The Effect of Variable Frequency Drive Use on Power Consumption in a Pump Feed Reactor at PT. Unilever Oleochemical Indonesia

Tedy Haryanto Habibie, Rahmaniar, Zuraidah Tharo

Abstract

Electric motors are a crucial component of energy consumption in industrial systems, so their control must be designed to meet load requirements. This study examines the behavior of a three-phase induction motor when supplied through an inverter with varying set points ranging from 10% to 100%. The inverter output voltage, current, and frequency were measured and then used to calculate the motor's active power based on the three-phase power equation with a power factor of 0.89. Data processing results show that the motor's power requirement changes significantly, from approximately 4.43 kW at the low set point to 185.72 kW when the inverter is operating at maximum capacity. The power increase is not proportional to the set point, but rather shows a steeper increase in the range above 60%. This phenomenon aligns with the characteristics of induction motors, which demand greater power when operating at high speeds and torque. These findings demonstrate that the inverter not only acts as a speed regulator but also influences the amount of power the electrical system must supply. By understanding this relationship, system planners can more accurately determine distribution network capacity, protection, and energy efficiency strategies.

Keywords: Reactor Feed Pump, Variable Frequency Drive, Electrical Power Consumption

Tedy Haryanto Habibie[1]
[1]Bachelor of Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia
e-mail: tedyhabibie1@gmail.com

Rahmaniar[2], Zuraidah Tharo[3]
[2,3]Master of Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia
e-mail: rahmaniar@dosen.pancabudi.ac.id[2], zuraidahtharo@dosen.pancabudi.ac.id[3]

Introduction

In this modern era, industry's dependence on a stable and continuous electricity supply is increasing [1]. The industrial sector is a major consumer of electrical energy, both in the planning stage and in daily operational activities. Therefore, energy utilization analysis is essential for efficient use of electrical energy [2]. Electrical installations have three main components: voltage sources, conductors, and resistance (Rahmaniar et al., 2022). The voltage source originates from industrial power plants [3]. Industrial growth in Indonesia shows rapid development, both on a large scale, medium scale, and even in household industries. Along with this progress, the need for appropriate production equipment is crucial to increase time and cost efficiency [4]. Electrical energy plays a vital role in supporting production processes and utility operations in the industrial world. One important factor in the operation of chemical companies is the use of induction motors as the main driver for various industrial equipment [5]. Currently, induction motors are widely chosen as machine drivers because almost 65% of industrial electrical energy consumption is absorbed by motors. Advantages such as simple construction, low cost, high efficiency, good durability, and easy maintenance make induction motors increasingly widely used [6].

Three-phase induction motors are the most widely used type of motor in large-scale industries. Electric motors convert electrical energy into mechanical energy, which is then used to drive pumps [7]. Its advantages include a relatively more economical price compared to other motors, a simple design, and easy maintenance. This motor is generally used for loads with constant speed, but changes in load can cause speed changes, requiring control by adjusting the frequency [8]. During operation, the motor's starting current must be carefully monitored. Direct starting at full voltage on a high-power motor can result in high starting current, which can potentially cause voltage sag (voltage drop) in other loads [9]. Induction motor speed control can be achieved using various methods. One method is the V/F method using a variable speed drive (VSD), which allows for more flexible motor speed control while simultaneously increasing energy efficiency [10]. Speed control in induction motors used in various sectors, from households to industry, is very important because it has an impact on electricity savings [11]. In line with the development of electric motor technology, control systems also continue to develop to increase the effectiveness of energy utilization. In pump applications, for example, inverters are widely used to adjust the motor speed according to the flow rate requirements. In this way, the pump's electricity consumption can be optimized, thus avoiding energy waste [12][13].

