Review Paper:

Performance analysis of a 50 MW grid-connected solar PV system for sustainable mining operations

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Abstract

The strategic use of renewable resources has become essential for guaranteeing energy security in response to rising energy demands. Mining operations require creative solutions to provide steady energy delivery because of their high energy needs and dependence on continuous power. A technically sound and financially advantageous option for extensive energy integration in these industries is grid-connected photovoltaic (PV) system. The performance of 50 MW grid-connected solar PV power plant in Peddapalli, a major mining hub with ideal solar conditions, is assessed in this study.

With an average yearly temperature of 27.3°C and a mean solar insolation of 4.97 kWh/m^2, the plant uses a seasonal tilt approach to maximize solar energy capture. A quarterly energy yield of 15,798.192 MWh, a capacity utilization factor (CUF) of 17.68% and a performance ratio (PR) of 86.12% are examples of key performance measures. By successfully integrating solar PV technology into mining operations, operational expenses and carbon emissions are decreased while issues with energy stability are resolved. This study provides helpful insights for utilizing renewable energy in energy-intensive businesses by highlighting the necessity of robust architecture, stable buildings and efficient energy management to maintain a consistent power supply.

Keywords: Mining operations, Sustainability, Photovoltaic, Power Output.

Introduction

In the last decade, the significance of renewable energy has surged, driven by the escalating energy demands of developing nations. Solar energy has emerged as a flexible and cost-effective resource for various uses with its modular, scalable design. The depletion of conventional energy sources has sparked more research into renewable energy, with solar energy emerging as a critical component of these initiatives.

India is a world leader in solar energy potential due to its strategic location, which receives almost 3,000 hours of sunshine annually[2]. Coal and lignite mining businesses are intent on boosting renewables to reduce mining's carbon footprints and moving closer to the goal of net carbon emission. Coal firms are pursuing both ground-mounted and roof-mounted solar installations.

In several of the former mining regions, it has been planned to build solar parks. As of 31.03.2022, coal/lignite PSUs had constructed 51 MW of windmills and solar arrays with a combined capacity of about 1598 MW. Over the following five years, 5560 MW of renewable energy will be installed. Coal India Limited (CIL) has developed solar power plants with a combined capacity of 8.9 MW including 2 MW of ground-mounted solar installations[9]. The fossil fuel producer Coal India has pledged to be a Net Zero Energy Company and is implementing a 3 GW solar power program by 2023–2024. Building solar power facilities in Port Blair and South Andaman, combined with an 8 MWhr battery energy storage system (BESS), to balance out solar electricity export to the grid, is one of NLCIL's noteworthy renewable energy projects.

This project will allow solar energy to supply Port Blair's and South Andaman's peak daytime energy needs. Due to this project, we will get lower annual diesel usage and lower carbon emissions. NLCIL Wind Mills with a capacity of 51 MW, is located in the Tirunelveli district, Tamilnadu. On August 29, 2014, the first wind turbine generator was put into service. As of July 2015, 31 wind turbine generators had been installed. In keeping with Atmanirbhar Bharat's objectives, to strengthen the local supply chain and ensure the availability of solar panels, Coal India Limited is constructing a wafer manufacturing facility[1].

Mining with renewable energy: A win-win strategy for sustainability: The demand for mining products in India will increase swiftly due to the country's strong economic growth. For "Make in India" to flourish, the mining industry needs to grow in order to meet consumption while also supporting the growth of related sectors such as manufacturing and infrastructure. Mine operating costs have emerged as a top concern for mining companies aiming to boost competitiveness. In the Indian mining industry, energy expenses account for at least 10% of total production costs, according to studies on energy efficiency in the mining sector released by the Central Institute of Mining and Fuel Studies (CIMFR).

For miners, using renewable energy systems at operating mines has become a means to lower energy costs, to protect against volatile fuel prices and to limit the risk of power outages caused by inconsistent grid supplies. Renewable

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energy options concurrently address issues with fuel pricing, logistics and emissions as Governments and mining businesses come under growing pressure to adopt sustainability[7].

