The Effect of PV Positioning On Power Losses In Grid-Connected Micro Hydro Power Plant Systems

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Abstract. This study rigorously investigates the effects of PV (photovoltaic) placement on the voltage profile and power losses in a grid-connected micro-hydro power system in West Sumatra, Indonesia. The primary objective is to identify optimal PV installation locations that minimize grid power losses while enhancing voltage stability in a 20 kV distribution network. Through comprehensive simulations, the study assesses the different effects of PV placement at different nodes in the network. The findings reveal that PV integration impacts voltage profiles and power losses differently across the network, with some locations showing improved voltage quality and others exhibiting voltage instability, which can lead to operational challenges. Notably, higher PV penetration is associated with increased grid power losses, reaching up to -9,9 % in certain configurations. These results underscore the need for advanced adaptive power control strategies, such as smart inverters and energy storage solutions, to maintain grid reliability. This study offers actionable insights for grid operators and policymakers aiming to balance the benefits of renewable energy integration with the technical requirements for stable and efficient power distribution.
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Keywords: *On-Grid PV, Distribution Network, Voltage Stability, Power Losses, Mini-hydro power plants.*

1 Introduction

Environmental degradation is a major global challenge, impacting human health, biodiversity, the ozone layer, air quality, natural resources, and the economy. A key driver is the rising CO2 emissions linked to growing energy demand [1]. The reduction of fossil energy supply, particularly petroleum, and the issue of global greenhouse gas emission reductions, has prompted the government to continue to increase its effort in ensuring the energy security and independence through renewable energy development [2].

Energy supply and use contribute to global warming, air pollution, acid rain, ozone depletion, deforestation, and radioactive emissions. Solutions include energy conservation, improved efficiency, reduced fossil fuel use, and increased renewable energy. Generating clean, efficient, and eco-friendly energy has become a major challenge for engineers and scientists. [3].

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Indonesia is in the process of transforming its energy demand with a view to achieving social and environmental benefits by 2060 and also Indonesia announced a NZE 2060 pledge to justify the selection of model horizon [4]. According to government regulation (GR), No. 79 of 2014 on the National Energy Policy, the target for utilizing the mix renewable energy in 2025 are at least 23% and 31% in 2050 [2]. To address this problem, Indonesia has prioritized the development of renewable energy as part of its efforts to carry out a more sustainable energy transition, Indonesia as one of the countries with abundant natural resources has great potential to produce renewables, such as water energy from rivers and waterfalls [5]. Indonesia, an equatorial archipelago, is rich in solar irradiance, making it an ideal location for harnessing solar energy [6]. Among them, the photovoltaic (PV) generation system has received great attention in research because it ap- pears to be one of the possible solutions to the environmental problem. [3].

The adoption of renewable energy-based distributed generation is growing worldwide, driven by clean energy policies and efforts to reduce carbon emissions. Solar power is a widely trusted option, supported by government incentives and subsidies. In Indonesia, fossil fuels still dominate, but the shift toward renewable energy, like solar power, is becoming crucial. West Sumatra, with its high solar irradiation and tropical climate, is ideal for solar PV systems. Off-grid systems suit its challenging geography, while integrating solar PV into existing grids can enhance voltage stability and reduce losses. Successful examples abroad, such as in Ireland and the UAE, highlight its potential in Indonesia, but further analysis is needed. [7].

Although there are previous studies exploring the impact of PV penetration on the distribution system, most of them only focus on one source, usually substations, and often only analyze urban loads without considering other conditions. No study has investigated the impact on the 20 kV distribution system supplied by various distributed generation sources, but for the existing condition of the electricity system, distributed generation includes various types of sources, not only PV. This limitation prevents these studies from capturing the problems that occur in the field. The interaction between various sources, such as substations and distributed generation, can significantly affect the performance of the distribution system. Therefore, more in-depth research and simulation are needed to comprehensively understand these interactions. Such research will provide a more complete picture of the dynamics of the distribution system, as well as produce more accurate insights into PV penetration.

To address these issues, this study aims to obtain a comprehensive evaluation of the parameters in the distribution network, including voltage profiles and power losses, when PV is installed in the network by considering various types of distributed generation to reflect the real conditions.

