

Impact of Voltage Fluctuations on the Performance of Domestic Water Pumps

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تأثير تذبذبات الجهد الكهربائي على أداء مضخات المياه المنزلية

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Abstract:

Electricity distribution networks often experience voltage fluctuations and severe voltage drops, which can adversely affect the performance and reliability of domestic water-pumping systems. These voltage disturbances may result in reduced hydraulic performance, increased energy consumption, and disruptions in water delivery. This study investigates the effects of voltage fluctuations on the performance, efficiency, and operational reliability of a standard 0.5 horsepower HP, single-phase induction-motor-driven centrifugal water pump. Experimental data, including RMS voltage, current, flow rate, pumping head, and motor rotational speed, were recorded over a 500-second operating cycle. The measured field data were compared with those obtained from an idealized constant-power theoretical model. The experimental results indicate that voltage drops below the nominal operating level are associated with significant degradation in pump performance. Under the constant-power assumption, a decrease in supply voltage causes an increase in line current, thereby increasing stator copper losses and imposing greater thermal stress on the motor. Undervoltage conditions also reduce the motor's electromagnetic torque capability and can increase motor slip, resulting in reduced rotational speed. The resulting reduction in motor speed is accompanied by decreases in volumetric flow rate and pumping head, leading to a reduction in overall pump efficiency. In addition, an empirical second-order polynomial model was developed to characterize the relationship between water flow rate and supply voltage. The model accurately quantified and predicted the nonlinear variation in flow rate with changes in supply voltage, demonstrating a strong correlation with the experimental field data ($R^2 = 0.981$). These findings demonstrate the sensitivity of domestic induction-motor water pumps to the voltage fluctuations and highlight the operational risks associated with sustained undervoltage conditions. The developed empirical model provides a practical basis for characterizing pump performance under voltage instability and assessing the effects of voltage fluctuations on domestic water-pumping systems.

Keywords: Grid Voltage Drop; Voltage Fluctuations; Single-Phase Induction Motor; Domestic Water Pump; Pump Performance; Pump Efficiency; Empirical Modelling; Constant-Power Model.

المخلص

غالبًا ما تشهد شبكات توزيع الكهرباء انخفاضات حادة ومتكررة في الجهد الكهربائي، مما يؤثر بشكل مباشر في أداء أنظمة مضخات المياه السطحية المنزلية، وينتج عنه انخفاض في كفاءة التشغيل، وارتفاع في استهلاك الطاقة، وانقطاع في إمدادات المياه. تتناول هذه الورقة البحثية دراسة تجريبية لتأثير تذبذب الجهد الكهربائي وانخفاضه في مضخة طرد مركزي أحادية الطور تعمل بالتيار المتردد، بقدرة 0.5 حصان. وقد جرت مقارنة البيانات الميدانية المقاسة بالبيانات المستمدة من نموذج نظري مثالي يعتمد على مبدأ القدرة الثابتة. تُظهر النتائج مدى تأثير مضخات المياه المنزلية بتقلبات الجهد الكهربائي، إذ تبين أن انخفاض الجهد عن المستوى التشغيلي الاسمي يؤدي إلى تدهور ملحوظ في أداء المضخة. ويتعرض محركها لانخفاض حاد في سرعة الدوران، مما يؤدي بدوره إلى انخفاض كبير في معدل التدفق الحجمي للمياه. وتُبرز هذه النتائج مدى حساسية مضخات المياه المنزلية العاملة بمحركات حثية لتقلبات جهد الشبكة، كما تسلط الضوء على المخاطر التشغيلية المرتبطة بحالات انخفاض الجهد.

الكلمات المفتاحية: تذبذبات جهد الشبكة؛ هبوط جهد الشبكة؛ محرك حثي أحادي الطور؛ مضخة مياه منزلية؛ أداء المضخة؛ التجربة الميدانية؛ نموذج القدرة الثابتة.

