Jurnal Pendidikan Teknologi Kejuruan, Vol. 6, No. 1, pp. 113-119, February 2023
e-ISSN 2621-1548; p-ISSN 2621-3273

Optimization and short-circuit analysis of photovoltaic penetration in off-grid system – A case study in newmont suriname gold mine

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Received 28th April 2023; 1st Revised 12th May 2023; 2nd Revised 20th May 2023; Accepted 30th May 2023

Cite this https://doi.org/10.24036/jptk.v6i2.32023

Abstract: Mining companies are highly dependent on fossil fuels to meet their electricity needs and mining activities such as the use of heavy equipment. Therefore, the greenhouse gas emissions due to burning of fossil fuels have become a major issue related to the impact on the environment due to mining activities. Renewable energy such as Photovoltaic (PV) can be an alternative solution to overcome this problem. This study aims to examine the optimal penetration of Photovoltaic (PV) at Processing Plant Newmont Suriname gold mine. HOMER software is used to design the most optimal Photovoltaic (PV) penetration. ETAP software is used for technical validation through load flow and short-circuit analysis.

Keywords: Hybrid power plant; HOMER; ETAP; NPC; COE; Short-circuit

1. Introduction

Power generation at mine sites are generally off-grid systems because of their remote location and utilize diesel generator because of their ease of installation and operation. The main obstacles in operating diesel generator are very high operational costs and environmental pollution due to greenhouse gas emissions. Suriname has significant solar energy potential with solar irradiation rate of 5 kWh/m^2 per day. The aim of this research is to design a hybrid power plant consisting of existing diesel generator and photovoltaic (PV) with the main objective of reducing greenhouse gas emissions and production costs due to the use of fossil fuels.

Newmont Suriname gold mine is located in Langatabbetje, Sipaliwini District, approximately 66 km south of Moengo District, Suriname. GPS coordinates of Langatabbetje is 5°11'09" N and 54°55'17" W. The potential of solar energy at the mine site is shown in Figure 1. Newmont Suriname processing plant is currently supplied by diesel generators with total installed capacity of 61.11 MW and a total net capacity of 52.78 MW. There are 7 units of diesel generator with each capacity of 8.73 MW (7.54 MW net capacity). The main load at the processing plant is in the form of electric motors which are used for mill, crusher, pump, conveyor, blower and agitator applications. The amount of load on the processing plant is determined by the level of production and the type of ore being processed. The higher level of production or the harder type of ore being processed, the more electricity consumption. Therefore processing plant does not have a specific pattern of daily, weekly or monthly peak load. The daily load curve for May 24 2022 to May 31 2022 period is shown in Figure 2. Historical load data for the 2019-2022 period can be seen in Table 1. The load profile that will be used for the simulation is obtained from load measurement data from March 2022 to March 2023 with 1 minute sampling interval. The raw data is then converted to comma separated values (CSV) data with a two-column format as load input to HOMER software.

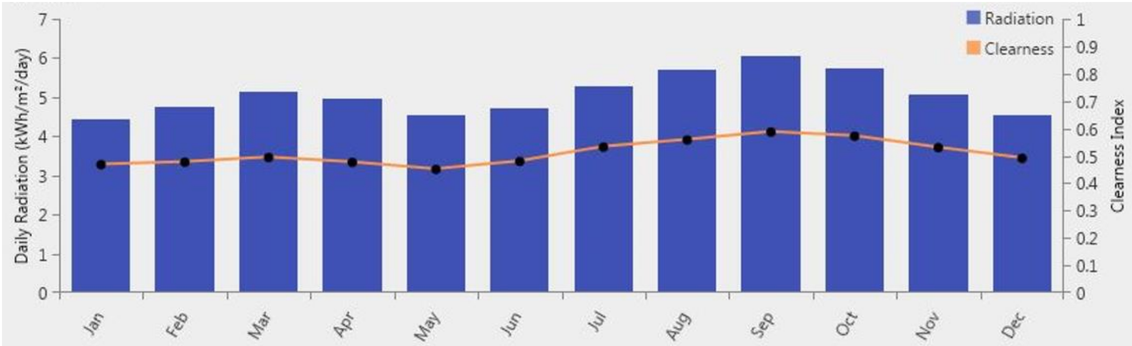

Figure 1. Daily irradiation rate

Table 1. Historical load data 2019-2022

Year	Energy Consumption (MWh)	Peak Load (MW)
2019	146.031	30,3
2020	145.077	32,5
2021	172.351	33,3
2022	169.131	34,3

