# An Overall Grid Modelling Tool
# for Modelling Smart Grids

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**Abstract.** The strategic positioning of new grid components may enhance the resiliency of a city to electricity outages, thus improve the quality of life that meets residents' needs. However, the cost and resilience associated to the grid are the two conflicting goals. This paper presents a user-interface-based Overall Grid Modelling (OGM) tool that allows city-level stakeholders to manipulate and control the tool for grid planning purposes. The OGM tool provides stakeholders the demonstration of cost and resilience needed to analyse the impact of altering the grid components, and through the normal and islanded operation (the penetration of microgrid).

**Keywords:** Grid planning · Grid resilience · Overall grid modelling tool · Smart grid

## 1 Introduction

An initial comprehensive holistic approach of a supply, demand and load balancing optimisation module was developed for grid distribution planning purposes [1]. The optimisation model allows the full integration of the wholesale electricity market price, distributed generators (renewable and non-renewable), battery storages, and the inclusion of outage events. The optimisation model is based on a cost minimisation function with the determination of economic balancing the output of generation units (economic dispatch and unit commitment). The outage event is included to evaluate the capability of the grid to sustain the outage through the isolation from the main grid and operation in islanded mode, or by isolating grid portions and dropping the load (normal grid-connected operation for unaffected grid nodes). The ability to sustain the islanded operation allows the resilience evaluation of the urban grid.

Even though numbers of tools exist to model grids as summarised in [2], they lack important features to enable an interactive analysis, especially the graphical user interfaces that allows stakeholders to manipulate and control the grid. Besides, having user interface enables the interactions with less experienced stakeholders. Therefore, an Overall Grid Modelling (OGM) tool is developed. The OGM tool is based on the integrated methodology and policy developed from the earlier IRENE deliverable [1,3]. The tool development is based on the

agile process, where the processes of specification, design, implementation and testing are concurrent, and as an iterative approach. The tool is developed in a series of increments where the user (stakeholder) will evaluate each increment and make proposals for later increments. The OGM tool aims to account the effects of grid planning that may benefit the city, for instance, through the introduction of renewable energy sources. The OGM tool enables the interactive feature that allows the decision makers (city-level stakeholders) to manipulate/control the OGM tool and varieties of analysis results across the grid are illustrated whenever a modification within the grid component is applied.

Overall, the OGM tool was developed for project IRENE [4,5], which accounts the collaborative city planning within multiple city-level stakeholders for resilient energy management. Project IRENE determines the better alternatives to mitigate vulnerabilities of urban electricity grids by utilizing the decentralized generation and smart control. This is to ensure availability of power supply for critical infrastructures are prioritized to enable minimal viable operation during large scale power outages or shortages.

This paper presents the context of the OGM methodology developed in [6] and further demonstrates the OGM tool at the IRENE workshop as part of the 2nd EAI International Conference on Smart Grid Inspired Future Technologies (SmartGIFT 2017).

The organisation of the paper is as follows. Section 2 presents the design of the OGM tool. Section 3 demonstrates the OGM tool user interface. Section 4 presents example analysis of grid simulations using the OGM tool. Section 5 concludes.

## 2  Design of the OGM Tool

The earlier developed optimisation module [1] automatically optimises the load during grid-connected or islanded operation. The optimisation problem is typically the economic dispatch in the combination of unit commitment problem comprising the distributed generators and energy storages. Both problems are associated with the amount of electrical power production problems.

With the implementation of the optimisation module into the OGM tool, the users are able to manipulate/control the tool and to calculate changes whenever a new case/scenario is applied (for instance, adding or remove an alternate generation sources). The tool does not only supports the simulation of electricity continuity planning from the technical perspective, but also ensures the cost concerned through the interventions for benefits of business planning [7].

The user interface of the OGM is developed using IntelliJ IDEA, the Java IDE software. For the numerical optimisation algorithm in Java, the dual-simplex algorithm is applied for such Linear Programming problem of the grid optimisation. The lp solve 5.5.2.3 [8] is applied as the library file for Java that is called to perform the numerical optimisation for the OGM tool.