Introduction

Power distribution networks are frequently subject to voltage fluctuations, in which the supply voltage continuously varies above and below its nominal value over time [1]. These fluctuations can result in unpredictable operating conditions, with voltage drops representing one of the most critical disturbances in electrical power systems. Voltage drops are among the most common power-quality problems encountered in electrical distribution networks [2]. The voltage drop is the difference in voltage between the power source and the load. It is the decrease in voltage across the components of a circuit. In addition, the voltage across the components is lower than the source voltage. Voltage drop occurs mainly due to the impedance of electrical conductors. In an electrical distribution network, this drop depends on several factors such as the properties of the conductors, including their length, cross-sectional area, material, and resistance. It also depends on the load current, power factor, system configuration, and operating temperature. Voltage drop affects system performance and electrical equipment. It may result in lighting problems, motor overheating, reduced motor torque, increased electrical losses, and lower equipment efficiency, particularly in pumps [3]. Pumps are the most common motor application in electrical distribution networks [4], [5]. Electric pumps are used in locations where water does not flow by gravity [6]. One of the most widely used types of pumps is the surface domestic water pump [7 and 8]. Most domestic surface pumps are driven by single-phase induction motors and therefore depend on the quality and stability of the electrical supply. Pumps are used in residential buildings to supply water from storage tanks and distribution systems. Undervoltage is one of the most critical voltage problems affecting domestic water pumps. When the supply voltage falls below the rated value, the motor may fail to develop sufficient electromagnetic torque to drive the required pumping load. In addition, the electromagnetic torque developed by an AC induction motor is approximately proportional to the square of the applied voltage. Therefore, even a small voltage drop can cause a significant reduction in the available torque. Moreover, excessive voltage reduction can increase motor current and temperature, reduce hydraulic performance, increase energy losses, and contribute to premature equipment failure. Proper electrical system design, adequate conductor sizing, reliable connections, and continuous monitoring of the supply voltage are therefore essential for maintaining safe and efficient pump operation. Understanding the relationship between voltage quality and pump performance can contribute to improved residential water-supply reliability, reduced maintenance requirements, and extended equipment service life.

This study investigates the effects of voltage fluctuations on the performance of domestic water pumps. The study evaluates pump performance degradation under voltage variations ranging from 180 V to 250 V, with a nominal supply voltage of 220 V. Synchronized measurements of voltage, current, rotational speed, pressure head, and flow rate were captured. These data quantify the link between voltage reductions and hydraulic output loss. An idealized constant-power model was formulated as a baseline. In addition, a second-order polynomial model was validated against experimental data. This model characterizes the non-linear relationship between supply voltage and discharge flow rate. Furthermore, the study evaluates risks from elevated motor current during low-voltage conditions.

Methodology

This study investigates the impact of voltage fluctuations on the performance, efficiency, and operational reliability of domestic single-phase induction-motor water pumps. The experimental methodology integrates empirical field measurements with theoretical modeling under conditions of voltage instability. Electrical parameters (voltage and current draw) and hydraulic/mechanical parameters (flow rate, head pressure, and motor

rotational speed) were recorded directly from an operational underground storage tank system. Subsequently, the measured field data were benchmarked against an idealized constant-power theoretical model to evaluate operational efficiency and deviations from the theoretical performance. The instrumentation suite comprised voltage and current transducers for continuous measurement of the electrical input. The instantaneous water flow rate was measured using a digital flow meter, the motor rotational speed was recorded using an optical tachometer, and the water head pressure was measured using a piezoresistive pressure transducer. Performance data were continuously recorded over a 500 s sampling period (~8 min). Electrical and hydraulic pump parameters were calculated in accordance with [9 and 10]. To assess the fidelity of the measured performance, the experimental data were statistically analyzed and benchmarked against the ideal constant-power model, expressed as:

$$I = \frac{P}{V} \quad (1)$$

where I is the root-mean-square (RMS) the line current, V is the RMS line voltage, and P represents the baseline active electrical input power.

The active electrical input power of the single-phase induction motor driving the water pump is defined by the following equation:

$$P_{in} = V I \cos \phi \quad (2)$$

where P_{in} is the active electrical input power, V is the root-mean-square line voltage, I is the RMS line current, and $\cos \phi$ is the power factor.

The electromagnetic torque generated by the induction motor is dependent on the supply voltage. Under simplified operating conditions, the electromagnetic torque is approximately proportional to the square of the applied voltage:

$$T_e \propto V^2 \quad (3)$$

where T_e is the electromagnetic torque and V is the applied voltage

The rotational speed of a single-phase induction motor is related to its synchronous speed and slip. The synchronous speed is determined by the supply frequency and the number of motor poles and is expressed as:

$$N_s = \left(\frac{120 f}{p} \right) \quad (4)$$

The actual rotor speed is given by:

$$N = (1-s) \cdot N_s \quad (5)$$

Therefore, N is given by:

$$N = (1-s) \cdot \left(\frac{120 f}{p} \right) \quad (6)$$

where N is the actual motor rotational speed (rpm), N_s is the synchronous speed (rpm), s is the motor slip (per unit), f is the supply frequency (Hz), and p is the number of motor poles.

The physical coupling between motor rotational speed and hydraulic delivery is governed by the centrifugal pump affinity laws:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad (7)$$

Where Q_1 and Q_2 are the volumetric flow rates, and N_1 and N_2 are the corresponding rotational speeds.

The corresponding relationship for the total pumping head is given by:

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2} \right)^2 \quad (8)$$

Where H_1 and H_2 are the corresponding total pumping heads.

The electrical losses in the pump motor windings can be approximated using the Joule heating relationship:

$$P_{loss} = I^2 R \quad (9)$$

where P_{loss} represents the copper losses in the motor windings and R represents the effective winding resistance. Hydraulic output power can be estimated from:

$$P_h = \rho g Q H \quad (10)$$

where P_h is the hydraulic output power, ρ is the density of water, g is the gravitational acceleration, Q is the volumetric flow rate, and H is the pumping head.

