Design and Field Test Results of High Renewable Penetration at a Korean Island Remote MicroGrid

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Outline

I Motivations

II Project Overview

III Design

IV Construction

V Operation Results

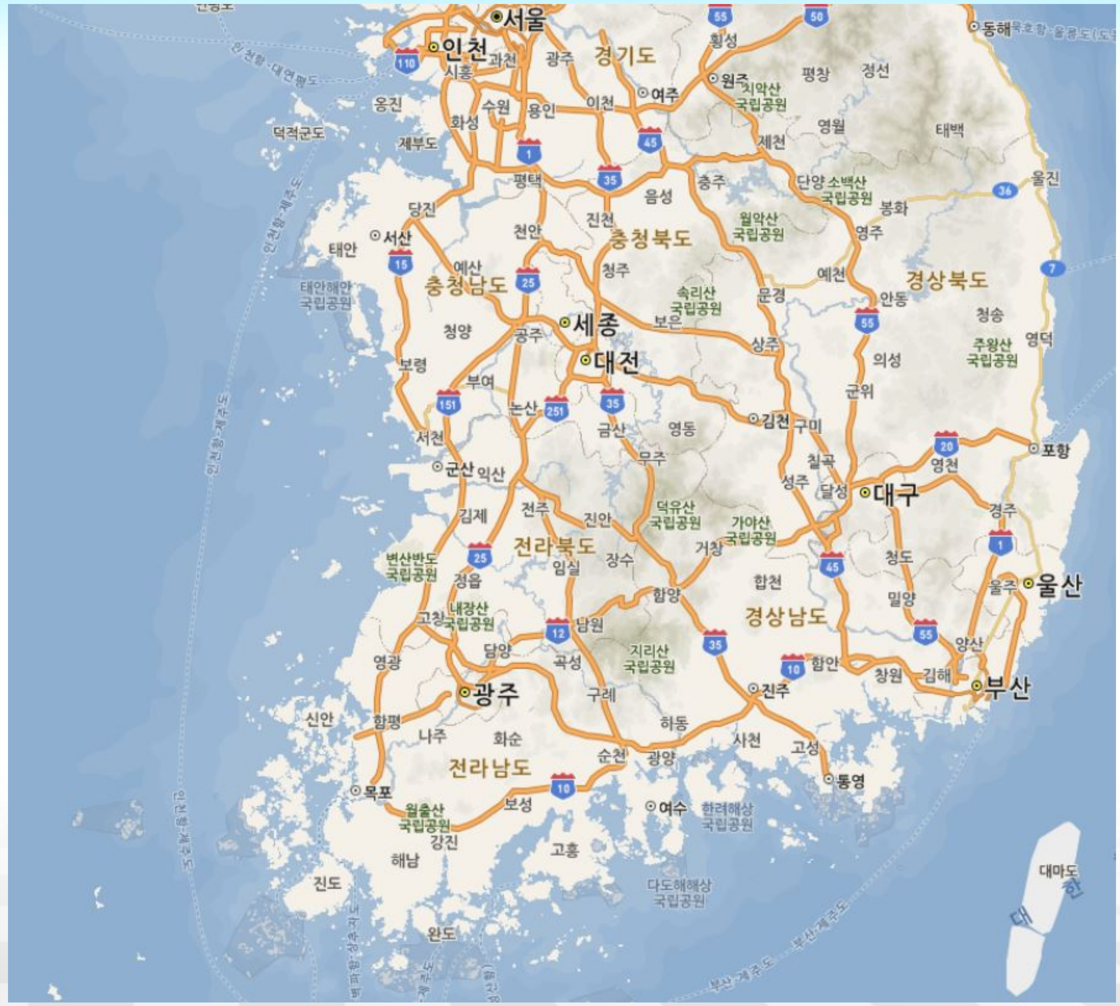
VI Conclusion

Why Remote MG in Korea?

- **127 diesel power plants's life will be ended within few years**

Owner	Number of Plants
KEPCO	63
Local Gov.	22
Inhabitants	42
Total	127

[Typical Power Plant of Korea]



[Many island in Korea]

Cost of Energy in Korea

0.142 $/kWh	vs	0.587 $/kWh
COE in Mainland (2014 year) Source : KEPCO		COE in Island (2014 year) Source : KEPCO

Project

2. Project Overview

Goal	Secure MicroGrid Total Solution for KEPCO's island & business
Team	**KEPCO Research Institute(PJ Owner), Jeonnam TP, KESRI, KIER**
Budget	**10M$(Govern.5.8M, KEPCO3.6, Local Govern.0.6M), '12.10~'15.10(36M)**

What to develop

Develop engineering process♪

- optimal combination of DG and evaluation of ec onomic feasibility
- system analysis and optimal location of DG

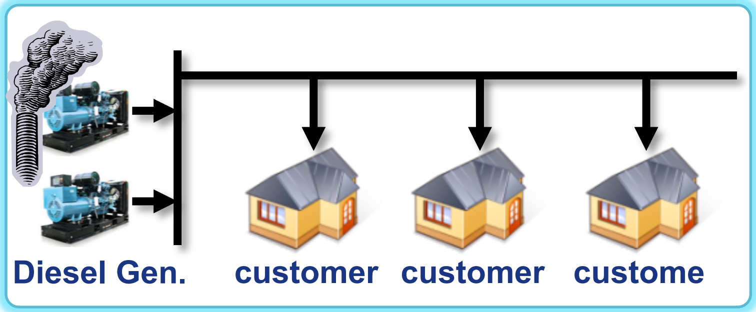
Develop EMS and operating technology ♪

- generation control, emergency control, load con trol, etc.
- operation manual, emergency operation manua l

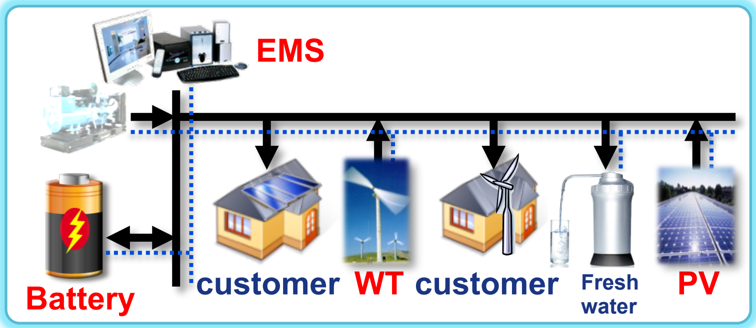
Demonstrate and secure Track Record ♪

- verify technology based on DG capacity combin ation
- Build infrastructure for commercialization throu gh site optimization

