Smart Home Energy Management System with Renewable and Storage Energy

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Outline

• Master Plan of Smart Grid in Taiwan
• Smart Grid Implementation Plan in Taiwan
• Smart Home/Building Energy Management System
• Future Prospects
Master Plan of Smart Grid in Taiwan
Worldwide Smart Grid Status

- Reliability enhancement by information network and technology to shorten outage duration time. That is supported by DOE from EISA 2007.

- 20/20/20: CO₂ reduction by 20% by 2020 compared with that of 1990. (AMI/AMR & EV)

- Smart Community alliance had made up by governor and manufacture, to demonstration the smart grid in Yokohama, Toyota, Kyoto, and Kitakyushu City.

- China announced the 12th 5-year plan, and will invest $250 billion (USD) in 7 areas (include generation, transmission, substation, distribution, dispatch, customer, and communication) for a strong and smart power grid.

- There are three phases to 5 implementation areas from power grid to service, which are integrated at Jeju Island as a smart grid test-bed.
Smart Grid Master Plan in Taiwan

- Smart Grid Master Plan is formally announced on 3 Sept. 2012.
- We will invest about USD $4 billion in six implementation areas to construct smart grid infrastructure during 2011-2030.

### Vision
To establish a high quality, high efficiency and environmental friendly smart grid to get forward the realization of the low carbon society and sustainable development.

### Objectives
- To Ensure Reliable Power Supply;
- To Encourage Energy Conservation and Emission Reduction;
- To Enhance the Use of Green Energy;
- To Develop Low-Carbon Industry.

### Phase
- **Phase I**
  - Technology Test
  - (2011~2015)
- **Phase II**
  - Technologies I. & P.
  - (2016~2020)
- **Phase III**
  - Technologies Extend App.
  - (2021~2030)

### Six Implementation Areas
- Smart Generation & Dispatch
- Smart Transmission
- Smart Distribution
- Smart Users

### Smart Grid Industry
- Smart Grid Environment Construction
To establish a high quality, high efficiency and environmental friendly smart grid to get forward the realization of the low carbon society and sustainable development.
(1) To Ensure Reliable Power Supply:
- The SAIDI (System Average Interruption Duration Index) should be maintained on the top five of the world in 2030. (2030: 15.5 min./year)
- Reducing the power transmission loss from 4.8% to 4.4% in 2030.

(2) To Encourage Energy Conservation and Emission Reduction:
- Reducing 100 million ton CO$_2$ emission per year in 2030.

(3) To Enhance the Use of Green Energy:
- Improving the renewable power interconnection capability to 30% in 2030.

(4) To Develop Low-carbon Industry:
- Driving smart grid industry to create NTD 700 billion value in 2030.
Smart Grid Implementation Plan in Taiwan
Overview of Taiwan Power Company

Taiwan Power Company (Taipower) is a state-owned electric power utility providing electric power to Taiwan and off-shore islands.

Overview of Taiwan Power System

Installed Capacity: 41,501MW (2012.08)

Peak Load: 33.79 GW (2011.08.18)

Total energy production: 142,838 GWh (2012.08)
## Nuclear Power Plants in Taiwan

<table>
<thead>
<tr>
<th>Station</th>
<th>Set</th>
<th>Capacity (MW)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Jinshan Nuclear Power Plant</td>
<td>1</td>
<td>636</td>
<td>Retire in 2018</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>636</td>
<td>Retire in 2019</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Kuosheng Nuclear Power Plant</td>
<td>1</td>
<td>985</td>
<td>Retire in 2021</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>985</td>
<td>Retire in 2023</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Maanshan Nuclear Power Plant</td>
<td>1</td>
<td>951</td>
<td>Retire in 2024</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>951</td>
<td>Retire in 2024</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; Lungmen Nuclear Power Plant</td>
<td>1</td>
<td>1350</td>
<td>Operate in 2014</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1350</td>
<td>Operate in 2016</td>
</tr>
</tbody>
</table>

