A CALCULATION-BASED APPROACH TO ASSESSING ENERGY EFFICIENCY IMPROVEMENT IN IRRIGATION PUMPING STATIONS

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Abstract: Irrigation pumping stations consume significant electrical energy to convey water under varying hydraulic conditions. This study presents a calculation-based method for assessing energy efficiency using hydraulic power, specific energy consumption, and pump affinity laws. A normalized example shows that reducing rotational speed to 80% of its reference value theoretically reduces shaft power by 48.8%. Actual energy savings depend on system characteristics, equipment efficiency, and water demand. The proposed method supports preliminary energy performance assessment and optimization.

Keywords: irrigation pumping station; energy efficiency; electric drive; variable-frequency drive; specific energy consumption; pump affinity laws.

Аннотация: Ирригационные насосные станции потребляют значительное количество электроэнергии для транспортировки воды в изменяющихся гидравлических условиях. В статье предложен расчётный метод оценки энергетической эффективности на основе гидравлической мощности, удельного расхода электроэнергии и законов подобия насосов. Расчётный пример показывает, что снижение частоты вращения до 80 % от исходного значения теоретически уменьшает мощность на валу на 48,8 %. Фактическая экономия зависит от характеристик системы, КПД оборудования и потребности в воде. Метод может применяться для предварительной оценки и оптимизации энергопотребления.

Ключевые слова: ирригационная насосная станция; энергетическая эффективность; электропривод; частотный преобразователь; удельный расход электроэнергии; законы подобия насосов.

Annotatsiya: Sug‘orish nasos stansiyalarida elektr energiyasi sarfini kamaytirish muhim vazifalardan biridir. Maqolada gidravlik quvvat, solishtirma

energiya sarfi va nasoslarning o‘xshashlik qonuniyatlari asosida energetik samaradorlikni baholash usuli taklif etilgan. Hisoblash misolida aylanish tezligini 80 foizgacha kamaytirish nazariy val quvvatini 48,8 foizga kamaytirishi ko‘rsatilgan. Haqiqiy energiya tejalishi tizim xususiyatlari, uskunalar samaradorligi va suv talabiga bog‘liq. Usul dastlabki baholash va energiya sarfini optimallashtirish uchun qo‘llanilishi mumkin.

Kalit so‘zlar: sug‘orish nasos stansiyasi; energetik samaradorlik; elektr yuritma; chastota o‘zgartirgich; solishtirma energiya sarfi; nasoslarning o‘xshashlik qonuniyatlari.

1. Introduction: Pumping stations are important energy-consuming components of irrigation infrastructure because electrical energy is converted into hydraulic energy to raise water and overcome conveyance resistance. Their performance is affected not only by the nominal efficiency of individual pumps and motors, but also by the way operating equipment is matched to actual water demand. A pump that operates far from its best-efficiency region, or a station that supplies more water or head than required, may consume energy inefficiently. System-level assessment is therefore more informative than evaluating the pump or motor in isolation [1, 2].

Variable-speed control can adapt pump operation to changing demand and may reduce energy consumption when a fixed-speed pump is otherwise controlled by throttling or operated away from its appropriate duty point. Nevertheless, the benefit is system-dependent. The classical affinity laws provide useful first-order relationships between rotational speed, discharge, head, and power, but they are approximate and do not fully describe changes in efficiency or the effects of static head and system characteristics [2, 3].

The aim of this study is to formulate a transparent calculation procedure for preliminary assessment of energy efficiency in irrigation pumping stations and to demonstrate, using normalized calculations, how rotational speed influences key hydraulic and energetic indicators. The contribution is methodological: the paper

sets out measurable indicators and a screening calculation that can later be calibrated with station-specific field data.

2. Materials and Methods: The assessment framework is intended for a pumping unit consisting of a centrifugal pump, electric motor, and—where installed—a variable-frequency drive (VFD). The minimum field dataset should include discharge Q (m^3/s), total head H (m), active electrical input power P_el (kW), rotational speed n (r/min or relative units), and operating duration. Where possible, pressure at suction and discharge, water levels, voltage, current, power factor, and the status of each operating pump should also be recorded.

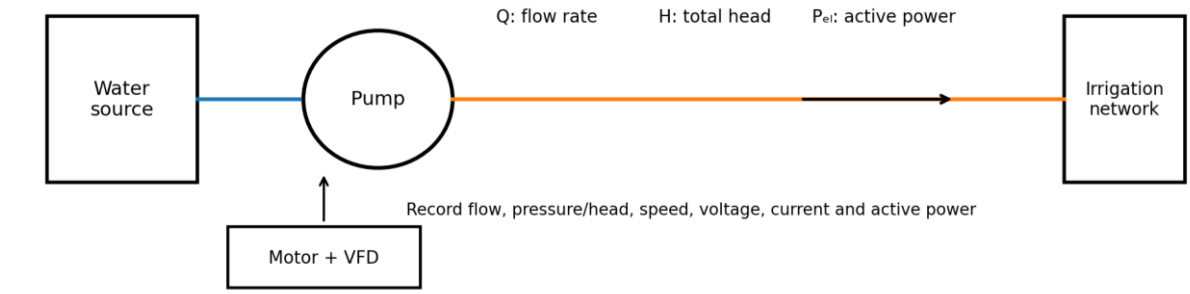


Figure 1. Conceptual arrangement of a pumping unit and the main variables required for energy assessment.

