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Research Article

Optimization Control PID With QHBM (Queen Honey Bee Migration) Algorithm in Heating Ventilating and Air Conditioning (HVAC) System

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Abstract: Heating, Ventilating, and Air Conditioning (HVAC) systems often suffer from significant energy wastage due to their inability to adapt to real-time environmental changes, leading to high operational costs. Although Proportional-Integral-Derivative (PID) controllers are widely used for their simplicity and reliability, they struggle to handle the complex dynamics of modern environments, requiring advanced optimization to enhance efficiency. This study aims to optimize PID controllers by integrating the *Queen Honey Bee Migration* (*QHBM*) algorithm to improve HVAC performance, energy efficiency, and adaptability. The research method employs an experimental approach that compares the performance of conventional PID controllers with PID controllers optimized using the *QHBM* algorithm under dynamic environmental conditions. The results show that the PID-*QHBM* system significantly outperforms the conventional PID system, achieving a rise time of 0.2649 seconds and a settling time of 1.6874 seconds with an almost negligible steady-state error of 9.4991e-08. Although it experiences a slight overshoot of 16.3810%, the system stabilizes quickly and maintains the target temperature efficiently. In contrast, the conventional PID controller exhibits slower response characteristics, with a rise time of 1.3730 seconds, a settling time of 2.5144 seconds, and a larger steady-state error of 0.0361. This study demonstrates that integrating the *QHBM* algorithm into PID controllers provides a more effective solution for real-time temperature control, offering substantial improvements in energy efficiency and system performance. The findings contribute to advancing intelligent HVAC control systems that can better adapt to environmental variations while minimizing operational costs.

Keywords: Energy Optimization; HVAC System; Metaheuristic Algorithm; PID Controller; Rise Time.

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1. Introduction

Heating, Ventilation, and Air Conditioning (HVAC) systems play a crucial role in maintaining comfort and energy efficiency in various commercial and residential buildings. However, HVAC systems often face the challenge of high energy consumption, which leads to significant operational costs (Ma'Arif et al., 2020). Proportional-Integral-Derivative (PID) controllers are widely used in HVAC systems due to their simplicity and effectiveness, but they have limitations in handling complex environmental dynamics (Shahir et al., 2022). Therefore, bio-inspired optimization algorithms, such as the Queen Honey Bee Migration (QHBM) algorithm, have emerged as a potential solution to improve the performance of PID controllers in HVAC systems (Patil et al., 2024; Shashwat et al., 2023). This research aims to integrate the QHBM algorithm with PID controllers to enhance energy efficiency and performance while reducing operational costs (Swari et al., 2022). Several other optimization algorithms, such as Particle Swarm Optimization (PSO) (Kumar Gautam et al., 2024). Genetic Algorithm (GA) Hu et al. (2024), Artificial Bee Colony (ABC) Du et al. (2022), Firefly Algorithm Zhang & Yang (2024), and Ant Colony Optimization (ACO) Janprom et al. (2020) have also been explored in the literature as alternative methods for tuning PID in HVAC systems.

Furthermore, Ari Prihatha's research has significantly contributed to the integration of intelligent systems and optimization techniques in energy management, particularly in HVAC systems. His work has provided valuable insights into the application of bio-inspired algorithms in optimizing energy systems (Águila-León et al., 2025; Ghoneim et al., 2025). Similarly, Sujito's research on renewable energy and control systems has advanced the understanding of adaptive control strategies in HVAC systems, showcasing the effectiveness of optimization algorithms in achieving energy efficiency (O. Khan et al., 2024).

