NEDO System Use Case #H1

Energy management of grid-connected microgrid that makes optimum use of biomass and mitigates negative effects of intermittent generators on distribution grid

Version 2.0

Dec 22, 2011

1 Descriptions of Function

1.1 Function Name

Energy management of grid-connected microgrid that makes optimum use of biomass and mitigates negative effects of intermittent generators on distribution grid.

1.2 Function ID

System Level Use Case H1

1.3 Brief Description

This use case describes energy management of a grid-connected microgrid system that optimizes the use of biomass (digestion gas, wood biomass) while making optimum use of renewable energy and mitigates the negative effects on distribution grid (with respect to demand-supply balance and power quality). The microgrid system is connected to distribution grid at a single point and is controlled by the energy management system (EMS) which maintains the amount of power purchased from the distribution grid to contribute to frequency control of the distribution grid and develops an optimum generation schedule in accordance with the load within the microgrid[1].

There are two types of distributed energy resources (DER) in this use case, intermittent and controllable:

[1] This use case is based on the results of the NEDO demonstration project conducted at sewage plant in Hachinohe city, Aomori prefecture, Japan. The structure of the facilities used in this demonstration project is shown on page 3.

Distributed Energy Resources

Renewable Energy (intermittent)
1. Four PV – total capacity 130 kW
2. Three WT – total capacity 20 kW

Controllable DER
1. Three Gas Engines (GasE) – total capacity 510 kW (primary generation source)
2. Lead-acid battery – total capacity 100 kW

There are six electrical loads in this use case:

Load

1. HACHINOHE City Hall (maximum power demand 360kW)
2. HACHINOHE Regional Water Supply Authority (maximum power demand 40kW)
3. KONAKANO Junior high school (maximum power demand 60kW)
4. KONAKANO Elementary school (maximum power demand 46kW)
5. KOYO Junior high school (maximum power demand 53kW)
6. KOYO Elementary school (maximum power demand 46kW)