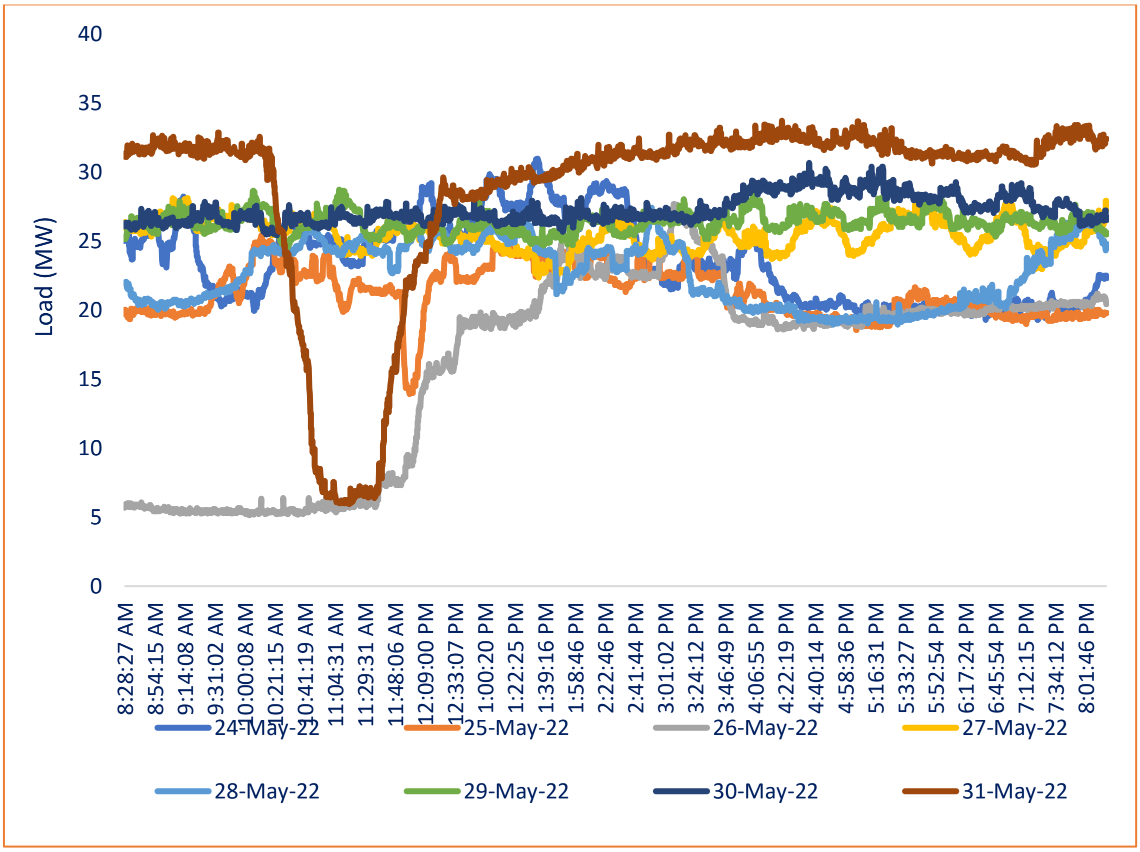

Figure 2. Daily load curve

2. Methods

The research methodology is divided into two stages, which are planning the most optimal hybrid power plant using HOMER software and evaluating the power quality of the selected power plants using ETAP software. The hybrid power system design consists of the existing diesel generator and PV. HOMER software is used to determine the most optimal hybrid system configuration based on Net Present Cost (NPC) values. Then ETAP software validate the power quality of the selected hybrid system configuration through load flow and short-circuit analysis. Load flow analysis aims to ensure that the voltage is within the limits allowed according to IEEE-1587-2018 standard. Short-circuit analysis was carried out to examine the effect of PV integration to short circuit current level because in general PV connected to distribution networks do not contribute significantly to short-circuit current in case disturbance occurs in the system. This is so because the short-circuit current of the PV array is determined by the inverter used and ranges from 110-120% of the inverter rated maximum output current. The reduced short-circuit current level due to PV integration may also cause a loss of sensitivity for protection devices to detect disturbances.

