DC Microgrid systems and it is applications for Off-Grid Remote Regions – Case Study: Chiang Mai World Green City

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Chiang Mai Rajabhat University, Thailand

APEC Off Grid Electrification Option for Remote Regions in APEC Economies
September 10, 2018
Chiang Mai Thailand
adiCET

Chiang Mai World Green City at CMRU
adiCET, CMRU

- Established in 2010
- Academic – R&D – Training institution for the well-being of the community by using green technologies.
- adiCET campus is on Chiang Mai World Green City (CMGC).
  - Build from 60 research and academic service projects
- Smart Community – Model Community uses 100% renewable energy.
adiCET Mission

Chiang Mai World Green City

Living Laboratory
- Green Community
  - Real-living community park
  - Learning center for people to experience the sustainable way of living
  - Source of Inspiration - bring ideas back and implement

Interdisciplinary Programs
- MS, PhD – Community Energy and Environment
- Internships
- Cooperative Studies
- Student exchange

Appropriate Green Technology Research
- Appropriate Technology Research
- Interdisciplinary Research: Science-Social Science
- Renewable Energy
- Community Smart Grid
- Smart Farm
- Community Energy Management
- Biomass Waste management
- Green Community Business

Academics

Research

Academic Services

Training & Community Development
- Renewable Energy and Energy Efficiency Training
- Community Energy Planning
- Community Development through sustainable projects
- Short Course Training
- Train Community Leaders
- Train Youth/ Vocational Students

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Smart Community Microgrid
Zero Waste - Bioenergy Cycle
Smart Community Development

~ 60 R&D / Training / Consultant Projects
Smart Community: Sustainable Community via integration of Renewable Energy & Green Technology with Smart Grid Infrastructure
“Flagship Project 1: Smart Community Microgrid”

Phase 1: Building Microgrid → Phase 2: Monitoring → Phase 3: Data Analysis & Integration → Phase 4: Control → Phase 5: Optimize
adiCET Smart Community Microgrid Component

technology

Renewable Energy
- PV
- Biodiesel
- Biogas
- Biomass

Smart Grid
- DC Microgrid
- AC Microgrid
- AC/DC Grid

Smart Load
- Smart Home
- Smart Farm
- Smart Office
- EV & Charging

Smart Operation Center
- Universal Monitoring System
- Database/Data center
- IOT/Analysis

Smart Control
- Demand Response
- Machine Learning
- App Development

Smart Consumer
- Living
- Training
- Operation
- Maintenance

Smart Community Integration
- Energy
- Food
- Water
- Waste

community

IT

Biomass Power Plant

Wood pellet & RDF

Charcoal & Wood

Biogas

Smart Farm & Hydroponic

Composting

Energy Crop

Generator

Smart Home

Solar Roof top

Grid

Electricity

Gasification

Electricity

Household Appliances
Liquid Manure → Biogas Power Plant (10 kW)
Food Waste → Biogas Power Plant (10 kW)
Crop Residue → Biogas Power Plant (10 kW)
Wood Waste → Biomass Gasification Power Plant (20 kW, batch daytime)
Yard Waste → Biomass Gasification Power Plant (20 kW, batch daytime)
Crop Residue → Biomass Gasification Power Plant (20 kW, batch daytime)
Waste Cooking Oil → Biodiesel Power Plant (10 kW)
Plant Oil → Biodiesel Power Plant (10 kW)
Waste Paper → Biodiesel Power Plant (10 kW)
Crop Residue → Biodiesel Power Plant (10 kW)
Crop Residue → Bioethanol Power Plant (5 kW)
Waste Cooking Oil → Bioethanol Power Plant (5 kW)

Generation Profile:
- Base Load – Batch (daytime)
- Base Load – Continuous (night time)
- Evening Peak
- Peak Load

Biogrid
Self-Sustaining Community in Remote Area
"Flagship Project 3: Smart Community"

2017, 2018 Approved Project for Energy Conservation Fund, Ministry of Energy, Thailand
Smart Community Database

Environmental
- Recycle waste (kg)
- Organic waste (kg)
- Hazardous waste (kg)
- The frequency of dumping waste (time)
- Date/time

Energy
- Production (kwh)
- Consumption (kw)
- Raw material of biogas and charcoal production (kg)
- Biogas and charcoal yield/consumption (kg)
- Fuel consumption in transportation (L)
- Date/time

Building
- Indoor/Outdoor temperature (°C) and humidity (%)
- Outdoor solar intensity (W/m²) and wind velocity (m/s)
- Water consumption (L) / Water flow rate average (L/min) and quality (Nephelometric Turbidity Units, pH, Coliform, BOD)
- Particulate in the air (PM)
- The frequency of using water (Time)
- Date/Time

Food
- Vegetable production (Kg)
- Using fertilizer (Kg)
- Another material in cultivation (Kg)
- Consumption and sale of vegetable (Kg)
- Date/Time

Economic
- Expenses (Baht)
- Income (Baht)
- Date/Time

“Analyze Community Context ➔ Balanced Community”
LIVING LABORATORY -
FOR GREEN COMMUNITY

We live here...
Reuse material house
We live here...
We study here...
Community Business
We learn here...
Smart Farm: On-ground
Smart Farm - Hydroponics
702 kW - Grid Connected
3.5 kW Rooftop Grid Connected
700 kW PV Training Center
Reduce Electricity Bill for University

Solar Modules
- Transform electricity from the sun to usable energy

Grid-Connected Inverter
- Converts direct current (DC) to alternating current (AC)