The contribution of Singareni Collieries to renewable energy-based sustainable development: The Government of Telangana and The Singareni Collieries Firm Limited (SCCL) jointly own this Government coal mining firm on a 51:49 equity basis. SCCL's primary business is coal mining. The company has entered the power generation industry as part of its diversification efforts and is running a 2*600 MW Thermal power plant near Jaipur. SCCL is dedicated to playing a prominent role in fostering the nation's industrial and economic growth while fostering a cleaner and safer environment for the country. SCCL has the vision to be an active player in India's developing solar sector by utilizing the rich treasure of alternate energy prevalent in the nation. Singareni Collieries Company Ltd (SCCL) has expanded its overall capacity for solar power generation to 224 MW over nine locations with the commissioning of its first floating solar power plant with a 5 MW capacity[8].

Review of Literature

Many factors are usually applicable to assess a PV plant's performance. Some are reference yield, performance ratio, final PV system yield and PV for utility-scale applications. Every day, a PV plant faces numerous challenges[7]. The challenge of consistently collecting sunlight and turning it into electricity is a significant issue with photovoltaic systems. Temperature, wind speed, humidity, dust deposition and other local climatic factors affect how much power the PV modules produce. Geographical factors such as latitude, longitude, declination and azimuth angles majorly impact electricity generation in photovoltaic plants. PV power output is generally reduced by temperature increases and dust collection on PV modules.

Energy capture is greatly enhanced by the seasonal tilt of solar PV panels, particularly in areas with large fluctuations in sun irradiation. Real-time monitoring and tilt angles are advantageous for PV systems. Capacity utilization factors (CUF) and performance ratios (PR) are frequently reported as primary metrics in studies on plants of similar sizes (e.g. 25–50 MW), with PR average close to 80% under ideal conditions and CUF typically around 15–18%[5]. These metrics are helpful standards for evaluating the dependability and efficiency of systems.

The following goals guide this work's performance evaluation of a 50 MWp grid-connected solar photovoltaic power plant.

• To examine the performance of PV plant output using the SCADA data system under observation: Using data from August 2024 to October 2024, this assessment is based on normalized characteristics including reference yield, final yield, array yield, PV module efficiency, inverter efficiency, system efficiency, performance ratio and capacity factor. The impact of temperature, dust and shading losses on PV plant efficiency under different seasonal conditions is also taken into consideration.

The solar PV grid connected plants

A grid-connected photovoltaic (PV) system is composed of several key components including solar panels, inverters, power conditioning units and equipment for interfacing with the electrical grid. Unlike stand-alone PV systems, which rely on battery storage to supply power when solar generation is low, grid-connected systems benefit from a continuous power supply by drawing from the grid when necessary and feeding excess generation back to it when solar production exceeds local demand. This design significantly enhances the system's efficiency, as energy storage losses associated with batteries are eliminated, maximizing the utility of generated solar energy[3].

When environmental conditions are optimal and the PV system generates more electricity than the connected load requires, surplus energy is transmitted to the grid. This process, often governed by policies like net metering or feed-in tariffs, supports grid stability and can offer financial incentives to system owners, reducing payback time on their initial investment. However, in off-grid or stand-alone systems, energy storage is essential for ensuring reliable power supply during periods of low sunlight. Batteries are employed to store energy produced during sunny periods, making it available during peak demand or nighttime.

This setup, though versatile, typically incurs energy losses due to battery inefficiencies, lowering the net available power for consumption connected PV systems, therefore, it is widely favored for urban and large-scale applications where grid reliability is strong, while stand-alone systems are more suitable for remote or isolated locations where grid access is unavailable[4]. In order to provide a steady and consistent power supply necessary for coal extraction operations, the energy produced by this 50 MW solar PV facility is primarily used to power neighboring mining operations. By sustaining ongoing mining operations and lowering operating expenses, this dependable energy source helps to boost coal production. Additionally, the use of solar energy demonstrates SCCL company's commitment in reducing carbon footprints by reducing its reliance on conventional fossil fuels. Installing solar power plants near mines promotes environmentally responsible mining practices, increases energy efficiency and aligns with sustainable development goals[6].

