Dynamic dual-layer network resilience assessment as a system architecting tool

Giota Paparistodimou[1]
BAE Systems
Research and Technology, 1471 South Street, Scotstoun, Glasgow, G14 0XN
giota.paparistodimou@baesystems.com

Philip Knight
University of Strathclyde
16 Richmond Street, Glasgow G1 1XQ
p.a.knight@strath.ac.uk

Malcolm Robb
BAE Systems
Research and Technology, 1471 South Street, Scotstoun, Glasgow, G14 0XN
Malcolm.Robb@baesystems.com

Gail Hughes
BAE Systems
Research and Technology, 1471 South Street, Scotstoun, Glasgow, G14 0XN
gail.hughes@baesystems.com

ABSTRACT

Modern complex systems should be resiliently designed to enable recovery in a variety of expected or unexpected environments. Resilience is defined as the ability to withstand and recover from disruptive events. The objective of developing resilient systems drives the need of analysis tools to guide the system architecture process. There is a need for the creation of resilience tools that are time-based and are applicable for the system architecture process. The larger literature offers a variety of methods and quantitative metrics for assessing resilience. Still, there is a lack of system architecting tools that focus on assessing the resilience of system architecture options considering the dual nature of the system's physical

[1] giota.paparistodimou@baesystems.com
Corresponding author information can be added as a footnote.

and functional aspects while taking into account the design of redundancy into the system's recoverability behavior. To bridge this gap, this paper proposes a dynamic network-based resilience assessment method that models systems as a dual layer functional and physical network. The method, which has been developed into a computational tool, generates a measure of resilience that serves as a quantitative evaluation indicator during system architecting. As a case study, the method is applied to eight power and propulsion system architecture options. The findings demonstrate that, even before a system architecture has matured, the tool supports informed decision-making, for example in terms of measuring the effectiveness of redundancy introduced to improve resilience, as well as early detection of system vulnerabilities.

SECTION 1: INTRODUCTION

Factors driving the need to design resilient systems include the growth in the scale and complexity of systems, the unpredictable nature of future threats and the drive for automated systems. As systems grow in complexity and sophistication, they become more unpredictable due to emerging behavior caused by interactions between interwoven parts [1], making resilience design and analysis an important and challenging task. The type and extent of future disruptions and their impact on the physical and functional aspects of systems becomes more difficult to forecast and analyze due to increasing unpredictability of the future threats and the essential complexity of the modern systems. The focus on designing autonomous systems necessitates the designing of resilient systems, as autonomous systems must be architecturally intrinsically resilient to withstand or recover from any anticipated or unforeseen disruption (relying less on humans to actuate a recovery from disruption).

These factors make the resilience concept central during the system architecture process, illustrating the importance of carefully analyzing their effects and a system's post-disruption recovery behavior driven by the complex architecture of the system. As redundancy is a common means of improving robustness and resilience, the appropriate level of redundancy and the appropriate type of redundancy that enable improved recoverability behavior post disruption become pertinent to the concept of resilience during the system architecture process. This underlines the significance of considering resilience of the system analytically and dynamically during the system architecture process to determine the most appropriate system architectural option and mitigate architectural vulnerabilities and to improve resilience inherently.

Much emphasis has been on developing resilient systems capable of maintaining or replenishing capabilities to address the challenges of predicting and preventing future disruptive events[2]. Resilience characterizes the ability to withstand disruptive events and to recover, and the wider literature offers various metrics and quantitative approaches to assess and develop resilient systems [3,4]. Methods and tools to support the assessment of alternative system architectures, particularly in early design, could be valuable in assisting informed decision making. Even though resilience of complex systems is a well-studied topic, assessment methods applicable to the early-stage design of systems that consider the dual physical and functional nature of systems and combined a recoverability analysis driven by the design of redundancy were not identified in the literature. This paper proposes a dynamic network-based method to cover this gap.

The proposed method evaluates the resilience of alternative system architecture options. A resilient system is defined as one where performance does not fall below a minimum criterion and that recovers to satisfactory performance within an acceptable restoration time post-disruption. The method described herein models a system architecture option as a dual layer functional and spatial network. The functional network represents the functional flows (for example energy, fluid, or information) of the components and the physical network catalogues their physical location in the system’s spatial dimensions. In the functional network, components are classified as operational (live at the instant prior to disruption) or standby/redundant (off prior to disruption but ready to start up post-disruption). The model allows all components to have a user-defined time to start up, which is utilized when standby components are starting up after a disruption. The method can systematically simulate different combinations of physical disruptions. After a disruption, the recovery process is initialized and actuated step-by-step according to a user-defined recovery strategy that automatically starts up standby components based on the component-specific start up times. The resilience is measured using two criteria: whether satisfactory performance is reached within an acceptable recovery time, and whether a minimum post-disruption performance level is always met.

The case study presented demonstrates the method's application to eight ship system options (Section 4). For each system architecture option, the method generates a resilience metric that allows for comparison and evaluation. It also provides information about the design of a recovery strategy. The method identifies the disruption events that result in zero resilience and, by evaluating such events, design improvements can be made.

The findings of the case study demonstrate the importance of carefully assessing the effectiveness of various types and levels of redundancy for recoverability, as well as identifying physical and functional system vulnerabilities at an early stage. The method is useful because it can provide quick insights during the system architecture process before the architecture matures and can assist in decision making when critical decisions must be made. Stakeholders can use the method to evaluate various system options and choose the preferred type of redundancy; physical and functional system architecture; and system recovery strategies.

The article is organized as follows: Section 2 offers a background literature review; Section 3 presents the proposed dynamic dual-layer network resilience assessment method; Section 4 presents the case study; Section 5 presents and discusses the results and explains their significance; and Section 6 outlines limitations, future research and conclusions.

SECTION 2: BACKGROUND LITERATURE

Definitions of resilience

Various definitions of resilience are found in the wider literature. Resilience is defined as “how a system rebounds from disrupting or traumatic events and returns to previous or normal activities”[5]. Similarly, resilience is explained as a “capability of a system to maintain its function and structure in the face of internal and external change and to degrade gracefully when it must" [6], and is a measure of "a system's ability to absorb continuous and unpredictable change and still maintain its vital functions" [7]. In addition, resilience is described as the "ability of a system to withstand a major disruption within acceptable degradation parameters and to recover with a suitable time and reasonable costs and risks" [8]. Resilience focusses on the "inherent ability of systems to absorb the effects of a disruption to their performance, referring to preparedness activities, and more recent definitions also account for the recovery of their performance" [4]. In quantitative terms, resilience is defined as the "ratio of recovery at time t to loss suffered by the system at some previous point in time t_d" [3] or as the chance that the initial system performance loss after a disruption is less than the maximum acceptable performance loss, and the time to complete recovery is less than the maximum acceptable disruption time [9].

These definitions highlight key aspects of resilience, such as it being a time-based dynamic property of systems[10,11], exhibiting manageable degradation after disruption[5], and relating to major (and potentially unpredictable) disruptions[12]. The notion of resilience, in terms of preserving and restoring important system functions following disruptions, is highlighted. Overall recovery/rebound, absorption, improvement, graceful degradation/extensibility, minimal deterioration, sustained adaptability, and survival are aspects of resilience that are mentioned in the literature. [5,13]

Generally, resilience is based on a "system level delivery function or figure-of-merit" [3] enabling the system performance to be calculated prior, during and post disruption. In addition, resilience measures frequently evaluate the performance of a system before and after a disruption [4]. In the resilience literature there are a wide range of performance objective variables that are aimed to be either minimized, preserved or maximized; however typically resilience metrics use performance variables that maximize or restore the system function to normal operations or acceptable level post disruption[13].

Wider literature on resilience methods

Literature reviews on resilience metrics and methods for engineering systems [4,14–17] provide a comprehensive background to better appreciate the methods available in the field.

In the literature [4] quantitative resilience assessment approaches are categorized into: general measures (deterministic, probabilistic, dynamic, static) and structural-based models (optimization, simulation and fuzzy logic models).

Deterministic resilience methods do not consider uncertainty as part of the resilience metric, while probabilistic capture the stochasticity associated with the system behavior[4]. For example, a deterministic resilience method that is time-dependent such as [3] measures resilience as the ratio of recovery to loss, by measuring the performance at time steps key for resilience (stable original state, disrupted state, stable recovered state). Resilience time-based method such as [23] that introduced a quantitative approach evaluating critical functionality over time, demonstrating how resilience and robustness can be achieved by trading off design parameters.

Probabilistic approaches can be used to calculate resilience, for example the probability of full recovery within an acceptable time in terms of the scale of the initial performance loss [18]. More examples of probabilistic approaches are of [19,20] that that proposed a Bayesian networks method for modelling and predicting the resilience of engineering system under various disruptions.

Structural-based optimization approaches focus on analyzing the system topology. [21] developed a method to optimize the network recovery by identifying optimal recovery modes and sequences. An example of a simulation-based approach is of [22] that uses topology generation simulation to analyze resilience by assessing the network ability to provide the required service level under large-scale and significant failures.

In general, the limitation of the non-structural driven methods is that they assess resilience by assessing the performance of the system irrespective of the structure of the system and system-specific features. Performance-based resilience models are “based on the set of physics equations that govern the dynamics of the system”[16]. In contrast, structural-based approaches assess the structure driven resilience, and examined how the resilience behavior is driven by the changes in the structure of the system.[16] .

The method proposed in this research article adds to the stream of structural-graph/network-based methods for resilience assessment while also investigating the effects of redundancy on recovery and assessing resilience; thus, the following paragraphs review areas relevant to this work contribution.

Graph/network theory and multilayer networks approaches for resilience

Research has explored graph-theoretic approaches for enhancing resilience in complex engineered systems. Graph/network theory approaches are structurally driven methodologies that analyze how the system's topology impacts resilience.

[23]proposed a graph spectral method to calculate system resilience and identify vulnerable components. [24]compared different graph-theoretic metrics for resilient System of Systems design, identifying density, modularity, and vulnerability among others as metrics that might be employed as early-stage design tools. [25] proposed a complex network framework for assessment of systems of systems robustness based on single and multi-layer networks using algebraic connectivity, inverse average path length, and largest connected component size as measures of robustness. These studies highlight the graph/network metrics ability to support early concept stage studies due to their efficiency to assess alternatives. However, these graph/network-based methods do not consider the network recovery driven on the redundancy designed in the network.

[26] presented a graph learning-based generative design method for resilient interdependent network systems, combining a performance estimator and candidate design generator to efficiently create robust designs. These studies reinforce the ability of graph/network theory in evaluating and improving system resilience, particularly in early design stages, without requiring detailed performance simulations [24,26].

Multilayer network models are increasingly used to analyze resilience in complex engineering systems. These models can represent interdependencies between different aspects of the system aiding assessment of system resilience. Various methods have been employed, with percolation theory being the most common approach[27]. Multi-layer methods have been identified in the literature such as for communication systems [28,29], for infrastructure systems[30–32] and for cyber physical systems and power grids [33–35]. However, these methods are not tailored for use for resilience assessment purposes in the early stages of design and do not consider the alternative design of redundancy on the recovery.

Network-based vulnerability analysis methods for early design stages in the field of naval engineering have also been proposed [36,37]. In particular,[36] proposed a multilayer network method using bipartite networks and their duals to model the physical and logical systems on a ship. This method has the advantage of detecting vulnerabilities that would otherwise go undetected if the functional and physical networks were examined independently. However, these method analysis does not dynamically consider post-disruption behavior of the system and does not analyze the effects of redundancy.

After a disruption, the behavior of a system performance fluctuates over time as the system reconfigures. It is acknowledged that “addition of dynamics to the network could prove useful in identifying other types of weakness in a design that can further inform naval decision makers” [37]. The need for dynamic analysis points to the need to examine the resilience of the systems by methods that captures the time-based behavior of the system.

In the wider network science literature, the concept of time-varying or temporal networks is suggested[38,39]. A temporal network can be simulated using a series of static network snapshots [39]. The network literature offers measures on assessing the robustness of temporal networks [40], aiding the efforts of analysis of the time-varying networks. This research paper utilizes concepts from multilayer time-varying network modelling to develop a methodology and a design tool that is appropriate for the early design stage, filling a gap in the literature that currently does not assess resilience in respect to the redundancy design for recoverability during the early system design stage.

Designing redundancy for resilience

Redundancy plays a crucial role in enhancing system resilience across various domains. In safety systems, redundancy is identified as a key source of resilient properties [41]. [42] explained that in systems engineering "redundancy discussions tend to centre around which components to make redundant, how much redundancy there should be, and what form the redundancy should take".

[43,44]proposed methods to address failure interactions in both binary and multistate systems, introducing a Modified Analytic Hierarchy Process and semi-Markov process models, respectively. [45] developed a method to determine feasible alternative SoS configurations that restore performance after a system failure, and also to anticipate gradual system degradation and transition to alternative configurations before failure occurs. In the network science, for self-healing systems modeled as

complex networks, adding redundant edges improves resilience to failures, though with diminishing returns [46].

Overall, these studies demonstrate that, redundancy implementation requires careful consideration of specific contexts and potential trade-offs. In engineering system design, traditionally engineers and designers focus in introducing redundancy as a qualitative heuristic to improve resilience [24]. Conversely, introducing more than required redundancy to improve resilience has diminishing returns as the overuse of redundancy leads to higher design, production and, operating costs, higher development time, higher complexity in the systems, addition use of use of resources from the environment, or more waste or emission levels[24,47]. This emphasizes the need for early design tools that allow for quantitative analysis and assessment of the effects of redundancy designed into system architecture options on recovery and early assessment of resilience.

Research novelties and main contribution

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The main novelties of the article are following:

1. The methodological concept of simulating a dual physical and functional layer time varying network model is distinct in the field of engineering system design resilience research. The tool simulates the dual layer physical and functional network model states prior, during disruption and in time steps immediately after disruption when standby redundancy kicks to enable recovery enabling resilience investigation.

2. The methodology offers an analytical early-stage design tool to assess the role of redundant components in managing resilience in physical and functional system descriptions which is a new approach in the literature. This aids in the transition away from the qualitative design heuristic approach and toward systematic redundancy analysis on resilience at an early design stage. Furthermore, it contributes to the combined design decision-making of the physical and functional aspects of the system, which may occur separately in different engineering teams and have a negative impact on resilience that will only be discovered later in the system's development life.

The article's main contribution is the development of a dual layer time-varying network model-based methodology as a design tool tailored for the engineering design field to support engineers and decision makers at early design stages. Deciding the physical, functional, and redundancy aspects of a system architecture are critical system engineering questions that must be answered early on and have significant influence on the successful development and operation of a resilient system through its life.

SECTION 3: DYNAMIC DUAL-LAYER NETWORK RESILIENCE ASSESSMENT METHOD

In this Section, the proposed method is presented. The stages of the method are the following: definition of inputs, systems modelling, performance metric calculation, disruption scenarios simulations, recovery strategy activation, and resilience assessment. The proposed system architecting tool is a computational implementation of the method written in MATLAB.

Input definition

The user defines the system architecture option under assessment, the disruption scenarios, recovery strategy, and the resilience assessment criteria. Inputs 1-10 are further explained below.

Input 1

Describes the system option's entire functional connectivity between its components as a network. The components are the nodes of the network and the functional flows are the edges. All the components of the system (live and standby) and all the functional flows (live and standby) are modelled. Nodes in the functional network represent components such as generators, pumps, and switches. Edges between nodes are directed, respecting the direction of flow between components.

Input 2

Defines the system spatial dimensions. Nodes of the physical network represent a point in the spatial unit; for example, one node will represent: x=1, y=5. Edges in the physical network represent physical adjacency. This creates a two-dimensional lattice network that represents the system's simplified spatial dimensions. Each point in this lattice network is assumed to be a spatial unit.

Input 3

Defines the location of components in each spatial unit in the lattice network (see Input 2). In this way, each component of the functional network (see Input 1) is assigned a location in the physical lattice network.

Input 4

Defines which components of the whole functional network are considered as operational/live and which are standby (redundant) components at the initial state, prior to disruption. This is the key input for defining the type and level redundancy. This allows the user to define different styles of redundancy (principle, selective, partial, standby and stand in) depending on the specifics of the system under consideration.

Input 5

Defines source (supply) and demand (sink) components of the system. Source nodes must have an outward flow (e.g., electricity, water, air, information), whereas demand nodes must have inward flow (e.g., electricity source component, sea water, chilled water, compressed air). Also, it is possible for a demand to have an outward flow if it is an intermediate component (e.g., a power unit that links to a downstream function). Thus, a component can have a dual role. For example, a sea water pump is a demand for electrical flow, and a source for the water.