Overview of Taiwan Power System

- Energy Policy of Taiwan

a. Steadily Reducing Nuclear Dependency
   a) No extension to life spans of existing plants, and the decommissioning plan should be launched as planned.
   b) The security of the 4th Nuclear Power Plant must be ensured prior to its commercial operation.

b. Replacing Nuclear with LNG for Base Load
   LNG total installation capacity is expected to reach 26,532 MW (accounting for 40% of total capacity of power installations) by 2030.

c. Promoting Renewable Energy Extensively
   Under the campaign of “one thousand wind mills” and “one million sunshine roofs”, the installed capacity of renewable energy is expected to reach 12,502 MW (accounting for 16% of total power installations) by 2030.
Smart Grid Implementation Plan in Taiwan

(1) Strategies

a. Smart Generation & Dispatching
   a) Upgrade traditional thermal power generation efficiency
   b) Integrate large scale renewable energies

b. Smart Transmission
   a) Increase transmission grid efficiency and reliability using new technologies
   b) Enhance capability of asset management

c. Smart Distribution
   a) Improve the reliability of distribution network
   b) Increase the penetration of distributed renewable energy

d. Smart Customer
   a) Improve energy usage efficiency through customer participation
   b) Reduce peak load by way of demand response
Southern California Edison

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Microgrid System

Data Center

STRATEGIC INITIATIVES OF
SMART GRID IN TAIWAN

(Data Center: Billing/Customer service
Distribution automation
Energy management
Outage management)

Smart Home

AMI

ADAS

80kW Diesel Generator

Southern California Edison

Meter (AMI) is the interface between customer loads and energy management systems and the grid

In Data Center:
Billing/Customer service
Distribution automation
Energy management
Outage management

(cont.)
## Objectives of Taiwan’s Smart-Grid Action Plan

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ensured Reliable Power Supply</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ensured Reliable Power Supply</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAIDI</strong> (min/customer · year)</td>
<td>21</td>
<td><strong>17.5</strong></td>
<td>16</td>
<td><strong>15.5</strong></td>
</tr>
<tr>
<td><strong>Reduced transmission loss (%)</strong></td>
<td>4.72</td>
<td><strong>4.64</strong></td>
<td>4.54</td>
<td><strong>4.42</strong></td>
</tr>
<tr>
<td><strong>Improve power supply bottleneck</strong></td>
<td>64 items</td>
<td>solve 20%</td>
<td>solve 40%</td>
<td>solve 80%</td>
</tr>
<tr>
<td><strong>Smart Substation</strong></td>
<td>-</td>
<td>25 stations</td>
<td>303 stations</td>
<td>583 stations</td>
</tr>
<tr>
<td><strong>DAS</strong></td>
<td>70%</td>
<td><strong>80%</strong></td>
<td>88%</td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td><strong>AMI (meters)</strong></td>
<td>HV 1,200</td>
<td>HV 23,000</td>
<td>LV 1M</td>
<td>National Wide Deployment</td>
</tr>
<tr>
<td></td>
<td>LV 6M</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Objectives of Taiwan’s Smart-Grid Action Plan

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Conservation and Emission-Reduction</strong></td>
<td>Emission-Reduction (million Ton./year)</td>
<td>-</td>
<td>11.78</td>
<td>35.99</td>
<td>114.71</td>
</tr>
<tr>
<td><strong>Enhance the Use of Green Energy</strong></td>
<td>Improving renewable power interconnection capacity (penetration)</td>
<td>10% under 15%</td>
<td>20%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td><strong>Develop Low-carbon Industry</strong></td>
<td>Smart Grid Revenues (NTD)</td>
<td>25 billion</td>
<td>100 billion</td>
<td>300 billion</td>
<td>700 billion</td>
</tr>
</tbody>
</table>
Reserve Margin (%) in Taiwan

Reserve capacity (MW) = Net Peaking Capability - Peak Load

Reserve margin (%) = \( \frac{\text{Reserve Capacity}}{\text{Peak Load}} \times 100\% \)

Status of DR Program in Taiwan

• Qualifications
  – Usual Capacity Contract >500kW

• Demand Reduction Hours
  – When demand reduction is required, users will be notified 15 min, 30 min or 1 hour ahead.
  – The demand reduction period can last for 2 or 4 hours based on user’s choice

