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Investigation of Pump Selection and Energy Efficiency in Agricultural Irrigation Systems

Tarımsal Sulama Sistemlerinde Pompa Seçimi ve Enerji Verimliliğinin İncelenmesi

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ABSTRACT

Agricultural irrigation is a critical component for the sustainability and productivity of the agricultural sector. Irrigation systems must be carefully selected to meet the water needs of agricultural areas and improve product quality. Pump types are at the center of irrigation systems and stand out as one of the main factors that determine irrigation efficiency by ensuring water movement. The parameters to consider when selecting a pump include technical features such as distribution distance, elevation differences, and water flow. Energy efficiency is also an important concept in agricultural irrigation systems. The energy consumption of a water pump is a determining factor in both economic and environmental terms.While energy efficiency reduces the overall cost of the irrigation system, it also helps minimize the company's carbon footprint. Advanced technology and innovative pump designs provide more water transfer capacity with less energy consumption. Therefore, investigating the energy efficiency dimension of pump types plays a critical role for the future of agricultural irrigation. Reliable and sustainable pump solutions allow farmers to maintain the ecological balance and increase production. Therefore, the aim of this study is to shed light on sustainable agricultural practices by examining the adequacy and efficiency of pump solutions in agricultural irrigation.

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ÖZ

Tarımsal sulama, tarım sektörünün sürdürülebilirliği ve verimliliği açısından kritik bir unsur teşkil etmektedir. Sınırlı su kaynaklarının etkin kullanımı, dünya genelindeki tarımsal üretim biçimlerinde büyük önem kazanmıştır. Pompa tipleri, sulama sistemlerinin kalbinde yer almakta olup, suyun hareketini sağlayarak sulama etkinliğini belirleyen ana etkenlerden biri olarak öne çıkar. Pompa seçiminde göz önünde bulundurulması gereken parametreler arasında dağıtım mesafesi, yükseklik farkları ve suyun debisi gibi teknik özellikler bulunmaktadır. Enerji verimliliği, tarımsal sulama sistemlerinde bir diğer önemli kavramdır. Su pompasının enerji tüketimi hem ekonomik hem de çevresel açıdan belirleyici bir faktördür. Enerji verimliliği, sulama sisteminin toplam maliyetlerini azaltırken aynı zamanda işletmenin karbon ayak izinin minimize edilmesine katkı sağlar. Gelişmiş teknoloji ve yenilikçi pompa dizaynları, daha az enerji harcayarak daha fazla su taşıma kapasitesi sunabilmektedir. Bu bağlamda, pompa tiplerinin enerji verimliliği boyutunu araştırmak, tarımsal sulamanın geleceği için kritik bir rol oynar. Güvenilir ve sürdürülebilir pompa çözümleri, çiftçilerin hem ekolojik dengeyi korumalarına hem de üretimlerini artırmalarına olanak sağlar. Dolayısıyla, bu çalışma, tarımsal sulamadaki pompa çözümlerinin yeterliliğini ve etkinliğini irdeleyerek, sürdürülebilir tarım uygulamalarına ışık tutmayı hedeflemektedir.

1. INTRODUCTION

Agricultural production is a critical sector for meeting the growing food needs of the world's population. However, the sustainability of agricultural production is largely dependent on the effective management of water resources. Much of the world's freshwater resources are used for agricultural irrigation. According to the World Water Council (2019), approximately 70% of water is used in the farming sector and this rate is increasing. Therefore, efficient water use is critical for both environmental sustainability and agricultural productivity. Agricultural irrigation plays a critical role in meeting the water needs of plants. In many regions of the world, irrigation is required due to insufficient natural water resources. The sustainability of agricultural production, especially in arid and semi-arid climates, is directly dependent on irrigation systems. The ability of farmers to use water at the right time and in the right amount increases crop yields and prevents the depletion of water resources [1]. However, the efficiency of irrigation systems is directly related not only to the amount of water used, but also to the energy used to transport and distribute water. Pumps used in agricultural irrigation systems play a fundamental role in carrying water from sources to fields. Thus, energy efficiency in irrigation systems is a critical factor in reducing costs and reducing environmental impacts. Irrigation pump systems typically have high energy consumption.

Pump selection and operating conditions have a direct impact on the energy efficiency of irrigation systems. Pump energy efficiency is critical to the sustainability of agricultural production, especially in developing countries where energy costs are high [2]. Energy costs can be one of the largest operating expenses in irrigation, so the efficient operation of pump systems has a direct impact on farmers' economic profitability. Moreover, the efficient operation of pumps is not only important from an economic standpoint, but also provides great environmental benefits. Energy-efficient pump systems reduce the use of fossil fuels by using less energy, which contributes to the reduction of greenhouse gas emissions [3]. This is a critical step to reduce the environmental impacts of agricultural production and promote sustainable agricultural practices.