This study uses a real network to ensure that the results are more relevant to the problems in Indonesia. This paper is structured as follows: to discuss the parameters used in the study, the methods applied, the existing distribution system without and with PV, the location of PV installation, and the scenarios used in this study.

2 Methodology

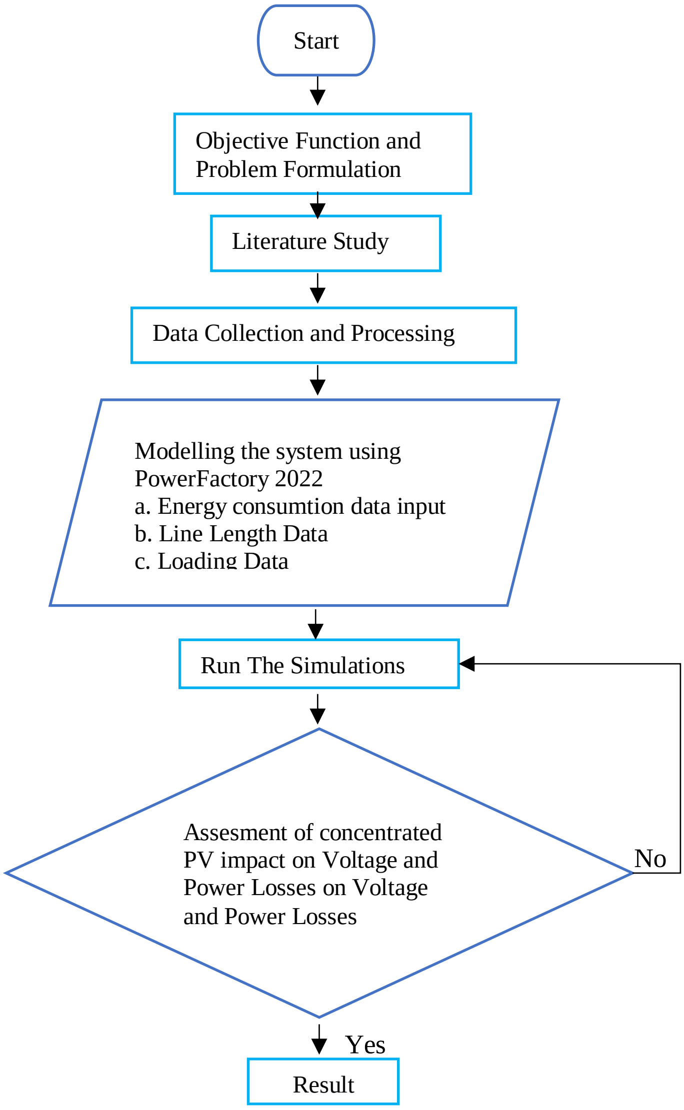


Figure 1 Flowchart of proposed method

2.1 Parameters

2.1.1 Voltage Profile

Table 1 Standards For Customer Services.

Variable	Standard	Source
Nominal Voltage	0.9 pu s/d 1.05 pu	SPLN No. 1 1995
Power Loss Maximum	5%	SPLN No. 72 1987
Power Factor	0,85	SPLN No. 70-1 1985

This table shows the operational standard of the electricity distribution network in Indonesia based on SPLN (State Electricity Company Standards), which includes nominal voltage, maximum power losses, and power factors that must be met by the distribution network. Voltage drop could be caused by several things, among them are the conductor length, distance to source, and load capacity. [8].

2.1.2 Power Losses

The placement of PV installations has a notable effect on the amount of power loss in the system. To determine these losses, the power loss is calculated using the following equation :

$$\%_{\text{losses}} = \frac{P\ Output}{P\ Input} \times 100\ \% \quad (1)$$

2.1.3 Placement of PV

The PV installation location determination includes three different points: two connected to separate substation busbars, and one connected to the distribution network. Various simulation scenarios are created to analyze the impact of PV installation on the distribution network, to determine the voltage and power losses and the simulation results are used to determine the best location.