Concept diagram



[Before applying remote MG technology]

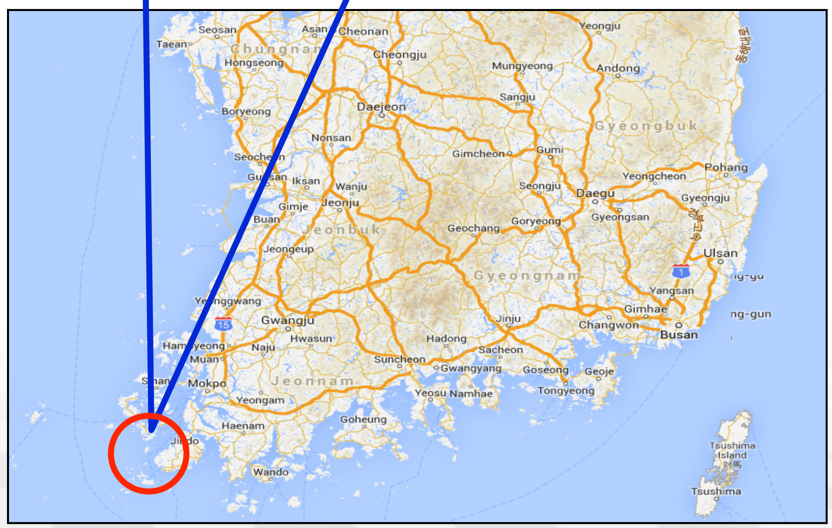


[After applying remote MG technology]

Test Island

Test Island : Gasado(southern side of Korea)

	Contents
Location	• Southern part of South Korea • Distance from main land : 6km • Area : 6.4km^2
Electrical System	• Genset : 100kW×3 (1993) • D/L : 2 line(total length : 8km)
Load	• Customer : 168house(286person) • Average Load : 96kW (Peak : 173kW, Min : 61kW) • Main Load : Radar, Lighting house Water supply
Site	• 50% : Owned by local government • 50% : Private owned

