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Research Article

The Planning Study of 145 MW Grid Connected Cirata's Floating PV to Support the Security of Supply in Jawa Bali Power Systems

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Abstract: *In this paper, a design planning study which includes energy supply projection, and grid impact are used to develop 145 MW AC Floating Photovoltaics (FPV) in Cirata Hydroelectric power plant (HEPP) that would interconnect in Jawa Bali system is presented. Firstly, the evaluation study is conducted to estimate FPV's energy production by defining parameters on object values to obtain the projection of solar energy production. Based on the calculation, the FPV has provided more than 300 GWh/year of energy production and reached 84% of its performance ratios. Subsequently, the grid interconnection study is performed to ensure the feasibility of this Variable Renewable Energy (VRE). The study also supports both strengthening grid security, and fulfilling the shares from renewable energy, due to the 23 % of national energy mixed. Ensuring the proper interconnection to the system, stability study was also carried out to observe whether the planning of the 145 MW is secure against the intermittency constrain due to its nature characteristic in the system either in 150 kV or 500 kV Transmission Lines (T/L) network. Consequently, the study analysis performed that FPV is ready to be integrated to utility grids, with minimum impact on its power system operation.*

Keywords: Floating Photovoltaic, Variable Renewable Energy

1. Introduction

The Jawa Bali power system as the biggest bulk power system in Indonesia, is expected to expand significantly to meet rapidly increasing demand and to provide electricity access to all consumers. Based on the national electricity supply business plan (RUPTL) for 2021-2030 projects an annual demand increases approximately to 5%, which the government of Indonesia (GOI) aims to meet with new installed capacity from renewables, striving to achieve 23% of total electricity generation from renewables by 2025.

PLN (Perusahaan Listrik Negara) as a major electric state company in Indonesia which has core business in providing supply of electricity. Additionally, it has launched a transformation breakthrough program since 2020, which has 4 main strategic goals, namely: lean, green, innovative and customer focused. Strengthening strategy of its green aspect can be initiated by launching large scale renewable program, in which one of the initiatives is by developing large scale of VRE in the country. Meanwhile, one of the world's largest FPV power plants, in Cirata, West Java province is preparing for the construction phase in Indonesia after it reached financial closed in early 2022. Thus, 145 MW AC grid connected Floating PV in Cirata is under construction currently, which is expected to achieve its commercially operation developed (COD) by early 2024.

The study delivered in this paper, identifies how to optimize the benefits of the Cirata FPV project, considering the potential seasonal variability in solar energy in each month, while maximizing the elaboration synergies with the existing hydroelectric plant to compensate the fluctuations resources generated from solar energy. It illustrates a mechanism to safely integrate the project into the Java-Bali power system, and the relevant tools that would be most efficient for the entire system. Ongoing analysis is part of efforts to prepare for the planned integration of larger scale from VRE shares in the generation composition. Therefore, Floating PV is becoming new trend to be proposed in renewable ecosystem due to certain advantages: optimizing utilization of reservoir, avoid land-use, providing complementary with hydropower electric (hybrid operation), which can reduce the evaporation and boost up energy yield up to more than 5% due to lower ambient temperature [3]. Currently, based on PLN Nusantara Power (PNP) research, as PLN subsidiary, stated that Indonesia has more than 192 dams and reservoirs, with catchment area approximately more than 80 thousand Hectares, and high potential to optimize the utilization as Floating PV Power plant more than 4,300 MWp (5% utilization of catchment area) based on the data and information from Ministry of Public Work [2].