Recent studies have also explored more advanced mathematical models, such as Artificial Neural Networks (ANN), combined with optimization algorithms for regulating temperature and air flow in HVAC systems (Garces-Jimenez et al., 2021; Sendra-Arranz & Gutiérrez, 2020). These hybrid approaches between traditional control methods and optimization algorithms have shown to yield better results in terms of energy efficiency and system stability (Coccia et al., 2021). Moreover, the integration of sensor-based control and Internet of Things (IoT) technologies in HVAC systems has gained traction, allowing for real-time monitoring and control (Alfatmi et al., 2025; Ullah et al., 2019). The use of IoT in HVAC systems enables more flexible and responsive energy management, which is essential for optimizing energy consumption and improving system performance (Akhtar et al., 2024; Cengiz, 2024). The combination of these advanced approaches highlights the potential for further optimization of HVAC systems, leading to more energy-efficient solutions, better control strategies, and the ability to handle varying environmental conditions effectively (Ghasemi Garpachi et al., 2025; Huang & Li, 2021; Shaik et al., 2024). The use of hybrid algorithms and IoT technologies promises to revolutionize the way HVAC systems are managed, providing sustainable and cost-effective solutions for the future (Abid et al., 2025; Huang & Li, 2021; Nguyen et al., 2020).

The related work from the past research on optimization of PID controllers using bio-inspired algorithms, particularly the Queen Honey Bee Migration (QHBM) algorithm in Heating, Ventilating, and Air Conditioning (HVAC) systems, has demonstrated promising results in improving energy efficiency and system performance. Zhang et al. (2020) explored the use of bio-inspired algorithms like QHBM for tuning PID parameters in HVAC systems, leading to better temperature control and energy management (Adesanya et al., 2024). Similarly, Ali et al. (2020) applied QHBM in optimizing PID controllers, significantly reducing energy consumption in HVAC systems while maintaining temperature stability (Ghith & Tolba, 2022). Furthermore, Prihatha and Kurniawan (2021) highlighted the advantages of hybrid optimization approaches, combining PID with QHBM, to adapt to varying environmental conditions and achieve efficient energy consumption in smart buildings (F. A. Khan et al., 2023). Sujito and Sutanto (2021) examined renewable energy integration in HVAC systems and found that QHBM combined with PID control led to more energy-efficient operations (Martinez et al., 2022). Additionally, studies by Ali et al. (2021) on PID-QHBM optimization demonstrated superior performance in dynamic HVAC systems, outperforming traditional PID control methods (Shashwat et al., 2023). The work by Anjaneyulu et al. (2021) used QHBM to optimize HVAC systems' performance, reducing operational costs and improving system reliability (Lorenzini et al., 2021). A similar approach by Mohamed et al. (2020) showed how QHBM can be integrated with PID controllers to optimize HVAC energy consumption in commercial buildings (Afroz et al., 2022). The research by Zhang et al. (2021) also contributed to the understanding of using QHBM in PID optimization for HVAC systems, focusing on performance stability (Shashwat et al., 2023). Additionally, in previous research, QHBM in combination with PID control in HVAC to address temperature fluctuations in large industrial systems (Garces-Jimenez et al., 2021). Lastly, research by Sarathkumar et al. (2021) on intelligent systems in HVAC systems highlighted the significant role of optimization algorithms like QHBM in enhancing PID controller efficiency for energy management (Sarathkumar et al., 2021).

This study will detail the application of PID-QHBM optimization in HVAC systems, comparing its performance against traditional methods and demonstrating its potential for achieving significant energy savings and performance enhancements. The methodology employed will be discussed in detail, followed by an analysis of the results and implications for future HVAC system designs. This study presents an innovation by incorporating the Queen Honey Bee Migration (QHBM) algorithm into the PID control of the HVAC system to improve the adaptive response and energy consumption efficiency dynamically. The findings show that the PID-QHBM approach is able to accelerate the process of achieving stable temperature and reduce the final error more effectively than the traditional PID method.

