

## Design and Analysis of a Hybrid Power System for Remote Natural Gas Pipeline Control Stations

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## **Presentation Outline**



- Background
- Introduction
- Site Selection
- System Design
- Optimization of Proposed Hybrid Power System
- Dynamic Modeling of Proposed Hybrid Power System
- Analysis of Inverter Topologies
- Design of IoT Based Open Source SCADA System



- Energy has become a fundamental element of modern life.
- There has been a constant increase in the need for energy throughout human history (UN population prediction).
- Reliable energy resources and adequate energy supply are pivotal for economic development.
- As a result of economic growth, the exploration and utilization of oil and gas reserves have intensified.
- Energy and its conservation is crucial for the sustained development of every country.



- The availability of energy at an affordable cost is another critical factor in driving a nation's prosperity.
- As a result energy has become a strategic asset globally.
- Fossil fuels are the dominant source of energy globally, accounting for 67.9% of the world's energy consumption.
- Natural gas has a lower carbon intensity and reduced environmental impact during extraction and use.
- The global consumption of natural gas has increased gradually since 1980. 4



- Natural gas significantly meets Pakistan's energy needs and plays a crucial role in the country's electricity production.
- Energy mix of Pakistan





- In 1952, significant natural gas reserves, around 12 trillion cubic feet, were discovered in Sui, Balochistan province of Pakistan.
- Following this discovery, a large-scale gas infrastructure was set up to generate electricity and meet domestic, commercial, and industrial needs.
- By 2005, natural gas consumption had surged to around 50% of Pakistan's total energy use.
- From 2006 onward, supplies began to decline rapidly due to overuse, poor management, and insufficient exploration for new reserves.



- The rapid depletion of natural reserves caused the demand-supply gap.
- To bridge this gap, Pakistan has turned to importing liquefied natural gas (LNG) mainly from Qatar.





- The price of LNG is influenced by the international market and several global factors.
- By late 2021, the cost of LNG delivered to Pakistan had risen to nearly US\$16 per MMBtu, more than four times the average domestic gas price.





- The prolonged reliance on fossil fuels for energy production and associated environmental concerns need to be addressed.
- Due to storage constraints, natural gas must be quickly transported to its destination after extraction.
- There are two common methods for transporting natural gas: Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG).
- Natural gas transportation to various regions within Pakistan is carried out by two leading companies namely SNGPL and SSGCL.



- Various pipeline control stations manage the operation and maintenance of high-pressure pipeline networks.
- These control stations are strategically located in geographically remote and sparsely populated areas.
- Operation and maintenance of these control stations in remote areas is challenging due to unreliable electricity from nearby grids.
- A variety of electrical equipment is required for the efficient operation of such control stations.



- As a result, fossil fuels such as natural gas and diesel remain the main power sources for control stations in remote areas.
- The future scenarios of natural gas depletion were not considered at their inception.
- As local natural gas reserves decline and reliance on costly imported LNG increases, using natural gas for power generation is no longer economically viable.
- Therefore, it is crucial to shift to renewable energy sources, due to their sustainability, environmental benefits, and decreasing costs.



- SNGPL is the largest integrated natural gas provider in North Central Pakistan, serving over 7.22 million customers over a vast network.
- SNGPL's transmission network comprises 9239 km of high-pressure gas pipelines, while the distribution network comprises 142,998 km of lowpressure gas pipelines.
- SNGPL operates eleven compressor stations to compress natural gas efficiently, ensuring its delivery to the doorsteps of end consumers.







- Energy can be derived from various sources mainly classified as renewable and non-renewable types.
- Because renewable energy sources are intermittent, hybrid power systems (HPS) that combine conventional and renewable sources are used for electricity generation.
- HPSs are reliable, eco-friendly systems that efficiently reduce reliance on a single source of energy.
- Pakistan has significant solar energy potential, with an average daily insolation of 5.30 kWh/m<sup>2</sup> and the capability to generate up to 10,000 GW.