In a constantly changing and competitive industrial environment, operational efficiency is a critical success factor. A scientific article by J. Raharjo (2020) reviews the importance of optimizing the use of variable frequency drives in controlling motor speed in industrial processes [14]. An inverter, also known as a variable frequency drive (VFD), is a device used to regulate motor speed by controlling the frequency of the input voltage. VFDs can be used on both AC and DC motors, although in practice the term inverter is more often used for AC motors [12]. Compared to soft starters, which only function to reduce initial current surges, VFDs offer the additional advantage of being able to regulate motor speed as needed. This makes VFDs a popular choice, not only because they provide a smoother startup process but also because they have been proven to save energy by regulating the power supply to the motor [6]. Supporting VFDs through pump control with affordable and sustainable access is a crucial factor for a country's economic development and industrial progress [15]. This paper will discuss the effect of using a variable frequency drive on a reactor feed pump with controlled rotational speed, with the aim of analyzing the pump's electrical power consumption.

Literature Review

2.1 Induction Motor

An induction motor is an electric machine that converts electrical energy into motion by coupling an electric field and has slip between the stator and rotor fields. In an induction motor, the rotor current is derived from a specific source, which is also an induced current resulting from the relative difference between the rotor rotation and the rotating field generated by the stator. In an induction motor, the field coil is absent, so flux generation is achieved solely by the power input to the stator. The stator is the non-rotating part located on the outside, while the rotor is the rotating part [13].In this modern era, industry's dependence on a stable and continuous electricity supply is increasing [1].

2.2 Variable Frequency Drive

A variable frequency drive (VFD) is an induction motor speed controller that uses frequency and voltage for control. The purpose of a VFD system is to control variable speed, improve energy efficiency, and provide flexibility in induction motor control by matching motor output to system load requirements. The VFD operates by decreasing or increasing motor speed by adjusting the supply frequency (Hz). The voltage is regulated proportionally to the frequency to maintain a constant magnetic flux. If the frequency is above the nominal value, the voltage will not increase further, and the motor enters the field weakening zone, where magnetic flux decreases, resulting in reduced torque [10].

2.3 Electrical Energy Analysis

Energy analysis is an activity conducted to evaluate the potential energy savings in a building or equipment. Energy analysis can be defined as a process for evaluating energy use by a building or equipment to ensure that the system's energy is being used efficiently and to identify opportunities to reduce energy consumption. An electrical load is a device or object that operates or functions using electrical energy, for example: lamps, household appliances, electronic devices, and devices used to convert electrical energy into other forms of energy, such as motion and heat, among others [2].

Research Methodology

This study uses a quantitative approach, as the data obtained are numerical and therefore can be analyzed objectively. The research object uses a three-phase induction motor controlled by an inverter. The motor is used as the primary object to observe how changes in the inverter's set point affect electrical power requirements. The inverter is operated from 10% to 100%, while each change is recorded through a series of measurements. The measuring instruments used consist of a digital multimeter to monitor current, voltage, and frequency, and a tachometer to determine the motor's rotational speed. All measurement data is recorded at each set point, then further processed to calculate motor power using the three-phase power formula. The power factor in the calculation is assumed to remain at 0.89 according to the reference test for similar motors. The data collection process is carried out in stages. The motor is run at each inverter set point level, then the frequency, voltage, current, and speed values are recorded. From these results, an overview of the power variation required by the motor under different operating conditions is obtained. The data is then displayed in tables and graphs to more clearly analyze the power change pattern.

3.1 Flowchart

The research stages are systematically structured and visualized in a flowchart to clarify the research steps.

