OVERVIEW OF NAGARJUNA SAGAR HYDRO POWER PLANT AND ANALYSIS OF GENERATORS

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Abstract:

Nagarjuna Sagar Hydropower Plant, located on the Krishna River in Telangana, India. As one of the country's major multipurpose infrastructure projects, the plant serves both power generation and water management needs, including irrigation and drinking water supply. The facility is equipped with multiple large-scale hydroelectric units and a substantial reservoir, contributing significantly to regional energy and resource sustainability.

This paper presents a comprehensive performance analysis of the plant's salient pole synchronous generators under two modes of operation: generating and pumping. In generating mode, the plant operates with high efficiency converting potential energy from stored water into electricity during peak demand periods. In pumping mode, which operates as electrical energy is used to pump water back to the reservoir during off-peak hours, enhancing storage and load balancing. Key parameters such as efficiency, and voltage regulation.

Keywords: *Hydroelectric Power, Nagarjuna Sagar, Synchronous Generators, Pumped Storage, Generator Efficiency, Electrical Power Systems.*

1. INTRODUCTION

The Nagarjuna Sagar Hydroelectric Power Plant (NSHES), built across the Krishna River between 1955 and 1967, is one of India's earliest and most significant multipurpose infrastructure projects. It serves irrigation, power generation, and water supply needs across Telangana and Andhra Pradesh. The dam forms one of the country's largest reservoirs, with a storage capacity exceeding 11,000 million cubic meters. The hydro station has a total capacity of 815.6 MW, including one 110 MW conventional unit and seven reversible 100.8 MW pump-turbine units, enabling both generation and pumped storage. It also includes Right and Left Canal Power Houses (90 MW and 60 MW, respectively). The plant is equipped with salient-pole synchronous generators, Francis and Kaplan turbines, advanced SCADA control, and protection systems.

Natarajan Sivakumar, Devadutta Das, Narayana Prasad Padhy, A.R. Senthil Kumar, and Nibedita Bisoyi (2013) discussed the role of pumped hydro-storage (PHS) as a flexible energy storage solution for India's growing power demand. They identified challenges such as limited off-peak power availability and lack of infrastructure but noted increasing state-level interest and government efforts to introduce dedicated tariffs and support new PHS projects[1]

Rajesh Madhu Krishna Mohan Ganta, Rehana Shaik, and C.T. Dhanya (2011) conducted a climate-based case study on the Nagarjuna Sagar Dam using hydrological modeling and CORDEX projections. Their study showed that reduced rainfall between 1980–2011 led to lower reservoir inflows and diminished environmental flows downstream. While future rainfall is expected to decline less sharply, the study emphasizes the importance of integrating climate-driven flow changes into water resource planning and ecological protection strategies[2].

Annisa Al Hasna Kurnial and Muhammad Sahal (2019) conducted a comparative study on generator efficiency between large-scale and micro-hydro power plants. Their analysis showed that the Wonogiri Hydroelectric Plant achieved higher efficiency (up to 92.85%) under optimal load, while the Parakandowo Micro-Hydro Plant averaged 65.33% efficiency, mainly due to reduced water discharge. The study emphasizes that generator efficiency is strongly influenced by plant scale and environmental conditions[3].

This paper presents a technical overview and analysis of NSHES generators, covering their construction, performance in both operating modes, and efficiency based on SCADA data. It also outlines future improvements through predictive maintenance and digital monitoring to enhance long-term reliability

2. OVER VIEW OF NSHES

Fig.1 Overview of NSHES

NSHES located on the Krishna River in Telangana, is one of India's largest and oldest hydroelectric power stations. Operated by TGGENCO, NSHES has a total installed capacity. 816 MW, comprising eight generating units—seven rated at 100.8 MW and one at 110 MW. These units utilize vertical Francis turbines coupled with synchronous generators, and are fed by penstocks embedded in the dam structure.