The site's geographic location: The SCCL 50 MW solar power facility is situated at an elevation of 169 meters, with latitudes 18.655 N and longitudes 79.534 E. Since the power produced by a solar plant is entirely dependent on the sun's insolation, the Singareni solar power plant is situated in a suitable geographic location that allows to absorb more solar radiation throughout the year.

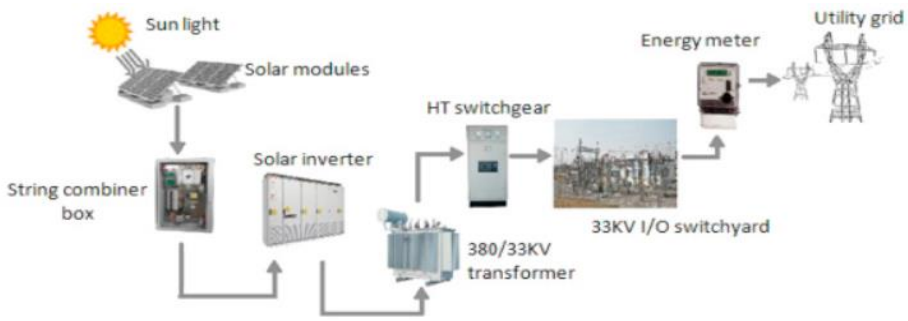

Fig. 1: Schematic diagram of SCCL 50 MW Solar PV

Fig. 2: Google image of SCCL 50 MW solar PV plant

Table 1
Solar Panel Specifications

Cell Technology	**Poly**
Voltage ($V_{OC.}$)	46.20 V
Current ($I_{SC.}$)	9.23 A
Maximum Power Voltage (V_{mp})	37.80 V
Maximum Power Current (I_{mp})	8.73 A
Maximum Power	330 W
Operating Temperature	-40 ^{O}C to 85 ^{0}C
Dimensions	1956 (L) × 992 (w) × 40 (T) mm

Solar pv plant layout: The 50 MW grid-connected solar photovoltaic (SPV) plant spans an area of approximately 250 acres and comprises of a total of 166,680 solar modules. Each module is equipped with 72 cells, with each cell capable of generating 4.5 watts of power. Collectively, the plant is configured with 4,167 strings, each consisting of 40 modules. In this 50 MW grid-connected SPV plant, the system architecture is designed to optimize power generation and efficient grid integration. Each inverter control room is connected to 7 string main boxes, which manage the inputs from the solar PV arrays. Each inverter control room houses 4 inverters and there are 10 such inverter rooms distributed across the plant.

For voltage transformation, two inverters from each control room are connected to one transformer, resulting in 40 inverters collectively linked to 20 transformers. The outputs from these 20 transformers are consolidated and directed to a 33 kV bus bar, which serves as the primary connection point for transmitting the generated power to the utility grid. This configuration ensures that generated solar power is efficiently conditioned and transformed for grid compatibility, with minimized energy losses and robust system reliability. Power is drawn from the grid to meet internal power needs on nights when there is no solar radiation to generate electricity. Lighting, initial battery starting and control room gadgets all use the electricity.

Tool for evaluating the PV system's performance: In this study, the performance of a grid-connected solar photovoltaic power plant is examined by manually extracting power generating parameters using a SCADA system. The cumulative exported energy for the financial year 2024-25(collected till 31st October, 2024) is approximately 36660 MW. The plant is running with a performance ratio (PR) of 78% and capacity utilization factor (CUF) of 20%.

