Long-Term Renewable Energy Planning in the Indonesian Context

A Lombok Island Study Case

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Long-Term Renewable Energy Planning in the Indonesian Context: A Lombok Island Study Case

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Abstract: In recent years, community microgrids have expanded their power systems with many aims. One of the most important goals of microgrids is to increase resiliency. The main objective of this paper is to develop effective planning tools for community microgrids within electrical distribution networks, with a specific focus on ensuring the provision of critical loads during natural disasters. Additionally, this paper emphasized emphasises long-term planning considerations by using DIgSILENT 15.2 tools. The primary goal of this issue is to create the best planning tools for community microgrids in order to increase the network's resilience to natural disasters, with a focus on important loads like hospitals and hotels. Also, the second goal is an optimization that seeks to reduce overall expenses. Finally, we'll talk about how to get two results: one is to choose a few microgrid-based loads to link to the electrical distribution network, and the other is to show that each microgrid has the power needed to support both its local loads and the system's vital loads in the event of a natural disaster. In this paper, the use of community microgrids for energy access against natural disasters in Indonesia is investigated by considering the case study of microgrids on Lombok Island. The study results, using the proposed framework, show that the presence of a microgrid structure in the distribution network expansion planning helps to improve operating conditions and supply critical loads in natural disasters.

Keywords: community microgrid; long-term planning; critical loads; natural disasters

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1. Introduction

The frequency and intensity of natural disasters (NDs) have been on the rise due to climate change in recent decades [1]. Resiliency is defined as the ability to swiftly adapt and restore power systems while also mitigating the risk of blackouts during natural disasters [2]. Research is now emerging to better understand the causes of blackouts, explore measures to strengthen and fortify the grid, and enhance the power grid's resilience against such disasters. This research focuses on examining the impact of natural disasters on electric power systems. Furthermore, emerging technologies such as microgrids (MGs) have the potential to enhance situational awareness and expedite system restoration processes. The major objective of [3] is to compile and assess the advancement of methods and tools that enable the prediction of power system issues related to natural disasters, such as the implementation of grid hardening measures and pre-storm operations, as well as the development of restoration models.

The resiliency and flexibility of power systems can be increased with the installation of new smart devices and the expansion of infrastructure. The main solution for this is to install community microgrids in some geographical areas to enhance resiliency and supply critical loads during natural disasters. The use of MGs in two modes, connected-to-grid and islanding, can restore power systems via a practical strategy. Indeed, MGs play an efficient role in increasing power system resilience. On the other hand, the development of MGs in power systems would enhance resiliency [4].

The suitable location and optimal capacity of energy storage units are achieved in [5] based on linear programming optimisation against earthquakes. The resiliency of the transmission system is determined by the size and location of the energy storage system and photovoltaic generation [6].

The share of renewable energy resources is increasing with the planning of community microgrids [7–9]. The planning of community microgrids has been accomplished for medium- and low-voltage distribution lines, especially in islanding mode and remote urban distribution networks [10,11]. The community microgrid can be used at the end of the branches of the feeder to improve the consumer power supply, resiliency, flexibility, and stability of the electrical distribution network [12,13]. This energy management system was developed with the approach of balancing generation and consumption within the renewable energy community [14].

The main objective of this paper is the planning of MGs for the entire energy system to supply critical loads during natural disasters on Lombok Island. There are two case-study areas: Mandalika (located in southern Lombok) and Gili Trawangan Island (in northwestern Lombok). The Mandalika area and Gili Trawangan Island represent a grid-connected MG, and an island MG is part of the Lombok electricity system. The simulation and modelling of the distribution network have just been considered for Gili Trawangan Island in this paper.

The main method applied in this research work is the planning of MGs with consideration of electrical constraints. DIgSILENT, as a practical tool, has been used for determining the location and capacity of MGs. In this methodology, at first, the Gili Trawangan feeder (inclusive single line diagram, SLD) is implemented in DIgSILENT, and then the planning of MGs based on electrical constraints is performed in order to supply the critical loads (such as hospitals, clinics, hotels, etc.), especially in a natural disaster.

Depending on the state of the investigated MG planning, the expansion planning can be divided into the location and capacity of MGs. The location deals with improving buses' voltage, i.e., which bus voltage needs to be increased with a MG. Comparatively, the capacity is more focused on supplying the critical loads that require renewable resources for a generation. The expected outcomes of this paper are an analysis of the location-capacity feasibility of a distribution network in Indonesia (the Gili Trawangan feeder on Lombok Island) based on MG technologies.

This paper investigates the feasibility of MG deployment in the Lombok electricity system with the following two elements:

- An overview of the electricity production units and main transmission lines on the island;
- The Indonesian grid codes' compatibility with MG installations.

The performance of the long-term planning of the community MGs is evaluated on the Gili Trawangan feeder that is connected to the upstream network via the Tanjung substation and supplies some critical loads over several years from 2022 until 2030, corresponding with our assumptions. It should be mentioned that MGs have tried to use actual data for the planning.

The rest of this paper is arranged as follows: Section 2 highlights the proposed method of planning. To obtain these, the input data are discussed in Section 3 and demonstrated with a case study in Section 4. Finally, Section 5 concludes this paper.

2. Materials and Methods

From a long-term investment point of view, community microgrid planning and operation will need to ensure resource allocation efficiency, facilitated by appropriate revenue flows, to achieve optimum outcomes for all stakeholders, including the community, investors, and providers [15]. The optimal planning of the interconnected network of multi-microgrids is discussed in [16]. In this reference, interconnection planning will enhance the reliability and economic operation of a community of microgrids. The proposed approach will apply to the optimal planning of interconnection among microgrids with variable renewable energy sources. The optimal planning takes into account various factors, including economics, reliability, variability of renewables, network- and resource-based uncertainties, and adaptability to accommodate the prevailing operating concerns.

The major goal of this paper is to create the best planning tools for community MGs to supply essential loads during natural disasters (NDs), with a focus on essential loads like hospitals and hotels. The optimisation that seeks to reduce total cost is also a secondary goal. Finally, we'll talk about how to achieve two results. The first is choosing a location to link the MG to the grid, and the second is showcasing the MG's generation capacity for the service to provide the system's vital loads during natural disasters. On the other hand, the problem's inputs call for the network topology, data on the load profile, and a projection of the load growth rate. Some of the constraints [4] that the problem must address are as follows:

Power Flow Constraints: Load flow necessitates the estimation of electrical parameters like bus voltages and line currents. Also, the MG assists in supplying the important loads modelled by the power islanding. To enable the evaluations above, the set of power equations should, therefore, be solved as precisely as feasible.

Operational Constraints: Equipment like buses, lines, and generators must operate safely under specified parameters in order to remain within safe operating limits. The voltage of buses should be kept as close to 1 p.u. as feasible (often 0.05 p.u.), and the loading of the branches linked to the transformer should not exceed the capacity of the transformer. The current flowing through a line should not exceed its thermal limit. These restrictions are included in the restrictions of this category, along with restrictions on storage capacity, power balance (supply and load), and limits on MG generation.

Topological Constraints: The distribution networks (DN) are often radial networks, and the radial network helps to ensure that the protective conditions operate as they should. Additionally, it is important to provide affordable, safe, and secure communication between MGs, lines, buses, and generation units.

The main objective of this section is to focus on the long-term planning of MGs. To successfully accomplish this goal, it is essential to determine the load growth rate that is applied to the baseline load. Understanding the rate at which the load is expected to increase over time is crucial for accurately forecasting future energy demands and effectively planning the capacity and expansion of MGs in the long term. By considering the load growth rate in the planning process, it becomes possible to ensure that the MGs are designed to meet the anticipated increase in energy demands and maintain reliable and efficient operation over the long term.

3. Input Data

3.1. Lombok

The overall electricity system for the island of Lombok with transmission lines and electricity production units originates from the "Electricity Supply Business Plan 2021–2030" [17].