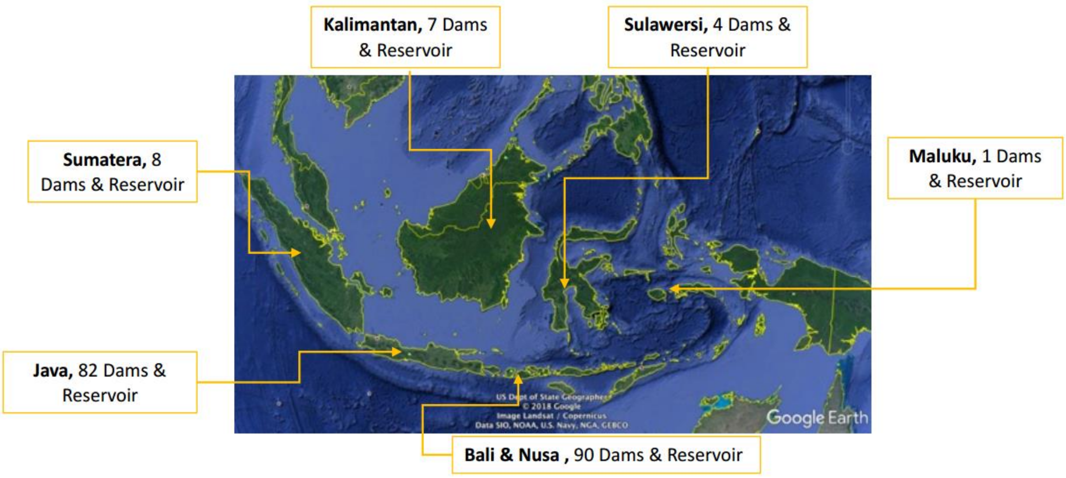

Figure 1. Potential Reservoir to developed for Floating PV in Indonesia

The first objective of this research is to evaluate the projected PV output energy production resulting from Cirata FPV. The second objective is to conduct the grid impact study to ensure the feasibility of the FPV integration into the system since the interconnecting VRE is compulsory needed to provide energy security and cost-effective. Hence, the composition of this research paper is divided into 4 main sections. Section one implies the introduction of FPV project which is developed in Cirata HEPP. Section two discusses the FPV technology. Thus, section three shows FPV evaluation study, while section four shows the simulation results of PFV's production energy and grid integration study as well.

Journal of Technology and Policy in Energy and Electric Power
Vol. 1, No. 1, 2024
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2. Materials and methods

2.1. FLOATING PHOTOVOLATIC TECHNOLOGY

Floating solar photovoltaics are solar panels mounted on a designed structure to be able to float on a water surface. The design itself is resemble to a land-based solar PV system, except that it needs a floating structure to float the panels on the water's surface. The main components of FPV consist of PV modules, inverters, floating platform system, anchoring and mooring system, cabling and DC combiner box, and transformer. A schematic of typical FPV is shown in Figure 2.

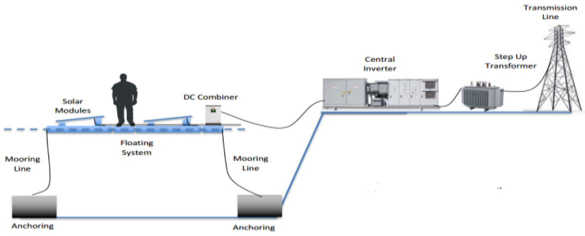

Figure 2. Potential Reservoir to developed for Floating PV in Indonesia [2]

The basic principle of FPV is much more similar with the land-based PV, where direct current (DC) electricity generated by the modules is conjucted by combiner boxes and converted to alternating current (AC) by inverters. For small-scale floating plants close to shore, it is possible to place the inverters on land, just a short distance from the array. Otherwise, both central or string inverters on specially designed floats are typically used. The platform, together with its anchoring and mooring system, is an integral part of any FPV installation [2].

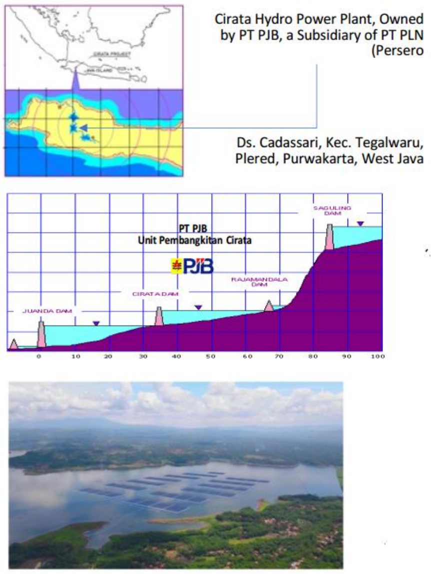

Figure 3. Overview location of illustrative Floating PV in Cirata dams [2]

The floating structure and anchoring system are the key components that diverge from the land-based PV system to the land-based. However the major concern in FPV has higher cost than land-based, where the floating system consumes relatively up to 30% of the investment cost [3].