The energy efficiency of pump systems is directly associated with the selection of the right type of pump. There are various types of pumps used for agricultural irrigation such as centrifugal pumps, reciprocating pumps, and submersible pumps. Each pump type should be selected according to different water flow and pressure conditions. Improper pump selection can result in energy loss, which reduces the overall efficiency of the system [4]. Centrifugal pumps are typically used in larger areas and must have the appropriate flow and pressure to operate efficiently. However, centrifugal pumps with low efficiency can result in energy losses. On the other hand, the use of modern technologies such as variable speed drives (VSDs) can reduce energy consumption by optimizing pump speed [5]. However, regular pump maintenance and system optimization are important steps to improve energy efficiency. In recent years, innovative irrigation technologies and applications have been developed to improve energy efficiency. Smart irrigation systems offer an important solution for improving energy efficiency in agriculture. Using sensors that monitor soil moisture and weather conditions, these systems determine irrigation needs in real time and use only the water needed. This ensures both more efficient use of water resources and reduced energy consumption [6].

Furthermore, the use of renewable energy sources, especially solar energy, can significantly reduce energy consumption in agricultural irrigation systems. Solar energy enables the operation of pumps in a sustainable manner, reducing energy costs and minimizing environmental impacts [7]. Solar energy enables the operation of pumps in a sustainable manner, reducing energy costs and minimizing environmental impacts. Studies have investigated the performance of different solar panel configurations for such applications [8]. Renewable energy sources, particularly solar energy, play a critical role in reducing energy consumption in agricultural irrigation systems. Solar-powered pumps not only reduce energy costs but also contribute to sustainable irrigation practices by minimizing environmental impacts [9-10]. Studies on solar irrigation systems have shown that these systems improve operational efficiency, providing economic benefits and reducing dependence on fossil fuels [11]. Furthermore, advanced technologies, such as variable speed drives (VSDs), used to optimize pump operations, can further enhance energy efficiency. These innovations are crucial for reducing energy waste and improving the overall efficiency and sustainability of irrigation systems, especially in regions facing energy challenges, where increasing energy efficiency and achieving savings are essential [12-14].

Such applications improve the economic efficiency of irrigation systems and strengthen the energy independence of farmers.

The aim of this study is to investigate the energy efficiency of pump types used in agricultural irrigation systems, and to discuss potential improvements to increase the efficiency of these systems. Recommendations to improve the efficiency of pump systems and the integration of innovative technologies can bring both economic and environmental benefits. In addition, this study aims to provide information that would be guiding for farmers, policy makers and engineers on water management and energy efficiency in agriculture.

2. MATERIAL AND METHOD

The energy efficiency of the pumps used in agricultural irrigation systems is one of the most important factors that directly affects the overall costs of the system. Since the pump is the main component in the transportation of water from the source to the target areas in the field, the efficiency of this system mostly depends on the design and operating conditions of the pump. Pumps with high energy efficiency not only carry water with less energy consumption but also improve the overall performance of the irrigation system. Therefore, when selecting a pump, both the initial investment cost and the long-term energy consumption and maintenance costs should be taken into consideration [4].

2.1 Effect of Pump Type Selection on Energy Efficiency

The type of pumps used for agricultural irrigation is determined based on the distance, flow rate and pressure requirements of the water to be transported. Different pump types have different energy efficiency levels. The selection of the pump types is critical for the efficient operation of the system. Commonly used pump types and their impact on energy efficiency are as follows:

Centrifugal pumps: Centrifugal pumps are the pumps that create high pressure by pushing water through rotating wings and operate in wide flow ranges and are mostly used in large areas. These pumps, when properly selected, are highly efficient, but can lead to energy losses in case of misuse or overload [3]. In order to increase the energy efficiency of centrifugal pumps, the design must be made to exactly match the flow and pressure requirements of the system.

Reciprocating pumps: Reciprocating pumps use piston displacement to pump water at a given volume. These pumps are generally preferred to meet high-pressure requirements. However, they have higher energy consumption and their efficiency is generally lower compared to centrifugal pumps [5]. To increase the efficiency of reciprocating pumps, it is important that the pump capacity is fully compatible with the needs of the irrigation system.

Submersible pumps: Submersible pumps are generally used to extract water from deep wells. Such pumps can consume high energy depending on the depth of the water, but energy efficiency can be achieved with proper design and maintenance [1]. In particular, a good analysis of depth and pressure requirements ensures the right choice of a submersible pump.

2.2 Energy Efficiency Criteria to be Considered in Pump Selection

There are some basic criteria to consider when selecting a pump to optimize energy efficiency:

Pump performance curve: It is important to examine the pump performance curve to determine the operating points at which the pump will operate efficiently. A properly selected pump provides high efficiency when operating in accordance with the flow and pressure requirements of the system. Correct analysis of the pump curve prevents energy loss [3]. Figure 1 shows the efficiency-flow relationship at different pump speeds for the norm 250-500 type pump for the irrigation system.