Transformer
- Step down the voltage to 22 kV

Graph showing energy consumption and reduction

Energy
- 349,012.96 kWh

Emission Reduction
- 197,576.24 kgCO₂

Reimbursement
- 1,296,396 Buht

Observations:
- The project reduced electricity bills by 702 gigawatts.
- From the graphs, energy consumption has decreased.
- Emission reduction is significant.
- Reimbursement details are provided.
DC MICROGRID-
FOR GREEN COMMUNITY
25 kW DC Off-Grid & 25 kW AC Grid Connected
Smart Community Microgrid

Load:
1 office
1 minimart,
1 restaurant
1 coffee shop
1 farm
6 houses
Diesel Generator 40 kW: Back up power
Off-grid: PV DC Microgrid Battery Bank (~100 kWh)  
Backup power/ Power Control and Stability

On-grid: PV AC Microgrid Battery Bank (~100 kWh)  
Backup power/ Power Control and Stability

Energy Storage for Community Grid
Solar Bus Stop EV Charging Station

T. Jaorum - Intern
W. Luangpraditkul - Researcher
Scope of DC Community

- Living Laboratory for community transition from AC → AC/DC → DC Community
- Evaluate Low Cost - Low Voltage DC Community Power System at the Smart Community
  - Phase 1: Lightings 24 VDC/ 1 House 240 VDC
  - Phase 2: Household Appliances 260-297 VDC
- Modify/Testing Household Appliances for DC & AC usage
  - Lighting, Refrigerator, Air Conditioner, Water Heater, Television, Computer, Rice Cooker, Microwave, Washing Machine
- Evaluate appliances during operation, stability and safety
  - Full DC
  - Full AC
  - Mixed DC & AC
Power Supply Controller

Central Battery Bank – DC

Battery

DC – AC Switch

Alarm

AC – Utility AC Microgrid

Load
Phase 1: Building Input Voltage
Phase 1: Voltage Output from Converter
Phase 1: Input Voltage vs Load Power of 240 VDC house
# 2nd Phase DC Microgrid

<table>
<thead>
<tr>
<th>Mode</th>
<th>Central Battery Voltage Stage</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>297 – 260 VDC</td>
<td>DC use directly from Central Battery bank</td>
</tr>
<tr>
<td>Battery Boosting</td>
<td>260 – 250 VDC</td>
<td>DC from Battery bank (260 VDC) &amp; Booster (54 VDC)</td>
</tr>
<tr>
<td>Biodiesel Generator Start</td>
<td>250 – 242 VDC</td>
<td>Generator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Charge Battery Bank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Charge Booster Batteries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If ran out of fuel, AC from Utility will convert to DC</td>
</tr>
<tr>
<td>Battery dead</td>
<td>Below 242 VDC</td>
<td>Automatically switch to AC</td>
</tr>
</tbody>
</table>

Note: Voltage range depends on Charger Specification, battery voltage range and electrical load device requirements.
Phase 2: Building Voltage

The graph shows the building voltage over time for various locations. The x-axis represents time in hours, and the y-axis represents the building voltage in volts. Different locations are indicated by different colored lines, with specific labels for Bouy House, Office, diamond, Box, Café, Sixty Mart, A-Frame, and Restaurant.
Phase 2: Building Power Consumption
Daytime DC & AC Operation

260 – 297 VDC

25 kW PV AC/ Utility
PV & House Battery Booster Operation

250 – 260 VDC

25 kW PV AC/ Utility
Night Time DC Operation

260 – 297 VDC

25 kW PV AC/ Utility
Night Diesel Generator DC

242 – 250 VDC

25 kW PV AC/ Utility
Load Test: Modify Each Appliance

- LED lightings
- Refrigerator
- Water Heater
- Television
- Air Conditioner 9,000 btu
- Air Conditioner 13,000 btu
- Air Conditioner 18,000 btu
DC vs. AC
Energy Consumption Comparison

<table>
<thead>
<tr>
<th>Device</th>
<th>DC vs. AC Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Lighting</td>
<td>45%</td>
</tr>
<tr>
<td>Computer</td>
<td>49%</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>23%</td>
</tr>
<tr>
<td>Air Conditioner 9,000 BTU</td>
<td>29%</td>
</tr>
</tbody>
</table>
DC Smart Plug

Measure Energy Consumption

Online Function
- Web and Application
  - Controls
  - Monitors
  - Program

Measurement Function
- Power consumption
- Behavior

Safety

Smart Function
- Smart Connection
- Smart Data Collection
- Energy saving

Prototype for DC Smart Plug

N. Songkittirote – M.S.
Issues to Overcome

- **System Issues**
  - Stability/Durability of components of the power supply when switching between DC and AC (capacitor, PLC)
  - The online connectivity with university network
  - Integrating Distributed Generations (voltage range - Diesel Generator)
  - Air conditioner in the battery house failed and causing battery to explode

- **Nature Issues**
  - During the rain, the voltage fluctuates from the utility line which cause the Hybrid Microgrid system to be disrupted.

- **Human Issues**
Battery

- Battery Explosion – Other battery start to be damaged (7-8 V)
- Hot weather
Conclusion

- Smart Community Concept: “Renewable Energy and Green Technology for Local Community”
  - Integrate with Community Resources - Ways of Living
  - Sufficiency Economy + Green Technologies (RE & EE)
  - Smart Grid as Infrastructure for Green Community Development

- DC Microgrid
  - DC Microgrid is possible for decentralized power application.
  - Must educate users/ Concern about safety
  - Must be cautious about electrical appliances – DC compatible
  - DC microgrid should be used for lightings and mounted appliances.
  - Must used plugs for DC to prevent Arc.
  - How can DC microgrid be integrated with AC microgrid?

- Moving Forward
  - Appropriate Technology; Monitoring/Optimization
  - Integration with Social Development and Economic Development
  - Create awareness/ Share best practices/ Demonstrations Sites/ Community Implementation
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