An actual measurement that carried out by existing 1 MW land-based PV in Cirata HEPP showed that the Cirata PV will have a yearly average capacity factor up to 20% [1], which it would generate electricity from the whole year round, based on the geographical condition and weather

Journal of Technology and Policy in Energy and Electric Power
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data information. Furthermore, the testing indicates that there is a significant difference between sunny and cloudy days, where in the wet season have a more variable solar production pattern compared with the sunny days in the dry season [16]. The Figureure 4 below illustrates the difference.

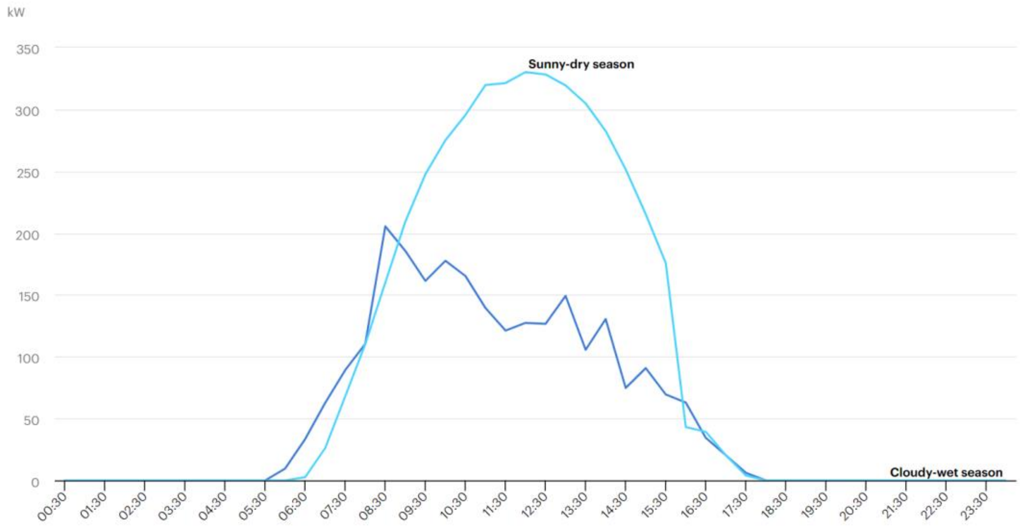

Figure 4. Solar PV production from the testing PV modul on a sunny day in the dry season and a cloudy day in the wet season [10]

The combination of power generation between existing Cirata hydro and solar PV can be complementary, in which the characteristic of hydro as load follower could facilitate as fast response to compensate the variability of PV output. On the other hand, limitations of hydro generation in the dry season can be fulfilled by the optimum solar irradiation. The integration of hydro-solar in one ecosystem of power generation provides the other benefit since VRE plant does not need to be provided with ancillary services [16].