The volumetric flow rate (Q) can also be expressed in terms of volume delivered over time:

$$Q = \frac{V_{vol}}{t} \quad (11)$$

Where V_{vol} is the water volume in m^3 and t is the time in second.

The average water flow velocity (V) in m/s inside the discharge pipe is determined by:

$$V = \frac{Q}{A} \quad (12)$$

Where A is pipe cross-sectional area in square meters calculated by:

$$A = \frac{\pi d^2}{4} \quad (13)$$

Where π equals 3.14 and d is the internal pipe diameter in meters.

Overall pump efficiency η is evaluated as the ratio of water output power to active electrical input power:

$$\eta = \frac{P_h}{P_{in}} \times 100 \quad (14)$$

where η is the percentage pump efficiency, P_h is the hydraulic output power, and P_{in} is the active electrical power input.

The relationship between the water flow rate and the applied RMS voltage was modeled using a second-order polynomial:

$$Q(V) = a \cdot V^2 + b \cdot V + c \quad (15)$$

Where $Q(V)$ is the water flow rate as a function of the RMS line voltage V , and a , b , and c are empirical coefficients obtained by fitting the model to the measured experimental data.

Results:

The performance of a 0.5-hp domestic water pump was evaluated under varying voltage conditions and under constant-power operation using the theoretical model. The electrical voltage, electric current, water flow rate, pump head, and pump speed were measured over a period of 500 seconds. The pump system's discharge was characterized. The results obtained under variable-power conditions and under constant-power were compared.

Figure 1 presents a time-series line graph showing the measured voltage over a period of 500 seconds. The primary x-axis represents time in seconds (s), ranging from 0 to 500, while the primary y-axis represents voltage in volts (V), ranging from 140 to 260. The graph features a highly volatile solid black line representing the measured voltage data. To provide context for this data, three horizontal dashed reference lines are included: A black line at 220 V indicates the nominal voltage, a red line at 198 V indicates the 90% threshold, and a magenta line at 176 V indicates the 80% threshold.

The measured voltage varies significantly over the observation period. From 0 to approximately 150 seconds, the voltage fluctuates erratically but generally remains around or above the nominal 220 V level, oscillating mostly between 210 V and 245 V. This is followed by a sharp and significant drop between 150 and 250 seconds, during which the voltage falls well below the nominal level, frequently dipping below the 198 V threshold and reaching a minimum of approximately 180 V around the 180–200-second mark. Following this low-voltage period, the voltage begins a steady recovery and rises rapidly. Between 250 and 400 seconds, the measured voltage surges above the nominal 220 V level, peaking at approximately 250 V near the 350-second mark. After this peak, the voltage gradually declines toward the nominal level, fluctuating around 220 V from 400 to 500 seconds, with occasional dips back to the 90% threshold. Overall, the graph demonstrates that the measured voltage is highly unstable, with periods of significant deviation both above and below the nominal 220 V level.

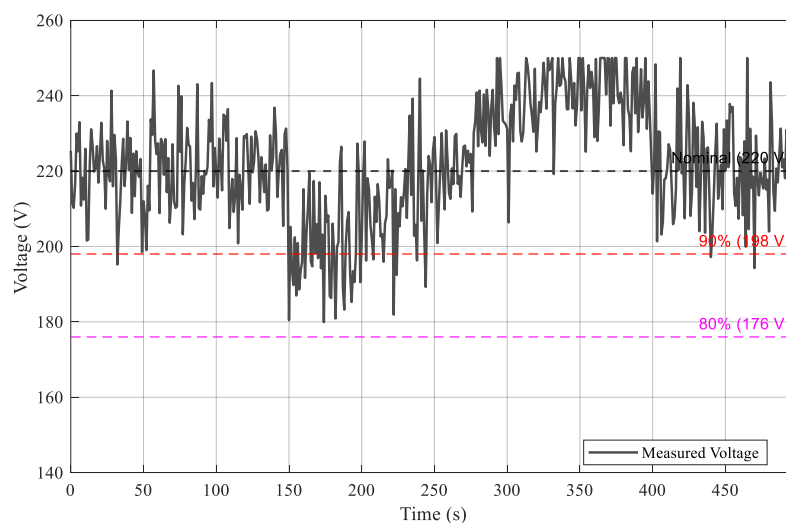


Figure 1 Measured Input Voltage Profile of the Domestic Water Pump.

Time-Series Voltage Characteristics is presented in Table 1 that outlines the chronological behavior of the measured voltage from time 0 to 500 hours.