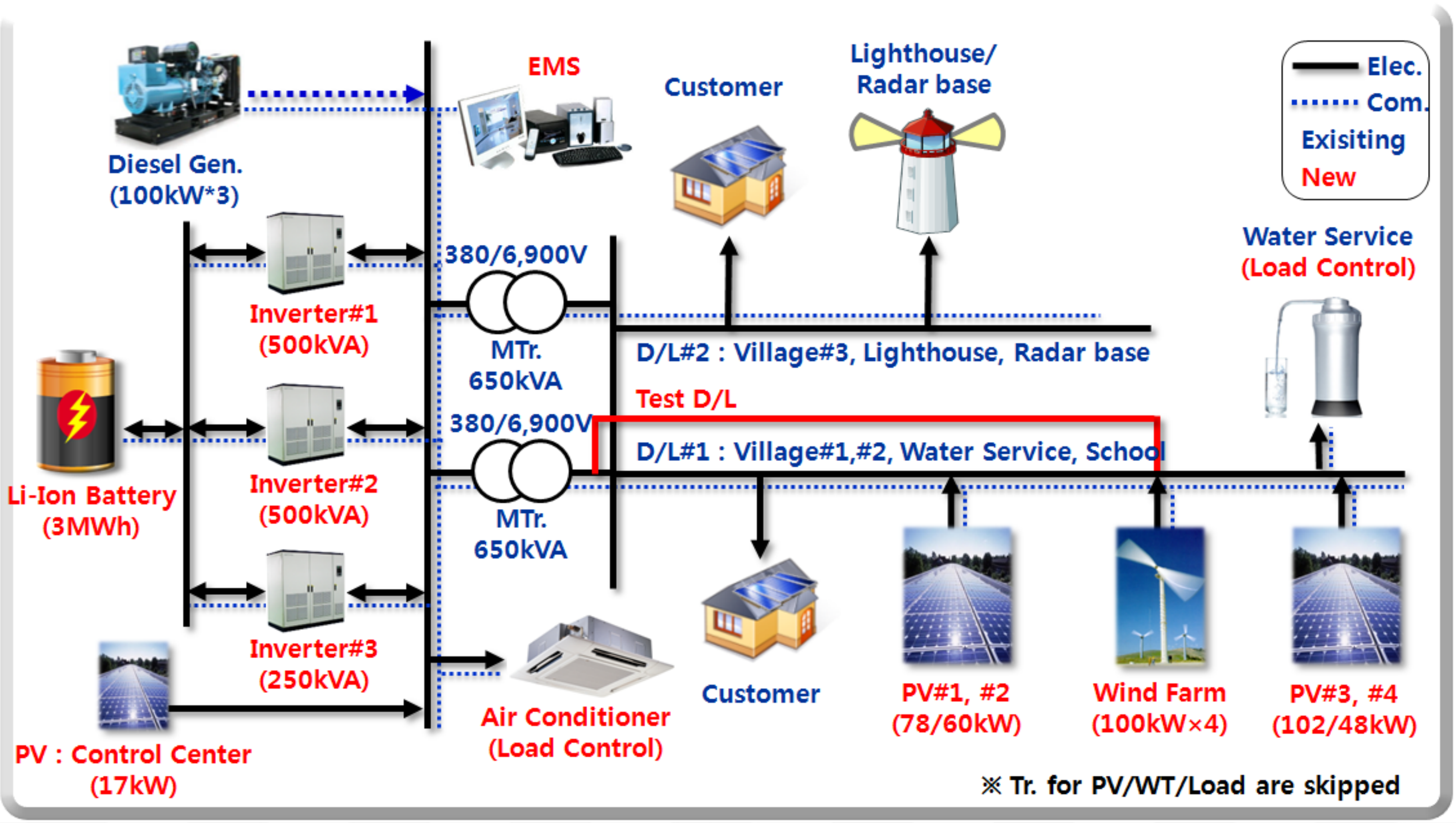


Design Target

- MicroGrid system supplied with 99% renewable energy

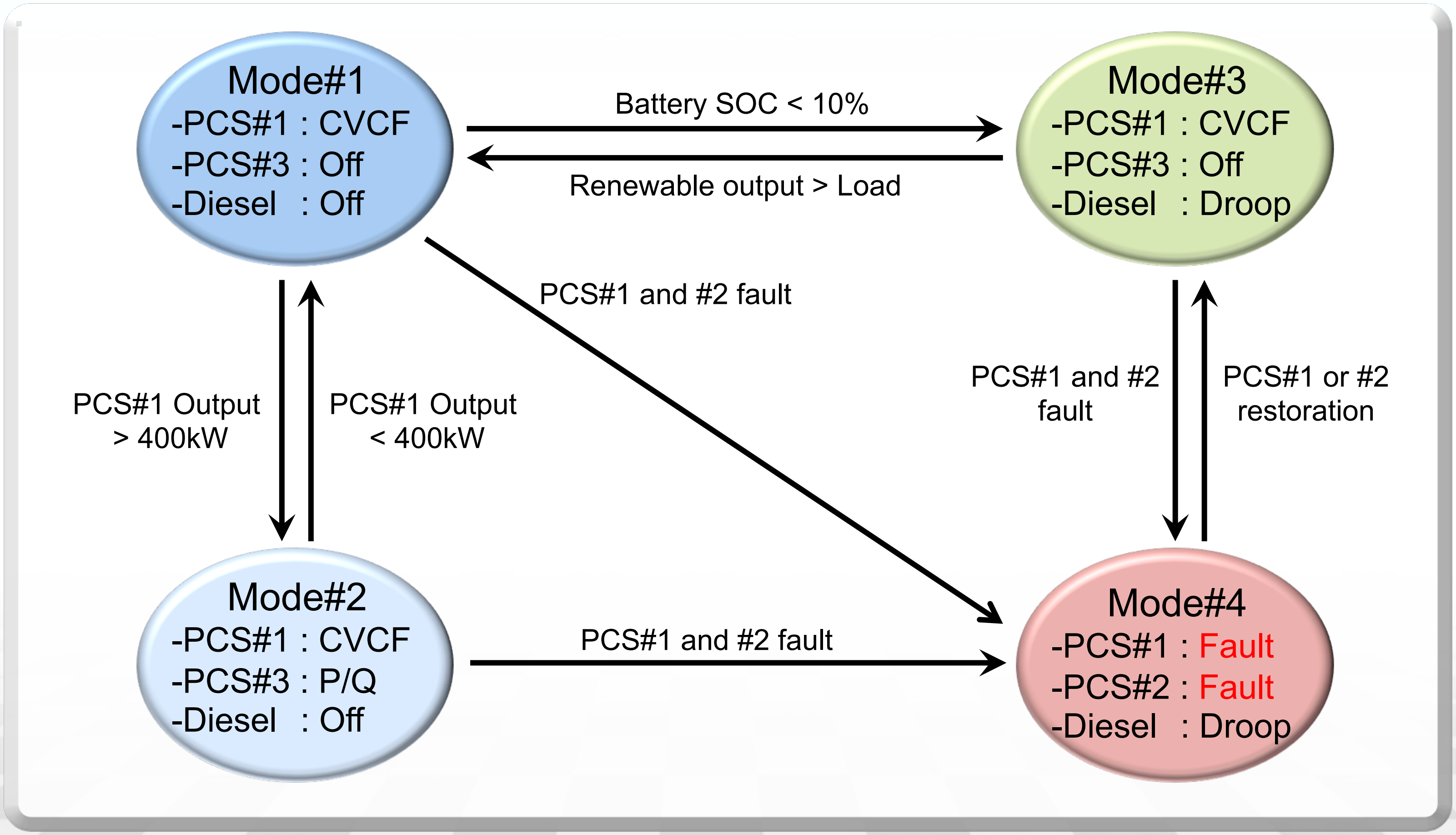
Classification	Contents	Note
Energy	99% renewable energy	Energy independent
No Wind/Sun	1 day	Battery size, Economical
Emergency	Using diesel generator	WT/PV fault No wind/sun
For field test	Renewable Capacity divided Exclusive line for test	Renewable mix test No outage at the village
EMS	Automatic control	System efficiency
Plug & Play	No communication for small PV	Economical
Site for WT/PV	Idle site, Roof, Reservoir	Water floating PV

System Architecture



Operation Mode

- Transition beteween mode#1, #2, #3 is done by EMS.
- Transition from/to mode#4 is done by operator after fault clearing



Main Equipment

[Monitoring & Control]

[Water Floating PV system : 48kW]

[Wind(100kW*4) & Solar Farm(total:314kW]

[Li-ion Battery : 3MWh]

Main Equipment

	Specification	Function & Feature
EMS	SCADA + Application	Battery SOC management, Forecasting of load & re newable energy, Direct load control, Automation
GFI (Grid Forming Inverter)	500kVA*2, 250kVA*1	Frequency & voltage control, P/Q control 500kVA #2 : Backup, 250kVA : for shortage of ratin g
Battery	3MWh, Li-ion	Electrical energy storage, 1C-rate, NMC type 3 GFIs are connected to 3MWh in parallel.
WT	100kW*4	PMSG+Full converter, Power limitation, Power fact or & Voltage control, LVRT, FRT
PV	314kW(8ea)	Power limitation, Monitoring of each module, Water floating PV system for limited site
Diesel Gen.	100kW*3	Droop control, Remote on/off
Load	Water pump Air conditioner	Water tank is used to energy storage. Battery room temp. control using surplus energy.

Feature of System

4. Construction

- ❖ Inverter-based power system
  - ✓ Inverter maintains voltage/frequency and battery SOC.
- ❖ Renewable energy penetration rate of world class level
  - ✓ Penetration rate : 400%(of peak load)
- ❖ Automatic operation by EMS
  - ✓ Automatic control depending on battery SOC
    : PV / WT / Diesel / Water supply / Air conditioner
- ❖ Usable both as commercial operation and as test site
  - ✓ Various tests are available without outage.
- ❖ Demand side management
  - ✓ water tank, air conditioner of battery room
- ❖ Design considering growth of Gasa Island
  - ✓ Site selection of WT & PV farm considering tourism resources
  - ✓ Water floating PV : Consideration for limited site of island

Eenrgy Management System

4. Construction

[Real-time periodic operation]

Load Forecasting

Renewable Generation Forecasting

<GLF>

Planning ON/OFF of load

(Demand management)

Planning unit commitment of gen.