In the event of a natural disaster that hits the entire Lombok electricity system, [17] will probably prioritise different parts of the island to supply electricity to the most critical ones. It could be expected that to secure the security of supply for vital cities, i.e., the capital Mataram, the Gili Islands will be disconnected from the main grid. In such a situation, the Gili Islands would have to operate in island mode [17].

The geographical location of the Mandalika area and Gili Islands on the entire Lombok Island is indicated in Figure 1.

Figure 1. Geographical location of the Mandalika areas and Gili islands in Lombok.

3.2. Gili Trawangan Island

Gili Trawangan Island is located to the west, north of Lombok. Its geographical location concerning Lombok and the neighbouring islands, Gili Meno and Gili Air, is depicted in Figure 2. The last island left is Gili Trawangan.

Figure 2. Geographical location of Gili islands (Gili Trawangan, Gili Meno, Gili Air).

An electrical SLD for the Gili Islands is represented in Figure 3. Ampenan and Tanjung substations, which accumulate and deliver the total power flow to the Gili Islands, are located on Lombok Island. These two substations ensure a stable connection for the Gili Islands with the MV electricity network. Also, in Figure 4, the Gili Trawangan SLD is shown. The route of the Gili Trawangan feeder from a substation to local loads is visible in Figure 4.

However, as previously described, the estimated peak power demand in Gili Trawangan is 3.3 MW, and the maximum local power production from an intermittent NRE generation unit is facilitated by the PV power plant, reaching 600 kW.

The projected peak power demand in Gili Trawangan from 2019 to 2030 is equivalent to a 315% increase [17]. The average yearly increase in peak power consumption is about 14%. Furthermore, the accumulated power capacity of the submarine cables is 36 MW [17,18].

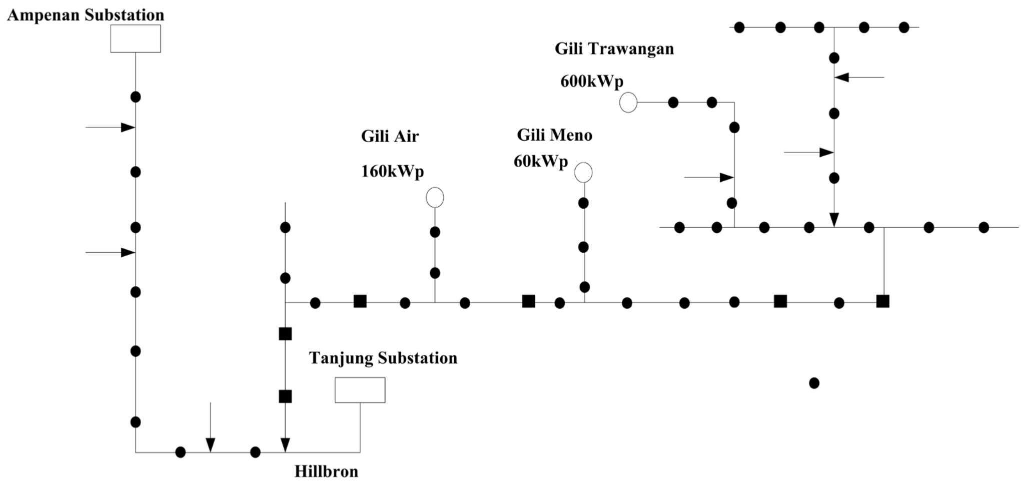


Figure 3. Electrical single line diagram (SLD) of the Gili islands and their connection to the Lombok electricity system.

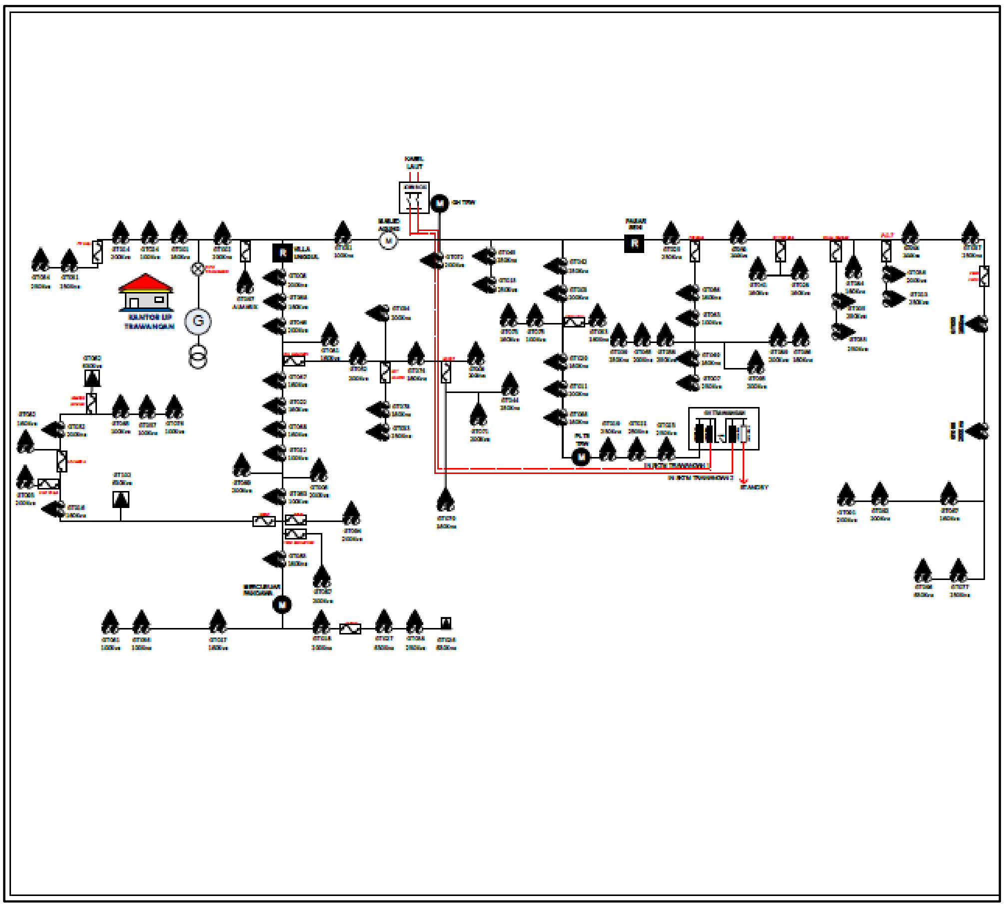


Figure 4. Distribution network of Gili Trawangan 20 kV SLD.

The accumulated submarine cable capacity of 36 MW can easily accommodate future peak power demands. Even considering that Gili Meno and Gili Air would experience the same percentage increase in peak power demand, the submarine cables will not be exposed to congestion within the next few decades.

If the solar PV plant capacity of 600 kW is not expanded by 2030, when the projected peak power demand is 13.7 MW, a power deficit of 13.1 MW would be present [17,18]. To avoid such a situation, the construction and commissioning of dispatchable generating units is a prerequisite for the deployment of an islanded MG to cover the residual demand.

4. Case Study

This section aims to focus on the long-term planning of a microgrid (MG) at the medium-voltage level (20 kV) of the Gili Trawangan feeder, utilising DIgSILENT or PowerFactory 15.2 software. The implementation process of the Gili Trawangan feeder on DIgSILENT is depicted in Figures 5 and 6.