HOMER is software used for modeling, planning and optimization of hybrid power systems. HOMER stands for Hybrid Optimization of Multiple Electric Renewables. Both hybrid power system components, diesel generator and PV, are simulated to obtain the most optimal configuration. The configuration with the most economical result based on Net Present Cost (NPC) will be selected. The simulation is carried out with two scenarios, current condition and the proposed hybrid system. Simulations with current conditions aim to find the base, as a comparison for Cost of Electricity (COE) and emission level reduction. The sensitivity variable used in both simulations is the price of Heavy Fuel Oil (HFO) with a range of 0.1 $/kg to 1.2 $/kg according to the price within last ten years. Figure 3 shows existing architecture and Figure 4 is the proposed hybrid system architecture. Table 2 shows comparison of the cost parameters of the hybrid power system components.

Tabel 2. Cost parameters of the hybrid power pystem

Cost	8,7 MW Diesel Generator	Photovoltaic (PV)
Initial	$0	$940.000/MW
Replacement	$7.400.000/unit	$940.000/MW
O&M	$75/op hour	$14.000/MW/year
Life Time	200.000 hours	25 years

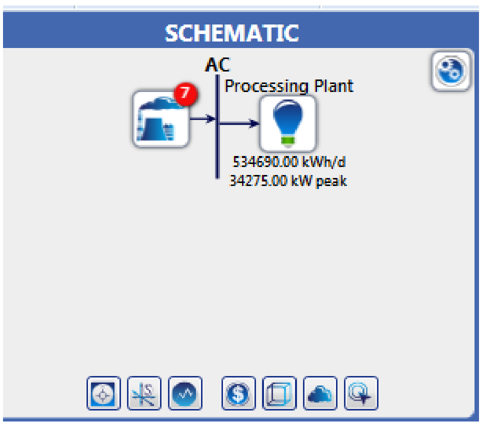

Figure 3. Existing Architecture

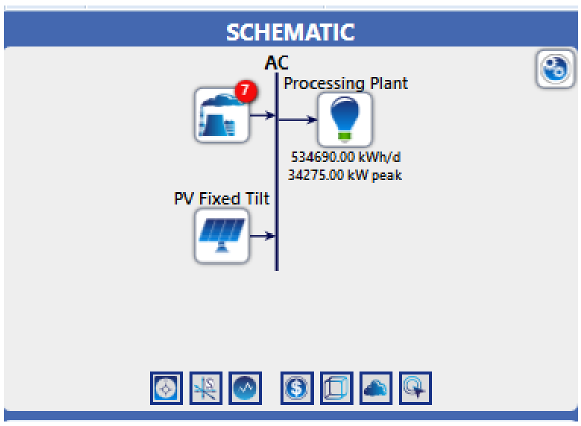

Figure 4. Hybrid System Architecture

3. Results and discussion

The optimization results show that the hybrid system consisting of diesel generator and 30 MW

PV is the most optimal configuration. COE and NPC values comparison between diesel generator and hybrid power system with current HFO price of $0.7/kg is shown in Table 3. Existing COE $17.1 cent/kWh will decrease to $16.3 cent/kWh with 30 MW PV penetration or equivalent to 16.9 percent of the renewable fraction and CO_2 emission levels will decrease from 142.682 tons/year to 123.852 tons/year.

Tabel 3. Simulation result

Parameter	Existing	Hybrid	Hybrid	Hybrid
PV Capacity (MW)	0	20	30	40
COE (cent$/kWh)	17.1	16.5	16.3	16.4
NPC (M $)	432.6	415.1	412.3	414.4
Initial Cost (M $)	0	18.8	28.3	37.7
Renewable Fraction (%)	0	12.5	16.9	19.6
CO2 Emission (k tons/year)	142.7	128.7	123.6	120.7

HOMER software produces an economically optimal design. For this reason, it is necessary to perform power analysis to ensure that the design previously obtained is technically feasible. This validation focuses on the effect of PV penetration on the voltage level and short-circuit current. The steps taken in the power quality assessment process are reassembling the configuration of existing power system and then selecting the capacity and specifications of selected PV and connecting it to existing power system, then carrying out simulations and measurements. The ETAP model used for the simulation is shown in Figure 5.

