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Evaluation of Photovoltaic Penetration on System Grid with Minimum Loading Approach

Dawam Habibullah[1], Khin Moe Moe[2], Syafii[1*]
[1]Electrical Engineering Department, Faculty of Engineering, Universitas Andalas, Indonesia
[2]Department of Electrical Power Engineering, Yangon Technological University, Myanmar
[*]Corresponding author, e-mail:syafii@eng.unand.ac.id

Abstract— The Indonesian government has also set a target to increase the contribution of renewable energy in the national energy mix to 23% by 2025. In this paper, an analysis of Maximum PV Capacity was used on the transmission network with a technical minimum loading approach simulation. From the simulation that has been done, it can be seen that the placement of PV in the two location points gets better results than the placement of one PV location point. The result shows that the feeder load for one PV location point is 74.3%, while for two PV location points 35.8%, which the value is still within safe limits, but for two PV location points, it gets better results. PV trip state frequency values obtained for one location point and two PV location points get a result of 2% of 50 Hz, which is still within safe limits. Harmonics at one PV location point are 5%, while for two PV location points, have better results by 2.4% and are still within the safe limits of the system.

Keywords: Photovoltaic penetration, Renewable energy, Minimum loading, Transmission network.

1. Introduction

Photovoltaic Capacity is the maximum penetration capacity of renewable energy that can be injected into a particular feeder without causing violations in the system and network boundaries based on the grid code due to maximum penetration of renewable energy, especially Solar Photovoltaic. Based on the 2020-2030 RUPTL, it has set a target to increase the contribution of renewable energy in the national energy mix to 23% in 2025 and 31% in 2050 [1][2]. The focus of the research conducted is the development of Hosting Capacity in theory, practical, aspects of discussion, Hosting Capacity and several limitations (thermal overloading, overvoltage, power quality, and protection) [3] [4][5].

The integration of renewable energy provides advantages and disadvantages, for the integration of renewable energy safely becomes very important. For this reason, it is necessary to determine the amount of renewable energy entering the grid [6]. The integration of renewable energy into the transmission network system needs to be considered to the effect of stability. Although, it is necessary to study transients in looking at the extreme conditions of a grid [7] [8]. In addition, the maximum integration of hosting capacity also causes a harmonic effect. This is because renewable energy equipment uses a lot of electronic component systems. So that harmonic studies, line ampacity, and voltage limits are criteria in the quality of electric power distribution [9][10][11].

In addition, the nature of renewable energy is intermittent to solar heat. In paper[12], saw conditions with quasi-dynamic systems survived 24 hours from characteristics on solar PV. In determining the maximum capacity, further study is needed. Several methods have been used both traditionally and with numerical computational. On paper [13][14], determine the amount of hosting capacity based on technical limitation capabilities. So, this study uses technical minimum loading (TML). The contribution to this study is by calculating TML based on grid area transmission. So that

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the contribution of each plant area is calculated in determining its capacity.

2. Method

The methodology in this study uses the Technical Minimum Loading (TML) approach method in thermal plants. From this capacity, candidates are sought based on the maximum laying scenario of PV Capacity integration. The methodology of this study is summarized in the following Figure 1 flowchart below:

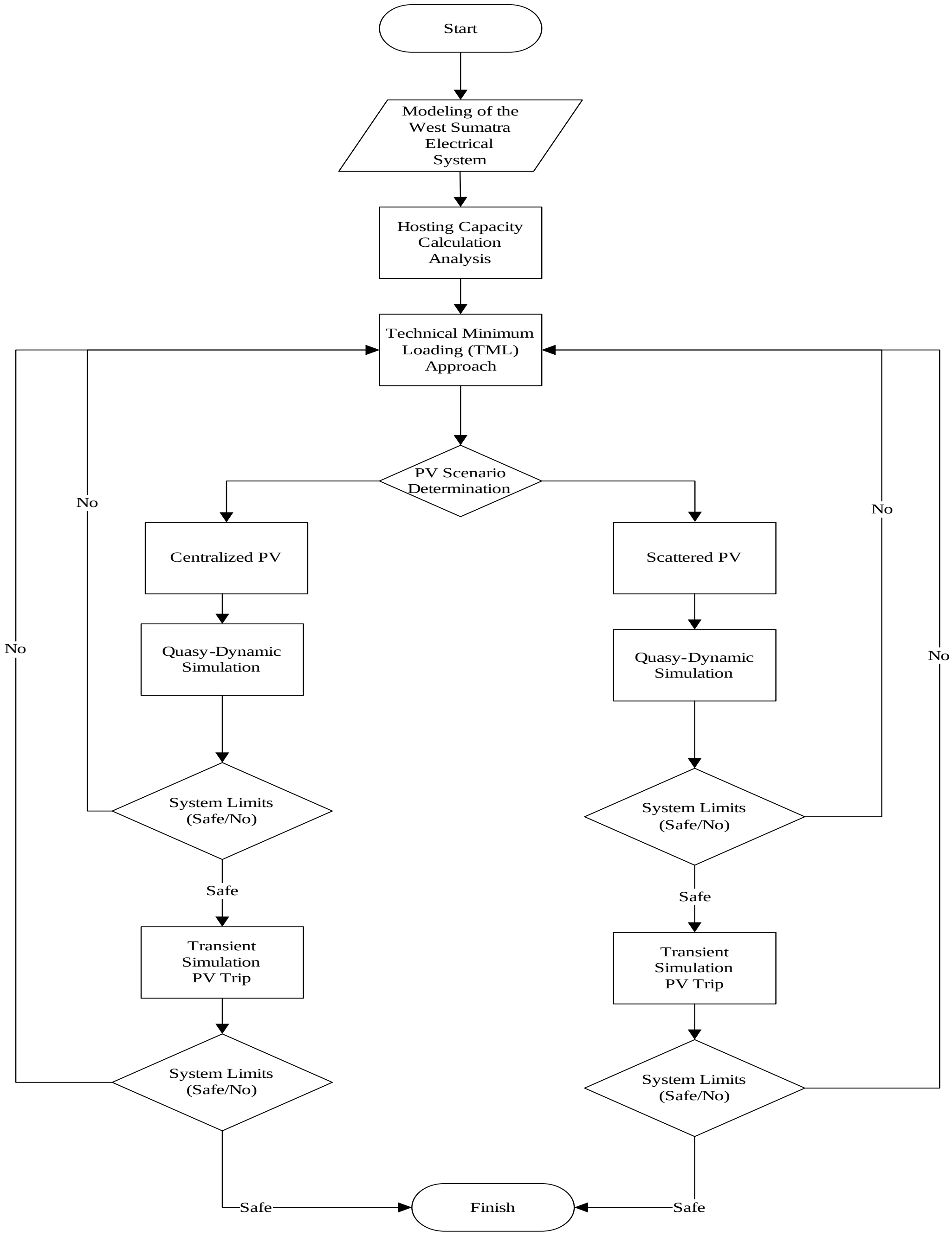

Figure 1. Hosting Capacity with TML

The second step is to analyze the Hosting Capacity calculation using the assumption approach of Technical Minimum Loading (TML). The concept of Hosting Capacity is the capacity of the electricity system available to accommodate and manage renewable sources, such as solar PV, wind turbines, etc. Hosting Capacity refers to the capacity of transmission and distribution systems available to manage and deliver energy from new renewable energy sources. The concept of Hosting Capacity can be determined by analyzing system load, network capacity, and system operational conditions. This can be done using simulation tools or real time data analysis [15][11].

In general, the concept of Hosting Capacity is to ensure that new renewable energy sources can be integrated safely and efficiently into existing electrical systems without reducing the stability of the Hosting Capacity concept system. This is as shown in Figure 2 [16]. In Figure 2, shown the areas / regions that are allowed to be accepted from the change in PV Capacity penetration capacity without causing system violations.