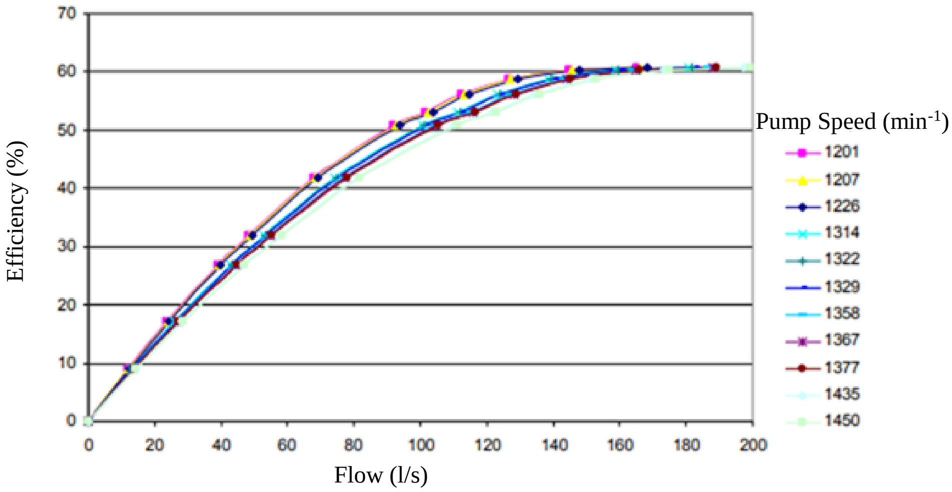

Figure 1. *Efficiency-Flow Curves at Different Pump Speeds*

Flow and pressure requirements of the system: One of the most important factors in pump selection is to correctly determine the flow and pressure requirements of the irrigation system. A wrong choice may cause the pump to overwork and thus lead to high energy consumption. In addition, the pump should be selected according to the pressure levels required by the system and the distance over which the water will be transported [1]. Figure 2 shows the power-flow relationship at different pump speeds for the norm 250-500 type pump for the irrigation system. The different pump speeds shown in the figure correspond to the possible pump operating points obtained from the flow hydrographs.

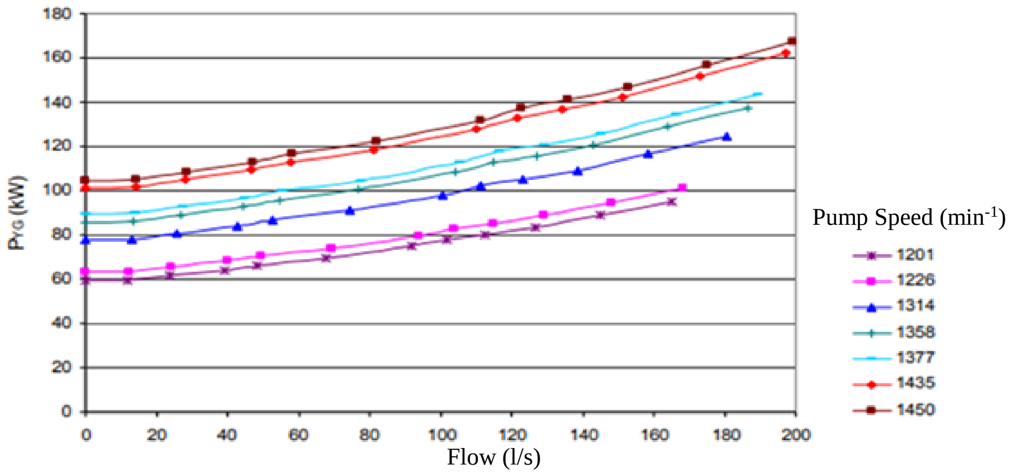

Figure 2. *Pump Power-Flow Curves*

Cavitation and efficiency: Cavitation is a phenomenon that can seriously reduce the efficiency of the pump. Models with a low risk of cavitation should be preferred in pump selection. Cavitation occurs due to the formation of water vapor as a result of a sudden pressure drop inside the pump and the explosion of the vapor, which leads to wear and energy loss in the pump [5]. In the current study, the pressure-flow rate-motor power for irrigating an agricultural area according to the operating conditions with centrifugal and submersible pumps was calculated and compared (Figure 3).

3. THE RESEARCH FINDINGS

Operating conditions:

- Height of the irrigation area: 50 meters
- Depth of water: 10 meters
- Targeted irrigation flow rate: 50 m^3/s

Assumptions on pump types: Centrifugal pump:

- Maximum flow rate: 150 m^3/s
- Maximum pressure: 30 meters
- Efficiency: 85%
- Motor power: 15 kW

Submersible pump:

- Maximum flow rate: 120 m^3/s
- Maximum pressure: 40 meters
- Efficiency: 80%
- Motor power: 20 kW

