CHAPTER I
INTRODUCTION

1.1. Background

The MERAKES production field is a vital part of Indonesia's offshore gas extraction efforts, situated approximately 1,500 meters below sea level. Producing primarily natural gas, with some condensate, MERAKES operates under extreme conditions characterized by high pressures 2,100 bar and low temperatures 4 °C. Such conditions are ideal for the formation of gas hydrates—crystalline compounds formed from hydrocarbons and water. Hydrate formation can result in severe blockages within subsea pipelines, drastically reducing the flow of gas and potentially halting production altogether. This issue is exacerbated in deepwater environments like MERAKES, where continuous injection of hydrate inhibitors such as mono-ethylene glycol (MEG) and methanol (MeOH) is essential.

Currently, MEG injection is controlled manually by operators who calculate the required dosage based on various variables, including gas discharge, water discharge, and pressure/temperature readings. However, this manual control system is prone to human error, which can lead to inefficiencies, increased operational risks, and significant financial consequences. Studies indicate that human error accounts for a substantial portion of hydrate-related production issues globally [1].

Hydrate formation is a global issue affecting the oil and gas industry, particularly in deepwater production. The industry spends approximately $500 million annually on the prevention and remediation of hydrate-related problems [2]. Hydrate blockages can occur unexpectedly, causing production delays and equipment damage that require costly interventions, including depressurization, heating, and chemical injection. In regions like the Gulf of Mexico and the North Sea, hydrate prevention is a priority due to the prevalence of deepwater fields operating under hydrate-forming conditions.

In Indonesia, natural gas is a critical component of the country's energy strategy, accounting for about 20% of the national energy mix [3]. The MERAKES production field is a key contributor to Indonesia's offshore gas supply. The government has prioritized the development of offshore resources to meet growing domestic demand and support energy exports. However, the challenging subsea environment in fields like MERAKES increases the risk of hydrate formation. Any disruption in gas production caused by hydrate blockages could have significant consequences for Indonesia's energy security and economic stability.

Statistical evidence highlights the urgency of addressing hydrate formation in deepwater gas production. Studies indicate that gas hydrates can reduce pipeline flow by up to 85%, and remediation efforts can cost between $300,000 to $1 million per incident depending on blockage severity [4]. In deepwater fields like MERAKES, where operational conditions are more extreme, the risk of hydrate formation is 30-40% higher compared to shallow water fields [5]. Furthermore, manual control of MEG injection is inherently limited by human intervention; operators must rely on real-time data to manually adjust MEG dosage based on variables like gas flow rates and wellhead pressure. Inaccuracies in these calculations or delays in adjusting dosage can lead to under-injection—resulting in hydrate formation—or over-injection—leading to wastage of expensive chemicals.

Given the global, national, and local implications of hydrate formation in offshore gas production—ranging from operational disruptions to significant financial losses—the limitations of manual MEG injection control have become increasingly apparent. These challenges necessitate the development of an automated system capable of optimizing MEG dosage in real-time. This thesis introduces the application of an Adaptive Neuro-Fuzzy Inference System (ANFIS) integrated with a Proportional-Integral-Derivative (PID) controller to effectively manage the MEG injection process. The ANFIS model is designed to handle multivariable inputs, including gas flow rates, water discharge rates, and pressure-temperature variations, while the PID controller ensures system stability and precise control of the injection rate. By automating and stabilizing the MEG injection process, the proposed system not only reduces risks associated with hydrate formation but also enhances operational reliability. Furthermore, it aims to significantly reduce the financial and operational costs associated with hydrate remediation, particularly in deepwater environments such as the MERAKES production field, where such risks are more pronounced.

1.2. Problem Identification

The current MEG injection system in the MERAKES production field relies heavily on manual intervention, where operators must input various parameters, such as gas discharge, water discharge from the Subsea Multiphase Flowmeter (MPFM), as well as pressure and temperature readings from the bottom hole of the well and both upstream and downstream of the pressure choke valve (PCV). These parameters are manually entered into the MEG injection calculation sheet to determine the required MEG dosage. Once calculated, the operator then inputs the results into the Distributed Control System (DCS).

This manual process introduces several challenges:

- Increased Risk of Human Error: The operator must recalculate the MEG injection dose whenever there is a change in any of the system parameters. This dependency on manual input increases the likelihood of human error, leading to potential miscalculations in MEG dosage [1].
- Delayed Response: When operational conditions change rapidly, manual recalculation of MEG dosage may delay adjustments, which can result in insufficient injection or over-injection, either of which can impact production efficiency and increase the risk of hydrate formation [2].
- Inability to Handle Multivariable Input Efficiently: The current system does not effectively handle multiple dynamic inputs simultaneously, leading to potential inaccuracies in maintaining the optimal MEG injection dosage [4].