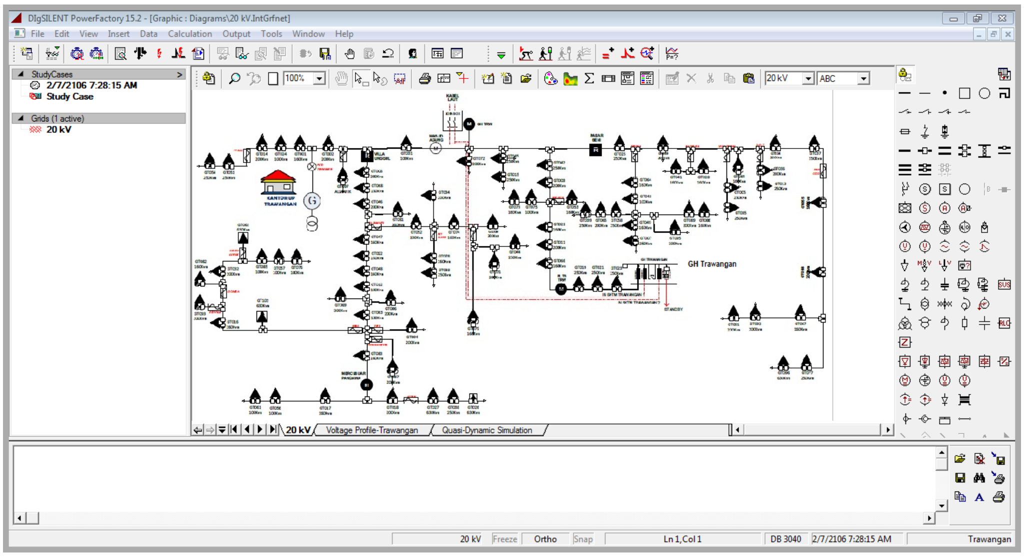


Figure 5. Import of Gili Trawangan feeder in DIgSILENT.

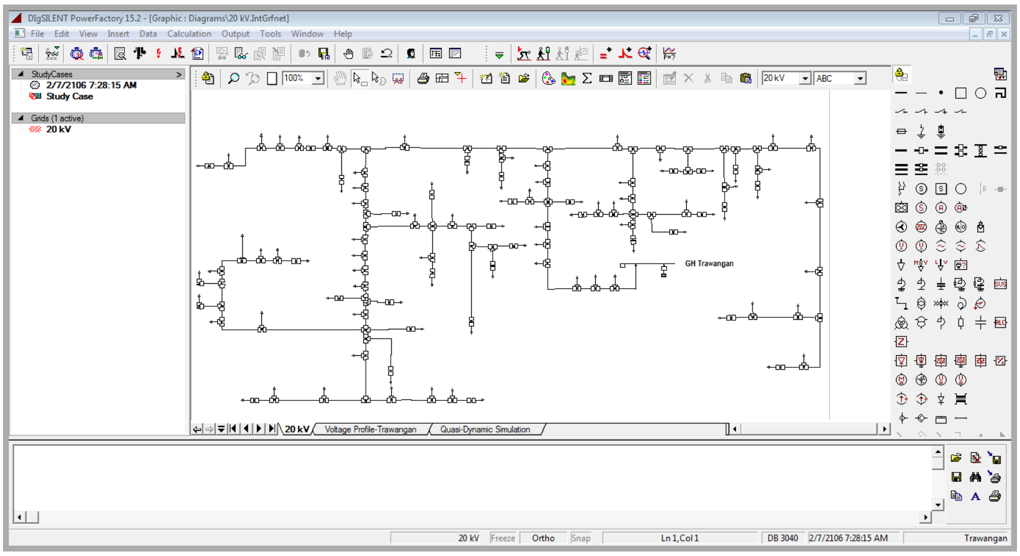


Figure 6. Implementation and modelling of the electrical equipment of 20 kV Gili Trawangan feeder on DIgSILENT.

In the initial step, electrical components such as branches, transformers, and loads are modelled in DIgSILENT. Subsequently, utilising operational constraints, the optimal size and optimal location of the MGs are determined. To accomplish this, some areas, especially at the ends of some branches of the feeder, are selected that have lower voltage (lower than the acceptable range) compared to other areas. Next, the optimal capacity of the MG is determined, taking into consideration the ability to supply the loads in the identified areas while ensuring that it does not exceed the electrical constraints and limitations. This ensures that the selected MG capacity is suitable for supplying the loads in the designated areas without compromising the overall system performance.

As seen in Figure 6, the Gili Trawangan SLD is implemented on DIgSILENT or PowerFactory, and this tool is used for modelling the Gili Trawangan feeder that is connected to the Tanjung substation. After that, the electrical constraints are considered, and then the siting and sizing of the MGs for supplying loads or critical loads are determined. In this way, we assumed some data that are expressed below.

Some assumptions for accomplishing this section include:

- Use the CU cable with 120 mm^2 from the DIgSILENT library (N2XS(F)2Y 1x120RM/16 12/20 kV);
- The distance of each section (between two nodes) is considered 1 km;
- The total length of the feeder is 180 km.

Results

This section presents the findings obtained from the DIgSILENT simulation conducted on the Gili Trawangan distribution network. The results offer valuable insights into the performance, behaviour, and effectiveness of the system, shedding light on the feasibility and potential benefits of implementing the microgrid within the Gili Trawangan distribution network. The heat map of the Gili Trawangan feeder is used to analyse and visualise the voltage levels at all buses as well as the loading of all branches. This approach provides a comprehensive overview of the voltage distribution and branch loading within the feeder, enabling a better understanding of potential voltage issues and areas of high branch utilisation. Figures 7–24 display the voltage profiles and loading information for each section of the Gili Trawangan feeder. These figures illustrate the voltage levels and branch loading both with and without the MG for each year from 2022 to 2030. By comparing these figures, the impact of the MG implementation on voltage stability and branch loading can be observed over the specified time period.

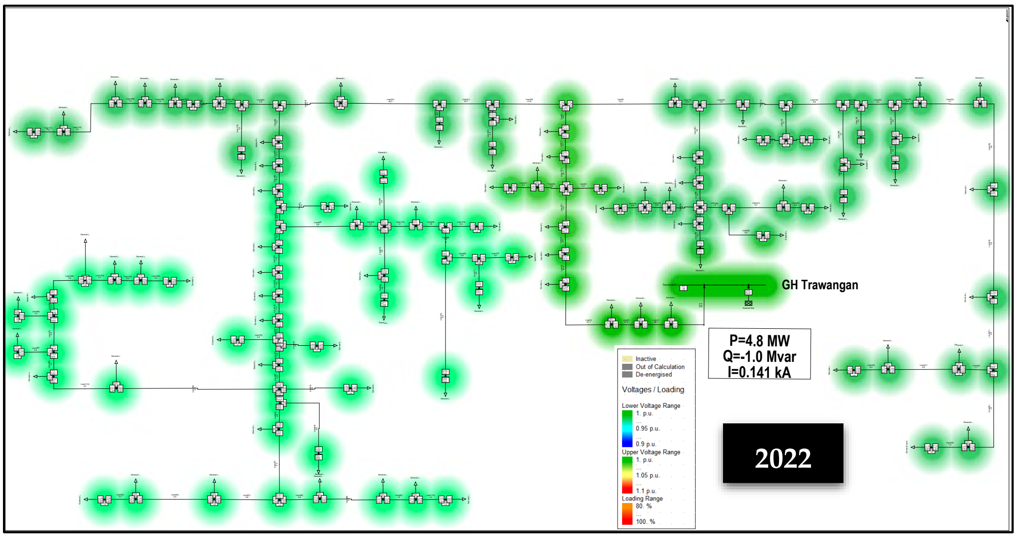


Figure 7. Heat map on DIgSILENT in 2022 for Gili Trawangan feeder.

As depicted in Figure 7, the results indicate that there is no immediate requirement for the installation of a MG since all electrical constraints are within normal ranges and the voltage in all nodes is within an acceptable range (above 0.95 p.u.) in 2022. Also, the voltage profile is shown in Figure 8, and the voltage of all nodes is above 0.97 p.u.