Table 1: Time-Series Voltage Characteristics

Time Interval (s)	Voltage Behavior	Threshold Crossings	Approximate Range (V)
0 - 150	Erratic fluctuation, generally above nominal	Stays above 90% (198V) threshold	210 - 245
150 - 250	Sharp, significant drop	Dips below 90% (198V), approaches 80% (176V)	180 - 220
250 - 400	Rapid recovery and surge	Crosses nominal (220V) upward	220 - 250
400 - 500	Gradual decline back to baseline	Occasionally touches 90% (198V) threshold	198 - 235

Figure 2 presents the experimentally measured voltage and current alongside the values obtained from the theoretical model, providing a comparison between the two. The primary x-axis represents voltage, ranging from 140 V to 260 V, while the primary y-axis represents current, ranging from 2 A to 5.5 A. A color bar on the right adds a secondary visual dimension by mapping the voltage of each circular marker from dark blue (lower voltages, around 180 V) through green to yellow (higher voltages, near 250 V). The measured data are represented by these colored circles, which exhibit a broad inverse relationship: as voltage increases, the current generally tends to decrease.

The theoretical data, given by $I=P/V$, represent an idealized constant-power curve shown as a red dashed line overlaid on the measured data. This theoretical line illustrates a perfect inverse proportionality, assuming a fixed power level of approximately 720 W (for example, 3.6 A at 200 V). Although the measured data generally follow the downward trajectory of this theoretical curve, they exhibit significant scatter and deviation. A large proportion of the data points, particularly those between 190 V and 230 V, lie above the red dashed line, indicating that the actual current draw is higher than that predicted by the constant-power model. Conversely, several data points, particularly at higher voltages above 230 V, fall below the theoretical line. This wide dispersion highlights the inherent variability and inefficiencies of the system under field conditions. It also demonstrates that the actual load does not behave as a perfect constant-power source.

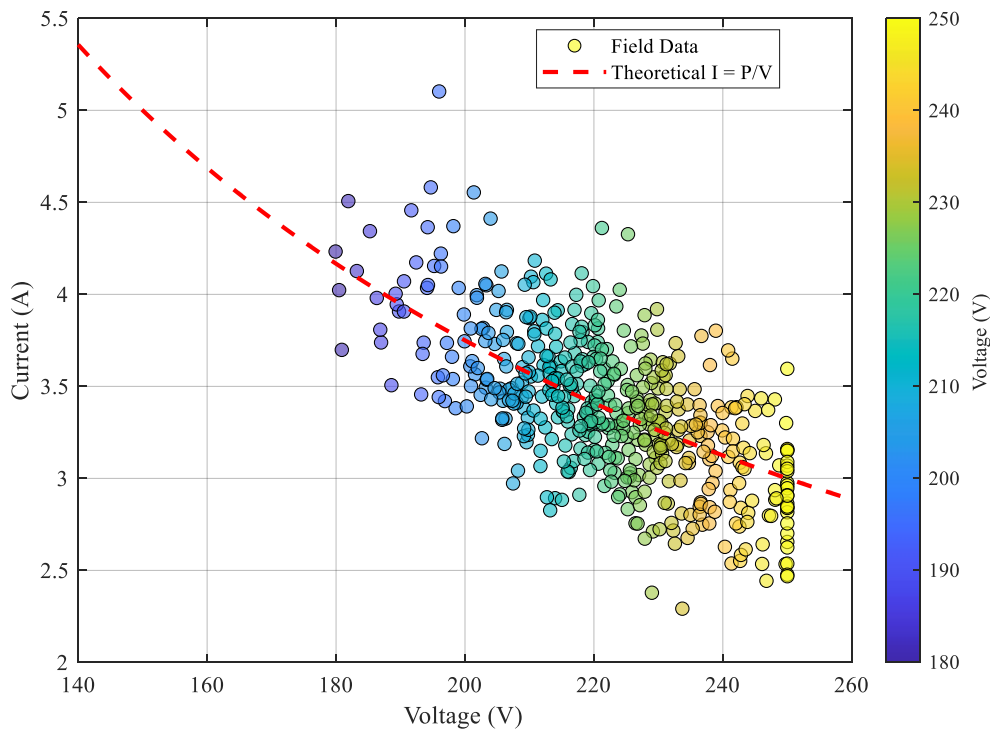


Figure 2. Voltage–current characteristic of the load: comparison of measured data with the theoretical constant-power model.

The Voltage vs. Current *along the flow rate data are tabulated in Table 2* which summarizes the mathematical and theoretical relationships observed in the field data.

Table 2: Voltage vs. Current and Flow Rate Relationships

Variable Relationship	Observed Trend	Theoretical/Model Fit	Key Observations
Voltage vs. Current	Inverse (Negative)	Theoretical $I = P/V$ (Constant Power ~720W)	Field data shows significant scatter. Higher-than-theoretical current draw occurs between 190V-230V. Lower-than-theoretical current draw occurs above 230V.
Voltage vs. Flow Rate	Positive (Non-linear)	Quadratic Fit	Flow rate ranges from ~2.0 m ³ /h (at 180V) to ~3.8 m ³ /h (at 250V). Accelerated growth (concave-up) occurs above 220V.

