Impact of 5 MWp Solar Power Plant Interconnection on Power Flow and Short Circuit Interruption in the 20 kV Medium Voltage Network at Area X Power System

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ABSTRACT

One example of the application of new renewable energy that is currently developing is solar power plant. Based on data from Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2019-2028, it is stated that the potential of solar energy in Indonesia is 207,898 MW (4.80 kWh / m² / day) and only 78.5 MW of capacity installed in Indonesia. In this study, a 5 MWp solar power plant was interconnected with a 20 kV medium-voltage network of Area X as one of the renewable energy applications in Indonesia. Interconnection studies include power flow analysis and three phase short circuit fault analysis. In the analysis of the power flow results obtained that the Solar Power Plant system is capable of supplying the load requirements to the system of 5,000 kW active power. It was also found that interconnection of solar power plant with the system resulted in an increase in the voltage level of each bus in the system by 0.08 to 1.41%, as well as changing the percentage of component loading by 0.01% -93.01%. The results of the three-phase short-circuit fault analysis show that the interconnection of the solar power plant system has a short-circuit fault current value of 5.70-7.01 kA, so the fault current value for the whole bus is still far below the value of the short-circuit current capacity of the protection system's short circuit worth 25 kA. The results of the interconnection study showed that interconnection of a 5 MWp solar power plant system with a 20 kV medium voltage network Area X can be carried out.

Keywords: *Interconnection; Solar power plant; load flow; short circuit.*

ABSTRAK

Salah satu contoh penerapan energi baru terbarukan (EBT) yang sedang berkembang adalah Pembangkit Listrik Tenaga Surya (PLTS). Berdasarkan data Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2019-2028 disebutkan bahwa potensi energi matahari (surya) di Indonesia sebesar 207.898 MW (4,80 kWh/m²/hari) dan hanya sebesar 78,5 MW kapasitas terpasang di Indonesia. Pada penelitian ini dilakukan studi interkoneksi PLTS 5 MWp dengan jaringan tegangan menengah 20 kV Daerah X sebagai salah satu penerapan energi baru terbarukan di Indonesia. Studi interkoneksi mencakup analisis aliran daya dan analisis gangguan hubung singkat tiga fasa. Pada analisis aliran daya diperoleh

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hasil bahwa sistem PLTS mampu menyuplai kebutuhan beban pada sistem sebesar 5.000 kW daya aktif. Didapatkan juga bahwa interkoneksi PLTS dengan sistem mengakibatkan kenaikan level tegangan dari setiap bus pada sistem sebesar 0,08-1,41%, serta membuat perubahan persentase pembebanan komponen sebesar 0,01% hingga 93,01%. Hasil analisis gangguan hubung singkat tiga fasa menunjukkan bahwa interkoneksi PLTS dengan sistem memiliki besar nilai arus gangguan hubung singkat sebesar 5,70-7,01 kA, sehingga nilai arus gangguan untuk seluruh bus masih jauh di bawah nilai kapasitas pemutusan arus hubung singkat sistem proteksi yang bernilai 25 kA. Hasil studi interkoneksi yang diperoleh menujukkan bahwa interkoneksi sistem PLTS 5 MWp dengan jaringan tegangan menengah 20 kV Daerah X dapat dilakukan.

Kata kunci: *Interkoneksi; PLTS; Aliran daya; Gangguan Hubung Singkat.*

1. Introduction

Energy is a basic need in life in the world, so its existence is needed. Various alternative energy sources have been developed; one is new and renewable energy. Power plants using renewable energy sources are being intensively carried out by many countries, including Indonesia. An abundant and clean source of renewable energy will produce energy that has minimal impact on the surrounding environment. Its abundant presence and government support for renewable energy resources have made Indonesia aggressively developing this type of power plant. Solar energy is one example of new and renewable energy because its availability is very abundant in nature and will not run out. The use of solar energy also does not pollute the environment.

One application of solar energy that is developing is the Solar Power Plant. Solar Power Plant is a generator with technology that utilizes solar energy into electrical energy. Based on data from Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2019-2028, it is stated that the potential of solar energy in Indonesia is 207,898 MW (4.80 kWh / m^2 / day) and only 78.5 MW installed capacity in Indonesia [1]. Therefore, the utilization of solar energy into electricity generation in Indonesia can be an opportunity because the potential utilization is considerable. Area X, located in eastern Indonesia, is used as a case study in the interconnection of solar power plants with existing networks. This study uses a solar power plant with a capacity of 5 MWp, which will later be connected to a medium voltage network of 20 kV Area X electricity center. The interconnection study is carried out by modeling the system, which will be simulated using ETAP 12.6.0 software.