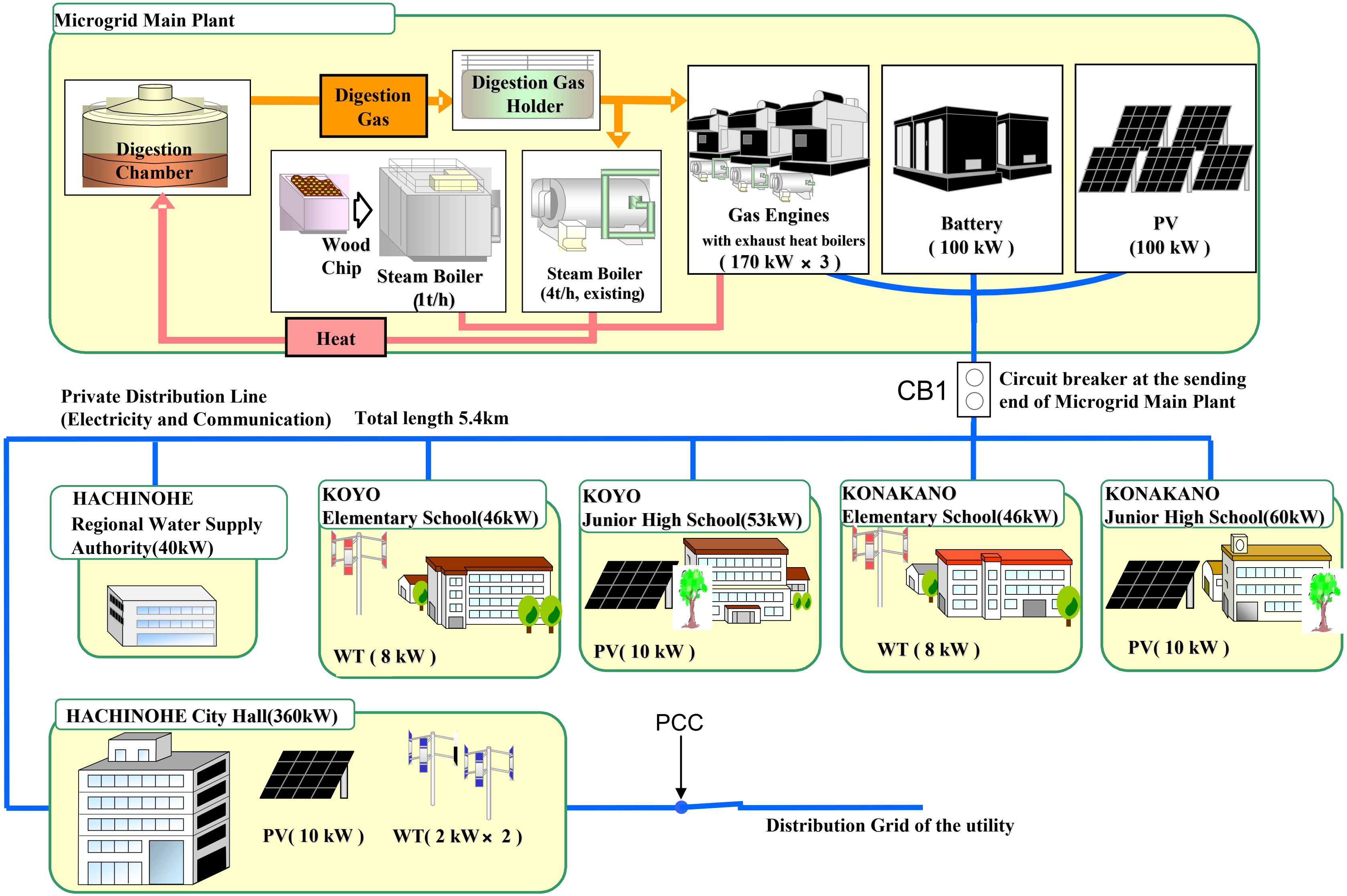

Fig.1. NEDO Hachinohe Project

1.4 Narrative

In this microgrid, a small-scale power network consisting of distributed energy resources (DER) and load is connected to the distribution grid at a single point (PCC). The DER and customers are connected via private power-line and communication line (fiber optic cable). By using this two-way ICT communication capability and energy management system (EMS), the microgrid has the functionality to mitigate negative effects on the distribution grid while making optimum use of renewable energy.

The EMS controls controllable DER only, not end-user loads. End-users connecting to the private distribution line (microgrid) are also connected to the utility's distribution grid. Therefore, automatic switching can be implemented when low voltage is detected by the low voltage relay at electric switchboard installed at end-users' premises.

The EMS implements this function in four ways:

Stage 1: Planning of Supply

This stage describes the function of supply planning that develops the optimum supply plan for electricity and heat (at 30-min. intervals) for a week on the previous day of the actual operation. The plan for a week (at 30-min. intervals) is developed after making a forecast of electricity/heat demand based on the correlation between statistically processed demand and meteorological data. Normally, the plan is developed on the day before the actual operation, but can be updated on the day of operation.

In developing the plan, unit commitment of electricity/heat generator, output dispatch of power-controllable electricity/heat generator and power flow at the coupling point (amount of power purchased and sold) are determined so as to minimize fuel and environmental costs, within the constraints of supply-demand balance, consumption of fuel (digestion gas, wood biomass), battery SOC, and reserve power to deal with variations (e.g., error in supply-demand forecast, fluctuation of intermittent renewable DER output).