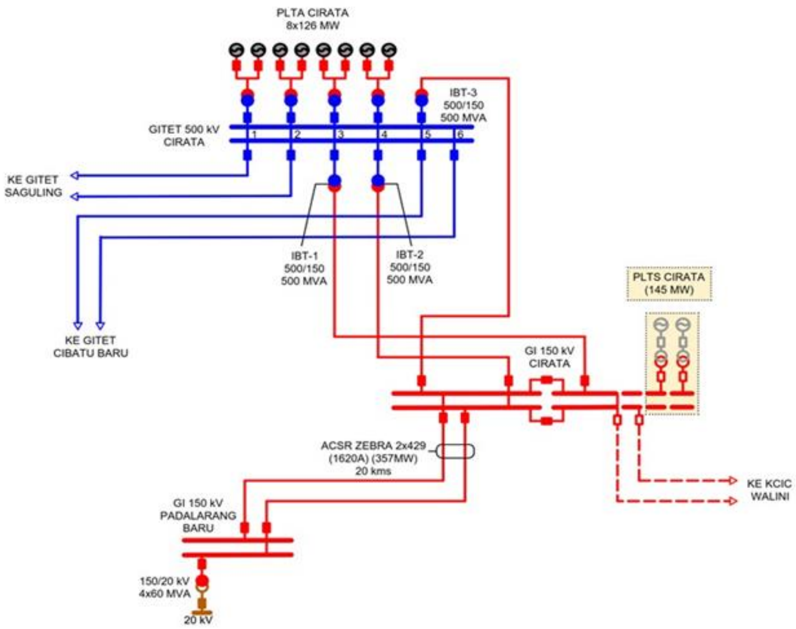

Figure 5. FPV’s single line that would integrate into the Cirata grid

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Figure 5 above shows single line diagram, in which the point of connection (POC) of FVP, will be interconnected into the Cirata HEPP substation through 2 circuit of 150 kV T/L and 90 MVA x 2 unit of power transformer. From the 150 kV T/L, the power is transferred into the 500 kV level in Jawa Bali system through Interbus Transformer (IBT) 2 x 500 MVA at the Cirata GITET (extra high voltage substation).

2.2. FPV GRID CONNECTED EVALUATION

2.2.1. Production Energy Evaluation

FPV Development in Cirata is expected to complement the electricity production from the existing hydroelectric plant in a hybrid combination. The hydro plant will produce more power in the wet season while the PV plant will produce more output power in the dry season. Thus, the higher capacity factor of the hydro plant during the wet season allows the system to manage lower PV production, while the additional PV production in the dry season can help with water availability issues, especially during peak load periods [7]. The steps below show a procedure that can be carried out to calculate the energy output obtained from a solar photovoltaic array, considering the following factors.

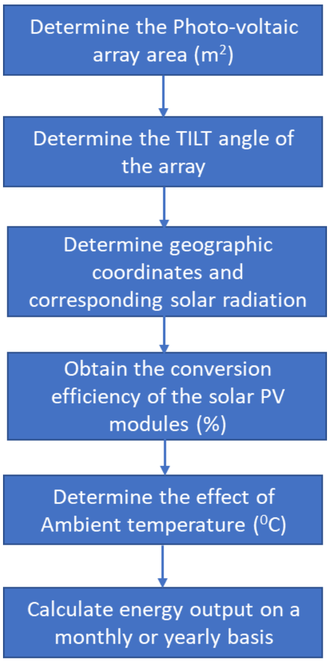


Figure 6. Theoretical steps to calculate PV output power.

The step process in Figure. 6 above to obtain estimate energy production study of the Cirata FPV basically can be carried out using PVSYS as simulation tool, which can model the energy conversion and losses at every step of the process. So, this simulation outputs expected are average annual energy production, performance ratio, and financial numbers. To limit the analysis, this study focuses on seeking energy and performance ratio.

Based on the data parameters collected from the meteorological solar radiation data which can be generated from the PVSYS, the data specification of PV and inverters is shown in table 1. Hence, a geographical site in Cirata has the coordinates of latitude 6.710 S, longitude 107.340 E and it has also the altitude 201 meters from sea level.

Table 1. Specification data of FPV and inverters used in Cirata HEPP

No	Parameters of Floating Photovoltaic	Values
1	Unit nominal power/module (Wp)	560
2	Number of PV module (unit)	342,862
3	Nominal (STC) (MWp)	192
4	Module conFigureuration	13,187 string x 26 In series
5	PV field orientation	tilt/azimuth 6/0^0

No	Parameters of Inverters	Values
1	Unit nominal power/module (Wp)	3,437
2	Number of inverter (unit)	43
3	Nominal (STC) (MWp)	147,791
4	Max power at T 25^0C (kWac)	3,593
5	P nominal ratio	1.3

2.2.1. Production Energy Evaluation

In order to assure the security aspect of transfering power from FPV to the utility grid, it is mandatory to have an assesment to maintain the stability and flexibility of the grid interconnection from VRE to the Jawa Bali power system. By definition, the grid integration study is an evalution study carried out in an analytical framework used to observe a power system under high penetration levels of VRE [3].