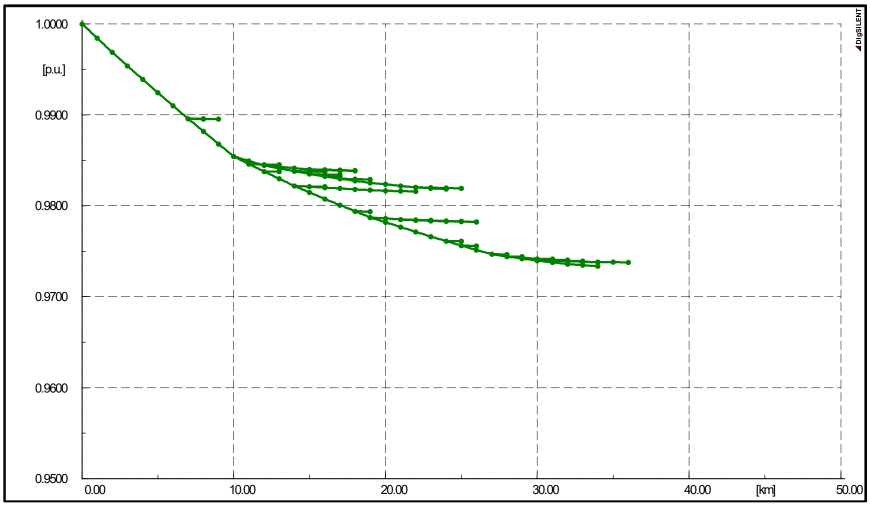


Figure 8. Voltage profile in 2022 for Gili Trawangen feeder.

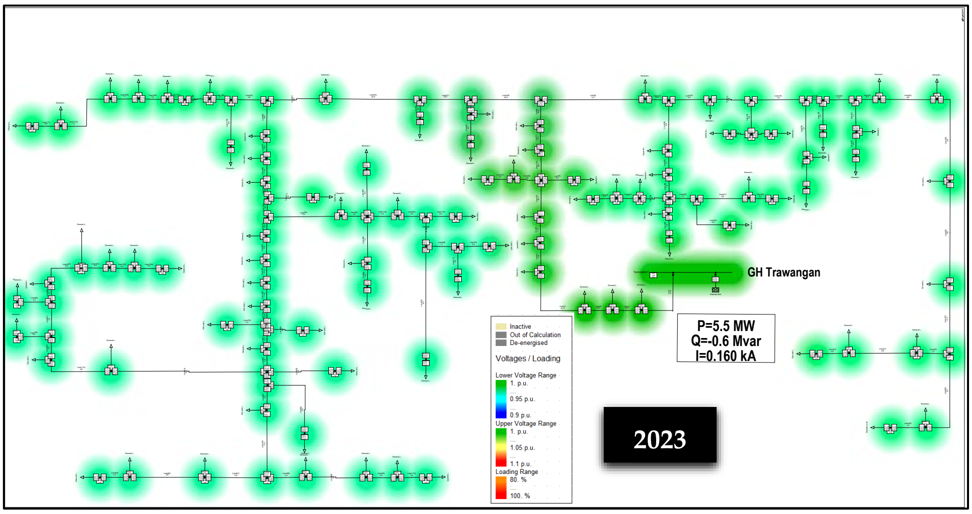


Figure 9. Heat map on DIgSILENT in 2023 for Gili Trawangen feeder.

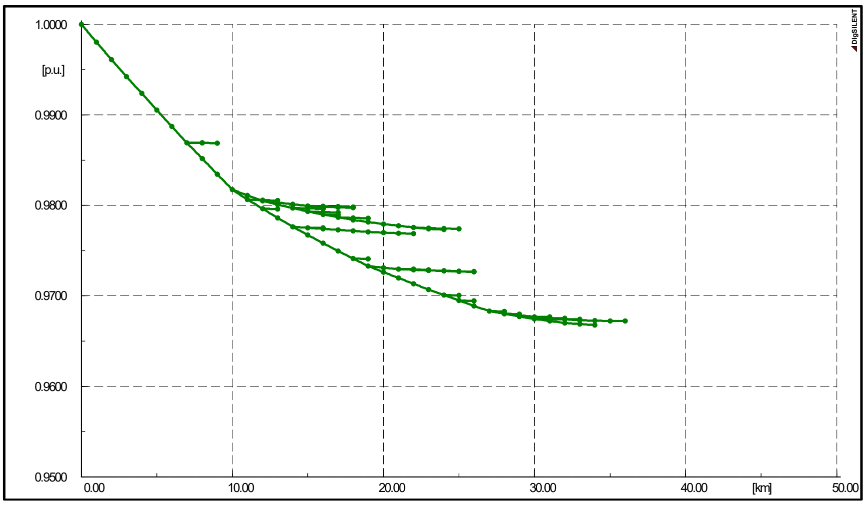


Figure 10. Voltage profile in 2023 for Gili Trawangen feeder.

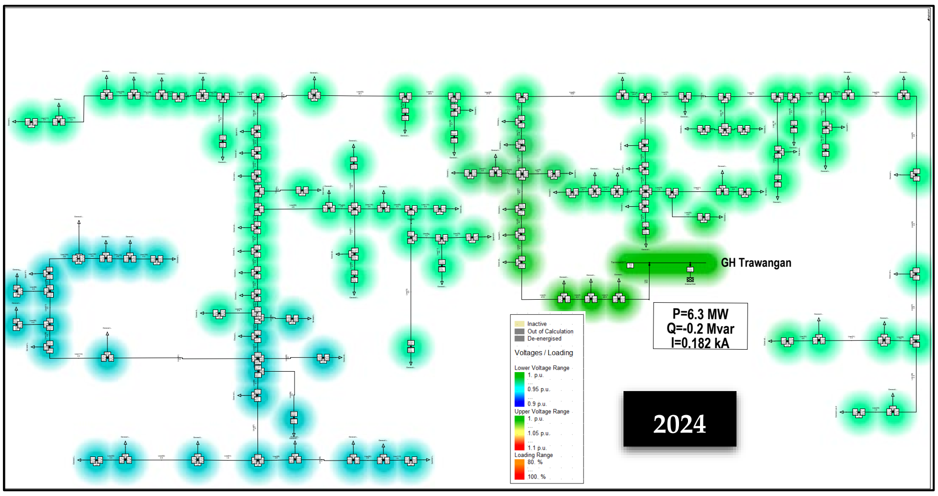


Figure 11. Heat map on DIgSILENT in 2024 for Gili Trawangen feed.

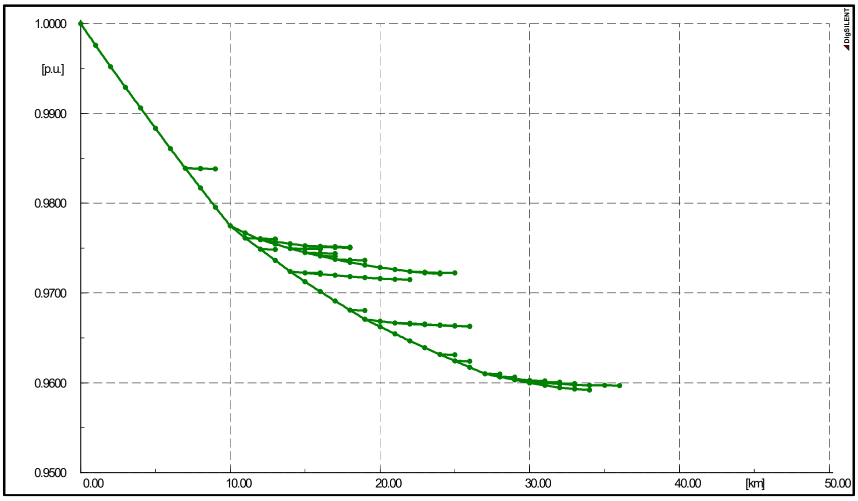


Figure 12. Voltage profile in 2024 for Gili Trawangen feeder.