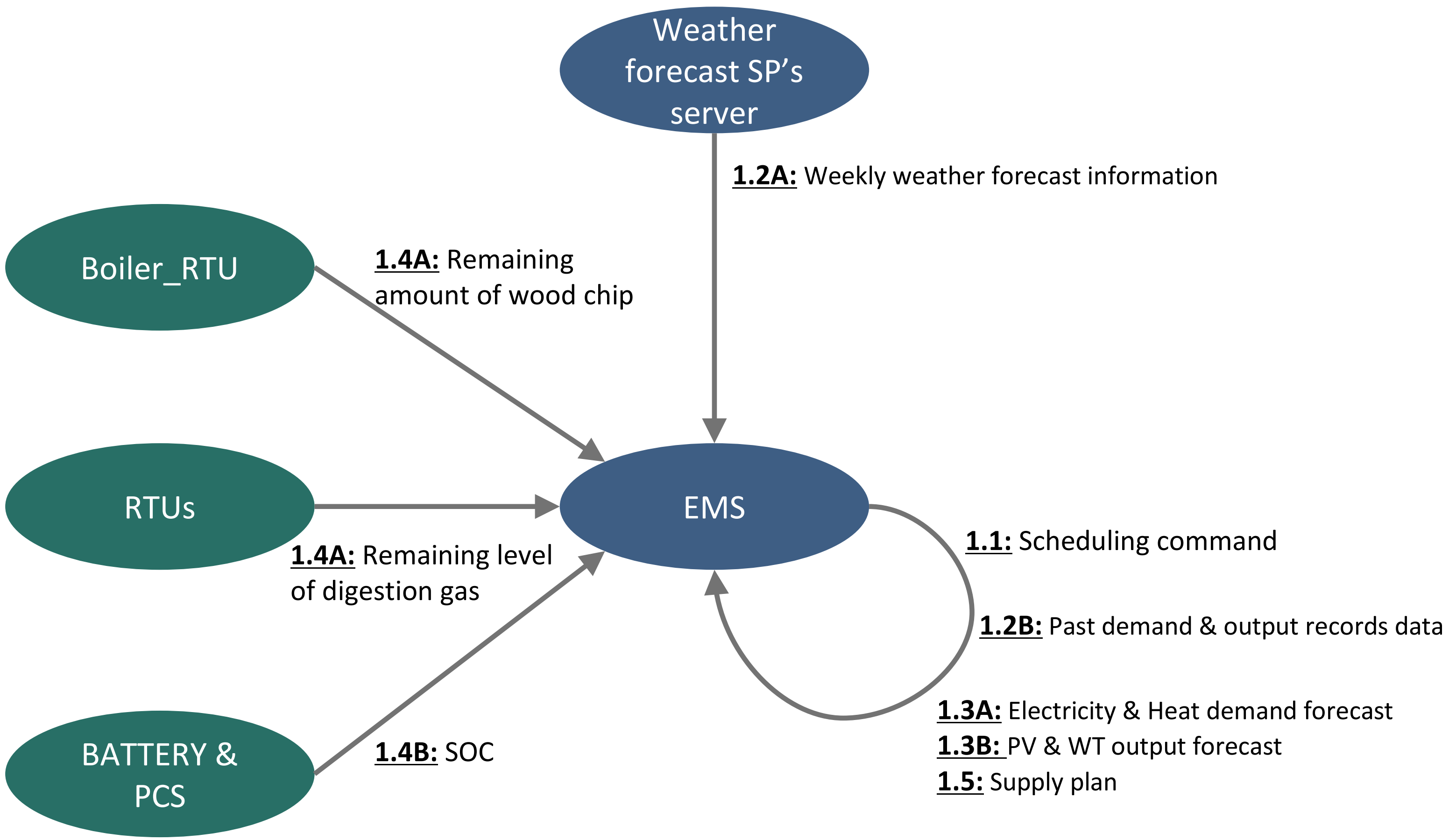

Fig.2. Diagram of Stage 1

Stage 2: Economic Dispatching Control

This stage describes the Economic Dispatch Control (EDC) function that develops the optimum electricity-heat supply plan (3-min. intervals) for the next two hours. By this function, output of each controllable DER is redistributed and controlled to reduce the error between supply plan developed on the previous day and the actual operation day to the most economic value within certain restrictions.