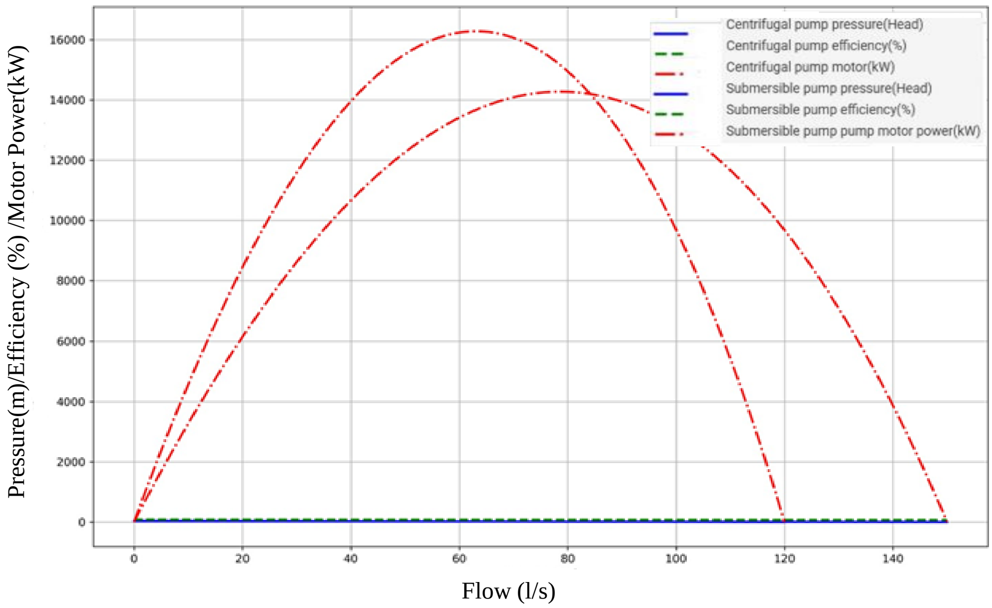

Figure 3. *Performance Curves of Centrifugal and Submersible Pumps*

According to the DIN 1944 standard, allowable error rates are divided into three precision classes and Table 1 shows the rates for these three classes. Table 2 shows the upper permissible limits (in %) for the total error rate in measurement according to the ISO classification.

Table 1. Permissible Error Rate for Pump Test Accuracy Classes (DIN1944)

Measurement Parameter	I	II	III
Tolerance in Flow Measurement (f_Q)	±%1.5	±%2.0	±%3.0
Manometric Height (f_{Hm})	±%1.0	±%1.5	±%2.0
Power Absorbed by the Pump (f_{PYG})	±%1.0	±%1.5	±%2.0
Tolerance on Pump Efficiency (fn)	±%2.0	±%3.0	-

Table 2. Total Error Rates in Measurement According to ISO Standarts

Measurement Large	ISO 5198 Sensitive Class (A Class)	ISO 3555 Eng.Class1 (B Class)	ISO 2548 Eng.Class2 (C Class)
Flow	±%1.5	±%2.0	±%3.5
Pomp Head	±%1.0	±%1.5	±%3.5
Shaft Power	±%1.0	±%1.5	±%3.7
Rotating Speed	±%0.2	±%0.5	±%2.0
Pump Efficiency	±%2.25	±%2.8	±%5.0

3.1 Energy Efficiency and Economic Effects

Ensuring energy efficiency directly reduces the costs of agricultural production. Especially in regions with high energy costs, the use of efficient pump systems provides significant economic savings. This increases the competitiveness of the producer and supports environmental sustainability.

Energy efficiency is of great importance not only for environmental sustainability but also for economic development and cost management. The energy used in agricultural irrigation systems is largely related to the efficiency of pump systems. Efficient operation of pumps means less energy consumption, which leads to reduced agricultural production costs. Improving energy efficiency in irrigation systems can help farmers become economically more competitive, especially in regions with high energy costs.

3.1.1 Energy Efficiency and Cost Savings

Agricultural irrigation is a major source of energy consumption, especially in regions with scarce water resources. Pumps used for irrigation processes consume large amounts of electrical energy, which increases the costs of irrigation processes. Energy used in agricultural production processes can account for a significant portion of farmers' total production costs. Therefore, improving energy efficiency can significantly reduce these costs.

Use of energy efficient pumps directly affects energy consumption. For example, when using VSDs and highly efficient motors, pump systems consume only the amount of energy required. This prevents unnecessary energy losses during irrigation. As a result, energy-efficient irrigation systems can save between 20% and 40% of energy costs [2]. These savings reduce the total operating costs of farmers and contribute to a sustainable production process.

Particularly in regions with high energy prices, achieving energy efficiency provides farmers with huge financial benefits in the long term. For example, solar-powered irrigation systems can significantly reduce the use of mains electricity, allowing energy costs to be reduced to near-zero levels [7]. Although solar-powered systems have high initial investment costs, in the long run they provide significant energy savings and bring farmers economic independence.

3.1.2 Energy Efficiency and Farmer Incomes

Energy efficiency can not only reduce costs but also increase farmers' incomes. Saving energy allows farmers to reduce irrigation costs and thus earn more profit. The use of energy-efficient pump systems allows farmers to allocate more budget to irrigation through savings in irrigation costs. This provides an advantage in terms of increasing the amount of production or making alternative agricultural investments.

Furthermore, the use of energy-efficient systems allows farmers to produce more crops with lower operating costs. This increases productivity in agriculture, leading to more income in production processes. For example, in systems using energy-efficient pumps, more efficient irrigation can be achieved by using less energy. This can increase plant growth and crop yields, thus increasing the total income of farmers [1].

3.1.3 Greenhouse Gas Emissions and Environmental Benefits

Energy efficiency provides great economic and environmental benefits. Efficient operation of the pump systems reduces greenhouse gas emissions by reducing energy consumption. This provides a significant environmental benefit, especially for irrigation systems operated by fossil fuels. When agricultural irrigation is carried out using fossil fuels, carbon dioxide (CO_2) and other greenhouse gases released into the atmosphere are major factors contributing to climate change. However, when energy efficiency is achieved, these emissions are significantly reduced.