The power generated is stepped up via transformers and integrated into the Southern Grid. In addition to electricity generation, NSHES also serves critical roles in irrigation, flood control, and drinking water supply, supported by the Left (Lal Bahadur) and Right (Jawahar) Bank Canal systems. The reservoir has a gross storage capacity of over 11.5 billion cubic meters, making it vital for both energy production and agricultural support.

2.1 RIGHT CANAL HYDRO ELECTRIC SCHEME (JAWAHAR CANAL)

The Right Canal Power House, named after Jawaharlal Nehru, has an installed capacity of 90 MW (3 × 30 MW units). It utilizes a peak discharge of 11,680 cusecs with a gross head of up to 86 ft, delivering around 220 million units annually. The units were commissioned between 1983 and 1990, with turbines from Boving, England and generators from GE, England.

Technical Specs:

- Turbines: Kaplan, Vertical, 150 rpm, 33.7 MW max output
- Generators**:** Salient Pole, 11 kV, 30 MW rated, 39.65 MVA max output, SCR: 1.45

2.2 LEFT CANAL HYDRO ELECTRIC SCHEME (LAL BAHADUR CANAL)

The Left Canal Power House, named after Lal Bahadur Shastri, handles 11,500 cusecs of irrigation discharge with a gross head of up to 80 ft. It consists of 2 × 30 MW units, commissioned at a cost of ₹64 crores, generating power from irrigation releases.

Technical Specs:

- Turbines: Kaplan type, 2 units by Boving, 30 MW each
- Generators**:** Synchronous AC, 2 units by GE, 30 MW, 11 kV, 50 Hz

2.3 GENERAL LAYOUT OF NSHES

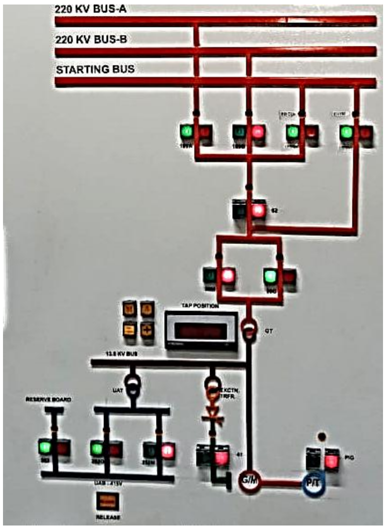

Fig.2 General layout of NSHES

The line diagram of the Nagarjuna Sagar Hydro Power Plant illustrates power flow from generators to the grid via 220 kV Bus-A and Bus-B, using circuit breakers and isolators for safe switching. A starting bus supplies auxiliary power during startup. In generating mode, water drives turbines to produce electricity, which is stepped up and transmitted. In pumping mode, power from the grid runs motor-generators in reverse to pump water back. A SCADA-based mimic panel enables real-time monitoring and control of plant operations.

2.4 NAGARJUNA SAGAR PUMPED STORAGE SCHEME

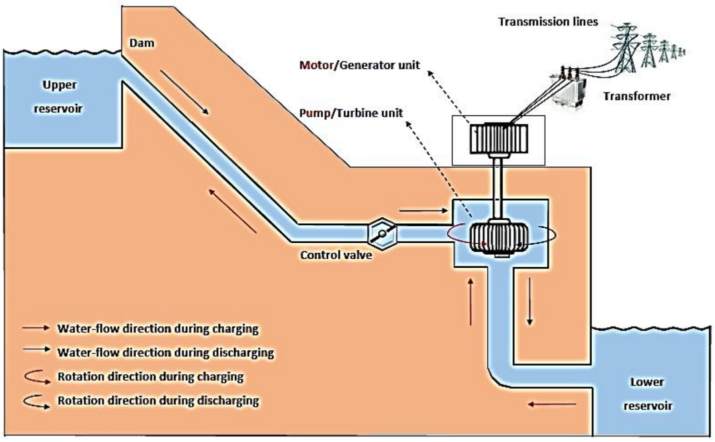

Fig.3 Layout of Pumped storage scheme

The Nagarjuna Sagar Main Power House (NSPH) has a total installed capacity of 815.16 MW, comprising one 110 MW generating unit and seven reversible pump-turbine units. The reversible units, supplied in two stages by Mitsubishi Electric (Japan), enable both generation and pumping modes. Eight penstocks (4.8 m dia) embedded in the dam's left bank feed the turbine units. BHEL supplied the first unit and supported excitation systems for others.