Figure 1 shows the workflow of the OGM system. The system starts by allowing users to define the components inside the grid (selection of consumer and
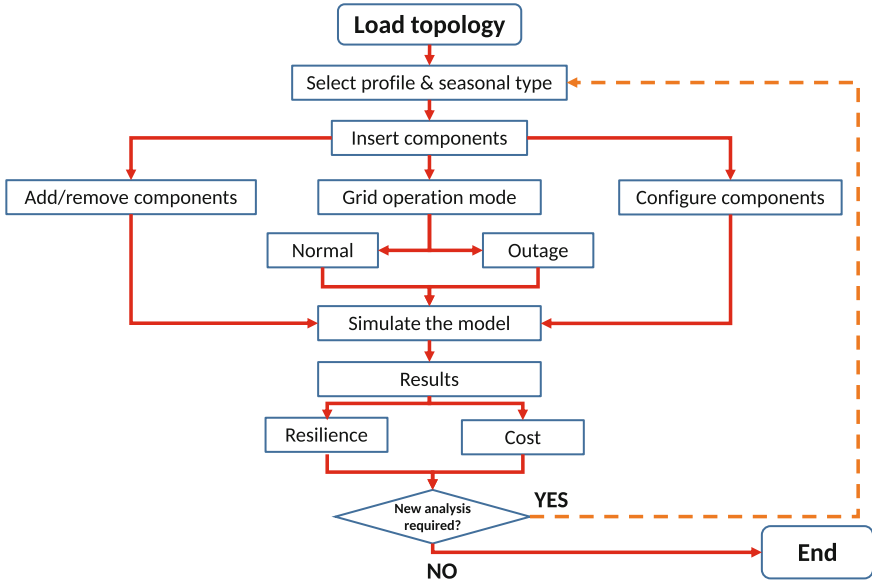
**Fig. 1.** The workflow of the OGM system.

seasonal profiles, addition, configuration and removal of grid components), and applying the grid operation mode (normal or outage simulation). The grid components are those associated with the electricity network system (consumers, generation sources, point of coupling nodes (transformers)). Once the input settings are accomplished, the optimisation algorithm is performed/simulated. A new output simulation window will report on cost of savings based on optimised generation costs, the resilience metric of the network during the islanded operation. If new analysis is required, the user can navigate to the input window to reconfigure the grid components easily.

## 3   The OGM Tool Interface

The user interface of the tool at the first instance is shown in Fig. 2. Figure 2 shows the clear user interface input window as before the user loads the network topology and configures the component specifications. Based on Fig. 2, the input user interface of the OGM tool consists of:

a. Status window - The status window explaining the progress of the overall simulation configured by the user;
b. Seasonal profile - The toggle selection of summer or winter seasonal demand profile;
c. Demand profile - The toggle selection of demand profile either the demand data adopted from the public domain, or the reduced-demand profile demand management capability;

d. Optimise - The action button to perform the numerical simulation;
e. Load system - The action button to load the network topology;
f. Outage simulation - The outage window for simulation of outage events;
g. Advanced options - The advanced features and additional input options for advanced users;
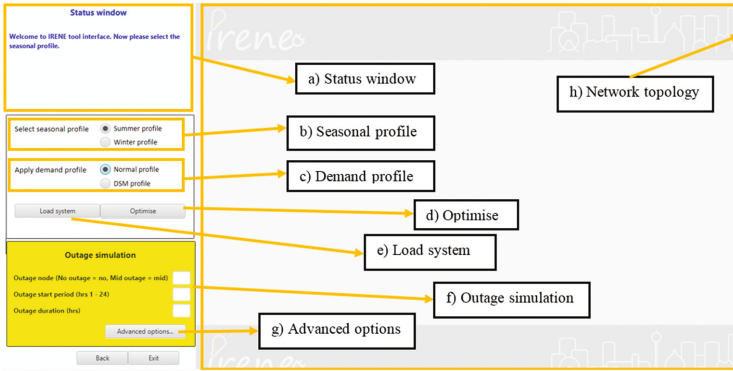h. Network topology - The input display for network topology to be loaded.



**Fig. 2.** The user interface input window of the OGM tool.

### 3.1    The Grid Topology and the Component Settings

In the input window, the user will select the type of seasonal and demand profile as before loading the network/grid topology. As outlined in [1], the IEEE 14-bus tree is used as the fundamental representation of grid architectural topology. The network topology presenting the integration of the grid and microgrid-connected is necessary. Such topology is implemented in this case as the main user interface for grid modelling and simulation, where the user can manipulate the whole integration of the grid (without altering the nodes/buses as constructed).