2.1.4 Proposed Method

This study uses the method described in Fig. 1. The process begins by determining the parameters of the electrical system, focusing on the voltage profile and power losses. After that, the distribution system is modeled in existing conditions, then power from PV is added. This distribution modeling includes two energy sources: the Main Substation and the Mini Hydro Power Plant (MHPP). Several simulation scenarios are carried out considering four potential locations for PV installation. Each scenario is observed to broadcast the impact of PV installation, with the aim of finding the most optimal location. The simulation uses PowerFactory 2022 software. After that, a detailed analysis is carried out regarding the voltage profile and power losses in each scenario. Through observation evaluation, the most efficient PV installation location is determined. This study ends by providing recommendations based on the results of the simulation.

2.2 Distribution System

This research focuses on the 20 kV distribution system originating from the main substation and connected to the mini hydro power plant (MHPP) system in Tongar, West Sumatra

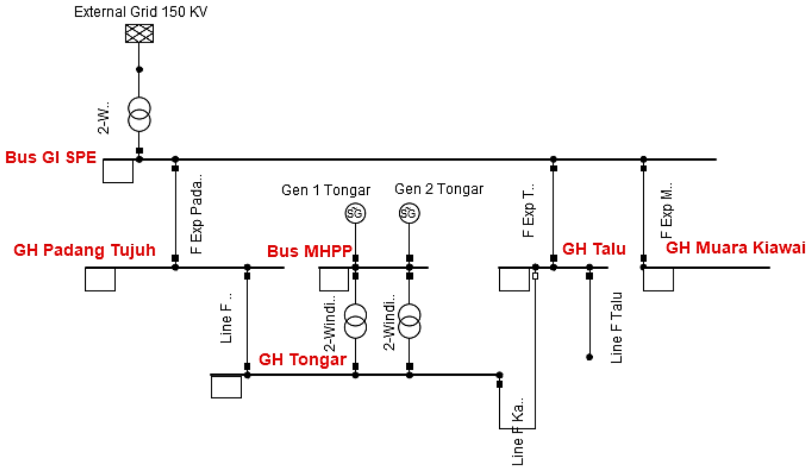


Figure 2 Single line diagram of Simpang Empat distribution system

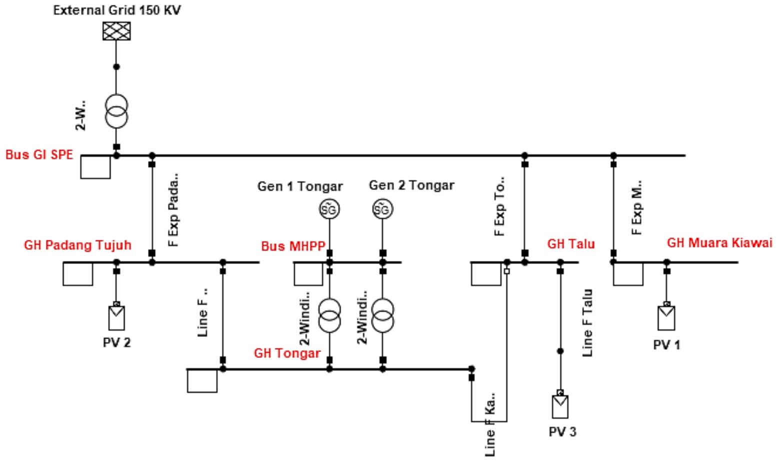


Figure 3 Single line diagram of Simpang Empat distribution system with PV

Table 2 Simulation Scenarios

Cases	PV Location			Notes
	PV1	PV2	PV3	
Case 1	-	-	-	None
Case 2	✓	-	-	Bus GH Muara Kiawai
Case 3	-	✓	-	Bus GH Padang Tujuh
Case 4	-	-	✓	F Talu Network
Case 5	✓	✓	-	Bus GH Muara Kiawai and GH Padang Tujuh
Case 6	✓	-	✓	Bus GH Muara Kiawai and F Talu Network
Case 7	-	✓	✓	GH Padang Tujuh and F Talu Network
Case 8	✓	✓	✓	System with PV

In this study, the distribution network receives power from the Main Substation and mini hydro power plant operating at a voltage of 20 kV. The system for PV optimization is placed on the Bus Substation Connection and on the network in Out Going. Based on the data, the peak load occurs at 13:00 with the load on TD#1 of the Simpang Empat Main Substation is 8.3 MW.

3 Result And Discussion

This section will present and discuss the results obtained from the simulations that have been carried out, along with the accompanying analysis.