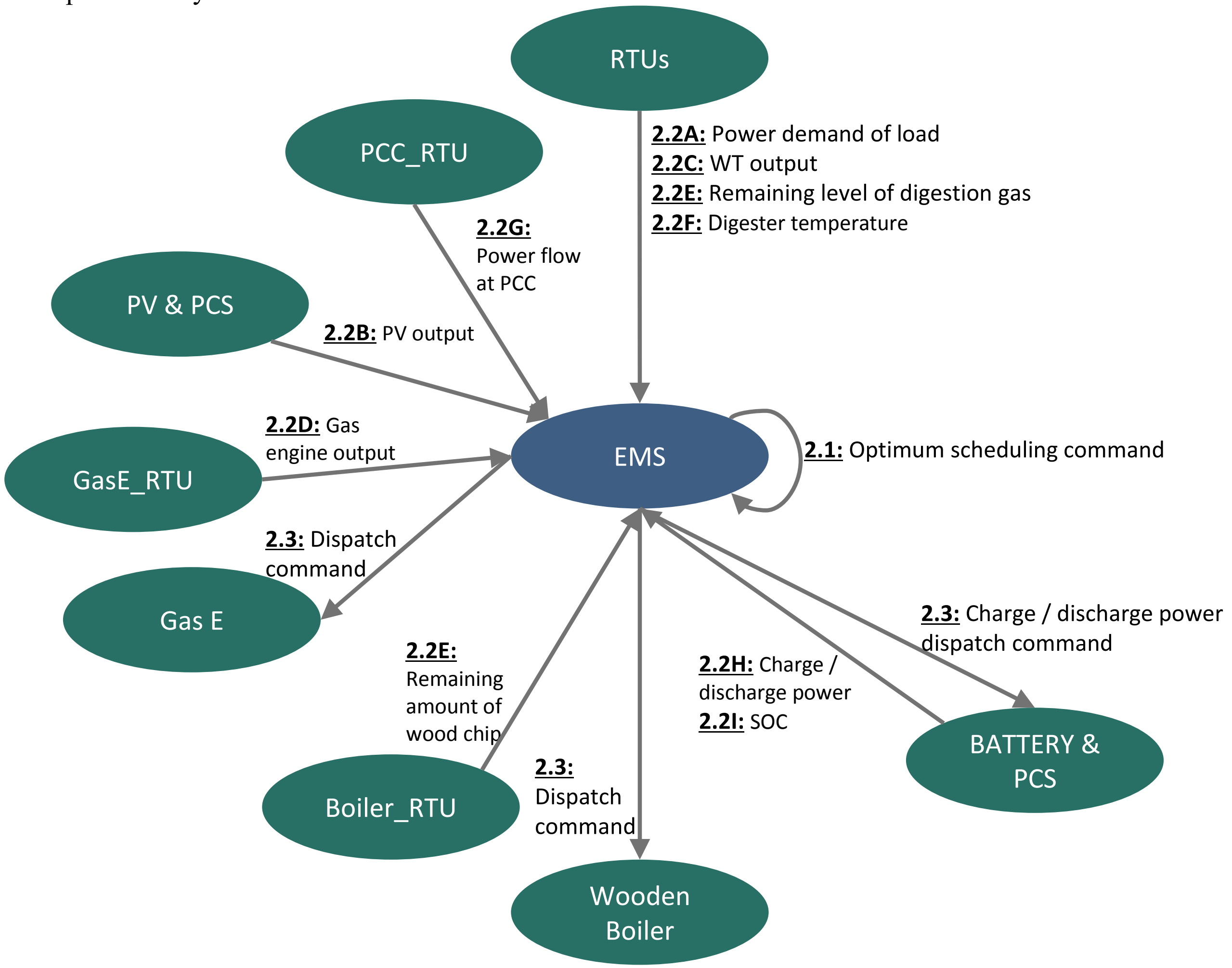

Fig.3. Diagram of Stage 2

Stage 3: Flat Tieline Control

This stage describes the Flat Tieline Control that maintains power flow at the PCC to the planned value by adjusting the output at 1-second intervals with consideration for the response characteristics of the generating equipment to be controlled. With this function, the supply-demand imbalance between the EDC (running at 3-min. intervals) and momentarily changing load and output of intermittent generators is compensated. Also, in order to absorb accumulated errors of control at 1-sec. intervals, compensation to meet target accuracy for control in about 360 seconds (6 minutes) is conducted.