The IEEE 14-bus tree network topology is loaded as shown in Fig. 3, where the topology consists of low-level microgrid connections, mid-level lines and a high-voltage line.

The next step involves the step of adding grid components (the generating and consuming components) and configuring the components. Figure 4 demonstrates an example of adding the 'Household' profile component into the input model. Figure 5 illustrates the configuration settings for the consumers, and generation for generators, renewables and energy storages. Specification settings for consumers and generations are provided by default and the user can apply the additional specifications provided for further simulations. Those settings can be modified if the user wishes to supply additional information of the generation settings that ensures the scalability of the modelled grid architecture (for instance, the generating capacity is sufficient to supply the overall demand when new components are added).
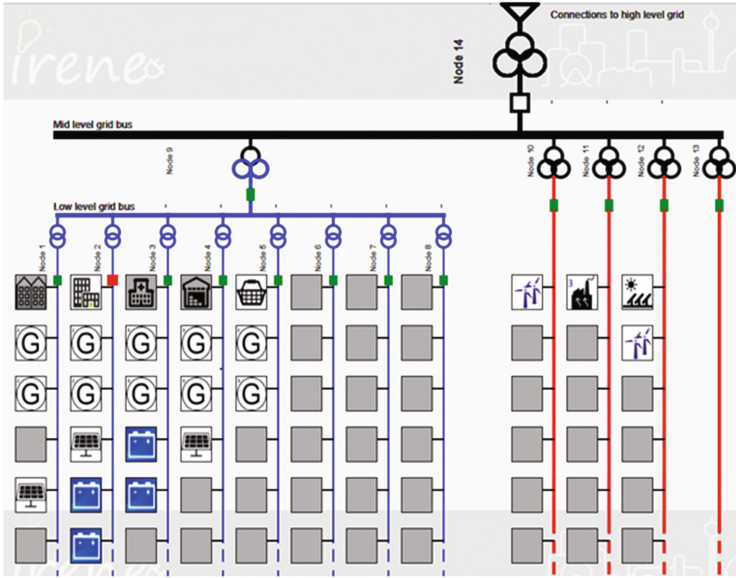
**Fig. 3.** OGM input user interface of the IEEE network topology. (Color figure online)
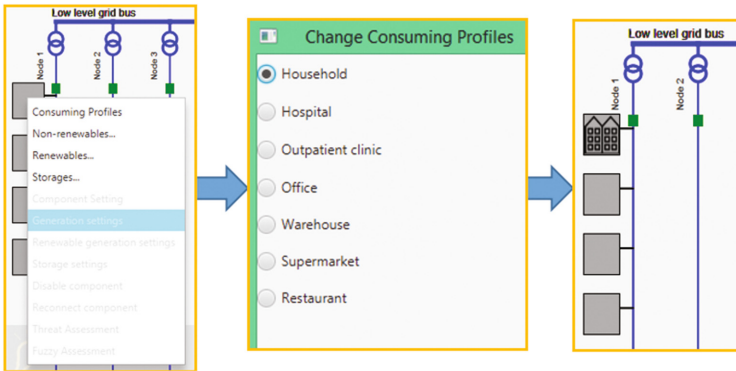


**Fig. 4.** The OGM user interface in adding a component.

### 3.2   Outage Simulation

In default configuration, if no outage is introduced in the input model, the OGM tool will apply the normal mode of simulation without outage. For the case of single node of failure/branch or a complete failure in a grid ($N$-1 compliance), the configuration is adjusted as illustrated in Fig. 3, where the outage is introduced in Node 2 by opening up the circuit breaker (green colour block is changed to red colour) in Node 2. The outage period and duration are set in the input outage simulation window (Fig. 2).

**Fig. 5.** The OGM user interface to configure the consumer profile, generation, renewable and storage settings.

The OGM tool calculates two indicators - resilience coefficients and costs (with or without savings) that inform users how the grid would operate during a blackout. The resilience coefficient in this paper is computed based on the extents in which the amount of energy demand within consumers are met when there is an outage in the grid [9]. The resilient coefficient is determined as the mean fraction of the demand served for the outage node divided by the overall demand. A grid is resilient when the computed resilient coefficient is maintained throughout the outage period. In contrast, the grid is considered as 'not resilient' during the business-as-usual operation mode (without outage) and also, 'not resilient' due to the fractional of failed served demand at particular outage period. The cost savings are determined based on the difference in between the business-as-usual operation of the traditional grid (without capability of islanding, and also without implementation of DGs, energy system storages and renewables), and the alternative operation mode, when DGs, energy storage systems and renewables are activated.