Input 6

Defines the maximum number of components (k) to be incapacitated (removed) during each disruption simulation scenario. In each attack, removal is limited to components within a spatial unit or adjacent spatial units.

Input 7

Defines the start-up times for components to become functionally available post-disruption. Thus, if a component is marked as standby, it may take some time before it is operational. However, a standby component that is disrupted cannot start up.

Input 8

Defines the minimum performance criterion that the system is required to achieve immediately post-disruption.

Input 9

Defines the satisfactory performance criterion for a system to be deemed to have recovered.

Input 10

The time (t_r) by which the system needs to have recovered to acceptable performance after a disruption.

System modelling

The method employs a dual layer network approach based on two networks: a functional network (Input 1) and a physical network (Input 2) and creates relationships between the two networks by relating the components of the functional network to the physical network (Input 3: locating components of functional network on the physical lattice network). The physical and functional networks are linked by means of an undirected bipartite graph where an edge represents the relationship “this component resides in this space” (or vice versa). Using the bipartite relationship, a physical topology of equipment location is developed by recording the equipment that is located in each spatial unit. The operational function network with the initial status prior to disruption is generated by taking Input 1 (the entire functional network) and removing connections emanating from or heading to standby components defined at Input 4. In this way, the operational function network includes only components that are operational prior to disruption. In other words, the operational functional network is a snapshot of the entire functional network, restricted to active components. Different operational functional networks can be used as the starting point for the analysis.

The system network representation changes over time. The initial state is the operational functional network prior to disruption; next the disrupted functional network excludes components negatively affected by a disruption; subsequently the method uses a network that includes standby redundancy components while still excluding anything that suffers disruption.

Figure 1 illustrates an example of dual layer functional and physical network prior to disruption depicting the source components (S) and demand component (D). The white colour indicates the components are alive/operational prior to disruption, and grey colour indicates redundant components in standby condition. The definitions of Inputs 1 to 5 define the system's operational state.

Performance measure

The ability of the operational network to behave as expected at a particular time is measured by a performance metric previously presented in the literature [47,48]. Performance is measured by examining the number of ways in which sources can connect to demand (sink nodes). Inputs for the performance metric are the entire functional network (Input 1), source and demand components (Input 5), and a list of operational and standby components (Input 4). The metric is designed to answer the question "can the system maintain or restore supply to the different flow demands?" and is evaluated at each time-step: before, during and post-disruption.

This metric calculates the ratio of the level of directed connectivity between sources and demands corresponding to the required performance at the initial state. After a disruption it can be updated dynamically to take account of reconfigurations of the system.

The performance metric operates with binary variables that take the value 1 if a flow reaches a demand component from a supply, and 0 otherwise. This is determined by checking the existence of paths that are necessary for performance between operational sources from the set $S = \{s_1, s_2, \ldots, s_n\}$ to the demands $O = \{o_1, o_2, \ldots, o_m\}$. A binary vector t is introduced whose i_{th} component equals 1 if and only if there exists a path from an operational source to demand o_i.

When a system reconfigures, due to the designed redundancy, then there may be a number of different sets of demands that correspond to full performance (for example, if there are two power packs then it may be only necessary for one of these to be operational). So, to measure performance the quantity:

$$R_C(G) = \frac{1}{M} \sum_{i=1}^{M} t_{k_i} \quad (1)$$

is calculated for each acceptable set of demands $C = \left\{o_{k_1}, o_{k_2}, \ldots, o_{k_M}\right\}$ and the performance is the maximum value of R_C over all possible sets C, that is:

$$Perf = \max_C R_C \quad (2)$$

The quantity *Perf* takes values in the range 0 to 1 and full performance is only achieved if *Perf* = 1, which means that at least one combination of connections that permits each of the required flows has been established. The measure can be calculated at every time step of the process.

This measure, $R_C(G)$, is time and graph/network dependent meaning that it depends on the choice of sources and demands.

Disruption scenarios

To assess the resilience of a system option, the simulation of various types of disruption is recommended. The method uses the physical network to pinpoint a disruption and the functional network's resilience is evaluated using the bipartite dual layer networks. To simulate the disruption, information from the definition of the physical network is required as per Inputs 2 and 3.

The physical network is used to determine which nearby components are affected if the disruption spreads beyond a single component. Note that a disruption of a component/node is simulated by incapacitating the node and any edges linked to that node (by setting rows and columns of the adjacency matrix of the operational network to zero).

A disruption is modelled through the network layers by identifying any possible combination of a given maximum number of components (as defined in Input 6: number of disrupted components) located either in the same or in adjacent spatial unit. For example, if the user defines Input 6 as k=3, the tool will evaluate all single component disruptions, any combination of two component disruptions, and any combination of three component disruptions.

The components in the physical network targeted for disruption are then removed in the functional network, and assessment of the performance of the network is calculated at each time step post-disruption by measuring resilience. Performance can change as the recovery strategy is enforced. The approach is deterministic and exhaustive as it identifies all possible combinations of physical disruptions but, by limiting combinations to those components which are co-located, stops the number of combinations growing too fast and allows for efficient computation.

The size of the system under evaluation should be used to determine the number of components (*k*) that need to be combined.

The Figure 2 depicts an example of disruption (snapshot) that is simulated in the physical network (*k*=2), and the results of the disruption are reflected in the functional network layer. The dark pattern shaded components and dotted connections indicate the two disrupted components, white are the components and black connections still working, and grey components and connections are redundant component at standby mode.

Recovery strategy

The recovery strategy entails reconfiguring the system to operate with alternative redundancy standby components and connections after a disruptive event occurs. This recovery strategy is defined based on the user-defined Input 4 (operational and standby components) and Input 7 (standby components start up times). The recovery is dependent on which components were on standby at the time a disruption happened, and their start up time. The user can alter the recovery strategy for specific system options by changing the relevant inputs.

The recovery strategy assumes that, unless destroyed by the disruption, all standby redundancy components are to be immediately given instruction to start up by a switching mechanism. The recovery strategy's goal is to recover the system to the user-defined satisfactory performance (Input 9), within the time frame specified as per the objective restoration time (t_r) defined in Input 10.

At each time step, recovery consists of adding edges to the disrupted network from the original functional network (Input 1). At one end of the edge is an undamaged standby component that has reached its start-up time, at the other is another piece of undamaged equipment (which could be another standby component). A functional flow is considered as recovered if the components feeding and demanding of the flow are available (Figure 3). That means components of the functional flow path between source and demand were either not affected by disruption or have become available due to standby redundant components coming online.

Figure 3 exemplifies a two-step recovery process where at the time step immediately post-disruption one component becomes available, and at the next time step a second component becomes available enabling the recovery of the network.

Resilience measure

Given the metrics introduced in this article, it is natural to define a resilient system if it meets the following two criteria:

- Performance must remain above a minimum value (Input 8) immediately post-disruption and throughout the recovery process.
- Performance recovers to reach a satisfactory level (Input 9) within an acceptable time.

To test, a series of simulations, which represent a variety of disruptions and recoveries, are run on a system option (*Opt*) and the performance measure is checked at constant time intervals throughout the process. The method records the performance immediately post-disruption and compares against the user-defined minimum value (Input 8). The satisfactory performance criterion (Input 9) is satisfied when all the required demand nodes are connected to sufficient available source nodes before the objective restoration time (Input 10) is reached. Thus, a resilient system option is expected to recover the satisfactory performance within the acceptable restoration time and does not fall under a minimum performance post-disruption.

The resilience metric can be calculated as the potency of an attack increases. Potency is measured in terms of the number of components that are damaged in a disruption, making sure the topology of the system is respected, according to the spatial network (Input 2). By removing all physically possible (same or adjacent spatial unit) combinations of a fixed number of components (k), the resilience (as a function of potency) is measured by calculating the fraction of scenarios that result in full recovery (either by successful employment of standby components or by the design withstanding an attack without compromising performance).

That is, the resilience of the system option (*Opt*) is given by equation 3.

$$Res(Opt, k) = \frac{\#recoveries}{\#events} \qquad (3)$$

Where k is the number of components damaged in a disruption (operational or standby), *#events* count all possible combinations of damaging k components and *#recoveries* count the number of combinations where the system meets the two resilience criteria. The user defines k based on the potency of disruption that requires the system to be analysed. The resilience can be averaged over varying intensities of attack to give a mean resilience $\overline{Res}$ given by equation 4. The resilience is average, given that the potency of attacks considered for assessment purposes is equal importance for compliance.

$$\overline{Res} = \frac{1}{k_{max}} \sum_{k=1}^{k_{max}} Res(Opt, k) \quad (4)$$

Figure 4 shows an example representing the process illustrating the example network states prior, during and post-disruption. The minimum performance and satisfactory performance criteria are assessed for each state post-disruption.

SECTION 4: CASE STUDY

This section presents a case study to demonstrate the applicability and utility of the proposed method for assessing the resilience of alternative ship system options. The options were derived from a generic naval ship power and propulsion system design, and do not represent real technical systems. The intention is to demonstrate the ability of the method to evaluate alternative options and identify vulnerabilities in the design. The case study additionally demonstrates the method's use in a Design of Experiments (DOE) setting with the aim of systematically evaluating the impacts of various design variables on resilience.

Generic ship system

In the generic system presented in Figure 5, power is generated by four main sources (two diesel generators and two gas turbines) that supply to two High Voltage (HV) Switchboards, which then power the two propulsion motors (via converters). The HV Switchboards are also linked to two transformers, which feed two 440 Voltage Switchboards (LV Switchboards), which then supply to twelve electrical distributor centres (EDCs) that in turn feed twelve consumers. There are two Steering Gear Power Packs; one is redundant. Each Steering Gear Power Pack is fed by both LV Switchboard 1 and LV Switchboard 2. An emergency generator and an emergency switchboard are included, which power the odd numbered EDCs and the two steering gear power packs. The HV Switchboards are linked by two HV Interconnectors and the LV Switchboards are linked by two LV Interconnectors. There are two main operational sources (one diesel generator and one gas turbine) each connected to a discrete HV Switchboard prior to disruption. The generic design does not include standby batteries. The general set up operational condition status prior to disruption was set as follows: LV Switchboard interconnectors are on standby, only one HV Switchboard interconnector is connected (second HV Switchboard interconnector on standby), emergency generator and emergency switchboard are on standby, only one steering gear in operation (second steering gear on standby), and both propulsion motors are live. The odd number consumers are live (Consumers 1,3,5,7,9,11) with the even consumers (Consumers 2,4,6,8,10,12) on standby. Therefore, several components are operational (white colour in Figure 5) at the initial state and other are on standby (grey colour in Figure 5) indicating a level of redundancy. In this system, stand in redundancy is designed for the main sources (the system architecture design has four main sources but only one or two are available at normal operational state). The ship is spatially arranged into 12-zones (Zone A to Zone L) and 6-decks (Deck 1 to Deck 6). The location of each component is based on its zone and deck placement as illustrated in Figure 6.

Generation of alternative system options

In the case study, the generic power and propulsion system option is varied based on three design variables (Table 2). The variation of the design variables results in different system options that have different levels of redundancy.

The design variables present engineering decisions that define system architecture of an option and are systematically changed to generate the eight options. For each design variable there are two engineering choices as presented in Table 2. They were chosen because they provide insights into three topics that are often of interest during the early-stage ship design:

- Variable 1 is concerned with the effect of adding batteries to the LV Switchboard.
- Variable 2 selects the intermediate level redundancy style between LV Switchboard, EDCs and consumers. There are two configurations for this: Alternative Supply (AS) and Double Supply (DS). An example of AS can be seen in Figure 7 (Option 2) where LV Switchboard 1 supplies the odd-numbered EDCs and LV Switchboard 2 supplies the even-numbered EDCs. An example of DS can be seen in Figure 8 (Option 3) where LV Switchboard 1 supplies all 12 EDCs and LV Switchboard 2 also supplies all 12 EDCs. The DS configuration designs redundancy at EDC level and AS designs redundancy at consumer level.
- Variable 3 allows for tests to determine how many main sources of electrical equipment (given a choice of 3 sources or 4) are advantageous for resilience.

A full factorial 2^3 DOE approach (two-level, full factorial design for three factors) is adopted to generate the different system options described in Table 3. The DOE approach used in the case study intends to demonstrate the tool and is suggested to support the generation of a limited number of alternatives based on an original system architecture, with a focus on specific redundancy styles that are being considered by the designers/user of the tool.

To design experiments to evaluate the resilience of the options, assumptions were made: the first related to the disruptive events, and the second to the physical size of the ship. The first assumption is that all options have the same operational status prior to disruption. This means that the number of operational sources prior to disruption is the same–only two are live in the operational network prior to disruption for all the eight options, and the disruptive event approaches are applied identically to all options. The second assumption is that the spatial dimensions of the ship, as defined by the number of zones and decks, are identical for all design options. In addition, the physical location of the equipment remains consistent across the options, as does the definition of resilience assessment criteria. This allows for comparisons based on the ship- systems option design variables described in Table 2.

The inputs tables and functional schematics for each option (Options 1 to 8) are shown in Table 4 to Table 11; they are read directly into the proposed tool for carrying out the resilience assessment.

Disruptions and performance criteria

A disruption is expected to affect the operation, and standby redundant components are expected to start up based on their start up times. Experiments simulated the systematic removal of components based on their physical location. All possible combinations of up to 4 components (*k*<=4), located in the same zone or adjacent zones on the same deck, were removed sequentially, simulating different possible disruptions for a particular disruption approach, each of the options was assessed based on the two performance criteria outlined in the previous part of the methodology (Resilience measure paragraph):

- Performance must remain above a minimum performance criterion (Input 8) immediately post disruption and throughout the recovery process.
- Performance recovers to reach the satisfactory performance criterion (Input 9) within an acceptable time.

Both criteria have to be met in order for the design to be considered resilient. The performance criteria definition is presented in Table 12.

SECTION 5: RESULTS AND DISCUSSION

Table 13 presents the resilience results for each option as calculated from the proposed tool. The resilience results range between 0 resilience (fragile system) to 1 that is 100% resilience (super-resilient system).

Additionally, Table 14 offers a summary of the pair component disruption that will result at zero resilience for each Option. Please note the numbers in the brackets are the identifiers of the components, and the name of the component corresponding to each identifier can be found in Table 4 to Table 11.

The discussion is divided into two parts. The first section presents specific disruption scenarios that were identified as having zero resilience, which means that either satisfactory performance was not able to be achieved post-disruption or system performance fell below the minimum performance, or both. These findings identified specific design vulnerabilities in the options, allowing for the consideration of mitigation design strategies and reflection on the aspects of the design driving the vulnerabilities. The second section of the discussion presents the overall resilience assessment results. The design options are ranked based on the calculated resilience metric, and a discussion of the most and least resilient options is included. Additionally, the mean effect and interaction plots are presented, discussing the effects of the three design variables on resilience.

Vulnerabilities identification

The system architectures alternatives are assessed against system requirements that set the minimum performance post disruption and the maximum recovery duration. These system requirements are equally important in respect to resilience for the naval ship case study.

A number of design vulnerabilities (when the resilience metric is calculated as zero) were identified in the case study, as described in the following. The following discussion is based on the results presented in the Table 14 (List of two combined components disruption resulting at zero resilience).

Combined LV switchboard 2 & EDC3 disruption

For Option 1 there is a combination of two component failures, namely the LV Switchboard 2 and EDC 3, which resulted in zero resilience. By referring to Figure 6 for Option 1, it can be seen that LV Switchboard 2 (Component 12) and EDC 3 (Component 15) were positioned in same zone E, making them vulnerable to being disrupted together. EDC 4 received power through LV Switchboard 2, and because LV Switchboard 2 is also disrupted, EDC 4 cannot receive power. This is because the Emergency Switchboard only feeds EDCs 1, 3, 5, 7, 9, and 11, leaving EDC 4 without power. As EDC 4 cannot receive power, Consumers 3 & 4 cannot receive power and Option 1 therefore fails the “satisfactory performance criterion” outlined in Table 12. Mitigation strategies include the incorporation of additional alternative power supplies for EDC 4 either from Emergency Switchboard or from LV Switchboard 1.

Combined EDC disruption

The results identified that combinations of two or more EDCs disruptions were a vulnerability of design for all the options, principally because they were co-located in the same zone and deck, which makes them susceptible to simultaneous disruption. Here, an additional redundancy either at the EDC level or at the consumer level was located in the same zone. Redundancy included at the EDC level is counteracted by the fact that the redundant component was co-located at the same area as its operational twin, making it susceptible to disruption at the same time. However, it is acknowledged that redundancy is not only designed for resilience but also for maintenance and availability, explaining possible reasons for installing the redundant components in adjacent locations.