Figure 3 illustrates the relationship between voltage and flow rate, demonstrating a strong, nonlinear positive correlation. The x-axis represents voltage, ranging from 170 to 250 V, while the y-axis represents flow rate, ranging from 2.0 to 4.0 m³/h. A color bar on the right provides an additional visual dimension by mapping the voltage of each data point from dark blue (lower voltages, around 180 V) through green to yellow (higher voltages, around 250 V). The measured data, represented by colored circular markers, show a clear upward trend, with the flow rate increasing as the voltage increases. The data points are tightly clustered around the central trend, indicating a relatively consistent relationship with low variability.

A solid red line overlaid on the data represents the “Quadratic Fit,” which closely models the observed relationship, with an R² value of 0.981. This high coefficient of determination indicates that the quadratic model provides a close fit to the measured data. The choice of a quadratic fit is further supported by the observed concave-upward trend, with the flow rate increasing at a faster rate at higher voltages (above 220 V) than at lower voltages.

The graph demonstrates that the flow rate does not increase linearly with voltage but instead follows a nonlinear, approximately quadratic growth pattern. As the system voltage rises from 180 V to 250 V, the flow rate nearly doubles, increasing from approximately 2.0 m³/h to nearly 3.8 m³/h, with the steepest increase occurring in the upper voltage range. The tight clustering of the measured data around the quadratic fit line, together with the R² value of 0.981, suggests that the quadratic model provides an accurate representation of the system’s observed performance.

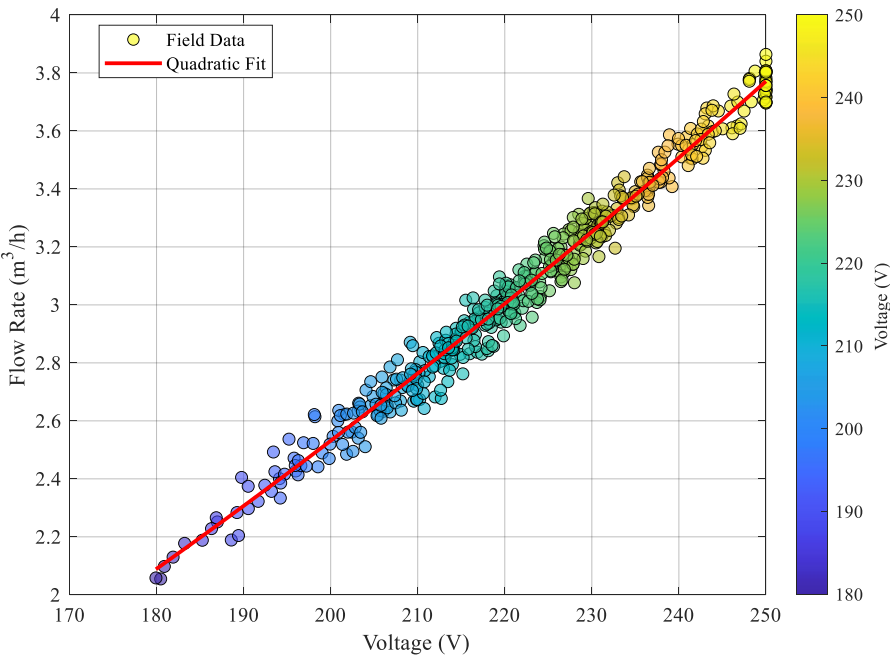


Figure 3. Voltage–flow rate characteristic (R² = 0.981).

Figure 4 illustrates the distribution of flow rate across three distinct operational conditions. The y-axis represents flow rate, ranging from 2.0 to 3.4 m³/h, while the x-axis categorizes the data into three groups: Normal (blue), Slight drop (yellow/orange), and Moderate drop (red).

The normal category, displayed on the far left, exhibits the highest overall flow rates. The blue box plot shows a median flow rate of approximately 3.0 m³/h. The interquartile range (IQR), representing the middle 50% of the data, spans approximately 2.88 to 3.15 m³/h, as indicated by the box. The whiskers, which extend to values within $1.5 \times \text{IQR}$, range from approximately 2.65 to 3.38 m³/h. This group exhibits the widest spread of the data and contains no visible outliers.

Moving to the middle, the Slight Drop category shows a noticeable decrease in flow rate, with the median dropping to approximately 2.65 m³/h. The interquartile range is noticeably narrower than that of the normal group, ranging from approximately 2.6 to 2.7 m³/h, indicating lower variability among the central 50% of the data. The whiskers extend from approximately 2.46 to 2.81 m³/h. This category contains a single outlier, represented by a small orange circle below the lower whisker at approximately 2.45 m³/h.

The moderate drop category, shown on the right, displays the lowest overall flow rates and the greatest deviation from the normal condition. The median flow rate is the lowest of the three categories, at approximately 2.39 m³/h. The interquartile range spans approximately 2.22 to 2.44 m³/h, indicating a wider spread than the slight drop category but a narrower spread than the Normal condition. The whiskers extend from approximately 2.06 to 2.54 m³/h, with no visible outliers in this group.

