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A 48-MW floating photovoltaic design and integration to a grid

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ABSTRACT

Photovoltaic is one of the renewable power sources with the highest growth in recent decades. However, large photovoltaic capacities require enormous areas for installing the modules, which is frequently troublesome. This issue could be addressed by a floating photovoltaic system since it can be installed on the surface of unutilised lakes, and dams. This study aims to design a 48-MW floating photovoltaic at Lake Singkarak and determine a connected substation to the West Sumatra Grid. PVsystem and digsilent powerfactory were used in this study as the calculation and simulation tools. The study's results discover that the 48-MW floating photovoltaic design consists of 96,000 photovoltaic modules of 500 Wp and 16 inverters of 3,000 kVA. Simulation results showed that Solok substation is the most optimum choice to connect the floating PV, as it provides better voltage profiles, fewer power losses and a shorter distance. The harmonic simulation also showed the THDv of 2.14% at 150 kV of Solok substation, which is still within acceptable limits.

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1. INTRODUCTION

Intergovernmental panel on climate change (IPCC) has strongly urged all nations to stop or at least gradually reduce the operation of thermal coal power plants to achieve the global warming target lower than 1.5 ºC by 2,100 [1], [2]. Since the Indonesian electricity mix is currently dominated by coal (65.93%) and gas (17.48%) [3], the transition into renewable energy sources should be conducted seriously. The Indonesian government has created a road map to achieve net zero emission by 2060, where renewable energy will become the dominant source of electricity [4]. As a tropical country, Indonesia has vast potential for photovoltaics. According to Indonesia's general plan for electricity supply (RUPTL), 4.7 GW of photovoltaic (PV) will therefore be constructed by 2025 [5].

Despite providing green electricity, large-scale PVs require large areas to produce the desired power output. However, due to the high land cost, PV-generated electricity price becomes higher. In many cases, obtaining the required land is challenging since lands are also needed for other living purposes, such as housing and agriculture. A floating photovoltaic (FPV) can solve this problem since it can be installed on lakes, dams, lagoons, former mining areas and other water surfaces [6].

One of the FPV location candidates is Lake Singkarak in West Sumatra. A floating PV with a capacity of 48-MW is planned to be constructed by 2025 on Lake Singkarak, as stated in RUPTL [5]. Lake Singkarak is the second largest lake on Sumatra Island, with an area of 106 km^2 [7] and will be the first FPV on Sumatra Island. Water from this lake has been utilized for a hydropower plant with a capacity of 175 MW [8]. Therefore, this study aims to design an FPV on Lake Singkarak and select the connected substation that provides the best performance in terms of power losses, voltage and harmonic. The FPV design is conducted using PVsyst software [9], whereas the performance test uses digsilent powerfactory simulation [10].

2. METHOD

2.1. Designing the FPV

The FPV design process is started by selecting PV modules and inverter size, then determining the number of strings and arrays of the FPV. The number of modules is calculated using (1), while the number of inverters and modules per inverter are calculated using (2), and (3), respectively. To arrange the PV strings and arrays, it is necessary to determine the specifications of the PV modules and inverters. A string is an arrangement of several PV modules connected in series, whereas an array is an arrangement of several strings connected in parallel. In a series connection, the voltage output will increase according to the module number, while in a parallel connection, the current output will rise according to the module number. Therefore, to determine the series-parallel connection of the PV modules, (4), (5), and (6) are used [11], [12].

$$Number\ of\ modules = \frac{PV\ capacity}{Module\ capacity} \tag{1}$$

$$Number\ of\ Inverter = \frac{PV\ capacity}{inverter\ capacity} \tag{2}$$

$$Number\ of\ modules/inverter = \frac{number\ of\ PV\ modules}{number\ of\ inverter} \tag{3}$$

$$Minimum\ modules\ of\ series\ network = \frac{V_{\min\_inverter}}{V_{oc\_module}} \tag{4}$$

$$Maximum\ modules\ of\ series\ network = \frac{V_{\max\_inverter}}{V_{mp\_module}} \tag{5}$$

$$Maximum\ strings\ of\ parallel\ network = \frac{I_{\max\_inverter\_input}}{I_{mp\_module}} \tag{6}$$

$V_{\min\_inverter}$ is the minimum input voltage of the inverter, $V_{\max\_inverter}$ is the maximum input voltage of inverter, V_{oc_module} is open circuit voltage of PV module, V_{mp_module} is the voltage at maximum power point of PV module, $I_{\max\_inverter\_input}$ is maximum input current of inverter and I_{mp_module} is current at maximum power point of PV module.