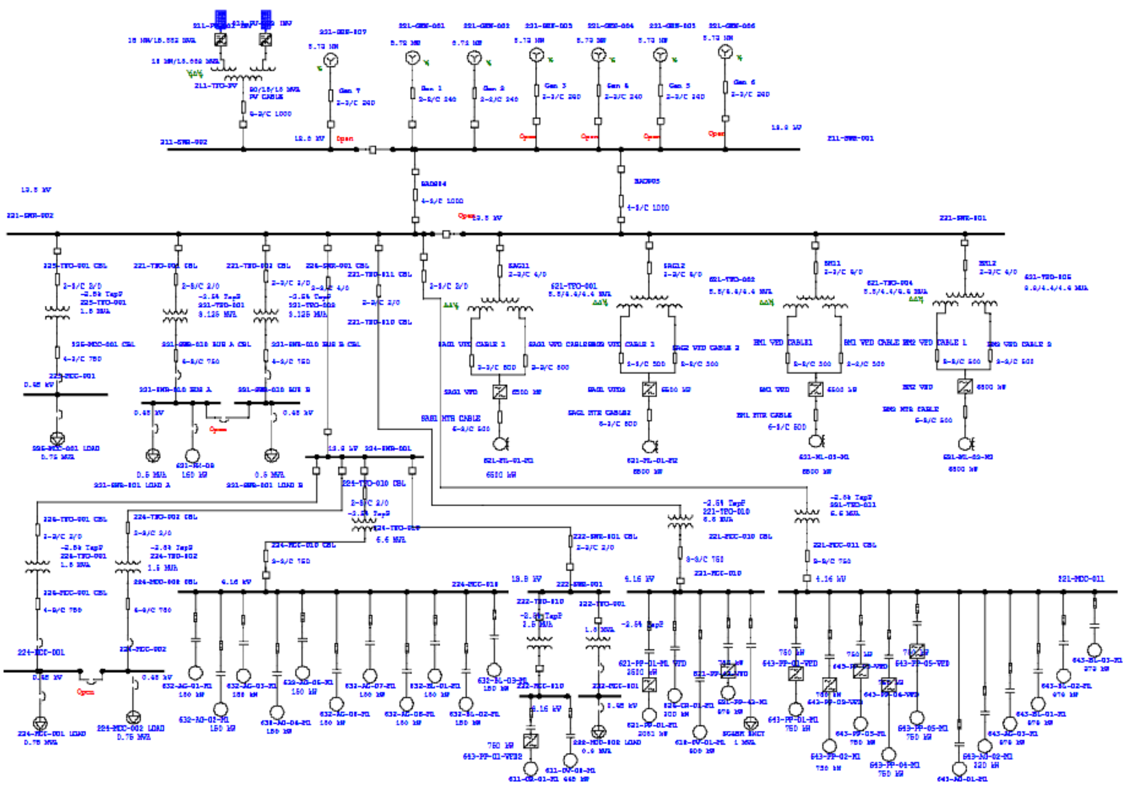

Figure 5. ETAP model

From HOMER simulation results, it is obtained that PV maximum output is 23 MW based on the level of irradiation at the mine site and PV capacity. Load flow analysis on ETAP was carried out with PV output 20 MW at 22 MW and 34 MW load and PV output 5MW when the system is operating with PV only. Table 4 shows that all bus voltage levels in each generation scenario are still within limits according to IEEE-1587-2018 standard.

The more percentage of PV penetration, the more it will affect the short-circuit current level in the system. The short-circuit current characteristics of renewable energy sources such as PV are different from those of synchronous generators when a fault occurs. The response of renewable energybased generators to short-circuit conditions is determined by the installed inverter. PV do not contribute significantly to the total short-circuit current in the system when a disturbance occurs. This is because PV array short-circuit current is only 10-20% more than the rated maximum output current at most, inverters are normally equipped with under voltage relays and over-current limiter in case of disturbances. In general, the decrease of short- circuit current level after PV penetration is shown in Table 5.

Table 4. Bus Voltage Level (kV)

Bus	Nominal Voltage	34 MW Load		22 MW Load		5 MW Load	
		5 DG	1 DG PV	4 DG	1 DG PV	1 DG	PV
211-SWR-001	13.8 kV	13.799	13.799	13.799	13.799	13.796	13.736
221-MCC-010	4.16 kV	4.212	4.212	4.212	4.219	4.211	4.230
221-SWR-001	13.8 kV	13.796	13.795	13.796	13.796	13.793	13.736
222-MCC-001	0.48 kV	0.489	0.489	0.489	0.489	0.488	0.486
222-MCC-010	4.16 kV	4.224	4.224	4.224	4.229	4.223	4.231
225-MCC-001	0.48 kV	0.482	0.482	0.482	0.483	0.482	0.480

The decrease in short-circuit current level also has an impact on the sensitivity of the protection devices. The protection system may not work because the value of the short circuit current that occurs during a fault is less than the existing relay setting. For example, in conditions when the system operates with PV only at load of around 5MW, the short circuit current on 221-SWR-001 is 3,618 kA (3-phase), 0,207 kA(L-G), 2,093 kA (L-L), 2,183 kA (L-L-G). BAO905 outgoing feeder relay setting from the power plant to the processing plant is 2,677 kA - IEC Normal Inverse - Time Dial 0.15.

