A Strategic Urban Grid Planning Tool to Improve the Resilience of Smart Grid Networks

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Abstract. The unresponsive and poor resilience of the traditional city architecture may cause instability and failure. Therefore, strategical positioning of new urban electricity or city components do not only make the city more resilient to electricity outages, but also a step towards a greener and a smarter city. Money and resilience are two conflicting goals in this case. In case of blackouts, distributed energy resources can serve critical demand to essential city components such as hospitals, water purification facilities, fire and police stations. In addition, the city level stakeholders may need to envision monetary saving and the overall urban planning resilience related to city component changes. In order to provide decision makers with resilience and monetary information, it is needed to analyze the impact of modifying the city components. This paper introduces a novel tool suitable for this purpose and reports on the validation efforts through a stakeholder workshop. The outcomes indicate that predicted outcomes of two alternative solutions can be analyzed and compared with the assistance of the tool.

Keywords: Stakeholder workshop · System design · Monetary cost
Grid resilience · Smart grid

1 Introduction

The increased interconnectivity and deployment of smarter grids, distributed energy resources (DER), as well as increased consumer demands and critical facilities but with limited amount of storage technology available to store excessive amount of generated energy make energy such a limited resource. The robustness and resilience of the grid can be formulated to evaluate the way to share a limited resource between multiple stakeholders. To find the optimal arrangements, stakeholders need to collaboratively plan an overall grid system. Additionally, robustness and resilience management is important for stakeholders to evaluate

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the improved grid system on possible undesirable events. This is because enhancing the robustness and resilience may (or may not) incur additional monetary costs.

Furthermore, the integration of a renewable into the grid is an another dimension of challenge that concerns multiple domains. One might consider the renewable energy-related landscape [3] aims to reduce greenhouse gas emission [21]. In addition, to find a suitable location for a biogas plant, the distances from the site to the biomass sources must be accounted for [7]. In the case of solar investments, an important concern is the interplay between the urban form and solar energy inputs [1]. Importantly, utility planners should consider how the grid can operate during contingency events (see e.g. [4,12]).

Additionally, there is a need to account for grid resilience – the ability of the grid to withstand a failure in an efficient manner [5]. Specifically, it concerns supplying electricity to critical infrastructures (e.g., hospitals) during blackouts, as well as the ability to quickly restore normal operation state [5]. Threat analysis related to non-adversarial and intentional threats (e.g., [18,19]) can highlight which components may deserve particular attention. DER can also be used to compensate for the discontinuity of electricity produced by intermittent renewables. However, optimizing the cost of dispatches of DG units is needed to ensure that this task performed efficiently. Stakeholders also may need to consider both monetary and resilience aspects to account how a city benefits from installation of new components such as DER. The considerations include the mitigation of fault and attack, threat ranking, the monetary cost and resilience analysis, and the impact on different critical infrastructures. In this regard, a decision making tool – Overall Grid Modelling (OGM) was built to demonstrate effect of grid component changes based on the perspectives of strategic planning within stakeholders.

This paper reports initial features and functionalities of the OGM tool related to several state-of-the-art tools for modelling and controlling smart grids in terms of its practicability and efficiency. The OGM tool validation efforts are conducted through a stakeholder workshop. These aspects are relevant to evaluate limits and possible overlaps in functionality, and the reasonably expected scalability of the OGM tool. It is an approach supported by the OGM tool, where the tool simulation provides a perception towards decision makers of the grid elements that they wish to optimize.

The overall organisation structure of the paper is as follows: Sect. 2 reviews the state-of-the-art modelling tools to ensure that the OGM tool is aligned with standard core functionalities of the existing tools. Section 3 presents the methodology of OGM tool usages. Section 3.1 reports the methodology of the stakeholder workshop organized that validates the functionalities of the OGM tool. Section 4 presents the findings through the stakeholder workshop. Finally, Sects. 5 and 6 discuss and conclude the findings.

2 State-of-the-Art Modelling Tools

In this section, a state-of-the-art modelling and controlling smart grid tools are reviewed. The review aims to identify functionalities that can be represented to users. The improvements in the interface can be studied in terms of the readability, the way how the output results presented, whether the tool provides a clear implication (positive or negative aspects) to users, and how the tool suits the users' needs and requirements with respect to the output results. The functionalities of the smart grid tools are cross-related in order to ensure that the OGM tool is well-aligned with standard core functionalities of existing smart grid tools.

DNV GL has developed a microgrid mathematical optimization tool [6] to evaluate the full integration of distributed generations, electrical, thermal storages, technological updates, building automation and customers' behavioural usages. The software module also includes the detailed policy drives, climate, technology cost projections and tariffs at which referring specifically to a particular geographical location. The holistic-based simulation aims at maximizing the economic value and reliability of electrical system and energy. The model simulates the day-ahead energy prices, demand forecasts, weather forecasts, dynamic performance of the buildings, storage, CHP, distributed generation, and demand management mechanism that optimizes the energy economics during the day. The optimization problem is formulated through the Mixed Integer Linear Programming (MILP) approach. The overall reliability of the grid is assessed by perturbing the grid with outages or contingencies through the relevant utility statistics (SAIDI, SAIFI). The optimization tool is also capable of maximizing the uninterruptable and critical load that can be served from available resources during the outage period.

