Jurnal Dinamis (*Scientific Journal of Mechanical Engineering*)
Journal homepage: https://talenta.usu.ac.id/dinamis/

Power Optimisation of Centrifugal Pumps in a 4-Storey Building

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ARTICLE INFO

Article history:
Received November 13th 2024
Revised November 22th 2024
Accepted June 29th 2025
Available online June 30th 2025

E-ISSN: 2809-3410

How to cite:
Riki Effendi, Ahmad Rijal Siswanto, Munzir Qadri, Franka Hendra. "Power Optimisation of Centrifugal Pumps in a 4-Storey Building", Jurnal Dinamis (Scientific Journal of Mechanical Engineering), Vol. 13, No. 1, pp. 1-7, June. 2025

ABSTRACT

The optimization of water distribution systems in high-rise buildings is essential for enhancing energy efficiency and reducing operational costs. This study examines the effects of implementing a Variable Frequency Drive (VFD) on a centrifugal pump system within a four-storey high-rise building at PT SBA. A case study approach was employed to measure key operational parameters—namely, electrical power consumption, water flow rate, and pressure distribution—both before and after VFD installation. The experimental results demonstrate that the VFD application resulted in a 20% reduction in power consumption, decreasing from 3.5 kW to 2.8 kW, while the water flow rate improved by 12.5%, rising from 80 LPM to 90 LPM. In addition, the pressure range was significantly stabilized, narrowing from 1.2–2.5 bar to 1.0–2.0 bar across the building's floors. An economic analysis based on the observed energy savings indicates an annual cost reduction of approximately Rp7,665,000, with a corresponding return on investment achieved in less than one year. The findings suggest that integrating VFD technology into centrifugal pump systems not only enhances operational efficiency and extends equipment lifespan by mitigating load fluctuations but also offers substantial economic benefits. This study provides a robust framework for the broader application of VFD-based optimization strategies in high-rise and industrial water distribution systems.

Keywords: power optimisation, centrifugal pump, high rise building, Variable Frequency Drive (VFD), energy efficiency.

ABSTRAK

Pengoptimalan sistem distribusi air pada gedung-gedung bertingkat tinggi sangat penting guna meningkatkan efisiensi energi serta mengurangi biaya operasional. Penelitian ini mengkaji efek penerapan Variable Frequency Drive (VFD) pada sistem pompa sentrifugal di sebuah gedung empat lantai milik PT SBA. Pendekatan studi kasus digunakan untuk mengukur parameter operasional utama—yaitu, konsumsi daya listrik, laju aliran air, dan distribusi tekanan—baik sebelum maupun sesudah pemasangan VFD. Hasil eksperimen menunjukkan bahwa penerapan VFD menghasilkan penurunan konsumsi daya sebesar 20%, dari 3,5 kW menjadi 2,8 kW, sementara laju aliran air mengalami peningkatan sebesar 12,5%, dari 80 LPM menjadi 90 LPM. Selain itu, rentang tekanan terstabil secara signifikan, menyempit dari 1,2–2,5 bar menjadi 1,0–2,0 bar di seluruh lantai gedung. Analisis ekonomi berdasarkan penghematan energi yang diamati mengindikasikan adanya pengurangan biaya tahunan sekitar Rp7.665.000, dengan pengembalian investasi tercapai dalam waktu kurang dari satu tahun. Temuan ini

http://doi.org/10.32734/dinamis.v13i1.21558

menunjukkan bahwa integrasi teknologi VFD ke dalam sistem pompa sentrifugal tidak hanya meningkatkan efisiensi operasional dan memperpanjang umur peralatan dengan mengurangi fluktuasi beban, tetapi juga menawarkan manfaat ekonomi yang signifikan. Penelitian ini menyediakan kerangka kerja yang kuat untuk penerapan strategi optimasi berbasis VFD secara lebih luas pada sistem distribusi air di gedung-gedung bertingkat tinggi maupun di lingkungan industri.