This interconnection study includes a study of power flow and short circuit interference. Power flow studies are needed to determine an electric power system's condition before and after the interconnection of solar power plants. Short-circuit fault studies are used to determine the value of short-circuit current. This is used to determine the protective equipment used on the system. These study results will determine whether the interconnection of solar power plants with existing networks can be carried out.

2. Basic Theory

2.1 Solar Power Plants

Solar cells or photovoltaic cells (PV) are devices consisting of semiconductor materials such as silicon, gallium arsenic, cadmium telluride, and other mixed materials that can convert direct sunlight into electricity using the principle of semiconductor devices. Solar cells offer a solution to today's society for their dependence on fossil fuels to generate electricity [2].

Solar power plants are solar cell-based or photovoltaic (photovoltaic, PV) based plants. Solar cells utilize sunlight to be converted into electrical energy. This system is combined with supporting components so that it can be used to meet electricity needs. The solar power plant system's preparation requires supporting components in addition to solar cell modules such as a series of solar cell modules, inverters, transformers, solar charge controllers, batteries. In the preparation of solar power plants connected to the medium-voltage network, these components are not used at all; only a few components are used as supporting components.

2.2 Solar Power Plants Interconnection with Medium Voltage Networks

The use of solar power plant systems can be used on medium voltage distribution network systems by connecting the solar power plant system to an existing medium voltage distribution network. The voltage drop occurs at the feeder due to the primary voltage source's distance in the electric power system to the load center. Solar power plant interconnection with medium voltage distribution networks provides a voltage repair effect on the load side. This system's interconnection also results in a power flow condition that can cause a decrease in the value of power losses that occur in all feeders [3]. The solar power plant system used is a system with a large enough capacity to penetrate well on medium voltage networks. The use of power transformers is needed in this system. The voltage level generated by the solar power plant can supply power to the medium voltage distribution network system (Figure 1).

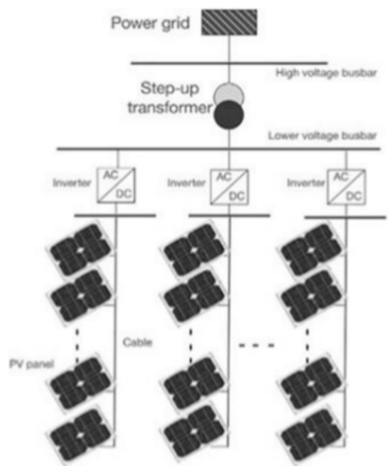

Figure 1 Solar Power Plants Interconnection with Medium Voltage Networks [4]

2.3 Solar Power Plants Installation Guidelines

Regulations related to the interconnection of power plants with Renewable Energy in Indonesia are regulated in the guidelines of PT PLN (Persero), where PT PLN (Persero) is a utility company and provider of Indonesian electricity. This guideline is used for new and renewable energy power plants with installed capacity up to 10 MW, connected at the connecting point, and operating in parallel with the PLN radial distribution system at 20 kV or lower. The guideline is based on Permen No. 4 / ESDM / 2012, Permen No. 17 / ESDM / 2013, Permen No. 19 / ESDM / 2013, and Permen No. 12 / ESDM / 2014 [5].

The guideline explains that renewable energy interconnection on the PLN network is not permitted when it causes interference. The voltage of other consumer services does not meet the requirements of the PT PLN (Persero) Electric Power Distribution Rules (+ 5% & -10%).

2.4 Power Flow Analysis

Power flow analysis is used to determine the condition of a system. This analysis reveals an electric power system's performance and flow (active and reactive) for certain circumstances when the system is working [6]. Calculating power flow information is needed in the form of estimated load requirements at each point served by the electric power system, transmission facility operating plans. The equation of power flow from one bus to another bus can be designed based on the information.

The concept of solving power flow, in general, is to calculate the magnitude of the voltage |V| and the voltage phase angle (δ) on each bus contained in a network in steady-state and when all three phases (R, S, and T) are in phase-stable conditions. The results obtained from the calculation of these components will be used to find the value of the active power (P) and reactive power (Q), as well as losses from the system. Power flow analysis using the Newton Raphson method is one of a method in calculating power flow, which has better calculations for larger and non-linear power systems because it is more efficient and practical. The number of iterations used in this method only takes a little to get a solution based on the system's size. This method is widely used because the convergence is much faster, and the power flow equation is formulated in polar form.