Pumped Storage Hydropower (PSH) works by moving water between two reservoirs. During low demand, water is pumped to the upper reservoir. When demand rises, it flows back through turbines to generate electricity. PSH enables energy reuse, long-duration storage, and grid flexibility—making it vital for integrating renewable energy into the power system

3.PARTS OF NSHES

3.1 DAM

A masonry gravity dam on the Krishna River with a height of 409 ft and a base width of 320 ft, used for water storage, irrigation, and power generation.

3.2 RESERVOIR

Stores up to 4.51 million acre-feet of live storage, with a full level of 594 ft, supporting irrigation and hydropower.

3.3 SPILLWAY

Equipped with 26 radial crest gates (45 ft × 44 ft), capable of handling excess floodwater across a 1545 ft span.

3.6 PENSTOCKS

Eight 16 ft diameter steel penstocks carry water to turbines for power generation.

3.7 POWER HOUSE

Open-air powerhouse with an installed capacity of 815.6 MW (1×110 MW + 7×100.8 MW), operational since 1978.

3.8 TURBINES

Francis vertical turbines with a total capacity of 815.6 MW, featuring reversible units for pumped storage.

3.9 GENERATORS

Eight synchronous generators (1×110 MW, 7×100.8 MW) by BHEL and Melco-Japan, working in both generation and pump modes.

3.11 CONTROL ROOM

SCADA-integrated, secure hub overseeing all powerhouses and dam operations, with real-time monitoring and emergency control.

3.12 TRANSFORMERS:

Step-up transformers convert 11–15.75 kV generator output to 132–400 kV for grid transmission. Built by BHEL.

3.13 SWITCHYARD

Connects plant output to the national grid, stepping up voltage and incorporating protection elements like breakers and CT/PT

4. GENERATORS AT NSHES

A generator in a hydropower plant is a machine that converts mechanical energy (from moving water) into electrical energy using the principles of electromagnetic induction.

4.1 WORKING PRINCIPLE

NSHES generators operate on Faraday's law of electromagnetic induction—when a conductor cuts magnetic flux, an EMF is induced. The EMF is proportional to the rate of change of flux, conductor length, and velocity:

$E = Blv \sin\theta$

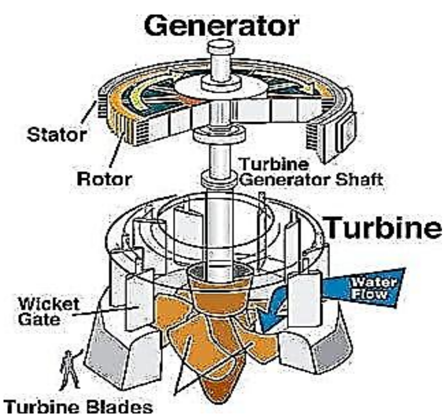

Fig 4 Internal view of Generator

4.2 CONSTRUCTION & OPERATION

Generators are vertical-axis synchronous machines with salient pole rotors, suited for low-speed, high-torque hydro turbines. The stator houses armature windings; the rotor carries field windings excited by DC supply. When water drives the Francis turbine, it rotates the rotor, inducing AC voltage in the stator.PMG (Permanent Magnet Generator) initiates excitation. The AVR regulates output voltage. Oil Lifting Pumps (OLP) lift the rotor on startup. The generated 11–13.8 kV output is stepped up to 220 kV and transmitted to the grid via busbars and transformers.