Overall, the box plot demonstrates a clear, progressive decline in flow rate as the condition changes from normal to slight drop and then to moderate Drop. The median flow rate decreases substantially across the three categories, while the overall spread of the data remains relatively consistent, except for the tighter clustering observed in the slight drop category and the presence of a distinct low-value outlier in the same group.

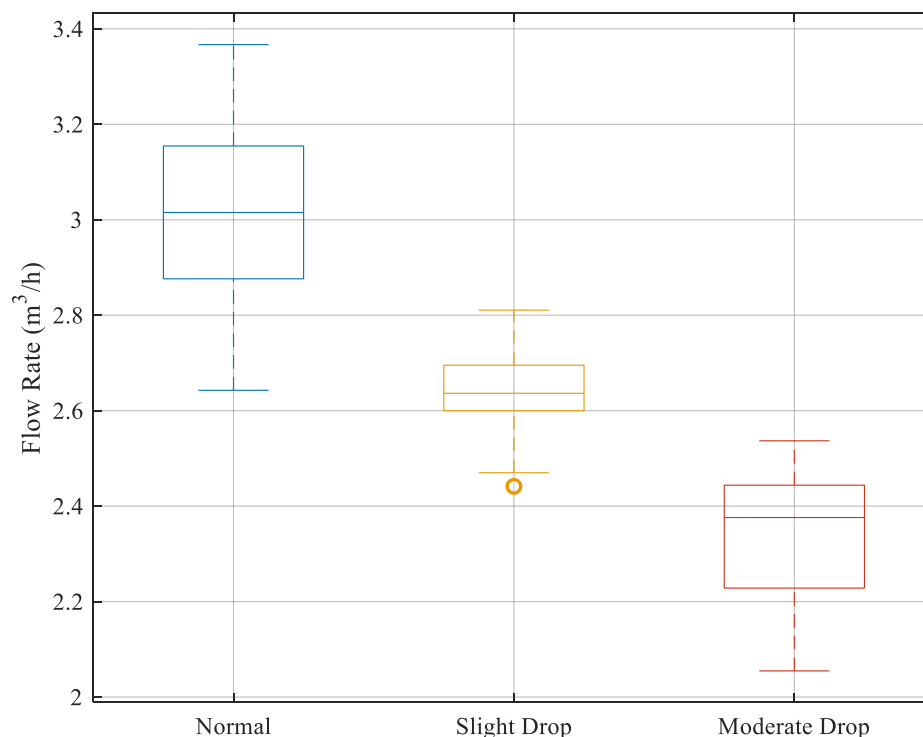


Figure 4: Flow Rate Distribution Across Voltage Bands

Table 3 summarizes the overall impact of voltage drops on the pump's mechanical and electrical performance.

Table 3: Mean Performance Metrics by Voltage Band

Voltage Band	Mean Flow Rate (m ³ /h)	Mean Head (bar)	Mean Speed (rpm)	Mean Current Draw (A)	Efficiency Proxy (Ratio)	Sample Count
Normal	~3.1	~2.6	~2900	~3.4	~1.0	~280
Slight Drop	~2.7	~2.3	~2700	~3.7	~1.0	~80
Moderate Drop	~2.3	~2.0	~2500	~4.0	~1.0	~50
Severe Drop	~2.3	~2.0	~2500	~4.1	~1.05	~30

Figure 5 illustrates the relationship between voltage, shown on the x-axis and ranging from 180 to 250 V, and normalized performance (p.u.), with the y-axis ranging from 0.6 to 1.3. The figure simultaneously presents three variables: Flow rate, represented by the blue line; Head, represented by the red line; and Speed, represented by the green line.

Overall, all three normalized parameters exhibit an increasing trend with voltage, indicating that the performance metrics generally increase as voltage increases. The green line, representing normalized Speed, is the smoothest and most stable of the three, demonstrating a steady, nearly linear increase from approximately 0.76 p.u. at 180 V to about 1.10 p.u. at 250 V. In contrast, both the flow rate and head lines exhibit noticeable fluctuations throughout the voltage range. While all three lines remain closely clustered at lower voltages (180–200 V), they begin to diverge noticeably as the voltage increases. Above 200 V, the flow rate line begins to diverge from the other two lines, consistently maintaining higher normalized values and ultimately reaching the highest peak, at approximately 1.25–1.30 p.u., at 250 V.

The head line also exhibits considerable fluctuations but generally remains below the flow rate line above 210 V, ending at approximately 1.20 p.u. Meanwhile, the head and speed lines frequently intersect between 210 V and 235 V, indicating periods in which normalized head temporarily exceeds or falls below normalized Speed.

Overall, the figure demonstrates that while speed increases predictably with voltage, both flow rate and head exhibit greater variability, with flow rate showing the most pronounced overall increase relative to its rated value at higher voltages.