(Economic dispatch)

Optimal scheduling of battery SOC

(Real-time control of water suppl y and diesel)

<ASC>

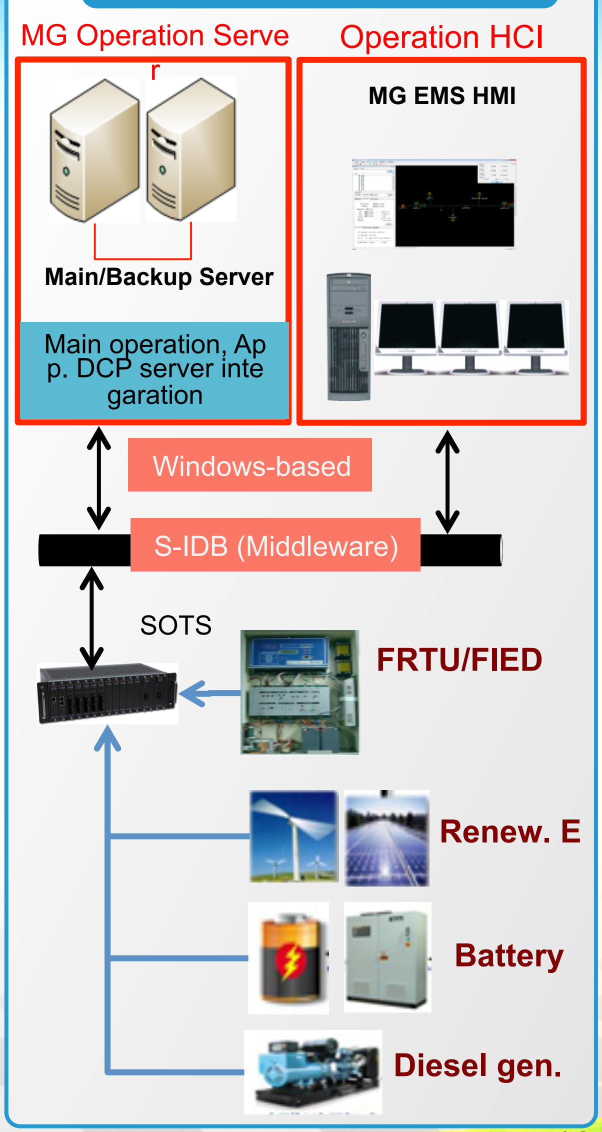
[Under abnormal SOC]

Emergency Control

<DEC>

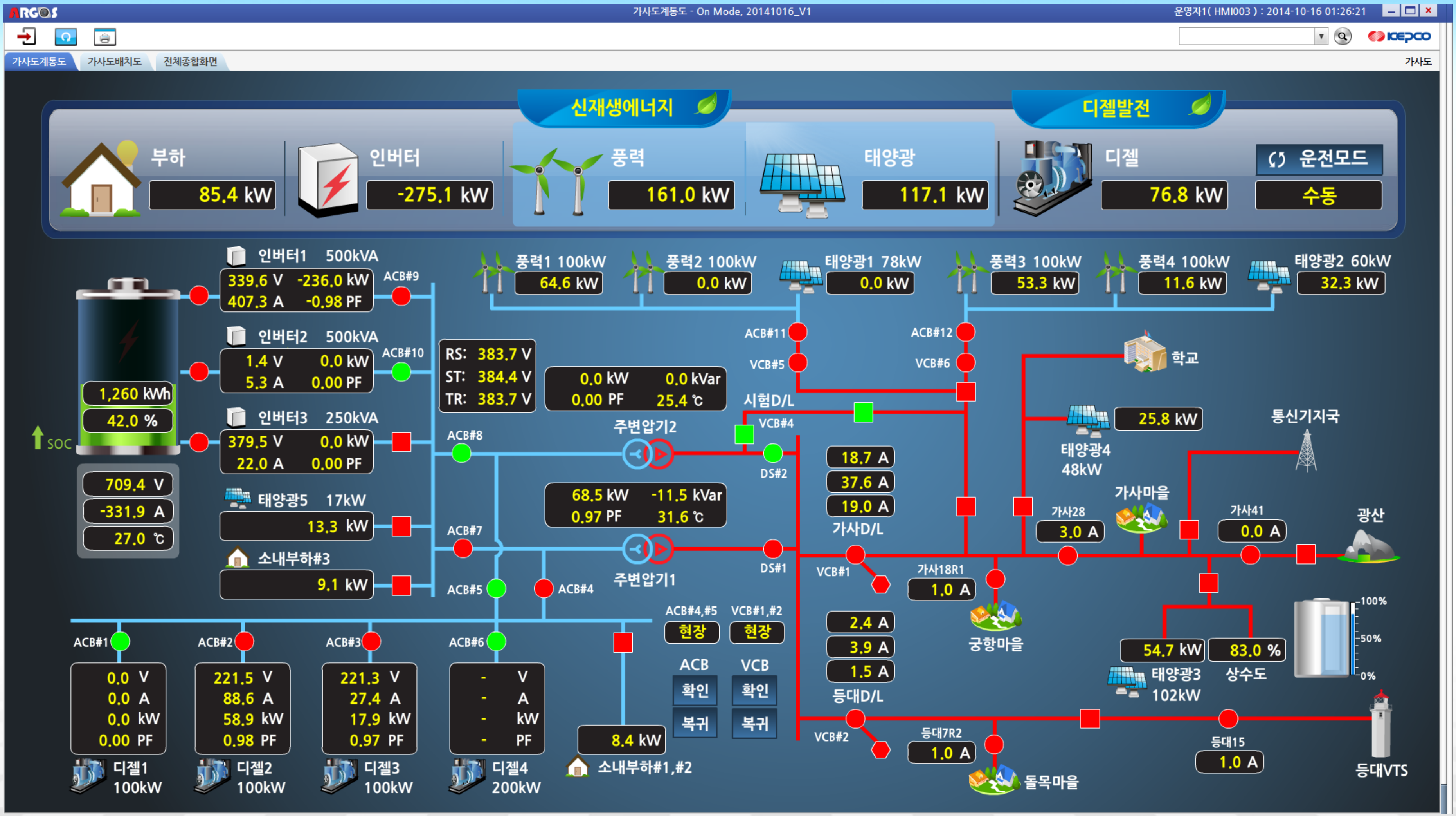
- **Surplus power : Real-time optimal demand management**
  - **- Unit commitment and control of water supply**
- **Power shortage : Economic dispatch of diesel gen.**
  - **- Unit commitment and control of diesel gen.**
- **Abnormal Battery SOC : Emergency control**
  - **- Load control : ON/OFF control of air con. and dummy load**
  - **- Generation control : ON/OFF and generation control of PV and WT**

