Planning Optimization Platform for Cluster Type Micro-grid Installations and Operations

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***Abstract*—This paper proposes an architecture for a planning optimization platform called the Grid of Grids Optimal Designer (GGOD) to facilitate the optimization of cluster type micro-grid installation and operation. Micro-grid clusters are groups of micro-grids with renewable energy that operate autonomously without power supply from main grids. The GGOD simulates micro-grid optimizations based on a service-oriented architecture and comprises three layers, i.e., end user, service broker, and service supply layers. The end-user layer corresponds to the client system, and the GGOD corresponds to the service broker and service supply layers. The service broker layer is for service management, and the service supply layer comprises various optimization components. Combinable optimization components are activated based on request text in extensible markup language format from end users. By combining optimization components, different optimizations are executed for a single request, the results of the same type of optimization methods are compared, and sudden operation environment changes are considered. Geospatial integrated resource planning and micro-grid facility planning are demonstrated as examples of GGOD applications.**

Keywords—optimization, simulation platform, planning, cluster type micro-grid, service-oriented architecture

I. Introduction

The United Nations has suggested sustainable development goals [1]. Electricity supply is important for sustainable development. However, in several regions of the world, electric power is not supplied, and when a serious disaster occurs, such as a flood, the main power grid can be damaged, which can have a considerable and prolonged impact on large areas. Thus, micro-grids [2], which supply powers by inside co-generators, are expected to act as a new power infrastructure. Autonomous micro-grids [3] are important because they can realize local power generation for local consumption. Such micro-grids are not dependent on the power supply from the main grids and take advantage of renewable power, such as wind and small/micro-hydroelectric power, to ensure the requisite power supply. Moreover, by connecting micro-grids in a power transmission network, micro-grids with surplus power can transfer it to a micro-grid with a shortage. Thus, micro-grids are mutually beneficial and communities become more sustainable.

However, the installation and operation of micro-grid facilities incur huge costs. Thus, optimal planning to minimize installation and operation costs and maximize availability is necessary. In this regard, optimization simulations would be effective. To date, many types of optimization simulation software have been developed, e.g., the Hybrid Optimization Models for Multiple Energy Resources (HOMER) [4] and the Wien Automatic System Planning Package (WASP) [5]. HOMER is a powerful tool for micro-grid cost optimization, including co-generation sources and renewable energy. WASP is a simulation tool to identify optimal power generation plans. Unfortunately, these simulators have some restrictions. For example, HOMER calculates minimized installation and operation costs considering the long-term operation and budget recovery. However, facility specification parameters should be fixed in advance. Therefore, HOMER does not output the best facility specifications. For this purpose, users prepare all specification parameters, input one of multiple parameters manually, and continue the simulation to obtain the minimum cost iteratively.

Thus, a simulation platform is required to address these issues. Herein, the Grid of Grids Optimal Designer (GGOD) simulation platform is proposed. GGOD is a platform to activate optimization/analysis components and control optimization processes as software services. This paper explains GGOD's architecture, and geospatial integrated resource planning (GIRP) and micro-grid facility planning are demonstrated as example applications of the proposed architecture.

II. Micro-grid Clusters

In this section, the concept and characteristics of autonomous cluster type micro-grids are discussed.

A. Concept and Characteristics of Cluster Type Micro-grids

Cluster type micro-grids are a group of micro-grids with an internal power supply. Each micro-grid corresponds to a power community, and, by connecting such micro-grids, cluster type micro-grids can be configured. The micro-grid cluster concept is shown in Fig. 1.

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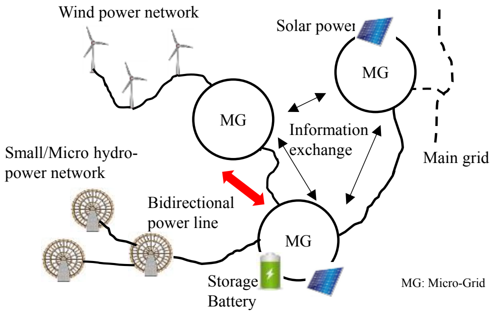

Fig. 1. Expandable micro-grid cluster

The characteristics of MGC are described as follows.