2.5 Short Circuit Fault

Short-circuit fault is a disruption that occurs in the components of the electric power distribution system and is a significant problem in developing and applying a protection system. Short circuit disturbance is a condition of direct connection when the two terminals have very little impedance so that a large current flow (abnormal) is called a short circuit current. The occurrence of short-circuits current causes a larger current than the rated current of the equipment and a decrease in voltage in the electric power system. That interference can damage the system equipment.

3. Research Methods

This research was conducted using ETAP 12.6.0 software. This study aims to obtain the effect of power flow and short circuit interference from the 5 MWp PLTS interconnection plan with a medium voltage network of 20 kV area X electricity network. This research begins with data collection. The data obtained are primary data used to make a single line diagram in ETAP 12.6.0 software. The next stage is designing the solar power plant system capacity based on current load needs and future load requirements in the area. After the capacity has been determined, proceed with comparing the amount of capacity obtained with the renewable energy generator connection rules. After the design is appropriate, it is continued with power flow simulation, and three-phase short-circuits faults. The results obtained can be analyzed for further stages in this study. Figure 2 is the stage of the research conducted.

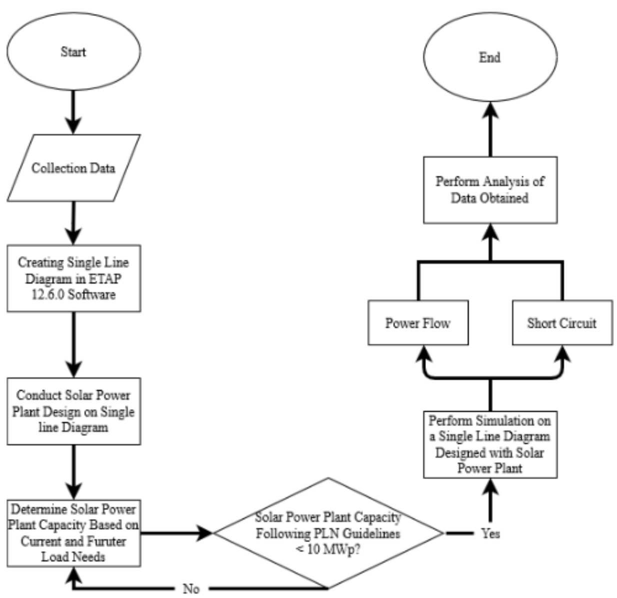

Figure 1 Research Flow Chart of 5 MWp Solar Power Plant Interconnection Study with Area Electricity Network X

The electric power system, which is the object of this research, is located in area X. This system is part of the national electricity company, PT PLN (Persero). The electricity needs of area x are fulfilled by a diesel power plant located in the complex of the central area x power station. This system consists of 11 plants connected to seven feeders, namely Load 1, Load 2, Load 3, Load 4, Load 5, Load 6, and Load 7. Electric energy generated at the area x power center is distributed to the load using a 20 kV medium-voltage network. The system uses a medium voltage overhead line All-Aluminum Alloy Conductor (AAAC) 3x70 mm^2, a substantial conductivity value of 156 A. In this study, the area x electricity network will be used, represented in a single line diagram (Figure 3). Area x electricity network will be interconnected with solar power plant systems in an on-grid configuration.

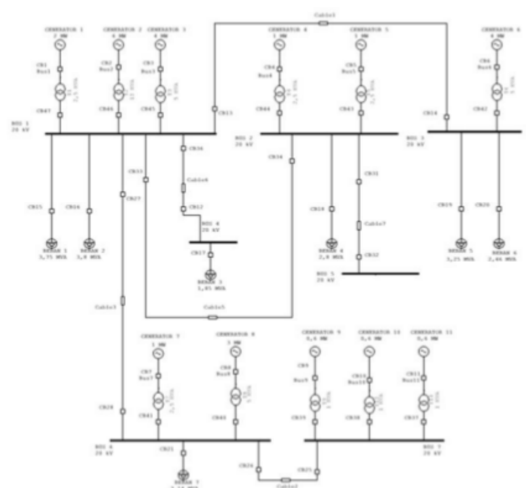

Figure 2 Single Line Diagram Electricity Center Area X

The solar power plant system is designed with a capacity of 5 MWp that is interconnected on-grid with a medium voltage network of 20 kV area x. Determination of PLTS Capacity is determined based on basic load requirements, future load requirements, and current conduct in the system. In the simulation design, the First Solar Series 6 (FS-6450) Thin-film CdTe type solar panel module is used with the required number of modules of 12,597.