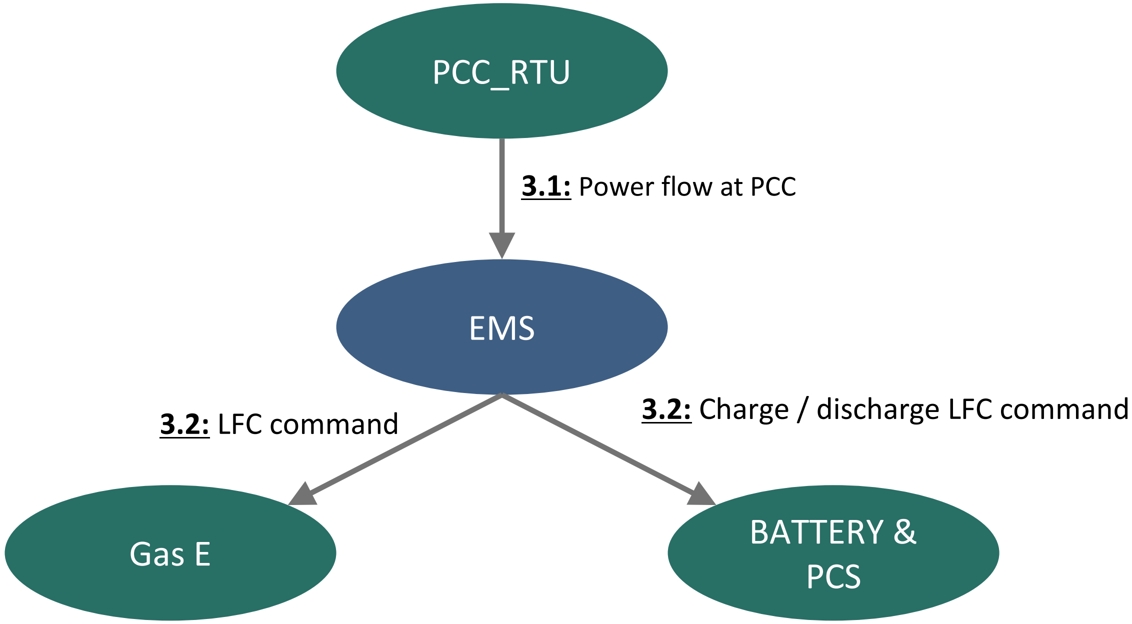

Fig.4. Diagram of Stage 3

The intended target accuracy for control is “to keep the 6-min. (360 sec.) moving average error between the amount of purchasing power planned on the previous day and the actual output at the PCC within 3% of electricity demand for each instant of time.” This is essentially different from “30-min. power balancing control” which is required in the Japanese power market. With “30-min. power balancing control” it is allowed to control power by adjusting the imbalance generated during the first half of the evaluation period in the second half to balance the total amount. However, this may end up expanding the fluctuation depending on output variation cycle of intermittent generators. The control described in this stage makes adjustments at 1-sec. intervals which can eliminate the error between planned and actual values at all times.

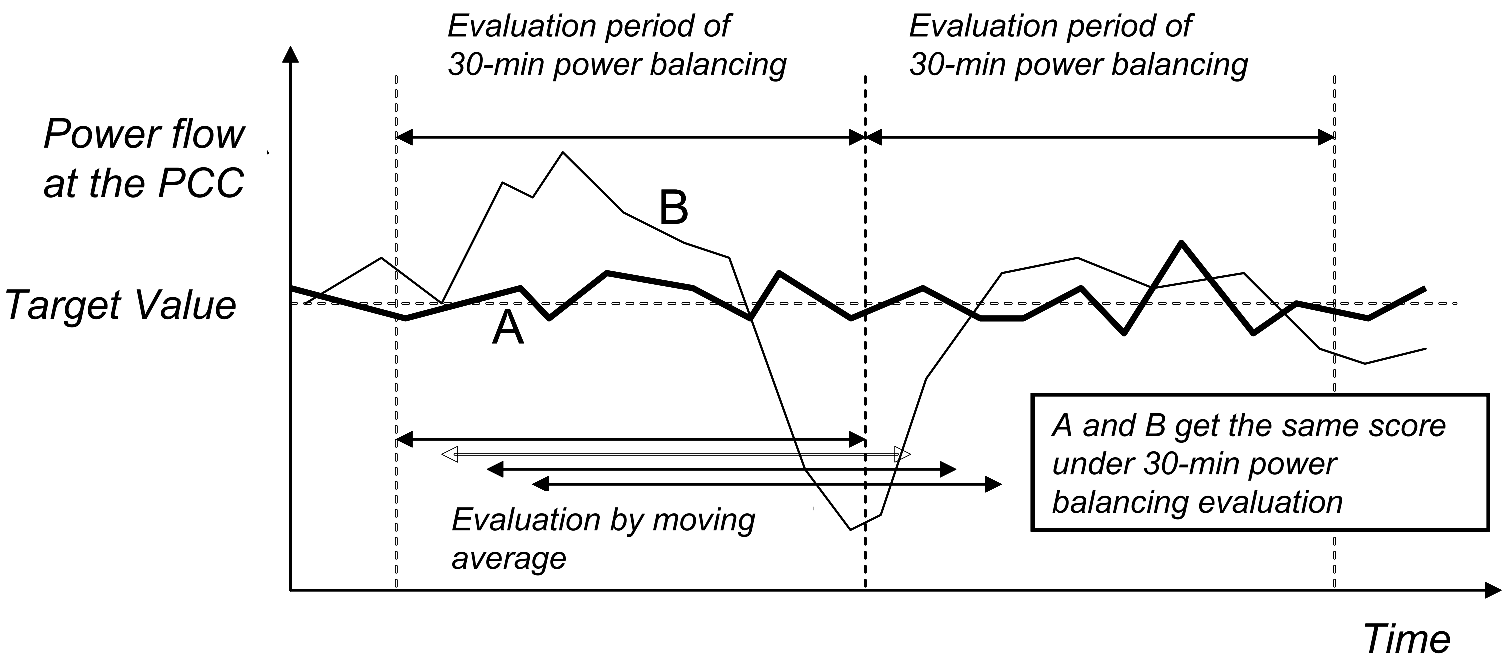

Fig.5. Difference between Flat Tieline Control and 30-min. power balancing control

Stage4：Negative Phase Sequence Current Compensation

This stage describes Negative Phase Sequence Current Compensation function that compensates negative phase sequence current resulting from an imbalance between phases of load within the microgrid.

EMS calculates total amount of negative phase sequence current in the microgrid from remotely measured Active power (P), reactive power (Q) and voltage (V) of each phase at multiple points in the microgrid.