3.1 Initial Conditions

In this simulation, the load applied corresponds to the peak demand during the day, specifically at 13:00. This peak load is selected as the load profile because it aligns with the operational hours of the PV system, which primarily generates electricity during daylight hours.

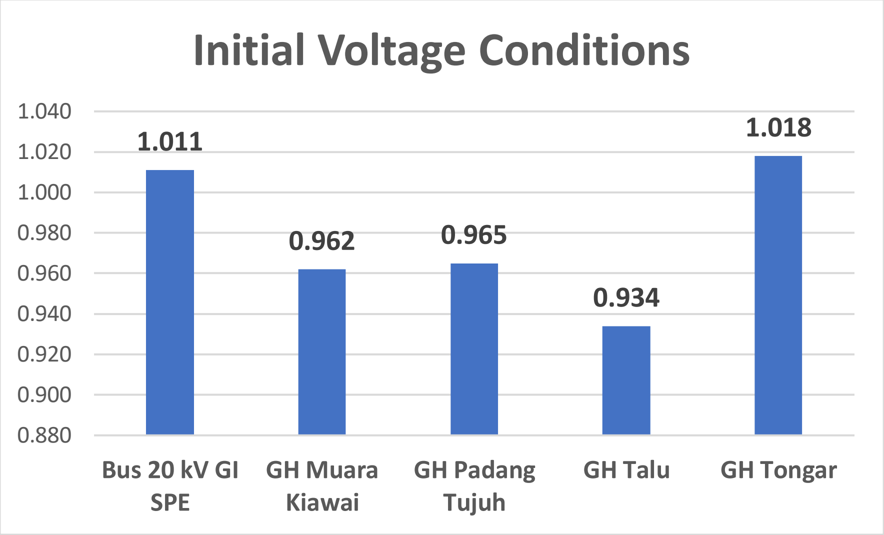
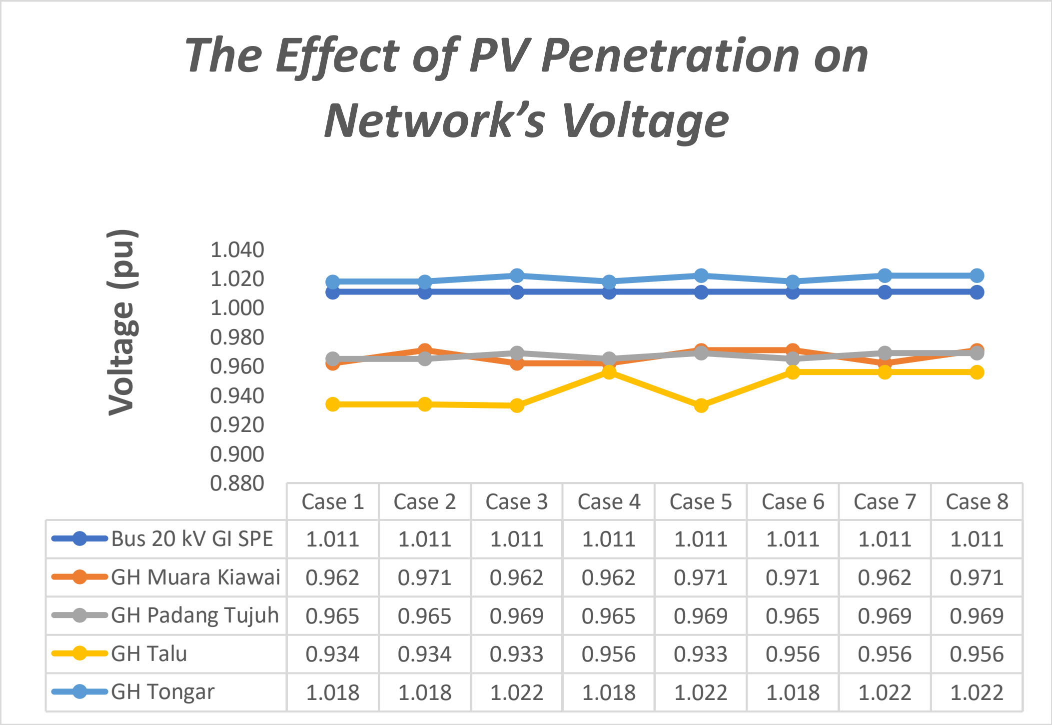


Figure 4 Voltage profile without pv penetration.