The Massachusetts Institute of Technology (MIT) has built a laboratory-scale microgrid based on the earlier model developed from computer simulation studies [17]. The institute aims to evaluate the transition of voltage that may lead to voltage instability (the disconnection and reconnection to the central power grid). The project focuses on a laboratory-scale power system that combines the energy generation and storage devices to serve local customers at low level grid. The Masdar Institute corporates with MIT by concentrating on analytical-based weighted multi-objective optimization methods. The analytical methods analyze the system configuration and operation planning simultaneously in order to determine the costs and emissions. The method generates a set of optimal planning/designs and operating strategies that minimizes costs and emissions simultaneously.

Siemens PTI provides a consultant service, software and training program to optimize system networks for generation, transmission and distribution and power plants for smart grids [16]. The consulting services offer expertise in system dynamics and threat analysis, energy markets and regulation, control systems, power quality, and steady-state and dynamic system evaluations. The software solutions with completed power system analysis tools include PSS®E, PSS®SINCAL PSS®NETOMAC, PSS®ODMS, PSS®MUST, and MOD®. Value propositions considered are: Reliability, fuel savings, and environmental benefits.

Microgrid Master Controller software developed by Etap Grid performs the detailed modelling, simulation and optimization of electrical systems [8]. The software controller predicts and forecasts energy generations and loads. The controller also integrates and automatically controls the microgrid elements, such as PVs, energy storages, back-up generations, wind, gas turbines, CHP, fuel cells, and demand management. The software automatically optimizes the grid during grid-connected or islanded grid operations. The economic cost calculation is the main value proposition in Etap Grid, as the software aims to lower the total cost of ownership by reducing the average cost of electricity from the national electricity price.

Argonne National Laboratory (ANL) offers a range of resilient-based tools, techniques, and engineering methods to optimize the interdependencies of energy and global security needs [2]. These include the power infrastructure modelling tool that inspects the impact of power outages in the large grid, and power system restoration optimization tool combined with AC power flow-based cascading failure/outage. The tool models the tendency of islanding operations, either synthetic based or natural threats. Example of applications include: identification of system vulnerabilities and implementation of preventative measures; critical power infrastructure, resiliency analysis; and system dependency/interdependency analysis with non-power infrastructure systems. The integrated system restoration optimization module supports restoration planning and operational decision-making in the transmission and distribution systems. The cascading failure module considers system monitoring, protection, control and further simulates the most important cascading techniques. The module further provides cascading risk analysis and generates credible cascading scenarios for restoration purposes.

2.1 Summary of Smart Grid Modelling Tool Functionalities

Table 1 summarizes important features of the mentioned modelling tools. Even though numbers of tools exist to model grids, they lack important features to enable an interactive resilience analysis, such as user interfaces and resilience calculations modules. Moreover, most of the tools do not provide user interfaces. This can hamper the interactive tool navigation and analysis as required by users. More importantly, having user interface enables interactions with users from various backgrounds. At the moment, only the DNV GL tool accounts for critical loads. Loads are important especially in times of blackouts urban-level loads can be more critical than others. Therefore, prioritization of critical loads are particularly relevant for a resilience analysis tool.

In contrast, the OGM tool introduced below, particularly focus on addressing the interaction needs and the aforementioned shortcomings. Through the implemented mathematical optimization module, the important features such as the simulation of outage, islanding operation, cost and resilience analysis are performed. The users are able to manipulate/control the tool and changes in the resilience coefficient are demonstrated that reflect grid structural changes implemented by users whenever a new case/scenario is applied (i.e., adding or remove a local generator). The methodology, policy and the development governing the OGM is available in the documentations [10,11]. The tool enables the decision makers to manipulate/control the grid component changes and varieties of resilience coefficient metric and cost analysis are illustrated through the alterations within the grid components. The tool provides decision makers the best option in terms of grid planning, and also the information on how the introduction of a city component increases grid resilience and also account for possible monetary savings. In line with International Electrotechnical Commision [9], the OGM tool supports simulation of electricity continuity planning and also ensuring the cost concerned through the interventions for benefits of business planning.

Table 1. Summary of modelling tools in comparison with the OGM tool. Adapted from [13].

Tool		DNV GL	MIT	Masdar Institute	Siemen PTI	Etap Grid	ANL	*OGM tool*
Functionality	Mathematical optimization	✓		✓	✓	✓	✓	✓
	User interface ready	✓			✓			✓
	Grid topology ready				✓			✓
	Prototype based		✓					
	Demand forecasts	✓				✓		✓
	Generation and storage modelling	✓	✓	✓	✓	✓	✓	✓
	Account for critical loads	✓					✓	✓
	Support of threat ranking						✓	✓
	Islanding operation	✓				✓	✓	✓
	Scenario/case studies	✓	✓		✓	✓		✓
	Outage/contingency simulations	✓			✓	✓	✓	✓
	Cost analysis	✓		✓	✓	✓		✓
	Emission analysis	✓		✓				
	Resilience analysis						✓	✓
	Reliability analysis	✓	✓	✓	✓		✓	
	Power flow analysis		✓		✓	✓	✓	

3 The OGM Tool

The OGM tool development was based on the agile process, where the processes of specification, design, implementation and evaluation strategies are concurrent, and as an iterative approach. The tool is developed in a series of increments where the user will evaluate each increment and make proposals for later improvements.