A comparison with other algorithms highlights its suitability for this application:

Table 1. Comparison ANFIS with Other Algoritms

Algorithm	Strengths	Weaknesses
Linear Regression	o Simple and interpretable o Performs well for linear relationships.	• Limited to linear relationships • Unable to model the nonlinear dynamics of hydrate formation.
Artificial Neural Network (ANN)	o Highly flexible o Capable of modeling complex, nonlinear relationships.	• Requires large datasets for training • lacks interpretability • Prone to overfitting without careful tuning.
Support Vector Machine (SVM)	o Effective for high-dimensional data o Robust to overfitting in certain scenarios.	• Poor interpretability • Requires careful kernel selection • Computationally expensive for large datasets.
Adaptive Neuro-Fuzzy Inference System (ANFIS)	o Combines human-like reasoning of fuzzy logic with learning capabilities of neural networks o Handles multivariable and nonlinear inputs effectively.	• Computationally intensive for large datasets • Performance highly dependent on input features and hyperparameter tuning.

The Adaptive Neuro-Fuzzy Inference System (ANFIS) offers a unique combination of fuzzy logic and artificial neural networks, making it particularly effective for addressing the limitations of the current system. To address these limitations, this research proposes an automated MEG injection control system that combines the Adaptive Neuro-Fuzzy Inference System (ANFIS) with a Proportional-Integral-Derivative (PID) controller. ANFIS is utilized to process multivariable inputs and optimize MEG dosage by modeling complex relationships between inputs. The PID controller ensures stability by dynamically adjusting the MEG injection rate based on the set-point generated by ANFIS.

This integration of ANFIS and PID control is expected to improve the efficiency and reliability of the MEG injection process, minimizing risks associated with hydrate formation. Additionally, the automated system will enhance operational safety and significantly reduce manual dependency in the MERAKES production field.

1.3. Objectives

This research aims to design and implement an automated MEG injection control system by integrating Adaptive Neuro-Fuzzy Inference System (ANFIS) logic with a Proportional-Integral-Derivative (PID) controller in MATLAB Simulink. The specific objectives of this study are to:

- Develop an ANFIS Model: Design and train an ANFIS model to process dynamic multivariable inputs, such as gas flow rates, water discharge rates, pressure, and temperature, and predict optimal MEG injection rates.
- Optimize the ANFIS Model: Compare three FIS generation methods (genfis1, genfis2, and genfis3) to identify the most accurate and efficient approach, leveraging hyperparameter tuning where applicable.
- Integrate ANFIS with PID Control: Develop a hybrid ANFIS-PID control system where the output of the ANFIS model serves as the set-point for the PID controller to maintain stability and precision in MEG injection.
- Simulate and Validate the System: Use MATLAB Simulink to simulate the proposed control system, evaluating its performance under dynamic conditions representative of the MERAKES production field.
- Evaluate Model Performance: Assess the performance of ANFIS models using quantitative metrics, including RMSE, NRMSE, MAPE, and R-squared, to determine their effectiveness in optimizing MEG injection and the integrated ANFIS-PID system [7].

- Derive Key Insights: Extract fuzzy rules and membership functions generated by the ANFIS model to provide insights into the decision-making process and inform future applications in hydrate prevention.

1.4. Expected Result

The outcomes of this research are anticipated to provide significant contributions to hydrate prevention in deepwater gas production by improving the efficiency, accuracy, and reliability of MEG injection systems. The expected results include:

1. Development of an Optimized ANFIS Model:
   - An ANFIS model that processes multivariable inputs to predict MEG injection rates with high accuracy [1].
   - Identification of the best-performing FIS generation method (genfis1, genfis2, or genfis3), with hyperparameter tuning applied for genfis2 and genfis3.
2. Improved Control System Performance:
   - Enhanced MEG injection control through the integration of ANFIS and PID controllers, ensuring rapid response to dynamic operational changes [2].
   - Quantifiable improvements in system performance metrics, including reduced error values (RMSE, NRMSE, MAPE) and better prediction accuracy (high R-squared values).
3. Reduction of Human Dependency:
   - Automation of MEG injection eliminates reliance on manual recalculations, significantly reducing the risk of human error and ensuring operational consistency [4].
4. Insights into Fuzzy Logic and Control Systems:
   - Extraction and analysis of fuzzy rules and membership functions from the ANFIS model, providing a deeper understanding of decision-making processes in multivariable systems [8].

5. Validated Control System via Simulation:
    - A validated simulation in MATLAB Simulink that demonstrates the effectiveness of the proposed ANFIS and ANFIS-PID systems under dynamic conditions.
    - Visual and quantitative comparisons of system behavior to evaluate stability, accuracy, and response time.