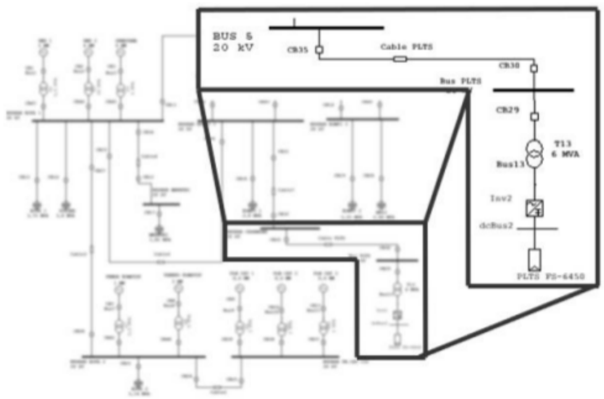

Figure 3 5 MWp Solar Power Plant System Design and 5 MWp Solar Power Plant Interconnection Location with a 20 kV Medium Voltage Network System

In the solar power plant system, a centralized inverter is used with a capacity of 3.75 MW to convert the electric current output from the solar power plant (DC) to AC. The resulting voltage level will then be raised to a 20 kV voltage level using a 6 MVA transformer. The 5 MWp solar power plant system is interconnected with a medium voltage network on the Bus 5 20 kV area x electricity grid system. The solar power plant system has an integration distance of 800 m. from Busbar 5 connected using a medium voltage overhead line of AAAC type 3x70 mm^2. In this simulation, the solar power plant system works at the optimum condition with the amount of power generated at 5 MW (Power factor = 1).

4. Result and Discussion

In the power flow simulation, there are two scenarios. The first scenario is scenario 1.1, which is when 5 MWp solar power plant has not been interconnected with a regional voltage network system of 20 kV area x—followed by scenario 1.2. In contrast to the previous scenario, this scenario is when 5 MWp solar power plant has been interconnected with a regional voltage network system of 20 kV area x.

Based on the results obtained from power flow simulations using scenarios 1.1 and 1.2, the results of power flow simulations from both scenarios can be seen in Table 1.

Table 1 Results of Power Flow in All Scenarios

No.	From	To	P [kW]	Q [kVAR]
		Scenario 1.1		
1.	Bus 1	Bus 4	1,558	964
2.	Bus 1	Bus 2	960	398
3.	Bus 1	Bus 3	2,318	1,089
4.	Bus 2	Bus 5	0	0
5.	Bus 6	Bus 1	2,026	1,015
6.	Bus 7	Bus 6	1,191	718
		Scenario 1.2		
7.	Bus 1	Bus 4	1,558	964
8.	Bus 1	Bus 2	-3,938	717
9.	Bus 1	Bus 3	2,319	1,142
10.	Bus 2	Bus 5	-4,937	307
11.	Bus 6	Bus 1	2,025	987
12.	Bus 7	Bus 6	1,191	718

On the results of the power flow obtained on the system, it shows a change when scenario 1.2 is carried out. The entry of 5 MWp solar power plant makes Bus 5 supply active power to Bus 2. Bus 5 is the bus where the solar power plant system is located. On Bus 2, the active power supply to Bus 1. The power flow transfer indicates that the solar power plant system's inclusion will help meet the load requirements

Based on changes in the voltage level's value per bus, a comparison of the value of the voltage level in scenario 1.1 and scenario 1.2 is shown in Table 2.

Table 2 Results of Voltage Level in All Scenarios

No.	Bus	kV	Voltage Level Scenario 1.1	Voltage Level Scenario 1.2	Alteration	
			Bus Voltage [%]	Bus Voltage [%]	[%]	[p.u]
1.	Bus 1	20	97.12	97.20	0.08	0.0008
2.	Bus 4	20	96.86	96.98	0.12	0.0012
3.	Bus 2	20	96.97	97.72	0.75	0.0075

4.	Bus 5	20	96.97	98.38	1.41	0.0141
5.	Bus 3	20	96.75	97.83	1.08	0.0108
6.	Bus 6	20	97.44	97.51	0.07	0.0007
7.	Bus 7	20	97.63	97.71	0.08	0.0008

In scenario 1.1, when the system has not been interconnected with a 5 MWp solar power plant system, the voltage level on each bus is in excellent condition following the power distribution rules (+ 5% and -10% nominal voltage) [7]. After interconnection with the 5 MWp solar power plant system in scenario 1.2, each bus's voltage level has increased. It is still in good condition following the renewable energy connection guidelines and power distribution rules (+ 5% and -10% nominal voltage) [5].