4.3 SAILENT POLE GENERATORS

These are low-speed, high-efficiency machines used in hydro plants. NSHES generators have 38 poles, DC-excited, and are grid-synchronized (50 Hz). Auxiliary parts include:

- Stator Core & Winding
- Rotor & Field Coils
- Brush Gear & Frames
- Coolers, Shaft, and Bearings

4.4 UNIT 1 GENERATOR

Unit 1 is a synchronous hydro generator manufactured by BHEL (1974), designed for low-speed, high-torque operation. It operates at 187.5 RPM (generation) and 375 RPM (pumping). The generator produces 11 kV, stepped up to 220 kV for grid transmission, with a power factor of 0.9.

Fig.5 Unit 1 Generator

Key Specifications:

- Capacity: 122 MVA
- Stator Voltage: 11 kV, Current: 429 A
- Rotor Voltage: 216 V, Current: 1214 A
- Frequency: 50 Hz, Rotation: Clockwise

4.5 UNIT 2-8 GENERATORS

Units 2–8, supplied by Mitsubishi Electric in 1982, are reversible pump-motor generators rated at 112 MVA. Operating at 13.8 kV and 158 RPM (generation) / 253 RPM (pumping), they support both modes efficiently. With a high flywheel effect (15,000 TM^2) and stator current of 4690 A, these units are ideal for pumped storage stability**.**

Fig.6 Unit 2-8 Generator

Key Specifications:

- Generator Capacity: 112 MVA, Motor: 106 MW
- Voltage: 13.8 kV, Current: 4690 A
- Rotor: 250 V, 1180 A
- Power Factor: 0.9 (Gen) / 0.95 (Motor)
- Frequency: 50 Hz, SCR: 1.0
- Manufacturer: Mitsubishi, Aug 1982

5. ANALYSIS OF GENERATORS

5.1 CASE STUDY 1 : GENERATING MODE

From the fig(7) unit 3 is in running condition in Generating mode

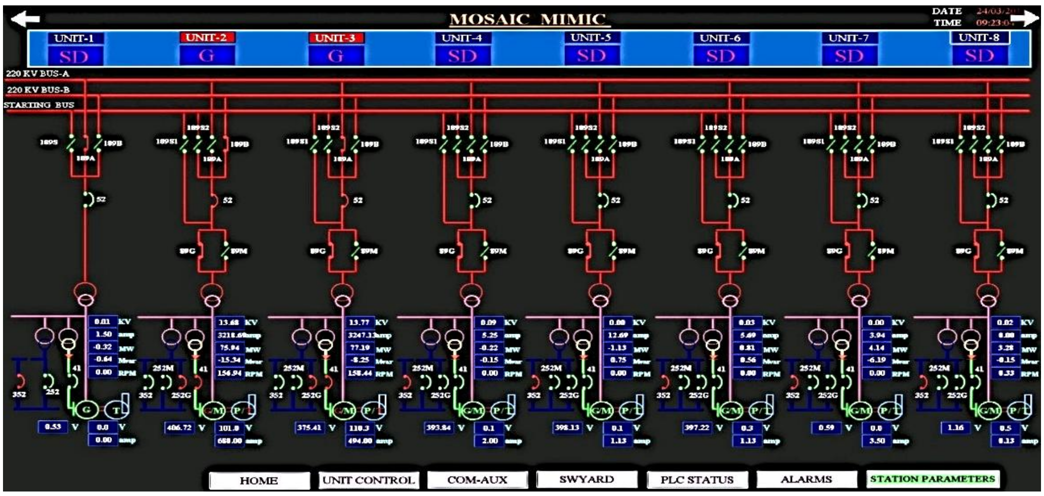

Fig 7 SCADA based monitor under generating mode

Unit 3 Performance Summary (Generating Mode):

- Output Power (Pout): 75.94 MW
- Input Power (Pin): 83.29 MW
- Copper Losses (Pcu): 6.32 MW
- Iron + Stray Losses: 1.12 MW
- Total Losses: 7.35 MW
- Efficiency: 91.16%
- Voltage Regulation: 1.44% (based on 5.78 V pole drop)

This analysis shows high generator efficiency and minimal voltage regulation, confirming stable performance during generation