In particular, irrigation using renewable energy sources (solar energy, wind energy) contributes greatly to reducing the carbon footprint. Renewable energy sources increase environmental sustainability by reducing dependence on fossil fuels. Solar-powered irrigation systems both reduce energy costs and minimize environmental damage [3]. Such innovative solutions help to ensure sustainability in the agricultural sector and minimize environmental impacts.

3.1.4 Return on Investment of Energy Efficiency Practices

The return on investments made to achieve energy efficiency is usually realized in the short term. Although energy efficient systems are initially installed at higher costs, they pay for themselves over time through energy savings. According to a study, the payback period of irrigation systems using VSDs and high-efficiency motors ranges from 2 to 4 years [5].

The return on such investments offers farmers not only energy savings, but also lower operating costs and long-term economic benefits. Furthermore, investments in energy efficient systems can be supported by incentives and subsidies offered by governments. Such policies encourage farmers to invest in such systems and accelerate the transition to sustainable agriculture.

3.1.5 Increasing Agricultural Competitiveness through Energy Efficiency

Energy-efficient agricultural irrigation systems can increase the competitiveness of farmers. Lower energy costs allow farmers to develop a more flexible pricing policy. Thanks to energy efficient systems, farmers who can keep their production costs under control can be more competitive in terms of market prices. This allows them to gain more market share in both local and global markets.

Furthermore, energy efficient irrigation systems enhance the quality of crops and make them more demandable for farmers. The relationship between irrigation efficiency and plant growth leads to obtain quality crops, which in turn increases the value of farmers in the market [1].

3.2 Energy Efficiency and Improvement Methods

3.2.1 Technological Developments to Improve Pump Efficiency

Energy efficiency is an important factor for the sustainability of agricultural irrigation systems, especially in developing countries. Various technological developments have been experienced in recent years to increase energy efficiency in pump systems. These developments have helped farmers to reduce energy costs while enabling pump systems to operate more efficiently. Some of the methods used to increase the energy efficiency of pump systems are as follows:

Variable speed drives (VSDs): Variable speed drives (VSDs) allow pump systems to adjust their speed based on water demand. The use of VSDs prevents pumps from running at unnecessarily high speeds, which saves energy. For example, when the water demand of the irrigation area decreases, the VSD system reduces energy consumption by lowering the pump speed. VSD can improve energy efficiency by 25% to 60%, resulting in significant cost savings in the long run [6]. Figure 4 shows the energy savings with VSD. Figure 5 shows a comparison of the amount of power used by controlling the valve with VSD.

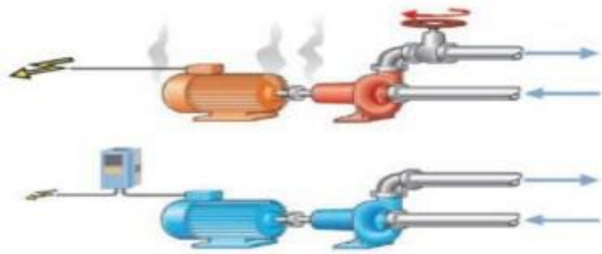

Figure 4. *Energy Saving Principle through VSD Speed Adjustment*

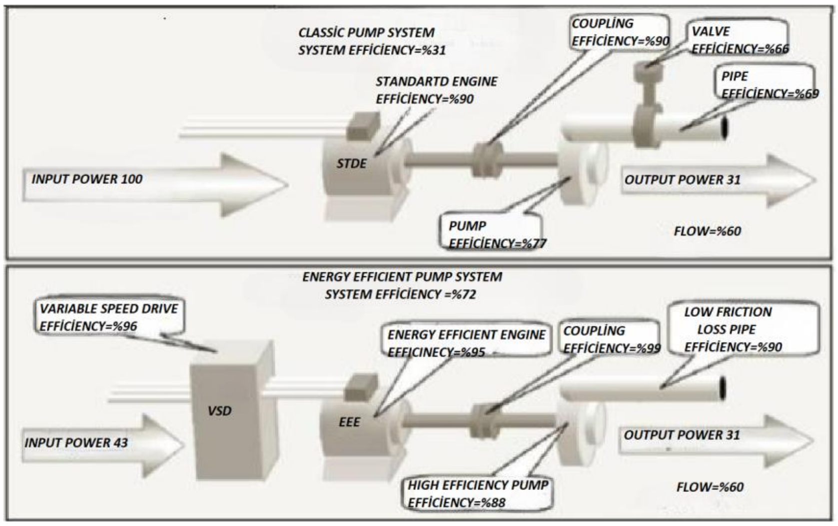

Figure 5. *Comparison of Energy Consumption of Conventional Pump System and Pump System with VSD*

Energy efficient motors and high-efficiency pumps: The efficiency of pump motors has a major impact on overall system efficiency. High-efficiency motors and pumps provide the same performance by using less energy. Modern motors ensure efficient operation of pump systems while minimizing energy losses. The right choice of pump and motor combination plays an important role in improving system efficiency [4].

