Proceedings of the Pakistan Academy of Sciences:
A. Physical and Computational Sciences: 58(S): 101-107 (2021)

ISSN (Print): 2518-4245; ISSN (Online): 2518-4253
http://doi.org/10.53560/PPASA(58-sp1)742

Pakistan Academy of Sciences

Research Article

Facility Planning Optimization Platform, GGOD, for Expandable Cluster-type Micro-grid Installations and Operations

Kazuaki Iwamura[1*], Yosuke Nakanishi[1], Udom Lewlomphaisarl[2], Noel Estoperez[3], and Abraham Lomi[4]

[1]Waseda University, Graduate School of Energy and Environment, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan
[2]National Advanced Automation and Electronics Research Unit, 112 Phahonyothin Road, Khlong Nueng, Khlong Luang District, Pathumthani 12120, Thailand.
[3]Mindanao State University, Illigan Institute of Technology, Illigan City, Andres Bonifacio Ave, Iligan City, 9200 Lanao del Norte, Philippines
[4]Renewable Energy Research Center, National Institute of Technology Malang, Jl. Raya Karanglo, Km. 2, Malang 65143, Indonesia

Abstract: This paper describes the architecture and the utilization for a facility planning optimization platform called GGOD, "Grid of Grids Optimal Designer" and applies it to expandable cluster-type micro-grid installations and operations. The expandable cluster-type micro-grid is defined as a group of micro-grids that are connected by bi-directional power transfer networks. Furthermore, power sources are also networked. Especially, by networking among power sources, powers necessary for social activities in-demand areas are secured. The proposed architecture is based on service-oriented architecture, meaning that optimization functions are executed as services. For flexibility, these services are executed by requests based on extensible mark-up language texts. The available optimizations are written in meta-data, which are accessible to end-users from the meta-data database system called clearinghouse. The meta-data are of two types, one for single optimization and the other for combined optimization. The processes in GGOD are conducted by the management function which interprets descriptions in meta-data. In meta-data, the names of optimization functions and activation orders are written. The basic executions follow sequential, branch, or loop flow processes, which execute combined optimizations, compare more than two kinds of optimization processes, and perform iterative simulations, respectively. As an application of the proposed architecture, the power generation sites and transmission networks are optimized in a geospatial integrated-resource planning scenario. In this application, a structure and a method for the combination of component functions in GGOD are exemplified. Moreover, GGOD suggests promotions of a lot of applications by effective combinations of basic optimization functions.

Keywords: Clearinghouse, Grid of Grids Optimal Designer, Power Generation Sites, Service-Oriented Architecture, Transmission Networks.

1. INTRODUCTION

A micro-grid is a feasible power supply system [1, 2] with sustainable power generation; accordingly, it has been introduced in many areas of the world. Moreover, new micro-grid concepts, the cluster-type micro-grids [3, 4], are expected to be introduced in non-electrified areas. Cluster-type micro-grids offer local power generation, resilient and sustainable operation using renewable powers, and power transfer with other micro-grids to balance power generations and consumptions over a large area.

However, reducing the installation and operation costs of micro-grids is imperative. This can be achieved by optimizing the installation and operation in simulations. Two well-known planning

Received: March 2021; Accepted: July 2021
*Corresponding Author: Kazuaki Iwamura <k-iwam315@ruri.waseda.jp>

optimization simulators are Hybrid Optimization Models for Multiple Energy Resources (HOMER) [5] and the Wien Automatic System Planning Package (WASP) [6].

HOMER, developed by National Renewable Energy Laboratory (NREL) in the USA, optimizes the installation and operation costs of various renewable power generators within a designated operation period. However, it does not optimize the facility specifications.

WASP considers the construction and operation costs in power-generation planning but ignores the construction costs of transmission networks that connect the power generating sites to the main grids or demand areas.

To resolve the above optimization problems, this study proposes a new planning optimization simulator called GGOD, "Grid of Grids Optimal Designer. GGOD is an evolving simulator, and the planning simulation platform and testbed have been developed in the current stage. This paper explains the GGOD architecture and presents an example of its application.

2. MATERIALS AND METHODS

2.1 Architecture of GGOD

The GGOD simulator is developed according to service-oriented architecture (SOA), which stores and executes the optimization functions as services. GGOD is incorporated into a total structure comprising three layers: the end-user layer, the service-manager layer, and the service execution layer. Figure 1 shows the architecture of GGOD. The functions of each layer are described below.