The required area for FPV installation can be calculated based on the module arrangement and dimension. The area must not be larger than applicable government regulation, i.e., 5% of the water body [13]. The FPV design also determines the optimal tilt and azimuth for floating PV. The floater type of the FPV modules is selected based on experiences in other countries.

2.2. Demand forecast and power system simulation before integration of the FPV

The Lake Singkarak FPV is planned to be operated in 2025. Therefore, to analyze the effect of FPV on the West Sumatra grid, the projected load of the system in 2025 is forecasted. The load growth rate is calculated from RUPTL data, and then the rate is used to predict each load point in the system shown in Figure 1. The power flow simulation is carried out with the forecasted demand and several new power plants connected to the system in 2025. The power flow simulation aims to collect voltage profiles and power losses on the system before the FPV connection.

2.3. Selecting the substation candidates for the FPV connection to the grid

To reduce cost and losses, the distance of the FPV to the substation must be as close as possible. Therefore, two nearest substations are selected as the candidate for connecting the FPV to the grid. Since the location of the FPV is chosen according to the substation's sites, the two nearest substations will result in a different place for the FPV. The geographic coordinates of the FPV locations are entered into PVsyst software to generate meteorological data for the site. Using the entered FPV specification and meteorological data, PVsyst calculates the yield energy from the FPV.

2.4. Simulation of the FPV integration to the grid

Power flow simulations of the FPV connection to the grid are carried out for each substation candidate. The simulation results, in terms of power losses and voltage magnitudes, are compared to find the best substation for the FPV connection. Since the electricity generated by an FPV is DC, an inverter is required to convert DC into AC. The conversion process of the inverter causes harmonic distortion. Therefore, it is necessary to analyze the harmonics generated by the FPV at the point of connection (PCC). The harmonic simulation is conducted using digsilent powerfactory to determine total harmonic distortion (THD). The THD of voltage (THD_v) can be calculated using (7). V_1 is the fundamental voltage, Vh is the harmonic voltage, and h is the harmonic order. The THD_v at each PCC is then compared to the THD_v standard of IEEE, as shown in Table 1 [14].

$$THD_v = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} x\ 100\% \qquad (7)$$

Table 1. IEEE Standard 519-1992 maximum voltage harmonic at PCC

Voltage at PCC	Individual component voltage distortion	Total voltage distortion (THD_v)
V ≤ 69 kV	3.00%	5.00%
69 kV < V ≤ 161 kV	1.50%	2.50%
V ≥ 161 kV	1.00%	1.50%