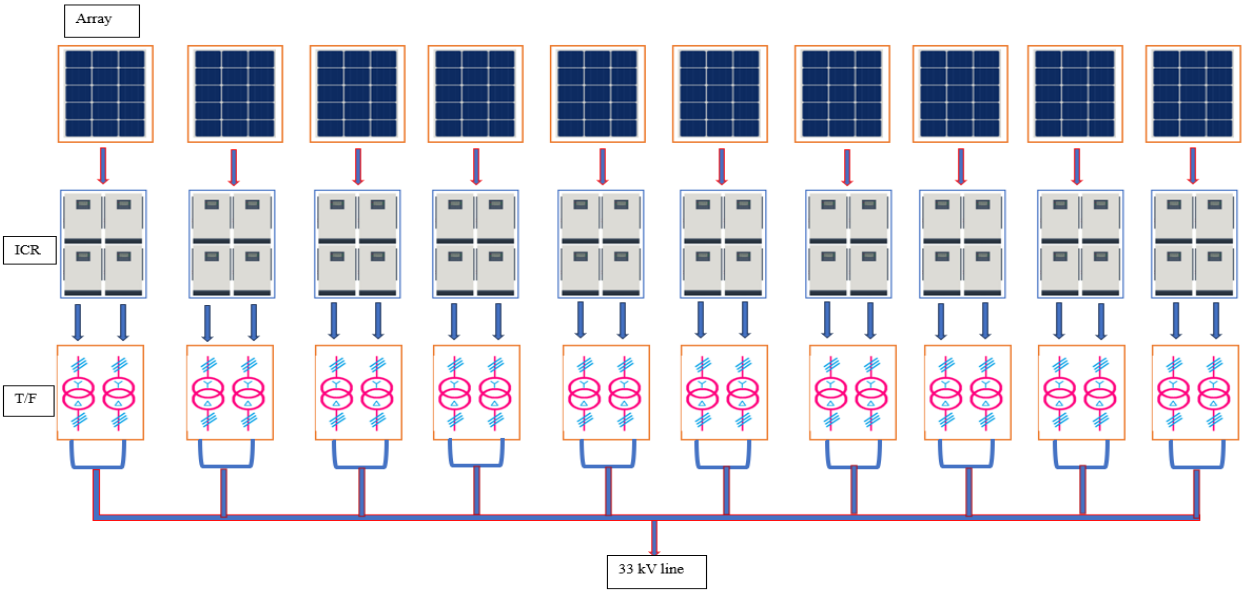

Fig. 3: Solar PV plant layout

Fig. 4: Mounted Solar panels structure at site location

Table 2
Inverter Specification

Maximum input power	**1417 kW**
V_{max} PV: DC	1000 V
I_{sc} PV: DC	4200 A
Maximum input current: DC	2576 A
Rated output power	1250 kW
Rated network voltage (3 phase, AC)	380 V
Rated output current (AC)	1899 A
Rated network frequency	50 Hz
Power factor	-0.8 to + 0.8
size	2400 × 700 × 2150 mm

Table 3
Transformer Specification

Rating		**2500 KVA**
Voltage at No- Load		
High voltage (HV)	**33000 V**	
Low voltage (LV_1)	**380 V**	
Low voltage (LV_2)	**380 V**	
Rated Current		
High voltage (HV)	**43.74 A**	
Low voltage (LV_1)	**1899.23 A**	
Low voltage (LV_2)	**1899.23 A**	
Phases		**3**
Frequency		**50 Hz**

Table 4
Performance Analysis of Grid connected Solar PV from August-2024 to October-2024

Month	Gross Generation (MWH)	Exported Units (MWH)	PoA in. kWH/ Sq.mtr	GHI in. kWH/ Sq.mtr	PR (%)	CUF (%)
Aug-24	5287.41	5003.71	4.6	4.66	69.37	14.09
Sep-24	5816.343	5506.157	4.98	5	57.7	14.355
Oct-24	5576.914	5377.198	5.6	5.4	60	14.80
Cuml FY-2024-25		36,660			78	20.00