Table 5. Short circuit current (kA)

Bus	System kV	Beban 34 MW		Beban 22 MW		7 DG PV
		5 DG	1 DG PV	4 DG	1 DG PV	
211-SWR-001	13.8 kV	15.615	10.617	13.458	8.494	21.334
221-MCC-010	4.16 kV	13.884	12.729	13.363	11.913	14.916
221-MCC-011	4.16 kV	14.631	13.453	14.099	12.614	15.683
222-MCC-001	0.48 kV	32.956	31.902	32.565	31.414	33.533
222-MCC-010	4.16 kV	6.465	6.161	6.350	5.957	6.632
225-MCC-001	0.48 kV	32.605	31.740	32.267	31.266	33.160

The results of 3-phase device duty with 7 diesel generators and PV scenario show that the maximum short circuit current is still below the switchgear capacity rating. The device duty results for the main switchgear of Power Plant (211-SWR-001/002) is shown in Table 6.

Table 6. Device Duty Bus 211-SWR-001 and 211-SWR-002

Bus		**Device**		**Device Capacity (kA)**				**Short-Circuit Current (kA)**					
ID	kV	ID	Type	Peak	Ib sym	Ib	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
211-SWR-001	13,8	211-SWR-001	Swgr	100				18,7	47,8				8,1
	13,8	Gen 1	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Gen 2	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Gen 3	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Gen 4	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Gen 5	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Gen 6	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	905	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	906	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Tie	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
211-SWR-002	13,8	211-SWR-001	Swgr	100				18,7	47,8				8,1
	13,8	Gen 7	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	PV	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1
	13,8	Tie	CB	100	40	48	27	18,7	47,8	16,1	22,8	16,2	8,1

Based on the results of optimization and technical validation of 30 MW PV penetration, it is proven that it will reduce operational costs, which is indicated by a decrease in Cost of Electricity (COE) and also play a role in reducing environmental pollution by reducing CO2 emission levels. Technically PV penetration is feasible to implement because the voltage level remains within the limits according to IEEE-1547-2018 standard and the maximum short-circuit current does not exceed the capacity of the installed switchgear. However, a decrease in the short circuit current level may result in a loss of sensitivity of the protective device. Therefore it is necessary to carry out a comprehensive protection coordination study prior to implementing hybrid power system to ensure that the protection equipment works in a system configuration where the short circuit current is at the lowest level.

4. Conclusion

The results show that the most optimal PV capacity is 30 MW. PV penetration reduces Cost of Electricity (COE) from $ 17.1 cent/kWh to $16.3 cent/kWh and CO2 emissions from 142,682 tons/year to 123,852 tons/year. PV penetration has been validated and the results of load flow analysis show that the voltage level is still within the permissible limits according to the IEEE-1547-2018 standard. The results of the short circuit analysis show that the PV penetration with the maximum configuration does not exceed the capacity of the installed switchgear and motor control center so that this penetration can be carried out without increasing the installed capacity.

References

A. Raghoebarsing, C.Gercek, A. Reinders. (2020). Public Survey Regarding the user acceptance of photovoltaic (PV) systems in Suriname, 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), 217-220. https://doi.org/10.1109/PVSC45281.2020.9300730

R.R. Medam, K. Kavitha, T. Chandrashekar. (2021). Techno-Economic Analysis of Hybrid Renewable Energy based Community Microgrid, IEEE Mysore Sub Section International Conference, 346-351. https://doi.org/10.1109/MYSURUCON52639.2021.9641673

N. Mourad, B. Mohamed. (2015). Short Circuit Current Contribution of Distributed Photovoltaic Integration on Radial Distribution Networks, 4th International Conference on Electrical Engineering (ICEE), 1-4. https://doi.org/10.1109/INTEE.2015.7416821

G. Missrani, N. Nabila, F.H. Jufri, D.R. Aryani, A.R. Utomo. (2019). Study on Short Circuit Current Contribution after Photovoltaic Solar Plant Integration in Lombok's Distribution Network, IEEE International Conference on Innovative Research and Development (ICIRD), 1-5. https://doi.org/10.1109/ICIRD47319.2019.9074685

J.H. Saad, P.G.Pranta, A.Anwar. (2022). Analysis of Protection Device Sensitivity in a Facility-Power System Due to Integration of Onsite Renewable Energy Sources, IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), 1-6. https://doi.org/10.1109/PESGRE52268.2022.9715749