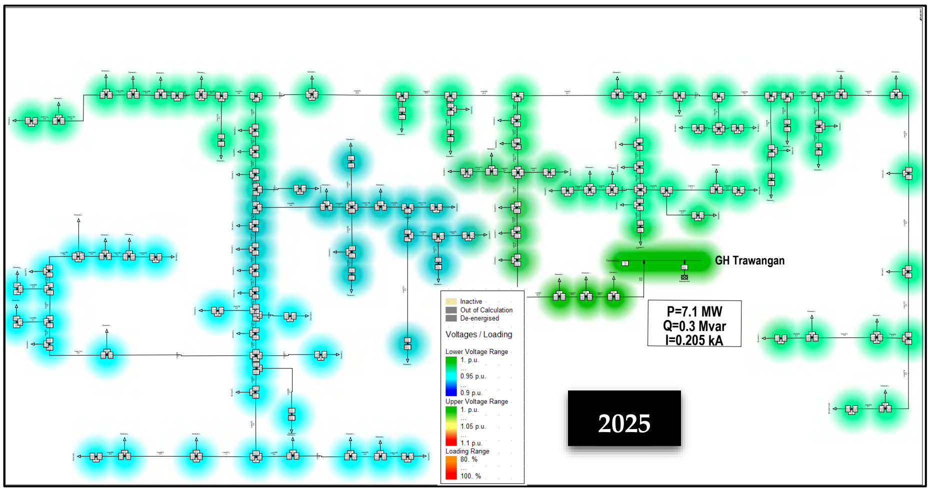


Figure 13. Heat map on DIgSILENT in 2025 for Gili Trawangen feeder.

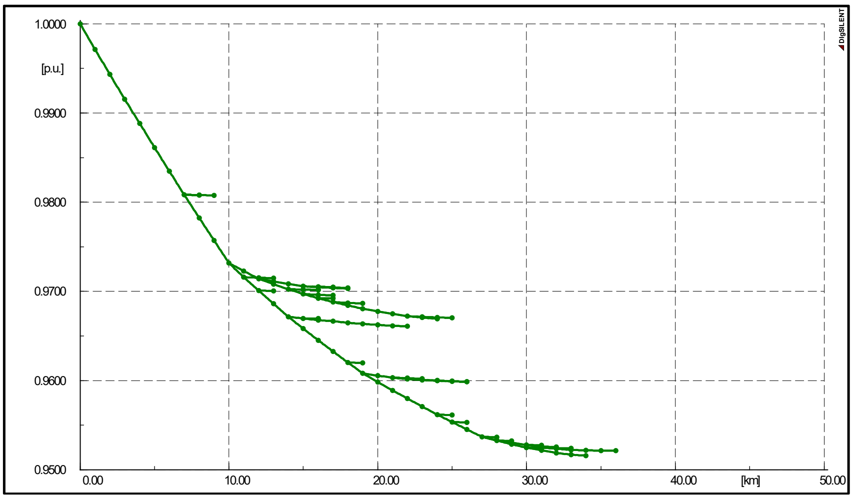


Figure 14. Voltage profile in 2025 for Gili Trawangen feeder.

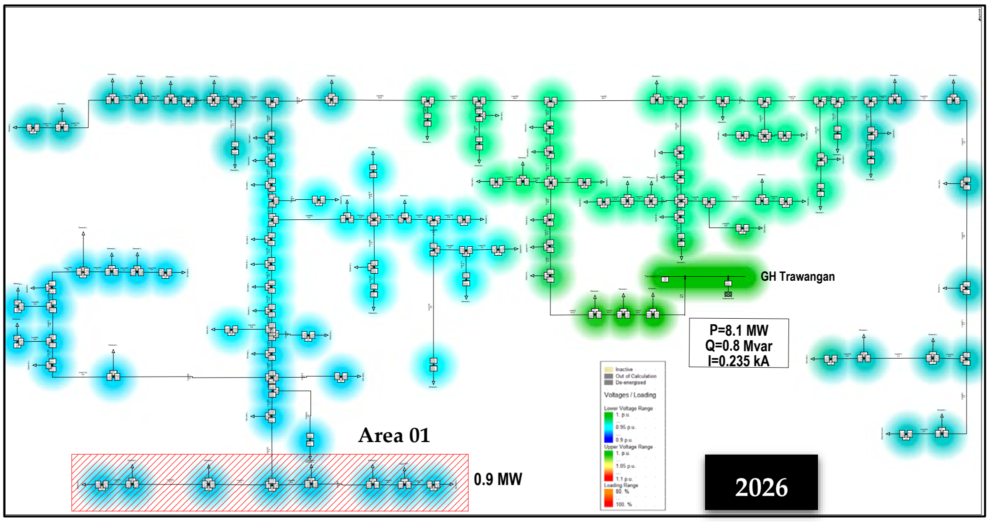
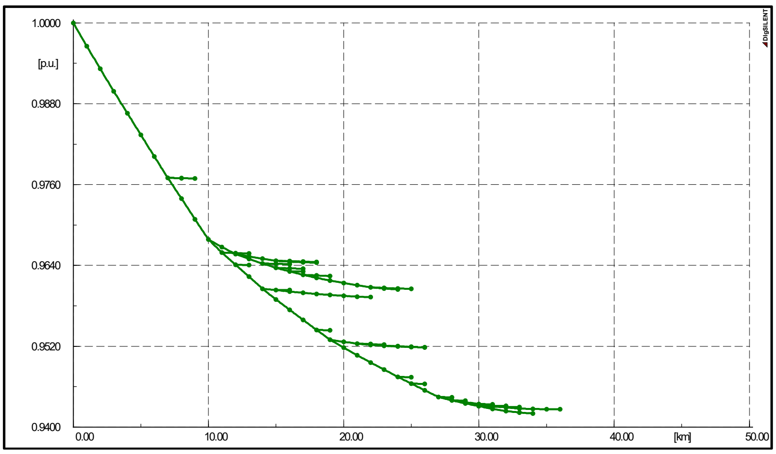
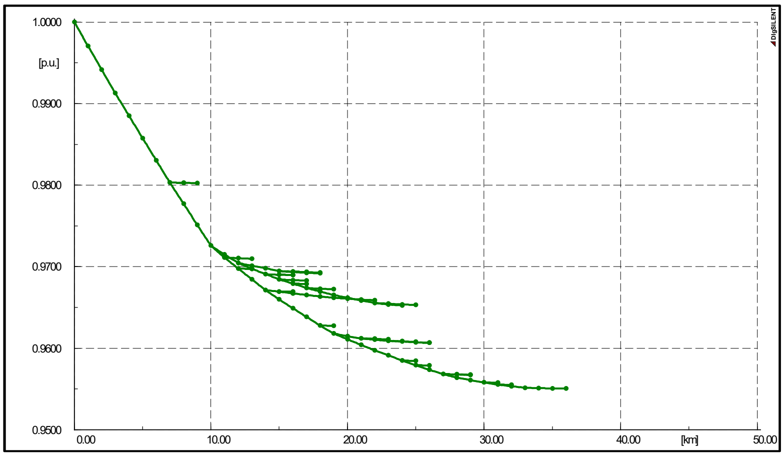


Figure 15. Heat map on DIgSILENT in 2026 for Gili Trawangen feeder.



(**A**)

Figure 16. *Cont.*



(**B**)

Figure 16. Voltage profile in 2026 for Gili Trawangen feeder, (**A**) without MG and (**B**) with MG.