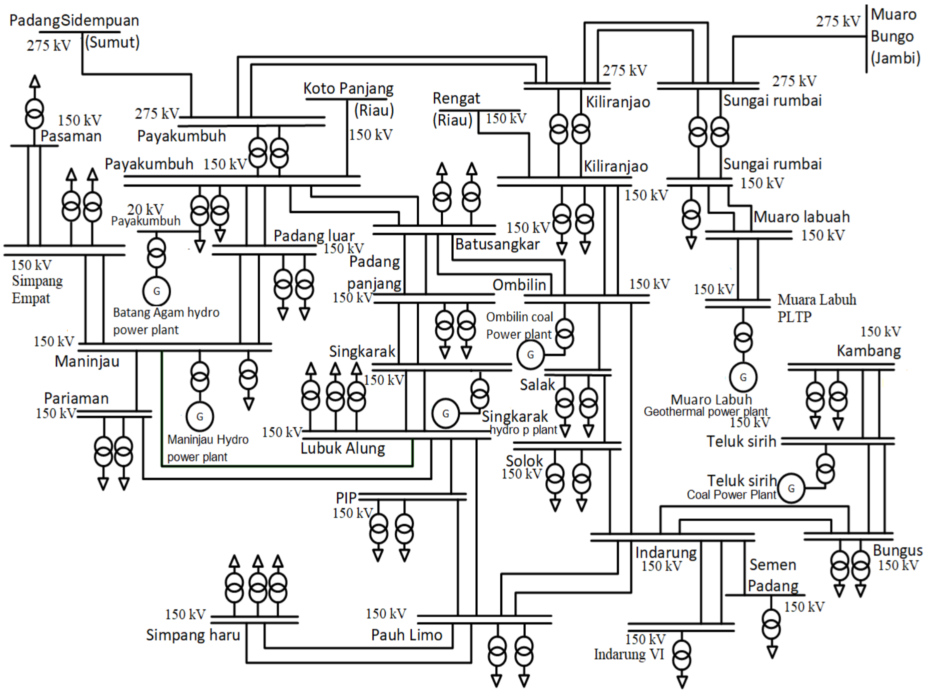


Figure 1. Single line diagram of west Sumatera grid

3. RESULTS AND DISCUSSION

3.1. Design of the FPV

The selected 500 Wp mono-crystalline PV modules for the Lake Singkarak FPV have specifications in Table 2, and the 3,000 kVA inverter specifications are in Table 3. The FPV design consists of 96,000 modules in 16 arrays with an arrangement of 30 modules/string and 200 strings/array, as shown in Table 4 and Figure 2. For the Lake Singkarak location, the best azimuth for the FPV is facing north (0°). Since the sun's rays are almost perpendicular for areas near the equator, such as Indonesia, the tilt angle of 0° is the most optimal angle to receive solar radiation. However, 0° or flat angles can cause puddles or dust build-up on the module surfaces. A minimum tilt angle of 10° is recommended to provide a self-cleaning mechanism [15]. Therefore, the FPV tilts 10° and has azimuth 0°.

Table 2. Photovoltaic module specification

Specification	Value	Specification	Value
Maximum power	500 Wp	Short circuit current (I_{sc})	13.90 A
Weight	25.1 kg	Voltage at maximum power (V_{mp})	38.38 V
Dimension	2,073 x 1,133 x 35 mm	Current at maximum power (I_{mp})	13.03 A
Open circuit voltage (V_{oc})	45.55 V	Module efficiency	21.3%

Table 3. Inverter specification

Specification	Value	Specification	Value
Rated AC power output	3,000 kVA	Min. input voltage $V_{dc\text{-}min}$	927 V
Frequency	50 Hz (47~53 Hz)	Max. input current $I_{dc\text{-}max}$ (at 35°C/50°C)	3,200 A/2970 A
Weight	3400 kg	Max. total harmonic distortion	< 3% at rated power
Dimension	2,780 x 2,318 x 1,588 mm	MPP V_{dc} range (at 25°C/50°C)	956 to 1,425 V/1,200 V
Efficiency	98.8%		

Table 4. Configuration of the singkarak lake FPV design

Configuration	Quantity	Configuration	Quantity
Number of modules	96,000	Number of strings per array	200
Number of inverters	16	Number of arrays	16-*array*
Number of modules per inverter	6,000	Tilt/Azimuth	10°/0° (*fixed tilted*)
Number of modules per string	30		