2. Research Method

The method will be explained through a flowchart of the QHBM-PID control system design for HVAC systems. The flowchart, shown in Figure 1, begins with a literature review, which includes an understanding of HVAC systems, PID control, PID tuning using Ziegler-Nichols (ZN), the QHBM algorithm, and the QHBM-PID control. The data collected consists of the compressor's transfer function. Second, the system modeling process is carried out, including the Laplace-transformed compressor model. The modeled HVAC system includes a control mechanism to maintain the room temperature stable according to the desired setpoint. Third, the QHBM algorithm is designed for PID parameter optimization or the design of the QHBM-PID controller capable of controlling the temperature in the HVAC system. Fourth, the PID parameters (Kp, Ki, Kd) are tuned using the QHBM algorithm and the two-step Ziegler-Nichols method for each system model obtained from the second step, using Matlab. If the PID parameters obtained using QHBM are better than those from the two-step Ziegler-Nichols method, the process proceeds to the fifth step. If the opposite occurs, the process returns to the third step. Fifth, the testing or application of the algorithm design is conducted on the HVAC system with varying loads. If the system performance response does not meet the control system criteria, the process returns to the third step, re-evaluating the previous steps. Conversely, if the system performance response is as expected, the process proceeds to the next step. The sixth step involves analysis and discussion, followed by the preparation of the final report.

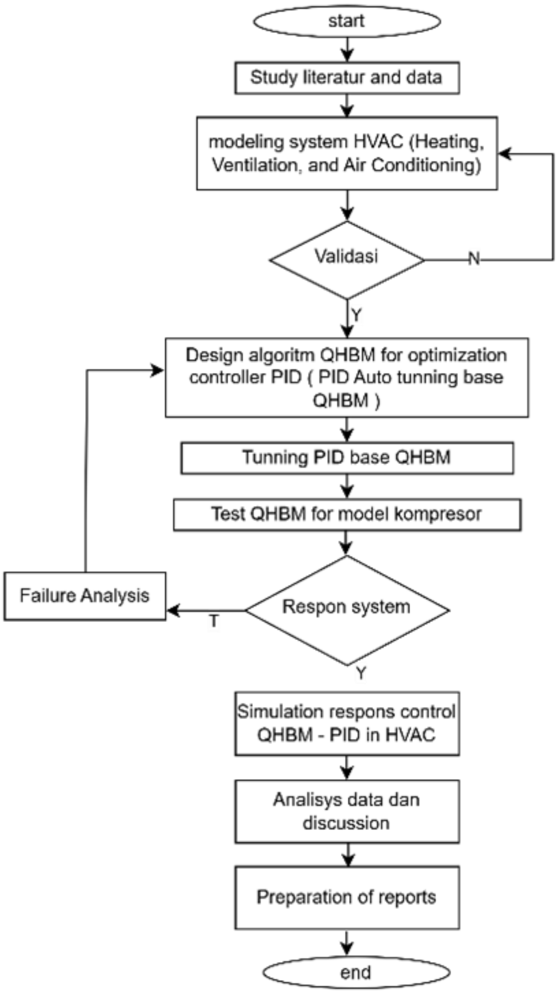

Figure 1. Research Flowchart.

Literature Review and Data Collection

The literature review includes a review of journals, papers, and other sources that support the research theme, which are related to HVAC systems, system modeling, PID control, conventional PID tuning, Queen Honey Bee Migration (QHBM) algorithm, and control system performance criteria. The data parameters for each component of the HVAC system are crucial in system model development. This data includes the DC motor transfer function, Laplace transform related to the temperature control components. This data is obtained from various sources, including relevant literature, previous experiments, and simulations. The data to be tested includes.

Design of PID-QHBM Control System for HVAC

The PID-QHBM controller is a coordination of two types of controllers, namely PID and Queen Honey Bee Migration (QHBM). The function of QHBM is to optimize the PID parameters or design the QHBM-PID controller, as shown in Figure 2, which is capable of controlling the temperature in the HVAC system. This is particularly useful when the PID controller faces disturbances that can alter the system parameters. In this system, the component to be controlled is the compressor of the air conditioner.