- Autonomous operation: Each micro-grid involves power supply and consumption. Owing to this structure, even if a serious disaster occurs, such as an earthquake, and power supply from the main grid is interrupted, autonomous and sustainable operations can be maintained.
- Renewable energy: The power required by a community is generated by co-generation and renewable power systems. Renewable power is feasible since power generation cost is ignored and environmental preservation is achieved.
- Power transfer among micro-grids: Information about power generation and consumption are exchanged among micro-grids. Then, surplus power in micro-grids is transferred to micro-grids experiencing power shortages. As a result, power supply and consumption can be balanced among multiple micro-grids.

B. *Types of Micro-grid Clusters*

Relative to micro-grid structure, there are two types of cluster type micro-grids. One is a connected group of micro-grids, where each micro-grid corresponds to a single community. For each micro-grid, power consumption and supply can be optimized via power transfer because micro-grids are connected and networked by bidirectional power transmission.

In addition, renewable power sources can be networked to form a cluster. For example, in a micro-hydroelectric power case, each micro-hydroelectric power source may generate 2-3 kW; however, by networking such sites, the total power would become 20-30 kW by connecting ten sites. When power transmission networks are dedicated in cluster, a new transmission facility should be constructed within an acceptable budget. For a cluster type micro-grid, planning optimization is inevitable. Thus, we proposed the GGOD simulation platform to realize effective planning optimization.

III. GGOD Architecture

In this section, the characteristics and architecture of GGOD are explained.

A. *GGOD Characteristics*

The characteristics of the GGOD are described as follows.

- Planning optimization platform
- Use of geospatial data
- Implementation of micro-grid researchers and engineers

1) Planning optimization platform: Various and core optimization/analysis tools are stored in a GGOD's tool storage. These tools are activated by the manager function. Note that the same kind of optimization tools can be stored in the repository.

2) Use of geospatial data: Three dimensional (3D) or 3D plus time change (4D) geospatial data (terrain, metrological conditions, construction prohibition data, etc.) are used to plan micro-grid installations considering real conditions. This corresponds to the geospatial planning in an IRENA report [6].

3) Implementation of micro-grid research and engineering knowledge: Knowledge of researchers and engineers with micro-grid development experience is implemented as optimization and analysis components. These components may be dependent on the different conditions of different countries. Thus, same types of components are stored and used in GGOD for each country.

B. *GGOD Architecture*

The architecture of GGOD is shown in Fig. 2.

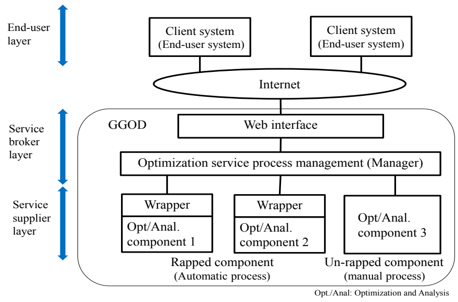

Fig. 2. GGOD architecture

The GGOD is based on a service-oriented architecture (SOA) [7]. A SOA is a software architecture in which application functions are managed as services, and these services are initiated after receiving an input data. Input data are prepared and passed by end users. GGOD supports flexible activation orders, e.g., both sequential and branch and loop orders are supported (processing orders are discussed in Section IV-C0). Thus, an optimization SOA (OSOA) is realized.

The OSOA comprises three layers, i.e., the end-user, service broker, and service supply layers. GGOD corresponds to the service broker and service supply layers, which are described in the following.

- End-user Layer: End users are client systems. A client submits a request to the manager function in the service broker layer. Note that client systems only receive optimization results.
- Service Broker Layer: The service broker layer comprises a web interface function and an optimization service process management function (referred to as the "manager"). The web interface function provides extensible markup language (XML) interfaces, such as metadata viewers, XML settings, and parsing. Note that the output data are returned in XML format. The manager is a service bus (SB)

function, wherein the SB analyzes the XML request from an end user, divides a request into individual optimization identification numbers, and determines the activation order of components in the service supply layer.

- Service Supply Layer: The service supply layer comprises optimization and analysis components. These components can be allocated in a distributed computation environment. The wrappers in Fig. 2 are access interfaces, such as data conversion. Components without wrappers are manual operation of package software.