The simulation model of PV grid connected is performed to represent the existing power grid conFigureurations as well as the N-1 contingency cases which used in the folowing study :

1. Power flow and system voltage study: used to monitor the static criteria regarding the voltage on the grid as the sizing of the main equipment in substation and transmission lines.
2. Dynamic analysis: used to conduct dynamic stability and transient of the grid in islanding conFigureuration when the grid is disconnected with the rest of power system. This analysis is based on typical scenarios regarding power fluctuations of the PV power station (rise in production, loss of power, and appearance of clouds).
3. Short-circuit calculations: used to calculate the short-circuit contributions on the FPV to comply with the maximum short-circuit rating values onsite equipment.

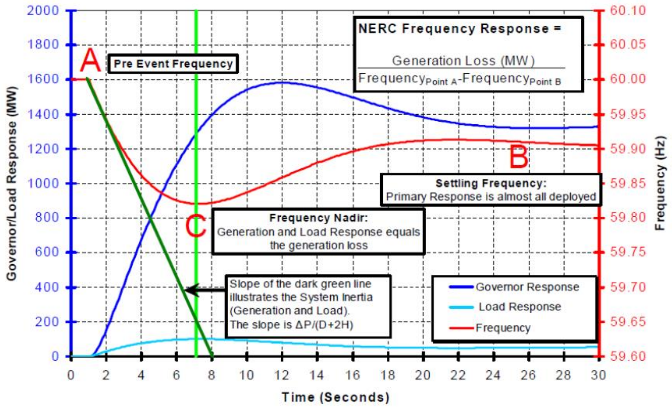


Figure 7. Frequency Response Basic

Figure.7 above implies the basic response of system frequency stability in one power system. Meanwhile, the red line represents system frequency where C-line has the lowest frequency, and B-line shows as the steady state frequency, when the primary controllers are respond the fluctuation condition of the system. Thus, green curve which represent system inertia is a slope when frequency drops at the first time. The blue curve reflects of free governor's respond to the system.

3. Results

3.1. Production Energy Calculation

From the data parameter obtained in section III, the simulation uses PVSYS to calculate the production energy and performance ratios of the FPV in Cirata as implied in table 2, which shows the PV output energy.

Table 2. Solar irradiation and monthly PV output power.

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	137.7	72.38	22.41	133.6	125.8	22241620	21969971	0.856
February	142.7	80.08	22.17	140.5	132.7	23560847	23292384	0.863
March	152.9	83.07	22.94	153.5	145.3	25624325	25327427	0.859
April	149.6	76.32	23.11	153.1	145.0	25652308	25361968	0.863
May	153.2	67.13	23.67	160.3	151.9	26923138	26615574	0.865
June	147.5	65.14	22.99	155.5	147.7	26310109	26009295	0.871
July	153.5	65.95	22.75	161.2	153.3	27262172	26945316	0.870
August	159.8	81.47	23.03	164.9	156.6	27840599	27525167	0.870
September	161.7	80.87	23.08	163.7	155.3	27408497	27100163	0.862
October	178.1	92.69	23.57	176.6	167.6	29538716	29208792	0.861
November	145.7	85.20	22.93	142.3	134.3	23860359	23583729	0.863
December	147.5	80.81	22.80	143.0	134.8	23902239	23620442	0.861
Year	1829.9	931.10	22.96	1848.3	1750.3	310124928	306560228	0.864

Calculating performance of FPV generally uses performance ratios (PR). This ratio can be defined as quality parameter of the PV itself. This also states as percentage that describe relationship between the actual and rating nominal of PV energy outputs [9]. Hence, it shows the proportion of the energy available for injecting power to the grid after deduction of energy loss, such as thermal and conduction losses. Figure below show the normalized production and performance ratios of the FPV which is calculated using PVSYS.