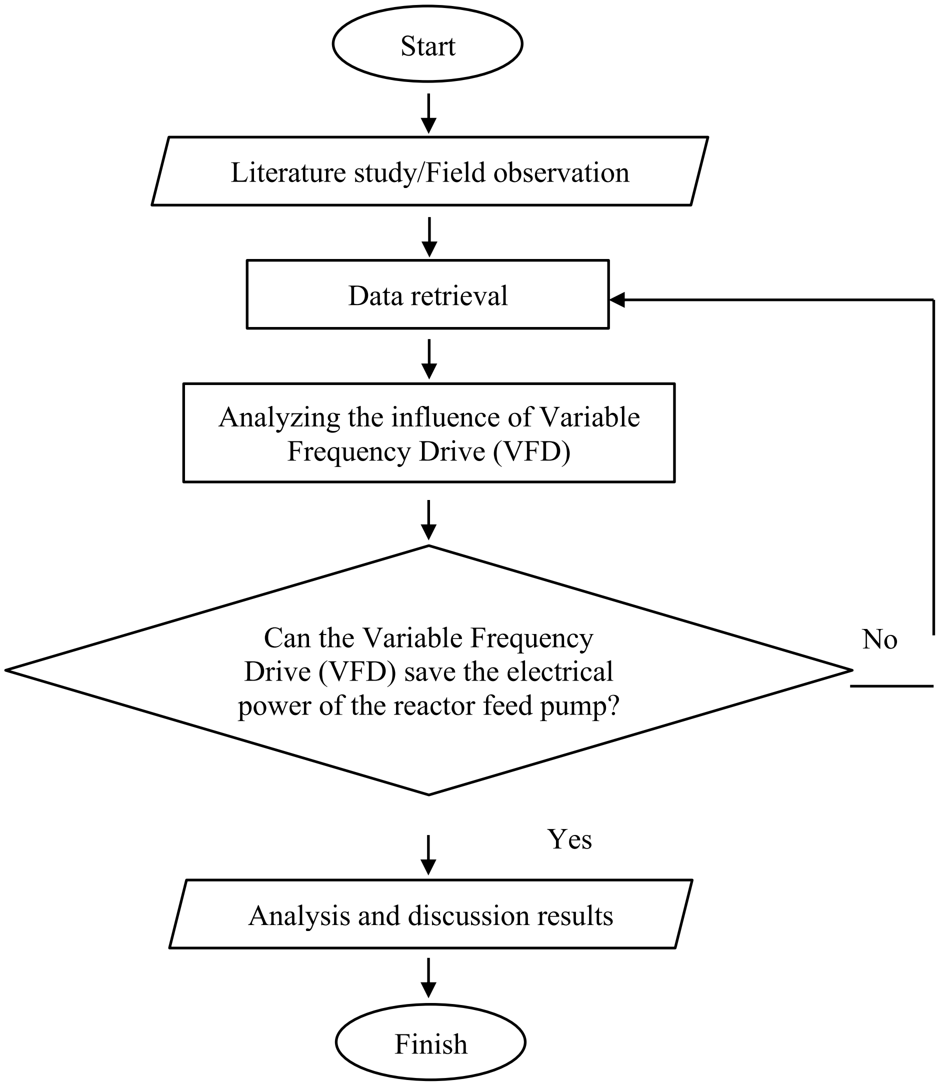

Figure 1. Flowchart

3.2 Research Location and Object

This research was conducted at the PT. Unilever Oleochemical Indonesia production facility, specifically in the hydrogen plant, in the reactor feed pump unit, which supplies liquid feedstock to the reactor process. This pump was selected based on its dynamic operating characteristics, which require periodic flow rate adjustments. Under these conditions, the pump is an ideal candidate for evaluating the application of a Variable Frequency Drive (VFD) as a motor speed controller.

3.3 Measurement Equipment

To ensure accuracy, several supporting instruments are used, including:

a. A DCS acts as a control center that sends command signals to the VFD. From this system, the operator can determine the setpoint for flow, pressure, or pump rotation speed according to the process requirements in the reactor.
b. The BOP displays important information from the VFD, such as output frequency, motor current, voltage, and operating status (RUN, STOP, or FAULT). This allows the operator to directly monitor the pump's condition without additional tools.

3.4 Reactor Feed Pump Induction Motor Specifications

The three-phase induction motor used to drive the hydrogen reactor feed pump at PT. UOI is essentially designed for heavy-duty, continuous operation. Its specifications include a supply voltage of 380–400 V at 50 Hz, an installed power typically in the tens of kilowatts range depending on the pump capacity, and a nominal speed of approximately 1,480 rpm for four-pole motors. The motor's operating current draw varies depending on the load but is always maintained within the nameplate limits to maintain high efficiency and prevent overheating. The motor also has a specific insulation class and protection rating, making it resistant to operating conditions in chemical plants, which are prone to high humidity and high temperatures. When combined with a VFD, the motor's speed can be flexibly adjusted to meet flow requirements, making its basic specifications not only a technical reference but also a foundation for energy efficiency and production process optimization efforts.