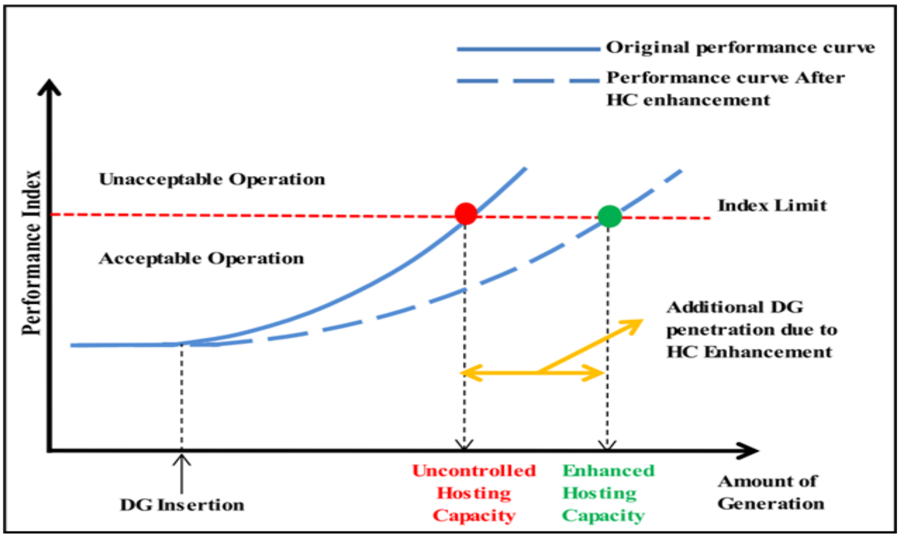

Figure 2. Hosting Capacity Capabilities Curve

This *Technical Minimum Loading* (TML) approach method uses the following equations:

Maximum Candidate VRE = *Day Load* – TML (1)

Day Load is the average minimum daily hourly load of each year. The assumptions of the TML of each generation are as follows:

a. Coal Power Plant: Total capacity (DMN) * 85% (AF) * 60% (TML)
b. Combine Cycle Power Plant: Total capacity (DMN) * 85% (AF) * 50% (TML)
c. Geothermal Power Plant: Total capacity (DMN) * 95% (AF) * 80% (TML)
d. Hydropower Plant: Total capacity (DMN) * 85% (AF) * 40% (TML)
e. RoR Hydro: Total capacity (DMN) * (AF)
f. EBT $\leq$ 10 MW: Total capacity (DMN) * (AF)

Where DMN= Net Capable Power, AF = Availability Factor

So, the calculation of TML assumptions is obtained as follows:

1. *Hydropower Plant* : Total capacity (DMN) * 85% (AF) * 40% (TML)
   Unit 1 : 16.19 MW * 85%(1) * 40%(1) = 5.51 MW
2. *Coal Power Plant* : Total capacity (DMN) * 85% (AF) * 60% (TML)
   Unit 1 F: 90.16 MW * 85%(1) * 60%(1) = 45.98 MW

The results of the total load capacity, a value of 603,584 MW was obtained. The total results of *the day load* capacity that have been obtained are used to calculate the size of PV Capacity candidates to be installed in the system. The amount of PV Capacity capacity in the installed system is calculated with the following results:

Total Load Capacity = 603.584 MW
Total Minimum Technical Loading Assumptions (TML) = 279.04 MW
Maximum Number of Candidates VRE = *Day Load* – Assumption TML
= 603.584 MW – 279.04 MW
= 324.54 MWp

PV sizing is the process of determining the exact size of the components of a solar power system to meet the energy needs of a particular grid. The main components of a photovoltaic system, including solar panels, inverters, batteries, and other balanced system components, such as charge controllers, cables, and support structures [4]. The capacity of Pv Capacity to be used is 325 MW using PV 500 Wp and inverter 3000 kVA.

3. Result and Discussion

This research simulation was conducted on the West Sumatra electricity system. The simulation analysis carried out in this study was at Outside the Peak Load Time (LWBP), precisely at noon at 13:30 WIB. So, this analysis is seen during extreme conditions during the day, with a lot of output power capacity that can be released by Solar PV. It is said that extreme conditions are during LWBP during the day load conditions, not during peak load conditions, So, there will be an assumption for overvoltage.