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Bus 20 kV GI SPE	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011
GH Muara Kiawai	0.962	0.971	0.962	0.962	0.971	0.971	0.962	0.971
GH Padang Tujuh	0.965	0.965	0.969	0.965	0.969	0.965	0.969	0.969
GH Talu	0.934	0.934	0.933	0.956	0.933	0.956	0.956	0.956
GH Tongar	1.018	1.018	1.022	1.018	1.022	1.018	1.022	1.022

Figure 5 Voltage profile at bus location for all casses with pv penetration

Table 3 Percentage Profile Of Voltage Increases With Pv Penetration

System PV	GH Muara Kiawai	GH Padang Tujuh	GH Talu	GH Tongar
Case 1	0.0%	0.0%	0.0%	0.0%
Case 2	**0.9%**	0.0%	0.0%	0.0%
Case 3	0.0%	**0.4%**	-0.1%	**0.4%**
Case 4	0.0%	0.0%	**2.4%**	0.0%
Case 5	**0.9%**	**0.4%**	-0.1%	**0.4%**
Case 6	**0.9%**	0.0%	**2.4%**	0.0%
Case 7	0.0%	**0.4%**	**2.4%**	**0.4%**
Case 8	**0.9%**	**0.4%**	**2.4%**	**0.4%**

This table shows the percentage of contribution or penetration of PV (photovoltaic) at several points of the substation (GH) in eight different scenarios (Case 1 to Case 8). At GH Muara Kiawai, PV penetration started from Case 2 with a stable contribution of 0.9% until Case 8, indicating the installation of PV that provides consistent energy supply and supports local loads. At GH Padang Tujuh, PV penetration was only seen since Case 3, with a small contribution of 0.4% that remained constant until Case 8, indicating gradual testing or limited capacity of PV installations at this point.

Meanwhile, GH Talu showed more significant fluctuations. In Case 3, there was a decrease in PV penetration of -0.1%, which was likely caused by system disturbances or power flow imbalances. However, PV contribution reached 2.4% in Cases 4, 6, and 8, but again experienced a temporary decrease in Case 5. This indicates potential operational problems that need attention, especially to maintain voltage stability and system reliability. In GH Tongar, PV penetration began to appear since Case 3 with a consistent contribution of 0.4% to Case 8, indicating that this point is relatively stable and does not experience significant disturbances.

In general, this table illustrates that PV penetration at various substation points has a varied pattern. GH Talu has the highest contribution, which is 2.4%, but also shows instability, while other substations such as GH Muara Kiawai and GH Tongar show lower but consistent PV penetration. The fluctuations in GH Talu underline the importance of using advanced control systems, such as inverters with reactive power regulation, and mitigation strategies such as energy storage or adaptive load management. This is important so that higher PV penetration does not disrupt power quality and grid stability. In addition, points with low penetration, such as GH Padang Tujuh and GH Tongar, show that there is still room to increase PV utilization without disrupting the grid.

Thus, this study provides insight into the importance of proper PV penetration management to maintain grid stability and maximize the benefits of renewable energy. Grid operators and policymakers need to consider the implementation of smart control systems and PV distribution optimization, especially in points with potential instability such as GH Talu. This research is relevant to support sustainable energy transition while maintaining the reliability of the electricity system.

Fig 4 displays the voltage readings at various points within the 20 kV distribution network: Bus 1 at 20 kV GI SPE (1.011 pu), Bus 2 at GH Muara Kiawai (0.962 pu), Bus 3 at GH Padang Tujuh (0.965 pu), Bus 4 at GH Talu (0.934 pu), and Bus 5 at GH Tongar (1.018 pu). The differences in voltage levels across these buses are due to variations in conductor type, conductor length, and the specific load demands on each busbar, leading to distinct voltage values at each location.

3.2 The Effect of PV Penetration on Network's Voltage

In this simulation, the impact of PV system installation on the voltage level in the distribution network is evaluated. Cases 2-8 cover scenarios after the installation of the PV system. Simulation results regarding voltage levels are shown in Fig 5.