When an end user sends an optimization processing request to the service broker layer, the SB analyzes the request and determines the activation order of components in the service supply layer. Then, the optimization results are obtained and returned to SB. When all service components are complete, the results are then returned to the end user. Table 1 shows examples of optimization and analysis components.

TABLE I. OPTIMIZATION COMPONENT EXAMPLES

Component		**Content**
Type	**Item**	
Optimization	Facility installation and operation	Cost minimization of micro-grid facilities (including renewable power)
	Renewable generation site selection	Grouping of renewable sites based on portfolio theory
	Transmission network generation	Transmission network generation based on minimization of construction cost
	Economical estimation	Economy based transmission expansion analysis
Analysis	Combinatorics	Shortest route finding, Minimum spanning tree
	Power flow	Stochastic power flow calculation
	Impact analysis	Assessment of environmental and social impacts

IV. PROCESSING IN GGOD

The optimization processing algorithm used in the GGOD platform is described in this section. GGOD employs data-driven activation of components in the service supply layer. GGOD includes the metadata store called clearing house. Component names, specifications of input data, and output data are written in the metadata. End users select metadata which corresponds to components end user wants to execute and submit requests. The manager function analyzes end-user requests, determines optimization processing, activates components, and sends input data to optimization and analysis components. The end users identify necessary components according to an objective description in the metadata.

A. Data-driven Activation of Optimization Components

Optimization processing is data driven, which means that the end-user sends requests with input data to GGOD, the optimizations are processed by GGOD, and only the results are returned to the end-user.

The optimization process is shown in Fig. 3.

Step 1: Service catalog

End users access a component catalog in the clearing house of the web interface function to select appropriate optimization components or processes.

Step 2: Service request

End users submit a request (XML format) to the SB function in GGOD.

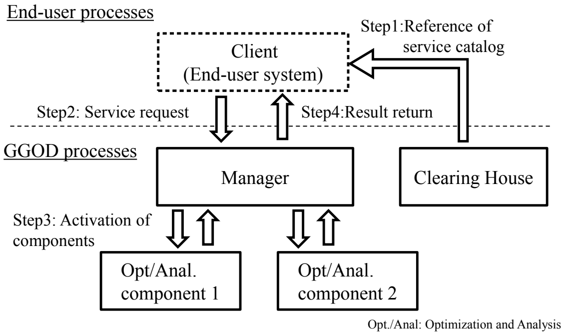

Fig. 3. Request and processing flows in GGOD

Step 3: Component activation

The SB function analyzes the request and creates the optimization order list. Then, components in service supply layer are activated by the SB function.

Step 4: Return results

The optimization results are stored and managed by the manager functions. After optimization processing, the results are returned to the end user.

B. Metadata and Clearing House

When GGOD is used by end users, all component specifications must be shown. Here, GGOD provides end users with metadata about the optimization and analysis components. The metadata includes descriptions of the processing content and the input and output data specifications. The metadata is written based on XML, which is a standard web service format for representing message and data. Note that XML is formatted using start and end tags. The following shows an example description of the optimization name.

<Name> Transmission_expansion </Name>

Here, <Name> is the start tag, “Transmission_expansion” is a concrete name, and </Name> is the end tag. XML is employed in GGOD because it enables flexible representations of practically any item.

GGOD also supports processing of metadata that describe combinations of components. A combination of optimizations provides results for a sequence of optimizations. Note that metadata describing a single component are referred to as single service metadata. A combination of components is referred to as combined service metadata. Single service metadata include the following elements.

- Component name: The component name is a unique identifier for each optimization.
- Explanation of optimization: The name, goal, and details of optimization processing are described in sentences. This allows end users to evaluate and select appropriate optimizations.
- Input data specifications: For the input data, the meaning of the data, the variable type, and the data range are described.
- Output data specifications: For the output data, the meaning of the data, the data type, and the output order of the iterative results are described.

All metadata are managed in the clearing house database. End users access the clearing house and select optimization components in GGOD by reviewing a component's metadata. In addition, end users can edit available combined service metadata and register these edits in the clearing house. The concept of the clearing house database is shown Fig. 4. Example metadata for a single optimization and a combined optimization are shown in Fig. 5.