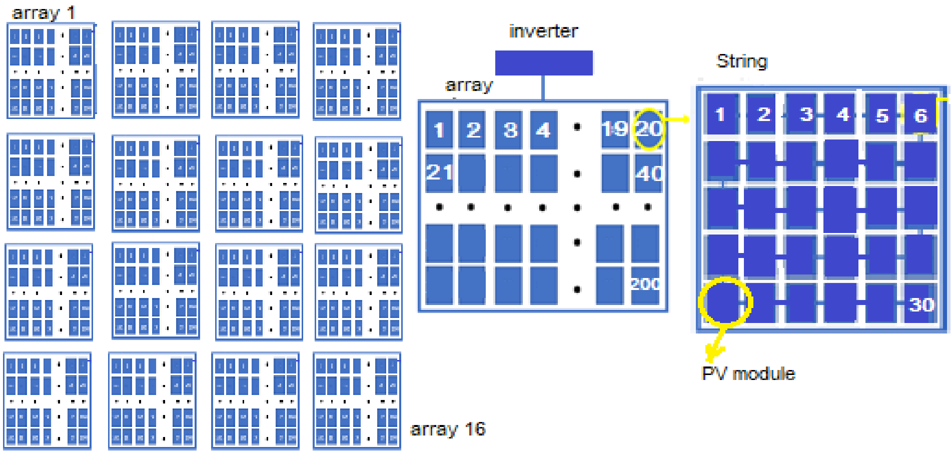


Figure 2. Design of the FPV arrays and strings

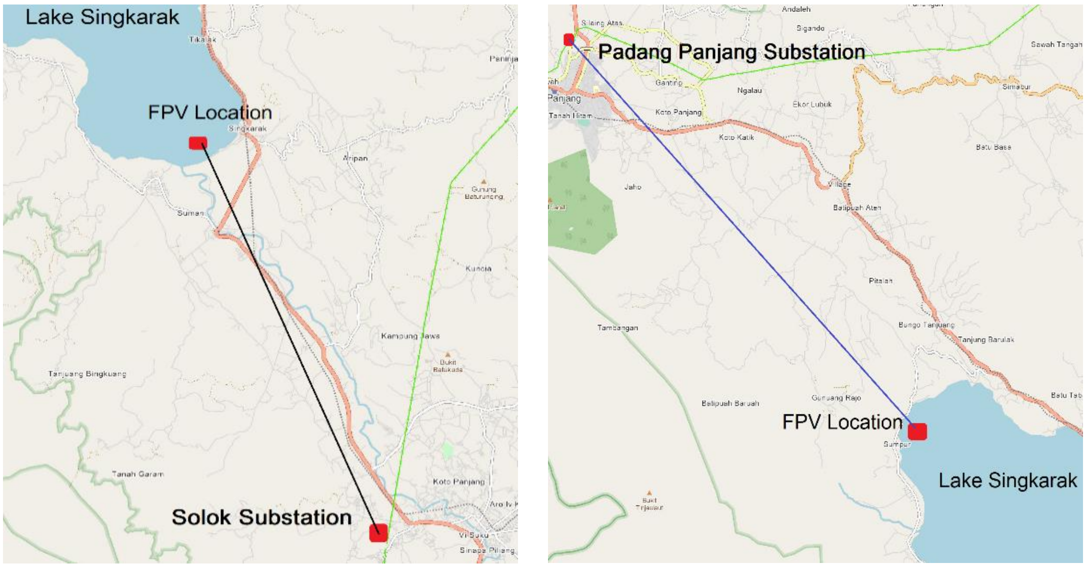
Based on this FPV arrangement, the required area for the FPV is calculated using the dimension of the PV modules in Table 2, the FPV configuration in Table 4 and the FPV layout in Figure 2. The distance between modules in the string is 0.02 m, between the strings in the array is 0.2 m, and between the arrays is 2 m. This gives an area of 246,980 m^2, equal to 0.23% of Lake Singkarak's water surface. Since the maximum space of the FPV is less than 5% of the lake area, the design meets the Indonesian Government standard [13].

Floater types of the FPV will be high-density polyethylene (HDPE) as it provides durability and strength [16]. This floater material has been used for FPVs in numerous countries [17], [18]. The complete design of the floater, which is a tradeoff cost against robustness, is beyond the scope of this study.

3.2. Location and connection of the FPV

To connect the FPV to the grid, two nearest substations are selected, i.e., Solok substation and Padang Panjang substation. Solok substation is south of Lake Singkarak, whereas Padang Panjang substation is north. For each substation, the location of the FPV is chosen, which gives the shortest distance to the substation. This means that the FPV will be in the southernmost part of the lake if it is connected to Solok substation, while if it is connected to Padang Panjang substation, the FPV location should be in the northernmost part of the lake. The locations of the FPV and the substations are shown in Figure 3. Figure 3(a) shows the FPV location that connect to Solok substation, whereas the connection to Padang Panjang substation is shown in Figure 3(b). The maps in Figure 3 are taken from the ESDM website [19].

These two candidates of the FPV location and substation are differences in distances, irradiance and FPV power output, as shown in Table 5. The FPV distances to the substations are calculated using the ESDM geoportal of electric power system [19]. The irradiance data for a year are taken from global solar atlas [20]. The southern part of Lake Singkarak, where the FPV is located for connection to Solok substation, has slightly higher irradiation than the northern part of Lake Singkarak; hence it produces more energy output, as shown in Table 5.