5.2 CASE STUDY 1 : PUMPING MODE

From the fig(8) unit 3 is in running condition in Pumping mode

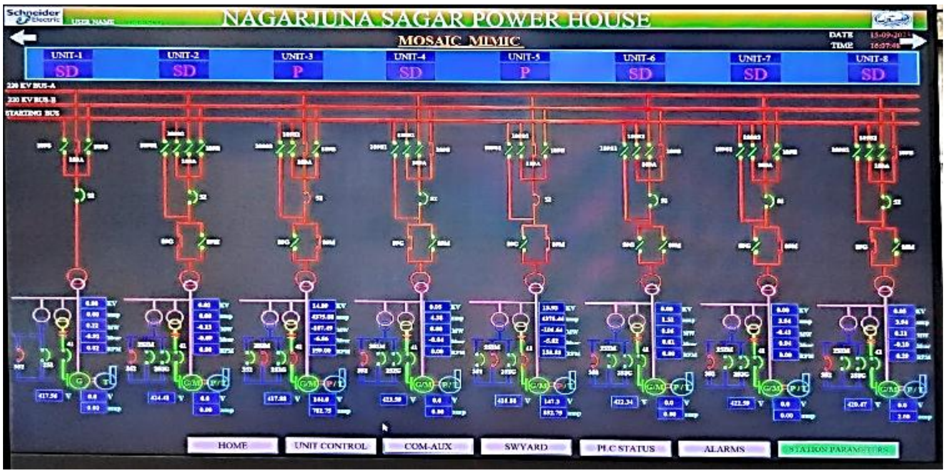

Fig 8 SCADA based monitor under pumping mode

Unit 3 Performance Summary (pumping Mode)

In pumping mode, Unit 3 operates as a motor, absorbing 107.49 MW of power. The apparent power is 107.79 MVA with a power factor of 0.9972 (leading).

Losses and Performance:

- Copper Loss: 11.48 MW
- Core Loss: 0.784 MW
- Mechanical Loss: 0.448 MW
- Pole Drop Loss: 2.88 MW
- Total Losses: 15.59 MW
- Efficiency: 85.5%

COMPARING RESULTS OF CASE STUDY 1 & CASE STUDY 2

1. **High Efficiency in Generating Mode**

- **Efficiency:** ~91.16%
- **Losses:** Relatively low (7.35 MW), mainly from copper and iron losses
- **Voltage Regulation:** Very low (~1.44%), indicating stable output voltage

The generator performs very efficiently in generating mode, with minimal losses and excellent voltage stability.

2. Lower Efficiency in Pumping Mode

- **Efficiency:** ~85.5%
- **Losses:** Higher (15.59 MW), due to increased copper, mechanical, and pole drop losses

Pumping mode involves more energy loss due to higher current draw and mechanical wear. Efficiency drops as expected for reverse operation.

3. Performance Comparison

Mode	Efficiency	Total Losses	Voltage Regulation
Generating	91.16%	7.35 MW	1.44%
Pumping	85.5%	15.59 MW	0

- Generating mode is more efficient and stable, making it optimal for long-duration operation.
- Pumping mode is useful for grid load balancing but incurs more losses and voltage fluctuations, which is typical in pumped storage systems.

6. CONCLUSION

This paper presented an overview and analysis of the Nagarjuna Sagar Hydro Power Plant, a vital infrastructure project on the Krishna River that provides both electricity and water for irrigation and drinking purposes. The plant operates in dual modes—generating and pumping—which enhance grid flexibility and energy storage capabilities.

In generating mode, the plant achieves a high efficiency of 91%, delivering electricity during peak demand. In pumping mode, operating at 85% efficiency, it stores energy by returning water to the reservoir during off-peak hours. While both modes are essential for maintaining system stability and sustainability, generating mode is more efficient and directly supplies power to the grid, making it the primary mode for energy output. Pumping mode complements it by enabling long-term water and energy resource management.

Overall, the Nagarjuna Sagar Hydro Power Plant exemplifies an integrated and sustainable hydroelectric system, effectively balancing energy production, water conservation, and regional development.

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