The results of loading on system components for all scenarios are shown in Table 3. Based on the results of the percentage of loading in scenario 1.1, all components are still within the safe operating limit of under 100%. In scenario 1.2, after the interconnection of the 5 MWp solar power system with the system, there is a decrease in some system components. In some components, there was an increase in the percentage of loading due to the inclusion of the solar power plant system, but the loading percentage was still within safe limits. The operation of all components is still within the maximum operating limit of 100%.

Table 3 Results of Loading System Components in All Scenarios

No.	System Components	Components Loading Scenario 1.1 [%]	Components Loading Scenario 1.2 [%]	Alteration Loading [%]
		Transformator		
1.	T1	60.30	59.50	-0.80
2.	T2	57.60	36.50	-21.10
3.	T3	67.30	42.70	-24.60
4.	T4	35.00	35.00	0
5.	T5	35.00	35.00	0
6.	T6	62.30	61.70	-0.60
7.	T7	36.20	36.20	0
8.	T8	61.90	61.70	-0.20

9.	T9	46.30	46.30	0
10.	T10	46.30	46.30	0
11.	T11	46.30	46.30	0
12.	T13	0	82.90	82.90
		Cable		
13.	Cable 1	48.79	49.21	0.42
14.	Cable 2	26.34	26.32	-0.02
15.	Cable 3	43.01	42.73	-0.28
16.	Cable 5	19.79	75.78	55.99
17.	Cable 6	34.89	34.88	-0.01
18.	Cable 7	0	93.01	93.01

In the three-phase short circuit fault simulation, two scenarios are performed. The first scenario is scenario 2.1, which is a scenario when 5 MWp solar power plant has not been interconnected with a regional voltage network system of 20 kV area x—followed by scenario 2.2. In contrast to the previous scenario, this scenario is a scenario when 5 MWp solar power plant has been interconnected with a regional voltage network system of 20 kV area x. The results of the three-phase short circuit fault for all scenarios are shown in Table 4.

Table 4 Three-Phase Short Circuit Fault Results in All Scenarios

No.	**Bus Name**	**Short Circuit Current [kA]**		**Alteration [kA]**
		Scenario 2.1	**Scenario 2.2**	
1.	Bus 1	6.99	7.01	0.02
2.	Bus 4	6.29	6.29	0.00
3.	Bus 2	6.39	6.44	0.05
4.	Bus 5	5.62	5.70	0.08
5.	Bus 3	6.54	6.54	0.00
6.	Bus 6	6.52	6.52	0.00
7.	Bus 7	5.80	5.80	0.00

Based on these results, it can be concluded that when interconnected the 5 MWp solar power plant with the system, there was an increase in the three-phase short-circuit fault current whose value was not large enough. This increase is still within the safe limit because the value of the short-circuit fault current for the whole bus is still far below the value of the short-circuit current capacity of the protection system, which is worth 25 kA so that a circuit breaker can overcome the three-phase short circuit fault current that occurs in the system.

5. Conclusion

Based on the results of simulations and analyzes that have been carried out in this study, it can be concluded that the results of the analysis of the flow of power obtained from the interconnection of a 5 MWp solar power plant with a medium voltage electricity network of 20 kV area x indicate that the solar power plant system is capable of supplying load requirements at a system of 5,000 kW active power. The interconnection of the 5 MWp solar power plant with the system also shows an increase in the voltage level of each bus on the system by 0.08% to 1.41% and making changes in the percentage of component loading by 0.01% to 93.01%. The results obtained are still following the guidelines for connecting renewable energy (+ 5%, -10% nominal voltage), and the standard loading is below 100%.

The three-phase short circuit fault analysis results show that the 5 MWp solar power plant's interconnection with a medium voltage 20 kV area x power grid has a three-phase short circuit fault current value of 5.70-7.01 kA for all buses so that the value of the short circuit fault current is still far below the value of the capacity of the short circuit current protection system which is worth 25 kA.

Based on the explanation of the power flow results and three-phase short circuit fault, the interconnection of the 5 MWp solar power plant with a medium voltage network of 20 kV area x is feasible.

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