Pump maintenance and monitoring systems: Regular maintenance and optimization of pump systems is critical to improve energy efficiency. Wear of pump vanes and other components leads to loss of efficiency. Therefore, automatic monitoring systems that monitor pump performance are beneficial to prevent energy losses [7]. In addition, pump systems need to be properly calibrated and adjusted in accordance with the operating conditions.

Feedback systems: After pumping water, it is important to recover and reuse excess water to ensure energy efficiency.

3.3 Integration of Modern Irrigation Systems

The types of pumps and energy efficiency used in agricultural irrigation systems, combined with modern irrigation technologies, can give more effective and efficient results. Smart irrigation systems optimize the irrigation process with sensors and automation technologies. Such systems enable more efficient use of water and energy.

3.3.1 Smart Irrigation Systems

Smart irrigation is supported by sensors that monitor soil moisture and weather conditions. These systems determine irrigation needs in real time and ensure that only the right amount of water is used. This method significantly reduces both energy and water consumption.

Soil moisture sensors measure moisture levels in the soil and determine the need for irrigation. These sensors can be used to optimize irrigation schedules. Weather sensors measure temperature, humidity, wind speed and precipitation. This data is used to determine irrigation needs. Soil temperature sensors measure soil temperature, which can change the water requirements of the plants. Collecting and analyzing this data improves irrigation system efficiency. Data collected by sensors is transmitted to cloud-based platforms or local data centers for analysis. These analyses are processed by algorithms and software that drive irrigation decisions. In smart irrigation systems, machine learning algorithms and artificial intelligence can be used to make more accurate predictions. For example, irrigation schedules can be more accurately determined by taking into account factors such as weather data and soil moisture.

Smart irrigation systems automatically control the irrigation unit. Many systems automate the irrigation process by connecting to this controller. These units also provide the ability to remotely control the irrigation system. Smart irrigation systems provide remote monitoring and control. Using smartphones or computers, farmers can monitor the irrigation system, view data and take action when necessary. Smart irrigation systems reduce unnecessary water use by accurately measuring the water requirements of the plants. This ensures that water is used efficiently and prevents water waste. As a result, it helps conserve water resources. In conventional irrigation systems, pumps and motors run continuously. However, smart irrigation systems operate only when needed, reducing energy consumption. Smart irrigation systems increase efficiency by providing irrigation conditions that best meet the needs of the plants. This results in healthier plants and higher crop yields.

Smart irrigation systems save farmers labor and time by automating the irrigation process. Farmers are freed from manually performing many tasks related to the irrigation process. Smart irrigation systems prevent the soil from receiving excess water during irrigation. This helps prevent soil erosion and salinity. Smart irrigation systems allow farmers for monitoring irrigation processes remotely. This feature allows to monitor the proper functioning of the irrigation system and makes a quick intervention in case of emergency.