Kata Kunci: *optimasi daya, pompa sentrifugal, gedung bertingkat, Variable Frequency Drive (VFD), efisiensi energi.*

1. Introduction

Water distribution systems constitute a critical infrastructure component in high-rise buildings, ensuring that potable water is reliably delivered to every occupied floor [1–3]. In these systems, centrifugal pumps are predominantly utilized to generate the necessary pressure to transport water throughout the building efficiently [4,5]. However, despite their widespread use, centrifugal pumps often operate inefficiently, resulting in excessive electrical energy consumption and, consequently, higher operational costs [6].

The complexity of achieving efficient pump operation is further compounded in multi-storey buildings, such as the four-storey facility at PT Sumber Berkat Anugerah (PT SBA), where water pressure requirements vary considerably from floor to floor. Inadequate optimization of pump performance can lead to energy imbalances and higher maintenance expenses, thereby imposing a significant financial burden on building management [7,8]. Given these challenges, the need for effective pump power optimization is both urgent and highly relevant for improving overall energy efficiency in high-rise buildings.

The present study seeks to address these challenges through the implementation of a Variable Frequency Drive (VFD) on a centrifugal pump system. By adjusting the pump's operating speed to match the varying pressure demands across different floors, the VFD is expected to reduce power consumption while maintaining or even improving water flow performance. A comparative analysis of operational parameters—recorded before and after VFD installation—forms the core of the methodology, providing robust evidence of the technology's efficacy in reducing energy usage and enhancing water distribution stability.

Previous studies have demonstrated that power optimization strategies can achieve significant energy savings in water distribution systems [14–17]. However, many of these studies do not fully examine the unique challenges presented by the dynamic load characteristics typical of multi-storey buildings. By focusing on the specific conditions encountered at PT SBA, this research aims to fill a crucial gap in the literature. Moreover, the application of VFD technology is anticipated not only to lower energy consumption but also to extend the operational lifespan of the pump by mitigating detrimental load fluctuations.

In the context of modern building design and sustainability, optimizing pump performance using a VFD represents a promising approach toward reducing energy costs and lowering the environmental impact of high-rise buildings [24–28]. The findings of this study are expected to provide valuable insights for engineers and facility managers, supporting the broader adoption of energy-efficient technologies in similar infrastructural settings.

2. Methods

To evaluate the potential energy savings and performance enhancements in a centrifugal pump system within a four-storey high-rise building at PT SBA, a case study research design was adopted. This approach provides a comprehensive, in-depth analysis of the water distribution system, enabling a robust assessment of the impact of a Variable Frequency Drive (VFD) on pump performance.

A centrifugal pump rated at 3 kW with a maximum flow rate of 100 liters per minute (LPM) was selected for the study. The building, which rises 15 meters and comprises four floors, exhibits distinct water pressure requirements on each level. Table 2.1 outlines the technical specifications for both the pump and the building. Measurements focused on three key operational parameters: electrical power consumption (in kW), water pressure (in bar) on each floor, and water flow rate (in LPM).

Table 2.1. Pump and Building Technical Specifications

Component	Specifications
Pump Type	Centrifugal Pump
Power	3 kW
Maximum Flow Rate	100 LPM
Building Height	15 metres
Number of Floors	4 floors

Figure 2.1. Centrifugal Pump at PT SBA

Measurements were made on several key parameters to determine the efficiency of the pump before and after optimisation, namely:

- Electrical Power (kW) consumed by the pump.
- Water Pressure (bar) on each floor, measured using a pressure sensor.
- Water Flow Rate (LPM), measured using a flow meter at the pump outlet.

Measurement Tools and Devices:

- Wattmeter to measure electrical power consumption.
- Flow meter and pressure sensor to determine the flow rate and pressure on each floor.

Power optimisation is performed by applying a Variable Frequency Drive (VFD) to the pump motor. The VFD is used to adjust the rotation speed of the motor according to the water pressure requirement on each floor, which allows adjusting the power consumption based on the changing load.

Research Procedure or Steps

a. Initial Data Collection
   Measurement of power consumption, pressure, and pump flow rate under initial operational conditions (without VFD).
b. VFD Installation
   A VFD was installed on the pump motor, followed by calibration to set the motor speed according to the pressure requirements on each floor.
c. Re-measurement
   After the installation of the VFD, the power consumption, pressure, and flow rate were re-measured to obtain data after optimisation.
d. Comparative Analysis
   Data before and after the installation of VFDs were statistically analysed to determine the effectiveness of the optimisation.