## 4   OGM Tool Analysis

This section explains the OGM tool analysis that performs the simulation for each indicated scenarios. The network topology of Fig. 3 is considered. Such topology has been applied in various IRENE's gaming simulation exercises and stakeholder workshops [10]. From Fig. 3, Nodes 1–5 consist the small-scale generations (back-up generations, PV panels and battery storages) and the loads (households, offices, hospitals, warehouses and supermarkets), while Nodes 10–14 consist of the mid-scale generation sources. Finally, Node 14 is the connection to the rest of the grids. The distribution of load profiles in this case is not intended to include the profiles of commercial services (e.g. hospitals, offices) and domestic households within the same bus. However, the variety of commercial services within a same node is still possible. Additionally, most of the commercial services are connected with their own substation due to the huge amount of loads required.

Two types of grid operations are simulated the normal and outage operation. The normal operation is accomplished when no outage occurs. However, the so-called 'economic-islanding' is operating in the normal mode where the small-scale generations automatically discharges energy within the microgrid level when the overall electricity market price is high. In this case the entire microgrid level is isolated from the mid and high level grid and self-capability of islanding operation is performed. The outage operation, in contrast, is triggered when there is an outage occurs within the low level nodes, or the complete grid outage. Two different operation modes are chosen in order to examine the resilience of the city in sustaining the normal and outage effects on the changes of the supply towards the demand profile across individual consumer and the overall demand, as well as the changes in the monetary savings and resilient coefficient in the grid level city.

### 4.1   Case 1 - Normal operation

In this case, assuming no failure occurs, the normal mode of operation is applied. The distributions of the overall demand, the cost savings and battery storage load are presented in Fig. 6. Cost savings are achieved (£964.05 within 24 h of simulated time) particularly for 'economic-islanding' normal mode of grid operations. The resilience coefficients are all zeros. This is because the grid resilience is not considered during the normal mode of operation (without any outage events). The battery storage also shows the capability of discharging (generating) energy to the consumers at time of high electricity price, and recharge at low-peak electricity price. The simulation, however, excludes the addition of installation and maintenance costs of individual generators.