Diagram of MG-EMS



Eenrgy Management System

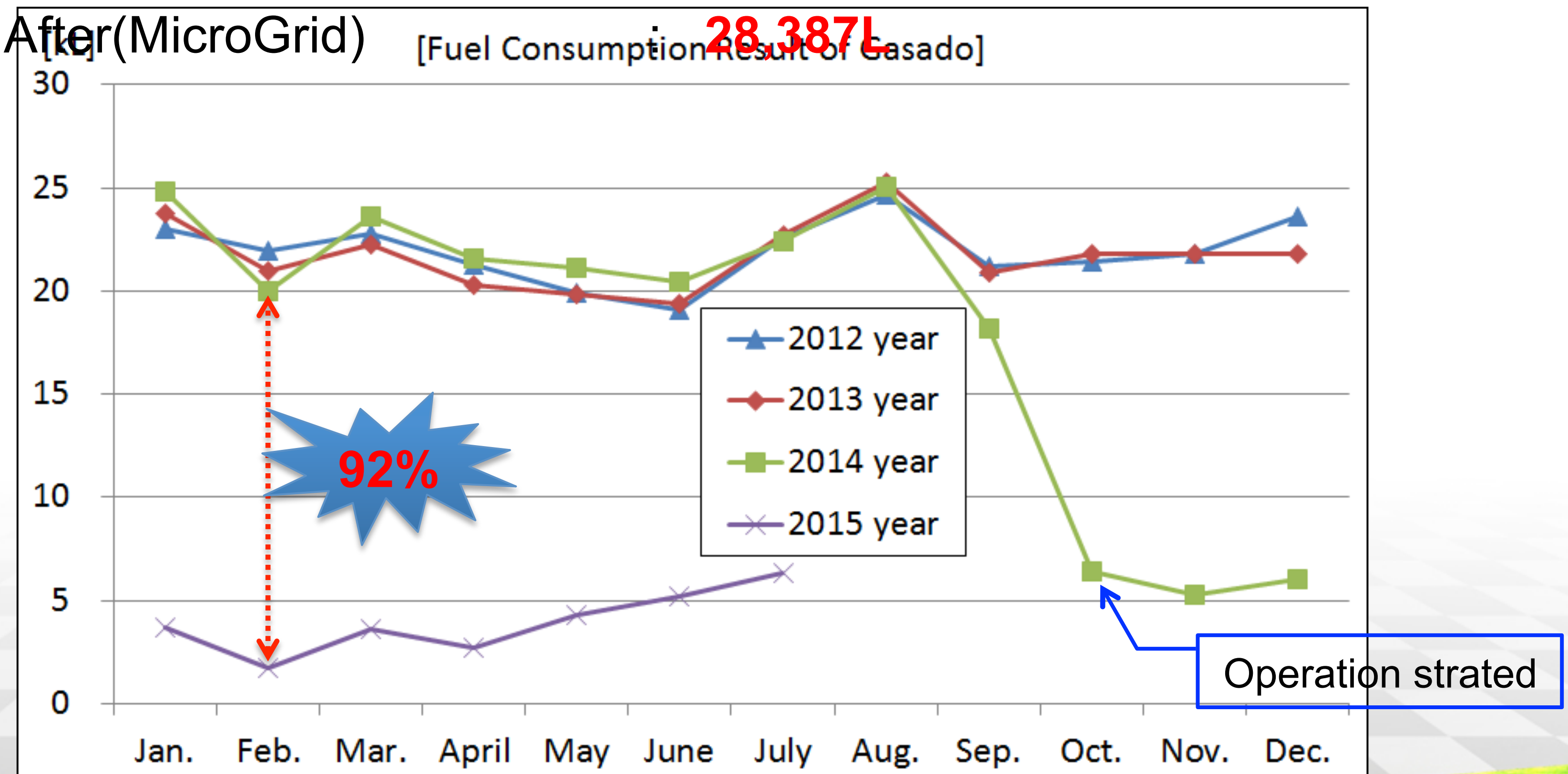
4. Construction



Fuel Saving

5. Operation Results

- Commercial operation from tape cutting ceremony(Oct. 2nd, 2015)
- Fuel saving results(compare to 2014 year) : 79.4%
  - ✓ Before(Diesel power plant) : **155,511L**
  - ✓ After(MicroGrid) : **28,387L**



Efficient operation of Gen Set

5. Operation Results

- ❖ Fuel efficiency of the gen set was improved by 14.2% using GFI(grid forming inverer).
  - ✓ Get set can be operated at the highest efficient region because GFI control the frequency.
- ❖ But, battery system's round-trip efficiency is usually 90~95%.
- ❖ So, gen set should be run in the highest efficiency section.