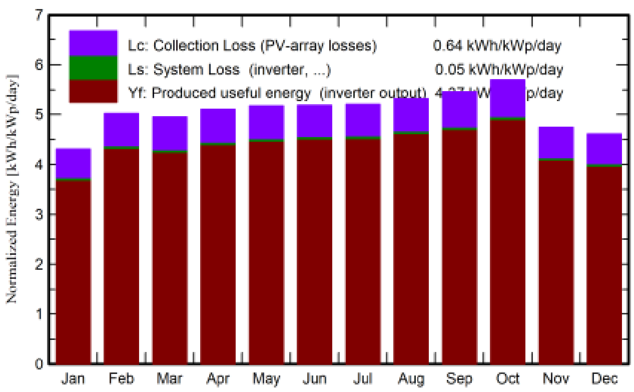


Figure 8. Normalized production of Cirata FPV

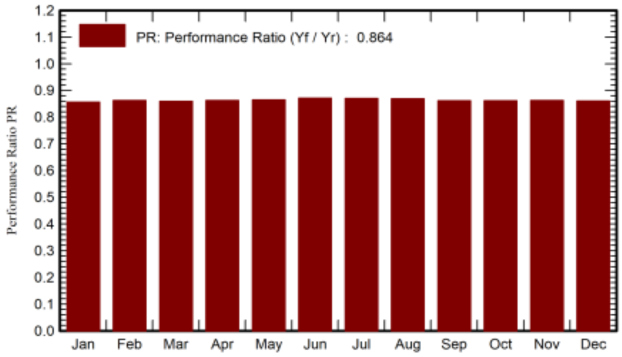


Figure 9. Performance Ratios

Based on the simulation, the production energy of FPV Cirata has provided approximately to 306,56 MWh/year with the annual performance ratio of that system was found equal to 84%. Thus, the study shows that there are factors influencing the FPV generation, such as: variation in ambient temperature, partial shading, and accumulation of dust on the PV module surface [12].

3.2. Transient Stability Evaluation

There are steps to perform stability transient analysis that conducted in the grid integration study [11] states:

- The study which uses Digsilent combine with ETAB as simulation tools, review the grid response if any outages occurred in FPV, and in Cirata HEPP itself.
- The analysis is conducted by time domain simulation which can illustrate generator dynamics in the system.

From the scenarios implied above the output parameters of FPV such as graphs of voltage angle, voltage, and frequency versus time can be obtained.

There are scenarios that simulated in this stability and transient study as the following mentioned:

1. FPV gets operation failures or outages.

   The purpose of this event is to review the changing of system frequency and its response in the system when FPV suddenly loses the supply 100%. Parameters to be considered are frequency excursion and generator output changing. The frequency respond below shows when FPV loses 100% of this supply, where system frequency drops to 49,8 Hz. This is within the area of the tolerable limit of the system. Meanwhile, voltages are fluctuating

Journal of Technology and Policy in Energy and Electric Power
Vol. 1, No. 1, 2024
https://doi.org/10.33322/jtpeep.v1i1/93

max. between 95.4% to 97.12% of the normal range when FPV supply drops to 100%. Thus, voltage and rotor angle are stable, and they would recover within less than 30 seconds.