Table 1. Reactor Feed Pump Induction Motor Specifications

No.	Three Phase Induction Motor Specifications	Description
1.	Power	160 kW
2.	In	271 A
3.	Speed	2981 Rpm
4.	Voltage	400 V
5.	Frequency	50 Hz
6.	Cos phi	0,89
7.	Type	M3JP 315SMC 2 IMB3/IM1001
8.	IP	55
9.	Serial Number	3GF13175089
10.	DE Bearing	6316/C3
11.	NDE Bearing	6316/C3
12.	Manufacturer	ABB
13.	Connection Type	Delta
14.	Status Connection	VFD
15.	Remark	Hydrogen Plant

3.5 Reactor Feed Pump Operational Data

Data in this study was collected in real-time through the Variable Frequency Drive panel, also known as the Basic Operator Panel (BOP). Data collection on reactor feed pumps using Variable Frequency Drives used a set point when controlling the motor rotational speed, with a range of 10-100% of the motor or reactor feed pump rotational speed. To calculate the electrical power consumption of the reactor feed pump, the following formula was used:

$$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi \qquad (1)$$

Information:

P_{out} = Power

V = Voltage

I = Current

Cosφ = 0,89 (based on the electric motor nameplate)

$\sqrt{3}$ ≈ 1,732

Table 2. Set Point 10% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
10%	4,9	146,3	41,4	69,34

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$

$P_{out} = \sqrt{3} \text{ x } 41{,}4 \text{ x } 69{,}34 \text{ x } 0{,}89$

$P_{out} = 4425{,}2 \text{ Watt}$

$P_{out} = 4{,}43 \text{ kW}$

Table 3. Set Point 20% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
20%	9,9	294,7	80,6	67,32

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$

$P_{out} = \sqrt{3} \text{ x } 80{,}6 \text{ x } 67{,}32 \text{ x } 0{,}89$

$P_{out} = 8364{,}3 \text{ Watt}$

$P_{out} = 8{,}36 \text{ kW}$

Table 4. Set Point 30% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
30%	14,8	443,1	120,0	67,45

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$

$P_{out} = \sqrt{3} \text{ x } 120{,}0 \text{ x } 67{,}45 \text{ x } 0{,}89$

$P_{out} = 12477{,}1 \text{ Watt}$

$P_{out} = 12{,}48 \text{ kW}$

Table 5. Set Point 40% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
40%	19,7	591,5	159,1	70,64

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$

$P_{out} = \sqrt{3} \text{ x } 159{,}1 \text{ x } 70{,}64 \text{ x } 0{,}89$

$P_{out} = 17326,6$ Watt

$P_{out} = 17,33$ kW

Table 6. Set Point 50% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
50%	24,7	740,9	198,6	80,19

$P_{out} = \sqrt{3}$ x V x I x Cosφ

$P_{out} = \sqrt{3}$ x 198,6 x 80,19 x 0,89

$P_{out} = 24559,9$ Watt

$P_{out} = 24,56$ kW

Table 7. Set Point 60% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
60%	29,7	889,3	237,9	118,26

$P_{out} = \sqrt{3}$ x V x I x Cosφ

$P_{out} = \sqrt{3}$ x 237,9 x 118,26 x 0,89

$P_{out} = 43401,2$ Watt

$P_{out} = 43,40$ kW

Table 8. Set Point 70% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
70%	34,6	1037,7	277,3	155,65

$P_{out} = \sqrt{3}$ x V x I x Cosφ

$P_{out} = \sqrt{3}$ x 277,3 x 155,65 x 0,89

$P_{out} = 66460,1$ Watt

$P_{out} = 66,46$ kW

Table 9. Set Point 80% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
80%	39,5	1186,1	316,6	199,79

$P_{out} = \sqrt{3}$ x V x I x Cosφ

$P_{out} = \sqrt{3}$ x 316,6 x 199,79 x 0,89

$P_{out} = 97626,5$ Watt

$P_{out} = 97,63$ kW

Table 10. Set Point 90% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
90%	44,5	1334,5	355,4	251,14

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$
$P_{out} = \sqrt{3} \text{ x } 355{,}4 \text{ x } 251{,}14 \text{ x } 0{,}89$
$P_{out} = 137625{,}8 \text{ Watt}$
$P_{out} = 137{,}63 \text{ kW}$

