed with a total capacity of 20 MW.
Technologies and Case Studies

- Nepal

- A hybrid system of a micro-hydro plant of 20kW, a 3kW wind turbine and a 5kW PV system exists in villages of Thingan and Kolkhop.
Technologies and Case Studies

- Biomass

- Already used for cooking and heating
- Rice, cashew nuts, coconut shells or other woody biomass can be used for the production of electricity.
- From a few kWs to several MWs
- Possibly lower cost than diesel generation
Technologies and Case Studies

• India
  ➢ A system of 5 gasifiers, of 100 MW each, provides electricity to the isolated island of Gosaba and its 1150 families
  ➢ Microgrids in electrified areas in cases of unstable grid (e.g. for the electrification of public spaces or water pumps)

• Cambodia
  ➢ Over 100 biomass gasification plants with average capacity of 200kW.
  ➢ The rice husk production could be enough to completely cover the electricity demand.

• Thailand
  ➢ 20 plants from 10kW up to 400kW.
Benefits from Rural Electrification

- Access to reliable electricity brought significant changes in both social and economic aspects of everyday life.

- **Social Impact**
  - Higher quality of light
  - Free from inhalation of toxic kerosene smoke.
  - Improved access to information, through mobile, television and radios.
  - Children can study longer and more effectively.
Benefits from Rural Electrification

Economic Impact

- The monthly cost of kerosene and diesel has been replaced by the payments for the micro-grid.
- New income earning activities are created, such as mobile phones and battery charging.
- New job opportunities and new workshops are easier to create and operate with the presence of electricity, which strengthens the local economy.
- Enterprises are able to remain open after dark.
Case Study of Hybrid System in rural Ethiopia

- Ethiopia has one of the lowest rates of electricity coverage, which is about 16%.
- Hybrid system that consists of a small hydropower plant, a diesel generator and solar panels along with batteries.
- HOMER software was used.
- 105 families, school, health center, flour mill.
- Deferrable load: water pumps.
- 166 kWh/day.
Case Study of Hybrid System

- Optimization results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4</td>
<td>20.7</td>
<td>7.13</td>
<td>9.0</td>
<td>LF</td>
<td></td>
<td></td>
<td>$71,923</td>
<td>884</td>
<td>$82,513</td>
<td>0.112</td>
<td>0.98</td>
<td>0.01</td>
<td>679</td>
<td>839</td>
</tr>
<tr>
<td>7.4</td>
<td>20.7</td>
<td>7.13</td>
<td>8</td>
<td>LF</td>
<td></td>
<td></td>
<td>$73,610</td>
<td>846</td>
<td>$83,746</td>
<td>0.113</td>
<td>1.00</td>
<td>0.00</td>
<td>145</td>
<td>179</td>
</tr>
<tr>
<td>7.4</td>
<td>20.7</td>
<td>14....</td>
<td>8</td>
<td>CC</td>
<td></td>
<td></td>
<td>$59,872</td>
<td>2,027</td>
<td>$84,141</td>
<td>0.114</td>
<td>0.96</td>
<td>0.00</td>
<td>1,762</td>
<td>1,204</td>
</tr>
<tr>
<td>7.4</td>
<td>20.7</td>
<td>7.13</td>
<td>8</td>
<td>LF</td>
<td></td>
<td></td>
<td>$77,682</td>
<td>824</td>
<td>$87,552</td>
<td>0.119</td>
<td>1.00</td>
<td>0.00</td>
<td>130</td>
<td>157</td>
</tr>
<tr>
<td>22.2</td>
<td>14....</td>
<td>8</td>
<td>13.5</td>
<td>CC</td>
<td></td>
<td></td>
<td>$63,561</td>
<td>10,314</td>
<td>$187,071</td>
<td>0.254</td>
<td>0.53</td>
<td>0.01</td>
<td>9,365</td>
<td>3,918</td>
</tr>
<tr>
<td>22.2</td>
<td>14....</td>
<td>16</td>
<td>13.5</td>
<td>CC</td>
<td></td>
<td></td>
<td>$49,228</td>
<td>17,133</td>
<td>$254,404</td>
<td>0.346</td>
<td>0.00</td>
<td>0.01</td>
<td>16,504</td>
<td>5,379</td>
</tr>
<tr>
<td>22.2</td>
<td>21....</td>
<td>13.5</td>
<td>LF</td>
<td></td>
<td></td>
<td></td>
<td>$57,802</td>
<td>18,926</td>
<td>$284,453</td>
<td>0.385</td>
<td>0.41</td>
<td>0.00</td>
<td>16,497</td>
<td>7,220</td>
</tr>
</tbody>
</table>

- Micro-hydro is not enough to solely support the load

- Most economic option: combination of micro-hydro plant (20.7 kW), diesel generator (7.13 kW) and PV panels (7.4 kWp).

- 98% renewable penetration

- The national energy tariff of energy in Ethiopia is around 0.04 $/kWh which is considerably lower than that of the proposed system 0.112 $/kWh.
Case Study of Hybrid System

- Comparison between Diesel-only, and Diesel-PV hybrid system.

- Introducing PV generation to a diesel based system, reduces the cost of energy and the fuel consumption.
HIL simulation for dynamic studies of off-grid systems

Diagram showing a synchronous generator connected to a simulated storage system. The laboratory PV inverter is also depicted. The graph illustrates frequency response with and without droop.
Conclusions

- United Nations has set 2030 as a target date for universal access to modern energy services.
- Micro-grids can provide cost-effective and reliable energy in remote areas in diverse ways.

**Case study:**
- Micro-hydro was the cheapest solution.
- The cost was higher than the utility grid.
- Introducing PV generation to a diesel based system reduces the cost of energy.
Thank you for your attention

www.smartrue.gr

kotsa@power.ece.ntua.gr