(a) (b)

Figure 3. Two candidates of FPV location and their connection to the grid: (a) to Solok substation and (b) to Padang Panjang substation

Table 5. Distance, irradiance, and energy output of the FPV candidates

Data types	FPV connected to Solok substation	FPV connected to Padang Panjang substation
Distance of FPV to substation	11.8 km	14.1 km
Direct normal irradiation	923.8 kWh/m^2	909.9 kWh/m^2
Global horizontal irradiation	1,645.6 kWh/m^2	1642.0 kWh/m^2
Diffuse horizontal irradiation	925.3 kWh/m^2	922.9 kWh/m^2
Energy output	68,959 MWh/year	66,892 MWh/year

3.3. Power flow and harmonic simulation

Power flow simulations are performed for the year 2025 condition. The percentage of the load increased each year is calculated from RUPTL [5], as shown in Table 6. It is assumed that each load point (substation) in the system has the same percentage of increase to obtain the load condition in 2025. Several new power plants are predicted already connected in 2025, according to the RUPTL, as shown in Table 7. Some small power plants that are distributed in the system (labelled as distributed in Table 7) are modelled as reducing loads on substations that do not have new plants. The amount of the reducing loads is proportional to the amount of the substation load.

Table 6. The percentage of increased load according to RUPTL 2021-2030

year	increased load (%)	year	increased load (%)
2022	6.2%	2024	7.74%
2023	6.92%	2025	8.48%

The simulations are conducted for three scenarios, i.e., (1) “no FPV scenario” for the system without the FPV, (2) “Solok FPV scenario” for the system with the FPV that connects to Solok substation and (3) “PPanjang FPV scenario” for the system with the FPV that connects to Padang Panjang substation. The system supplies total loads of 605.92 MW, 121.32 Mvar and has a 25 Mvar capacitive compensator. It is assumed that the FPV generates the maximum possible output with a unity power factor; hence do not supply reactive power. Results of the simulations in terms of power losses, voltage profiles and THD_V are shown in Table 8.

Table 8 shows that the voltage profiles for all scenarios are in the accepted range, i.e., 0.9-1.05 pu for 150 kV and 0.95-1.05 pu for 275 kV, according to Sumatra Grid Code [21]. The FPV connection slightly reduces the lowest voltage profile because no additional reactive power compensation is installed. The voltage profile results of the Solok FPV scenario are marginally better than the PPanjang FPV scenario. The effect of the FPV connection to the local substation voltages is shown in Table 9, which indicates that FPV integration can increase the voltage of the connected substation, as also in [22], [23]. Since Solok FPV results in a better voltage profile margin in Table 8 and the best voltage profile for both Padang Panjang and Solok substation in Table 9, hence; the Solok FPV is preferable.

Table 7. New connected power plants until 2025

Type	Location	Connect to substation	Capacity (MW)
Hydro	Bayang Nyalo	Bungus 2	6
	Pelangai Hulu	Kambang 1	9.8
	Rabi Jonggor	Pasaman	4.5
	Muara Sako	Kambang 2	3
	Sikarbu	Simpang Empat 1	2
	Tras	Singkarak	1.6
	Tuik	Kambang 2	6.3
	Bendungan PU Batanghari	Sungai Rumbai	5
	Tarusan	Bungus 1	3.2
	distributed	distributed	140.3
Geothermal	Muara Labuh 2	Muara labuh	80
	Distributed	Distributed	40
Other DGs	FPV Singkarak	-	48

Table 8. Power flow and harmonic simulation results of the three scenarios

Parameters	No FPV	Solok FPV	PPanjang FPV
Voltage profile	0.982–1.006 pu	0.981–1.006 pu	0.980–1.006 pu
Power losses	6.84 MW	7.52 MW	8.15 MW
THD_V of the connected substation	-	2.14%	2.59%
Max individual component voltage distortion	-	1.081%	1.684%

The connection of the FPV increases the system power losses, as shown in Table 8, but there is no overload on any power system components. The increase in power losses due to PV capacity growth has been studied in [23]. In this simulation, the increase is mainly due to the shift of power flow in the system since the output of Teluk Sirih Coal Power Plant is reduced to accommodate the FPV supply. The power losses of the Solok FPV are less than the PPanjang FPV because Solok substation has more load (23.32 MW) than Padang Panjang substation (11.34 MW). Thus, more power output of the Solok FPV can directly supply the local load, and the less remaining power will flow to other substations creating fewer power losses. Moreover, the distance from FPV to its substation is shorter for Solok FPV than PPanjang FPV, as shown in Table 5, which also creates fewer power losses.