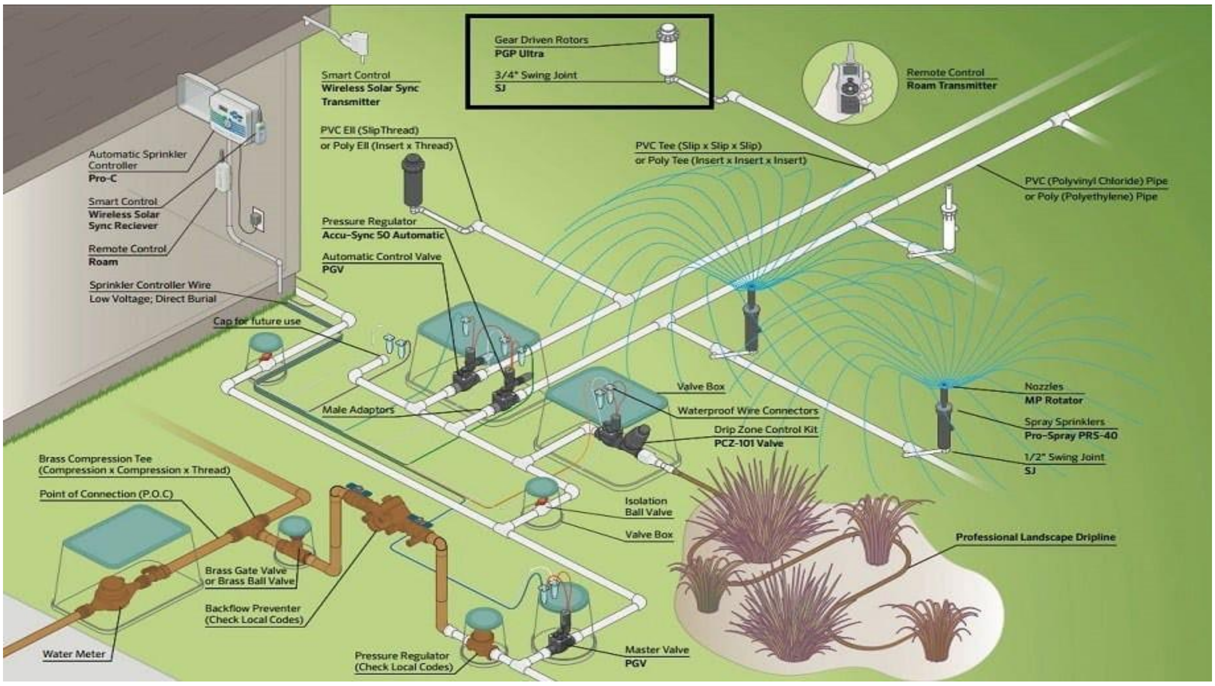

Figure 6. *Scheme of smart irrigation system*

3.3.2 Drone Technology and Remote Monitoring

Drones are effectively used in agriculture to monitor irrigation processes. They enable remote monitoring of large agricultural areas, ensuring efficient operation of irrigation systems and preventing water loss. They use advanced sensors to analyze soil moisture, plant health, and environmental conditions. With this data, irrigation is applied only where it is needed and at the right time. Targeted irrigation avoids excessive energy consumption by using water and energy only where it is needed. This makes irrigation more efficient and reduces energy costs. Drones monitor irrigation needs in real time and determine when irrigation is needed in a given area. Optimal irrigation schedules increase energy efficiency since pumps are operated only when needed and excess energy waste is avoided. Drones can quickly detect blockages or malfunctions in irrigation systems. This prevents a malfunctioning irrigation system from wasting energy. Drones can also identify areas where water is not being distributed evenly, allowing irrigation equipment to be used more efficiently. Remote monitoring is often used in combination with satellite imagery, sensors and weather data. These technologies make irrigation decisions more accurate and eliminate unnecessary energy use. With remote monitoring, irrigation is applied at the right place and time to ensure optimal use of energy and water.

Remote monitoring systems continuously monitor weather data and adjust irrigation schedules based on rainfall forecasts. This avoids additional irrigation after natural rainfall and saves energy. Data obtained from remote monitoring is analyzed to optimize energy consumption. This ensures that pumps and irrigation systems are operating properly, avoids unnecessary energy consumption, and makes irrigation operations more efficient. Figure 7 shows agricultural irrigation using drone technology and remote monitoring.

Figure 7. *Irrigation with drone technology*

3.4 Points to Consider in Pump Selection

Points to consider in pump selection include a number of factors that have a direct impact on the effectiveness and efficiency of agricultural irrigation systems. First, basic parameters such as system suction depth, the head of the pump and desired flow rate should be clearly defined. These parameters are directly related to the intensity of irrigation practices and the topographical characteristics of the land; therefore, pump selection should be carefully evaluated together with the characteristics of the water source.

The choice of pump type is also important in terms of energy efficiency. Since energy consumption is a factor that directly affects the cost of agricultural irrigation, pump efficiency is closely related to the economics of any irrigation system. Selecting pumps with high efficiency ratings will help reduce energy costs in the long run. Pump efficiency classifications are usually based on pump efficiency standards (such as IE3, IE4) for electric pumps, and choosing according to these standards is a critical step in both saving energy and reducing environmental impact [15]. In addition, pump materials and design should also be considered. In particular, the chemical and physical properties of the water to be worked in play a decisive role in the material selection of the pump.

For example, corrosion-resistant materials should be preferred, especially in systems operating with saline or acidic water sources. All of these factors suggest the need for a multi-faceted analysis in the pump selection process; not just a short-term solution, but a long-term strategy to create a sustainable and efficient agricultural irrigation system. Choosing the right pump is therefore a critical element in terms of both economic impacts and ecosystem health.

3.4.1 Determination of Flow and Pressure Requirements

To increase the efficiency and sustainability of irrigated agriculture activities, accurately determining flow and pressure requirements is a critical step in irrigation system design. Flow refers to the rate at which water passes through a point in a given period of time, while pressure refers to the force that causes water to move through a system. Both have a direct effect on the performance of the irrigation system. The required flow rate depends on various factors such as the size of the agricultural land, plant species, the topography and the climatic conditions. Therefore, these parameters should be considered in order to provide sufficient water.

In addition to determining flow requirements, it is important to accurately estimate the pressure requirements of the irrigation system. The relevant pressure can be calculated based on the elevation at which the water enters the irrigation system and the irrigation method to be used (e.g., drip irrigation, sprinkler). Each method has its own specific pressure range and requirements, which are a critical element to consider in the system design process. For example, lower pressure levels are preferred for drip irrigation systems, while higher pressure levels may be required for sprinkler systems. Therefore, it is important to take an integrated approach so that both flow and pressure calculations are performed in a harmonized manner.

A detailed analysis of flow and pressure requirements is also effective in selecting the most appropriate pump type and increasing energy efficiency. At this stage, assessing available water resources and minimizing potential losses plays a critical role. In addition, integrating the right sensors and automation systems to manage the variability found in agricultural land optimizes both flow and pressure control [16].

3.4.2 Efficiency and Energy Consumption

Efficiency and energy consumption are critical to the sustainability and economic effectiveness of agricultural irrigation systems. While irrigation pump systems play an effective role in delivering water to agricultural areas, they also contribute to environmental impacts through their energy consumption. Pump efficiency defines how efficiently a pump moves water with a given energy consumption. Pumps with high efficiency consume less energy while delivering a given flow rate, which reduces operating costs. Energy efficiency is often directly related to the design, operating conditions and maintenance processes of the pump system. For example, correct sizing of the system, optimum selection of pump types and regular maintenance practices are important steps in reducing energy consumption [17].

