Resilient Hybrid Technology for High-Value Microgrid (RHYTHM) Project

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RHYTHM Project Overview

Project Budget
2.2 million USD (Government 1.8M, Private 0.3M)
£ 998,307 UK (Government)

Project Period
2016.03.01 – 2019.02.28 (3 years)

Team
Korea side: 7 Institutes; UK Side: 2 Institutes

Project Goal
Development of strategies for improving the resilience of AC-DC hybrid microgrids

* RHYTHM: Resilient Hybrid Technology for High-value Microgrids
RHYTHM Project Overview

Research Team

Project Head
Incheon Nat’l Univ.
Prof. Hak-Man Kim

Project Head
Imperial College
London
Prof. Tim C. Green

Industries: 2, Universities: 4,
National Research Institute: 1

Universities: 2
RHYTHM Project Overview
Developed Core Technologies

01 Development of EMS algorithm for resilient operation of hybrid microgrids

02 Design of Interlinking converter considering resiliency of hybrid microgrids

03 Development of control strategy for stability in islanded mode operation

04 Design of reliable and low latency communication system for real-time communication

05 Design of hybrid AC and DC microgrid for improving resiliency and engineering tools
RHYTHM Project Overview
Work Packages and Respective Tasks

**WP1** EMS
Development and testing of operation algorithm for resilience enhancement of AC DC hybrid microgrid.

**WP2** Interlinking Converter
Development of multi-level converter considering redundancy, real-time communication, fault protection, etc.

**WP3** Safety Enhancement Control
Design of control schemes for enhancing safety, seamless control, and stability enhancement during islanded operation.

**WP4** Design and Business Model
Optimal design of software tool for analysis and business model proposition along with evaluation.

**WP5** Pilot Plant Testing
Testing of the developed operation/control strategies in pilot plant having 200kW AC microgrid and 200kW DC microgrid.
RHYTHM Project Overview
EMS Core Tasks and Testbed

Core Tasks

- To develop resilient EMS algorithm (by Incheon Nat’l Univ.)
- To develop detail BESS model with BEMS model for EMS (by Incheon Nat’l Univ. and Univ. of Oxford)
- To design and develop prototype EMS (by KERI)
- To develop Testbed (by KERI)
- To test performance (by KERI and Incheon Nat’l Univ.)

Configuration

- 100kVA DC MG
- 200kVA AC MG
- 100kVA ILC
Resilient Operation
Challenges and Potential Solutions

- **Resilient Operation**: The objective is to minimize the load shedding amount and to maximize survivability during events.

- **Before the Event**: Prepare the microgrid to minimize the load shedding during events.

- **During the event**: Maximize the survivability of loads, especially critical loads.

### Challenges in resilient operation

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<tr>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>Event Time</td>
<td>Resources</td>
<td>Duration</td>
</tr>
<tr>
<td>Event occurrence time is not known precisely</td>
<td>Limited resources are available during the event</td>
<td>Event duration is not known precisely</td>
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Resilient Operation
Preparation Phase [Readiness for Potential Events]

Normal operation (without considering resiliency)

Estimate the event occurrence time

Event occurrence Possible?

- Yes
- No

Activate proactive-operation: Maintain SoC of batteries to utilize during event
Resilient Operation
Proactive Operation Results

Without Resilience Algorithm

SoC is reduced to Min. level for increasing operation profit
Objective is Cost minimization

With Resilience Algorithm

SoC is maintained to enhance the survivability during events
Objective is Reliability maximization

Due to higher renewables, SoC is reduced to Min. Level
Other intervals maintain SoC
Resilient Operation
Survivability Enhancement Scheme [Emergency Operation]

The objective is to maximize the survivability of critical loads during the event time

- **Define Priorities for Load**, available resource may not be sufficient to fulfil all the loads during the event period

- **Maintain SoC**: to survive critical loads, event duration is not accurately known and renewables are uncertain.

- **Shift Load-Shedding Towards End**: The event duration is not know, shifting load shedding towards end can potentially avoid unnecessary load shedding.
Resilient Operation
Survivability Enhancement Results

Without Resilient Algorithm
Load shedding is carried-out randomly, decided by the optimization algorithm.