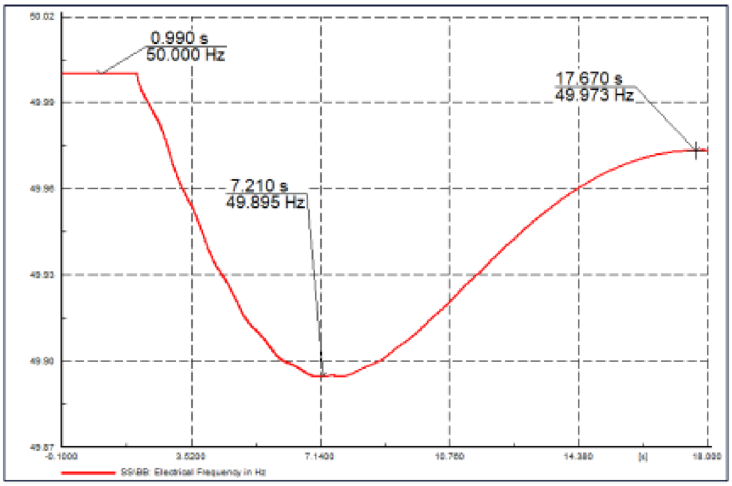


Figure 10. Frequency response when FVP loss the supply 100%

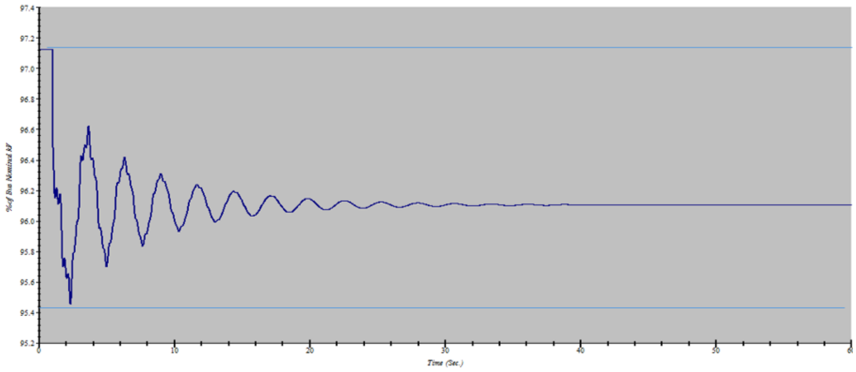
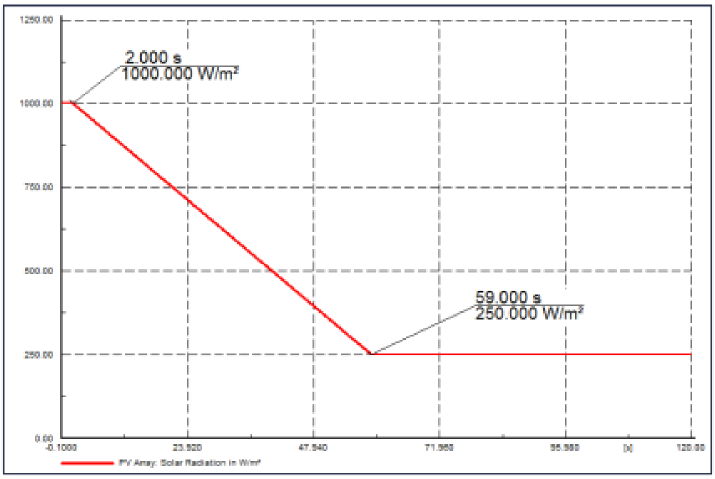


Figure 11. Voltage variation when FPV loss the supply 100%

2. PV Output drops gradually from 100% to 25% within 50 seconds.



Solar radiation (W/m2)

Figure 12. Loss of Solar radiation output from 100% to 25%

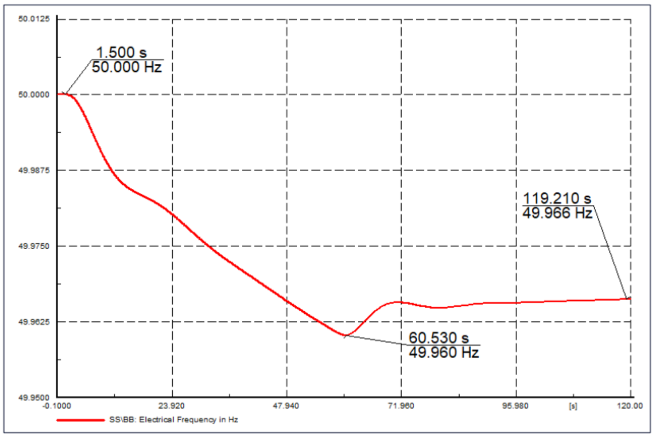


Figure 13. Frequency response when FVP drops 100% to 25%

The frequency response in Figure 13 shows when FPV loses output 100% to 25%, where system frequency drops to 49,96 Hz. Similarly, solar radiation also drops to 25% of its energy output within 57 seconds.

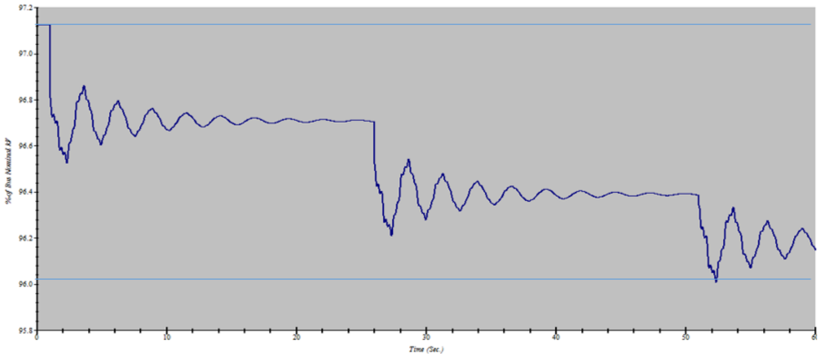


Figure 14. Voltage variation when the supply drops 100% to 25%

The voltages are also fluctuating at the normal range when FPV supply drops from 100% to 25%. Subsequently, voltage and rotor angle are stable (d̨ $<16^{0}$), and they would recover less than 30 seconds.