The OGM tool incorporates a GUI (see Table 1). To facilitate continuous interactions in a user-friendly and easily controllable manner, the user is also able to simulate several use-case scenario in order to observe the output changes directly where the components can be introduced/removed/moved within the grid (i.e. the addition/removal of particular consumption profiles, critical loads, generators, storages, renewables, outage simulation and islanding analysis). The tool allows concurrency in updating new trends of input information provided by the user using the existing model. The OGM tool is aimed for decision makers (Municipal authority planner, DNO, Developers, Critical Infrastructure Operator, Business and Citizen Representative) with various technical/conceptual background that aims to be easily-interpretable, without incorporating complex power-flow model and analysis. The expertise of the decision makers is essential to account for sound strategic grid planning.

An example of a network topology tree (or the system architecture) is shown in Fig. 1, where the architecture included a number of city grid components. The distribution of grid components as in Fig. 1 is presented in Table 2.

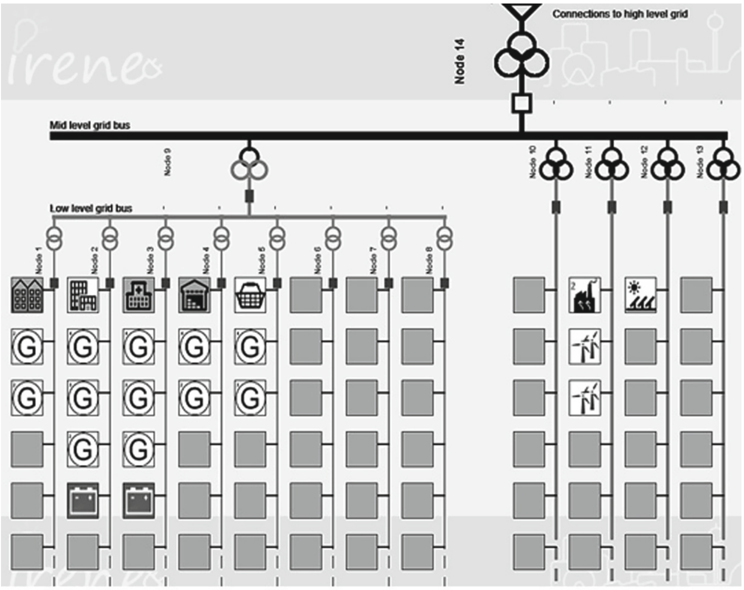

Fig. 1. The baseline system architecture of the OGM tool.

The tool simulates outage consequences using the input of known outage scenario through the known critical loads and specifics of generation profiles. Then, computations modules in the OGM will process the outage scenario. Output results will demonstrate the monetary savings and resilience indicator through the component changes. Through the output results, the decision makers will select most suitable alternative for grid outage mitigations and repeat the simulation if needed.

The threat analysis and ranking is another distinctive feature of the OGM tool, where the tool provides the analysis of non-adversarial threats (e.g., [18,

Table 2. Number of distributed generators, energy storages, types of consumer profiles and their populations included.

Node no.	Number of generators		Number of energy storage	Profiles included	Populations
	Non-renewable	Renewable			
1	2	0	0	Households	2500
2	3	0	1	Offices	2
3	3	0	1	Hospitals	2
4	2	0	0	Supermarkets	3
5	2	0	0	Warehouses	8
6	0	0	0	-	-
7	0	0	0	-	-
8	0	0	0	-	-
9	1	0	0	-	-
10	0	0	0	-	-
11	1	2	0	-	-
12	0	1	0	-	-
13	0	0	0	-	-
14	0	0	0	-	-

19]) as well as threats related to intentional disruptive actions (e.g., [14,20]). This enables decision makers to enter threat characteristics to calculate relative value of threat event frequencies. Subsequently, they can apply the output threat analysis to envision which grid component approaches should be prioritised.

This tool assumes the 'power sharing mechanism' through the hardware solution to island a microgrid (de-attach and re-attach it to the main grid) can be located at the point of coupling nodes (transformers). Thus, each node with a critical load might strive to be self-sustaining: balance the (critical) supply and demand. A node can be either connected or disconnected completely from the main grid. Currently, only one connection to the main grid for each single nodes in the tool is considered and hence forth a meshed network is not considered. The tool particularly focuses on threats that lead to outages: (1) those resulting in the disconnection of a node from the main grid; and (2) outage of a component (e.g., a DER as an electricity generation component).

The tool calculates two indicators – resilience coefficients and monetary costs (with or without savings) – to inform users how the grid would operate during an outage event. Resilience is the ability of a power system to remain or withstand a failure, and to restore quickly to the normal operating state [5]. In order to justify the grid resilience, a resilience performance metric is used. 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 [5]. A grid is robust and resilient when the computed resilient coefficient is high, or is maintained throughout the outage period. The resilient coefficient is determined as the mean fraction of the demand served for the outage node divided by the overall demand to be served. Similar to [13], the resilience coefficient in this case is therefore the fraction of demand served for ith consumer ($P_{i,t}$) divided by the total demand D ($P_{I,t}$) in the contingency state at time t:

$$\alpha_R(t) = \frac{P_{i,t}}{P_{I,t}}. \tag{1}$$

The monetary cost C in this paper is calculated as the difference between the business-as-usual traditional grid operation cost (without capability of islanding, and also without implementation of DGs, energy system storages and renewables (C_{BAU})) and the optimized grid operation cost (when DERs are activated). The negative monetary cost value computed indicates that the monetary saving is not achieved - the particular improvement incurs additional costs.