Then, the allocations for negative phase sequence current to generator and compensating equipment are determined. The role of compensating equipment is taken by a photovoltaic power conditioning system.

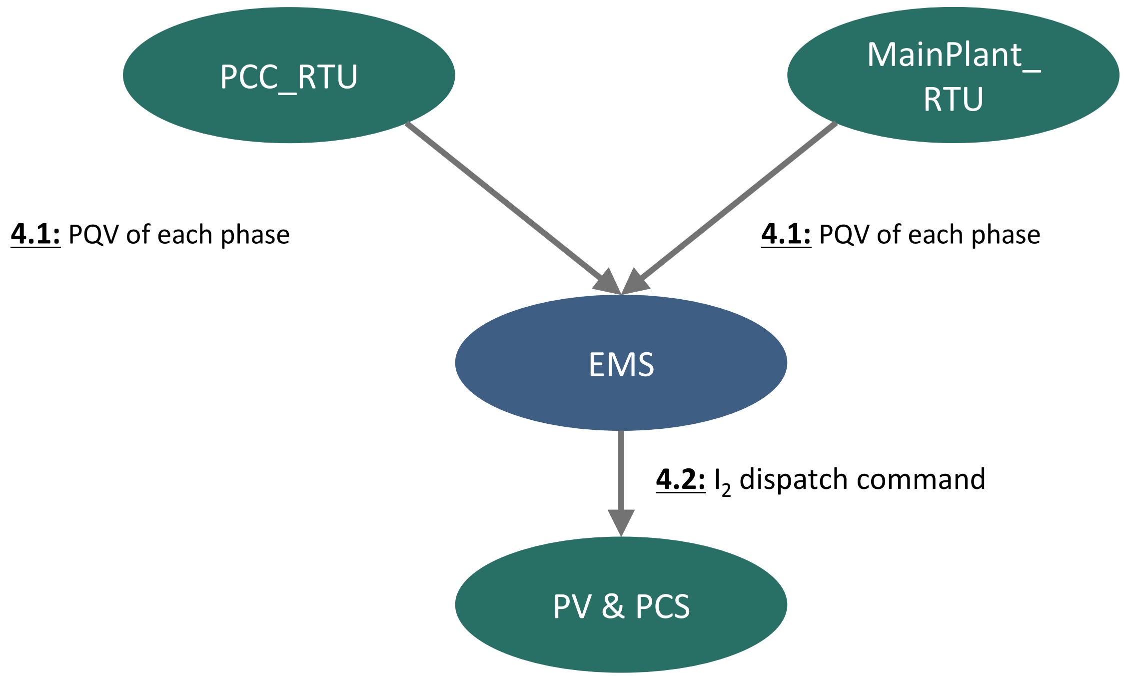

Fig.6. Diagram of Stage 4

<Acronyms>

EMS	Energy Management System
DER	Distributed Energy Resources
Gas E	Gas Engine generator
ICT	Information and Communication Technology
PCC	Point of Common Coupling

PCS	Power Conditioning System
PV	Photovoltaic generation system
WT	Wind Turbine generation system
RTU	Remote Terminal Unit
SOC	State of Charge
LFC	Load Frequency Control
I_2	Negative phase sequence current

1.5 Actor (Stakeholder) Roles

Grouping (Community)'		***Group Description***
Actor Name	***Actor Type (person, organization, device, system, or subsystem)***	***Actor Description***
EMS	System	Energy Management System for this microgrid. EMS has the functions of monitoring, control and scheduling of the microgrid.
Weather forecast SP's server	Device	Server of the entity which provides weather forecast information service.
RTUs	Device	Devices to measure power demand of load, output of WT, remaining level of digestion gas in gas holder and digester temperature on a real-time basis.
Gas E	Device	Gas engine generator. Control signals are sent from EMS to Gas engine.

Grouping (Community) '		*Group Description*
Actor Name	*Actor Type (person, organization, device, system, or subsystem)*	*Actor Description*
PV & PCS	Device	Photovoltaic generation system (PV) and PCS.
BATTERY & PCS	Device	Battery and PCS. Control signals are sent from EMS to PCS.
Wooden Boiler	Device	Wood chip boiler.
Boiler_RTU	Device	Device to measure remaining amount of wood chips in a wood chip pit on a real-time basis.
GasE_RTU	Device	Device to measure output of gas engine generator on a real-time basis.
PCC_RTU	Device	Device to measure electric variables at the points of common coupling (PCC).
MainPlant_RTU	Device	Device to measure electric variables at CB1* (circuit breaker at the sending end of Main Plant). * refer to Fig.1

1.6 Information exchanged

Information Object Name	*Information Object Description*
Weekly weather forecast information	Weather, amount of solar radiation, highest and lowest temperature for a week.
Past demand & output records data	Database of past demand (electricity, heat) and output (PV, WT) records data.
Electricity & Heat demand forecast	Demand forecast for electricity and heat for a week generated by EMS based on the weekly weather forecast and the past power demand records data.