1.5. Scope of Work

This research is focused on the design, simulation, and performance evaluation of a MEG injection control system utilizing the Adaptive Neuro-Fuzzy Inference System (ANFIS) combined with a Proportional-Integral-Derivative (PID) controller. The following outlines the scope of this study:

1. Design and Simulation:
    - Developing a hybrid ANFIS-PID control system to automate the MEG injection process.
    - Simulating the system's performance using MATLAB/Simulink under varying operational conditions, such as changes in gas and water discharge rates, pressure, and temperature.
    - The ANFIS function in MATLAB will be used to process multivariable inputs, generate fuzzy inference rules, and dynamically adjust the MEG injection flow rate. [1].
2. Multivariable Inputs and ANFIS Processing:
    - Managing multiple input variables, including gas flow rate, water flow rate, pressure, and temperature.
    - Generating and optimizing fuzzy rules and membership functions through MATLAB's ANFIS tool to determine precise MEG injection dosages [8].
3. Performance Evaluation:
    - Evaluation of ANFIS Performance: The standalone performance of the ANFIS system will be evaluated first, focusing on its ability to

predict the MEG dosage with high accuracy. Performance metrics such as RMSE, NRMSE, MAPE, and R-squared will be used to assess the predictive accuracy of ANFIS with varying multivariable inputs.

- Evaluation of the ANFIS-PID Hybrid System: The performance of the system will be evaluated based on time-domain characteristics, including response time, overshoot, and control stability [7].

4. Assumptions:
   - The study assumes that the parameters used in the simulation (e.g., gas and water flow rates, pressure, temperature) are consistent with real-world data from the MERAKES production field.
   - The control system will be designed under the assumption that the required MEG dosage follows current industry standards for hydrate prevention.
5. Exclusions:
   - This research will not involve the physical implementation of the control system in the field.
   - The study is limited to simulation-based validation using the ANFIS and ANFIS-PID function in MATLAB and comparisons with other advanced control algorithms.
6. Time Frame and Tools:
   - Focusing on simulation time frames without addressing long-term operational challenges or integration with hardware systems.
   - The scope of the study is restricted to the tools used, specifically the ANFIS and ANFIS-PID function in MATLAB/Simulink.

1.6. Research Methodology

This research adopts a simulation-based approach to develop, evaluate, and optimize an automated MEG injection control system, utilizing Adaptive Neuro-

Fuzzy Inference System (ANFIS) integrated with Proportional-Integral-Derivative (PID) control. The research methodology follows these key steps:

1. Study Design: The primary objective is to create an automated MEG injection control system using ANFIS to process dynamic multivariable inputs. The study focuses on simulating the system's performance under various operational conditions to assess its effectiveness in preventing hydrate formation in the MERAKES production field. The system's stability is further enhanced by integrating PID control to ensure optimal performance and precision in MEG injection.
2. Tools and Software: MATLAB/Simulink will be used as the primary tool for modeling, simulating, and evaluating the proposed control system. The ANFIS function within MATLAB will process multivariable inputs and generate fuzzy rules, while the PID controller will manage system stability. The combination of ANFIS and PID in a simulation environment allows for a comprehensive evaluation of the control system's potential..
3. Data Collection and Input Parameters: System parameters, including gas flow rate, water discharge rate, pressure, and temperature, will be collected from historical operational database. These parameters will serve as inputs to the ANFIS controller, which will generate fuzzy rules and membership functions. The data will be sourced from real-world and industry standards for deepwater gas production [2][7].
4. System Simulation: The simulation process involves modeling the hybrid ANFIS-PID control system in MATLAB/Simulink. The ANFIS component will process multivariable inputs, while the PID control ensures system stability. The simulation will test the control system's ability to handle dynamic changes in gas and water flow rates, pressure, and temperature, mimicking real operational conditions [6][7] [8].
5. Performance Evaluation: The ANFIS system's performance will be evaluated based on several key performance indicators (KPIs), RMSE,

NRMSE, MAPE and R-squared. The evaluation will focus on the overall system's ability to maintain optimal MEG injection rates, reduce the risk of hydrate formation, and ensure operational stability. The comparison will primarily focus on the performance of the hybrid ANFIS-PID system [4].

6. Validation and Testing: The results from the simulations will be validated through a comparison of system performance under various operational conditions. Validation will include the comparison of the ANFIS-PID control system's performance against expected outcomes based on real-world data from the MERAKES production field.
7. Conclusion and Reporting: Based on the results of the simulation and performance evaluations, conclusions will be drawn regarding the efficacy of the ANFIS-PID control system in preventing hydrate formation. The findings will be documented and presented, including recommendations for potential real-world implementation.