$$C(t) = C_{BAU} - C_{optimized}. \tag{2}$$

Figure 2 shows the example of resilience coefficient and monetary costs calculated for the grid as described in Fig. 1. The top panel presents the plot of monetary savings in comparison to the business-as-usual and the optimized grid planning. The bottom panel illustrates the distribution of resilience coefficient metric. Negative monetary savings indicate additional costs, whereas positive savings indicate the cost saving of the improvement in the grid operation. The resilience coefficient would be between 0–1 (the resilience coefficient is computed as zero at a particular time interval when no outage occurs) because of the fraction of demand served over the overall demand during an outage event.

The GUI implementation of the OGM is developed using IntelliJ IDEA, the Java IDE software. The dual-simplex is used for the numerical grid optimization of the Linear Programming problem. The lp_solve 5.5.2.3 [15] is applied as the library file for Java that is called to perform the optimization algorithm for the OGM tool.

3.1 Methodology

The stakeholder workshop was conducted to validate the applicability and the scalability of the OGM tool, using the expertise of the stakeholders with years of experience in real-life domains. In the beginning of the workshop, mini-lectures on the logic and assumptions behind the development of the OGM tool, as well as the smart grid technologies were delivered to introduce stakeholders to major ideas of smart grids, as well as the current issues and challenges. The OGM tool was demonstrated to stakeholders to clarify the idea how modelling tools can be used to improve the resilience of the overall grid.

The configuration as defined in Fig. 1 was simulated which further enabled fellow stakeholders to modify the grid components with the intention of improving the resilience of the grid. During the workshop session, exercise handouts were given to three stakeholders who represented different stakeholder roles (City planner, Distribution Network Operator, Citizen & Business representatives). The stakeholders need to collaborative decide how to introduce new components or modifying the existing components to improve resilience of the grid. The system architecture in Fig. 1 and Table 2 was used as the baseline configuration,

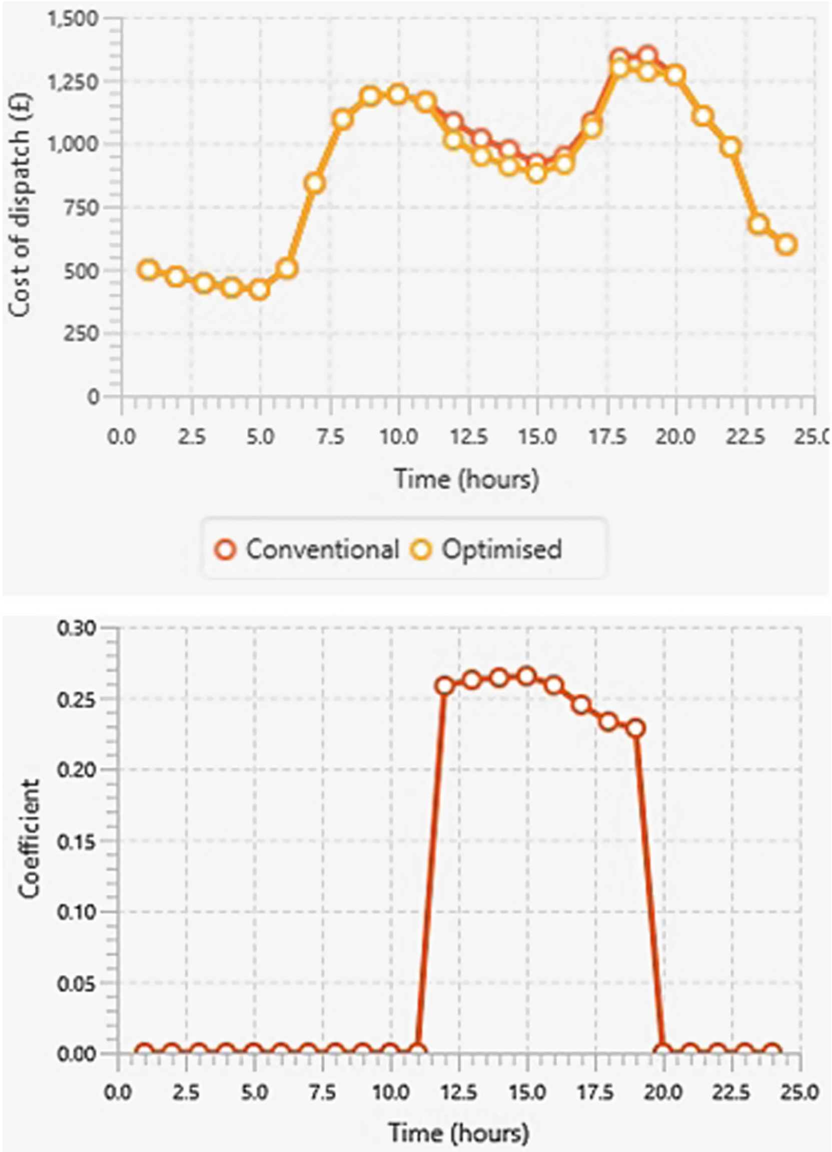

Fig. 2. Resilience coefficient and monetary costs calculated for the grid: top panel – plot of monetary savings in relation to the business-as-usual and the optimized solution; bottom panel – the distribution of resilience coefficient. Outage starts at 1200 with durations of eight hours.

where the amount of renewable sources are low. In addition to the description of the grid architecture, stakeholders were briefed on the changes that the grid context might undertake. It was suggested that the populations within the city are increased, and towards the decarbonization plan. Specifically, amount of city components would be as follows: Households = 4500; Offices = 3; Hospitals = 3; Supermarkets = 5; Warehouses = 12.