Mitigation strategies include re-locating components in different zones, decks or sides of the compartment for example either port or starboard to minimize the possibility of being disrupted at the same time. Another mitigation strategy is to provide structural reinforcement to protect EDCs from disruption.

Combined EDC & Consumer disruption

The results show that for design options 3, 4, 7 and 8, which have no redundancy at the consumer level (redundancy is at the EDC level), there were twelve two-component disruption scenarios that included an odd EDC (e.g., EDC1) and even consumer (e.g. Consumer 2) being removed at the same time that led to zero resilience. This indicates that the additional redundancy at the EDC level from LV Switchboard level failed to compensate for the lack of redundancy at consumer level. Possible mitigation strategies include the separation of EDCs from consumers minimizing the possibility that they could be disrupted together, or to include additional redundancy at the consumer level.

Combined Diesel Generator 3 & HV Switchboard 1 disruption

This disruption combination indicated that for options with three main sources (Option 2, 4, 6, and 8), a combined disruption involving HV Switchboard 1 fed by the two main sources (Diesel Generators 1 & 2), and removal of Diesel Generator 3 led to zero resilience. The disruption scenario mitigation approach is to ensure that HV Switchboard 1 and Diesel Generator 3 are located in different zones, or to ensure that additional redundant main sources are included in the system.

These examples demonstrate the method's ability to detect design vulnerabilities early in the design process. Without the aid of a quantitative analysis at early-stage ship design, experts may misidentify design vulnerabilities or misjudge benefits and drawbacks of redundancy when making early design decisions for ship systems. When these design vulnerabilities are discovered later in the development process, using detailed design tools, it may necessitate costly and time-consuming mitigation approaches and implementation of design changes to increase resilience.

Resilience assessment

The tool generates a resilience measure that allows for an evaluation of all eight options considered in the case study. Figure 17 depicts the mean resilience results from those shown in Table 13 in a sorted (Pareto) histogram chart containing columns sorted in descending order. The orange line represents the cumulative total percentage. Option 5 was identified as the design option with the highest resilience, a logical result agreeing with experts' subjective expectations as it incorporated the four main sources and additional batteries, and also redundancy at the consumer level. Option 1 was identified as the second-best resilience design option. This option had the four main sources, no batteries and redundancy at the consumer level. The method's identification of this particular option as second was not expected by the subject matter's experts and is worthy of more detailed investigation. Option 4, with three main sources, no batteries, and no redundancy at the consumer level had the worst resilience results. The second worst result was Option 2, which included three main sources, no batteries and redundancy at the consumer level. Again, this result was a logical result agreeing with the subject matter's experts' expectations.

The resilience results in Figure 18 show that the resilience behavior of system options changes when a higher number of components (k=1, 2, 3, 4) is removed, and that all the options had similar resilience behavior with the removal of a single component (k=1). However, the ranking of resilience does appear to stabilize once 2 components have been disrupted, although Options 6&7 switch places between 2 and 3 component disruptions.

In addition, Mean Effects plots (Figure 19) and Interactions plots (Figure 20) are generated based on using DOE (Taguchi Analysis) using Minitab software.

An interesting result (Figure 19) that the mean effects plot showed was that including redundancy at the consumer level (AS) was more beneficial than redundancy at the EDC level (DS). This result is one that is worthy of further investigation in order to evaluate the benefits and drawbacks of each style of redundancy. The DOE results, indicating that options with batteries (B) and options with 4 main sources (FM) instead of three main sources (TM) were of increased resilience, were expected - verifying the validity of the results that the proposed tool is generating.

The interaction plots (Figure 20) showed that options without batteries (NB) but with four main sources (FM) had higher resilience scores than options with batteries (B) but with three main sources (TM). Additionally, the interaction plots indicated that options with redundancy at the EDC level (DS) and four main sources were more resilient than options with redundancy at the consumer level (AS) and three main sources. Therefore, the number of main sources was the most influential design variable. An interesting result is that an option with batteries (B) and redundancy at the EDC level (DS) has a similar level of resilience as an option without batteries (NB) and redundancy at the consumer level (AS).

SECTION 6: REFLECTIONS

The methodology of this article shares key concepts with two previous works in the literature. The first is of the original work of [3], which introduced the concept of analyzing resilience as a function of time based on states (prior, during, and post disruption) and calculating a resilience metric based on a figure of merit. The other work to which this methodology relates is from naval ship engineering, where a static multilayer network method is proposed to analyze the vulnerability of ship distributed systems [36]. A comparison with these works is provided in Table 15 highlighting the novelties and the additional insights the proposed method offers.

Redundancy is a well-known engineering system design principle that increases system resilience. Determining the components and connections to design redundancy, as well as the amount and type of redundancy, are critical engineering design decisions made early in the development process. These decisions have an immediate impact on system architecture, development costs and time, system reliability, availability, and system performance. The tool enables comparisons of a number of alternative system architectures with different levels and styles of redundancy, highlighting the point of no return when increasing redundancy. Furthermore, the proposed method indicates potential inefficiencies in the design of redundancy that would be difficult to detect with a functional level analysis alone without the use of an early-stage design tool. The aspect of designing redundancy for resilience is not covered by the other methods in the literature [3,36]. This is beside the fact that such questions are common in early-stage design and are sometimes overlooked because different engineering disciplines deal with physical and functional designs separately, making decisions that ignore the impact on resilience. These design flaws are in some cases discovered after detail analysis, making them more expensive to correct. The design tool is suggested in an assessment and verification context. A prominent system architecture is developed by the designers, or mandated by the customer, or reused from previous projects. A system architecture iteration process occurs in which the level of redundancy, pattern, technology, and system vulnerabilities are examined. In this context, the tool provides quantitative evaluation indicators to assess a finite number of system architecture options, which may include different technologies, levels, and types of redundancy, during the early development stages when key decisions are made. The results are generated in a time-efficient modelling and analytical fashion, allowing for the rapid consideration and evaluation of resilience. The computational time efficiency of the tool is driven in the context of the constraints that are imposed to it during its development only realistically possible physical disruptions are simulated, system architecture descriptions are not suggested to be very large or high fidelity, and a limited number of alternative architectures are expected to be evaluated.

This provides input for quick decision-making before fixing the decisions for the system architectures. The generated results are also evidence of requirement compliance, allowing assurance that design decisions are aligned with objective requirements during system architecture process.

The results of the proposed method offer a starting point for a multi-parameter trade-off analysis. Different options of redundancy have different effects on performance, cost, construction-time, reliability, operability, ease of manufacture, and original equipment manufacturer delivery times. For example, the user can further the analysis by calculating the cost of the various system options and weighing them against the quantitative improvement that specific type of redundancy has had on resilience.

The findings of the case study are bound to these eight specific design options with the specific functional and physical architectures and are not intended for any generalization, but the proposed dual-network resilience assessment tool has a wider applicability. The method is intended as a system architecting tool where high-level system architecture is to be decided. The method is not intended to replace the use of detailed design tools, which are expected to be used later in the process to perform in-depth analysis.

SECTION 7: CONCLUSIONS AND FUTURE WORK

The paper describes a dynamic dual-layer network resilience assessment tool for the system architecture process. It was demonstrated in a case study by applying the tool to eight different system options and analysing the resulting resilience. The case study identifies component disruption combinations that result in zero resilience, enabling system architecture improvements in the system architecture. Furthermore, the resilience assessment classifies options from the most to the least resilient option, as well as evaluating the effects of different design variables that represent different types of redundancy on resilience.

The method is able to consider different system options easily and efficiently (in computational effort and time), allowing design changes or updates to be made quickly, and to identify design vulnerabilities enabling mitigation. The significance of this relates to the criticality of system architecture decisions, as decisions made have unintended design consequences have significant cost and project delay implications when identified and require rectification during the later stages of the design. The method provides resilience measurements with which to compare different systems options and demonstrate compliance with resilience requirements prior to the development of the detailed design. Furthermore, assessing the specific instances that lead to a calculated resilience of zero aids in identifying physical and functional vulnerabilities, and leads to system design improvements. This information is particularly useful during system architecting as this is when decisions on the functional redundancy and physical solution are typically taken. The method's advantages include the ability to accept low-information-fidelity inputs, integrate functional and physical analysis, model functional architectures composed of various flows, and dynamically simulate a disruption and recovery process. The method's drawback is that, because all measurements are binary, it is not feasible to calculate specific physical performance characteristics of the system's components.

A limitation of the tool is that it does not include a detailed physical representation of the system geometry. Another limitation of the tool is that it does not consider the propagation of cascading functional failures; this could be investigated in the future. Future research will aim to advance the tool to enable the component's transverse location to be defined. In addition, future research will concentrate on the automatic generation of alternative system options based on the optimisation of competing design variables such as time to recovery, redundancy level, cost of redundancy, and maximum achievable post-disruption performance. Future research avenues include assessing resilience in the face of a second sequential disruption and investigating system recovery if some of the standby redundant components do not start up as expected.

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NOMENCLATURE

AS	Alternate Supply
B	Battery
DOE	Design Of Experiment
DS	Double Supply
EDC	Electrical Distribution Centre
FM	Four Main sources
HV	High Voltage
LV	Low Voltage
NB	No Battery
SWB	Switchboard
TM	Three Main sources

REFERENCES

[1] INCOSE, 2023, *INCOSE Systems Engineering Handbook*, Wiley. [Online]. Available: https://www.wiley.com/en-us/INCOSE+Systems+Engineering+Handbook%2C+5th+Edition-p-9781119814313. [Accessed: 08-Jan-2025].

[2] Department of Defense, 2011, "FACT SHEET: Resilience of Space Capabilities." [Online]. Available: http://www.defense.gov/Portals/1/features/2011/0111_nsss/docs/DoDFactSheet-Resilience.pdf.

[3] Henry, D., and Emmanuel Ramirez-Marquez, J., 2012, "Generic Metrics and Quantitative Approaches for System Resilience as a Function of Time," Reliab Eng Syst Saf, **99**, pp. 114–122. https://doi.org/10.1016/j.ress.2011.09.002.

[4] Hosseini, S., Barker, K., and Ramirez-Marquez, J. E., 2015, "A Review of Definitions and Measures of System Resilience," Reliab Eng Syst Saf, **145**, pp. 47–61. https://doi.org/10.1016/j.ress.2015.08.006.

[5] Woods, D. D., 2015, "Four Concepts for Resilience and the Implications for the Future of Resilience Engineering," Reliab Eng Syst Saf, **141**, pp. 5–9. https://doi.org/10.1016/j.ress.2015.03.018.

[6] Allenby, B., and Fink, J., 2005, "Toward Inherently Secure and Resilient Societies," Science (1979), **309**(5737), pp. 1034–1036. https://doi.org/10.1126/science.1111534.

[7] Pregenzer, A. L., 2011, "Systems Resilience: A New Analytical Framework for Nuclear Nonproliferation," Albuquerque,NM:Sandia National Laboratories, **8**, pp. 1–21. https://doi.org/10.2172/1034890.

[8] Haimes, Y. Y., 2009, "On the Definition of Resilience in Systems," Risk Analysis, **29**(4), pp. 498–501. https://doi.org/10.1111/j.1539-6924.2009.01216.x.

[9] Chang, S. E., and Shinozuka, M., 2004, "Measuring Improvements in the Disaster Resilience of Communities," Earthquake Spectra, **20**(3), pp. 739–755. https://doi.org/10.1193/1.1775796.

[10] Mirchandani, C., 2020, "Resilience Modeling in Complex Systems," Procedia Comput Sci, **168**, pp. 232–240. https://doi.org/10.1016/j.procs.2020.02.262.

[11] Pumpuni-Lenss, G., Blackburn, T., and Garstenauer, A., 2017, "Resilience in Complex Systems: An Agent-Based Approach," Systems Engineering, **20**(2), pp. 158–172. https://doi.org/10.1002/SYS.21387.

[12] Weick, K. E., and Sutcliffe, K. M., 2011, "Managing the Unexpected: Resilient Performance in an Age of Uncertainty (Google EBook)," p. 224. [Online]. Available: https://books.google.com/books/about/Managing_the_Unexpected.html?id=GU55MJOp1OcC. [Accessed: 07-Jan-2025].

[13] Wied, M., Oehmen, J., and Welo, T., 2020, "Conceptualizing Resilience in Engineering Systems: An Analysis of the Literature," Systems Engineering, **23**(1), pp. 3–13. https://doi.org/10.1002/sys.21491.

[14] Cheng, Y., Elsayed, E. A., and Huang, Z., 2022, "Systems Resilience Assessments: A Review, Framework and Metrics," Int J Prod Res, **60**(2), pp. 595–622. https://doi.org/10.1080/00207543.2021.1971789.

[15] Naghshbandi, S. N., Varga, L., Purvis, A., McWilliam, R., Minisci, E., Vasile, M., Troffaes, M., Sedighi, T., Guo, W., Manley, E., and Jones, D. H., 2020, "A Review of Methods to Study Resilience of Complex Engineering and Engineered Systems," IEEE Access, **8**, pp. 87775–87799. https://doi.org/10.1109/ACCESS.2020.2992239.

[16] Cassottana, B., Roomi, M. M., Mashima, D., and Sansavini, G., 2023, "Resilience Analysis of Cyber-Physical Systems: A Review of Models and Methods," Risk Analysis, **43**(11), pp. 2359–2379. https://doi.org/10.1111/risa.14089.

[17] Yodo, N., and Wang, P., 2016, "Engineering Resilience Quantification and System Design Implications: A Literature Survey," Journal of Mechanical Design, **138**(11). https://doi.org/10.1115/1.4034223/384079.

[18] Chang, S. E., and Shinozuka, M., 2004, "Measuring Improvements in the Disaster Resilience of Communities," https://doi.org/10.1193/1.1775796, **20**(3), pp. 739–755. https://doi.org/10.1193/1.1775796.

[19] Yodo, N., Wang, P., and Zhou, Z., 2017, "Predictive Resilience Analysis of Complex Systems Using Dynamic Bayesian Networks," IEEE Trans Reliab, **66**(3), pp. 761–770. https://doi.org/10.1109/TR.2017.2722471.

[20] Yodo, N., and Wang, P., 2016, "Resilience Modeling and Quantification for Engineered Systems Using Bayesian Networks," Journal of Mechanical Design, **138**(3). https://doi.org/10.1115/1.4032399/384110.

[21] Vugrin, E. D., Turnquist, M. A., and Brown, N. J. K., 2014, "Optimal Recovery Sequencing for Enhanced Resilience and Service Restoration in Transportation Networks," International Journal of Critical Infrastructures, **10**(3–4), pp. 218–246. https://doi.org/10.1504/IJCIS.2014.066356.

[22] Sterbenz, J. P. G., Hutchison, D., Çetinkaya, E. K., Jabbar, A., Rohrer, J. P., Schöller, M., and Smith, P., 2010, "Resilience and Survivability in Communication Networks: Strategies, Principles, and Survey of Disciplines," Computer Networks, **54**(8), pp. 1245–1265. https://doi.org/10.1016/j.comnet.2010.03.005.

[23] Mehrpouyan, H., Haley, B., Dong, A., Tumer, I. Y., and Hoyle, C., 2015, "Resiliency Analysis for Complex Engineered System Design," AI EDAM, **29**(1), pp. 93–108. https://doi.org/10.1017/S0890060414000663.

[24] Chatterjee, A., Helbig, C., Malak, R., and Layton, A., 2023, "A Comparison of Graph-Theoretic Approaches for Resilient System of Systems Design," J Comput Inf Sci Eng, **23**(3). https://doi.org/10.1115/1.4062231/1160385.

[25] Markina-Khusid, A., Jacobs, R. B., Antul, L., Cho, L., and Tran, H. T., 2022, "A Complex Network Framework for Validated Assessments of Systems of Systems Robustness," IEEE Syst J, **16**(1), pp. 1092–1102. https://doi.org/10.1109/JSYST.2021.3064817.

[26] Wu, J., and Wang, P., 2023, "Generative Design for Resilience of Interdependent Network Systems," Journal of Mechanical Design, **145**(3). https://doi.org/10.1115/1.4056078/1148484.