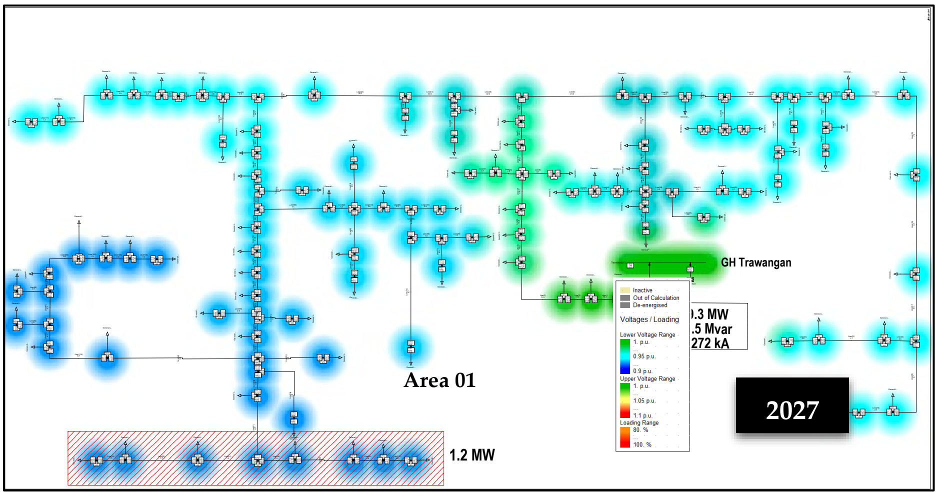
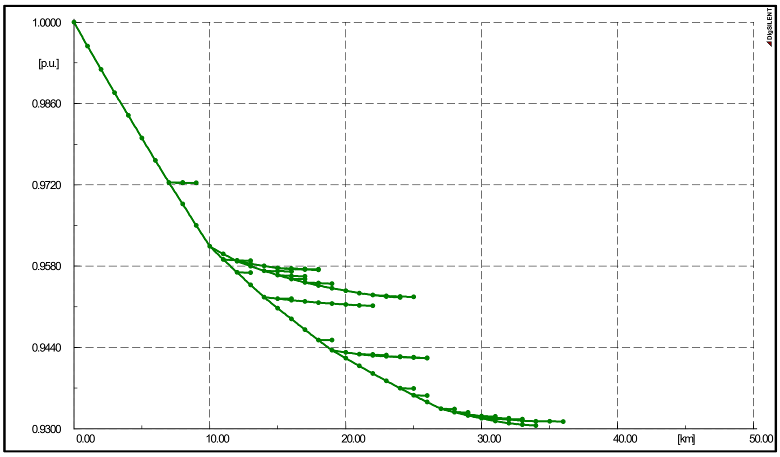
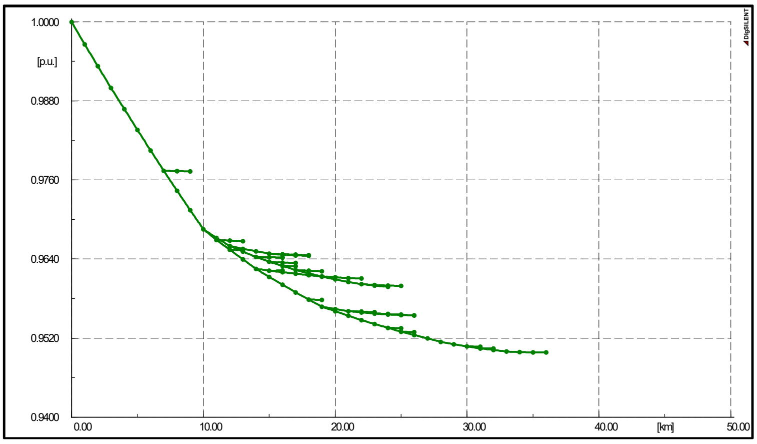


Figure 17. Heat map on DIgSILENT in 2027 for Gili Trawangen feeder.



(**A**)

Figure 18. *Cont.*



(**B**)

Figure 18. Voltage profile in 2027 for Gili Trawangen feeder, (**A**) without MG and (**B**) with MG.

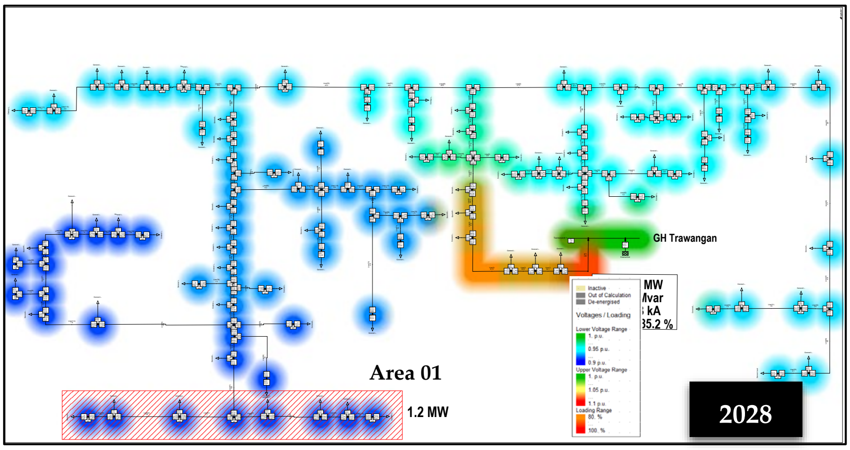
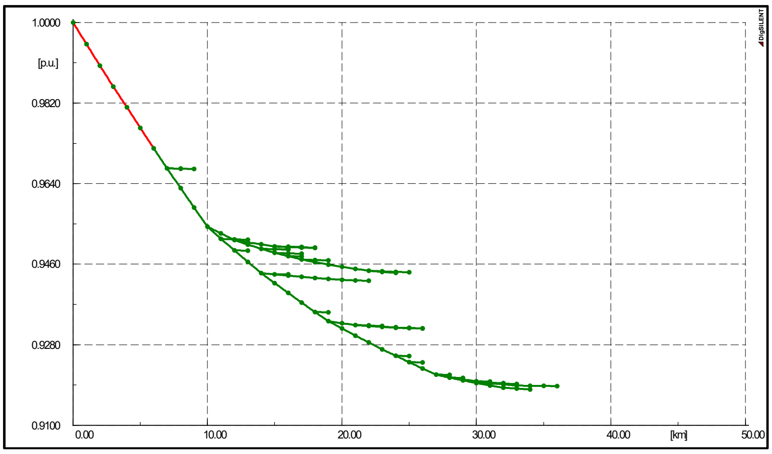
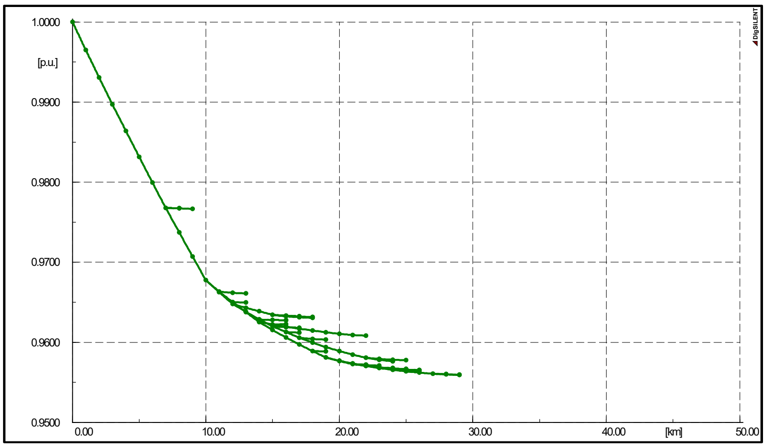


Figure 19. Heat map on DIgSILENT in 2028 for Gili Trawangen feeder.



(**A**)

Figure 20. *Cont.*



(**B**)

Figure 20. Voltage profile in 2028 for Gili Trawangen feeder, (**A**) without MG and (**B**) with MG.