2.1. Hydraulic power and overall efficiency: The hydraulic power transferred to water is calculated as:

$$P_h = \rho g Q H / 1000 \text{ (kW)} \quad (1)$$

where ρ is water density (approximately 1,000 kg/m^3 under ordinary conditions), g is gravitational acceleration (9.81 m/s^2), Q is discharge (m^3/s), and H is total head (m). When P_{el} is measured at the electrical input to the complete pumping unit, the wire-to-water efficiency is estimated as:

$$\eta_{(ww)} = P_h / P_{el} \times 100\% \quad (2)$$

The measurement boundary must be stated clearly. If electrical power is measured upstream of the VFD, the calculated efficiency includes drive losses; if measured at the motor terminals, it does not include losses upstream of that point.

2.2. Specific energy consumption: The specific electrical energy consumption per unit volume of delivered water is:

$$e = E_{el} / V \ (kWh/m^3) \ (3)$$

where E_{el} is electrical energy consumed during the assessment period (kWh) and V is the corresponding delivered water volume (m^3). For comparisons between operating modes, both quantities must refer to the same time interval and the same measurement boundary.

2.3. First-order effect of rotational speed: For geometrically similar operating conditions and approximately unchanged efficiency, the classical affinity relationships for a centrifugal pump can be written in normalized form as:

$$Q_2 / Q_1 \approx n_2 / n_1; \ H_2 / H_1 \approx (n_2 / n_1)^2; \ P_2 / P_1 \approx (n_2 / n_1)^3. \ (4)$$

These relationships are used here only for a normalized screening example. They do not replace the pump performance curve or the system curve. In particular, static head can prevent discharge from changing linearly with speed, while pump, motor, and VFD efficiencies may vary with the operating point [2, 3].

3. Results: Because no measured dataset from a named pumping station was supplied for this draft, the results below are an illustrative calculation rather than an empirical field study. The reference operating point is normalized to Q_1 = 100%, H_1 = 100%, P_1 = 100%, and n_1 = 100%. The relative values are calculated directly from Equation (4), assuming ideal affinity-law behavior and unchanged efficiency.

n_2/n_1 (%)	Q_2/Q_1 (%)	H_2/H_1 (%)	P_2/P_1 (%)	Idealized power reduction (%)
100	100.0	100.0	100.0	0.0
90	90.0	81.0	72.9	27.1
80	80.0	64.0	51.2	48.8
70	70.0	49.0	34.3	65.7

60	60.0	36.0	21.6	78.4

Table 1. Normalized theoretical pump parameters derived from the ideal affinity laws.

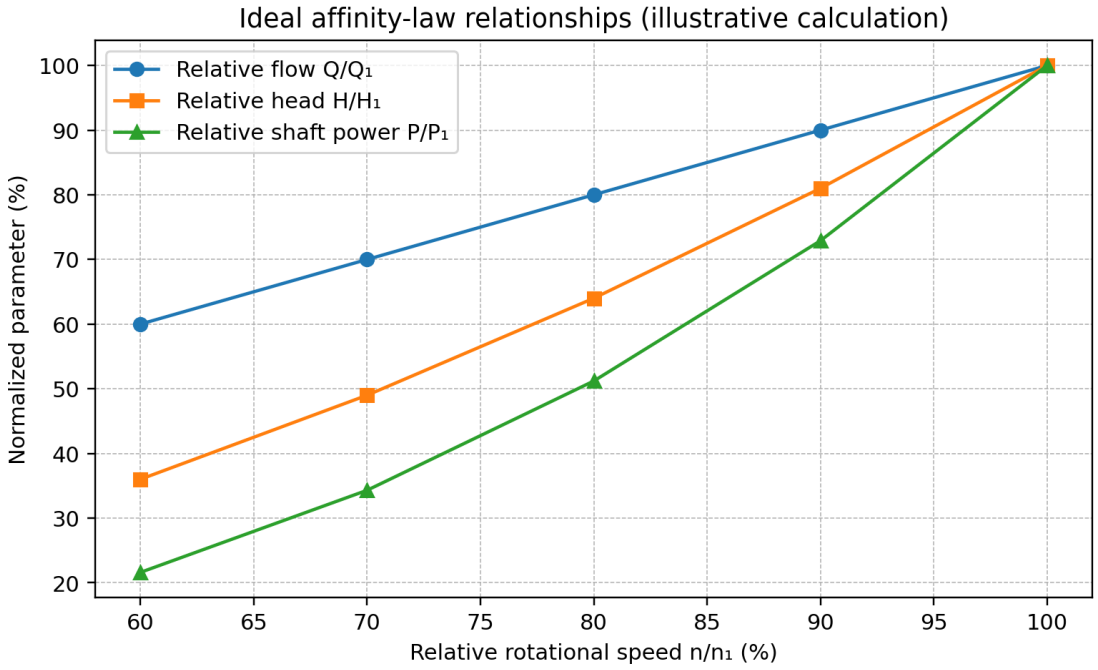


Figure 2. Idealized relationships between rotational speed and normalized pump parameters.