Instrumentation for the study included a wattmeter to record electrical power consumption, flow meters to determine the water flow rate at the pump outlet, and pressure sensors to measure the water pressure on each floor. An initial dataset was established by recording these parameters under standard operating conditions (without the VFD) to serve as a baseline.

Subsequent to baseline data collection, a Variable Frequency Drive was installed on the pump motor. The VFD was methodically calibrated to adjust the pump's rotational speed in accordance with the specific water pressure demands of each floor. Following calibration, a second round of measurements was conducted under similar operational conditions to capture the effects of the VFD implementation.

Comparative analysis of the pre- and post-VFD data was performed using standard statistical tests to determine the significance of the observed changes in power consumption, water pressure stability, and water flow rate. Graphical representations were prepared to visually illustrate the improvements in energy efficiency and pump performance following the optimization process.

To ensure data accuracy, all measurement instruments were thoroughly calibrated prior to use, and standardized protocols were followed to minimize potential measurement errors. This comprehensive methodological framework offers a reliable basis for evaluating the effectiveness of VFD technology in reducing energy consumption, enhancing water distribution efficiency, and lowering operational costs in high-rise building systems.

3. Results and Discussion

Presentation of Measurement Results Before and After Optimisation

The measurement results of power consumption, pressure, and water flow rate in the centrifugal pump before and after the application of VFD optimisation are shown in Table 3.1 and Figure 3.2 below. Optimisation is carried out to adjust the power based on the water distribution needs on each floor.

Table 3.2 Parameter Measurement Results Before and After Optimisation

Parameters	Before Optimisation	After Optimisation
Power Consumption (kW)	3.5	2.8
Pressure (bar)	1.2 - 2.5	1.0 - 2.0
Flow Rate (LPM)	80	90

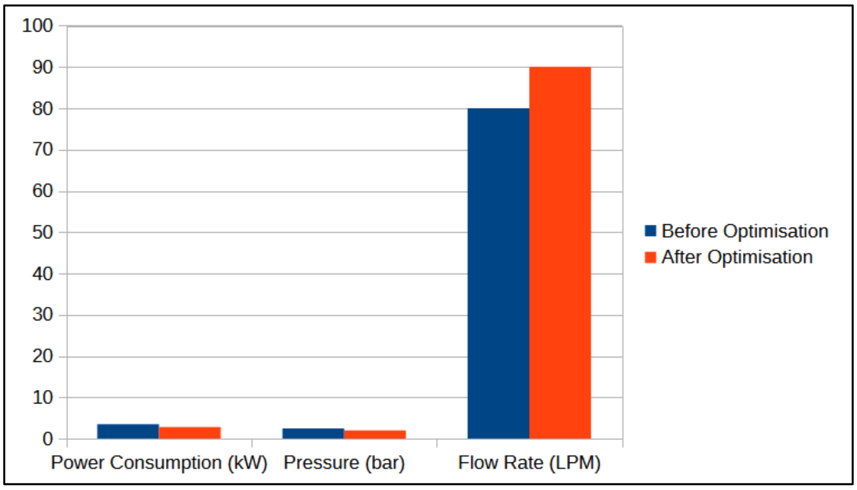

Figure 3.2. Reduction of centrifugal pump power consumption after the application of VFD.

From the measurement results, it can be seen that the power consumption decreased by 20%, from 3.5 kW to 2.8 kW after optimisation. In addition, there was a 12.5% increase in the water flow rate, from 80 LPM to 90 LPM, indicating an improvement in the efficiency of the water distribution system.

Energy Efficiency Comparison

With a 20% reduction in power consumption, these energy savings are projected to significantly reduce electricity operating costs. Based on calculations, the energy savings can reach 1.4 kW per hour, which on an annual basis can provide significant economic savings for the company, especially in high usage scenarios.

Pump Performance Evaluation on Each Floor

The pressure distribution analysis after optimisation shows a more even pressure on each floor of the building. Before optimisation, the pressure varied between 1.2 to 2.5 bar, while after optimisation the pressure variation was reduced to 1.0 to 2.0 bar. These results show that the use of VFDs helps maintain the stability of water pressure as required, especially on higher floors.