After providing the information, stakeholders were asked to discuss what grid updates might be introduced to ensure that a city can withstand a blackout with less negative impact as possible. The aim of this exercise is to investigate how the manipulation of the OGM tool can guide the fellow stakeholders to improve the resilience of a complex urban grid, in the context of collaborative decision making in the situation of uncertainty.

Two different outage scenarios (4 and 8 h) were chosen to examine the impact of grid component changes on the resilience of the city in sustaining both the shorter or longer outages. In addition, the outage in every single node is also examined in order to examine the outage effects on the changes of the supply and across individual consumer and the overall demand, as well as the changes in the monetary savings and resilient coefficient in the grid level city as shown in Table 3. The 'economic-islanding' capability during the normal grid operation is enabled that employs DERs to provide demand management capability at times of high electricity price, rather than drawing the electricity from the main grid [11]. Questionnaires were disseminated to fellow stakeholders at the end of the workshop.

Table 3. Type of grid operations and the indicators applied.

Grid operation			Indicators	
			Resilient coefficient	Monetary cost
Normal (Economic islanding enabled)				✓
Outage	**Duration** (hrs)	**Type**		
	4	single	✓	✓
	8	single	✓	✓
	4	complete	✓	✓
	8	complete	✓	✓

4 Validating the Tool

4.1 Results

In order to access the effectiveness of the collaborative decisions as made by fellow stakeholders, normal and failure of grid operations are simulated for each node, and also the complete grid outage. Outages occur due to the grid failures (e.g. a line-disconnection between the microgrid and main grid level, and also the line disconnection within the microgrid nodes). When there is a failure event, the islanding capability is triggered to ensure uninterrupted operation during a utility system outage through the N-1 compliance [11]. Decisions placed and the performance of the implemented decisions by stakeholders are compared with the baseline case in terms of resilience coefficients and monetary savings. The decisions were evaluated using the OGM tool and the timeline for the simulation is allowed for 24 h. The grid with various operating conditions were simulated for the baseline case and two solutions as placed by stakeholders in considering decarbonization strategy.

After some discussions, stakeholders proposed the first solution based on the modification of grid components in the baseline case (Fig. 1), as shown in Fig. 3. The updates were:

1. Remove a generator from Node 2;
2. Remove a generator from Node 3;
3. Add a PV generator in Node 2;
4. Add a wind generator in Node 2;
5. Add an energy storage system in Node 1.

The second solution as proposed by stakeholders, using the baseline case (Fig. 1) were presented in Fig. 4, which were:

1. Remove an energy storage system in Node 3;
2. Add a generator in Node 3.

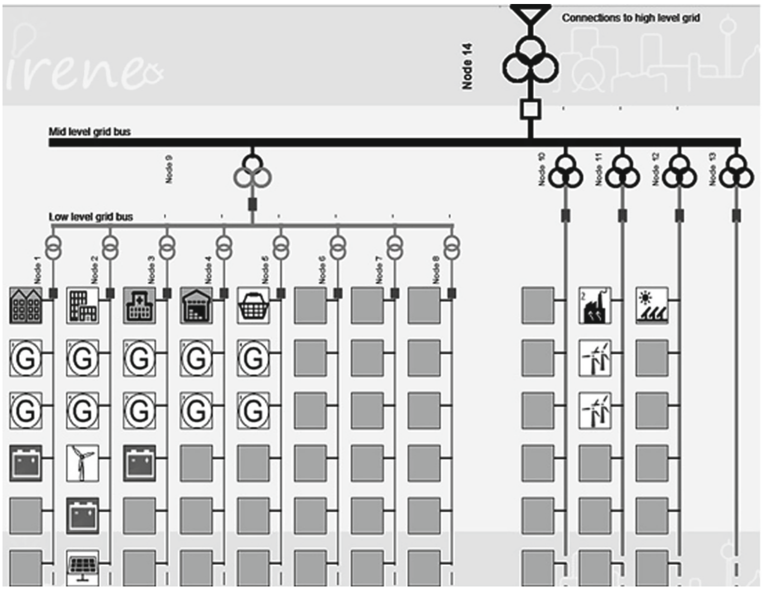

Fig. 3. The first solution of system architecture as proposed by stakeholders.