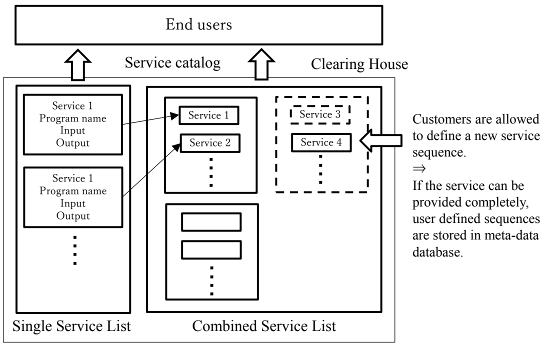

Fig. 4. Clearing house for optimization service

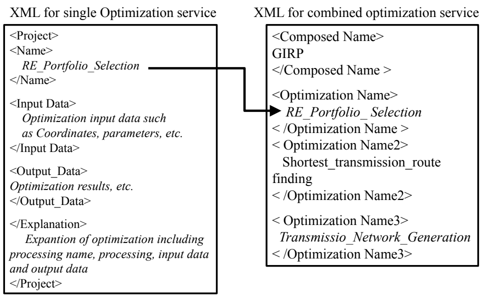

Fig. 5. XML texts of metadata for optimization

C. Optimization Process

The metadata determine the optimization process flow. Three types of unit optimization flow are supported by GGOD, as shown in Fig. 6.

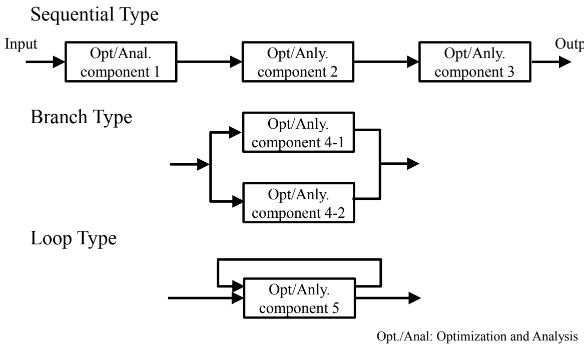

Fig. 6. Optimization flow diagram

- Sequential type: Here, the optimization is executed in sequence. This is explained in section *A.*, in V using GIRP as an example. In GIRP, renewable energy site selection, shortest transmission route finding, and transmission network generation are processed sequentially.
- Branch type: Here, part of the optimization processing is branched. This flow is primary used to compare multiple optimization algorithms. For example, processing time and accuracy using two meta-heuristic optimization methods, such as a genetic algorithm and an artificial immune system, are executed in a branched manner and then compared.
- Loop type: When multiple input data are prepared, optimization is executed using each input data in sequence. An example is given in the section *B., in* V. When micro-grid facility planning is executed, the end user would prepare some facility specifications, such as solar panel and storage battery specifications. GGOD optimizes the installation and operation cost of each specification in sequence with the support of HOMER to finds an optimal facility combination by comparing all results.

V. IMPLEMENTATION EXAMPLE

In this section, two applications of GGOD, i.e., GIRP and micro-grid facility planning, are discussed.

A. GIRP

GIRP is facility planning tool for transmission expansion and introducing renewable power.

GIRP comprises three optimization components, i.e., renewable energy portfolio selection, shortest transmission route finding, and construction cost optimization. The optimization process in GIRP is shown in Fig. 7.

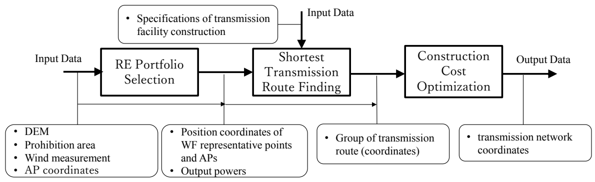

Fig. 7. GIRP optimization process

1) RE portfolio selection: Feasible wind farm areas are selected based on portfolio selection in modern economy theory [8]. In power generation planning, risks in portfolio theory correspond to power generation uncertainty, and returns correspond to the high average value of collected powers.