[27] Mahabadi, Z., Varga, L., and Dolan, T., 2023, “A Survey of Multilayer Networks Modelled to Assess Robustness in Infrastructure Systems,” Proceedings of the Institution of Civil Engineers: Smart Infrastructure and Construction, **176**(3), pp. 117–125. https://doi.org/10.1680/JSMIC.22.00015/ASSET/IMAGES/SMALL/JSMIC176-0117-F3.GIF.

[28] Alashaikh, A., Tipper, D., and Gomes, T., 2018, “Exploring the Logical Layer to Support Differentiated Resilience Classes in Multilayer Networks,” Annales des Telecommunications/Annals of Telecommunications, **73**(1–2), pp. 63–79. https://doi.org/10.1007/S12243-017-0616-1/TABLES/9.

[29] Kuikka, V., and Rantanen, H., 2023, “Resilience of Multi-Layer Communication Networks,” Sensors, **23**(1). https://doi.org/10.3390/s23010086.

[30] Huynh, P. K., Rahman, M. M., Yadav, O. P., Le, T. Q., and Le, C., 2024, “Assessing Robustness and Vulnerability in Interdependent Network Infrastructure: A Multilayer Network Approach,” Proceedings - Annual Reliability and Maintainability Symposium. https://doi.org/10.1109/RAMS51492.2024.10457643.

[31] Li, Q., Dong, S., and Mostafavi, A., 2019, “Modeling of Inter-Organizational Coordination Dynamics in Resilience Planning of Infrastructure Systems: A Multilayer Network Simulation Framework,” PLoS One, **14**(11), p. e0224522. https://doi.org/10.1371/journal.pone.0224522.

[32] Ulak, M. B., Konila Sriram, L. M., Kocatepe, A., Ozguven, E. E., and Arghandeh, R., 2022, “Resilience Characterization for Multilayer Infrastructure Networks,” IEEE Intelligent Transportation Systems Magazine, **14**(4), pp. 121–132. https://doi.org/10.1109/MITS.2021.3049368.

[33] Alonso, M., Turanzas, J., Amaris, H., and Ledo, A. T., 2021, “Cyber-Physical Vulnerability Assessment in Smart Grids Based on Multilayer Complex Networks,” Sensors, **21**(17), p. 5826. https://doi.org/10.3390/s21175826.

[34] Dagnas, R., Barbeau, M., Garcia-alfaro, J., Yaich, R., and Garcia-Alfaro, J., 2024, “Resilience Assessment of Multi-Layered Cyber-Physical Systems,” *IFIP Networking 2024-IOCRCI*. [Online]. Available: https://hal.science/hal-04559568. [Accessed: 05-Jan-2025].

[35] Kazim, M., Pirim, H., Shi, S., and Wu, D., 2024, “Multilayer Analysis of Energy Networks,” Sustainable Energy, Grids and Networks, **39**, p. 101407. https://doi.org/10.1016/j.segan.2024.101407.

[36] Brownlow, L. C., Goodrum, C. J., Sypniewski, M. J., Coller, J. A., and Singer, D. J., 2021, “A Multilayer Network Approach to Vulnerability Assessment for Early-Stage Naval Ship Design Programs,” Ocean Engineering, **225**, p. 108731. https://doi.org/10.1016/j.oceaneng.2021.108731.

[37] Goodrum, C. J., Shields, C. P. F., and Singer, D. J., 2018, “Understanding Cascading Failures through a Vulnerability Analysis of Interdependent Ship-Centric Distributed Systems Using Networks,” Ocean Engineering, **150**(November 2017), pp. 36–47. https://doi.org/10.1016/j.oceaneng.2017.12.039.

[38] Holme, P., and Saramäki, J., 2012, “Temporal Networks,” Phys Rep, **519**(3), pp. 97–125. https://doi.org/10.1016/J.PHYSREP.2012.03.001.

[39] Salama, M., Ezzeldin, M., El-Dakhakhni, W., and Tait, M., 2022, “Temporal Networks: A Review and Opportunities for Infrastructure Simulation,” Sustain Resilient Infrastruct, **7**(1), pp. 40–55. https://doi.org/10.1080/23789689.2019.1708175.

[40] Scellato, S., Leontiadis, I., Mascolo, C., Basu, P., and Zafer, M., 2013, “Evaluating Temporal Robustness of Mobile Networks,” IEEE Trans Mob Comput, **12**(1), pp. 105–117. https://doi.org/10.1109/TMC.2011.248.

[41] Bastan, O., Fiedler, P., Benesl, T., and Arm, J., 2019, “Redundancy as an Important Source of Resilience in the Safety II Concept,” IFAC-PapersOnLine, **52**(27), pp. 382–387. https://doi.org/10.1016/J.IFACOL.2019.12.690.

[42] Chen, C. C., and Crilly, N., 2014, “Modularity, Redundancy and Degeneracy: Cross-Domain Perspectives on Key Design Principles,” *8th Annual IEEE International Systems Conference, SysCon 2014 - Proceedings*, IEEE, pp. 546–553. https://doi.org/10.1109/SysCon.2014.6819309.

[43] Wang, J., and Li, M., 2015, “Redundancy Allocation for Reliability Design of Engineering Systems with Failure Interactions,” Journal of Mechanical Design, **137**(3). https://doi.org/10.1115/1.4029320/376160.

[44] Wang, J., and Li, M., 2015, “Redundancy Allocation Optimization for Multistate Systems with Failure Interactions Using Semi-Markov Process,” Journal of Mechanical Design, **137**(10). https://doi.org/10.1115/1.4031297.

[45] Uday, P., and Marais, K., 2013, “Exploiting Stand-in Redundancy to Improve Resilience in a System-of-Systems (SoS),” Procedia Comput Sci, **16**, pp. 532–541. https://doi.org/10.1016/J.PROCS.2013.01.056.

[46] Rodrigues Mendes Ribeiro, R., Bessani, M., De Souza Sant Anna Fogliatto, M., and Dias Maciel, C., 2019, “Resilience Assessment of Self-Healing Systems with Redundancy,” IEEE Latin America Transactions, **17**(9), pp. 1546–1551. https://doi.org/10.1109/TLA.2019.8931189.

[47] Paparistodimou, G., Duffy, A., Whitfield, R. I., Knight, P., and Robb, M., 2020, “A Network Science-Based Assessment Methodology for Robust Modular System Architectures during Early Conceptual Design,” Journal of Engineering Design, **31**(4), pp. 179–218. https://doi.org/10.1080/09544828.2019.1686469.

[48] Paparistodimou, G., Duffy, A., Whitfield, R. I., Knight, P., and Robb, M., 2020, “A Network Tool to Analyse and Improve Robustness of System Architectures,” Design Science, **6**, p. e8. https://doi.org/10.1017/dsj.2020.6.

Figure Captions List

Fig. 1	Methodology conceptualization prior to disruption: initial network
Fig. 2	Methodology conceptualization at the moment of disruption: disrupted network
Fig. 3	Methodology conceptualization post-disruption: recovery network
Fig. 4	Overview of methodology concept: dynamically simulating dual-layer network states (prior, during, and post disruption)
Fig. 5	Functional schematic option 1 (white boxes indicate operational and grey standby components at initial conditions)
Fig. 6	Physical schematic for options 1 and 3 (white boxes indicate operational and grey standby components at initial conditions)
Fig. 7	Functional schematic option 2 (white boxes indicate operational and grey standby components at initial conditions)
Fig. 8	Functional schematic option 3 (white boxes indicate operational and grey standby components at initial conditions)
Fig. 9	Functional schematic option 4 (white boxes indicate operational and grey standby components at initial conditions)
Fig. 10	Functional schematic option 5 (white boxes indicate operational and grey standby components at initial conditions)

Table Caption List

Table 1: User defined inputs of the methodology

Method Stage input	Input Number	Input Name	Input Explanation
System modelling	Input 1	Entire functional network	Functional flows/connectivity between components.
	Input 2	Entire physical network	Grid network.
	Input 3	Component location physical network	Physical location of each component.
Resilience measure	Input 4	Operational and standby functional components	Assignment of components as operational or standby (redundant).
Performance measure	Input 5	Source and demand definition	Assignment of source and demand components in the functional network
Disruption approach	Input 6	Scale of disruption	Define number of components to be incapacitated.
Recovery strategy	Input 7	Component start up times	Assigning the time that a component needs to start up if on standby.
Resilience assessment	Input 8	Minimum performance criterion	System performance required immediately post-disruption.
	Input 9	Satisfactory performance criterion	System performance to be deemed recovered.
	Input 10	Objective restoration component time criterion(tr)	Time (tr) by which the system must have recovered to satisfactory performance after a disruption.