Skenario 1: Centered of Photovoltaic

The results of the Quasi-Dynamic simulation, it was found that for network load without PV connection, the highest line loading value was 23.5% at 21:01 WIB. While the lowest line loading value was 15.69% at 09:58 WIB. Then, the line loading value after PV interconnection obtained the highest result of 85.5% at 12:01 WIB. While the lowest line loading value was 1.24% at 06:42 WIB. This is shown as shown in Figure 3.

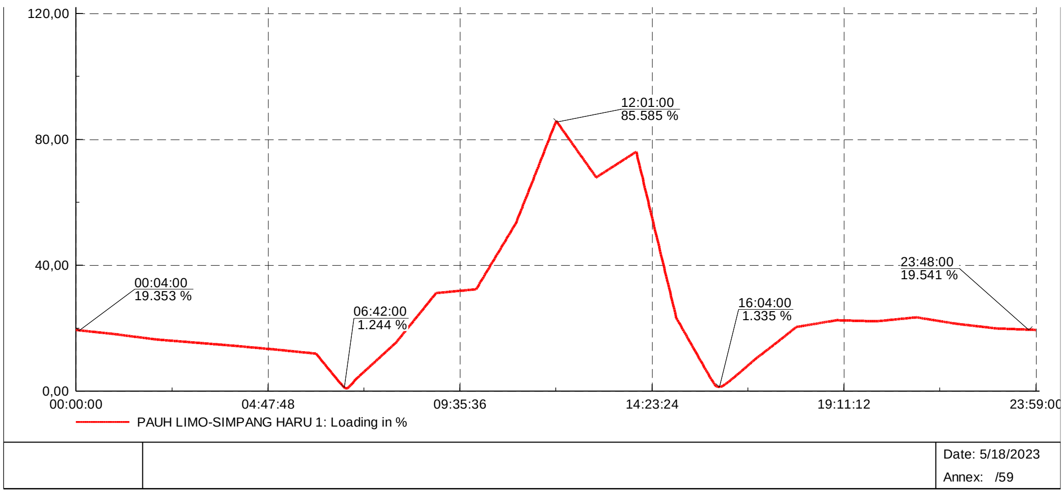

Figure 3. Line Loading 1 Point of Photovoltaic

The results of Quasi-Dynamic simulation performed for a maximum of 1 PV laying point, obtained results as shown in Figure 4 below. The results of this simulation, several busbars were taken closest to the PV installation. As a result of PV, it was found that the highest voltage value was found on the Simpang Haru bus (PV placement point) with a voltage value of 1,006 pu at 09:03 WIB. Meanwhile, the lowest voltage results on the Simpang Haru busbar with a value of 0.987 pu at 19:06 WIB or when the interconnection with PV is no longer there. However, the highest and lowest voltages still meet the safe limits of voltage standards in 150kV systems, which are +5% and -10%.