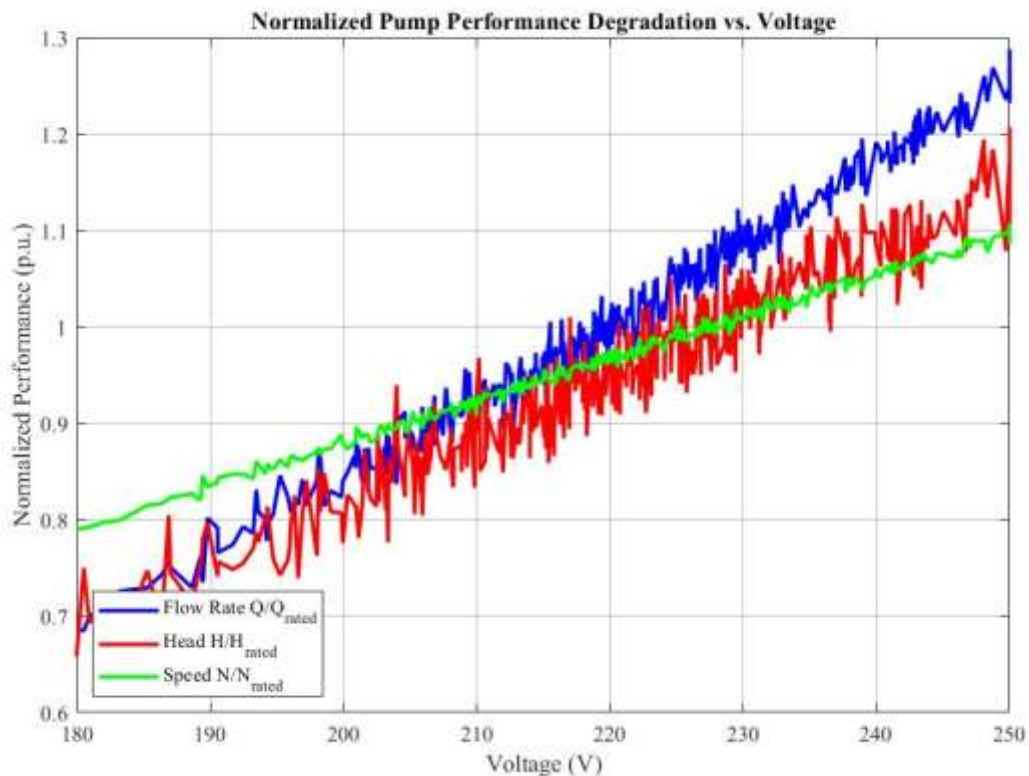


Figure 5: Normalized Pump Performance Variation with Voltage;

This table compares how different pump parameters respond to increasing voltage.

Table 4: Normalized Performance Trends vs. Voltage

Normalized Parameter	Trend Direction	Volatility	Observed Range (180V to 250V)
Speed (N/N_{rated})	Positive, Linear	Low (Smooth curve)	~0.76 to ~1.10 p.u.
Head (H/H_{rated})	Positive	High (Erratic fluctuations)	~0.68 to ~1.20 p.u.
Flow Rate (Q/Q_{rated})	Positive, Accelerating	High (Erratic fluctuations)	~0.75 to ~1.30 p.u.

Figure 6 presents data evaluating the pump’s performance across four distinct voltage conditions: Normal, Slight Drop, Moderate Drop, and Severe Drop. The color scheme consistently uses blue for Normal, yellow for Slight Drop, orange for Moderate Drop, and dark red for Severe Drop.

The first row of charts focuses on the pump’s physical and mechanical performance. Subplots (a) Flow Rate, (b) Head, and (c) Pump Speed all demonstrate a clear, monotonic downward trend as the voltage condition deteriorates. Specifically, the mean flow rate decreases progressively from approximately 3.1 m³/h under Normal conditions to approximately 2.3 m³/h under Severe Drop conditions. Similarly, the mean head pressure decreases from about 2.6 bar to 2.0 bar, while the pump speed decreases from nearly 2900 rpm to approximately 2500 rpm. These results indicate that as the voltage decreases, the pump’s ability to deliver water and generate pressure is significantly reduced.

The second row highlights the electrical and operational consequences of the voltage drops. Subplot (d), Current Draw, shows an inverse relationship with the mechanical performance metrics. As the voltage condition deteriorates from Normal to Severe Drop, the mean current draw increases from approximately 3.3 A to over 4.0 A. This behavior is characteristic of induction motors, which can draw increased current under reduced-voltage conditions as they attempt to maintain the required torque and power output, potentially increasing the risk of overheating.

Subplot (e), Efficiency Proxy, shows a very slight upward trend, remaining close to a ratio of 1.0 and increasing to approximately 1.05 under the Severe Drop condition. This suggests that, despite the overall degradation in pump performance, the ratio of useful work to input energy, as defined by this specific proxy, remains relatively stable or increases marginally according to the calculation used.