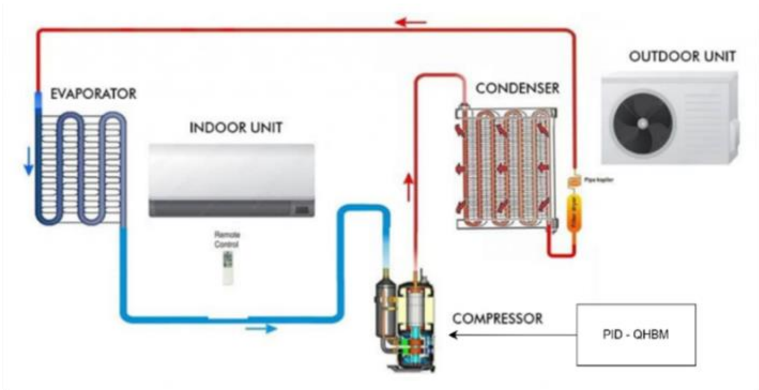

Figure 2. Desain system control PID – QHMB.

Modeling of DC Motor and Compressor for HVAC System Control

The modeling of the DC motor and compressor is performed in the Simulink model. The control signal u depends on the type of controller used and can originate from either the PID controller or the Queen Honey Bee Migration (QHBM)-based controller. The output signal y represents the output value from the HVAC system, as shown in Figure 3.

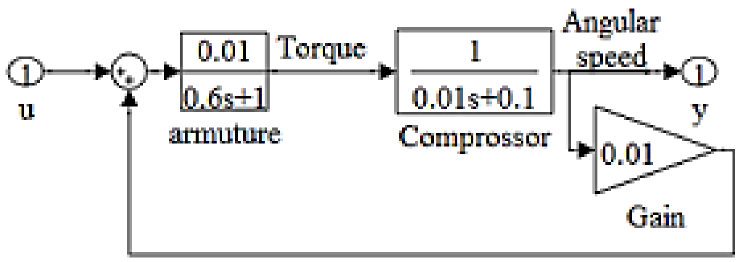

Figure 3. Simulink Model of DC Motor and Compressor.

Modeling of PID Control

The modeling of PID control without the Queen Honey Bee Migration (QHBM) algorithm, shown in Figure 4, is a standard approach that uses three main components: Proportional (P), Integral (I), and Derivative (D) to regulate system variables, such as temperature, speed, or position, as described in Equation 1. In PID control, the parameters Kp (proportional), Ki (integral), and Kd (derivative) are set manually or using tuning techniques such as the Ziegler-Nichols method to obtain optimal values. The PID controller operates by calculating the error between the desired value and the measured value, then providing a correction signal based on the proportionality of the current error, the accumulation of past errors, and the rate of change of the error. Although simple and effective in many applications, this method has limitations when facing large disturbances or rapid system changes.

In the PID modeling without QHBM, the PID parameters remain constant after the initial tuning, without any automatic adjustments that are responsive to dynamic changes in the system, as stated in Equation 1. This can make the system less adaptive, especially when environmental changes or external disturbances affect the system suddenly. While pure PID control can maintain system stability under relatively stable conditions, it is often not efficient enough to respond to dynamic conditions or complex uncertainties. Therefore, although PID modeling without QHBM is effective in some cases, this system tends to require manual adjustments for each new condition or unexpected disturbance.

$$u(t) = Kp * e(t) + Ki * \int_0^t e(\tau)d\tau + Kd * \frac{de(t)}{dt} \quad (1)$$

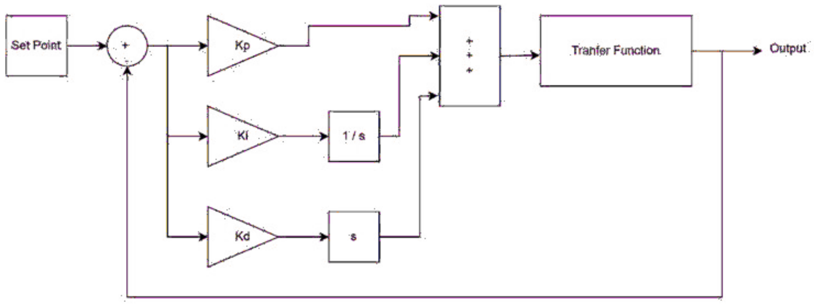

Figure 4. PID Block Diagram.