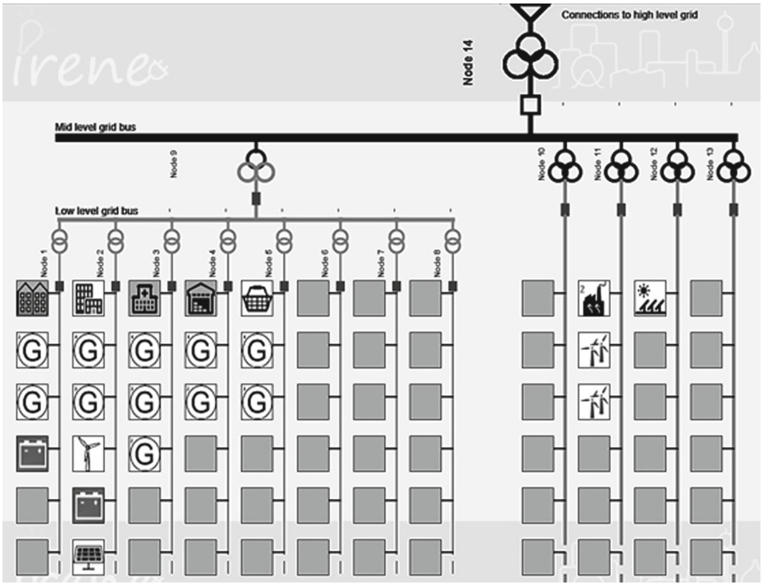

Fig. 4. The second solution of system architecture as proposed by stakeholders.

Case 1 – Normal Operation. In this case, assuming no failure occurred, the normal mode of operation was applied. The monetary cost and resilience coefficient achieved for baseline, first and second solutions as proposed by stakeholders were shown in Table 4. Based on Table 4, the first solution proposed by stakeholders achieved higher amount of monetary savings than the first solution, and also higher than the Baseline case. Higher amount of cost savings achieved during the 'economic-islanding' normal mode of grid operations. The resilience coefficients were all zeros as the grid resilience was not considered during the normal operation mode (without any outage events). The simulation, however excluded the addition of start-up investment, installation and maintenance costs of individual DERs.

Case 2 – Four Hours of Outage Duration. In Case 2, the outages in microgrid or the entire grid was assumed occur at 0900 for the duration of four hours. The capability of 'economic-islanding' was disabled in the case of outage events. Table 5 showed the result of the simulation using the baseline, followed by the first and the second solution. Negative sign indicated that additional costs were introduced (no monetary savings are achieved). Overall the baseline scenario promoted highest amount of cost savings than the decisions as imposed by stakeholders. This was due to the introduction of renewables that required higher amount of costs for generations compared with conventional generators. However, cost savings were reduced in the first solution, where energy storages were employed. As energy storages generated zero cost during the discharging state, this created significant amount of cost savings. As all fractions of demands were successfully met during the outage events, therefore the computed resilience coefficients were identical.

Case 3 – Eight Hours of Outage Duration. In this case, similar to Case 2, the outages within the microgrid or the entire grid was assumed occur at 0900 however with prolonged outage duration of eight hours. The 'economic-islanding' capability was also not permitted. Each outage node disconnections was evaluated. Table 6 showed the result of the simulation using the baseline scenario, the first and second solution as proposed by stakeholders. Similarly as in the previous case, Negative sign indicated additional costs are introduced. Overall the first solution proposed by stakeholders promoted the highest amount of cost savings. The implementation of back-up generations results in higher monetary costs than employing energy storages (where energy storages generated zero cost during discharging state, and charge at low peak electricity price).

Similar to Case 2, as all fractions of demands were successfully met during the outage events, therefore the computed resilience coefficients were identical, but with varied coefficients due to prolonged projections of outage durations.

Table 4. Case 1 – cost savings and resilience coefficient in normal mode.

	Baseline	First solution	Second solution
Cost savings (£)	885.72	**1023.26**	890.76
Resilience coefficient	0	0	0

Table 5. Case 2 – cost savings and resilience coefficient in outage mode.

Outage node	Cost savings (£)			Resilient coefficient		
	Baseline	First	Second	Baseline	First	Second
Node 1	−299.75	−489.9	−489.9	0.111	0.111	0.111
Node 2	−556.84	−546.98	−546.98	0.430	0.430	0.430
Node 3	−291.56	−286.57	−486.07	0.240	0.240	0.240
Node 4	−410.3	−400.01	−400.01	0.144	0.144	0.144
Node 5	−428.09	−437.74	−437.74	0.074	0.074	0.074
Grid outage	−296.76	−325.23	−400.23	1	1	1
Total savings £	**−2283.3**	−2486.43	−2760.93	–	–	–

Table 6. Case 3 – cost savings and resilience coefficient in outage mode.

Outage node	Cost savings (£)			Resilient coefficient		
	Baseline	First	Second	Baseline	First	Second
Node 1	−670.87	−659	−659	0.111	0.111	0.111
Node 2	−1571.89	−955.64	−955.64	0.430	0.430	0.430
Node 3	−867.42	−622.1	−622.1	0.240	0.240	0.240
Node 4	−710.95	−646.53	−646.53	0.144	0.144	0.144
Node 5	−690.21	−689.65	−689.65	0.074	0.074	0.074
Grid outage	1817.43	1850.51	2118.89	1	1	1
Total savings £	−5411.34	**−4307.06**	−4637.06	–	–	–

5 Discussion

Overall, the stakeholder workshop was successfully conducted and two different scenarios of grid configuration changes were proposed by stakeholders, in comparison with the baseline case. The stakeholder workshop indicated that the proposed tool can support extensive collaboration between stakeholders who actively engage in discussions with each others for increasing the robustness of the electricity network. During the workshop, stakeholders suggested several ideas for improving the OGM tool, such as to account for the capital costs of investments, integrate flexibility to allow for city configurations, improve the user-friendly interface, store output parameters for comparisons based on different component alterations, and also to breakdown cost savings to reflect where changes affect the whole grid system.