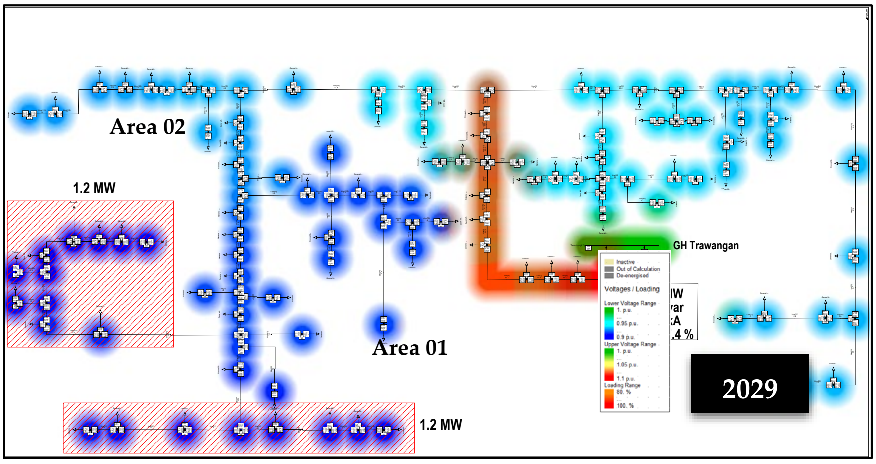
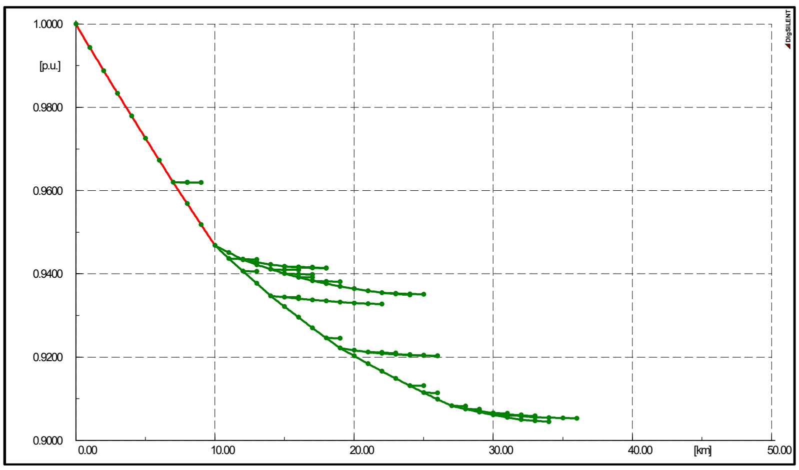
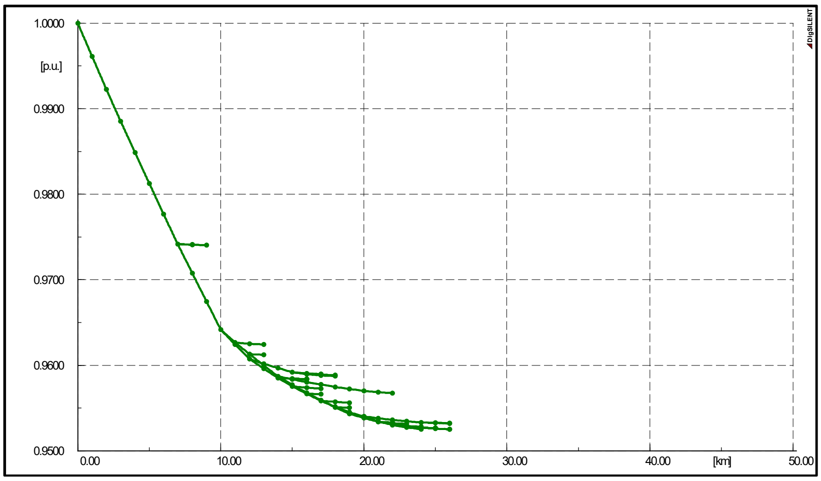


Figure 21. Heat map on DIgSILENT in 2029 for Gili Trawangen feeder.



(**A**)

Figure 22. *Cont.*



(**B**)

Figure 22. Voltage profile in 2029 for Gili Trawangen feeder, (**A**) without MG and (**B**) with MG.

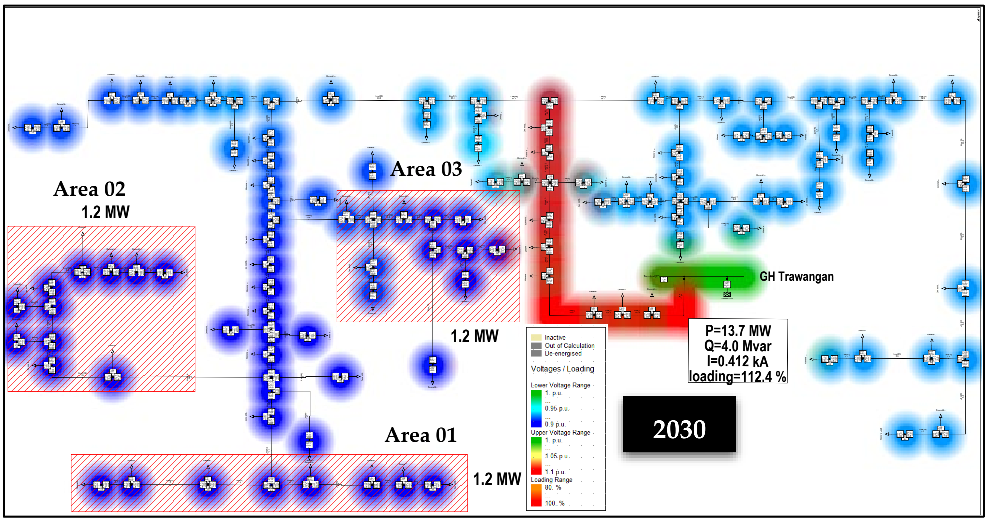


Figure 23. Heat map on DIgSILENT in 2030 for Gili Trawangen feeder.

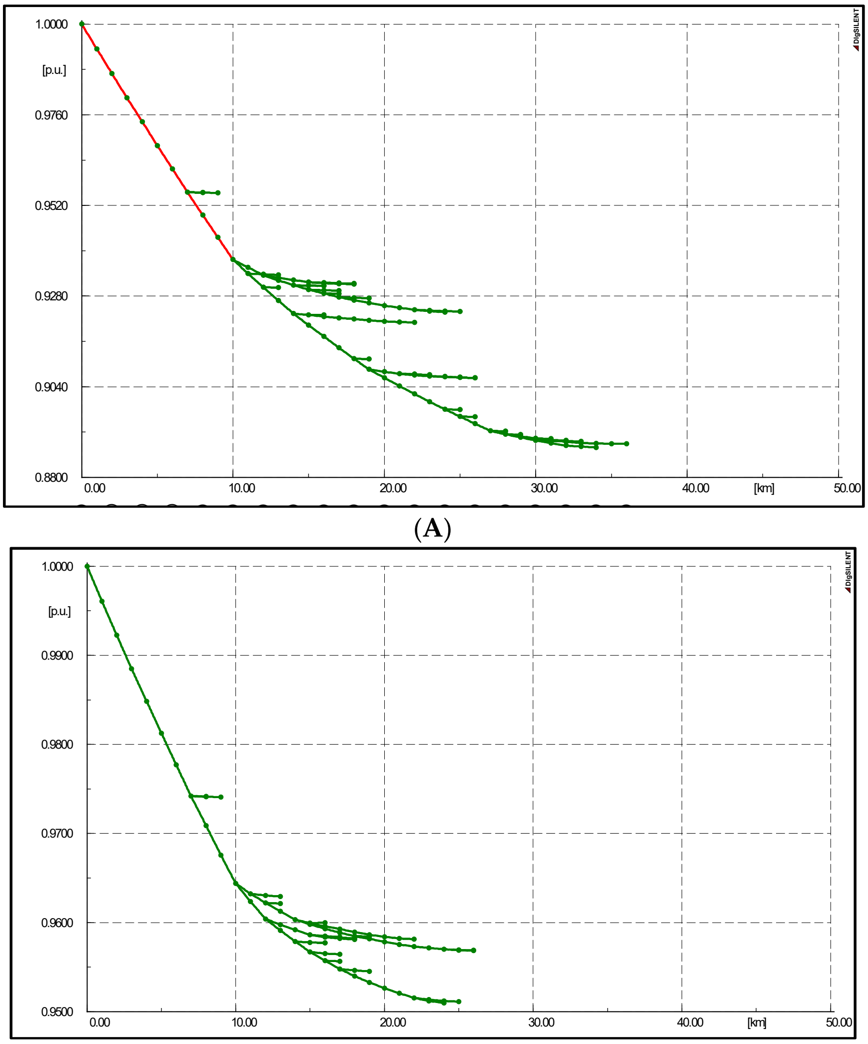
Figures 9 and 10 show that all the electrical constraints are acceptable and that we don't need to use the MG in 2023.

As is shown in Figures 11–14, after considering the load growth rate, there is no need to use the MG in 2024 and 2025, and, still, all the electrical constraints are acceptable. All the nodes' voltages are still above 0.95 p.u. in Figure 14.