3. Outages occur at the 150 kV T/L Cirata – FPV. This scenario is used to review the FRT (Fault Ride-Through) capability when the outages occur in the T/L, and voltage would drop within 120 ms.

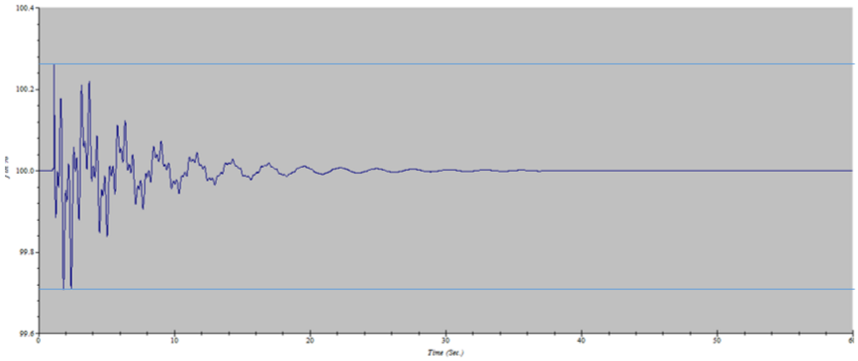


Figure 15. Frequency response when an outage occurs in its T/L

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The frequency response in fig 15 shows variety range between 49.86 Hz to 50.14 Hz, when short circuit fault occurs in the T/L from FPV to Cirata HEPP. Hence, both voltage and rotor angle are stable (ḑ < 30^0 and it would be turning back to normal). The voltage itself reaches steady state within 120 ms.

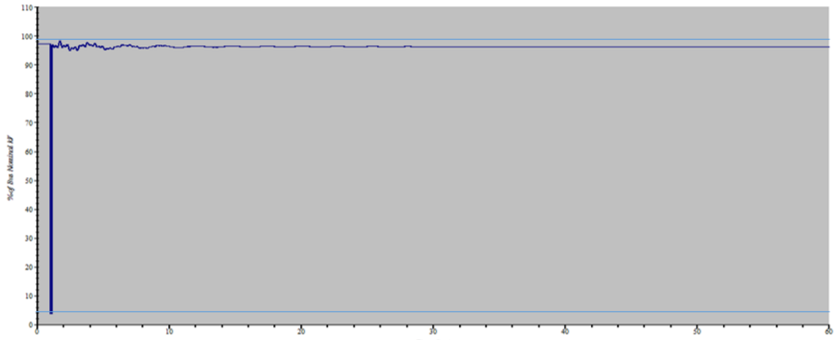

Figure 16. Voltage variation when an outage occurs in its T/L

From the fig. 15 and 16, indicates both the system frequency, and voltage are within tolerable normal operation when short circuit fault occurs in its power grid. So, there is no violation of frequency and voltage in the system.

5. Conclusion

1. The potential resources of FPV could harness more unexploited VRE to support net zero emission. Despite the challenges, the Cirata FPV is a promising way to provide the alternative solution of low carbon electricity.
2. Based on the simulation, Cirata FPV can provide up to 300 GWh/year of estimated energy production with high performance ratio (PR) of 84%. It means the higher PR values the more efficiently the FPV plant operates.
3. The transient stability study which is conducted under different scenarios shows the parameters: voltage angle, system frequency and voltage are well maintained within the tolerable range. So, the grid integration of the Floating PV to the system is safe. Thus, it supports security of supply in Jawa Bali systems with more VRE.
4. The outcome of the proposed study can open wider opportunity to expand the solar potential resources of floating PV development in other areas in Indonesia.

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