The questionnaire feedback was delegated to fellow stakeholders at the end of the workshop. The questionnaire feedback was shown in Table 7. The outcomes of the workshop showed that the tasks related to grid component changes in responding to decarbonization strategy could be effectively performed in an understandable manner. Results can be compared and a better alternative based on the comparisons could be selected.

One of the stakeholder with electricity market knowledge noted that no expert knowledge was required to use the OGM tool. Additionally, another stakeholder praised the calculations and the scope of the OGM tools in performing the necessary tasks. The stakeholders positively noted the practicability of the demand management capability in the OGM tool, assumptions on uninterruptible loads, the efficiency of OGM tool in running/re-running a simulation, the ease of understanding the performance metric 'resilience coefficient' in measuring the performance of different grid topologies/configurations, and being useful as a collaborative-decision making system. One of the stakeholder recognized an opportunity of the tool to assist with network congestion as a very important aspect that is of value to utility companies. However, the immediate benefit could be realized if the tool will be road tested with some utility companies so

Table 7. Questionnaire results.

Question	Rating scale (1 – Very negative, 7 – Very positive)						
	1	2	3	4	5	6	7
	Number of respondents						
Q1. Knowledge on smart grids	0	0	1	1	0	1	0
Q2a. Practicability of demand management capability	0	0	0	0	2	0	1
Q2b. Practicability of controlled generations	0	0	0	1	1	1	0
Q2c. Practicability of islanded operation during outage	0	0	0	1	2	0	0
Q2d. Practicability of disconnected load during outage	0	0	0	2	1	0	0
Q2e. Practicability of critical loads	0	0	0	0	1	1	1
Q2f. Practicability of uninterruptible loads	0	0	0	0	2	1	0
Q3a. Effectiveness of OGM tool in addressing outage	0	0	0	2	1	0	0
Q3b. Effectiveness of the demand forecast	0	0	1	0	0	2	0
Q4a. Speed of OGM tool to run/re-run a simulation	0	0	0	1	0	1	1
Q4b. Speed of OGM tool to construct/re-construct grid components	0	0	1	1	0	1	0
Q4c. Speed of OGM tool to run/re-run demand forecast	0	0	0	1	2	1	0
Q5a. Level of knowledge required in using the tool	0	0	1	0	1	1	0
Q5b. Level of easiness in using the tool	0	0	0	1	1	1	0
Q6. Reason for rating as 5 or above in Q5	–No expert knowledge required to use the tool –Tool is for special market, so industry knowledge is required						
Q7. Understandable of resilient coefficient metric	0	0	2	0	1	0	0
Q8. Practicability of resilient coefficient metric	0	0	2	1	0	0	0
Q9. Practicability of evaluating electricity network	0	0	0	1	1	1	0
Q10. Fast in providing simulation analysis	0	0	0	0	1	2	0
Q11a. Usefulness of the tool in addressing outage in urban electricity network	0	0	0	0	1	2	0
Q11b. Usefulness of the tool as a collaborative decision support system	0	0	0	0	0	3	0
Q11c. Usefulness of the tool in establishing collaborative frameworks among stakeholders	0	0	0	0	1	2	0

that it could be proven and validated. This would help define the next steps of activity and help make the tool appealing to a range of potential market sectors.

However, one of the stakeholder (business and citizen representative) argued that specialised industry knowledge was required in order to fully understandable in using the OGM tool. This was because business and citizen representative might have low level electricity and smart grid background knowledge. Still, the time needed to construct/ re-construct the grid components was found inefficient. Also, the last stakeholder explicitly voted that high level of knowledge was required in using the tool. One of the stakeholder mentioned that even though the OGM tool was almost immediately applicable, there should be a need to recognition that cross connections would also exist in addition to the vertical hierarchy (single line electricity connection). As a tool to explore islanding, the tool would need to additionally consider the transition from grid to microgrid and back again. Additionally, at some instance stakeholders noted the unrealistic practicability of using the metric 'resilient-coefficient' in tool simulations.

6 Conclusion

This paper presents an approach of using a strategic urban grid planning tool to improve the resilience of smart urban electricity networks. The approach allows decision makers to envision and manipulate grid component changes and further examine the resilience coefficient metric and the potential monetary savings across the grid. New analysis results are demonstrated whenever a grid component modification is applied. The approach is supported by the OGM tool. The tool simulates and provides a feedback towards decision makers of the grid elements that they wish to improve.

The tool was validated during a stakeholder workshop. Different cases and solutions were proposed by stakeholders were calculated to show the trade-off in between the resilient coefficient and monetary savings. The OGM tool was found useful to point out those complex aspects as proposed that should be considered to minimize such trade-offs.

In summary, the idea and logic of using the tool for grid planning are well-received. The survey feedback gathered would not only further supports and complements the analysis, but also to improve the efficiency and practicability the OGM tool.