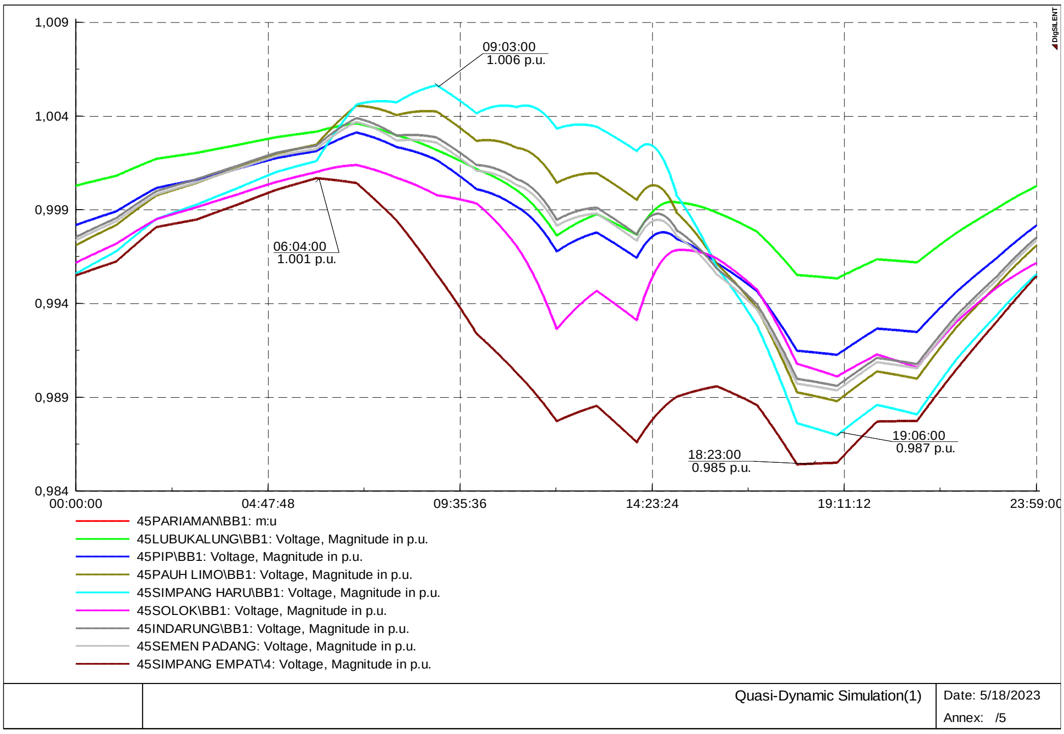

Figure 4. Quasi-Dynamic 1 point of Photovoltaic

The effect due to this transient has an impact on the frequency swing. This frequency swing is caused by the impact of rotor coarseness in the generation. In simulating transients and PV trips, it is as if the PV scenario is lost, swings are obtained against the system frequency. Swing frequency due to this PV trip will have an impact on frequency. The range of frequency upper limit values is 50.084 Hz and the lowest frequency is 49.889 Hz which runs for 24 seconds and returns to the normal frequency of 50 Hz as shown in Figure 5 below. This value is categorized as still in the safe stage because the system is still within the frequency range limits according to the grid code rules. Based on the grid code, the frequency range to operate continuously, which is 49.00 Hz <= f <= 51.00 Hz.

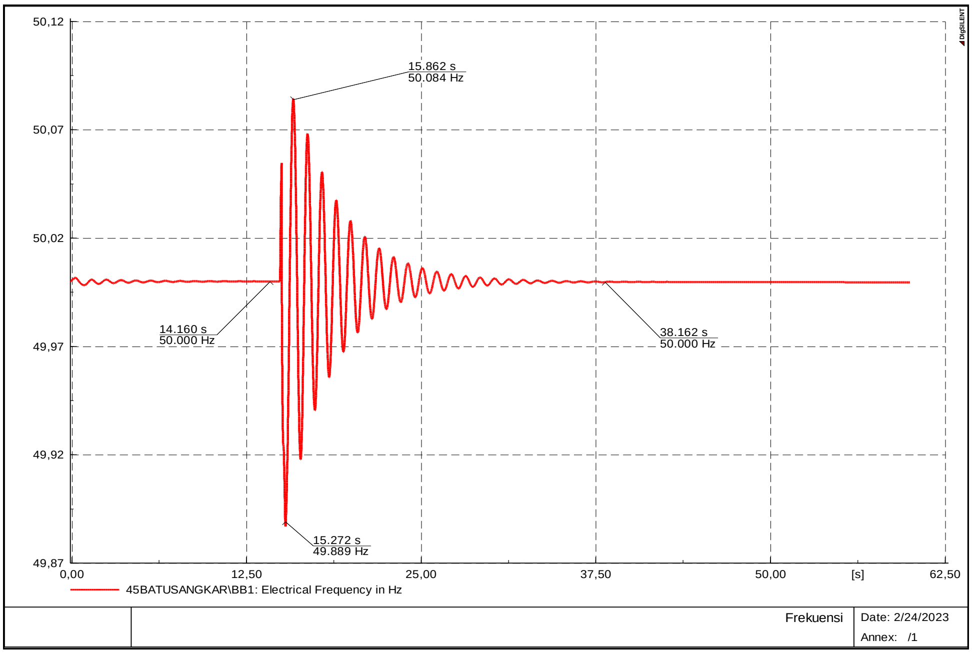

Figure 5. Frequency Trip of 1 Point Photovoltaic

Skenario 2: Spread Photovoltaic

The load flow simulation in this scenario was carried out at 13:30 WIB. From the results obtained, it can be indicated that the inclusion of maximum VRE penetration at two points can cause an increase in line loading. This line loading increase occurs in the closest location to the Hosting Capacity penetration placement position, namely Simpang Haru bus and Simpang Empat bus.