Subplot (f), Data Distribution, provides important context for interpreting these results. It displays the sample count for each voltage condition, revealing a highly unbalanced dataset. The Normal condition dominates, with nearly 280 samples, while the Slight Drop and Moderate Drop categories contain significantly fewer samples, with approximately 80 and 50 samples, respectively. The Severe Drop condition has the lowest sample count, at approximately 30 samples.

The unequal sample sizes should be considered when interpreting the mean performance metrics. In particular, the metrics for the more severe voltage-drop conditions are based on substantially smaller sample sizes, which may reduce their statistical robustness compared with the Normal baseline.

This table provides a statistical breakdown of flow rate variability under different operational conditions.

Table 5: Flow Rate Distribution Statistics

Condition	Median Flow Rate (m ³ /h)	Interquartile Range (IQR) (m ³ /h)	Whisker Range (Min - Max) (m ³ /h)	Outliers
Normal	~3.00	2.88 - 3.15	2.65 - 3.38	None
Slight Drop	~2.65	2.60 - 2.70	2.46 - 2.81	1 (at ~2.45 m ³ /h)
Moderate Drop	~2.39	2.22 - 2.44	2.06 - 2.54	None

The figure illustrates that voltage drops are associated with reduced pump mechanical performance and increased electrical current draw, while the efficiency proxy remains relatively stable according to the specific calculation used.

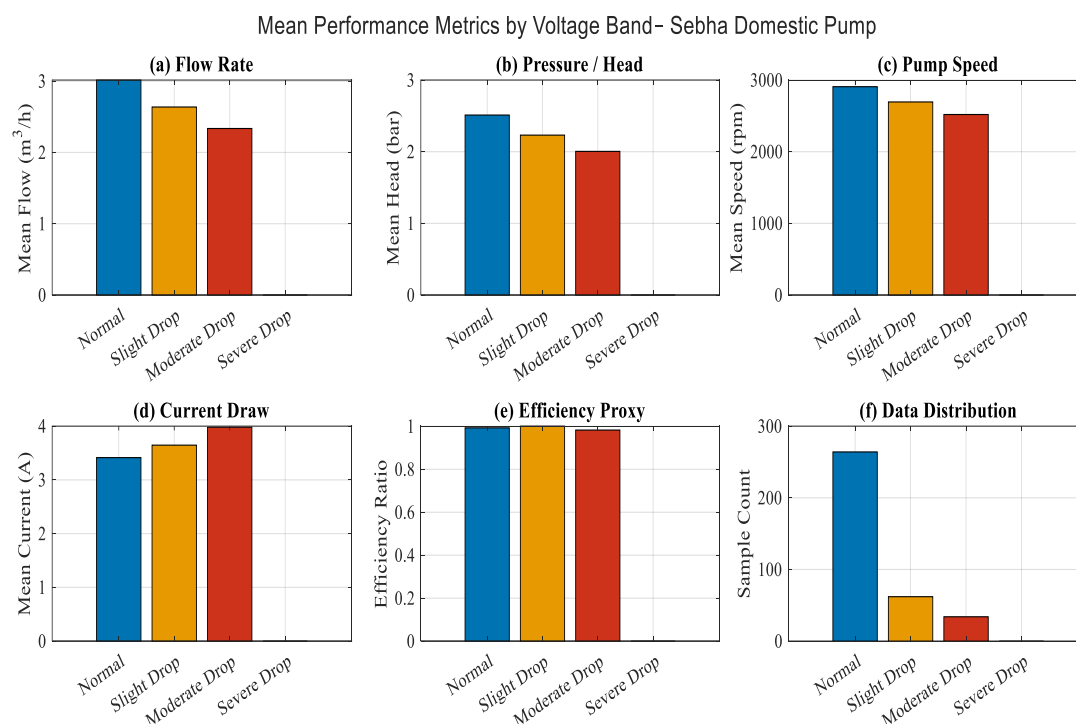


Figure 6. Mean Performance Metrics by Voltage Band for the Domestic Water Pump

Conclusion

This study investigates the performance of a domestic water pump under voltage fluctuations ranging from 180 V to 250 V, relative to a nominal supply voltage of 220 V. The system's discharge capacity exhibits a nonlinear response. Voltage reductions significantly impair the pump's operational performance. Specifically, an 18.18% drop from the nominal supply voltage leads to a 13.79% decrease in pump speed and reduces the water flow rate to 33.33% of its nominal value. To compensate for this lower voltage, the pump's induction motor increases its current draw by 21.21%, subjecting the system to elevated thermal stress and escalating the risk of motor overheating during prolonged low-voltage operation. These findings underscore the critical need for voltage-stabilization mechanisms to ensure consistent water delivery and safeguard domestic pumping systems against performance degradation and hardware failure.

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