• Frequency of DR Operation
  – Maximum reduction time is once a day
  – At least once per month during Summer
  – At least twice during non-Summer

• DR Capacity Contract
  – Contract is agreed by both sides, but not less than the minimum DR contracted capacity
  – Minimum DR contracted capacity is calculated as follows:
    • If usual contracted capacity is less than 5000kW, DR reduction rate should be no less than 20%
    • If usual contracted capacity is more than 5001kW, DR reduction rate should be no less than 10%
• Electricity Bill Reduction
  – Customer’s electricity bill will be deducted by how long ahead they choose to be notified for DR operation

<table>
<thead>
<tr>
<th>Notification Time</th>
<th>Base Charge Reduction (NT$/kW/month)</th>
<th>Energy charge Reduction (NT$/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min ahead</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>30 min ahead</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>1 hour ahead</td>
<td>20</td>
<td>4</td>
</tr>
</tbody>
</table>

US$:NT$ = 1:30
2011: System Planning and Interface development

2012: Smart Building EMS Demonstration

2013: All System Integration and Cost Effectiveness Analysis

AC Power Line from Taipower Grid

AMI

DS2 PLC

Electricity Tariff Structure

Technical Specifications

Standards

(許志義教授)

(蘇木春教授)

(陳建富教授)

(林政廷經理)

Personal Computer

WiFi AP

Ethernet

Home Gateway

AMI控制中心

配電自動化

控制系統

(許志義教授)

(李偉仁教授)

(莊哲男教授)

(陳建富教授)

(林政廷經理)

Data Collection Management

Load Pattern Analysis

Weather, Load, and Real-time Prediction System

Multi-objective Decision Making System

Temperature and Humidity, illumination sensing control

EMS Software Interface

Remote data and program burning

EMS Software Development

Chip Design and Fabrication

Wireless AP

Zigbee

Zigbee Device

WT

EV

Battery

Micro Inverter

Chip Design and Fabrication

CoDesign

(許志義教授)

(蘇木春教授)

(黃燕昌教授)

(黃昭明教授)

(許志義教授)

(蘇木春教授)

(黃燕昌教授)

(黃昭明教授)

(陳建富教授)

(楊宏澤教授)

(王醴教授)

(楊宏澤教授)

(許志義教授)

(蔡孟伸教授)

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(陳建富教授)

(楊宏澤教授)

(王醴教授)

(楊宏澤教授)

(許志義教授)

(蔡孟伸教授)
# Low Voltage AMI Timeline

<table>
<thead>
<tr>
<th>Stage</th>
<th>Year</th>
<th>Meter NO. to be installed</th>
<th>Working Items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1’st Stage (Tech.test)</strong></td>
<td>2009</td>
<td>50</td>
<td>Communication Technology Testing</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>300~500</td>
<td>Define Function and standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Test platform Plan</td>
</tr>
<tr>
<td><strong>2’nd Stage (Preliminary Installation)</strong></td>
<td>2011</td>
<td>10,000</td>
<td>MIDMS Meter Function Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Meter Function Std. ID.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construct Test Platform</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construct New TOU FEEs</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td></td>
<td>Technology Confirm &amp; C/B Ass.</td>
</tr>
<tr>
<td><strong>3’rd Stage (Fundamental Installation)</strong></td>
<td>2013</td>
<td>1,000,000</td>
<td>Meters Installation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>New TOU Fee Execution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Load Management and Demand Response Study</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4’th Stage (Extended Installation)</strong></td>
<td>2016</td>
<td>5,000,000</td>
<td>Construct Distribution Automation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Apply Load Management and Demand Response</td>
</tr>
</tbody>
</table>

Advanced Metering Infrastructure

Energy Meters
- Smart Appliances
- Home Automation Network
  - PLC, WiFi, ZigBee

Communication
- Load Shedding/
  Energy Saving
- Local area network, i.e.
  PLC, WiFi, ZigBee
- Aggregator
  - Wide Area Network, i.e.
    GPRS/3G, WiMax, Optical fiber