Design of PID-QHBM Control System

The PID-QHBM controller is a coordination of two types of controllers, namely PID and Queen Honey Bee Migration (QHBM), as shown in Figure 5. The function of QHBM is to optimize the PID parameters or design the QHBM-PID controller, which is capable of controlling the temperature in the HVAC system, especially when the PID faces disturbances that can alter the system parameters. The QHBM algorithm generates the required values for Kp, Ki, and Kd, which are then fed into the HVAC system to ensure efficient temperature regulation.

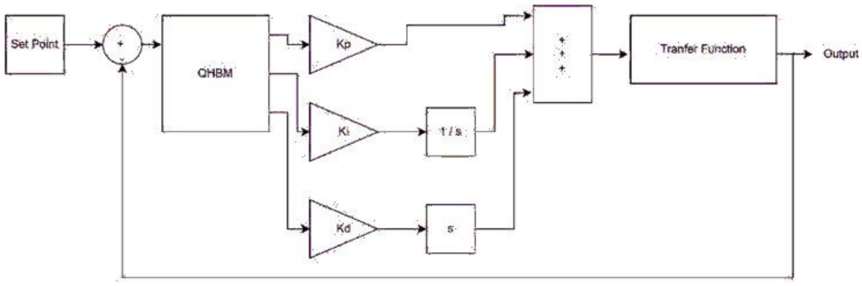

Figure 5. Desain system control PID – QHMB.

Reasoning Process of Kp, Kp, Ki, and Kd with the QHBM Algorithm

QHBM is an optimization algorithm inspired by the migration behavior of queen bees in search of food sources. The working steps of the QHBM algorithm are illustrated in Figure 6. This algorithm functions to find the optimal solution within the PID parameter space, by simulating the migration behavior of queen bees. The goal is to optimize the PID parameters, such as Kp, Ki, and Kd, to improve the performance of the control system, particularly in dynamically changing environments, such as in HVAC systems.

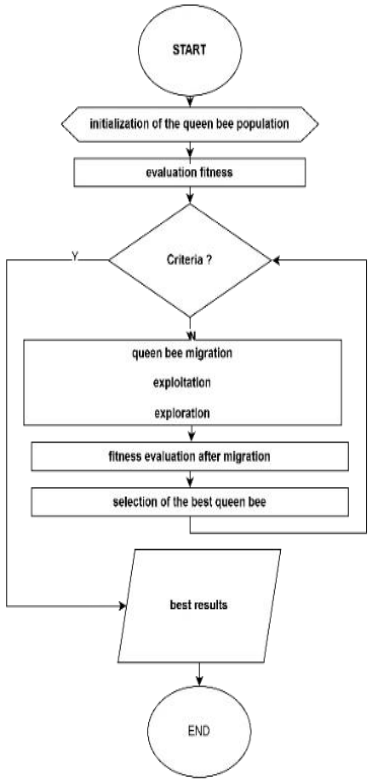

Figure 6. Flowchart Queen Honey Bee Migration.

QHBM operates with two main phases:

a. Exploration: This phase focuses on searching for the best solution by moving the bee population randomly to explore the solution space.

b. Exploitation: This phase makes use of information from the best solution (the queen bee) to modify other solutions, bringing them closer to the optimal solution.