Effectiveness Analysis of VFD Usage

The use of VFDs in the pump motors showed high effectiveness in adjusting the motor speed to the water distribution requirements. At lower loads, the VFD successfully reduced the power required to achieve optimal pressure, without sacrificing the required flow rate or pressure at the highest floor. These results indicate that the use of VFDs can extend pump life by reducing high load fluctuations.

Discussion of Economic Efficiency

With the energy savings obtained of 1.4 kW per hour and an estimated electricity cost of Rp1,500 per kWh, an estimated cost savings of Rp 2,100 per hour is obtained. In using the pump for 10 hours per day, this efficiency results in savings of approximately Rp 21,000 per day or Rp 7,665,000 per year. If the investment for the VFD installation is Rp 5,000,000, the ROI will be achieved in less than one year, making this investment very profitable, as shown in table 3.3

Table 3.3 Estimated Economic Savings from Power Optimisation

Parameter	Value
Power Saving (kW)	1.4
Electricity Cost (Rp/kWh)	1,500
Daily Savings (Rp)	21,000
Annual Savings (Rp)	7,665,000
VFD Installation Cost (Rp)	5,000,000
ROI	< 1 year

Implications and Recommendations

The results of this study show that power optimisation of centrifugal pumps with VFDs provides significant benefits in energy efficiency and operational cost savings. Moreover, these findings align with previous studies that have reported considerable energy savings and improved pump performance following the application of VFD technology [29-32]. Nonetheless, it is important to acknowledge that the present study is limited to a specific building configuration and operational context. Future research should extend the evaluation to buildings with a higher number of floors and consider long-term operational stability under varying load conditions. Additional investigations could also incorporate a more detailed error analysis and the effects of environmental variables to further validate the robustness of the optimization process.

In summary, the results from this study provide compelling evidence that the integration of a VFD into a centrifugal pump system in a four-storey high-rise building can significantly enhance energy efficiency and operational performance. The combined technical and economic benefits presented here offer a persuasive case for the broader adoption of VFD technology in water distribution systems, contributing to both operational cost reductions and enhanced system reliability.

4. Conclusions

In conclusion, this study demonstrates that the implementation of a Variable Frequency Drive (VFD) on a centrifugal pump within a four-storey high-rise building significantly enhances both energy efficiency and operational performance. The experimental results indicated a 20% reduction in power consumption—from 3.5 kW to 2.8 kW—and a concomitant 12.5% increase in water flow rate—from 80 LPM to 90 LPM. Moreover, the application of the VFD contributed to a more uniform pressure distribution across the building's floors, stabilizing the pressure range between 1.0 and 2.0 bar. These improvements yield an estimated energy saving of 1.4 kW per hour, which corresponds to an annual electricity cost reduction of approximately Rp7,665,000, thereby allowing for the recoupment of the VFD investment of Rp5,000,000 in less than one year.

Beyond the demonstrable economic benefits, the study suggests that the use of VFD technology may prolong pump life by mitigating the stress associated with rapid load fluctuations. While the current investigation was confined to a specific building configuration and operational context, the promising findings indicate that VFDs could be effectively applied in other high-rise buildings and industrial settings that demand precise pressure control and efficient water distribution.

Future research is recommended to assess the long-term reliability and performance of VFD systems under varied operational conditions. Further studies could also explore the integration of complementary control strategies to optimize pump operations even further, thereby providing a more comprehensive understanding of the implications for maintenance costs, energy conservation, and environmental sustainability.

In summary, this study provides a robust framework for enhancing centrifugal pump performance through VFD implementation, offering practical insights for reducing operational costs and advancing energy efficiency in water distribution systems.

Acknowledgments

The authors gratefully acknowledge the management of PT SBA for granting access to the building facilities and technical resources essential for carrying out this research. We extend our sincere thanks to the technical staff and engineers at the participating institutions for their expert assistance in data collection, instrumentation setup, and system calibration. In addition, we are indebted to our colleagues and peer reviewers for their constructive feedback that has helped refine and enhance the quality of this study. Finally, we appreciate the support provided by UMJ and UNPAM, which contributed significantly to the successful execution of this project.

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