Each line in this graph represents the voltage at a different point or substation, namely the 20 kV Bus GI SPE, GH Muara Kiawai, GH Padang Tujuh, GH Talu, and GH Tongar.

Overall, the analysis of this graph shows that PV penetration has different impacts at each point of the network. Some locations, such as GH Muara Kiawai and GH Tongar, experienced improved voltage quality, while locations such as GH Talu experienced disturbances indicating potential operational problems. This indicates the need for better mitigation and management strategies, especially at critical points, to maintain voltage stability and ensure that PV penetration can support the renewable energy transition without compromising the network. This study is relevant to provide recommendations to network operators and policymakers regarding the importance of adaptive control systems in managing PV penetration and improving power quality.

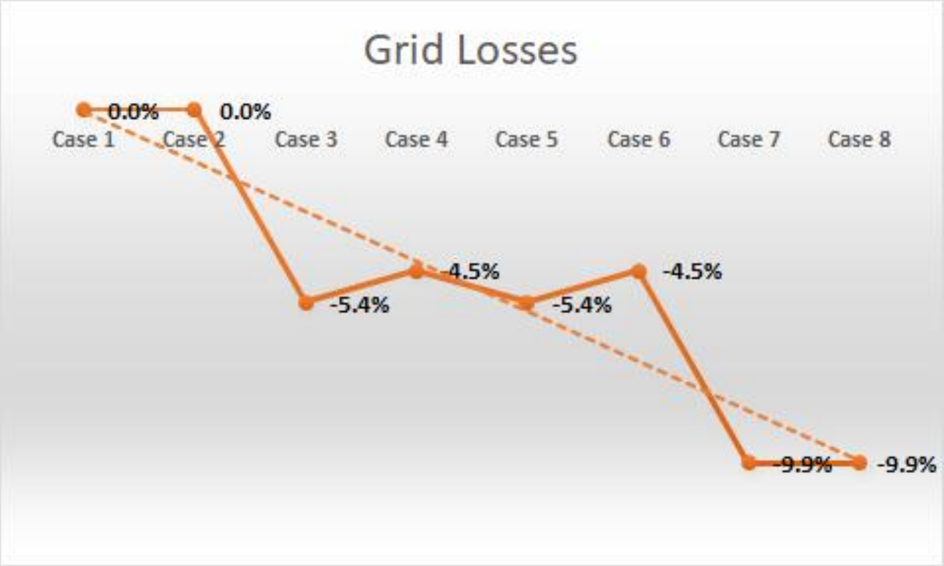


Figure 6 Power Losses for PV Deployment

The figure shows the percentage change in grid losses for eight different scenarios, illustrating the decrease in losses as the scenarios change. In Case 1 and Case 2, the losses remain at 0.0%, reflecting the initial conditions without intervention. A sharp decrease is seen in Case 3 with losses reaching -5.4%, indicating an increase in efficiency due to distribution optimization or control adjustments. Fluctuations occur in Case 4 to Case 6, with losses ranging from -4.5% to -5.4%, which, although still better than the initial conditions, indicate limited improvement. In Case 7, the loss decrease reaches -9.9%, indicating the effectiveness of better control strategies or network optimization, such as resource coordination and advanced control technology. The condition remains stable in Case 8, indicating that maximum efficiency has been achieved. This decrease highlights the importance of optimization strategies, adaptive control, and smart technologies in reducing grid losses and supporting energy efficiency.

4 Conclusion

Based on the research in this paper, the placement of the PV (photovoltaic) system has a significant impact on the voltage profile and power losses in the electricity network connected to the micro-hydro power plant in West Sumatra. The simulation results show that PV penetration has a different effect on each point in the network. Some locations, such as GH Muara Kiawai and GH Tongar, experienced an increase in voltage quality, while GH Talu showed operational disruptions and voltage instability. This emphasizes the need to implement mitigation strategies, such as smart inverter control and energy storage, to maintain grid stability.

In terms of grid losses, it was found that suboptimal PV penetration can cause increased power losses, as seen in the Case 7 and Case 8 scenarios with the highest loss of -9,9 %. These fluctuating losses indicate that increasing PV penetration without proper regulation can disrupt power flow and reduce grid efficiency.

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