As the agility concept is strongly supported by the OGM tool development, the continuous improvement strategy based on feedbacks obtained are implemented into the tool in responding to the requirements from fellow decision makers. The practicality and efficiency of the tool are continuously enhanced to improve the overall experience in using the tool to support the grid planning through the information provided by decision makers. Future major improvements would be related to moving towards the meshed grid topology, as the current tree representation of the grid architecture implemented in the OGM tool is one of the limitations pointed out by stakeholders.

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References

1. Amado, M., Poggi, F.: Solar urban planning: a parametric approach. Energy Procedia **48**, 1539–1548 (2014)
2. Argonne National Laboratory (ANL): Resilient infrastructure capabilities (2016). http://www.anl.gov/egs/group/resilient-infrastructure/resilient-infrastructure-capabilities. Accessed 19 Jan 2017
3. Barjis, J.: Collaborative, participative and interactive enterprise modeling. In: Filipe, J., Cordeiro, J. (eds.) ICEIS 2009. LNBIP, vol. 24, pp. 651–662. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-01347-8_54
4. Bennett, B.: Understanding, Assessing, and Responding to Terrorism: Protecting Critical Infrastructure and Personnel. Wiley, Hoboken (2007)
5. Bollinger, L.A.: Fostering climate resilient electricity infrastructure (2015). http://repository.tudelft.nl/islandora/object/uuid:d45aea59-a449-46ad-ace1-3254529c05f4/datastream/OBJ/download. Accessed 06 Dec 2016
6. DNV GL: Microgrid optimizer - a holistic operational simulation tool to maximize economic value or electrical power reliability (2016).. http://production.presstogo.com/fileroot7/gallery/DNVGL/files/original/3a1dd794f6ff46b9a279175c15af0f11.pdf. Accessed 05 Dec 2016
7. Dugan, R., McGranaghan, M.: Sim city. IEEE Power Mag. **9**(5), 74–81 (2011)
8. ETAP Grid: Power technologies international (2015). http://etap.com/Documents/Download%20PDF/ETAP-Grid-2015-LQ.pdf (2015). Accessed 19 Jan 2017
9. IEC: White paper - microgrids for disaster preparedness and recovery with electricity continuity and systems. Technical report, IEC WP Microgrids, Switzerland (2014)
10. IRENE: D2.2 - Root causes identification and societal impact analysis. Technical report (2016)
11. IRENE: D3.1 - System architecture design, supply demand model and simulation. Technical report (2016)
12. Jung, O., et al.: Towards a collaborative framework to improve urban grid resilience. In: Proceedings of 2016 IEEE International Energy Conference (ENERGYCON), 4–8 April, pp. 1–6. IEEE (2016). https://doi.org/10.1109/ENERGYCON.2016.7513887
13. Lau, E.T., Chai, K.K., Chen, Y., Vasenev, A.: Towards improving resilience of smart urban electricity networks by interactively assessing potential microgrids. In: Proceedings of the 6th International Conference on Smart Cities and Green ICT Systems (SmartGreens 2017), Porto, Portugal, 22–24 April 2017, pp. 1–8 (2017). https://doi.org/10.5220/0006377803520359
14. Le, A., Chen, Y., Chai, K.K., Vasenev, A., Montoya, L.: Assessing loss event frequencies of smart grid cyber threats: encoding flexibility into FAIR using bayesian network approach. In: Hu, J., Leung, V.C.M., Yang, K., Zhang, Y., Gao, J., Yang, S. (eds.) Smart Grid Inspired Future Technologies. LNICST, vol. 175, pp. 43–51. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-47729-9_5

15. lp_solve: Introduction to lp_solve 5.5.2.5 (2015). http://lpsolve.sourceforge.net/5.5/. Accessed 19 Oct 2016
16. Siemens PTI: Power technologies international (2016). http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/planning-data-management-software/PTI/Pages/Power-Technologies-International-(PTI).aspx. Accessed 19 Jan 2017
17. Stauffer, N.: The microgrid - a small-scale flexible, reliable source of energy (2012). http://energy.mit.edu/news/the-microgrid/. Accessed 19 Jan 2017
18. Vasenev, A., Montoya Morales, A.L.: Analysing non-malicious threats to urban smart grids by interrelating threats and threat taxonomies. In: Proceedings of 2016 IEEE International Smart Cities Conference (ISC2), Trento, Italy, 12–15 September 2016, pp. 1–4. IEEE (2016)
19. Vasenev, A., Montoya Morales, A.L., Ceccarelli, A.: A Hazus-based method for assessing robustness of electricity supply to critical smart grid consumers during flood events. In: Proceedings of the 11th International Conference on Availability, Reliability and Security, ARES 2016, Salzburg, Austria, 31 August–02 September 2016, pp. 223–228. IEEE (2016)
20. Vasenev, A., Montoya, L., Ceccarelli, A., Le, A., Ionita, D.: Threat navigator: grouping and ranking malicious external threats to current and future urban smart grids. In: Hu, J., Leung, V.C.M., Yang, K., Zhang, Y., Gao, J., Yang, S. (eds.) Smart Grid Inspired Future Technologies. LNICST, vol. 175, pp. 184–192. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-47729-9_19
21. Zubelzu, S., Alvarez, R., Hernandez, A.: Methodology to calculate the carbon footprint of household land use in the urban planning stage. Land Use Policy **48**, 223–235 (2015)