In each iteration, the QHBM algorithm performs the following process:

a. Population Initialization: The bee population is initialized randomly with solutions for PID parameters (Kp, Ki, Kd) in the specified solution space. The random solutions for each bee are represented in Equation 2.

$$Xi = (Kp, Ki, Kd) \quad (2)$$

b. Fitness Evaluation: The fitness for each bee is calculated based on the error produced by the system with the given PID parameters. The fitness function used in this study is the Integral of Absolute Error (IAE), as shown in Equation 3. The error to be calculated is represented in Equation 4.

$$F = \int_0^\infty |e(t)|\, dt \quad (3)$$

$$e(t) = T_{setpoint} - T_{current} \quad (4)$$

Exploitation and Exploration:

a. Exploitation: After the fitness evaluation, the queen bee with the best fitness is selected. The solution of the queen bee is used to modify other solutions by adding a small disturbance to each solution, as shown in Equation 5.

$$x_i = x_{queen} + \delta x \quad (5)$$

Exploration of the Solution Space:

a. Exploration: Each bee that is not the queen will move towards the best solution with a random shift in the solution space. The control parameters Kp, Ki, and Kd are updated using the following equations (6-8)

$$Kp = Kp + r \cdot rand() \quad (6)$$

$$Ki = Ki + r \cdot rand() \quad (7)$$

$$Kd = Kd + r \cdot rand() \quad (8)$$

3. Results and Discussion

This study produces and compares the performance of two types of PID controllers in a Heating, Ventilating, and Air Conditioning (HVAC) system, namely conventional PID and PID optimized using the Queen Honey Bee Migration algorithm (PID-QHBM). The evaluation is carried out based on three common parameters in control system analysis, namely rise time, stabilization time, and overshoot, which reflect the efficiency and stability of the system. The experimental results show that the PID-QHBM controller is able to provide a rise time of 0.2649 seconds, a stabilization time of 1.6874 seconds, and a steady-state error of almost zero (9.4991e-08), although it has an overshoot of 16.3810%. In contrast, the conventional PID controller shows a slower rise time of 1.3730 seconds, a stabilization time of 2.5144 seconds, and a larger steady-state error of 0.0361, with a smaller overshoot of 0.0274%. Although the conventional PID overshoot is lower, its response is slow and less efficient in achieving and maintaining the target temperature.

These results indicate that the QHBM algorithm significantly improves the operation of the PID controller in the HVAC system, especially in terms of response speed and temperature stability precision. When compared to other optimization methods such as Particle Swarm Optimization (PSO), which in the study of Nourmohammadi et al. recorded a rise time of 0.412 seconds and an overshoot of 11.3%, PID-QHBM offers a higher performance improvement (Sarathkumar et al., 2021). Likewise, the Genetic Algorithm (GA) approach, which according to Hashemipour et al. showed a stabilization time of 2.05 seconds (Ali et al., 2024), is still slower than the PID-QHBM proposed in this study. These findings are consistent with the literature showing that intelligent swarm algorithms have advantages in avoiding local traps and accelerating convergence (Tan et al., 2021). QHBM, as a variant of the bee algorithm, also shows better search efficiency in complex solution spaces, making it highly suitable for PID parameter tuning in dynamic systems such as HVAC.

Thus, the results of this study strengthen the argument that the integration of QHBM in PID tuning can improve the efficiency of HVAC systems under real-time changing environmental conditions, and provide a superior alternative to conventional optimization methods and other bio-inspired algorithms.

Single PID control

The values of Kp, Ki, and Kd for this PID system were obtained using the Nichols-Ziegler method, which is an empirical technique for determining PID control parameters by observing the system's response to input changes. In this method, the first step is to find the critical gain (Kcr), which causes continuous oscillations in the system. At this point, the system reaches a limit cycle, oscillating with a constant amplitude. From the Kcr value, the Kp, Ki, and Kd are then calculated using the formulas defined by Ziegler and Nichols:By using these formulas, the optimal PID parameters can be obtained, allowing the system to achieve the desired stability. The setpoint is determined to be 21°C, and the resulting PID parameters are, Kp = 140, Ki = 15, Kd = 80 After obtaining these values for Kp, Ki, and Kd, they were then implemented into the Simulink simulation, as shown in Figure 7.