In 2026, it will be necessary to install one MG with a 0.9 MW capacity at the end of the feeder (area 01) to improve the voltage and supply some loads in area 01, as shown in Figure 15. The voltages of the nodes in area 01 before the installation of the MG are less than 0.95 p.u. in Figure 16A, but after the installation of the MG with 0.9 MW capacity, they are more than 0.95 p.u. in Figure 16B.

Then, the capacity of the installed MG in area 01 must increase to 1.2 MW because of the increasing load growth rate in Gili Trawangan in 2027 (Figure 17). After increasing the available MG, the bus voltage is improved in area 01 (Figure 18A,B).

As shown in Figure 19, the MG with a 1.2 MW capacity is suitable for supplying the loads in area 01, so the loads can be supplied with this MG by 2028, and according to Figure 20, the bus voltage moves to an acceptable range after the installation of the MG.



(**A**)

(**B**)

Figure 24. Voltage profile in 2030 for Gili Trawangen feeder, (**A**) without MG and (**B**) with MG.

In 2029, besides the previous MG, another MG at area 02, shown in Figure 21, with a capacity of 1.2 MW, will be needed. After using the MG in area 02, the overloadings at the beginning of the Gili Trawangan feeder are decreased, and the voltage drop at the end of one branch of this feeder is improved. In Figure 22A,B, the loading of each section and bus voltage are shown along the length of the Gili Trawangan feeder. The buses' voltage reduces until 0.9 p.u., before the installation of MGs, and voltages increase after the MGs.

Finally, a third MG must be installed at area 03 with the same capacity as the second MG (1.2 MW), shown in Figure 23, for the improvement of the voltage at the end of some branches in area 03 of the Gili Trawangan feeder and also to reduce the overloading of some first branches in 2030.

Considering Figure 24A,B, the bus voltage will improve, as will the loading of some branches at the first of the Gili Trawangan feeder, which will reduce to below 100% loading.

With consideration of electrical network constraints, load profile, load growth rate, and feeder current or power, it is necessary to install three MGs with a capacity of 1.2 MW at three different areas (the ends of three branches of the Gili Trawangan feeder) to supply the loads after eight years (2022–2023). After the implementation of DIgSILENT, the location and generation capacity of these MGs were demonstrated and shown in Figures 25 and 26.

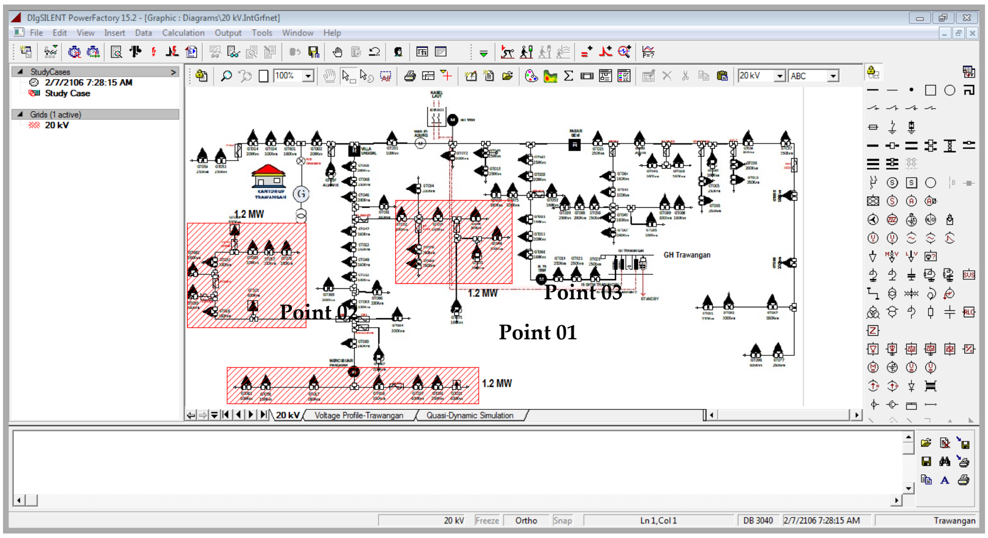


Figure 25. Location and generation capacity of three MGs in the Gili Trawangan feeder.

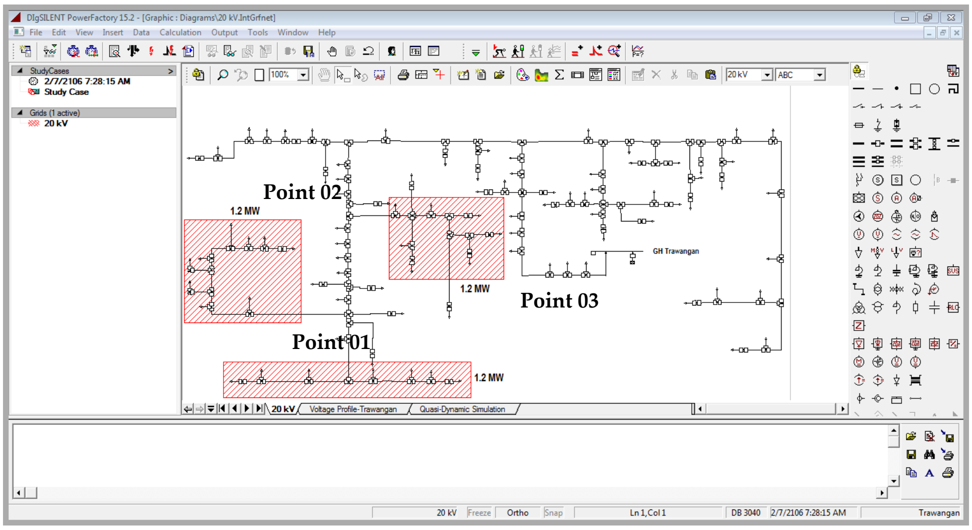


Figure 26. Location and generation capacity of three MGs on DIgSILENT.

5. Conclusions

For community microgrids, the primary goals should be social, economic, and environmental. This will almost certainly result in a variety of long-term planning programmes and implementation plans that can best realise objectives like supplying the essential loads, improving voltage, reducing overloading, maximising efficiency, and lowering overall costs. The analysis of community microgrids offers insights and high-level frameworks to support community microgrid investment planning to accomplish desired results in a decision-making setting marked by renewable energy resources, significant uncertainty, and storage. This study's goal was not to identify the best configuration for each individual microgrid application but rather to lay the groundwork for a strategic options evaluation and challenge identification that will help communities, public investors, and private investors who are interested in community microgrids achieve a more reliable and efficient electricity supply.

Although there are trade-offs between various tactics and planning programmes, it should be the general rule that the community microgrid's objectives are best addressed. The community microgrid's ownership and control structure, as well as knowledge of the current situation and expectations for the future, will all be factors in determining the best structure.

This paper at first, tried to implement the electrical equipment on DIgSILENT based on existing data and some assumptions for long-term planning. Secondly, in considering the load growth rate and having power in the first year (2022), the load has been estimated for the next few years until 2030. Finally, in a way, the location and size of the MGs were determined so that they can supply the loads (or at least the critical loads) while all the constraints will be in the acceptable range and not exceeded.

As shown in the results section, we need to install three MGs at three different areas (ends of three branches of the feeder) of Gili Trawangan's feeder based on electrical constraints that can supply the critical loads during natural disasters with the installation of MGs in these areas. The main objectives of the installation of MGs in these areas are to supply the critical loads in natural disasters and minimise the total costs of the electrical distribution network (DN) with the deferral of feeder and transformer expansion.

Furthermore, an electrical battery system has to potentially be installed to act as an emergency response in the event of an electrical fault or natural disaster.

Meanwhile, we must be reminded that these calculations are approximate, because there is no more information about the real network with details. All these calculations are based on some assumptions, and for understanding and making better decisions, it is necessary to have real electrical data from the electrical distribution network (DN) that can be used to determine the accurate location and capacity of MGs.

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