Decision making/ Services
- Data Management System
- Energy Control Platform
- Power Plant Management System

Data Management System
- PMU (Phasor Measurement Unit)
- FTU (Feeder Terminal Unit)

Electrical System
Supplying Optimization
- Transparent Energy Info.
- Real-time Demand Analysis
- Optimized Electricity Dispatch
Residential Renewable Energy Systems

Module Inverter
(Decrease the efficiency and lower the partial shading effects)

PV generation System

Power Factor Correction
(Increase the efficiency)

Wind Power System

Energy Storage System or EV
(Increase the electricity supply reliability and coordinate with energy management optimization)

IC Design
(Lower the Cost)

Home Gateway
(Energy management optimization)

Wired/Wireless Communication
Zigbee, PLC (Protocols, Standards …)

Islanding Detection
Insures system stability by fast detection with minimized NDZ

Utility Grid
110V_ac, 60Hz

PCC

Module Inverter
\[ V_{o1} = V_1 \angle \phi_1 \]

\[ i_{o1} \]

\[ V_{o2} = V_2 \angle \phi_2 \]

\[ i_{o2} \]

\[ V_{o3} = V_3 \angle \phi_3 \]

\[ i_{o2} \]
Home Area Network

User and machine monitoring and control system

Home Gateway

- Ethernet
- WiFi
- AC power line

PLC master
- PLC slave
- e-meter

Zigbee receiver

Zigbee meter module

IPTV

Ethernet

Datacenter

Internet

NILM technique

User and machine monitoring and control system

Internet datacenter

Smart home/building electrical circuits/power loops

Power meter with NILM functions

Home gateway

PC/mobile/tablet
Renewable Energies in a Smart Home

Digital Signal Processor (DSP) programing design:
MPPT control, Power factor correction (PFC) control (Wind-turbine), charging/discharging control, grid-connected control, power flow control, islanding detection…

Power conversion circuit design and implementation:
DC-DC Converter, Inverter, soft-switching technology, high step-up technology, bi-direction charging circuit…

User and machine monitoring and control system
Computing Intelligence Applications in Smart Home EMS

User and Machine Monitoring and Control System:
(1) Residential Load Forecasting
(2) Solar/Wind Power Generation Prediction

Home Gateway:
(1) Scheduling Optimization of Home appliances
(2) Air-condition (Lighting) Optimization Control
(3) EV Smart Charging Scheduling
Fuzzy Logic Control Algorithm for Air-conditioners

- Temperature and humidity
- Electricity Tariff

Calculate Humidity Index

Adjustable

Fuzzy Rule

<table>
<thead>
<tr>
<th></th>
<th>low</th>
<th>medium</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>28</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>medium</td>
<td>OFF</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>high</td>
<td>OFF</td>
<td>28</td>
<td>28</td>
</tr>
</tbody>
</table>

Home Gateway

Zigbee module

IR

behavior learning
Residential Load Forecasting

Similar day selection

History data

Neural network 1: primary forecasting

Input Signal $x_1$ $w_{j1}$ $x_2$ $w_{j2}$ $\cdots$ $w_{jm}$ $x_m$

Activation Function

Output $y_j$

Neural network 2: error forecasting

Input Signal $x_1$ $w_{j1}$ $x_2$ $w_{j2}$ $\cdots$ $w_{jm}$ $x_m$

Activation Function

Output $y_j$
Scheduling Optimization of Home Appliances

Optimization objective

Min (Cost)
Subject to:
- Comfort level
- Convenience

Optimization solving methods:
- Particle Swarm Optimization (PSO)
- Simulated Annealing (SA)
- Genetic Algorithms (GA)

Scheduled Loads of a Typical Medium House

Base Load
Stove
Refrigerator
Freezer
Air-Conditioner
Clothes Dryer
Clothes Washer
Dishwasher
Electric Water Heater
Electric Vehicle

Residential load forecasting result

Time-of-use

Renewable energy generation forecasting

Proposed Time-of-Use Price

Time (hour)