In Table 8 can be seen that after the FPV connection, the THD_v of Solok substation is 2.14% and Padang Panjang substation is 2.59% which is reasonable if compared to the THD_v in another study for 60 MW PV [24]. The Solok substation THD_v is less than the maximum allowed THDv, i.e., 2.5% according to the IEEE standard for 150 kV, as in Table 1. The maximum individual voltage distortion is also less than the limit in Table 1. Therefore, the connection to Solok substation is more desirable than Padang Panjang substation.

Table 9. Voltage per unit at the two substation candidates

Scenario	V Solok substation	V Padang Panjang substation
No FPV	0.987	0.997
Solok FPV	0.991	0.997
PPanjang FPV	0.986	0.999

The criteria to select FPV locations in [25] is that the distance to the nearest grid is at most 10 km. However, in this study, with an 11.8 km distance to the grid, the FPV still contributes to the grid voltages if connected to an appropriate substation. This condition is achieved without additional reactive power compensation, as applied in [25]. Moreover, this study found that the voltage rise occurs on the connected bus, whereas other bus voltages may remain the same or even lower. This result improves what has been studied in [22], which states that the penetrations of considerable PV cause voltage rise in the network. The impact of large PV systems integration on high voltage/transmission levels is influenced by many conditions; hence the bus voltage results do not always increase.

4. CONCLUSION

The design of 48-MW Lake Singkarak Floating PV employs 96,000 PV modules of 500 Wp and 16 inverters of 3,000 kVA, with an arrangement of 30 modules/string, 200 strings/array with a total of 16 arrays. The PV module tilts 10°, and its azimuth is 0°. The best grid for connecting the FPV is Solok substation because it provides the shortest distance, fewer power losses and better voltage profiles than the connection to Padang Panjang substation. The THD_v in the 150 kV Solok substation after the FPV connection is 2.14% which is an acceptable value according to the IEEE standard.

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REFERENCES

[1] J. Jewell, V. Vinichenko, L. Nacke, and A. Cherp, "Prospects for powering past coal," *Nature Climate Change*, vol. 9, no. 8, pp. 592–597, Aug. 2019, doi: 10.1038/s41558-019-0509-6.

[2] Y. Lu, F. Cohen, S. M. Smith, and A. Pfeiffer, "Plant conversions and abatement technologies cannot prevent stranding of power plant assets in 2 °C scenarios," *Nature Communications*, vol. 13, no. 1, p. 806, Feb. 2022, doi: 10.1038/s41467-022-28458-7.

[3] Kementerian ESDM, "Performance achievements of the ESDM sector in 2021 and plans for 2022 (in Indonesian)," *Website Kementerian ESDM*. Electricity subsector of ESDM, p. 43, 2022, [Online]. Available: https://www.esdm.go.id/assets/media/content/content-capaian-kinerja-sektor-esdm-tahun-2021-dan-rencana-tahun-2022.pdf.

[4] S. Permana, N. Trianti, and A. Rahmansyah, "Nuclear energy contribution for net zero emission and national energy mix 2060 in Indonesia," *Journal of Physics: Conference Series*, vol. 2243, no. 1, p. 012066, Jun. 2022, doi: 10.1088/1742-6596/2243/1/012066.

[5] PT. Perusahaan Listrik Negara, "Electricity Supply Business Plan of PT. PLN (PERSERO) 2021-2030." PT PLN, Jakarta, 2021.

[6] J. Song and Y. Choi, "Analysis of the potential for use of floating photovoltaic systems on mine pit lakes: Case study at the Ssangyong open-pit limestone mine in Korea," *Energies*, vol. 9, no. 2, p. 102, Feb. 2016, doi: 10.3390/en9020102.

[7] N. Peranginangin, R. Sakthivadivel, N. R. Scott, E. Kendy, and T. S. Steenhuis, "Water accounting for conjunctive groundwater/surface water management: Case of the Singkarak-Ombilin River basin, Indonesia," *Journal of Hydrology*, vol. 292, no. 1–4, pp. 1–22, Jun. 2004, doi: 10.1016/j.jhydrol.2003.12.018.

[8] E. Kurniawan and A. A. Simaremare, "Evaluation of trashrack replacement design for malalo intake of singkarak hydro power plant in west sumatera," *Journal of Physics: Conference Series*, vol. 2193, no. 1, p. 012053, Feb. 2022, doi: 10.1088/1742-6596/2193/1/012053.