Initially, wind velocities and directions are collected by the Japan metrological agency. Commercial topography data, i.e., digital elevation model (DEM) data, are obtained from Geospatial Information Authority of Japan, and wind farm (WF) prohibition area data, are obtained from the Ministry of the Environment, Japan. Feasible wind power generation area candidates are selected as groups of topographical meshes in consideration of prohibition areas and sufficient wind speed. Then, the mesh with the strongest wind speed attribute is retrieved.

Next, neighboring meshes are aggregated to obtain low variances of total power generations. High average wind power generation areas are selected using a one-by-one confirmation method [9]. Mesh aggregations are iterated until the upper limit of the total power generation is reached. After obtaining groups of low variance and high wind power generation meshes as feasible power generation areas, a representative point in each area is selected to connect generation areas by transmission line figure. Through extensive experiments, a representative point in each area that is nearest to an access point (AP) is considered feasible because the construction cost of a transmission network among representative points and APs is minimized. Here, input data include the following.

- DEM (height of ground)
- Prohibition area data (nature preservation area)
- Wind measurement data (speed and direction)
- AP coordinates

The output data include the following.

- Coordinates of WF representative points
- Output power from selected WF nodes

For hydro power generation, a different method is introduced in [10]

2) Shortest transmission route finding (STRF): The Dijkstra algorithm [11] is used for shortest transmission route finding. This algorithm can be processed on the DEM. Here, the objective functions are the transmission line construction costs, which are affected by terrain conditions and land coverage. The attributes of prohibition areas are stored as attributes of DEM Thus, STRF finds minimum construction cost routes among WFs and APs. The input data include the following.

- DEM geospatial data
- Prohibition area data (nature preservation area)
- Position coordinates of WF and AP nodes
- Specifications of transmission facility construction

The output data include the following.

- Coordinates of shortest routes between two WF nodes and between a WF node and an AP node

3) Transmission network generation: The final component is networking among WFs and the connections to APs and demand areas [12, 13]. All transmission routes among WFs and APs are generated in the STRF process). Therefore, optimal networks with minimized construction cost without looped routes and overloads are selected. There is a limit of wind power introduction. Therefore, only some WF areas are selected. Then, because the number of WFs is greater than 100, the number of WF selection patterns is 2^{100}. As a result, evaluating the cost of all combinations of WFs and APs is impossible. There, a meta-heuristic method, i.e., a genetic algorithm, is applied [13]. Here, the input data include the following.

- Coordinates of shortest routes between two WF nodes and between a WF node and an AP node
- Data for specifications of transmission facilities, such as power transmission capacities

The output data include the following.

- Coordinates of transmission networks

Input data and output data of first component becomes input data of second component. The input data of the third component is the output data of the second component and input data of the first component.

The results of the first and third components are shown in Figs. 8 and 9, respectively.

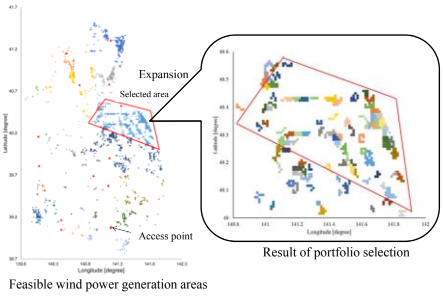

Fig. 8. Portfolio selection of wind power generation areas

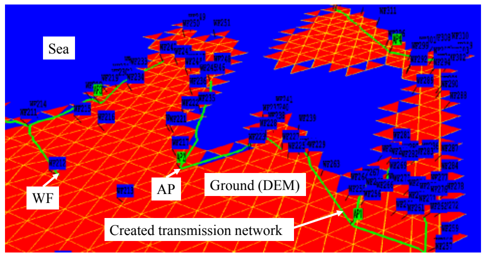

Fig. 9. Results of optimal transmission network selection

B. Facility Specification Optimization of Single Micro-grid

In this example, the optimization of micro-grid facility specifications for installation and operation is introduced. Here, HOMER is used for the optimization of the micro-grid. HOMER optimizes cost by fixing the facility specifications, such as power generation capacity and facility investment cost [14]. However, some users may want to determine the best facility specifications while minimizing costs. GGOD supports this optimization by combination with HOMER. Fig. 10 shows the optimization process, which is a loop flow (Fig. 6). In each loop, GGOD selects one facility specification and passes the specification data to the HOMER optimization components. Thus, once all results are analyzed, the end user can find optimal facility specifications.