Table 11. Set Point 100% on BOP VFD

Set Point	Frequency	Speed	Voltage	Current
100%	49,2	1483,9	348,7	345,45

$P_{out} = \sqrt{3} \text{ x V x I x Cos}\varphi$
$P_{out} = \sqrt{3} \text{ x } 348{,}7 \text{ x } 345{,}45 \text{ x } 0{,}89$
$P_{out} = 185719{,}8 \text{ Watt}$
$P_{out} = 185{,}72 \text{ kW}$

Results

To better understand the relationship between frequency changes in the VFD and the behavior of the three-phase induction motor that drives the reactor feed pump, operational data was recorded in stages from the 10% to 100% set point. The data collected included operating frequency, rotational speed, output voltage, current, and power consumption, as calculated in the previous chapter.

Table 12. Calculation Results of Electrical Power Consumption Data for Reactor Feed Pump

Percentage (%)	Frequency (Hz)	Speed (Rpm)	Vout (V)	Current (A)	Power (kW)
10	4,9	146,3	41,4	69,34	4,43
20	9,9	294,7	80,6	67,32	8,36
30	14,8	443,1	120,0	67,45	12,48
40	19,7	591,5	159,1	70,64	17,33
50	24,7	740,9	198,6	80,19	24,56
60	29,7	889,3	237,9	118,26	43,40
70	34,6	1037,7	277,3	155,65	66,46
80	39,5	1186,1	316,6	199,79	97,63
90	44,5	1334,5	355,4	251,14	137,63
100	49,2	1483,9	348,7	345,45	185,72

From measurements of a reactor feed pump driven by a three-phase induction motor via a VFD, it is clear that changes in frequency have a direct impact on the motor's rotational speed, output voltage, current, and power consumption. At 10% (4.9 Hz), the motor rotates at only around 146 rpm with a very low power output of approximately 4.43 kW. This reflects light-load operation, which also results in low fluid flow. However, as the frequency is gradually increased, energy consumption increases significantly. The most interesting trend appears when the motor passes the 50% point (24.7 Hz). At this point, the speed reaches 740 rpm, with a power output of approximately 24.56 kW. A current surge begins to be felt, reaching 80.19 A, even though the voltage remains relatively stable below 200 V. At 60% and 70%, the current rises sharply to 155 A, and the power more than doubles to 66.46 kW. This is in line with the affinity law of centrifugal pumps, that power requirements increase in proportion to the cube of the speed.

As the 80–100% setpoint approaches, this trend becomes even more pronounced. At 80% (39.5 Hz), the power consumption reaches nearly 100 kW, then increases again to 137.6 kW at 90%, finally reaching 185.7 kW at the full frequency of 49.2 Hz. At this maximum, the current is a very high 345.45 A, with an output voltage of 348.7 V. This energy surge in high-load areas demonstrates why VFD use is so important: without frequency regulation, the pump will always operate at maximum power, even though the process demand is not always that high. Comparing the 50% and 100% conditions, the power difference is significant: from 24.56 kW to 185.7 kW, or nearly eightfold. However, the resulting fluid flow does not increase eightfold, but rather follows a non-linear pump curve. In other words, this is where the energy efficiency opportunity lies. Pump operation at medium load with VFD can suppress electricity consumption well below full operating conditions, without sacrificing continuity of supply to the reactor.

These findings demonstrate that VFDs are not just speed control devices, but also key to more intelligent energy consumption management. For PT. UOI, this means VFDs can help balance reliable hydrogen reactor feed supply with significant power savings.