The highest line loading value before PV installation was 41.3%, while the highest line loading during PV installation was spread across 2 locations at 38.47%. It is still within the limit of not exceeding 100% load. This condition is used as an n-1 or n-1-1 contingency condition with a maximum loading of 50% and is still in safe condition because it has not exceeded 50% line loading.

Quasi-Dynamic simulation for 2 substation location points in PV Plant installation can be seen in Figure 6. From the simulation, it can be seen that the voltage profile is good and increased due to the inclusion of 2 PV installation locations. At Simpang Empat Substation, the highest PV voltage value occurred at 12:02 WIB with a voltage value of 1,017 pu, while the lowest voltage value was 0.95 pu.

In the installation of PV at the Simpang Haru Substation, the highest voltage results occurred at 12:00 WIB with the highest voltage value of 0.999 pu, while the lowest voltage value was 0.95 pu. This voltage value increases when PV installation occurs. Installation at these 2 points can later be used as a reference for PV Plant installation based on the lowest voltage value in the system.

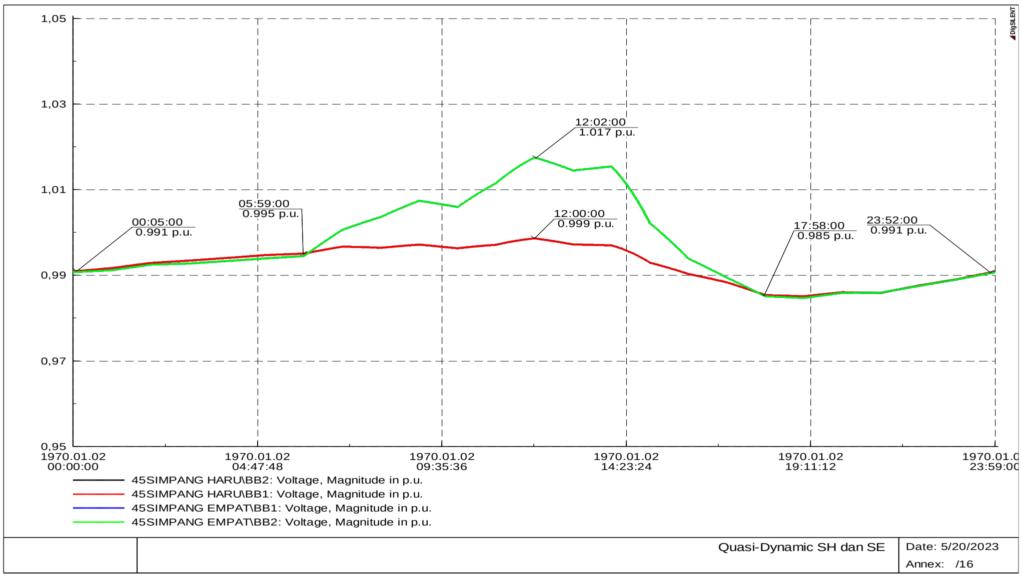

Figure 6. Quasi-Dynamic 2 Point of PV

In the allocation of 2 PV trip locations, the frequency results are the same, then for 2 PV trip locations will be tested with 1 PV trip location because of the different placement locations that are likely to occur trips in one location. For this reason, the frequency results of the trip of 1 PV location and 1 PV location cannot be seen. From the results of the transient simulation carried out, the magnitude of the frequency change from -49.935 Hz +50.050 or has a swing frequency of about ±2%. From the results obtained are not much different from trip 2 PV locations even the value is better than trip 2 PV locations. This is because the amount of capacity lost is less than trip 2 PV locations can be seen as shown in Figure 7.