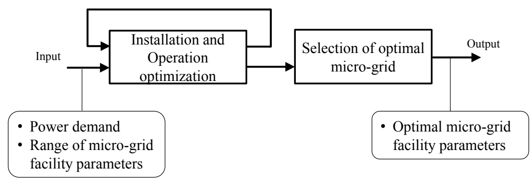

Fig.10 Optimization process in micro-grid facility planning

Fig. 11 shows a single result as an example. The two axes represent PV capacity and storage battery capacity. Here, the vertical axis is cost (represented as net present cost for facility installation and operation over 25 years). This micro-grid

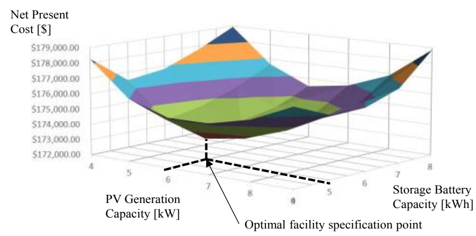

Fig. 11 Results of facility planning for single micro-grid

uses photovoltaic generation (PV) panels, storage batteries, and diesel power generators. Note that the main grid is not connected. The PV capacity takes values from 4 kW to 9 kW. The storage battery capacity takes values from 4 kWh to 8 kWh. The generation capacity of the diesel power generators is fixed at 10 kW. The power demand data is prepared every 15 min in one year and used repeatedly in every installation and operation optimization process. Thus, the minimum cost by the net present cost appears, which represent total costs of installations and future operations by the current rebate cost. Notably, HOMER calculates the optimal cost once all parameters are fixed, and GGOD activates the HOMER functions as a component repeatedly until optimal facility combinations are obtained.

VI. Discussion

SOA architecture is considered to optimize cluster type micro-grid installation and operation. The benefits of using GGOD are summarized as follows.

- Time reduction of optimization design: Development time for optimization processes can be reduced by using existing optimization/analysis components.
- Knowledge sharing: Optimization components are developed by researchers and engineers who assisted the development of GGOD. As a result, optimization knowledge can be shared by using components.
- Combined optimization: Combined optimizations are supported; thus, comparison and selections of the best solutions is realized. In addition, Optimization processes are represented by flexible processing in Fig. 6.
- GGOD is an evolving system based on storing components. The GGOD platform integrates a variety of knowledge from different sources.

VII. Conclusions

This paper has proposed the GGOD simulation platform to optimize micro-grid installation and operation. The proposed GGOD platform realized based on SOA. The characteristics of GGOD are as follows:

- Various optimizations are stored and available.
- Some optimizations can be executed on geospatial data which represents real conditions.
- Knowledges of micro-grid researchers and engineers are implemented as optimization/analysis components.

The proposed platform GGOD considers data-driven structures. Thus, it is easy for end users to use GGOD by sending requests written in XML texts.

Two examples of GGOD component are introduced. One is a GIRP, which is executed by sequential type optimization flow, and the other is a facility specification optimization of single micro-grid, which is executed by loop type optimization flow.

Future work includes the following.

- Expansion to distributed environment: Optimization components could be allocated across distributed servers In future, we plan to extend GGOD to a distributed environment.
- Planning integration: According to the IRENA report [6], cooperation between long-term planning which manages 20–40 year planning and short-term planning manages in few weeks to 1 year planning is important. We will plan to integrate these concepts into GGOD.

Acknowledgment

This research was supported by Japan Science and Technology Agency, the National Science and Technology Development Agency of Thailand, and the Department of Science and Technology of The Philippines as part of the e-ASIA Joint Research Program (e-Asia).

Moreover, we want to acknowledge Professor Hiroshi Takamori of Waseda University, Dr. Jassada Kudtongngam, and Mr. Unpong Supakchukul of NECTEC for their fruitful discussion on GGOD concepts.

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