- *End-user layer:* The end-user layer represents the client systems, which send optimization requests to and receive optimization results from the service-manager layer.

- *Service manager layer(broker):* The service-manager layer includes web-adjusted interface functions and management functions. The web-adjusted interface functions comprise the clearinghouse function for storing meta-data, the data conversion function, and the acceptance-and-dispatch functions. The meta-data provided by the clearinghouse function explain optimization and analysis components to end-users. The data conversion function converts a request data sent by end-users to a command sequence of optimization and analysis. The acceptance-and-dispatch function receives requests from end-users and returns optimization results to requesting client systems (result dispatch). The manager function activates optimization and/or analysis components in the service execution layer, and monitors and manages the progress of the optimization processes.

- *Service execution layer(supplier).* The service execution layer contains optimization and/or analysis components, which are registered in a database called a repository. There are two types of components: wrapped functions for automatic execution, and non-wrapped functions that enable the use of commercial software packages by manual operation. Examples of optimization and analysis components are shown in Table 1. As GGOD is an evolving system, the registration of new components enables the execution of new optimizations and analyses.

Table 1. Examples of components

Component		
Classification	**Component name**	**Content of functions**
Optimization	Facility installation and operation	Introduction cost minimization for micro-grid power facilities
	Renewable power generation site selection	Clustering of renewable sites based on geographical portfolio theory
	Transmission network generation	Transmission network generation based on cost minimization of facility construction
	Economical estimation	Techno-economical transmission expansion analysis
Analysis	Combinatorics	Shortest path finding, Minimum spanning tree search
	Power flow analysis	Stochastic power flow analysis
	Impact analysis	Impact assessment on the environment and social activities

2.2 Optimization Method and Process in GGOD

Optimizations and analyses in GGOD are executed by two processing flows, the meta-data reference, and the optimization. The optimization execution is shown in Figure 2.

2.2.1 Meta-data based method for optimizations process

The clearinghouse function in the web-adjusted interface provides the meta-data for optimization and analysis to end-users. The meta-data explain the optimization/analysis processing and indicate the input and output data specifications. Optimization component suppliers register the optimization/analysis components into the repository and the meta-data into the meta-database. The end-users confirm the meta-data and decide optimization processes to be executed.

Meta-data are written in the extensible mark-up language (XML) format. XML data are expressed by a start-tag (<*>), the contents, and an end-tag (</*>), for instance, <Name> Content </Name>. Meta-data of single components differ from those of combinations of more than two single components. Meta-data for single components give the name of optimization, the explanation of optimization processing, and the input and output data forms and specifications. The meta-data of combined components provide the names of the single components and their execution order. Multiple optimizations can be ordered in three basic ways (Figure 3): sequential process type for executing the multiple optimizations in series, branch process type for performance comparisons of more than two types of optimization components, and loop process type for iterative executions.

2.2.2 Optimization process

The optimization service starts when a request arrives from the acceptance-and-dispatch function in the web-adjusted interface. The management

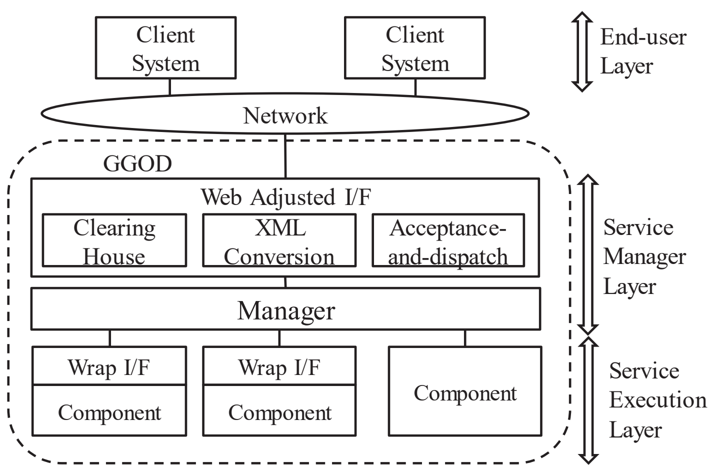

Fig. 1. Optimization process in GGOD.