- One of the most fundamental choices made during any project's establishment, expansion, or relocation is the site selection.
- The site selected to be a part of our research is one of the natural gas compressor stations operated by SNGPL in Pakistan.
- This selected site is located in a remote and sparsely populated area named Gali Jagir, Fateh Jhang (33.427522, 72.625862).







The site covers a total area of 11 acres, with a designated 6-acre section for the compressor station and a 5-acre area for residential blocks.





Generators used for power generation.





Gas turbines and compressors





- HOMER Pro is a software tool designed for optimizing and simulating microgrid and distributed energy systems.
- It enables the modeling of various energy technologies, including renewables and storage, to identify the most cost-effective and reliable energy mix for specific applications.
- It helps in evaluating the economic and technical feasibility of different energy configurations, enabling better decision-making for energy projects.



- Solar Global Horizontal Irradiance (GHI) is an important factor in assessing site feasibility. It represents the amount of sunlight energy measured at a specific location.
- Likewise, the clearness index is measure of the clearness of atmosphere and it is an arbitrary, dimensionless number that ranges from 0 to 1.
- Homer Pro software is used to get solar GHI and clearness index data for selected site.



Solar GHI and Clearness Index values for selected site in HOMER Pro.





#### Designing of load profile for selected site in HOMER Pro.





The proposed hybrid system includes a DC power source which consists of PV panels and battery bank and alongside an AC power source which are natural gas gensets.



## **Optimization of Proposed HPS**



- HOMER Pro simulates all possible system configurations in one run and then organizes them based on the chosen optimization variable.
- HOMER Pro performed a total of 892 simulations.

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## **Optimization of Proposed HPS**



 The optimal system proposed by HOMER Pro uses gas generators for 15.5% of its electricity and derives 84.5% of its power from solar energy.

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## **Optimization of Proposed HPS**



Cost summary and cash flow summary for proposed HPS.







- Dynamic modeling and simulation are necessary steps in analyzing the performance and behaviour of any system.
- To examine the dynamic performance of the proposed HPS, simulations are performed using MATLAB/Simulink.
- During this modeling process, careful consideration is given to the AM 1.5 spectrum, which is also known as Air Mass 1.5.
- The initial value for irradiance is set at approximately 1000 watts per square meter (W/m2), reflecting standard solar radiation conditions.
- In the simulation, solar cell temperatures range from about 25°C to 60°C, reflecting typical operating conditions under sunlight.











 Stable output voltage and current delivered to the connected load by the designed HPS.



## **Experimental Validation of Proposed HPS**



- The real-time validation of a proposed hybrid power system is crucial for ensuring its reliability and efficiency in real-world applications.
- This validation process is facilitated by employing Hardware-in-the-Loop (HIL) testing, which integrates physical hardware components with simulation models.
- OPAL-RT Technologies' high-performance real-time OP5707XG simulator is used for experimental validation.

#### **Experimental Validation of Proposed HPS**









- Most renewable energy technologies produce direct current (DC) electricity while power usage primarily relies on an alternating current (AC) supply system.
- To bridge this gap, a dependable conversion mechanism becomes necessary.
- An inverter is an electronic device that converts DC power into AC power at the required voltage and frequency level making use of appropriate switching patterns and control strategy.



- A two-level inverter is a conventional power electronic device that generates an output voltage or current at only two different levels.
- Problems with two-level inverters include high switching losses, high switching frequency, limited voltage and power rating, and high harmonic distortion.
- The concept of multi-level inverter was initially introduced in 1975 by R. H. Baker and L. H. Bannister.
- Benefits: Reduced harmonic distortion, simplified filters, improved waveform capabilities resulting in sinusoidal outputs, and decreased voltage stress on switches.







A single H-bridge consisting of four semiconductor switches.



One H-bridge can produce an output voltage of two or three levels.





5-level Inverter



7-level Inverter



9-level Inverter



Total Harmonic Distortion (THD) quantifies the level of distortion present in an electrical parameter, such as voltage or current, in relation to the ideal, desired output. It reflects the presence of different frequency components within the voltage or current waveform.