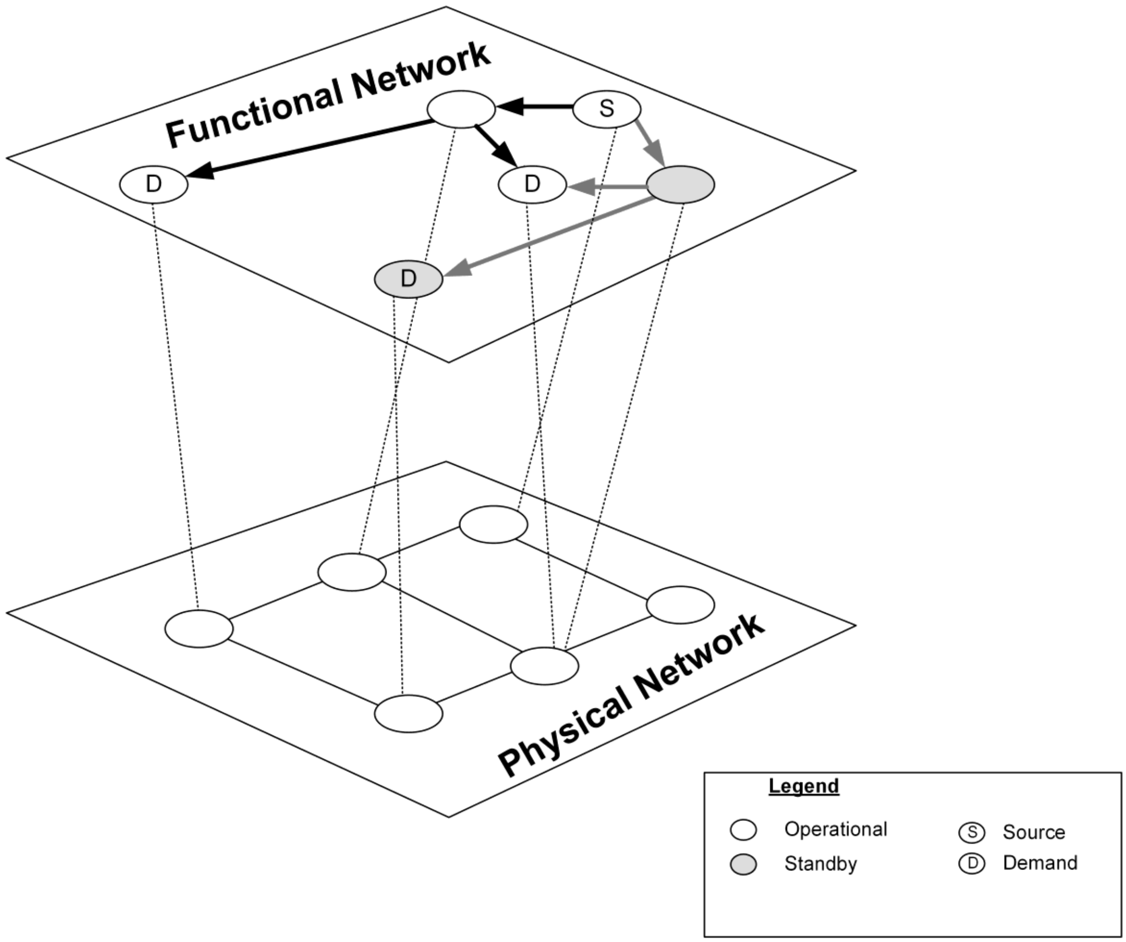


Figure 1: Methodology conceptualization prior to disruption: initial network

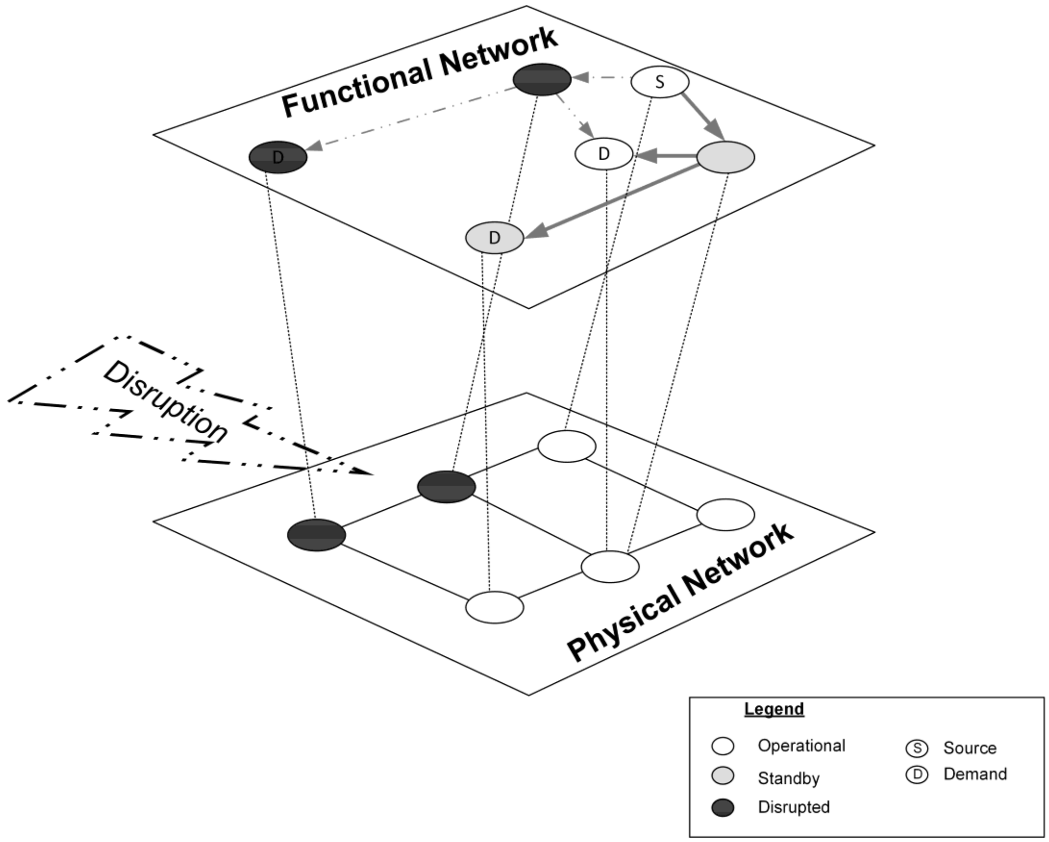
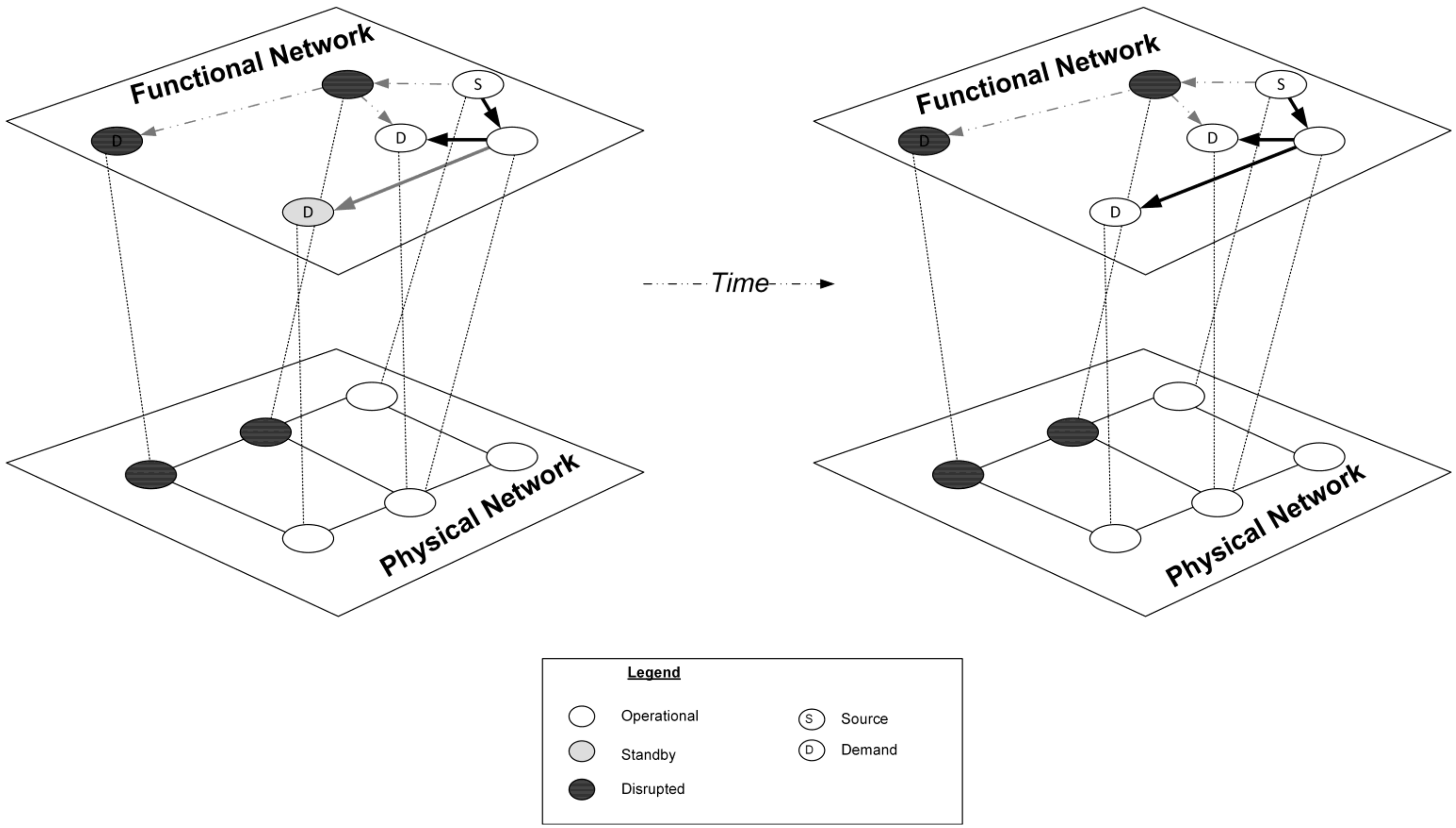
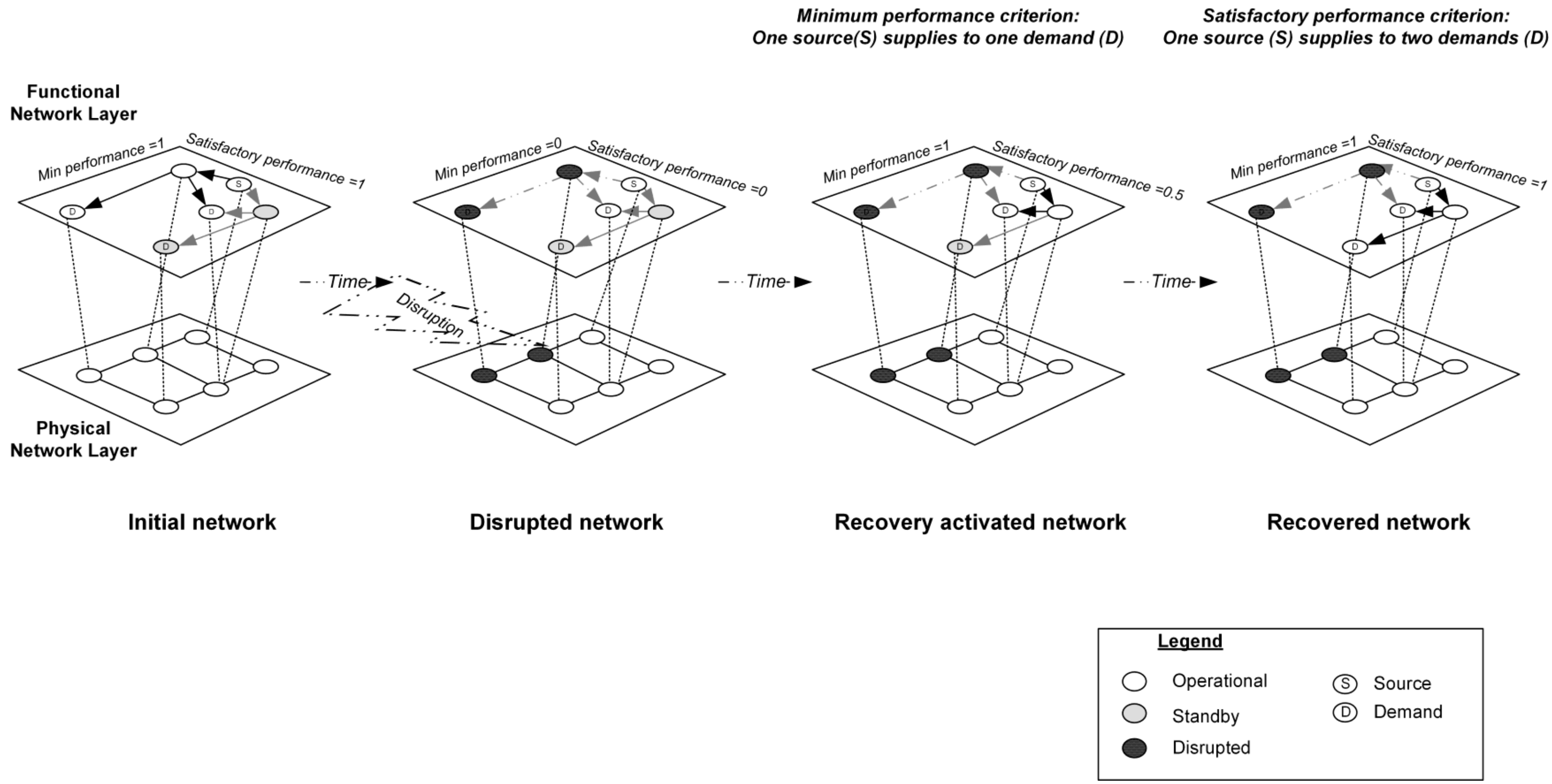


Figure 2: Methodology conceptualization at the moment of disruption: disrupted network

1083



1084
1085
1086 Figure 3: Methodology conceptualization post-disruption: recovery network



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1091 Figure 4: Overview of methodology concept: dynamically simulating dual-layer network states (prior, during, and post disruption)

Table 2: Three design variables (factors) with two-levels (options) as input for system options generation

Factors	Description	1 (Level)	-1 (Level)
Variable 1	Batteries option	NB (no batteries)	B (batteries)
Variable 2	Type of redundancy: EDC level or Consumer level	AS (alternative supply/ redundancy at Consumers)	DS (double supply/ redundancy at EDCs)
Variable 3	Number of main sources	FM (four main sources)	TM (three main sources)

Table 3: Eight system options generated-based DOE 2^3 design

	Batteries option	LV_SWB-EDC-Consumer	Number of main sources
Option 1	1 NB	1 AS	1 FM
Option 2	1 NB	1 AS	-1 TM
Option 3	1 NB	-1 DS	1 FM
Option 4	1 NB	-1 DS	-1 TM
Option 5	-1B	1 AS	1 FM
Option 6	-1B	1 AS	-1 TM
Option 7	-1B	-1 DS	1 FM
Option 8	-1B	-1 DS	-1 TM

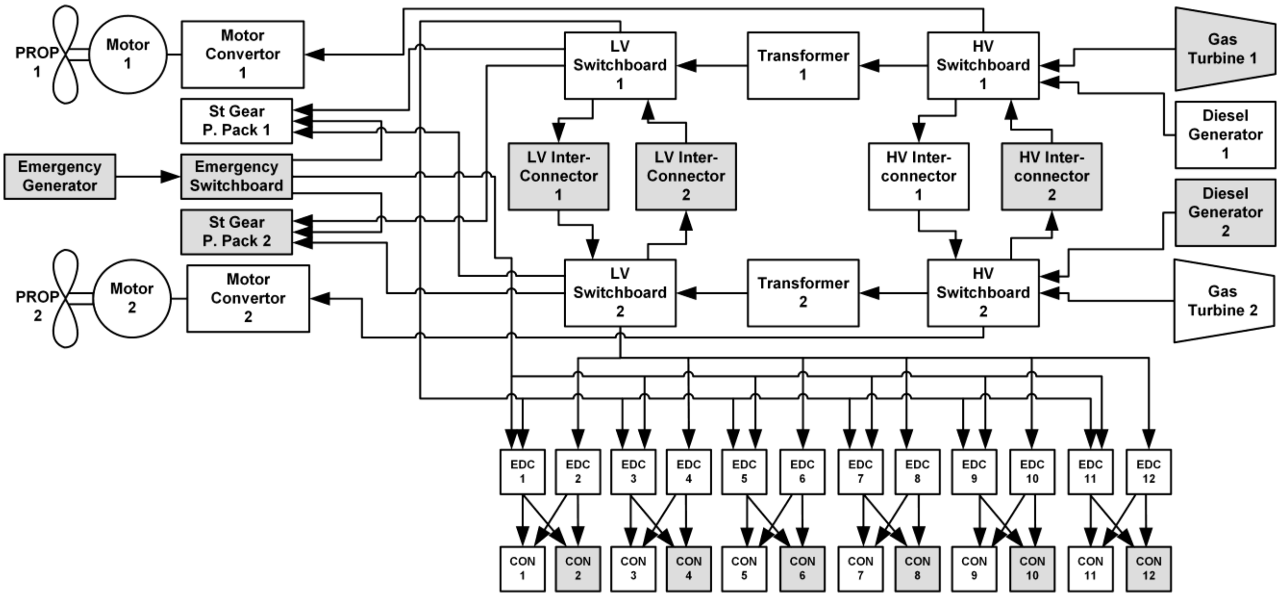

Figure 5: Functional schematic option 1 (white boxes indicate operational and grey standby components at initial conditions)

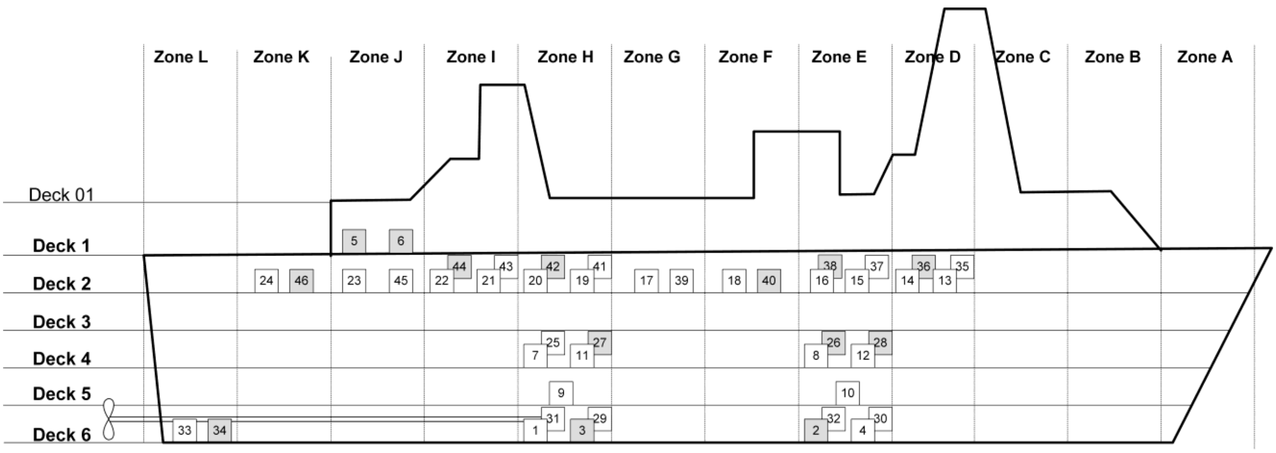

Figure 6: Physical schematic for option 1 and 3 (white boxes indicate operational and grey standby components at initial conditions)

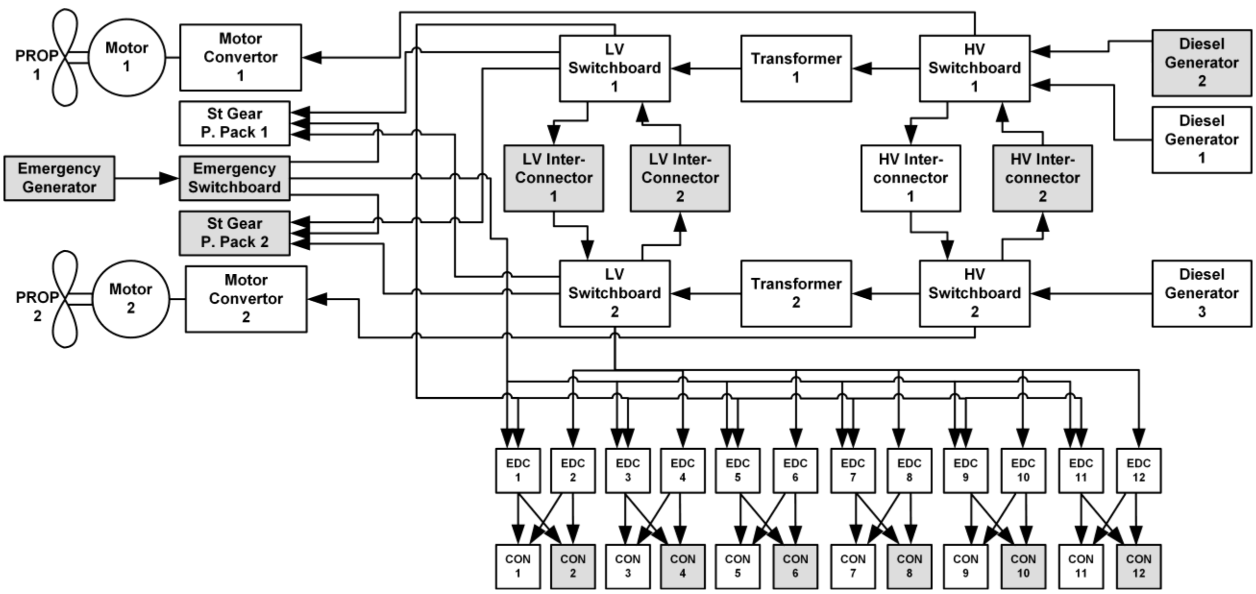

Figure 7: Functional schematic option 2 (white boxes indicate operational and grey standby components at initial conditions)

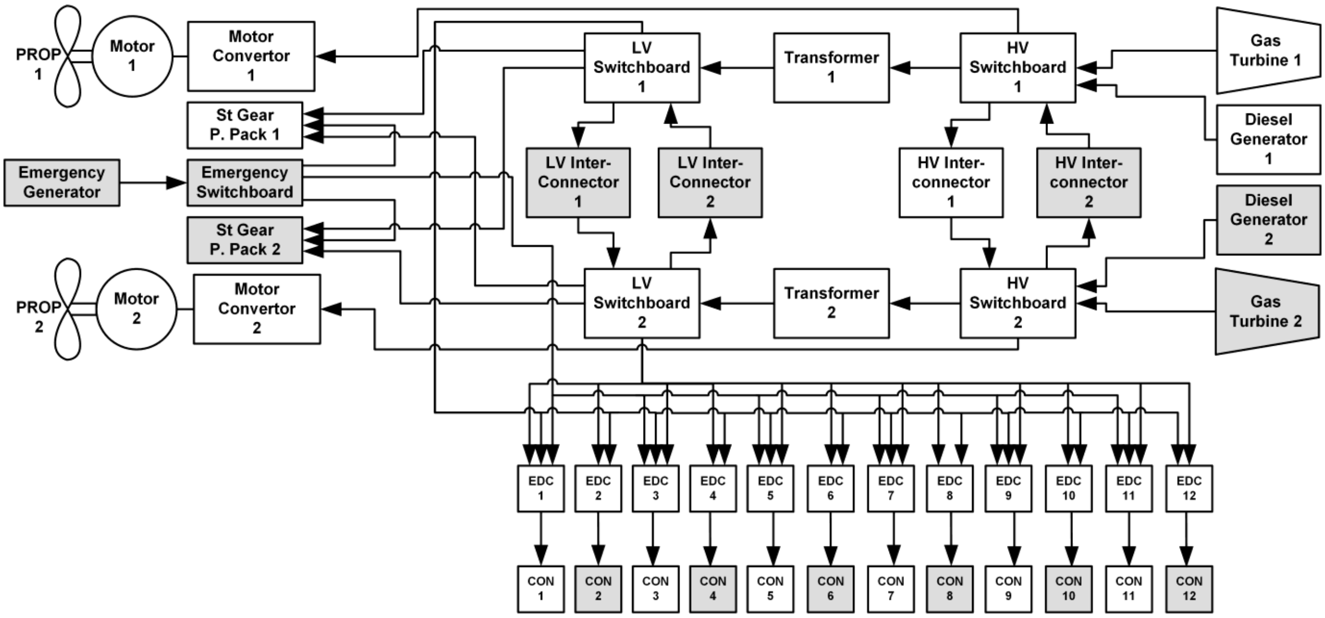

Figure 8: Functional schematic option 3 (white boxes indicate operational and grey standby components at initial conditions)