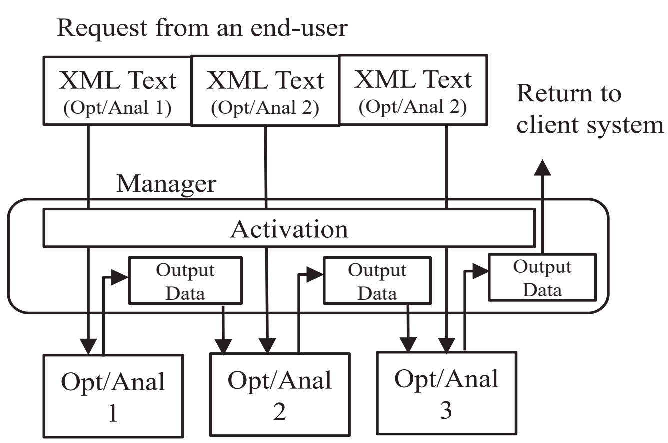

Fig. 2. Optimization process in GGOD.

function analyzes the request texts, converts the single optimizations into a group of requests, and determines the optimization processing order, thereby monitoring and managing the optimization processes. After the optimization process, the output of processing results is temporarily stored in the memory for use by the subsequent optimization/ analysis components.

3. RESULTS

GGOD optimization is applied to geospatial integrated-resource planning (GIRP), a facility installation planning of renewable power generation clusters and power transmission networks that transfer renewable powers to the access points (APs) of main grids or demand areas. The GIRP planning corresponds to geospatial planning in the International Renewable Energy Agency report [7]. The objectives of GIRP are (i) optimizing the selection of renewable power generation sites to minimize the total variance of generated powers, and (ii) optimizing transmission routes to minimize the total construction cost. In the present application, the power is generated from winds. The optimization processing order, contents of input and output data are shown in Figure 4.

3.1 Renewable Power Selection

Wind power generation sites are obtained based on the modern portfolio selection theory in financial research [8]. First, feasible wind power generation areas are determined using three-dimensional geographic data (terrain data) and wind velocity data. Terrain geographic data are ground-height data that corresponds to a digital elevation model (DEM), which also provides mesh data. All meshes are regular squares and the height values are assigned at four corner points. The wind velocities are measured at observation stations. The velocities at the centers of all squares in the DEM mesh are calculated by interpolating at least four measured data.

Next, a mesh of the highest velocities is selected. Then, the neighboring meshes are gathered to minimize the fluctuation variance of power generations among the selected meshes. The selection processes are iterated [9] until the variances at the wind power generation areas and wind farm (WF) sites are minimized.

3.2 Shortest-Transmission Route-Finding

Step 1 of the proposed flow selects the wind power generation sites. The power transmission routes are then searched using the shortest-transmission route-finding algorithm in the DEM. This scheme applies the Dijkstra algorithm [10] to obtain the power transmission routes among the WFs searched in the renewable power selection, and the APs (i.e., the connection points in the existing transmission network or demand areas). Thus, all routes that combine the WFs and AP points are calculated.

3.3 Transmission Network Selection

The final optimization process is transmission network selection. All WF candidates are selected by renewable power selection, and all candidates of the transmission routes are searched by shortest-transmission route finding. The transmission networks without loops are then selected and connected to the APs or demand areas. The selection is constrained by insisting that the total power generation capacity of the WFs exceeds the target capacity. The objective is to select the transmission networks that minimize the total facility construction costs of both WFs and transmission network lines [11, 12].

The total number of selections of 100 WF sites is 2^{100}. As checking all selections is impractical, the appropriate WFs and their transmission networks are found by meta-heuristics based on the genetic algorithm. The genetic algorithm minimizes objective functions (of the construction costs in this example) by performing crossover, mutations, and selections to achieve its goal [10]. The final optimized selections of WFs and transmission network networks are shown in Figure 5.

The target value of total power selection is set to 2 GW previously. The main results by optimization are as follows.

- Selected total power capacity: 2.02 GW.
- The total length of transmission networks: 279.2 km

The target of the power selection is satisfied.

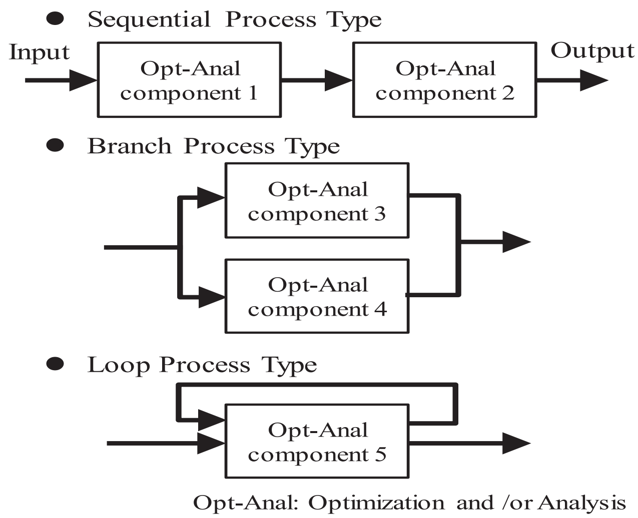

Fig. 3. Processing orders for basic optimizations in GGOD.