With Resilient Algorithm
Load shedding is shifted towards the end of the scheduling horizon.
This can avoid unnecessary load shedding, if event is cleared earlier.
Incorporation of BESS Model in EMS

Limitations of BESS Model In EMS

- The resiliency depends on amount of energy available in the batteries but incorrect estimation of SoC can reduce the resilience
- Generally, battery model in EMS is simplified and it results in SoC mismatch

**Factors causing SoC mismatch**

- The operation interval of EMS is in minutes or hours but the SoC of batteries changes more frequently
- Linearized charging/discharging efficiencies are utilized in EMS but efficiencies changes non-linearly in batteries
- Internal resistance is ignored in EMS but it influences the SoC and varies with the life of BESS

* EMS: Energy Management System; BEMS: Battery Energy Management System*
Incorporation of BESS Model in EMS

Incorporation Method

Challenging to operate both models together due to difference in model fidelity and utilization of different quantiles for SoC computation

- EMS runs optimization and sends charging/discharging profiles to battery model
- Battery model estimates SoC and send the SoC profile to EMS (every operation intervals)
- EMS checks the error and optimizes if the error is big enough
The proposed SoC converges to the SoC of battery (real SoC), thus resiliency will not be compromised.

There is discrepancy between the battery SoC and the SoC of EMS.
RHYTHM Project Overview
Core Control Tasks & Testbed

Core Tasks

- To develop AC control algorithm to improve resilience (by Chungbuk Nat’l Univ.)
- To develop DC control algorithm to improve resilience (by Hanyang Univ.)
- To develop ILC control algorithm to improve resilience (by Incheon Nat’l Univ.)
- To develop HILS-based Testbed (by Incheon Nat’l Univ.)
- To test performance (Korea team and Imperial College London)
Control Strategy for AC-DC Hybrid MG

System Configuration of HILS-based Testbed

Utility Grid 380 V
AC Bus
DC Bus

Static Switch Line simulator
AC Microgrid
DC Microgrid + Interlinking Converter

AC DGs
DG1
DG2
DG3

DG4
DG5
DG6

DC DGs

ILC

DC Bus
DC Load 1
DC Load 2
AC Bus
AC Load 1
AC Load 2
Control Strategy for AC-DC Hybrid MG
An Example of AC Microgrid Control

Test Results of Seamless Grid Synchronization

- Grid synchronization performance under grid synchronization mode (8 cycle)
- Mode transfer performance when mode changes from SBGC to GC mode (8 cycle)
- Mode transfer performance considering with the unintentional islanding (11 cycle)

PORELSLIDE18

- SBGC: Standby mode for grid connection
- GC: Grid connection
Control Strategy for AC-DC Hybrid MG
An Example of AC Microgrid Control

Test Results of Improving Stability by Virtual Impedance
- Compare Before applying VI and After applying VI

✓ Decrease of total harmonic distortion (THD) → Improving converter stability
Control Strategy for AC-DC Hybrid MG
ILC Test – Coordinated control of AC and DC microgrids using ILC

Initially, AC microgrid is operated on light load condition.
The shared power among AC and DC microgrids is calculated by primary control of ILC. But, it causes steady-state errors in AC and DC microgrids.

Initially, DC microgrid is operated on heavy load condition.
After applying the secondary controller, the frequency and voltage are settled at 60Hz and 380V.

<AC Microgrid>  <Interlinking Converter>  <DC Microgrid>
Collaborative Activities
RHYTHM Workshops in Korea and UK

May-2017
Incheon National University, Korea

July 2016
Imperial College London, UK

May 2018
KERI, Changwon, Korea

July 2017
Oxford University, UK
Collaborative Activities
Visiting & Exchanging Researchers
Conclusions

Project Overview
An overview of the project including budget, research team, and goals are presented.

Resilient Control
Hybrid AC-DC MG control schemes developed are summarized.

Resilient Operation
Resilient EMS algorithm and impact of high fidelity battery model are analyzed.

Research Collaboration and Outcomes
Research exchanges and outcomes of the project are summarized.
Published Journal Papers (Reference)


Thank you for your attention

Questions...?