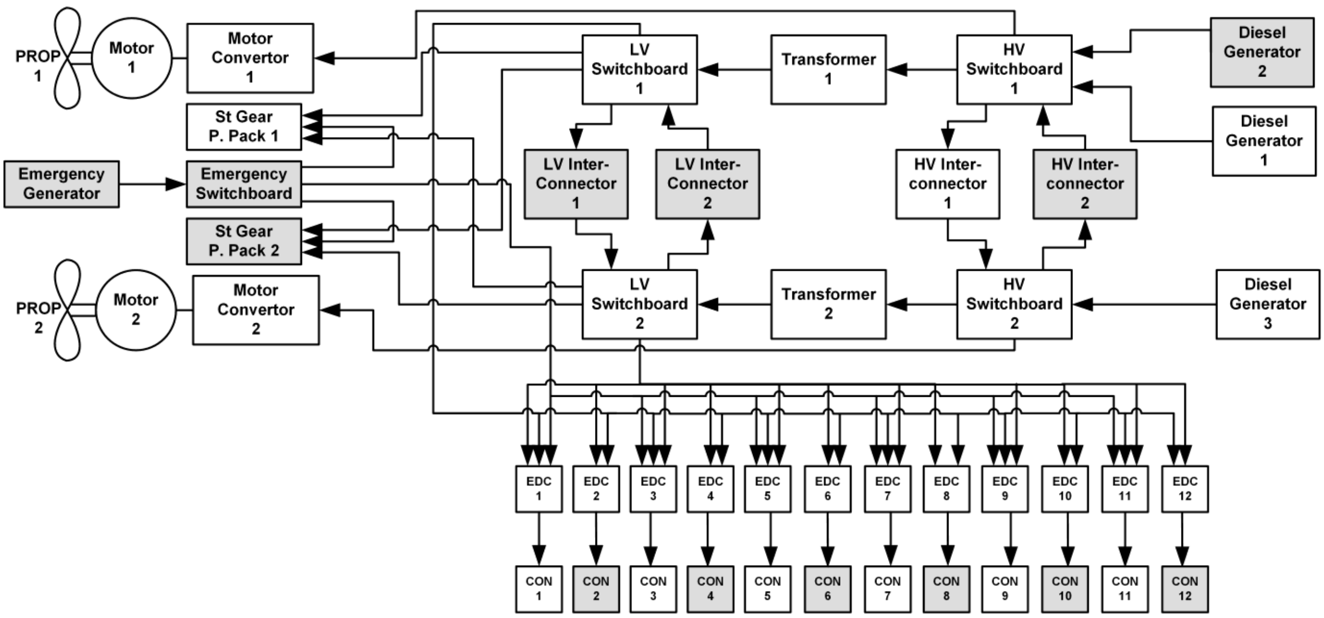

Figure 9: Functional schematic option 4 (white boxes indicate operational and grey standby components at initial conditions)

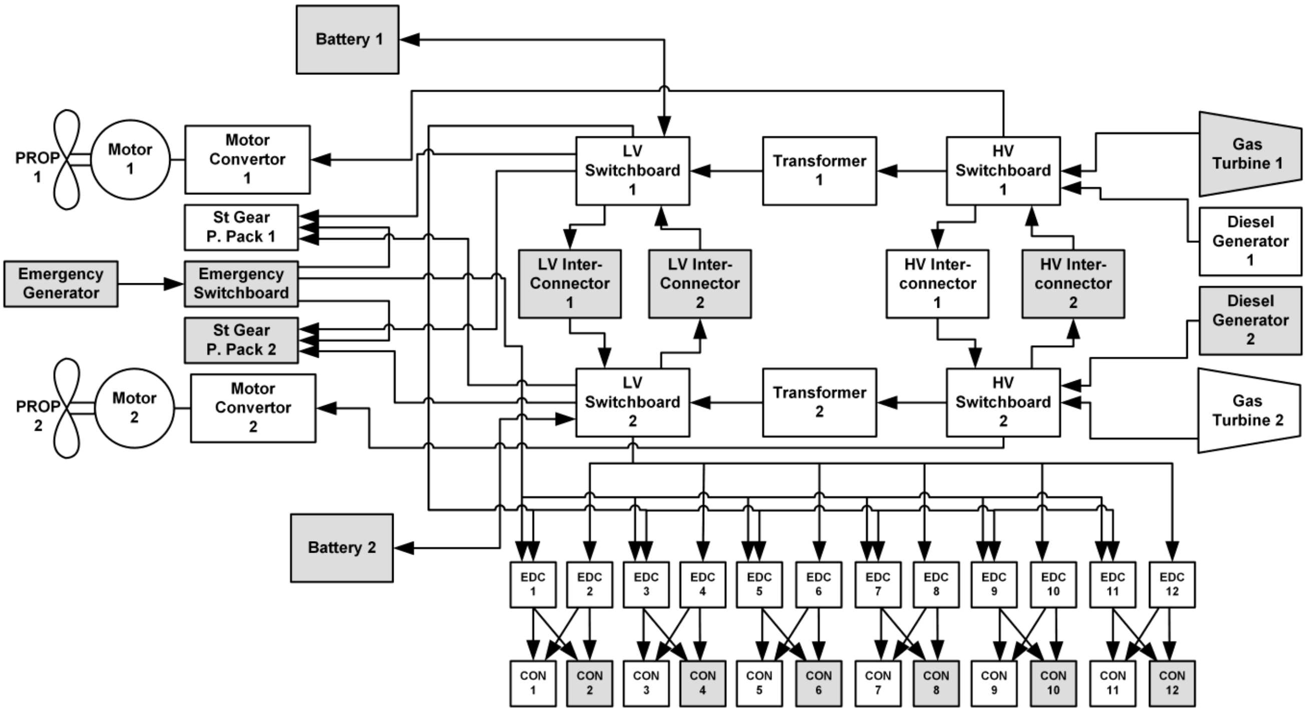

Figure 10: Functional schematic option 5 (white boxes indicate operational and grey standby components at initial conditions)

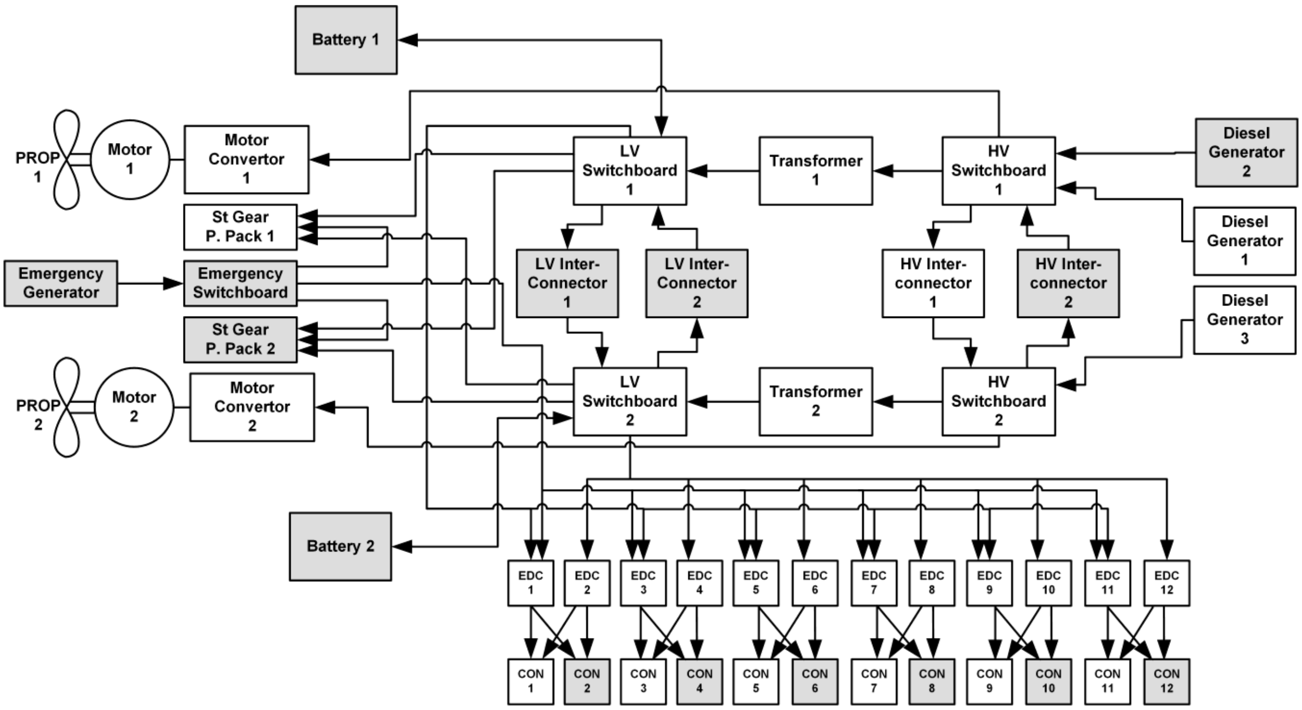

Figure 11: Functional schematic option 6 (white boxes indicate operational and grey standby components at initial conditions)

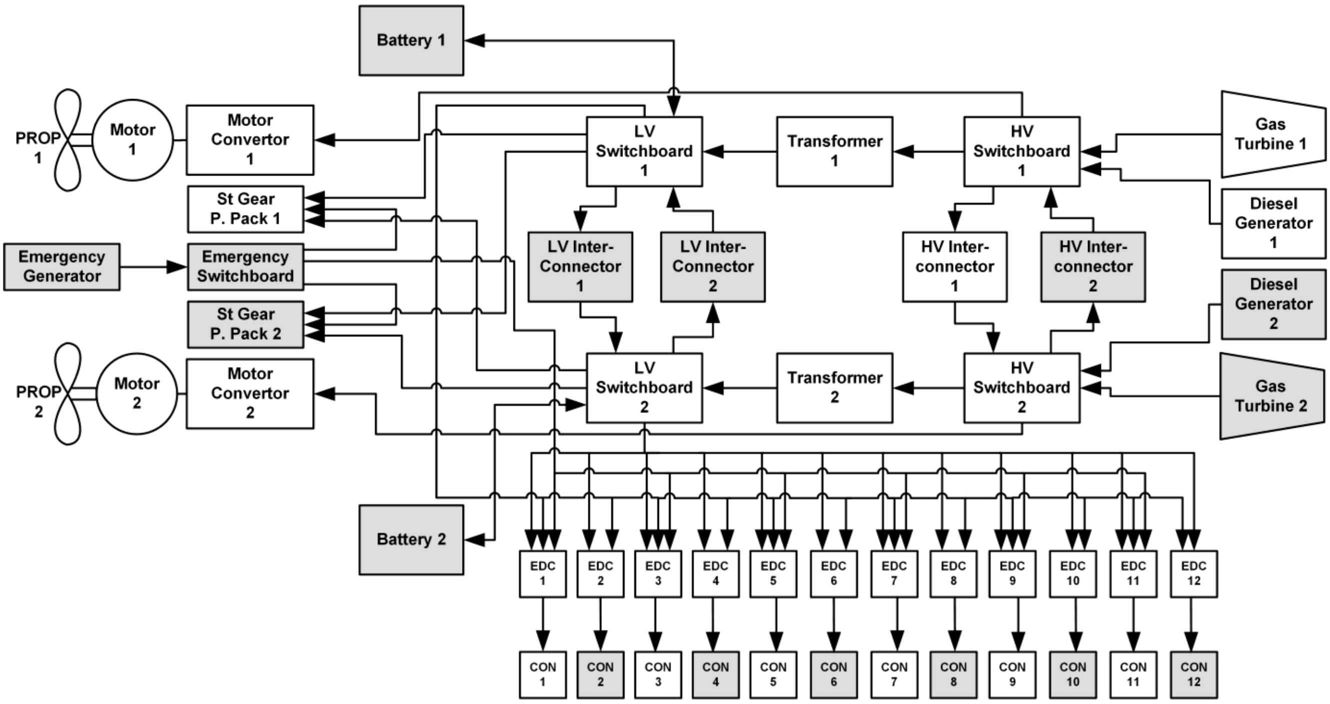

Figure 12: Functional schematic option 7 (white boxes indicate operational and grey standby components at initial conditions)

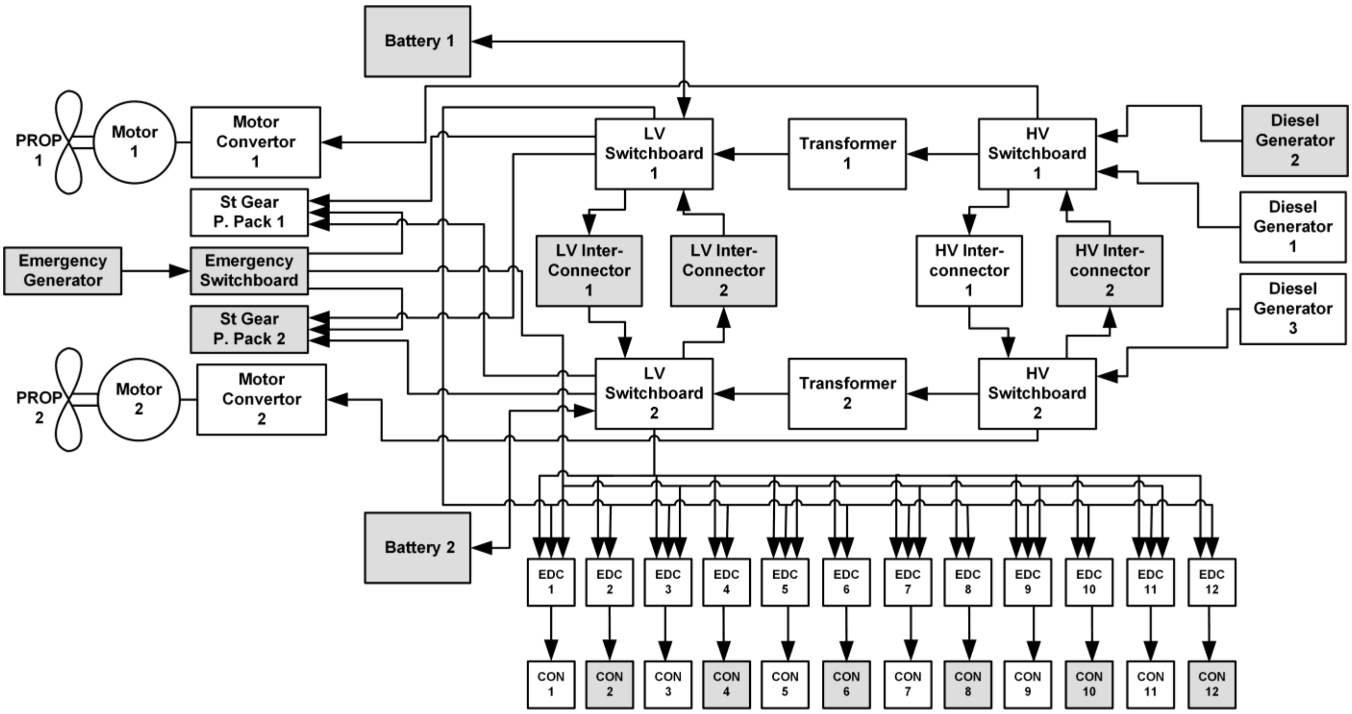

Figure 13: Functional schematic option 8 (white boxes indicate operational and grey standby components at initial conditions)