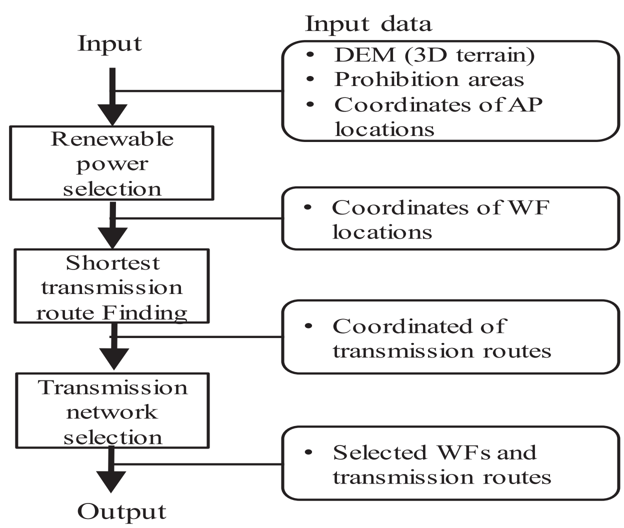

Fig. 4. The optimization process of GGOD.

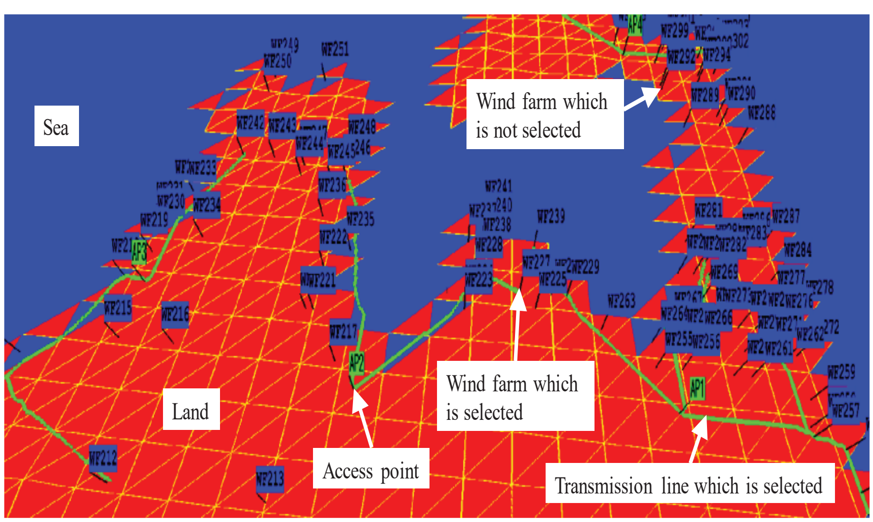

Fig. 5. Results of GIRP (Optimized selections of WFs and Transmission networks).

The total length changes according to the selection of power sites. In other power selection cases, the total lengths of transmission networks are more than 298.1 km. Thus the optimization is accomplished. Total processing time is optimization processing times. The time of processing management by GGOD is negligible.

4. DISCUSSION

The GGOD executed optimization processes based on meta-data interpretation. The important points are described below.

- Optimization processes are decomposed into basic functions, renewable power selection, shortest-transmission route finding, and transmission network selection. These functions can be developed separately and each function would be utilized in other applications. A combination of basic functions generates interesting results. By enriching basic functions, application fields would be expanded.
- The management function properly analyzes meta-data and activates optimization and analysis functions.
- Optimization and analysis functions are developed by a lot of researchers and engineers. The availability of these functions depends on meta-data description. Especially, accuracies for descriptions of input/ output data specifications are important.
- Geographical processing is an important characteristic of GGOD.

5. CONCLUSION

This paper introduced an SOA-based facility planning optimization platform called GGOD, a flexible optimization service that offers many kinds of optimization services. GGOD is composed of three layers: the end-user layer, the service manager layer, and the service execution layer. The end-user layer is composed of client systems, while the service manager and service execution layers are implemented in GGOD. The service manager layer is the broker function that activates and manages the optimization functions in the service execution layer. The service execution layer includes optimization and analysis tools.