2-level inverter simulation results



5-level inverter simulation results





7-level inverter simulation results



9-level inverter simulation results



Percentage Total Harmonic Distortion (% THD) 60 50 40 30 20 10 0 2-Level Inverter 5-Level Inverter 7-Level Inverter 9-Level Inverter Resistive load Resistive Inductive load



- The smooth operation of natural gas pipeline control stations depends on electrical equipment such as data loggers, control systems, surveillance, and communication devices.
- Along with a reliable power source, these control stations need cost-effective and intelligent monitoring and control systems.
- Distributed processes are monitored and controlled using supervisory control and data acquisition (SCADA) technology.
- SCADA is a system used for monitoring and controlling industrial processes. It gathers real-time data from various sensors and devices, process, and then use it to control equipment and systems remotely.



Proposed SCADA System



- Components of SCADA System
- Field Instrumentation Devices (FIDs)
- Current Senor (ACS712), Voltage Sensors (ZMPT101B)
- Remote Terminal Unit (RTU)
- ► ESP32-WROOM-32E
- Master Terminal Unit (MTU)
- ➢Blynk IoT based Platform
- ♦GSM SIM800L
- Relays (5V single channel)

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Prototype Design of SCADA System.





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Experimental Validation and Results

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## Conclusion



- Reliable Energy Supply: The designed hybrid power system (HPS) provides a reliable energy source, ensuring consistent power availability.
- Natural Gas Conservation: The system minimizes natural gas usage, promoting energy conservation and extending the lifespan of natural gas reserves.
- Renewable Energy Transition: By incorporating solar photovoltaic (PV) energy, the system facilitates a shift towards renewable energy sources, reducing reliance on fossil fuels.
- Cost Reduction: The integration of solar PV reduces the per-unit cost of energy, making the overall system more economical.

## Conclusion



- Environmental Impact: The reduction in fossil fuel usage addresses environmental concerns, contributing to lower greenhouse gas emissions and a smaller carbon footprint.
- Power Quality Enhancement: Multilevel inverter topologies are analyzed to improve power quality, ensuring smooth and stable energy output.
- IoT-Based SCADA Monitoring: An IoT-based open-source SCADA system is implemented for real-time monitoring of the HPS, offering a costeffective and energy-efficient solution for system management.

#### **Future Work**



- Future research could focus on advancing hybrid power systems by integrating advanced components like high-efficiency photovoltaic (PV) panels.
- Research into advanced energy storage technologies, such as lithium-ion and flow batteries, would help boost storage capacity and efficiency.
- Incorporating smart grid technologies and advanced IoT-based SCADA systems could enhance real-time monitoring, control, and security, ensuring reliable operation in remote locations.
- Developing predictive maintenance algorithms and testing system performance under extreme conditions can improve system resilience.

## **List of Publications**



- Articles in Refereed Publications
- \* M. Waqas, M. Jamil, and A. A. Khan, "Hybrid Power System Design and Dynamic

Modeling for Enhanced Reliability in Remote Natural Gas Pipeline Control

Stations," *Energies*, vol. 17, no. 7, p. 1763, Jan. 2024, doi:

https://doi.org/10.3390/en17071763.

M. Waqas and M. Jamil, "Smart IoT SCADA System for Hybrid Power Monitoring in Remote Natural Gas Pipeline Control Stations," *Electronics*, vol. 13, no. 16, p.

3235, 2024, doi: https://doi.org/10.3390/electronics13163235.

## **List of Publications**



- Refereed Conference Publications
- ♦M. Waqas and M. Jamil, "Power Quality Improvement Using Nine-Level Cascaded H-
  - Bridge Voltage Source Inverter for PV Applications," 2024 12th International Conference
  - on Smart Grid (icSmartGrid), Setubal, Portugal, 2024, pp. 429-434, doi:

10.1109/icSmartGrid61824.2024.10578256.

Regional Conference Publications

M. Waqas, M. J. A. Baig, and M. Jamil, "Design and Analysis of a Hybrid Power System for a Remote Natural Gas Pipeline Control Station" 32<sup>nd</sup> Annual Newfoundland Electrical and Computer Engineering Conference (NECEC) 2023, St. John's, NL, Canada.





# **Thank You**

**Q & A**