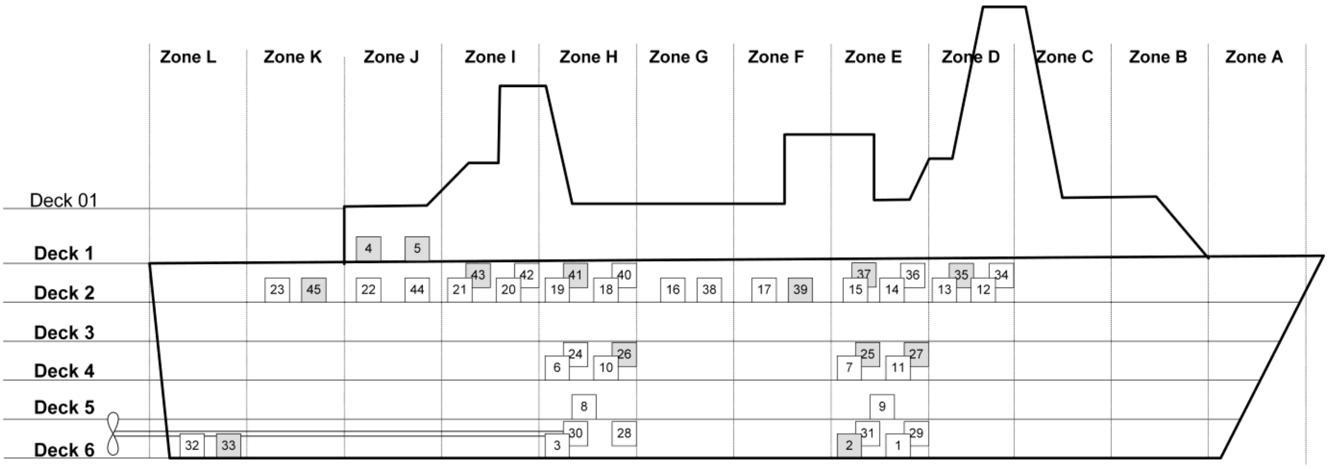

Figure 14: Physical schematic for options 2 and 4 (white boxes indicate operational and grey standby components at initial conditions)

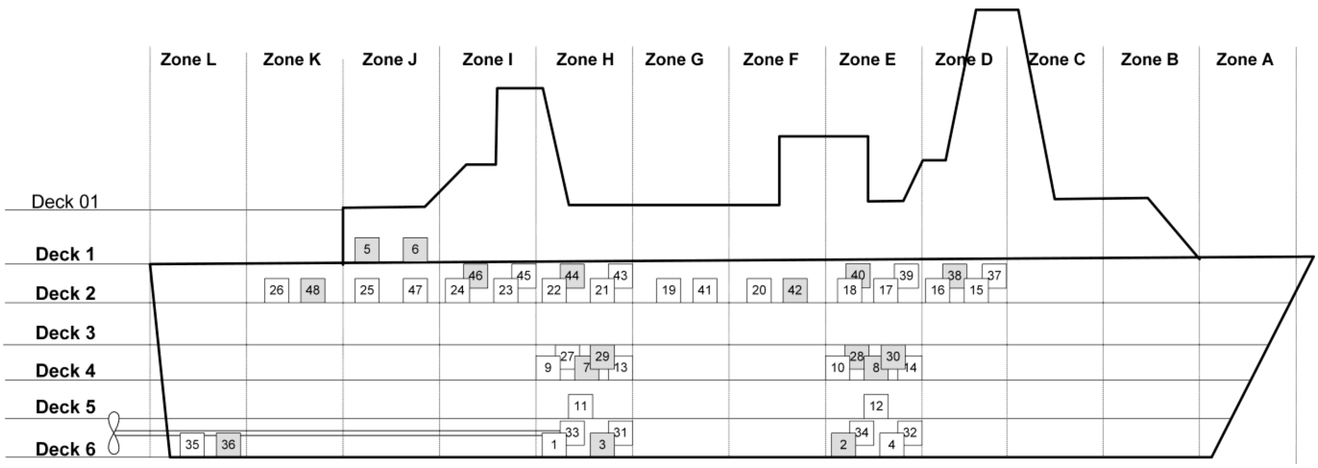

Figure 15: Physical schematic for options 5 and 7 (white boxes indicate operational and grey standby components at initial conditions)

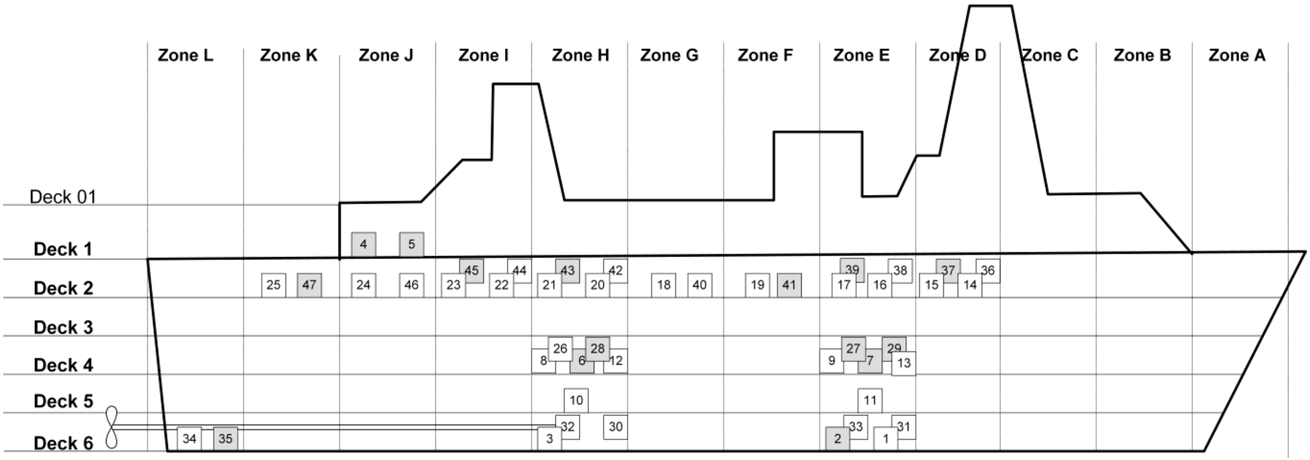

Figure 16: Physical schematic for options 6 and 8 (white boxes indicate operational and grey standby components at initial conditions)

Table 4: Input Definition Summary for Option 1 (grey cells filled with 1 indicate connectivity between components)

	Option 1	Diesel Generator 1	Diesel Generator 2	Gas Turbine 1	Gas Turbine 2	Emergency Generator 1	Emergency Switchboard 1	HVSwitchboard 1	HVSwitchboard 2	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational(O) /Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	H	6
2	Diesel Generator 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Gas Turbine 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	120	H	6
4	Gas Turbine 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	E	6
5	Emergency Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
6	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
7	HV Switchboard 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
8	HV Switchboard 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
9	Transformer 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
10	Transformer2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
11	LV Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
12	LV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
13	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
14	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
15	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
16	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
17	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	G	2
18	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	F	2
19	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
20	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
21	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
22	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
23	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	J	2
24	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	K	2
25	HV Interconnector1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
26	HV Interconnector2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
27	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
28	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
29	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
30	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
31	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
32	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
33	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
34	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
35	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
36	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
37	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
38	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
39	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
40	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
41	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
42	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
43	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
44	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
45	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
46	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 5: Input Definition Summary for Option 2 (grey cells filled with 1 indicate connectivity between components)

	Option 2	Diesel Generator 1	Diesel Generator 2	Diesel Generator 3	Emergency Generator 1	Emergency Switchboard 1	HVSwitchboard 1	HVSwitchboard 2	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	E	6
2	Diesel Generator 2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Diesel Generator 3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	H	6
4	Emergency Generator 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
5	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
6	HV Switchboard 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
7	HV Switchboard 2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
8	Transformer 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
9	Transformer2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
10	LV Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
11	LV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
12	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
13	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
14	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
15	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
16	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	G	2
17	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	F	2
18	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
19	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
20	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
21	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
22	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	J	2
23	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	K	2
24	HV Interconnector1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
25	HV Interconnector2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
26	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
27	LV Interconnector2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
28	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
29	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
30	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
31	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
32	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
33	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
34	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
35	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
36	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
37	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
38	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
39	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
40	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
41	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
42	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
43	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
44	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
45	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 6: Input Definition Summary for Option 3 (grey cells filled with 1 indicate connectivity between components)

	Option 3	Diesel Generator 1	Diesel Generator 2	Gas Turbine 1	Gas Turbine 2	Emergency Generator 1	Emergency Switchboard 1	HVSwitchboard1	HVSwitchboard2	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	H	6
2	Diesel Generator 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Gas Turbine 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	120	H	6
4	Gas Turbine 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	E	6
5	Emergency Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
6	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
7	HV Switchboard 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
8	HV Switchboard 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
9	Transformer 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
10	Transformer2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
11	LV Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
12	LV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
13	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0			O	10	D	2
14	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
15	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			O	10	E	2
16	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0			O	10	E	2
17	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0			O	10	G	2
18	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			O	10	F	2
19	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			O	10	H	2
20	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0			O	10	H	2
21	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			O	10	I	2
22	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			O	10	I	2
23	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0			O	10	J	2
24	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			O	10	K	2
25	HV Interconnector1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
26	HV Interconnector2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
27	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
28	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
29	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
30	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
31	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
32	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
33	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
34	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
35	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
36	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
37	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
38	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
39	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
40	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
41	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
42	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
43	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
44	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
45	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
46	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 7: Input Definition Summary for Option 4 (grey cells filled with 1 indicate connectivity between components)

	Option 4	Diesel Generator 1	Diesel Generator 2	Diesel Generator 3	Emergency Generator 1	Emergency Switchboard 1	HVSwitchboard 1	HVSwitchboard 2	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	E	6
2	Diesel Generator 2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Diesel Generator 3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	H	6
4	Emergency Generator 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
5	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
6	HV Switchboard 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
7	HV Switchboard 2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
8	Transformer 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
9	Transformer2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
10	LV Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
11	LV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
12	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0			O	10	D	2
13	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
14	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			O	10	E	2
15	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0			O	10	E	2
16	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0			O	10	G	2
17	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			O	10	F	2
18	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			O	10	H	2
19	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0			O	10	H	2
20	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			O	10	I	2
21	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			O	10	I	2
22	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0			O	10	J	2
23	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			O	10	K	2
24	HV Interconnector1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
25	HV Interconnector2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
26	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
27	LV Interconnector2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
28	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
29	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
30	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
31	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
32	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
33	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
34	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
35	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
36	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
37	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
38	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
39	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
40	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
41	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
42	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
43	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
44	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
45	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 8: Input Definition Summary for Option 5 (grey cells filled with 1 indicate connectivity between components)

	Option 5	Diesel Generator 1	Diesel Generator 2	Gas Turbine 1	Gas Turbine 2	Emergency Generator 1	Emergency Switchboard 1	Battery 1	Battery 2	HVSwitchboard1	HVSwitchboard2	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	H	6
2	Diesel Generator 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Gas Turbine 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	120	H	6
4	Gas Turbine 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	E	6
5	Emergency Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
6	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
7	Battery 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	H	4
8	Battery 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	E	4
9	HV Switchboard 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
10	HV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
11	Transformer 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
12	Transformer2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
13	LV Switchboard 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
14	LV Switchboard 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
15	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
16	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
17	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
18	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
19	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	G	2
20	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	F	2
21	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
22	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
23	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
24	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
25	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	J	2
26	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	K	2
27	HV Interconnector1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
28	HV Interconnector2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
29	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
30	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
31	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
32	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
33	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
34	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
35	SteeringGearPowerPack1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
36	SteeringGearPowerPack2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
37	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
38	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
39	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
40	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
41	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
42	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
43	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
44	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
45	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
46	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
47	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
48	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 9: Input Definition Summary for Option 6 (grey cells filled with 1 indicate connectivity between components)

	Option 6	Diesel Generator 1	Diesel Generator 2	Diesel Generator 3	Emergency Generator 1	Emergency Switchboard 1	Battery 1	Battery 2	HV Switchboard1/forward	HV Switchboard 2/aft	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack1	SteeringGearPowerPack2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	E	6
2	Diesel Generator 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Diesel Generator 3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	H	6
4	Emergency Generator 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
5	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
6	Battery 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	H	4
7	Battery 2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	E	4
8	HV Switchboard 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
9	HV Switchboard 2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
10	Transformer 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
11	Transformer2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
12	LV Switchboard 1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
13	LV Switchboard 2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
14	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
15	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
16	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
17	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0			O	10	E	2
18	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	G	2
19	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0			O	10	F	2
20	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
21	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0			O	10	H	2
22	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
23	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			O	10	I	2
24	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	J	2
25	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1			O	10	K	2
26	HV Interconnector1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
27	HV Interconnector2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
28	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
29	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
30	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
31	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
32	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
33	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
34	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
35	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
36	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
37	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
38	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
39	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
40	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
41	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
42	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
43	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
44	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
45	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
46	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
47	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 10: Input Definition Summary for Option 7 (grey cells filled with 1 indicate connectivity between components)

	Option 7	Diesel Generator 1	Diesel Generator 2	Gas Turbine 1	Gas Turbine 2	Emergency Generator 1	Emergency Switchboard 1	Battery 1	Battery 2	HV Switchboard1/forward	HV Switchboard 2/aft	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGearPowerPack 1	SteeringGearPowerPack 2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational (O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	H	6
2	Diesel Generator 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Gas Turbine 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	120	H	6
4	Gas Turbine 2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	E	6
5	Emergency Generator 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
6	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
7	Battery 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	H	4
8	Battery 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	E	4
9	HV Switchboard 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
10	HV Switchboard 2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
11	Transformer 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
12	Transformer2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
13	LV Switchboard 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
14	LV Switchboard 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
15	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0			O	10	D	2
16	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
17	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			O	10	E	2
18	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0			O	10	E	2
19	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0			O	10	G	2
20	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			O	10	F	2
21	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			O	10	H	2
22	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0			O	10	H	2
23	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			O	10	I	2
24	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			O	10	I	2
25	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0			O	10	J	2
26	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			O	10	K	2
27	HV Interconnector1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
28	HV Interconnector2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
29	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
30	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
31	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
32	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
33	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
34	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
35	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
36	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
37	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
38	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
39	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
40	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
41	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
42	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
43	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
44	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
45	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
46	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
47	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
48	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 11: Input Definition Summary for Option 8 (grey cells filled with 1 indicate connectivity between components)

	Option 8	Diesel Generator 1	Diesel Generator 2	Diesel Generator 3	Emergency Generator 1	Emergency Switchboard 1	Battery 1	Battery 2	HV Switchboard1/forward	HV Switchboard 2/aft	Transformer 1	Transformer2	LV Switchboard 1	LV Switchboard 2	EDC 1	EDC 2	EDC 3	EDC 4	EDC 5	EDC 6	EDC 7	EDC 8	EDC 9	EDC 10	EDC 11	EDC 12	HV Interconnector1	HV Interconnector2	LV Interconnector1	LV Interconnector2	Motor Convertor 1	Motor Convertor 2	Motor 1	Motor 2	SteeringGear PowerPack 1	SteeringGear PowerPack 2	Consumer 1	Consumer 2	Consumer 3	Consumer 4	Consumer 5	Consumer 6	Consumer 7	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12	Source(S)	Demand (D)	Operational(O)/ Standby(S)	Time to start up (sec)	Zone	Deck
1	Diesel Generator 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	60	H	6
2	Diesel Generator 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	60	E	6
3	Diesel Generator 3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		O	120	H	6
4	Emergency Generator 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	30	J	1
5	Emergency Switchboard 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			S	0	J	1
6	Battery 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	H	4
7	Battery 2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S		S	0	E	4
8	HV Switchboard 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
9	HV Switchboard 2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
10	Transformer 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	H	5
11	Transformer2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	10	E	5
12	LV Switchboard 1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	H	4
13	LV Switchboard 2	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0			O	0	E	4
14	EDC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0			O	10	D	2
15	EDC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			O	10	D	2
16	EDC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			O	10	E	2
17	EDC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0			O	10	E	2
18	EDC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0			O	10	G	2
19	EDC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			O	10	F	2
20	EDC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			O	10	H	2
21	EDC 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0			O	10	H	2
22	EDC 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			O	10	I	2
23	EDC 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			O	10	I	2
24	EDC 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0			O	10	J	2
25	EDC 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			O	10	K	2
26	HV Interconnector1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	30	H	4
27	HV Interconnector2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
28	LV Interconnector1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	H	4
29	LV Interconnector2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			S	30	E	4
30	Motor Convertor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	H	6
31	Motor Convertor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			O	180	E	6
32	Motor 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	H	6
33	Motor 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	E	6
34	Steering Gear Power Pack 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	10	L	6
35	Steering Gear Power Pack 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	10	L	6
36	Consumer 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	D	2
37	Consumer 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	D	2
38	Consumer 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	E	2
39	Consumer 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	E	2
40	Consumer 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	G	2
41	Consumer 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	F	2
42	Consumer 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	H	2
43	Consumer 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	H	2
44	Consumer 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	I	2
45	Consumer 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	I	2
46	Consumer 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	O	0	J	2
47	Consumer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		D	S	0	K	2