Date

Power Consumption (Watts)

Time (30min)
SHEMS User Interface Design – Web Based
• Android based APP Design
Standard and Specification - OpenADR

Web-base Transport Infrastructure

OpenADR Alliance for OpenADR v2.0 with a, b, c versions:

- **OpenADR v2.0a**
  - DRAS ↔ Simple DARS Client
- **OpenADR v2.0b**
  - DRAS ↔ All DRAS Client
- **OpenADR v2.0c**
  - Utility & Renewable ↔ Client

**DR transmission mode**

--Pull mode--

--Push mode--
Noninvasive Load Monitoring (NILM)

Smarter Meter developed for NILM

5V DC input

3-CH PT input

4-Chennel CT input

3-Phase Voltage input

RS485 5V Power Supply Module

Xbee Pro Module

SD Card

JTAG

STM32F

NAND

SRAM
Structure of Hardware

- STM32F103
- ARM Cortex-M3

**Components:**
- I2C1
- SPI1
- USRT1
- USART2
- USART3
- GPIO
- SDIO
- FSMC
- NFM-05-05
- 5W Power supply module
- AC
- +5V
- Battery
- RTC
- 512KB Flash
- 64KB SRAM
- RJ45 Connector
- DM9000A
- DAVICOM
- ADI / ADM2587E
- 1G bytes NAND Flash
- Samsung / K9F8G08
- 1M bytes SRAM
- ISSI / IS61WV51216
- Xbee pro module
- Isolated RS485
- RS232 expansion
- LEDS and buttons
- microSD Card
- 3-Phases I&V input
Applications of the Smarter Meter for NILM

AC power supply system

House
Applications (Cont.)

110V/60Hz voltage \[ \text{current} \]

(time)

Signature
of an appliance and its state
Application (Cont.)
Detected appliances and their state transitions
Estimate and decompose the total power consumption
Application (Cont.)

- 125kWh/month $25.00
- 120kWh/month $24.00
- 90kWh/month $18.00
- 43kWh/month $8.60
- 12kWh/month $2.40
Smart Building Energy Management System (SBEMS) Demonstration

(1) Propose Electricity Tariff Structure
(2) Integrate systems of all the sub-projects
(3) Define the control structure and strategy of DR
(4) Demonstrate the SBEMS
(5) Analyze costs/benefits

Advanced Distribution Automation Systems

AMI Data Center

Communication

69kV Substation

Power line

AMI

AMI

Zigbee

Gateway

NILM

Gateway

Zigbee

Office

Refrigerator

PC

Printer

Charge Station

Laboratory

PV System

Wind Power
System

PLC

PLC

User And Machine Monitoring and Control System

Electric Vehicles

National Cheng Kung University
Tainan City
Future Prospects
Low-Carbon Island Project in Penghu

- Low Carbon Island Project in Penghu (59km from Taiwan, inhabitants 89,000, average load 45MW, peak load 83MW)
Low-Carbon Island Project in Penghu

- To verify and demonstrate the key technologies and related business models

AMI (Startup 500 Meters/total user 30,000)

Solar thermal

Micro-grid

Smart Substation Auto.

EMS/DSM, ToU & DR Model over 200 Customer Side Service/Management

Solar PV (2MW)

Wind Farm

Large-scale Wind Farm (96MW)

Small-scale Wind Farm (220kW)

Electrical Vehicle (include E. Motorcycle and Charging Stations)
Low-Carbon Island Project in Penghu

• A field demonstration of low-carbon green living, low-carbon services, and carbon-reduction technologies

• Combining with tourism service to have negative demand growth in low-carbon homes

  ▶ In 2015, the target of having a decrease of 50% of carbon emissions compared to 2005 to be reached

  ▶ In 2015, 50% of renewable energy penetration level

  ▶ Electricity consumption growth rate to be dropped by 7%, and per capita carbon emission to be reduced to 2.1 tons per year.

  ▶ Establishing investment model of Taiwan's first large-scale wind turbine in prefectural stock (the benefit of the island to be 1.6 times more)
Thank You for Your Attention!