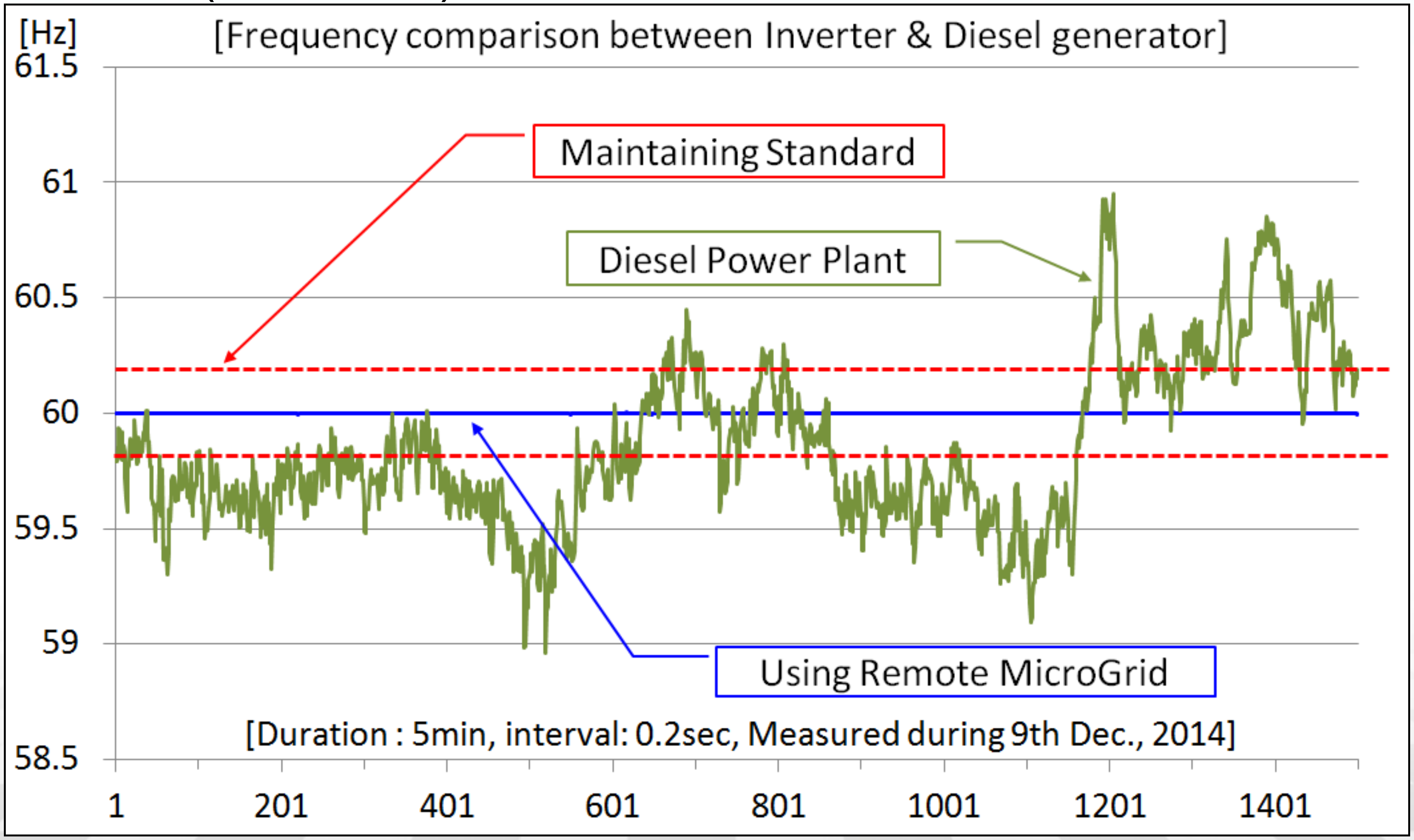
[Fuel consumption comparison of a diesel generator]

Operation Type	At Diesel Power Plant	At Remote Microgrid
	2 gen-set in parallel during 24Hours	one gen-set with grid forming inverter (GFI) during 24Hours
Fuel Consumption	766.2 L/24 h	562.7 L/24 h
Total Production	2319.3 kWh	1946.2 kWh
Average Power	96.6 kW	81 kW
Energy per Fuel	3.02 kWh/L	3.45 kWh/L
Fuel per Energy	0.3304 L/kWh	0.2892 L/kWh

Power Quality

❖ Frequency maintain ratio(0.2sec sampling)

- ✓ Previous(Diesel power plant) : **57%**
- ✓ Present(MicroGrid) : **100%**

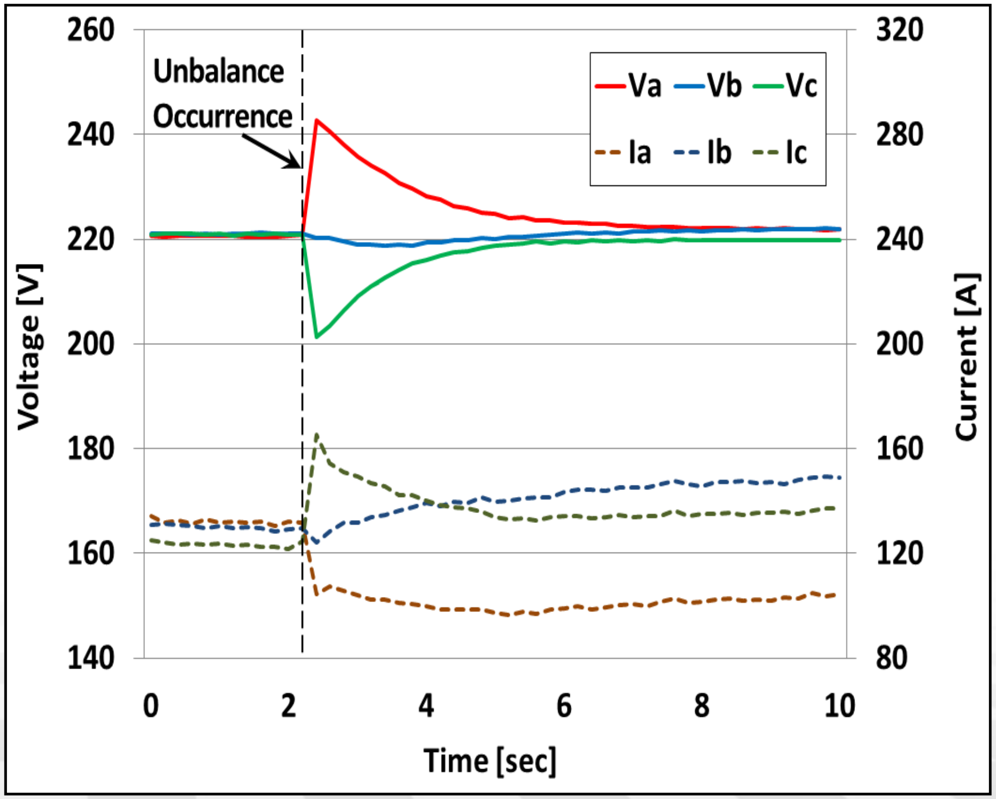


Power Quality

5. Operation Results

- ❖ Unbalanced voltage restoration test
  - ✓ Under unbalanced load, inverter restores unbalanced voltage to the balanced state.