Conclusion

This study presented a performance evaluation of a 50 MW grid-connected solar photovoltaic power plant installed in Peddapalli, monitored over three months. The results demonstrate that the plant operates with solid performance metrics, achieving a high-performance ratio (PR) and capacity utilization factor (CUF). The system has shown exceptional reliability, with an availability rate close to 99%, ensuring consistent energy supply to the grid, which shows that the mines are operating with continuous power supply without any interruption.

On the other hand, it increases the production of coal, which increases SCCL company production and boosts its revenue. The large-scale solar installations by the Singareni Collieries Company Limited (SCCL) are driven by strategic goals to support sustainable energy needs, to reduce environmental impact and to enhance energy security. The key benefits realized by SCCL through this solar initiative include:

- **Reducing Carbon Footprint**: Solar energy generation produces no greenhouse gases or air pollutants during operation, making it an environmentally friendly alternative to fossil fuels.
- **Sustainable Energy Supply**: Solar power contributes to meeting energy demand in a manner that aligns with ecological preservation, supporting the transition towards sustainable power generation.
- **Enhanced Energy Security**: Solar energy diversifies the energy supply, reinforcing grid stability and reducing dependence on non-renewable energy sources.

These findings underscore the potential for large-scale solar PV plants to play a vital role in achieving both environmental and energy security objectives, showcasing the viability of solar as a cornerstone of future energy strategies.

References

1. Bano S. and Soni D.S., A Study on Financial Performance of Coal India Limited (CIL), Digit. Living Redefining Cult. with Technol. Ind. Educ. Soc. Entrep., 148–165 **(2024)**

2. Bojja S.K., Kunar B.M. and Murthy C.S.N., Bifacial solar pv systems : a sustainable solution for energy, 2024 IEEE 4th Int. Conf. Sustain. Energy Futur. Electr. Transp., 1–6 **(2024)**

3. Darteh O.F., Wang G., Liu Q., Liu X. and Acakpovi A., Enhancing Grid-Connected PV System Performance: Loss Analysis and Efficiency Improvement Strategies, Proc. - 2023 IEEE 23rd Int. Conf. Softw. Qual. Reliab. Secur. Companion, QRS-C 2023, 668–674 **(2023)**

4. Kumar B.S., Kunar B.M. and Murthy C.S.N., Performance Evaluation and Machine Learning Analysis of 3 kW Grid-Connected Bifacial Solar Photovoltaic Systems, *J. Inst. Eng. Ser. B*, Doi: 10.1007/s40031-025-01204-5 **(2025)**

5. Narasimman K., Gopalan V., Bakthavatsalam A.K., Elumalai P.V., Iqbal Shajahan M. and Joe Michael J., Modelling and real time performance evaluation of a 5 MW grid-connected solar

photovoltaic plant using different artificial neural networks, *Energy Convers. Manag.*, **279**, 116767 **(2023)**

6. Rouholamini M., Chen L. and Wang C., Modeling, Configuration and Grid Integration Analysis of Bifacial PV Arrays, *IEEE Trans. Sustain. Energy*, **12(2)**, 1242–1255 **(2021)**

7. Shafiullah M., Ahmed S.D. and Al-Sulaiman F.A., Grid Integration Challenges and Solution Strategies for Solar PV Systems: A Review, *IEEE Access*, **10**, 52233–52257 **(2022)**

8. Suresh Chandra Ch., Evaluation of Sustainability of Singareni Collieries Company Limited using Triple Bottom Line Approach, Test Eng. Manag., 5770-5776 **(2020)**

9. Transition J. and Paper W., Just transition working paper series, Singh Mudit Kumar and Swarnakar Pradip **(2023)**

10. https://scclmines.com/scclnew/index.asp#x.

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