The important characteristics of GGOD are listed below. (i) By registering various optimization and analysis components in GGOD, GGOD will become more available to many applications. (ii) The stored geospatial data enables analyses of real-world conditions. (iii) GGOD is an evolving system that registers and applies new optimization/ analysis components. These components are easily incorporated by updating the previous components and meta-data.

The optimization processing comprises meta-data selection and optimization steps. The meta-data is written in the XML format, which flexibly states the optimization name, an explanation of the optimization, and the specifications of the input and output data.

To demonstrate the usefulness of the platform, GGOD was applied to GIRP. The GIRP was executed by sequentially executing three optimization/ analysis components: renewable power selection, shortest-transmission route finding, and transmission network selection. The result shows that optimization is executed successfully. The processing capability and processing time depend on the effectiveness of optimization components.

In future work, the available optimization/ analysis components will be extended to distribute optimal components to various power researchers and engineers.

6. ACKNOWLEDGEMENTS

This research was supported by the Japan Science and Technology Agency, the National Science and Technology Development Agency of Thailand, the Department of Science and Technology of The Philippines, and RISTEK/BRIN (Ministry of Research and Technology/National Research and Innovation Agency) as part of the e-ASIA Joint Research Program (e-Asia) Grant Number JPMJSC17E1.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

8. REFERENCES

1. C. Schwaegerl, and L. Tao. The microgrids concept. In: *Microgrids: Architecture and control.* N. Hatziargyriou (Ed). Wiley, New Jersey, USA. p. 4–7 (2014). DOI: 10.1002/9781118720677.ch01
2. B. Novianto., K. Abdullah., A.S. Uyun., E. Yandri., N.S. Muhammad., H. Susanto., Z. Vincēviča-Gaile, R.H. Setyobudi, and Y. Nurdiansyah. Smart micro-grid performance using renewable energy. *E3S Web Conference* 188(00005): 1–11 (2020). DOI: 10.1051/e3sconf/202018800005
3. K. Iwamura., Y. Nakanishi., H. Takamori., U. Lewlomphaisarl., N. Estoperez, and A. Lomi. Optimal design suite for expandable micro-grid clusters. *7th International Conference on Renewable Energy Research and Applications,* Paris, France, 2018, p. 354–359 (2018). DOI: 10.1109/ICRERA.2018.8566707
4. S. Ahmad., M.H. Zafar., M. Ashraf., I. Khan, and F.Q. Khan. Energy-Efficient TDMA based Clustering Scheme for WSN. *Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences* 55 (3): 53–65 (2018)
5. Homer. *HOMER page website.* [Online] from https://www.homerenergy.com, (2019) [Accessed on July 27th, 2019].
6. WASP. *WASP page website*. [Online] from https://www.energyplan.eu. (2019) [Accessed on July 27th, 2019].
7. International Renewable Energy Agency. *Planning for the renewable future: Long-term modelling and tools to expand variable renewable power in emerging economies.* [Online] from https://www.irena.org/publications/2017/Jan/Planning-for-the-renewable-future-Long-term-modelling-and-tools-to-expand-variable-renewable-power. (2017) [Accessed on July 27th, 2019].
8. S.D. Stewart., C.D. Piros, J.C. Heisler. *Portfolio Management: Theory and Practice.* John Wiley & Sons, US (2019).
9. K. Nishiyama., K. Iwamura, and Y. Nakanishi. Optimized site selection for new wind farm installations based on portfolio theory and geographical information. *8th IEEE PES Innovative Smart Grid Technologies Conference North America* (Washington, USA, 2019). DOI: 10.1109/ISGT.2019.8791636
10. B. Korte, and J. Vygen. *Combinatorial Optimization, Theory and Algorithms.* Springer Nature, Switzerland AG. (2018).
11. B.R. Phillips, and R.S. Middleton, SimWIND: A geospatial infrastructure model for optimizing wind power generation and transmission. *Energy Policy* 43:291–302(2012). DOI: 10.1016/j.enpol.2012.01.006
12. K. Iwamura., R. Kobayashi., K. Nishiyama, and Y. Nakanishi. A combined geospatial approach to extension planning of wind farms and transmission networks. *8th IEEE PES Innovative Smart Grid Technologies Conference Europe* (Sarajevo, Bosnia-Herzegovina, 2018). p. 1–6 (2018). DOI: 10.1109/ISGTEurope.2018.8571437