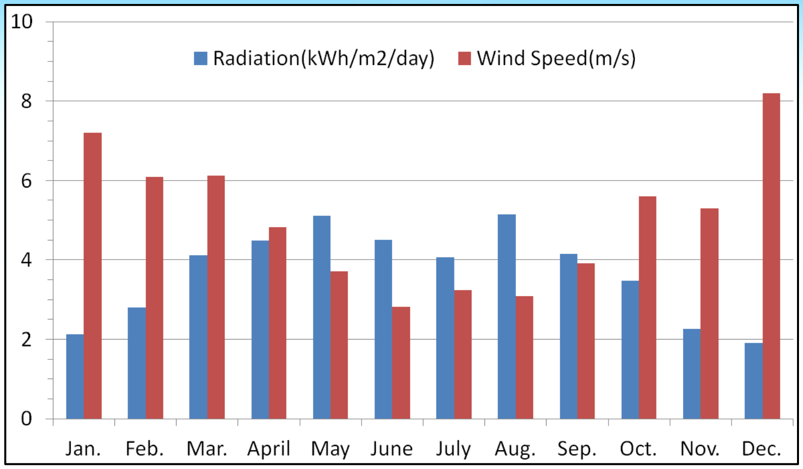
Test line	BESS mode		CVCF
	PV Output		85kW
	Dummy load		A/B/C : 80/80/80 kW
Measure point			Inverter output
Unbalance occurrence (Dummy load)			A/B/C : 0/80/80 kW
Voltage	Before Unbalance Load	A	220.7 V
		B	221.1 V
		C	221.0 V
	After Restoration	A	221.9 V
		B	222.1 V
		C	220.0 V



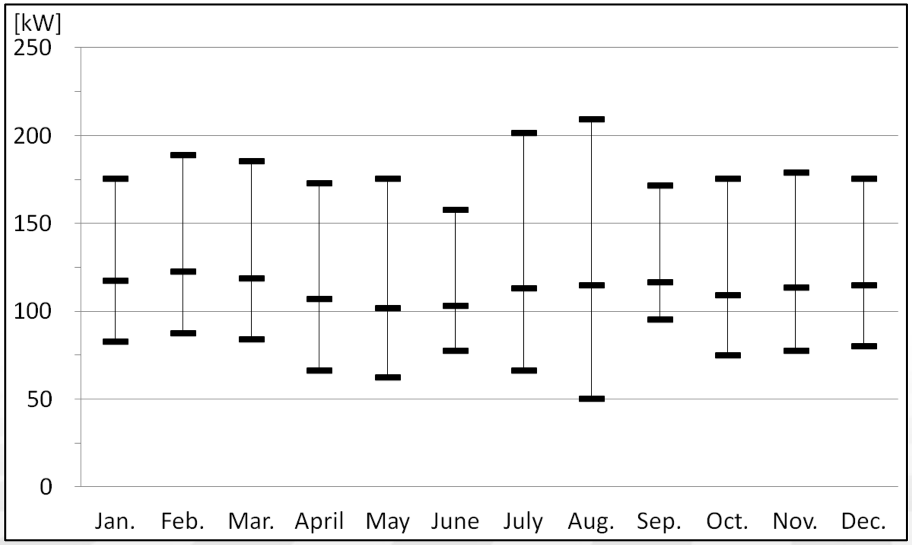
HOMER Simulation

5. Operation Results

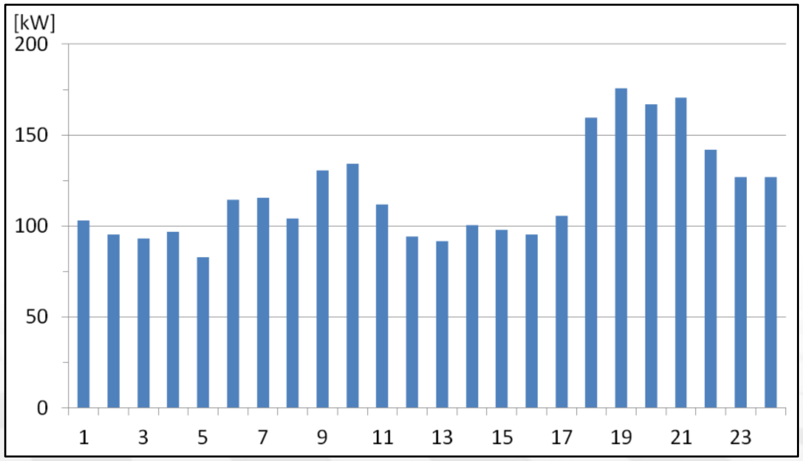
- Radiation : 3.68kWh/m^2/day
- Wind Speed : 5.0m/s @ 30m
- Temperature : 13.4℃
- Average Load : 100kW
- Fuel Price : 0.912$/L
- Real Interest Rate : 2.98%



[Yearly Weather Profile]



[Yearly Load Profile]



[Daily Load Profile]

HOMER Simulation

5. Operation Results

- There are some difference between expected and operation results for PV and fuel consumption.
- But, there is much difference for WT due to
  - ✓ Frequent stop or output restriction of WT in winter season
  - ✓ Lower average wind speed compared to collected wind speed data