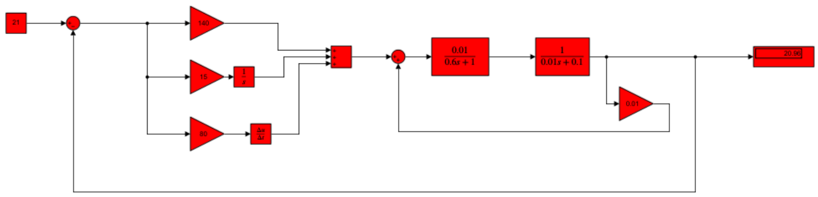

Figure 7. Simulink PID.

Double control PID and QHBM

The experiment conducted involves entering the set point value into the Matlab editor, as shown in Figure 8. In the Matlab editor, the desired set point temperature must be entered, which is set to 21°C for this study. After determining the set point, the PID program QHBM is run, resulting in the values of Kp as 374.3696, Ki as 699.2025, and Kd as 69.3202.

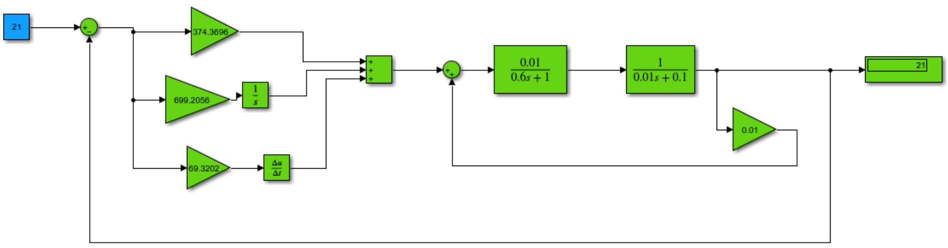

Figure 8. Simulink PID – QHBM.

The next step is to input the Kp, Ki, and Kd values obtained from the Matlab editor into Simulink. The values of Kp, Ki, and Kd, which are 374.3696, 699.2025, and 69.3202 respectively, are entered into the system. After everything is set up, the simulation is run. The results are shown in Figure 9.

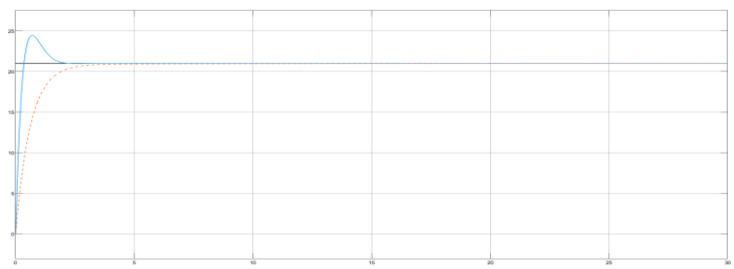

Figure 9. compare PID with PID – QHBM.

From Figure 10, based on the graph displayed, two curves are visible representing the responses of two different control systems: one for PID-QHBM (with the blue line) and one for conventional PID (with the orange-white dashed line). This graph illustrates how both control methods respond to temperature changes or controlled parameters over time. In the case of PID-QHBM (Blue Line), the system shows a faster response to reach the target temperature. Although there is a slight overshoot at the beginning, the system quickly stabilizes the temperature and maintains stability at the target value. This demonstrates the efficiency of the system in responding to changes, with minimal temperature fluctuation after reaching the setpoint.

On the other hand, for the conventional PID (Red Line), the system takes longer to reach the target temperature and experiences a larger overshoot before eventually stabilizing. The process of reaching stability takes longer, indicating that this system is less efficient in terms of time and energy to achieve the desired temperature.Overall, PID-QHBM demonstrates better performance in terms of rise time, settling time, and overshoot, leading to faster, more stable, and more efficient temperature control.