Another important factor affecting energy consumption is whether or not the operating point of the pump system is within the pump's most efficient operating range. Ideally, the pump should operate in accordance with the efficiency curves provided by the manufacturer. Otherwise, the pump may operate at both low efficiency and overload, resulting in both energy loss and wear on the system. In addition, the design of the piping and fittings used in the system is one of the factors affecting energy losses. Low-resistance piping and appropriate diameters optimize water flow, reducing pump workload and helping to make more efficient use of energy resources.

In conclusion, the efficiency of pumps in agricultural irrigation is of great importance for both economic and environmental sustainability. In this context, minimizing energy consumption has the potential to increase agricultural productivity and business profitability.

For farm managers and irrigation professionals, identifying strategies to improve energy efficiency is a critical step to improve the overall performance of irrigation systems. Therefore, there has been an increasing tendency in the agricultural sector towards innovative solutions such as sensor-based automation systems, monitoring and control technologies to achieve high efficiency and low energy consumption [18].

3.4.3 Measures that can be Taken to Increase Energy Efficiency

Measures that can be taken to improve energy efficiency are critical to ensuring the sustainability of agricultural irrigation systems. These measures aim to reduce both energy consumption and to make use of water resources efficiently. First, it is necessary to focus on the design and modernization of irrigation systems. Old and inefficient pump systems should be replaced with integrated pump systems using energy-efficient electric motors and frequency converters. Such systems can be adjusted according to the required water flow and pressure, minimizing unnecessary energy consumption.

In addition, optimizing irrigation timing is an important factor in improving energy efficiency. Smart irrigation technologies can be integrated with soil moisture sensors and weather forecasting systems to more accurately determine irrigation needs. This saves both water and energy. The use of renewable energy sources is also important. Pumps powered by solar or wind energy reduce reliance on fossil fuels, lower operating costs, and reduce environmental impact.

Physical characteristics of agricultural lands such as topography and soil structure are also factors that affect the efficiency of irrigation systems. Therefore, proper analysis of the land and selection of appropriate irrigation techniques are essential to avoid energy losses. In addition, the implementation of regular maintenance and control procedures to ensure proper operation of the system is another factor that increases energy efficiency. In this context, training operators, raising awareness about energy efficiency and promoting the right practices will lead to results that increase efficiency in agricultural irrigation [19].

4. CONCLUSION

This study examined the critical role of pump selection and energy efficiency in agricultural irrigation systems and analyzed the performance of different pump systems in different irrigation scenarios. The results clearly show that the selection of highly energy-efficient pumps provides significant economic and environmental benefits. As a result of the analysis, high-efficiency pumps were found to provide 15-30% lower energy consumption compared to conventional pumps. In particular, pumps equipped with VFDs can reduce the overall energy consumption of the irrigation system by 20% compared to pumps operating at constant speed. In addition, the inverse relationship between pump efficiency and energy consumption indicates that errors in the design phase of the system should be reduced. The study revealed that for every 1 kWh of energy saving, irrigation costs are reduced by 5-8%. In addition, data from field studies in different irrigation areas show that pump selection has a direct impact on irrigation efficiency. In the application examples, it was observed that irrigation efficiency increased by 10-15% and water use efficiency increased by up to 20% with the right pump selection.

These results show that pump systems with high energy efficiency not only provide cost advantage, but also allow for more efficient use of water. Technologies that increase system efficiency play an important role in irrigation management. In particular, the integration of automation and remote monitoring systems has enabled more precise management of irrigation processes and reduced water losses by 25%. At the same time, these technologies make it possible to monitor and optimize the performance of pump systems, significantly reducing maintenance requirements.

Recommended strategies to improve energy efficiency are:

- Use of high-efficiency pump systems.
- Integration of smart irrigation technologies.
- Use of renewable energy sources.
- Ensuring pump maintenance and optimization.

Implementation of these strategies increases the efficiency of agricultural production and reduces operating costs. It also ensures the widespread use of sustainable agricultural practices.

In conclusion, proper pump selection is critical to increasing energy efficiency and reducing costs in agricultural irrigation systems. The results of the study show that the potential for increasing energy efficiency in the agricultural sector is quite high and investments in this area will provide economic benefits in the long run. In addition, the introduction of incentive arrangements for energy efficiency in irrigation systems by policymakers and raising awareness among farmers will be an important step for a more sustainable and efficient agriculture.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

DECLARATION OF ETHICAL CODE

In this study, the authors undertake that they comply with all the rules within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" and that they do not take any of the actions under the heading "Actions Contrary to Scientific Research and Publication Ethics" of the relevant directive.

AUTHORS' CONTRIBUTIONS

Fatih KOÇYİĞİT: Writing-original draft preparation, data collection, data curation, visualization. Reşit AZİZOĞLU: Conceptualization, methodology, validation, analysis, writing-review and editing, supervision.

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