Table 12: Case study performance criteria for resilience metric calculation

Performance criteria	Total demand components	Demand components definition
Satisfactory performance criterion	Total Eight: Six consumers, one steering gear and one motor - available within the restoration time (tr).	1. (Consumer 1 OR Consumer 2) AND 2. (Consumer 3 OR Consumer 4) AND 3. (Consumer 5 OR Consumer 6) AND 4. (Consumer 7 OR Consumer 8) AND 5. (Consumer 9 OR Consumer 10) AND 6. (Consumer 11 OR Consumer12) AND 7. (Steering Gear 1 OR Steering Gear 2) AND 8. (Motor 1 OR Motor2)
Minimum performance criterion	Total Six: Four consumers, one steering gear, and one motor – available immediately post-disruption.	1. (Consumer 1 OR Consumer 2 OR Consumer 3 OR Consumer 4) AND 2. (Consumer 5 OR Consumer 6) AND 3. (Consumer 7 OR Consumer 8 OR Consumer 9 OR Consumer 10) AND 4. (Consumer 11 OR Consumer12) AND 5. (Steering Gear 1 OR Steering Gear 2) AND 6. (Motor 1 OR Motor2)

Table 13: Average resilience calculation results for k=1,2,3,4 combined component disruption

System Option	Resilience calculations				
	1 component disruption	2 components disruption	3 components disruption	4 components disruption	Mean
Option 1	0.978	0.942	0.845	0.752	0.879
Option 2	0.978	0.913	0.746	0.558	0.799
Option 3	0.978	0.913	0.781	0.690	0.841
Option 4	0.978	0.865	0.643	0.479	0.741
Option 5	0.979	0.948	0.867	0.792	0.896
Option 6	0.979	0.929	0.800	0.653	0.840
Option 7	0.979	0.922	0.813	0.740	0.863
Option 8	0.979	0.910	0.768	0.649	0.826

Table 14: Resilience calculation results for a k=2 combined components disruption (showing the ID of the components for each Option in the columns) resulting at zero resilience

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
1	[12 15]	[3 6]	[13 14]	[3 6]	[14 17]	[3 8]	[15 16]	[3 8]
2	[13 14]	[11 14]	[15 16]	[11 14]	[15 16]	[13 16]	[17 18]	[14 15]
3	[15 16]	[12 13]	[17 18]	[12 13]	[17 18]	[14 15]	[19 20]	[16 17]
4	[17 18]	[14 15]	[19 20]	[14 15]	[19 20]	[16 17]	[21 22]	[18 19]
5	[19 20]	[16 17]	[21 22]	[16 17]	[21 22]	[18 19]	[23 24]	[20 21]
6	[21 22]	[18 19]	[23 24]	[18 19]	[23 24]	[20 21]	[25 26]	[22 23]
7	[23 24]	[20 21]	[13 36]	[20 21]	[25 26]	[22 23]	[15 38]	[24 25]
8	[35 36]	[22 23]	[14 35]	[22 23]	[37 38]	[24 25]	[16 37]	[14 37]
9	[37 38]	[34 35]	[15 38]	[34 35]	[39 40]	[36 37]	[17 40]	[15 36]
10	[39 40]	[36 37]	[16 37]	[36 37]	[41 42]	[38 39]	[18 39]	[16 39]
11	[41 42]	[38 39]	[17 40]	[38 39]	[43 44]	[40 41]	[19 42]	[17 38]
12	[43 44]	[40 41]	[18 39]	[40 41]	[45 46]	[42 43]	[20 41]	[18 41]
13	[45 46]	[42 43]	[19 42]	[42 43]	[47 48]	[44 45]	[21 44]	[19 40]
14		[44 45]	[20 41]	[44 45]		[46 47]	[22 43]	[20 43]
15			[21 44]	[12 35]			[23 46]	[21 42]
16			[22 43]	[13 34]			[24 45]	[22 45]
17			[23 46]	[14 37]			[25 48]	[23 44]
18			[24 45]	[15 36]			[26 47]	[24 47]
19				[16 39]				[25 46]
20				[17 38]				
21				[18 41]				
22				[19 40]				
23				[20 43]				
24				[21 42]				
25				[22 45]				
26				[23 44]				

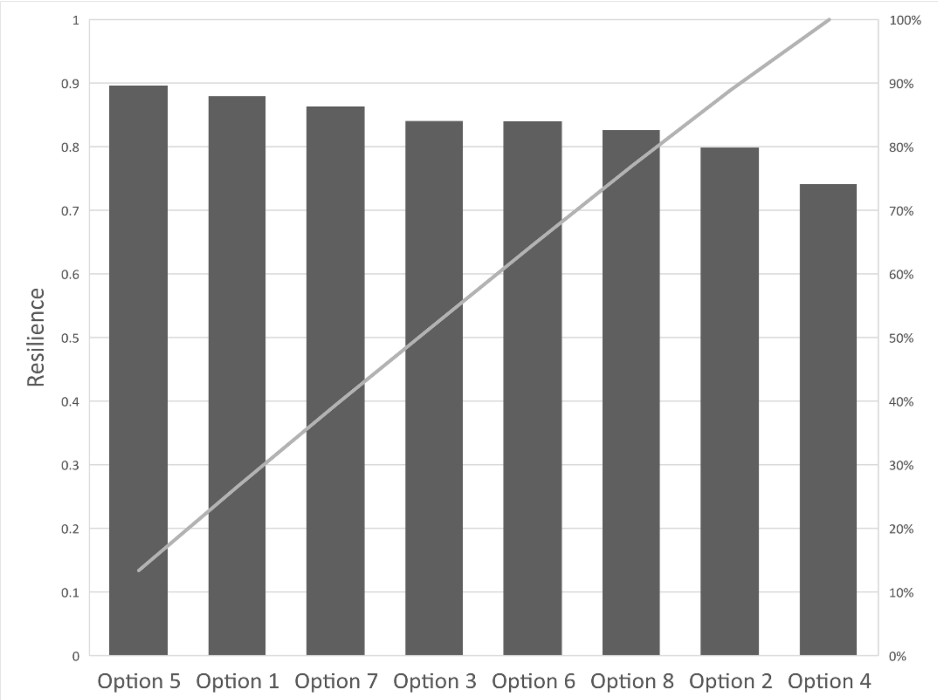

Figure 17: Mean resilience results for the system options of the case study

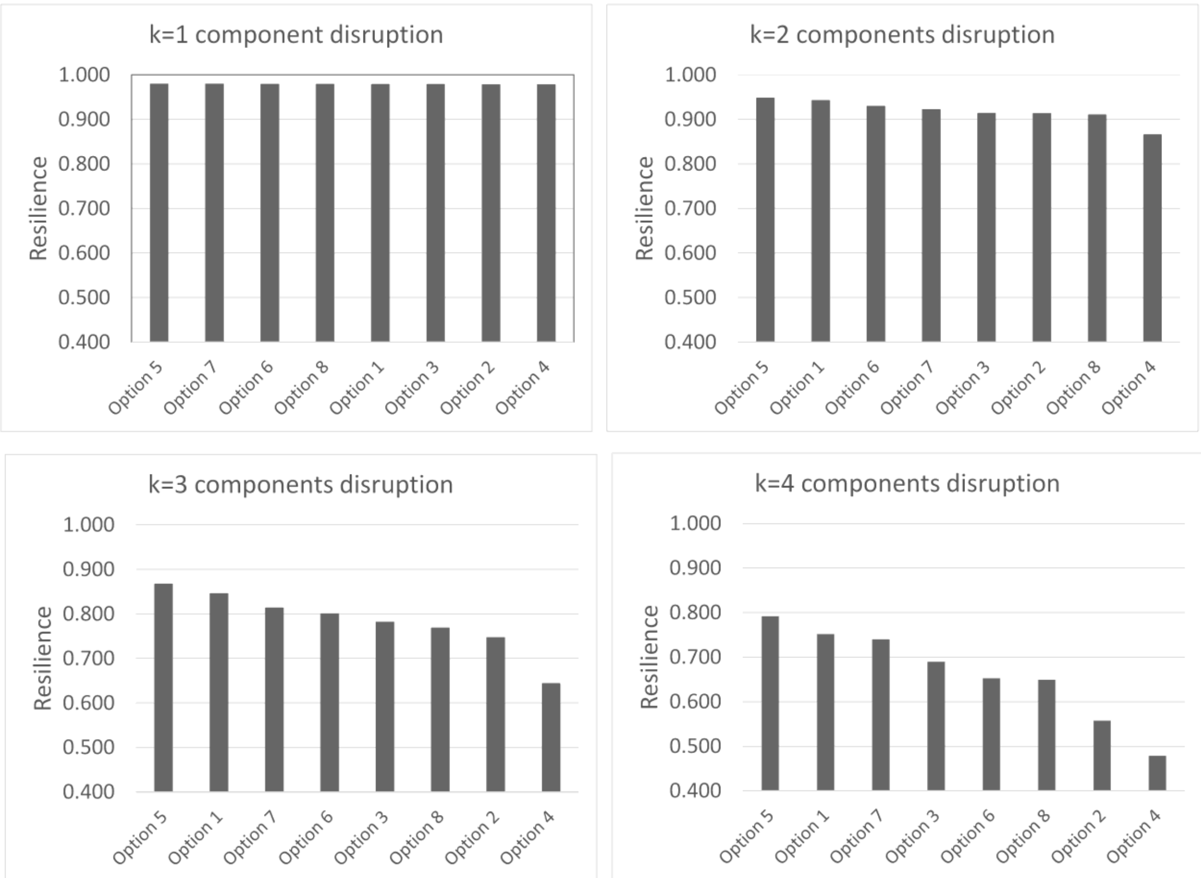

Figure 18: Resilience results for k = 1, 2, 3, 4 components disruption

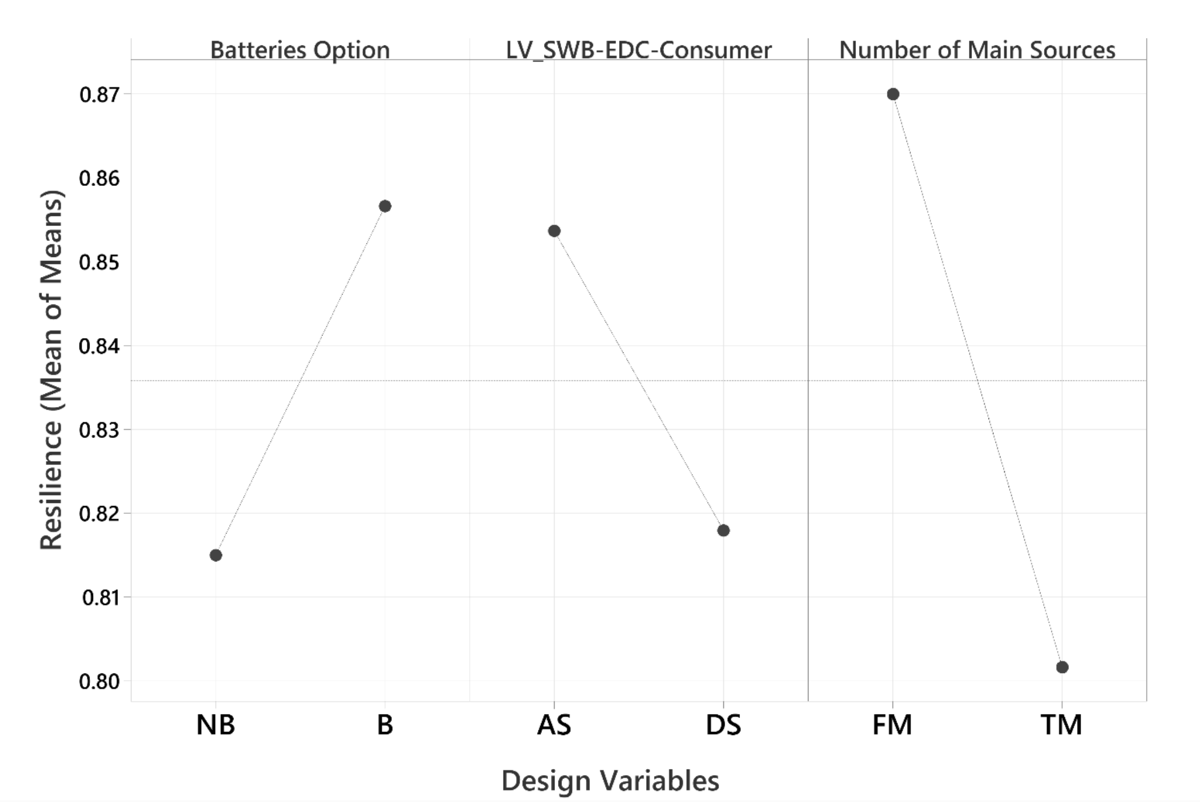

Figure 19: Mean effects plot for the design variables against resilience

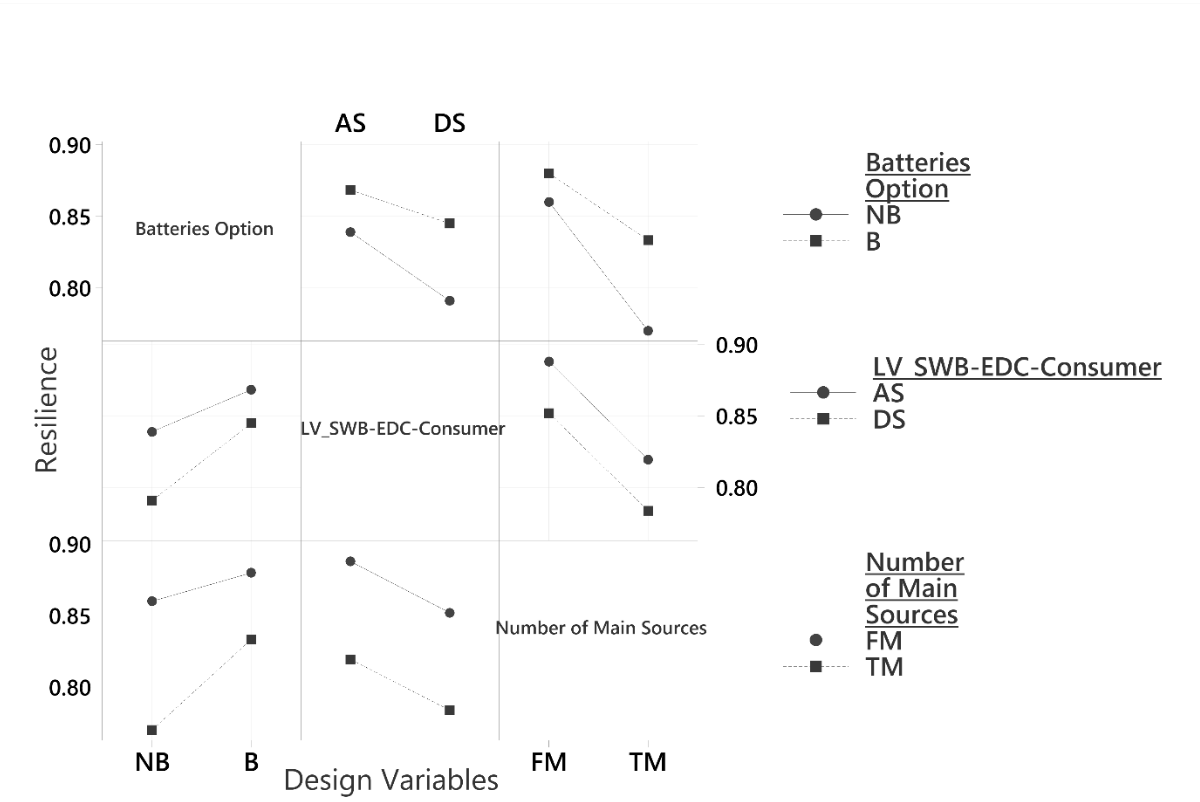

Figure 20: Interaction plot for the design variables against resilience

Table 15: Methodological aspects incorporated in the proposed method compared to two relatable methods existing in the literature

Methodological aspects	**[3]**	**[36]**	**Proposed Method**
Redundancy analysis			*Incorporates*
Time-based analysis	*Incorporates*		*Incorporates*
Physical & functional network-based system representation		*Incorporates*	*Incorporates*
Resilience calculation based on recovery	*Incorporates*		*Incorporates*