Generator		Unit	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Ave.
Wind Turbine	Expected	MWh	67.8	72.0	146.9	123.3	83.6	88.4	97.0
	Results	MWh	33.3	42.1	56.6	55.7	50.2	31.4	44.9
PV	Expected	MWh	32.8	21.9	20.4	23.6	25.3	36.4	26.8
	Results	MWh	27.7	23.5	15.0	21.1	23.7	35.9	24.5
Diesel Generator	Expected	MWh	17.0	20.4	8.1	5.9	13.0	5.0	11.6
	Results	MWh	20.3	16.8	21.1	12.7	6.2	13.5	15.1
Total Production	Expected	MWh	117.5	114.3	175.4	152.8	121.9	129.8	135.3
	Results	MWh	81.3	82.5	92.6	89.4	80.1	80.9	84.5
Renewable Fraction	Expected	%	86	82	95	96	89	96	91
	Results	%	75	80	77	86	92	83	82
Fuel Consumption	Before	kL	21.8	21.8	21.8	24.8	20.0	23.6	22.3
	Expected	kL	5.1	6.1	2.5	1.8	3.9	1.5	3.5
	Results	kL	6.4	5.3	6.0	3.7	1.7	3.6	4.5

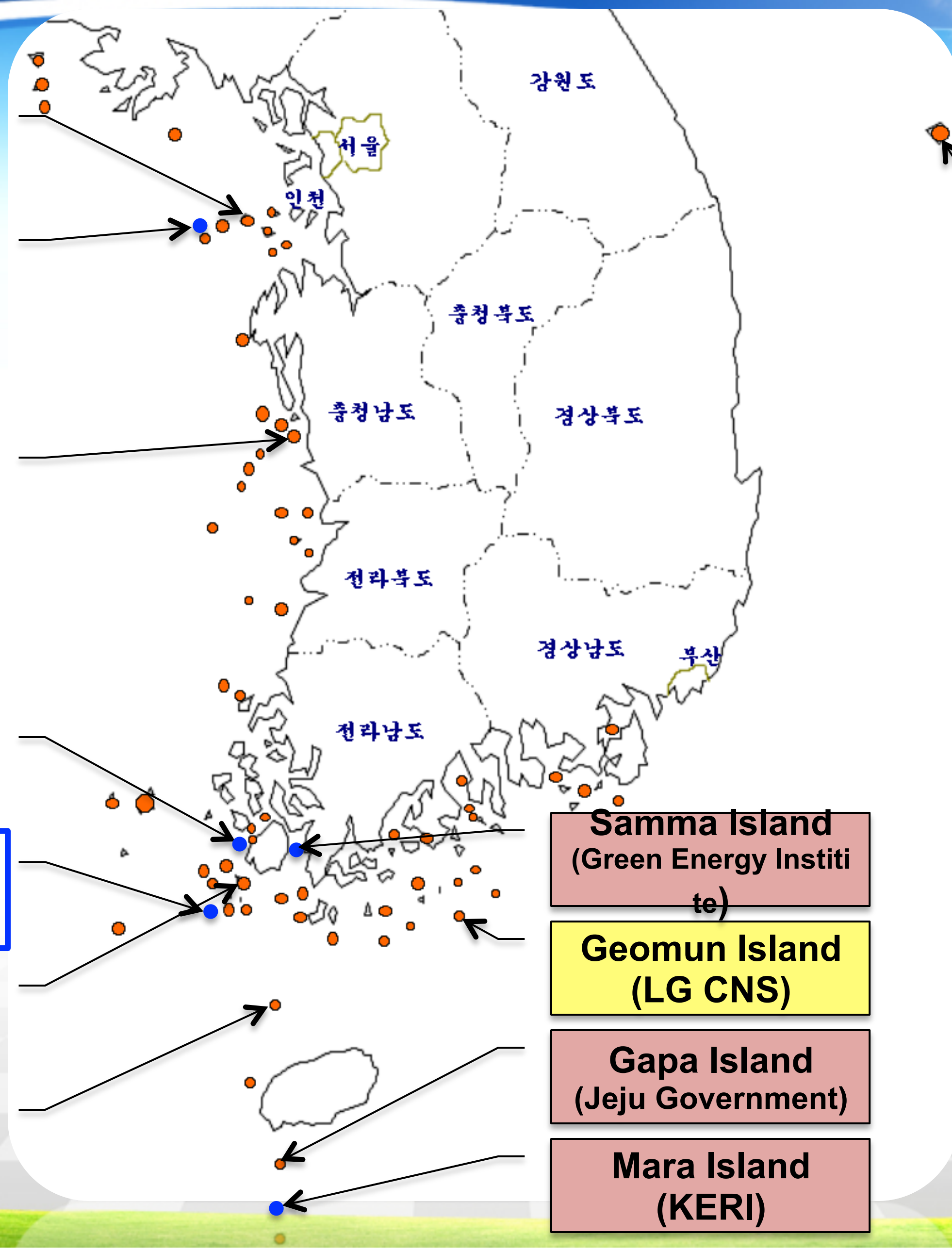
Challenges to Project

- ❖ Advanced system configuration in Korea
- ❖ Vague worrying about WT's noise from th e residents
- ❖ Graveyard moving
- ❖ 200 ton installation crane delivery and co crete dispatch
- ❖ Typhoon & Heavy rain
- ❖ Steep ground & slope of PV/WT site
- ❖ Overnight test for no interruption of electr c power

[Foudation of PV at the sloped site]

[Concrete mixing at the island]

More Plan in Korea



Deokjeok Island (KT)

Baega Island (Incheon TP)

Sapsi Island (WOOJIN Ind.)

Gasa Island (KEPCO)

Geocha Island (KEPCO)

Jo Island (LG CNS)

Chuja Island (POSCO)

Ulleung Island (KEPCO&LG CNS)

Samma Island (Green Energy Institute)

Geomun Island (LG CNS)

Gapa Island (Jeju Government)

Mara Island (KERI)

KEPCO
Local government

Completed

Planned

Summary

- ❖ KEPCO developed high penetrated remote Micorgird with EMS
  - ✓ There is no problem to operate the high penetrated remote Micorgird using large battery system.
- ❖ Mismatch between expected and operation results
  - ✓ Stop or output restriction of WT in winter season
  - ✓ Lower wind speed compared to collected wind speed data
- ❖ Too much dumped energy in winter season
  - ✓ Due to high wind speed in winter season in Korea
  - ✓ We should develop another load(thermal) or storage system.
- ❖ Power quality of remote MG is better that the diesel power plant.
- ❖ The gen set could be run in the highest efficiency region using the battery system.

※ More reading : Wookyu Chae, Design and Field Tests of an Inverted Based Remote MicroGrid on a Korean Island, *Energies* 2015, 8, 8193-8210, Wookyu Chae

MicroGrid, Light the World

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