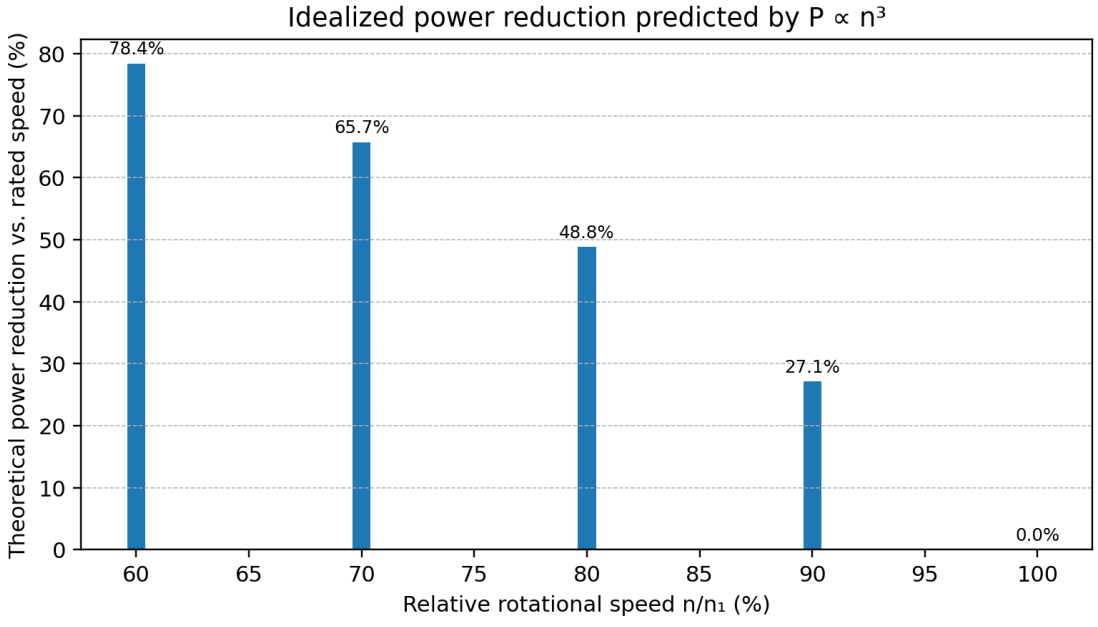


Figure 3. Theoretical reduction in shaft power relative to the reference speed, assuming P ∝ n³.

The normalized calculation shows that the theoretical shaft power decreases more rapidly than discharge as speed is reduced. At 90%, 80%, 70%, and 60% of reference speed, the idealized power reductions are 27.1%, 48.8%, 65.7%, and 78.4%, respectively. These figures describe the mathematical consequence of the cubic affinity relationship; they are not predictions of actual electricity savings for a specific irrigation station. The corresponding discharge also decreases in the simplified model, so reduced power must not be treated as an energy saving unless the required water volume and head are still delivered.

4. Discussion: The calculation demonstrates why rotational-speed control is worth assessing, but also why a single affinity-law estimate is insufficient for investment decisions. The actual operating point is determined by the intersection of the pump curve and the system curve. If a large part of the required head is static, reducing speed may lead to a disproportionate decrease in discharge or may make the required delivery impossible. Conversely, where demand varies and friction losses dominate, speed control can provide an effective means of matching pump output to system requirements [1, 2].

A field-based validation should compare the baseline and proposed operating modes under equivalent delivery conditions. For each mode, the discharge, total head, active electrical power, operating time, and delivered volume should be measured. The primary indicators should be wire-to-water efficiency and specific energy consumption, while the delivered water volume and minimum required head should be treated as constraints. A robust assessment should also account for the VFD's own losses, motor efficiency at partial load, pump efficiency away from its best-efficiency point, and possible changes in parallel-pump scheduling.

Accordingly, the next stage of the research should obtain manufacturer pump curves and field measurements from a selected irrigation pumping station. The normalized model can then be calibrated and compared with measured data. Any claimed percentage of energy saving should be reported only after this comparison and should state the operating conditions, measurement period, and uncertainty.

5. Conclusion: A calculation-based framework for preliminary assessment of energy efficiency in irrigation pumping stations has been presented. The method combines hydraulic power, wire-to-water efficiency, specific energy consumption, and the classical pump affinity relationships. The normalized example indicates that, under ideal assumptions, shaft power varies approximately with the cube of rotational speed; at 80% of reference speed, the theoretical shaft power is 51.2% of the reference value. This is an illustrative theoretical result and not a measured station-level saving. In practice, the suitability of variable-speed operation must be verified against the system curve, required water delivery, and the efficiencies of the pump, motor, and drive. Future work should validate the proposed assessment procedure using measured hydraulic and electrical data from a selected irrigation pumping station.

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