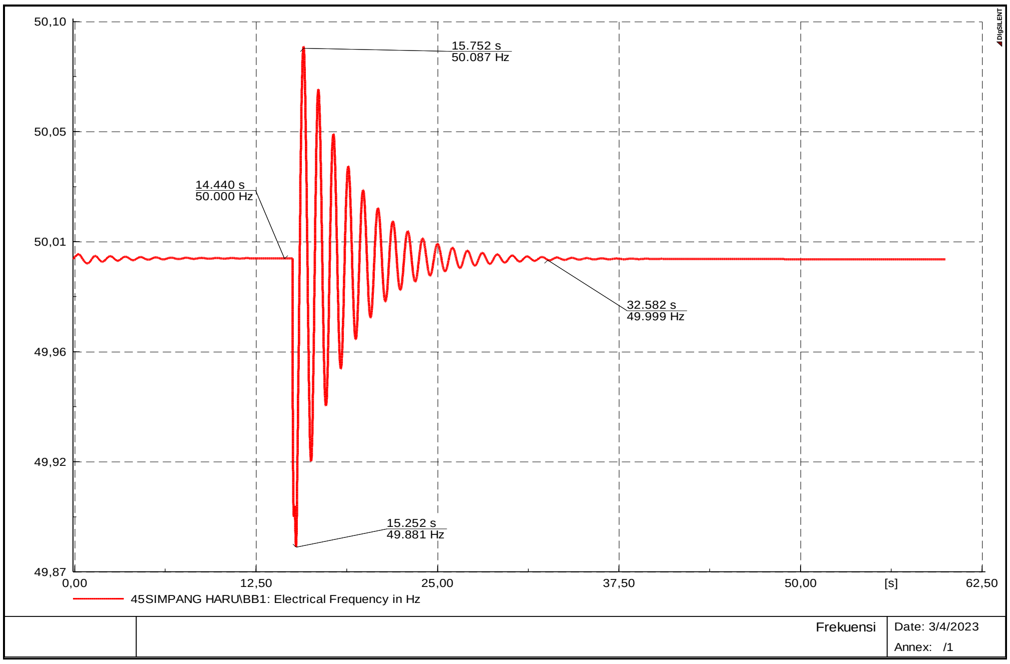

Figure 7. Frequency Trip 2 Point of Photovoltaic

In the summary subchapter, it will be grouped into several categories in [illegible] problems from the allocation of centralized or scattered PV placement. This is intended so that the placement of this location can be a consideration in determining the right PV Plant location. In addition to determining the location based on the lowest voltage level. Here, the value of PV Plant with 2 locations for the total PV candidate is divided into two capacities so that a summary is obtained in Table 2 below:

Tabel 2. PV Plant Installation Location Summary

No.	*Load* Flow Simulation *Items*	Result
1.	Voltage	**Location of 1 PV *Plant*** Before PV installation : 148.22 kV. After PV installation : 150 kV. **Location of 2 PV *Plant*** Location 1 Smpang Haru: The highest voltage value is 149,85 kV. Location 2 Interchange: The highest voltage value is 152,55 kV.
2.	Line Loading	**1 PV Plant**: 68.28% **2 PV Plant**: 38.47%
3.	Transient PV Trip	Frequency: ± 2% dari 50 Hz **1 PV Plant**: Lowest voltage flicker 148.7 kV **2 PV Plant**: Lowest voltage flicker 146.25 kV

4. Conclusion

In this research, the conclusions can be white in this section. The existence of a *Technical Minimum Loading* approach can be used to determine the amount of PV capacity of the system where the results obtained can be used as a consideration in the study of PV capacity placement in transmission networks. In addition, this consideration makes the newness presented by PV in the transmission network can be applied to *on-grid* systems to face up of renewable energy as a massive target for installing renewable energy with a capacity of 23% in 2025. The *Quasi-Dynamic simulations were conducted*, the categories of results seen were from the voltage, line loading, PV trips, and harmonics. In the simulation that has been done, it can be seen that the allocation of 2 PV location points gets better results than the allocation of 1 PV location point. In the result can be seen from the peak load during the day and the overall load of the 24-hour load profile (LWBP), as well as the line loading for 1 PV location point of 68.28%, while for 2 PV location points it is 38.47% which value is still within safe limits. However, for 2 PV location points, better results are obtained. PV trip state frequency values obtained for 1 location point and 2 PV location points get a result of 2% of 50 Hz which is still within safe limits operation.

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