Information Object Name	*Information Object Description*
PV & WT output forecast	PV & WT output forecast for a week generated by EMS based on the weekly weather forecast and the past PV and WT output records data.
Remaining level of digestion gas	Remaining level of digestion gas in a digestion gas holder.
Remaining amount of wood chips	Remaining amount of wood chip in a wood chip pit.
SOC	State of Charge (SOC) of battery.
Supply plan	Operation plan developed by EMS for gas engine generator, wood chip boiler, digestion gas boiler and battery.
Power demand of load.	Real time power demand of load.
PV output	Real time output of PV.
WT output	Real time output of WT.
Gas engine output	Real time output of gas engine generator.
Digester temperature	Temperature of digestion chamber.
Power flow at PCC	Real time power flow at PCC (Point of Common Coupling).
Charge/discharge power	Real time charge/discharge power of battery.
Dispatch command	Dispatch command value for gas engine and wood chip boiler.
Charge/discharge power dispatch command	Charge/discharge power dispatch command for battery.
PQV of each phase	Real time P, Q and V of each phase at PCC and CB1.
LFC command	LFC command value for gas engine generator.

Information Object Name	Information Object Description
Charge/discharge LFC command	Charge/discharge LFC command value for battery.
I_2 dispatch command	Dispatch command to compensate negative phase sequence current.

1.7 Activities/Services

Activity/Service Name	Activities/Services Provided
Electricity & Heat demand forecast	Forecast electricity and heat demand at 30 min. interval for a week
Supply plan	Supply plan developed by EMS for gas engine generator, wood chip boiler, digestion gas boiler and battery
PV & WT output forecast	PV & WT output forecast based on weekly weather forecast and past output records data

1.8 Contracts/Regulations

Contract/Regulation	Impact of Contract/Regulation on Function
N/A	

Policy	From Actor	May	Shall Not	Shall	Description (verb)	To Actor
N/A						

Constraint	Type	Description	Applies to
N/A			

2 Step by Step Analysis of Function

2.1 Steps to implement function – Energy management of grid-connected microgrid

2.1.1 Preconditions and Assumptions

Actor/System/Information/Contract	***Preconditions or Assumptions***
Microgrid Equipment Data(e.g. Capacity, Range)	Equipment data (e.g. Capacity, Range) have already been determined in database or by manual entry.
Optimization mode	Optimization mode can be selected from minimization of CO2 emission or minimization of cost. The mode is selected by the operator in advance.
Purchasing power	Purchasing power from distribution grid is basically constant. In case constant purchasing power is not achieved by the shortage of digestion gas, it can be changed up to two times a day (ordinary at the morning and the evening).