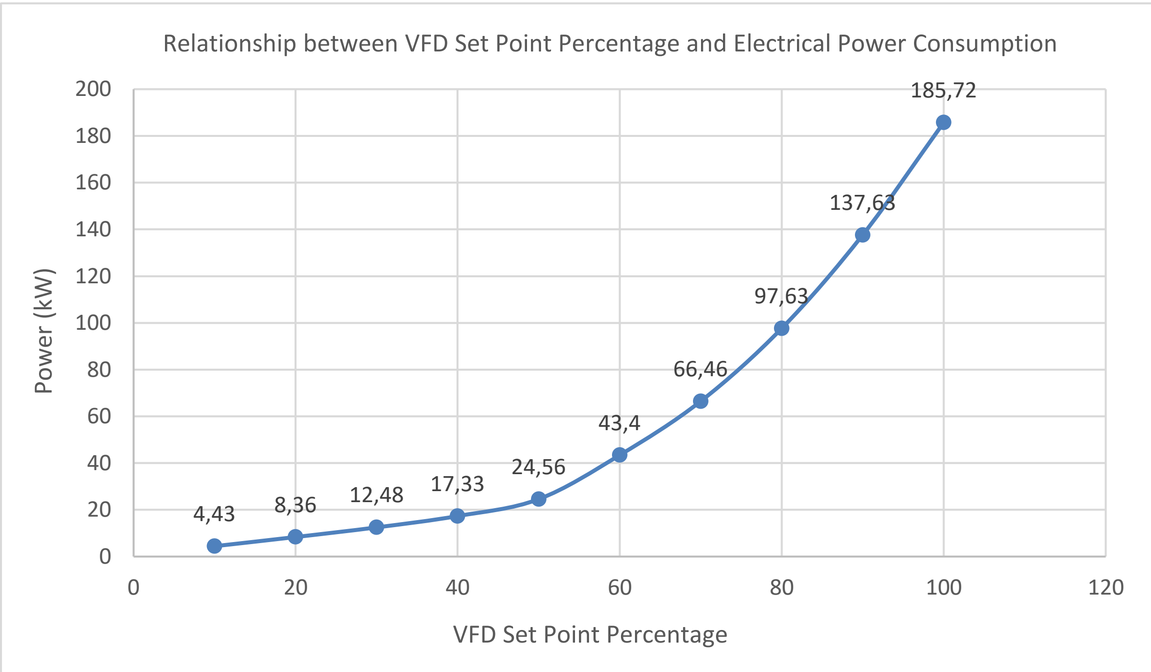

Figure 2. Relationship between VFD Set Point Percentage and Electric Power Consumption

The following graph shows the relationship between the VFD set point percentage and pump power consumption. The graph clearly shows that as the set point (frequency/motor speed) increases, power consumption increases sharply, especially after passing the 50% mark. This increase follows the law of pump affinity, where power increases as the cube of the speed.

Looking at the graph, pump power consumption increases slowly at first, but once the VFD set point passes the middle, the increase becomes very sharp. In the 10–30% range, the motor load is still light, with power only moving from around 4 kW to 12 kW, resulting in a flattening of the graph. Once it reaches 40–50%, the trend begins to steepen; at 50%, power is already 24 kW, and when it is increased slightly to 60%, it immediately exceeds 43 kW.

The most striking feature is in the upper area, 70–100%. Here, the graph really climbs sharply, almost like a jump. From 66 kW at 70% speed, the power jumps to almost 186 kW when the pump is running at full speed. So, even though the motor speed only increases by half from 70% to 100%, the electricity consumption nearly triples.

This figure shows that operating the pump at full capacity is actually energy-intensive, unless absolutely necessary. In fact, at the midpoint around 40–60% the pump is already supplying a stable flow to the reactor, yet still using significantly less electricity. This clearly demonstrates that a VFD is not just a speed control device, but also a strategy for maintaining efficiency, as it can select the operating point that best balances process needs and electricity consumption.

Conclusion

The use of a Variable Frequency Drive (VFD) on the reactor feed pump at PT Unilever Oleochemical Indonesia has been shown to significantly impact electrical power consumption. Data shows that at a low set point (10%), motor power is only 4.43 kW, while at full operation (100%) it jumps to 185.72 kW. The increase in frequency and motor speed is not directly proportional to the increase in power, because energy requirements increase much more sharply according to the pump affinity law. At intermediate levels, specifically 40–60%, the power required is still below 45 kW, but the pump is able to maintain a stable supply to the reactor. This confirms that the VFD functions not only as a speed regulator, but also as an energy efficiency tool, because it allows the pump to operate according to process requirements without having to always be at maximum load.

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