### 4.2   Case 2 - Outage operation

In this example, outage event is triggered in Node 2 as configured in Fig. 3, at 0900 in the morning, with six hours of outage duration. The 'economic-islanding' capability is disabled in the case of outage events. Figure 7 shows the result of the outage simulation of the overall demand and its deviated demand during the outage, the plot of cost savings, the battery load, and the resilient coefficient. It can be seen that in order to compensate the deviation of outage loads, £1386.65 additional costs are required. The amount of cost saving is highly dependent on the distribution of consuming and generating components configured by users, the state of operation within small-scale generations, and the outage durations. The amount of cost saving in this case is the optimised amount of cost that reduces the cost of damages during the outages. In this case all loads are served during the outage events. Therefore, computed resilience coefficients are maintained in this case.
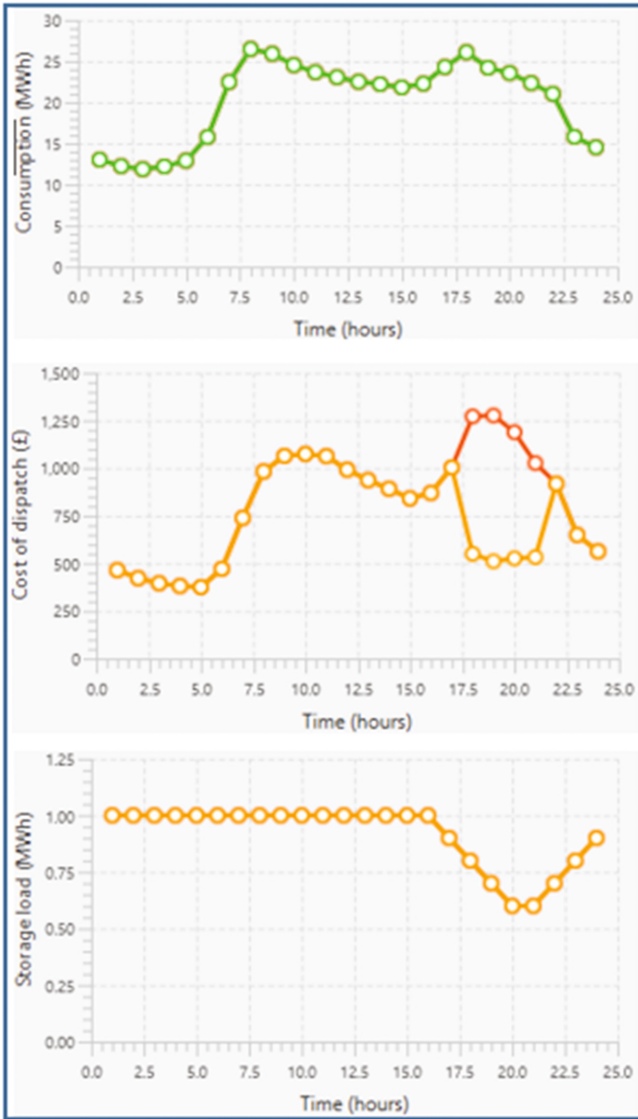
**Fig. 6.** The overall demand, monetary costs and battery storage load calculated for the grid during the normal operation: top panel - overall grid demand; middle panel - plot of monetary savings in relation to the business-as-usual (red plot) and the optimised solution (orange plot); bottom panel - battery storage load. (Color figure online)
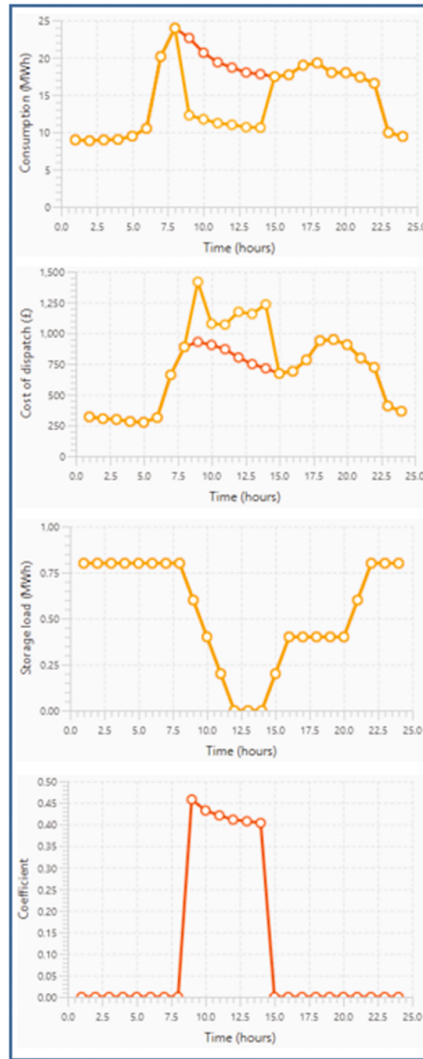
**Fig. 7.** The overall demand, monetary costs, battery storage load and resilience coefficient calculated for the grid during the outage operation: first panel - the overall grid demand without outage (red plot) and the outage demand (orange plot); second panel - plot of monetary savings in relation to the business-as-usual (red plot) and the optimised solution (orange plot); third panel - battery storage load; bottom panel - the distribution of resilience coefficient (Color figure online).

## 5   Conclusion

This paper presents a user-interface-based OGM tool that allows city-level stakeholders to manipulate/control the tool for grid planning purposes. The OGM tool

calculates two indicators - resilience coefficients and costs (with or without savings) that inform stakeholders how the grid would operate at different situations (normal and islanded operation). The demonstration of the OGM tool will be performed at the IRENE workshop as part of the 2*nd* SmartGIFT 2017.

Types of inputs to the OGM were illustrated that allow stakeholders to evaluate the overall grid resilience and also costs incurred. Different cases (normal and islanded operations) were presented that showed the trade-off in between the resilient coefficient and cost savings (e.g. one may wish to achieve the resilience of electricity network but may incur additional investments). The OGM tool is therefore needed to ensure that such trade-offs should be minimised.

Overall, the OGM tool intends to enable an interactive analysis with user-interface experiences for fellow stakeholders from diverse background (for instance, city planners, distributed network operators and grid system operator) to be available to use the tool as a collaborative planning for a city-level grid. The target future work for the OGM tool shall account for the meshed-network analysis, the grid scalability and a complete business-planning model in addition to electricity continuity planning to examine the detailed monetary costs of different approaches in grid planning interactively.

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