2.1.2 Steps

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes
1.1	By 23:00 of the previous day	EMS	Execute scheduling command	EMS starts development of Supply Plan.	EMS	EMS	Scheduling command	
1.2A		EMS	Acquisition of weekly weather forecast information	EMS acquires weekly weather forecast information.	Weather forecast SP's server	EMS	Weekly weather forecast information	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes
1.2B		EMS	Acquisition of past demand and output records data	EMS acquires past demand (electricity, heat) and output (PV, WT) records data.	EMS	EMS	Past demand & output records data	
1.3A		EMS	Electricity & heat demand forecast	EMS forecasts electricity & heat demand based on weekly weather forecast and past electricity & heat demand records data.	EMS	EMS	Electricity & heat demand forecast	
1.3B		EMS	PV & WT output forecast	EMS forecasts PV & WT output based on weekly weather forecast and past output records data.	EMS	EMS	PV & WT output forecast	
1.4A		EMS	Acquisition of remaining fuel level	EMS acquires remaining amount of digestion gas and wood chips.	RTUs Boiler_RTU	EMS	Remaining level of digestion gas Remaining amount of wood chips	
1.4B		EMS	Acquisition of SOC	EMS acquires SOC of battery.	BATTERY & PCS	EMS	SOC	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes
1.5		EMS	Development of supply plan	EMS develops supply plan based on electricity & heat demand forecast, remaining fuel level and SOC of battery.	EMS	EMS	Supply plan	Plan at 30-min. interval for a week.
2.1	0:00 on the day	EMS	Optimum scheduling command	EMS commands optimum scheduling.	EMS	EMS	Optimum scheduling command	
2.2A	On-going monitoring data by EMS	EMS	Acquisition of power demand of load	EMS acquires power demand of load.	RTUs	EMS	Power demand of load	
2.2B	On-going monitoring data by EMS	EMS	Acquisition of PV output	EMS acquires PV output.	PV & PCS	EMS	PV output	
2.2C	On-going monitoring data by EMS	EMS	Acquisition of WT output	EMS acquires WT output.	RTUs	EMS	WT output	
2.2D	On-going monitoring data by EMS	EMS	Acquisition of gas engine output	EMS acquires gas engine output.	GasE_RTU	EMS	Gas engine output	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes
2.2E	On-going monitoring data by EMS	EMS	Acquisition of remaining fuel level	EMS acquires remaining amount of digestion gas and wood chips.	RTUs Boiler_RTU	EMS	Remaining level of digestion gas Remaining amount of wood chips	
2.2F	On-going monitoring data by EMS	EMS	Acquisition of digester temperature	EMS acquires digester temperature.	RTUs	EMS	Digester temperature	
2.2G	On-going monitoring data by EMS	EMS	Acquisition of power flow at PCC	EMS acquires power flow at PCC.	PCC_RTU	EMS	Power flow at PCC	
2.2H	On-going monitoring data by EMS	EMS	Acquisition of charge / discharge power	EMS acquires charge / discharge power of battery.	BATTERY & PCS	EMS	Charge /discharge power	
2.2I	On-going monitoring data by EMS	EMS	Acquisition of SOC of battery	EMS acquires SOC of battery.	BATTERY & PCS	EMS	SOC	
2.3	Once every 3 minutes	EMS	Dispatch command Charge / discharge power dispatch command	EMS provides command for supply plan; dispatch command for gas engine and wood chip boiler; and charge / discharge power dispatch command.	EMS	Gas E Wooden Boiler BATTERY & PCS	Dispatch command Charge / discharge power dispatch command	at 3-min. intervals for two hours

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes
3.1	On-going monitoring data by EMS	EMS	Acquisition of power flow at PCC	EMS acquires power flow at PCC.	PCC_RTU	EMS	Power flow at PCC.	
3.2	Once every 1 seconds	EMS	LFC command	EMS provides gas engine with LFC command and battery with charge / discharge LFC command so that the power flow at the PCC conforms to the purchasing power determined in the supply plan (Stage 1).	EMS	Gas E BATTERY & PCS	LFC command Charge / discharge LFC command	
4.1	On-going monitoring data by EMS	EMS	Acquisition of Active power (P), Reactive power(Q), Voltage(V) of each phase	EMS acquires P, Q and V of each phase in PCC_RTU and MainPlant_RTU.	PCC_RTU MainPlant_RTU	EMS	PQV of each phase	
4.2		EMS	I_2 dispatch command	EMS calculates negative phase sequence current (amplitude, phase) and provides PV & PCS with I_2 dispatch command.	EMS	PV & PCS	I_2 dispatch command	

2.1.3 Post-conditions and Significant Results

Actor/Activity	*Post-conditions Description and Results*
Power flow at PCC	Keeps the 6-min. (360 sec.) moving average error between the amount of purchasing power planned on the previous day and the actual output at the PCC within 3% of electricity demand for each instant of time.
Negative phase sequence current at PCC	Negative phase sequence current at PCC is partially suppressed.

2.2 Architectural Issues in Interactions

FUTURE USE

2.3 Diagram

FUTURE USE

3 Auxiliary Issues

3.1 References and contact

ID	Title or contact	Reference or contact information
[1]	Regional Power Grid with Renewable Energy Resources: A Demonstrative Project in Hachinohe	CIGRE 2006 Paris Session
[2]	Structures of small power supply networks and a practical example with renewable energy resources	IEEE Power Engineering Society General Meeting, 2007
[3]	Operational Analysis of a Microgrid: The Hachinohe Demonstration Project	CIGRE 2008 Paris Session

3.2 Action Item List

ID	Description	Status
[1]		
[2]		

3.3 Revision History

No	Date	Author	Description
0.0	Aug 26 2011	H.Tanaka H.Iwasaki H.Maejima	Draft for Review 1
1.0	Oct 16 2011	J.Reilly	Draft for Review 2
2.0	Dec 22 2011	Y.Kojima M.Watanabe H.Tanaka H.Iwasaki H.Maejima J.Reilly	Final Draft