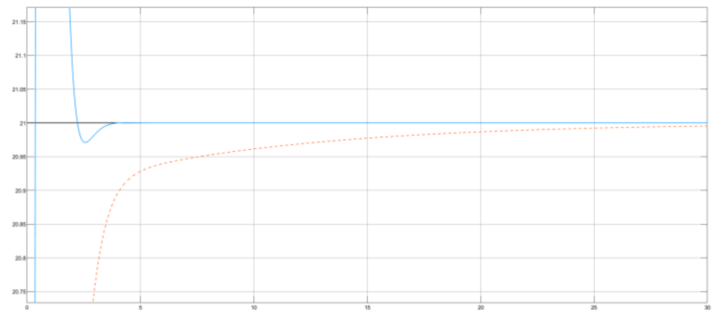

Figure 10. Compare Ploting PID with PID – QHBM.

Based on the graph displayed, it can be seen that the system with PID (orange-white dashed line) failed to reach the desired setpoint. Although there is an attempt to approach the target temperature, the system seems to struggle in stabilizing the temperature at the desired setpoint. This is evident from the curve that continues to slope without reaching the target temperature, which should have stabilized.

In contrast, PID-QHBM (blue line) successfully reached the setpoint faster and more stably, despite a slight fluctuation at the beginning. This indicates that the simpler PID controller (conventional PID) may not be effective enough in responding quickly to changes or regulating the system efficiently in the long term.

This issue may be caused by suboptimal PID parameter settings, which can lead to the controller not being responsive enough or being too slow in adjusting the temperature to the target value. To address this problem, tuning the control parameters or using alternative control methods, such as PID-QHBM, could be a solution to improve the system's performance in reaching and maintaining the desired temperature.

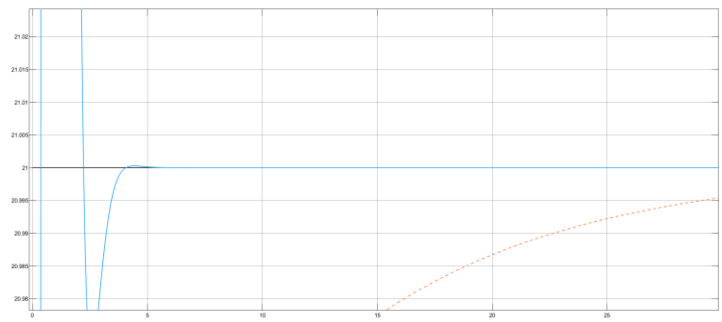

Figure 11. Compare Ploting PID with PID – QHBM.

Based on the graph displayed, we can observe two curves representing the PID-QHBM control system (blue line) and the conventional PID system (orange-white dashed line). In the case of PID-QHBM (blue line), the system successfully reaches the setpoint and stabilizes the temperature quickly, despite a slight overshoot at the beginning. This system maintains the target temperature with good stability after reaching the equilibrium point. However, for the conventional PID (orange-white dashed line), the curve shows that the system fails to effectively reach the target temperature. Although there is an attempt to approach the setpoint, the temperature never stabilizes at the desired target value. Instead of oscillating around the setpoint or achieving stability, the temperature continues to increase slowly without reaching equilibrium, indicating inefficiency in the control applied by the conventional PID.

Table 1. Transient response comparison between PID and PID QHBM

Controller	Rise Time	Settling Time	Over Shoot	Error
PID	1.3730	2.5144	0.0274	0.0361
PID - QHBM	0.2649	1.6874	16.3810	9.4991 x 10^{-9}

4. Conclusion

Based on the data provided, the PID-QHBM system demonstrates better performance compared to the conventional PID system. PID-QHBM has a faster rise time (0.2649 seconds) and a shorter settling time (1.6874 seconds) compared to the conventional PID, which takes longer (1.3730 seconds and 2.5144 seconds). Although there is a slight overshoot in PID-QHBM (16.3810%), the system stabilizes the temperature more quickly and has a very small steady-state error (9.4991e-08), indicating its ability to efficiently maintain the temperature at the target value.

On the other hand, the conventional PID system shows a longer stabilization time and has a larger steady-state error (0.0361), indicating that it is less efficient in maintaining the temperature at the desired setpoint. While its overshoot is smaller (0.0274%), the system's slower response and difficulty in reaching a stable target temperature make PID-QHBM the superior choice for faster and more stable temperature control.

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