[9] A. Mermoud and B. Wittmer, "PVSYST user's manual." PVSYST SA, Satigny, 2014.

[10] DIgSILENT GmbH., "DIgSILENT powerfactory (version 15) user manual." DIgSILENT GmbH, Gomaringen, 2014, [Online]. Available: http://www.digsilent.de.

[11] M. A. Omar and M. M. Mahmoud, "Improvement approach for matching pv-array and inverter of grid connected pv systems verified by a case study," *International Journal of Renewable Energy Development*, vol. 10, no. 4, pp. 687–697, Nov. 2021, doi: 10.14710/ijred.2021.36082.

[12] A. W. Hasanah, R. Hariyati, and M. N. Qosim, "On grid integrated photovoltaic concept with the STT-PLN building (in Indonesian)," *Energi & Kelistrikan*, vol. 11, no. 1, pp. 17–26, Jul. 2019, doi: 10.33322/energi.v11i1.394.

[13] Ministry of PUPR, "'Regulation of the minister of public works and public housing concerning amendments to the regulation of the minister of public works and public housing No. 27/PRT/M/2015 on Dams Regulatory." Ministry of PUPR, 2020.

[14] T. M. Blooming and D. J. Carnovale, "Application of IEEE STD 519-1992 harmonic limits," in *IEEE Conference Record of Annual Pulp and Paper Industry Technical Conference*, 2006, pp. 1–9, doi: 10.1109/papcon.2006.1673767.

[15] R. Kurnianto, A. Hiendro, and H. M. I. Yusuf, "Optimum orientation angles for photovoltaic arrays to maximize energy gain at near equator location in Indonesia," *International Review of Automatic Control*, vol. 10, no. 1, pp. 86–91, Jan. 2017, doi: 10.15866/ireaco.v10i1.11017.

[16] J. Dai *et al.*, "Design and construction of floating modular photovoltaic system for water reservoirs," *Energy*, vol. 191, p. 116549, Jan. 2020, doi: 10.1016/j.energy.2019.116549.

[17] R. Cazzaniga, "Floating PV structures," in *Floating PV Plants*, Elsevier, 2020, pp. 33–45.

[18] S. Oliveira-Pinto and J. Stokkermans, "Assessment of the potential of different floating solar technologies-overview and analysis of different case studies," *Energy Conversion and Management*, vol. 211, p. 112747, May 2020, doi: 10.1016/j.enconman.2020.112747.

[19] ESDM, "Website of ESDM Geoportal," *geoportal.esdm*, 2022. https://geoportal.esdm.go.id/ketenagalistrikan (accessed Jul. 21, 2022).

[20] The World Bank Group, "Global Solar Atlas'," globalsolaratlas.info, 2022. https://globalsolaratlas.info/map (accessed Jun. 01, 2022).

[21] Kementrian ESDM, "Rules of the electric power system network (Grid Code) (in Indonesian)," 2020. https://jdih.esdm.go.id/storage/document/PM ESDM No 20 Tahun 2020.pdf (accessed Jul. 18, 2022).

[22] A. Patil, R. Girgaonkar, and S. K. Musunuri, "Impacts of increasing photovoltaic penetration on distribution grid - Voltage rise case study," in *2014 International Conference on Advances in Green Energy, ICAGE 2014*, Dec. 2014, pp. 100–105, doi: 10.1109/ICAGE.2014.7050150.

[23] K. Kamil, K. H. Chong, and H. Hashim, "Impact of high penetration of solar pv output to line loading, voltage and power losses," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 1.6 Special Issue, pp. 361–367, Dec. 2019, doi: 10.30534/ijatcse/2019/5381.62019.

[24] Q. Liu, Y. Li, L. Luo, Y. Peng, and Y. Cao, "Power quality management of PV power plant with transformer integrated filtering method," *IEEE Transactions on Power Delivery*, vol. 34, no. 3, pp. 941–949, Jun. 2019, doi: 10.1109/TPWRD.2018.2881991.

[25] K. J. Nyoni, A. Maronga, P. G. Tuohy, and A. Shane, "Hydro-connected floating pv renewable energy system and onshore wind potential in zambia," *Energies*, vol. 14, no. 17, p. 5330, Aug. 2021, doi: 10.3390/en14175330.

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